APPENDIX 5

ARROW LNG PLANT

Surface Water Impact Assessment

arrow energy
go further

REPORT:

ARROW LNG PLANT

Input to the Environmental Impact Statement

SURFACE WATER IMPACT ASSESSMENT

Fluvial Geomorphology and Hydrology

August 2011

Document history

Version and Revision:

Version no. V7.0

Author/s Jason Carter
Rohan Lucas
Greg Ellett
Brett Tywcross

Checked Greg Ellett, Jason Carter

Approved Jason Carter

Distribution:

Version no. V7.0

Issue date August 2011

Issued to Kristen Wicks (Coffey Environments)

Description: Final

Citation:

Please cite this document as: Carter, J. Lucas, R. Ellett, G & Twycross, B. (2011). ARROW LNG PLANT – Input to the Environmental Impact Statement – SURFACE WATER ASSESSMENT – Fluvial Geomorphology and Hydrology. By Alluvium Consulting for Arrow Energy Holdings Pty Ltd and Coffey Environments Pty Ltd, Brisbane.

Acknowledgements:

We would like to acknowledge and thank the following people for their input in this report:
Kristen Wicks, Rebecca Lumley, Barton Napier

Ref:
L:\Projects\2010\P210002_Shell_Australia_LNG_Project\1_Deliverables\Review_September_2011\P210002-R01_Arrow_LNG_Plant_EIS_Geomorphology and Hydrology_V7.0.docx

Project Contacts:

Jason Carter
Natural Resources Manager
Alluvium Consulting
3/62 Walker Street
Townsville QLD 4810
T (+61) (7) 4724 2170
F (+61) (7) 4724 1639

Kristen Wicks
Consultant
Coffey Environments
Level 2, 12 Creek Street Brisbane QLD 4000 Australia
T (+61) (7) 3002 0400
F (+61) (7) 3002 044

Arrow Energy Holdings contact:

Street Address
AM60, Level 19
42 - 60 Albert Street
Brisbane Queensland 4000
Australia

Postal Address
GPO Box 5262
Brisbane Queensland 4001
Australia

Phone: +61 7 3012 4000
Fax: +61 7 3012 4001

Executive Summary

This report has been prepared as input to the preparation of the "Arrow LNG Plant – Environmental Impact Statement". Surface water aspects of the project have been examined in three parts: fluvial geomorphology and hydrology (this report); LNG plant stormwater quality, separate report (Alluvium 2011); and study area water quality, a separate report (Aquateco, 2011).

Location

The study area covers 8,017.6 ha in central Queensland on Curtis Island, part of the mainland north of Gladstone and marine area between.

Legislation

There is a range of legislation relevant to geomorphology and hydrology. Within that range, the *Water Act 2000* (Qld) is of particular relevance as it sets out permitting and licensing requirements and also governs the management of certain works (including filling) in waterways. Written advice from DERM (15 February, 2011) has stated that the features in the project area on Curtis Island are not watercourses as defined by the *Water Act 2000* (Qld) and therefore do not require authorisations under the provisions of the act.

Method

An assessment approach developed by Coffey Environments (2011a) has been applied in this study to determine the significance of impacts upon identified environmental values based upon sensitivity and magnitude. Impacts before and after the application of proposed mitigation measures have been assessed to enable the effectiveness of those mitigation measures in reducing the predicted impact to be assessed.

Existing Environment

Catchments and watercourses in the study area are listed in Table E1-1 below.

Table E1-1. ***Catchments and watercourse names***

Catchment	Watercourse
Curtis Island	
Catchment 2	One mapped waterway – W1.
East catchment	No mapped waterways.
Southeast catchment	One mapped waterway W2.
Main catchment	One main waterway with headwater tributaries W3.
West catchment	With two mapped waterways – W4 and W5.
Catchment 3	One main waterway with headwater tributaries W6.
Mainland	
Calliope River	Auckland Creek. Calliope River.
Catchment 1	Poorly defined watercourses with channel modifications in the area of industrial development at Yarwun. Identified as W7.
Boat Creek	Boat Creek. Tributary identified as W8, has been channelised around the industrial area at Yarwun (and the channelised drain is not mapped as a watercourse) and

Catchment	Watercourse
	flows to Boat Creek. W9 is a headwater tributary of Boat Creek. W10, W11 and W12 are headwater streams that enter floodout zones (without defined channels) before discharging to the coast. W13 is comprised of two mapped channels, one that enters a floodout zone and the other discharging directly to the coast.

Hydrology

Hydrology had been examined for the Calliope River, Auckland Creek and Curtis Island.

Fluvial Geomorphology

An assessment has been made of the study area watercourses in relation to geomorphic category (including an assessment of intactness of riparian vegetation and wetland characterisation).

Environmental Values (EVs)

Specific environmental values for watercourses in the study area are not defined within the *Environmental Protection (Water) Policy Act 2009* (Qld) (EPP Act). Environmental values have therefore been developed from the project based on desktop/archival/baseline and field investigations and with consideration of the following:

- Water Resource (Calliope River Basin) Plan (Queensland Government, 2006).
- Curtis Coast Regional Coastal Management Plan (Environmental Protection Agency, 2003))

Sustainable function and use of ecosystems is the primary environmental value of watercourses, wetlands and their catchments. Attributes that define the primary environmental value, are themselves values that collectively describe the intrinsic characteristics and properties of the watercourse or wetland and the associated catchment. The following attributes define the environmental values of surface water assets and are consistent with the above Plans.

1. Physical integrity, fluvial processes, form and morphology of watercourses and wetlands including riparian vegetation.
2. Hydrology of watercourses and wetlands in the catchment - quantity, duration and timing of stream flows.
3. Primary and secondary recreational use.
4. Physical and hydrologic character contributing to cultural and spiritual values.

There are no declared wild rivers in the project area.

Project Activities and Impacts

Project activities that have the potential to result in environmental impacts to hydrology and geomorphology of watercourses and wetlands during construction, operational service and decommissioning are:

- Construction of the LNG plant and associated infrastructure (marine facilities and construction camps).
- Construction of TWAF7 and TWAF8 watercourse crossings for roads/tracks.
- Discharge and storage of hydro test water.
- Launch site 1 near the mouth of the Calliope River.
- Feed gas pipeline. This does not cross any mapped waterways or wetlands, except in the vicinity of the mainland tunnel entry shaft and tunnel spoil disposal area, which is discussed separately. The feed gas pipeline is not discussed further in this report.
- Mainland tunnel entry shaft and tunnel spoil disposal area.

- Dredge site 1 at the mouth of the Calliope River from launch site 1 past Mud Island to the main shipping channel.

Avoidance, Mitigation and Management Measures

Avoidance, mitigation and management measures with reference to the project activities that have the potential to impact on the hydrology and geomorphology of surface water are provided and are targeted at the prevention of generation of sediment and management of sediment. Site specific measures include:

- Best practice waterway diversion design.
- Design waterway diversion/s and adjacent flood corridor/s to manage a minimum of a 1:100 year ARI event.
- LNG plant design and implementation of a Stormwater Management Plan.
- Bunding of construction works site to avoid tidal inundation.
- Storm surge protection for project activities to an elevation of 2.82m AHD (+ freeboard) for the current 100 year storm surge or an elevation of 3.33m AHD (+ freeboard) for the 2050 100yr storm surge.
- Whilst a 100 yearARI flood event and storm event are considered as a minimum a greater level of protection may be considered."

Residual Impact

The post-mitigation residual impacts are all identified as being low or negligible. The exceptions are the loss of wetlands at the LNG Plant site and mainland tunnel entry shaft and tunnel disposal area, where the loss of wetlands is identified as Moderate.

Cumulative Impact

A common potential cumulative impact is the timing of construction, which could occur concurrently with some projects. For the LNG plant, the geomorphic and hydrologic impacts from the construction, operation and decommissioning of the facility can be managed. There will be three additional LNG plants on Curtis Island, which are expected to have a negligible cumulative impact on altered hydrology (timing and volumes of runoff from facilities) and geomorphic processes, if identified mitigation measures are applied.

Conclusions

With consideration of the assessments detailed in this report the following conclusions are drawn:

Geomorphology

- Many potential impacts can be managed through adequate application of standard mitigation measures to control the generation and control of sediment.
- Some site specific mitigation measures are also required. These are:
  - Designing waterway diversion/s to ensure that geomorphic processes continue to operate at approximately natural rates during operation of the plant and following decommissioning thereby providing for sustainable function.
  - Monitoring waterway diversion/s to ensure construction and operation to design intent.
  - Stabilisation of earthworks where tidal influence may result in erosion.
  - Bunding or elevation of construction areas at risk of tidal inundation.
  - Ongoing monitoring of the dredged channel of the Calliope River will be required to check that the dredged channel does not increase erosion rates over natural levels. If erosion occurs, monitoring will identify the issue and enable design and application of appropriate remediation measures.
- At TWAF7 the existing crossing through the in-filled meander neck cut off channel of Auckland Creek will require upgrade and adequate scour protection.
- Some wetland areas will be lost as part of the project. These will not be replaced. An exception may be the replacement of some of the coastal/sub-coastal floodplain tree swamp area at the site of the

LNG plant. Some replacement may be able to be achieved as part of the construction of waterway diversion/s. Detailed design is required. Some minor offset for loss of wetlands may also be possible through the construction and operation of sediment detention basins as part of the management of stormwater at the LNG plant (see Alluvium 2011). Consideration of offsets for the loss of the ecological value of wetlands is detailed in Coffey (2011b).

Hydrology

- At the LNG plant site, changes to direction and discharge points of surface flow paths will occur. This will reduce discharges from waterway W3 and increase discharges to W4 and possibly W1 and/or W2 depending upon the final design. Additional erosion protection works (rock riprap) will be required for receiving waterways.
- Flooding (resulting in impacts to identified EVs) can be managed through appropriate design of waterway diversion/s and adjacent flood corridor/s to manage a minimum of a 1:100 year ARI event.
- Changes to the hydraulics of the Calliope River channel as a result of dredging may occur. Impacts and mitigation measures have been discussed above.
- At TWAF7 the existing crossing through the in-filled meander neck cut off channel of Auckland Creek will require upgrade and adequate scour protection. Design of that upgrade will need to consider flood risk and potential offsite flood impacts if hydraulics are changed.

Glossary

Aggradation	Deposition of sediment that builds up a watercourse bed.
Alluvium	Sand, silt, clay, gravel, or other matter deposited by flowing water, on riverbeds and floodplains.
Bars	Instream deposits of sediment.
Bedload	Particles of sand, gravel, or soil carried by flow in a watercourse on or immediately above its bed.
Channel	The portion of a watercourse between the top of banks.
Colluvium	Material deposited by gravity or local wash at the base of slopes.
confined and partly-confined	A watercourse is confined where it is prevented from migrating laterally and vertically through the process of erosion. Where a watercourse is only confined on one bank it is said to be partly-confined.
Floodplain	The area of a valley floor periodically inundated by flooding.
Fluvial geomorphology	The science that describes, explains and predicts the shape and form of waterways.
Headcut / headward erosion	An active erosion feature in a watercourse usually manifest as a small waterfall, eroding the bed in an upstream direction.
Hydrology	The scientific study of the properties, distribution, and effects of water on the land surface and atmosphere.
Incised	Vertical cut, down into a floodplain or valley.
Indurated	Hardened sedimentary materials, largely due to cementation by mineral matter deposited from solution in water.
Meander	A loop or bend in a river that erodes its inside bends and deposits on the outside of its bends and so moves over time.
Neck cutoff	Neck - the area across the neck of a river bend. Cutoff – Occurs when erosion of a bend across the neck creates a new channel.
Paleochannel	deposits of unconsolidated sediments or semi-consolidated sedimentary rocks deposited in ancient, currently inactive river and stream channel systems.
Planform	The view as seen looking down from above.
Sinuosity	Having a bending or curving shape.

Acronyms

AHD	Australian Height Datum
ARI	Average Recurrence Interval
ASL	Above sea level
BOM	Bureau of Meteorology
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	Digital Elevation Model
DERM	Department of Environment and Resource Management
DIP	Department of Infrastructure and Planning
DNRW	Department of Natural Resources and Water
EM Plan	Environmental Management Plan
EPP	Environmental Protection (Water) Policy Act 2009
EVs	Environmental values
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
HAT	Highest astronomical tide

LIDAR	Light Detection and Ranging data
LAT	Lowest astronomical tide
LNG	Liquefied Natural Gas
MOF	Materials offloading facility
TWAF	Temporary workers accommodation facility
UNESCO	United Nations Educational, Scientific and Cultural Organization

Contents

Figures

Tables

1 Introduction and Project Description

1.1 Introduction

This report has been prepared as input to the preparation of the “Arrow LNG Plant – Environmental Impact Statement”. Surface water aspects of the project have been examined in three parts: fluvial geomorphology and hydrology (this report); LNG plant stormwater quality, separate report (Alluvium 2011); and study area water quality, a separate report (Aquateco, 2011).

1.2 Project Description

Proponent

Arrow CSG (Australia) Pty Ltd (formally known as Shell CSG (Australia) Pty Ltd) (Arrow Energy) proposes to develop a liquefied natural gas (LNG) plant on Curtis Island off the central Queensland coast near Gladstone. The project, known as the Arrow LNG Plant (formally known as the Shell Australia LNG Project), is a component of the larger Arrow LNG Project.

The proponent is a subsidiary of Arrow Energy Holdings Pty Ltd which is wholly owned by a joint venture between subsidiaries of Royal Dutch Shell plc and PetroChina Company Limited.

Arrow LNG Plant

Arrow Energy proposes to construct the Arrow LNG Plant in the Curtis Island Industry Precinct at the southwestern end of Curtis Island, approximately 6km north of Gladstone and 85km southeast of Rockhampton, off Queensland’s central coast. In 2008, approximately 10% of the southern part of the island was added to the Gladstone State Development Area to be administered by the Queensland Department of Local Government and Planning. Of that area, approximately 1,500 ha (25%) has been designated as the Curtis Island Industry Precinct and is set aside for LNG development. The balance of the Gladstone State Development Area on Curtis Island has been allocated to the Curtis Island Environmental Management Precinct, a flora and fauna conservation area.

The Arrow LNG Plant will be supplied with coal seam gas from gas fields in the Surat and Bowen basins via high-pressure gas pipelines to Gladstone, from which a feed gas pipeline will provide gas to the LNG plant on Curtis Island. A tunnel is proposed for the feed gas pipeline crossing of Port Curtis.

The project is described below in terms of key infrastructure components: LNG plant, feed gas pipeline and dredging.

LNG Plant

Overview. The LNG plant will have a base-case capacity of 16Mtpa, with a total plant capacity of up to 18Mtpa. The plant will consist of four LNG trains, each with a nominal capacity of 4Mtpa. The project will be undertaken in two phases of two trains (nominally 8 Mtpa), with a financial investment decision undertaken for each phase.

Operations infrastructure associated with the LNG plant includes the LNG trains (where liquefaction occurs; see ‘Liquefaction Process’ below), LNG storage tanks, cryogenic pipelines, seawater inlet for desalination and stormwater outlet pipelines, water and wastewater treatment, a 110m high flare stack, power generators (see ‘LNG Plant Power’ below), administrative buildings and workshops.

Construction infrastructure associated with the LNG plant includes construction camps (see ‘Workforce Accommodation’ below), a concrete batching plant and laydown areas.

The plant will also require marine infrastructure for the transport of materials, personnel and product (LNG) during construction and operations (see ‘Marine Infrastructure’ below).

Construction Schedule. The plant will be constructed in two phases. Phase 1 will involve the construction of LNG trains 1 and 2, two LNG storage tanks (each with a capacity of between 120,000m^3 and 180,000m^3), Curtis Island construction camp and, if additional capacity is required, a mainland workforce accommodation camp. Associated marine infrastructure will also be required as part of Phase 1. Phase 2 will involve the construction of LNG trains 3 and 4 and potentially a third LNG storage tank. Construction of Phase 1 is scheduled to commence in 2014 with train 1 producing the first LNG cargo in 2017. Construction of Phase 2 is anticipated to commence approximately five years after the completion of Phase 1 but will be guided by market conditions and a financial investment decision at that time.

Construction Method. The LNG plant will generally be constructed using a modular construction method, with preassembled modules being transported to Curtis Island from an offshore fabrication facility. There will also be a substantial stick-built component of construction for associated infrastructure such as LNG storage tanks, buildings, underground cabling, piping and foundations. Where possible, aggregate for civil works will be sourced from suitable material excavated and crushed on site as part of the bulk earthworks. Aggregate will also be sourced from mainland quarries and transported from the mainland launch site to the plant site by roll-on, roll-off vessels. A concrete batching plant will be established on the plant site. Bulk cement requirements will be sourced outside of the batching plant and will be delivered to the site by roll-on roll-off ferries or barges from the mainland launch site.

LNG Plant Power

Power for the LNG plant and associated site utilities may be supplied from the electricity grid (mains power), gas turbine generators, or a combination of both, leading to four configuration options that will be assessed:

- Base case (mechanical drive): The mechanical drive configuration uses gas turbines to drive the LNG train refrigerant compressors, which is the traditional powering option for LNG facilities. This configuration would use coal seam gas and end flash gas (produced in the liquefaction process) to fuel the gas turbines that drive the LNG refrigerant compressors and the gas turbine generators that supply electricity to power the site utilities. Construction power for this option would be provided by diesel generators.

- Option 1 (mechanical/electrical – construction and site utilities only): This configuration uses gas turbines to drive the refrigerant compressors in the LNG trains. During construction, mains power would provide power to the site via a cable (30MW capacity) from the mainland. The proposed capacity of the cable is equivalent to the output of one gas turbine generator. The mains power cable would be retained to power the site utilities during operations, resulting in one less gas turbine generator being required than the proposed base case.

- Option 2 (mechanical/electrical): This configuration uses gas turbines to drive the refrigerant compressors in the LNG trains and mains power to power site utilities. Under this option, construction power would be supplied by mains power or diesel generators.

- Option 3 (all electrical): Under this configuration mains power would be used to supply electricity for operation of the LNG train refrigerant compressors and the site utilities. A switchyard would be required. High-speed electric motors would be used to drive the LNG train refrigerant compressors. Construction power would be supplied by mains power or diesel generators.

Liquefaction Process

The coal seam gas enters the LNG plant where it is metered and split into two pipe headers which feed the two LNG trains. With the expansion to four trains the gas will be split into four LNG trains.

For each LNG train, the coal seam gas is first treated in the acid gas removal unit where the carbon dioxide and any other acid gasses are removed. The gas is then routed to the dehydration unit where any water is removed and then passed through a mercury guard bed to remove mercury. The coal seam gas is then ready for further cooling and liquefaction.

A propane, precooled, mixed refrigerant process will be used by each LNG train to liquefy the predominantly methane coal seam gas. The liquefaction process begins with the propane cycle. The propane cycle involves three pressure stages of chilling to pre-cool the coal seam gas to -33°C and to compress and condense the mixed refrigerant, which is a mixture of nitrogen, methane, ethylene and propane. The condensed mixed refrigerant and precooled coal seam gas are then separately routed to the main cryogenic heat exchanger, where the coal seam gas is further cooled and liquefied by the mixed refrigerant. Expansion of the mixed refrigerant gases within the heat exchanger removes heat from the coal seam gas. This process cools the coal seam gas from - 33°C to approximately -157°C. At this temperature the coal seam gas is liquefied (LNG) and becomes 1/600th of its original volume. The expanded mixed refrigerant is continually cycled to the propane precooler and reused.

LNG is then routed from the end flash gas system to a nitrogen stripper column which is used to separate nitrogen from the methane, reducing the nitrogen content of the LNG to less than 1 mole per cent (mol%). LNG separated in the nitrogen stripper column is pumped for storage on site in full containment storage tanks where it is maintained at a temperature of - 163°C.

A small amount of off-gas is generated from the LNG during the process. This regasified coal seam gas is routed to an end flash gas compressor where it is prepared for use as fuel gas.

Finally, the LNG is transferred from the storage tanks onto LNG carriers via cryogenic pipelines and loading arms for transportation to export markets. The LNG will be regasified back into sales specification gas on shore at its destination location.

Workforce Accommodation

The LNG plant (Phase 1), tunnel, feed gas pipeline, and dredging components of the project each have their own workforces with peaks occurring at different stages during construction. The following peak workforces are estimated for the project:

- LNG plant Phase 1 peak workforce of 3,500, comprising 3,000 construction workers: 350 engineering, procurement and construction (EPC) management workers and 150 Arrow Energy employees.
- Tunnel peak workforce of up to 100.
- Feed gas pipeline (from the mainland to Curtis Island) peak workforce of up to 75.
- A dredging peak workforce of between 20 and 40.

Two workforce construction camp locations are proposed: the main construction camp at Boatshed Point on Curtis Island, and a possible mainland overflow construction camp, referred to as a temporary workers accommodation facility (TWAF). Two potential locations are currently being considered for the mainland TWAF; in the vicinity of Gladstone city on the former Gladstone Power Station ash pond No.7 (TWAF7) or in the vicinity of Targinnie on a primarily cleared pastoral grazing lot (TWAF8). Both potential TWAF sites include sufficient space to accommodate camp infrastructure and construction laydown areas. The TWAF and its associated construction laydown areas will be decommissioned on completion of the Phase 1 works.

Of the 3,000 construction workers for the LNG plant, it is estimated that between 5% and 20% will be from the local community (and thus will not require accommodation) and that the remaining fly-in, fly-out workers will be accommodated in construction camps. The 350 EPC management and 150 Arrow Energy employees are expected to relocate to Gladstone with the majority housed in company facilitated accommodation.

The tunnel workforce of 100 people and gas pipeline workforce of 75 people are anticipated to be accommodated in the mainland in company facilitated accommodation. The dredging workforce of 20 to 40 workers will be housed onboard the dredge vessel.

Up to 2,500 people will be housed at Boatshed Point construction camp. Its establishment will be preceded by a pioneer camp at the same locality which will evolve into the completed construction camp.

Marine Infrastructure
Marine facilities include the LNG jetty, materials offloading facility (MOF), personnel jetty and mainland launch site.

LNG Jetty. LNG will be transferred from the storage tanks on the site to the LNG jetty via above ground cryogenic pipelines. Loading arms on the LNG jetty will deliver the product to an LNG carrier. The LNG jetty will be located in North China Bay, adjacent to the northwest corner of Hamilton Point.

MOF. Delivery of materials to the site on Curtis Island during the construction and operations phases will be facilitated by a MOF where roll-on, roll-off or lift-on, lift-off vessels will dock to unload preassembled modules, equipment, supplies and construction aggregate. The MOF will be connected to the LNG plant site via a heavy-haul road.

Boatshed Point (MOF 1) is the base-case MOF option and would be located at the southern tip of Boatshed Point. The haul road would be routed along the western coastline of Boatshed Point (abutting the construction camp to the east) and enters the LNG Plant site at the southern boundary. A quarantine area will be located south of the LNG plant and will be accessed via the northern end of the haul road.

Two alternative options are being assessed, should the Boatshed Point option be determined to be not technically feasible:

- South Hamilton Point (MOF 2): This MOF option would be located at the southern tip of Hamilton Point. The haul road from this site would traverse the saddle between the hills of Hamilton Point to the southwest boundary of the LNG plant site. The quarantine area for this option will be located southwest of the LNG plant near the LNG storage tanks.

- North Hamilton Point (MOF 3): This option involves shared use of the MOF being constructed for the Santos Gladstone LNG Project (GLNG Project) on the northwest side of Hamilton Point (south of Arrow Energy's proposed LNG jetty). The GLNG Project is also constructing a passenger terminal at this site, but it will not be available to Arrow Energy contractors and staff. The quarantine area for this option would be located to the north of the MOF. The impacts of construction and operation of this MOF option and its associated haul road were assessed as part of the GLNG Project and will not be assessed in this EIS.

Personnel Jetty. During the peak of construction, base case of up to 1,100 people may require transport to Curtis Island from the mainland on a daily basis. A personnel jetty will be constructed at the southern tip of Boatshed Point to enable the transfer of workers from the mainland launch site to Curtis Island by high-speed vehicle catamarans (Fastcats) and vehicle or passenger ferries (ROPAX). This facility will be adjacent to the MOF constructed at Boatshed Point. The haul road will be used to transport workers to and from the personnel jetty to the construction camp and LNG plant site. A secondary access for pedestrians will be provided between the personnel jetty and the construction camp.

Mainland Launch Site. Materials and workers will be transported to Curtis Island via the mainland launch site. The mainland launch site will contain both a passenger terminal and a roll-on, roll-off facility. The passenger terminal will include a jetty and transit infrastructure, such as amenities, waiting areas and car parking. The barge or roll-on ,roll-off facility will have a jetty, associated laydown areas, workshops and storage sheds.

The two location options for the mainland launch site are:

- Launch site 1: This site is located north of Gladstone city near the mouth of the Calliope River, adjacent to the existing RG Tanna coal export terminal.
- Launch site 4N: This site is located at the northern end of the proposed reclamation area for the Fishermans Landing Northern Expansion Project, which is part of the Port of Gladstone Western Basin Master Plan. The availability of this site will depend on how far progressed the Western Basin Dredging and Disposal Project is at the time of construction.

Feed Gas Pipeline
An approximately 8-km long feed gas pipeline will supply gas to the LNG plant from its connection to the Arrow Surat Pipeline (formerly the Surat Gladstone Pipeline) on the mainland adjacent to Rio Tinto's Yarwun alumina refinery. The feed gas pipeline will be constructed in three sections:

- A short length of feed gas pipeline will run from the proposed Arrow Surat Pipeline to the mainland tunnel entry shaft, which will be located on a mudflat south of Fishermans Landing, just south of Boat Creek. This section of pipeline will be constructed using conventional open-cut trenching methods within a 40m wide construction right of way.
- The next section of the feed gas pipeline will traverse Port Curtis harbour in a tunnel to be bored under the harbour from the launch shaft to a receival shaft on Hamilton Point. The tunnel under Port Curtis will have an excavated diameter of up to approximately 6m and will be constructed by a tunnel boring machine that will begin work at the mainland launch shaft. Tunnel spoil material will be processed through a de-sanding plant to remove the bentonite and water and will comprise mainly a finely graded fill material, which will be deposited in a spoil placement area established within bund walls constructed adjacent to the launch shaft. Based on the excavated diameter, approximately 223,000m^3 of spoil will be treated as required for acid sulfate soil and disposed of at this location.
- From the tunnel receival shaft on Hamilton Point, the remaining section of the feed gas pipeline will run underground to the LNG plant, parallel to the above ground cryogenic pipelines. This section will be constructed using conventional open-cut trenching methods within a 30m wide construction right of way. A permanent easement up to 30m wide will be negotiated with the relevant land manager or owner.

Should one of the electrical plant power options be chosen, it is intended that a power connection will be provided by a third party to the mainland tunnel entry shaft, whereby Arrow Energy would construct a power cable within the tunnel to the LNG plant.

Other infrastructure, such as communication cables, water and wastewater pipelines, may also be accommodated within the tunnel.

Dredging
Dredging required for LNG shipping access and swing basins has been assessed under the Gladstone Ports Corporation's Port of Gladstone Western Basin Dredging and Disposal Project. Additional dredging within the marine environment of Port Curtis may be required to accommodate the construction and operation of the marine facilities. Up to five sites may require dredging:

- Dredge site 1 (dredge footprint for launch site 1): The dredging of this site would facilitate the construction and operation of launch site 1. This dredge site is located in the Calliope River and extends from the intertidal area abutting launch site 1, past Mud Island to the main shipping channel. The worst-case dredge volume estimated at this site is approximately 900,000m^3.

- Dredge site 2 (dredge footprint for launch site 4N): The dredging of this site would facilitate the construction and operation of launch site 4N. This dredge site would abut launch site 4N and extend east from the launch site to the shipping channel. The worst-case dredge volume identified at this site is approximately 2,500m^3.
- Dredge site 3 (dredge footprint for Boatshed Point MOF 1): The dredging of this site would facilitate the construction and operation of the personnel jetty and MOF at Boatshed Point. This dredge site would encompass the area around the marine facilities, providing adequate depth for docking and navigation. The worst-case dredge volume identified at this site is approximately 50,000m^3.
- Dredge site 4 (dredge footprint for Hamilton Point South MOF 2): The dredging of this site would facilitate the construction and operation of the MOF at Hamilton Point South. This dredge site would encompass the area around the marine facilities, providing adequate depth for docking and navigation. The worst-case dredge volume identified at this site is approximately 50,000m^3.
- Dredge site 5 (dredge footprint for LNG jetty): The dredging of this site will facilitate the construction of the LNG jetty at Hamilton Point. This dredge site extends from the berth pocket to be dredged as part of the Western Basin Strategic Dredging and Disposal Project to the shoreline and is required to enable a work barge to assist with construction of the jetty. The worst-case dredge volume identified is approximately 120,000m^3.

The spoil generated by dredging activities will be placed and treated for acid sulfate soils (as required) in the Port of Gladstone Western Basin Dredging and Disposal Project reclamation area.

1.3 Study Area

Throughout this report the following terms are used:

“study area” – the area that was studied in relation to the project area.

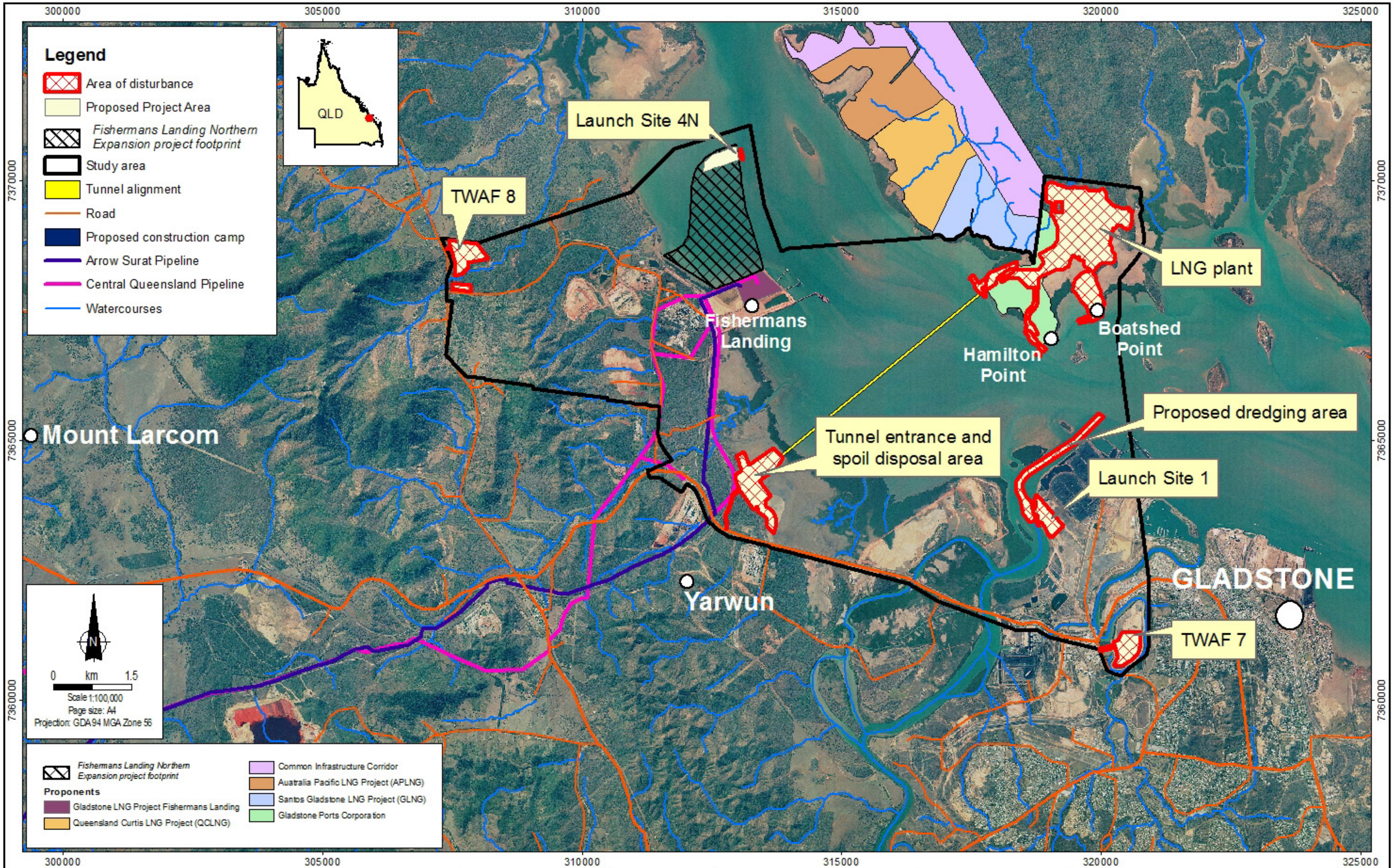
“project area” – the area of potential disturbance by project activities within the study area.

