SUPPLEMENTARY GROUNDWATER ASSESSMENT
ARROW ENERGY SURAT GAS PROJECT
SUPPLEMENTARY REPORT TO THE EIS

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ABBREVIATIONS

ALOS	Advanced Land Observation Satellite
APLNG	Australia Pacific Liquefied Natural Gas Project
BOM	Bureau of Meteorology
CMA	Cumulative Management Area
CGPF	Central Gas Processing Facility
CSG	Coal Seam Gas
DA	Drainage Area
DERM	Queensland Department of Environment and Resource Management (currently known as Department of Environment and Heritage Protection)
DEEDI	Department of Employment, Economic Development and Innovation
DEM	Digital Elevation Model
DNRM	Department of Natural Resources and Mines
DEHP	Department of Environment and Heritage Protection
EIS	Environmental Impact Statement
EPBC	Environment Protection and Biodiversity Conservation
FCF	Field Compression Facility
GA	Geoscience Australia
GAB	Great Artesian Basin
GDE	Groundwater Dependent Ecosystem
GLNG	Gladstone Liquefied Natural Gas Project
IAA	Immediately Affected Area
InSAR	Interferometric Synthetic Aperture Radar
IPF	Integrated Production Facility
KCB	Klohn Crippen Berger

ABBREVIATIONS

LAA	Long-term Affected Area
LNG	Liquefied Natural Gas
MDBC	Murray Darling Basin Commission
MNES	Matters of National Environmental Significance
NTEC	Environmental Technology
OGIA	Office of Groundwater Impact Assessment
PB	Parsons Brinckerhoff
PSC	Project Steering Committee
QGC	Queensland Gas Company
QPED	Queensland Petroleum Exploration Database
QWC	Queensland Water Commission
SAR	Sodium Adsorption Ratio
SEWPaC	Sustainability Environment, Water, Population and Communities
SIMS	Spring Impact Management Strategy
SKM	Sinclair Knight Merz
SPN	Stable Point Network
SREIS	Supplementary Report for the Environmental Impact Assessment
SRMS	Scaled Root Mean Square
SWS	Schlumberger Water Services
TAG	Technical Advisory Group
TDS	Total Dissolved Solids
UWIR	Underground Water Impact Report
WMS	Water Monitoring Strategy

ABBREVIATIONS

WERD	Water Entitlements Registration Database
WTF	Water Treatment Facility

ABBREVIATIONS

GLOSSARY

Abstraction	The removal of water from a resource e.g. the pumping of groundwater from an aquifer.
Adsorption	The adhesion of molecules of gas, liquid, or dissolved constituents to a surface (compare Desorption)
Alluvium	Unconsolidated deposits such as sands, gravels and clays deposited by flowing water such as rivers and streams.
Anthropogenic	Caused by human activity.
Aquifer	A saturated geological layer or formation that is permeable enough to yield economic quantities of water.
Aquitard	A geological formation having low (but not zero) permeability to water, such as a silty or clayey layer.
Baseflow	Sustained flow of a stream in the absence of direct run-off, due to groundwater discharge.
Bore	A hole drilled in the ground to obtain samples of soil or rock, intersect groundwater for extractive use, monitoring or investigation, or for a range of other purposes. In Australia is also a commonly used term for a constructed groundwater well.
Brackish	Water containing moderate salt concentrations significantly less than sea water, with Total Dissolved Solids typically between 1,000 and 10,000 mg/L. (Compare Fresh, Saline and Brine).
Brine	Saline water with a total dissolved solids concentration greater than 40,000 mg/L or coal seam gas water after it has been concentrated through water treatment processes and/or evaporation.
Catchment	An area which discharges to a common point.
Coal Seam Gas Water	Groundwater that is necessarily or unavoidably brought to the surface in the process of coal seam gas exploration or production. Coal seam gas water typically contains significant dissolved salts, has a high sodium adsorption ratio (SAR) and may contain other components that have the potential to cause environmental harm if released to land or waters through inappropriate management. Coal seam gas water is a waste, as defined under the section 13 of the Environment Protection Act (DERM, 2011).
Confined Aquifer	An aquifer in which groundwater is confined under pressure.

GLOSSARY

Confining Layer	Geological material through which significant quantities of water cannot move, located below unconfined aquifers, above and below confined aquifers.
Desorption	The processes releasing molecules of gas, liquid, or dissolved constituents from a surface (compare Adsorption).
Discharge	Removal of water from or flow out of an aquifer, including flow to surface water, another aquifer, or artificial means such as pumping. See also 'abstraction'.
Dissolved Solids	Soluble compounds such as salts which are in solution.
Drawdown	The drop in the watertable or potentiometric level when water is being pumped from a well.
Ecohydrogeology	The study of interaction between ecosystems and groundwater.
Ecosystem	A system made up of the community of living things (animals, plants, and microorganisms) which are interrelated to each other and the physical and chemical environment in which they live.
Fluvial	Pertaining to a river or stream.
Flux	The rate of flow (mass transport) of a fluid or other material or compound transported by that fluid.
Formation	A geological structure such as a rock mass or layer.
Fresh Water	Water containing low salt concentrations, typically less than 1,000 mg/L. (Compare Brackish, Saline and Brine).
Groundwater	Any sub-surface water, generally present in an aquifer or aquitard.
Groundwater Flow	The movement of water in an aquifer.
Hydraulic Conductivity	A standard measure of the permeability of a geological formation or its ability to transmit groundwater flow.
Hydraulic Gradient	The slope of the watertable in an unconfined aquifer, or the potentiometric surface in a confined aquifer.
Hydraulic Head	A measure of the pressure head of water in aquifer, commonly measured as the elevation to which water will rise in a constructed well.

GLOSSARY

Hydrogeology	The study of the inter-relationships of geologic materials and processes with water, especially groundwater.
Isotopic analysis	Determination of stable isotope ratios to age date groundwater.
Lithology	The physical composition of a rock.
Nutrients	A chemical that an organism needs to live and grow, or a substance used in an organism's metabolism obtained from its environment.
Perched Aquifer	An unconfined aquifer of limited extent located above the true watertable.
Permeability	The ability to transmit fluids through a porous medium.
Potentiometric Level	A measure of the pressure head of water in an aquifer at a given location, usually used in reference to a confined aquifer.
Potentiometric Surface	An imaginary layer which defines the potentiometric levels for a confined aquifer. In an unconfined aquifer it is more commonly termed as the watertable.
Recharge	Addition of water to or flow into an aquifer (generally) from rain. Also used to describe water entering an aquifer from surface water, groundwater, or artificial means.
Runoff	Rain water that flows across the land surface without entering the sub-surface.
Saline Water	Water containing high levels of dissolved salts, typically between 10,000 and 40,000 mg/L. (Compare Fresh, Brackish and Brine).
Saturated Zone	The zone in which the voids in the rock are completely filled with water. The watertable represents the top of the saturated zone in an unconfined aquifer.
Sediment	Unconsolidated geological material which has been formed by a process of deposition as discrete particles.
Specific Yield	The ratio of the volume of water a rock will release by gravity drainage to the bulk volume of the rock.
Spring	The land to which water rises naturally from below the ground and the land over which the water then flows.
Stratigraphy	The sequential classification of geological materials based on their age of formation.

GLOSSARY

Sustainable Yield	Amount of water that can be abstracted from an aquifer over a long period of time without dewatering the aquifer or impacting the resource.
Total Dissolved Solids	Concentration of total dissolved salts (TDS).
Unconfined Aquifer	An aquifer with no confining layer between the water table and the ground surface where the water table is free to rise and fall.
Unsaturated Zone	The part of the geological stratum above the saturated zone, also called the vadose zone. The unsaturated zone may be dry, or may contain water under partially saturated conditions.
Uplift	The relative upward movement of rocks due to tectonic forces.
Watertable	The top of the saturated zone in an unconfined aquifer.
Well	A hole drilled into a groundwater resource (aquifer), oil or gas resource reservoir) and constructed with a casing and screen or similar. In Australia also commonly referred to as a 'bore'.

UNITS

GL	Gigalitres
km	Kilometres
m	Metres
mg/L	Milligrams per litre
mm/yr	Millimetres per year
ML/d	Megalitres per day
ML/yr	Megalitres per year
GL/yr	Gigalitres per year
µS/cm	Micro-siemens per centimetre

UNITS

EXECUTIVE SUMMARY

Arrow Energy Pty Ltd (Arrow) submitted an Environmental Impact Statement (EIS) for the Surat Gas Project in December 2011. The EIS was approved by the Queensland Government for public release in March 2012. This Supplementary Report to the Environmental Impact Statement (SREIS) completes Arrow's response to comments on the EIS received by the public and government, provides further information on the project and the potential impacts, and provides confirmation or updates to the conclusions of the EIS.

The supplementary groundwater assessment does not repeat the impact assessment conducted for the purposes of the EIS. Rather it considers the revised project description, and new relevant technical information to evaluate the suitability of the mitigation measures presented in the EIS.

Scope of Work

The scope of work undertaken for the supplementary groundwater assessment was:

- Identification of groundwater-related revisions to the project description.
- Review of new information available since the preparation of the EIS in December 2011.
- Further consideration of certain information used to inform the EIS.
- Revised groundwater modelling to evaluate any changes to groundwater impacts under the current development plan.
- Review of the mitigation measures based on the revised development plan, to evaluate the relevance and present any additional mitigation measures where required.

Numerical Groundwater Modelling

Since the submission of the Arrow EIS in December 2011, the Underground Water Impact Report (UWIR) for the Surat Cumulative Management Area (CMA) (QWC, 2012) and supporting numerical groundwater model (Surat CMA Groundwater Model, incorporating the Central Condamine River Alluvium Groundwater Model) was approved by the Chief Executive of Department of Environment and Heritage Protection (DEHP) and took effect from December 2012. The groundwater model was used to predict the cumulative impacts of proposed coal seam gas developments in the Surat CMA.

The groundwater model developed for the SREIS has been based on the Office of Groundwater Impact Assessment (OGIA) groundwater modelling for the Surat CMA and Condamine Alluvium. It includes a calibrated model, and uncertainty analysis modelling predictions. The primary purpose of this model is to revise the groundwater impact predictions based on Arrow's current development plan, which has a smaller 'footprint' than previously considered in the EIS and by the OGIA, and to confirm whether the impacts previously modelled for the EIS provided a suitable basis for the impact assessment conducted.

This model is consistent with the modelling approach undertaken by OGIA, and is a modification of the OGIA Surat CMA Groundwater Model. This is to:

- Achieve conceptual and technical consistency with the UWIR and supporting groundwater model, and enable direct comparison with impact predictions made in the UWIR.
- Recognise that the assessment of cumulative impacts and establishing integrated management arrangements is the responsibility of the OGIA and these have been set in the UWIR.

EXECUTIVE SUMMARY

Impact Assessment

The impact assessment method adopted for the groundwater technical study prepared for the EIS was reapplied in the SREIS. The method adopted is as follows:

- Confirm that the impacts identified in the EIS remain relevant.
- Identify any new impacts, or impacts that no longer apply to the project.
- Determine those impacts requiring re-assessment to assess their significance.
- Confirm that the pre-mitigation magnitude of impacts applied during the EIS remain appropriate.
- Develop new mitigation and management measures where required. Revise or delete any mitigation and management measures developed during the EIS that are no longer appropriate.
- For new or changed mitigation measures or impacts, determine the residual magnitude of impact following application of the mitigation and management measures.

Based on the impact predictions from the Arrow SREIS Groundwater Model, which includes the Arrow current development plan, it is demonstrated that the residual significance assessment completed in the EIS did not understate the residual (mitigated) impacts.

Mitigation and Management Measures

A review of mitigation and management measures identified in the EIS showed that the measures are still relevant for the management of groundwater-related impacts, and no measures have been removed. In addition new mitigation and management measures include:

- Obligations outlined under the Surat CMA UWIR, including Spring Impact Management Strategy.
- Development of a GDE management framework.
- Completion of bore assessments.
- Responsible tenure holder obligations.
- Offsetting Arrow's component of the modelled flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown.
- Adopting the Code of Practice for Constructing and Abandoning Coal Seam Gas Wells in Queensland.

Ongoing Research

The UWIR outlined a number of specific future research directions. Areas currently targeted for research include:

- Condamine Interconnectivity Research Project (CIRP).
- Influence of geological structures on groundwater flow in the Surat CMA.
- Hydrogeology of the Walloon Coal Measures.
- Re-conceptualisation of the groundwater systems in the Surat CMA.

Arrow Energy, in collaboration with the OGIA has commenced investigations into the interconnectivity between the Condamine Alluvium and the Walloon Coal Measures. Arrow is committed to working with the OGIA and the coal seam gas industry in improving the understanding of the hydrogeology of the Surat Basin.

1 INTRODUCTION

1.1 Background to the Supplementary EIS

Coffey Environments Australia Pty Ltd (Coffey Environments) was commissioned by Arrow Energy Pty Ltd (Arrow) to provide the groundwater assessment component of the Environmental Impact Statement (EIS) for the Surat Gas Project. A conceptual description of the Surat Gas Project (the project description) was developed to inform the Surat Gas Project EIS. The project description formed the basis upon which all impact assessment studies were conducted and as of March 2011 was fixed, to allow studies to be undertaken.

The scope of work included in the groundwater assessment component of the EIS is listed below:

- Review of the legislative framework relevant to the groundwater aspect of the project.
- A desktop review of relevant Great Artesian Basin (GAB), Surat Basin and coal seam gas literature.
- Description of the environmental values associated with groundwater assets in the project development area and ranking the sensitivity of those values.
- Numerical groundwater modelling to assess impacts (conducted by Schlumberger Water Services and peer reviewed by Coffey Environments and Dr Lloyd Townley of NTEC Environmental Technology (now CDM Smith)).
- An assessment of the pre-mitigated magnitude of project activities on groundwater environmental values to determine the significance of those impacts.
- Proposal of management and mitigation measures to protect environmental values.
- An assessment of residual impact significance rankings to the identified environmental values after implementation of mitigation and management measures.
- Provision of recommended monitoring and commitment options.
- Assessment of potential cumulative impacts of the project.

The impact of the project on groundwater systems in the region is related to the environmental values and their sensitivity to change. These environmental values and the sensitivity assigned to them will be present throughout the lifetime of the project and should, therefore, be a constant consideration as the project moves through design, construction, operation and decommissioning phases. A significance assessment approach was adopted for the EIS, which considered both the sensitivity of the environmental values and the magnitude of the identified impact.

Potential groundwater related impacts associated with the proposed Surat Gas Project field development and production program identified during the EIS process generally fell within the following categories:

1) Direct impacts caused by coal seam depressurisation.

2) Indirect impacts caused by coal seam depressurisation.

3) Impacts caused by field and infrastructure development, operation and decommissioning.

4) Cumulative impacts caused by other developments.

Management and mitigation measures were identified to minimise the identified impacts. These were considered appropriate for the reduction of impacts as demonstrated by the assessment of residual impacts, which ranged from very low to moderate. A robust groundwater baseline assessment and groundwater monitoring program was proposed to underpin the assessment of management and mitigation measure effectiveness.

Arrow lodged the draft EIS for the Surat Gas Project in December 2011, which was approved by the State Government for public release in March 2012. The period for public review and comment closed on 14 June 2012.

1.2 Objectives of the Supplementary Report to the EIS

The Supplementary Report to the Environmental Impact Statement (SREIS) completes Arrow's responses to comments received on the EIS, provides further information on the project and the potential impacts, and provides confirmation or updates to the conclusions of the EIS as necessary.

The SREIS has been prepared to:

- Present any revisions to the project concept.
- Present the findings of any further impact assessment deemed necessary as a result of these changes.
- Respond to the public and government submissions made on the EIS.

The supplementary groundwater assessment does not repeat the impact assessment conducted for the purposes of the EIS. Rather it considers the revised project description, and new relevant technical information to evaluate the suitability of the mitigation and management measures presented in the EIS.

1.3 Supplementary Groundwater Assessment Scope of Works

For the purpose of the supplementary groundwater assessment report, the following major tasks were completed:

- Identification of groundwater-related revisions to the project description.
- Review of new information available since preparation of the EIS in December 2011.
- Further consideration of some information used to inform the EIS.
- Revised groundwater modelling, based on the updated project description, and informed by new technical information available, to evaluate the relevance of the model and the predictive results presented in the EIS.
- Review of the management and mitigation measures based on the revised impact assessment, to evaluate the relevance and present additional management and mitigation measures where required.

1.4 Supplementary Groundwater Assessment Study Method

Details of the study method and information sources considered for the supplementary groundwater assessment are presented in Section 4.

In summary, the assessment contained four stages, including:

- Review of new information available since the release of the EIS.
- Review of revised numerical groundwater modelling completed using Arrow's current development plan.
- Review of the potential impacts identified in the EIS.
- Review of the EIS impact assessment results and associated mitigation and management measures with respect to the revised model outputs.

2 GROUNDWATER-RELATED CHANGES TO THE PROJECT DESCRIPTION

The information below presents the key groundwater-related changes to the project description for assessment in the SREIS.

2.1 Changes to the Project Development Area

Ongoing exploration and improved knowledge of coal seam gas reserves has resulted in a number of parcels of land within Arrow's project development area being relinquished, primarily in the former Goondiwindi development region, as shown in Figure 2.1. This results in a project development area reduction of 30%.

2.2 Conceptual Field Development

Field development planning has advanced since preparation of the EIS, with the overall project development area being separated into twelve drainage areas (DAs). Each DA is identified by sequential numbering that corresponds with the central gas processing facility (CGPF) in that DA. Gas reserves within each DA will be fed into the corresponding CGPF. The extent and the locations of the DAs are presented in Figure 2.1. Division of the project into DAs allows the project to be phased, or staged, across the regions to optimise production over the life of the project.

Consequently, the SREIS will discuss the sequence of the project's development in terms of the DAs, as opposed to the five development regions that were described in the EIS. Figure 2.2 presents a comparison of the current DAs and the development regions used for the EIS.

It is currently expected that eight of these DAs will initially be developed for the Surat Gas Project (DA1, DA2, DA5, DA7, DA8, DA9, DA10 and DA11), with each drainage area incorporating wells, a water gathering network, a gas gathering network and a CGPF. If required, a field compression facility (FCF) may be installed in DA1, DA2, DA5, DA7, DA10 and DA11 between production wells and the CGPFs to improve pressure at sites where the wellhead pressure is not sufficient to transport the gas directly from the wells to the CGPF. The indicative development sequence is presented in Table 2.1. The remaining DAs identified (DA4, DA6 and DA12) may be developed with favourable reservoir outcomes and future market conditions.

Table 2.1: Indicative development sequence of production facilities

Year	Production Facility Construction							
	DA9	**DA2**	**DA8**	**DA1**	**DA7**	**DA5**	**DA10**	**DA11**
2013								
2014								
2015	CGPF	CGPF	CGPF					
2016				CGPF	CGPF			
2017								
2018						CGPF	CGPF	CGPF
2019								
2020								
2021								
2022								
2023		FCF*		FCF*				
2024					FCF*			
2025						FCF*		FCF*
2026							FCF*	

*These facilities will only be developed if required.

Two of the eight DAs (DA2 and DA9) will comprise water treatment facilities (WTF) (Figure 2.1) located adjacent to a CGPF. In the EIS this arrangement was referred to as an integrated production facility (IPF). That term will no longer be used in the SREIS and instead the facilities are referred to by their function i.e., CGPF and WTF.

2.2.1 Changes to Production Areas and Production Volumes

The EIS coal seam gas field development plan footprint is shown on Figure 2.2. Since the production of the EIS, Arrow has updated its coal seam gas field development plan, leading to a smaller footprint of development and revised water production volumes. The supplementary groundwater assessment is based on this revised development plan.

Given these revisions to the coal seam gas production profile across the project development area, Arrow's current development plan has been adopted in predictive groundwater modelling for the SREIS (GHD, 2013). This enables confirmation of the model and also the potential impacts and associated mitigation measures identified in the EIS, and determination of the requirement for any new or revised environmental commitments.

For the overall SREIS, a project life of 35 years is defined, from 2014 to 2049. However, for the supplementary groundwater assessment, the predicted groundwater drawdown impacts take into consideration water extraction prior to 2014 (associated with Arrow's historical and current coal seam gas production) and also water production after 2049 (to recognise some water production as wells are decommissioned and taken off-line). Therefore, for the purposes of groundwater modelling for the SREIS, a project timeframe from 2005 to 2052 is considered.

Table 2.2 provides a summary of the predicted water production volumes from the reservoir modelling and planning development tool for the EIS and SREIS.

Table 2.2: Summary of Arrow water production volumes

Water Production	EIS field development plan (2011-2041)	SREIS Arrow current development plan (2005-2052)
Total (GL)	694	510

GL = Gigalitres; Total = total water production over life of project

2.3 Production Wells

The EIS described that around 7,500 wells would be drilled across the project development area. With the relinquishment of approximately 30% of the project development area, the anticipated number of production wells has reduced to 6,500.

Production wells will generally be 300 m to 750 m vertical depth depending on the depth of the coal seams and their economic viability. Arrow may deploy deviated wells and multi-well pad drilling where geology and coal depths allow, typically where target coals are greater than 400 m vertical depth. The spacing between wells will vary according to the coal depth and coal permeability.

The original EIS conceptualised that vertical wells would be drilled with a separation distance between wells averaging a minimum of 800 m across the project development area. The use of deviated drilling technology may allow the surface well pad sites for multi-well pads to be separated over a distance in excess of 2,000 m where possible. However, the "in coal" separation of each well will be approximately equivalent to vertical well separation distances required to maintain optimal coal seam gas recovery. This will reduce the number of well pads required and assist in minimising associated surface impacts.

2.4 Management of Coal Seam Gas Water and Salt

Since the release of the EIS in March 2012 Arrow has revised its Coal Seam Gas Water and Salt Management Strategy. A conceptual water management overview is presented in Figure 2.3. The revised strategy is presented in Attachment 5 of the SREIS, and the groundwater-related components of the strategy, including the manner in which they will offset flux impacts to the Condamine Alluvium, are presented in Sections 7 and 8.

3 RELEVANT LEGISLATION, POLICIES AND GUIDELINES TO THE SREIS

The following sections describe legislation, policies and guidelines relevant to the groundwater assessment for the SREIS, including updates to legislation where this has occurred since the release of the EIS.

3.1 Commonwealth Legislation

3.1.1 Environment Protection and Biodiversity Conservation Act (EPBC Act) 1999

The Environment Protection and Biodiversity Conservation (EPBC) Act is Commonwealth legislation that provides for the protection of matters of national environmental significance (MNES), including the community of native species dependant on natural discharge of groundwater from the GAB, or listed threatened species that are reliant on springs. Any action with the potential for significant impacts to these must be referred to the Minister for Sustainability, Environment, Water, Population and Communities (SEWPaC), and may require approval under this Act.

3.1.1.1 EPBC Act Protected Matters: Nationally Important Wetlands

Wetlands considered to be of national importance have been mapped and can be accessed via the SEWPaC online Protected Matters Search Tool. Supporting documentation (Environment Australia, 2001) provides a description of each listed wetland including ecological and hydrological characteristics. From this, an assessment of whether the wetland may be groundwater dependent can be made.

3.2 Queensland Legislation

3.2.1 **Petroleum and Gas (Production and Safety) Act 2004** (reprinted as in force on 31 March 2013)

Under Section 185 of the P&G Act, a petroleum tenure holder may take or interfere with groundwater to the extent that it is necessary and unavoidable during the course of an activity authorised under the petroleum tenure, including coal seam gas extraction. The right to take water for or during petroleum purposes as defined in the P&G Act considers the following details:

- No limit to the volume of water that may be taken (Section 185 (3)).
- Underground water taken or interfered with, under subsection (1)(a), from a petroleum well is associated water (also termed groundwater and/or coal seam gas water within this report).

The aforementioned underground water rights attract certain obligations described as underground water obligations. These are defined in Chapter 3 of the Water Act (Qld) (2000) (the Water Act).

3.2.2 **Water Act (Qld) 2000** (Reprinted as in force 31 March 2013)

The Queensland Government has changed legislation to improve the management of water in the petroleum and gas industry. The changes to the Water Act and the Water Supply (Safety and Reliability) Act 2008 have been driven by the rapid expansion of the coal seam gas industry.

The overall purpose of the Water Act is to provide for the sustainable management of water and other resources, the establishment and operation of water authorities, and for other purposes. In particular, the Act:

- Provides a comprehensive regime for the planning and management of all water resources (including vesting to the State the rights over the use, flow and control of all surface water, groundwater, rivers and springs) in Queensland.
- Sets out the process for applying for a Water Licence (where water is to be utilised outside of a Petroleum Lease or not on adjacent land owned by the same person).
- Sets out the process for assessing, reporting, monitoring and negotiating with other water users regarding the impact of coal seam gas production on aquifers.

Chapter 3 of the Water Act provides for the management of impacts on underground water caused by the exercise of underground water rights by petroleum tenure holders. This is achieved by defining several key underground water obligations that tenure holders must discharge, specifically:

- Undertaking Baseline Assessments to identify the location, construction, groundwater level and groundwater quality of existing water bores.
- Preparing underground water impact reports (UWIRs) which includes:
  - Description of the regional geology and hydrogeology (including aquifers, their quality and connections to formations from which coal seam gas water is extracted) based on the existing information, and
  - Description of the petroleum and gas production in the tenure.
  - Prediction of groundwater drawdown as a result of the exercise of underground water rights by tenure holders including identification of:
    - Areas of each aquifer in the tenure where groundwater drawdown is predicted to exceed the bore trigger threshold (defined in the Water Act as 2m for an unconsolidated aquifer and 5m for a consolidated aquifer):
      - In the next three years (an Immediately Affected Area (IAA)).
      - At any time (a Long-term Affected Area (LAA)).
    - Potentially affected springs. A potentially affected spring is defined as a spring overlying an aquifer where the water level in the aquifer is predicted in a UWIR to decline by more than the spring trigger threshold, at the location of the spring, at any time due to the exercise of underground water rights. The spring trigger threshold is 0.2 m.
  - Report obligations including:
    - Water Monitoring Strategy (WMS) including a program for monitoring changes in groundwater levels and water quality.
    - Spring Impact Management Strategy (SIMS) including:
      - Details of potentially affected springs in the tenure,
      - Assessments of the connectivity of the spring to the underlying aquifers,

        - A prediction of risk and likely impact to the ecosystem and cultural and spiritual values of the spring, and
        - Development of a strategy (where required) to mitigate impacts to the spring based on information gathered from the aforementioned studies.
    - Assignment of responsible tenure holder for report and make good obligations if the report is prepared for a cumulative management area (CMA).
    - Program for annual review.
- Make good obligations including the requirement to:
    - Undertake a bore assessment for all bores located in an IAA to determine whether the bore has, or is likely to start having, an impaired capacity i.e. the bore can no longer provide a reasonable quantity or quality of groundwater due to a decline in groundwater level because of the exercise of underground water rights by petroleum tenure holders.
    - Enter into a make good agreement with the owner of the bore which documents the outcome of the bore assessment and defines make good measures for the bore to be undertaken by the tenure holder including any of the following:
        - Ensuring the bore owner has access to a reasonable quantity and quality of water.
        - Monitoring the bore.
        - Compensating the bore owner.

3.2.2.1 Declaration of the Surat Cumulative Management Area

A cumulative management area (CMA) may be declared where the impacts on water levels caused by multiple individual petroleum and gas projects overlap. In March 2011 the Queensland Government declared a CMA in the Surat and southern Bowen Basins, known as the Surat CMA. The Office of Groundwater Impact Assessment (OGIA) (formerly Queensland Water Commission (QWC)) is, amongst other groundwater management functions, responsible for preparing UWIRs for CMAs including the Surat CMA.

3.2.2.2 Preparation of the Surat CMA Underground Water Impact Report

The Surat CMA UWIR (QWC, 2012) was approved by the Department of Environment of Heritage and Protection (DEHP) and took effect on 1 December 2012.

The Surat CMA UWIR includes all the elements of a UWIR required by the Water Act and was developed, in part, from information provided to OGIA by:

- Arrow for the Surat Gas Project.
- Queensland Gas Company (QGC) for the Queensland Curtis Liquefied Natural Gas Project (LNG) (QCLNG) project.
- Santos, for the Gladstone LNG (GLNG) project.
- Origin Energy, for the Australia Pacific LNG (APLNG) project.

The UWIR is discussed in more detail in Sections 8 and 9.

3.2.3 Water Supply (Safety and Reliability) Act 2008 (Reprinted as in force 14 May 2013)

The Water Supply (Safety and Reliability) Act 2008 aims to provide for the safety and reliability of water supply in Queensland. It sets out the process for applying to be a water service provider where the owner of any water supply infrastructure intends to charge for supply. Water service providers must submit and maintain several management plans including:

- Environmental Management Plan.
- Strategic Asset Management Plan.
- System Leakage Management Plan.
- Drought Management Plan.
- Drinking Water Quality management Plan (only if supplying drinking water).

The Act also sets out the obligations in relation to the potential to impact on drinking water supplies and the requirement for Recycled Water Management Plans. The coal seam gas industry is automatically captured by this process for injection, direct supply or discharge of water, however an exemption can be applied for.

3.2.4 Nature Conservation Act (NCA) 1992

The NCA is Queensland State government legislation that provides for the conservation of nature through the development of an integrated and comprehensive conservation strategy for the whole of the State. The NCA classifies species according to conservation status and the framework has been applied in the assessment of springs across the Surat CMA to identify biologically important springs.

3.3 Queensland Policies and Codes of Practice

3.3.1 Coal Seam Gas Water Management Policy

A revised Coal Seam Gas Water Management Policy was prepared byDEHP and released in December 2012. The objective of the policy document is to encourage the beneficial use of coal seam gas water and brine/salt in a way that protects the environment and maximises productive use of these resources. To achieve this objective, the policy identifies priorities for the management of coal seam gas water and brine/salt. Arrow’s coal seam gas water and salt management strategy reflects the priorities outlined in the policy, thereby facilitating compliance with the government’s objective for the management of coal seam gas water and brine/salt. Arrow’s Coal Seam Gas Water and Salt Management Strategy is presented in Attachment 5 of the SREIS.

The policy identifies that the management and use of coal seam gas water should be consistent with the following priorities:

- **Priority 1**. Coal seam gas water is used for a purpose that is beneficial to either the environment, existing or new water users or existing or new water-dependent industries.
- **Priority 2**. After feasible beneficial use options have been considered, treating and disposing coal seam gas water in a way that firstly avoids, and then minimises and mitigates, impacts on environmental values.

The policy identifies that the management and use of brine/salt should be consistent with the following priorities:

- **Priority 1**. Brine or salt residues are treated to create useable products wherever feasible.
- **Priority 2**. After assessing the feasibility of treating the brine or solid salt residues to create useable and saleable products, disposing of the brine and salt residues in accordance with strict standards that protect the environment.

3.3.2 Code of Practice for Constructing and Abandoning Coal Seam Gas Wells in Queensland

The Code of Practice (Queensland Government, 2011) was facilitated by the Department of Employment, Economic Development and Innovation (DEEDI). These functions within DEEDI are now administered by the Department of Natural Resources and Mines (DNRM). The code of practice aims to ensure that all coal seam gas wells are constructed and abandoned to a minimum acceptable standard. This ensures that these activities are completed in a consistent manner and the processes are effectively monitored to ensure that:

- The environment, in particular underground sources of water, is protected.
- Risk to public and coal seam gas workers is managed to a level as low as reasonably practicable.
- Regulatory and applicable Australian and International Standards, as well as the Operator's internal requirements, are complied with.
- The life of a coal seam gas well is managed effectively through appropriate design and construction techniques, ongoing monitoring and end of life decommissioning.

It is intended that this Code of Practice will have enforceable effect in Queensland by being called up under the P&G Regulation as a "safety requirement". However the provisions of the P&G Act and the P&G Regulation will take precedence over the Code should any cases occur where conflict arises.

3.4 Other Guidelines, Industry Tools and Frameworks

3.4.1 Australian Groundwater-Dependent Ecosystems Toolbox

The Australian Groundwater Dependent Ecosystem toolbox (GDE toolbox) was developed to provide an intuitive framework for the identification and management of GDEs as well as to better understand ecological groundwater requirements. The classification of GDE type presented in the toolbox is consistent with the GDE Atlas (Richardson et al, 2011; Bureau of Meteorology (BoM), 2013) described in Section 3.4.2 including:

- Type 1: Aquifer and cave ecosystems.
- Type 2: Ecosystems dependent on surface expression of groundwater.
- Type 3: Ecosystems dependent on subsurface expression of groundwater.

The GDE toolbox contains two parts: Part 1 Assessment Framework (Richardson et al, 2011) and Part 2 Assessment Tools (Richardson et al, 2011a). The GDE Assessment Framework (Part 1) consists of three stages:

- Stage 1: Baseline understanding of GDE location, classification of ecosystem type and basic conceptualisation of ecohydrogeological setting.

- Stage 2: Characterisation of groundwater reliance, which can be achieved through the collection of physical parameters including groundwater levels, hydraulic gradients and fluxes, as well as geochemical and isotopic analysis.
- Stage 3: Characterisation of ecological response to change in groundwater conditions, achieved only through analysis of detailed monitoring data to provide a quantified understanding. This may not be achieved in the short-term (such as the typical timeline for the preparation of management plans and approvals processes). Stage 3 assessment may take years to decades of research and monitoring (Richardson et al, 2011).

Part 2 of the GDE Toolbox defines the assessment tools as a suite of practical and technically robust methods for the collation and assessment of data as described by the requirements of the framework (Part 1). Ultimately through the application of appropriate tools, GDE landscapes may be identified and water requirements for the maintenance of ecosystems may be established.

The primary focus for the development of the GDE toolbox was to provide a framework through which ecological water requirements could be established. This framework sets out a logical sequence of assessment stages that can also be applied to identify potential GDE landscapes that may be impacted by petroleum tenure activities (equivalent to Stage 1). From this, appropriate management and mitigation measures can be established, including further assessment in line with Stages 2 and 3 of the GDE Toolbox assessment framework where appropriate.

3.4.2 Atlas of Groundwater Dependent Ecosystems

The National Atlas of Groundwater Dependent Ecosystems (GDE Atlas) (BoM, 2013) presents the current understanding of GDEs across Australia and provides a national scale mapped database of the locations of known and potential GDEs, supported by hydrogeological and ecological lines of evidence.

The GDE Atlas provides regional scale data that can form the starting point for the identification of potential GDE landscapes to allow GDEs to be considered in groundwater management, and specifically for this project, the management of potential impacts to GDEs.

The GDE Atlas includes ecosystem types that are relevant to the Arrow EIS Terms of Reference and may be present within the Surat CMA including:

- The surface expression of groundwater (springs, wetlands, rivers).
- The subsurface presence of groundwater (vegetation).

Subterranean GDEs are presented in the GDE Atlas however the extent of mapping for this GDE type is limited to Tasmania only therefore has not been considered further here.

The GDE Atlas classifies ecosystems based on multiple lines of scientific evidence including previous fieldwork, literature and mapping, combined with analysis of nation-wide layers of satellite remote sensing data. The physical characteristics that describe each ecosystem are also provided. Where a potential for dependence on groundwater has been identified, ecosystems have been mapped as:

- Identified in previous field study.
- Identified in previous desktop study.
- High potential for groundwater interaction (indicating a strong possibility the ecosystem is interacting with groundwater).

- Moderate potential for groundwater interaction.
- Low potential for groundwater interaction (indicating it is relatively unlikely the ecosystem will be interacting with groundwater, and will include ecosystems that are not interacting with groundwater).

The GDE Atlas contains further attribute data to assist with the assessment of whether the ecosystems are actually dependent on groundwater, including a field that assigns a level of confidence in the assessment of high, moderate or low potential based on the number of lines of evidence use to generate the classification.

4 ASSESSMENT METHOD AND INFORMATION SOURCES

To inform the development of the supplementary groundwater impact assessment the study method comprised four main components:

- A detailed desktop review of information available since the release of the EIS covering additional government and industry research and studies, and numerical groundwater modelling (refer Sections 5 and 6). Some information sourced considered in the EIS were re-visited in light of the new information available.
- Review and assessment of the results of numerical groundwater modelling completed specifically for the SREIS using the current development plan to allow re-assessment of impact magnitude (refer Section 7).
- Review of the potential impacts identified in the EIS (refer Section 8) to assess adequacy with respect to the changed project description and current development plan. Additional impacts and/or impacts no longer relevant to the project were identified.
- Review and revision of the impact assessment including management and mitigation measures to capture any additional impacts or changes to (either increase or decrease) impact significance as reported in the EIS (refer Sections 8 and 9).

4.1 Desktop Assessment Information Sources

Since the preparation of the EIS a significant volume of research and numerous studies have been completed (or have commenced) that enhance the current understanding of the geological and hydrogeological setting of the Surat CMA, as well as the understanding of groundwater environmental values in the project development area. In particular a volume of work was conducted and further studies are underway to improve the understanding of the physical environment, including:

- The types of groundwater dependent ecosystems present within the Surat CMA, their potential connectivity to various aquifer units, groundwater chemistry characteristics and ecological values.
- Groundwater quality characteristics of aquifers within the Surat Basin, including collation of a unified groundwater quality database completed by Worley Parsons (Worley Parsons, 2012).
- Interconnectivity between the Walloon Coal Measures and the Condamine Alluvium through conceptualisations of structure and groundwater chemistry relationships.
- The mechanisms associated with potential subsidence in response to coal seam gas extraction.

Review of conceptualisations and predictive outputs from numerical groundwater modelling completed since the release of the EIS was also completed. This included consideration of:

- Detailed modelling of the Condamine Alluvium.
- Regional scale groundwater modelling of the Surat CMA.

The relationship between the detailed Condamine Alluvium model and the regional scale groundwater model was also assessed as part of the review. Further discussion is provided in Section 6.

In conjunction with the desktop review of numerical groundwater models, the supplementary groundwater impact assessment presents the results of numerical groundwater modelling specifically completed for the SREIS. This model predicted groundwater drawdown in response to Arrow's current development plan. Details of the modelling methodology are presented in Section 7.

The information sources reviewed as part of the supplementary groundwater impact assessment are presented in Table 4.1 and Table 4.2. Table 4.1 contains the information sources related to the physical environment, while Table 4.2 contains the information sources related to numerical groundwater modelling.

Table 4.1: Summary of information sources related to the physical environment

Document	Author / Source	Format	Relevance / Application
Surface water – groundwater connectivity assessment. A report to the Australian Government from the CSIRO Murray Darling Basin Sustainable Yields Project.	Parsons et al (2008)	Report	Overview of the Murray Darling Basin surface-groundwater connectivity assessment including mapping of the Condamine-Balonne catchment, presenting stream reaches that are identified as groundwater fed.
Australian groundwater-dependent ecosystem toolbox Part 1: assessment framework Part 2: assessment tools	Richardson et al (2011and 2011a)	Report	Part 1 defines types of GDEs and outlines a consistent framework for identification of actual GDEs in a landscape. Part 2 provides assessment tools for the identification of GDEs and quantification groundwater dependence.
Atlas of Groundwater Dependent Ecosystems (GDE Atlas), Phase 2. Task 5 Report: Identifying and mapping GDEs	SKM (2012)	Report	Methodology report for the development of the GDE Atlas layers.
Underground Water Impact Report (UWIR) for the Surat Cumulative Management Area	Queensland Water Commission (2012)	Report	Provides results of cumulative impact modelling, defines groundwater drawdown trigger levels to establish IAAs and LAAs, defines WMS for the regional monitoring network, defines SIMS where it is predicted the long term water level drawdown will exceed 0.2 m and describes responsibilities and obligations of relevant petroleum tenure holders,

Table 4.2: Summary of information sources related to the physical environment (cont'd)

Document	Author / Source	Format	Relevance / Application
Hydrogeological Attributes Associated with Springs in the Surat Cumulative Management Area.	Klohn Crippen Berger (2012)	Report (supporting UWIR)	Provides hydrogeological attributes at selected springs in the Surat CMA, including evaluation of spring source aquifer. Spring site selection was based on a desktop assessment completed by OGIA to identify priority sites for field investigation including: • All springs in the Surat CMA associated with species listed under the EPBC Act (1999) and the listed ecological community 'The community of native species dependent on the discharge of groundwater from the Great Artesian Basin'. • All springs not previously surveyed by the Queensland Herbarium located on a petroleum lease or located within 20 km of a petroleum lease in the Surat CMA. The hydrogeological attribute survey assessed 23 spring complexes comprising 86 individual spring vents. Specifically the following attributes were recorded during the survey of each site: Spring location and elevation and photographic record of each site. • Classification of wetland system and landscape feature. • Surficial geology. • Spring flow rate (if measureable) and frequency of inundation. • Field (physiochemical) water quality parameters, as well as samples collected for analysis of general water quality parameters and stable isotope analysis where flow permitted. • In-field assessment of source aquifer resulting in the assignment of a likely source aquifer to each spring. This enabled the identification of springs as being sourced from GAB aquifers (or otherwise).

Table 4.3: Summary of information sources related to the physical environment (cont'd)

Document	Author / Source	Format	Relevance / Application
Ecological and Botanical survey of springs in the Surat Cumulative Management Area.	Queensland Herbarium (2012)	Report (supporting UWIR)	Provides ecological attributes at selected springs in the Surat CMA. Spring site selection was as per the hydrogeological attribute survey outlined above. The ecological attribute survey revisited a number of spring complexes previously surveyed, as well as spring sites previously unsurveyed. A total of 162 spring wetlands or vents were mapped during the survey, and an additional 23 previously unrecorded spring locations were identified (but not mapped) during the survey. Specifically the following attributes were recorded during the survey of each site: • Spring location, elevation and area (for spring wetlands). • Spring status (active vs inactive). • Spring definition (spring vent vs spring wetland). • Spring mound height. • Classification of recharge or discharge spring. • Frequency of inundation. • Vegetation, flora, fauna and invasive species, including presence of State/Commonwealth listed species. • Spring condition. The survey provides a baseline data set for future comparison and has classified springs where EPBC Act (1999) listed species and communities are present, as well as species listed in the Nature Conservation Act (1992). This information has been used by OGIA to assess the spring conservation values and inform the spring risk assessment completed for springs identified as being potentially impacted by groundwater extraction from petroleum tenure holders in the Surat CMA.

Table 4.4: Summary of information sources related to the physical environment (cont'd)

Document	Author / Source	Format	Relevance / Application
Desktop assessment of the Source Aquifer for Springs in the Surat Cumulative Management Area.	Klohn Crippen Berger (2012a)	Report (supporting UWIR)	Provides desktop assessment of likely spring source aquifer (or conversely rules out aquifers as sources) for selected springs in the northern Surat CMA to assist with establishing management and mitigation measures for springs identified as being potentially impacted by groundwater level drawdown in source aquifer resulting from petroleum tenure holder activities.
Assessment of the risks and potential consequences to springs in the Surat Cumulative Management Area.	Queensland Water Commission (2012a)	Report (supporting UWIR)	The spring survey information outlined above was used by OGIA to complete a risk assessment of spring sites identified as being potentially affected by coal seam gas and petroleum activities. This was used to inform the SIMS.
EPBC Spring Identification EPBC 100 km Spring Survey: Phase 1	Halcrow (2012)	Report	Identified new springs (springs not included in previous assessments by Queensland Herbarium and KCB) within 100 km of the maximum extent of drawdown in the Surat CMA through remote sensing and thematic mapping. Further assessment undertaken identified which of these springs are likely to be impacted by coal seam gas activity and recommendations were made for detailed characterisation of these sites (Phase 2 and 3 work). A total of 69 potential spring targets were identified for Phase 2: Aerial Validation assessment.
Spring Survey Phase 2: Aerial Validation	Halcrow (2013)	Report	Phase 2 work implemented the recommendations from Phase 1 (Halcrow, 2012) to complete aerial validation of newly identified springs, to specify the need for ground validation (or otherwise). The aerial validation survey identified 15 springs for ground validation.
Atlas of Groundwater Dependent Ecosystems (GDE Atlas)	Bureau of Meteorology (2013) (custodian)	Online interactive webpage	Provides mapped potential GDE landscapes and data on physical setting of GDEs.

Table 4.5: Summary of information sources related to the physical environment (cont'd)

Document	Author / Source	Format	Relevance / Application
EPBC Act Protected Matters: Nationally Important Wetlands	SEWPaC (2013) (custodian)	Online interactive webpage	Provides locations and site specific information on wetlands listed as nationally important.
Healthy HeadWaters Activity 1.2: Spatial Analysis of Coal Seam Gas Water Chemistry	Worley Parsons (2012)	Report	Provides unified database of historical groundwater and stratigraphic information for the Surat and Bowen basins from existing publically available data sources.
Groundwater connections between the Walloon Coal Measures and the Alluvium of the Condamine River.	Hillier (2010)	Report	Report prepared for the Central Downs Irrigators Limited. Review of available data (geological and hydrogeological) to assess connectivity between Condamine Alluvium and Walloon Coal Measures. Recommends additional work to identify data gaps, including permeability of the formations, water levels in the Walloon Coal Measures and development of a groundwater flow model.
Healthy HeadWaters Activity 1.1: Conceptualisation of the Walloon Coal Measures beneath the Condamine Alluvium.	Klohn Crippen Berger (2011)	Report	Describes the distribution and hydrogeological characteristics of the Walloon Coal Measures in the vicinity of the Condamine Alluvium through the development of a three dimensional geological model.
Central Condamine Alluvium: -Stage I – Data Availability Review -Stage II – Conceptual Hydrogeological Summary -Stage III – Detailed Water Balance	Klohn Crippen Berger (2010; 2010a and 2011a)	Report	Provides detailed conceptualisation of Condamine Alluvium physical setting with respect to geology and hydrogeology, including assessment of likely interaction with surrounding formations and units based on available data. The data collected in Stage II work was used to build a detailed water balance for the Condamine Alluvium to quantify the major and minor water balance components and provide a starting point for steady state and transient numerical groundwater model development.

Table 4.6: Summary of information sources related to the physical environment (cont'd)

Document	Author / Source	Format	Relevance / Application
Healthy HeadWaters Activity 6.1: Injection of treated coal seam gas water into the Condamine Alluvium: Technical Feasibility Assessment.	Klohn Crippen Berger (2011c)	Report	Assesses the feasibility of injecting treated coal seam gas water into the Condamine Alluvium. To complete the assessment a detailed understanding of the hydrogeological setting was required which included developing geological cross sections at 22 locations and an assessment of the hydrogeological properties of the Condamine Alluvium.
Summary of advice in relation to the potential impacts of coal seam gas extraction in the Surat and Bowen Basins, Queensland.	Geoscience Australia and Habermehl, M.A., (2010)	Report	Summary of expert advice provided to SEWPaC in relation to the likely groundwater impacts of proposed and potential future coal seam gas extraction activities in the Surat and Bowen Basins in Queensland by Australia Pacific (APLNG), Queensland Gas Company/British Gas (Queensland Curtis LNG - QCLNG) and Santos Limited (Gladstone LNG - GLNG).
Baseline Report on InSAR Monitoring on the Surat – Bowen Basin. InSAR Historical Study of the Surat-Bowen Basin Fourth delivery (for Arrow Energy tenure)	Altamira (2012 and 2012a)	Report	Presents the results of the study and analysis of ground motion using InSAR technology over the period of December 2006 to February 2011 to establish baseline ground motion for comparison with surface deformation monitoring during approved coal seam gas developments.
An analysis of coal seam gas production and natural resource management in Australia: Issues and ways forward.	Williams et al (2012)	Report	The report provides a review of literature on coal seam gas production in Australia and overseas to identify potential impacts of the industry on natural resource management issues in the Australian landscape. Social, economic and community development issues associated with the expansion of the industry are identified.

Table 4.7: Summary of numerical groundwater modelling information sources

Document	Author / Source	Format	Relevance / Application
Groundwater Modelling of the Surat Basin, Report 6-114/R4.	Schlumberger Water Services (SWS) (2011)	Report	Numerical simulation of the groundwater produced in association with coal seam gas operations and predictions on the cumulative impacts. Predictions of the modelling were used to underpin the EIS and the development of mitigation measures. Further discussion is presented in Section 6.
Central Condamine Alluvium Stage IV – Numerical Modelling.	Klohn Crippen Berger (2011b)	Report	The Condamine Alluvium model was developed by DERM to support water resource management of the Condamine Alluvium aquifer. Further discussion is presented in Section 6.
Report for QWC17-10 Stage 2 Surat Cumulative Management Area Groundwater Model Report.	GHD (2012)	Report	The OGIA commissioned the development and calibration of a regional groundwater model for the Surat CMA and adjoining aquifers. This model is referred to as the OGIA Surat CMA groundwater model and further discussion is presented in Section 6
Predictive uncertainty of the Regional-Scale Groundwater Flow Model for the Surat Cumulative Management Area.	WaterMark Numerical Computing (2012)	Report	The OGIA Surat CMA groundwater model was used to predict the cumulative impacts of the proposed coal seam gas developments in the Surat CMA. WaterMark (2012) presents method and result of uncertainty analysis and predictive modelling completed on the Surat CMA groundwater model. Analysis was completed using the 'null space Monte Carlo method (NSMC). Further discussion is presented in Section 6. This work is summarised in the Surat CMA UWIR (QWC, 2012).

5 UPDATES TO THE UNDERSTANDING OF EXISTING ENVIRONMENT

A detailed review of information sources was completed as presented in Section 4 to improve knowledge of the physical environment in and around the project development area based on information released since the EIS. Some existing information sources that were not incorporated into the EIS were also reviewed where appropriate and some information sources considered in the EIS were re-visited in light of the new information available.

The following sections describe the relevant information sources and study results.

5.1 Regional Geology

This section describes updates to the physical geological setting of the Surat CMA based on detailed studies completed since the release of the EIS. The geological setting provided in the EIS underpinned the conceptualisation developed for the Arrow EIS Groundwater Model (SWS, 2011).

The OGIA conceptualised the geological setting of the Surat CMA as part of the development of the OGIA Surat CMA Groundwater Model (refer Section 6) used to inform the UWIR (QWC, 2012). This model was developed subsequent to the Arrow EIS Groundwater Model and incorporated newer data (including the stratigraphic setting of the Condamine Alluvium aquifer based on the Condamine Alluvium Groundwater Model), as well as data collected by other tenure holders to which Arrow did not have access. However, on a regional scale the geological conceptualisations are considered to be consistent, and the geological setting presented in the EIS is still considered relevant.

Studies (KCB, 2010; KCB, 2010a; KCB, 2011; KCB, 2011a) to improve the understanding of groundwater flow processes within the Central Condamine River Alluvium (CCRA), have also been completed. These included development of the Condamine Alluvium groundwater model that provides for a finer scale assessment of the hydrogeological processes in comparison to the OGIA Surat CMA Groundwater Model. Further detail on model development, comparison of the models and model linkages is provided in Section 6.

A detailed description of the current understanding of the Condamine Alluvium based on the Central Condamine Alluvium Stage II – Conceptual Hydrogeological Summary (KCB, 2010a) and Central Condamine Alluvium Stage III – Detailed Water Balance (KCB, 2011a) is provided below.

5.2 Regional Hydrogeology

This section presents further detail on the physical hydrogeological setting of the Surat CMA based on studies completed since the release of the EIS. As per the Regional Geology (Section 5.1) the hydrogeological setting provided in the EIS also underpinned the Arrow EIS groundwater model (SWS, 2011), and is still considered relevant for the current assessment. Further detail on the Condamine Alluvium has been provided including discussion on the potential connectivity between the Walloon Coal Measure and Condamine Alluvium.

In addition further detail on groundwater-surface water connectivity studies completed in and surrounding the project development area is provided in Section 5.2.2.

5.2.1 Condamine Alluvium

The hydrogeology of the Condamine Alluvium has been the subject of several significant historical studies (Lane, 1979; Huxley, 1982; SKM, 2002; Barnett and Muller, 2008). These were used by Klohn Crippen Berger as a basis to update detail of the system's hydrogeology through a four staged process during 2010 and 2011 as part of the Groundwater Management Modelling of the Central Condamine Alluvium project, as follows:

- Stage I – Data Availability Review (KCB, 2010).
- Stage II – Conceptual Hydrogeological Summary (KCB, 2010a).
- Stage III – Detailed Water Balance (KCB, 2011a).
- Stage IV – Numerical Modelling (KCB, 2011b).

The majority of these historical studies have been used as a scientific basis for management of groundwater resources in the Condamine Alluvium, which is utilised for irrigation, town water, industry and stock and domestic supply.

The Condamine Alluvium collectively describes the alluvial flood plain that comprises predominantly Quaternary basal alluvium and overlying finer grained sheetwash sediment associated with the Condamine River and tributaries.

The alluvial plain extends in a south-north direction from east of Millmerran in the south to around Chinchilla in the north (refer Figure 5.1). The Condamine Alluvium is present in the central and eastern regions of the project development area.

In the south (upper region/headwaters) the alluvium is deposited in a relatively symmetrical paleo-channel structure and is typically less than 50 m thick. As the system progresses downstream to the north the alluvial plain broadens (up to 20 km wide near Dalby) and the paleo-channel becomes asymmetrical with the deepest part of the channel located east of centre, resulting in a steeper eastern bank and more gently sloping western boundary. In the central floodplain the sequence thickness reaches up to 130 m. To the north the alluvium thins and merges with the Tertiary Chinchilla Sands.

The alluvial sediments comprise fine to coarse grained gravels and channel sands interbedded with clays. These are predominantly located as a basal sequence and also dominate the west of the system associated with present day drainage. The finer grained sheetwash deposits overlie the fluvial floodplain deposits (alluvium), and thicken to the east. Individual clay and silt horizons of the sheetwash can be over 20 m thick and are likely to represent confining layers where laterally continuous. The sheetwash is derived from the Tertiary Main Range Volcanics to the east that form a significant vertisol (black soil) cover over much of the Condamine Valley.

The base of the alluvium overlies Mesozoic strata comprising siltstone, sandstone, shale, coal and occasionally basalt. The Walloon Coal Measures are the dominant formation underlying the alluvium in the central plains (QWC, 2012). To the north and north-east the alluvium is bounded by the Hutton Sandstone (Surat Basin) and the lateral equivalent in the east the Marburg Sandstone (Clarence Morton Basin) which are capped by Tertiary basalts. Transitioning to the south-east along the eastern margin the Marburg Sandstone typically underlies the alluvium. To the west the alluvium is bounded by the Kumbarilla Beds which is a basin margin facies including the lateral equivalents of Springbok and Gubberamunda Sandstones (KCB, 2010a).

A series of small basement highs are present that are roughly coincident with the current river course. These may represent geological contacts (KCB, 2010a).

A layer of basal alluvial clays and weathered material exists between the lowermost granular sediments of the Condamine Alluvium and the uppermost unit of the Walloon Coal Measures. Due to the presence of this weathering, identifying the base of the Alluvium and top of the Mesozoic strata is difficult in many drill logs drill. KCB (2010a) defined (based on drill logs) the base of the lowermost granular material as “hydraulic basement", with this surface shown in a series of cross-sections cross-cutting the Condamine River. The weathered zone beneath the hydraulic basement (known as the transition layer in the UWIR for the Surat CMA) is believed to have lower permeability than the basal sediments of the Condamine Alluvium. The thickness and permeability of this layer is likely to influence the degree of connectivity between the Condamine Alluvium and Walloon Coal Measures. The Walloon Coal Measures themselves are also dominated by siltstone and mudstones, which, other than the coal seams, are of lower permeability than the overlying alluvium.

Figure 5.1 presents a schematic cross section illustrating the relationship between the Condamine Alluvium and the underlying formations through the centre of the project development area. It highlights the manner in which the Condamine Alluvium is incised into the Walloon Coal Measures. To the north, along the western margin of the alluvium the Springbok Sandstone also underlies the Condamine Alluvium and to the south, along the eastern margin the Hutton Sandstone underlies the Condamine Alluvium.

5.2.1.1 Recharge mechanisms of the Condamine Alluvium

The Condamine Alluvium is primarily recharged from leakage of the Condamine River and associated tributaries (KCB, 2010a). Recharge is also sourced from direct rainfall recharge. Historical studies (Lane, 1979; Huxley, 1982; SKM, 2002 and Barnett and Muller, 2008) concluded that due to the presence of a surficial, low permeability layer of black soil, diffuse recharge of rainfall through the soil zone was negligible. However, water balance modelling completed by KCB (KCB, 2011a) indicates that while rainfall recharge rates are low (0-25 mm/yr), volumetrically diffuse rainfall recharge to the watertable is a major component of the water balance as it occurs over such a large area.

Minor recharge mechanisms for the Condamine Alluvium, as set out in KCB (2011a) include interaction with underlying formations, bedrock contribution from the east and west, flux from upstream (throughflow), tributary and meander channel seepage, flood recharge and irrigation deep drainage.

5.2.2 Groundwater-surface water connectivity

In 2008 CSIRO commissioned a study as part of the Murray-Darling Basin (MDB) Sustainable Yields Project series to assess surface water-groundwater interactions in nominated catchments throughout the MDB (Parsons et al, 2008). The assessment aimed to determine the direction and magnitude of groundwater flux to or from major rivers in the MDB at a given time. This allowed assessment of the potential for the river to support GDEs.

Individual connectivity assessments were completed for 13 river catchments across the MDB, and a summary report also compiled to present the key findings of each assessment. The Condamine-Balonne system that runs through the Surat CMA, and more specifically the project development area (refer Figure 5.2) was assessed using a snapshot of groundwater and surface water elevation and flow data from March 2006. The neighbouring Border Rivers system was also assessed, which incorporates some of the southern Surat CMA.

A watertable elevation surface was developed to establish the relationship between river reach and groundwater. River reaches were classified as gaining (receiving groundwater), losing (seepage from river to groundwater) or seasonally variable (river reach may fluctuate between gaining and losing throughout time). A further category of 'maximum losing' was also introduced to represent rivers that are hydraulically disconnected from groundwater. Typically this coincided with areas of high groundwater extraction, and lowered watertable.

The study indicated the Condamine River to be a losing river throughout most of the Condamine Alluvium (refer Figure 5.2). In areas of the Condamine Alluvium where significant development of groundwater resources has occurred historically, primarily for agriculture and stock and domestic purposes, groundwater levels in the surrounding aquifer have declined to the point where there is now disconnection between the river and groundwater (the groundwater table is below the base of the river bed). Watertable elevation in some areas of the Condamine Alluvium is up to 20 m below the river bed as a result of groundwater extraction (Barnett and Muller, 2008). In the vicinity of the project development area, Barnett and Muller (2008) map this to be occurring from around Cecil Plains to Millmerran. KCB (2010b) proposed that the mapped river length of disconnection may extend downstream further than that presented in the CSIRO mapping, extending north of Cecil Plains to the Tipton Line.

The Border Rivers catchment assessment indicates variable groundwater and surface water interaction, typically with gaining river reaches in the upper catchment, transitioning to losing river reaches as the narrower upland valleys give way to wider plains. Approaching the confluence of the Barwon River the reaches vary between low level gaining and losing. None of the watercourses mapped within the Border Rivers catchment as part of this assessment fall within the project development area.