The study area covers 8,017.6 ha in central Queensland as shown in Figure 1-1, page 7, and is comprised of:

- 4,167.6 ha (52%) Mainland (Calliope basin).
- 600.7 ha (7.5%) Curtis Island.
- 30.5 ha (0.4%) Small islands.
- 3,218.8 ha (40.1%) Marine.

Surface Water Features that May be Disturbed by Project Activities

The main area of disturbance by project activities will be on Curtis Island where construction of the LNG plant and associated facilities will require diversion of minor waterways; loss of an area of coastal wetland; and management and discharge of stormwater. On the mainland in the Calliope River basin there may be disturbance of watercourses at the mouth of the Calliope River, where a channel will be dredged for access to launch site 1; and potentially a road crossing to TWAF 7, which may involve the upgrade of an existing crossing on Auckland Creek. Some loss and disturbance of coastal wetlands is expected at the mainland tunnel launch site, launch site 1 and potentially at TWAF 7.



Source:
Roads from DME.
Study area, pipelines, proposed facilities from Arrow Energy.
Watercourses modified from DERM 1:100,000 mapping.
Conceptual tunnel alignment from Coffey Environments.

alluvium

Date: 30.05.2011
MXD: P210002
File Name: P210002-F001
Rev: 1

Arrow Energy
Arrow LNG Plant

arrow energy

Study area location

Figure No: 1-1

2 Legislative Context

This section discusses legislative aspects that may have relevance to geomorphology and hydrology.

The design, construction, operation and decommissioning of the project infrastructure will be undertaken over the lifetime of the project in accordance with the *Petroleum and Gas (Production and Safety) Act 2004* (Qld), *Environmental Protection Act 1994* (Qld), *Environmental Protection (Waste Management) Policy 2000* (Qld) and the *Draft Guidelines for the Assessment and Management of Contaminated Land in Queensland 1998*. Key legislation governing the management of geomorphology and hydrology in regards to the project includes:

- *Water Act 2000* (Qld), which sets out permitting and licencing requirements for taking or interfering with water and other resources.
- *Water Supply (Safety and Reliability) Act 2008* (Qld). A development permit may be required for construction of a referrable dam. Whether or not this is required will depend upon the final project design.
- *Environment Protection Act 1994* (Qld).
- *Environmental Protection (Water) Policy 2009* (Qld).
- *Petroleum and Gas (Production and Safety) Act* (Qld).
- *Petroleum Act 1923* (Qld).
- *Water Resource (Calliope River Basin) Plan 2006.*
- *Calliope River Resource Operations Plan (May 2008).*
- *The Central Queensland Strategy for Sustainable Development – 2004 and Beyond.*
- *Environmental Protection Regulation 2008* (Qld), the *Environmental Protection (Waste Management) Policy 2000* (Qld) and the *Environmental Protection (Waste Management) Regulation 2000* (Qld). This legislation is relevant primarily to water quality and is discussed elsewhere in the water quality impact assessment (Aquateco, 2011).
- *Sustainable Planning Act 2009* (Qld). The Sustainable Planning Act (SP Act) provides the framework for Queensland's planning development assessment system and replaces the *Integrated Planning Act 1997* (Qld). A range of approvals may be necessary under the SP Act.

Some additional considerations include:

The *Water Act 2000* (Qld) sets out permitting and licensing requirements and also governs the management of certain works in waterways. Those works include destroying vegetation, excavating or placing fill in a watercourse, lake or spring. This may be relevant for infrastructure development at the temporary workers accommodation (TWAF7) should that option be pursued. Written advice from DERM (15 February, 2011) has stated that the features in the project area on Curtis Island are not watercourses and therefore do not require authorisations under the provisions of the act.

Rehabilitation and decommissioning of LNG plant, feed gas pipeline and associated infrastructure will be undertaken in accordance with relevant regulatory requirements, Australian Standards and industry guidelines including the *Petroleum and Gas (Production and Safety) Act 2004*, Environmental *Protection Act 1994*, Australian Pipeline Industry Association *Code of Environmental Compliance – onshore pipelines 1995*; and the Australian Petroleum Production and Exploration Association *Code of Environmental Practice 2008*.

Additional legislation considered in other reports includes:

- *Coastal Protection and Management Act 1995* (Coffey 2011b).
- *Vegetation Management Act 1999* (Ecosure 2011).
- *Nature Conservation Act 1992* (Ecosure 2011).
- *Great Barrier Reef Marine Park Act 1975* (Coffey 2011b).
- *Fisheries Act 1994* (Aquateco 2011).
- *Native Title Act 1993* (CQCCHM 2011).

- *Aboriginal and Cultural Heritage Act 2003* (CQCCHM 2011).

2.1 Approvals Relevant to Geomorphology and Hydrology

A list of required approvals relevant to surface water is identified in the table below.

Table 2-1. *Required approvals relevant to geomorphology and hydrology*

Approval Source	Responsible Authority	Relevant Aspect of Project
Environment Protection and Biodiversity Conservation Act 1999 (Cwlth). The Commonwealth has determined the project constitutes a controlled action under relevant controlling provisions of the EPBC Act.	Department of Sustainability, Environment, Water, Population and Communities.	Any aspect of the project which is likely to impact on a relevant matter of national environmental significance.
Fisheries Act 1994 (Qld)	Department of Employment, Economic Development and Innovation.	If operational works are required for waterway barrier works a development approval may be required (see also Sustainable Planning Act).
Sustainable Planning Act 2009 (Qld).	Department of Infrastructure and Planning.	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 PAG Act. The project may also require, depending on final 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 (see also Fisheries Act and Water Act).
State Development and Public Works Organisation Act 1999 (Qld).	Coordinator-General of the state of Queensland.	Evaluating the EIS for the project.
Water Act 2000 (Qld). *Sustainable Planning Act 2009* (Qld). Development permit for operational work.	DERM.	A development permit may be required to: • Take or interfere with water from a watercourse. • Take or interfere with artesian water. • Take or interfere with overland flow water or sub artesian water.
Water Act 2000 (Qld). *Sustainable Planning Act 2009* (Qld). Riverine protection permit.	DERM.	A riverine protection permit is required to do any or all of the following activities in a watercourse, lake or spring: • Destroy vegetation. • Excavate. • Place fill.

Approval Source	Responsible Authority	Relevant Aspect of Project
Water Act 2000 (Qld). Allocation notice for quarry material.	DERM.	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 may occur during certain project activities.
Water Supply (Safety and Reliability) Act 2008 (Qld). *Sustainable Planning Act 2009* (Qld). Development permit for removing quarry material from a watercourse.	DERM.	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 may occur during certain project activities.
Water Supply (Safety and Reliability) Act 2008 (Qld). *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* (Qld).	DERM.	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* (Qld). This only applies to dams of a certain size and does not include dams that contain hazardous waste.

3 Study Method

3.1 Overview

The assessment approach taken in this study has been the use of sensitivity and magnitude to determine the significance of impacts. The significance of impacts has been assessed by considering the sensitivity of identified environmental values and the magnitude of the impact, before and after the application of mitigation measures. This has then enabled the effectiveness of the proposed mitigation measures in reducing the predicted impact to be assessed. Further details of the method for the assessment of significance of impacts is provided in Section 3.2.

The method is structured as follows:

- Overview.
- Assessment of significance of impacts.
- Baseline data and information.
- Assessment of hydrology.
- Assessment of geomorphology.

The first stage in the assessment was the identification of the existing environment and environmental values, which was undertaken through desktop/archival/baseline investigations followed by targeted field investigations. Field investigations were undertaken mainly in June 2010 but also, in February 2011, with supplementary investigations of the sites TWAF7 and TWAF8. The results of the baseline investigations including field investigations are presented as Attachment A.

The results of those investigations were then used to:

- Undertake an assessment of issues and potential impacts (Section 5, page 42).
- Inform and develop management and avoidance, mitigation and management measures (Section 5.3, page 46).
- Inform the identification of residual impacts (Section 7, page 56).
- Inform an assessment of cumulative impacts (Section 9, page 64).
- Provide input to the development of inspection and monitoring strategies, (Section 8, page 61).

With reference to the above process, conclusions have been drawn and are presented in Section 10, page 68.

3.2 Assessment of Significance of Impacts

The significance assessment method was developed by Coffey Environments (Coffey Environments, 2011a) specifically for projects of this nature. The method as detailed below has been applied by Alluvium to the assessment of significance of impacts in regard to geomorphology and hydrology. For an assessment of ecological values see Ecosure (2011) and for an assessment of marine and estuarine ecological values see Coffey Environments (2011b). The results of the application of the method are presented in Sections 5, 7, 8, 9 and 10 as identified above.

Approach

The impact assessment method has been used to determine the potential impact of the project activities on the environmental values of the study area.

Defining environmental values

The Environment Protection Act 1994 describes an environmental value as 'A measure of how we value the environment in which we live. A quality or physical characteristic of the environment that is conducive to ecological health or public amenity or safety.' The Terms of Reference for the

Environmental Impact Statement of this project also state that values should be described in terms of values within the Environmental Protection (Water) Policy 2009, sustainability, including both quality and quantity, physical integrity, fluvial processes and morphology of watercourses, including riparian zone vegetation and form any water resource plans, land and water management plans. The relevant environmental values for the study area are defined in section 4.5.

An assessment using sensitivity and magnitude to determine the significance of an impact has been adopted. In this approach, the significance of an impact has been assessed by considering the sensitivity of the environmental value and the magnitude of the impact, before and after the application of mitigation measures. This has enabled the effectiveness of the proposed mitigation measures in reducing the predicted impact to be assessed.

This approach assumes the identified impacts will occur, as this conservative method enables a more comprehensive understanding and assessment of the likely impacts of the project. It focuses attention on the mitigation and management of potential impacts through the identification and development of effective design responses and environmental controls.

The sensitivity of environmental values is determined from its susceptibility or vulnerability to threatening processes or as a consequence of its intrinsic value. The significance of impacts on these environmental values is determined by assessing the magnitude of a potential impact on the environmental values having regard to their sensitivity. The magnitude of impact on an environmental value is an assessment of the geographical extent, duration and severity of the impact.

The effectiveness of mitigation measures is indicated by whether the magnitude of potential impacts has been reduced and hence whether the significance of the potential impacts on the environmental value has been reduced.

Sensitivity Criteria

The sensitivity of environmental values has been determined with respect to its conservation status, intactness, uniqueness or rarity, resilience to change and replacement potential. These contributing factors are described below in terms of geomorphology and hydrology values (for ecological values see Ecosure, 2011).

- **Conservation Status** is assigned to an environmental value by governments (including statutory and regulatory authorities) or recognised international organisations (e.g., UNESCO) through legislation, regulations and international conventions.

  For coastal wetlands the study area is within the Port Curtis Wetland, which is listed in the Directory of Important Wetlands (Environment Australia, 2001). In close proximity to the study area are other Nationally Important Wetlands of The Narrows Wetland, Great Barrier Reef Marine Park (which is also World Heritage listed).

  There are no wild rivers in the study area.
- **Intactness** of the environmental values was assessed with respect to existing condition, particularly its representativeness. An assessment of geomorphic condition including the intactness of riparian vegetation was undertaken as part of this study in recognition of the role that riparian vegetation plays in fluvial process and morphology of watercourses by stabilising banks and moderating flows by increasing roughness and thereby reducing velocities. The level of intactness of wetlands was also considered and identified.
- **Uniqueness or rarity** of environmental values was an assessed with consideration of watercourse geomorphic types and wetland types was considered with regard to occurrence, abundance and distribution. None of the watercourse or wetland types is unique or rare in the region.
- **Resilience to change** of environmental values was assessed based on ability to cope with change including that posed by threatening processes. This factor is an assessment of the ability of environmental values to adapt to change without adversely affecting intactness, uniqueness or rarity. For all watercourse geomorphic types, robustness has been identified.

- **Replacement potential** of environmental values was assessed with regard to the potential for a representative or equivalent example of an environmental value to be found to replace any losses. This is linked to uniqueness or rarity (see above) to identify replacement potential.

The criteria for determining high, moderate and low sensitivity are set out below.

<u>High sensitivity</u>

- The environmental value is intact and retains its intrinsic value.
- It is unique to the environment in which it occurs. It is isolated to the affected system or area which is poorly represented in the region, territory, country or the world.
- It is fragile and predominantly unaffected by threatening processes. Small changes would lead to substantial changes to the prescribed value.
- It is not widely distributed throughout the system/area and consequently would be difficult or impossible to replace.

<u>Moderate sensitivity</u>

- The environmental value is in a moderate to good condition despite it being exposed to threatening processes. It retains many of its intrinsic characteristics and structural elements.
- It is relatively well represented in the systems/areas in which it occurs but its abundance and distribution are limited by threatening processes.
- Threatening processes have reduced its resilience to change. Consequently, changes resulting from project activities may lead to degradation of the prescribed value.
- Replacement of unavoidable losses is possible due to its abundance and distribution.

<u>Low sensitivity</u>

- The environmental value is in a poor to moderate condition as a result of threatening processes which have degraded its intrinsic value.
- It is not unique or rare and numerous representative examples exist throughout the system/area.
- It is abundant and widely distributed throughout the host systems/areas.
- There is no detectable response to change or change does not result in further degradation of the environmental value.
- The abundance and wide distribution of the environmental value ensures replacement of unavoidable losses is assured.

Magnitude Criteria

The magnitude of impacts on environmental values is an assessment of the geographical extent, duration and severity of the impact. These criteria are described below.

- **Geographical extent** is an assessment of the spatial extent of the impact where the extent is defined as site, local, regional or widespread (meaning state-wide or national or international).
- **Duration** is the timescale of the effect i.e., if it is short, medium or long term.
- **Severity** is an assessment of the scale or degree of change from the existing condition, as a result of the impact. This could be positive or negative. The criteria for determining high, moderate and low impacts are set out below.

<u>High magnitude impact</u>

A high magnitude impact is an impact that is widespread, long lasting and results in substantial and possibly irreversible change to the environmental value. Avoidance through appropriate design responses is required to address the impact.

<u>Moderate magnitude impact</u>

A moderate magnitude impact is an impact that extends beyond the area of disturbance to the surrounding area but is contained within the region where the project is being developed. The impacts are short term and result in changes that can be ameliorated with specific environmental management controls.

Low magnitude impact
A localised impact that is temporary or short term and either unlikely to be detectable or could be effectively mitigated through standard environmental management controls.

Assessment of Significance of Impacts
Table 3-1 shows how, using the criteria described above, the significance of impacts has been determined having regard to the sensitivity of the environmental value and the magnitude of the expected change.

Table 3-1. ***Matrix of significance***

Magnitude of Impact	Sensitivity of Environmental Values		
	High	Moderate	Low
High	Major	High	Moderate
Moderate	High	Moderate	Low
Low	Moderate	Low	Negligible

A description of the significance of an impact derived using Table 3-1 is set out below.

Major Impact
A major impact occurs when impacts will potentially cause irreversible or widespread harm to an environmental value that is irreplaceable because of its uniqueness or rarity. Avoidance through appropriate design responses is the only effective mitigation.

High Impact
A high impact occurs when the proposed activities are likely to exacerbate threatening processes affecting the intrinsic characteristics and structural elements of an environmental value. While replacement of unavoidable losses is possible, avoidance through appropriate design responses is preferred to preserve its intactness or conservation status.

Moderate Impact
A moderate impact occurs where, although reasonably resilient to change, the environmental value would be further degraded due to the scale of the impacts or its susceptibility to further change. The abundance of the environmental value ensures it is adequately represented in the region, and that replacement, if required, is achievable.

Low Impact
A low impact occurs where an environmental value is of local importance and temporary and transient changes will not adversely affect its viability provided standard environmental controls are implemented.

Negligible Impact
A degraded (low sensitivity) environmental value exposed to minor changes (low magnitude impact) will not result in any noticeable change in its intrinsic value and hence the proposed activities will have negligible impact. This typically occurs where the activities occur in industrial or highly disturbed areas.

Residual Impact
Residual impacts are those potential impacts remaining after the application of mitigation measures and design response. The extent to which potential impacts have been reduced has been determined by undertaking an assessment of the significance of the residual impacts. This is a measure of the effectiveness of the design response and/or mitigation measures in reducing the magnitude of the potential impacts, as the sensitivity of the environmental value does not change.

3.3 Baseline Data and Information

Data used as the baseline to define and assess the geomorphology and hydrology of the study area included:

- Stream and wetland layers from the Queensland Wetlands Programme “wetland mapping and classification for Queensland” (Version 2.0 – January 2010).
- A 1:100,000 scale stream layer provided by Arrow Energy, which was modified by Alluvium to improve its usefulness for this project assessment. Modifications included remapping watercourses within the study area boundary and creating a traceable stream network and applying Strahler stream ordering, a useful tool to assist resource projects that may impact upon watercourses (further details are provided in Attachment B).
- Digital mapping from the Queensland Wetlands Programme “Hyd_Wetland” layer version 2.0.
- A 1:100,000 scale digital elevation model (DEM) created by Alluvium from the 5 metre map interval contours provided in digital form by Arrow Energy.
- SPOT satellite imagery supplied by Arrow Energy.
- Geology of the project area provided by Arrow Energy.
- Flow data “watershed” from the Department of Environment and Resource Management (DERM).
- LIDAR data for part of Curtis Island provided by Arrow Energy.
- Various reports and data as listed in the References section.

The information gathered and prepared for this report has been collated and presented such that it can be used by Arrow Energy as a framework to aid in site selection and management of environmental, construction and in-service operational risk. Mapping data is available in ESRI ArcView digital format to support Arrow Energy planning.

3.4 Assessment of Hydrology

3.4.1 Assessment Method

The assessment was undertaken using the following method.

- Examination of climate data from Bureau of Meteorology.
- Examination of flow data and flood risk data from DERM “Watershed”, the surface water data archive of the former Department of Natural Resources and Water, which includes gauging station information and streamflow data summaries.
- Search of relevant reports and data on flooding and flood risk for the project area, primarily “Calliope Flood Study” (Sargent Consulting, 2007) and “Auckland Creek Flood Study” (GHD, 2006).
- Overview of water use and surface water extraction (ANRA,2010a; Queensland Government, 2007).
- Identification of sub-catchments.

  To aid with the assessments required for the EIS the Calliope and Curtis island basins have been further divided to a catchment and sub-catchment level for the study area. The identification of catchments and sub-catchments is useful for a number of purposes including: identification of major streams for the assessment of hydrology, water quality and aquatic ecology; and to contribute to the geomorphic assessment of watercourses.

  The identification of catchments and sub-catchments was undertaken using the program CatchSIM and then manually rectified with consideration given to identifying a size of sub-catchments that would provide the most useful tool to aid the project’s various assessments. The sub-catchments were only examined from the most upstream extent of catchments above the study area, downstream to the point immediately below the study area.

Where streams were unnamed on Geosciences Australia 1:100,000 mapping the subcatchments were given numbers. On Curtis Island, a more detailed hydrologic assessment has been undertaken (Attachment B), requiring a more detailed identification of subcatchments in the area of the LNG plant. Those subcatchments have been given names (main, east, west and southeast) to aid flood assessments.

- Assessment of flooding of the catchments in the study area on Curtis Island.

  Assessment of existing conditions has been undertaken largely as a desktop exercise with a field assessment on 15 and 16 June 2010. Investigations involved reviewing climate records, available terrain data and aerial photography. Hydrologic and hydraulic modelling were also undertaken to understand the likely surface water conditions at the site. The industry accepted model RORB was used, which is a general runoff and streamflow routing program used to calculate flood hydrographs from rainfall and other channel inputs. Further details are provided as Attachment B.

3.4.2 Limitations of Sub-catchment Identification and Hydrology Assessments

The accuracy of the sub-catchment mapping is limited by the quality of the data available, which was LIDAR point data for part of the LNG facility area on Curtis Island and 5m contours elsewhere. However, this is considered to be sufficient for the purposes of this study.

A summary of available hydrology for key project components is provided in Table 7-2in Section 7 - Design Constraints, page 59.

3.5 Assessment of Geomorphology

3.5.1 Assessment method

The assessment was undertaken using the following method.

- Modification of the 1:100,000 scale Queensland Wetlands Programme “Hyd_Stream” layer version 2.0, to refine spatial accuracy and include the application of the River Styles geomorphic categorisation utilising SPOT satellite imagery and Google Earth aerial photography, topography and geologic information.
- Field assessment of selected locations, were undertaken mainly in June 2010 but also in February 2011 to assess options for TWAF7 and TWAF8, and targeted watercourses across the project area.
- Review of relevant reports and data of the geomorphic character and condition of the study area streams.
- Inclusion of extent and intactness of riparian vegetation as a component of geomorphic stability.

3.5.2 Stream Ordering

Stream ordering provides an indication of the relative size of a watercourse within a climatic and geomorphic setting. A classification of Strahler stream order was applied to the project watercourses. Strahler's (1952) stream order system is a simple method of classifying stream segments based on the number of tributaries upstream. A stream with no tributaries (headwater stream) is considered a first order stream. A segment downstream of the confluence of two first order streams is a second order stream. Thus, a n^{th} order stream is always located downstream of the confluence of two $(n-1)^{th}$ order streams (Strahler, 1952).

An example is shown in Figure 3-1 below.

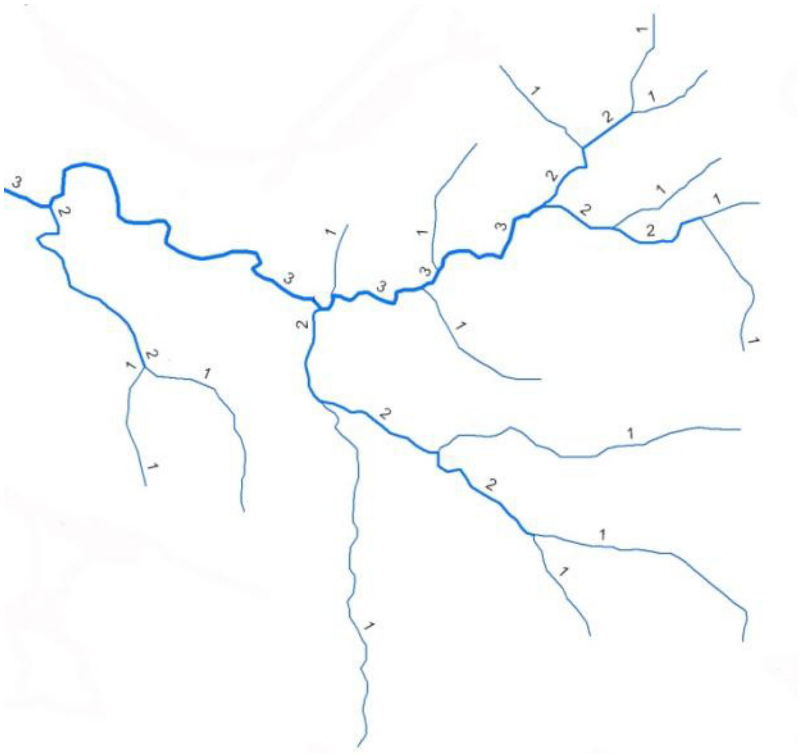


Figure 3-1. ***Strahler stream ordering***

3.5.3 Geomorphic Categorisation

The assessment of the geomorphic character and behaviour of the watercourses in the study area has been undertaken using the River Styles framework (Brierley and Fryirs, 2005). This has predominantly been a desktop exercise using aerial photography, topography and geology and has been supported by selected field work. A more detailed river styles assessment would include additional field work assessing at least a reach, generally close to reference, of each of the river styles identified in the desktop assessment. This would then provide for typical cross section and planform sketches illustrating geomorphic unit assemblages as well as ground photos. However, that additional level of assessment was not warranted given the limited length of watercourses that are expected to be impacted by the project.

The River Styles framework (Brierley and Fryirs, 2005) provides a set of procedures from which to integrate catchment-scale geomorphic understanding of river forms, processes and linkages. The framework allows for the description and explanation of the within-catchment distribution of river forms and processes. River Styles record the character and behaviour of rivers throughout a catchment. The approach is hierarchical and can be implemented at the desired range of scales.

To assist readers in understanding the geomorphic assessment, some commonly used terms are described in the Glossary.

For this assessment, all watercourses mapped for this study have been assessed at a desktop level and selected reaches ground-truthed, including reaches that have been identified as potentially being impacted by project activities. A key component of the technique is the relationship of the watercourse and any associated floodplains to the valley or landscape setting in which they occur.

Key distinctions are confined valley, partly confined valley and alluvial unconfined settings.

- **Confined valley** settings are defined by >90% of the channel being in contact with the valley side or margin. In these situations there is minimal floodplain, and rivers in this setting are often steep and bedrock controlled.
- **Partly confined** valley settings are defined by 10-90% of the channel abutting the valley margin. Floodplains are common in these settings but often they are broken into discrete pockets or sections as the channel crosses from one side of the valley to another. The shape of the valley (i.e., straight vs. curved and irregular in width), and the wavelength of the channel crossing the valley floor combine to dictate the length of the floodplain pockets. Lower sinuosity channels will cross from one side of the valley to the other less frequently than a more sinuous channel.
- **Alluvial** settings are defined by the channel being in contact with the valley margin for less than 10% of its length. Floodplains are usually continuous along both sides of the channel in these settings. There are two main sub-groupings within the alluvial setting, which are defined on the nature of the channel. ***Alluvial discontinuous*** River Styles are characterised by channel forms that are not continuous. These categories are not robust and have low resilience (high sensitivity) to changes in catchment conditions, hence are often found in an incised or channelised state and behave more like an Alluvial Continuous stream. ***Alluvial continuous*** River Styles contain channel/s that are continuous. This is the broadest and most diverse of the three main groups. The numerous sub-groups within this type are defined on the:
    - Number of channels.
    - The sinuosity of the channel/s.
    - The dominant grain size in the channel bed.

Thus a fine grained single channel that has a moderate to high sinuosity is called *Fine grained meandering*.

The geomorphic categories identified from the desktop and field assessments are shown in Table 3-2. Mapping, examples of each category (River Style) and further details are provided in Section 4 - Existing Environment.

Table 3-2. ***River styles of the study area***

Valley-setting and River Style	Attributes relevant to project planning
Confined valley setting **Confined -** occasional floodplain pockets, frequent bedrock controls	Robust stream form with low sensitivity to disturbance.
Confined valley setting **Headwater –** thin alluvial/colluvial deposits in narrow valley floor that is near contiguous with hillslopes, much exposed bedrock/indurated Tertiary sediments	Robust stream form with low sensitivity to disturbance. Usually a first order stream in the upper catchment. Generally steeper gradient and stable with bedrock controls, which are naturally erosion resistant rock layers that prevent bed deepening by erosion.
Confined valley setting **Partly confined low sinuosity** valley and channel with planform controlled discontinuous floodplain	Robust stream form with low sensitivity to disturbance. Often feature naturally erosion resistant rock layers that prevent bed deepening by erosion.
Confined valley setting **Partly confined meandering** channel with planform controlled discontinuous floodplain	May be subject to more rapid rates of erosion on the outside of bends than other partly-confined watercourses. Bedrock controls will be present.
Alluvial or partly confined valley setting (no channel when intact) **Valley fill**, alluvial and colluvial sediments across valley floor with no channel.	These watercourse types store large amounts of sediment and play a critical role in sediment and water flux in the landscape. Can be subject to rapid erosion if disturbed and/or flow is concentrated (such as occurs with pipes

Valley-setting and River Style	Attributes relevant to project planning
	through roads). Careful rehabilitation required if planned to be disturbed.
Alluvial valley setting (Continuous channel) **Low-moderate sinuosity fine grained**	Susceptible to erosion if disturbed.
Alluvial valley setting (Continuous channel) **Low-moderate sinuosity gravel bed**	Less susceptible to erosion than low-moderate sinuosity fine grained but still requires considered erosion control if disturbed.
Laterally unconfined valley setting, continuous channels. Two types have been identified in the project area: **Tidal - low moderate sinuosity** **Tidal - meandering**	Susceptible to erosion of disturbed.

3.5.4 Riparian vegetation

As a component of the geomorphic assessment, riparian vegetation was assessed for intactness along all of the mapped watercourses. Ecological values of riparian vegetation have not been assessed as part of this report but are considered in Ecosure (2011). This was done by examination of aerial imagery and with ground truthing of key sites. Two categories were identified in line with identified environmental values (EVs) and as input to the assessment of sensitivity. Those categories were:

- Intact – where riparian vegetation was judged to be predominantly undisturbed from clearance, agricultural, industrial or urban activity.
- Disturbed - Slightly to Moderately – a broad category ranging from minor disturbance to areas of cleared banks and reaches.

3.3.5 Wetland Characterisation

The data used to identify wetlands in the study area is from the Queensland Wetlands Programme (version 2.0 – February 2009). The wetland GIS layer was clipped to the study area and wetland types identified.

4 Existing Environment

As part of the existing environment two other projects (the proposed Queensland Curtis LNG project and Gladstone LNG Project) are expected to have been constructed on Curtis Island and have therefore been considered as part of the existing environment. This is identified in more detail in Section 9 – Cumulative Impacts.

4.1 Drainage Divisions, Basins, Catchments and Sub-catchments

The study area as shown in Figure 1-1 covers 8,017.6ha, which is comprised of:

- 4,167.6 ha (52%) Mainland (Calliope basin).
- 600.7 ha (7.5%) Curtis Island.
- 30.5 ha (0.4%) Small islands.
- 3,218.8 ha (40.1%) Marine.

The study area lies within the Calliope Basin (basin number 132) and Curtis Island (basin number 131) within Australia's Northeast Coast Drainage Division[1]. An area of 3,218.8ha is marine and separates the mainland from Curtis Island.

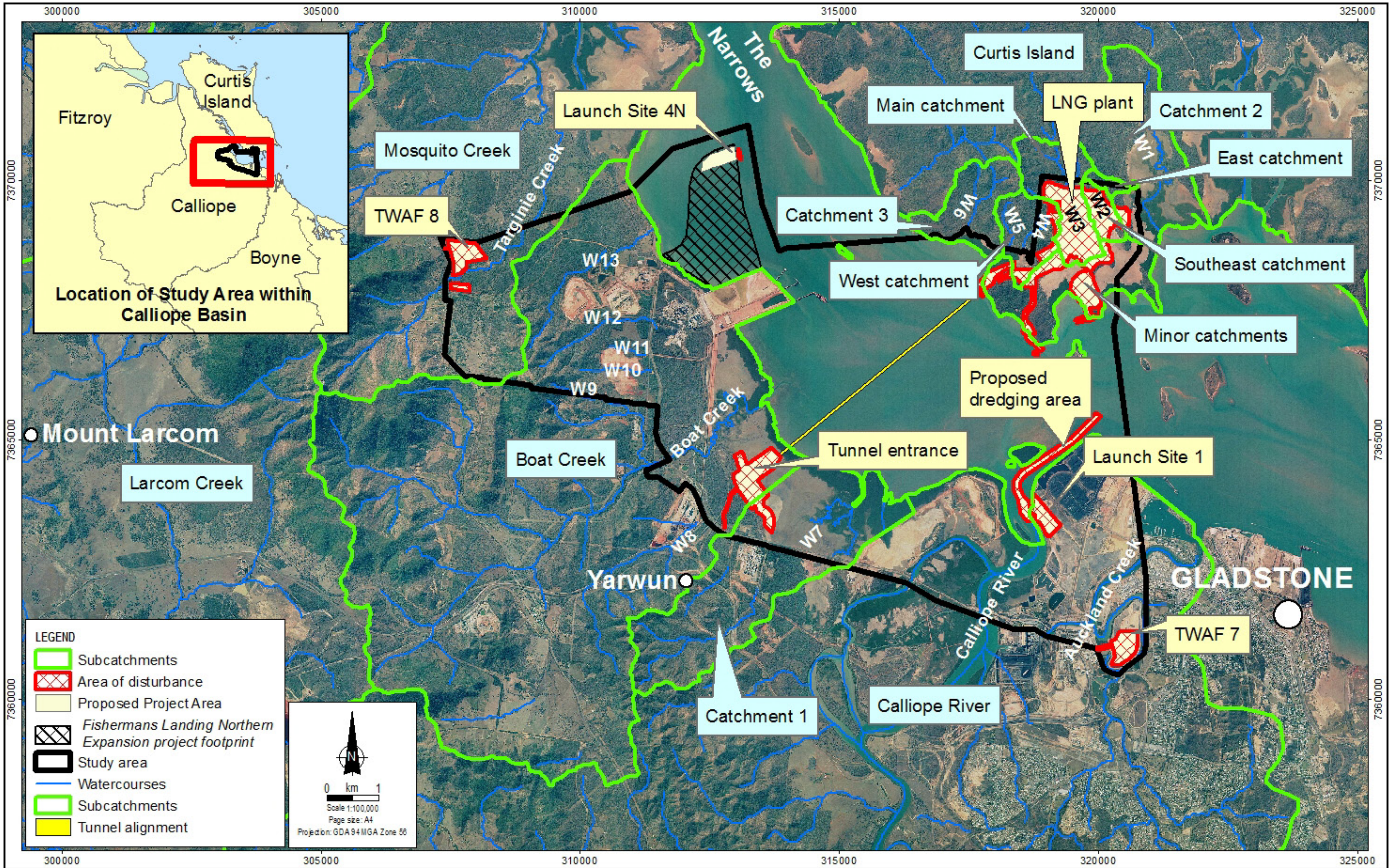
Sub-catchments, as identified using the method in Section 3.4, page 15, are shown in Figure 4-1, page 22.