The CSIRO assessment was completed for a snapshot in time. However it is reasonable to expect that river and groundwater interaction may vary over time (due to seasonal variation or long-term climatic or groundwater extraction trends etc.). A potential change in groundwater-surface water interaction is more likely where the assessment indicates low gaining or low losing river reaches, and less likely to vary where maximum losing (i.e. disconnected river) has been identified. In addition the relationship may vary over short distances, and the connectivity assessment did not take into account local-scale variability.

Regardless, the assessment provides an informative assessment of groundwater and surface water interaction. Given the general decline and lack of recovery in water levels since the 1960s (Barnett and Muller, 2008; KCB, 2010a), it is also considered likely that the losing and disconnected stream reaches of the Condamine River presented in Figure 5.2 will reflect the current conditions.

5.2.3 Hydraulic Interconnectivity between the Walloon Coal Measures and the Condamine Alluvium

The Walloon Coal Measures represent the main basement unit for some of the Condamine Alluvium (QWC, 2012). The alluvium is incised into the Walloon Coal Measures by up to 130 m. A layer of weathered sediments of lower permeability exists between the lower-most productive parts of the Condamine Alluvium and the uppermost coal beds in the underlying Walloon Coal Measures (Lane, 1979; QWC, 2012)). In the UWIR this is referred to as the transition layer, and consists of combination of low permeability basal alluvial clays of the Condamine Alluvium and the weathered upper siltstones and mudstones of the Walloon Coal Measures (QWC, 2012). Figure 5.3 presents a conceptualisation of this transition layers, as well as inferred thickness across the Surat CMA. This shows that the inferred thickness of the layer is variable, even over relatively short distances and the transition layer thickens to the north of the Condamine Alluvium.

The thickness and permeability of the transition layer influences the degree of connectivity between the Condamine Alluvium and the Walloon Coal Measures. This interconnectivity is an area of focussed research by the OGIA in collaboration with Arrow Energy. Some previous assessments are listed below.

- Healthy HeadWaters: Conceptualisation of the Walloon Coal Measures beneath the Condamine Alluvium. KCB (2011).
- Healthy HeadWaters: Injection of treated coal seam gas water into the Condamine Alluvium Feasibility of injecting coal seam gas water into the Central Condamine Alluvium: Technical Feasibility Assessment. KCB (2011c).

Additional studies are also underway to further understand the relationship between the Condamine Alluvium and Walloon Coal Measures. This includes the Condamine Interconnectivity Research Project (CIRP) that is being led by OGIA with major input from Arrow. Further detail is provided in Section 9.

Typically differences in groundwater quality between the Condamine Alluvium and the Walloon Coal Measures are observed. Salinity within the Walloon Coal Measures is predominantly high (up to 20,000 mg/L with an average of around 4,500 mg/L) whereas salinity in the overlying Condamine Alluvium is typically lower with an average of approximately 1,000 mg/L. However, water quality in the alluvium tends to deteriorate and become more saline toward the eastern, more confined edges of the alluvium and in the down valley (north to north-westerly) direction. Interaction with weathered bedrock may be a contributing factor to these trends (KCB, 2010a).

The presence of significant differences in observed groundwater quality in two adjacent formations can provide a useful indicator of the degree of interconnectivity between the formations (GHD, 2013). Considering significant vertical gradients from the Walloon Coal Measures to the overlying alluvium are thought to be present throughout much of the Condamine Alluvium, a widespread deterioration in water quality in the aquifer has not been observed. This lack of degraded water quality in the alluvium suggests a relatively small amount of flow in response to the apparent head difference and that the degree of connectivity between the two formations is relatively minor (GHD, 2013).

In addition, KCB (2010a) present mapped distribution of Total Dissolved Solids (TDS) from 1960-2009. The mapping indicates that the down-gradient deterioration in water quality has been present historically.

A number of recent studies have considered the available monitoring data to quantify the magnitude of hydraulic connection between the formations (Hillier, 2010; KCB, 2010; KCB, 2011; KCB, 2011a; QWC, 2012). Monitoring data from the Walloon Coal Measures in the area of the Condamine Alluvium are generally constrained to the region below the margin of the alluvium, where the coal measures are shallow and the alluvium is thin, or to the upper weathered zone of the coal measures directly under the alluvium.

Water levels in the Walloon Coal Measures and the Condamine Alluvium were likely to be similar prior to the development of the groundwater resources of the Condamine Alluvium. However, water levels have been lowered in the Condamine Alluvium due to water extraction for irrigation, town supply, industry and stock and domestic purposes, resulting in groundwater levels in the Walloon Coal Measures now believed to be higher than those in the Condamine Alluvium by up to 20 m. This indicates an upward vertical gradient from the Walloon Coal Measures to the overlying Condamine

Alluvium. There is the potential for a reverse gradient to exist at some locations. However the data suggests a net flow of water from the Walloon Coal Measures to the overlying Condamine Alluvium.

5.2.3.1 Condamine Alluvium connectivity to other units

The Condamine Alluvium is also known to overlie the Hutton Sandstone on the eastern margins and Kumbarilla Beds (including the Springbok and Gubberamunda Sandstone equivalents). The Tertiary Main Range Volcanics overlies the Hutton and Marburg Sandstones and abuts the Condamine Alluvium (refer Figure 5.1).

The potential for groundwater movement between the Condamine Alluvium and other formations has been evaluated in KCB (2010a), indicating:

- A generally neutral to slightly upward vertical gradient between the Condamine Alluvium and underlying Hutton Sandstone exists, indicating that the Condamine Alluvium may receive groundwater from the Hutton Sandstone.
- The Main Range Volcanics, a significant regionally productive aquifer in their own right, show consistently higher hydraulic head than the adjoining Condamine Alluvium indicating a gradient from the Volcanics to the Alluvium. Connection between the two units is generally impeded by lower permeability sheetwash sediments that dominate the eastern margin of the alluvium. This leads to a “damming” effect with higher groundwater heads (levels) in the basalts.

5.3 Groundwater Dependent Ecosystems

As detailed in Section 4, information relating to the presence and type of GDEs in the Surat CMA has improved since the release of the EIS. Detailed desktop assessment, site surveys, remote sensing and risk assessment have been completed, with the majority of detailed investigation focussing on the verification and assessment of spring GDEs. Investigations are ongoing, and the information collected provides a baseline dataset for future evaluation of spring GDEs with respect to potential impacts.

The following sections outline the types of GDEs that have been identified within the Surat CMA and presents the findings of the detailed desktop assessment with respect to GDEs in the Surat CMA and project development area.

5.3.1 Types of Groundwater Dependent Ecosystems in the Surat CMA

Based on the information sources reviewed in Section 4, and as described in detail below, the following types of GDEs (as described in the GDE Toolbox) have been identified within the Surat CMA:

- Ecosystems dependent on the surface expression of groundwater including:
    - Springs, spring wetlands, spring fed watercourses.
    - Groundwater discharge to rivers and wetlands.
- Ecosystems dependent on the subsurface presence of groundwater, including plant roots accessing shallow groundwater. These are termed vegetation GDEs.

Typically springs, spring wetlands and spring fed watercourses identified in the study area have been investigated through detailed field investigations to validate their presence and groundwater dependence. The GDE Atlas has identified many potential GDE landscapes, including potential areas where groundwater discharges to rivers and wetlands, or where plants may access groundwater. These have not been verified as being actual GDEs, and further discussion on the likelihood of the landscapes actually being groundwater dependent is provided below.

The UWIR presents six types (type a – f) of springs that may be found within the Surat CMA as presented in Figure 5.4.

Springs in the Surat CMA are typically a result of the presence of a geological structure (type c) that acts as a conduit for groundwater flow from deeper aquifers which are also known as discharge springs. Discharge springs may also occur where there is a thinning of a confining layer (type d).

A cluster of spring vents (in similar geology and fed by the same source aquifer) located no more than 6 km apart is known as a spring complex.

The remaining spring types presented in Figure 5.4 describe the interaction of the watertable or a perched aquifer with the ground surface, and are typically known as recharge springs as they often occur in aquifer recharge areas. They represent shorter groundwater flow paths and more local to intermediate flow systems. Springs that are a window into the watertable, where the watertable discharge directly to a river or wetland feature are also referred to in the UWIR as watercourse springs or baseflow fed watercourses.

5.3.2 Spring vents and watercourse springs

A spring vent is a point where there is a permanent surface expression of groundwater, and may be mounded or flat. A watercourse spring occurs where the natural land surface has been eroded sufficiently to intersect the watertable. The Queensland Herbarium also defines a spring wetland as being where an area of ground is maintained in a damp condition by one or multiple spring vents (Queensland Herbarium, 2012).

DEHP maintains an inventory of identified springs in the Queensland Springs Dataset. Many of these sites have been studied in detail through the completion of field surveys including those completed in 2011 by KCB and the Queensland Herbarium (KCB, 2012 and Queensland Herbarium, 2012), as outlined in Table 4.1. Spring vents and watercourse springs identified through these investigations within the Surat CMA are presented in Figure 5.5.

To date 71 spring complexes (comprising 330 known spring vents) and 43 watercourse springs have been identified in the Surat CMA, some of which are Matters of National Environmental Significance (MNES). The majority of springs identified are associated with GAB aquifers and are listed as spring vents. EPBC listed communities have been identified at 92 spring vents and 36 spring vents have EPBC listed species. NCA listed species have been identified at 43 spring vents.

The identified springs are concentrated in the northern extent of the Surat CMA as well as in the south-east of the Surat CMA in the Clarence-Moreton Basin. The springs in the northern areas are assigned to the Gubberamunda Sandstone, Hutton Sandstone, Evergreen Formation (including Boxvale Sandstone member) or Precipice Formation as the source aquifer. A lesser number have either the Birkhead Formation or Clematis Sandstone listed as a secondary option for the potential source aquifer. In the south-east, springs are generally associated with drainage from the Main Range Volcanics, therefore do not represent GAB aquifer sourced springs.

A summary of the results for the 2011 spring surveys (KCB, 2012; Queensland Herbarium, 2012), as well as records of any additional known springs in the Surat CMA is presented in Appendix A. This provides a summary of the key hydrogeological and ecological attributes including assigned source aquifers, whether water quality sampling was completed during the survey, estimated spring flow rates, presence of EPBC and NCA listed species / communities and conservation ranking.

5.3.2.1 Spring vent conservation ranking

A conservation ranking relating to the biological importance of a spring vent was developed by the Queensland Herbarium for each spring surveyed in 2011 (KCB, 2012; Queensland Herbarium, 2012) based on the site-specific information collected during the surveys. The conservation ranking resulted in each spring vent and complex being assigned a value of between 1 (highest importance) to 5 (lowest importance), or not applicable.

The criteria used to determine the conservation rankings and the results of the assessment are presented in Appendix B and the results are also presented in Figure 5.5. Springs listed with a ranking of not applicable relate to those not assessed during the 2011 Queensland Herbarium survey as they did not meet the survey selection criteria (refer Table 4.1), with the exception of spring complex 590, located on the western boundary of the Surat CMA (refer Figure 5.5), that was not assessed in 2011 however was assigned a conservation ranking based on existing information.

The assessment identified eight spring complexes within the Surat CMA with a Category 1 ranking.

5.3.2.2 UWIR potentially affected springs

The Water Act defines a spring as being potentially affected if it overlies an aquifer where the long-term predicted impact on water pressure at that location, resulting from the extraction of water by petroleum tenure holders, exceeds 0.2 m. Therefore a spring may be listed as potentially affected even when the source aquifer is not predicted to experience drawdown.

To date all springs associated with the 13 complexes identified as being potentially affected by water extraction resulting from petroleum tenure activities in the Surat CMA have been assessed for hydrogeological and ecological attributes. Of the 71 spring complexes identified in the CMA, there are five where the predicted decline in water levels in the source aquifer for the spring is more than 0.2 m at the location of the spring (QWC, 2012). Responsible tenure holders have been assigned to each of these spring complexes.

There are no known springs or potentially affected spring vents or watercourse springs identified within the project development area and Arrow Energy is not the designated responsible tenure holder for any potentially impacted springs inside or outside of the project development area.

Whilst no springs have been identified as being present within the project development area, further consideration for springs located closest to Arrow Energy tenure (within a nominal 30 km) has been made, all of which have been identified in the Surat CMA UWIR SIMS (including assignment of responsible tenure holders where required). The following spring complexes were identified within 30 km of the project development area (also refer Figure 5.5):

- Spring complex 584 (Wambo).
- Spring complex 585 (Bowenville).
- Spring complex 601 (Main Range Volcanics 3).
- Spring complex 602 (Main Range Volcanics 4).

Of the four spring complexes identified within 30 km of the project development area, only spring complex 584 is listed as being potentially affected under the Surat CMA UWIR SIMS. Spring complexes 585, 601 and 602 are located within the Clarence-Moreton Basin to the east of the project development area, outside of the GAB, and are described in the Surat CMA UWIR as being associated with basalts that form local flow systems, disconnected from the flow regimes in the underlying GAB formations (QWC, 2012).

Under the OGIA nominated selection criteria (refer Table 4.1) spring complexes 601 and 602 were not included in the detailed surveys undertaken during 2011 (KCB, 2012; Queensland Herbarium, 2012). Spring complex 585 was assessed by the Queensland Herbarium 2011 spring survey (Queensland Herbarium, 2012).

Spring complex 584 (Wambo Creek) is located to the west of the project development area and consists of several spring vents and seep areas. The springs emerge from the western bank of Wambo Creek. The field and desktop surveys suggested that the spring vent is sourced from a local flow system through sediments at outcrop, rather than discharge from deeper underlying GAB formations (KCB, 2012). This assessment was based on the following:

- Low salinity (231 µS/cm) which is inconsistent with Surat Basin aquifers.
- Anecdotal evidence that the vent reacts to climatic patterns, which is inconsistent with a deeper confined artesian aquifer source.
- Dominant groundwater age of modern water, which is inconsistent with a deeper confined artesian aquifer source.
- Possible anthropogenic influence on groundwater with elevated nitrate levels above background, a common indicator of impact from agricultural activity on local scale flow systems.
- Lack of artesian aquifers in the upper GAB formations in the area.

Desktop and field assessment of the site indicated the spring is sourced from shallow alluvial sediments or Orallo Formation at outcrop (KCB, 2012). The spring site has been flooded multiple times in recent years and the Queensland Herbarium survey (Queensland Herbarium, 2012) described the main spring vents (OR1) to be heavily effected by floodwaters.

Spring complex 584 was assessed during the Queensland Herbarium and KCB 2011 field surveys, and has been assigned a conservation ranking of 3, noting that no EPBC listed communities or EPBC / NCA listed species were identified at the site by the Queensland Herbarium. Spring Complex 584 has been assigned to QGC as the responsible tenure holder under the UWIR.

Spring complex 584 was also assessed under the OGIA assessment of risks and potential consequences to springs in the Surat CMA (QWC, 2012a). This risk assessment was completed to inform the development of the UWIR SIMS, in particular to identify spring sites where mitigation measures should be further investigated. The risk assessment took into consideration the likelihood and consequence of impact for springs already identified as being potentially impacted.

Spring complex 584 was assigned a risk ranking of 3 (medium) and was not selected as a site for development of mitigation measure options.

Watercourse springs mapped by the OGIA in the Surat CMA UWIR identified within 30 km of the project development area were also identified (Figure 5.5), and include:

- Watercourse spring sites W14 and W15, with source aquifer of the Hutton Sandstone.
- Watercourse spring sites W77 and W78, with source aquifer of the Mooga / Gubberamunda Sandstone.
- Watercourse spring site W100, with source aquifer of the Quaternary sediments.
- Watercourse spring site W160, with source aquifer of the Kumbarilla Beds.

For watercourse springs, the source aquifer relates to the corresponding outcrop geology. There is limited additional information available regarding the watercourse spring site characteristics, and watercourse springs were not included in the OGIA risk assessment of potentially affected springs.

5.3.3 Nationally important wetlands

A search of the EPBC Act ‘Protected Matters: Nationally Important Wetlands’ directory identified seven wetlands within the Surat CMA. A single listed wetland (Lake Broadwater) is located within the project development area.

Table 5.1 provides a summary of the wetlands with comment on the likelihood of the wetland being groundwater dependent based on supporting documentation provided in the directory (Environment Australia, 2001; SEWPaC, 2013). This indicates that of the wetlands identified within the Surat CMA, only the Boggomoss Springs are known to be groundwater dependent. The Boggomoss Springs were assessed during the 2011 spring surveys (KCB, 2012 and Queensland Herbarium, 2012) as described in Section 5.3.2 and presented in Appendix A. The Balonne River floodplain, located in the south-west corner of the Surat CMA, has the potential to be both groundwater and surface water fed. Closer to the Balonne River there may be groundwater discharge to the river. Moving further into the floodplains groundwater levels are expected to drop off and have less interaction with the surface of the floodplain.

Lake Broadwater is located within the project development area. It is not considered to be groundwater dependent based on site description details (Environment Australia, 2001) which indicate that it is surface water fed from a local catchment. The lake is shallow (maximum depth around 4 m) and water quality is good. The lake’s water supply is listed as being principally runoff, floodout and stream flow from the catchment. It fills and occasionally floods with the summer rainfall and recedes thereafter and has been known to dry out completely, which support the assessment of it not being groundwater dependent.

The locations of the identified wetlands within the Surat CMA are presented in Figure 5.6.

Table 5.1: Summary of nationally important wetlands within the Surat CMA

Wetland Name	**Wetland Category**	**Wetland Type**	**Likely groundwater dependence**
Balonne River Floodplain	Inland Wetland	B1: Permanent river and streams B2: Seasonal/irregular rivers and streams B4:Riverine floodplains B5: Permanent freshwater lakes B10: Seasonal/intermittent freshwater ponds B14: Freshwater swamp forest	Assumed partial groundwater dependence.

Table 5.1: Summary of nationally important wetlands within the Surat CMA (cont'd)

Wetland Name	Wetland Category	Wetland Type	Likely groundwater dependence
Boggomoss Springs	Inland Wetland	B17: Freshwater springs, oases and rockpools	Groundwater dependent – known GAB spring.
Fairbairn Dam	Human made wetland	C1: Water storage area	Water source listed as principally runoff and stream flow from catchment. Assumed non-groundwater dependent.
Lake Broadwater	Inland Wetland	B2: Seasonal/irregular rivers and streams B5: Permanent freshwater lakes B10: Seasonal/intermittent freshwater ponds B14: Freshwater swamp forest C1: Water storage area	Water supply to lake listed as principally runoff, floodout and stream flow, and known to go dry. Water storage area classification implies surface water contribution. Assumed non-groundwater dependent.
Lake Nuga Nuga	Inland Wetland	B2: Seasonal/irregular rivers and streams B6: Seasonal/intermittent freshwater lakes	Water supply to lake listed as principally runoff, floodout and stream flow. Assumed non-groundwater dependent.
Palm Tree and Robinson Creeks	Inland Wetland	B2: Seasonal/irregular rivers and streams B10: Seasonal/intermittent freshwater ponds	Water supply listed as principally runoff and stream flow. Water depth is seasonally variable and semi-permanent. Assumed non-groundwater dependent.
The Gums Lagoon	Inland Wetland	B10: Seasonal/intermittent freshwater ponds B14: Freshwater swamp forest	Lagoon fills once every 7-10 years. Assumed non-groundwater dependent.

Source: Environment Australia (2001) and SEWPaC (2013)

5.3.4 CSIRO connectivity mapping

As described in Section 5.2.2 baseflow fed river and stream reaches have been identified in rivers in the Condamine-Balonne and Border Rivers catchments (Parsons et al, 2008). The Condamine River runs through the project development area from around Millmerran to near Chinchilla (refer Figure 5.2), however most of the river length through this section is classed as 'losing' with a high to medium confidence level. Losing rivers and streams are characterised by the loss of surface water to groundwater or unsaturated soil zone therefore do not support GDEs.

A small section of the Condamine River south of Chinchilla on the western boundary of the project development area is mapped as being ‘low gaining’ and represents a section of baseflow fed river.

The western extent of the Condamine River and northern reaches of the Balonne River are mapped as gaining, indicating a likelihood that these stream reaches are characterised with a component of baseflow that may support GDEs. With the exception outlined above, these stream reaches occur outside of the project development area.

The Border Rivers catchment assessment indicates variable groundwater and surface water interaction, typically with gaining river reaches in the upper catchment south of Millmerran, transitioning to losing river reaches as the narrower upland valleys give way to wider plains. Approaching the confluence of the Barwon River the reaches vary between low level gaining and losing.

Gaining stream reaches within the Condamine-Balonne and Border River catchments are typically smaller in extent and magnitude of groundwater flux than many of the southern catchments that make up the large MDB (Parsons et al, 2008). In general, the upper regions of northern catchments assessed under the CSIRO connectivity project have less gaining stream reaches when compared to the southern catchments. This is consistent with the findings of Neal et al (2004), where it was identified that rivers in the northern MDB catchments have significantly lower baseflow indices than those in the southern catchments.

5.3.5 GDE Atlas mapping layers – surface expression of groundwater

The GDE Atlas (BoM, 2013) presents a wide range of landscapes that may potentially contain ecosystems dependent on groundwater for some or all of their water requirements. GDEs that potentially access the surface expression of groundwater mapped in the GDE Atlas (wetlands and baseflow fed watercourses) are presented in Figure 5.7, and represent a subset of the GDEs presented in the GDE Atlas based on the following criteria:

- Exclusion of GDEs classified as having a low potential for interaction with groundwater that are unlikely to represent actual GDEs. This also removed any instance of GDEs attributed as being ‘disconnected, losing’ with respect to groundwater-surface water connectivity, that are not considered to represent true GDEs.
- Exclusion of wetlands classified as ‘artificial/highly modified wetlands (dams, ring tanks, irrigation channels, drains, canals)’.
- Exclusion of GDEs classified as springs, as the locations of known springs, verified by field surveys, are presented in Figure 5.5.

The location of potential GDEs accessing the surface expression of groundwater are presented in Figure 5.7 and represent regions where groundwater potentially discharges to watercourses and wetlands. These areas of potential interaction are typically distributed across the Surat CMA along watercourses. Within and in the vicinity of the project development area, they are classified as watercourse or riverine systems along floodplains and swamps.

The reaches of the Condamine River mapped as gaining by CSIRO (Parsons et al, 2008) (Figure 5.2) are represented in this figure under the classification of being identified in a previous study. These areas coincide with areas that are mapped as either having a high or moderate potential for interaction with groundwater based on the GIS rules adopted for the GDE Atlas mapping (BoM, 2013). These are considered likely to be reliant in part on groundwater baseflow.

Conversely, where CSIRO (Parsons et al, 2008) mapping identified maximum losing river reaches (where the Condamine River is disconnected from the watertable), the GDE Atlas presents ecosystems with moderate potential for being groundwater dependent. As such, the regions mapped as potentially dependent on groundwater, from around Chinchilla to south-east of Millmerran, are not considered to actually represent groundwater discharge to stream and river features. This is supported by watertable elevation mapping (KCB, 2010a) and bore hydrographs (DNRM, 2012) that show the watertable in the vicinity of the Condamine River is typically 5-20 m below ground level, as well as watertable contouring (KCB, 2010a) that indicates the Condamine River to be a losing river. In addition the Condamine River is known to dry out. This data supports the assessment that the Condamine River in this area does not represent a GDE.

It is also noted that there is a moderate potential for Lake Broadwater to support GDEs, however as discussed in Section 5.3.3 Lake Broadwater is considered to be fed by surface water, not groundwater.

Based on the information presented above, the potential GDE landscapes identified in Figure 5.7 that have been assigned a high potential for groundwater interaction, or have been identified as part of previous studies, are considered to represent actual GDEs. Within the project development area this includes:

- Reaches of Roche Creek, north-east of Wandoan.
- Reaches of Juandah Creek south of Wandoan.
- Reaches of the Condamine River south of Chinchilla that correlate with gaining river reaches in the CSIRO connectivity study.
- A tributary of Wyaga Creek in upland areas at the southern tip of the project development area.

5.3.6 GDE Atlas mapping layers – subsurface presence of groundwater

As described in Section 5.3.1, GDEs reliant on the subsurface presence of groundwater relates to vegetation that is accessing the watertable and/or capillary fringe. This may occur where depth to groundwater is near surface or where the vegetation has sufficient rooting depth to access deeper groundwater.

The GDE Atlas maps these ecosystems that potentially rely on the subsurface presence of groundwater. No vegetation GDEs presented in the vicinity of the project development area have been identified through previous field or desktop assessment. A sub-set of the GDE Atlas mapping is provided in Figure 5.8 based on the following criteria:

- Exclusion of GDEs classified as having a low potential for interaction with groundwater as they are unlikely to represent actual GDEs.
- Exclusion of GDEs classified as being situated in a location where the watertable is >20 m below ground level. This depth to groundwater exceeds typical plant rooting depth (<10 m) (Yee Yet and Silburn, 2003).

Extensive areas of potential GDE landscapes are mapped in this GDE Atlas layer. Within and in the vicinity of the project development area these potential GDEs are concentrated to the north-east between Wandoan and Chinchilla, and to the south-west between Tara and Inglewood.

The majority of the regions are located immediately outside of the project development area, and correlate to heavily vegetated areas of parks, reserves and state forests, as shown on Figure 5.8. The ecosystem type is typically dry eucalyptus woodlands to open woodlands primarily on sand-plains or depositional plains. To the west this coincides with upland areas of the Kumbarilla Ridge and to the north-east these areas of GDEs coincide with upland areas of the Great Dividing Range. These upland areas represent recharge (intake) areas of the GAB.

There is a general absence of groundwater monitoring bores in the region of potential GDEs mapped to the north of Chinchilla to adequately understand whether groundwater could be supporting deep rooted vegetation.

In the region where the Condamine Alluvium is present (refer Figure 5.1) there is a general absence of GDEs mapped as potentially accessing the subsurface presence of groundwater. This correlates with areas of agricultural development and where the watertable is sufficiently deep to be beyond the rooting depth of vegetation present. Queensland Government monitoring bore hydrographs (DNRM, 2012) indicate groundwater levels are typically between 10-40 m below ground level in the area of the Condamine Alluvium.

There are areas within the project development area mapped with a high potential for interaction with the subsurface presence of groundwater. These areas are primarily represented as riparian vegetation along the Condamine River, however based on the information outlined above, many of these mapped regions are not considered to truly represent GDEs. These regions of riparian vegetation may be a function of vegetation accessing water from losing stream reaches, or a perched aquifer, rather than the true watertable. If vegetation is accessing a perched aquifer, then this likely to be of limited spatial extent and disconnected from the underlying watertable.

5.4 Groundwater Quality

Groundwater quality data presented in the EIS was sourced from the Queensland Government Groundwater Database (accessed October 2009) and related to data associated with the project development area. To provide a more comprehensive summary of groundwater quality across the Surat CMA, additional sources of groundwater quality data from recent studies were reviewed. These are described below.

Worley Parsons (2012) developed a unified database of historical groundwater and stratigraphic information for the Surat and Bowen Basins from existing data sources, primarily the Queensland Government Groundwater Database and the Geological Survey of Queensland Petroleum Exploration Database. The collated data was assessed and vetted so that a representative data set across the Surat CMA over a consistent time period was available for further assessment as part of the Coal Seam Gas Water Feasibility Study commissioned by the Queensland Government.

Worley Parsons (2012) presented a comprehensive summary of available hydrochemical information for regional aquifers and aquitards. Although the data is variable, it presents a characterisation of regional aquifer and aquitard hydrochemistry which is considered usable in the absence of more reliable data.

5.4.1 Groundwater Chemistry

A summary of the groundwater chemistry for major formations within the Surat Basin as well as the Cainozoic cover of alluvium and Tertiary Volcanics are presented in Table 5.2 and Table 5.3 respectively. Water type based on major ion composition, total dissolved solids (TDS) and pH are provided, with the 10^{th} and 90^{th} percentiles presented for TDS and pH as well as the median value. The number of samples (n) used in the assessment is also shown for each formation. It is noted that Worley Parsons (2012) removed data outliers from the database. Further detail on groundwater quality is provided in Appendix 6 of Worley Parsons (2012).

The dominant water types presented in Tables 5.2 and 5.3 are noted to be generally consistent with those identified in the EIS.

Table 5.2: Summary of Surat Basin groundwater chemistry by major unit

Unit	**Dominant Water Type**	**TDS (mg/L)**			**pH (units)**		
		10^{th}	**90^{th}**	**Median**	**10^{th}**	**90^{th}**	**Median**
Precipice Sandstone (n=113)	Na^+ - HCO_3^-	95	848	151	6.7	8.3	7.4
Evergreen Formation (sandstone) (n=82)	Na^+ - HCO_3^-	111	1177	252	6.8	8.3	7.6
Evergreen Formation (aquitard) (n=33)		129	5812	787	7.0	8.4	8.0
Hutton Sandstone (n=234)	Na^+ - HCO_3^- to Na^+ - Cl^-- HCO_3^-	218	2554	752	7.4	8.6	8.1
Eurombah Formation (n=10)	Na^+ - HCO_3^- to Na^+ - HCO_3^- - Cl^-	188	1748	760	7.5	8.6	8.2
Walloon Subgroup (sandstones) (n=83)	Na^+ - HCO_3^- to Na^+ - Cl^-- HCO_3^-	646	5465	1685	7.3	8.5	8.1
Walloon Subgroup (coals) (n=302)		856	8952	2741	7.3	8.6	8.0
Springbok Sandstone (n=79)	Na^+ - HCO_3^- - Cl^- to Na^+ - Cl^-- HCO_3^-	505	6686	1211	6.9	8.6	7.7
Westbourne Formation (n=11)	Na^+ - Cl^-- HCO_3^-	772	6500	1195	6.9	8.7	8.2
Gubberamunda Sandstone (n=669)	Na^+ - HCO_3^- to Na^+ - Cl^-- HCO_3^-	422	2419	689	7.5	8.7	8.3
Bungil Formation, Mooga Sandstone and Orallo Formation (BMO Group) (n=556)	Na^+ - HCO_3^- to Na^+ - HCO_3^- - Cl^-	620	3069	1080	7.6	8.7	8.3

Table 5.2: Summary of Surat Basin groundwater chemistry by major unit (cont'd)

Unit	Dominant Water Type	TDS (mg/L)			pH (units)		
		10th	90th	Median	10th	90th	Median
Rolling Downs Group (n=616)	Na^+ - Cl^- to Na^+ - Cl^-- HCO_3^-	546	17188	2170	7.0	8.5	8.0

Source: Worley Parsons (2012)

Table 5.3: Summary of Cainozoic cover groundwater chemistry

Unit	Dominant Water Type	TDS (mg/L)			pH (units)		
		10th	90th	Median	10th	90th	Median
Tertiary Volcanics (n=419)	Na^+ - HCO_3^-	322	2351	713	7.4	8.5	8.1
Alluvium (n=1297)	Na^+ - HCO_3^- with variable Cl^- influence	298	5670	714	6.8	8.3	7.6

Source: Worley Parsons (2012)

5.5 Groundwater Use

Groundwater has historically been utilised extensively throughout the Surat CMA for a range of purposes including irrigation, agriculture, grazing, industry and urban supply. Primarily groundwater is extracted from GAB aquifers, the Condamine Alluvium and Main Range Volcanics for these purposes.

Groundwater extraction associated with the petroleum and gas industry is increasing with the expansion of coal seam gas activity throughout the CMA.

The following sections present information on groundwater use within the Surat CMA as sourced from the UWIR (QWC, 2012). This supplements the information provided in the EIS.

5.5.1 Non-petroleum and gas related groundwater extraction

The Condamine Alluvium has historically been over-developed and over-allocated with respect to the productive yield of the system (DNRM, 2012a) resulting in significant lowering of the watertable, and in some areas resulting in disconnection of the Condamine River with the Condamine Alluvium, as described in Section 5.2.

Since 1970, the impact on this resource has been recognised and further access to Condamine Alluvium groundwater systems was limited. A moratorium to limit development of groundwater in this area was published in June 2008 for the Alluvium and the Basalts in the Upper Condamine Catchment. This moratorium was recently amended to further restrict new take of groundwater in the system (DNRM, 2012a).

A summary of the non-petroleum groundwater extraction bores and extraction volumes reported in the Surat CMA UWIR is provided in Table 5.4. There are over 21,000 water bores within the Surat CMA with a combined water extraction in the order of 215,000 ML/yr. Of this, around 85,000 ML/yr is sourced from GAB formations and 130,000 ML/yr is sourced from other aquifers. The total groundwater extraction presented in Table 5.4 represents groundwater used for agricultural, industrial, urban and stock and domestic purposes.

Aquifers having the greatest number of groundwater bores and extraction volume include the Condamine Alluvium and Tertiary Main Range Volcanics, and to a lesser extent the Walloon Coal Measures and Hutton/Marburg Sandstone.

Table 5.4: Summary of non-petroleum groundwater extraction in the Surat CMA

Formation Type	Aquifer Name	Number of Registered Bores	Estimated Groundwater Extraction (ML/yr)
Non-GAB Upper Formations	Alluvium (Undifferentiated)	757	8,273
	Condamine Alluvium	3,948	55,000
	Tertiary Main Range Volcanics	7,638	62,719
	Rolling Downs Group	210	1,150
	TOTAL Non-GAB Upper	**12,553**	**127,142**
GAB Formations	Bungil Formation + Mooga Sandstone	1,099	9,075
	Orallo Formation	60	330
	Gubberamunda Sandstone	908	13,822
	Westbourne Formation	3	15
	Springbok Sandstone	223	1,714
	Walloon Coal Measures	2,054	16,927
	Eurombah Formation	18	381
	Hutton/ Marburg Sandstones	2,828	28,261
	Evergreen Formation	302	1,829
	Precipice/ Helidon Sandstones	292	10,528
	Moolayember Formation	86	433
	Clematis Sandstone	195	2,123
	TOTAL GAB	**8,068**	**85,438**
Non-GAB Lower Formations	Rewan Group	37	185
	Bandanna Formation	43	215
	Bowen Permian	366	1,830
	Basement Rocks	125	565
	TOTAL Non-GAB Lower	**571**	**2,795**
TOTAL		**21,192**	**215,375**

Source: QWC (2012)

5.5.2 Petroleum and Gas activity associated groundwater extraction

Petroleum tenure holders have a right to take groundwater under the P&G Act. There are two types of petroleum and gas activities:

- Conventional oil and gas production from dominantly sandstone formations.
- Coal Seam Gas production from coal formations.

Conventional petroleum and gas is produced from the Surat Basin, the adjacent Bowen Basin and other basins within Queensland. According to the OGIA (QWC, 2012) the most significant extraction within the Surat CMA has been from the Precipice Sandstone and Evergreen Formation of the Surat Basin and the Showgrounds Sandstone of the Bowen Basin.

Petroleum tenure holders are required under the P&G Act and Petroleum Act to report to DNRM on the volume of water they extract during production and testing of their wells. Data relating to water production obtained by the OGIA in early 2011 from DNRM and tenure holders shows that:

- There were 154 conventional oil and gas wells extracting water from Surat and Bowen Basin GAB formations and 83 extracting water from older Permian and Devonian formations underlying the Bandanna Formation. Most of the water had been produced from the GAB formations. Current annual water extraction is approximately 1,800 ML/yr and this rate has not been significantly exceeded over the past 30 years (QWC, 2012).
- There were 1,160 coal seam gas wells extracting water. Total water extraction reported to OGIA in 2011 was approximately 18,000 ML.

5.6 Subsidence

In 2010 Geoscience Australia completed a review of available information from coal seam gas proponents (Origin Energy, QGC and Santos) to provide expert advice to SEWPaC in relation to the likely groundwater impacts of proposed coal seam gas activities in the Surat and Bowen Basins. It was concluded that there was the potential for subsidence to occur, however based on an assessment of coal seam gas activities in similar environments, the risk of impacts to shallow groundwater systems was considered to be very low (Geoscience Australia and Habermehl, 2010). It was also recommended that monitoring activities be implemented or continued, and should include an assessment of both surface and subsurface deformation.

Similarly Williams et al (2012) identify the potential for land subsidence to occur as a result of coal seam gas extraction, and identify subsidence as a natural resource management issue that requires attention.

In recognition of this, Altamira Information was engaged to complete a ground motion baseline study on behalf of Arrow Energy, Origin Energy, QGC and Santos (Altamira, 2012). The study involved analysing ground motion using satellite interferometry in the Surat and Bowen Basins. The study was undertaken in response to Commonwealth conditions of approval for the QCLNG Project (operated by QGC), GLNG Project (operated by Santos) and the APLNG Project (operated by Origin Energy) i.e. for "*baseline and ongoing geodetic monitoring to quantify deformation at the land surface within the proponent's tenures"*. The project established a baseline of ground surface motion across the Surat and Bowen Basins coal seam gas fields prior to significant expansion of coal seam gas production.

Altamira Information's Persistent Scatter Interferometry technique, named Stable Point Network (SPN), was used for the study. The SPN technique was applied in order to measure the ground motion for the period December 2006 to February 2011 using archive Advanced Land Observation Satellite (ALOS) imagery. This involved the processing of 698 Synthetic Aperture Radar images from seven different satellite tracks to cover the 55,000 km^2 area of interest.

The majority of the measurement points showed stability (magnitude of ground motion below 8 mm/yr) and did not show any apparent large scale deformation pattern (refer Figure 5.9). Nevertheless, many small patches of uplift and subsidence that were related to natural or anthropogenic factors were found throughout the study area. Some areas of the project development area were unable to be assessed due to interference from continual land modifications resulting in decreased measurement points and substantial noise in the data. This was observed in particular to the east of Cecil Plains and to the west of Dalby where land is extensively modified due to intensive agricultural activities (Figure 5.9).

Several areas showed deformation at a rate greater than 16 mm/yr. Some areas of ground motion are observed over different terrain, in some cases very close to rural tracks. In many cases subsiding points were detected over the boundaries of ponds or irrigation dams. Also, uplift patterns were seen over riverbanks, which might be caused by the significant rainfall events that occurred in 2010. Importantly, there were several existing operational coal seam gas fields in the study area where no significant ground surface motion was detected. A specific report was prepared by Altamira to report the findings of the historical ground motion rates within Arrow's tenure boundaries (Altamira, 2012a).

6 POST EIS GROUNDWATER MODELLING UPDATES

6.1 Background

Numerical groundwater modelling was conducted for the EIS (referred to herein as the Arrow EIS Groundwater Model) to predict groundwater drawdown in response to the Surat Gas Project including cumulative drawdown (SWS, 2011).

Since the submission of the Arrow EIS in December 2011, the UWIR for the Surat CMA (QWC, 2012) and supporting numerical groundwater model was approved by the Chief Executive of DEHP and took effect from 1 December 2012. The model was used to predict the cumulative impacts of proposed coal seam gas developments in the Surat CMA. These predictions are summarised in the UWIR.

The numerical groundwater model supporting the UWIR (refer Section 6.2.2) comprised the OGIA Surat CMA Groundwater Model (GHD, 2012) incorporating the Condamine Alluvium Groundwater Model (KCB, 2011b).

A revised numerical groundwater model has also been prepared for the Arrow SREIS, referred to herein as the Arrow SREIS Groundwater Model (GHD, 2013). This revised model is consistent with the modelling approach undertaken by OGIA, and is a modification of the OGIA Surat CMA Groundwater Model.

The revised model was adopted to:

- Achieve conceptual consistency with the UWIR and supporting groundwater model, and enable direct comparison with impact predictions made in the UWIR.
- Recognise that the assessment of cumulative impacts and establishing integrated management arrangements is the responsibility of the OGIA and these have been set in the Surat CMA UWIR. Further, the UWIR (incorporating predictions from the OGIA Surat CMA Groundwater Model) defines Arrow's obligations including bore assessments and groundwater monitoring.

The Arrow SREIS Groundwater Model replicates the groundwater model files from the OGIA Surat CMA Groundwater Model with two changes:

1. Incorporating elements from the revised project description (the revised water production profile in the Arrow current development plan); and
2. Modelling offset of groundwater flux scenario via application of ‘virtual injection’ i.e. substitution of groundwater allocations from the Condamine Alluvium.

6.2 Groundwater Model Evolution

Groundwater modelling is a process of continual updating as new data and information is collected. This section provides a comparison of the Arrow EIS Groundwater Model (SWS, 2011) and the modelling undertaken to support the Surat CMA UWIR (QWC, 2012).

6.2.1 Arrow EIS Groundwater Model

Arrow engaged Schlumberger Water Services (SWS) to undertake numerical simulation of drawdown impacts caused by groundwater produced by the Surat Gas Project as defined in the EIS. Predictions from the modelling were used to underpin the impact assessment in the EIS and the development of mitigation measures. The model incorporated available, most up-to-date data and information, including publically available data outside the project development area, to form a conceptual model and develop the numerical groundwater model. The model and report were completed in June 2011, independently peer reviewed, and presented with the final Arrow EIS submission.

6.2.2 Groundwater Models Developed Post EIS

Two groundwater models were developed after the submission of the EIS and are considered in this supplementary groundwater assessment. The purpose of these two models differ from the objective of the Arrow EIS Groundwater Model, hence the conceptualisation and method of groundwater modelling undertaken was specific to each study. These two models are; the Central Condamine River Alluvium model (herein referred to as the Condamine Alluvium Groundwater Model) and the OGIA Surat CMA Groundwater Model (which incorporates the Condamine Alluvium Groundwater Model).

The Condamine Alluvium Groundwater Model was developed independently of the coal seam gas industry. It was conceptualised, constructed and calibrated as part of a staged assessment completed by KCB (2011b) on behalf of the Department of Natural Resources and Mines (DNRM, formerly part of the Department of Environment and Resource Management (DERM)). The aim of this model was to assist resource managers to administer the groundwater resources within the Central Condamine River Alluvium Area (DERM, 2009).

The OGIA Surat CMA Groundwater Model (GHD 2012; QWC, 2012; WaterMark, 2012) was commissioned by the OGIA and was initially constructed and calibrated by QWC and GHD. This work is reported in GHD (2012). The model area is shown on Figure 6.1 and covers:

- The entire Surat CMA;
- All areas where the Bandanna Formation is present at outcrop/subcrop in the southern half of the Bowen Basin; and
- The full extent of the Surat Basin in Queensland.

Some further minor revisions, uncertainty analysis and predictive modelling were then carried out in relation to the OGIA Surat CMA Groundwater Model by QWC and WaterMark (WaterMark, 2012). WaterMark also utilised the Condamine Alluvium Groundwater Model to make predictions on groundwater level impacts to the Condamine Alluvium aquifer (groundwater level impact predictions are discussed in Section 7). All of the above work is summarised in the Surat CMA UWIR (QWC 2012). The objective of the model was to provide a:

- Tool for the OGIA to assess water level or pressure changes in the immediate term (1-3 years) as well as over the longer-term (20-100 years) in all aquifers across the model domain.
- Basis for establishing impacts caused by coal seam gas tenure holders in the Surat CMA.
- Basis to enable improved understanding, prediction and management of cumulative impacts of coal seam gas development on groundwater resources in the Surat CMA.

Figure 6.2 is a block diagram showing the Condamine Alluvium Groundwater Model geology and its context within the OGIA Surat CMA model domain. The Condamine Alluvium Groundwater Model domain provides a more localised representation of a sub-area of the OGIA Surat CMA Groundwater Model, and was developed at a higher resolution (smaller cell size).

In recognition of this pre-existing and more detailed Condamine Alluvium Groundwater Model, development of the OGIA Surat CMA Groundwater Model was undertaken such that:

- Key features of the Condamine Alluvium Groundwater Model were incorporated into the OGIA Surat CMA Groundwater Model construction and calibration; and
- The Condamine Alluvium Groundwater Model was used to predict groundwater level impacts in the Condamine Alluvium, based on modelled flow outputs from the OGIA Surat CMA Groundwater Model. Net modelled interlayer fluxes between the Condamine Alluvium and the underlying strata are initially extracted from the OGIA Surat CMA Groundwater Model. These modelled flows are then incorporated into the more detailed Condamine Alluvium Groundwater Model to calculate coal seam gas and non-coal seam gas related impacts within the Condamine Alluvium. Interlayer flux into the Condamine Alluvium comprises upward flow from the Walloon Coal Measures (QWC, 2011). Flux impacts resulting from coal seam gas water production therefore cause a small reduction in the existing flux, which nevertheless remains upward from the Walloon Coal Measures to the Condamine Alluvium.

Independent external review formed an integral component of the modelling work undertaken for OGIA. This was achieved through regular consultation with both the project Technical Advisory Group (TAG) and Project Steering Committee (PSC). Through these groups input was received from DERM, CSIRO and SeWPAC, including independent modelling and GAB experts and other stakeholders.

All modelling work was undertaken with due reference to the Murray Darling Basin Commission (MDBC) Groundwater Flow Modelling Guideline (Middlemis et al., 2000) which was the de-facto Australian guideline for groundwater modelling work at the time. The fundamentals of these guidelines are similar to those of the recently published Australian Groundwater Modelling Guidelines (Barnett et al, 2012).

The OGIA Surat CMA Groundwater Model (incorporating the Condamine Alluvium Groundwater Model) has been approved by DEHP and underpins the regulation of Arrow’s operations. Therefore Arrow considers that the OGIA Surat CMA Groundwater Model to be the most appropriate available tool for assessing:

- The regional scale impacts of the Arrow Surat Gas Project;
- Condamine Alluvium specific impacts; and
- The revised cumulative impacts of proposed coal seam gas developments in the Surat Basin based on Arrow’s current development plan.

6.3 Model Comparisons

This section presents a summary of the main differences between the development and construction of the Arrow EIS Groundwater Model (which was used to underpin the EIS) and the OGIA Surat CMA Groundwater Model (which forms the basis of the Arrow SREIS Groundwater Model that underpins this supplementary groundwater assessment). Table 6.1 provides a comparison of the major model components and features. The Condamine Alluvium Groundwater Model has also been presented.

Table 6.1: Comparison of groundwater models

Assessment	**Arrow EIS Groundwater Model** (SWS, 2011)	**Condamine Alluvium Groundwater Model** (KCB, 2010a, 2010b, 2011a, 2011b, 2011c)	**OGIA Surat CMA Groundwater Model** (GHD, 2012; QWC 2012; WaterMark, 2012)
Date of build	Between 2009 and 2011	Between 2010 and 2011	Between 2011 and 2012
Model code	MODFLOW 2000	MODFLOW 2000 MODFLOW-SURFACT (MODHMS)	MODFLOW 2005
Model domain	453 km x 270 km	201 km x 55 km	547.5 km x 661.5 km
Number of cells	1,834,650	21,874	3,058,335
Grid	1 km x 1 km	500 m x 500 m	1.5 km x 1.5 km
Source of data inputs	Arrow Energy and publically available data	Publically available data	All coal seam gas proponents and publically available data
Number of layers	15	2	19
Layering	1. Condamine Alluvium 2. Lower Cretaceous sequence 3. Mooga Sandstone 4. Orallo Formation 5. Gubberamunda Sandstone 6. Westbourne Formation 7. Springbok Sandstone 8. 10 m thick shale 9. Juandah Coal Measures	1. Sheetwash 2. Alluvium	1. Condamine Alluvium (based on Condamine Alluvium Groundwater Model) 2. Griman Creek/ Wallumbilla Formation and Surat Siltstone 3. Bungil Formation and Mooga Sandstone 4. Orallo Formation 5. Gubberamunda Sandstone 6. Westbourne Formation

Table 6.1: Comparison of groundwater models (cont'd)

Assessment	**Arrow EIS Groundwater Model** (SWS, 2011)	**Condamine Alluvium Groundwater Model** (KCB, 2010a, 2010b, 2011a, 2011b, 2011c)	**OGIA Surat CMA Groundwater Model** (GHD, 2012; QWC 2012; WaterMark, 2012)
Layering (cont'd)	10. Tangalooma Sandstone 11. Taroom Coal Measures 12. Durabilla/ Eurombah Formation 13. Hutton Sandstone 14. Evergreen Formation Precipice Sandstone		7. Upper Springbok Sandstone 8. Lower Springbok Sandstone 9. Walloon Coal Measures (upper aquitard) 10. Walloon Coal Measures (coal, mudstone, siltstone and sandstone) 11. Walloon Coal Measures (lower aquitard) 12. Hutton/ Marburg Sandstone 13. Evergreen Formation 14. Precipice Sandstone 15. Moolayember Formation 16. Clematis / Showground Sandstones 17. Rewan Group 18. Bandanna Formation Permian Sediments
Groundwater systems	• Condamine Alluvium • Surat Basin	• Condamine Alluvium	• Condamine Alluvium • Surat Basin • Bowen Basin
Method for simulating groundwater extraction	Multi-node well (MNW) boundary package	Multi Node Well No.2 (MWN2) and Fracture Well (FWL4)	EVT package simulates coal seam gas production and landholder abstraction is simulated using the well package

Table 6.1: Comparison of groundwater models (cont'd)

Assessment	**Arrow EIS Groundwater Model** (SWS, 2011)	**Condamine Alluvium Groundwater Model** (KCB, 2010a, 2010b, 2011a, 2011b, 2011c)	**OGIA Surat CMA Groundwater Model** (GHD, 2012; QWC 2012; WaterMark, 2012)
Modelled scenarios	• Scenario 1 – Arrow Only Reference Case • Scenario 2 – Combined Base Case (Arrow and other coal seam gas projects associated with proponents that has taken their Final Investment Decision (Santos GLNG & QGC)) • Scenario 3 – Cumulative Case (all 4 primary coal seam gas proponents)	• Water management scenario 1: 100% of authorised pumping rate • Water management scenario 2: 50% of authorised pumping rate • Water management scenario 3: 0% of authorised pumping rate	• Base Run: Modelling water extraction from 1995 onward accounting for non-P&G extraction only • P&G Production Run: Modelling water extraction from current and proposed P&G activities added to the Base Run water extraction. This scenario also includes impact predictions using the Condamine Alluvium Groundwater Model
Calibration	• Steady State (pre-1995) – manual calibration • Transient (1st June 2005 to 1st January 2011) – manual calibration	• Steady State (conditions representative of 1/1/1980) – Initial manual testing followed by automated calibration using PEST • Transient (1st January 1980 to 1st July 2009) – Initial manual testing followed by automated calibration using PEST	• Steady State – pre coal seam gas extraction conditions to 1995 • Transient calibration – Condamine Alluvium sub-model • Transient calibration – Daandine coal seam gas production field sub-model • Automated calibration software (PEST)
Sensitivity/Uncertainty Analysis	Sensitivity analysis undertaken for Scenario 1 only. Assesses the influence that hydraulic parameters of key stratigraphic units have on model drawdown predictions	Qualitative sensitivity analysis Basic sensitivity analysis of adjustable parameters based on PEST calibration results	Calibration Uncertainty Analysis using the null space Monte Carlo method

6.3.1 Sources of Data Inputs

For the purposes of developing a conceptual geological/hydrogeological model and undertaking development and calibration of the numerical groundwater models publically available data and in conjunction with private data were utilised (SWS, 2011; KCB, 2010a, 2010b, 2011a, 2011b, 2011c: GHD, 2012). The data sources used in each groundwater model are summarised below and presented in Table 6.2.

6.3.1.1 Stratigraphic and Geological Representation

The geological profile in the Arrow EIS Groundwater Model was developed using layer surface models derived from publically available borehole data including water bores and petroleum and mineral wells. A 15 layer model was constructed with the Condamine Alluvium comprising one layer only and the Walloon Subgroup is sub-divided into 5 layers.

The OGIA Surat CMA Groundwater Model utilised point borehole data sets and other published geological surfaces developed by Geoscience Australia (GA) and SRK Consulting (SRK). The SRK and GA data sets were adopted since they cover both the Surat and Bowen Basins and were developed independently of the coal seam gas industry. The detailed local model of the Condamine Alluvium developed by KCB (KCB, 2011b) was utilised. The top and bottom elevations of this two layer Condamine Alluvium Groundwater Model were incorporated directly into the OGIA Surat CMA Groundwater Model. The OGIA model was constructed with 19 layers. There are 14 layers to represent the Surat Basin and 5 layers to represent the underlying Bowen Basin. A 3 layer system was adopted for the Walloon Subgroup.

The stratigraphic profile of the Arrow EIS and OGIA Surat CMA Groundwater Models are equivalent. The thickness and extent of the Condamine Alluvium are similar, given that different data sources were used to construct the top layer of the models. The Kumbarilla Beds in both models are represented by the Mooga Sandstone, Gubberamunda Sandstone, Westbourne Formation and Springbok Sandstone.

The groundwater models have used a different number of layers to represent the Walloon subgroup. The OGIA Surat CMA Groundwater Model sequence is:

- A thin layer of conceptually low permeability material separating the Juandah Coal Measures from the Springbok Sandstone above.
- A composite coal seam defined by the vertical distance between the top of the uppermost and base of the lowermost productive coal seam.
- A lower aquitard layer defined by the distance between the base of the lowermost productive coal seam and base of the Walloon Coal Measures (i.e. the top of the underlying Hutton Sandstone).

The Arrow EIS Groundwater Model split the Walloon Subgroup into 5 layers:

- An upper mudstone/siltstone (called 10 m shale) to represent the low permeability material overlying the coal seams.
- An upper coal seam layer - Juandah Coal Measures.
- An intermediate layer - Tangalooma Sandstone.
- A lower coal seam layer – Taroom Coal Measures.

- A lower aquitard unit representing the Durabilla and Eurombah Formations.

The thickness of the lower units of the Surat Basin (i.e. Hutton Sandstone and Precipice Sandstone) were revised in the OGIA Surat CMA Groundwater Model based on more recent drilling activities post the submission of the Arrow EIS (GHD, 2012).

Even though the Arrow EIS and OGIA Surat CMA hydrostratigraphic models were developed independently of each other, with some minor differences in the overall data sets, for a regional groundwater model at this scale they are considered comparable and appropriate for the purposes of impact assessment.

Table 6.2: Data sources

	Stratigraphic and geological representation		Groundwater flow and aquifer hydraulics		Groundwater extraction	
	Publically Available	**Proprietary**	**Publically Available**	**Proprietary**	**Publically Available**	**Proprietary**
Arrow EIS Groundwater Model	Exon (1976) Queensland Petroleum Exploration Database (QPED) Green (1997) Power and Devine (1970)	Arrow Energy stratigraphic logs (mainly Walloon Subgroup)	Henning (2005) Queensland Groundwater Database, maintained by DERM (QGWD) Habermehl (1980) Parsons Brinckerhoff (2004) New Acland Coal EIS (SKM, 2009) Wandoan Coal project EIS (PB, 2008) Santos GLNG Project EIS (URS, 2009) Barnett & Muller (2008)	Arrow Energy groundwater pressures at specific coal seam gas monitoring wells	QGWD Water Entitlement and Registration Database (WERD) (note: this data informed discussion in the EIS, but was not modelled as abstraction)	Arrow Energy groundwater pressures at specific coal seam gas monitoring wells

Table 6.2: Data sources (cont'd)

	Stratigraphic and geological representation		Groundwater flow and aquifer hydraulics		Groundwater extraction	
	Publically Available	**Proprietary**	**Publically Available**	**Proprietary**	**Publically Available**	**Proprietary**
Condamine Alluvium Groundwater Model	1:250,000 geological map sheets (Roma, Chinchilla, Surat, Dalby, Ipswich, St George, Goondiwindi, Warwick) Exon (1976) Quarantotto (1979)	Digital Elevation Model (DEM) provided by DERM Contoured bedrock basement layer provided by DERM	Lumsden (1966) Lane (1979) Huxley (1982) Barnett & Muller (2008)	Unfiltered QGWD export of groundwater level records within the study area for the period 1900-2011 Information related to current and ongoing installation of automated pressure transducers at selected sites	DERM (2008)	
OGIA Surat CMA Groundwater Model	1:250,000 geological map sheets Great Artesian Bore Audit (Barclay, 2001) Queensland Carbon Dioxide Geological Storage Atlas (Bradshaw et al., 2009)	OGIA provided the mapping showing the estimated subcrop areas of each of the main GAB units in the Surat and Clarence-Moreton Basins	QGWD Groundwater levels provided by Arrow, Santos, QGC and Origin QPED Database	Condamine Alluvium Groundwater Model (KCB, 2011b) Surat Gas, GLNG, QCLNG, APLNG Projects	QGWD	Historical groundwater extraction was provided by OGIA and included: Conventional P&G water production volumes reported to the DEEDI

Table 6.2: Data sources (cont'd)

	Stratigraphic and geological representation		Groundwater flow and aquifer hydraulics		Groundwater extraction	
	Publically Available	**Proprietary**	**Publically Available**	**Proprietary**	**Publically Available**	**Proprietary**
OGIA Surat CMA Groundwater Model (cont'd)	Bowen and Surat Structural Framework Study (SRK, 2008) QGWD Raster datasets interpreted by Geoscience Australia	Geological boundaries were provided by OGIA Stratigraphic data for boreholes provided by Arrow, Santos, QGC and Origin Condamine Alluvium Groundwater Model (KCB, 2011b)				Coal seam gas water production volumes reported to DEEDI Estimated stock and domestic extractions Licensed volumetric entitlements Estimated actual coal seam gas extractions All coal seam gas companies provided an estimate of future extraction from proposed fields

Groundwater Extraction

The projected water extraction rates from the GLNG, QCLNG and APLNG Projects in the Arrow EIS were sourced from publically available data, directly from their respective EIS reports. Figure 6.3a shows the modelled extraction rates adopted in the Arrow EIS Groundwater Model. The Arrow EIS Groundwater Model did not simulate non-coal seam gas extraction (i.e. irrigation, stock, town supply).

The OGIA reviewed historical water extraction data provided by all four primary coal seam gas proponents in the OGIA Surat CMA Groundwater Model. In the OGIA model simulations, the wells initially extract water at a rate based on the relationship between pumping rate and time. The OGIA established this relationship from historical water production data independent of the water production forecasts provided by the four primary coal seam gas proponents for their coal seam gas projects (the Surat Gas Project, together with the GLNG, QCLNG and APLNG Projects). Estimated water extraction totals for non-coal seam gas groundwater users along with the volumetric entitlements for all licensed and stock and domestic bores within the OGIA Surat CMA modelled area were based on data provided by DERM, and data analysis performed by KCB (2011b) of both metered and unmetered historical groundwater abstractions.

Figure 6.3b details the water extraction rates that were simulated by the Arrow SREIS Groundwater Model. The water extraction rates for the GLNG, QCLNG and APLNG Projects and non-coal seam gas case groundwater users were adopted directly from the OGIA Surat CMA Groundwater Model simulations. The Arrow only case represents the Arrow current development plan.

The variation in the Arrow only water production profile used in the Arrow SREIS Groundwater Model in comparison with the EIS production profile is directly related to the revision of Arrow's water production development plan since the EIS submission.

6.3.2 Model Boundary Conditions

The boundary conditions of a groundwater model can be represented with different methods using industry standard groundwater modelling software. Even though different methods may have been adopted to represent boundary flux and groundwater extraction, the model function and prediction from the Arrow EIS and OGIA Surat CMA Groundwater Models are still comparable. A brief summary of the different approaches adopted is presented below.