Only some watercourses are named on 1:100,000 scale mapping (National Topographic Map, Gladstone). Unnamed watercourses in the project area have therefore been given the following references as shown in Table 4-1 and Figure 4-1 and will be discussed by those names herein.

[1] Australia's drainage divisions and river basins were formally defined by the Australian Water Resources Council in the early 1960s and, with minor modifications resulting from improved mapping of the inland arid zone area, have been the basis for the study of Australian hydrology since then. The 12 drainage divisions were defined by both the major topographic features of the continent and the main climatic zones to give broadly homogeneous hydrologic regions. Within the drainage divisions the 245 river basins are defined by the major watershed lines (Australian Government, Bureau of Meteorology, 2009).

Table 4-1. ***Watercourse names***

Catchment	Watercourse
Curtis Island	
Catchment 2	With one mapped waterway W1
East catchment	No mapped waterways
Southeast catchment	One mapped waterway W2
Main catchment	One main waterway with headwater tributaries W3
West catchment	With two mapped waterways W4 and W5
Catchment 3	One main waterway with headwater tributaries W6
Calliope Basin	
Calliope River	Auckland Creek Calliope River
Catchment 1	Poorly defined watercourses with channel modifications in the area of industrial development at Yarwun. Identified as W7.
Boat Creek	Boat Creek Tributary identified as W8, has been channelised around the industrial area at Yarwun (and the channelised drain is not mapped as a watercourse) and flows to Boat Creek. W9 is a headwater tributary of Boat Creek. W10, W11 and W12 are headwater streams that enter floodout zones (without defined channels) before discharging to the coast W13 is comprised of two mapped channels, one that enters a floodout zone and the other discharging directly to the coast.
Mosquito Creek	Targinie Creek.



Source:
Study area, proposed facilities from Arrow Energy.
Watercourses modified from DERM 1:100,000 mapping.

alluvium

Date:	30.05.2011
MXD:	P210002
File Name:	P210002-F4-1
Rev:	1

Arrow Energy

Arrow LNG Plant

arrow energy

Sub-catchments

Figure No: 4-1

4.2 Hydrology

4.2.1 Climate

The climate of the Gladstone area can be described as subtropical. PAEHolmes (2011) identify the average annual rainfall as being 878 mm for Gladstone Radar (1957 to 2010), and 793 mm for Gladstone Airport (1993 to 2010). The bulk of the rainfall occurs during the summer months, with averages of approximately 100-190 mm. During winter, average monthly rainfall varies between 20 and 45 mm. Mean monthly minimum temperatures range between 21 and 23°C in the summer and decrease to 11.7°C in the winter at Gladstone Airport. The mean maximum temperatures can range between 30 and 32°C in the hottest months and decrease to about 23°C during the coldest part of the year.

For detailed information on climate of the study area see PAEHolmes (2011) .

4.2.2 Calliope River Catchment Hydrology

The Calliope River catchment sits within the Fitzroy River Basin, the largest basin draining into the Great Barrier Reef lagoon. Confined by the Calliope Range to the west, the Boyne Range to the south and the Mt Alma and Mt Larcom Ranges to the north, the Calliope River catchment covers an area of 1,860km^2 (Sargent, 2006). An often reported larger area of 2,250km^2 includes coastal streams that flow directly to the coast (including Auckland Creek, Boat Creek and Mosquito Creek within the study area) and are not tributaries of the Calliope River. The location of the study area within the Calliope catchment is shown in Figure 1-1, page 7.

The Calliope River commences in the Calliope Range flowing initially south-east and then easterly towards the township of Calliope. Before reaching the township the river turns in a north-easterly direction, dropping from the ranges to the coastal plain where it meanders its way to the coast on the north-west edge of Gladstone, a stream length of approximately 100km. Its main tributaries include Alma Creek, Larcom Creek, Oaky Creek, Paddock Creek and Double Creek, all of which are outside the study area.

Typically less than 5km wide, though around 16km at its widest, the coastal plain is narrow and has little relief with most terrain below 50m above sea level (ASL). Maximum elevation in the catchment is approximately 940m AHD with several peaks above 700m AHD. Eroding gullies are common in the steep ranges parallel to the coast (RGSQ, 2011).

Located in the central coast region, under the Tropic of Capricorn, the catchment is in a subtropical climate zone typified by a summer rainfall where almost two-thirds of rain falls between December and March. Rainfall is low to moderate in the undulating coastal plains and increases to moderate to high as a result of orographic influences in the steeper ranges. The mean annual rainfall over the catchment (1920 – 1969) is 800-1,000mm. (ANRA, 2010a).

Development is considered low (< 30% allocation of water resource) and with no storages in the catchment, hydrology is considered relatively unmodified from natural condition while limited water quality information shows little change (ANRA, 2010a). With a mean annual runoff of 301,000 ML/year, actual flows are considered near to natural flows. Numerous floods on the Calliope River have been recorded since records began in 1938 with the largest being in 1947 and, more recently, the fifth largest in 2003. Regional flooding throughout Queensland in 2010/2011 saw the Calliope River subject to flooding in December 2010, though the magnitude of the event was unknown at the time of preparing this report.

Approximately 85% of the catchment area is zoned rural, 5% as forest and the remainder zoned to development for infrastructure, village and residential use. Over 80% of the catchment has been cleared and less than 1% of the catchment is within protected areas (GBRMPA, 2010). Calliope River itself contains an almost continuous, narrow strip of riparian vegetation along most of its length (C&R Consulting in Queensland Government, 2007). Cattle grazing is the dominant land use in the catchment, primarily confined to the coastal plains where much of the natural vegetation has been thinned or removed, while the ranges mostly retain undisturbed eucalypt forests (RGSQ, 2011).

The 2000-2002 National Land and Water Resources Audit theme assessments (ANRA, 2010a) recorded consumptive use of surface water at approximately 92% irrigation, 6% urban/industrial and 2% rural. Water use, primarily from the Calliope River and its tributaries, has been estimated at between 1,500 and 4,500 ML/yr, assuming all licences are being used (Queensland Government, 2007).

There are no identified current consumptive water users in or downstream of the areas planned to be disturbed by the project with the exception of the coastal wetlands of Port Curtis and limited domestic stock water from Targinie Creek in and downstream from TWAF8. Historically, grazing by domestic stock has seen the construction of small dams within the study area on Curtis island, but these are no longer in service for that purpose. On the mainland there have been no consumptive uses at or downstream of the planned project infrastructure, with the exception of limited stock water use in Targinie Creek.

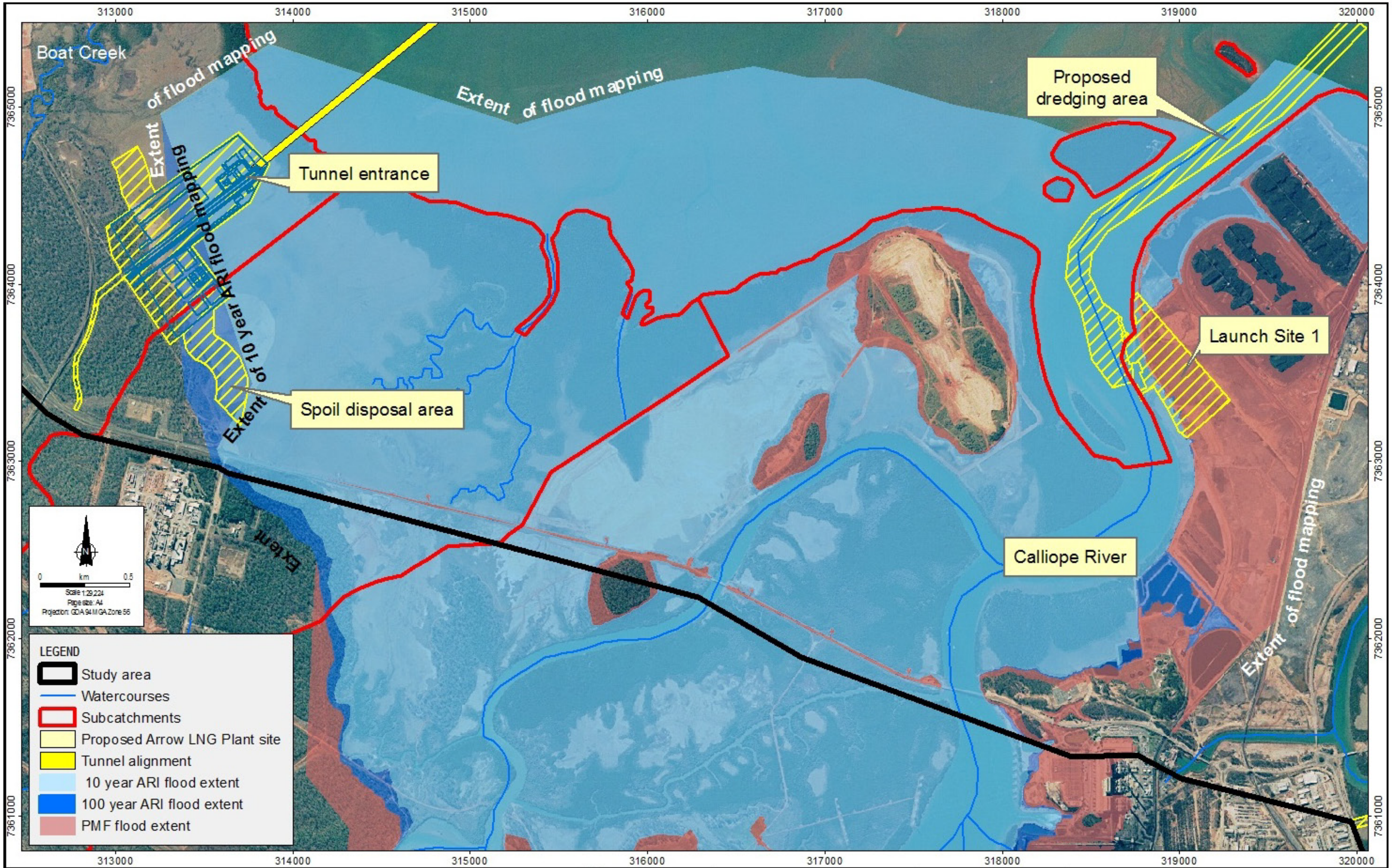
The development of erosion and salinity problems on marginal land has led to land management being identified as a high priority to reduce sediment loads being transported by rivers into the Great Barrier Reef lagoon. The natural flows of the Calliope River will likely play a significant role in maintaining the ecology of the Gladstone Harbour estuary given the modification and reduction in freshwater flows of the Boyne River (from the construction of Boondooma Dam) (Queensland Government, 2003), which is south east of the study area.

There is only one streamflow gauging station (132001A) currently in operation in the Calliope River catchment. Opened in 1938 at Castlehope, 32.8km upstream from the river's outlet, it has a catchment area of 1,288km^2. One other gauging station (132002A) on the Calliope River operated at Mount Alma from 1968 to 1988 however, this is in the upper catchment with a catchment area of only 165km^2.

A recent flood study of the Calliope River (Sargent, 2006) used historic streamflow records from the Castlehope gauge (outside the study area) to assess the current flood risk downstream of the gauging station. The study identified a number of road crossings, including two low level crossings on the Calliope River, which would be subject to inundation by flows of 10 year ARI (Average Recurrence Interval) or less. The study also identified up to 15 properties in the township of Calliope that are liable to flooding from Leixlip Creek during a 100 year ARI event, with one property fronting Clyde Creek, which is liable to flooding during a 10 year ARI event and another on Clyde Creek, which is liable to flooding during a 100 year ARI event (Sargent, 2006).

Sargent's 2006 study provides flood mapping for the lower Calliope River, and includes the area of launch site 1 and part of the mainland tunnel entry shaft and tunnel spoil disposal area. A manually rectified scanned image of that flood mapping is shown as Figure 4-2. The mapping, prepared for the 10, 20, 50, 100, 200, 500 year ARI and for probable maximum flood, shows that these two areas are in a zone of flood inundation at varying events from as low as 10 year ARI to probable maximum flood.

Sargent (2006) also identified ongoing geomorphic changes to the Calliope River channel resulting from fluvial processes (e.g., widening of the channel predominantly during flood events) over the past 100 years. Continued channel change affects the ability to calibrate hydraulic models with distant historic flood events and thus the accuracy of modelling results is reduced.



Source:
Study area, proposed facilities from Arrow Energy.
Watercourses modified from DERM 1:100,000 mapping.
Flood mapping from Sargent (2006) Mapping is manually rectified and intended only as a preliminary guide.

Date: 03.05.2011
MXD: P210002
File Name: P210002-F003
Rev: 1

Arrow Energy

Arrow LNG Plant

Flood mapping
Lower Calliope River

Figure No: 4-2

4.2.3 Auckland Creek Catchment Hydrology

Auckland Creek is located within the Calliope catchment, flowing through and to the west of Gladstone (Figure 4-1, page 22). Auckland Creek is not a tributary of the Calliope River and is significant for the location of TWAF7, which lies within a meander of the creek (see Figure 4-3, page 27).

GHD (in 2006) identified that the upper portion of the Auckland Creek catchment consists of large areas of native bushland that remain in generally good condition. Several residential developments have been constructed within the upper catchment area, with consequent clearing of native vegetation. Creeks within the upper catchment are generally ephemeral, with flows only occurring during larger rainfall events significant enough to generate substantial overland flow. Land uses in the mid-catchment include residential development, recreational land and light industrial areas. Weirs have been placed at two locations within the Auckland Creek system forming Lake Tondoon and Lake Callemondah. The lower catchment area consists of tidally influenced waterways and tidal flats below Lake Callemondah. The waterways of the lower catchment area are typically saline and tidally influenced, with the weir at the downstream end of Lake Callemondah representing the divide between the freshwater and saltwater sections of Auckland Creek.

For Auckland Creek, GHD (2006) undertook an assessment of flooding for Gladstone City Council. This consisted of a review of previous studies and new hydrologic and hydraulic modelling. Water levels at the downstream boundary of the model (tailwater levels) have been defined on the basis of extreme tides. These include the highest astronomical tide and the 100 yr ARI storm tide level.

A total of five flood events were modelled, 20, 50, 100, 500 year ARI and probable maximum precipitation. Each of these events was assessed for existing and ultimate catchment development scenarios.

The extent of flooding for the ultimate land use for the 100 year ARI and probable maximum flood are shown as figures Figure 4-4, page 28, and Figure 4-5, page 29, respectively to illustrate example flood events.

alluvium	Date: 08.08.2011 MXD: P210002-F4-3 File Name: P210002-FB4-3 Rev: 1	Arrow Energy Arrow Energy LNG Plant	arrow energy	TWAF 7	Figure No: 4-3

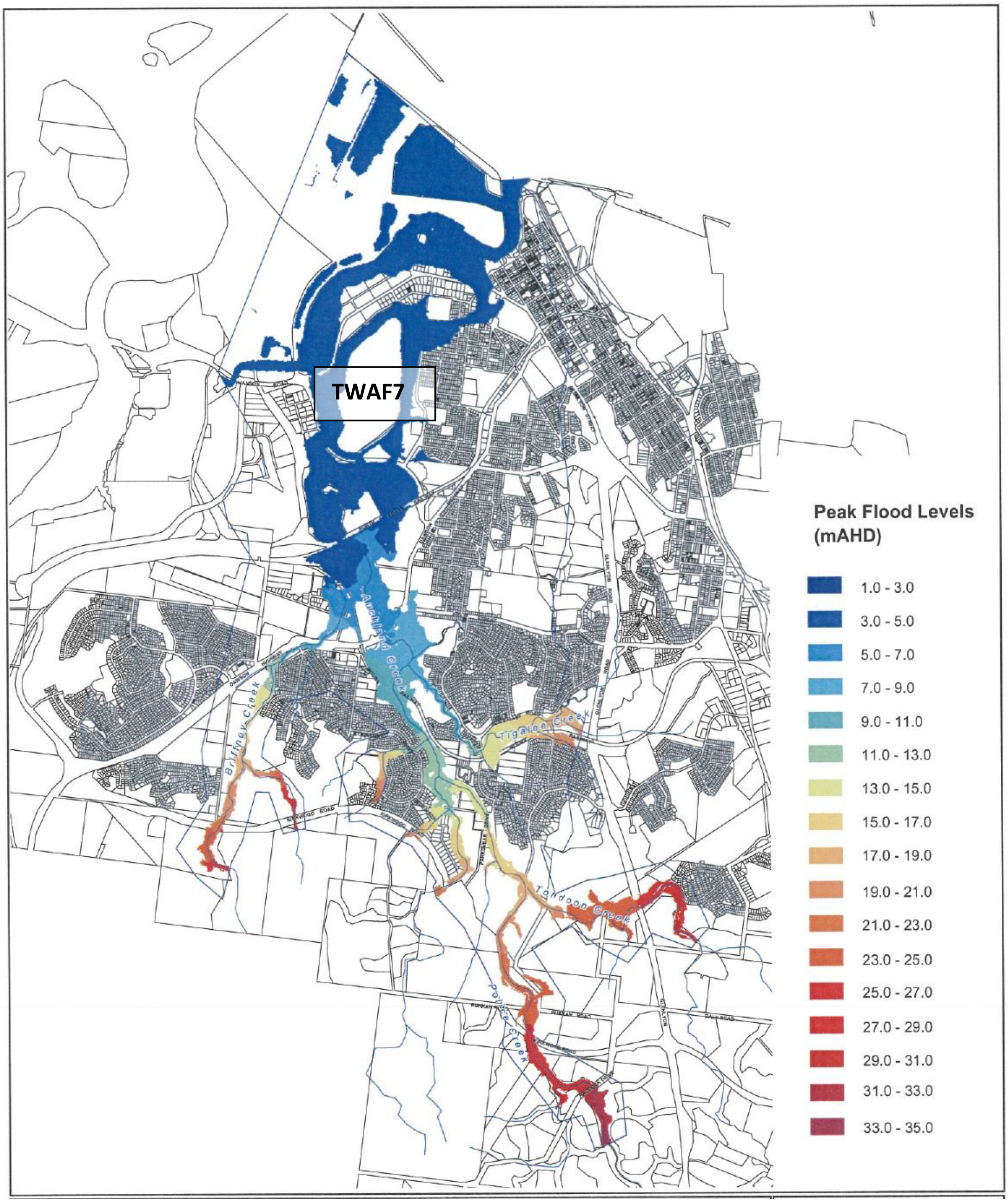


Figure 4-4. ***Flood mapping – 100 year ARI*** (GHD, 2006)

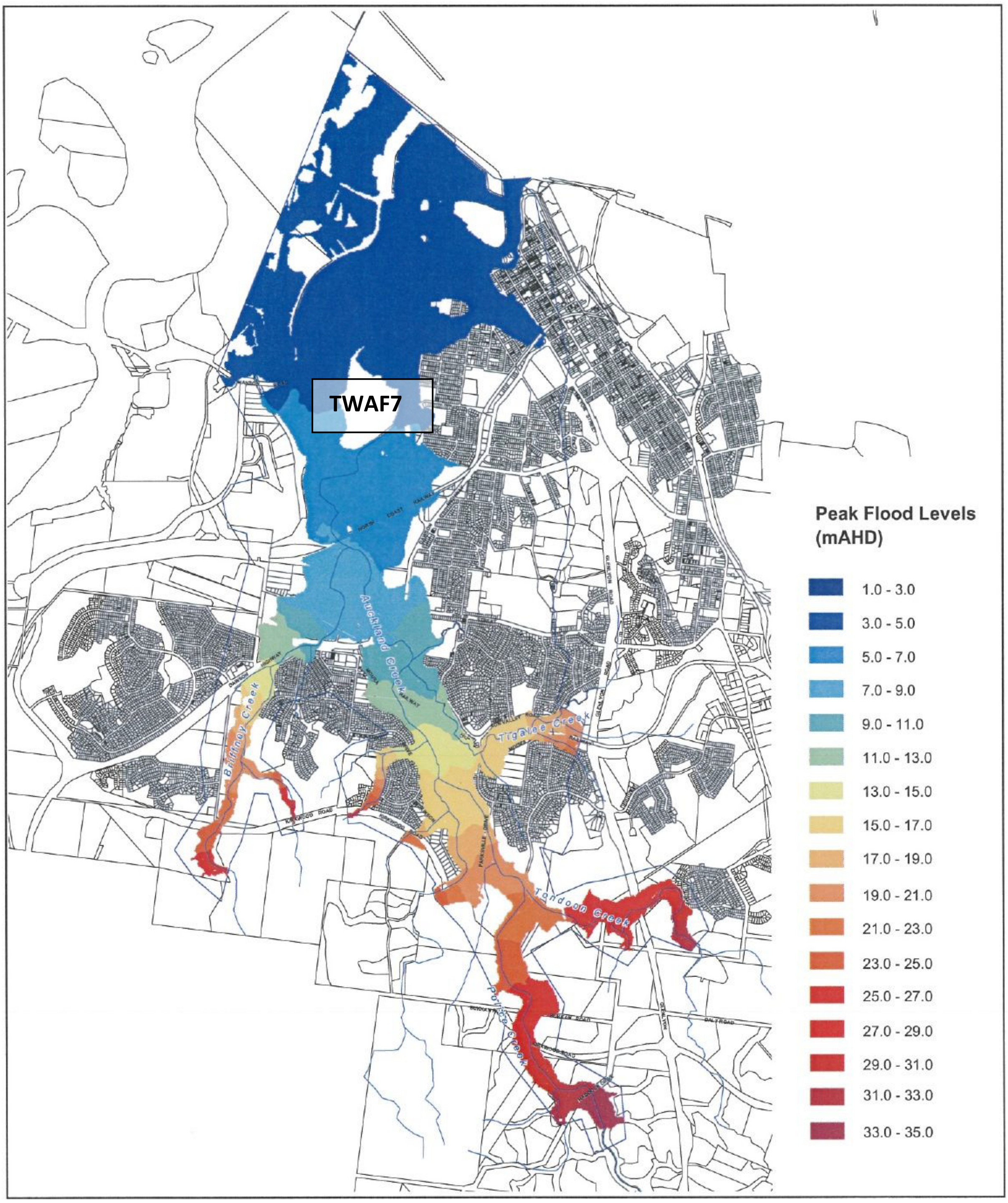


Figure 4-5. ***Flood mapping – probable maximum flood PMF*** (GHD, 2006)

4.2.4 Targinie Creek and Boat Creek

There are no known hydrologic studies or other data specifically for other mainland watercourses (including Targinie Creek, Boat Creek and Mosquito Creek). Assessment of the tunnel entry site is included in the "Coastal Processes, Marine Water Quality, Hydrodynamics and Legislation Assessment (BMT WBM, 2011).

4.2.5 Curtis Island hydrology

Overview

Curtis Island is approximately 45km in length and up to 14km wide with many sub-catchments over its area of 570km^2. It has low relief with the highest point being Mt Barker (approximately 30kms north of the LNG plant) at 163m ASL. A mean annual rainfall of 800-900mm (based on recordings over a 50 year period from 1920 to 1969) feeds numerous ephemeral streams (ANRA, 2010b). This is consistent with the annual average rainfall identified in PAEHolmes (2011) and Katestone Environmental (2011) for the monitoring data from the Bureau of Meteorology (BoM) mainland stations at Gladstone Airport and Radar Hill.

There are no significant storages in the catchment and though there is no gauging station on the island, modelling estimates a mean annual runoff of 79,000 ML/yr (ANRA, 2010b).

Limited clearing of natural vegetation has been undertaken for grazing and forestry activities.

All Curtis Island streams drain into the Great Barrier Reef World Heritage Area. Streams on the Arrow site drain to Port Curtis, which is also within the Great Barrier Reef World Heritage Area. Port Curtis wetland (which partly lies within the study area) is also listed on the listed on the Directory of Important Wetlands in Australia. The Calliope and Boyne Rivers provide significant freshwater input to shallow estuarine and marine waters and wetlands, which is important in maintaining ecological health.

Detailed hydrology

The construction of the LNG plant will require alteration of waterways in and around the site. As part of the assessment of requirements for those works, a flood study has been undertaken identifying riverine and storm surge flooding. For riverine flooding modelling identifies flood extents under current conditions. As part of the detailed design of the LNG plant, drainage and flood assessment of post construction conditions will be undertaken. For storm surge, an existing and post construction flood assessment has been undertaken. Details are provided as Attachment B.

4.3 Fluvial Geomorphology

4.3.1 Mainland

The study area on the mainland crosses several local coastal catchments including Boat Creek, Targinie Creek and a number of small unnamed first order creeks, draining the eastern side of the coastal range. It also includes the lower, tidal reaches of the Calliope River and Auckland Creek (Figure 4-1, page 22).

The geology and climatic conditions in these catchments have developed relatively thin and often cohesive soil horizons that remain reasonably stable following clearing and development in the catchment. These conditions mean that watercourses are not over-supplied with sediment as is the case through much of central Queensland.

Small first order watercourses are the dominant stream type by length in the study area. Tidal reaches also make up a substantial portion of the waterway network within the study area. The sinuosity and hence meander migration behaviour of these reaches is linked with catchment area, width of valley and length of tidal zone/coastal plain.

4.3.2 Curtis Island

There are two distinct zones for waterways on Curtis Island, relatively narrow valley floors with steep valley side slopes and the tidal zones. The transition between the two can be reasonably short. The mapped waterways on Curtis Island (many minor yet high energy waterways are not mapped) are generally confined or partly confined. Depth to bedrock is generally shallow with thin alluvial or colluvial deposits. Field observations identified that many unmapped gullies are up to 3m deep with an invert on bedrock.

The main waterway draining through the LNG plant area is a high energy cobble bed meandering partly confined waterway with occasional vertical and horizontal bedrock controls. Meander migration bank erosion is highly active on this waterway where bedrock controls are not present. The fire regime on Curtis Island appears to be influencing sediment loads in the waterways when heavy rains cause debris flows after fire when the land surface has minimal cover. Sediment slugs (localised deposits of eroded soil and gravel) and erosion heads (active erosion features manifest as small waterfalls in creek beds) are notable features on minor waterways.

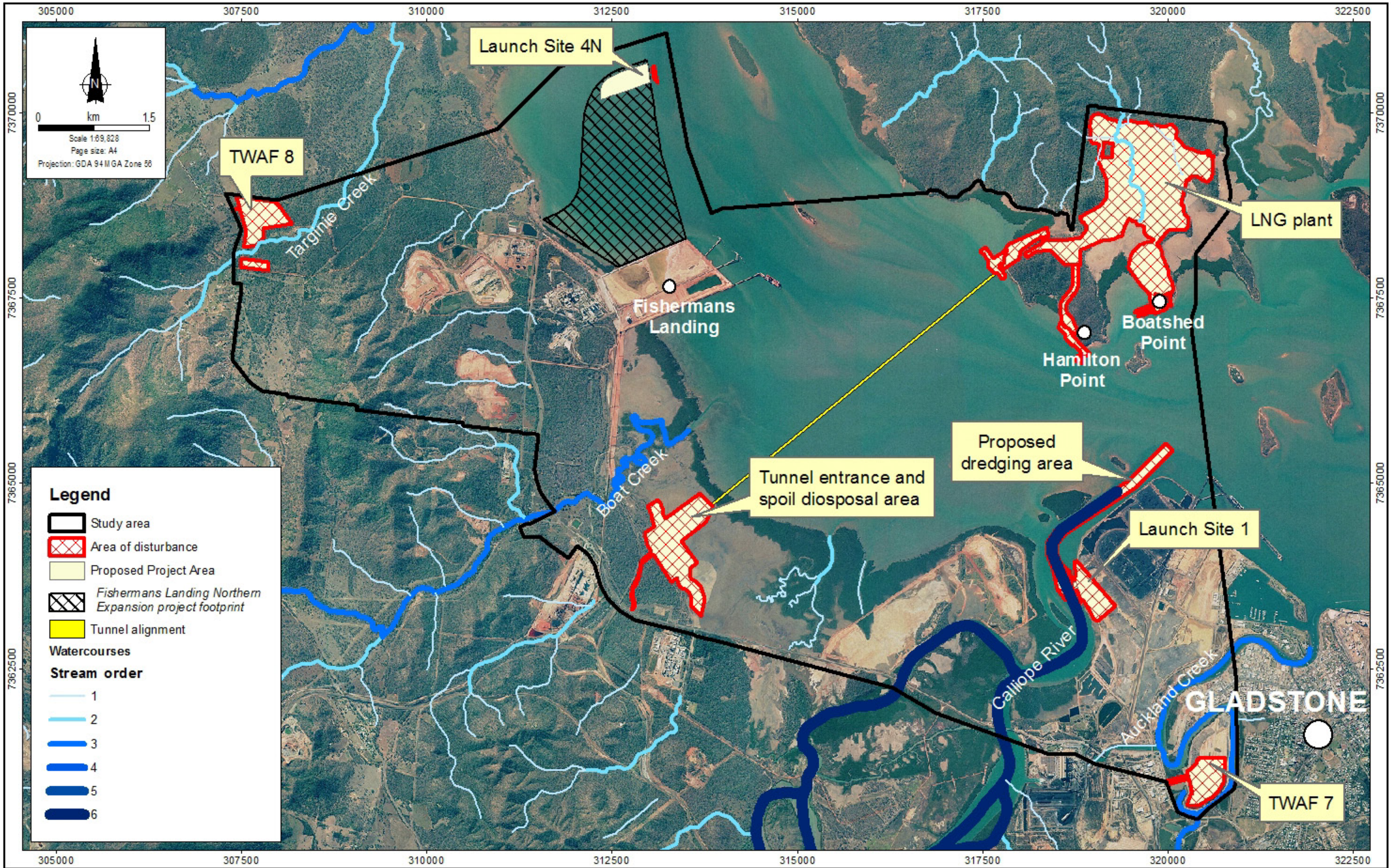
4.3.4 Stream orders

The stream orders for the study area catchments are shown in Figure 4-6, page 32. Stream lengths and Strahler stream orders are also presented for the area within the study area boundary in Table 4-2.

Table 4-2. Watercourse lengths and Strahler stream orders within the study area boundary

Strahler stream order	*km*	*%*
1	*17.7*	*44.7*
2	*5.0*	*12.55*
3	*9.9*	*25.08*
6	*7.0*	*17.55*
TOTAL	***39.6***	***100***

1st and 2nd order watercourses make up 61.71% of the mapped watercourse network.



Source:
Study area from Arrow Energy.
Watercourses modified from DERM 1:100,000 mapping.

alluvium

Date: 08.08.2011
MXD: P210002
File Name: P210002-F4-6
Rev: 1

Arrow Energy

Arrow LNG Plant

arrow energy

Stream orders

Figure No: 4-6

4.3.5 Geomorphic categorisation

In total, 39.6km of watercourses were assessed within the study area. The watercourse lengths by geomorphic category are shown in Table 4-3 and in Figure 4-7, page 35. Examples in the study area are detailed in Attachment A and locations of examples are shown in Figure 4-7.

Table 4-3. ***Geomorphic category (River Style) and watercourse length***

Geomorphic Category (River Style)	km	% of total length in study area	Reaches found in these Watercourses	Comments and study area examples (level of intactness)
Confined	<0.1	0.25	W3	E1: Only one short reach of this type is in the study area, which will not be disturbed. (intact)
Headwater	2.7	6.82	W9, W10 & W13	E2: No headwater creeks are planned to be disturbed in the study area. (intact)
Low-moderate sinuosity fine grained	2.7	6.82	Boat Creek, W4 & W8	E3: Part of Boat Creek and W13 (not planned to be disturbed by project activities) on the mainland and first order watercourse W4 on Curtis Island (partially currently disturbed by prior agricultural use).
Low-moderate sinuosity gravel bed	2.3	5.81	Targinie Creek	E4: Targinie Creek on the mainland at TWAF8. Low capacity channel with frequent out of channel flows (partially disturbed by agricultural use including clearance and grazing).
Partly confined low sinuosity	5.5	13.89	W2, W3, W12 & W13	E5: Found throughout the study area on both the mainland (W12 & W13) and Curtis Island (W2 & W3). Reaches of waterways W2 & W3 will be infilled and diverted (partially currently disturbed by prior agricultural use).
Partly confined meandering planform	1.5	3.79	W3	E6: Found in the area of disturbance on Curtis Island at transition from hillslope and valley to floodplain. This reach of waterway will infilled and diverted (partially currently disturbed by prior agricultural use).
Valley fill	2.2	5.56	W3, W10 & W11	E7: W10 & W111 on the mainland will not be disturbed. W3 will be infilled and diverted (partially currently disturbed by prior agricultural use) .
Tidal - meandering	9.1	22.98	Boat Creek & W7	E8: Neither of these watercourses will be disturbed (partially currently disturbed by prior agricultural use).
Tidal - low moderate sinuosity	13.5	34.09	Auckland Creek and Calliope River	E9: Launch site 1 is located in this type on the Calliope River and will have some disturbance (currently disturbed). Auckland Creek in the study area is an example of this type and may have some disturbance at an upgraded road crossing (currently highly disturbed).
TOTAL	**39.6**	**100**		

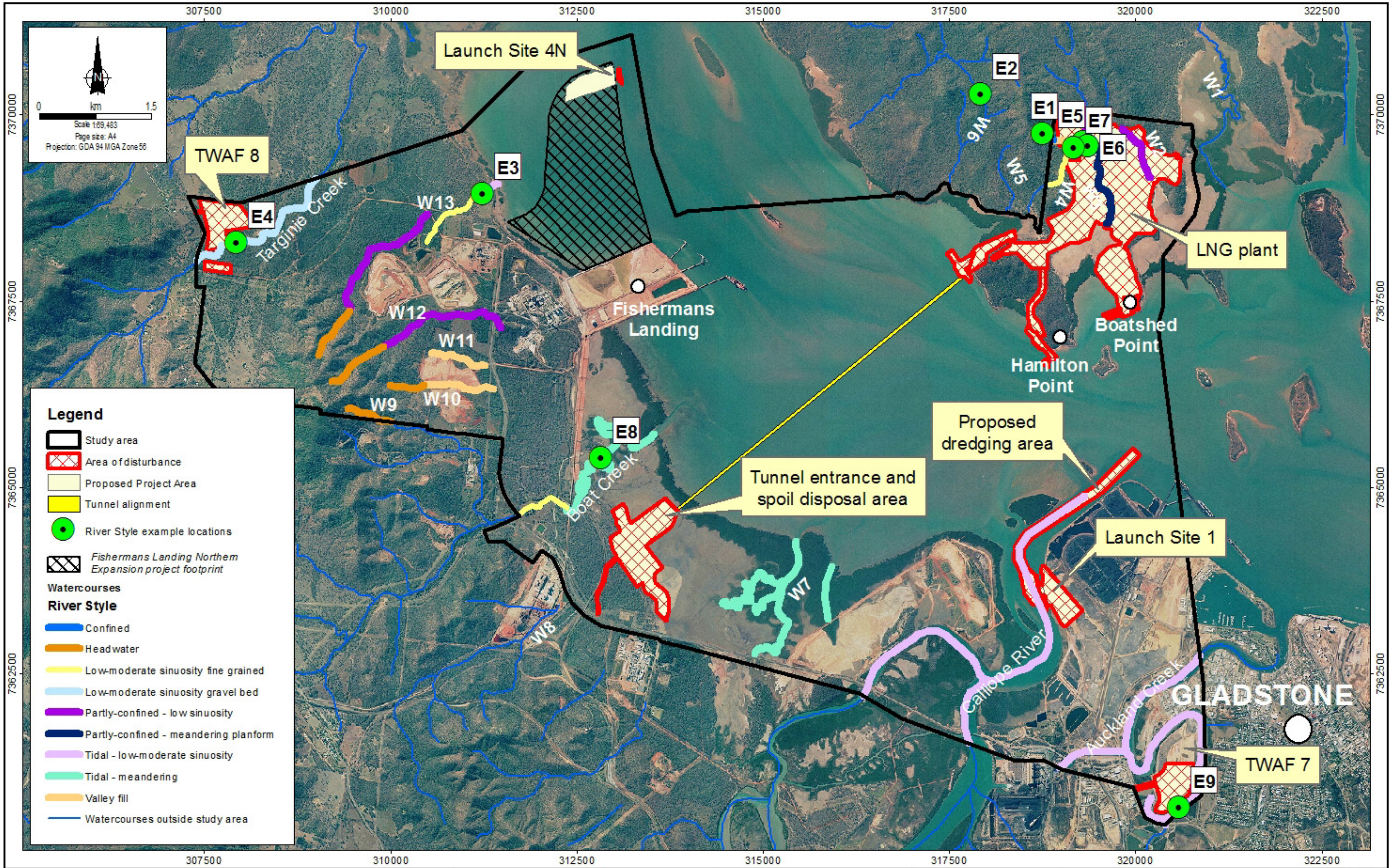
Riparian vegetation

As a component of the geomorphic assessment, riparian vegetation was assessed for intactness along all of the mapped watercourses in the study area. This was done with regard to the role that riparian vegetation plays in fluvial process and morphology of watercourses by stabilising banks and moderating flows by increasing roughness and thereby reducing velocities. The watercourse lengths by vegetation intactness are shown in Table 4-4 and Figure 4-7, page 35. As a general rule the more intact the riparian vegetation the more likely it is that fluvial process and morphology are operating close to natural, undisturbed condition. However, other factors such as modified flows regimes and weed invasion are also influencing factors.

It could be argued that some reaches of watercourses are highly disturbed (such as Auckland Creek TWAF7 and parts of the Calliope River near the mouth), however, such a distinction does not significantly affect the level of sensitivity and categorising all disturbed streams in this single category is a conservative approach.

Table 4-4. Riparian vegetation intactness by geomorphic category length

Riparian vegetation intactness by geomorphic category length	Intact km	% of total Intact	Disturbed km	% of total Disturbed
Confined	0.1	100	0	0
Headwater	2.7	100	0	0
Low-moderate sinuosity fine grained	0.66	24.4	2.07	76.7
Low-moderate sinuosity gravel bed	0	0	2.34	100
Partly confined low sinuosity	3.59	65.27	1.87	34
Partly confined meandering planform	0.61	40.67	0.85	56.7
Valley fill	0.43	19.5	1.77	80.5
Tidal - meandering	5.43	59.7	3.67	40.3
Tidal - low moderate sinuosity	0	0	13.5	100



Source:
Study area from Arrow Energy.
Watercourses modified from DERM 1:100,000 mapping.

alluvium

Date: 08.08.2011
MXD: P210002
File Name: P210002-F006
Rev: 1

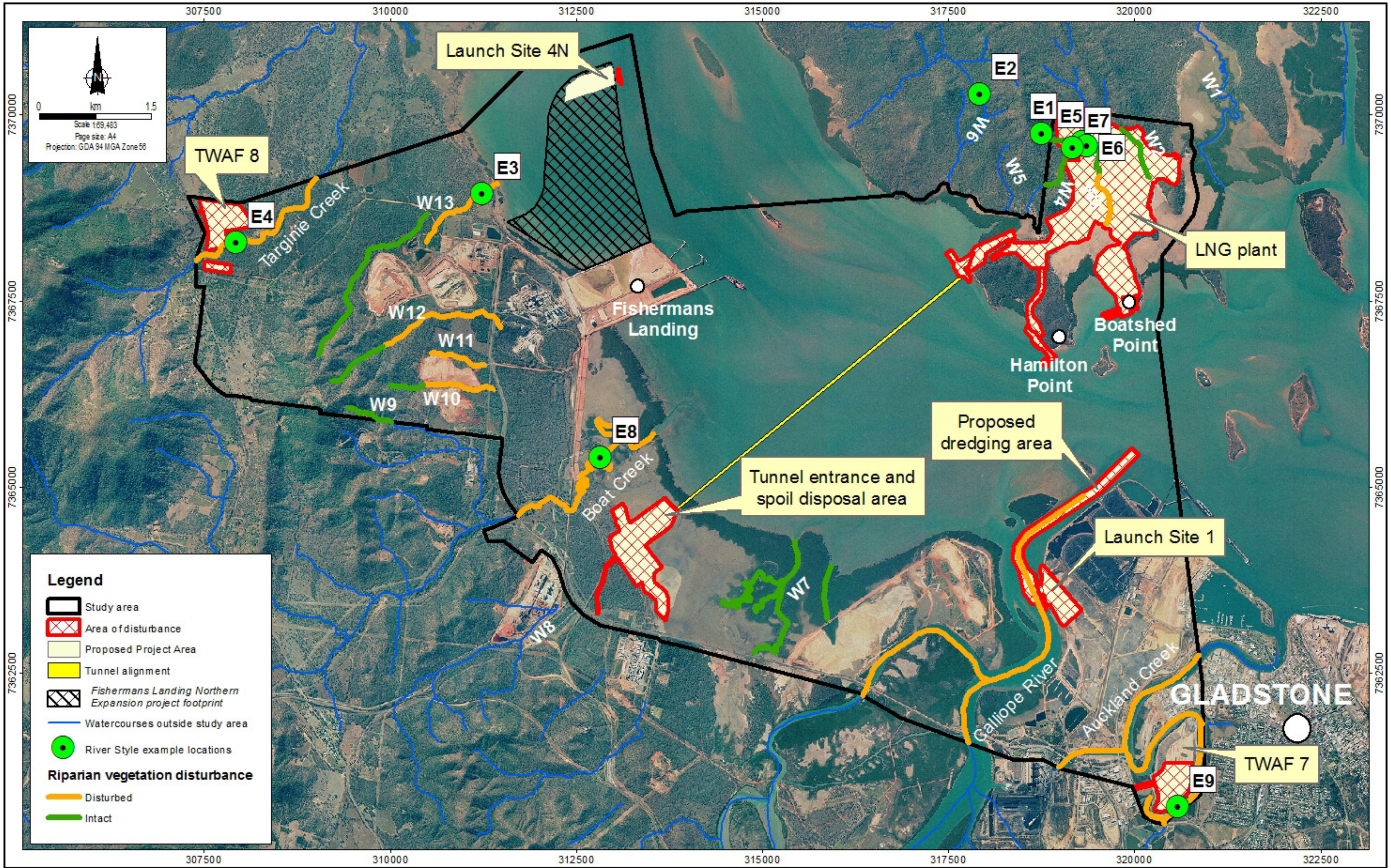
Arrow Energy

Arrow LNG Plant

arrow energy

Geomorphic Categories

Figure No: 4-7



Source:
Study area from Arrow Energy.
Watercourses modified from DERM 1:100,000 mapping.

alluvium	Date: 08.08.2011 MXD: P210002 File Name: P210002-F4-8 Rev: 1	Arrow Energy Arrow LNG Plant	arrow energy	Current extent of riparian vegetation disturbance	Figure No: 4-8

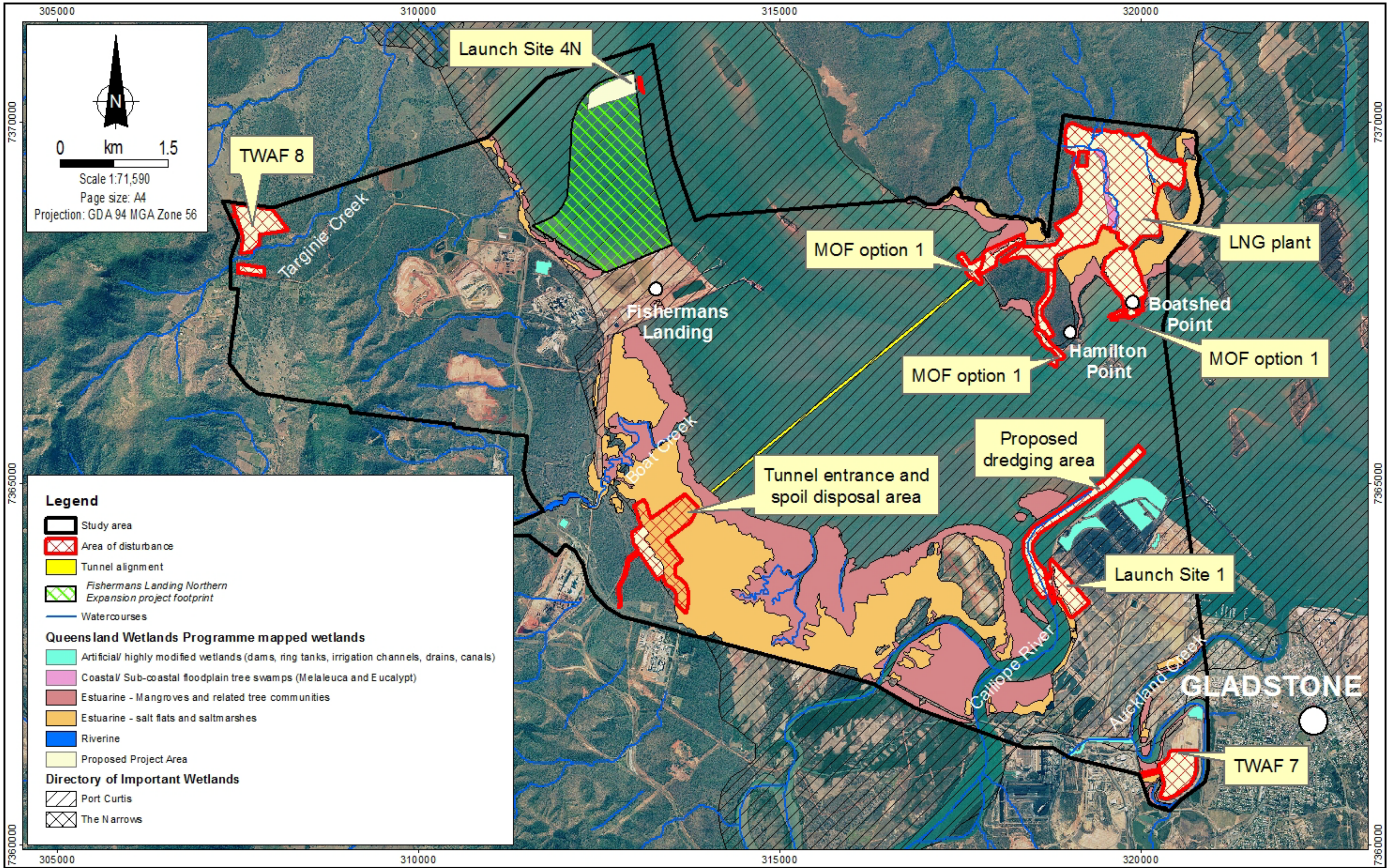
4.4 Wetland Characterisation

The data used to identify wetlands in the study area is from the Queensland Wetlands Programme (version 2.0 – February 2009). All waterbodies including wetland types are shown in Figure 4-9, page 38 and are comprised of the types identified in Table 4-5. It should be noted that the wetlands at TWAF7 are highly disturbed due to former land use and vegetation clearance. Wetlands along the mouth of the Calliope River at and adjacent to launch site 1 are also highly disturbed due to vegetation clearance, development and continuing access. Wetlands of the mainland are otherwise disturbed by recreational access by vehicles to varying degrees and infilled in the Fishermans landing area. Wetlands on Curtis Island in the study area are predominantly undisturbed with the exception of some access by vehicles and prior agricultural use.

The information presented here as part of the assessment of geomorphology and hydrology. For and assessment of wetland vegetation and ecology see Ecosure (2011) and for an assessment of marine and estuarine ecological values see Coffey Environments (2011b).

Table 4-5. ***Wetlands in the study area***

Wetlands	Ha	% of study area	Comments
Artificial highly modified wetlands	60.23	0.75	None to be disturbed in study area.
Estuarine – Mangroves and related tree communities	653.56	8.15	Potential disturbance at launch site 1 and TWAF7 on the mainland and in the footprint of the LNG plant and associated infrastructure on Curtis Island.
Estuarine – salt flats and salt marshes	744.03	9.28	Potential disturbance at launch site 1 and TWAF7 on the mainland and in the footprint of the LNG plant and associated infrastructure on Curtis Island.
Riverine	4.78	0.06	A reach of Boat Creek, not to be disturbed.
Coastal/Sub coastal floodplain tree swamps (Melaleuca and Eucalypt)	112.86	1.41	One example in the study area on Curtis Island currently with some disturbance due to prior agricultural use (clearing and road crossing). This reach will be infilled and a diversion constructed to bypass the LNG plant.
TOTAL	**1,575.46**	**19.65**	



Source:
Study area from Arrow Energy.
Watercourses modified from DERM 1:100,000 mapping.
Wetlands from Qld Wetlands Programme V2 digital mapping.

alluvium

Date: 08.08.2011
MXD: P210002
File Name: P210002-F4-9
Rev: 1

Arrow Energy
Arrow LNG Plant

arrow energy

Wetlands

Figure No: 4-9

4.5 Environmental Values

Specific environmental values for watercourses and wetlands in the study area are not defined within the *Environmental Protection (Water) Policy Act 2009* (Qld) (EPP Act). Environmental values have therefore been developed for the project based on desktop/archival/baseline and field investigations and with consideration of the following:

- State of the Environment Reporting Taskforce 2000 (Australian and New Zealand Environment and Conservation Council (ANZECC) 2000).
- Water Resource (Calliope River Basin) Plan (Queensland Government, 2006).
- Curtis Coast Regional Coastal Management Plan (Environmental Protection Agency, 2003).

Sustainable function and use of ecosystems is the primary environmental value of watercourses, wetlands and their catchments. Attributes that define the primary environmental value, are themselves values that collectively describe the intrinsic characteristics and properties of the watercourse or wetland and the associated catchment. The following attributes define the environmental values of surface water assets and are consistent with the above Plans.

1. Physical integrity, fluvial processes, form and morphology of watercourses and wetlands including riparian vegetation.
2. Hydrology of watercourses and wetlands in the catchment - quantity, duration and timing of stream flows.
3. Primary and secondary recreational use.
4. Physical and hydrologic character contributing to cultural and spiritual values.

Recreational values are discussed in SKM (2011). Cultural and spiritual values are discussed in CQCHM (2011).

Information about the attributes is set out in the preceding sections, particularly categorisation of stream geomorphology and hydrology (method described in Section 3.2).

There are no declared wild rivers in the project area.

4.6 Sensitivity of Environmental Value

Table 4-6, page 40 describes the sensitivity of environmental values of the study area (as described in Section 4.2) relating to the attributes defined above. Because the project is being developed in geographically different locations, the sensitivity of environmental values at those locations will differ and depend on the condition of the catchments, watercourses and wetlands. The approach taken is therefore the identification of the sensitivity of environmental values at each of the locations of project activities with regard to hydrology and geomorphology.

The following table identifies each project site and the associated surface water assets, and using the sensitivity criteria detailed in Section 3.2, assesses the sensitivity of the environmental values) described above) of those assets.

Table 4-6. Sensitivity of Environmental Values (EVs) at sites of project activities

Site	Surface water asset (catchment, watercourse, wetland)	Conservation status	Intactness	Uniqueness or rarity	Resilience to change	Replacement potential	Sensitivity
LNG plant site.	Local catchments; waterway W3 (valley fill reach).	None.	Largely intact but some disturbance of waterways from former clearance and agriculture.	Not unique or rare. Limited or no recreational use.	Valley fill reach susceptible to erosion of disturbed.	There are many similar waterways in the region.	Moderate
LNG plant site.	Local catchments; waterways W2, W3 & W4 draining to estuarine wetlands adjacent to Boatshed Point.	Partly within coastal wetlands within Port Curtis Wetland (Directory of Important Wetlands).	Largely intact but some disturbance of waterways from former clearance and agriculture. Wetlands largely intact with limited disturbance.	Not unique or rare. Limited or no recreational use.	Headwater streams are resilient to change. Resilience decrease as watercourses near marine areas through footprint of LNG plant.	There are many similar waterways and extensive wetlands around Curtis Island and in the region.	Low
TWAF7.	Auckland Creek catchment; Auckland Creek including estuarine wetlands.	None.	In poor condition due to former land use with almost complete clearance.	Primarily watercourse with limited fringing mangroves Not unique or rare.	Subject to natural geomorphic change over time through erosion and deposition. Can be stable for many years and subject to rapid change in extreme flow events.	Not applicable as the site is in poor condition.	Low
TWAF8.	Targinie Creek catchment; Targinie Creek.	None.	Moderate to good condition.	Not unique or rare.	Resilient to change to some extent but can be subject to change if highly disturbed.	There are many similar waterways in the area and region.	Low
Feed gas pipeline.	Boat Creek Catchment and Catchment 1.	N/A	Area to be disturbed has no mapped waterways. All disturbances will be in the mainland tunnel entry shaft and tunnel spoil disposal area.	N/A	N/A	N/A	N/A
Mainland tunnel entry shaft and tunnel spoil disposal area	Boat Creek Catchment and Catchment 1; Estuarine salt flats and salt marshes.	Coastal wetlands within Port Curtis Wetland (Directory of Important	No mapped watercourses will be disturbed. Disturbance confined to Estuarine salt flats and marshes, which are	Not unique or rare.	Resilient to change.	Many areas of similar extensive wetlands in the area and region.	Low

Site	Surface water asset (catchment, watercourse, wetland)	Conservation status	Intactness	Uniqueness or rarity	Resilience to change	Replacement potential	Sensitivity
		Wetlands).	largely intact.				
Launch site 1.	Calliope River catchment; Calliope River including estuarine wetlands.	Coastal wetlands within Port Curtis Wetland (Directory of Important Wetlands).	Disturbed area of Calliope River estuary bank.	Not unique or rare.	Resilient to change due to location on inside bend of Calliope River.	Many areas of similar extensive estuarine river bank in area and region.	Low
Dredge site 1.	Calliope River catchment; Calliope River.	Coastal wetlands within Port Curtis Wetland (Directory of Important Wetlands).	Currently intact reach of estuarine bed.	Not unique or rare.	Resilient to minor change but could result in bed and bank erosion if changes are significant.	Many areas of similar extensive estuarine reaches in area and region.	Moderate

5 Issues and Potential Pre-mitigation Impacts

5.1 Project Activities

Project activities that have the potential to result in environmental impacts to hydrology and geomorphology of watercourses and wetlands during construction, operational service and decommissioning are:

- Construction of the LNG plant and associated infrastructure (marine facilities and construction camps).
- Construction of TWAF7 including road crossing and TWAF8.
- Discharge and storage of hydro test water.
- Launch site 1 near the mouth of the Calliope River.
- Feed gas pipeline. This does not cross any mapped waterways or wetlands, except in the vicinity of the mainland tunnel entry shaft and tunnel spoil disposal area, which is discussed separately. The feed gas pipeline is not discussed further in this report.
- Mainland tunnel entry shaft and tunnel spoil disposal area.
- Dredge site 1 at the mouth of the Calliope River from launch site 1 past Mud Island to the main shipping channel.

It should be noted that consideration of potential impacts from the construction of the tunnel entry shaft and tunnel spoil disposal area has been confined to flood risk to the site (primarily from tidal inundation and storm surge) and erosion. Increased flood risk due to alteration of flood heights as a consequence of the construction of the tunnel entry shaft and tunnel spoil disposal area is of such a low potential significance that it is not considered through assessment in this report. An assessment of the potential risk of increasing flood heights in the Calliope River from the much larger Wiggins Island Coal Terminal Project (Section 8 of the Environmental Impact Statement (Connel HATCH, 2006)) has been made, which concluded that development had no major risk and only isolated increase of less than 0.1m. It is reasonable to conclude that the tunnel entry shaft disposal area site, which is much smaller and further from the Calliope River mouth would have an almost immeasurable effect on the Calliope River. It is also located sufficiently distant from Boat Creek to be able to state that the potential risk is negligible and does not warrant further investigation

5.2 Potential Pre-mitigation Impacts

Potential pre-mitigation impacts from these activities during construction, operation and decommissioning are described in Table 5-1 below.

Table 5-1. ***Potential issues and potential pre-mitigation impacts***

Site	Surface water asset (catchment, watercourse, wetland)	Potential issues	Potential pre-mitigation impacts
Construction of LNG plant	Local catchments; waterway W3.	• Valley fill reach susceptible to erosion if disturbed and will be disturbed as part of the LNG plant construction.	• Upstream erosion and downstream deposition.
Construction of LNG plant	Local catchments; waterways W2, W3 & W4 draining to estuarine wetlands adjacent to Boatshed Point and Hamilton Point.	• Disturbance of watercourses and wetland areas leading to loss of some of these features and changes to hydrology (direction and discharge points of surface flow paths)[2]. • Rainfall and runoff during construction. • Generation of sediment from stockpiles during rainfall. • Flood risk. • Tidal movement (including storm surge). • Hydrotest water. Options for use and disposal of hydrotest water are: sea water (will be sourced and disposed to the sea (Boatshed Point) and therefore not discussed further in this report); freshwater to be sourced from the RO plant and disposed of to sediment retention pond.	• The wetlands identified as coastal/sub-coastal floodplain tree swamps (11.29 ha) will be removed as part of the LNG plant construction process and the waterway will be replaced with a diversion. • In the footprint of the LNG plant an area of approximately 2.3 ha of estuarine salt flats and salt marshes will be in-filled as part of the construction process. • Possible loss of wetlands identified as estuarine – mangrove and related tree communities: MOF option 1 – 0.5 ha; MOF option 2 – 0.6 ha; MOF option 3 – 2.4 ha. MOF option 3 may also result in loss of 0.4 ha of salt flats and salt marshes. • Erosion and generation of sediment from rainfall and runoff. • Generation of sediment from tidal movement in areas disturbed within high tide extents (including storm surge). • Inundation of parts of the construction site from flooding. • Changes to direction and discharge points of surface flow paths. • Premitigation impact of disposal of hydrotest water - erosion and generation of sediment if discharged form sediment retention pond.
Operation of LNG plant	Local catchments; waterways W2, W3 & W4 draining to estuarine wetlands adjacent to	• Flood risk. • Mixing of upslope clean water flows with runoff from operational areas.	• Erosion and generation of sediment from rainfall and runoff. • Changed surface flow paths and mixing of surface flows generated from on and off site.

[2] The waterways in the vicinity of the LNG plant are first and second order (Identified as waterways W2, W3 & W4 in Figure 4-1, page 23) and will require diversion and modification as part of the construction and operation of the facility. Written advice from DERM (15 February 2011) has stated that the features in the area of disturbance on Curtis Island are not watercourses (as defined under the Act) and therefore works to interfere with them do not require authorisations under the provisions of the Act. Nevertheless, these waterways will require due consideration as part of the planning, design, construction and operation process. They will also require due consideration at decommissioning of the LNG plant and LNG plant diversion. Options are discussed in Attachment B.

Site	Surface water asset (catchment, watercourse, wetland)	Potential issues	Potential pre-mitigation impacts
Decommissioning of LNG plant	Boatshed Point. Local catchments; waterways W2, W3 & W4 draining to estuarine wetlands adjacent to Boatshed Point.	• Generation of sediment from disturbed areas during rainfall. • Management of self-sustaining waterways without the need for ongoing maintenance. • Generation of sediment from disturbed areas during rainfall.	• Post decommissioned waterways erode at greater than pre-construction rates resulting in sediment discharges downstream. • Erosion and generation of sediment from rainfall and runoff.
Construction of TWAF7	Auckland Creek catchment; Auckland Creek including estuarine wetlands.	• There is a road crossing connecting the mainland to site TWAF7, which is in a meander loop of Auckland Creek that will be upgraded. • Risk of riverine flooding. • Tidal inundation (including storm surge). • Generation of sediment from disturbed areas during rainfall. • Alterations to the crossing could adversely affect flood flows and result in offsite impacts. • Geomorphic change is possible in large flow events resulting in the neck cut-off eroding (see Figure 4-3). • Ensuring that the site following decommissioning does not have any adverse impacts to hydrology or geomorphology compared to current condition. • Generation of sediment from disturbed areas during rainfall. • Risk of flooding.	• Riverine flooding during construction resulting in erosion and generation of sediment. • Tidal inundation of road crossing construction works results in soil disturbance and generation of sediment. • The alterations of the existing road crossing could potentially change the hydraulic conditions of flood flows resulting in off-site impacts. • A large flood event or events could result in channel change at the road crossing neck cutoff of the meander loop resulting in damage to infrastructure and possible additional erosion. • The altered crossing will remain after the site is decommissioned. If the design of the altered crossing does not retain or increase the hydraulic capacity of the crossing, the post decommissioned crossing could result in adverse hydraulic conditions compared to pre-construction conditions leaving ongoing potential for offsite impacts during flooding.
Construction of TWAF8	Targinie Creek catchment; Targinie Creek.	• Risk of flooding during construction, operation and decommissioning. • Risk of changing localised flood conditions if area of disturbance encroaches on current area of potential flood envelope causing a constriction of flows. • Generation of sediment from adjacent disturbed areas during rainfall. • Minor increase in runoff due to sealed surfaces during operation.	• Erosion and generation of sediment from rainfall and runoff including increased runoff from sealed and disturbed surfaces. • Inundation of parts of the site and infrastructure from flooding. • Localised changes to flood extents.
Construction of launch site 1	Calliope River catchment; Calliope River including estuarine wetlands.	• Flood risk. • Tidal inundation (including storm surge). • Disturbance of river bank.	• Wetlands identified as coastal/sub-coastal floodplain tree swamps (up to 1.7 ha) will be removed or disturbed as part of the construction process.

Site	Surface water asset (catchment, watercourse, wetland)	Potential issues	Potential pre-mitigation impacts
		• Rainfall and runoff during construction.	• An area of up to 1.6 ha of estuarine salt flats and salt marshes is planned to be removed or disturbed as part of the construction process. • Erosion and sediment generation.
Operation of launch site 1	Calliope River catchment; Calliope River including estuarine wetlands.	• Flood risk. • Storm tide inundation. • Erosion and generation of sediment from disturbed areas during rainfall. • Bank erosion from boat wash/wave action.	• Erosion and sediment generation form disturbed areas and boat wash/wave action. • Tidal inundation of Infrastructure.
Decommissioning of launch site 1	Calliope River catchment; Calliope River including estuarine wetlands.	• Disturbance of river bank. • Generation of sediment from disturbed areas during rainfall.	• Erosion and sediment generation.
Construction of mainland tunnel entry shaft and tunnel spoil disposal area	Boat Creek Catchment and Catchment 1; Estuarine salt flats and salt marshes.	• Disturbance and loss of wetland areas. • Changed surface runoff. • Flood risk. • Tidal movement (including storm surge). • Rainfall and runoff during construction.	• An area of approximately 52.4 ha of wetlands mapped as salt flats and salt marshes will be infilled for the mainland tunnel entry shaft and tunnel spoil disposal area. • Erosion and generation of sediment from rainfall and runoff. • Generation of sediment from tidal movement in areas disturbed within high tide extents. • Inundation of parts of the construction site from flooding.
Dredging of dredge site 1	Calliope River catchment; Calliope River.	• Either erosion or sedimentation depending upon sediment supply and transport capacity. Disturbance and generation of sediment in the mouth of the Calliope River.	• Potential infilling of the dredged channel with sediment if the supply of sediment from upstream is greater than the ability of flow in the channel to transport sediment. • Potential erosion of the upstream face of the dredged channel.
Operation of dredge site 1	Calliope River catchment; Calliope River.	• Geomorphic change due to riverine high flows and/or tidal movement.	• Maintenance dredging of the channel could result in upstream headward bed deepening and bank slumping, which propagate beyond the maintenance period..

5.3 Magnitude of Potential Impacts

In this section the magnitude and significance of pre-mitigation impacts are described in relation to each environmental value (as per the method described in Section 3.2, page 11). The significance (sensitivity and magnitude) of the potential impacts on the identified environmental values has then been determined with reference to Table 3-1, page 14, to identify a pre-mitigated assessment of the significance of each impact.