Flux Boundaries

The Arrow EIS Groundwater Model used constant head boundary conditions along the west, and portions of the east model boundary to allow for regional groundwater inflows and outflows from outside the study area. These boundary conditions were required because the model domain is limited and does not always follow natural groundwater boundaries.

The OGIA model adopted general head boundaries (GHB) to address some of the issues noted with the regional flow boundary assignments. In particular, constant head boundaries can act as "infinite" sources or sinks for groundwater in response to stresses (e.g. drawdown due to groundwater extraction) when applied in close proximity to these boundary conditions. Therefore, if drawdown effects propagate to the model boundaries, the use of constant head boundary conditions may lead to an underestimation of groundwater drawdown impacts. These concerns were addressed in the OGIA Surat CMA Groundwater Model by removing all constant head boundary conditions from the model and assigning GHB conditions in key aquifers only, while using default "no flow" boundary conditions for the aquitards.

GHBs were also adopted in the Condamine Alluvium Groundwater Model to represent fluxes into and out of the model domain boundaries, which were subdivided into five conceptual boundaries. These included:

- Flux from the Walloon Coal Measures.
- Flow from the Upper Condamine Alluvium.
- Flow from the Main Range Volcanics aquifer to the east.
- Tributary leakage from the east.
- Flow out of the model downstream near the Chinchilla Weir.

An assessment was undertaken of the differences in simulated fluxes across the constant head boundaries used in the EIS model, for the 3 scenarios modelled. The results show that:

- The simulated constant head boundary fluxes are not significantly changed over the production periods, reducing by 0.4% to 0.9% over the 61 year period.
- Little difference in constant head boundary flux is observed between the three scenarios. The maximum difference was 0.4% of the total CHB flux, between Scenarios 1 and 3.
- The total constant head boundary flux is only about 0.0003% of the total model cumulative flux for all three scenarios, representing only a small component of the model water balance.

In conclusion, the simulated constant head boundary fluxes in the Arrow EIS Groundwater Model are relatively small, and changed little across the production period. This indicates that model predictions are unlikely to be adversely influenced by boundary condition effects.

Recharge

In the Arrow EIS Groundwater Model, a blanket recharge rate of 1 mm/yr (based on Kellett et al., 2003) was applied only to areas where aquifer units outcrop. Where confining layers outcrop at the surface no recharge was applied. To achieve better calibration, an enhanced recharge rate of 5 mm/yr was applied to the footprint of the Main Range Volcanics. Recharge was also applied to the highest active layer of the model.

While recharge to the main GAB aquifer units has been estimated by Kellett et al., (2003), estimates vary and there has been ongoing research into which aquifers contribute significant recharge to the GAB. Recharge in the OGIA Surat CMA Groundwater Model was therefore varied on a zonal basis during model calibration. In most zones, recharge was allowed to vary between 1 and 30 mm/yr based on maximum and minimum long-term average estimates included in Kellett et al., (2003). The long-term average net recharge to the Main Range Volcanics was 5.2 mm/yr, comparable to 5 mm/yr adopted in the Arrow EIS Groundwater Model. A majority of the area to the west of Dalby had a recharge rate of between 0 – 3 mm/yr in the OGIA Surat CMA Groundwater Model, again comparable to the adopted 1 mm/yr adopted in the Arrow EIS Groundwater Model. The spatial distribution of calibrated groundwater recharge rates in the OGIA Surat CMA Groundwater Model is generally in good agreement with the findings from the previous studies.

A zero recharge rate was assumed for the Condamine Alluvium in the OGIA Surat CMA Groundwater Model. This is because the groundwater levels and river stage elevations that have been adopted to represent the Condamine Alluvium are typically well below ground level. Therefore groundwater levels in the steady-state calibration model are effectively held at an artificially low level by the modelled river cells. Under this arrangement, modelled groundwater levels in the Condamine Alluvium are insensitive to recharge.

In the more detailed Condamine Alluvium Groundwater Model, deep drainage to the watertable and leakage for continuous deep drainage from irrigated areas and ring tanks were applied as a range of recharge values calculated during the calibration process of the Condamine Alluvium Groundwater Model. Figure 3.10 of KCB (2011b) displays the recharge potential map developed during the modelling process.

6.3.3 Simulated Groundwater Extraction

The effects of coal seam gas production can be simulated by several methods using industry standard groundwater modelling software. Two of these methods have been used to represent coal seam gas production in the Surat Basin:

1. Simulating the actual production wells and removing the anticipated production volumes from these wells. Simulated extractions in the Arrow EIS Groundwater Model was undertaken using the MODFLOW ‘Multi-Node Well’ (MNW) package (Halford and Hanson, 2002).
2. Identifying the estimated target pressure and using the evapotranspiration package (EVT package) to achieve this level of drawdown, as adopted in the OGIA Surat CMA Groundwater Model.

The Arrow EIS Groundwater Model used water production rates from the reservoir model to simulate coal seam gas production. The amount of drawdown (decrease in water pressure) was a function of the production rate and the hydraulic parameterisation of the model as calibrated against observation data. The OGIA Surat CMA Groundwater Model used pressure targets so that the modelled water production was a function of the amount of pressure decrease required to meet that pressure targets.

The purpose of groundwater models is to predict groundwater drawdown, and these models are unable to account precisely for dual-phase gas-water production. Hence, model water production can differ from actual water production using reservoir planning tools, and the latter indicates lower production rates. Hence, the modelling should be considered conservative in this regard.

6.3.4 Model Calibration

Calibration of the Arrow EIS Groundwater Model was undertaken by manually varying parameters, within the documented ranges, in order to improve the match between simulated and observed groundwater levels. Pre-1995 groundwater levels were extracted from the QGWD to set a groundwater surface for the steady-state calibration model. Hydraulic conductivity and recharge were varied during the steady-state calibration, while constant heads were set based on the contouring of observed historical groundwater levels and were not adjusted further during calibration. The transient calibration was focussed on the Walloon Coal Measures where extraction from the Arrow coal seam gas operations has been monitored and groundwater level observations were available. Boundary conditions were not varied however hydraulic conductivity and storage parameters were. The Scaled Root Mean Square (SRMS) is a useful statistic for assessing calibration quality (Middlemis et al., 2000). The SRMS for the calibrated models is provided in Table 6.3.

The calibration of the Condamine Alluvium and OGIA Surat CMA steady-state and transient models was undertaken using the PEST suite of software (Doherty, 2010). PEST is an automated technique to assist with optimising parameters in a groundwater model.

The OGIA also adopted the calibrated data from the Condamine Alluvium Groundwater Model to define the thickness, hydraulic conductivity, storage parameters and time-variant head boundary conditions for the Condamine Alluvium layer in the OGIA Surat CMA Groundwater Model. Therefore groundwater levels in the steady state OGIA Surat CMA Groundwater Model and transient sub-model within the Condamine Alluvium were effectively fixed at the levels calculated by the Condamine Alluvium Groundwater Model (KCB, 2011b).

Table 6.3: SRMS results

Model	**Steady-state Calibration**	**Transient Calibration**
Arrow EIS Groundwater Model	6.8%	8.8%
Condamine Alluvium Groundwater Model	-	4.06%
OGIA Surat CMA Groundwater Model	3.7%	-

Considering the variable lithology of the Surat Basin, the regional size of the models and the resulting relatively coarse cell sizes adopted, the SRMS is considered to be acceptable in terms of calibration performance. A comparison of calibrated model parameters from the Arrow EIS and OGIA Surat CMA Groundwater Models is provided in Appendix C.

6.3.5 Sensitivity and Uncertainty Analysis

Sensitivity analysis was undertaken as part of the Arrow EIS Groundwater Model to provide an understanding of which model hydraulic parameters had the greatest control on simulated drawdown and an understanding of the potential magnitude range of drawdown that could be expected from the production of associated water from coal seam gas activities under different parameter conditions. The analysis focused on the specific storage (Ss) of all layers and the vertical hydraulic conductivity (Kv) of some of the key lithological units. A total of 15 sensitivity runs were simulated. The findings showed that there was little difference between any of the sensitivity run steady-state SRMS values compared with the calibrated case.

The final calibrated parameters presented by OGIA are considered to be close to optimal, in terms of the modelled fit to the adopted calibration targets, however it is recognised that similar levels of fit could have been achieved using a range of different parameter sets. This uncertainty analysis involved the generation of 200 model predictions based on 200 different statistically generated parameter sets, resulting in 200 different predictions of groundwater level impacts. As the groundwater flow model is non-linear, these new parameters were no longer strictly calibrated. While the parameter sets are de-calibrated from the manual calibration they are nevertheless constrained by the calibration and represent parameter sets that give a similar calibration fit due to the non-uniqueness of the solution.

These predictions were then processed to identify maximum predicted drawdown impacts in each of the aquifers present within the Surat CMA. The 200 predictions were ranked in an increasing order from lowest to highest predicted drawdown. Predictions beyond the 5^{th} and 95^{th} percentiles were treated as outliers. The maximum value of the remaining predictions was used in determining the groundwater impacts.

Qualitative sensitivity analysis of the Condamine Alluvium Groundwater Model was carried out during model development and during manual calibration, however a complete sensitivity analysis of all major model components was not undertaken.

7 ARROW SREIS NUMERICAL GROUNDWATER MODEL

The Arrow SREIS Groundwater Model has been developed to support the supplementary groundwater assessment. The model represents a repeat of the groundwater modelling and uncertainty analysis previously conducted by the OGIA for the Surat CMA UWIR but based on the current development plan for the Surat Gas Project. It includes a calibrated model and a set of uncertainty analysis modelling predictions using the 'null space Monte Carlo' method (NSMC). The model is reported in more detail in Appendix D.

The primary purpose of this model is to revise the groundwater impact predictions based on the Arrow current development plan, which has a smaller 'footprint' than previously considered in the EIS and by the OGIA, and to evaluate whether the groundwater drawdowns previously modelled for the EIS provided a suitable basis for the impact assessment conducted.

The use of the OGIA Surat CMA and Condamine Alluvium Groundwater Models and the NSMC uncertainty analysis is seen as a robust methodology for assessing the groundwater impacts of the Arrow current development plan, and importantly, provides technical consistency with the OGIA modelling as this has been used to support the development of the UWIR for the Surat CMA (QWC, 2012). The Arrow SREIS Groundwater Model was prepared by GHD and independently reviewed by CDM Smith.

7.1 Presentation of Cumulative Impacts

Since submission of the EIS, the OGIA developed an independent numerical groundwater model (OGIA Surat CMA Groundwater Model) in order to predict the cumulative impacts of all coal seam gas developments, and to provide a technical basis to support the UWIR. Assessing and modelling cumulative impacts and establishing integrated management arrangements are the legislated responsibility of the OGIA. The UWIR and OGIA Surat CMA Groundwater Model was approved and endorsed by the Chief Executive of EHP in December 2012, and the cumulative impact predictions are summarised in the UWIR (QWC, 2012).

Arrow are obligated to monitor groundwater aquifers and mitigate against cumulative impacts under the requirements and direction of the OGIA, for which existing modelling has already been undertaken.

Because the Arrow SREIS Groundwater Model is based on the OGIA Surat CMA Groundwater Model, but with the revised development plan which reduces footprint and groundwater production, cumulative impacts will be reduced compared with the OGIA modelling, upon which Arrow's statutory obligations have previously been determined in the UWIR. Nevertheless, cumulative impacts have been modelled for the current development plan in the Arrow SREIS Groundwater Model, and the results are presented in detail in Appendix D.

7.2 SREIS Modelled Scenarios

Four predictive scenarios have been simulated in the Arrow SREIS Groundwater Model:

1. **Non Coal Seam Gas Case** (Referred to as the 'Base Run' in the OGIA Surat CMA Groundwater Model). This scenario models non-P&G industry extraction only from 1995 onward;
2. **Base Case**. This scenario models current and proposed coal seam gas water extraction associated with the GLNG, QCLNG and APLNG Projects and other petroleum activities from 1995 onward. Arrow coal seam gas activities are excluded;

3. **Cumulative Case** (Referred to as the 'P&G Production Run' in the OGIA Surat CMA Groundwater Model). This scenario models all current and proposed water extraction from petroleum and gas activities from 1995 onwards. Extraction associated with the GLNG, QCLNG, APLNG and Arrow Surat Gas Projects are included in the this scenario, in addition to non-P&G extraction; and
4. **Substitution Case**. This scenario has been run to quantify net impacts on groundwater levels in the Condamine Alluvium with and without offset by 'virtual injection' via substitution (refer Section 7.6).

The **Arrow Only Case** was not modelled as a separate scenario. The impacts have been calculated by determining the difference between predicted groundwater levels and flows for the Base Case and those for the Cumulative Case.

Figure 7.1 shows the Arrow current development footprint and hydrograph locations which are centred on the proposed extraction blocks used to simulate groundwater extraction across the project development area over time.

7.3 Arrow SREIS Groundwater Model Set Up

The Arrow SREIS Groundwater Model is based on a replication of the OGIA Surat CMA Groundwater Model files. The only change to the OGIA Surat CMA Groundwater Model as part of the current modelling, is to the MODFLOW EVT input files (refer Section 7.3.2 below) which have been revised to incorporate Arrow's current (reduced) development case. In all other respects the model is identical to that described in the UWIR.

Groundwater level impacts in the Condamine Alluvium aquifer have been assessed by simulating modelled flux changes to the Condamine Alluvium Groundwater Model (calculated using the OGIA Surat CMA Groundwater Model) as described in Section 7.3.4. The input file for the Condamine Alluvium Groundwater Model has been revised, in order to assess the impacts of Arrow's current development plan. No other changes have been made to the Condamine Alluvium Groundwater Model. In all other respects the Condamine Alluvium Groundwater Model is identical to that described in the Surat CMA UWIR.

7.3.1 Benchmarking

Prior to using the OGIA Surat CMA Groundwater Model for the current study a series of checks were undertaken to confirm that it was possible to re-produce a selection of the previously reported model results and calculated impacts. This 'benchmarking' analysis is provided in Appendix D.

A comparison of cumulative modelled flow volumes for both the 'baseline' and 'cumulative impact' runs (that were provided by the OGIA, and reported in the UWIR (QWC, 2012)) was undertaken initially. Both of these runs were repeated using the input files provided to confirm that the same results could be independently generated on a different computing platform. As shown in Appendix D cumulative volumes are identical (to 4 decimal places) which confirmed that the model setup and hardware platform would produce effectively identical results.

As a further check of the accuracy of model output processing undertaken for the current study, Condamine Alluvium flux impacts for the maximum impact realisation were also recalculated (as shown in Appendix D) based on a re-run of the OGIA Surat CMA Groundwater Model files for comparison with Figure 5-100 in WaterMark (2012). The maximum impact realisation was selected for this test since output from this run was previously used to assess maximum impacts on the Condamine Alluvium. Visual comparison of the results of this analysis (refer Appendix D) confirmed that the predicted maximum impacts on the Condamine Alluvium have been successfully reproduced.

7.3.2 Simulated Water Production – Previous Models

Water production in the EIS was simulated using the MODFLOW WELL package. This package simulates the actual production wells, and water extraction rates are specified for the wells, based on water production volumes derived from the reservoir modelling under the original development proposal. In the Arrow EIS, it was predicted that a total of 694 GL of water would be produced.

The aim of coal seam gas water extraction in the OGIA Surat CMA Groundwater Model was to achieve a target aquifer pressure, rather than a specific water flow rate. To achieve this, coal seam gas water extractions were simulated using the MODFLOW EVT package, and increased until the target pressures were achieved. Utilising the EVT package to simulate production wells in this manner allows for head-dependent extraction rates, whereby production rates decline as pressure in the formation declines.

The apparent tendency for the OGIA Surat CMA Groundwater Model to over-predict total extraction was noted in the UWIR during the previous modelling work undertaken by the OGIA (QWC, 2012). This effect arises because the real-world effects of dual-phase flow (i.e. flow of both water and gas from a well) cannot be simulated precisely in numerical models such as MODFLOW (or other regional scale groundwater flow models) (QWC, 2012) and also because of simplification associated with up-scaling.

In addition to the above, the OGIA modelling excluded tenure in the vicinity of Goondiwindi which had already been relinquished at the time of development of the UWIR, and a total water production of 717 GL was modelled.

This over-simulation of total extraction volumes is considered to be conservative from an impact assessment point of view. The potential impacts of coal seam gas development, including the time taken for groundwater to recover to pre-development levels, will be related to the total volume of water extracted, which is likely to be over-predicted using the adopted approach.

Hence the potential impacts are likely to be lower than predicted by the OGIA Surat CMA Groundwater Model.

7.3.3 SREIS Simulated Water Production

Groundwater extraction from coal seam gas production in the Arrow SREIS Groundwater Model is also handled using the MODFLOW EVT package, consistent with the OGIA's approach. To achieve this, the OGIA EVT input files used have been revised to provide consistency with Arrow's current development plan, which has reduced extractions compared with the OGIA modelling.

Using the EVT package, the Arrow SREIS Groundwater Model simulates a water production volume of 702 GL with a peak extraction rate of 140 ML/d anticipated between 2021 and 2024. In this regard, it is emphasised that the purpose of the groundwater models is to predict drawdown impacts under depressurisation scenarios, but not to predict accurate water production.

Field development planning tools (based on reservoir modelling) for Arrow's current development plan have indicated that actual total water production expected for the duration of the Arrow Surat Gas Project will be approximately 510 GL.

As described in Section 7.3.3, the difference between the Arrow SREIS Groundwater Model and the Arrow reservoir modelling represents conservatism in the numerical groundwater modelling, consistent with the approach described above for the OGIA modelling. Actual impacts will be anticipated to be lower than modelled.

Table 7.1 provides a comparison between modelled water production in the Arrow SREIS Groundwater Model and previous models.

Table 7.1: Arrow Surat Gas Project modelled water production comparison

Model	**Arrow EIS Groundwater Model**	**OGIA Surat CMA Groundwater Model**	**Arrow current development plan**	
			Field Development Planning	**Arrow SREIS Groundwater Model**
Water production simulation method	MODFLOW Wells (MNW) package	MODFLOW EVT package	-	MODFLOW EVT package
Arrow water production (GL)	694	717*	510	702

*Note: Surat CMA UWIR did not include production from Goondiwindi Development Area, as Arrow had already provided a revised development plan.

7.3.4 SREIS Simulated Water Production – Condamine Alluvium

Groundwater drawdown in the Condamine Alluvium aquifer has been assessed by:

- Estimating the maximum predicted flux from the Condamine Alluvium to the underlying formations using the Arrow SREIS Groundwater Model; and
- Applying this flux to the Condamine Alluvium Groundwater Model to simulate the impact on groundwater levels in the Condamine Alluvium.

The primary advantage of this approach, which was previously adopted by the OGIA, is that the drawdown in the Condamine Alluvium is simulated on a more detailed, higher resolution modelling platform (i.e. the Condamine Alluvium Groundwater Model).

The above approach, using the Condamine Alluvium Groundwater Model, was also undertaken to simulate the ‘virtual injection’ of treated coal seam gas water via substitution of groundwater allocations from the Condamine Alluvium. Substitution has been proposed as a method to offset the Arrow component of the of modelled likely flux impacts to the Condamine Alluvium by supplying treated groundwater to existing Condamine Alluvium groundwater users for use in lieu of their current allocations.

The substitution area is to the west of Dalby, in an intensively developed location within the greater Condamine Alluvium. This area was selected because maximum coal seam gas related drawdowns are expected in this part of the Condamine Alluvium (refer Figures 7.2 and 7.7), and it has been assumed that sufficient existing entitlement holders would agree to substitution in order to offset Arrow’s proportion of the predicted flux impacts (63 GL) for the calibrated model.

Substitution arrangements would be in place for the period during which Arrow is able to supply treated water. This has been modelled to occur over a 25 year period from 2018 to 2043 (refer Appendix D) and the volumes that can be supplied are equal to approximately 2.5 GL/yr (or 6.9 ML/d).

The substitution scenario modelled assumed supply of water for substitution over a 25 year period. This was simulated by running the Condamine Alluvium Groundwater Model with the 50% abstraction scenario and reducing existing groundwater pumping over 25 years. The volume offset over the 25 year period was equal to component of modelled likely flux impacts to the Condamine Alluvium.

7.4 Arrow SREIS Groundwater Model Predictions - Arrow Only Case

This section summarises the predicted impacts of the Arrow Surat Gas project only. Model extraction rates for Arrow's current development plan, based on the calibrated model (i.e. best case) are shown on Figure 6.3b. Predictions indicate a peak extraction rate of around 140 ML/d is likely to occur between around 2021 to 2024 (Figure 6.3b).

The maximum predicted impact drawdowns, based on the calibrated model, in the main aquifers in the Surat CMA (i.e. Condamine Alluvium, Springbok Sandstone, Walloon Coal Measures and Hutton Sandstone) as a consequence of Arrow's current development plan alone are shown in Figures 7.2 to Figure 7.5. An additional 200 model simulations were undertaken as part of the uncertainty analysis and the outcomes can be found in Appendix D. Peak drawdown in the Precipice Sandstone is less than 0.7 m and of limited extent (GHD, 2013).

Predicted drawdown time series at the centre of each of the proposed extraction blocks i.e. the hydrograph locations shown in Figure 7.1, have also been extracted for the calibration case, and plots showing drawdowns at each location for the Springbok Sandstone, Walloon Coal Measures, Hutton Sandstone and the Precipice Sandstone are included in Appendix D. Reference to these plots indicates that time lags between extraction in the Walloon Coal Measures and impacts in the adjacent aquifers increase with separation. Hence peak impacts in the Springbok and Hutton Sandstones typically occur at 20 and 75 years respectively after peak impact in the Walloon Coal Measures. Drawdown impacts to the deeper Precipice Sandstone are very small, and occur much later in time.

Figure 7.2 shows the maximum predicted Arrow related drawdown in the Condamine Alluvium aquifer (calibrated model) and indicates drawdown of up to around 0.5 m in central parts of the Condamine Alluvium. However, this maximum drawdown is only evident in a small proportion (<10%) of the Condamine Alluvium, and drawdowns are typically less than 0.18 m across the remainder of the Condamine Alluvium.

Predicted flux changes to the Condamine Alluvium for the 5th percentile, calibration model, 95th percentile and maximum realisations are shown in Figure 7.6. The results indicate relatively minor impacts peaking at between 1.25 and 2.8 ML/d, representing only a small component (0.9% to 2%) of the simulated 140 ML/d peak extraction rate defined by Arrow's current development plan. The flux impact (under the calibrated model of the Arrow only case) to the Condamine Alluvium is 63 GL over the period referred to in the UWIR for the Surat CMA (QWC, 2012) i.e. the next 100 years. The total flux impact (under the maximum realisation) over the same period is 73 GL (Figure 7.6).

As described in Section 6, interlayer flux into the Condamine Alluvium comprises upward flow from the Walloon Coal Measures. Therefore flux changes resulting from coal seam gas water production cause a small reduction in the existing upward flux, which nevertheless remains upward from the Walloon Coal Measures to the Condamine Alluvium (GHD, 2012).

Interlayer fluxes between other stratigraphic units resulting from Arrow operations are presented in Appendix D.

7.4.1 Groundwater Pressure Recovery

Following the cessation of coal seam gas production, the degree of groundwater pressure recovery is different for each modelled aquifer. The rate of pressure recovery is influenced by aquifer and confining layer parameters, as well as the sequencing of coal seam gas production. Hydrographs for each drainage area are provided in Appendix D, and demonstrates that residual pressure loss will remain for extended periods in some formations, but at relatively low levels.

7.5 SREIS Groundwater Model Predictions - Cumulative Case

Total modelled water extraction from current coal seam gas projects to be operated by Arrow, Santos, QGC and Origin within the Surat CMA are shown in Figure 6.3b, and indicate a peak extraction of around 550 ML/d in 2015. Cumulative impacts have been calculated by subtracting predicted groundwater levels and flows for the Non Coal Seam Gas Case from the Cumulative Case (refer Section 7.2).

The maximum predicted drawdown based on the calibrated model case in the main aquifers in the Surat CMA (i.e. Condamine Alluvium, Springbok Sandstone, Walloon Coal Measures and Hutton Sandstone) as a consequence of cumulative impacts of coal seam gas projects are shown in Appendix D. An additional 200 runs were simulated as part of the uncertainty analysis and the outcomes can be found in Appendix D.

Predicted drawdown time-series at the centre of each of the proposed extraction blocks (i.e. the hydrograph locations shown in Figure 7.1) have also been extracted for the calibrated model, and hydrographs of drawdown at each location for the Springbok Sandstone, Walloon Coal Measures and the Hutton Sandstone are included in Appendix D. Peak impacts in the Springbok and Hutton Sandstones typically occur up to around 100 years after peak impact in the Walloon Coal Measures. (Drawdown impacts to the deeper Precipice Sandstone are smaller, and occur much later in time – refer Appendix D)

Figure 7.7 shows the maximum predicted cumulative impact in the Condamine Alluvium (calibrated model) and indicates drawdown of up to 0.9 m in the vicinity of DA8 near Dalby. Drawdown of less than 0.24 m is typical across the remainder of the Condamine Alluvium. Predicted cumulative drawdown in the Condamine Alluvium is therefore higher than that for the Arrow only case.

Cumulative predicted flux changes to the Condamine Alluvium for the 5^{th} percentile, calibration model, 95^{th} percentile and maximum realisations are provided in Appendix D. The results suggest relatively minor impacts peaking at between 1.8 and 3.8 ML/d (compared to the simulated 550 ML/d cumulative peak extraction rate).

The flux changes as a result of cumulative water extraction (i.e. all proponents) to the Condamine Alluvium is 79 GL over a 100 year modelled period for the calibrated model, and 101 GL over a 100 year period for the maximum impact realisation (Appendix D).

Interlayer fluxes between other stratigraphic units resulting from cumulative impacts are presented in Appendix D.

7.6 Condamine Alluvium – Substitution Offset Scenarios

Model simulations of the Condamine Alluvium Groundwater Model were undertaken to assess net impacts on the Condamine Alluvium with offsets by ‘virtual injection’ of treated coal seam gas water via substitution (refer Section 7.3.4) for both the Arrow and cumulative scenarios.

7.6.1 Arrow Impact to the Condamine Alluvium - with offset

Figure 7.8 shows predicted Arrow only related groundwater level impacts on the Condamine Alluvium (based on the calibration model) after the implementation of 'virtual injection' via substitution. This figure can be compared with the drawdown contours in Figure 7.2, which show the predicted impact without substitution.

Without substitution, predicted drawdowns in the area west of Dalby are up to 0.5 m (Figure 7.2), and predicted average drawdown over the Condamine Alluvium for the calibrated model is 0.18 m.

With substitution the results indicate:

- Average drawdowns over the Condamine Alluvium are reduced from 0.18 to 0.03 m (i.e. on average, predictions indicate a 0.03 m net decrease in Condamine Alluvium groundwater levels after offsetting).
- Minor net positive impacts in some areas.

Predicted Arrow only related drawdowns in the Condamine Alluvium with and without substitution are therefore below the 2 m trigger threshold specified in the Water Act for unconsolidated aquifers such at the Condamine Alluvium.

The Condamine Alluvium and its tributaries have been extensively developed for irrigation, industrial, stock and domestic purposes and are characterised by the over-development and over-allocation with respect to the productive yield of the system (DNRM, 2012a). The effects of groundwater extraction are shown on Figure 7.9, which provides a comparison between the pre-development potentiometric surface (1969) and the groundwater surface in 2008. The figure shows the development of a groundwater depression centred to the north-east where recorded drawdowns are in excess of 20 m.

Since 1970, the cumulative impact on this resource was recognised and further access to Condamine Alluvium groundwater systems was limited. A moratorium to limit development of groundwater in this area was published in June 2008 for the Alluvium and the Basalts in the Upper Condamine Catchment. This moratorium was recently amended to further restrict new take of groundwater in the system (DNRM, 2012a).

Current estimates of water extraction from the Condamine Alluvium by non-coal seam gas stakeholders is approximately 55 GL/yr (QWC, 2012). According to DNRM (2012a) this is 40.4 GL more than the sustainable level of the groundwater system, and hence it is therefore likely that additional drawdown as a result of non-coal seam gas extraction will occur.

The predicted Arrow flux impact to the Condamine Alluvium is 63 GL over 100 years (GHD, 2013) and a groundwater level drawdown of up to 0.5 m (average of 0.18 m).

To offset this flux change (and associated groundwater level drawdown) Arrow propose to substitute groundwater allocations to the west of Dalby, in the area of maximum predicted drawdown as a result of coal seam gas activities. This area constitutes a small portion of the entire Condamine Alluvium. The proposed substitution scenario assumes that Arrow will supply water for substitution over a 25 year period and therefore the volumes that can be supplied are equal to approximately 2.5 GL/yr (or 6.9 ML/d). Modelling has demonstrated that substitution:

- Reduced average drawdown by 0.15 m over this period.
- Is sufficient to offset Arrow's component of flux changes to the Condamine Alluvium.

The flux changes to, and associated drawdown in, the Condamine Alluvium are relatively small when compared to the observed groundwater drawdown attributable to non-coal seam gas extraction. It is therefore clear that substitution could not be used to offset non-coal seam gas related drawdown impacts to the Condamine Alluvium.

7.6.2 Cumulative Impacts to the Condamine Alluvium - with offset

Figure 7.10 shows predicted cumulative project related groundwater level impacts on the Condamine Alluvium (based on the calibration model) after the implementation of 'virtual injection' via substitution. This figure can be compared with the drawdown contours in Figure 7.7, which show the predicted impact without substitution.

Without substitution, predicted drawdowns in the area west of Dalby are up to 0.9 m (Figure 7.7), and predicted average drawdown over the Condamine Alluvium for the calibrated model is 0.24 m.

With substitution the results indicate:

- Groundwater level increase of up to 0.2 m in the modelled substitution area (Figure 7.10).
- Average drawdowns over the Condamine Alluvium are reduced from 0.24 to 0.09 m (i.e. on average predictions indicate a 0.09 m net decrease in Condamine Alluvium groundwater levels after offsetting).
- Net positive impacts in some areas.

Predicted cumulative case drawdowns with and without 'virtual injection' of Arrow's component of the modelled flux from the Condamine Alluvium via substitution are therefore below the 2 m trigger threshold specified in the Water Act for unconsolidated aquifers such at the Condamine Alluvium.

7.7 Comparison with the Impacts Predicted in the EIS

Based on the groundwater impacts predicted from the Arrow SREIS Groundwater Model, it is demonstrated that the groundwater impacts identified in the Arrow EIS have not been understated.

Some differences in the spatial and temporal distribution of groundwater drawdown impacts in both the EIS and SREIS are observed. This is expected, due to:

- The different water production plans and project phasings (i.e. drainage areas as opposed to development regions) modelled.
- Differences in modelled geology.
- Differences in adopted aquifer parameters.
- Different water production modelling approaches.
- Availability of additional (more recent) calibration data.

A comparison of groundwater drawdown impacts predicted to arise as a result of Arrow's current development plan proposed in the EIS and the revised case presented in the SREIS is presented below.

7.7.1 Comparison of Arrow Only Predicted Impacts

Table 7.2 provides a summary of the predicted maximum drawdown impacts in the key aquifers for the Arrow only scenarios, based on the calibrated model, and a discussion of the differences is presented below.

Table 7.2: Modelled Arrow only drawdown comparison - EIS and SREIS

Key Aquifers	EIS			SREIS		
	Average Drawdown (m)	Maximum Drawdown (m)	[1]Time of Maximum Drawdown	Average Drawdown (m)	Maximum Drawdown (m)	[2]Time of Maximum Drawdown
Condamine Alluvium	<0.5	1	48	0.18	0.5	105
Springbok Sandstone	<5	30	13	<2	10	50
Walloon Coal Measures	<2	75	13	<50	350	30
Hutton Sandstone	<10	30	16	<5	8	105
Precipice Sandstone	<5	15	31	-	0.7	110

1) Time of maximum drawdown in years from commencement of project development

2) Time of maximum drawdown in years from 1995.

Condamine Alluvium (Shallow Groundwater System)

EIS - Modelled Arrow only drawdown predictions for the Condamine Alluvium (without offset) peaks at just over 1 m. The greatest drawdown was indicated to occur around 2059 in the vicinity of the Dalby area, along the western extent of the Condamine Alluvium.

SREIS - Modelled Arrow only drawdown in the Condamine Alluvium (without offset) peaks at 0.5 m and averages 0.18 m (in the calibrated model). The greatest drawdown was predicted to occur at around 2100 in the vicinity of the Dalby area (drainage areas DA7 and DA8), along the western extent of the Condamine Alluvium (Figure 7.2 and Appendix D).

Springbok Sandstone (Intermediate Groundwater System)

EIS - Modelled Arrow only drawdown predictions for the Springbok Sandstone aquifer is 30 m. The greatest drawdown was indicated to occur around 2024 in the vicinity of the Dalby area.

SREIS - Modelled Arrow only drawdown predictions for the Springbok Sandstone is expected to be less than 10 m, with maximum impact to the west of Dalby in 2045, and a reduced impact in the area west of Cecil Plains in 2075 (Figure 7.3 and Appendix D).

Walloon Coal Measures (Coal Seam Gas Groundwater System)

EIS - Modelled Arrow only drawdown predictions for the Walloon Coal Measures indicates a peak around 2024 at a value in excess of 75 m.

SREIS - Modelled Arrow only drawdown predictions for the Walloon Coal Measures is indicated to be less than 50 m in most areas. In the more central-westerly areas, where the coal seam formation is relatively deep, the impacts are expected to be up to 350 m with maximum impact to the west of Cecil Plains in 2025 (Figure 7.4 and Appendix D).

Hutton and Precipice Sandstones (Deep Groundwater System)

EIS - Modelled Arrow only drawdown predictions for the Hutton Sandstone and Precipice Sandstone is 30 m and 20 m respectively. By 2062 drawdown is predicted to reduce to approximately 15 m in both formations.

SREIS - Modelled Arrow only drawdown predictions for the Hutton Sandstone is indicated to reach 8 m with maximum impact between Dalby and Cecil Plains in 2100 (Figure 7.5 and Appendix D).

Maximum impact in the Precipice Sandstone is expected to be less than 0.7 m in drainage area DA5 southwest of Chinchilla in 2105, with impacts generally less than 0.3 m in other areas, but extended for longer periods of time.

7.8 Condamine Alluvium Interlayer Flux

The interlayer flux estimates to the Condamine Alluvium due to Arrow operations only, and cumulative coal seam gas operations are provided in Table 7.3 to enable comparison between the OGIA Surat CMA and Arrow SREIS Groundwater Models.

The interlayer fluxes determined are the average estimated flux changes to the Condamine Alluvium based on a time period of 100 years from the commencement of production.

Table 7.3: Predicted Condamine Alluvium interlayer flux estimates

	Time period	Arrow Only Case (GL)		[2]Cumulative Case (GL)	
		Calibrated Model	Maximum Case	Calibrated Model	Maximum Case
[1]OGIA Surat CMA Groundwater Model	100 years	n/a	n/a	84	110
Arrow SREIS Groundwater Model	100 years	63	73	79	101

1) Arrow only impact not determined by OGIA
2) Includes Arrow, Santos, QGC and Origin Energy operations

The comparison shows that the cumulative interlayer flux impact to the Condamine Alluvium predicted by the Arrow SREIS Groundwater Model (for the current development plan) is lower than that predicted by the OGIA Surat CMA Groundwater Models.

As described in Section 6, interlayer flux into the Condamine Alluvium comprises net upward flow from the Walloon Coal Measures. Therefore flux changes resulting from coal seam gas water production cause a small reduction in the existing upward flux, which nevertheless remains net upward from the Walloon Coal Measures to the Condamine Alluvium (GHD, 2013). In addition, some locations show positive flux changes resulting from substitution (i.e. an increased upward flux into the Condamine Alluvium). However where this occurred, the positive fluxes were reset to zero, thereby providing an additional level of conservatism, when simulating drawdown impacts in the Condamine Alluvium Groundwater Model (GHD, 2013).

Net interlayer fluxes between other stratigraphic units resulting from Arrow impacts are presented in Appendix D.

7.9 Summary

Based on the assessment of the Arrow SREIS groundwater modelling results, and comparisons with the OGIA Surat CMA Groundwater Model and the Arrow EIS Groundwater Model, the following is summarised:

7.9.1 Summary of Impacts to the Condamine Alluvium

The cumulative interlayer flux is lower than that predicted in the UWIR (QWC, 2012).

The maximum Arrow only drawdown in the Condamine Alluvium simulated by the Arrow SREIS Groundwater Model is 0.5 m, representing a significant reduction from the EIS case (just over 1 m). Under offsetting scenarios, groundwater level increases of up to 0.2 m in the modelled substitution area are indicated.

The maximum cumulative drawdown in the Condamine Alluvium is 0.9 m, representing a significant reduction from the EIS case (2.5 m). Under offsetting scenarios, groundwater level increases of up to 0.2 m in the modelled substitution area are indicated.

7.9.2 Impacts to the GAB Aquifers

Unmitigated impacts for the Springbok Sandstone, Hutton Sandstone and Precipice Sandstone aquifers simulated by the Arrow SREIS Groundwater Model are lower than predicted by the Arrow EIS Groundwater Model. Modelled unmitigated drawdown for the Walloon Coal Measures is indicated to be less than 50 m in most areas, however in the more central-westerly areas (drainage area DA11, between Cecil Plains and Tara, where the coal seam formation is relatively deep) the impacts are expected to be up to 350 m. Drawdown impacts are indicated to occur later for the GAB aquifers than as modelled in the EIS.

7.10 Model Review

The Arrow SREIS Groundwater Model was independently reviewed by CDM Smith, a specialist company with professional expertise in the development of numerical groundwater models.

7.11 Conclusions

Based on the Arrow SREIS Groundwater Model predictions made for groundwater depressurisation impacts for the Arrow only and cumulative cases, it is concluded that:

- The modelling provides a robust assessment of groundwater impacts to the Condamine Alluvium and GAB aquifers;
- The previous modelling that supported the EIS impact assessment did not understate the overall impacts to the Condamine Alluvium and GAB aquifers;

- The Arrow only and cumulative impacts under the Arrow current development plan will be lower than previously modelled by OGIA, and
- The modelling approach and input parameters are considered to be conservative.

8 EIS IMPACT ASSESSMENT – REVIEW AND UPDATE

The impact assessment method adopted for the groundwater technical study prepared for the EIS is also adopted in this section. The method used for the supplementary groundwater assessment is as follows:

- Confirm that the impacts identified in the EIS remain relevant.
- Identify any new impacts, or impacts that no longer apply to the project.
- Determine those impacts requiring re-assessment of their significance.
- Confirm that the pre-mitigation magnitudes of impact applied during the EIS remain appropriate in light of the information presented in Section 2 (changes to the project description), Section 5 (updates to the understanding of the existing environment), and Section 7 (results of the revised numerical groundwater modelling predictions).
- Develop new mitigation and management measures where required.
- Revise or delete any mitigation and management measures developed during the EIS that are no longer appropriate.
- For new or changed mitigation and management measures or impacts, determine the residual magnitude of impact following application of the mitigation and management measures.

The following sections review the potential project impacts, environmental values, magnitude of impact and the significance of re-assessed impacts both pre and post-mitigation measure implementation.

8.1 Assessment of Potential Impacts

This section provides a review of the potential impacts to groundwater systems identified in the EIS, and determines whether they remain relevant to this supplementary groundwater assessment. In addition, any new impacts, or impacts that are no longer relevant, have been identified.

Once the potential impacts were confirmed as still being relevant to the supplementary assessment, a determination was made regarding the need to revisit the magnitude rankings applied as part of the EIS. Re-assessment of the magnitude ranking is triggered by one or more of the following:

- Changes to the project description, specifically Arrow's revised current development plan (refer Section 2) that could result in a varied impact profile by way of location (spatial extent) or timeframe with the potential requirement for new mitigation measures to be implemented in order to manage these impacts.
- Additional sources of information reviewed (refer Sections 4 and 5) that provide updates to the understanding of the existing environment and definition of environmental values and associated sensitivity rankings.

The results of this process are presented in Tables 8.1 to 8.3. Further discussion on the magnitude of these potential impacts is provided in Section 8.3.

8.1.1 Depressurisation Impacts

Depressurisation of the Walloon Coal Measures required for coal seam gas extraction may result in direct and indirect impacts. Direct impacts will result in potentiometric surface drawdown in the Walloon Coal Measures. Indirect impacts to aquifers above and below the Walloon Coal Measures from coal seam gas aquifer depressurisation may occur as a result of the direct impact (potentiometric surface drawdown in the Walloon Coal Measures).

Table 8.1 presents the potential impacts that may arise from depressurisation of the Walloon Coal Measures and identifies those that have been triggered for re-assessment.

Table 8.1: Potential impacts from depressurisation of the Walloon Coal Measures

Activity / impact	Changes since EIS	Potentially affected groundwater systems	Trigger for review of EIS assessment
Direct Impacts			
Potentiometric surface drawdown resulting in reduced supply to existing or future groundwater users.	Drawdown profile has changed in response to Arrow's revised development plan.	Coal Seam Gas groundwater system	Re-assessment completed due to revised project description and updated groundwater model predictions.
Potentiometric surface drawdown resulting in reduced supply to GDEs fed by the Walloon Coal Measures.	Additional information available on location and attributes of GDEs.		Re-assessment completed due to revised project description, updated groundwater model predictions and additional information on GDEs.
Indirect Impacts			
Groundwater flux between adjacent aquifers above and below the Walloon Coal Measures causing groundwater quality impacts.	Change in groundwater flux impact.	Shallow, Intermediate and Deep groundwater systems. (Coal Seam Gas groundwater system impacts identified as direct impacts).	Re-assessment completed due to revised project description and updated groundwater model predictions.
Potentiometric surface drawdown in adjacent aquifers causing reduced supply to existing or future groundwater users.	Drawdown profile has changed in response to Arrow's revised development plan.		Re-assessment completed due to revised project description and updated groundwater model predictions.

Table 8.1: Potential impacts from depressurisation of the Walloon Coal Measures (cont'd)

Activity / impact	Changes since EIS	Potentially affected groundwater systems	Trigger for review of EIS assessment
Indirect Impacts (cont'd)			
Potentiometric surface drawdown in adjacent aquifers causing reduced groundwater availability for GDEs.	Additional information available on location and attributes of GDEs.	Shallow, Intermediate and Deep groundwater systems. (Coal Seam Gas groundwater system impacts identified as direct impacts).	Re-assessment completed due to updated groundwater model predictions and additional information on GDEs.
Potentiometric surface drawdown in adjacent aquifers causing impacts to cultural/spiritual values.	Drawdown profile has changed in response to Arrow's revised development plan.		No re-assessment required. Spiritual and cultural values will be protected through the implementation of the Cultural Heritage Management Plan (CHMP) prepared for the project.
Potentiometric surface drawdown in adjacent aquifers due to leakage through coal seam gas wells (well failure) causing groundwater quality impacts from inter-aquifer flows.	Change in groundwater flux impact.		Re-assessment completed due to revised project description and additional information on groundwater quality.

Table 8.1: Potential impacts from depressurisation of the Walloon Coal Measures (cont'd)

Activity / impact	Changes since EIS	Potentially affected groundwater systems	Trigger for review of EIS assessment
Indirect Impacts (cont'd)			
Induced flow (leakage) between adjacent aquifers above and below the Walloon Coal Measures causing physical changes to aquifer structure leading to subsidence.	Additional information is available on baseline conditions and the mechanisms for coal seam gas extraction to result in subsidence.	Subsidence at ground surface has the potential to impact on surface water values (primarily hydrology). These impacts are discussed in Chapter 9 of the SREIS and the supporting supplementary geomorphology and hydrology surface water assessment (Appendix 5 of the SREIS). Loss of structural integrity may affect all groundwater systems where significant pressure reduction occurs.	Assessment completed based on the availability of new information, specifically the Altamira baseline assessment (Altamira, 2012).

8.1.2 Coal seam gas field development and operations impacts

Field development activities that have the potential to impact on environmental values include both wellfield and infrastructure development. The potential impacts associated with field development and operations are presented in Table 8.2, including where impacts are considered to have changed from the EIS and those that are triggered for re-assessment.

Table 8.2: Potential impacts from coal seam gas field development

Activity / impact	Changes since EIS	Potentially affected groundwater systems	Trigger for review of EIS assessment
Wellfield Development and Sub-surface Impacts			
Production well installation – cross-contamination of aquifers.	Reduced number of wells to be installed.	Shallow, Intermediate and Coal Seam Gas Groundwater Systems. (Deep Groundwater System is excluded based on depth and that this groundwater system will not be intersected by coal seam gas production wells).	No re-assessment required. Revisions to the project description have not resulted in changes to drilling techniques or methods used to install, maintain and monitor subsurface equipment.
Production well installation – contamination by drilling process.			
Production well installation – contamination by surface process.			
Monitoring bore installation – cross-contamination of aquifers.	Reduced number of wells to be installed.	All groundwater systems. Monitoring wells will potentially intersect all groundwater systems.	No re-assessment required. Revisions to the project description have not resulted in changes to drilling techniques or methods used to install, maintain and monitor subsurface equipment.
Monitoring installation – contamination by drilling process.			
Monitoring bore installation – contamination by surface process.			
Installation of sub-surface infrastructure – contamination from leaks and spills.	No change.	All groundwater systems.	No re-assessment required. Revisions to the project description have not resulted in changes the methods of fuel and chemical storage, handing and disposal.

Table 8.2: Potential impacts from coal seam gas field development (cont'd)

Activity / impact	Changes since EIS	Potentially affected groundwater systems	Trigger for review of EIS assessment
Water Storage, Infrastructure, Processing and Distribution Impacts			
Storage of chemicals, fuels, oils – contamination of groundwater systems.	No change.	Shallow, Intermediate and Coal Seam Gas Groundwater Systems. (Deep Groundwater System is excluded based on depth and isolation from these surface processes.)	No re-assessment required. Revisions to the project description have not resulted in changes the methods of fuel and chemical storage, handling and disposal.
Waste generation and storage (including brine) – contamination of groundwater systems.	Reduced number of water treatment facilities and reduced water production forecast.		No re-assessment required. Revisions to the project description have not resulted in changes the methods of waste storage and handling.
Waste water and sanitation (effluent) – contamination of groundwater systems.	No change.		

Table 8.2: Potential impacts from coal seam gas field development (cont'd)

Activity / impact	Changes since EIS	Potentially affected groundwater systems	Trigger for review of EIS assessment
Infrastructure Footprint Impacts			
Reduced aquifer recharge due to placement of impervious surface coverings.	Overall project area decreased by around 30%. The number of facility locations has reduced.	Shallow, Intermediate and Coal Seam Gas Groundwater Systems. (Deep Groundwater System is excluded based on depth and isolation from these surface processes.)	No re-assessment required. Whilst the areas of sub-block relinquishment do not contain facilities, the number of facilities has also reduced. However the overall proportion of impervious surface coverings within the entire project development area remains small, and the impact is unchanged.
General impacts associated with installation of gas reticulation facilities and compressor stations.	Reduced number of production facilities.		

8.1.3 Coal seam gas water impacts

The potential impacts resulting from the management of coal seam gas water are presented in Table 8.3, including where impacts are considered to have changed from the EIS, and those that are triggered for re-assessment.

Table 8.3: Potential impacts from coal seam gas water

Activity / impact	Changes since EIS	Potentially affected groundwater systems	Trigger for review of EIS assessment
Impact to shallow groundwater systems caused by seepage of untreated coal seam gas water from storage facilities.	Reduced number of water storage facilities however peak and total volumes of water produced remain comparable.	Shallow Groundwater System. (Intermediate, Coal Seam Gas and Deep Groundwater Systems are excluded based on depth and isolation from these surface processes.)	No re-assessment required. Revisions to the project description have not resulted in changes to the methods used to store coal seam gas water. In addition, the controls adopted to control spills or leaks have not changed.
Altered groundwater flow direction caused by seepage from coal seam gas water storage facilities.			
Impact to shallow groundwater caused by seepage of brine from storage facilities.			
Unplanned discharge of untreated coal seam gas water to the land surface.			
Unplanned discharge of untreated water or brine to the land surface.			
Infrastructure for distribution of water, including substitution.	Additional infrastructure required. No new impacts as potential impacts from distribution network are assessed under potential impacts from coal seam gas field development.	Shallow, Intermediate and Coal Seam Gas Groundwater Systems. (Deep Groundwater System is excluded based on depth and isolation from these surface processes).	

8.2 Environmental Values

Section 5 of the groundwater impact assessment report prepared for the EIS identified the groundwater environmental values of the project development area. The identified values remain relevant for the supplementary groundwater assessment.

The sensitivity of the environmental values to impacts resulting from project activities was determined by assessing their intrinsic characteristics, or susceptibility to threatening processes.

The sensitivity ranking assigned to each groundwater system represents an overall ranking for all aquifers associated with the particular system. The process for assigning an overall sensitivity ranking to groundwater systems involved an assessment of the intrinsic properties and hydrogeological processes that contributed to the value of each system against defined criteria for conservation status (biological value, consumptive and productive use, cultural and spiritual value), rarity, resilience, dynamics and rehabilitation potential.

The sensitivity of groundwater environmental values is presented in Section 9.2 of the groundwater impact assessment report prepared for the EIS and the overall sensitivity rankings remain unchanged for this supplementary groundwater assessment. This is because the sensitivity of the environmental value is independent of project activities. Some revisions to individual components that make up the overall sensitivity ranking score have been made based on new information (e.g. spring source aquifers and identification of EPBC/NC Act species and communities at some springs).

The changes are presented in Table 8.4 as well as justification for the change. As shown in Table 8.4, the changes do not impact the overall sensitivity classification for the groundwater systems.

Table 8.4: Summary of revised groundwater sensitivity classification

Groundwater System	EIS Sensitivity Ranking Score	EIS Sensitivity Classification	SREIS Sensitivity Ranking Score	SREIS Sensitivity Classification	Justification for change
Shallow Groundwater System	20	Moderate	No change.		
Intermediate Groundwater System	18	Moderate	19	Moderate	Biological conservation status assessment revised from 3 (moderate) to 4 (high) to account for the Gubberamunda Sandstone being nominated as spring source aquifer. No springs with source aquifer of the Gubberamunda Sandstone are listed as having EPBC species/communities present. All other sensitivity criteria scores remain unchanged from EIS.
Coal Seam Gas Groundwater System	15	Low	No change		
Deep Groundwater System	24	High	25	High	Biological conservation status assessment revised from 4 (high) to 5 (very high) to account for the deep groundwater system aquifers being nominated as spring source aquifers, where EPBC listed species/communities have been identified at those spring locations. All other sensitivity criteria scores remain unchanged from EIS.

Groundwater system sensitivity ranking score classification: Very Low = <10; Low = 10-15; Moderate = 16-20; High = 21-25; Very High = >25

8.3 Magnitude of Arrow-only Impacts – Pre-mitigation and management

An assessment of the magnitude of impact resulting from project activities was made in the EIS based on the Arrow EIS Groundwater Model predictions of drawdown and the original project description. Section 7.7 presents a comparison of the degree of groundwater drawdown impact between the EIS and the SREIS under the Arrow-only modelling scenarios.

For the purpose of the spring impact assessment, a 10 km buffer zone was applied beyond the extent of the predicted 0.2 m drawdown contour to aquifer systems other than the Condamine Alluvium (refer Figures 8.1 and 8.2). This was done provide additional conservatism in the modelling predictions for the identification of potentially affected spring vents and watercourse springs, and is consistent with the approach adopted by OGIA in the Surat CMA UWIR (QWC, 2012). The buffer zone was limited to the extent of the aquifer where the buffer zone exceeded the extent of the aquifer.

Predicted impacts to the entire Condamine Alluvium have been presented therefore no buffer zone was applied.

The assessment of impact magnitude for the SREIS has been undertaken by taking into consideration the severity, duration and geographical extent of the potential impact based on the predictions from the Arrow SREIS Groundwater Model under the calibration realisation.

Table 8.5 presents the magnitude of impact, prior to the application of mitigation measures for both the EIS and SREIS. Where a change in impact magnitude from the EIS occurs, justification for the change is also provided.

Table 8.5: Magnitude of Arrow-only Impacts – Pre-mitigation and management

Impact	Groundwater system	Sensitivity	Magnitude of impact		Justification
			EIS assessment	SREIS assessment	
Direct Impacts					
Potentiometric surface drawdown resulting in reduced supply to existing or future groundwater users.	Coal Seam Gas Groundwater System	Low	Very High	Very High	Modelling predicts maximum drawdown of 350 m in the Walloon Coal Measures at around 2030, and an average drawdown of <50 m. The maximum drawdown is centred on DA11, and the extent of 5 m drawdown extends beyond the project development area boundary. Where the greatest drawdown impact is predicted (DA11), impact drawdown is expected to recover by 50% within 30 years of peak drawdown being observed, and 80% recovery within around 60 years. The impact magnitude is considered to be very high with respect to severity, extent and duration, consistent with the EIS assessment.
Potentiometric surface drawdown resulting in reduced supply to GDEs fed by the Walloon Coal Measures.	Coal Seam Gas Groundwater System	Low	Moderate	Very Low	No springs are identified as having the Walloon Coal Measures as their source aquifer. The Walloon Coal Measures do not outcrop within the predicted extent of 0.2 m drawdown. There are some areas within the 10 km buffer zone beyond the 0.2 m drawdown boundary where the Walloon Coal Measures outcrop, however in these areas there are no mapped potential GDEs. Elsewhere there is no impact predicted in regions where the Walloon Coal Measures outcrop and may support GDEs as a watertable aquifer.

Table 8.5: Magnitude of Arrow-only Impacts – Pre-mitigation and management

Impact	Groundwater system	Sensitivity	Magnitude of impact		Justification
			EIS assessment	SREIS assessment	
Direct Impacts					
Potentiometric surface drawdown resulting in reduced supply to GDEs fed by the Walloon Coal Measures. (cont'd)	Coal Seam Gas Groundwater System	Low	Moderate	Very Low	Therefore severity, duration and extent of impact is very low. The assessment of magnitude has changed from EIS due to additional information available on spring source aquifers. The EIS conservatively assumed the Coal Seam Gas groundwater system supported springs, however currently available information indicates it does not support known springs.
Indirect Impacts					
Groundwater flux between adjacent aquifers above and below the Walloon Coal Measures causing groundwater quality impacts.	Shallow Groundwater System	Moderate	High[1]	Low	Although the modelling does not directly predict changes to water quality, such impacts will not be significant because any inter-aquifer flows caused by the extraction of poorer quality water from the Walloon Coal Measures will not involve flow of poor quality water into better quality aquifers. Modelling indicates that pre-coal seam gas inter-layer fluxes within the Surat CMA are predominantly upwards (GHD, 2013), including from the Walloon Coal Measures to the Condamine Alluvium (QWC, 2012; GHD, 2013). Depressurisation of the Walloon Coal Measures would reduce this flux to aquifers above the Walloon Coal Measures and increase flux to the Walloon Coal Measures from underlying aquifers. This will act to reduce the potential for contamination of over or underlying aquifers from poorer quality water of the Walloon Coal Measures.
	Intermediate Groundwater System	Moderate	High[1]	Low	
	Deep Groundwater System	High	High[1]	Low	

Table 8.5: Magnitude of Arrow-only Impacts – Pre-mitigation and management

Impact	Groundwater system	Sensitivity	Magnitude of impact		Justification
			EIS assessment	SREIS assessment	
Indirect Impacts (cont'd)					
Potentiometric surface drawdown in adjacent aquifers causing reduced supply to existing or future groundwater users.	Shallow Groundwater System	Moderate	High	Moderate	Modelling predicts a maximum drawdown in the Condamine Alluvium of 0.5 m with an average across the whole of the Condamine Alluvium of 0.18 m. Drawdown is predicted across the Condamine Alluvium (refer Figure 7.2), and extends beyond the project development area. Modelling predicts maximum drawdown in the Condamine Alluvium to occur at around 2100 in the vicinity of the Dalby area (drainage areas DA7 and DA8), along the western extent of the Condamine Alluvium (Figure 7.2). The shallow aquifer system including the Condamine Alluvium is dynamic with several recharge mechanisms and is expected to recover when groundwater extraction associated with coal seam gas activities is removed. The severity of impact is low, however impact duration and extent trigger a moderate classification of magnitude. The assessment of impact magnitude has been revised from EIS based on reduced severity of maximum predicted drawdown.

Table 8.5: Magnitude of Arrow-only Impacts – Pre-mitigation and management

Impact	Groundwater system	Sensitivity	Magnitude of impact		Justification
			EIS assessment	SREIS assessment	
Indirect Impacts (cont'd)					
Potentiometric surface drawdown in adjacent aquifers causing reduced supply to existing or future groundwater users. (cont'd)	Intermediate Groundwater System	Moderate	High	High	Modelling predicts a maximum drawdown in the Springbok Sandstone of 10 m with an average drawdown of <2 m. The extent of drawdown impact is centred on DAs 7, 8 and 11. Drawdown impact extends beyond the project development area, mainly to the west (refer Figure 7.3). There is minimal drawdown (<1 m) predicted in the overlying Gubberamunda Sandstone, or Mooga and Bungil Units, and this is restricted to a small area as presented in Appendix D. Where maximum drawdown is observed water levels in the Springbok Sandstone recover to around 50% of maximum drawdown after around 50 to 250 years, depending on the specific location. The magnitude of impact is therefore considered to be high, consistent with the EIS assessment. Modelling predicts the following drawdown in the deep groundwater system: • Maximum of 8 m and average of <5 m in the Hutton Sandstone. • Maximum of 0.7 m in the Precipice Sandstone. The severity of impact to the Precipice Sandstone aquifer is low in comparison with the EIS results, however significant water extraction by existing users occurs from the Hutton Sandstone and a maximum drawdown of 8 m may impact existing or future groundwater users. The extent of drawdown is centred on DAs 8 and 9, extending beyond the project development area to the east and west (refer Figure 7.5).

Table 8.5: Magnitude of Arrow-only Impacts – Pre-mitigation and management

Impact	Groundwater system	Sensitivity	Magnitude of impact		Justification
			EIS assessment	SREIS assessment	
Indirect Impacts (cont'd)					
Potentiometric surface drawdown in adjacent aquifers causing reduced supply to existing or future groundwater users. (cont'd)	Deep Groundwater System	High	High	High	Where maximum drawdown is observed water levels in the Hutton Sandstone recover to around 50% of maximum drawdown after around 300 to 400 years, depending on the specific location. The magnitude of impact is therefore considered to be high, consistent with the EIS assessment.
Potentiometric surface drawdown in adjacent aquifers causing reduced groundwater availability for GDEs.	Shallow Groundwater System	Moderate	Very Low	Moderate	Modelling predicts maximum drawdown in the Condamine Alluvium of 0.5 m with an average drawdown of 0.18 m. A single spring complex is located within the region of predicted Condamine Alluvium drawdown (Spring Complex 585). This is a non-GAB recharge spring, no EPBC listed species or communities have been identified at the spring complex location. As described in Section 5.3.2, the spring complex is associated with local flow systems, on the boundary of the Main Range Volcanics and Condamine Alluvium. The maximum drawdown predicted in the Condamine Alluvium at the spring location as a result of Arrow-only impacts is 0.3 m, which is above the spring trigger threshold. There is a general absence of mapped potential GDEs within area of the Condamine Alluvium. Where the Condamine River is likely to receive groundwater baseflow south of Chinchilla (refer Figure 5.2) the Condamine Alluvium has a predicted drawdown of <0.1 m.

Table 8.5: Magnitude of Arrow-only Impacts – Pre-mitigation and management

Impact	Groundwater system	Sensitivity	Magnitude of impact		Justification
			EIS assessment	SREIS assessment	
Indirect Impacts (cont'd)					
Potentiometric surface drawdown in adjacent aquifers causing reduced groundwater availability for GDEs. (cont'd)	Shallow Groundwater System (cont'd)	Moderate	Very Low	Moderate	Also in the Condamine Alluvium some ecosystems potentially dependent on the subsurface presence of groundwater coincide with regions of predicted drawdown, however depth to water information suggests that groundwater is typically beyond the rooting depth of plants therefore will be unaffected by drawdown in the Condamine Alluvium. At the margins of the Condamine Alluvium where depth to the watertable may be shallower and there may be ecosystems dependent on the subsurface presence of groundwater, in particular in the northern parts, the predicted drawdown is <0.2 m. Away from the Condamine Alluvium where significant areas of potential GDEs have been identified, deeper units outcrop and the discussion on the potential for impacts to GDEs from these systems is provided below.

Table 8.5: Magnitude of Arrow-only Impacts – Pre-mitigation and management

Impact	Groundwater system	Sensitivity	Magnitude of impact		Justification
			EIS assessment	SREIS assessment	
Indirect Impacts (cont'd)					
Potentiometric surface drawdown in adjacent aquifers causing reduced groundwater availability for GDEs. (cont'd)	Shallow Groundwater System (cont'd)	Moderate	Very Low	Moderate	Spring Complex 584 is located to the west of the project development area beyond the predicted area of impact. The source aquifer has been defined by OGIA as Quaternary sediments or shallow Orallo Formation. The assessment of no impact in the spring source aquifer at this location is also consistent with OGIAs assessment (QWC, 2012). Based on this information, the magnitude of impact is considered to be moderate. This assessment has changed from the EIS due to the potential impact at Spring Complex 585 that may exceed the spring trigger threshold.
Potentiometric surface drawdown in adjacent aquifers causing reduced groundwater availability for GDEs. (cont'd)	Intermediate Groundwater System	Moderate	Low	Moderate	Modelling predicts maximum drawdown in the intermediate groundwater system of 10 m (Springbok Sandstone). No springs with a source aquifer from the intermediate groundwater system (Gubberamunda and Springbok Sandstone) are located within predicted area of 0.2 m drawdown or 10 km buffer zone (refer Figure 8.1).

Table 8.5: Magnitude of Arrow-only Impacts – Pre-mitigation and management

Impact	Groundwater system	Sensitivity	Magnitude of impact		Justification
			EIS assessment	SREIS assessment	
Indirect Impacts (cont'd)					
Potentiometric surface drawdown in adjacent aquifers causing reduced groundwater availability for GDEs. (cont'd)	Intermediate Groundwater System (cont'd)	Moderate	Low	Moderate	A single watercourse spring (site W160) is located at the western boundary of the 10km buffer zone for predicted drawdown at 2094 (refer Figure 8.1). This watercourse spring has a source aquifer nominated as the Kumbarilla Beds that outcrop at this location. The risk of drawdown impact to this watercourse spring is considered to be very low given: • It is located at the outer extent of the conservatively assumed 10 km buffer zone for predicted drawdown at 2094. • It is beyond the 10 km buffer zone for the predicted drawdown at 2050. • At this location it is likely the Westbourne Formation is present overlying the Springbok Sandstone and will likely act as an aquitard that would prevent propagation of impacts from the Springbok Sandstone to overlying units. Spring complex 584 is located within the 10 km buffer zone and 0.2 m drawdown zone for the Springbok Sandstone drawdown predictions for 2050 and 2094 respectively.

Table 8.5: Magnitude of Arrow-only Impacts – Pre-mitigation and management

Impact	Groundwater system	Sensitivity	Magnitude of impact		Justification
			EIS assessment	SREIS assessment	
Indirect Impacts (cont'd)					
Potentiometric surface drawdown in adjacent aquifers causing reduced groundwater availability for GDEs. (cont'd)	Intermediate Groundwater System (cont'd)	Moderate	Low	Moderate	This spring complex is considered to have a source aquifer of either Quaternary sediments (shallow groundwater system) or shallow Orallo Formation (intermediate groundwater system). No drawdown is predicted in these formations at this location therefore there is no impact predicted to this spring complex. The Springbok Sandstone is expected to outcrop to the west of the Condamine Alluvium, and along much of the western boundary of the project development area. Differentiation between the Springbok Sandstone and other formations that comprise the Kumbarilla Beds is difficult in this area. As described above the Westbourne Formation will act as a confining layer over the western portion of the Springbok Sandstone, restricting the propagation of drawdown impact to overlying GDEs, however the boundary of the Westbourne Formation extent is not well defined. Immediately west of the Condamine Alluvium, where the Springbok Sandstone may outcrop, there is a general absence of mapped potential GDEs (ecosystems potentially dependent on both the surface expression of groundwater and subsurface presence of groundwater), however further west there is some potential for ecosystems potentially dependent on the subsurface presence of groundwater to be impacted by drawdown in the Springbok Sandstone, depending on the extent of Springbok Sandstone outcrop.

Table 8.5: Magnitude of Arrow-only Impacts – Pre-mitigation and management

Impact	Groundwater system	Sensitivity	Magnitude of impact		Justification
			EIS assessment	SREIS assessment	
Indirect Impacts (cont'd)					
Potentiometric surface drawdown in adjacent aquifers causing reduced groundwater availability for GDEs. (cont'd)	Intermediate Groundwater System (cont'd)	Moderate	Low	Moderate	The magnitude of impact is considered to be moderate based on the potential for drawdown impact to ecosystems mapped as potentially reliant on groundwater. No spring complexes or watercourse springs are predicted to be impacted. The assessment of magnitude has changed from EIS due to additional information available on the location of potential GDE landscapes.
Potentiometric surface drawdown in adjacent aquifers causing reduced groundwater availability for GDEs. (cont'd)	Deep Groundwater System	High	High	Very Low	Modelling predicts the following drawdown in the deep groundwater system: • Maximum of 8 m and average of <5 m in the Hutton Sandstone. • Maximum of 0.7 m in the Precipice Sandstone. No springs with a source aquifer from the deep groundwater system are located within predicted areas of drawdown or the 10 km buffer zone beyond the 0.2 m drawdown extent. The Hutton (and Marburg equivalent) Sandstone does not outcrop where there is predicted drawdown in the aquifer. However some small regions of outcrop area present at the eastern boundary of the 10 km buffer zone beyond the 0.2 m drawdown extent. As no potential GDEs are identified in these areas, the Hutton Sandstone (and Marburg Sandstone equivalent) is not considered to be a source aquifer for ecosystems potentially reliant of the subsurface presence of groundwater or other potential GDEs accessing the surface expression of groundwater.

Table 8.5: Magnitude of Arrow-only Impacts – Pre-mitigation and management

Impact	Groundwater system	Sensitivity	Magnitude of impact		Justification
			EIS assessment	SREIS assessment	
Indirect Impacts (cont'd)					
Potentiometric surface drawdown in adjacent aquifers causing reduced groundwater availability for GDEs. (cont'd)	Deep Groundwater System	High	High	Very Low	The magnitude of impact is therefore considered to be very low. The assessment of magnitude has changed from the EIS due to additional information on the location and source aquifers of GDEs within and surrounding the project development area.
Potentiometric surface drawdown in adjacent aquifers due to leakage through coal seam gas wells (well failure) causing groundwater quality impacts from inter-aquifer flows.	Shallow Groundwater System	Moderate	Low	Low	The potential inter-aquifer well fluxes that would be caused by the failure rate of a small percentage of wells is not considered to be hydrologically significant compared to inter-aquifer fluxes through confining layers over large regional areas. Inter-aquifer fluxes that occur locally due to failed wells are expected to decline rapidly, as local pressure equilibrium is approached between the formations in the vicinity of the wells. In the longer term as aquifer pressures recover after the cessation of impacting activity, modelling shows that differential pressures are observed to reduce between formations, further reducing the potential for adverse impact. Based on the above, the magnitude of impact is considered to be low, consistent with the EIS.
	Intermediate Groundwater System	Moderate	Low	Low	
	Deep Groundwater System	High	Low	Low	

Table 8.5: Magnitude of Arrow-only Impacts – Pre-mitigation and management

Impact	Groundwater system	Sensitivity	Magnitude of impact		Justification
			EIS assessment	SREIS assessment	
Indirect Impacts (cont'd)					
Induced flow (leakage) between adjacent aquifers above and below the Walloon Coal Measures causing physical changes to aquifer structure leading to subsidence.	Shallow Groundwater System	Moderate	NA[2]	Very Low	To result in adverse differential movement of rock formations, the subsidence would need to be significant and occur on a localised scale, at differing rates. As subsidence is not expected to be significant (Geoscience Australia and Habermehl, 2010) and is expected to be widespread, differential movement is not expected. The magnitude of impact of depressurised formations which might cause adverse physical effects due to subsidence is therefore considered to be very low.
	Intermediate Groundwater System	Moderate	NA[2]	Very Low	
	Deep Groundwater System	High	NA[2]	Very Low	

Table Notes:

1: The EIS assessed indirect impacts associated with coal seam gas extraction (i.e. potentiometric surface drawdown reducing supply to existing users and water quality impacts from inter-aquifer flow) together in the significance assessment. For this assessment the potential impacts have been separated, and the assessment of High magnitude for the EIS is considered to be a conservative assessment, related mainly to potentiometric surface drawdown impacts.

2: Loss of structural integrity due to subsidence was not assessed in the EIS, however an assessment of subsidence impacts was completed, and concluded that subsidence was unlikely to have significant impact.

8.3.1 Summary

Based on the impact predictions from the Arrow SREIS groundwater model, which includes the Arrow current development plan, it is demonstrated that the impacts identified in the original EIS have typically not been understated. With the exception of the impact magnitude to GDEs supported by the shallow and intermediate groundwater systems, the revised assessment has either confirmed the EIS magnitude assessment or reduced the magnitude ranking based on the updated information available.

The magnitude of impact to GDEs potentially supported by the shallow groundwater system was increased from very low in the EIS to moderate in this assessment. This ranking was made due to the presence of non-GAB Spring Complex 585 on the eastern margin of the Condamine Alluvium, where the drawdown prediction is 0.3 m. Spring Complex 585 was not presented in the EIS as it was not included in the GAB Spring Complexes database complied by the Queensland Herbarium and used for the EIS assessment. Under the Water Act the predicted level of drawdown is greater than the spring trigger threshold, therefore spring complex 585 may be affected.

The magnitude of impact to GDEs potentially supported by the intermediate groundwater system was also increased from very low in the EIS to moderate in this assessment. This ranking was made due to the potential for drawdown in the Springbok Sandstone to impact ecosystems that have a high potential to be dependent on the subsurface presence of groundwater immediately east of the Condamine Alluvium.

8.4 Cumulative impacts caused by other developments

The objective of the supplementary report is to evaluate whether the impact predictions reported in the EIS and SREIS for Arrow-only production are consistent. If confirmed to be consistent, it is inferred that the cumulative impacts have not been underestimated.

For the EIS, numerical groundwater modelling was conducted to predict groundwater drawdown in response to the Surat Gas Project. The EIS presented the contribution of Arrow's Surat Gas Project to cumulative impacts for three scenarios.

Scenario 1 predicted the groundwater drawdown as a result of Arrow’s forecast coal seam gas water extraction for the Surat Gas Project.

Scenario 2 included extraction from Arrow’s Surat Gas Project along with the other coal seam gas projects for which the proponent had taken their final investment decision; GLNG and QCLNG Projects.

Scenario 3 predicted the cumulative drawdown as a result of all four coal seam gas projects in the Surat Basin, regardless of final investment decision status, and therefore included the Surat Gas Project, and the GLNG, QCLNG and APLNG projects.

Scenarios 2 and 3 were designed to assess the cumulative impacts with other proponents, and the calibrated modelled results were used to support the impact assessment and development of mitigation measures.

Modelling conducted since the EIS by the OGIA and by Arrow for the SREIS considered cumulative scenarios using data provided by GLNG, QCLNG and APLNG.

The OGIA Surat CMA Groundwater Model included a ‘base run’ scenario that was limited to non-petroleum and gas users, as well as a petroleum and gas ‘production run’ scenario that included non-petroleum and gas users, as well as current and proposed petroleum and gas extraction from proposed coal seam gas developments. The difference between these scenarios represents the cumulative impacts that can be attributed to petroleum and gas activities (QWC, 2012).

The modelling is calibrated, peer reviewed, and considered to provide a comprehensive assessment of cumulative impacts. It has demonstrated that significant impacts will not occur to the Condamine Alluvium. For the Condamine Alluvium, the Arrow SREIS groundwater modelling predicts lower impacts under Arrow's current development plan than previously reported in the EIS.

Because the impact predictions from the Arrow SREIS Groundwater Model are lower than those presented in the EIS, it can be concluded that the cumulative impacts will not have been understated with respect to Arrow's contribution.

8.5 Mitigation and Management Measures

The mitigation measures identified in the EIS were reviewed to assess whether they remain relevant to this supplementary groundwater assessment. The review showed the mitigation and management measures are still relevant for groundwater-related impacts, and no measures have been removed.

In addition, new mitigation and management measures were identified, including:

- Obligations outlined in the Surat CMA UWIR.
- Management of other GDEs.
- Bore assessments.
- Responsible tenure holder obligations.
- Offsetting the Arrow component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of coal seam gas water extraction from the Walloon Coal Measures. Modelled likely flux impacts are defined as those simulated in the calibrated OGIA Surat CMA Groundwater Model realisation occurring over the period referred to in the UWIR for the Surat CMA (QWC, 2012) i.e. the next 100 years.
- Implementation of the Code of Practice for Construction and Abandoning Coal Seam Gas Wells in Queensland.

These additional mitigation and management measures are discussed below, as well as in the Coal Seam Gas Water and Salt Management Strategy (with the exception of the Code of Practice for Construction and Abandoning Coal Seam Gas Wells in Queensland) provided in Attachment 5 of the SREIS. Details of monitoring programs that will be adopted by Arrow are provided in Section 9.

8.5.1 Obligations outlined in the Surat CMA UWIR

As presented in Section 3.2.2 the OGIA has prepared a UWIR for the Surat CMA (QWC, 2012). The UWIR is based on the requirements of Chapter 3 of the Water Act, and outlines the requirement for the management and mitigation of impact to potentially affected springs in the Surat CMA through a Springs Impact Management Strategy (SIMS).

The Surat CMA UWIR also sets out requirements for monitoring and ongoing management of groundwater levels, groundwater quality, and existing groundwater bores and springs within the Surat CMA. These are described in Section 9.1.

Spring Impact Management Strategy

Under the Water Act, springs that may be potentially affected by dewatering and depressurisation activities required to extract coal seam gas must be identified. A spring is considered to be potentially affected by the exercise of underground water rights if it overlies an aquifer where the long-term predicted drawdown at the location of the spring exceeds 0.2 m.

The Surat CMA UWIR includes a SIMS that will be used to manage impacts to springs. Specifically the SIMS requires:

- Identification of potentially affected springs.
- Assessment of the connectivity to underlying aquifers and the risks to the springs.
- A spring monitoring program (refer Section 9.1.3).
- A spring impact mitigation strategy.

The SIMS sets out the current understanding of potentially affected spring vents and spring watercourses based on predictions from the OGIA Surat CMA Groundwater Model. The SIMS is directed at only those springs where an impact of more than 0.2 m is predicted in the source aquifer of the spring.

The strategy sets out potential options for mitigation measures that are to be considered further prior to specific actions being made for mitigation measure implementation. These options include:

- Offset impacts by relocating existing water bores.
- Offset impacts through surrender of existing water entitlements by bore owners that are not needed.
- Offset impacts through improved water use efficiency.
- Offset impacts through supply substitution from another source.
- Injection of treated water into spring source aquifers.
- Managing coal seam gas water extraction, including timing extractions to avoid impacts to springs if possible.

No springs are identified on Arrow tenure, and Arrow is not the assigned responsible tenure holder for any off-tenure springs. However should Arrow become the responsible tenure holder in the future Arrow will adopt the SIMS.

8.5.2 Management of Other GDEs

The obligations for spring management set out in the Surat CMA UWIR SIMS will form the basis for Arrow's management and mitigation of potential impacts to springs identified in the SIMS.

The EPBC Act provides for the protection of MNES including the community of native species dependent on natural discharge of groundwater from the GAB, or listed threatened species that are reliant on springs. Where potentially affected springs include MNES, Arrow will, in collaboration with holders of adjacent and nearby petroleum tenures (to the extent possible), develop a plan to provide an early warning system for the monitoring and management of these springs. This plan will:

- Detail the monitoring that will be undertaken for each spring including:
    - Work that will be performed as part of the SIMS.
    - Baseline sampling to establish the pattern of seasonal variation in spring presence, extent, physical characteristics and ecology.
    - Ongoing sampling.
- Propose an early warning system monitoring network including groundwater monitoring bores detailed in the Water Monitoring Strategy.
- Identify trigger levels and specific actions to avoid, minimise and manage impacts to these springs from CSG water extraction.

For GDEs not covered by the Surat CMA UWIR SIMS or under the EPBC Act MNES, (i.e. those dependent on the subsurface presence of groundwater, or ecosystems potentially dependent on the surface expression of groundwater, not identified in the Surat CMA UWIR), Arrow will manage other GDEs according to the following framework:

- Identification of potential GDE landscapes.
- Use of modelling to predict impacts.
- Undertaking a risk assessment to identify GDEs at risk of impact. Where GDEs are identified as being at risk of impact, further assessment is warranted, including detailed field studies and monitoring to ascertain connectivity of GDE to underlying aquifers.
- Monitor and manage impacts as required, including further research.
- Routinely update/refine conceptual understanding of GDEs in the vicinity of the project development area as additional data is obtained. This will inform the need for impact mitigation and the selection of mitigation measures that are likely to be most effective.

8.5.3 Bore Assessments

Arrow is committed, and has statutory requirements, to undertake Bore Assessments in Immediately Affected Area bores (QWC, 2012). These assessments are used to evaluate whether a bore has impaired capacity, or is likely to have impaired capacity in the future, as a result of groundwater extraction associated with coal seam gas activities.

A water bore has impaired capacity if there is a decline in the water level of the aquifer at the location of the water bore because of the exercise of underground water right, and as a result of the decline the water bore can no longer provide a reasonable quantity or quality of water for its authorised use or purpose.

Bore Assessments must be undertaken in accordance with DEHPs Bore Assessment Guideline, and involve the following:

- Preliminary assessment.
- Field assessment of current bore condition.
- Determination of whether water levels have declined, or are predicted to decline.
- Determination of whether declining water levels are due to the exercise of underground water rights by the petroleum tenure holder.
- Determination of whether the bore can or will continue to provide a reasonable quantity and quality of water for it authorised use or purpose. This includes determination of the current bore yield.

Depending on discussion with the landholder, as well as the findings of each assessment stage, not all steps may be required to complete the water bore assessment.

8.5.4 Responsible Tenure Holder Obligations

Under the Water Act petroleum tenure holders have obligations associated with the right to take groundwater in the process of producing petroleum and gas. These comprise make good obligations and report obligations.

8.5.4.1 Make Good Obligations

Make good obligations require the petroleum tenure holder to complete Bore Assessments as outlined in Section 8.5.3 and enter into and comply with Make Good Agreements with the bore owner. If asked, the petroleum tenure holder may also be required to negotiate a variation of the Make Good Agreement.

The requirements of Make Good Obligations are detailed in Section 3 and the Coal Seam Gas Water and Salt Management Strategy presented in Attachment 5 of the SREIS.

8.5.4.2 Report Obligations

Under the Water Act a report obligation is a requirement with which a responsible tenure holder must comply under an approved UWIR or final report. Under the Surat CMA UWIR responsible tenure holder report obligations include:

- Water monitoring activities: These obligations involve constructing monitoring bore installations, carrying out baseline assessments and reporting data on an ongoing basis.
- Spring impact management activities: These obligations involve implementing a program for monitoring springs and a program to assess options for mitigating the impact of water extraction on springs.

8.5.5 Offset of Arrow’s component of the modelled likely flux to the Condamine Alluvium

Arrow is committed to offsetting its component of modelled likely flux of groundwater from the Condamine Alluvium as a result of coal seam gas water extraction from the Walloon Coal Measures through a process of ‘virtual injection' in the area of greatest predicted drawdown.

Further detail on the method of ‘virtual injection’ is provided in Section 7 and the predicted response of water levels in the Condamine Alluvium to the application of ‘virtual injection’ is discussed in detail in Section 7.6.

8.5.6 Code of Practice for Constructing and Abandoning Coal Seam Gas Wells in Queensland

Coal seam gas production requires the drilling and installation of strategically located production wells across the development areas, and the installation of groundwater and gas monitoring and/or investigation wells. This cannot be avoided, as wells are required to access the gas resource.

The EIS described that around 7,500 wells would be drilled across the project development area. With the relinquishment of approximately 30% of the project development area, the anticipated number of production wells has reduced to approximately 6,500 over the project life.

The EIS identified a range of potential impacts associated with well failure during construction, operation and decommissioning phases of the project, including the potential to cause aquifer interconnectivity. A range of mitigation measures were identified to ameliorate the potential impacts.

Since the publication of the EIS, a new guideline has been developed for coal seam gas wells in Queensland - the ‘Code of Practice for Constructing and Abandoning Coal Seam Gas Wells in Queensland’ (Queensland Government, 2011). This new Code of Practice was developed in a regulatory context that foresaw the need for specific requirements to ensure that concerns are addressed in present day and future coal seam gas development.

The Code of Practice was facilitated by the former Department of Employment, Economic Development and Innovation (DEEDI) and aims to ensure that all coal seam gas wells are constructed and abandoned to a minimum acceptable standard. This ensures that these activities are completed in a consistent manner and the processes are effectively monitored to ensure that:

- The environment, in particular underground sources of water, is protected.
- Risk to public and coal seam gas workers is managed to a level as low as reasonably practicable.

- Regulatory and applicable Australian and International Standards, as well as the Operator's internal requirements, are complied with.
- The life of a coal seam gas well is managed effectively through appropriate design and construction techniques, ongoing monitoring and end of life decommissioning.

The Code of Practice presents a benchmark standard to underpin coal seam gas well management that exceeds previous specifications and it is intended that this Code of Practice will have enforceable effect in Queensland by being called up under the Petroleum and Gas Regulations as a "safety requirement". However the provisions of the Petroleum and Gas Act and regulation will take precedence over the Code should any cases occur where conflict arises.

In summary, application of the Code of Practice, together with the mitigation measures provided in the EIS, are expected to reliably mitigate any potential impacts associated with any well that may fail.

8.6 Magnitude of Arrow-only Impacts – Residual Impacts

Based on the adoption of the mitigation and management measures identified in the EIS and additional measures outlined above, the significance of residual impacts can be re-assessed. Only those project-related impacts that have been triggered for re-assessment by changes in the project description or the availability of additional information since the release of the EIS are included in the residual impact assessment.

Table 8.6 presents the significance of residual impacts after the application of mitigation and management measures for the SREIS. Only new mitigation and management measures are identified in Table 8.6, however the residual significance assessment presented considers relevant mitigation and management measures outlined in the EIS as well.

Table 8.6: Arrow only impacts - residual impact assessment

Impact	Groundwater system	Sensitivity	Magnitude (pre-mitigation and management)	Summary of additional mitigation and management measures	SREIS residual impact assessment (post-mitigation and management)		Change in residual significance ranking from EIS
					Magnitude	Significance Ranking	
Direct Impacts							
Potentiometric surface drawdown resulting in reduced supply to existing or future groundwater users.	Coal Seam Gas Groundwater System	Low	Very High	Bore assessments. Responsible tenure holder obligations including Make Good.	Low	Low	No change.
Potentiometric surface drawdown resulting in reduced supply to GDEs fed by the Walloon Coal Measures.	Coal Seam Gas Groundwater System	Low	Very Low	Obligations outlined in the Surat CMA UWIR. Management of other GDEs. Responsible tenure holder obligations.	Very Low	Very Low	No change.

Table 8.6: Arrow only impacts - residual impact assessment (cont'd)

Impact	Groundwater system	Sensitivity	Magnitude (pre-mitigation and management)	Summary of additional mitigation and management measures	SREIS residual impact assessment (post-mitigation and management)		Change in residual significance ranking from EIS
					Magnitude	Significance Ranking	
Indirect Impacts							
Induced flow (leakage) between adjacent aquifers above and below the Walloon Coal Measures causing groundwater quality impacts from inter-aquifer flows.	Shallow Groundwater System	Moderate	Low	Bore assessments. Responsible tenure holder obligations including Make Good.	Low	Moderate	No change.
	Intermediate Groundwater System	Moderate	Low		Low	Moderate	No change.
	Deep Groundwater System	High	Low		Low	Moderate	No change.

Table 8.6: Arrow only impacts - residual impact assessment (cont'd)

Impact	Groundwater system	Sensitivity	Magnitude (pre-mitigation and management)	Summary of additional mitigation and management measures	SREIS residual impact assessment (post-mitigation and management)		Change in residual significance ranking from EIS
					Magnitude	Significance Ranking	
Indirect Impacts (cont'd)							
Potentiometric surface drawdown in adjacent aquifers causing reduced supply to existing or future groundwater users.	Shallow Groundwater System	Moderate	Moderate	Offsetting the Arrow component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of coal seam gas water extraction from the Walloon Coal Measures. Average drawdown across the Condamine Alluvium is reduced from 0.18 m (pre-mitigated) to 0.03 m (substitution case). Responsible tenure holder obligations including Make Good.	Low	Moderate	No change.

Table 8.6: Arrow only impacts - residual impact assessment (cont'd)

Impact	Groundwater system	Sensitivity	Magnitude (pre-mitigation and management)	Summary of additional mitigation and management measures	SREIS residual impact assessment (post-mitigation and management)		Change in residual significance ranking from EIS
					Magnitude	Significance Ranking	
Indirect Impacts (cont'd)							
Potentiometric surface drawdown in adjacent aquifers causing reduced supply to existing or future groundwater users. (cont'd)	Intermediate Groundwater System	Moderate	High	Bore assessments. Responsible tenure holder obligations including Make Good.	Low	Moderate	No change.
	Deep Groundwater System	High	High		Low	Moderate	No change.
Potentiometric surface drawdown in adjacent aquifers causing reduced groundwater availability for GDEs.	Shallow Groundwater System	Moderate	Moderate	Offsetting the Arrow component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of coal seam gas water extraction from the Walloon Coal Measures.	Very Low	Low	No change.

Table 8.6: Arrow only impacts - residual impact assessment (cont'd)

Impact	Groundwater system	Sensitivity	Magnitude (pre-mitigation and management)	Summary of additional mitigation and management measures	SREIS residual impact assessment (post-mitigation and management)		Change in residual significance ranking from EIS
					Magnitude	Significance Ranking	
Indirect Impacts (cont'd)							
Potentiometric surface drawdown in adjacent aquifers causing reduced groundwater availability for GDEs. (cont'd)	Shallow Groundwater System (cont'd)	Moderate	Moderate	Average drawdown across the Condamine Alluvium is reduced from 0.18 m (pre-mitigated) to 0.03 m (substitution case). Predicted drawdown at Spring Complex 585 under the substitution case is 0.05 m, which is below the spring trigger threshold. Where ecosystems potentially reliant on the subsurface presence of groundwater have been identified (Figure 5.8), as well as gaining stream reaches through the Condamine Alluvium (Figure 5.2 and 5.7), the predicted drawdown under the 'virtual injection' scenario is typically between 0 to 0.2 m, and in some areas an overall increase in water levels is predicted.			

Table 8.6: Arrow only impacts - residual impact assessment (cont'd)

Impact	**Groundwater system**	**Sensitivity**	**Magnitude (pre-mitigation and management)**	**Summary of additional mitigation and management measures**	**SREIS residual impact assessment (post-mitigation and management)**		**Change in residual significance ranking from EIS**
					Magnitude	**Significance Ranking**	
Indirect Impacts (cont'd)							
Potentiometric surface drawdown in adjacent aquifers causing reduced groundwater availability for GDEs. (cont'd)	Shallow Groundwater System (cont'd)	Moderate	Moderate	Obligations outlined in the Surat CMA UWIR. Management of other GDEs. Responsible tenure holder obligations.			
	Intermediate Groundwater System	Moderate	Moderate	Obligations outlined in the Surat CMA UWIR. Management of other GDEs. Responsible tenure holder obligations.	Very Low	Low	No change.
	Deep Groundwater System	High	Very Low		Very Low	Low	Reduced from low to very low based on additional information relating to the presence and characteristics of GDEs since the EIS.

Table 8.6: Arrow only impacts - residual impact assessment (cont'd)

Impact	**Groundwater system**	**Sensitivity**	**Magnitude (pre-mitigation and management)**	**Summary of additional mitigation and management measures**	**SREIS residual impact assessment (post-mitigation and management)**		**Change in residual significance ranking from EIS**
					Magnitude	**Significance Ranking**	
Indirect Impacts (cont'd)							
Potentiometric surface drawdown in adjacent aquifers due to leakage through coal seam gas wells (well failure) causing groundwater quality impacts from inter-aquifer flows.	Shallow Groundwater System	Moderate	Low	Application of Code of Practice for Constructing and Abandoning Coal Seam Gas Wells in Queensland.	Very Low	Low	No change.
	Intermediate Groundwater System	Moderate	Low		Very Low	Low	No change.
	Deep Groundwater System	High	Low		Very Low	Low	No change.

Table 8.6: Arrow only impacts - residual impact assessment (cont'd)

Impact	Groundwater system	Sensitivity	Magnitude (pre-mitigation and management)	Summary of additional mitigation and management measures	SREIS residual impact assessment (post-mitigation and management)		Change in residual significance ranking from EIS
					Magnitude	Significance Ranking	
Indirect Impacts (cont'd)							
Induced flow (leakage) between adjacent aquifers above and below the Walloon Coal Measures causing physical changes to aquifer structure leading to subsidence.	Shallow Groundwater System	Moderate	Very Low	No planned mitigation and management measures.	Very Low	Low	Insufficient information available at time of EIS so no ranking applied.
	Intermediate Groundwater System	Moderate	Very Low		Very Low	Low	
	Deep Groundwater System	High	Very Low		Very Low	Low	

8.6.1 Summary

Based on the impact predictions from the Arrow SREIS Groundwater Model, which includes the Arrow current development plan, it is demonstrated that the residual significance assessment completed in the EIS did not understate the residual (mitigated) impacts. The assessment shows that there is no change to the residual impact assessment from that presented in the EIS, with the exception of the lowering of the residual significance ranking for the potential impacts to GDEs associated with the deep groundwater system from low to very low. This was based on additional available information relating to the location and source aquifer of GDEs within and surrounding the project development area that indicates GDEs dependent on the deep groundwater system will not be impacted, together with further mitigation and management measures.

The potential for groundwater extraction leading to physical changes in aquifer structure, resulting in subsidence, which was not assigned a significance ranking in the EIS due to insufficient information available at the time, has been assigned a residual significance ranking of low for the shallow, intermediate and deep groundwater systems.

New mitigation and management measures that will be adopted by Arrow typically reflect the new regulatory framework developed for management of groundwater associated with coal seam gas developments in Queensland since the release of the EIS. This framework was outlined in the EIS. For instance, whilst the Surat CMA UWIR SIMS is considered to be a new mitigation and management measure as it is a legislated requirement of petroleum tenure holders released since the EIS, the premise of the SIMS is provided in the Water Act and the mitigation and management measures were already stipulated in the EIS. As such, the application of the new mitigation and management measures typically resulted in the same residual significance assessment rankings.

9 MONITORING, REPORTING AND RESEARCH

In addition to commitments outlined in the EIS, Arrow is committed to the implementation of monitoring programs and the management of commitments through reporting processes.

9.1 Baseline and Impact Monitoring

9.1.1 Baseline Assessments

Arrow is required, under the Water Act, to undertake baseline assessments on water bores, in its tenure.

A baseline assessment is an assessment of a water bore undertaken by a petroleum tenure holder to obtain information about the bore. In accordance with the Water Act, a baseline assessment plan (BAP) must be developed for each tenure in which production of coal seam gas, or production testing (during exploration) occurs. The BAP includes a baseline assessment timetable (BAT) that details when an assessment of each bore in the tenure will be undertaken. Assessments of bores in closest proximity to production of coal seam gas or production testing are undertaken first.

Assessments are undertaken in accordance with the DEHP's Guideline for Baseline Assessments (DERM, 2011) to obtain information about the bore, including:

- The location of the bore.
- The level and quality of groundwater in the bore.
- Historical water use.
- How the bore is constructed including the aquifer into which the bore is drilled.
- The type of infrastructure used to pump water from the bore.

Both registered and un-registered bores are to be assessed, hence reasonable endeavours are made to contact all landholders in each tenure that may own a water bore. The results of completed baseline assessments must be provided to the bore owner and the OGIA to update existing databases of groundwater bores. This will enable identification of bores that may be impacted by extraction of coal seam gas water in the future.

The Surat CMA UWIR also requires petroleum tenure holders to carry out baseline assessments for any bores outside of tenure in which a water level impact of more than one metre is expected within the next three years. As the predicted region of one metre impact will progressively expand, as further development of coal seam gas occurs, the UWIR will revise the predicted area of one metre drawdown every three years, until this region coincides with the aquifer Long-Term Affected Areas.

At the time of reporting Arrow had completed around 350 baseline assessments in the Surat Basin.

9.1.2 UWIR Water Monitoring Strategy

A water monitoring strategy (WMS) is included in the Surat CMA UWIR. The WMS includes an integrated regional monitoring network to collect data on water pressure and water quality in the Surat CMA across a network of around 500 monitoring points at 142 sites, monitoring all major aquifers and aquitards in the Surat CMA. The objectives of the WMS are to:

- Establish background trends.
- Identify changes in aquifer conditions within and near areas of petroleum development.
- Identify changes in aquifer conditions near critical groundwater use.
- Identify changes in aquifer condition near springs.
- Improve future groundwater flow modelling.
- Improve understanding of connectivity between aquifers.

The WMS assigns requirements to petroleum tenure holders to establish the regional monitoring network, undertake routine monitoring and reporting of results and report water production data from petroleum gas and wells. The OGIA will routinely assess the monitoring results and report on these annually. Arrow will implement the elements of the WMS for which it has been assigned responsibility.

At the time of reporting Arrow's established monitoring bore network consisted of 45 monitoring bores. The Surat CMA UWIR outlines a further 47 monitoring bores for installation in 2013 and a further 26 monitoring bores for installation by 2016. The monitoring bore network will consist of nested water bore sites (multiple bores screening different formations at the same location) within and outside of the project development area and will monitor the following formations:

- Condamine Alluvium, including transition layer between Walloon Coal Measures.
- Main Range Volcanics.
- Various coal seams, aquifers and aquitards of the Walloon Coal Measures.
- Westbourne Formation.
- Springbok, Hutton and Precipice Sandstones.
- Evergreen Formation.
- Bandanna Formation.

Water pressure monitoring will be completed on a fortnightly basis and water quality will be monitored at designated bores on an annual basis. Arrow's existing monitoring network, and the monitoring bores proposed in the Surat CMA UWIR for installation in 2013 are presented in Figure 9.1. Locations have not been finalised for bores proposed for installation beyond 2013 as these are subject to negotiations with individual landowners. However the UWIR (QWC, 2012) presents intended approximate locations for the installation of bores planned beyond 2013.

9.1.3 UWIR Spring Monitoring Program

Under the Surat CMA UWIR SIMS, a spring monitoring program is aimed at identifying changes in the volume and chemistry of water flowing to a spring, and any changes to the general characteristics of springs. The program targets potentially affected springs with a risk score of 3 or higher.

In conjunction with data collected under the WMS, the data collected under the SIMS will enable early detection of unexpected impacts to springs and inform selection of mitigation measures if required. The monitoring program includes representative spring vents from each potentially affected spring complex. A total of 33 spring vents (comprising 10 spring complexes) and 5 spring watercourses have been nominated for monitoring under the program. The spring monitoring program locations are presented in Figure 9.2 and the results of the monitoring must be reported to the OGIA every six months.

No monitoring obligations are currently assigned to Arrow, however Arrow are committed to the spring monitoring program should obligations be assigned in future revisions of the Surat CMA UWIR.

The closest spring to Arrow tenure set out in the spring monitoring program is the Wambo Complex (complex number 584, site number 711), located approximately 14.5 km west of the boundary of Arrow tenure, south-east of Miles. Monitoring obligations for this spring complex have been assigned to QGC. QGC are undertaking quarterly monitoring of the spring complex and results reported to OGIA every 6 months.

9.1.4 Subsidence Monitoring

As presented in Section 5.6, Altamira performed a ground motion baseline study on behalf of Arrow, Santos, Origin Energy and QGC (Altamira, 2012). The study analysed ground motion using satellite interferometry (InSAR) in the Surat and Bowen Basins. The study was undertaken in response to Commonwealth conditions of approval for the GLNG, QCLNG and APLNG Projects.

The Altamira study established a baseline of ground surface motion across the Surat Basin coal seam gas fields prior to significant expansion of coal seam gas production. Future assessment of subsidence can be measured against this baseline.

Arrow are committed to ongoing subsidence monitoring, as presented in the Coal Seam Gas Water and Salt Management Strategy (Attachment 5 of the SREIS).

In addition, research project work regarding subsidence impact of aquifer drawdown due to coal seam gas extraction has been commissioned by the Office of Water Science (a directorate within SEWPaC), and will provide further understanding of the potential for subsidence resulting from coal seam gas development. The findings of this research project are currently undergoing review by the IESC (Independent Expert Scientific Committee for Coal Seam Gas and Large Coal Mining Development). Hence, results are not yet available.

9.2 Surat CMA UWIR Periodic Reporting and Review Requirements

The OGIA will report to DEHP annually. These reports will be published on the OGIA's website and will include a summary and assessment of monitoring data collected by responsible tenure holders under the WMS and SIMS. Arrow will periodically report data collected under these strategies (as required) to the OGIA.

In addition the OGIA will run the OGIA Surat CMA Groundwater Model every 12 months using updated estimates of water production rates and monitoring data from petroleum tenure holders. This aims to assess whether planned changes to production rates will result in material changes to Immediately Affected Areas and Long-Term Affected Areas. Where material changes are predicted, the new results will be submitted to DEHP, along with a summary of the monitoring results.

The OGIA will update the Surat CMA UWIR every three years, including review of appropriateness of groundwater flow model, monitoring strategies (WMS and SIMS) and responsible tenure holder arrangements. Together with the 12 monthly model runs, this process allows OGIA predictions about future water levels and Immediately Affected Areas and Long-Term Affected Areas to be progressively refined.

The OGIA will maintain a database to store data collected under monitoring plans carried out in accordance with the monitoring programs of the Surat CMA UWIR. The OGIA will also store baseline data collected by petroleum and gas operators as a part of their individual obligations under the Water Act.

9.3 Ongoing Research

9.3.1 OGIA Future Research Directions

In the Surat CMA UWIR the OGIA outlined a number of specific future research directions that are either planned or underway by various research bodies. Areas currently targeted for research include:

- Condamine Interconnectivity Research Project (CIRP).
- Influence of geological structures on groundwater flow in the Surat CMA.
- Hydrogeology of the Walloon Coal Measures.
- Re-conceptualisation of the groundwater systems in the Surat and Bowen Basins in Surat CMA.
- Second generation regional flow modelling for the Surat CMA.
- Improving knowledge about springs.

Arrow, in collaboration with the OGIA, have commenced investigations into the interconnectivity between the Condamine Alluvium and the Walloon Coal Measures (i.e. the CIRP), as described in Section 9.3.2.

9.3.2 Condamine Interconnectivity Research Project

Consistent with commitments made in the EIS, Arrow has commenced an *'investigative program that will help quantify the connectivity between the Condamine Alluvium and the Walloon Coal Measures'.* In conjunction with OGIA's implementation of the Surat CMA UWIR future research directions (refer Section 9.3.1), the CIRP was developed and includes elements to be undertaken by Arrow and OGIA (OGIA, 2013).

The scope of the investigative program has been publically endorsed by OGIA's Technical Advisory Panel. Specifically the study aims to:

- Quantify the magnitude of hydrogeological connections between the Condamine Alluvium and the Walloon Coal Measures through field testing.
- Verify modelled flux impacts (refer Section 7) to the Condamine Alluvium and the effect this will have on groundwater resources in the Condamine Alluvium.

As defined in the Surat CMA UWIR (QWC, 2012) the scope of work for the CIRP requires completion of the following tasks:

- Synthesise existing data to identify three to four potential sites for detailed investigation.
- Drill and install dedicated monitoring and test bores at the selected sites.
- Carry out detailed geophysical logging, geologic sampling (coring) and drill stem tests for newly constructed monitoring bores and (to the extent practicable) local existing wells.

- Carry out water quality/isotope sampling and analysis to identify hydrogeochemical fingerprints for formation water.
- Carry out pumping tests for periods long enough to establish hydraulic stress across the contact.
- Synthesise information collected to update existing knowledge about the interconnectivity.
- Reconceptualise the sub-regional groundwater flow system using the new knowledge about connectivity.

Under the Project Field Activities set out in the CIRP (Activity 2), Arrow will carry out pumping tests at selected locations. This will involve targeted groundwater bore drilling and installation to facilitate tests. The data obtained from the drilling and pumping test programs will be used to support ongoing groundwater modelling and further assess aquifer connectivity at locations where the Condamine Alluvium and Walloon Coal Measures are:

- In contact with each other (with or without the presence of the hydraulic separation layer at the base of the Condamine Alluvium).
- Separated by the Westbourne Formation and/or the Springbok Sandstone.

The optimal pumping test configuration has been determined through modelling which includes drilling and installation of monitoring bores at:

- One site that will assess the Condamine Alluvium and Walloon Coal Measures, where they are separated by stratigraphic units, and where groundwater extraction already occurs as part of existing coal seam gas activities (Daandine-Kumbarilla site).
- A second site that will assess the Condamine Alluvium and Walloon Coal Measures, where they are in direct contact, and where pumping from irrigation bores within the Condamine Alluvium occurs (Dalby-Kogan site).

These sites are presented in Figure 9.1. Once monitoring and pumping test bores are established, Arrow will complete water level and quality monitoring, and pumping tests to determine aquifer parameters.

Additional field investigations (if necessary), including location and test type, will be based on the outcomes and findings from the first two sites.

This information will be used to further conceptualise the groundwater systems, develop local scale numerical modelling to quantify flux (i.e. movement) of groundwater between the Condamine Alluvium and Walloon Coal Measures, and to refine Arrow's internal groundwater models. All data obtained will also be provided to OGIA for assessment and consideration in the groundwater model used to inform the Surat CMA UWIR.

10 CONCLUSIONS

The supplementary groundwater assessment was prepared in response to the comments received on the EIS. Updated technical information available since the submission of the EIS, changes to legislation and the regulatory framework, and revisions to the project description was considered.

The objectives of the supplementary groundwater assessment were to consider the revised project description and new relevant technical information, including identification of any significant changes in the potential groundwater impacts associated with the Surat Gas Project, to:

- Evaluate whether the impact predictions reported in the EIS and SREIS for Arrow-only production are understated.
- Evaluate the suitability of mitigation and management measures presented in the EIS.
- Consider whether any additional mitigation and management measures would be required.

Further numerical groundwater modelling was undertaken, that was consistent with the approach adopted by the OGIA, and was used to make groundwater drawdown, recovery and flux impact predictions based on Arrow's revised development plan.

The impact assessment framework adopted for the EIS was then re-applied in the supplementary assessment.

The impact assessment, based on the additional modelling, demonstrated that the assessment of residual significance completed in the EIS did not understate the residual (mitigated) impacts and that the mitigation measures identified in the EIS are still relevant for the management of groundwater-related impacts.

In addition to commitments outlined in the EIS, Arrow will also

- Adopt new mitigation and management measures required under the Surat Cumulative Management Area Underground Water Impact Report.
- Offset Arrow's component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of coal seam gas water extraction from the Walloon Coal Measures.

Arrow is also committed to working with the OGIA and the coal seam gas industry in improving the understanding of the hydrogeology of the Surat Basin through ongoing research.

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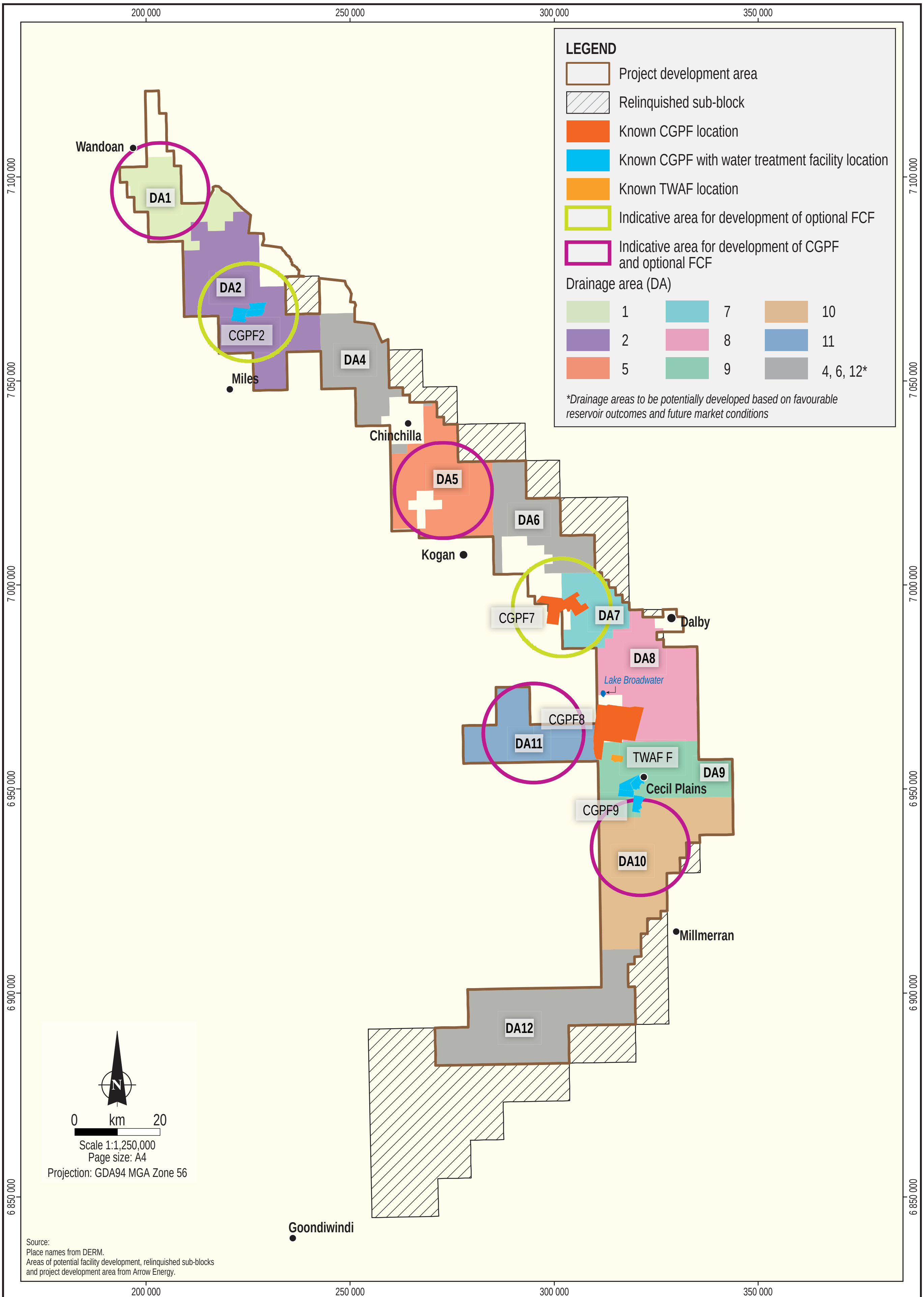
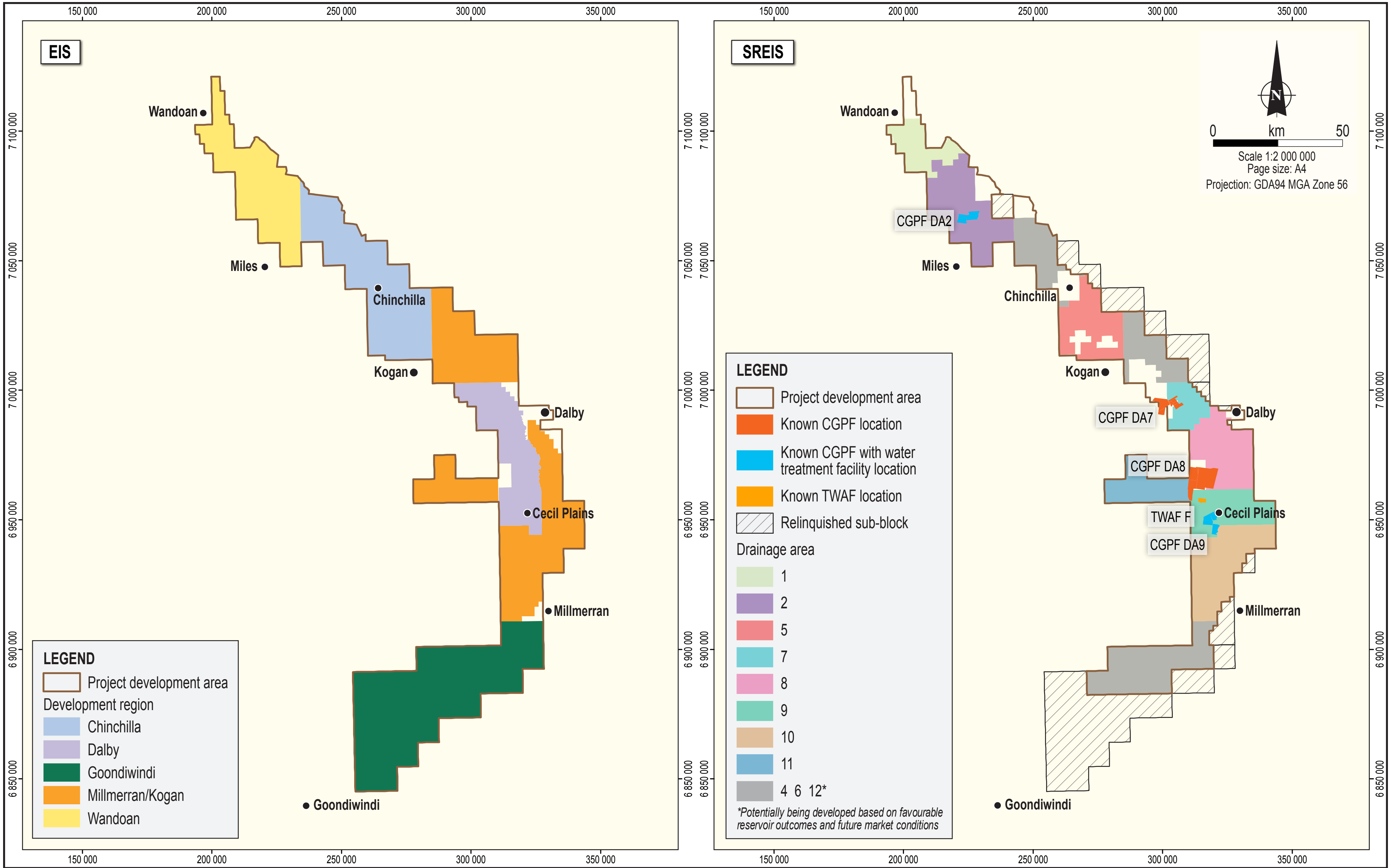
Figures

Supplementary Groundwater Assessment
Arrow Energy Surat Gas Project
Supplementary Report to the EIS



coffey environments	Date: 15.06.2013 MXD: 7040AF_GW03_GIS034_v1_1 File Name: 7040_GW03_F02.01_GIS_VS	Arrow Energy Surat Gas Project	arrow energy go further	Conceptual location of production facilities	Figure No: 2.1



Source:
Place names and roads from DERM.
Development regions drainage areas areas of potential facility development and relinquished sub-blocks from Arrow Energy.

coffey environments

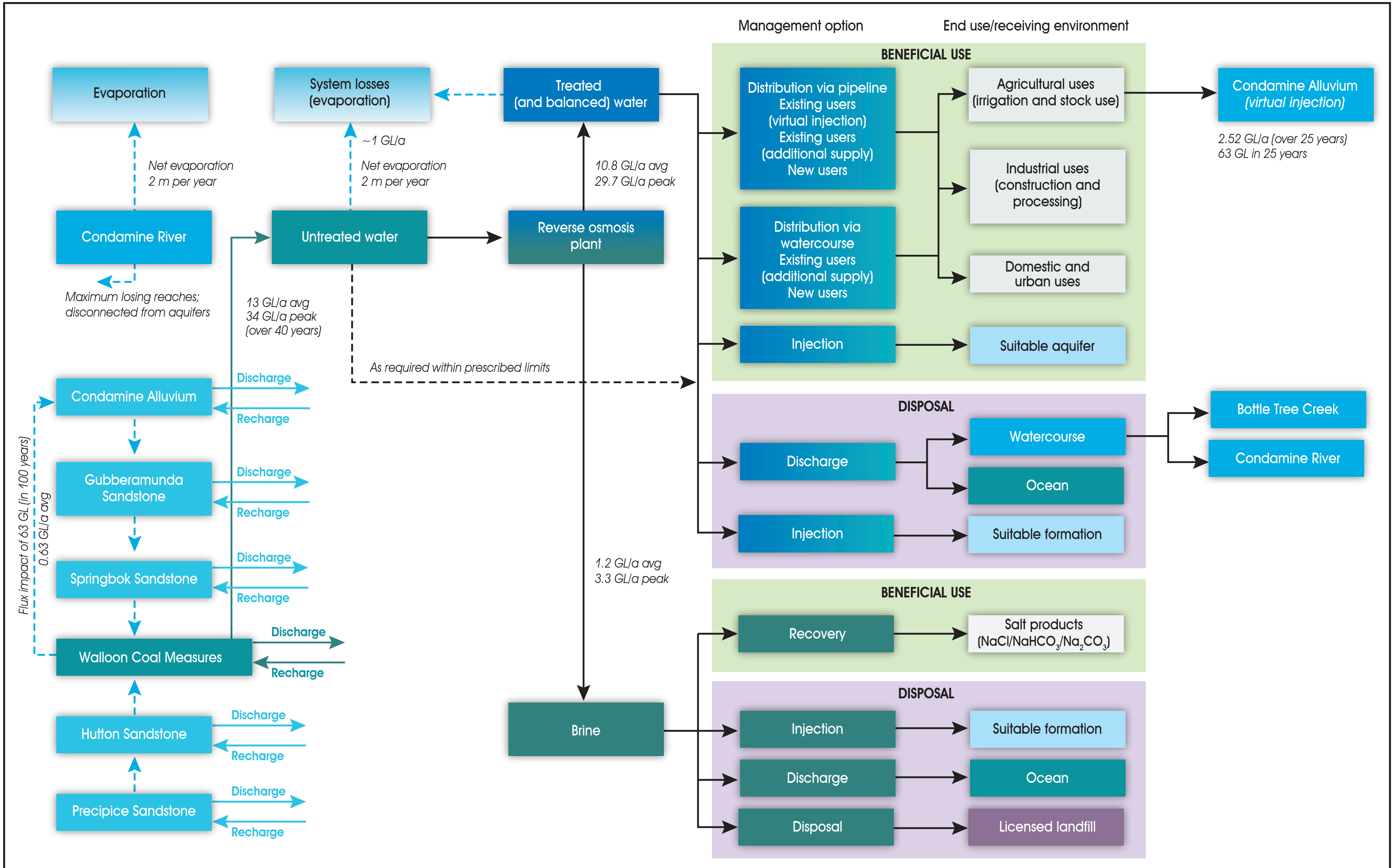
Date: 27.06.2013
MXT: 7040AF_GW03_GIS033_v1_2
File Name: 7040_GW03_F02.02_GIS

Arrow Energy
Surat Gas Project

arrow energy go further

Arrow production areas

Figure No: 2.2



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Date: 25.06.2013

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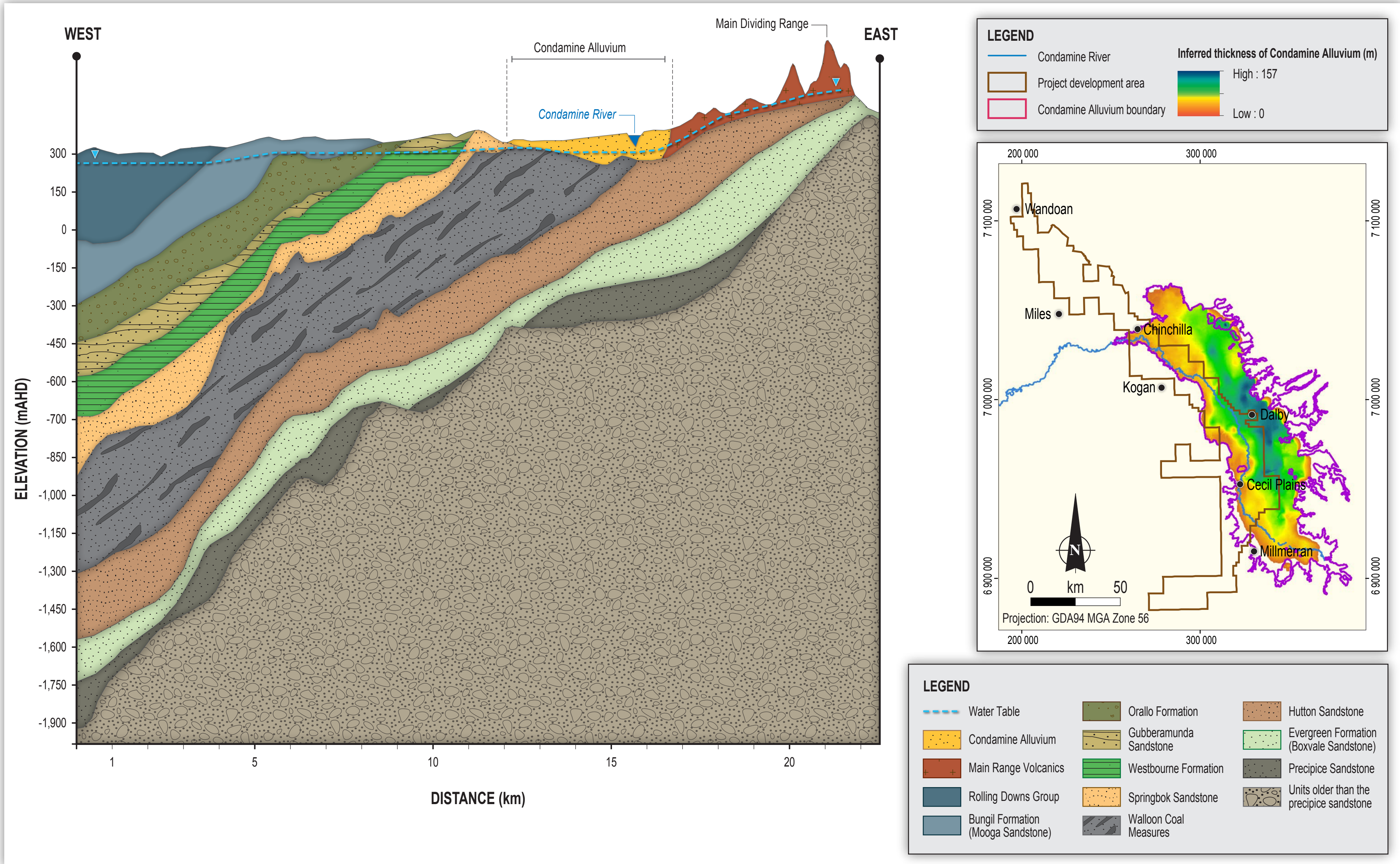
Arrow Energy