Table 5-2. ***Potential issues and potential pre-mitigation impacts***

Site	Surface water asset	Sensitivity	Potential pre-mitigation impacts	Magnitude Criteria	Magnitude	Significance
Construction of LNG plant	Local catchments; waterway W3.	Moderate	• Upstream erosion and downstream deposition.	• Geographical extent - sub catchment waterways upstream erosion and downstream erosion and deposition. • Duration – time of construction but could propagate beyond without the application of mitigation. • Severity – negative moderate impacts on and off-site.	Moderate	Moderate
Construction of LNG plant	Local catchments; waterways W2, W3 & W4 draining to estuarine wetlands adjacent to Boatshed Point and Hamilton point.	Low	• The wetlands identified as coastal/sub-coastal floodplain tree swamps (11.3 ha) will be removed as part of the LNG plant construction process and the waterway will be replaced with a diversion. • In the footprint of the LNG plant an area of approximately 2.3 ha of estuarine salt flats and salt marshes will be in-filled as part of the construction process. • Possible loss of wetlands identified as estuarine – mangrove and related tree communities: MOF option 1 – 0.5 ha; MOF option 2 – 0.6 ha; MOF option 3 – 2.4 ha. MOF option 3 may also result in loss of 0.4 ha of salt flats and salt marshes. • Erosion and generation of sediment from rainfall and runoff. • Generation of sediment from tidal movement in areas disturbed within high tide extents. • Inundation of parts of the construction site from flooding. • Changes to direction and discharge points of surface flow paths. • Disposal of hydro test water - erosion and generation of sediment if discharged form sediment retention pond.	• Geographical extent - sub catchment waterways upstream erosion and downstream erosion and deposition. Loss of up to 14.1 ha of wetlands. Diversion of approximately 2.6 kms of minor waterways. • Duration – erosion and deposition: time of construction but could propagate beyond without the application of mitigation. Loss of wetlands and diverted waterways permanent. • Severity – negative high impacts.	High	Moderate
Operation of LNG plant	Local catchments; waterways	Low	• Erosion and generation of sediment from rainfall and runoff.	• Geographical extent - sub catchment waterways upstream erosion and downstream erosion and deposition.	Moderate	Low

Site	Surface water asset	Sensitivity	Potential pre-mitigation impacts	Magnitude Criteria	Magnitude	Significance
	W2, W3 & W4 draining to estuarine wetlands adjacent to Boatshed Point.		• Changed surface flow paths and mixing of surface flows generated from on and off site.	• Duration – time of operation but could propagate beyond without the application of mitigation. • Severity – negative moderate impacts on and off-site.		
Decommissioning of LNG plant	Local catchments; waterways W2, W3 & W4 draining to estuarine wetlands adjacent to Boatshed Point.	Low	• Post decommissioned waterways erode at greater than pre-construction rates resulting in sediment discharges downstream. • Erosion and generation of sediment from rainfall and runoff.	• Geographical extent - sub catchment waterways upstream erosion and downstream erosion and deposition. • Duration – time of construction but could propagate beyond without the application of mitigation. • Severity – negative moderate impacts on and off-site.	Moderate	Low
Construction of TWAF7	Auckland Creek catchment; Auckland Creek including estuarine wetlands.	Low	• Riverine flooding during construction resulting in erosion and generation of sediment in areas below flood level. • Tidal inundation of road crossing construction works results in soil disturbance and generation of sediment. • The alterations of the existing road crossing could potentially change the hydraulic conditions of flood flows resulting in off-site impacts. • A large flood event or events could result in channel change at the road crossing neck cutoff of the meander loop resulting in damage to infrastructure and possible additional erosion. • The altered crossing will remain after the site is decommissioned. If the design of the altered crossing does not retain or increase the hydraulic capacity of the crossing, the post decommissioned crossing could result in adverse hydraulic conditions compared to pre-construction conditions leaving ongoing potential for	• Geographical extent - localised erosion and deposition. Possible offsite increased flooding. • Duration – time of construction but could propagate beyond without the application of mitigation. Possible offsite increased flooding a long term risk. • Severity – negative low erosion impacts on and off-site. Increased flood risk moderate.	Moderate	Low

Site	Surface water asset	Sensitivity	Potential pre-mitigation impacts	Magnitude Criteria	Magnitude	Significance
			offsite impacts during flooding.			
Construction of TWAF8	Targinie Creek catchment; Targinie Creek.	Low	• Erosion and generation of sediment from rainfall and runoff including increased runoff from sealed and disturbed surfaces. • Inundation of parts of the site and infrastructure from flooding. • Localised changes to flood extents.	• Geographical extent – deposition downstream. • Duration – time of construction but could propagate beyond without the application of mitigation. • Severity – negative low impacts on and off-site.	Moderate	Low
Construction of launch site 1	Calliope River catchment; Calliope River including estuarine wetlands.	Low	• Wetlands identified as coastal/sub-coastal floodplain tree swamps (up to 1.7 ha) will be removed or disturbed as part of the construction process. • An area of up to 1.6 ha of estuarine salt flats and salt marshes is planned to be removed or disturbed as part of the construction process. Erosion and sediment generation.	• Geographical extent – localised impact with some off-site impacts from sediment discharge. • Duration – during construction but could propagate beyond without the application of mitigation. • Severity – negative moderate impacts on and off-site.	Moderate	Low
Operation of launch site 1	Calliope River catchment; Calliope River including estuarine wetlands.	Low	• Erosion and sediment generation form disturbed areas and boat wash/wave action. • Tidal inundation of Infrastructure.	• Geographical extent – localised impact with some of-site impacts from sediment discharge. • Duration – during operation could propagate beyond without the application of mitigation. • Severity – negative moderate impacts on and off-site.	Moderate	Low
Decommissioning of launch site 1	Calliope River catchment; Calliope River including estuarine wetlands.	Low	• Erosion and sediment generation.	• Geographical extent – localised impact with some off-site impacts from sediment discharge. • Duration – during decommissioning works but could propagate beyond without the application of mitigation. • Severity – Negative moderate impacts on and off-site.	Moderate	Low
Construction of mainland tunnel	Boat Creek Catchment	Low	• An area of approximately 52.4 ha of wetlands mapped as salt flats and salt marshes will be infilled for the mainland	• Geographical extent – localised impact with some off-site impacts from sediment	High	Moderate

Site	Surface water asset	Sensitivity	Potential pre-mitigation impacts	Magnitude Criteria	Magnitude	Significance
entry shaft and tunnel spoil disposal area	and Catchment 1; Estuarine salt flats and salt marshes.		tunnel entry shaft and tunnel spoil disposal area. • Erosion and generation of sediment from rainfall and runoff. • Generation of sediment from tidal movement in areas disturbed within high tide extents. • Inundation of parts of the construction site from flooding.	discharge. • Duration – time of construction but could propagate beyond without the application of mitigation. • Severity – Negative moderate impacts on and off-site.		
Construction of dredge site 1	Calliope River catchment; Calliope River.	Moderate	• Potential sedimentation if supply exceeds transport. • Potential erosion if transport exceeds supply.	• Geographical extent – off-site impacts from sediment discharge. • Duration – time of construction but could propagate beyond without the application of mitigation. • Severity – negative moderate impacts on and off-site.	Moderate	Moderate
Operation of dredge site 1	Calliope River catchment; Calliope River.	Moderate	• Maintenance dredging of the channel could result in upstream headward bed deepening and bank slumping.	• Could propagate upstream erosion for unknown distance with downstream deposition and continue beyond project life. • Duration – time of operation during high flows and potentially many years beyond. • Severity – negative moderate impacts on and off-site.	Moderate	Moderate

6 Avoidance, Mitigation and Management Measures

6.1 Overview

Section 6.2 provides generic avoidance, mitigation and management measures with reference to the project activities (as detailed in Section 5) that have the potential to impact on the hydrology and geomorphology of surface water in the study area. Section 6.3 details additional site specific measures for each of the identified project activities.

6.2 Generic Avoidance, Mitigation and Management Measures

Some avoidance, mitigation and management measures are common to some or all project activities. These listed and discussed here.

Table 6-1. ***Generic avoidance, mitigation and management measures***

Potential pre-mitigation impacts	Avoidance, mitigation and management measures
Erosion and generation of sediment from disturbed areas from rainfall and runoff.	• Stockpiles should be located away from watercourses and wetlands to reduce the likelihood of sediment washing into the watercourses. • Where appropriate, control measures such as drains, swales, silt fencing and sediment traps should be constructed around the lower slopes of stockpiles and regularly maintained at all sites where material will be stockpiled (LNG Plant, TWAF7, TWAF8, mainland tunnel entry shaft, and launch site 1). • Maintenance of stormwater management structures should include: repair of subsidence and erosion; removal of sediment (and safe disposal to appropriate secure area); repair of silt fencing; removal of litter and weeds. • Soil should be graded away from watercourses. • Sediment and erosion control measures should be implemented on slopes approaching watercourses and wetlands to prevent sediment discharge to watercourses. This may include the use of sediment traps, silt fencing, riprap and vegetation and diversion berms, all of which should be appropriately maintained. • Dewatering of ponds, if required, will be undertaken at a rate and location that will not result in erosion and additional erosion protection measures will be implemented if required. Development and implementation of a site drainage plan for construction.
Generation of sediment from tidal movement in areas disturbed within high tide extents (including storm surge).	• Bunding of construction areas (mainland tunnel launch site and tunnel spoil disposal area; potentially LNG Plant site areas and launch site 1, where tidal inundation is possible; and TWAF7 road crossing) at risk of tidal inundation. • Construction of inundation protection bunds for infrastructure above identified storm surge heights. The conservative BMT WBM (2011) design storm tide maximum level of 4.06 AHD for detailed design and future planning should be adopted (see Attachment B, Section B2.5).
Loss of riparian vegetation	• Locally occurring native plant species will be used to replace riparian vegetation disturbed during construction. Specific plans will be developed for each site of disturbance with the aim of reinstating as near as practical the original suite of native plant species. Exotic sterile grasses may be used where a temporary cover is required to aid stabilisation.

6.3 Site Specific Avoidance, Mitigation and Management Measures

In addition to the generic avoidance, mitigation and management measures described in section 6.2 there are a range of site specific actions that should be applied to the project activities that have the potential to impact upon the hydrology and/or geomorphology of the study area.

Table 6-2. *Site specific avoidance, mitigation and management measures*

Site	Potential pre-mitigation impacts	**Site specific avoidance, mitigation and management measures** (in addition to generic measures presented in table 6.2)
Construction of LNG plant (waterway W3)	• Upstream erosion and downstream deposition.	• Sensitive valley fill waterway will require site specific erosion control measures and be incorporated as part of the diversion design discussed below.
Construction of LNG plant (waterways W2, W3 & W4 draining to estuarine wetlands adjacent to Boatshed Point and Hamilton point.)	• The wetlands identified as coastal/sub-coastal floodplain tree swamps (11.3 ha) will be removed as part of the LNG plant construction process and the waterway will be replaced with a diversion. • In the footprint of the LNG plant an area of approximately 2.3 ha of estuarine salt flats and salt marshes will be in-filled as part of the construction process. • Possible loss of wetlands identified as estuarine – mangrove and related tree communities: MOF option 1 – 0.5 ha; MOF option 2 – 0.6 ha; MOF option 3 – 2.4 ha. MOF option 3 may also result in loss of 0.4 ha of salt flats and salt marshes. • Changes to direction and discharge points of surface flow paths. • Disposal of hydro test water - erosion and generation of sediment if discharged form sediment retention pond.	• The wetlands identified as being removed and/or infilled will be lost permanently. Some replacement coastal/sub-coastal floodplain tree swamps may be possible by incorporating appropriate revegetation of suitable areas as part of diversion construction. • Where possible, clearing the slopes upslope of the LNG Plant that feed into the waterway diversion should be delayed until the waterway diversion/s construction is due to be undertaken. • Where filling is occurring, stabilise slopes to prevent erosion and sediment discharge to the adjacent remnant salt flats and salt marshes. Stabilisation methods should predominantly be vegetative but can also include rock armouring at the interface of high tides. • Designing diversion/s to industry standard, which will manage rates of erosion and sedimentation to no greater than natural rates. This will require concept, functional and detailed design. • Not adversely impacting upon upstream and downstream reaches by managing erosion and deposition rates to be no more than natural rates (to be determined as part of the diversion design). This will require detailed design of diversion/s. • Design waterway diversion/s and adjacent flood corridor/s to manage a minimum of a 1:100 year ARI event. • Bunding of construction areas at risk of tidal inundation may be required depending upon the construction sequence. This will need to be considered for the LNG plant footprint and the selected MOF option. • Changes to direction and discharge points of surface flow paths will occur. This will reduce discharges from waterway W3 and increase discharges to W4 and possibly W1 and/or W2 depending upon the final design. Additional erosion protection works (rock riprap) will be required for receiving waterways. • Following main construction activities, disturbed areas with the potential to

Site	Potential pre-mitigation impacts	**Site specific avoidance, mitigation and management measures** (in addition to generic measures presented in table 6.2)
		generate sediment should be treated with appropriate stabilisation measures (vegetation, erosion control matting, and rock revetment) to prevent the generation of sediment. • Rehabilitation of diversion/s banks should be undertaken immediately after construction. • Design waterway diversion/s and adjacent flood corridor/s to manage a minimum of a 1:100 year ARI event. • Mitigation for hydrotest water (quality) is to test the water for oxygen scavengers and biocides, treat water if necessary before disposal to sediment basin. If required additional erosion protection to be added to sediment basin and overland flow.
Operation of LNG plant	• Changed surface flow paths and mixing of surface flows generated from on and off site.	• Design and implement a Stormwater Management Plan, which will include on-site management of stormwater by separation for off-site clean water runoff and treatment before discharge via constructed waterway/s downslope of the plant.
Decommissioning of LNG plant	• Post decommissioned waterways erode at greater than pre-construction rates resulting in sediment discharges downstream.	• The diversion's will be permanent and will be designed so that the waterways will continue to operate in equilibrium with upstream and downstream reaches without the need for ongoing maintenance. Drainage within the site following decommissioning will be required to be designed and constructed to operate without the need for ongoing maintenance.
Construction of TWAF7	• Riverine flooding during construction resulting in erosion and generation of sediment. • Tidal inundation (including storm surge) of road crossing construction works results in soil disturbance and generation of sediment. • The alterations of the existing road crossing could potentially change the hydraulic conditions of flood flows resulting in off-site impacts. • A large flood event or events could result in channel change at the road crossing neck cutoff of the meander loop resulting in damage to infrastructure and possible additional erosion. • The altered crossing will remain after the site is decommissioned. If the design of the altered crossing does not retain or increase the hydraulic capacity of the crossing, the	• Design crossing so as not to change the hydraulic conditions of flood flows that could result in off-site impacts. • Timing of construction works to avoid highest risk of riverine flood flows and to manage high tides, which will require bunding. • An assessment of changes to hydraulic conditions as a result of alterations to the road crossing should be undertaken. • In conjunction with the design of the upgraded access road crossing, a geomorphic assessment should be made to consider the risk of the neck cut-off developing further as a result of the changed crossing and develop management measures if required. • Erosion protection (rock riprap) for altered road crossing and to manage additional erosion risk.

Site	Potential pre-mitigation impacts	Site specific avoidance, mitigation and management measures (in addition to generic measures presented in table 6.2)
	post decommissioned crossing could result in adverse hydraulic conditions compared to pre-construction conditions leaving ongoing potential for offsite impacts during flooding.	
Construction of TWAF8	• Localised changes to flood extents. • Inundation of parts of the site and infrastructure from flooding.	• Flood assessment required if this site is to be developed.
Construction of launch site 1	• Wetlands identified as coastal/sub-coastal floodplain tree swamps (up to 1.7 ha) will be removed or disturbed as part of the construction process. • An area of up to 1.6 ha of estuarine salt flats and salt marshes is planned to be removed or disturbed as part of the construction process.	• Minimise potential disturbance by establishing no go areas during construction to protect wetlands outside of the area of disturbance.
Operation of launch site 1	• Erosion and sediment generation from disturbed areas and boat wash/wave action.	• Site specific rock protection of banks adversely affected by project related boat wash/wave action. • Adhere to required speed limits within the Calliope River to minimise wash from vessels.
Construction of mainland tunnel entry shaft and tunnel spoil disposal area	• An area of approximately 52.4 ha of wetlands mapped as salt flats and salt marshes will be infilled for the mainland tunnel entry shaft and tunnel spoil disposal area. • Inundation of parts of the construction site from flooding.	• The identified wetlands will be infilled and not replaced. Mitigation measures for this impact are therefore not provided. • Drainage should be implemented that facilitates delivery of surface runoff around the construction works and delivers it without causing erosion downslope.
Construction of dredge site 1	• Potential sedimentation if supply exceeds transport. • Potential erosion if transport exceeds supply. • All dredged material will be disposed of to the Western Basin Dredging and Disposal Project (with impacts assessed under the Gladstone Ports Corporation's Port of Gladstone Western Basin Dredging and Disposal Project).	• Development and implementation of a dredging monitoring plan that will include monitoring of upstream headward bed deepening and bank slumping. If monitoring indicates an impact appropriate mitigation measures are to be implemented. i.e. site specific erosion control designs.
Operation of dredge site 1	• Maintenance dredging of the channel could result in upstream headward bed deepening and bank slumping. • Dredging of the channel could result in continuing upstream headward bed deepening and bank slumping beyond project life.	• As per construction above. • As per construction above.

7 Residual Impact

7.1 Residual Impact Assessment

In this section the mitigation measures described in Section 6 are assumed to be applied. The residual impacts described below are those still expected to occur after the application of mitigation measures. A determination has been made of the post-mitigated magnitude of each impact in relation to each environmental value (as per the method described in Section 3.2, page 11). The significance (sensitivity and magnitude) of the residual impacts on the identified environmental values has then been determined with reference to Table 3-1, page 14.

With reference to the sustainability of geomorphic and hydrologic values, the aim of mitigation measures is to provide for self-sustaining hydrologic and geomorphic function during operation of the project and post decommissioning. If mitigation measures are implemented effectively, waterways will operate in a self-sustaining manner without the need for ongoing maintenance. With the exception of the diversion of minor waterways on Curtis Island all waterways will continue to function in their pre project condition. The diversion of minor waterways on Curtis Island will also function in a geomorphically and hydrologically self-sustaining manner but will have altered flow paths.

Note: Consideration of the ecological impacts for wetlands and riparian vegetation are detailed in Aquateco (2011), Coffey (2011b) and Ecosure (2011) and not considered in this report.

The assessment of residual impact is shown in Table 7-1, page 57.

Table 7-1. *Residual impact assessment*

Site	Surface water asset (catchment, watercourse, wetland)	Sensitivity of EVs	Residual Impacts (post mitigation measures)	Magnitude	Significance (Sensitivity of EVs plus Magnitude)
Construction of LNG plant	Local catchments; waterway W3.	Moderate	• Lower part of waterway W3 (valley fill) reach infilled and replaced with a diversion but stable with no ongoing impacts.	Low	Low
Construction of LNG plant	Local catchments; waterways W2, W3 & W4 draining to estuarine wetlands adjacent to Boatshed Point and Hamilton point.	Low	• Lower reaches of waterways W3 & W2 infilled and replaced with diversion/s but stable with no ongoing impacts. • Loss of up to 17.3 ha of wetlands permanent with limited opportunity for replacement.	High	Moderate
Operation of LNG plant	Local catchments; waterways W2, W3 & W4 draining to estuarine wetlands adjacent to Boatshed Point.	Low	• None	Low	Negligible
Decommissioning of LNG plant	Local catchments; waterways W2, W3 & W4 draining to estuarine wetlands adjacent to Boatshed Point.	Low	• Possible minor generation of sediment.	Low	Negligible
Construction of TWAF7	Auckland Creek catchment; Auckland Creek including estuarine wetlands.	Low	• Possible minor generation of sediment.	Low	Negligible
Construction of TWAF8	Targinie Creek catchment; Targinie Creek.	Low	• Possible minor generation of sediment.	Low	Negligible
Construction of launch site 1	Calliope River catchment; Calliope River including estuarine wetlands.	Low Moderate	• Possible minor generation of sediment. • Calliope River mouth up to 3.3 ha of wetlands to be removed or disturbed as part of the construction process.	Low Low	Negligible Low

Site	Surface water asset (catchment, watercourse, wetland)	Sensitivity of EVs	Residual Impacts (post mitigation measures)	Magnitude	Significance (Sensitivity of EVs plus Magnitude)
			•		
Operation of launch site 1	Calliope River catchment; Calliope River including estuarine wetlands.	Low	• None	Low	Negligible
Decommissioning of launch site 1	Calliope River catchment; Calliope River including estuarine wetlands.	Low	• Possible generation of sediment.	Low	Negligible
Construction of mainland tunnel entry shaft and tunnel spoil disposal area	Boat Creek Catchment and Catchment 1; Estuarine salt flats and salt marshes.	Low	• Permanent loss of 52.4 ha of wetlands that will not be replaced. • Possible minor generation of sediment.	High	Moderate
Construction, operation and decommissioning of dredge site 1	Calliope River catchment; Calliope River.	Moderate	• No impacts if geomorphicaly stable. Will require monitoring.	Low	Low

7.2 Design Constraints

Design constraints are impacts that the environment may have on the project, as opposed to impacts the project may have on the environment. Sometimes project activities can lead to design constraints as they can change the environmental conditions. Some potential impacts from and to project activities require additional assessment and development of site specific mitigation measures. These are discussed below.

7.2.1 Flood modelling

Wherever practical project infrastructure should be located above significant flood risk (1:100 year ARI as determined by flood assessment). Where this is not practical project infrastructure should be protected from flood inundation to a minimum of 1:100 year ARI and with reference to protection works not causing adverse increase in flood heights.

Flood modelling has been undertaken as part of this study for the LNG plant. Further detailed modelling will be required dependent upon final site selection and detailed design as part of the design process for required diversion/s. A summary of available hydrology and flood literature and assessment requirements is provided in Table 7-2.

Table 7-2. ***Summary of available hydrology for key project components***

Project activity	Available hydrology / flood assessments	Limitations of hydrology and additional assessment required during detailed design
LNG plant	As part of an assessment of flooding for the LNG plant the hydrology of the small catchments on Curtis Island has been assessed as part of this study for those subcatchments in which the LNG plant will be constructed and those *adjacent* to the east and west. Findings are presented in Attachment B. Storm surge has also been assessed as part of the flood assessment and maximum flood heights identified for project sites that could be affected.	Further flood modelling will be required as part of required diversion design for the LNG plant. An assessment of existing conditions has been undertaken for this study and the findings presented in Attachment B. The final design will require the construction of one or more waterway diversions with reference to the LNG plant specific mitigation measures detailed in Section 6.
TWAF 7	A flood study has been undertaken by GHD (2006) for Gladstone City Council. The report provides flood inundation mapping for 50, 100, 500 year (ARI) floods together with probably maximum precipitation event mapping. A study has been undertaken by GHD (2011) as part of the project development. The report identifies the heights to which the road crossing and accommodation facilities need to be constructed to manage flood risk.	If this site is to be developed and as part of that the road access is altered such that it reduces hydraulic capacity of the neck cutoff of Auckland Creek then a reassessment of flood risk should be undertaken. The potential impact of the road crossing and accommodation facility will require assessment at the detailed design stage if this option is pursued.
TWAF 8	No site specific hydrology available.	If this site is to be developed. A site specific flood assessment should be undertaken.
Launch site 1 and mainland tunnel entry shaft and tunnel spoil disposal area	A flood study has been undertaken by Sargent (2006), which includes the lower Calliope River. The report provides flood mapping for all of Launch Site 1 area and part of the mainland tunnel entry shaft and tunnel spoil disposal area. Additional information relevant to these sites for storm surge has been assessed as part of the storm surge assessment for the LNG plant.	Further detailed flood modelling may be required to assess potential post development off-site impacts.

7.2.2 Storm surge

Similar to flood modelling, an assessment of storm surge has been undertaken for this study for the LNG plant site only and are presented in Attachment B. It is noted that BMT WBM (2011) identify a more conservative 100 year ARI design storm tide level of between 3.53 to 4.06 AHD including allowances for future climate change. This is based on the 100 year planning period plus a further 6% allowance for tide amplification. For consistency of approach Alluvium recommends adoption of the more conservative BMT WBM design storm tide maximum level of 4.06 AHD for detailed design and future planning.

7.2.3 Stormwater Management

Management of stormwater in and around the LNG plant will require further detailed design to separate clean water from upslope of the LNG plant from mixing with stormwater from the plant prior to treatment and discharge of that stormwater. As part of the EIS an assessment has been made of stormwater quality ((Arrow LNG Plant – Input to the EIS - Stormwater Quality Assessment (Alluvium, 2011)). In addition to describing the management of water quality, the report outlines drainage and other management measures to intercept and treat stormwater prior to discharge.

Detailed design is required to integrate the management of stormwater and clean, offsite drainage.

7.2.4 Dredging

MBT WBM (2011) identifies that "*except during major flood events, sediment transport processes are governed by tidal currents and sediment particles displace locally on each tidal cycle, remaining with the estuary. Dredging the mouth of the Calliope would cause changes to bed shear stress magnitudes, which govern the bed load transport potential and also influence the rate of deposition of fine material*". The report goes on to say that "*there is clearly a potential for fine sediment siltation in the Arrow LNG swing basin which would need to be addressed by a maintenance dredging program*" and "*a monitoring program will be needed to assess the ecological and morphological response of the river to the changes in low tide water levels*". This suggests that the initiation of headward erosion may not occur and that sedimentation and infilling of the dredged channel may in fact be an issue (in terms of maintenance requirements) but major riverine flood events may still be important.

Alluvium supports the need for monitoring , which should include an assessment of the bed grade, river flows and sediment transport capacity. Sargent (2006) notes that the Clifton Channel, which extends to just off the Calliope River Mouth is maintained to a depth of 10.4 m (-13.2 m AHD) and that whilst this dredging could initiate headward erosion, this does not appear to have been the case, with some filling of deep holes along the channel. Sargent also notes that there is ongoing natural channel change in the lower reaches of the Calliope River. Monitoring of the dredged channel will also require consideration of ongoing natural channel changes.

8 Inspection and Monitoring

Generic performance criteria, standards and monitoring requirements for sediment generation and discharge are detailed in Table 8-1. Additional site specific requirements are provided in Table 8-2, page 62 with reference to the generic requirements.

Table 8-1. Generic performance criteria, standards and monitoring requirements

Performance criteria	Monitoring requirements
Construction Sediment generation and discharge are within identified release limits.	• Sediment control measures (sediment fences, drains, swales and sediment detention basins) should be monitored on a weekly basis and reconfigured as appropriate in response to changing site activities during construction. • Water prior to discharge, should be monitored on a monthly basis during the construction period and within 24 hours of a rainfall event that exceeds 25mm depth of rainfall.
Operation Sediment generation and discharge are within identified release limits.	• Sediment control measures (drains, swales and sediment and stormwater detention basins) should be monitored on a quarterly basis. • Water prior to discharge, should be monitored on a quarterly basis during the operational period and within 24 hours of a rainfall event that exceeds 25mm depth of rainfall.
Decommissioning Sediment generation and discharge are within identified release limits.	• Sediment control measures (sediment fences, drains, swales and sediment detention basins) should be monitored on a weekly basis and reconfigured, if required, as appropriate in response to changing site activities during decommissioning. • Water prior to discharge, should be monitored on a monthly basis during the decommissioning period and within 24 hours of a rainfall event that exceeds 25mm depth of rainfall. • Once decommissioning works are completed, the following monitoring to continue until there are no residual impacts from project activities: o Sediment control measures (drains, swales and sediment detention basins) should be monitored on a quarterly basis.

Table 8-2. Additional performance criteria, standards and monitoring requirements

Project activity	Surface water assets (catchment, watercourse, wetland)	Performance criteria	Monitoring requirements
Construction of LNG plant	Local catchments; waterways W2, W3 &W4 draining to estuarine wetlands adjacent to Boatshed Point and Hamilton point.	Sediment generation and discharge are within identified release limits. Waterway diversion/s conform to design standard.	• Construction monitoring of the waterway diversion to ensure conformance with design intent. Survey and site assessment by suitably qualified and experienced waterway engineer during construction to be detailed in "As constructed design report". Frequency of site assessment to be determined by construction timetable but not less than bi-monthly.
Operation of LNG plant	Local catchments; waterways W2, W3 &W4 draining to estuarine wetlands adjacent to Boatshed Point and Hamilton point.	Sediment generation and discharge are within identified release limits. Waterway diversion/s performing to design standard.	• After rehabilitation it is recommended that a detailed geomorphic assessment be undertaken by a suitably qualified and experienced person with audit reporting detailing condition, success of rehabilitation works , required remedial works (if any) and a timetable for remediation works. • Operation monitoring of the waterway diversion/s to ensure conformance with design intent. Survey and site assessment by suitably qualified and experienced person annually.
Decommissioning of LNG plant	Local catchments; waterways W2, W3 &W4 draining to estuarine wetlands adjacent to	Sediment generation and discharge are within identified release limits. Waterway diversion/s performing to design standard.	• Final assessment and reporting should be undertaken during and following decommissioning. Final assessment should include ongoing monitoring at a determined frequency until such time as rehabilitation works are completed and effective and monitoring demonstrates that areas of impact from project works are geomorphically stable within pre-construction rates of erosion and deposition showing that the geomorphology and hydrology of the LNG plant site are self-sustaining (i.e., without the need for ongoing maintenance). Given that the LNG plant has a projected lifespan of 25 years it is possible that waterways can be demonstrated, through monitoring, that they are stable and do not require any maintenance beyond decommissioning but this needs to be

Project activity	Surface water assets (catchment, watercourse, wetland)	Performance criteria	Monitoring requirements
	Boatshed Point and Hamilton point.		documented.
Construction of TWAF 7	Auckland Creek catchment; Auckland Creek including estuarine wetlands.	Sediment generation and discharge are within identified release limits.	• Monitor during rainfall, river levels during construction. • Monitor weather to identify storm surge risk.
Operation of mainland tunnel entry shaft and tunnel spoil disposal area	Boat Creek Catchment and Catchment 1; Estuarine salt flats and salt marshes.	Sediment generation and discharge are within identified release limits.	• Monitoring of bund walls or site platform (depending upon final design) after storm events coinciding with high tides where wave action may have resulted in damage and erosion to embankments.
Construction and operation of dredge site 1	Calliope River catchment; Calliope River	Sediment generation and discharge are within identified limits.	• Survey of bed and banks prior to dredging and annually afterwards (following each wet season) to monitor headward or lateral erosion of dredged channel. Monitoring needs to be continued until it can be demonstrated that there are no impacts beyond the project life or to identify remediation requirements if erosion causing negative impacts occurs.

9 Cumulative Impacts

Available information on the projects selected for the cumulative impact assessment was reviewed to determine the nature and extent of potential impacts as relevant to the physical, environmental, social and economic values of the Gladstone region. A qualitative approach was then used to identify the cumulative impacts from other projects with this project.

9.1 Criteria for Determining Other Projects

The baseline for assessment of cumulative impacts includes all existing developments constructed and operating in the Gladstone region, and those projects that have taken a financial investment decision at the date of this version.

The cumulative impact assessment has only included projects that have been approved by the Queensland Coordinator-General or have sufficient information in the public domain (i.e., an EIS) to enable an assessment of the potential impacts. Projects included in the cumulative impact assessment have met the following criteria:

1. The project is located in the Gladstone region.
2. The project is being assessed by one of the following:
   a. The *State Development and Public Works Organisation Act 1971* (Qld) and has been declared by the Queensland Coordinator-General as a 'project of state significance' for which the status of the EIS is either complete or, as a minimum, has an Initial Advice Statement published on the Department of Infrastructure and Planning (DIP) website.
   b. The *Environmental Protection Act 1994* (Qld) and has completed an EIS or has an Initial Advice Statement (or similar) listed on the Department of Environment and Resource Management (DERM) website.
3. The project is envisaged in statutory planning documentation.

Projects that are unlikely to impact of the environmental values relevant to geomorphology and hydrology have been excluded from the cumulative impact assessment.

The objective of the assessment has been to determine the cumulative impacts of approved or proposed developments including how much the Arrow LNG Plant contributes to the overall impact on relevant environmental values. The list of projects included in the cumulative impact assessment in Table 9-1, page 65, along with the criteria that warrant their inclusion in the list and an assessment of the potential cumulative impact. The following projects, whilst in the region, were determined to not have any potential geomorphic or hydrologic impacts to surface waters and are therefore not included in the cumulative impact assessment:

- Yarwun Alumina Refinery Expansion Project (Rio Tinto).
- Hummock Hill Island Community Project (Eaton Place Pty Limited).
- QER's Stuart Oil Shale Project.
- Aldoga Aluminium Smelter Project.
- Gladstone Steel Plant Project – Boulder Steel Ltd.
- Gladstone-Fitzroy Pipeline Project - Gladstone Area Water Board.
- Boyne Island Aluminium Smelter Extension of Reduction Lines Project - Rio Tinto Aluminium.
- Yarwun Alumina Refinery Expansion Project - Rio Tinto.