Surat Gas Project

arrow energy go further

Conceptual coal seam gas water and brine management overview

Figure No: 2.3



Source:
Place names and Condamine River from DERM.
Cross-section reproduced from GHD (2013) Figure 13.
Project development area and Condamine Alluvium boundary and base depths from Arrow Energy.

coffey environments

Date: 20.06.2013

File Name: 7040_GW03_F05.01_VS

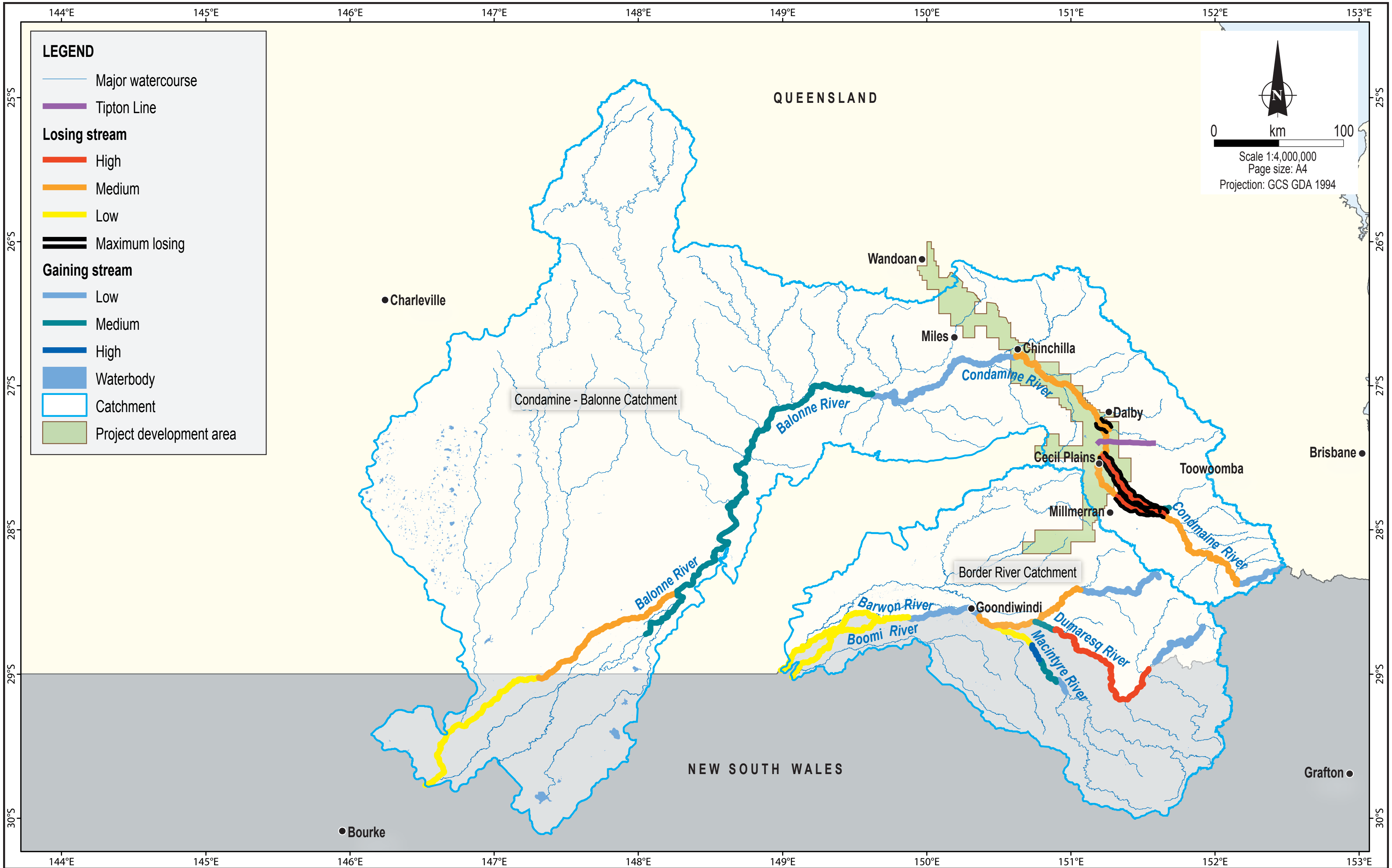
Arrow Energy

Surat Gas Project

arrow energy go further

Schematic cross-section of Condamine Alluvium and underlying units

Figure No: 5.1



Source:
Place names, waterbodies and watercourses from GEODATA250k.
Project development area from Arrow Energy.
Catchments and connectivity classifications derived from CSIRO report Surface–groundwater connectivity assessment, CSIRO Murray-Darling Basin Sustainable Yields Project', S. Parsons, R. Evans and M. Hoban, September 2008

coffey environments

Date:	17.06.2013
MXT:	7040AF_GW03_GIS010_v1_1
File Name:	7040_GW03_F05.02_GIS

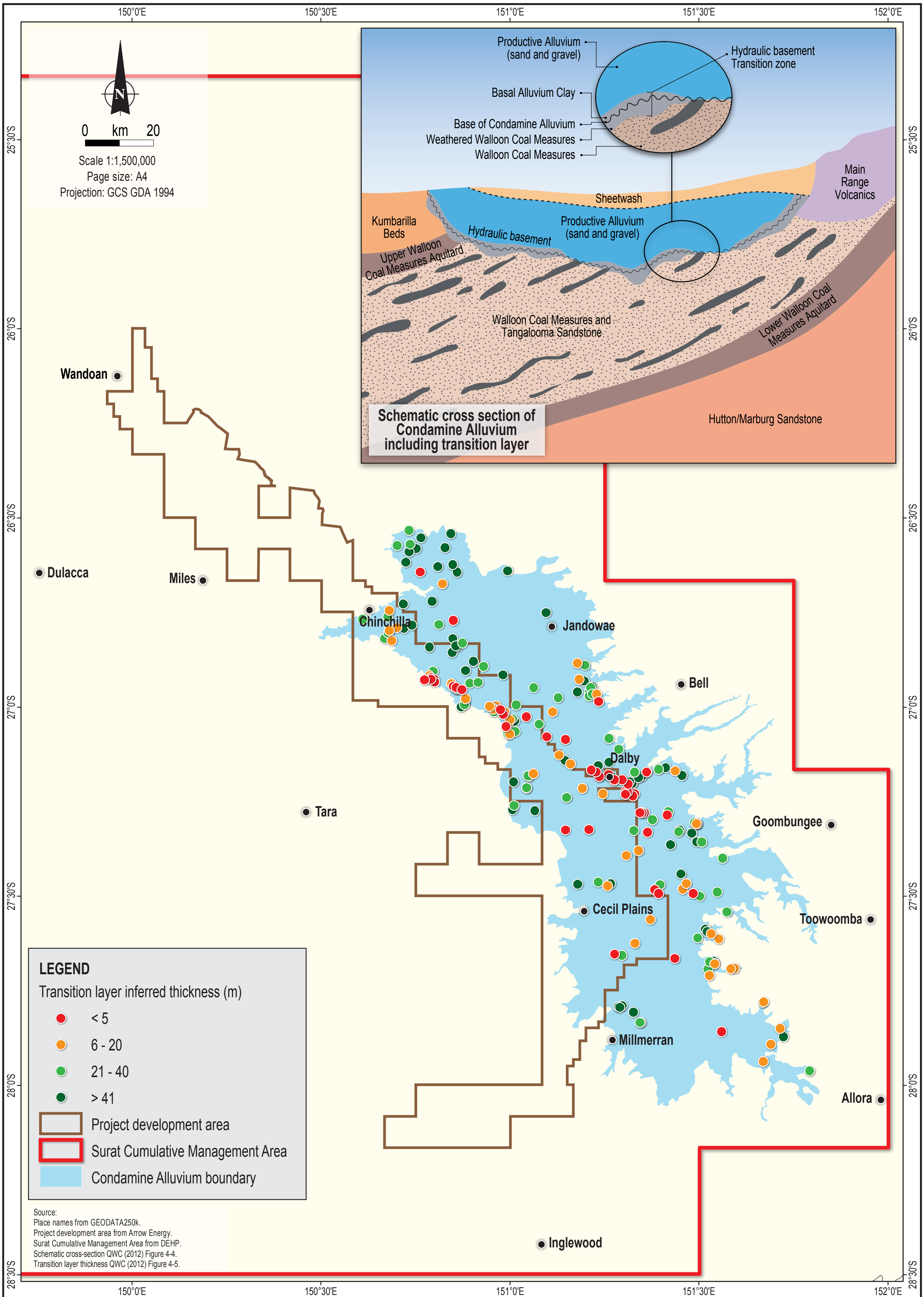
Arrow Energy

Surat Gas Project

arrow energy go further

Surface-groundwater connectivity for the Condamine-Balonne and Border River Catchments

Figure No: 5.2



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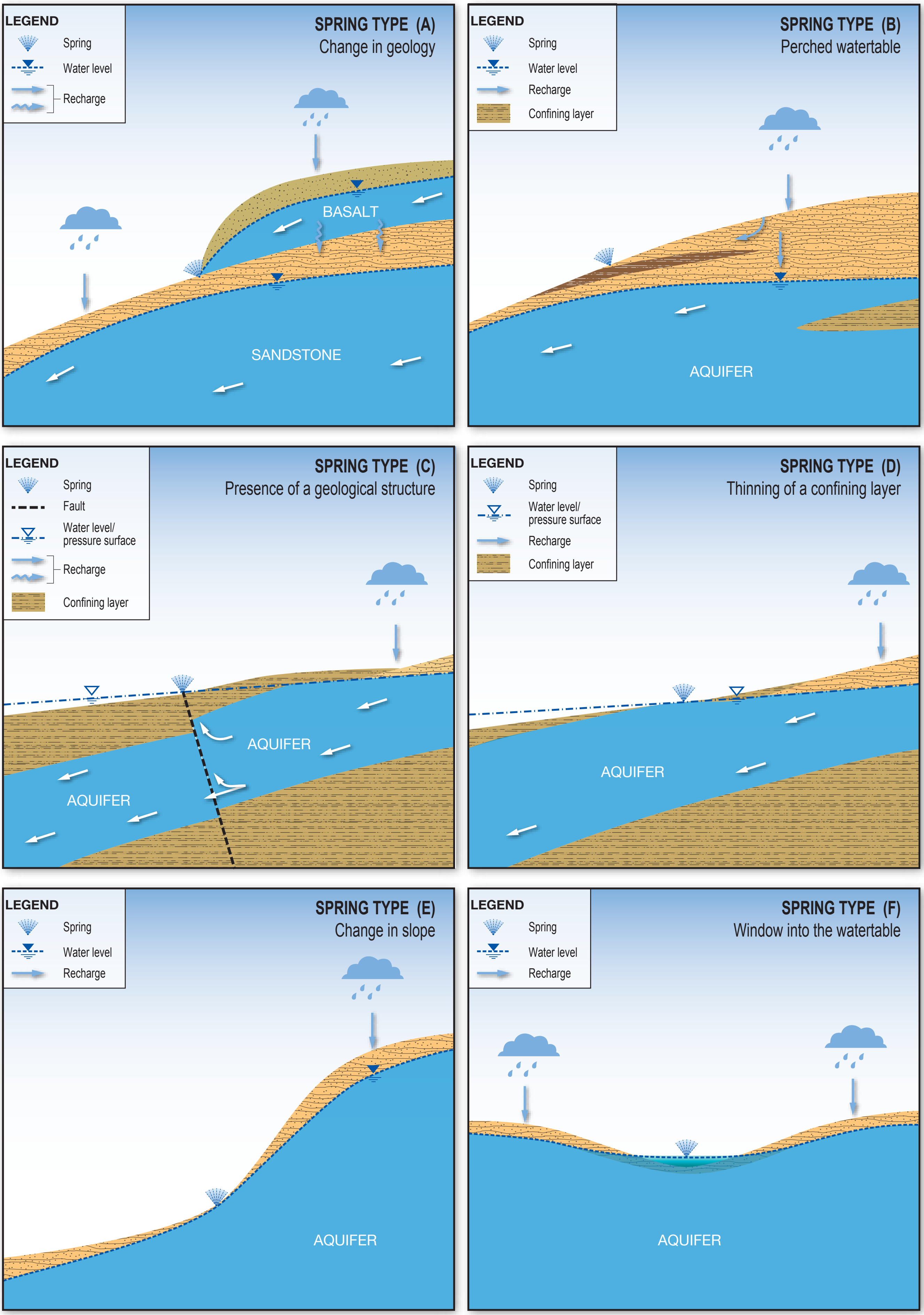
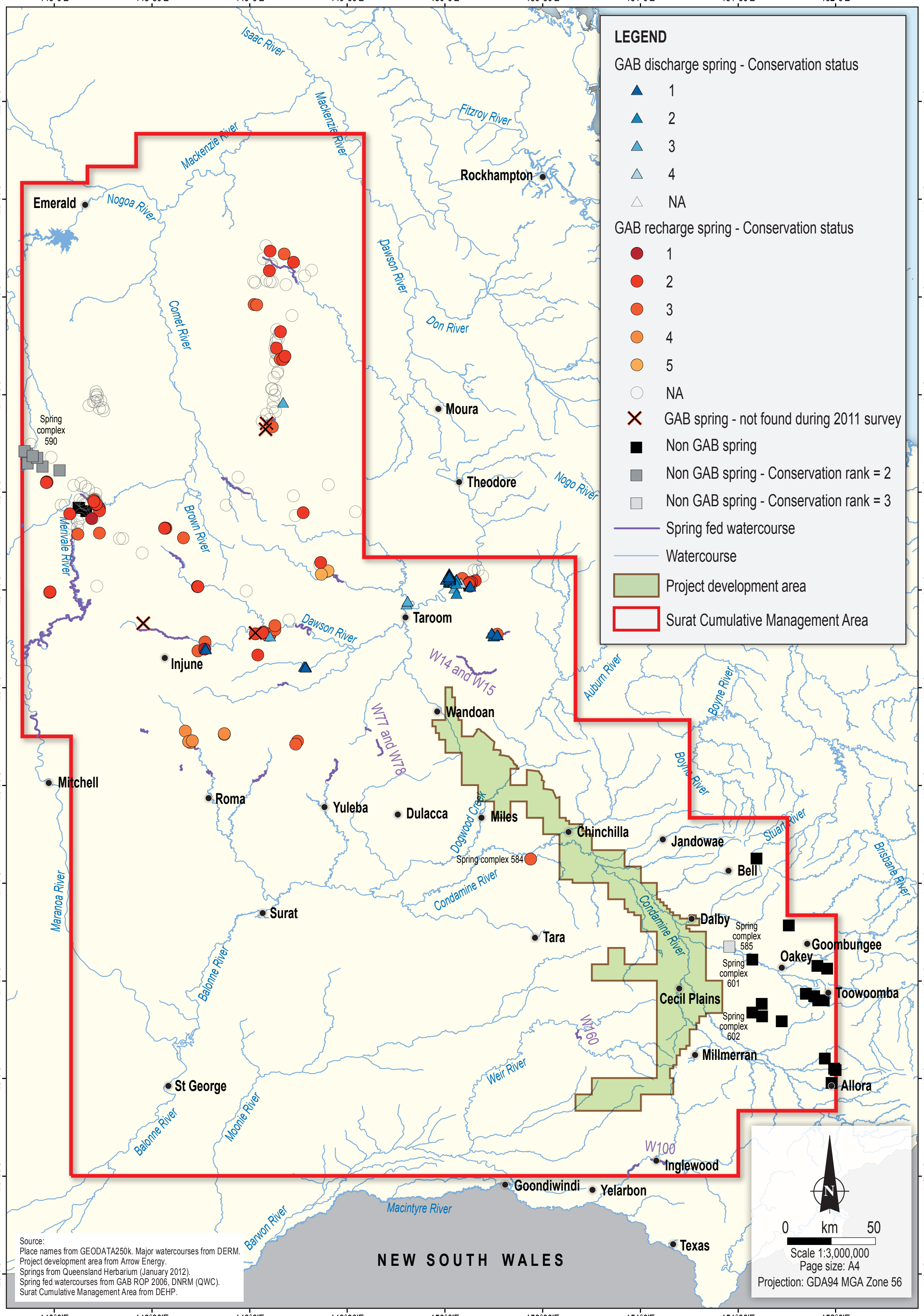


Source: QWC (2012) Figure 8-1

coffey environments	Date: 03.06.2013	Arrow Energy	arrow energy go further	Types of springs in the Surat CMA	Figure No: 5.4
	File Name: 7040_GW03_F05.04_HB	Surat Gas Project			



coffey environments

Date: 26.06.2013
MXD: 7040AF_GW03_GIS006_v1_4
File Name: 7040_GW03_F05.05_GIS_HU

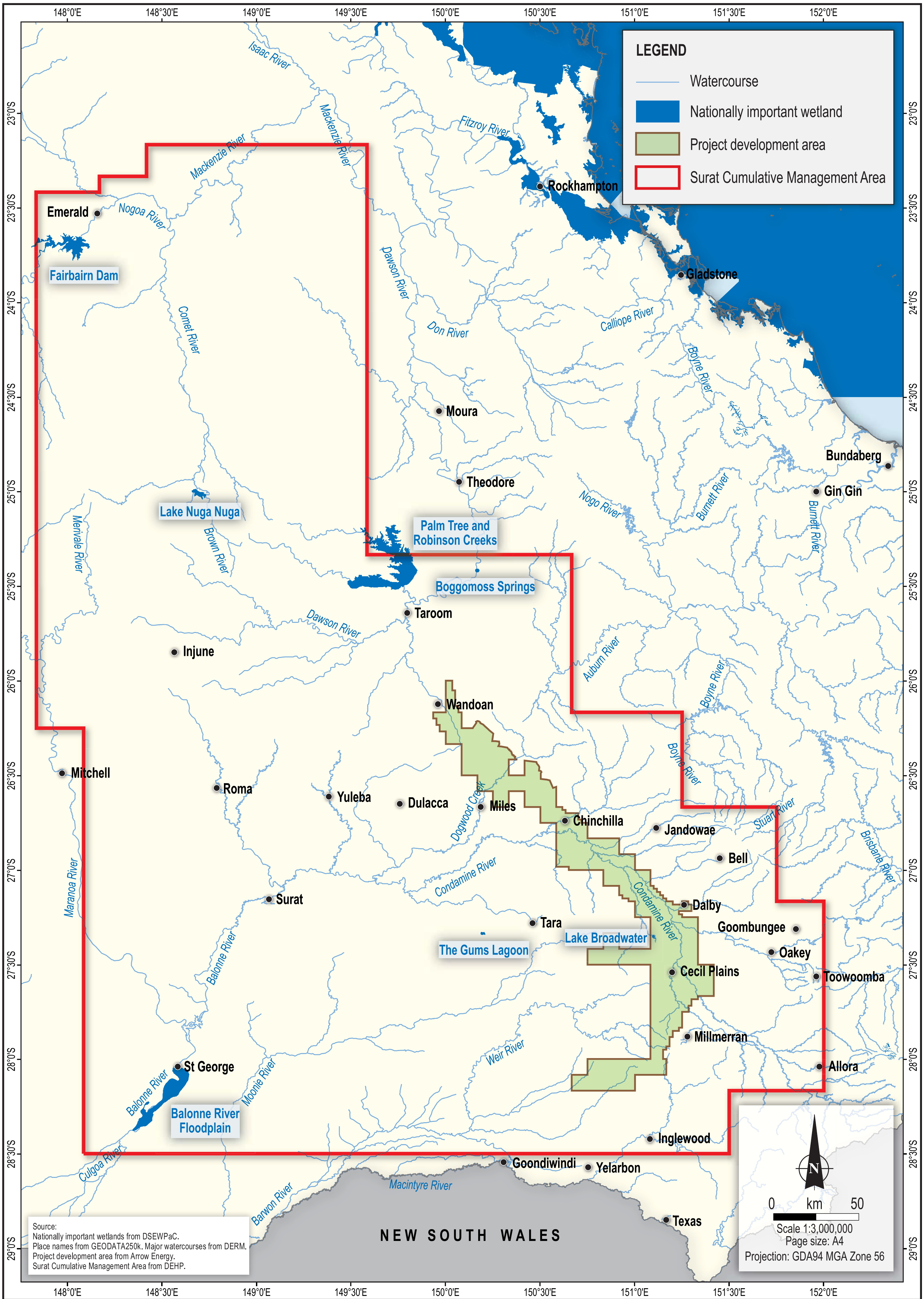
Arrow Energy

Surat Gas Project

arrow energy go further

Mapped spring vents and watercourse springs

Figure No: 5.5



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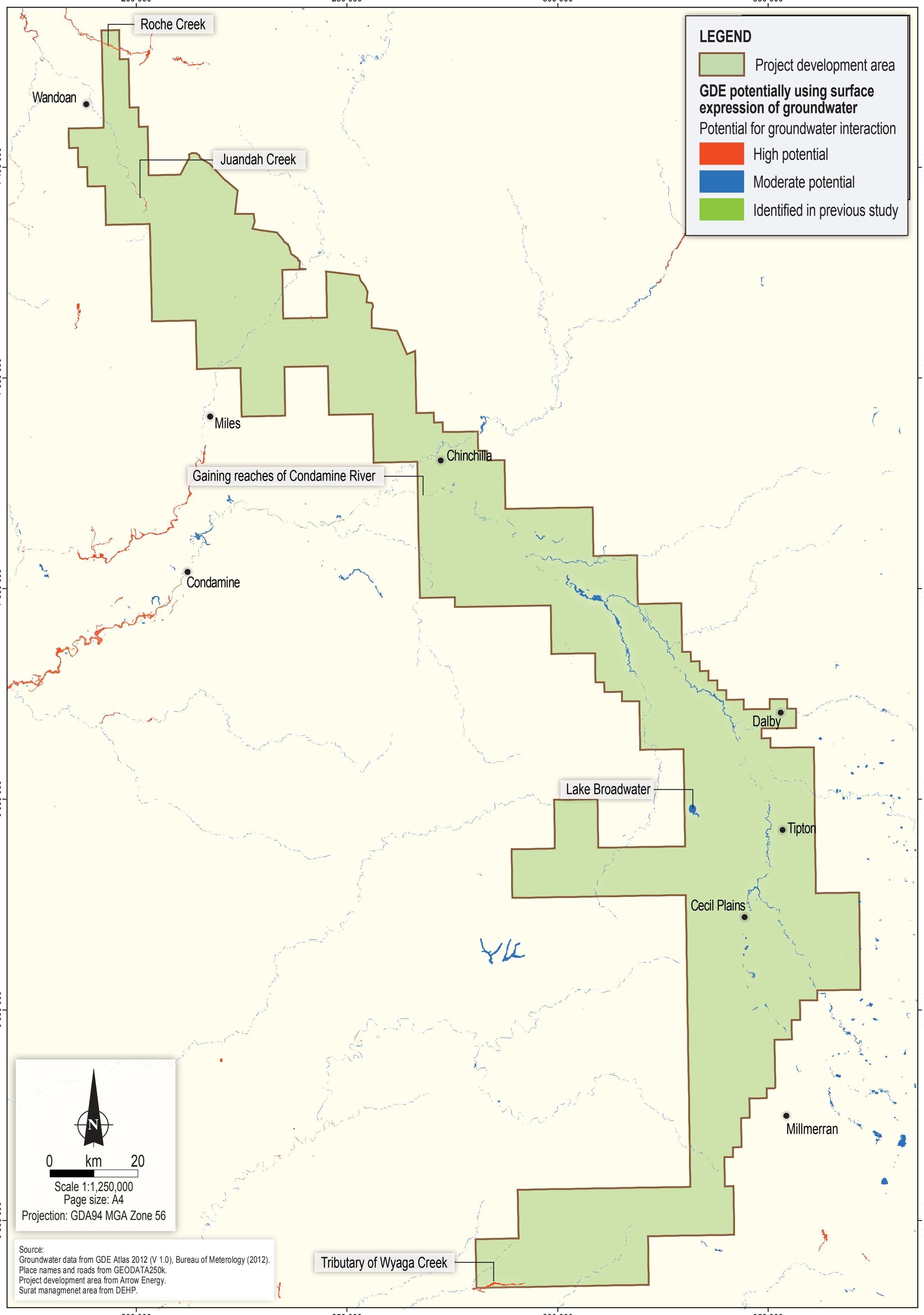
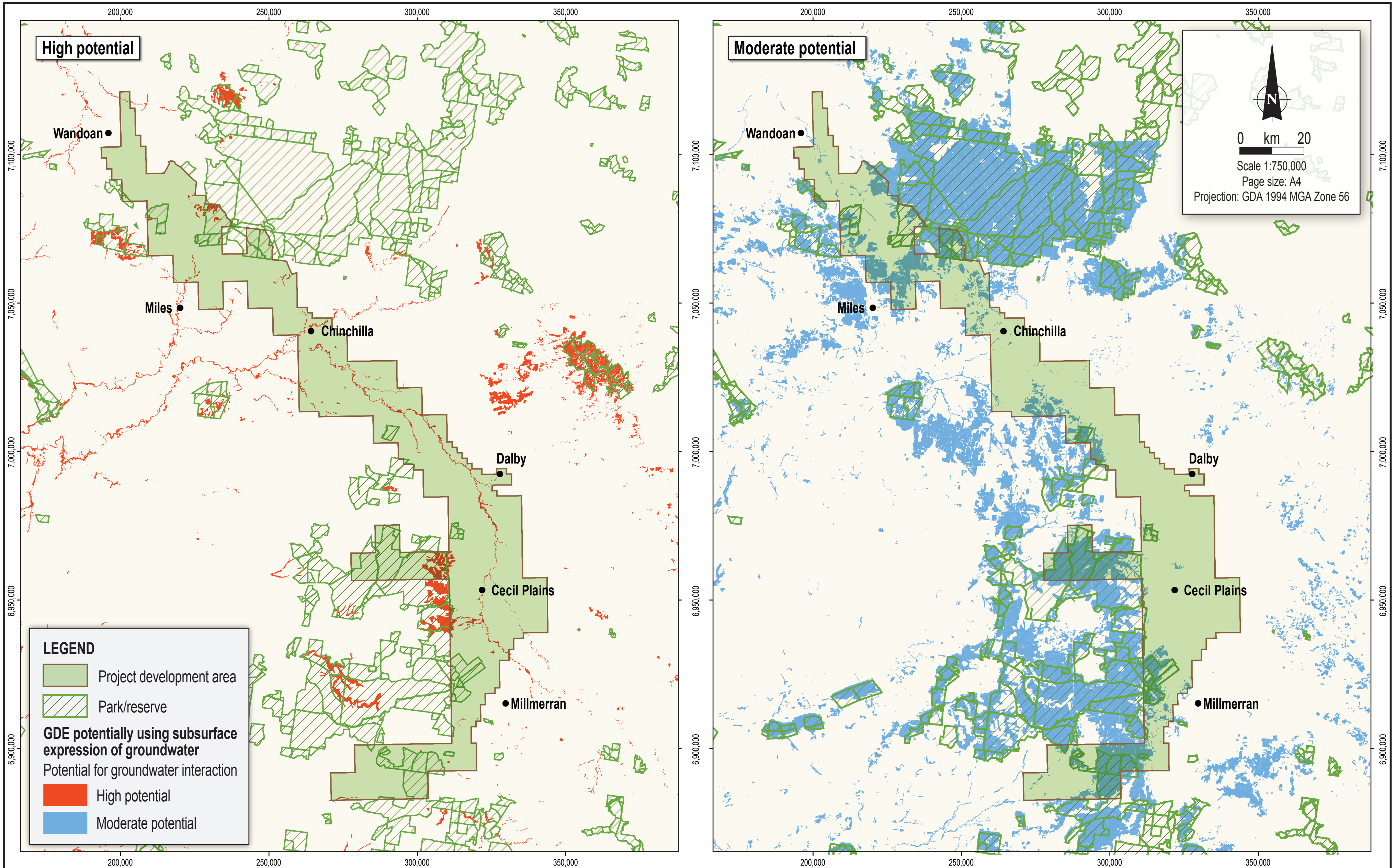


coffey environments	Date: 27.06.2013 MXD: 7040AF_GW03_GIS004_v1_3 File Name: 7040_GW03_F05.07_GIS_HU	Arrow Energy Surat Gas Project	arrow energy go further	Mapped GDEs potentially using surface expression of groundwater	Figure No: 5.7



Source:
Groundwater data from GDE Atlas 2012 (V 1.0), Bureau of Meterology (2012).
Place names from GEODATA250k.
Project development area from Arrow Energy.
Parks/reserves from DEHP.

coffey environments

Date: 27.06.2013
MXD: 7040AF_GW03_GIS083_v1_1
File Name: 7040_GW03_F05.08_GIS_GL

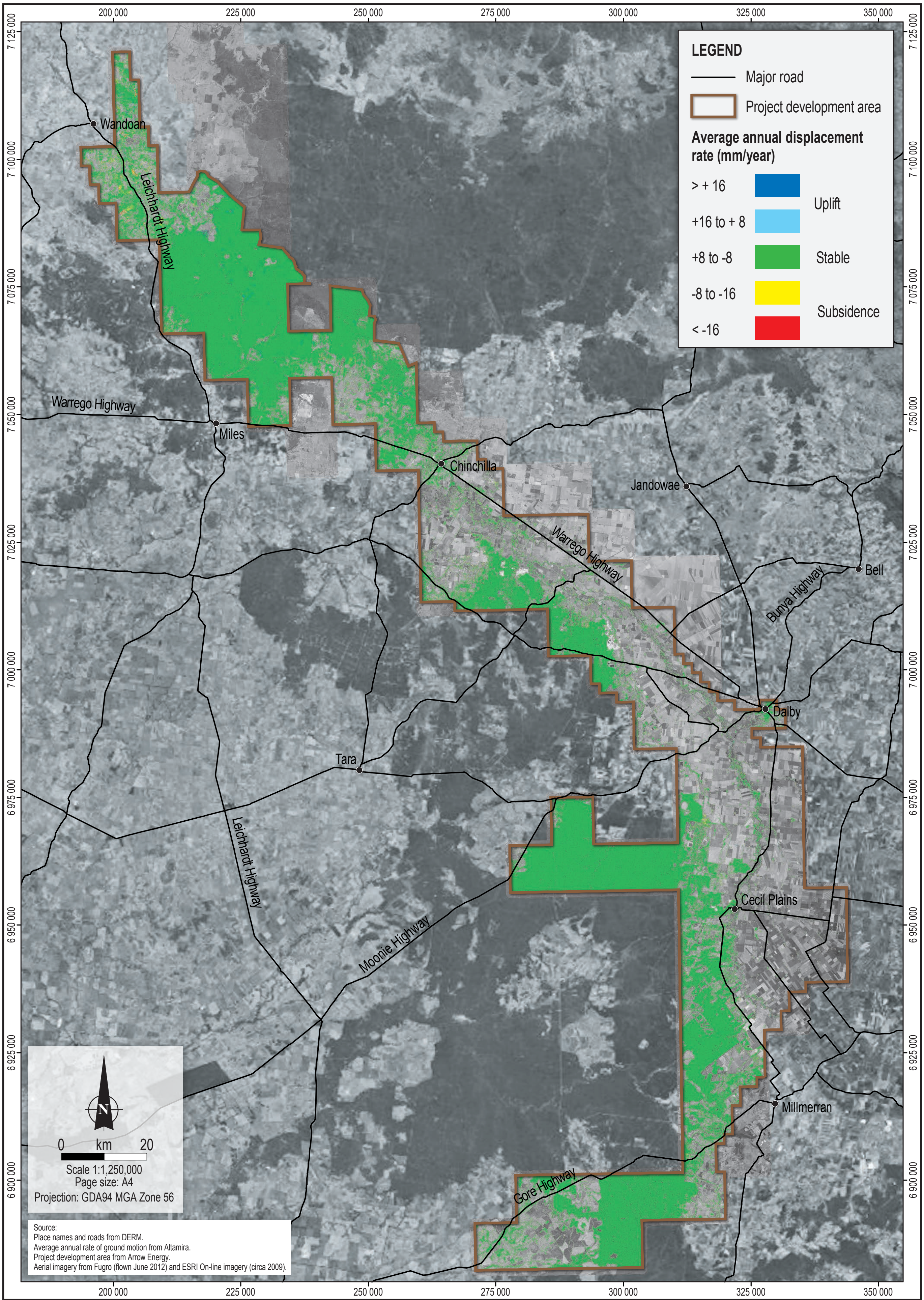
Arrow Energy

Surat Gas Project

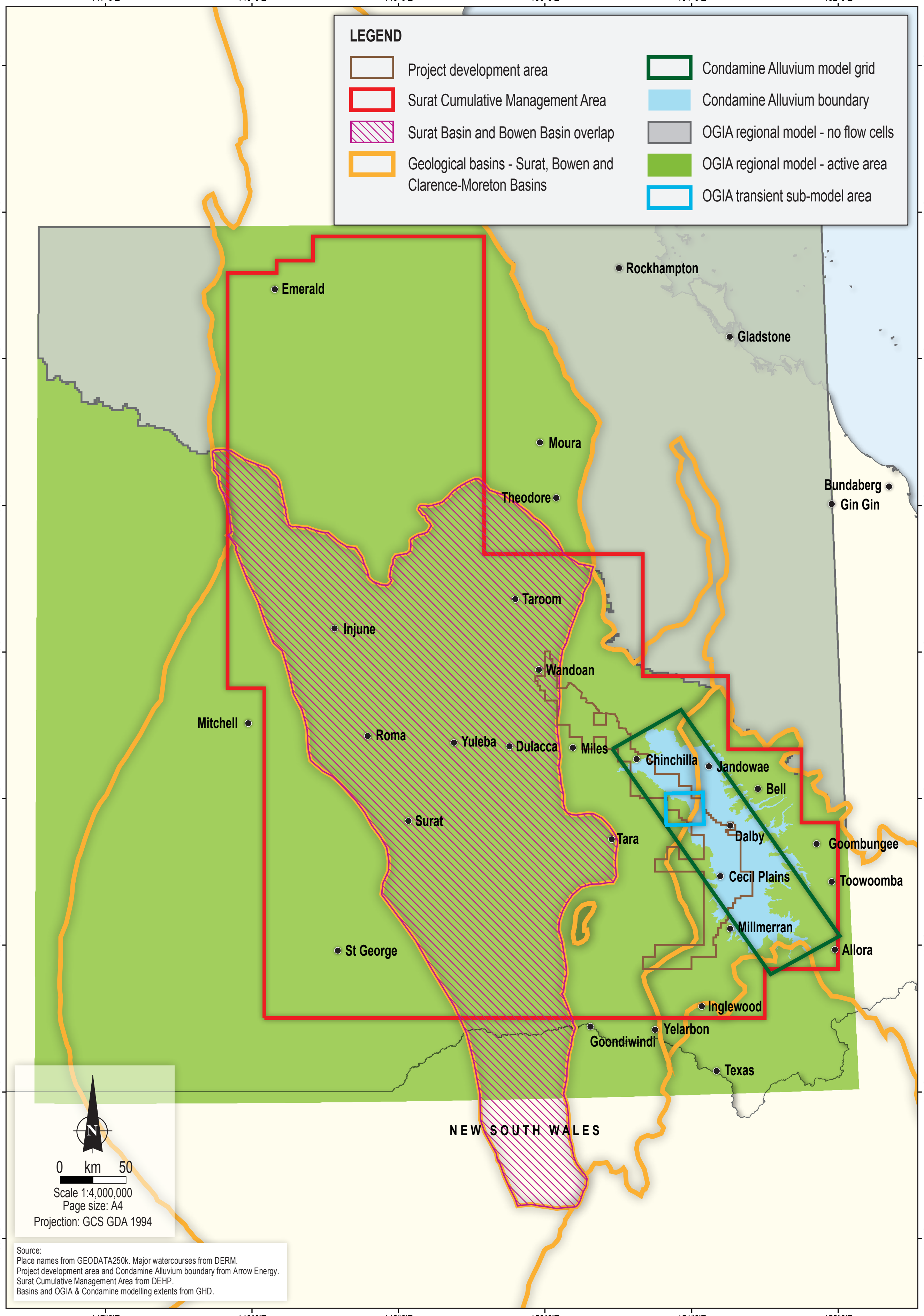
arrow energy go further

Mapped GDEs potentially using subsurface presence of groundwater

Figure No: 5.8

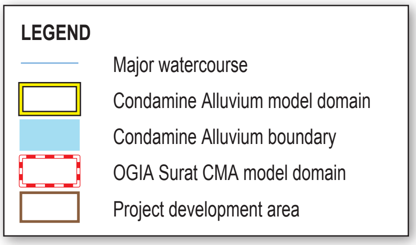


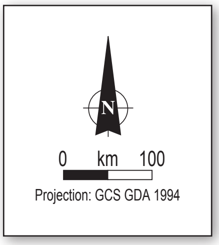
coffey environments	Date: 12.06.2013 MXD: 7040AF_GW03_GIS012_v1_3 File Name: 7040_GW03_F05.09_GIS_JO	Arrow Energy Surat Gas Project	arrow energy go further	Historical average annual rate of ground motion within the project development area (2006 to 2011)	Figure No: 5.9

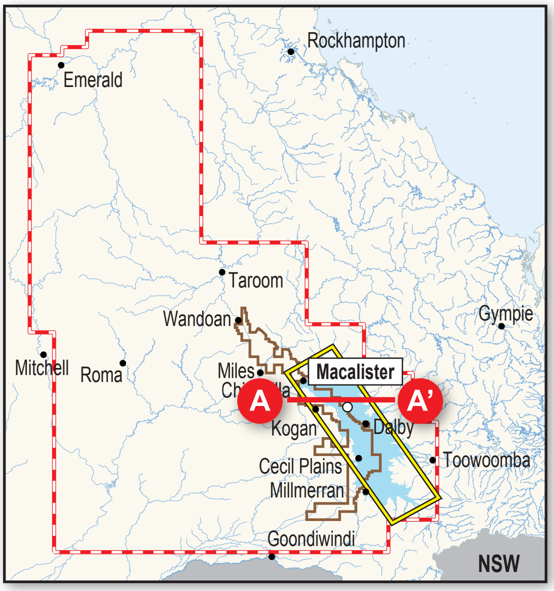


Source:
Place names from GEODATA250k. Major watercourses from DERM.
Project development area and Condamine Alluvium boundary from Arrow Energy.
Surat Cumulative Management Area from DEHP.
Basins and OGIA & Condamine modelling extents from GHD.

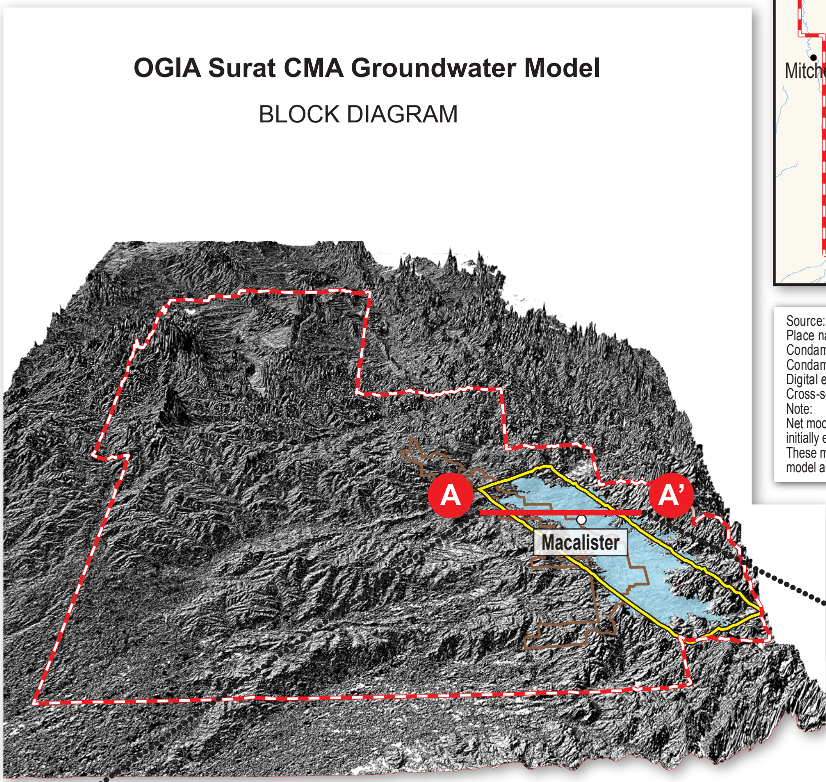
coffey environments	Date: 24.06.2013 MXD: 7040AF_GW03_GIS013_v1_1 File Name: 7040_GW03_F06.01_GIS_VS	Arrow Energy Surat Gas Project	arrow energy go further	Groundwater model extents	Figure No: 6.1

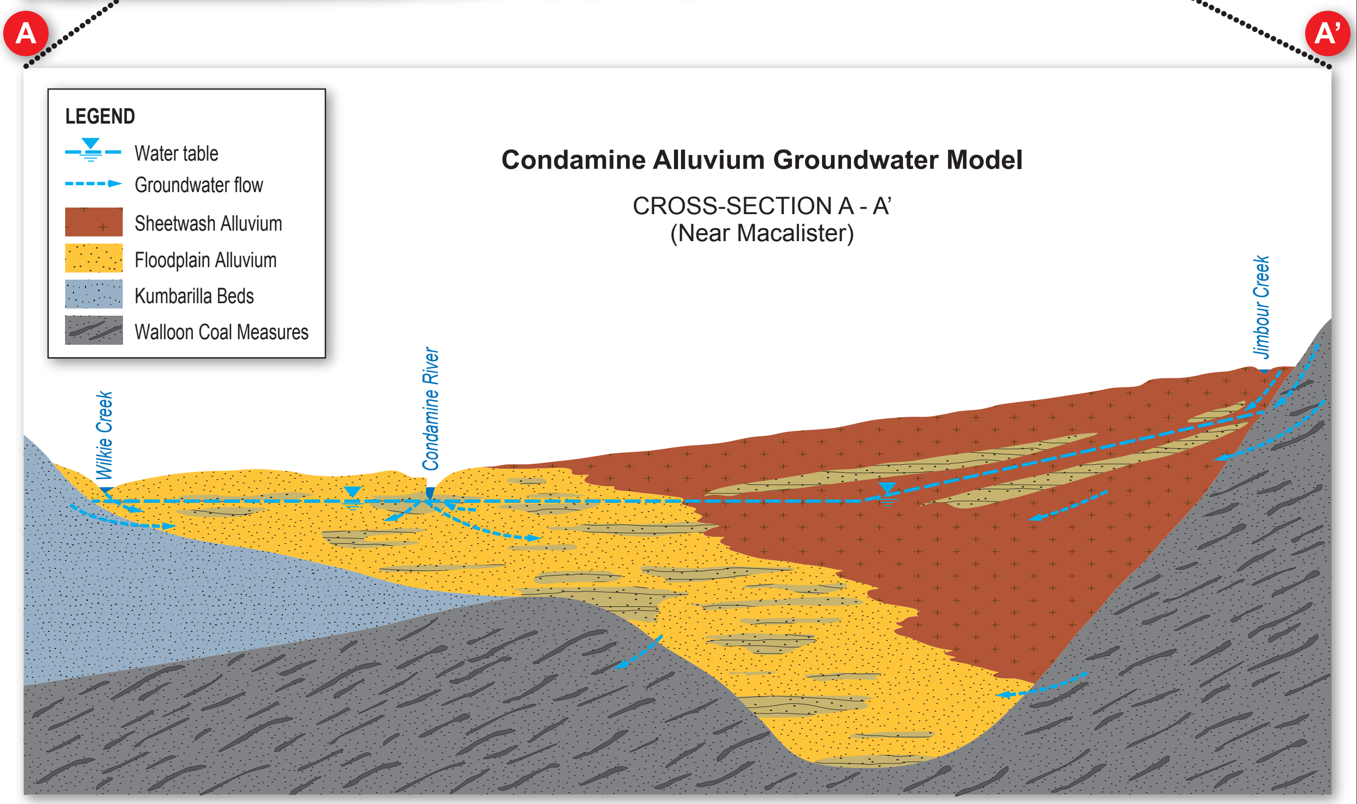






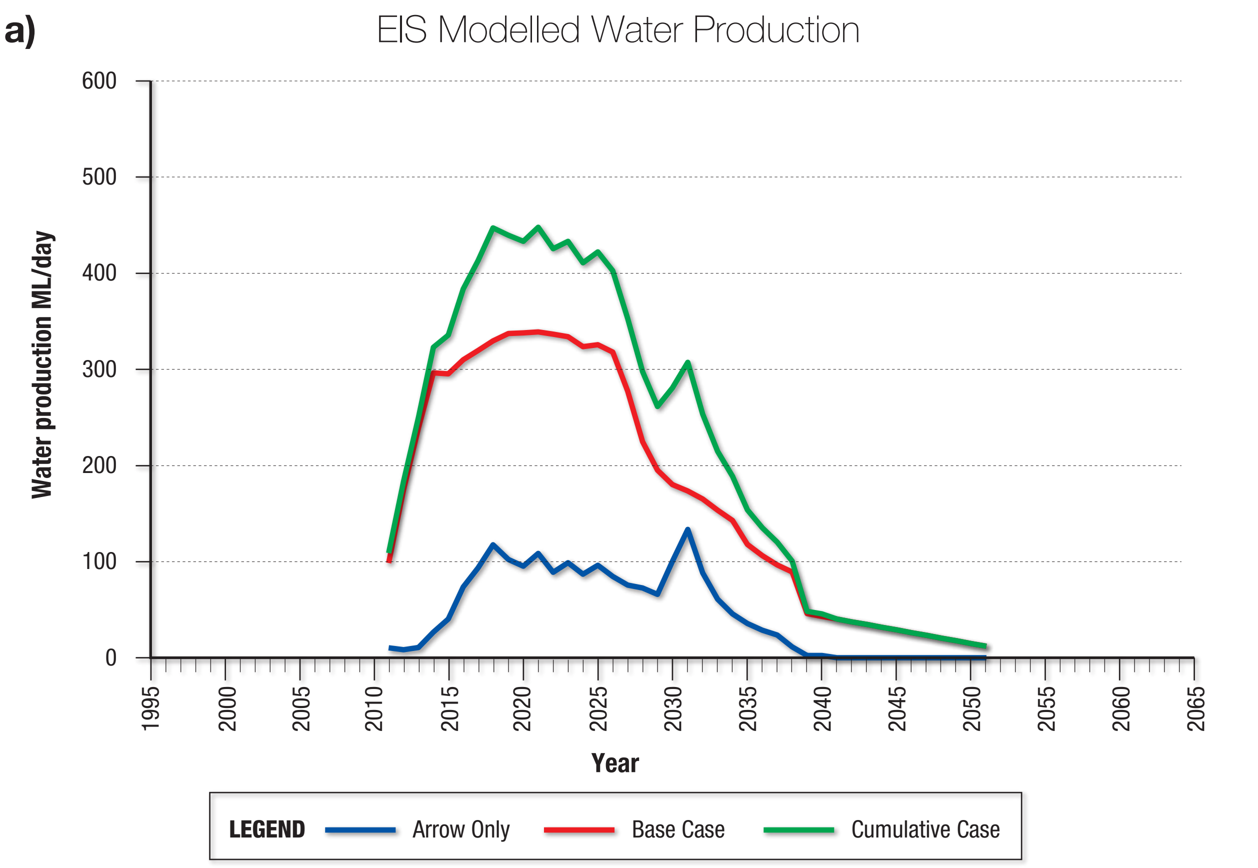
Source:
Place names and watercourses from DERM. Surat CMA from EHP.
Condamine Alluvium boundary and project development area from Arrow Energy.
Condamine alluvium model grid derived from Klohn Crippen Berger report (indicative boundary only).
Digital elevation model from Commonwealth of Australia (Geoscience Australia) 2011.
Cross-section from Huxley (1982).
Note:
Net modelled interlayer fluxes between the Condamine alluvial aquifer and the underlying strata are initially extracted from the OGIA Surat CMA groundwater model.
These modelled flows are then incorporated into the more detailed Condamine Alluvium groundwater model and used to calculate P&G and non-P&G related impacts.



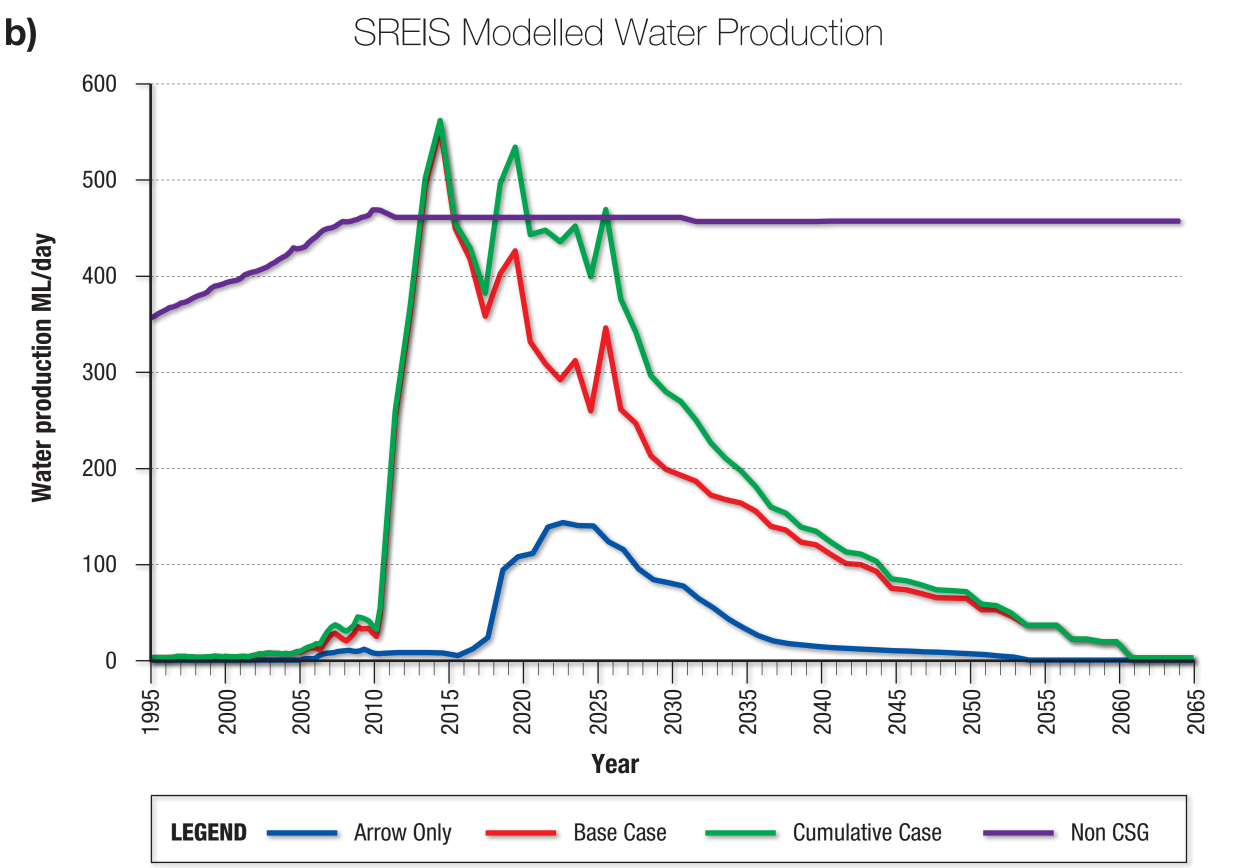


coffey environments	Date: 26.06.2013 MXT: 7040AF_GW03_GIS011_v0_3 File Name: 7040_GW03_F06.02_GIS_HB	Arrow Energy Surat Gas Project	arrow energy go further	Schematic of model linkages	Figure No: 6.2

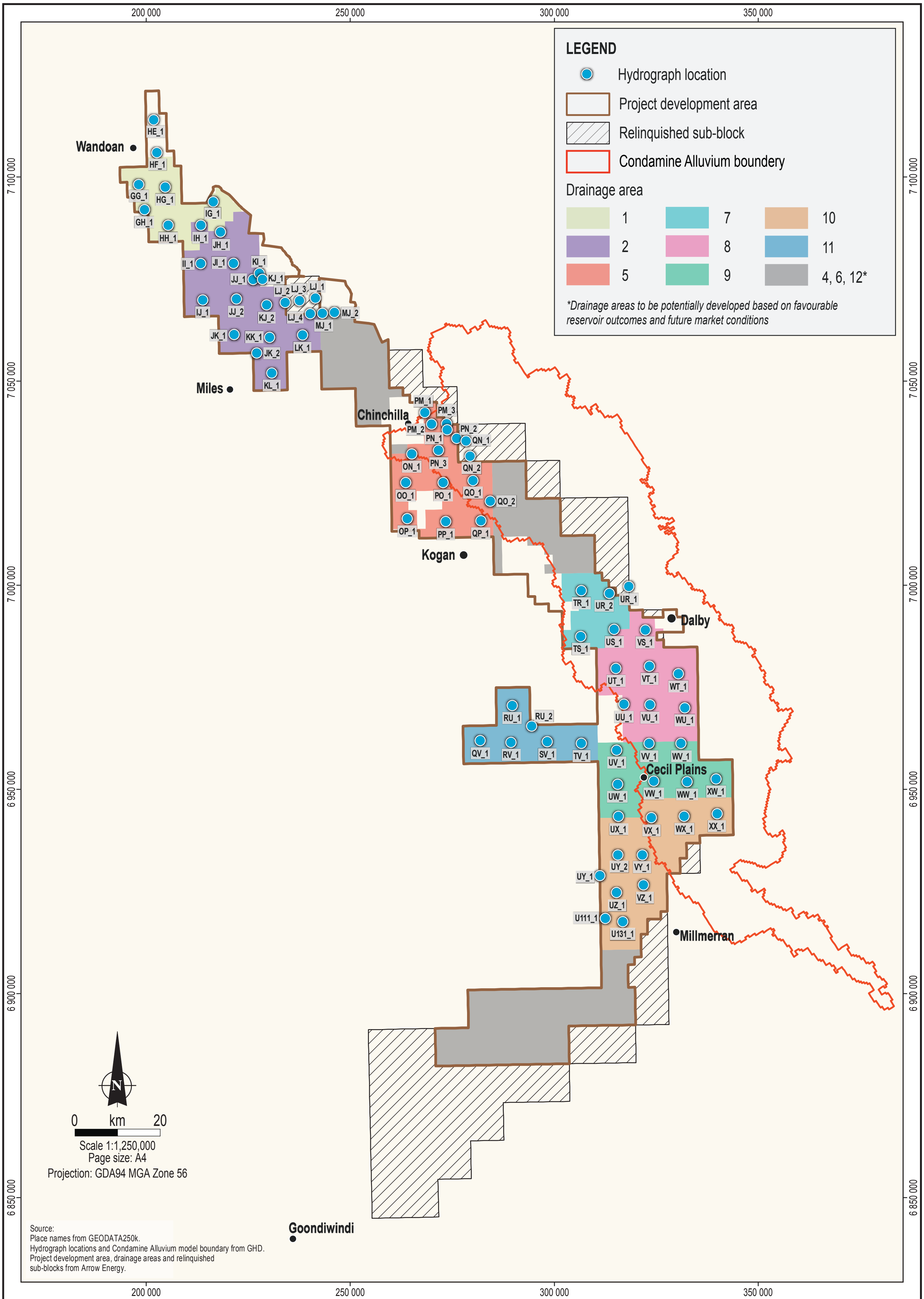
a)