9.1.1 Assessment of Cumulative Impacts from Other Projects

The following projects have been assessed solely in terms of their cumulative impacts on geomorphology and hydrology. Therefore the ecological impacts of loss of wetlands are not considered in this report. In general cumulative impacts have been considered in terms of disturbance of watercourses (geomorphic impact) and changes to hydrology, principally from localised changes to subcatchments, increases in impervious areas with associated increase in runoff and the need to manage stormwater.

Table 9-1. Other projects included in the cumulative impact assessment

Name of project	Proponent(s)	Relevance to the Arrow LNG Plant	Potential geomorphic and hydrologic impacts to surface waters
Queensland Curtis LNG project	QGC Pty Limited (BG Group business)	Construction of a pipeline on the mainland and across to Curtis Island. Development of an LNG plant on Curtis Island with a maximum capacity of up to 12 Mtpa.	This project will be constructed prior to the Arrow LNG Plant and is therefore already considered in the baseline assessment as part of the existing environment. The proposed QCLNG plant on Curtis Island could duplicate impacts of the Arrow LNG Plant on minor waterways in terms of infilling and diversion. Other than localised impact in the vicinity of the LNG plant (potential minor increases in runoff from impervious areas and increases in peak discharge) there are not expected to be any off site impacts and consequently negligible cumulative hydrologic impacts. There will be infilling and diversion with subsequent loss of minor waterways and replacement with alternative drainage channels. There will also be a cumulative loss of coastal wetlands on that section of the Curtis Island coast. In terms of geomorphic and hydrologic impact however, the loss of these wetlands on Curtis Island can be considered to be a negligible impact.
Gladstone LNG Project	Santos Limited (and partners Petronas, Total and KOGAS)	Construction of a pipeline on the mainland and across to Curtis Island. Development of an LNG plant on Curtis Island with a maximum capacity of up to 10 Mtpa.	This project will be constructed prior to the Arrow LNG Plant and is therefore already considered in the baseline assessment as part of the existing environment. Impacts as per the Queensland Curtis LNG project.
Australia Pacific LNG Project	Australia Pacific LNG Ltd (ConocoPhillips and Origin Energy)	Construction of a pipeline on the mainland and across to Curtis Island. Development of an LNG plant on Curtis Island with a maximum capacity of up to 18 Mtpa.	The proposed APLNG plant on Curtis Island could duplicate impacts of the Arrow LNG Plant on minor waterways in terms of infilling and diversion. Other than localised impact in the vicinity of the LNG plant (potential minor increases in runoff from impervious areas and increases in peak discharge) there are not expected to be any off site impacts and consequently negligible cumulative hydrologic impacts. There will be infilling and diversion with subsequent loss of minor waterways and replacement with alternative drainage channels. There will also be a cumulative loss of coastal wetlands on that section of the Curtis Island coast. In terms of geomorphic and hydrologic impact however, the loss of these wetlands on Curtis Island can be considered to be a negligible impact.
Western Basin Strategic Dredging and Disposal Project	Gladstone Ports Corporation Limited	Dredged material will be placed into reclamation areas near Fisherman's Landing to create a land reserve.	This project is on the northern side of the existing Fishernans Landing reclamation area and adjacent to the Fishermans Landing Northern Expansion Project. A total of 235 ha will be reclaimed under this project with a potential 36 million cubic metres to be dredged deepening and widening of existing channels and swing basins. Without modelling the effects of all projects the extent of any cumulative impact upon hydrology from the approximately 52.4 ha of the Arrow LNG plant tunnel entry disposal area, the extent of any cumulative impact cannot be determined but can reasonably expected to be negligible.
Fishermans Landing Northern Expansion Project	Gladstone Ports Corporation Limited	Expansion of Fishermans Landing by reclamation. Reclamation will provide for the containment of dredge material from future maintenance and capital dredge programs.	This project is on the northern side of the existing Fishernans Landing reclamation area and adjacent to the Western Basin Strategic Dredging and Disposal Project. The project will reclaim and area of 173.5 ha. Similar to the Western Basin Strategic Dredging and Disposal Without modelling the effects of all projects the extent of any cumulative impact upon hydrology from the approximately 52.4 ha of the Arrow LNG plant tunnel entry disposal area, the extent of any cumulative impact cannot be determined but can reasonably expected to be negligible.

Name of project	Proponent(s)	Relevance to the Arrow LNG Plant	Potential geomorphic and hydrologic impacts to surface waters
Arrow Surat Pipeline Project (formerly Surat Gladstone Pipeline Project)	Arrow Energy Ltd	Construction of a high-pressure gas pipeline to transport coal seam gas from Dalby to Gladstone.	There are expected to be no geomorphic or hydrologic impacts if hydrologic conditions are not altered and adequate rehabilitation measures are applied during and post construction when crossing waterways.
Central Queensland Pipeline Project	Enertrade (AGL Energy and Arrow Energy)	Construction of a high pressure gas transmission pipeline from Moranbah to Gladstone.	There are expected to be no geomorphic or hydrologic impacts if hydrologic conditions are not altered and adequate rehabilitation measures are applied during and post construction when crossing waterways.
Wiggins Island Coal Terminal Project	Central Queensland Ports Authority and Queensland Rail	Development of a coal terminal (25 Mtpa initially and an upgrade capability to a nominal 70 Mtpa in later stages) and associated infrastructure in the Port of Gladstone. Dredging and reclamation.	This development notably includes a rail line, rail loop, sidings and associated infrastructure requiring infilling of floodplain at the mouth of the Calliope River. Flood modelling (Connell Hatch 2007) identifies no hydrologic changes in the area of launch site 1 or dredged channel and a reduction in flood heights in the area of the mainland tunnel launch site, due to infilling of the floodplain between that site and the Calliope River.
Gladstone Nickel Project	Gladstone Pacific Nickel Limited	Development of a greenfield high pressure acid leach refinery in the Gladstone State Development Area. Development of slurry and water pipelines between Marlborough and the plant site. Development of a tailings storage facility in the Gladstone State Development Area and ore importing facilities at the Port of Gladstone.	Relevant potential impacts from this project include extraction of water from the Calliope River for cooling and localised changes to subcatchments, runoff and management of stormwater. The Environmental Impact Statement Supplemental (URS in association with RLMS, 2008) identifies no significant hydrological impacts from extraction of water from the Calliope River.
Gladstone Steel Plant Project	Boulder Steel Limited	Development of an integrated steel making plant (2.1 Mtpa initially and increasing to 5 Mtpa in later stages) at a site in the GSDA Aldoga Precinct.	Relevant impacts are localised changes to subcatchments, runoff and management of stormwater. Any hydrologic of geomorphic cumulative impacts can be expected to be negligible.
Moura Link-Aldoga Rail Project	Queensland Rail Ltd	Development of a new rail line via the Moura Short Line to the existing North Coast Line. Development of a rolling stock maintenance yard at Aldoga. Quadruplication of the North Coast Line from the new yard to east of Yarwun.	This development is not in the same subcatchments as the Arrow LNG Plant project area and is expected to have negligible geomorphic or hydrologic cumulative impacts.

Name of project	Proponent(s)	Relevance to the Arrow LNG Plant	Potential geomorphic and hydrologic impacts to surface waters
Hummock Hill Island Community Project	Eaton Place Pty Limited	Development of a residential and tourism community, including education facilities and a golf course, to accommodate the population of approximately 4,000 on Hummock Hill Island.	Outside of the study area, any hydrologic impacts from the Hummock Hill Island Community Project will be confined to the Island and immediate surrounding marine environment and managed through stormwater management planning. At a regional scale it will result in disturbance of minor ephemeral waterways and can therefore be considered to have geomorphic minor cumulative impact.
Gladstone LNG Project (Fishermans Landing)	Gladstone LNG Pty Ltd	Development of a 1.6 Mtpa (initial) LNG plant and export terminal at Fisherman's Landing.	Development on existing reclaimed land. Any impacts would be confined to localised potential for minor increases in runoff from impervious areas, controlled through stormwater management. There are expected to be no geomorphic or hydrologic impacts if hydrologic conditions are not altered and adequate rehabilitation measures are applied during and post construction when crossing waterways.

A common potential cumulative impact is the timing of construction, which could occur concurrently with some projects. For the LNG plant, the geomorphic and hydrologic impacts from the construction, operation and decommissioning of the facility can be managed. There will be three additional LNG plants on Curtis Island, which are expected to have a negligible cumulative impact on altered hydrology (timing and volumes of runoff from facilities) and geomorphic processes, if identified mitigation measures are applied.

10 Conclusions

With consideration of the assessments detailed in Sections 2 to 9 the following conclusions are drawn:

10.1 Geomorphology

- Many potential impacts can be managed through adequate application of standard mitigation measures to control the generation and control of sediment.
- Some site specific mitigation measures are also required. These are:
  - Stabilisation of earthworks where tidal influence may result in erosion.
  - Bunding of construction areas at risk of tidal inundation.
  - Development of a dredging monitoring plan to include ongoing monitoring of the dredged channel of the Calliope River will be required to check that the dredged channel does not increase erosion rates over natural levels. If erosion occurs, monitoring will identify the issue and enable design and application of appropriate remediation measures.
  - As the cut and fill earthworks proposed for the LNG plant will remove the primary drainage path through the site it is necessary to provide one or more waterway diversions to transport rainfall runoff from the north of the catchment, around the site and into the sea. Two options exist although additional drainage will be required to intercept any runoff from undeveloped slopes, upslope of the facility. Primarily, the options are to divert flows to the east or to the west. Detailed design of the diversions and associated drainage will be required as part of finalisation of the facility plans. This will include designing to ensure that geomorphic processes continue to operate at approximately natural rates during operation of the plant and following decommissioning thereby providing for sustainable function.
  - Monitoring waterway diversion/s to ensure construction and operation to design intent.
- At TWAF 7 the existing crossing through the in-filled meander neck cut off channel of Auckland Creek will require upgrade and adequate scour protection.
- Some wetland areas will beinfilled as part of the project. These will not be replaced . The only exception may be the replacement of some of the coastal/sub-coastal floodplain tree swamp area at the site of the LNG plant. Some replacement may be able to be achieved as part of the construction of waterway diversion/s. Detailed design is required. Some minor offset for loss of wetlands may also be possible through the construction and operation of sediment detention basins as part of the management of stormwater at the LNG plant (see Alluvium 2011). Consideration of offsets for the loss of the ecological value of wetlands is detailed in Coffey (2011b).

10.2 Hydrology

Identified impacts to hydrology are:

- At the LNG plant site, changes to direction and discharge points of surface flow paths will occur. This will reduce discharges from waterway W3 and increase discharges to W4 and possibly W1 and/or W2 depending upon the final design. Additional erosion protection works (rock riprap) will be required for receiving waterways.
- Flooding (resulting in impacts to identified environmental values) can be managed through appropriate design of waterway diversion/s and adjacent flood corridor/s to manage a minimum of a 1:100 year ARI event.
- Changes to the hydraulics of the Calliope River channel as a result of dredging will occur. Impacts and mitigation measures have been discussed above.
- At TWAF 7 the existing crossing through the in-filled meander neck cut off channel of Auckland Creek will require upgrade and adequate scour protection. Design of that upgrade will need to consider flood risk and potential offsite flood impacts if hydraulics are changed.
- At TWAF 8, if site infrastructure encroaches on the flood extent of Targinie Creek, some localised changes in flood hydraulics may occur. This will require a site specific flood assessment if this option is developed.

- Changes in rainfall pattern and sea level rises predicted as a consequence of climate change will not have any adverse impact upon the hydrology or geomorphology of the waterways in the vicinity of the LNG plant. This also applies to Storm Surge as a result of cyclonic activity.

11 Terms of Reference Cross-reference Table[3]

ToR Section No.	Terms of Reference Requirement	Technical Report Section No.
3.4	The definition of waters in the Environmental Protection (Water) Policy 1997 (EPP Water) includes the bed and banks of waters, so this section should address impacts on benthic sediments as well as the water column. Where a licence or permit will be required under *the Water Act 2000* to take or interfere with the flow of water, this section of the EIS should describe the amount of water to be taken and the details of the works to be constructed, and impacts of the works.	Section 2 and 2.1
3.4.1	Surface water and watercourses	
	Describe the environmental values of the surface waterways of the affected area in terms of: • Values identified in the EPP (Water) and Australian and New Zealand Environment and Conservation Council, *State of the Environment Reporting Taskforce 2000* (ANZECC 2000)	Section 4.5
	• Sustainability, including both quality and quantity.	Quantity – Section 7.1 Quality issues addressed in Aquateco (2011) and Alluvium (2011)
	• Physical integrity, fluvial processes and morphology of watercourses, including riparian zone vegetation and form.	Section 4 See also Ecosure (2011)
	• Any water resource plans, land and water management plans, declared or proposed wild river areas relevant to the affected catchment.	Section 2 and section 3.2
	A description should be given of the surface watercourses and their quality and quantity in the area affected by the project with an outline of the significance of these waters to the river catchment system in which they occur. Details provided should include:	Section 4

[3] Text in bold is outside the scope of this report.

ToR Section No.	Terms of Reference Requirement	Technical Report Section No.
	• A description of existing surface drainage patterns.	
	• A description of existing and historical flow regimes in major streams and wetlands.	Section 4.2
	• A description of present and potential water uses downstream of the areas affected by the project.	Section 4.2
	Details should be provided on the likelihood of flooding, history of flooding (including extent, levels and frequency). Flood studies should include: • A range of annual exceedance probabilities for affected waterways, based on observed data if available, or use appropriate modelling techniques and conservative assumptions if there are no suitable observations. The flood modelling should include: • Local flooding due to short duration events from contributing catchments on site, as well as larger scale regional flooding including waterways downstream. The EIS should provide a description, with photographic evidence where appropriate, of the geomorphic condition of any watercourses likely to be affected by project works and operations. The results of this description should form the basis for the planning and subsequent monitoring of rehabilitation of the affected watercourses. **An assessment is required of existing water quality in surface waters and wetlands likely to be affected by the proposal. The basis for this assessment should be a monitoring program, with sampling stations located upstream and downstream of the project areas. The water quality monitoring should capture seasonal variations** or variations with flow	Section 4.2 & Attachment B1 Section 4.3 & Attachment A See Aquateco (2011)
	where applicable**. A relevant range of physical, chemical and biological parameters should be measured to provide a baseline for affected creek or wetland systems.**	N/A for physical parameters Chemical parameters see Aquateco (2011)
3.4.1.2	Potential impacts and mitigation measures The water management systems for all project elements should be described, addressing **surface water quality**, quantity, drainage patterns and sediment movements. The beneficial (environmental, production and recreational) use of nearby surface water should be discussed. An analysis of potential impacts on affected creeks should be carried out. This analysis should identify any likely inundation and duration, as this may affect emergency vehicle access	Section 6 See also Alluvium (2011) & BMT WBM (2011) Section 4.2 & Attachment B1

ToR Section No.	Terms of Reference Requirement	Technical Report Section No.
	Monitoring programs should be described which will assess the effectiveness of management strategies for protecting water quality during the construction, operation and decommissioning of the project. Monitoring programs should also be designed to evaluate changes in the physical integrity and geomorphic processes associated with changed flow regimes in affected water courses. **Where on-site storage of water sourced from waste water treatment plants is proposed, the EIS should detail how this water would be managed to ensure environmental harm and human health risk is avoided. The EIS should also describe the design features of any such storages to effectively contain saline water and other harmful constituents.** Key water management strategy objectives include: • Maintenance of sufficient quantity and quality of surface waters to protect existing beneficial downstream uses of those waters (including maintenance of in-stream biota). • Maintenance or replication of the existing geomorphic conditions of local watercourses. • Minimisation of impacts on flooding levels and frequencies both upstream and downstream of the project. **The EIS should include a risk assessment for uncontrolled emissions to water due to system or catastrophic failure, implications of such emissions for human health and natural ecosystems, and strategies to prevent, minimise and contain impacts.** The EIS should describe the proposed project component stormwater drainage systems and the proposed disposal arrangements, including any off-site services and downstream impacts. **Where dams, weirs, or ponds are proposed, the EIS should investigate the effects of predictable climatic extremes (droughts, floods) upon the structural integrity of the containing walls, and the quality of water contained, and flows and quality of water discharged.** **A dam failure impact assessment should be carried out for any proposed dams that, due to their size, trigger the need for such an assessment under the *Water Act 2000*. Any dams that are likely to be referrable under the *Water Act 2000* should be noted and emergency response procedures incorporated into the project's environmental management plan (EM Plan).** **The need, or otherwise, for licensing of any dams (including referable dams) or creek diversions, under the *Water Act 2000,* or the *Fisheries Act 1994,* or the construction or raising of any waterway barrier works under the *Fisheries Act 1994*, should be discussed. The process for water allocation and water discharge should be established in consultation with DERM. Consideration should also be given to any water allocation and management plans.** **The environmental values of the surface waters potentially affected by the project should be identified in accordance with the EPP (Water). Surface water quality objectives should be determined after consideration of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* and the *Queensland Water Quality Guidelines (DERM, 2009).*** **Risks from potentially contaminated surface water flow, particularly during flood events should be assessed.** Options for flood mitigation and the effectiveness of mitigation measures should be discussed with particular **reference to sediment, salinity and**	Section 8 See Planager (2011) Auateco (2011) & Alluvium (2011) Section 6.3 Section 4.2 & Attachment B1 See Planager (2011) Attachment B1 and Alluvium (2011) N/A N/A N/A Aquateco (2011) Aquateco (2011) Section 4.2 & Attachment B1

ToR Section No.	Terms of Reference Requirement	Technical Report Section No.
	other emissions of a hazardous or toxic nature to human health, flora or fauna.	
7	The purpose of this section is to provide a summary of the cumulative impacts from the project which should have regard to both geographic location and environmental values. Cumulative impacts should take into consideration the effects of other known, existing or proposed project(s) where details of such projects have been provided to the proponent by the DIP or which are otherwise published to the greatest extent possible. In particular, the likelihood of cumulative impacts arising from possible shared gas transmission pipeline easements and adjoining or nearby LNG plant proposals should be addressed, where adequate information is available. With respect to Gladstone in particular, the cumulative social and economic impacts arising from large project workforces associated with proposed industrial projects being constructed in overlapping timeframes should be addressed. The requirements of any relevant state planning policies, environmental protection policies, national environmental protection measures, statutory policies, water resource planning and any other relevant plans should also be addressed. The methodology used to determine the cumulative impacts of the project should be discussed, including (to the extent possible) qualitative and quantitative criteria.	Section 9

12 References

Alluvium (2011). Arrow LNG Plant – Input to the Environmental Impact Statement: LNG Plant Stormwater Quality Impact Assessment. Report RO1 by Alluvium for Arrow Energy Holdings Pty Ltd and Coffey Environments Pty Ltd.

Aquateco (2011) Arrow LNG Plant Freshwater Aquatic Ecology Impact Assessment. Prepared for Arrow Energy Holdings Pty Ltd and Coffey Environments Pty Ltd.

Australian and New Zealand Environment and Conservation Council, State of the Environment Reporting Task Force (2000). *Core environmental indicators for reporting on the state of the environment*. Environment Australia, Canberra.

Australian Natural Resources Atlas (ANRA) Rivers – Assessment of River Condition – Queensland: accessed 12th October 2009.

http://www.anra.gov.au/topics/water/condition/qld/index.html

Australian Natural Resources Atlas (ANRA, 2009a). Water Resources – Allocation and Use – Queensland: accessed 12th October 2009.

http://www.anra.gov.au/topics/water/allocation/qld/basin-calliope-river.html

Australian Natural Resources Atlas (2009b). Water Resources – Allocation and Use – Queensland: accessed 12th October 2009.

http://www.anra.gov.au/topics/water/allocation/qld/basin-curtis-island.html

Australia Pacific LNG Project Volume 5: Attachment. Attachment 26: Flooding, Drainage and Stormwater Management – LNG Facility (2010).

BMT WBM (2011). Arrow LNG Plant EIS Coastal Processes, Hydrodynamics and Marine Quality Impact Assessment. Prepared for Arrow Energy Holdings Pty Ltd and Coffey Environments Pty Ltd.

Brierley, G.J. and Fryirs K.A. (2005). *Geomorphology and River Management: Applications of the River Styles Framework*. Blackwell Publishing, Oxford, UK.

Bureau of Meteorology, (BOM, 2009). Australian Drainage Divisions and River Basin Boundaries: accessed 12th October 2009).

http://www.bom.gov.au/hydro/wr/basins/index.shtml

Bureau of Meteorology (BOM, 2011). Climate Statistics for Australian Locations – Gladstone Radar: accessed 16th March 2011.

http://www.bom.gov.au/climate/averages/tables/cw_039123_All.shtml

Bureau of Meteorology (BOM, 2011). Australian Tsunami Warning System: accessed 16th March 2011.

http://www.bom.gov.au/tsunami/about/atws.shtml

Coffey Environments (2011a). Guidance Note: Assessment of Significance of Impacts (version 2, 21 January 2011). Coffey Environments Australia Pty Ltd. Brisbane, Queensland.

Coffey Environments (2011b). *Marine and Estuarine Ecology Technical Report for Arrow Energy Liquified Natural Gas Plant*. Prepared for Arrow Energy Holdings Pty Ltd.

Connell Hatch (2006). Environmental Impact Statement Wiggins Island Coal Terminal Central Queensland Ports Authority and Queensland Rail. Connell Hatch, Brisbane, Queensland.

CQCHM (2011). Arrow LNG Plant Indigenous Cultural Heritage Impact Assessment. Report prepared by Central Queensland Cultural Heritage Management Pty Ltd for Arrow Energy Holdings Pty Ltd and Coffey Environments Australia. Brisbane, Queensland.

Department of Environment and Resource Management (2007), Historical Monitoring Data – Watershed: accessed November 2009.

http://www.derm.qld.gov.au/watershed/index.html

Division of National Mapping (NATMAP) (1982), National Topographic Map, 9150 Gladstone, Topographic Map - 1:100 000. Commonwealth of Australia.

Ecosure (2011), *Arrow LNG Plant: Terrestrial Ecology Technical Report*. Prepared for Arrow Energy Holdings Pty Ltd and Coffey Environments Pty Ltd.

Environmental Protection Agency (2003). *Curtis Coast Regional Coastal Management Plan*. Environmental Protection Agency, Queensland Government.

Environment Australia (2001). *A Directory of Important Wetlands in Australia, Third Edition*. Environment Australia, Canberra.

Geoscience Australia (2011). Hazards – where do Tsunamis Occur?: accessed 16 march 2011.

http://www.ga.gov.au/hazards/tsunami/tsunami-basics/where.html

GHD (2006) Auckland Creek Flood Study, for Gladstone City Council.

GHD (2011) . Report for Concept Studies for Launch Sites & TWAFs – Gladstone Temporary Workers Accommodation Facilities Report – DRAFT. For Arrow Energy.

Great Barrier Reef Marine Park Authority (GBRMPA, 2007): Calliope River Catchment – Catchment Information: accessed March 2011.

http://www.gbrmpa.gov.au/__data/assets/pdf_file/0005/7439/Calliope.pdf

Hardy et al (2004) *Queensland climate change and community vulnerability to tropical cyclones: Ocean hazards assessment – Stage 3.* Report for Queensland Government.

Harper B.A. (1998) Storm Tide Threat in Queensland: History, Prediction and Relative Risks. Dept of Environment and Heritage, Conservation Tech Rep No. 10, RE 208, Aug, 1998, ISSN 1037-4701 (Reprinted Jan 1999).

James Cook University (dead link).

http://mmu.jcu.edu.au/water_level_return_periods/QLD_coast/gh_levels_atlas.html

Katestone Environment Pty Ltd (2011). *Description of Climate in the Arrow LNG Plant Area, Gladstone Queensland.* Prepared for Arrow Energy Holdings Pty Ltd and Coffey Environments Pty Ltd.

Maritime Safety Queensland (2010). Semidiurnal Tidal Planes, Queensland Tide Tables 2011: accessed 16 March 2011.

http://www.msq.qld.gov.au/~/media/4f5e9fd9-dd82-4c45-818a-6210ed9f3fdf/pdf_semidiurnal_planes_2011.pdf

Natural Resources and Water (2007). *Calliope River Basin water resource plan consultation report*.

PAEHolmes (2011). *Arrow LNG Plant Project – Climate Change Assessment*. Prepared for Arrow Energy Holdings Pty Ltd and Coffey Environments Pty Ltd.

Queensland Government (2006). Water Resource (Calliope River Basin) Plan.

Queensland Government, Environmental Protection Agency, Queensland Parks and Wildlife Service (2003). *Curtis Coast Regional Coastal Management Plan*.

Queensland Government, Natural Resources and Water (2007). *Calliope River Basin water resource plan consultation report*.

Royal Geographic Society of Queensland (RGSQ, 2009) accessed March 2010:

http://www.rgsq.org.au/24-151c.htm

Sargent Consulting (2006). *Calliope River Flood Risk Assessment Study – Milestone Report 5 Final Report* prepared for Calliope Shire Council and Gladstone City Council.

SKM (2011). Arrow LNG Plant Social Impact Assessment. Report prepared by Sinclair Knight Merz Pty Ltd for Arrow Energy Holdings Pty Ltd and Coffey Environments Australia Pty Ltd. Brisbane, Queensland.

Strahler, A. N. (1952). *Dynamic basis of geomorphology*. Geological Society of America Bulletin, 63, 923-938.

URS in association with RLMS (2008). *Gladstone Nickel Project Environmental Impact Statement Supplement – Volume 3 Appendices H – M*. Prepared for Gladstone Pacific Nickel, February 2008.

Attachment A - Geomorphic Category Examples

A1 Geomorphic Category Examples Within and Adjacent to the Study Area

The following examples of geomorphic types (River Styles) are representative of the various River styles identified within the study area. A map showing their location is provided as Figure 4-7, page 35.

Confined – Confined Valley with Occasional Floodplain Pockets

<table>
<tr><td>Position in catchment</td><td colspan="2">Usually in steeper terrain in relatively straight valleys.</td></tr>
<tr><td>Channel Geometry</td><td colspan="2">Varies between symmetrical and asymmetrical and generally compound cross section. Variable width to depth ratio. Generally shallow channel on bedrock becoming deeper downstream below geologic timescale headcuts (waterfalls).</td></tr>
<tr><td>Channel Pattern</td><td colspan="2">Single. Valley walls dictate planform, low sinuosity.</td></tr>
<tr><td>Geomorphic Units</td><td><u>Channel zone</u>: Bedrock steps, riffle/cascade, short backwater or plunge pools.</td><td><u>Floodplain zone</u>: benches on the inside of valley spur controlled bends.</td></tr>
<tr><td>Geomorphic Behaviour</td><td colspan="2">Moderate to steep slope, bedrock or coarse bedload dominated. Bends not free to migrate downstream or laterally (i.e., is laterally fixed). Reworking of bars and floodplain pockets on inside bends. May slowly erode valley wall if not composed of bedrock.</td></tr>
<tr><td>Sediment Transfer Behaviour</td><td colspan="2">Transfer in balance over the long-term, but floodplain pockets accumulate slowly and flush over short interval.</td></tr>
</table>

Example 1

Photo: Rohan Lucas and Jason Carter.

Plate 1. Example E1: Confined, W3 on Curtis Island upstream from LNG plant E 318752 N 7369754 (inside study area but outside area of disturbance)

Headwater

Position in catchment	Usually 1st order streams in steeper terrain.	
Channel Geometry	Generally shallow channel on bedrock/indurated colluvium that is near contiguous with abutting hillslopes.	
Channel Pattern	Single. Valley walls dictate planform, occasional discontinuous shallow narrow floodplain pockets (colluvial deposits) at wider sections of valley.	
Geomorphic Units	Channel zone: Bedrock steps, riffle/cascade, short backwater or plunge pools.	Floodplain zone: none.
Geomorphic Behaviour	Moderate to steep slope, bedrock dominated.	
Sediment Transfer Behaviour	Source zone, transfer in balance over the long-term, but colluvial/alluvial deposits accumulate slowly and flush over short interval.	

Project Area Example

Photo: Rohan Lucas and Jason Carter.

Plate 2. Example E2: W3 headwater reach on Curtis Island E 317920 N 7370285 (outside study area)

Alluvial Continuous – Low to Moderate Sinuosity Fine Grained

<table>
<tr><td>Position in catchment</td><td colspan="2">Boat Creek and unnamed creek on the mainland and first order watercourse on Curtis Island. Low in the catchment immediately upstream from tidal reaches.</td></tr>
<tr><td>Channel Geometry</td><td colspan="2">Symmetrical, with low to moderate width-depth ratio.</td></tr>
<tr><td>Channel Pattern</td><td colspan="2">Narrow single channel, low to moderate sinuosity, continuous floodplain. May be occasional higher level flood channels.</td></tr>
<tr><td>Geomorphic Units</td><td><u>Channel zone</u>: benches, small pools, and small bars if any.</td><td><u>Floodplain zone</u>: flat floodplain, levees, swamps, flood channels.</td></tr>
<tr><td>Geomorphic Behaviour</td><td colspan="2">Very low rates of change in cohesive sediments. May have inset low flow channel meandering between paired benches.</td></tr>
<tr><td>Sediment Transfer Behaviour</td><td colspan="2">Slow accretion of banks and levees. Subject to aggradation if increased inputs of coarser material from catchment.</td></tr>
</table>

Project Area Example

Photo: Rohan Lucas and Jason Carter.

Plate 3. Example E3: W13 on the mainland. E 311239 N 7368942 (inside study area but outside area of disturbance)

Alluvial Continuous – Low to Moderate Sinuosity gravel bed

Position in catchment	Targinie Creek on the mainland at the site of potential TWAF 8. Mid catchment.	
Channel Geometry	Symmetrical, with low to moderate width-depth ratio.	
Channel Pattern	Narrow single channel, low to moderate sinuosity, continuous floodplain. May be occasional higher level flood channels.	
Geomorphic Units	Channel zone: benches, small pools, and small bars if any.	Floodplain zone: flat floodplain, levees, swamps, flood channels.
Geomorphic Behaviour	Vertical and horizontal soft rock control. Cobbles in bed. Very low rates of change in cohesive sediments. Low capacity channel with frequent out of channel flows at TWAF 8.	
Sediment Transfer Behaviour	If cleared there is a high risk of erosion of upper finer grained horizon until coarse sediment is stripped.	

Project Area Example

Photo: Rohan Lucas.

Plate 4. Targinie Creek on the mainland. E 307937 N 7368288 (inside study area but outside area of disturbance).

Partly-confined with Low Sinuosity Planform Controlled Discontinuous Floodplain

<table>
<tr><td>Position in catchment</td><td colspan="2">Found on both the mainland and Curtis Island where there is moderate or greater relief.</td></tr>
<tr><td>Channel Geometry</td><td colspan="2">Compound, symmetrical on straights, asymmetrical on bends. Often deeply incised below floodplain pockets and narrow.</td></tr>
<tr><td>Channel Pattern</td><td colspan="2">The valley is relatively straight or irregular and the valley planform controls the channel planform. The single channel has low sinuosity and abuts the valley margin for 10 – 50 % of its length. The floodplain is discontinuous and may be terraced.</td></tr>
<tr><td>Geomorphic Units</td><td>Channel: pools, riffles, runs, benches, point bars.</td><td>Floodplain: generally featureless, occasional shallow depression wetlands.</td></tr>
<tr><td>Geomorphic Behaviour</td><td colspan="2">Moderate to low slopes. Bed material can be fine grained cohesive, indurated sediments, bedrock or mobile coarse sediment veneer. Rates of change dependent on sediment characteristics and gradient. Bedrock will limit larger scale rates of change.</td></tr>
<tr><td>Sediment Transfer Behaviour</td><td colspan="2">In balance over the long term unless oversupply from catchment disturbance induced erosion.</td></tr>
</table>

Project Area Example

Photo: Rohan Lucas and Jason Carter.

Plate 5. W2 on Curtis Island. E 319296   N 7369635 (inside the area of disturbance).

Partly-confined with Meandering Planform Controlled Discontinuous Floodplain

position in catchment	Found in the project area on Curtis Island at transition from hillslope and valley to floodplain. Example is the un-named creek at the LNG plant location on Curtis Island.	
Channel Geometry	Compound, symmetrical on straights, asymmetrical on bends. May be shallow and regularly engages floodplain.	
Channel Pattern	Valley can be straight or irregular and channel meanders independent of valley planform. Rate of meander migration dependent on sediment size and cohesiveness. Moderate sinuosity.	
Geomorphic Units	Channel: pools, riffles, runs, benches, point bars.	Floodplain: flood/abandoned channels.
Geomorphic Behaviour	Moderate to low slopes. Bed material can be fine grained cohesive, indurated sediments, bedrock or mobile coarse sediment veneer. Rates of change dependent on sediment characteristics and gradient. Bedrock will limit larger scale rates of change.	
Sediment Transfer Behaviour	In balance over the long term unless oversupply from catchment disturbance induced erosion.	

Project Area Example

Photo: Rohan Lucas and Jason Carter.

Plate 6. Un-named waterway on Curtis Island, active bank migration. E 319362 N 7369582(inside the area of disturbance)

Alluvial Discontinuous – Valley Fill

position in catchment	Many first and second order un-named waterways in upper catchments. Generally un-named watercourses. Only one example (intact) on Curtis Island. Examples on the mainland are not planned to be disturbed.	
Channel Geometry	Whole valley floor is 'channel'. Valley margins are 'banks'. Fill is flat or slightly higher in centre than at valley margins.	
Channel Pattern	When intact there is no channel, hence valley is planform. When incised may meander within valley constraints and behave like Partly-confined with meandering planform controlled discontinuous floodplain.	
Geomorphic Units	Channel zone: none where intact. When channelised, include runs and erosion heads.	Floodplain zone: the whole valley floor is the flow path when intact.
Geomorphic Behaviour	Slow accretion of valley floor if undisturbed. Can be highly sensitive to disturbance.	
Sediment Transfer Behaviour	Slow accumulation of fine sediment. Very important stores of sediment in the landscape. Major source of sediment if incising.	

Project Area Example

Photo: Rohan Lucas and Jason Carter.

Plate 7. E7: W3 on Curtis Island. E 319168 N 7369657 (inside the area of disturbance).

Tidal – Meandering

<table>
<tr><td>Example waterways and position in catchment</td><td colspan="2">Examples of Tidal – meandering: Reaches of Boat Creek and unnamed creek to the south-east, No examples identified on Curtis Island. Lower catchment prior to entering the sea.</td></tr>
<tr><td>Channel Geometry</td><td colspan="2">Symmetrical on straights, asymmetrical on bends. Well defined banks. Levees. Narrow low tide channel within a wide high tide flooded plain or marsh.</td></tr>
<tr><td>Channel Pattern</td><td colspan="2">Sinuosity varies dependent on scale of channel and length within the tidal zone.</td></tr>
<tr><td>Geomorphic Units</td><td>Channel zone: point/scroll bars, range of tidal bars, islands.</td><td>Floodplain zone: typically flat or gently inclined away from the channel(s); flood channels, paleochannels, large swamps, cutoffs, all with wetland vegetation (in the project area this is predominantly flooded daily, mangrove swamps</td></tr>
<tr><td>Geomorphic Behaviour</td><td colspan="2">Mud and/or sand dominated. Fluvial and tidal processes. Bends slowly migrating. Floodplain both lateral and vertical building. Extensive wave erosion of banks on wider reaches.</td></tr>
<tr><td>Sediment Transfer Behaviour</td><td colspan="2">Long term aggradation of mud and sand.</td></tr>
</table>

Project Area Example: Tidal – Meandering

Photo: Rohan Lucas and Jason Carter.

Plate 8. Example E8: Boat Creek on the mainland. E 312832 N 7365400 (inside study area but outside the area of disturbance)

Tidal – Low moderate sinuosity

<table>
<tr><td>Example waterways and position in catchment</td><td colspan="2">Examples of Tidal – low moderate sinuosity: Calliope River and Auckland Creek on the mainland. Lower catchment prior to entering the sea.</td></tr>
<tr><td>Channel Geometry</td><td colspan="2">Symmetrical on straights, asymmetrical on bends. Well defined banks. Levees. Narrow low tide channel within a wide high tide flooded plain or marsh.</td></tr>
<tr><td>Channel Pattern</td><td colspan="2">Sinuosity varies dependent on scale of channel and length within the tidal zone.</td></tr>
<tr><td>Geomorphic Units</td><td>Channel zone: point/scroll bars, range of tidal bars, islands.</td><td>Floodplain zone: typically flat or gently inclined away from the channel(s); flood channels, paleochannels, large swamps, cutoffs, all with wetland vegetation (in the project area this is predominantly flooded daily, mangrove swamps</td></tr>
<tr><td>Geomorphic Behaviour</td><td colspan="2">Mud and/or sand dominated. Fluvial and tidal processes. Bends slowly migrating. Floodplain both lateral and vertical building. Extensive wave erosion of banks on wider reaches.</td></tr>
<tr><td>Sediment Transfer Behaviour</td><td colspan="2">Long term aggradation of mud and sand.</td></tr>
</table>

Plate 9. Example E9: Auckland Creek on the mainland (highly disturbed). E 320585 N 7360703 (inside study area at TWAF7)

Attachment B - Flood Assessment: LNG plant

B1 Introduction

This attachment provides an assessment of existing flood conditions and flood risk within the catchments on Curtis Island where the LNG plant will be constructed. The assessment will inform the design process for the diversion of minor waterways around the facility for which conceptual routes are provided.

This appendix covers:

- Catchment Characteristics:
- Climate and Rainfall
- Hydrology
- Sea and Surface Water Interaction
- Existing Conditions Flood Extents
- Surface Water Management
- Climate Change

B2.1 Catchment Characteristics

Curtis Island is approximately 45km long and 14km wide having a central ridge along the long axis of the island with Mt Barker reaching the maximum elevation of 163m near the northern end.

The proposed LNG plant falls across four primary catchments, the largest of which is 1,86ha (1.86km^2). All drain directly to the sea (see Figure B2-1, page 91).

A number of streams pass through the proposed site. The largest of these streams is unnamed though with an 8m wide bed and 2.5m high banks it would, at times, convey large flows. Evidence also suggests that a broad floodplain is occasionally engaged by overbank flows. The catchment areas of the streams are generally steep with multiple gully lines draining to the main watercourse. Indicative of high energy flows, these watercourses typically have a bedload of cobbles.

B2.2 Climate and Rainfall

Curtis Island is located approximately 100 km south of the Tropic of Capricorn in a sub-tropical climate with average temperatures between 18 and 28°C and may be subject to cyclones. The weather station at Southend on Curtis Island has been in operation since 1973 but provides limited climatic information. Hence, to gain a more comprehensive picture, records from a number of other stations on the mainland and one on Rundle Island, northeast of Curtis Island, have been referred to. Historical records indicate that rainfall has a typical wet season pattern with the majority (approximately 60%) of rain falling between December and March. For most of the sites the mean annual rainfall is similar to that listed for Gladstone Radar in Table B2-1, below. The Gladstone Post Office (1872-1958) has a much higher mean annual rainfall of 1,020mm, which may in part be due to higher than average rainfall in the 30 years prior to commencement of any of the other weather stations used.

The Gladstone Radar station is the only one that records daily evaporation; having a mean annual daily evaporation of 4.8 mm though this varies to reflect the seasons from greater than 6mm from November to January to around 3mm in mid-year.

More detailed assessment of the climate of Curtis Island can be found in PAEHolmes (2011) . In addition, the Description of Climate in the Arrow LNG Plant Area, Gladstone Queensland (Katestone Environmental, 2011) provides further climate data for the Gladstone area and is not repeated here.

Table B2-1. ***Bureau of Meteorology Average Climate Conditions for Gladstone Radar (station 039123) from 1957 to 2011***

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year Total
Ave Rainfall (mm)	140.1	148.3	83.3	47.5	58.7	38.4	34	32.1	28.2	60.9	74.7	134.5	883.8
Ave Days rain ≥ 10mm	3.6	3.5	2	1.3	1.3	1.1	1	0.8	0.9	1.8	2.4	3.6	23.3
Ave Daily Evap (mm)	6.3	5.9	5.3	4.4	3.4	3	3.1	3.5	4.4	5.5	6.1	6.3	4.8
Ave Temp Min-Max(°C)	22.5 - 31.2	22.4 - 30.9	21.5 - 30.2	19.6 - 28.4	17 - 25.7	14.3 - 23.3	13.4 - 22.8	14.3 - 24.1	16.5 - 26.5	18.7 - 28.4	20.5 - 29.9	21.9 - 31	18.6 - 27.7

(BOM, 2011a)

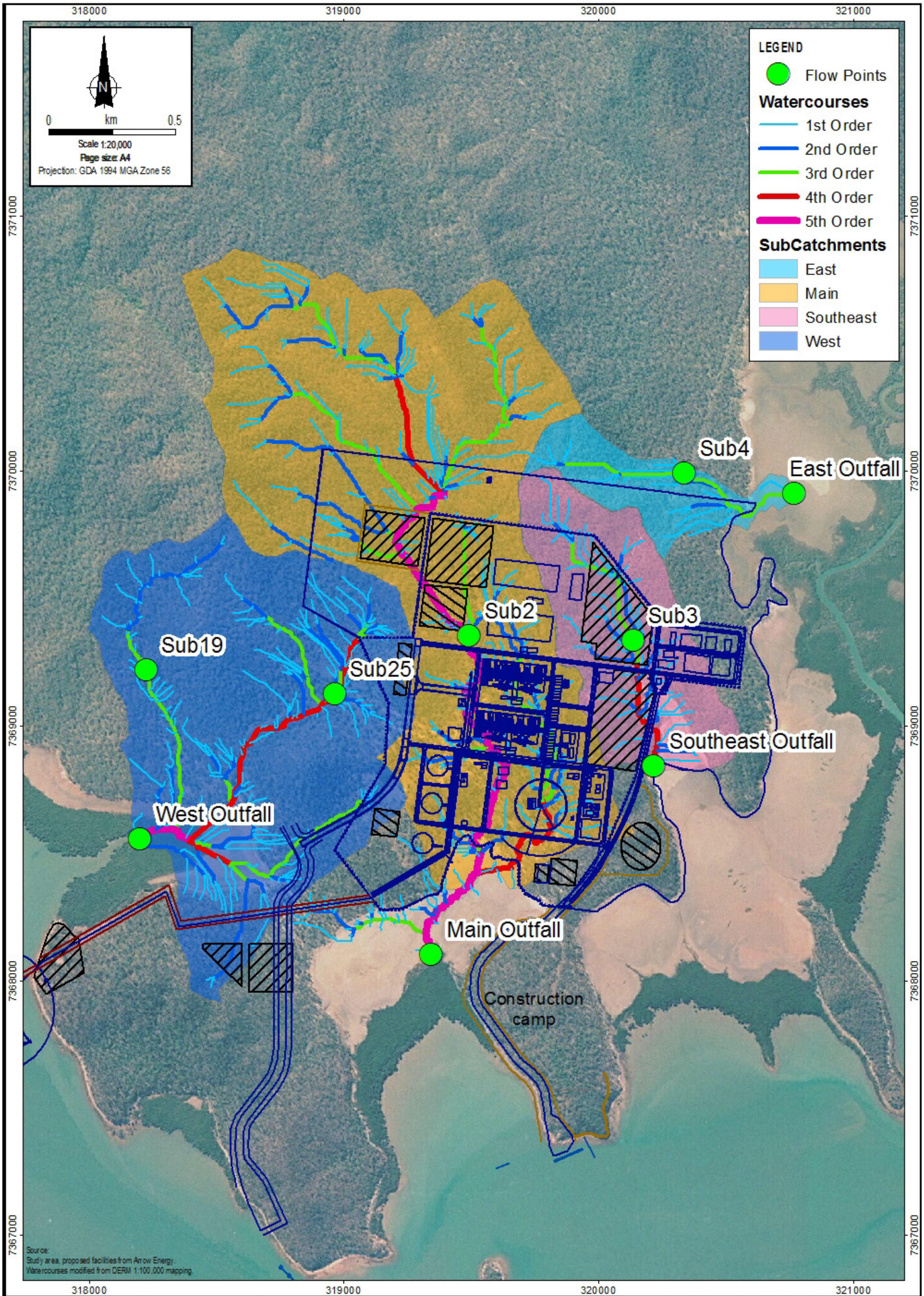
As an ungauged catchment, mean annual runoff has been estimated at 79,000 ML/yr through modelling of the mean daily rainfall and catchment area and calibrating with a geographically similar catchment (Curtis Island (ANRA, 2009))

B2.3 Hydrology

A hydrologic analysis was undertaken to estimate the magnitude and frequency of stream flows that could be expected at the site. Without rainfall or flow records, rainfall was estimated using statistically derived, regional rainfall parameters. A catchment model was created from the digital terrain model and rainfall estimates were routed through the catchment to determine the magnitude and frequency of streamflow hydrographs at the LNG plant site. As the site is split into 4 primary catchments, each were modelled separately and the peak discharges for each are listed below in Table B2-2.

Table B2-2. ***Peak Discharges for Subcatchments Surrounding LNG Plant***

	Peak Flow Rate, Q, (m3/s) for various Average Recurrence Intervals (ARI)						
RORB Location	**1 Year**	**2 Year**	**5 Year**	**10 Year**	**20 Year**	**50 Year**	**100 Year**
East Outfall	0.9395	1.7082	2.9727	3.7569	4.877	5.9507	7.0147
Southeast Outfall	1.9398	3.3325	5.6243	7.1976	9.3183	11.658	13.8676
West Outfall	4.4952	7.9542	13.4284	16.8996	21.6028	27.2644	32.2567
Main Outfall	6.9891	11.9611	20.0898	25.3312	32.5936	41.6173	49.5091



alluvium	Date: 08.08.2011 MXD: P210002-F0201_v2 File Name: P210002-FB2-1 Rev: 1	Arrow Energy Arrow Energy LNG Plant	arrow energy	LNG Plant Curtis Island Existing Conditions Peak Flow Locaitons	Figure No: B2-1

B2.5 Sea and Surface Water Interaction

Tidal inundation

In the absence of tidal charts specifically for Curtis Island, the tidal characteristics for either Gladstone (standard port) or Fishermans Landing can be adopted for the LNG site (see Table B2-3). Both locations are a similar distance from the site and exhibit similar tidal conditions. While Fishermans Landing is slightly more conservative Gladstone has been used in preference due to its more direction orientation to the LNG plant.

Table B2-3. ***Tidal Conditions for Gladstone and Fishermans Landing***

	Gladstone (Standard Port)		Fishermans Landing	
Tidal Condition	**Height above LAT**	**Level AHD (-2.268m)**	**Height above LAT**	**Level AHD (-2.43m)**
Highest Astronomical Tide	4.83	2.562	5.12	2.69
Mean High Water Springs (MHWS)	3.96	1.692	4.2	1.77
Mean High Water Neaps (MHWN)	3.11	0.842	3.3	0.87
Mean Sea Level (MSL)	2.34	0.072	2.41	-0.02
Mean Low Water Neaps (MLWN)	1.57	-0.698	1.66	-0.77
Mean Low Water Springs (MLWS)	0.72	-1.548	0.76	-1.67
Lowest Astronomical Tides (LAT)	0	-2.268	0	-2.43

Source: Maritime Safety Queensland (2010)

The tidal flats to the immediate south of the site will experience inundation only during Mean High Water Neaps (or greater) tidal conditions.

The LNG plant has been sited to mostly avoid natural tidal inundation. This is demonstrated in Figure B2-2, where it can be seen that the influence of highest astronomical tide for either Gladstone or Fishermans Landing will only interfere with a small section of the southern extent of the site. It should be noted that this encroachment is based on existing ground levels – it is proposed to in-fill the south of the site to 11m AHD, which will place it over 8m clear of highest astronomical tide.

Storm Surge

The PAEHolmes (2011) climate change impact assessment report indicates the existing 100yr ARI storm surge level at Gladstone (Auckland Point) to be 2.82m AHD (citing Hardy et al 2004). Based on existing ground levels this will extend the salt water encroachment a further 50m into the site (see, Figure B4-1 page 101), but based on the proposed earth works this will not pose a threat to the site once constructed).

Harper (1998) reported on storm tide threats for the Queensland Government with estimates of the 100 year ARI storm level at Gladstone at around 3.2m AHD or 0.8m above Highest Astronomical Tide, equivalent to 3.362m AHD today. More recent modelling by James Cook University has estimated 100 year ARI storm tide levels for 50 sites along Queensland's east coast. Modelling was used to predict the return period of water levels and waves during tropical cyclones. This was undertaken for two scenarios: 2003 conditions and greenhouse conditions, the latter used to demonstrate sensitivity to climate change and predict the upper limits resulting from possible climate change scenarios up to 2050. Results for Gladstone, Emu Park (approximately 80 km to the north-west) and Tannum Sands (approximately 16 km to the south-east) are summarised in Table B2-2, below.

Table B2-2. JCU Modelling Results for 100yr ARI Storm Tide Levels (m, AHD)

RORB Location	Emu Park	Gladstone	Tannum Sands
2003 Conditions	2.87	2.82	2.50
2050 Greenhouse Conditions	3.28	3.33*	3.01

Source: JCU (2010?)

* - PAEHolmes quote a figure of 3.3 AHD from the Hardy et al (2004) study.

NB: It is noted that BMT WBM (2011) identifies a more conservative 100 year ARI design storm tide level of between 3.53 to 4.06 AHD including allowances for future climate change. This is based on the 100 year planning period plus a further 6% allowance for tide amplification. For consistency of approach Alluvium recommends adoption of the more conservative BMT WBM design storm tide maximum level of 4.06 AHD for detailed design and future planning.

Tsunami

Tsunamis usually result from seismic activity in the earth's crust under the ocean and are often associated with tectonic plate boundaries.

According to the Bureau of Meteorology (BOM, 2011b), Australia is vulnerable to tsunamis due to the location of active tectonic plates to the east and north of mainland Australia. A tsunami generated by activity at one of these tectonic plates could reach the Australian coastline in 2 to 4 hours and cause significant inundation to low-lying areas.

Geoscience Australia (2011) describes the threat to Australia as varying from relatively low for most of the coastline to moderate on the north west coast of Western Australia. Preliminary modelling of tsunami hazards to Australia supports this with preliminary mapping showing the most vulnerable parts of Australia as being the north west and south east.

Generally, the Tsunami hazard along the east coast of Queensland is considered low.

alluvium	Date: 08.08.2011 MXD: P210002-F002_Revb File Name: P210002-FB2-2 Rev: 1	Arrow Energy Arrow Energy LNG Plant	arrow energy	LNG Facility Curtis Island Existing Conditions Tidal and Storm Surge Inundation	Figure No: B2-2

B2.6 Existing Conditions Flood Extents

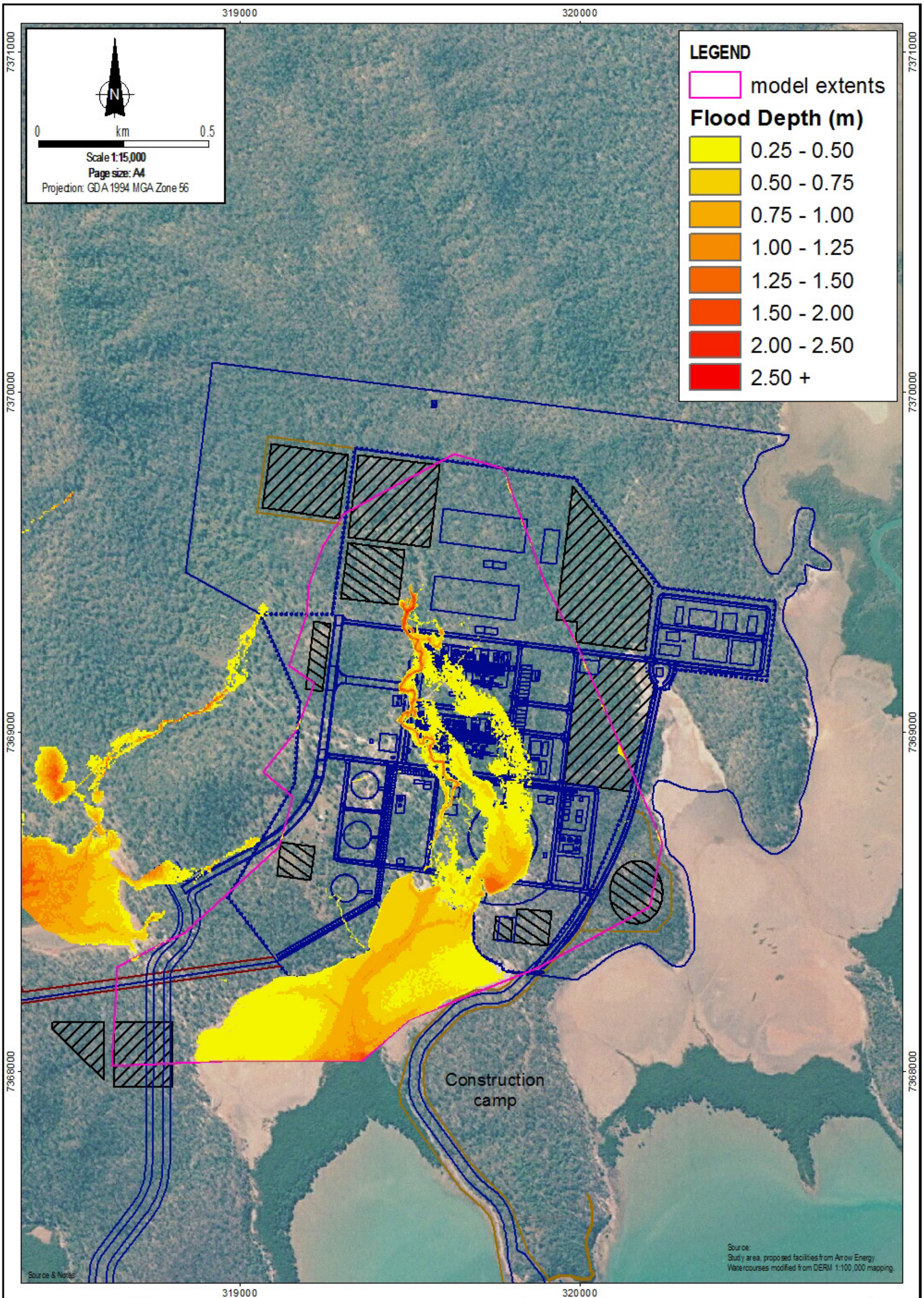
Hydraulic modelling was undertaken to assess flood extents for various ARI events under current conditions at the site. A mixture of 1d and 2d modelling was required as the overland flow experienced through the middle of the site was difficult to represent using solely 1d methods.

While a significant portion of the south end of the proposed site would be inundated during a 100 yr event, overland flow depths usually remained below 1m and were purely as a result of flash flooding, which would rapidly subside. While velocities could exceed 1m/s this would rarely coincide with areas of high depth so, overall, the flood hazard is low to moderate.

Due to the steepness of slope the sea level used as a downstream boundary condition had little impact on the catchment's ability to drain. Therefore, a conservative value equivalent to the Gladstone highest astronomical tide of 2.562m AHD was adopted and used throughout all the model runs.

The flood extent for the 100yr, 1.5hour event is shown in Figure B2-3, page 96. It must be noted that while the plant footprint is overlayed on the flood extent the waterway diversion required as part of the development will reduce flows on site to just the local runoff.

While the figure indicates that the flooding occurs only on the south half of the site it is likely that, based on the existing conditions, flooding would occur further north as well. Due to the limited detailed topography data available the model extent had to be limited to the southern area with the northern area being accounted for by a hydrological node input in the middle of the site.



alluvium	Date: 08.08.2011 MXD: P210002-F003_Revb File Name: P210002-FB2-3 Rev: 3	Arrow Energy Arrow Energy LNG Plant	arrow energy	LNG Plant Curtis Island Existing Conditions 100 Year Flood Extents	Figure No: B2-3

B3 Surface Water Management

B3.1 Diversion Options

As the cut and fill earthworks proposed for the LNG plant will remove the primary drainage path through the site it is necessary to provide waterway diversion/s and drainage to transport rainfall runoff from the north of the catchment, around the site and into the sea. It will also be necessary to manage runoff from the LNG plant and separate it from clean water that will flow from upslope and around the LNG plant.

Toe drains that intercept runoff from the batters are an integral feature of the LNG plant bench design. The capacity of the toe drains to divert flows from the primary drainage path around the bench has not been resolved and consequently, a number of options exist to divert runoff and drainage path flows. They are shown in Figure B3-1, page 98 and listed below :

1. A western diversion
2. An eastern diversion
3. A western toe drain
4. An eastern toe drain

The main diversion options divert flows to the east and/or to the west (summarised in Table B3-1 below), as several catchments are intercepted and topographic constraints may favour one option over the other. The toe drains design requires further consideration before further analysis as to the effectiveness of these structures for drainage path diversion and runoff management can be assessed. An alternative option, to pipe flows through the site has been discounted as to convey 50yr ARI flows the diameter would have to be sized to convey over $30m^3/s$ and would most likely be impractical and not self-sustaining beyond decommissioning.

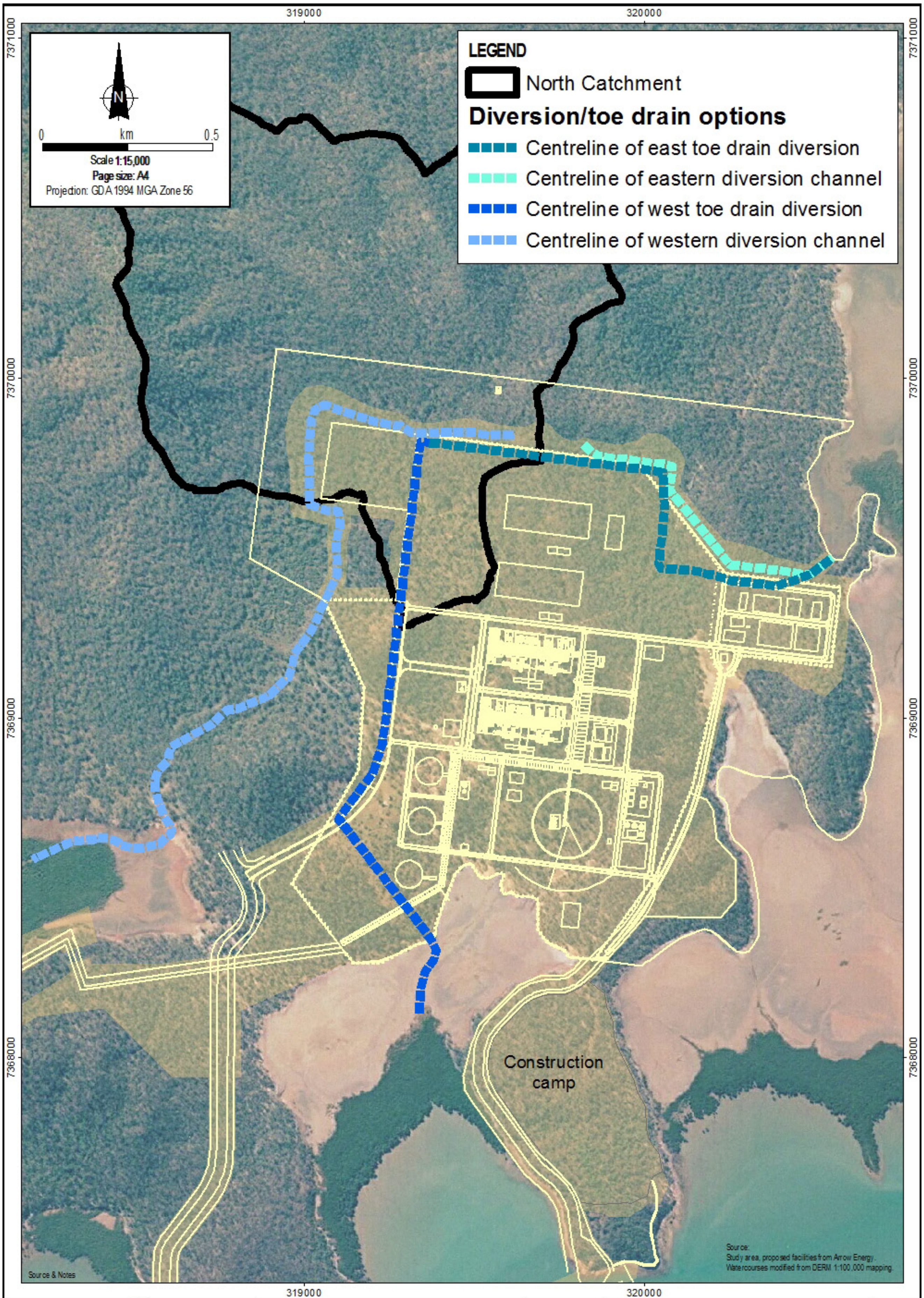
Table B3-1. ***Summary Outline of Diversion Options***

Diversion	East Option	West Option
Plan Length	1,290m	2,800 m
Max Elevation Change	35m	38m
Average Gradient	1.1% (0.011m/m)	0.8% (0.008m/m)
Potential Cutting Depth	20-25m	20-25m
50yr ARI Flow Velocity*	2.62m/s	2.34m/s

* - $33m^3/s$, trapezoidal channel bottom width 5m, 2m flow depth

The existing 50yr ARI velocities through the main channel through the site are, on average, 1m/s peak to 2.5m/s in some instances (see Appendix C of Attachment B). Without the possibility of overland flow the diversions will be required to transport the entire flow in channel hence the velocity increase to approximately 3.6 m/s (based on the conceptual cross section). Either option will require rock armouring if not constructed in competent bedrock to minimise long term erosion.

It must be noted that the majority of the characteristics for the eastern diversion option have been determined from 10m contour data and is unlikely to be a good indication of the detailed design. It is expected that both western and eastern diversion and/or toe drain options will be required.



alluvium	Date: 08.08.2011 MXD: P210002-F003_Revb File Name: P210002-FB3-1 Rev: 1	Arrow Energy Arrow Energy LNG Plant	arrow energy
LNG Plant Curtis Island Post Development Diversion/toe drain options	Figure No: B3-1		

B3.2 Diversion Design Guidelines

The waterway/s to be diverted will be in-filled as part of the construction process for the facility. Surface water flows from upstream of the facility will be intercepted, kept separate from facility runoff, diverted around the facility and discharged downslope into other waterways that will be modified to manage additional flows. This is expected to require two diversion and/or toe drain channels one flowing west the other flowing east but will be determined upon the final design of the facility.

The design of the diversion/s will include the following features and considerations.

- Diversion/s and receiving waterways should not have erosion or deposition at greater than natural rates.
- Diversion/s should be in the form of a corridor, which may contain a formalised channel and constructed floodplain zone.
- The design should allow for the transport of sediment from upstream of the LNG plant, through the diversion corridor.
- Design should consider post decommissioning channel form and the need to provide for a self-sustaining waterway, without the need for maintenance beyond facility life.

B3.3 Monitoring diversion performance

Monitoring of the performance of the diversion/s will be undertaken as shown In .

Table B3-2. ***Monitoring Components***

MONITORING PACKAGE COMPONENTS	OBJECTIVE
1: Baseline monitoring	To establish a baseline data set prior to construction.
2: Construction monitoring	To demonstrate that construction works have been undertaken to specification.
3: Operations monitoring	To maintain channel condition and reduce risk to project infrastructure.
4: Relinquishment monitoring	To demonstrate the diversion is operating as a waterway in equilibrium with and not adversely impacting on adjoining reaches at and post decommissioning of the LNG plant.