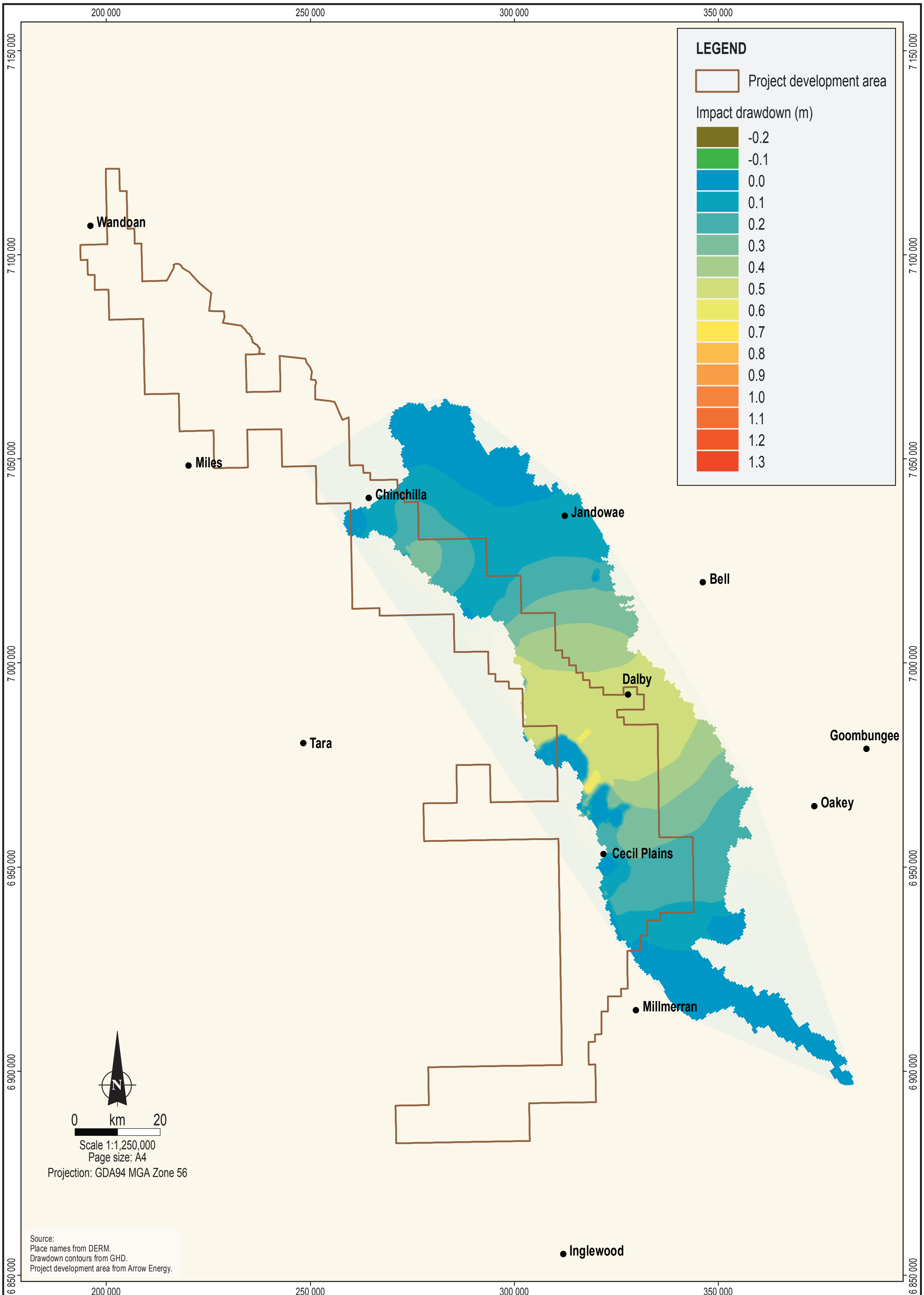
b)



coffey environments	Date: 26.06.2013 File Name: 7040_GW03_F06.03_HB	Arrow Energy Surat Gas Project	arrow energy go further	Modelled water extraction rates	Figure No: 6.3



coffey environments	Date: 20.06.2013 MXD: 7040AF_GW03_GIS015_v1_1 File Name: 7040_GW03_F07.01_GIS_HU	Arrow Energy Surat Gas Project	arrow energy go further	Arrow current development plan footprint and hydrograph locations	Figure No: 7.1



coffey environments

Date: 20.06.2013
MXD: 7040AF_GW03_GIS073_v1_2
File Name: 7040_GW03_F07.02_GIS_GL

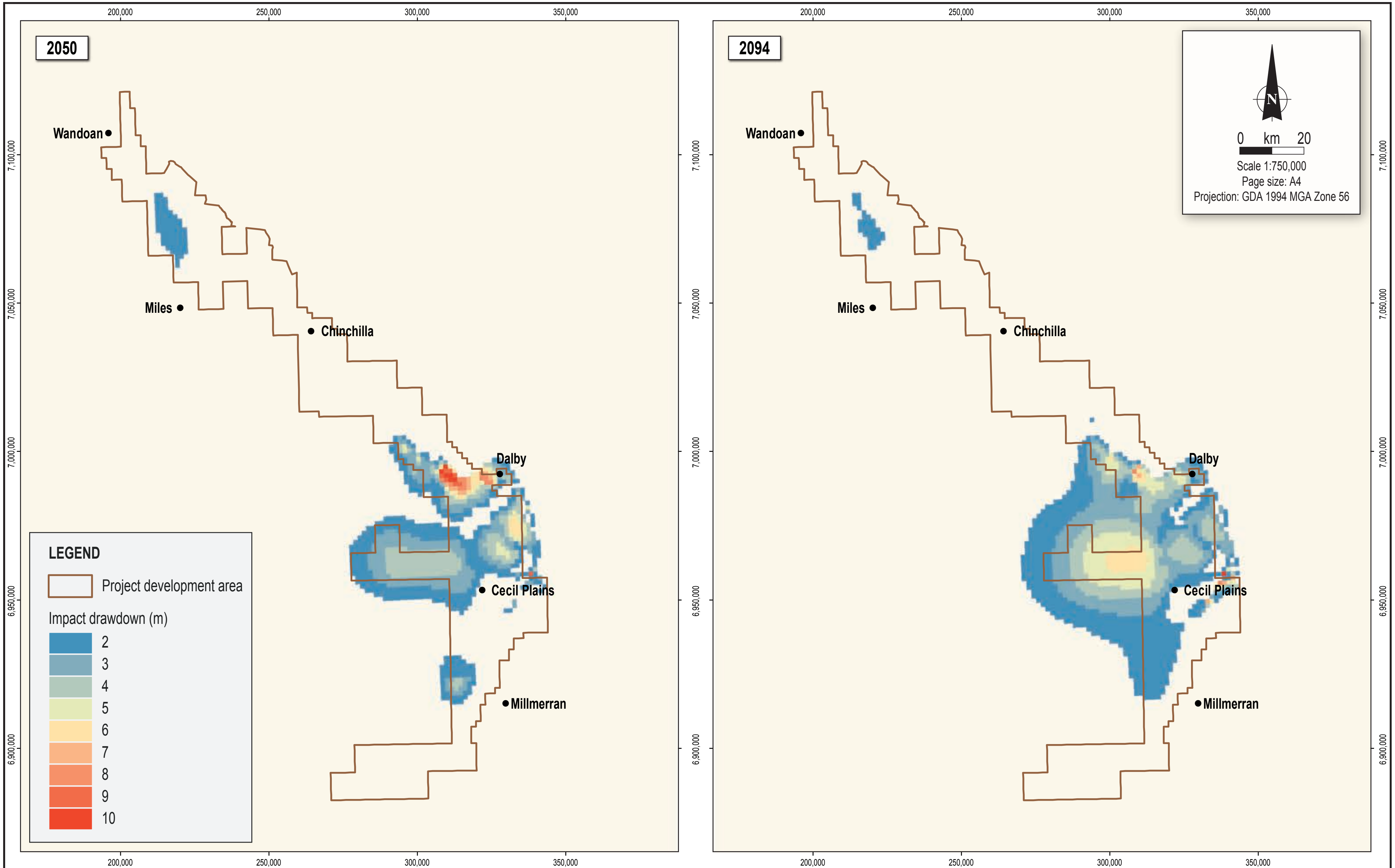
Arrow Energy

Surat Gas Project

arrow energy go further

Predicted Arrow impact drawdown after 120 years, Condamine Alluvium - calibration realisation

Figure No: 7.2



Source:
Place names from DERM.
Drawdown contours from GHD.
Project development area from Arrow Energy.

coffey environments

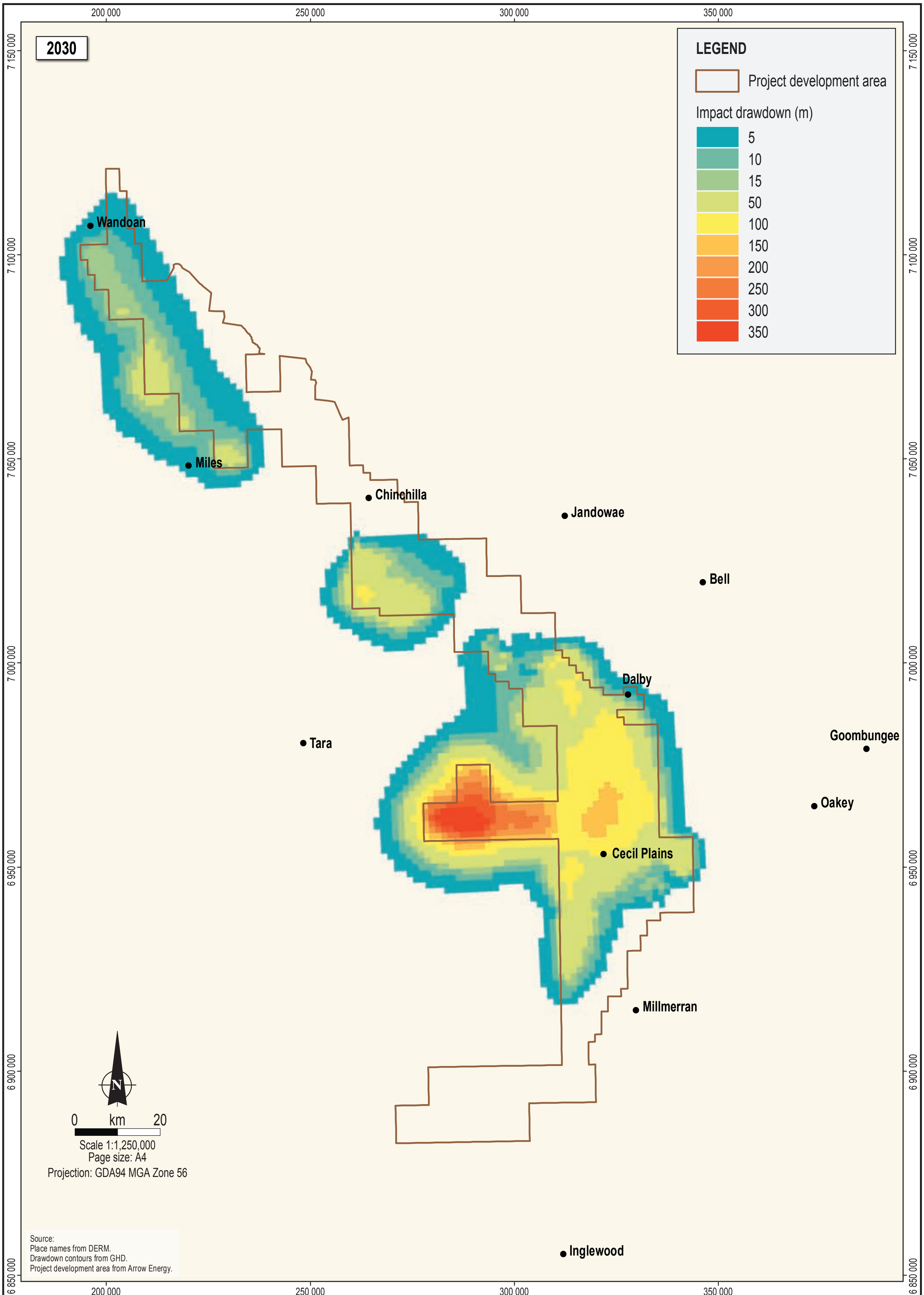
Date: 24.06.2013
MXD: 7040AF_GW03_GIS081_v1_2
File Name: 7040_GW03_F07.03_GIS_GL

Arrow Energy
Surat Gas Project

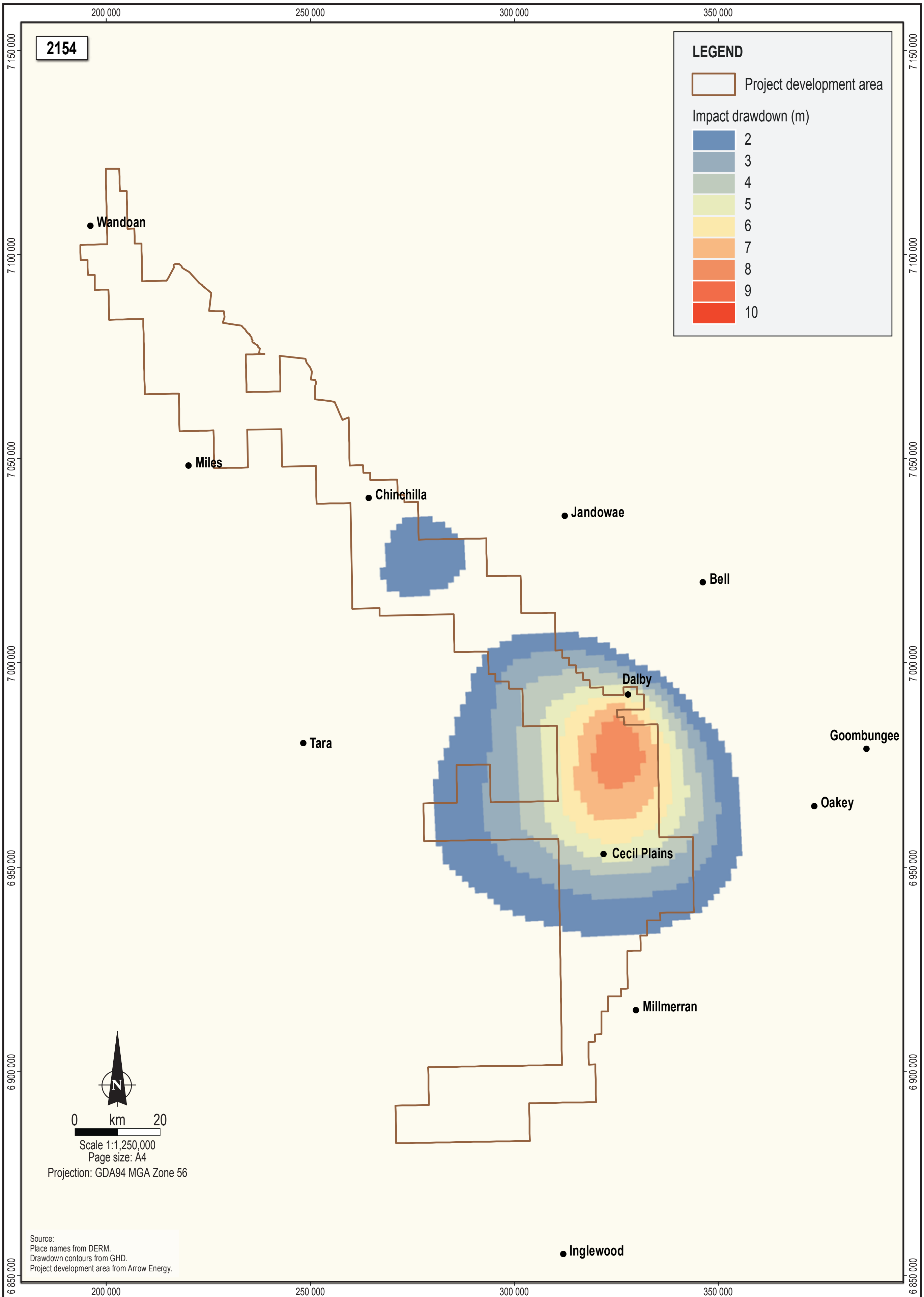
arrow energy go further

Predicted Arrow impact drawdown in the Springbok Sandstone – calibration realisation

Figure No: 7.3



coffey environments	Date: 24.06.2013 MXD: 7040AF_GW03_GIS079_v1_2 File Name: 7040_GW03_F07.04_GIS_GL	Arrow Energy Surat Gas Project	arrow energy go further	Predicted Arrow impact drawdown in the Walloon Coal Measures – calibration realisation	Figure No: 7.4



coffey environments

Date: 24.06.2013
MXD: 7040AF_GW03_GIS080_v1_2
File Name: 7040_GW03_F07.05_GIS_GL

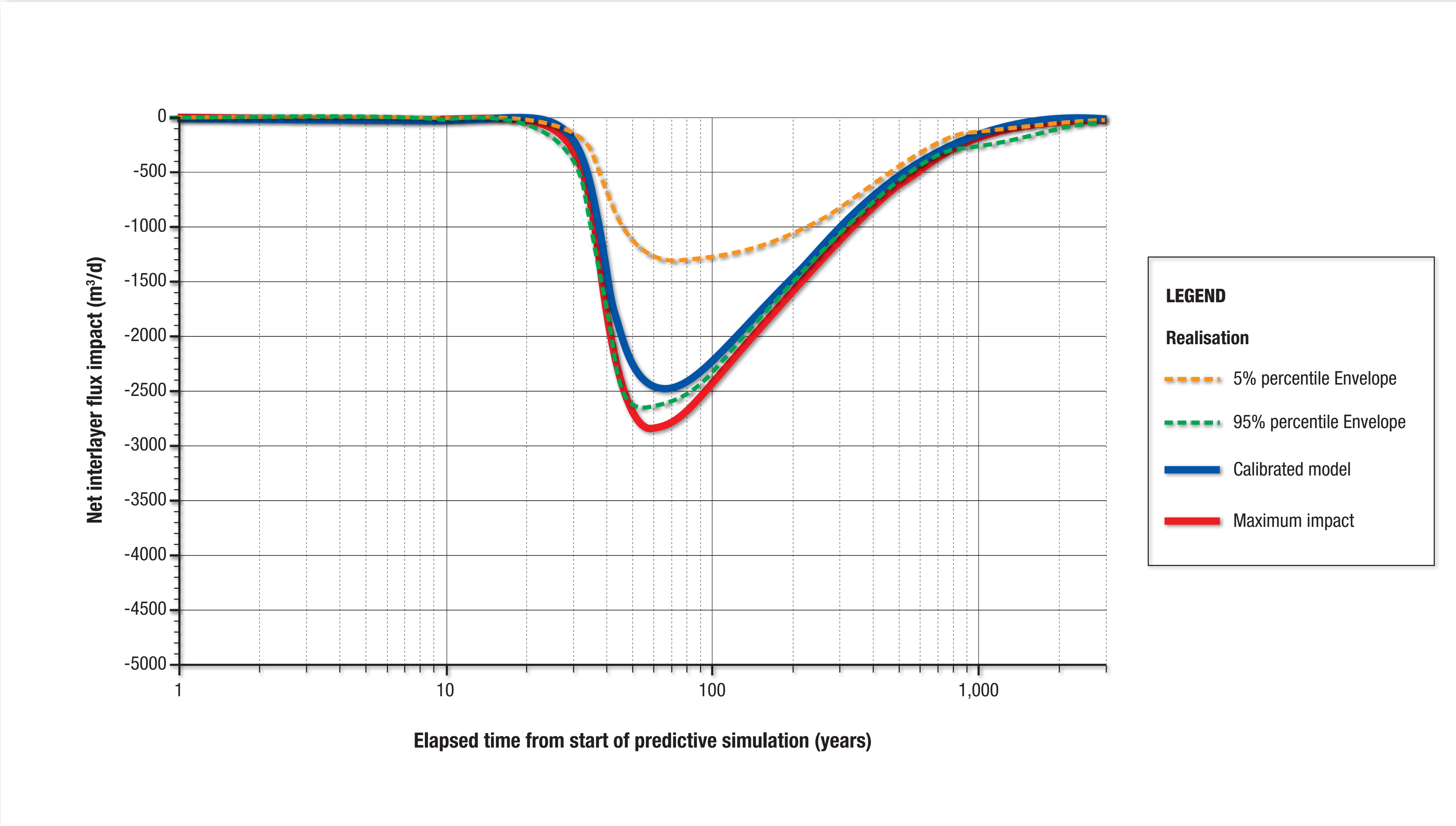
Arrow Energy

Surat Gas Project

arrow energy go further

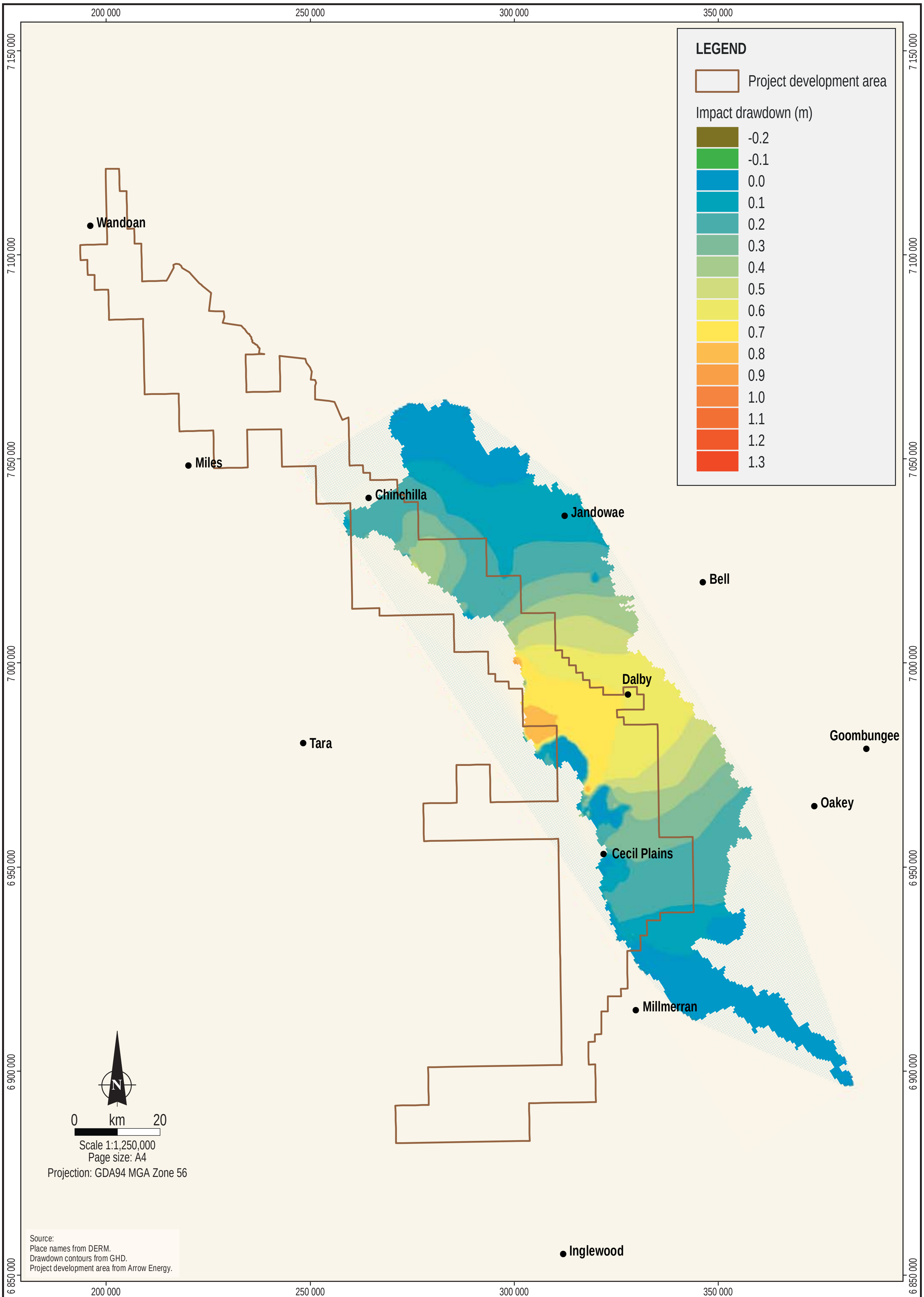
Predicted Arrow impact drawdown in the Hutton Sandstone - calibration realisation

Figure No: 7.5



Source: GHD, 2013.

coffey environments	Date: 26.06.2013	Arrow Energy	arrow energy go further	Interlayer flux Arrow impact – Condamine Alluvium
	File Name: 7040_GW03_F07.06_HB	Surat Gas Project		Figure No: 7.6



coffey environments

Date: 20.06.2013
MXD: 7040AF_GW03_GIS075_v1_2
File Name: 7040_GW03_F07.07_GIS_GL

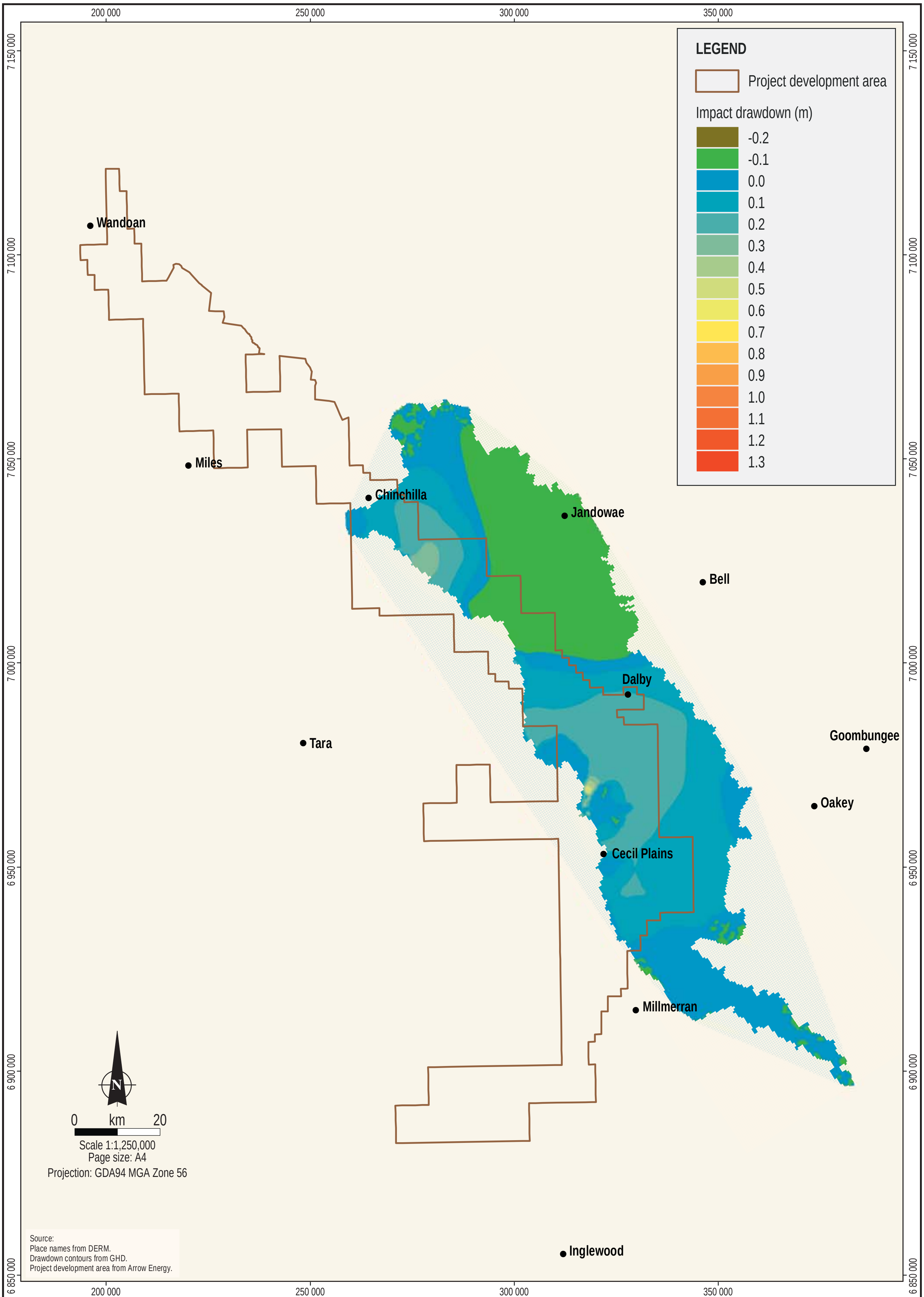
Arrow Energy

Surat Gas Project

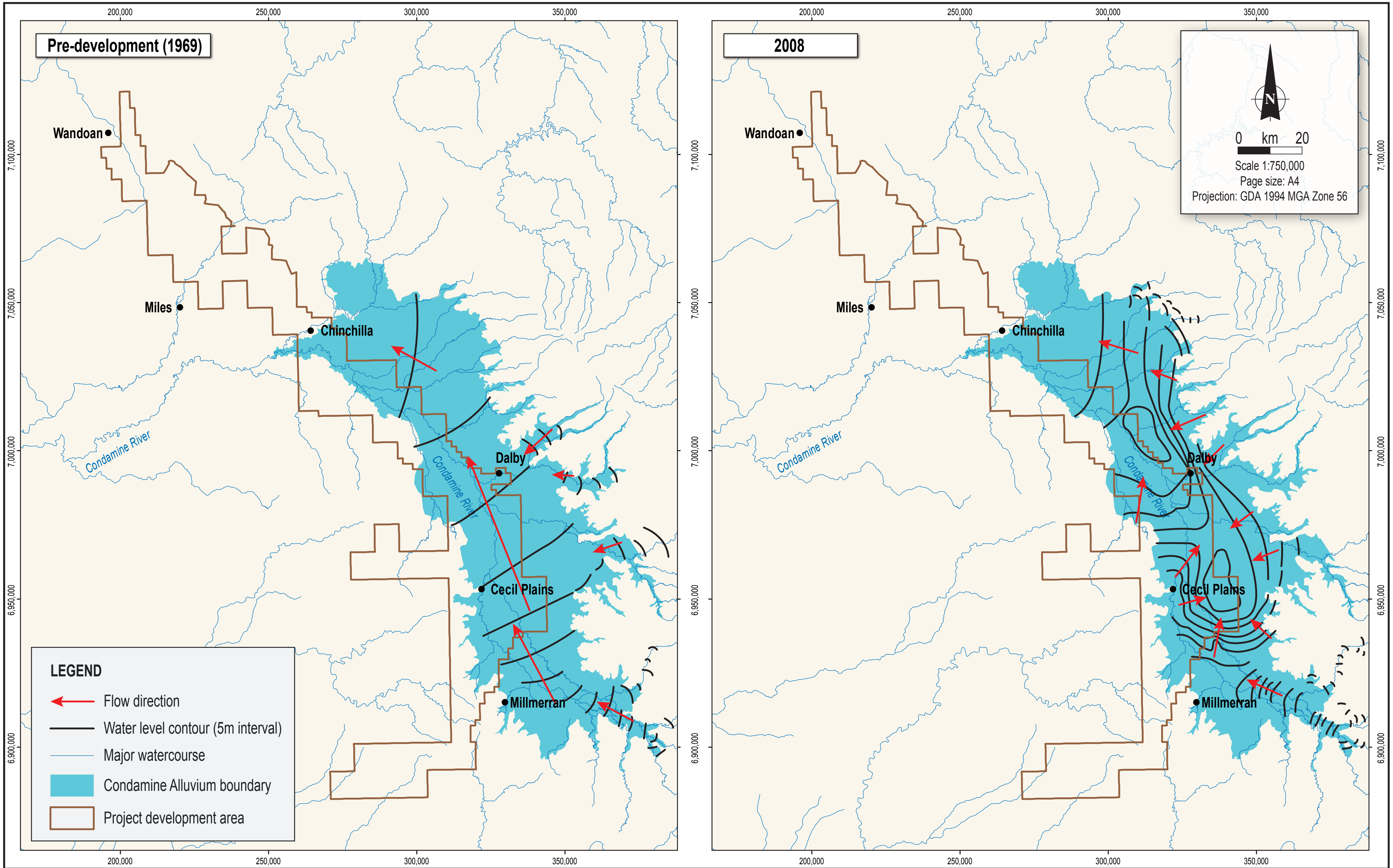
arrow energy go further

Predicted Cumulative impact drawdown after 120 years, Condamine Alluvium - calibration realisation

Figure No: 7.7



coffey environments	Date: 20.06.2013 MXD: 7040AF_GW03_GIS074_v1_2 File Name: 7040_GW03_F07.08_GIS_GL	Arrow Energy Surat Gas Project	arrow energy go further	Predicted Arrow impact drawdown after 120 years, Condamine Alluvium with substitution - calibration realisation	Figure No: 7.8



Source:
Place names from GEODATA250k. Watercourses from DERM.
Project development area and Condamine Alluvium boundary from Arrow Energy.
Water level contours and flow directions digitised from DNRM report
'Upper Condamine Alluviums groundwater systems background summary" (September, 2012).

coffey environments

Date: 27.06.2013
MXD: 7040AF_GW03_GIS082_v1_3
File Name: 7040_GW03_F07.09_GIS_GL

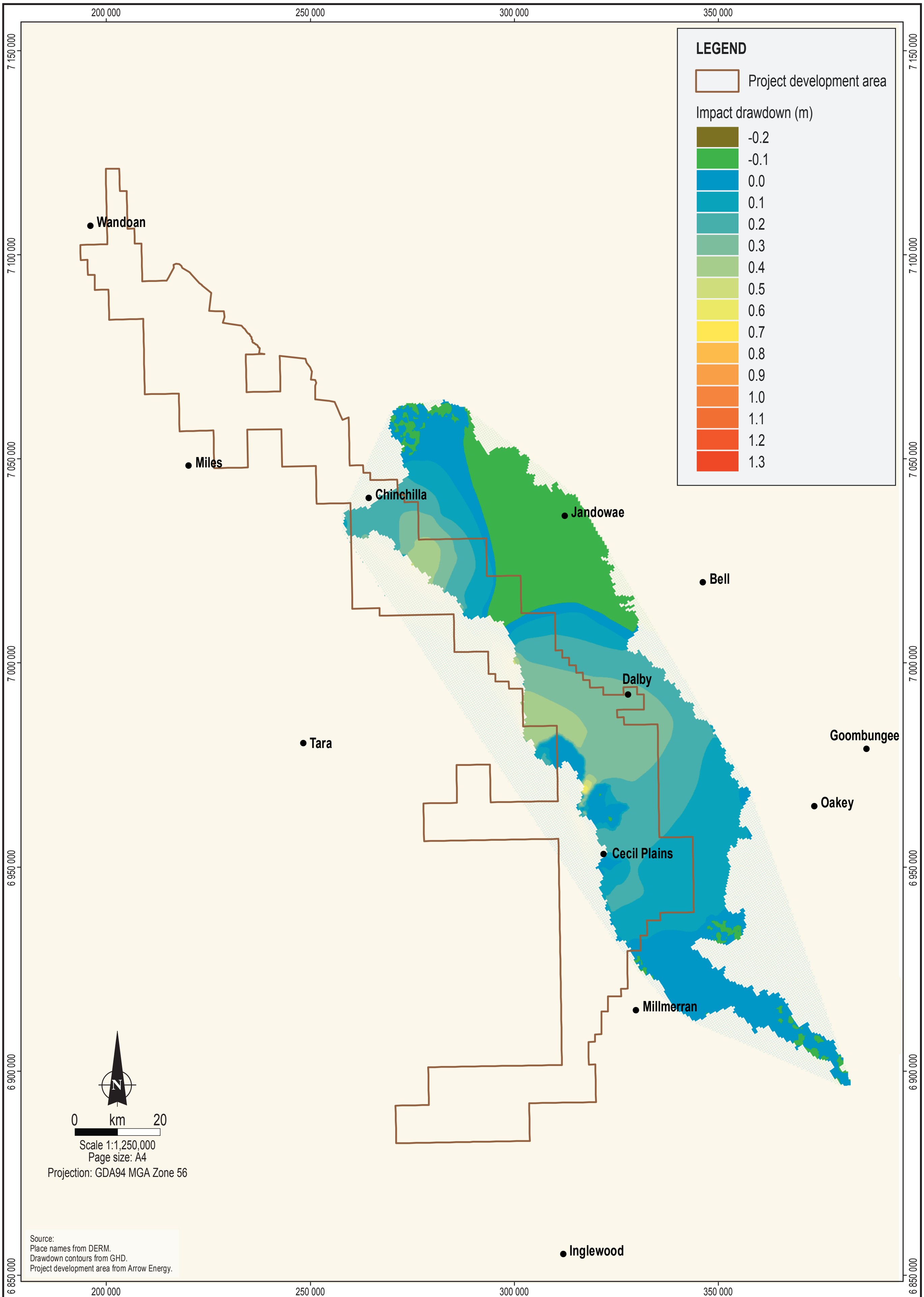
Arrow Energy

Surat Gas Project

arrow energy go further

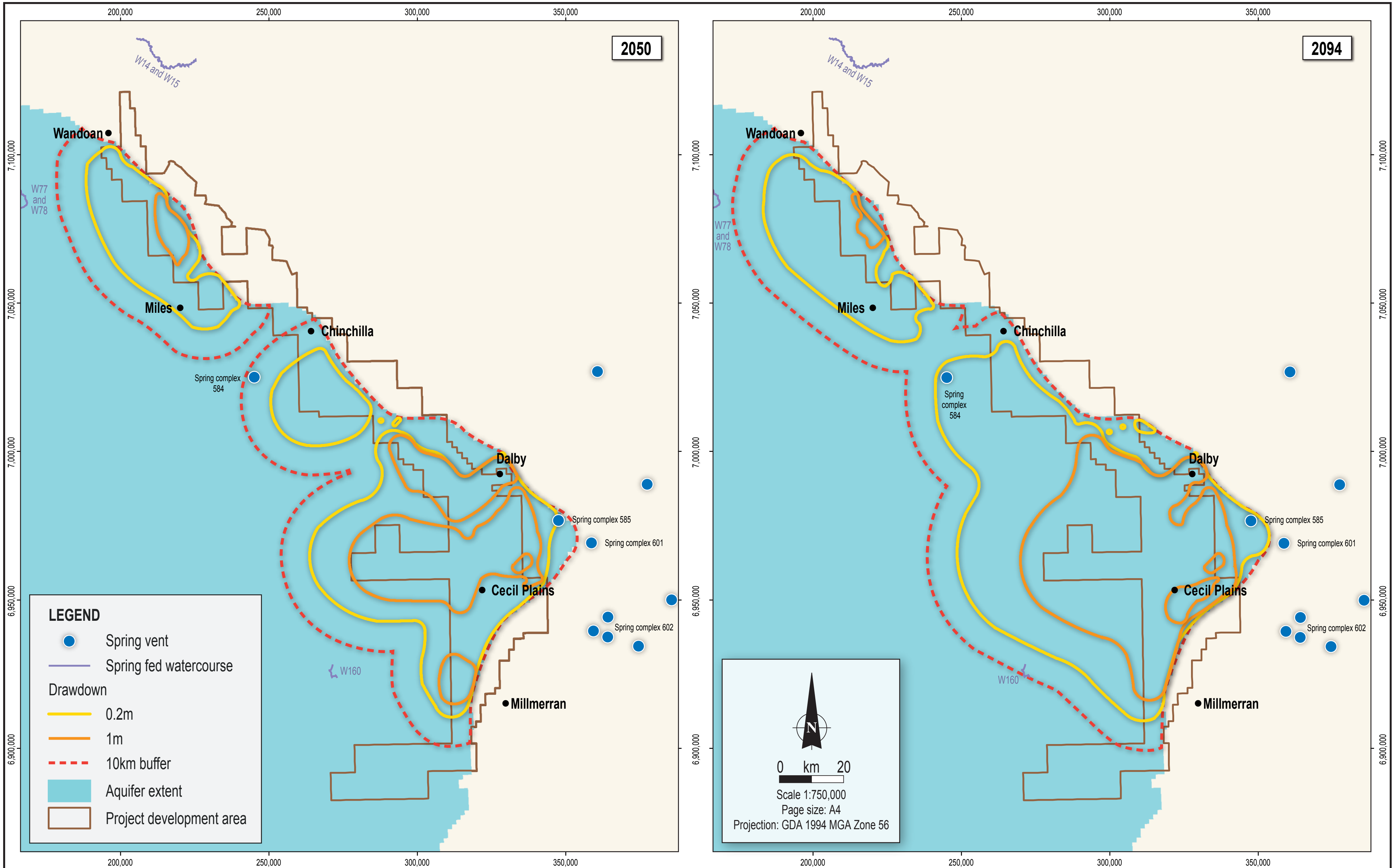
Potentiometric surface changes in the Condamine Alluvium

Figure No: 7.9



coffey environments

Date: 20.06.2013	Arrow Energy	arrow energy go further	Predicted Cumulative impact drawdown after 120 years, Condamine Alluvium with substitution– calibration realisation	Figure No: 7.10
MXD: 7040AF_GW03_GIS076_v1_2	Surat Gas Project			
File Name: 7040_GW03_F07.10_GIS_GL				



Source:
Place names from GEODATA250k.
Project development area from Arrow Energy.
Springs from Queensland Herbarium (January 2012).
Spring fed watercourses from GAB ROP 2006, DNRM (QWC).
Drawdown extents from Coffey, derived from GHD aquifer modelling.

coffey environments

Date: 27.06.2013
MXD: 7040AF_GW03_GIS085_v1_3
File Name: 7040_GW03_F08.01_GIS_VS

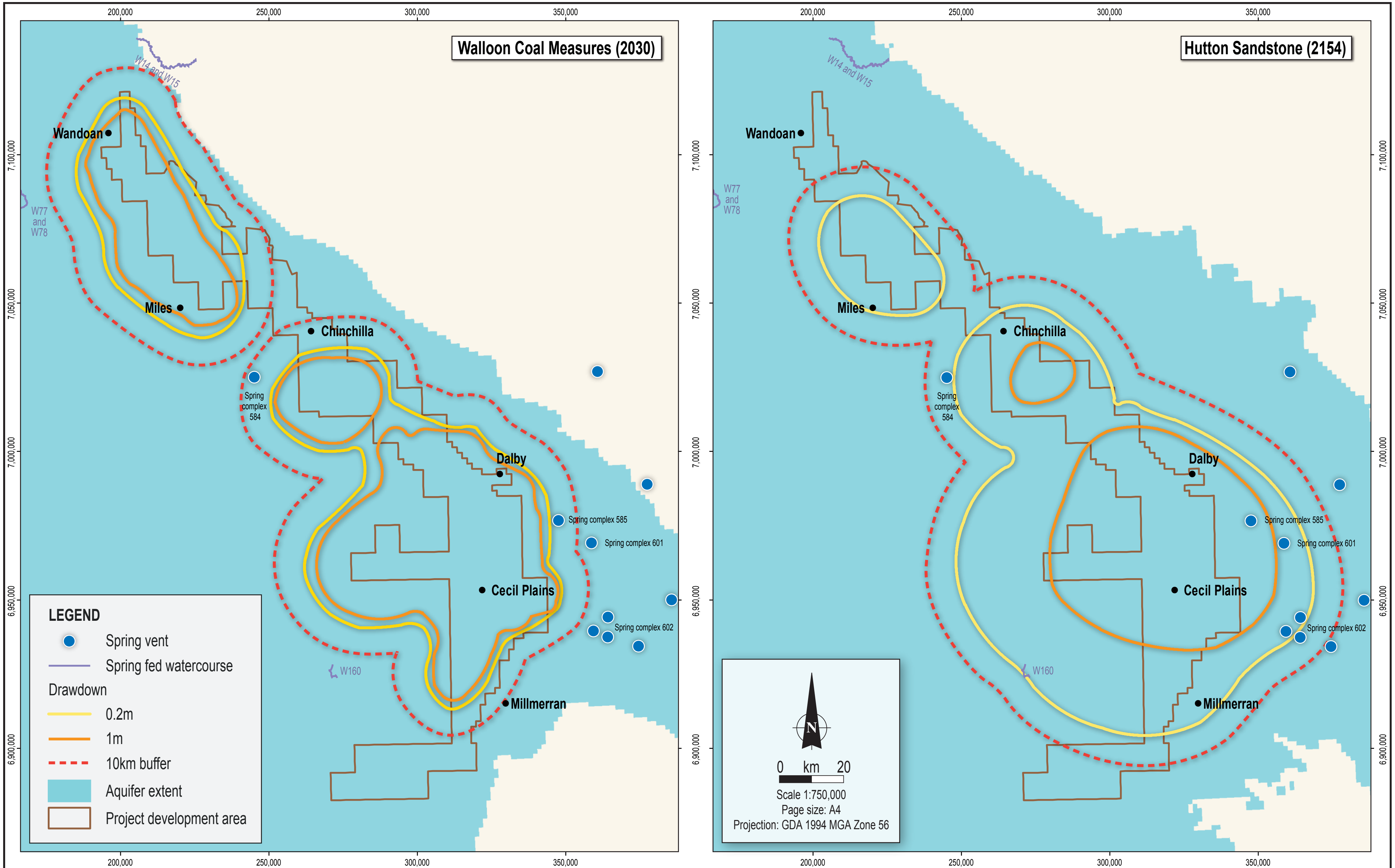
Arrow Energy

Surat Gas Project

arrow energy go further

GDE assessment drawdown extents including buffer zones Springbok Sandstone

Figure No: 8.1



Source:
Place names from GEODATA250k.
Project development area from Arrow Energy.
Springs from Queensland Herbarium (January 2012).
Spring fed watercourses from GAB ROP 2006, DNRM (QWC).
Drawdown extents from Coffey, derived from GHD modelling.

coffey environments

Date: 26.06.2013
MXD: 7040AF_GW03_GIS086_v1_2
File Name: 7040_GW03_F08.02_GIS_VS

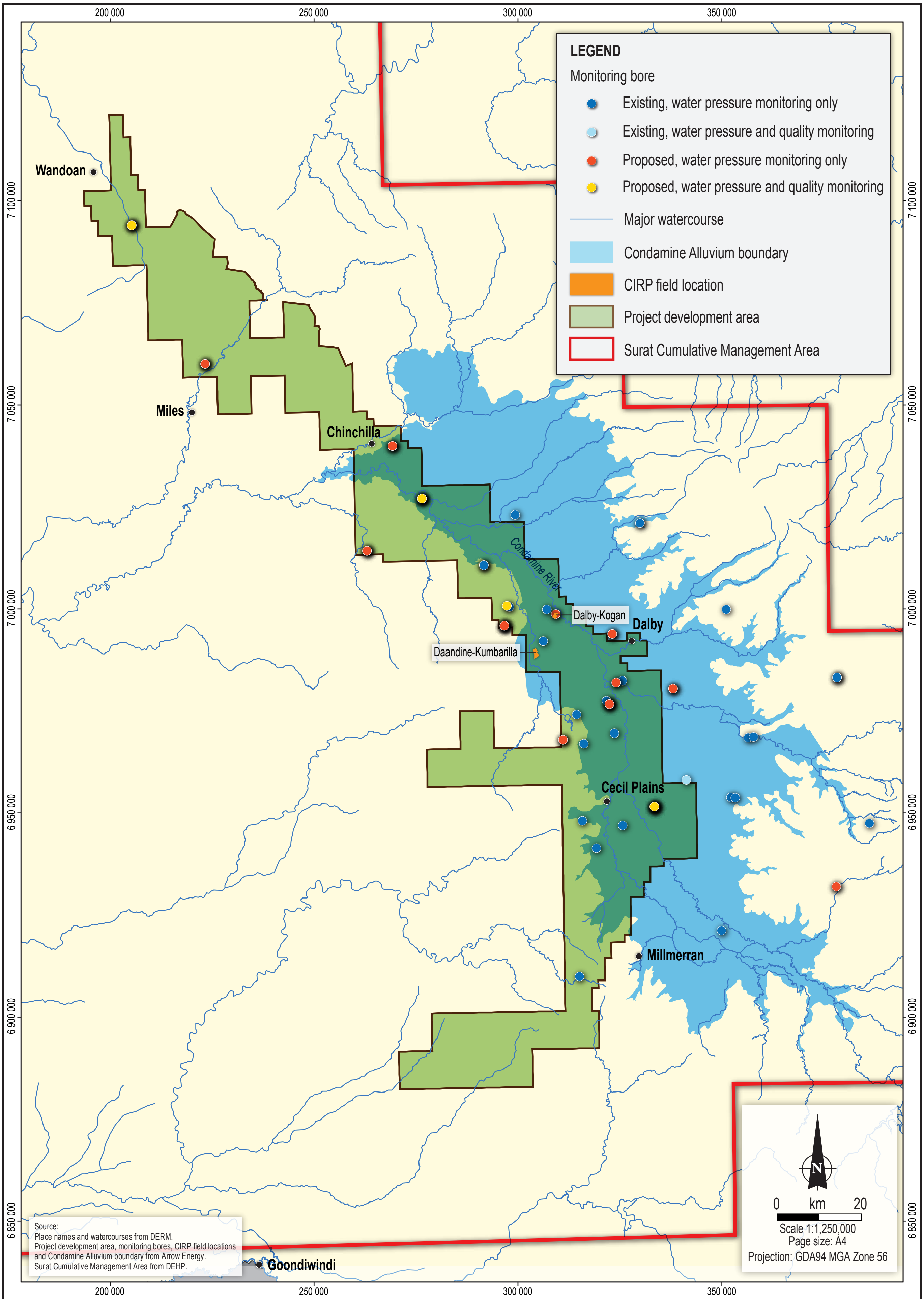
Arrow Energy

Surat Gas Project

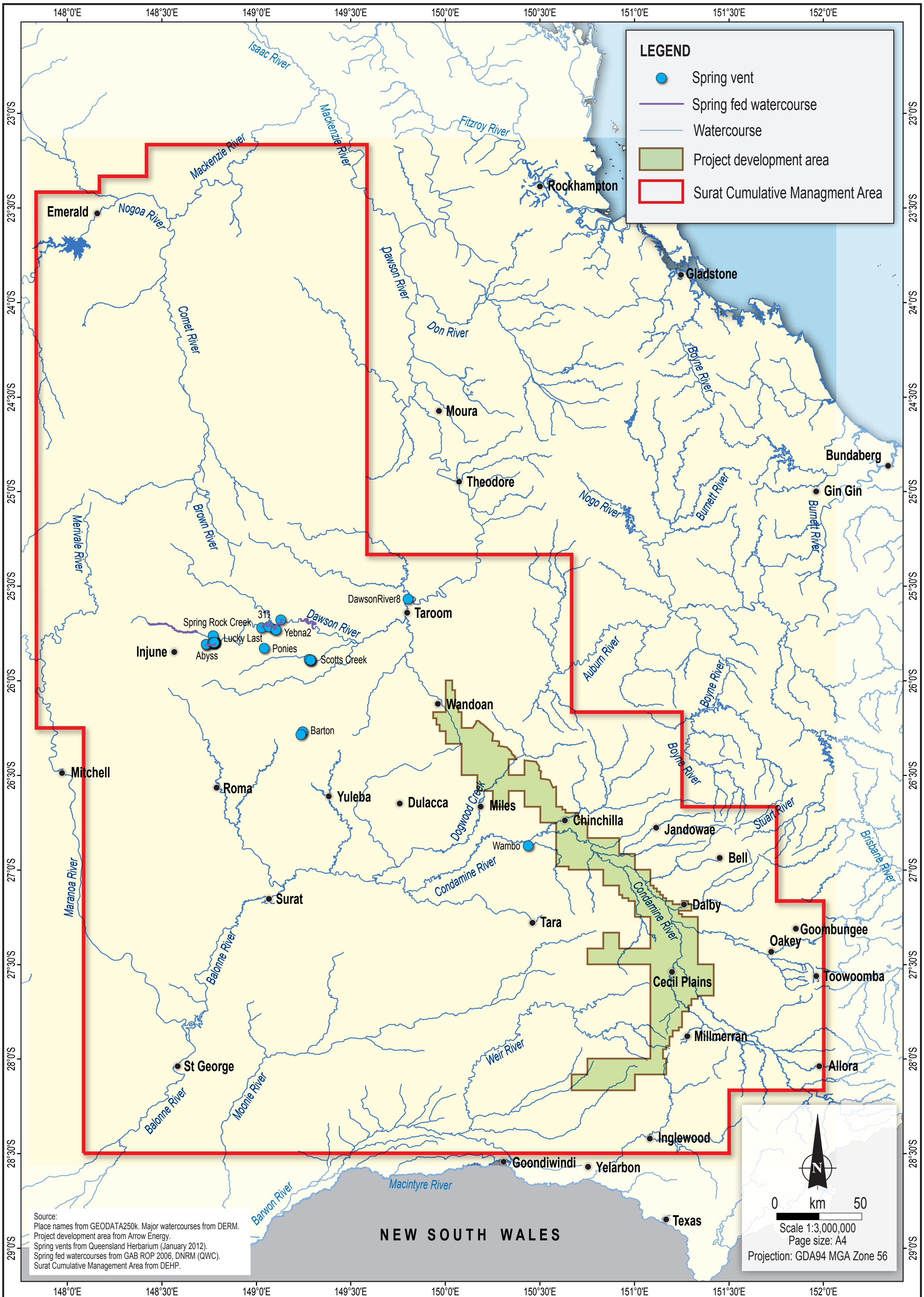
arrow energy go further

GDE assessment drawdown extents including buffer zones - Walloon Coal Measures and Hutton Sandstone

Figure No: 8.2



coffey environments	Date: 26.06.2013 MXD: 7040AF_GW03_GIS078_v1_3 File Name: 7040_GW03_F09.01_GIS_GL	Arrow Energy Surat Gas Project	arrow energy go further	Arrow's existing and 2013 proposed monitoring bore locations	Figure No: 9.1



coffey environments	Date: 20.06.2013 MXD: 7040AF_GW03_GIS077_v1_1 File Name: 7040_GW03_F09.02_GIS_JO	Arrow Energy Surat Gas Project	arrow energy go further	UWIR SIMS monitoring sites	Figure No: 9.2

Appendix A
2011 QWC Spring Survey
Key Data Summary

Supplementary Groundwater Assessment
Arrow Energy Surat Gas Project
Supplementary Report to the EIS

Appendix A: 2011 QWC Spring Survey Key Data Summary

Queensland Herbarium Database (Queensland Herbarium, 2012)

Complex Name	Complex Number	Site Number	Site Name	Data Source	Date	GAB Spring	Watercourse Spring	Discharge Spring	Mound Spring	Estimated spring flow (L/min)	EPBC Listed Community	EPBC Listed Species	NCA Listed Species	Conservation Ranking (spring wetland/vent level)	Conservation Ranking (Complex)
16	16	548	Numma	SPRLOC	16-Mar-02	Yes	No	No	No	0.65	No	No	No	3	3
254	254	nv5	Tommy's	SPRLOC		Yes	No	No	No	5.00	No	No	No	NA	NA
267	267	nv6	Canterbury	SPRLOC		Yes	No	No	No	5.00	No	No	No	NA	NA
267	267	nv7	Canterbury	SPRLOC		Yes	No	No	No	5.00	No	No	No	NA	NA
302	302	539	Benaby	SPRLOC	14-Mar-02	Yes	No	No	No	163.60	No	No	No	2	2
302	302	539.1	Duckhole	SPRLOC	14-Mar-02	Yes	No	No	No	0.18	No	No	No	NA	2
306	306	nv371	HenryCrk	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
308	308	nv383	Clematis	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
309	309	nv384	BlackfellowCrk	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
310	310	nv370	ZamiaSprs	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
311	311	499	Riverpaddock	2011 QWC survey	19-Jun-11	Yes	No	No	No		No	No	No	3	2
311	311	500	ColoradoPad	2011 QWC survey	19-Jun-11	Yes	Yes	No	No		No	No	No	3	2
311	311	500.1		2011 QWC survey	19-Jun-11	Yes	No	No	No		No	No	No	NA	2
311	311	535	Glasby'sPad	2011 QWC survey	12-May-11	Yes	No	No	No		No	No	No	2	2
311	311	536	SpringPad	2011 QWC survey	12-May-11	Yes	No	No	No	0.20	No	No	No	2	2
311	311	536.1		2011 QWC survey	12-May-11	Yes	No	No	No		No	No	No	NA	2
311	311	536.2		2011 QWC survey	12-May-11	Yes	No	No	No		No	No	No	NA	2
311	311	537	RivPad	2011 QWC survey	11-May-11	Yes	No	No	No	0.26	No	No	No	3	2
311	311	692		2011 QWC survey	19-Jun-11	Yes	Yes	No	No		No	No	No	4a	2
311	311	693	Springwater (Santos)	2011 QWC survey	12-May-11	Yes	No	No	No	0.31	No	No	No	3	2
311	311	694		2011 QWC survey	12-May-11	Yes	No	No	No	0.01	No	No	No	3	2
311	311	695		2011 QWC survey	11-May-11	Yes	Yes	No	No	0.0004	No	No	No	3	2
311	311	696		2011 QWC survey	11-May-11	Yes	Yes	No	No	0.001	No	No	No	3	2
311	311	697		2011 QWC survey	11-May-11	Yes	Yes	No	No	0.001	No	No	No	3	2
311	311	698		2011 QWC survey	11-May-11	Yes	Yes	No	No	0.003	No	No	No	3	2
311	311	699		2011 QWC survey	11-May-11	Yes	No	No	No	0.15	No	No	No	3	2
311	311	704	nv364	2011 QWC survey	22-Jun-11	Yes	No	No	No	0.01	No	No	No	3	2
311	311	x431	nearGlasby	2011 QWC survey	12-May-11	No	No	No	No		No	No	No	NA	NA
325	325	nv363	Round Mtn	SPRLOC		Yes	No	No	No		No	No	No	NA	NA
326	326	705	SpringCreek	2011 QWC survey	31-Jul-11	Yes	No	No	No	3.06	No	No	No	3	3
327	327	nv385		SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
328	328	nv374	GasmanSps	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
331	331	nv402	Cracow	SPRLOC		Yes	No	No	No	66.67	No	No	No	NA	NA
331	331	nv404	Cracow	SPRLOC		Yes	No	No	No	66.67	No	No	No	NA	NA
334	334	nv405	Cracow	SPRLOC		Yes	No	No	No	66.67	No	No	No	NA	NA
335	335	nv406	TurtleCk	SPRLOC		Yes	No	No	No	66.67	No	No	No	NA	NA
35	35	nv367	springton	SPRLOC		Yes	No	No	No	8.33	No	No	No	NA	NA
35	35	nv386	Rusty's	SPRLOC		Yes	No	No	No	8.33	No	No	No	NA	NA
78	78	551	Middle	SPRLOC	19-Mar-02	Yes	No	No	No	0.65	No	No	No	3	3
78	78	552	Mud	SPRLOC	19-Mar-02	Yes	No	No	No	1.15	No	No	No	3	3
Abyss	592	286	Abyss	2011 QWC survey	16-Apr-11	Yes	No	No	No	0.76	No	Yes	Yes	1b	1b
Abyss	592	286.1	Abyss	2011 QWC survey	16-Apr-11	Yes	No	No	No	0.24	No	No	No	NA	1b
Abyss	592	286.2	Abyss	2011 QWC survey	16-Apr-11	Yes	No	No	No	0.34	No	No	No	NA	1b
Abyss	592	286.3	Abyss	2011 QWC survey	16-Apr-11	Yes	No	No	No	0.02	No	No	No	NA	1b
Abyss	592	682	Cabin Spr	2011 QWC survey	17-Apr-11	Yes	No	No	Yes	2.72	No	No	No	3	3
Abyss	592	716	Cabin Spr2	2011 QWC survey	17-Apr-11	Yes	No	No	No	0.09	No	No	No	NA	3
Barton	283	702	BartonSps	2011 QWC survey	30-Jul-11	Yes	No	No	No	1.14	No	No	No	3	3
Barton	283	703	BartonSps	2011 QWC survey	30-Jul-11	Yes	No	No	No	0.00	No	No	No	3	3
Boggomoss	5	10	Boggo6	2011 QWC survey	03-Apr-11	Yes	No	Yes	Yes	2.22	Yes	No	No	2	1b
Boggomoss	5	11	Boggo7	2011 QWC survey	02-Apr-11	Yes	No	Yes	Yes	7.37	Yes	No	No	2	1b

Appendix A: 2011 QWC Spring Survey Key Data Summary

Queensland Herbarium Database (Queensland Herbarium, 2012)

Complex Name	Complex Number	Site Number	Site Name	Data Source	Date	GAB Spring	Watercourse Spring	Discharge Spring	Mound Spring	Estimated spring flow (L/min)	EPBC Listed Community	EPBC Listed Species	NCA Listed Species	Conservation Ranking (spring wetland/vent level)	Conservation Ranking (Complex)
Boggomoss	5	12	Boggo8	2011 QWC survey	02-Apr-11	Yes	No	Yes	Yes	1.00	Yes	No	No	3	1b
Boggomoss	5	13	Boggo9	2011 QWC survey	02-Apr-11	Yes	No	Yes	No	1.28	Yes	No	No	3	1b
Boggomoss	5	14	Boggo10	2011 QWC survey	02-Apr-11	Yes	No	Yes	Yes	1.41	Yes	No	No	3	1b
Boggomoss	5	15	Boggo11	2011 QWC survey	02-Apr-11	Yes	No	Yes	Yes	1.21	Yes	No	No	2	1b
Boggomoss	5	2	Mt Rose1	2011 QWC survey	31-Mar-11	Yes	No	Yes	Yes	6.30	Yes	No	No	2	1b
Boggomoss	5	29	Mt Rose8	2011 QWC survey	31-Mar-11	Yes	No	Yes	Yes	0.10	Yes	No	No	2	1b
Boggomoss	5	3	Mt Rose2	2011 QWC survey	01-Apr-11	Yes	No	Yes	Yes	1.59	Yes	No	No	2	1b
Boggomoss	5	33	MtRose11	2011 QWC survey	31-Mar-11	Yes	No	Yes	Yes	22.79	Yes	No	No	2	1b
Boggomoss	5	37	Sprck4	2011 QWC survey	23-Jun-11	Yes	No	Yes	Yes	0.04	Yes	No	No	4a	1b
Boggomoss	5	37.1	Sprck4	2011 QWC survey	23-Jun-11	Yes	No	Yes	Yes	0.0004	Yes	No	No	NA	1b
Boggomoss	5	44	Balkl3	2011 QWC survey	20-Jun-11	Yes	No	Yes	Yes	9.09	Yes	No	No	2	1b
Boggomoss	5	53	Mt Rose12	2011 QWC survey	31-Mar-11	Yes	No	Yes	Yes	0.87	Yes	No	No	2	1b
Boggomoss	5	54	Boggo18	2011 QWC survey	02-Apr-11	Yes	No	Yes	Yes	0.19	Yes	No	No	2	1b
Boggomoss	5	55	Boggo19	2011 QWC survey	03-Apr-11	Yes	No	Yes	Yes	1.80	Yes	No	No	2	1b
Boggomoss	5	56	Boggo20	2011 QWC survey	05-Apr-11	Yes	No	Yes	Yes	2.50	Yes	No	No	2	1b
Boggomoss	5	56.1		2011 QWC survey	05-Apr-11	Yes	No	Yes	Yes	1.56	Yes	No	No	NA	1b
Boggomoss	5	57	Boggo21	2011 QWC survey	03-Apr-11	Yes	No	Yes	Yes	36.56	Yes	No	No	2	1b
Boggomoss	5	58	Boggo22	2011 QWC survey	03-Apr-11	Yes	No	Yes	Yes	2.94	Yes	No	No	2	1b
Boggomoss	5	61	Mt Rose14	2011 QWC survey	30-Mar-11	Yes	No	Yes	Yes	10.59	Yes	No	No	2	1b
Boggomoss	5	62	Bogres23	2011 QWC survey	05-Apr-11	Yes	No	Yes	Yes	0.45	Yes	No	No	2	1b
Boggomoss	5	63	Boggo stat	2011 QWC survey	02-Apr-11	Yes	No	Yes	Yes	1.13	Yes	No	No	2	1b
Boggomoss	5	68	Bogres24 (Mound 1)	2011 QWC survey	05-Apr-11	Yes	No	Yes	Yes	3.02	Yes	Yes	Yes	1b	1b
Boggomoss	5	68.1	Bogres24 (Mound 2)	2011 QWC survey	05-Apr-11	Yes	No	Yes	Yes	7.95	Yes	Yes	Yes	NA	1b
Boggomoss	5	683	Mt Rose8	2011 QWC survey	31-Mar-11	Yes	No	Yes	Yes	0.52	Yes	No	No	3	1b
Boggomoss	5	691		2011 QWC survey	20-Jun-11	Yes	No	Yes	No	2.26	Yes	No	No	3	1b
Boggomoss	5	7	Boggo3	2011 QWC survey	03-Apr-11	Yes	No	Yes	Yes	9.26	Yes	Yes	Yes	1b	1b
Boggomoss	5	8	Boggo4	2011 QWC survey	03-Apr-11	Yes	No	Yes	Yes	13.38	Yes	No	No	2	1b
Boggomoss	5	9	Boggo5	2011 QWC survey	03-Apr-11	Yes	No	Yes	Yes	1.30	Yes	No	No	2	1b
Bowenville	585	SP4	Bowenville Reserve	2011 QWC survey	23-Jun-11	No	No	No	No		No	No	No	3	3
Boxvale	586	nv437	Boxvale	SPRLOC		Yes	No	No	No		No	No	No	NA	NA
Bunya1	596	SP2	BUNYA SPRING	Condamine Alliance	24-Nov-06	No	No	No	No		No	No	No	NA	NA
Carnarvon Gorge	296	553	Mickeys creek	2011 QWC survey	02-Jun-11	Yes	No	No	No		No	No	No	2	1a
Carnarvon Gorge	296	554.3		2011 QWC survey	03-Jun-11	Yes	No	No	No		No	No	No	NA	1a
Carnarvon Gorge	296	677		2011 QWC survey	03-Jun-11	Yes	No	No	No	20.00	No	No	Yes	3	1a
Carnarvon Gorge	296	678		2011 QWC survey	03-Jun-11	Yes	No	No	No	20.00	No	No	Yes	3	1a
Carnarvon Gorge	296	712	Phaius	2011 QWC survey	03-Jun-11	Yes	No	No	No	40.00	No	Yes	Yes	1b	1a
Carnarvon Gorge	296	713		2011 QWC survey	02-Jun-11	Yes	No	No	No	20.00	No	No	Yes	2	1a
Carnarvon Gorge	296	714	MickeyRidge	2011 QWC survey	02-Jun-11	Yes	No	No	No	20.00	No	No	No	3	1a
Carnarvon Gorge	296	715		2011 QWC survey	02-Jun-11	Yes	Yes	No	No		No	No	No	NA	1a
Carnarvon Gorge	296	554	Ward'sCanyon	SPRLOC	20-Mar-02	Yes	Yes	No	No	6.30	No	No	No	2	1a
Carnarvon Gorge	296	555	HellholeGorge	SPRLOC	20-Mar-02	Yes	No	No	No	11.18	No	No	No	2	1a
Carnarvon Gorge	296	556	MossGarden	SPRLOC	20-Mar-02	Yes	No	No	No	0.24	No	No	No	2	1a
Carnarvon Gorge	296	nv387	Foleys spring	SPRLOC		Yes	No	No	No	16.80	No	No	No	NA	1a
Carnarvon Gorge	296	nv388	Ferntree Sp	SPRLOC		Yes	No	No	No	16.80	No	No	No	NA	1a
Carnarvon Gorge	296	nv389	Cabbage Tree Sp	SPRLOC		Yes	No	No	No	16.80	No	No	No	NA	1a
Carnarvon Gorge	296	nv390	Arch Ck	SPRLOC		Yes	No	No	No	16.80	No	No	No	NA	1a
Carnarvon Gorge	296	nv391	Auchenflower Sp	SPRLOC		Yes	No	No	No	16.80	No	No	No	NA	1a
Carnarvon Gorge	296	nv392	Boowinda Ck	SPRLOC		Yes	No	No	No	16.80	No	No	No	NA	1a
Carnarvon Gorge	296	nv394	Un-named2	SPRLOC		Yes	No	No	No	16.80	No	No	No	NA	1a
Carnarvon Gorge	296	nv395	Un-named3	SPRLOC		Yes	No	No	No	16.80	No	No	No	NA	1a

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Complex Name	Complex Number	Site Number	Site Name	Data Source	Date	GAB Spring	Watercourse Spring	Discharge Spring	Mound Spring	Estimated spring flow (L/min)	EPBC Listed Community	EPBC Listed Species	NCA Listed Species	Conservation Ranking (spring wetland/vent level)	Conservation Ranking (Complex)
Carnarvon Gorge	296	nv396	Un-named4	SPRLOC		Yes	No	No	No	16.80	No	No	No	NA	1a
Carnarvon Gorge	296	nv399	Un-named6	SPRLOC		Yes	No	No	No	16.80	No	No	No	NA	1a
Carnarvon Gorge	296	nv400	Un-named7	SPRLOC		Yes	No	No	No	16.80	No	No	No	NA	1a
Carnarvon Gorge	296	nv401	Un-named8	SPRLOC		Yes	No	No	No	16.80	No	No	No	NA	1a
Carnarvon Gorge	296	nv435	Mickey'sCrkA	SPRLOC		Yes	No	No	No	6.30	No	No	No	NA	1a
Carnarvon Gorge	296	nv8	CarnarvonNP	SPRLOC		Yes	No	No	No	16.67	No	No	No	NA	1a
Cleanskins	510	nv417	cleanskinpaddock	SPRLOC		Yes	No	No	No	163.60	No	No	No	NA	NA
Cockatoo3	593	685		2011 QWC survey	18-Jun-11	Yes	No	No	No	45.00	No	No	No	3	3
CockatooCrk	9	66	SANDCK3	SPRLOC	31-Jul-96	Yes	No	Yes	No	0.04	Yes	No	No	3	1b
CockatooCrk	9	319	Marama	2011 QWC survey	18-Jun-11	Yes	No	Yes	Yes	3.78	Yes	No	Yes	1b	1b
CockatooCrk	9	320	Blackle1	2011 QWC survey	16-Jun-11	Yes	No	Yes	No	0.43	Yes	No	Yes	1b	1b
CockatooCrk	9	320.1	Blackle1	2011 QWC survey	16-Jun-11	Yes	No	Yes	No	0.05	Yes	No	No	NA	1b
CockatooCrk	9	321	Blackle2	2011 QWC survey	16-Jun-11	Yes	No	Yes	Yes	0.05	Yes	Yes	Yes	1b	1b
CockatooCrk	9	321.1	Blackle2	2011 QWC survey	16-Jun-11	Yes	No	Yes	Yes	0.003	Yes	No	No	NA	1b
CockatooCrk	9	321.2	Blackle2	2011 QWC survey	16-Jun-11	Yes	No	Yes	Yes	0.001	Yes	No	No	NA	1b
CockatooCrk	9	321.3	Blackle2	2011 QWC survey	16-Jun-11	Yes	No	Yes	Yes	0.0004	Yes	No	No	NA	1b
CockatooCrk	9	321.4	Blackle2	2011 QWC survey	16-Jun-11	Yes	No	Yes	Yes	0.002	Yes	No	No	NA	1b
CockatooCrk	9	321.5	Blackle2	2011 QWC survey	16-Jun-11	Yes	No	Yes	Yes	0.0003	Yes	No	No	NA	1b
CockatooCrk	9	321.6	Blackle2	2011 QWC survey	16-Jun-11	Yes	No	Yes	Yes	0.002	Yes	No	No	NA	1b
CockatooCrk	9	321.7	Blackle2	2011 QWC survey	16-Jun-11	Yes	No	Yes	Yes	0.0004	Yes	No	No	NA	1b
CockatooCrk	9	321.8	Blackle2	2011 QWC survey	16-Jun-11	Yes	No	Yes	Yes	0.001	Yes	No	No	NA	1b
CockatooCrk	9	64	SandCk1	2011 QWC survey	17-Jun-11	Yes	No	Yes	Yes	34.24	Yes	Yes	Yes	1b	1b
CockatooCrk	9	64.1	SandCk1	2011 QWC survey	17-Jun-11	Yes	No	Yes	No		Yes	No	No	NA	1b
CockatooCrk	9	65	SandCk2	2011 QWC survey	17-Jun-11	Yes	No	Yes	Yes	3.69	Yes	Yes	Yes	1b	1b
CockatooCrk	9	65.1	SandCk2	2011 QWC survey	17-Jun-11	Yes	No	Yes	No		Yes	No	No	NA	1b
CockatooCrk	9	65.2	SandCk2	2011 QWC survey	17-Jun-11	Yes	No	Yes	No		Yes	No	No	NA	1b
CockatooCrk	9	684	Marama	2011 QWC survey	18-Jun-11	Yes	No	Yes	No	0.06	Yes	No	No	3	1b
Conom	84	nv356	nv356	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
Conom	84	nv357	nv357	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
Conom	84	nv358	nv358	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
CrystalBall	232	317	CrystBrl	SPRLOC	22-Apr-99	Yes	No	No	Yes	597.93	No	No	No	2	2
CrystalBall	232	317.1	CrystalA	SPRLOC	22-Apr-99	Yes	No	No	No	3.33	No	No	No	NA	2
CrystalBall	232	317.2	CrystalB	SPRLOC	22-Apr-99	Yes	No	No	No	3.33	No	No	No	NA	2
CrystalBall	232	318	CrystBII	SPRLOC	22-Apr-99	Yes	No	No	No	68.44	No	No	No	3	2
DamDyke	256	nv9	Bulldog	SPRLOC		Yes	No	No	No	0.08	No	No	No	NA	NA
DawsonRiver2	2	42	BALKL1	2011 QWC survey	20-Jun-11	Yes	No	Yes	Yes	6.96	Yes	No	No	2	2
DawsonRiver3	3	16	Daw1	SPRLOC	25-May-95	Yes	No	No	No	72.05	No	No	No	2	2
DawsonRiver3	3	17	Daw2	SPRLOC	25-May-95	Yes	No	No	No	136.54	No	No	No	2	2
DawsonRiver3	3	18	Daw3	SPRLOC	25-May-95	Yes	No	No	No	17.99	No	No	No	2	2
DawsonRiver3	3	19	Daw4	SPRLOC	25-May-95	Yes	No	No	No	21.73	No	No	No	2	2
DawsonRiver3	3	20	Daw5	SPRLOC	25-May-95	Yes	No	No	No	63.12	No	No	No	2	2
DawsonRiver3	3	21	Daw6	SPRLOC	25-May-95	Yes	No	No	No	11.18	No	No	No	2	2
DawsonRiver3	3	34	SprCk1	SPRLOC	27-Jan-96	Yes	No	No	No	108.91	No	No	No	3	2
DawsonRiver3	3	35	SprCk2	SPRLOC	27-Jan-96	Yes	No	No	No	79.43	No	No	No	3	2
DawsonRiver3	3	36	SprCk3	SPRLOC	27-Jan-96	Yes	No	No	No	79.43	No	No	No	2	2
DawsonRiver3	3	69	DAWSON7	SPRLOC	31-Jul-96	Yes	No	No	Yes	23.03	No	No	No	2	2
DawsonRiver4	4	39	Prices1	SPRLOC	29-Jan-96	Yes	No	No	No	0.03	No	No	No	2	2
DawsonRiver4	4	47	PricesP7	2011 QWC survey	21-Jun-11	Yes	No	No	No	1.55	No	No	No	2	2
DawsonRiver4	4	47.1	PricesP7	2011 QWC survey	21-Jun-11	Yes	No	No	No	0.30	No	No	No	NA	2
DawsonRiver4	4	45	PRICES4	SPRLOC	17-Jun-96	Yes	No	No	No	0.09	No	No	No	2	2

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Complex Name	Complex Number	Site Number	Site Name	Data Source	Date	GAB Spring	Watercourse Spring	Discharge Spring	Mound Spring	Estimated spring flow (L/min)	EPBC Listed Community	EPBC Listed Species	NCA Listed Species	Conservation Ranking (spring wetland/vent level)	Conservation Ranking (Complex)
DawsonRiver4	4	46	PRICESP6	SPRLOC	17-Jun-96	Yes	No	No	No	0.01	No	No	No	3	2
DawsonRiver4	4	47.2	PricesP7	2011 QWC survey	21-Jun-11	Yes	No	No	No	0.001	No	No	No	NA	2
DawsonRiver4	4	47.3	PricesP7	2011 QWC survey	21-Jun-11	Yes	No	No	No	0.03	No	No	No	NA	2
DawsonRiver4	4	47.4	PricesP7	2011 QWC survey	21-Jun-11	Yes	No	No	No	0.05	No	No	No	NA	2
DawsonRiver4	4	47.5	PricesP7	2011 QWC survey	21-Jun-11	Yes	No	No	No	0.01	No	No	No	NA	2
DawsonRiver4	4	47.6	PricesP7	2011 QWC survey	21-Jun-11	Yes	No	No	No	0.12	No	No	No	NA	2
DawsonRiver4	4	47.7	PricesP7	2011 QWC survey	21-Jun-11	Yes	No	No	No	0.02	No	No	No	NA	2
DawsonRiver4	4	47.8	PricesP7	2011 QWC survey	21-Jun-11	Yes	No	No	No	0.24	No	No	No	NA	2
DawsonRiver4	4	47.9	PricesP7	2011 QWC survey	21-Jun-11	Yes	No	No	No	0.12	No	No	No	NA	2
DawsonRiver4	4	48	PricesP8	2011 QWC survey	21-Jun-11	Yes	No	No	No	0.07	No	No	Yes	2	2
DawsonRiver4	4	50	Pricsp10	2011 QWC survey	21-Jun-11	Yes	No	No	No	0.03	No	No	No	3	2
DawsonRiver4	4	690		2011 QWC survey	23-Jun-11	Yes	Yes	No	No	0.24	No	No	Yes	3	2
DawsonRiver4	4	49	PRICESP9	SPRLOC	17-Jun-96	Yes	No	No	No	0.43	No	No	No	2	2
DawsonRiver4	4	51	PRICSP11	SPRLOC	17-Jun-96	Yes	No	No	No	0.02	No	No	No	2	2
DawsonRiver6	6	1	Boggo1	2011 QWC survey	04-Apr-11	Yes	No	Yes	Yes	11.71	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	22	Boggo13	2011 QWC survey	06-Apr-11	Yes	No	Yes	Yes	6.15	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	23	Boggo15	2011 QWC survey	05-Apr-11	Yes	No	Yes	Yes	13.34	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	24	Boggo16	2011 QWC survey	29-Mar-11	Yes	No	Yes	Yes	132.85	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	25	Boggo17	2011 QWC survey	29-Mar-11	Yes	No	Yes	Yes	5.04	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	27	Boggo14	2011 QWC survey	05-Apr-11	Yes	No	Yes	Yes	2.52	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	30	Mt Rose9	2011 QWC survey	01-Apr-11	Yes	No	Yes	Yes	1.62	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	31	Mt Rose10	2011 QWC survey	01-Apr-11	Yes	No	Yes	Yes	122.72	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	32	Boggo18	2011 QWC survey	29-Mar-11	Yes	No	Yes	Yes	35.09	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	4	Mt Rose3	2011 QWC survey	30-Mar-11	Yes	No	Yes	Yes	974.98	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	43	BALKL2	2011 QWC survey	20-Jun-11	Yes	No	Yes	Yes	0.34	Yes	No	No	2	1b
DawsonRiver6	6	5	Mt Rose 4	2011 QWC survey	30-Mar-11	Yes	No	Yes	Yes	69.55	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	59	Mt Rose13	2011 QWC survey	29-Mar-11	Yes	No	Yes	Yes	4.33	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	6	Boggo2	2011 QWC survey	06-Apr-11	Yes	No	Yes	Yes	20.69	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	60	Bogres22	2011 QWC survey	05-Apr-11	Yes	No	Yes	Yes	5.54	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	681		2011 QWC survey	29-Mar-11	Yes	No	Yes	Yes	22.50	Yes	Yes	Yes	1b	1b
DawsonRiver6	6	x346	nv346	SPRLOC	21-Jun-11	No	No	No	No		No	No	No	NA	NA
DawsonRiver8	8	26	Palm1	SPRLOC	25-May-95	Yes	No	Yes	Yes	0.65	Yes	No	No	3	3
DawsonRiver8	8	28	Palm2	SPRLOC	25-May-95	Yes	No	Yes	Yes	0.03	Yes	No	No	3	3
DawsonRiver8	8	38	MrsWhite	2011 QWC survey	18-Jun-11	Yes	No	Yes	Yes	58.12	Yes	No	No	3	3
Eden Vale	76	700	Eden Vale	2011 QWC survey	02-Aug-11	Yes	No	No	No	3.21	No	No	No	3	3
Eden Vale	76	701		2011 QWC survey	02-Aug-11	Yes	No	No	No		No	No	No	3	3
Eden Vale	76	nv600	ed1	Craig Eddie		Yes	No	No	No		No	No	No	NA	3
Eden Vale	76	nv601	ed10	Craig Eddie		Yes	No	No	No		No	No	No	NA	3
Eden Vale	76	nv602	ed12	Craig Eddie		Yes	No	No	No		No	No	No	NA	3
Eden Vale	76	nv603	ed16	Craig Eddie		Yes	No	No	No		No	No	No	NA	3
Eden Vale	76	nv605	ed20	Craig Eddie		Yes	No	No	No		No	No	No	NA	3
Eden Vale	76	nv607	ed5	Craig Eddie		Yes	No	No	No		No	No	No	NA	3
Elgin	307	x380	ConciliationCrk	2011 QWC survey	31-Aug-11	No	No	No	No		No	No	No	NA	NA
Elgin	307	x381	ConciliCrkSouth	2011 QWC survey	31-Aug-11	No	No	No	No		No	No	No	NA	NA
Elgin	307	nv359	nv359	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
Elgin	307	nv372	BlackGinCrk1	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
Elgin	307	nv373	BlackGinCrk2	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
Elgin	307	nv375	BlackGinCrk3	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
Elgin	307	nv376	PeachCrk	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
Elgin	307	nv377	StockyrdCrk	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA

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Elgin	307	nv378	mudonhill	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
Elgin	307	nv379	SprCreeek	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	NA
Elgin2	594	540	GlenElgin	2011 QWC survey	30-Aug-11	Yes	No	Yes	Yes	19.63	Yes	No	No	3	3
ExpedRange	304	541	SprCrk1	SPRLOC	15-Mar-02	Yes	No	No	No	3.06	No	No	No	2	2
ExpedRange	304	542	SprCrk2	SPRLOC	15-Mar-02	Yes	No	No	No	0.65	No	No	No	2	2
ExpedRange	304	543	SprCrk3	SPRLOC	15-Mar-02	Yes	No	No	No	0.02	No	No	No	3	2
ExpedRange	304	544	SprCrk4	SPRLOC	15-Mar-02	Yes	No	No	No	0.18	No	No	No	3	2
ExpedRange	304	544.1	SprCrk4A	SPRLOC	15-Mar-02	Yes	No	No	No	0.18	No	No	No	NA	2
ExpedRange	304	544.2	SprCrk4B	SPRLOC	15-Mar-02	Yes	No	No	No	0.18	No	No	No	NA	2
ExpedRange	304	544.3	SprCrk4C	SPRLOC	15-Mar-02	Yes	No	No	No	0.18	No	No	No	NA	2
ExpedRange	304	545	Take-u-a-week	SPRLOC	15-Mar-02	Yes	No	No	No	108.91	No	No	No	2	2
ExpedRange	304	546	Taylors Crk	SPRLOC	15-Mar-02	Yes	No	No	No	65.76	No	No	No	2	2
ExpedRange	304	nv2	CentralCrk	SPRLOC		Yes	No	No	No	5.00	No	No	No	NA	2
ExpedRange	304	nv3	ParkAvenue	SPRLOC		Yes	No	No	No	5.00	No	No	No	NA	2
ExpedRange	304	nv348	nv348	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	2
ExpedRange	304	nv349	nv349	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	2
ExpedRange	304	nv350	nv350	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	2
ExpedRange	304	nv351	nv351	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	2
ExpedRange	304	nv352	nv352	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	2
ExpedRange	304	nv353	CentralCrkSouth	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	2
ExpedRange	304	nv354	ParkAvSps	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	2
ExpedRange	304	nv355	nv355	SPRLOC		Yes	No	No	No	16.79	No	No	No	NA	2
Lenore Hills	583	710		SPRLOC	31-Aug-11	Yes	No	No	No	0.31	No	No	No	3	3
Lenore Hills	583	nv621		SPRLOC		Yes	No	No	No		No	No	No	NA	3
Lenore Hills	583	nv622		SPRLOC		Yes	No	No	No		No	No	No	NA	3
LonelyEddie	339	706	LonelyEddie	2011 QWC survey	01-Aug-11	Yes	No	No	No	0.21	No	No	No	3	2
LonelyEddie	339	707		2011 QWC survey	01-Aug-11	Yes	No	No	No	0.39	No	No	No	3	2
LonelyEddie	339	708		2011 QWC survey	01-Aug-11	Yes	No	No	No		No	No	No	3	2
LonelyEddie	339	709		2011 QWC survey	01-Aug-11	Yes	No	No	No	0.42	No	No	No	2	2
LuckyLast	230	287	Fourdog	2011 QWC survey	16-Apr-11	Yes	No	Yes	Yes	32.70	Yes	Yes	Yes	1b	1b
LuckyLast	230	340	Lucky last	2011 QWC survey	10-May-11	Yes	No	Yes	Yes	2.70	Yes	Yes	Yes	1b	1b
LuckyLast	230	686		2011 QWC survey	10-May-11	Yes	No	Yes	Yes	0.98	Yes	No	No	2	1b
LuckyLast	230	687		2011 QWC survey	10-May-11	Yes	No	Yes	Yes	0.81	Yes	Yes	Yes	1b	1b
LuckyLast	230	687.1		2011 QWC survey	10-May-11	Yes	No	Yes	Yes		Yes	No	No	NA	1b
LuckyLast	230	687.2		2011 QWC survey	10-May-11	Yes	No	Yes	Yes		Yes	No	No	NA	1b
LuckyLast	230	687.3		2011 QWC survey	10-May-11	Yes	No	Yes	Yes		Yes	No	No	NA	1b
LuckyLast	230	687.4		2011 QWC survey	10-May-11	Yes	No	Yes	Yes		Yes	Yes	Yes	NA	1b
LuckyLast	230	687.5		2011 QWC survey	10-May-11	Yes	No	Yes	Yes		Yes	No	No	NA	1b
LuckyLast	230	687.6		2011 QWC survey	10-May-11	Yes	No	Yes	Yes		Yes	Yes	Yes	NA	1b
LuckyLast	230	688		2011 QWC survey	10-May-11	Yes	No	Yes	Yes	2.88	Yes	No	No	2	1b
LuckyLast	230	689		2011 QWC survey	10-May-11	Yes	No	Yes	Yes	0.11	Yes	Yes	Yes	1b	1b
MainRangeVolc1	599	SP45	LILLIGREN SPRING	Condamine Alliance	15-Dec-06	No	No	No	No		No	No	No	NA	NA
MainRangeVolc2	600	SP1	KEARNEYS SPRING	Condamine Alliance	21-Nov-06	No	No	No	No		No	No	No	NA	NA
MainRangeVolc2	600	SP15	WELLCAMP SPRING	Condamine Alliance	07-Dec-06	No	No	No	No		No	No	No	NA	NA
MainRangeVolc2	600	SP42	WESTBROOK CREEK	Condamine Alliance	14-Dec-06	No	No	No	No		No	No	No	NA	NA
MainRangeVolc2	600	SP43	EUSTONDALE SPRING	Condamine Alliance	14-Dec-06	No	No	No	No		No	No	No	NA	NA
MainRangeVolc3	601	SP3	JONDARYAN WOOLSHED	Condamine Alliance	27-Nov-06	No	No	No	No		No	No	No	NA	NA
MainRangeVolc4	602	SP6	LEIGH SPRING	Condamine Alliance	06-Dec-06	No	No	No	No		No	No	No	NA	NA
MainRangeVolc4	602	SP7	STONE SPRING	Condamine Alliance	06-Dec-06	No	No	No	No		No	No	No	NA	NA
MainRangeVolc4	602	SP8	SPRINGSIDE	Condamine Alliance	06-Dec-06	No	No	No	No		No	No	No	NA	NA

Appendix A: 2011 QWC Spring Survey Key Data Summary

Queensland Herbarium Database (Queensland Herbarium, 2012)

Complex Name	Complex Number	Site Number	Site Name	Data Source	Date	GAB Spring	Watercourse Spring	Discharge Spring	Mound Spring	Estimated spring flow (L/min)	EPBC Listed Community	EPBC Listed Species	NCA Listed Species	Conservation Ranking (spring wetland/vent level)	Conservation Ranking (Complex)
MainRangeVolc5	603	SP9	JIMNA SPRINGS	Condamine Alliance	06-Dec-06	No	No	No	No		No	No	No	NA	NA
MainRangeVolc6	604	SP10	WILLOWS SPRING	Condamine Alliance	06-Dec-06	No	No	No	No		No	No	No	NA	NA
MainRangeVolc6	604	SP11	RADIO SPRINGS	Condamine Alliance	06-Dec-06	No	No	No	No		No	No	No	NA	NA
MainRangeVolc6	604	SP37	SPRING CREEK	Condamine Alliance	13-Dec-06	No	No	No	No		No	No	No	NA	NA
MainRangeVolc6	604	SP38	SPRING CREEK SOUTH	Condamine Alliance	13-Dec-06	No	No	No	No		No	No	No	NA	NA
Marburg1	598	SP44	MERIGANDAN CREEK	Condamine Alliance	15-Dec-06	No	No	No	No		No	No	No	NA	NA
Marlong	236	309	MahlongI	SPRLOC	21-Apr-99	Yes	No	No	No	16.79	No	No	No	2	2
Marlong	236	310	Willow	SPRLOC	21-Apr-99	Yes	No	No	No	29.80	No	No	No	2	2
Marlong	236	315	MahlonII	SPRLOC	21-Apr-99	Yes	No	No	No	37.06	No	No	No	3	2
Merivale	589	nv438	Merivale	SPRLOC		Yes	No	No	No	0	No	No	No	NA	NA
Moffat	235	316	Stemmaca	SPRLOC	22-Apr-99	Yes	No	No	No	16.79	No	No	No	2	2
Moffat	235	316.1	TopMoffat	SPRLOC	22-Apr-99	Yes	No	No	No	15	No	No	No	NA	2
Moffat	235	316.2	1mile	SPRLOC	22-Apr-99	Yes	No	No	No	15	No	No	No	NA	2
MoffatBasalt	595	nv604	ed18	Craig Eddie		No	No	No	No		No	No	No	NA	NA
MoffatBasalt	595	nv606	Wonga spring (ed3)	Craig Eddie		No	No	No	No		No	No	No	NA	NA
MoffatBasalt	595	nv608	Ochre Spring (ed6)	Craig Eddie		No	No	No	No		No	No	No	NA	NA
Moolayember	233	408	Moolayember	2011 QWC survey	31-Jul-11	Yes	Yes	No	No	16.79	No	No	No	3	2
Moolayember	233	675		2011 QWC survey	31-Jul-11	Yes	No	No	Yes	16.21	No	No	No	2	2
Moolayember	233	676		2011 QWC survey	31-Jul-11	Yes	No	No	Yes	1.37	No	No	No	2	2
Newton	85	538	Glenhaughton	SPRLOC	13-Mar-02	Yes	No	No	No	12.25	No	No	No	2	2
Newton	85	nv328	fenced house	SPRLOC		Yes	No	No	No	5.00	No	No	No	NA	2
Newton	85	nv331	misc-others	SPRLOC		Yes	No	No	No		No	No	No	5	2
Newton	85	nv332	NEWTON SPRING	SPRLOC		Yes	No	No	No		No	No	No	5	2
Carnarvon basalt	590	174	BlacBull	SPRLOC_NON_GAB	24-Jan-99	No	No	No	No	0.65	No	No	No	2	2
Carnarvon basalt	590	175	BlueWate	SPRLOC_NON_GAB	24-Jan-99	No	No	No	No	2.36	No	No	No	2	2
Carnarvon basalt	590	304	New	SPRLOC_NON_GAB	20-Apr-99	No	No	No	No	16.79	No	No	No	2	2
Carnarvon basalt	590	311	Riley'sG	SPRLOC_NON_GAB	21-Apr-99	No	No	No	No	1.15	No	No	No	2	2
Carnarvon basalt	590	312	Piebald	SPRLOC_NON_GAB	21-Apr-99	No	No	No	No	0.24	No	No	No	2	2
Carnarvon basalt	590	313	WildHors	SPRLOC_NON_GAB	21-Apr-99	No	No	No	No	1.15	No	No	No	2	2
Carnarvon basalt	590	314	Murder	SPRLOC_NON_GAB	21-Apr-99	No	No	No	No	1.15	No	No	No	2	2
Oaky1	597	SP5	SPRING CREEK	Condamine Alliance	27-Nov-06	No	No	No	No		No	No	No	NA	NA
Ponies	229	284	Pony hill	2011 QWC survey	22-Jun-11	Yes	No	No	No	1.83	No	No	No	2	2
Prices	580	40	Prices2	2011 QWC survey	21-Jun-11	Yes	No	Yes	Yes	2.33	Yes	Yes	Yes	1b	1b
Prices	580	41	Prices3	2011 QWC survey	21-Jun-11	Yes	No	Yes	Yes	2.93	Yes	Yes	Yes	1b	1b
Prices	580	52	Prices5	2011 QWC survey	21-Jun-11	Yes	No	Yes	Yes	3.37	Yes	Yes	Yes	1b	1b
Prices	580	67	Prices12	2011 QWC survey	21-Jun-11	Yes	No	Yes	Yes	1.76	Yes	No	No	2	1b
Rainbow Spring	1	549	RainbowFalls	SPRLOC	16-Mar-02	Yes	No	No	No	61.38	No	No	No	2	2
Rainbow Spring	1	550	Two-mile	SPRLOC	17-Mar-02	Yes	No	No	No	0.24	No	No	No	2	2
Rainbow Spring	1	nv337	BalamooEast	SPRLOC		Yes	No	No	No	8.33	No	No	No	NA	2
Rainbow Spring	1	nv339	NorthEscarp	SPRLOC		Yes	No	No	No	8.33	No	No	No	NA	2
Rainbow Spring	1	nv340	Ardurad	SPRLOC		Yes	No	No	No	8.33	No	No	No	NA	2
Rainbow Spring	1	nv343	Rockland	SPRLOC		Yes	No	No	No	133.33	No	No	No	NA	2
Rainbow Spring	1	nv365	BalamooWest	SPRLOC		Yes	No	No	No	8.33	No	No	No	NA	2
Rainbow Spring	1	nv366	BalamooCentral	SPRLOC		Yes	No	No	No	8.33	No	No	No	NA	2
Rainbow Spring	1	nv368	MiiosaCRk2	SPRLOC		Yes	No	No	No	5.00	No	No	No	NA	2
Rainbow Spring	1	nv369	MiiosaCRk3	SPRLOC		Yes	No	No	No	5.00	No	No	No	NA	2
Rainbow Spring	1	nv4	Blackdawn	SPRLOC		Yes	No	No	No	5.00	No	No	No	NA	2
Scotts Creek	260	189	Saltfla1	2011 QWC survey	28-Jul-11	Yes	No	Yes	Yes	50.53	Yes	Yes	Yes	1b	1b
Scotts Creek	260	190	Saltfla2	2011 QWC survey	28-Jul-11	Yes	No	Yes	Yes	1.25	Yes	Yes	Yes	1b	1b
Scotts Creek	260	191	Saltfla3	2011 QWC survey	28-Jul-11	Yes	No	Yes	Yes	56.18	Yes	Yes	Yes	1b	1b

Appendix A: 2011 QWC Spring Survey Key Data Summary

Queensland Herbarium Database (Queensland Herbarium, 2012)

Complex Name	Complex Number	Site Number	Site Name	Data Source	Date	GAB Spring	Watercourse Spring	Discharge Spring	Mound Spring	Estimated spring flow (L/min)	EPBC Listed Community	EPBC Listed Species	NCA Listed Species	Conservation Ranking (spring wetland/vent level)	Conservation Ranking (Complex)
Scotts Creek	260	192	Creek	2011 QWC survey	28-Jul-11	Yes	No	Yes	No	1.45	Yes	Yes	Yes	1b	1b
Scotts Creek	260	192.1	Creek	2011 QWC survey	28-Jul-11	Yes	No	Yes	No		Yes	No	No	NA	1b
SF212	68	547	Cooinda	SPRLOC	16-Mar-02	Yes	No	No	No	6.30	No	No	No	2	2
SF212	68	nv341	SF212	SPRLOC		Yes	No	No	No	5.00	No	No	No	NA	2
Springwood	588	nv609		SPRLOC		Yes	No	No	No		No	No	No	NA	NA
Springwood	588	nv610		SPRLOC		Yes	No	No	No		No	No	No	NA	NA
Springwood	588	nv611		SPRLOC		Yes	No	No	No		No	No	No	NA	NA
Springwood	588	nv612	Middle Spring	SPRLOC		Yes	No	No	No		No	No	No	NA	NA
Springwood	588	nv613	Turtle Spring	SPRLOC		Yes	No	No	No		No	No	No	NA	NA
Springwood	588	nv614	Oak Spring	SPRLOC		Yes	No	No	No		No	No	No	NA	NA
Springwood	588	nv615	Top Spring	SPRLOC		Yes	No	No	No		No	No	No	NA	NA
Springwood	588	nv616		SPRLOC		Yes	No	No	No		No	No	No	NA	NA
Springwood	588	nv617	Dingo Spring	SPRLOC		Yes	No	No	No		No	No	No	NA	NA
Springwood	588	nv618	Fishers Spring	SPRLOC		Yes	No	No	No		No	No	No	NA	NA
Springwood	588	nv619	Salisbury Spring	SPRLOC		Yes	No	No	No		No	No	No	NA	NA
Springwood	588	nv620	Mountain Spring	SPRLOC		Yes	No	No	No		No	No	No	NA	NA
SpRockCrk	561	285	Creek	2011 QWC survey	17-Apr-11	Yes	Yes	No	No		No	No	No	3	3
SprRidge	506	184	Sridge1(Zerk)	2011 QWC survey	29-Jul-11	Yes	No	No	No	3.31	No	No	No	4b	4b
SprRidge	506	185	Sridge2(Zerk)	2011 QWC survey	29-Jul-11	Yes	No	No	No	0.73	No	No	No	4b	4b
SprRidge	506	186	Sridge3(Zerk)	2011 QWC survey	29-Jul-11	Yes	No	No	No	8.11	No	No	No	4b	4b
Timor	587	x436	Timor	2011 QWC survey		No	No	No	No		No	No	No	NA	NA
VI_mile	507	187	VI Mile	2011 QWC survey	07-May-11	Yes	No	No	No	10.66	No	No	No	4b	4b
VI_mile	507	188	NewCamp	2011 QWC survey	08-May-11	Yes	No	No	No		No	No	No	4b	4b
VI_mile	507	679		2011 QWC survey	07-May-11	Yes	No	No	No	2.06	No	No	No	4b	4b
VI_mile	507	680		2011 QWC survey	08-May-11	Yes	No	No	No	2.00	No	No	No	4b	4b
VI_mile	507	680.1		2011 QWC survey	08-May-11	Yes	No	No	No	1.61	No	No	No	NA	4b
Wambo	584	711		2011 QWC survey	06-May-11	Yes	No	No	No	1.81	No	No	No	3	3
Wambo	584	711.1		2011 QWC survey	06-May-11	Yes	No	No	No		No	No	No	NA	3
Yebna	74	nv329	nv329	SPRLOC		Yes	No	No	No	8.33	No	No	No	NA	NA
Yebna2	591	534	yebnasboggo	2011 QWC survey	19-Jun-11	Yes	No	Yes	No	0.03	Yes	No	No	3	3

Table notes

SPRLOC = Queensland Herbarium Spring Locations Database (prior to 2011 QWC survey)

Appendix A: 2011 QWC Spring Survey Key Data Summary

KCB Hydrogeological Attribute Survey Database (KCB, 2012)

Spring Complex Name	Spring Complex Number	KCB Vent Number	Location Number	KCB Vent Location ID	QLD Herb Complex Name	QLD Herb Complex Number	QLD Herb Vent Number	Location Source QLD Herb	Infield Source Assessment	Field Estimated Source Aquifer (Option 1)	Field Estimated Source Aquifer (Option 2)	Water Quality Sample Reference	Flow (L/s)	pH	ORP (mV)	DO (mg/L)	EC (µS/cm)	Temp (°C)	Methane (CH4)	Oxygen (O2)	Sample_Quality	Major Ions	Metals	Nutrients	TOC + DOC	O18 - D	C-14
326	326	NV382	1	382.1	326	326	705.0	No	GAB - Surat Basin	Clematis Sandstone	Unknown / Uncertain	NV382	minor	7.86	137.7	9.7	566	9.9	1500-1550	20.9	Average	Yes	Yes	Yes	Yes	Yes	Yes
326	326	NV382	2	382.2	326	326	Na	No	Na	Na	Na	No Sample															
326	326	NV382	3	382.3	326	326	Na	No	Na	Na	Na	No Sample															
584	584	OR1	1	584.1	Wambo	584	711.0	Yes	Unconsolidated surface sediments	Quaternary sediments	Orallo Formation	WCKOR1	0.5 - 1.0	5.87		0.67	231	22.8		20.9	Excellent	Yes	Yes	Yes	Yes	Yes	Yes
584	584	OR1	2	584.2	Wambo	584	711.1	Yes	Unconsolidated surface sediments	Quaternary sediments	Orallo Formation	No Sample															
Abyss	592	286	1	286.1	Abyss	592	286.3	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	No Sample	Micro flow						720-800	20.9							
Abyss	592	286	2	286.2	Abyss	592	286.0	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	No Sample	0.01			4.42	4250	20.2	660-720	20.9							
Abyss	592	286	3	286.3	Abyss	592	286.0	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	No Sample	0.01	7.02		3.82	961	20.2	600-700	20.6							
Abyss	592	286	4	286.4	Abyss	592	286.3	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	No Sample	Na														
Abyss	592	286	5	286.5	Abyss	592	Na	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	LL230-286 16/4/11	No flow	5.57		4.4	5200	19.9			Average	Yes	Yes	Yes	Yes	Yes	No
Abyss	592	286	6	286.6	Abyss	592	286.1	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	LL230-286 10/5/11	0.05	6.72			2350				Average	Yes	Yes	Yes	Yes	Yes	No
Abyss	592	285A and 285B	1	592.1	Abyss	592	682.0	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	LL230-285B	No flow	7.7		4.75	1000	27.7			Average	Yes	Yes	Yes	Yes	Yes	No
Abyss	592	285A and 285B	2	592.2	Abyss	592	716.0	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	No Sample															
Barton	283	NV333	1	333.1	Barton	283	703.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample	seep	7.8	116.8	6.49	759	14.9	610-640	20.9							
Barton	283	NV333	2	333.2	Barton	283	702.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	NV333	0.5	7.33	146	9.26	370	16.4	620-670	20.9	Good	Yes	Yes	Yes	Yes	Yes	Yes
Boggomoss	5	37 and Spring Creek	1	37.1	Boggomoss	5	37.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	minor seep	7.5	100	2.91	602	5	1500	20.9							
Boggomoss	5	37 and Spring Creek	2	37.2	DawsonRiver4	4	Na	No	Na	Na	Na	No Sample															
Boggomoss	5	37 and Spring Creek	3	37.3	DawsonRiver4	4	690.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	minor	7.62	197	6.56	159.4	10.7	1100-1250	20.9							
Boggomoss	5	37 and Spring Creek	4	37.4	DawsonRiver4	4	690.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	SPRCK01	0.5	6.17	120	5.94	245	16.5	1100-1250	20.9	Excellent	Yes	Yes	Yes	Yes	Yes	No
Boggomoss	5	44	1	44.1	Boggomoss	5	691.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	no flow	7.3	261	1.67	429	8	670-700	20.9							
Boggomoss	5	44	2	44.2	Boggomoss	5	44.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	BALVNT44	0.5	7.1	-48	1.98	426	10.4	170	20.9	Average to good	Yes	Yes	Yes	Yes	Yes	No
Carnarvon Gorge	296	NV397 & NV398	1	296.1	Carnarvon Gorge	296	714.0	No	GAB - Surat Basin	Hutton Sandstone	Boxvale Sandstone Member	No Sample	0.2	7.14	76.4	3.22	822	15.3		20.9							
Carnarvon Gorge	296	WardsHead 1, 2 & 3	1	296.11	Carnarvon Gorge	296	678.0	No	GAB - Surat Basin	Boxvale Sandstone Member	Hutton Sandstone	WDHD1A	5	6.53	143.2	6.09	228	20.2	25-75	20.9	Excellent	Yes	Yes	Yes	Yes	Yes	Yes
Carnarvon Gorge	296	WardsHead 1, 2 & 3	2	296.12	Carnarvon Gorge	296	678.0	No	GAB - Surat Basin	Boxvale Sandstone Member	Hutton Sandstone	WDHD1	0.5	7.06	92.1	2.04	599	12.5	5-15	20.9	Good	Yes	Yes	Yes	Yes	Yes	No
Carnarvon Gorge	296	WardsHead 1, 2 & 3	3	296.13	Carnarvon Gorge	296	554.3	No	GAB - Surat Basin	Boxvale Sandstone Member	Hutton Sandstone	WDHD3	0.2	6.18	56.4	2.95	101	13.7		20.9	Good	Yes	Yes	Yes	Yes	Yes	No
Carnarvon Gorge	296	WardsHead 1, 2 & 3	4	296.14	Carnarvon Gorge	296	678.0	No	GAB - Surat Basin	Boxvale Sandstone Member	Hutton Sandstone	No Sample															
Carnarvon Gorge	296	NV397 & NV398	2	296.2	Carnarvon Gorge	296	714.0	No	GAB - Surat Basin	Hutton Sandstone	Boxvale Sandstone Member	No Sample	0.2	6.84	58.1	1.9	429	17.3	5	20.9							
Carnarvon Gorge	296	NV397 & NV398	3	296.3	Carnarvon Gorge	296	714.0	No	GAB - Surat Basin	Hutton Sandstone	Boxvale Sandstone Member	NV398	0.2	7.2	52.4	4.68	545	18.9		20.9	Good	Yes	Yes	Yes	Yes	Yes	No
Carnarvon Gorge	296	NV397 & NV398	4	296.4	Carnarvon Gorge	296	713.0	No	GAB - Surat Basin	Hutton Sandstone	Boxvale Sandstone Member	No Sample	no flow	6.85	74.9	2.73	518	14.4	75-85	20.9							
Carnarvon Gorge	296	555	1	555.1	Carnarvon Gorge	296	555.0	No	GAB - Surat Basin	Precipice Sandstone	Moolayember Formation	VNT555	1 to 5	7.16	109	7.19	272	17.4	10-25	20.9	Excellent	Yes	Yes	Yes	Yes	Yes	No
Carnarvon Gorge	296	556	1	556.1	Carnarvon Gorge	296	556.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	VNT556	5 to 10	7.73	79	5.51	211	15.7		20.9	Good	Yes	Yes	Yes	Yes	Yes	Yes
Cockatoo Creek	9	319, 319A and 319B	1	319.1	Cockatoo3	593	685	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	No Sample	0.75 to 1.25	7.58	-6	2.27	415	23.7	850-920	20.9							
Cockatoo Creek	9	319, 319A and 319B	2	319.2	CockatooCrk	9	684.0	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	CCVNT319	0.1	7.76	131	7.01	900	11			Good	Yes	Yes	Yes	Yes	Yes	Yes
Cockatoo Creek	9	319, 319A and 319B	3	319.3	CockatooCrk	9	319.0	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	No Sample	1	8.43	162	9.26	596	14.1									
Cockatoo Creek	9	319, 319A and 319B	4	319.4	CockatooCrk	9	319.0	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	No Sample		8.55	177	7.14	1138	13.5	670	20.9							
Cockatoo Creek	9	320	1	320.1	CockatooCrk	9	320.0	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	No Sample	Minor flow	6.75	47	2.4	588	14.4	320-370	20.9							
Cockatoo Creek	9	320	2	320.2	CockatooCrk	9	320.1	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	Vent320	Minor flow	6.88	-71	0.46	532	18.2	320-370	20.9	Average	Yes	Yes	Yes	Yes	Yes	No
Cockatoo Creek	9	321	1	321.1	CockatooCrk	9	321.1	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	No Sample															
Cockatoo Creek	9	321	2	321.2	CockatooCrk	9	321.0	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	CCNVENT321	Surface pools	6.76	-150	0.32	631	17.1	150-210	20.9	Average	Yes	Yes	Yes	Yes	Yes	No
Cockatoo Creek	9	321	3	321.3	CockatooCrk	9	321.6	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	No Sample															
Cockatoo Creek	9	64	1	64.1	CockatooCrk	9	64.0	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	CCVENT64	Large area of	7.15	58	2.23	310	19.5	15-35	20.9	Excellent	Yes	Yes	Yes	Yes	Yes	Yes
Cockatoo Creek	9	65, 66	1	65.1	CockatooCrk	9	65.1	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	CCVNT65	Seep mound	6.87	17	1.9	298	20	50-140	20.9	Good	Yes	Yes	Yes	Yes	Yes	No
Cockatoo Creek	9	CCNVENT	1	9.1	CockatooCrk	9	Na	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	CCNVENT1	Seep area	7.4	-67	1.57		15.8	700	20.9	Average	Yes	Yes	Yes	Yes	Yes	No
DawsonRiver2	2	42	1	42.1	Boggomoss	5	42.0	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	BARVNT42	2	6.58	60	0.61	132.4	23.9	50-150	20.9	Excellent	Yes	Yes	Yes	Yes	Yes	Yes
DawsonRiver4	4	47, 48, 49, 50 & 51	1	4.1	DawsonRiver4	4	47.1	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample															
DawsonRiver4	4	39, 40, 41, 52 & 67/nv346	1	4.11	Prices	580	52.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample															
DawsonRiver4	4	39, 40, 41, 52 & 67/nv346	2	4.12	Prices	580	52.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	<1	7.61	190	5.03	166.7	9.4									
DawsonRiver4	4	39, 40, 41, 52 & 67/nv346	3	4.13	Prices	580	39.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	1 to 3	7.75	97	5.95	230	16.5									
DawsonRiver4	4	39, 40, 41, 52 & 67/nv346	4	4.14	Prices	580	67.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	PCKVNT67	<1	7.12	173	7.54	211.9	10	650	20.9	Excellent	Yes	Yes	Yes	Yes	Yes	No
DawsonRiver4	4	39, 40, 41, 52 & 67/nv346	5	4.15	Prices	580	40.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	< 1	7.11	328		205		140-220	20.9							
DawsonRiver4	4	39, 40, 41, 52 & 67/nv346	6	4.16	Prices	580	41.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	<1	7.47	-30	0.05	197.8	22.5	200-330	20.9							
DawsonRiver4	4	47, 48, 49, 50 & 51	2	4.2	DawsonRiver4	4	47.4	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample															
DawsonRiver4	4	47, 48, 49, 50 & 51	3	4.3	DawsonRiver4	4	47.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	0.1	6.71	61	0.42	45.3	16.1	220-340	20.9							

Appendix A: 2011 QWC Spring Survey Key Data Summary

KCB Hydrogeological Attribute Survey Database (KCB, 2012)

Spring Complex Name	Spring Complex Number	KCB Vent Number	Location Number	KCB Vent Location ID	QLD Herb Complex Name	QLD Herb Complex Number	QLD Herb Vent Number	Location Source QLD Herb	Infield Source Assessment	Field Estimated Source Aquifer (Option 1)	Field Estimated Source Aquifer (Option 2)	Water Quality Sample Reference	Flow (L/s)	pH	ORP (mV)	DO (mg/L)	EC (µS/cm)	Temp (℃)	Methane (CH4)	Oxygen (O2)	Sample_Quality	Major Ions	Metals	Nutrients	TOC + DOC	O18 - D	C-14
DawsonRiver4	4	47, 48, 49, 50 & 51	4	4.4	DawsonRiver4	4	47.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	0.3	8.31	73	0.93	31.5	15.2	400-500	20.9							
DawsonRiver4	4	47, 48, 49, 50 & 51	5	4.5	DawsonRiver4	4	47.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	10	8.01	263	8.03	236.8	17.7									
DawsonRiver4	4	47, 48, 49, 50 & 51	6	4.6	DawsonRiver4	4	47.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	PCKVNT51	0.1	7.22	152	1.62	328	15.3	260-370	20.9	Good	Yes	Yes	Yes	Yes	Yes	No
DawsonRiver4	4	47, 48, 49, 50 & 51	7	4.7	DawsonRiver4	4	51.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample															
DawsonRiver6	6	43	1	43.1	DawsonRiver6	6	43.0	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	No Sample									No Sample						
DawsonRiver6	6	1, 6, 7, 22, 27, 56, 60 & 62	1	6.1	DawsonRiver6	6	7.0	Yes	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	pooled water	6.01	175	4.55	189	13.8									
DawsonRiver6	6	1, 6, 7, 22, 27, 56, 60 & 62	10	6.10	Boggomoss	5	56.0	Yes	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample															
DawsonRiver6	6	1, 6, 7, 22, 27, 56, 60 & 62	2	6.2	DawsonRiver6	6	22.0	Yes	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	pooled water	6.01	197	1.6	229.7	10.2									
DawsonRiver6	6	1, 6, 7, 22, 27, 56, 60 & 62	3	6.3	Boggomoss	5	68.1	Yes	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	pooled water	5.71	173	4.58	193	11.4	250-330								
DawsonRiver6	6	1, 6, 7, 22, 27, 56, 60 & 62	4	6.4	DawsonRiver6	6	27.0	Yes	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	pooled water	5.37	219	1.78	208	14.8	100-230								
DawsonRiver6	6	1, 6, 7, 22, 27, 56, 60 & 62	5	6.5	DawsonRiver6	6	1.0	Yes	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample															
DawsonRiver6	6	1, 6, 7, 22, 27, 56, 60 & 62	6	6.6	DawsonRiver6	6	1.0	Yes	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	BORSVNT1	pooled water	6.65	63	4.73	401	8.5			Average	Yes	Yes	Yes	Yes	Yes	No
DawsonRiver6	6	1, 6, 7, 22, 27, 56, 60 & 62	7	6.7	DawsonRiver6	6	60.0	Yes	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample															
DawsonRiver6	6	1, 6, 7, 22, 27, 56, 60 & 62	8	6.8	DawsonRiver6	6	62.0	Yes	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample															
DawsonRiver6	6	1, 6, 7, 22, 27, 56, 60 & 62	9	6.9	DawsonRiver6	6	6.0	Yes	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample															
DawsonRiver8	8	38	1	38.1	DawsonRiver8	8	38.0	No	GAB - Surat Basin	Hutton Sandstone	Birkhead Formation	LCVNT38	no flow	7.64	129	3.88	1397	16.8	60-170	20.9	Average	Yes	No	No	No	No	No
DawsonRiver8	8	38	2	38.2	DawsonRiver8	8	Na	No	Na	Na	Na	No Sample															
DawsonRiver8	8	38	3	38.3	DawsonRiver8	8	Na	No	Na	Na	Na	No Sample	0.5	8.72	142	4.77	1393	20.9									
EdenVale	76	330.1	1	330.1	Eden Vale	76	701.0	No	GAB - Surat Basin	Boxvale Sandstone Member	Unknown / Uncertain	LDNV330.1	minor flow	5.69	53.9	1.68	456	17.3	160-520	20.9	Average	Yes	Yes	Yes	Yes	Yes	No
EdenVale	76	330.2	1	76.1	Eden Vale	76	700.0	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	LDNV330	<0.5		161.3	5.75	64	12.6	190-690	20.9	Average	Yes	Yes	Yes	Yes	Yes	0
EdenVale	76	330.2	2	76.2	Eden Vale	76		No	Na	Na	Na	No Sample		6.7	110.6	6.04	110	11.3									
EdenVale	76	330.2	3	76.3	Eden Vale	76		No	Na	Na	Na	No Sample		7.33	74	9.84	85	13.3									
Lonely Eddie	339	NV416	1	416.1	LonelyEddie	339	706.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	LHNV416MSP	3	5.36	197	3.45	287	21.2	900	20.9	Excellent	Yes	No	No	No	No	No
Lonely Eddie	339	NV416	2	416.2	LonelyEddie	339	707.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	LHNV416	4	5.26	193	2.96	145	21.8	920	20.9	Excellent	Yes	Yes	Yes	Yes	Yes	Yes
Lonely Eddie	339	NV416	3	416.3	LonelyEddie	339	708.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	2	5.03	207	5.89	160	18.9									
Lonely Eddie	339	NV416	4	416.4	LonelyEddie	339	709.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	0.2	5.22	224	6.82	133	13.2									
Lucky Last	230	287	1	287.1	LuckyLast	230	287.0	Yes	GAB - Surat Basin	Boxvale Sandstone Member	Precipice Sandstone	No Sample	No flow	6.2		0.93	821	18.2									
Lucky Last	230	287	2	287.2	LuckyLast	230	287.0	No	GAB - Surat Basin	Boxvale Sandstone Member	Precipice Sandstone	LL230-287	0.25	6.7		1.9	370	17.3			Average	Yes	Yes	Yes	Yes	Yes	No
Lucky Last	230	340	1	340.1	LuckyLast	230	687.1	Yes	GAB - Surat Basin	Boxvale Sandstone Member	Precipice Sandstone	No Sample	Pool	7.14		0.09	841	19.9	140								
Lucky Last	230	340	2	340.2	LuckyLast	230	687.2	Yes	GAB - Surat Basin	Boxvale Sandstone Member	Precipice Sandstone	No Sample	Pool	7.14		0.09	841	19.9	140								
Lucky Last	230	340	3	340.3	LuckyLast	230	687.3	Yes	GAB - Surat Basin	Boxvale Sandstone Member	Precipice Sandstone	No Sample	Outflow minor	7.44		2	513	19.3									
Lucky Last	230	340	4	340.4	LuckyLast	230	687.4	Yes	GAB - Surat Basin	Boxvale Sandstone Member	Precipice Sandstone	No Sample	Outflow minor	7.44		2	513	19.3									
Lucky Last	230	340	5	340.5	LuckyLast	230	687.5	Yes	GAB - Surat Basin	Boxvale Sandstone Member	Precipice Sandstone	No Sample	Surface seep	6.69				20.1	140-170								
Lucky Last	230	340	6	340.6	LuckyLast	230	687.6	Yes	GAB - Surat Basin	Boxvale Sandstone Member	Precipice Sandstone	No Sample	Surface seep	6.69				20.1	140-171								
Moolayember	233	408 & 408.1	1	233.1	Moolayember	233	408.0	No	GAB - Surat Basin	Clematis Sandstone	Unknown / Uncertain	WR408	minor flow	5.97	125.5	1.73	197	12.7	1100-1200	20.9	Average	Yes	Yes	Yes	Yes	Yes	No
Moolayember	233	408 & 408.1	2	233.2	Moolayember	233	676.0	No	GAB - Surat Basin	Clematis Sandstone	Unknown / Uncertain	408.1	minor outflow	6.62	31	0.34	236	27.8	160-200	20.9	Average	Yes	Yes	Yes	Yes	Yes	No
Moolayember	233	408 & 408.1	3	233.3	Moolayember	233	675.0	No	GAB - Surat Basin	Clematis Sandstone	Unknown / Uncertain	No Sample															
Moolayember	233	408 & 408.1	4	233.4	Moolayember	233	Na	No	Na	Na	Na	No Sample															
No complex	0	NV436	1	436.1	Timor	587	x436	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	No Sample															
Pony Hills	229	284	1	284.1	Ponies	229	284.0	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	PHVNT284	0.1	6.62	250		217	11.8			Average	Yes	Yes	Yes	Yes	Yes	No
Scotts Creek	260	189 & 191	1	189.1	Scotts Creek	260	189.0	No	GAB - Surat Basin	Hutton Sandstone	Birkhead Formation	No Sample		8.6	67.6	6.78	1740	16.3	590-650	20.9							
Scotts Creek	260	189 & 191	2	189.2	Scotts Creek	260	191.0	No	GAB - Surat Basin	Hutton Sandstone	Birkhead Formation	MRB191		8.62	25.8	6.59	2772	11.8	790-800	20.9	Average	Yes	Yes	Yes	Yes	Yes	No
Scotts Creek	260	189 & 191	3	189.3	Scotts Creek	260	191.0	No	GAB - Surat Basin	Hutton Sandstone	Birkhead Formation	No Sample		8.71	24.5	4.26	2935	13.3	1800*	20.9							
Scotts Creek	260	189 & 191	4	189.4	Scotts Creek	260	189.0	No	GAB - Surat Basin	Hutton Sandstone	Birkhead Formation	MRB189		7.6	87.2	6.06	1358	13.3			Excellent	Yes	Yes	Yes	Yes	Yes	Yes
Scotts Creek	260	192 & 192A	1	260.1	Scotts Creek	260	192.1	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	No Sample		8.81	106.8	5.73	1400	25.1	1100-1200	20.9							
Scotts Creek	260	192 & 192A	2	260.2	Scotts Creek	260	192.0	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	No Sample		8.62	112.5	5.02	1550	11.9									
Scotts Creek	260	192 & 192A	3	260.3	Scotts Creek	260	192.0	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	MRB192SCK	1	8.18	99.5	7.99	1334	16.9			Good	Yes	Yes	Yes	Yes	Yes	No
Scotts Creek	260	192 & 192A	4	260.4	Scotts Creek	260	190.0	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	No Sample		8.56	123.3	9.52	1474	14.2									
Scotts Creek	260	192 & 192A	5	260.5	Scotts Creek	260	190.0	No	GAB - Surat Basin	Hutton Sandstone	Unknown / Uncertain	No Sample	10	8.79	108.5	5.11	1313	25.8	650-700	20.9							
Six Mile	507	187	1	187.1	VI_Mile	507	187.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	SM187	0.25	7.44		1.33	322	19.7		20.9	Good	Yes	Yes	Yes	Yes	Yes	Yes
Six Mile	507	187	2	187.2	VI_Mile	507	187.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample															
Six Mile	507	187	3	187.3	VI_Mile	507	187.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample															
Six Mile	507	187A	1	187A.1	VI_Mile	507	679.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	SM187A	1 to 3	6.56		1.28	56.4	19.6		20.9	Average	Yes	Yes	Yes	Yes	Yes	Yes
Six Mile	507	187A	2	187A.2	VI_Mile	507	679.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample	1 to 3	6.63		2.18	101	19.6		20.39							
Six Mile	507	187A	3	187A.3	VI_Mile	507	679.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample					110										
Six Mile	507	187A	4	187A.4	VI_Mile	507	679.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample		7.3		3.54	253.3	18									
Six Mile	507	187B	1	187B.1	VI_Mile	507	680.1	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	SM187B	No flow	6.88		2.29	103.9	15		20.9	Average	Yes	Yes	Yes	Yes	Yes	No