B4 Climate Change

PAEHolmes (2010) outlines the expected impact of climate change on the environmental variables affecting Curtis Island as follows:

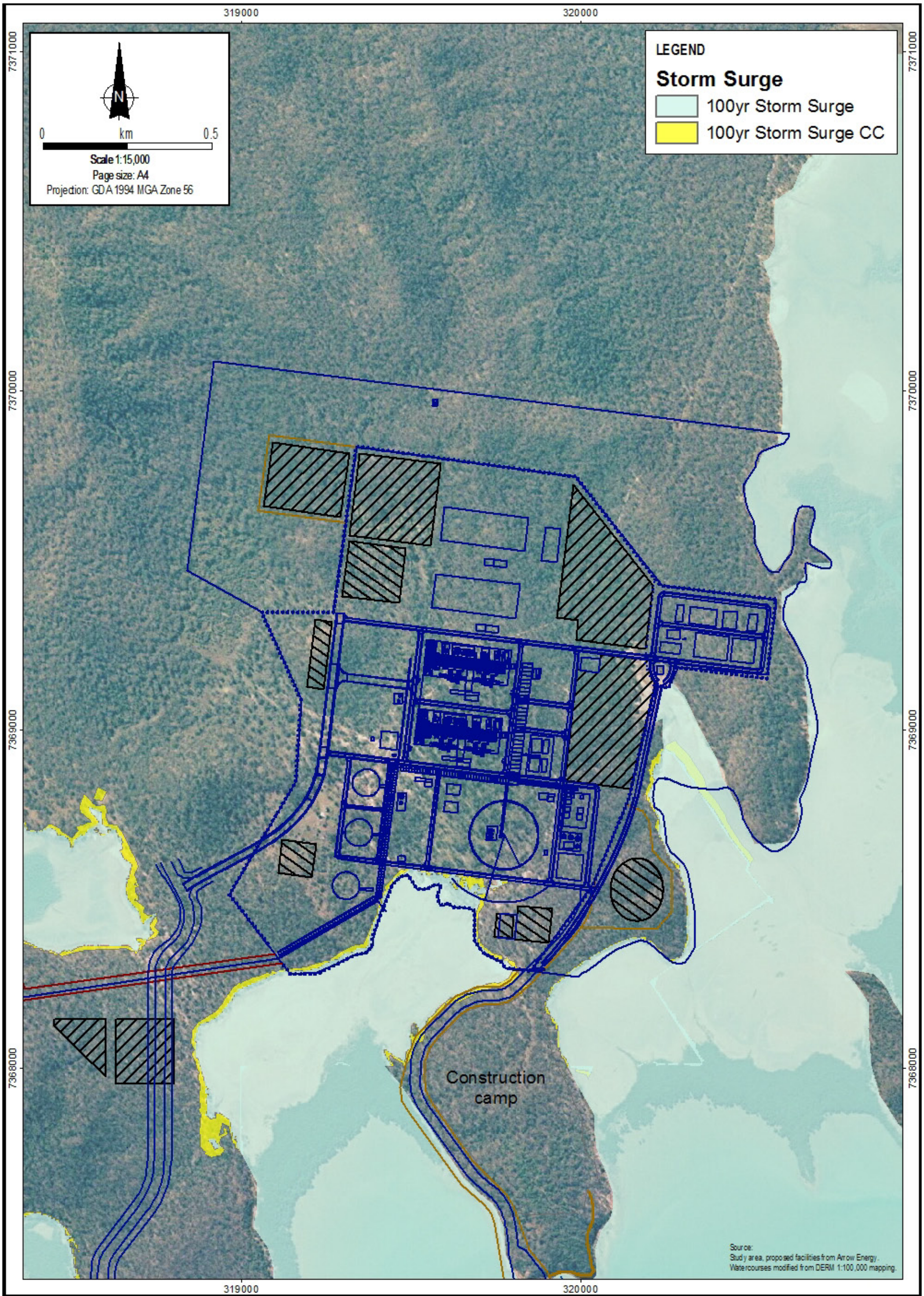
- Rainfall is expected to decrease by 3% by 2030 and decrease by between 6 and 10% by 2070.
- The Intergovernmental Panel on Climate Change (IPCC) (2007) predicts that the global sea level will rise by 18-59cm by 2100.

Assuming that the state rainfall trend also applies to the intensity of rainfall the peak runoff generated from the site may decrease as a result of climate change.

As discussed in Section B2.5 the existing 100yr ARI storm surge level, is 2.82m AHD. PAEHolmes indicate that Hardy et al. (2004) predict the climate change 100 year ARI storm surge, taking into account increased sea level and increased cyclone intensity, to be 3.3m (see Figures B4-1, page 101 and Figure B4-2, page 102). This is a 0.5m increase over current and is mostly due to the anticipated 0.3m sea level rise that Hardy et al. adopted for the assessment. As discussed in section B2.5, the JCU study determined the 100yr storm surge to be 3.33m when making an allowance for climate change.

In regard to sea level rise, given the topography of the site, salt water encroachment is not expected to greatly increase as a result of sea level rise and once the site is in-filled for construction it should not have any impact at all. As discussed in Section B2.5 the steepness of the local catchments results in the sea level having little impact on the storm water drainage.

alluvium	Date: 03.05.2011	Arrow Energy	arrow energy	LNG Plant Curtis Island	Figure No:
	MXD: P210002-F006_Revb			Existing Conditions	B4-1
	File Name: P210002-FB4-1 Rev: 1	Arrow Energy LNG Plant		Storm Surge Innundation (inc C C)	



alluvium	Date: 03.05.2011 MXD: P210002-F006_Revb File Name: P210002-FB4-2 Rev: 1	Arrow Energy Arrow Energy LNG Plant	arrow energy	LNG Plant Curtis Island Post Development Storm Surge Innundation (inc C C)	Figure No: B4-2

B5 Conclusions

- As the cut and fill earthworks proposed for the LNG plant will remove the primary drainage path through the site it is necessary to provide one or more waterway diversions and/or toe drains to transport rainfall runoff from the north of the catchments, around the site and into the sea.
- Primarily, the options are to divert flows to the east or to the west.
- Detailed design of the diversions and/or toe drains and associated drainage will be undertaken as part of finalisation of the facility plans.
- Changes in rainfall pattern and sea level rises predicted as a consequence of climate change will not have any adverse impact upon the hydrology or geomorphology of the waterways in the vicinity of the LNG plant. This also applies to Storm Surge as a result of cyclonic activity.
- Monitoring of the diversion/s performance will be undertaken from pre-construction to post-decommissioning.

B6 References

Australia Pacific LNG Project Volume 5: Attachment. Attachment 26: Flooding, Drainage and Stormwater Management – LNG plant (2010)

Australian Natural Resources Atlas (2009), Water resources - Allocation and use – Queensland: accessed 16 March 2011

http://www.anra.gov.au/topics/water/allocation/qld/basin-curtis-island.html

Bureau of Meteorology (BOM, 2011a), Climate Statistics for Australian Locations: accessed 16 March 2011

http://www.bom.gov.au/climate/averages/tables/cw_039123_All.shtml

Bureau of Meteorology (BOM, 2011b), Australian Tsunami warning System: accessed 16 March 2011

http://www.bom.gov.au/tsunami/about/atws.shtml

Geoscience Australia (2011), Hazards – Where do Tsunamis Occur: accessed 16 March 2011

http://www.ga.gov.au/hazards/tsunami/tsunami-basics/where.html

Hardy et al (2004) Queensland climate change and community vulnerability to tropical cyclones: Ocean hazards assessment – Stage 3. Report for Queensland Government.

Harper B.A., Storm Tide Threat in Queensland: History, Prediction and Relative Risks. Dept of Environment and Heritage, Conservation Tech Rep No. 10, RE 208, Aug, 1998, ISSN 1037-4701 (Reprinted Jan 1999).

Intergovernmental Panel on Climate Change (IPCC) (2007) *Climate Change 2007*, the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change.

James Cook University (JCU, 2010?), Dead link, accessed 16 March 2011

http://mmu.jcu.edu.au/water_level_return_periods/QLD_coast/gh_levels_atlas.html

Katestone Environment Pty Ltd (2011), Description of Climate in the SALNG Project Area, Gladstone Queensland.

Marine Safety Queensland (2010) Semidiurnal Tidal Planes, Queensland Tide Tables 2011, The State of Queensland (Department of Transport and Main Roads). Accessed 16 March 2011 at:

http://www.msq.qld.gov.au/~/media/4f5e9fd9-dd82-4c45-818a-6210ed9f3fdf/pdf_semidiurnal_planes_2011.pdf

PAEHolmes (2011). *Arrow LNG Plant Project – Climate Change Assessment*. Prepared for Arrow Energy Holdings Pty Ltd and Coffey Environments Pty Ltd.

Attachment B - Appendix A Design Rainfall Data, Curtis Island

IFD Data for Curtis Island

Rainfall Intensity Frequency Duration data for; Curtis Island (south) Qld

Geographic Location: 23.7768 Deg. South 151.2281 Deg. East

AUSIFD Version 2.0 15-Feb 2011

Duration (mins)	1 Year ARI (mm/hr)	2 Year ARI (mm/hr)	5 Year ARI (mm/hr)	10 Year ARI (mm/hr)	20 Year ARI (mm/hr)	50 Year ARI (mm/hr)	100 Year ARI (mm/hr)
5	110	143	185	210	245	292	329
10	86	111	143	162	189	224	253
20	63	82	105	119	138	164	184
30	52	67	86	97	113	134	150
45	41.9	54	69	78	91	107	121
60	35.8	46.2	59	67	77	91	103
90	27.5	35.6	46	52	61	73	82
120	22.7	29.5	38.4	43.9	51	61	69
150	19.5	25.4	33.3	38.3	44.9	54	61
180	17.3	22.5	29.7	34.2	40.2	48.4	55
240	14.2	18.6	24.7	28.6	33.8	40.8	46.5
300	12.2	16	21.4	24.9	29.5	35.8	40.9
360	10.8	14.2	19.1	22.3	26.4	32.2	36.8
720	6.76	8.96	12.3	14.5	17.4	21.4	24.7
1440	4.37	5.88	8.39	10.1	12.3	15.4	18
2880	2.76	3.76	5.59	6.87	8.53	10.9	13

Attachment B - Appendix B RORB Modelling

Peak Flow Rates (m^3/s)

East Model

RORB Location	1 Year	2 Year	5 Year	10 Year	20 Year	50 Year	100 Year
sub4	0.4584	0.8889	1.533	1.9244	2.4867	2.9744	3.4928
Outfall	0.9395	1.7082	2.9727	3.7569	4.877	5.9507	7.0147

Southeast Model

RORB Location	1 Year	2 Year	5 Year	10 Year	20 Year	50 Year	100 Year
sub3	0.878	1.612	2.7507	3.497	4.4967	5.536	6.6068
Outfall	1.9398	3.3325	5.6243	7.1976	9.3183	11.658	13.8676

West Model

RORB Location	1 Year	2 Year	5 Year	10 Year	20 Year	50 Year	100 Year
sub25	1.1765	2.1836	4.109	5.1767	6.5467	7.5557	8.7956
sub19	0.7707	1.3479	2.3464	2.9602	3.7913	4.7105	5.5939
Outfall	4.4952	7.9542	13.4284	16.8996	21.6028	27.2644	32.2567

Main Catchment Model

RORB Location	1 Year	2 Year	5 Year	10 Year	20 Year	50 Year	100 Year
Sub2	5.4391	9.5418	16.1896	20.4668	26.6107	33.2213	39.2096
Outfall	6.9891	11.9611	20.0898	25.3312	32.5936	41.6173	49.5091

See Figure B2-1, page 91, for flow locations.

Attachment B - Appendix C Hydraulic Modelling

Hydraulic modelling was not undertaken for the East and Southeast catchments.

100 yr West Model (1d HECRAS model. Manning's set to constant 0.07)

River	Reach	River Station	Q Total (m^3/s)	Min Ch Elev (m)	W.S Elev (m)	Vel Chnl (m/s)
west catchment	150	950	8.66	15.71	16.22	1.91
west catchment	150	900	8.66	14.3	14.95	1.11
west catchment	150	850	8.66	12.85	13.57	1.83
west catchment	150	800	8.66	10.78	12.09	1.37
west catchment	150	750	8.66	9.88	10.78	1.5
west catchment	150	550	8.66	3.88	4.38	1.2
west catchment	150	500	8.66	1.94	2.74	1.8
west catchment	150	450	8.66	2.18	2.61	0.2
west catchment	150	400	8.66	2	2.59	0.14
west catchment	150	350	8.66	2	2.59	0.07
west catchment	150	300	8.66	1.88	2.59	0.06
west catchment	150	250	8.66	1.61	2.59	0.05
west catchment	150	200	8.66	1.47	2.59	0.06
west catchment	150	150	8.66	1.33	2.59	0.04
west catchment	50	77.14	31.68	1.12	2.58	0.11
west catchment	50	50	31.68	1.2	2.58	0.12
west catchment	4	21.91	31.68	1.02	2.57	0.43
west catchment	4	3.67	31.68	0.96	2.56	0.41
trib 2	906	1205.62	8.8	15.03	15.41	0.75
trib 2	906	1155.62	8.8	13.59	14.58	1.24
trib 2	906	1105.62	8.8	13.2	13.73	0.93
trib 2	906	1055.62	8.8	12.16	12.78	1.09
trib 2	906	1005.62	8.8	11.74	11.98	0.47
trib 2	906	955.62	8.8	11.09	11.35	0.61
trib 2	906	905.62	8.8	9.57	10.76	0.8
trib 2	906	805.62	14.32	8.12	10.06	1.08
trib 2	906	755.62	15.33	7.82	9.28	2.19
trib 2	906	705.62	15.33	7.4	8.54	1.16
trib 2	906	655.62	15.33	6.27	7.84	1.6
trib 2	906	605.62	15.55	7	7.35	0.6
trib 2	906	555.62	15.55	6.31	6.99	0.84
trib 2	906	505.62	15.55	5.51	6.08	1.34
trib 2	906	455.62	15.55	4.01	5.38	0.74
trib 2	906	405.62	15.43	4.42	4.56	0.72
trib 2	906	355.62	15.43	3.02	3.63	0.77

trib 2	906	305.62	15.43	2.81	3.42	0.55
trib 2	906	255.62	15.43	2.02	2.85	2.12
trib 2	906	205.62	17.26	1.93	2.62	0.25
trib 2	906	155.62	17.26	1.88	2.59	0.2
trib 2	906	105.62	17.26	1.6	2.59	0.08
trib 2	906	55.62	17.26	1.47	2.59	0.1
trib 1	55	1455.29	5.59	51.53	52.49	2.2
trib 1	55	1405.29	5.59	41.85	42.73	2.28
trib 1	55	1355.29	5.59	35.87	36.91	2.08
trib 1	55	1305.29	5.59	31.99	32.77	1.99
trib 1	55	1255.29	5.59	28.99	29.47	1.46
trib 1	55	1205.29	5.59	26.74	27.27	1
trib 1	55	1155.29	5.59	24.77	25.38	1.92
trib 1	55	1105.29	5.59	21.83	22.83	1.2
trib 1	55	1055.29	5.59	20.49	21.77	1.17
trib 1	55	1001.49	5.59	19.36	19.96	1.72
trib 1	55	955.29	5.59	17.74	18.55	0.79
trib 1	55	905.29	5.59	16.46	17.37	1.42
trib 1	55	855.29	5.59	15.19	16.29	1.11
trib 1	55	805.29	5.59	14.99	15.57	1.03
trib 1	55	755.29	5.59	13.66	14.72	1.09
trib 1	55	705.29	5.59	13.24	14.02	0.91
trib 1	55	655.29	6.62	12.3	13.61	0.96
trib 1	55	605.29	6.62	12.19	12.62	1.28
trib 1	55	555.29	6.62	11.34	12.04	0.66
trib 1	55	505.29	6.62	10.88	11.63	0.95
trib 1	55	455.29	6.62	9.69	10.74	1.79
trib 1	55	405.29	6.67	7.77	9.37	1.85
trib 1	55	355.29	6.67	7.1	8.61	1.44
trib 1	55	305.29	6.67	6.59	7.7	1.78
trib 1	55	255.29	6.67	6.66	6.95	0.58
trib 1	55	205.29	6.67	5.62	5.79	0.42
trib 1	55	155.29	6.67	3.71	4.05	1.41
trib 1	55	105.29	6.67	2.01	2.59	0.06
trib 1	55	55.29	6.67	1.51	2.59	0.05

100 yr Main Model (1d HECRAS model. Manning's set to constant 0.07)

River	Reach	River Station	Q Total (m^3/s)	Min Ch Elev (m)	W.S Elev (m)	Vel Chnl (m/s)
trib 1	50	1550	9.23	12.57	13.02	0.34
trib 1	50	1500	9.23	12.12	12.45	0.57
trib 1	50	1450	9.23	11.43	11.8	0.94
trib 1	50	1400	9.23	10.81	11.23	0.63
trib 1	50	1350	9.23	10.42	10.8	0.64
trib 1	50	1300	9.23	9.99	10.38	0.61
trib 1	50	1250	9.23	9.34	9.51	0.89
trib 1	50	1200	9.23	8.74	8.71	0
trib 1	50	1150	9.23	7.91	8.18	1.03
trib 1	50	1100	9.23	7.47	7.84	0.37
trib 1	50	1050	9.23	7.34	7.61	0.5
trib 1	50	1000	9.23	6.84	7.06	0.65
trib 1	50	950	9.23	6.25	6.6	0.5
trib 1	50	900	9.23	5.88	6.16	0.62
trib 1	50	850	9.23	5.63	5.87	0.3
trib 1	50	800	9.23	5.36	5.6	0.53
trib 1	50	750	9.23	4.89	5.2	0.5
trib 1	50	700	9.23	4.56	4.82	0.5
trib 1	50	650	9.23	4.27	4.45	0.37
trib 1	50	600	9.23	3.8	4.14	0.45
trib 1	50	550	9.23	3.63	3.97	0.36
trib 1	50	500	11.47	3.35	3.88	0.32
trib 1	50	450	11.47	3.41	3.79	0.41
trib 1	50	400	11.47	3.13	3.61	0.52
trib 1	50	350	11.47	2.77	3.45	0.33
trib 1	50	300	11.47	3.13	3.36	0.3
trib 1	50	250	11.47	2.72	3.09	0.54
trib 1	50	200	11.47	1.91	2.87	0.74
trib 1	50	150	11.47	1.99	2.86	0.15
trib 1	50	100	11.47	2.03	2.85	0.11
trib 1	50	50	11.47	1.82	2.85	0.12
main catchment l	500	1850	39.21	13.55	14.31	1.67
main catchment l	500	1800	39.21	12.04	13.03	2.1
main catchment l	500	1750	39.21	9.71	11.78	1.51
main catchment l	500	1700	39.21	9.51	10.88	2.86
main catchment l	500	1650	39.21	9.1	10.6	0.9
main catchment l	500	1600	39.21	9.05	9.88	2.02
main catchment l	500	1550	39.21	7.85	9.93	0.45
main catchment l	500	1500	39.21	7.39	9.49	1.72
main catchment l	500	1450	39.21	7.54	9.25	0.94
main catchment l	500	1400	39.21	6.82	9.13	0.82
main catchment l	500	1350	39.21	6.88	8.59	0.69
main catchment l	500	1300	39.21	6.62	8.25	1.94
main catchment l	500	1250	39.21	6.23	7.97	1.11
main catchment l	500	1200	39.21	5.91	7.32	2.01
main catchment l	500	1150	39.21	5.75	7.06	1.04
main catchment l	500	1100	39.21	4.89	6.87	0.89
main catchment l	500	1050	39.21	5.17	6.65	1.06
main catchment l	500	1000	39.21	4.74	6.34	1.15
main catchment l	500	950	39.21	4.47	6.11	0.7

main catchment l	500	900	39.21	4.37	5.71	1.96
main catchment l	500	850	39.21	4.32	5.18	0.99
main catchment l	500	800	39.21	3.47	4.15	1.82
main catchment l	500	750	39.21	3.4	3.84	0.23
main catchment l	500	700	39.21	2.33	3.76	0.54
main catchment l	500	650	39.21	2.62	2.98	1.6
main catchment l	500	600	39.21	1.93	2.96	0.27
main catchment l	500	550	39.21	1.83	2.9	0.61
main catchment l	500	500	39.21	1.74	2.86	0.37
main catchment l	50	450	46.15	1.63	2.83	0.35
main catchment l	50	400	46.15	1.75	2.81	0.32
main catchment l	50	350	47.15	1.59	2.78	0.35
main catchment l	50	300	47.15	1.64	2.75	0.37
main catchment l	50	250	47.15	1.61	2.71	0.43
main catchment l	50	200	49.51	1.55	2.68	0.38
main catchment l	50	150	49.51	1.68	2.65	0.36
main catchment l	50	100	49.51	1.65	2.59	0.45
main catchment l	50	50	49.51	1.63	2.56	0.32

50 yr Main Model (1d HECRAS model. Manning's set to constant 0.07)

River	Reach	River Station	Q Total (m^3/s)	Min Ch Elev (m)	W.S Elev (m)	Vel Chnl (m/s)
trib 1	50	1550	7.71	12.57	12.99	0.32
trib 1	50	1500	7.71	12.12	12.43	0.54
trib 1	50	1450	7.71	11.43	11.77	0.91
trib 1	50	1400	7.71	10.81	11.21	0.58
trib 1	50	1350	7.71	10.42	10.77	0.63
trib 1	50	1300	7.71	9.99	10.36	0.56
trib 1	50	1250	7.71	9.34	9.48	0.85
trib 1	50	1200	7.71	8.74	8.71	0
trib 1	50	1150	7.71	7.91	8.15	0.99
trib 1	50	1100	7.71	7.47	7.82	0.35
trib 1	50	1050	7.71	7.34	7.58	0.47
trib 1	50	1000	7.71	6.84	7.03	0.6
trib 1	50	950	7.71	6.25	6.57	0.46
trib 1	50	900	7.71	5.88	6.13	0.6
trib 1	50	850	7.71	5.63	5.85	0.28
trib 1	50	800	7.71	5.36	5.58	0.51
trib 1	50	750	7.71	4.89	5.17	0.47
trib 1	50	700	7.71	4.56	4.8	0.46
trib 1	50	650	7.71	4.27	4.43	0.34
trib 1	50	600	7.71	3.8	4.12	0.41
trib 1	50	550	7.71	3.63	3.94	0.34
trib 1	50	500	9.55	3.35	3.85	0.3
trib 1	50	450	9.55	3.41	3.76	0.4
trib 1	50	400	9.55	3.13	3.56	0.52
trib 1	50	350	9.55	2.77	3.4	0.3
trib 1	50	300	9.55	3.13	3.32	0.25
trib 1	50	250	9.55	2.72	3.06	0.51
trib 1	50	200	9.55	1.91	2.81	0.76
trib 1	50	150	9.55	1.99	2.8	0.14
trib 1	50	100	9.55	2.03	2.8	0.1
trib 1	50	50	9.55	1.82	2.8	0.11
main catchment l	500	1850	33.22	13.55	14.25	1.57
main catchment l	500	1800	33.22	12.04	12.98	2.01
main catchment l	500	1750	33.22	9.71	11.63	1.44
main catchment l	500	1700	33.22	9.51	10.85	2.51
main catchment l	500	1650	33.22	9.1	10.54	0.86
main catchment l	500	1600	33.22	9.05	10.15	1.41
main catchment l	500	1550	33.22	7.85	9.82	1.13
main catchment l	500	1500	33.22	7.39	9.44	1.56
main catchment l	500	1450	33.22	7.54	9.17	0.96
main catchment l	500	1400	33.22	6.82	9.04	0.78
main catchment l	500	1350	33.22	6.88	8.51	0.68
main catchment l	500	1300	33.22	6.62	8.19	1.79
main catchment l	500	1250	33.22	6.23	7.93	1.04
main catchment l	500	1200	33.22	5.91	7.26	2.07
main catchment l	500	1150	33.22	5.75	7	1
main catchment l	500	1100	33.22	4.89	6.82	0.85
main catchment l	500	1050	33.22	5.17	6.6	1.02

main catchment l	500	1000	33.22	4.74	6.28	1.16
main catchment l	500	950	33.22	4.47	6.05	0.67
main catchment l	500	900	33.22	4.37	5.65	1.88
main catchment l	500	850	33.22	4.32	5.13	0.94
main catchment l	500	800	33.22	3.47	4.11	1.77
main catchment l	500	750	33.22	3.4	3.76	0.22
main catchment l	500	700	33.22	2.33	3.69	0.51
main catchment l	500	650	33.22	2.62	2.95	1.5
main catchment l	500	600	33.22	1.93	2.89	0.25
main catchment l	500	550	33.22	1.83	2.84	0.55
main catchment l	500	500	33.22	1.74	2.8	0.34
main catchment l	50	450	38.99	1.63	2.78	0.32
main catchment l	50	400	38.99	1.75	2.76	0.29
main catchment l	50	350	39.66	1.59	2.73	0.32
main catchment l	50	300	39.66	1.64	2.71	0.33
main catchment l	50	250	39.66	1.61	2.68	0.38
main catchment l	50	200	41.62	1.55	2.65	0.33
main catchment l	50	150	41.62	1.68	2.62	0.31
main catchment l	50	100	41.62	1.65	2.58	0.38
main catchment l	50	50	41.62	1.63	2.56	0.27

2 yr Main Model (1d HECRAS model. Manning's set to constant 0.07)

River	Reach	River Station	Q Total (m^3/s)	Min Ch Elev (m)	W.S Elev (m)	Vel Chnl (m/s)
trib 1	50	1550	2.26	12.57	12.84	0.19
trib 1	50	1500	2.26	12.12	12.31	0.41
trib 1	50	1450	2.26	11.43	11.67	0.54
trib 1	50	1400	2.26	10.81	11.05	0.48
trib 1	50	1350	2.26	10.42	10.7	0.33
trib 1	50	1300	2.26	9.99	10.15	0.8
trib 1	50	1250	2.26	9.34	9.49	0.25
trib 1	50	1200	2.26	8.74	8.65	0
trib 1	50	1150	2.26	7.91	8.07	0.62
trib 1	50	1100	2.26	7.47	7.69	0.26
trib 1	50	1050	2.26	7.34	7.47	0.27
trib 1	50	1000	2.26	6.84	6.91	0.39
trib 1	50	950	2.26	6.25	6.45	0.28
trib 1	50	900	2.26	5.88	6.02	0.45
trib 1	50	850	2.26	5.63	5.74	0.15
trib 1	50	800	2.26	5.36	5.5	0.38
trib 1	50	750	2.26	4.89	5.05	0.33
trib 1	50	700	2.26	4.56	4.69	0.28
trib 1	50	650	2.26	4.27	4.3	0.09
trib 1	50	600	2.26	3.8	3.96	0.24
trib 1	50	550	2.26	3.63	3.77	0.22
trib 1	50	500	2.74	3.35	3.7	0.19
trib 1	50	450	2.74	3.41	3.64	0.27
trib 1	50	400	2.74	3.13	3.3	0.72
trib 1	50	350	2.74	2.77	3.15	0.16
trib 1	50	300	2.74	3.13	3.12	0
trib 1	50	250	2.74	2.72	2.8	0.41
trib 1	50	200	2.74	1.91	2.6	0.4
trib 1	50	150	2.74	1.99	2.6	0.06
trib 1	50	100	2.74	2.03	2.6	0.04
trib 1	50	50	2.74	1.82	2.59	0.05
main catchment l	500	1850	9.54	13.55	13.93	1
main catchment l	500	1800	9.54	12.04	12.67	1.6
main catchment l	500	1750	9.54	9.71	10.89	0.94
main catchment l	500	1700	9.54	9.51	10.56	1.06
main catchment l	500	1650	9.54	9.1	10.04	1.08
main catchment l	500	1600	9.54	9.05	9.67	0.65
main catchment l	500	1550	9.54	7.85	9.3	1.09
main catchment l	500	1500	9.54	7.39	8.99	0.88
main catchment l	500	1450	9.54	7.54	8.66	0.83
main catchment l	500	1400	9.54	6.82	8.53	0.53
main catchment l	500	1350	9.54	6.88	8	0.54
main catchment l	500	1300	9.54	6.62	7.79	0.9
main catchment l	500	1250	9.54	6.23	7.6	0.75
main catchment l	500	1200	9.54	5.91	6.9	1.89
main catchment l	500	1150	9.54	5.75	6.67	0.73
main catchment l	500	1100	9.54	4.89	6.52	0.62
main catchment l	500	1050	9.54	5.17	6.36	0.75

main catchment l	500	1000	9.54	4.74	5.89	1.43
main catchment l	500	950	9.54	4.47	5.67	0.49
main catchment l	500	900	9.54	4.37	5.35	1.34
main catchment l	500	850	9.54	4.32	4.87	0.65
main catchment l	500	800	9.54	3.47	3.93	1.5
main catchment l	500	750	9.54	3.4	3.35	0
main catchment l	500	700	9.54	2.33	3.29	0.32
main catchment l	500	650	9.54	2.62	2.84	0.63
main catchment l	500	600	9.54	1.93	2.62	0.11
main catchment l	500	550	9.54	1.83	2.61	0.22
main catchment l	500	500	9.54	1.74	2.6	0.13
main catchment l	50	450	11.4	1.63	2.59	0.13
main catchment l	50	400	11.4	1.75	2.59	0.11
main catchment l	50	350	11.63	1.59	2.58	0.12
main catchment l	50	300	11.63	1.64	2.58	0.12
main catchment l	50	250	11.63	1.61	2.57	0.13
main catchment l	50	200	11.96	1.55	2.57	0.11
main catchment l	50	150	11.96	1.68	2.57	0.1
main catchment l	50	100	11.96	1.65	2.56	0.11
main catchment l	50	50	11.96	1.63	2.56	0.08

Attachment C - Digital Data and Metadata

C1 Context and datasets

C2.1 Arrow LNG Plant

This digital data has been prepared to assist in the assessment of surface water aspects of Arrow LNG Plant.

C2.1 Datasets

Dataset TITLE, CUSTODIAN, VERSION

ArcView personal geodatabase "**EIS_Study_Area_GIS_surface_water_files_V1"**

The database contains the following files:

Shapefile	Description	Custodian
EIS_Study_Area_v5	A project boundary provided by Arrow that defines the geographic extent of the Arrow LNG study area.	Arrow
EIS_Study_Area_watercourses_ V1_GDA1994z56	A stream layer created by modifying the Queensland Wetlands Programme layer HYD_stream" "wetland mapping and classification for Queensland" (Version 2.0 – September 2009).	Alluvium Consulting (Queensland) modified from Environmental Protection Agency (now Department of Environment and Resource Management (DERM)).
EIS_Study_Area_watercourses_ V1_GDA1994z56_clipped	The above stream layer clipped by the EIS study area.	Alluvium Consulting (Queensland) modified from Environmental Protection Agency (now DERM).
Project_Subcatchments_100k_ GDA1994z56_V1	A layer created using the program CatchSIM and then manually rectified to provide a breakdown of subcatchments intersecting the EIS study area. The subcatchments were chosen based on a scale that was considered useful for analysis of various tasks.	Alluvium Consulting (Queensland) modified from (formerly) Department of Natural Resources and Water (2009) data currently DERM.
EIS_Study_Area_wetlands_V1_ GDA1994z56	A wetland layer clipped by the study area from the Queensland Wetlands Programme layer HYD_Wetland" "wetland mapping and classification for Queensland" (Version 2.0 – September 2009).	Alluvium Consulting (Queensland) modified from Environmental Protection Agency (now DERM).

Dataset JURISDICTION

Queensland.

Description ABSTRACT

These data sets have been complied as part of the Surface Water Impact Assessment for the Arrow LNG Plant. They relate to the assessment of surface water resources in the study area.

Description SEARCH WORD(S)

Surface water

Streams

Wetlands

Water

Catchments

Description (GEOGRAPHIC BOUNDARY)

Parts of the Calliope Basin (basin number 132) and Curtis Island (basin number 131) within Australia's Northeast Coast Drainage Division.

Dataset CURRENCY

Beginning June 2010. Ending April 2011.

Dataset STATUS

Final.

Dataset PROGRESS

Final.

Dataset MAINTENANCE AND UPDATE FREQUENCY

Complete as at April 2011.

Access STORED DATSET FORMAT(S)

DIGITAL: ESRI Personal Geodatabase

DATUM: Geocentric Datum of Australia 1995 (GDA1994)

PROJECTION: Projected

Access AVAILABLE FORMAT TYPE(S)

ESRI Personal Geodatabase

Access CONSTRAINTS

For use only for the Arrow LNG Plant unless otherwise authorised by Arrow Energy Holdings Pty Ltd.

Data Quality LINEAGE, POSITIONAL ACCURACY and ATTRIBUTE ACCURACY

The individual data sets vary in their scale and quality. A description of how they were prepared and their limitations is provided in the Sections 2 and 3. It is also recommended that EPA (now DERM) metadata is reviewed in relation to the datasets “HYD_wetland” and “HYD_Stream”.

Mapping accuracy is suitable for general constraints assessments at the Project Area scale. At an individual site level it should be used as a guide only. The precise location of stream channels and wetland boundaries requires more detailed analysis and field assessment when undertaking infrastructure location planning.

Data quality LOGICAL CONSISTENCY

All polygons and polylines visually checked at scale of approximately 1:5,000 and inconsistencies manually checked and rectified.

Data Quality COMPLETENESS

The data sets are complete as at March 2011.

Contact Information CONTACT ORGANISATION

Jason Carter
Natural Resources Manager
Alluvium Consulting
3/62 Walker Street
Townsville QLD 4810
T (+61) (7) 4724 2170 F (+61) (7) 4724 1639

or

Kristen Wicks
Consultant
Coffey Environments Australia
Level 2, 12 Creek Street Brisbane QLD 4000 Australia
T (+61) (7) 3002 0400 F (+61) (7) 3002 0444

Metadata date METADATA DATE

March 2011.

Additional Metadata ADDITIONAL METADATA

HYD_wetland: http://www.epa.qld.gov.au/register/p01769aa.pdf
HYD_Stream:http://www.epa.qld.gov.au/wetlandinfo/site/MappingFandD/WetlandMandDBackground.html