Appendix A: 2011 QWC Spring Survey Key Data Summary

KCB Hydrogeological Attribute Survey Database (KCB, 2012)

Spring Complex Name	Spring Complex Number	KCB Vent Number	Location Number	KCB Vent Location ID	QLD Herb Complex Name	QLD Herb Complex Number	QLD Herb Vent Number	Location Source QLD Herb	Infield Source Assessment	Field Estimated Source Aquifer (Option 1)	Field Estimated Source Aquifer (Option 2)	Water Quality Sample Reference	Flow (L/s)	pH	ORP (mV)	DO (mg/L)	EC (µS/cm)	Temp (℃)	Methane (CH4)	Oxygen (O2)	Sample_Quality	Major Ions	Metals	Nutrients	TOC + DOC	O18 - D	C-14
Six Mile	507	187B	2	187B.2	VI_Mile	507	680.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample															
Six Mile	507	187B	3	187B.3	VI_Mile	507	680.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample															
Six Mile	507	188	1	188.1	VI_Mile	507	188.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample															
Six Mile	507	188	2	188.2	VI_Mile	507	188.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample															
Six Mile	507	188	3	188.3	VI_Mile	507	188.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample															
Six Mile	507	188	4	188.4	VI_Mile	507	188.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	SM188	10	6.46		1.93	237	19.9		20.9	Average	Yes	Yes	Yes	Yes	Yes	No
Six Mile	507	188	5	188.5	VI_Mile	507	188.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample															
SpringRockCreek	561	285	1	285.1	SpRockCrk	561	285.0	Yes	GAB - Surat Basin	Boxvale Sandstone Member	Precipice Sandstone	LL230-285	1	6.93		4.16	1224	20.9	290-300	20.9	Excellent	Yes	Yes	Yes	Yes	Yes	No
Springwater	311	535	1	535.1	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	No Sample															
Springwater	311	535	2	535.2	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	No Sample															
Springwater	311	535	3	535.3	311	311	693.0	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	No Sample															
Springwater	311	535	4	535.4	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	No Sample	10	8.16	128	7.7	269	14.4									
Springwater	311	536	1	536.1	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	No Sample	No flow	7.85	-82.2	6.37	211.5	12.1		20.9							
Springwater	311	536	2	536.2	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	No Sample															
Springwater	311	536	3	536.3	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	SW536A	Minor flow	7.32	146.1	6.03	303	13.8		20.9	Excellent	Yes	Yes	Yes	Yes	Yes	Yes
Springwater	311	536	4	536.4	311	311	536.2	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	No Sample															
Springwater	311	536	5	536.5	311	311	536.0	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	No Sample	2 to 3	6.7			280	17.7		20.9							
Springwater	311	536A	6	536A.1	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	No Sample															
Springwater	311	536A	7	536A.2	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	No Sample															
Springwater	311	536A	8	536A.3	311	311	694.0	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	No Sample		7.41	-56.9	6.1	355	13.9		20.9							
Springwater	311	536A	9	536A.4	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	SW536A	0.25 to 0.5 L/s	7.56	-66.2	6.8	454	14.6		20.9	Good	Yes	Yes	Yes	Yes	Yes	No
Springwater	311	537	1	537.1	311	311	537.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	SW537	0.25 to 0.5	8.02	-95	3.19	669	21.7			Good	Yes	Yes	Yes	Yes	Yes	Yes
Springwater	311	537	2	537.2	311	311	537.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	Plate 4	7.56	-69	8.3	261	15.7									
Springwater	311	537	3	537.3	311	311	537.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample															
Springwater	311	537	4	537.4	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample															
Springwater	311	537A	1	537A.1	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	No Sample															
Springwater	311	537A	2	537A.2	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	No Sample															
Springwater	311	537A	3	537A.3	311	311	699.0	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	No Sample															
Springwater	311	537A	4	537A.4	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	No Sample															
Springwater	311	537A	5	537A.5	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Clematis Sandstone	SW537A	See Plate 4	8.7	-135.7	4.37	246	16.9		20.9	Excellent	Yes	Yes	Yes	Yes	Yes	Yes
SprRidge	506	184, 185 & 186	1	506.1	SprRidge	506	184.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample	seep	6.43	153.4	1.34	123	9.5	90-140	20.9							
SprRidge	506	184, 185 & 186	2	506.2	SprRidge	506	185.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample	seep	6.8	139.2	6.38	53	14.6									
SprRidge	506	184, 185 & 186	3	506.3	SprRidge	506	185.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	No Sample	seep	6.77	136.1	6.78	55	14.9									
SprRidge	506	184, 185 & 186	4	506.4	SprRidge	506	186.0	No	GAB - Surat Basin	Gubberamunda Sandstone	Unknown / Uncertain	SPRD186	1 to 2	7.29	119.5	2.81	131	11.5	390-450	20.9	Good	Yes	Yes	Yes	Yes	Yes	Yes
Yebna	311	499	1	499.1	311	311	500.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	YBVNT499	1	6.23	55	0.18	225	25.4			Excellent	Yes	Yes	Yes	Yes	Yes	Yes
Yebna	311	499	2	499.2	311	311	499.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	2 to 3	6.52	66	2.19	185	25.4	20-85	20.9							
Yebna	311	500	1	500.1	311	311	500.0	No	GAB - Surat Basin	Precipice Sandstone	Evergreen Formation	YBVNT500	Minor flow	7.58	296	6.55	1044	9.8	45-160	20.9	Good	Yes	Yes	Yes	Yes	Yes	No
Yebna	311	500B & 500A	1	500A.1	311	311	500.1	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample	0.5	7.79	422	6.72	1145	14.1	100-230	20.9							
Yebna	311	500B & 500A	2	500A.2	311	311	Na	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample		7.42	173	7.76	537	15.9	130-230	20.9							
Yebna	311	500B & 500A	3	500A.3	311	311	692.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample		7.4	137	9.77	382	13.1									
Yebna	311	500B & 500A	4	500A.4	311	311	692.0	No	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	No Sample		7.59	288	7.61	214	16.7	200-240	20.9							
Yebna	311	534	1	534.1	Yebna2	591	Na	No	GAB - Surat Basin	Evergreen Formation	Precipice Sandstone	No Sample	No flow	7.74	324	6.21	1170	9.8	480-540	20.9							
Yebna	311	534	2	534.2	Yebna2	591	Na	No	GAB - Surat Basin	Evergreen Formation	Precipice Sandstone	No Sample	No flow	8.49	251	10.38	224	10.2	480	20.9							
Yebna	311	534	3	534.3	Yebna2	591	Na	No	GAB - Surat Basin	Evergreen Formation	Precipice Sandstone	No Sample	No flow	8.3	363	8.08	280	11.7	430	20.9							
Yebna	311	534	4	534.4	Yebna2	591	534.0	No	GAB - Surat Basin	Evergreen Formation	Precipice Sandstone	No Sample	No flow	7.48	372	7.35	313	7.8									
Yebna	311	534	5	534.5	Yebna2	591	534.0	No	GAB - Surat Basin	Evergreen Formation	Precipice Sandstone	YBVNT534	No flow	8.08	275	7.09	351	11.2			Average	Yes	Yes	Yes	Yes	Yes	No
Yebna	311	nv364	1	nv364.1	311	311	704.0	Yes	GAB - Surat Basin	Precipice Sandstone	Unknown / Uncertain	NV364	10 to 15	6.31	97	2.63	368	21.8	650-680	20.9	Excellent	Yes	Yes	Yes	Yes	Yes	Yes

Appendix B
Spring Conservation Ranking Criteria and Results

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Appendix B: Spring Conservation Ranking Criteria and Results

Conservation Ranking	Description	Number of Spring Complexes	Spring Complex Number(s)
Category 1a	Contains at least one GAB endemic species not known from any other location beyond this spring complex.	1	296
Category 1b	Contains endemic species known from more than one spring complex; or has populations of threatened species listed under State or Commonwealth legislation that do not conform to Category 1a.	7	5, 6, 9, 230, 260, 580, 592
Category 2	Provides habitat for populations of plant and/or animal species not known from habitat other than spring wetlands within 250km.	16	1, 2, 3, 4, 68, 85, 229, 232, 233, 235, 236, 302, 304, 311, 339, 590
Category 3	Spring wetland vegetation without isolated populations (Category 2) with at least one native plant species that is not a widespread coloniser of disturbed areas.	14	8, 16, 76, 78, 283, 326, 561, 582, 583, 584, 585, 591, 593, 594
Category 4a	Spring wetland vegetation comprised of exotic and/or only native species that are wide spread colonisers of disturbed areas.	0	-
Category 4b	The original spring wetland is destroyed by impoundment or excavation. The probability of important biological values being identified in the future is very low.	2	506, 507
Category 5	All springs inactive.	0	-
Not applicable	Springs were not selected by OGIA for inclusion in field survey.	32	35, 74, 84, 254, 256, 267, 306, 307, 308, 309, 310, 325, 327, 328, 331, 334, 335, 510, 586, 587, 588, 589, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604
	Total	**72**	

Source: Queensland Herbarium, 2012

Appendix C
Summary of Calibrated Model Parameters

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Appendix C: Summary of Calibrated Model Parameters

Table C1: Calibrated horizontal hydraulic conductivity

Unit	Arrow EIS Groundwater Model	OGIA Surat CMA Groundwater Model
	Average Horizontal Hydraulic Conductivity (m/day)	Average Horizontal Hydraulic Conductivity (m/day)
Condamine Alluvium	5	16
Lower Cretaceous Units	0.001	-
Main Range Volcanics	-	0.11
Rolling Downs Group	-	0.021
Bungil Formation/Mooga Sandstone	0.5	1.5
Orallo Formation/ Kumbarilla Beds	0.1	0.032
Gubberamunda Sandstone	0.5	0.69
Westbourne Formation	0.001	0.0014
Springbok Sandstone	0.5	0.65
WCM (upper aquitard)	0.05	0.00061
WCM (productive coal)	0.05	0.031
WCM (lower aquitard)	0.05	0.0022
Hutton Sandstone	0.1	0.52
Evergreen Formation	0.001	0.00013
Precipice Formation	1	0.34
Moolayember Formation	-	0.0014
Clematis Sandstone	-	0.2
Rewan Group	-	0.054
Banana Formation	-	0.032

Table C2: Calibrated vertical hydraulic conductivity

Unit	Arrow EIS Groundwater Model	OGIA Surat CMA Groundwater Model
	Vertical Hydraulic Conductivity (m/day)	Vertical Average Hydraulic Conductivity (m/day)
Condamine Alluvium	0.5 & 0.001	16
Lower Cretaceous Units	0.00001	-
Main Range Volcanics	-	0.00044
Rolling Downs Group	-	0.000021
Bungil Formation/Mooga Sandstone	0.05	0.081
Orallo Formation/ Kumbarilla Beds	0.002	0.000032
Gubberamunda Sandstone	0.05	0.055
Westbourne Formation	0.00001	0.0000057
Springbok Sandstone	0.05	0.11
WCM (upper aquitard)	0.001	0.000015
WCM (productive coal)	0.00001	0.000006
WCM (lower aquitard)	0.001	0.000026
Hutton Sandstone	0.002	0.028
Evergreen Formation	0.00001	0.00000057
Precipice Formation	0.1	0.026
Moolayember Formation	-	0.00013
Clematis Sandstone	-	0.027
Rewan Group	-	0.000097
Banana Formation	-	0.0000064

Table C3: Calibrated values – specific storage

Unit	Arrow EIS Groundwater Model	OGIA Surat CMA Groundwater Model
	Specific Storage	Specific Storage
Condamine Alluvium	0.05	0.1 – 0.001
Lower Cretaceous Units	0.000005	-
Main Range Volcanics	-	0.005
Rolling Downs Group	-	0.00005
Bungil Formation/Mooga Sandstone	0.000005	0.00005
Orallo Formation/ Kumbarilla Beds	0.000005	0.00005
Gubberamunda Sandstone	0.000005	0.00005
Westbourne Formation	0.000005	0.00005
Springbok Sandstone	0.000005	0.00005
WCM (upper aquitard)	0.000005	0.00005
WCM (productive coal)	0.000001	0.000034 – 0.0000001
WCM (lower aquitard)	0.000005	0.00005
Hutton Sandstone	0.000005	0.00005
Evergreen Formation	0.000005	0.00005
Precipice Formation	0.000005	0.00005
Moolayember Formation	-	0.00005
Clematis Sandstone	-	0.00005
Rewan Group	-	0.00005
Banana Formation	-	0.000034 – 0.0000001
Pre-Bandana Age Units	-	0.00005

Appendix D
Arrow Energy Surat Gas Project
Groundwater Modelling Report

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Appendices

1. Introduction

1.1 Background and Objectives

GHD was commissioned by Arrow Energy, in April 2013, to undertake numerical groundwater modelling work to support the Arrow Surat Gas Project (SGP) Supplementary Report to the Environmental Impact Statement (SREIS).

The current Arrow SGP development case has been assessed in the SREIS by modifying the modelling presented by the Queensland Water Commission (QWC), now Office of Groundwater Impact Assessment (OGIA) in the Underground Water Impact Report (UWIR) for the Surat Cumulative Management Area (CMA) (QWC, 2012). The modelling work undertaken to support the UWIR involved a combination of the Surat CMA Groundwater Model (GHD, 2012), probabilistic uncertainty analysis (Watermark Numerical Computing, 2012), and use of the Condamine Alluvium Groundwater Model (Klohn Crippen Berger, 2011) to calculate impacts within the Condamine Alluvium. Note QWC will hereafter be referred to as the OGIA except when referencing reports published by QWC.

The combined use of the OGIA Surat CMA Groundwater Model and Condamine Alluvium Groundwater Model and the probabilistic modelling approach adopted by the OGIA (QWC, 2012) is considered to represent the most appropriate methodology currently available (June 2013) for assessing the regional-scale groundwater impacts of CSG developments within the Surat CMA. The overall objective of the numerical modelling work undertaken for the SREIS reported herein was therefore to repeat the modelling previously completed by (and on behalf of) the OGIA but based on the current Arrow SGP development case.

A groundwater model of the Central Condamine River Alluvium (CCRA) was previously conceptualised, constructed and calibrated as part of a staged assessment completed by Klohn Crippen Berger (KCB) on the behalf of the Department of Natural Resources and Mines (DNRM, formerly part of the Department of Environment and Resource Management (DERM)). This work is reported in a series of KCB reports (KCB, 2010a, 2010b, 2010c, and 2011). A brief summary of the CCRA model developed by KCB, hereafter referred to as the ‘Condamine Alluvium Groundwater Model’, is presented in Section 2.1 of this report.

The OGIA Surat CMA Groundwater Model was initially constructed and calibrated by the OGIA and GHD (GHD, 2012; see Section 2.2). Some further minor revisions and detailed uncertainty analysis were then carried out by the OGIA and Watermark Numerical Computing (2012, see Section 2.3) the results of which are presented in the Surat CMA UWIR (QWC, 2012). This model and the associated uncertainty analysis work is hereafter referred to collectively as the ‘OGIA Surat CMA Groundwater Model’ (GHD, 2012; Watermark Numerical Computing, 2012; and QWC, 2012).

Figure 1 shows the extent of the OGIA Surat CMA Groundwater Model and Condamine Alluvium Groundwater Model domains. As shown in Figure 1 the Condamine Alluvium Groundwater Model domain represents only a small sub-area of the OGIA Surat CMA Groundwater Model. Hence the Condamine Alluvium Groundwater Model includes a more detailed representation of this area. In recognition of the existing more detailed Condamine Alluvium Groundwater Model, development of the OGIA Surat CMA Groundwater Model was undertaken (GHD, 2012) such that:

- Key components of the Condamine Alluvium Groundwater Model were incorporated into the OGIA Surat CMA Groundwater Model construction and calibration; and

- The Condamine Alluvium Groundwater Model was used to predict groundwater level impacts in the Condamine Alluvium, based on groundwater flow (hereafter referred to as fluxes) impacts calculated using the OGIA Surat CMA Groundwater Model.

These inter-relationships between the two models are shown in Figure 2 and are discussed further in Sections 2.2.5 and 2.3.2.

Figure 3 shows the extent of the five Arrow development regions within the Surat Basin (i.e. Chinchilla, Dalby, Millmerran/Kogan, Goondiwindi and Wandoan) presented in the Environmental Impact Statement (EIS) for the SGP. The shaded areas represent areas where CSG production wells are proposed under Arrow's current development plan. Ongoing exploration and improved knowledge of coal seam gas reserves has resulted in a number of parcels of land within Arrow's SGP development area being relinquished. The footprint of the current project development area and proposed CSG well-fields is therefore smaller than that previously assessed in the EIS and by the OGIA (QWC, 2012).

The overall project development area has been sub-divided into 12 sequentially numbered drainage areas (DA), as shown in Figure 4. Gas from each DA will be supplied to individual central gas processing facilities (CGPFs). It is currently expected that eight of these DAs will initially be developed for the Arrow SGP (DA1, DA2, DA5, DA7, DA8, DA9, DA10 and DA11), with each drainage area incorporating wells, a water gathering network, a gas gathering network and a CGPF. Additional DAs may be developed later.

1.2 Report Contents and Purpose

This Report includes a summary of the predictive numerical modelling work undertaken by GHD in order to assess the regional scale groundwater impacts of Arrow's current SGP development case for SREIS purposes and is structured as follows:

- Section 1 provides an introduction to the project, presents a summary of the relevant background to the project and discusses the objectives of the work;
- Section 2 provides a summary of work previously undertaken by GHD (2012), Watermark Numerical Computing (2012), QWC (2012) and KCB (2010a, 2010b, 2010c, and 2011) relating to the construction, calibration, and use of the OGIA Surat CMA Groundwater Model and Condamine Alluvium Groundwater Model;
- Section 3 describes the methodology adopted for the current SREIS predictive modelling;
- Section 4 presents predicted numerical modelling results;
- Section 5 presents the conclusions;
- Section 6 Glossary; and
- Section 7 References.

1.3 Scope and Limitations

This report: has been prepared by GHD for Arrow Energy and may only be used and relied on by Arrow Energy for the purpose agreed between GHD and the Arrow Energy as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Arrow Energy arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer section 1.4 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Arrow Energy and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

GHD has not been involved in the preparation of the Supplementary Groundwater Assessment and has had no contribution to, or review of the Supplementary Groundwater Assessment, prepared by Coffey other than in the Arrow Energy Surat Gas Project – Assessment of Regional Impacts report prepared by GHD. GHD shall not be liable to any person for any error in, omission from, or false or misleading statement in, any other part of the Supplementary Groundwater Assessment, prepared by Coffey.

As stipulated in the Deed of Licence the following Model and Licensed Data Notice also applies to use of the Condamine Alluvium Groundwater Model and the OGIA Surat CMA Groundwater Model:

"The parties acknowledge that copyright exists in the Model and Licensed Data. In consideration of the State permitting use of the Model and Licensed Data you acknowledge and agree that the State gives no warranty in relation to the Model and Licensed Data (including accuracy, reliability, completeness, currency or suitability) and accepts no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use of the Model and Licensed Data. The Model and Licensed Data must not be used for direct marketing or be used in breach of any privacy laws."

1.4 Assumptions

As previously mentioned in Section 1.1 the numerical modelling work undertaken for the SREIS largely represents a repeat of the groundwater impact assessment work previously completed as part of preparation of the UWIR for the Surat CMA (QWC, 2012) but based on the current development case data provided by Arrow. All information relating to the OGIA Surat CMA Groundwater Model and the Condamine Alluvium Groundwater Model were provided to GHD by the OGIA and/or Arrow under a licence agreement between Arrow and the OGIA. GHD has not independently verified or checked the information provided beyond the agreed scope of work. It is therefore assumed that all of the information provided, in particular the numerous model input files, are free from errors and omissions that could affect the outcomes of the current study.

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2. Summary of Previous Model Development Work

2.1 Condamine Alluvium Groundwater Model

2.1.1 Introduction

Klohn Crippen Berger Ltd (KCB) were engaged by the Queensland Department of Environment and Resource Management (DERM) to complete a groundwater flow model of the Central Condamine River Alluvium (CCRA) the overall objective, as stated by KCB (2011), being to:

"Assess and characterise the groundwater system of the CCRA and to develop scientific and management tools, including a groundwater flow model, to assist resource managers to administer the groundwater resources within the CCRA Area."

The following sub-sections provide a short summary of the KCB report of the work completed (KCB, 2011).

2.1.2 Model Review

Model construction and calibration work was subject to ongoing input and review by the project team which included:

- Leon Leach of the DERM Resource Sciences Centre
- Linda Foster of the QWC;
- David Free and Adrian McKay of DERM Toowoomba; and
- John Hillier;

A peer review of the model construction and calibration work was also undertaken by Andrew Durick of AGE Consultants Pty Ltd.

2.1.3 Conceptualisation

Study Area Description

The Condamine study area (see Appendix C, Figure 2.1) comprises the Condamine River catchment from its headwater near Killarney, to slightly downstream of Chinchilla, where the main aquifer abruptly narrows and the Condamine River changes from northerly to westerly flowing. Tributary alluvium is excluded from the area studied and the numerical model developed.

Condamine Alluvium

The hydrogeological setting of the Condamine River within the Surat Basin is illustrated in Appendix A, Figure 13.

Key conceptual elements that are mentioned by KCB in the Condamine model report (KCB, 2011) include:

- The CCRA is a broad description used for the alluvium and sheetwash deposits which underlie the Condamine River;
- Fluvial alluvium dominates the western portion of the system and extends the full width of most sections beneath the sheetwash material;

- The system is heavily utilised for groundwater supply;
- The generally coarser-grained nature of the fluvial alluvium relative to the overlying sheetwash deposit, makes this layer the preferred water supply target;
- The underlying basement rock predominantly comprises siltstones, sandstones, shales, coals, and to a lesser extent basalts.
- The contact between the basement and the overlying alluvial sediments is typically characterised by a clayey zone which is thought to represent weathered basement material developed prior to deposition of overlying alluvium.
- Small basement ridges separate the alluvium into two segments running parallel to the river system and may be representative of bedding, weathering or geological contacts.

Groundwater Extraction and Impact

Metered groundwater extraction has not varied greatly between each of the three preceding decades with average total abstractions of 43,745 ML/yr, 44,643 ML/yr and 44,143 ML/yr (KCB, 2011) from 1980 to 1990, 1990 to 2000 and 2000 to 2010 respectively. These extraction rates are lower than the 550,000 ML/yr (or 55 GL/yr) quoted for the Condamine Alluvium in the Surat CMA UWIR (QWC, 2012). The apparent discrepancy between these two estimates is understood to be related to the inclusion of an allowance for un-metered groundwater extraction in the larger 55GL estimate developed for the later UWIR report (QWC, 2012).

A comparison of observed groundwater levels in 2008 and in the 1960's suggests groundwater level drawdown of between 2 m and 26 m (DERM, 2008). Most drawdown is reported to be between 10 km and 20 km south of the Cecil Plains line, and east of the North Branch of the Condamine River (KCB, 2011).

2.1.4 Numerical Model Design

Introduction

Model design considered the relative importance of components contributing to the overall water budget of the groundwater system. Groundwater abstraction, deep drainage, river leakage were considered to have a major influence on groundwater flow and hence were considered to require detailed representation. Basement rock leakage, tributary leakage from the east, alluvium inflow from upstream, alluvium outflow downstream, irrigation deep drainage, flood recharge and interaction with the underlying Walloon Coal Measures were all considered to be less important to the overall water budget.

Model Extent and Grid Resolution

The model comprises 402 rows and 110 columns each of which is 500 m x 500 m (Appendix C, Figure 3.1). Within this grid the study area is described by 21,874 cells with the remainder of the grid designated as 'no flow' cells. The model domain is rotated 33° west from north so that the model grid was aligned with what was believed to be the principal direction of groundwater flow.

Model Code Selection

Modelling was undertaken using the MODFLOW-SURFACT modelling code predominantly to resolve problems reported during the calibration phase with dry model cells. This MODFLOW variant also includes a more sophisticated well simulation package (i.e. the Fracture Well (FWL4) package) which was seen as advantageous (KCB, 2011).

Modelling Approach

Model development and calibration was tailored to best meet the study objectives which predominantly related to assisting with administration of groundwater resources on a regional scale, rather than site specific management at any given location within the CCRA.

The conceptual hydrogeological model and water balance presented by KCB (2010b and 2010c) was preserved where possible during model construction. Local refinement of conceptualisation was reportedly required in some areas (for example, establishing minimum layer thicknesses for numerical stability).

Transient simulations were undertaken of the period from January 1980 to July 2009, which represents a period of relatively reliable abstraction data supported by metered abstraction records. This period also included a historic episode of above average rainfall (1980 to ~1990) followed by a period of generally below average rainfall (~1990 to 2009). The simulation period was divided into 354 monthly stress periods with each stress period separated into 6 time-steps using a time step multiplier of 1.2.

Key performance indicators were set in consultation with DERM and aligned with the Murray Darling Basin Commission modelling guidelines (Middlemis, Merrick and Ross, 2000). The agreed target comprised a Scaled Root Mean Fraction Square (SRMFS) and Scaled Root Mean Square (SRMS) of less than 5 % (KCB, 2011).

Groundwater Model Layer Development

A two-layer model was used to simulate the hydrostratigraphic units in the area comprising the sheetwash (Layer 1) and alluvium (Layer 2) of the CCRA. Whilst sheetwash is largely absent to the west of the Condamine River “a veneer of fine grained black soils does extend across most of the system.” (KCB, 2011).

Model layers for the base of the sheetwash and the hydraulic basement were constructed from surface topography and structure contours (KCB, 2010b) with some modifications to ensure a minimum layer thickness for the purposes of maintaining model stability (KCB, 2011).

In representing the stratigraphy of the area the following adjustments to model layers were made for the purposes of achieving numerical stability:

- Where possible, the base of Layer 1 was set as low as possible to avoid cell drying issues through regional lowering of the piezometric surface. In most areas where this was required (particularly in the west of the system), this was reported to have a negligible effect on the simulation as Layer 1 in these areas were assigned hydraulic parameters consistent with the alluvium (not the sheetwash).
- Layer 2 was assigned a minimum thickness of 10 m. In most areas of the model domain, this modification was not required as this unit typically exceeds this thickness across most of the system. This was reported to be required in the east of the area, where the contact with the eastern system flank is least well known This was not considered an unreasonable modification given the assumed geochronology of the system (a moving channel system from east to west being 'pushed ' by the sheetwash);
- The blacksoil was not represented as a stand - alone layer, but its effect on recharge was accounted for in the recharge (deep drainage) boundary condition development (KCB, 2011).

Boundary Conditions

Areas outside the main channel alluvium were designated as ‘no flow’ cells and comprised about 50 % of cells contained within the model’s domain of 402 rows and 110 columns. These areas encompass the Main Range Volcanics, along the eastern margins, and the Kumbarilla beds to the west. A detailed description of bedrock geology underlying and/or flanking the CCRA is provided in KCB (2010b).

General Head Boundary Cells

The way in which the Condamine alluvial aquifer interacts with the underlying consolidated strata is not completely understood. For the Condamine Alluvium Groundwater Model KCB used general head boundary cells to represent of fluxes into and out of the model domain. Five conceptual reaches (Reach 0-4) were identified as shown in Appendix C, Figure 3.8.

Heads within GHB cells were defined as constant throughout the transient simulation based on an average condition established from observed CCRA water levels on 1/1/1980. In later stress periods fluxes across general head boundaries were varied in response to fluctuations in water levels within the CCRA.

Conductance terms were initially set using analytical calculations and industry experience coupled with previously assessed water budget estimates, estimates of the area of boundary influence, and anticipated head difference between the boundary and the CCRA. Fluxes across boundaries were monitored during the calibration process with minor adjustments made to conductance terms to ensure that the modelled flux volumes were broadly consistent with those estimated in previous water balance work (KCB, 2010c). Modelled conductance values varied between 5.0×10^{-3} m^2/day for fluxes into the Walloon Coal Measures, up to 32 m^2/day for outflow from the CCRA in the vicinity of Chinchilla Weir and 0.2 m^2/day for fluxes with bedrock to the east and tributary alluvium leakage.

Drain and River Boundary Cells

Conceptually KCB (2011) report that groundwater discharge to surface water systems is “thought to be negligible within the model domain (for the transient calibration period).” Hence, whilst there may be isolated occurrences of discharge the effects of sustained abstraction in the region make it unlikely that they are representative of the main aquifer system. Conversely leakage from the river into the underlying aquifer was thought to be a significant component of the water balance.

Interaction between the river and groundwater was modelled using the MODFLOW River package and inputs of river bed elevation, river stage elevation and bed conductance. This package simulates the relative levels in the river and aquifer to determine the presence of a gaining (groundwater discharge into the river) or losing (leakage from the river into the aquifer) river reaches.

The elevation of the Condamine River was obtained from a Digital Elevation Model (DEM) with adjustments for any discrepancies between the DEM and spot values from available surveys or weir data.

River gauge data were used to compile a time series of river stage for each river cell on a monthly time step over the period of simulation. Missing data within a record were in-filled by means of correlation and where records were unavailable stage data were developed from flows at the nearest gauge, using uniform flow formula and simplified cross section geometry. River stage during high flow conditions, within ponded sections upstream of weirs, was derived from the full supply level of the weir.

An initial bed conductance measurement was based on estimates from water balance studies (KCB, 2010c). Values of stream loss presented by Lane (1979) range from 38.5 ML/annum/km to 115 ML/annum/km, with an average rate of 66.7 ML/annum/km.

2.1.5 Initial Parameterisation

Drainage to the water table was estimated externally from MODFLOW using recharge potential maps and effective rainfall estimates (KCB, 2010c). Additional leakage was added to represent continuous drainage from irrigated areas and ring tanks. A range of recharge distributions were calculated for testing during the model calibration process.

An initial demarcation of the two model layers into zones of constant aquifer parameter values was based on the conceptual hydrogeological model defined in KCB (2010b). The distribution of zones is shown in Appendix C, Figure 3.14.

Complex layering and deposition has created a series of lateral sand and gravel beds often bound and inter-bedded by lower permeability units within the CCRA. It was concluded by KCB (2010b) that the demarcation of zones based on historical pumping tests presented in Lane (1979) and Lloyd (1971) (after Huxley, 1982 and Lane, 1979) was not possible due to heterogeneity of alluvial sediments. Therefore, initial estimates of horizontal hydraulic conductivity were assumed to be two orders of magnitude greater than vertical hydraulic conductivity.

The following summary of initial aquifer properties for the sheetwash (Layer 1) and alluvium (Layer 2) of the CCRA is taken from KCB (2011):

- Zone 1 (of Layer 1) and Zone 4 (of Layer 2) represents the alluvium, and had a starting permeability of 20 m/d, 0.03 (specific yield) and 0.0002 (specific storage).
- Zone 2 (of Layer 1) represents the sheetwash, and had a starting permeability of 0.3 m/d and 0.005 (specific yield) and 0.0001 (specific storage).
- Zone 3 (of Layer 1) and Zone 5 (of Layer 2) represent the Tertiary Chinchilla Sand with a permeability of 5 m/d and 0.01 (specific yield) and 0.0002 (specific storage).

The distribution of zones in Layer 1 reflects the relative absence of sheetwash from areas to the west of the Condamine River and the presence of Chinchilla Sand in the northern downstream area. Whilst the underlying Layer 2 consists mainly of alluvium.

The study area has seen significant groundwater extraction over a prolonged period. The majority of groundwater abstraction is from the alluvium of Layer 2. An analysis of 749 boreholes produced transient monthly abstraction data at the locations within the model domain shown in Appendix C, Figure 3.9 (KCB, 2011). Based on advice from DERM unmetered groundwater extractions were simulated at 100 % of authorised pumping rates.

The robustness of the calibrated model to extreme pumping situations was tested for three water management scenarios which were agreed with DERM. These were the simulation of 100 %, 50 % and 0 % of 2009 authorised use volumes for the entire 30 year model calibration period. These scenarios are discussed further in Section 2.1.8.

2.1.6 Numerical Model Calibration

Calibration Approach

Model calibration involved a number of steps including: initial manual calculations to identify any issues that would slow model processing; implementation of a number of MODFLOW variants prior to the final model development in MODFLOW SURFACT; this was followed by an initial calibration of the groundwater model involving manual adjustment of aquifer parameters; finally calibration of both steady state and transient models was undertaken using the model independent parameter estimation code PEST (Doherty, 2010 and 2011).

PEST was used to cycle through parameter values of hydraulic conductivity, storage and river leakage within each of the defined model zones until a best fit with measured head data was achieved. Some control on the final solution was maintained through periodic intervention and assessment of PEST results with manual adjustment, where necessary.

In order to minimise the number of calibration parameters, as many model ‘parameter’ estimates as possible were ‘fixed’. Modelled extraction was ‘fixed’ on the basis that a large proportion of total extraction is measured by DERM and the total modelled extraction estimate is considered accurate. Deep drainage to the water table was also fixed.

Model calibration was therefore carried out by varying the hydraulic conductivity, storage and river leakage.

A steady state version of the model was calibrated initially to provide the following insights:

- review the system water balance assumptions and model boundary conditions;
- assess compliance with the conceptual understanding of the system; and
- develop initial parameter values for the transient calibration .

Using the initial heads from the steady state simulation as a starting condition, a transient calibration was then carried out using PEST in regularisation mode, with pilot points and Singular Value Decomposition Assist (SVDA, Doherty, 2010 and 2011).

According to KCB (2011) the following parameter groups were adjusted during the calibration:

- horizontal hydraulic conductivity in Layer 1 and Layer 2 (Kxy1 and Kxy2), with no anisotropy;
- specific yield in Layer 1 and Layer 2 (Sy1 and Sy2);
- storage compressibility in Layer 1 and Layer 2 (Ss1 and Ss2);
- river bed conductance for river reaches defined in Appendix C, Figure 3.8 (Rv); and ,
- vertical hydraulic conductivity in Layer 1 and Layer 2 (Kz1 and Kz2) as a factor of Kxy1 and Kxy2.

All parameters except river bed conductance and Kz (vertical hydraulic conductivity) were calibrated using pilot points. In addition to pilot points, the conceptual zones shown in Appendix C, Figure 3.14 were also included in the calibration.

The calibration process included periodic interruptions to simulations to enable manual checks which ensured the magnitude of components in the water budget were within previously identified limits.

The primary calibration set for the transient model calibration consisted of 91 monitoring bores within Layer 2. The remainder of the monitoring bore data within the transient calibration period was set aside for use in model verification.

Calibration Results

A good visual correlation between observed and modelled groundwater level hydrographs was reported in most areas although it was noted that the groundwater model was unable to depict local drawdown effects at individual boreholes, due to the resolution of the grid (500 m x 500 m). Scatter plots for three stress periods, 1990, 2000 and 2009, are shown in Appendix C, Appendix VI-1,2 and 3 and exhibit r^2 values of 0.92, 0.88 and 0.92, respectively. A small number of outliers are reported to represent bores that are screened within sheetwash and are therefore unrepresentative of conditions in the regional aquifer (KCB, 2011).

KCB (2011) report that “Generally the model predicts high RMS randomly across the model domain, although RMS is slightly higher within a series of bores in the easterly area of the model domain beneath the sheetwash.” KCB also suggest that the high RMS error may reflect structural errors within the model or calibration process and / or inadequate input data including such items as:

- Difficulty in representing layer thicknesses which has consequences for the simulation of groundwater storage and available resources for pumping;
- Inaccuracies in defining river bed geometry which affects the description of surface – groundwater interaction;
- Lack of short period groundwater level hydrographs which affects the representation of recharge and groundwater response;
- Issues with groundwater extraction data with adverse consequences for the simulation of groundwater withdrawal and response, and especially the specification of model starting conditions;
- Lack of information on the interaction with surrounding basement rock and the actual rate of lateral flows which affect the water balance.

Inspection of the residual errors by KCB (2011) suggested a normal distribution. Therefore, in accordance with MDBC guidelines (Middlemis, Merrick and Ross, 2000) the RMS was used to measure the model calibration performance. A mean error in groundwater level estimation of about -0.6 m was suggested by the distribution of groundwater level results and indicated that the model tended to underestimate groundwater levels.

A further measure of the model's performance was obtained from an estimate of the Scaled RMS. A scaled RMS of 4.1 % was reported which was within the criteria set by DERM and is less than the 5 % general reference value described by the MDBC guidelines (Middlemis, Merrick and Ross, 2000). A lower scaled RMS value of around 2.5 % could reportedly have been achieved if the results of five bores, which may be representative of localised permeable zones within the sheetwash layer, were excluded.

Statistics of flow components extracted from the transient groundwater model are summarised in Table 1 for the period January 1980 (stress period 1) to June 2009 (stress period 354).

Table 1 Condamine Alluvium Groundwater Model – Transient Water Balance

IN/OUT	Component	Minimum (ML/d)	Average (ML/d)	Peak (ML/d)
IN	River Leakage	8.862	32.512	279.459
IN	Lateral and Vertical Inflow from adjacent units	10.558	10.824	11.228
IN	Recharge	2.355	28.193	307.886
IN	Total Inflows	-	71.531	-
OUT	Baseflow to Rivers	0	0.772	2.152
OUT	Lateral and Vertical Outflow to adjacent units	0.108	0.253	0.275
OUT	Groundwater Extraction	7.226	202.923	712.949
OUT	Total Outflows	-	203.949	-

In general the magnitude of water balance components summarised in Table 1 are in line with pre-modelling estimates made by KCB (2010c) and therefore suggest that:

- Aquifer inflows are dominated by leakage from the river system and rainfall recharge;
- Vertical and/or lateral inflow from the surrounding bedrock units is significant but of lower magnitude; and
- Outflows are dominated by groundwater extractions, whilst baseflow to rivers and outflow to adjacent bedrock units are both negligible.

2.1.7 Model Sensitivity

Model Sensitivity

A complete sensitivity analysis involving a record of water balance and groundwater level results following successive selection of parameters or boundaries for variation, whilst keeping all others fixed, was not undertaken by KCB (2011). However, KCB (2011) report that the model was particularly sensitive to changes in extraction quantities but was less sensitive to variations in rainfall recharge.

Use of PEST in the calibration process provided information on the model's sensitivity to changes in parameters and showed that "hydraulic conductivity in model Layer 2 (Kxy2), specific yield in Layers 1 and 2 (Sy 1 & Sy 2) and river bed conductance (Riv) are the most sensitive parameter groups." (KCB, 2011).

Model Verification

Model verification was carried out using groundwater levels from the 92 monitoring bores that were not used in the calibration process. This data set includes some bores within the sheetwash layer (model layer 1) for which calibration was not specifically targeted.

No statistics of agreement between modelled and observed groundwater levels are presented by KCB (2011) although a visual inspection of hydrographs shows a reasonably good agreement.

2.1.8 Numerical Model Predictions

KCB obtained agreement from DERM to run three water management scenarios based on the authorised use for 2009 (current) and two proportional levels of use, namely 50 % of 2009 authorised pumping rates and a zero pumping scenario. These scenarios were intended to test how the model responds to extreme pumping situations and were not representative of planning scenarios.

The 100 % scenario represented an extraction of 71 GL, whilst the 50 % scenario would represent extractions of half this amount (35 GL/yr see section 4.3.1).

2.2 OGIA Surat CMA Groundwater Model

2.2.1 Introduction

QWC previously commissioned GHD and Watermark Numerical Computing to develop a regional groundwater flow model for the Surat CMA. The model was then used to predict the cumulative impacts of proposed CSG developments in the Surat CMA. These predictions are summarised in the Underground Water Impact Report (UWIR) for the Surat CMA (QWC, 2012). The modelling work underpinning this assessment is summarised in the following detailed technical reports:

- Surat Cumulative Management Area Groundwater Model Report, (GHD, 2012); and
- Predictive Uncertainty of the Regional-Scale Groundwater Flow Model for the Surat Cumulative Management Area, (Watermark Numerical Computing, 2012).

The following sections provide a brief summary of work reported in these two (2) dedicated reports.

Since the Arrow SGP involves extraction from the Walloon Coal Measures (WCM) of the Surat Basin, discussion of the underlying Bowen Basin and the Bandanna Formation (the main CSG target in the Bowen Basin) has been largely excluded from the following sections.

2.2.2 External Review

Independent external review formed an integral component of the modelling work undertaken for QWC. This was achieved through regular consultation with both the project Technical Advisory Group (TAG) and the Project Steering Committee (PSC). Through these groups input to the OGIA Surat CMA Groundwater Model was received from a number of independent numerical modelling and GAB ‘experts’ and other stakeholders including DERM, the Commonwealth Scientific and Industrial Research Organization (CSIRO) and the Department of Sustainability, Environment, Water, Population and Communities (SEWPAC). Based on these consultation meetings the project TAG and PSC were able to review and endorse a number of key outputs of the modelling work including:

- Conceptualisation of the study area;
- Numerical model design and approach; and
- Confirmation that the calibrated model was ‘fit for purpose’ for use as a quantitative tool for assessing cumulative impacts of water extraction from Coal Seam Gas (CSG) fields.

On this basis the OGIA Surat CMA Groundwater Model has since been adopted and used to assess the cumulative impacts of the CSG industry for the Surat CMA UWIR report (QWC, 2012) and also by individual CSG proponents for assessing the impacts of individual development proposals. The model is therefore considered to be the most appropriate available tool for assessing:

- The regional scale impacts of the Arrow Surat Gas Project; and
- The revised cumulative impacts of proposed CSG developments in the Surat Basin based on the most recent development plans provided by each of the CSG companies.

2.2.3 Conceptualisation

The adopted conceptual model of the Surat CMA area previously reported in GHD (2012) was largely developed by QWC drawing on a range of previous studies and previous experience of managing groundwater resources in the area. In addition to presenting a unified conceptual model for the Surat CMA this work focussed on the following key areas and hydrogeological units:

- The main CSG targets in the Surat and Bowen basins, i.e. the Walloon Coal Measures (WCM) and Bandanna Formation;
- The degree of interaction between these CSG bearing units and surrounding aquifers.

Regional Setting

CSG extraction is targeted on the WCM of the Surat and Clarence-Moreton basins and the Bandanna Formation of the underlying Bowen Basin. There are a number of regional aquifers within these basins that are used for water supplies. Overlying these basins are also extensive areas of unconsolidated younger alluvial superficial sediments and volcanics, which contain significant aquifers in localised areas, such as the Condamine Alluvium.

Both the Surat and Bowen basins comprise a sequence of alternating layers of water-bearing (permeable) sandstone aquifers and non-water-bearing (low permeability) siltstone or mudstone aquitards that generally dip in a south-westerly direction. The thickness of the sedimentary sequence reaches nearly 2,500 m in places. The individual sandstone, siltstone and mudstone formations range in thickness from less than 100 m to more than 600 m.

Regionally, the main aquifers and aquitards in the Surat Basin approximate the stratigraphic units or geological formations. Table 2 displays the sequence of the aquifers and aquitards within the Basin. Locally most of the aquifers contain minor interbedded siltstone and mudstone that are reflected in lower bore yields in some areas. Similarly, several aquitards contain minor aquifers of permeable sandstones and siltstones that can yield a reasonable quantity of water in these otherwise unproductive formations.

Conceptual cross sections of the Surat and Bowen Basins are shown in Appendix A, Figures 13 and 14.

Walloon Coal Measures

The WCM typically comprise siltstone, mudstone, fine- to medium-grained lithic sandstone, and coal deposited from rivers and in lakes and swamps across the Surat and Clarence-Moreton basins (Scott et al., 2004).

A generalised representation of the stratigraphy of the WCM is provided in Appendix A, Figure 8. The geology is complex, layers thicken and thin, and the coal seams in particular are often not laterally persistent (Scott et al., 2004).

At the basin scale the WCM are considered to be an aquitard. The coal seams are generally the more permeable units within a sequence of dominantly low permeability mudstones, siltstones or fine grained sandstones.

The WCM typically demonstrate a very low degree of connectivity with over and underlying aquifer units.

In the Condamine area the alluvium of the Condamine River is incised into the WCM by up to around 130 m and the coal measures therefore represent the main basement unit for most of the central area of the Condamine Alluvium, as shown in Appendix A, Figure 13. However, a layer of weathered clay and low permeability material typically exists between the deepest productive parts of the Condamine Alluvium (the hydraulic basement) and the uppermost coal beds in the underlying WCM (Lane, 1979). This layer is a combination of low permeability basal alluvial clays of the Condamine Alluvium, and the weathered upper part of the WCM, which are often indistinguishable from each other.

As previously noted the coal seams within the WCM are separated by lower permeability mudstone, siltstone and fine grained sandstone. These relatively low-permeability layers act as aquitards generally separating the productive coal seams from the Springbok Sandstone aquifer above and the Hutton and Marburg sandstone aquifers below, except in areas where the upper aquitard has been eroded away.

Table 2 Stratigraphy of the Surat, Clarence-Moreton and Bowen Basins

Model Layer	Surat Basin	Clarence-Moreton Basin
1	Colluvium; Alluvium (Condamine); Chinchilla Sands	
1a	Main Range Volcanics	
2	Griman Creek Formation; Surat Siltstone; Wallumbilla Formation: Coreena Member, Doncaster Member	
3	Bungil Formation: Minmi Member, Nullawart Sst Member, Kingull Member; Mooga Sandstone; Southlands Formation; Kumbarilla Beds	Kumbarilla Beds
4	Orallo Formation; Southlands Formation; Kumbarilla Beds	Kumbarilla Beds
5	Gubberamunda Sandstone; Kumbarilla Beds	Kumbarilla Beds
6	Injune Creek Group: Westbourne Formation; Kumbarilla Beds	Kumbarilla Beds
7	Injune Creek Group: Springbok Sandstone; Kumbarilla Beds	Kumbarilla Beds
8	Injune Creek Group: Springbok Sandstone; Kumbarilla Beds	Kumbarilla Beds
9	Injune Creek Group: Walloon Coal Measures	Walloon Coal Measures
10	Injune Creek Group: Walloon Coal Measures	Walloon Coal Measures
11	Injune Creek Group: Walloon Coal Measures; Eurombah Formation	Walloon Coal Measures
12	Hutton Sandstone	Bundamba Group: Marburg Sst; Marburg Sub Group: Koukandowie Formation (Heifer Creek Sst Member, Ma Ma Creek Member)
13	Evergreen Formation; Boxvale Sst	Bundamba Group: Marburg Sst; Marburg Sub Group: Koukandowie Formation (Ma Ma Creek Member), Gatton Sandstone
14	Precipice Sandstone	Bundamba Group: Helidon Sst; Woogaroo Sub Group: Ripley Road Sandstone
15	Bowen Basin: Moolayember Formation; Snake Creek Mst Mem; Wandoan Formation	Bundamba Group: Helidon Sst; Woogaroo Sub Group: Raceview Fm
16	Bowen Basin: Clematis Group sandstones; Showgrounds Sandstone; Wandoan Formation	Bundamba Group: Helidon Sst; Woogaroo Sub Group: Aberdare Conglomerate
17	Bowen Basin: Rewan Group	
18	Bowen Basin: Bandanna Formation; Blackwater Group; Baralaba Coal Measures	
19	Bowen Basin: Permian Sediments	

Legend
- Minor discontinuous aquifer
- Major aquifer
- Productive coal seam

2.2.4 Hydrostratigraphic Model Development

The three-dimensional representation of the hydro-stratigraphic units which underpins the OGIA Surat CMA Groundwater Model (GHD 2012) was based on a combination of pre-existing borehole data sets and outputs from previous basin scale studies. A 19-layer system was adopted, including at least one layer for each major hydrostratigraphic unit present within the Surat CMA (Table 2). Fourteen layers were adopted to represent the strata present within the Surat Basin, with a further five layers to represent the Bowen Basin.

The elevation of the top of each of the main consolidated stratigraphic units, excluding the Quaternary and Tertiary age superficial deposits and the subdivisions of the Springbok Sandstone and the Walloon Coal Measures, were initially defined using the following data:

- Interpreted borehole log data obtained from the Queensland Petroleum Exploration Database (QPED) and the Queensland Groundwater Database (GWDB), supplemented with borehole logs provided by the CSG companies (Arrow, Santos, Origin and QGC);
- Geological contour elevations extracted from the Bowen and Surat Basins Regional Structural Framework Study (SRK, 2008) for model layers 9, 12, 13, 14 and 18;
- Geological contour elevations provided by Geoscience Australia (GA) for model layers 16 and 17; and
- Interpreted geological mapping provided by the OGIA showing the extent of the estimated subcrop area of each of the main stratigraphic units beneath the overlying superficial deposits (Appendix A, Figure 7).

These data sets were combined and used to develop a 3D hydrostratigraphic model of each of the consolidated strata (i.e. model layers 2 to 19 inclusive) present within the Surat CMA on a 500 m by 500 m, grid using the geological modelling package MINEX developed by GEMCOM.

2.2.5 Numerical Model Design and Overall Approach

The key characteristics of the OGIA Surat CMA Groundwater Model (GHD 2012) can be summarised as follows:

- The adopted model area (Figure 1) comprises a 547.5 km (east-west) by 661.5 km (north-south) rectangle which based on the adopted grid resolution 1,500 m by 1,500 m results in a model of 441 rows by 365 columns with up to 160,965 model cells in each layer;
- A 19 layer model was developed as summarised in Table 2 comprising 14 layers representing the Surat Basin and a further 5 layers representing the underlying Bowen Basin;
- A three-layer system was adopted for the WCM (model layers 9 to 11) as follows:
  - Layer 9 an upper aquitard layer defined by the vertical distance between the uppermost productive coal seam and the top of the WCM;
  - Layer 10 a composite coal seam and aquitard layer defined by the vertical distance between the top of the uppermost and base of the lowermost productive coal seam; and
  - Layer 11 a lower aquitard layer defined by the vertical distance between the base of the lowermost productive coal seam and the base of the WCM, i.e. the top of the underlying Hutton Sandstone;
- The MODFLOW 2005 code was selected for model development largely based on the desire to both optimise the model calibration and quantitatively assess the uncertainty associated with model predictions using stochastic modelling techniques;
- No significant interaction with adjacent basins to the north and west is thought to be occurring and hence these model boundaries have been simulated as MODFLOW no-flow boundaries;

- Potentially significant interaction with the Clarence-Moreton Basin to the east and the remainder of the GAB to the south of the model area was anticipated so the remaining external model boundaries were simulated using the MODFLOW general head boundary package;
- Surface water – groundwater interaction within the modelled area was simulated, using the MODFLOW Drain package or the MODFLOW River (parameterised so that modelled River cells act like Drains). This methodology was considered to represent a conservative assumption from an impact assessment point of view;
- Estimated extraction relating to licensed volumetric entitlements, stock and domestic and conventional gas and oil extractions, from all of the consolidated units present within the model area, were included;
- Construction and calibration of a steady state model representing long term average pre CSG extraction conditions were undertaken initially to provide boundary conditions for a subsequent calibration of a transient sub-model and predictive simulations;
- Consistency with the pre-existing Condamine Alluvium Groundwater Model (Section 2.1) was maintained through the incorporation of calibrated parameter and modelled groundwater level data from the sub-model area (Figure 2);
- Groundwater extractions, groundwater recharge and surface water – groundwater interaction within the Condamine Alluvium were therefore not represented explicitly within the OGIA Surat CMA Groundwater Model since the more detailed local-scale Condamine Alluvium Groundwater Model is considered to be a more appropriate tool for representing these processes; and
- Similarly current extractions from other minor alluvial systems outside of the Condamine Alluvium were not represented in the model. Extractions from these systems are understood to be minor and the resolution of the OGIA Surat CMA Groundwater Model was also considered too coarse to allow accurate representation of these areas.

2.2.6 Model Calibration

Calibration of OGIA Surat CMA Groundwater Model (GHD 2012) was carried out as follows:

- Outside of the Condamine Alluvium initial parameters and permissible values for calibration purposes were derived from a combination of previous modelling and other studies (including Kellett et al., 2003; USQ, 2011; Santos, 2010; and Merrick, 2010) and summary statistics generated from field tests;
- Within the Condamine Alluvium initial parameters for the alluvial aquifer were extracted from the calibrated Condamine Alluvium Groundwater Model (Section 2.1) and remained 'fixed' throughout the calibration process;
- For most layers single initial parameter values were adopted;
- For layers where the available hydraulic conductivity data suggested a statistically significant depth relationship (i.e. the WCM, Precipice Sandstone and Bandanna Formation) initial values were calculated on a cell by cell basis using a depth relationship
- A relatively wide range of permissible values was typically adopted for each layer in order to reduce the likelihood of bias being introduced into the final calibrated values;
- Calibration of the steady state version of the OGIA Surat CMA Groundwater Model and the transient sub-model (of the area around the Arrow operated Kogan North and Daandine CSG wellfields) was carried out using the PEST Model Independent Parameter Estimation and Uncertainty Analysis software suite and Singular Value Decomposition

Assist (SVDA), a pilot point approach and Tikinhov Regularisation to optimise the model parameters (Doherty, 2010 and 2011);

- Optimisation of the modelled parameters involved repeated model runs to first assess parameter sensitivity before optimising each parameter. In this case a parallelised version of PEST, known as BEOPEST (Hunt et al., 2010), was used across a number of processors in order to minimise the time taken to calibrate the model;
- Initial calibration of the steady-state OGIA Surat CMA Groundwater Model was undertaken through reference to average groundwater levels from 1,541 bores which provide groundwater level data for the various consolidated strata present within the area;
- Groundwater level data for boreholes monitoring shallow alluvium and other un-consolidated strata were excluded from the calibration since the resolution of the Surat CMA Groundwater Model was considered too coarse to allow accurate representation of these areas;
- Subsequent re-calibration of the OGIA Surat CMA Groundwater Model under steady state conditions included an additional groundwater inflow target from the Condamine Alluvium of 16,200 m^3/d based on a pre-modelling water balance assessment (KCB, 2010c);
- Steady State calibration was achieved by varying water table recharge (on a zonal basis), general head boundary conductance; horizontal hydraulic conductivity (Kh) for aquifer layers, vertical hydraulic conductivity (Kv) for aquitards and vertical anisotropy (i.e. the ratio between Kh and Kv) for all layers;
- Construction and calibration of a nested transient sub-model of the existing Arrow operated Kogan North and Daandine CSG wellfields (Figure 1) was also carried out predominantly to provide calibrated storage parameters for the WCM;
- Calibration of the transient sub-model was undertaken through reference to observed groundwater level data from four (4) Arrow and two (2) DNRM monitoring bores located in and around the Arrow operated Kogan North and Daandine CSG wellfields;
- Calibrated parameters from the nested transient sub-model were then passed back into the OGIA Surat CMA Groundwater Model and the steady-state calibration re-run, but this time fixing selected parameters in the area of the sub-model;
- Calibrated long term average water table and net recharge values for each modelled zone are listed in Table 4. In this case 'net recharge' is considered to be equivalent to the modelled water flux to the deeper confined system and is therefore typically significantly less than the recharge rates applied to the uppermost active model layer; and
- Calibrated hydraulic conductivity and anisotropy values for the OGIA Surat CMA Groundwater Model are summarised in Table 5, Table 6 and Table 7.

Calibrated Water Balance Results

Calibrated long-term average water balance results for the entire area of the OGIA Surat CMA Groundwater Model are summarised in Table 3.

Total long-term average water table recharge to the modelled area which includes the entire Queensland portion of the Surat Basin, part of the Clarence-Moreton Basin and the southern portion of Bowen Basin was reported to be 5,209 ML/d (or 1,901,331 ML/yr). This is equivalent to an average rate of 6.8 mm/yr for the 278,883 km^2 active model area and equates to approximately 1.2 % of long-term average annual rainfall at Roma Airport (approximately 582 mm/yr based on data for the period 1910 to 2010).

Total long-term average water table recharge to the modelled area of Surat Basin, which excludes the Mulgildie Basin, is reported to be 3,467 ML/d (or 1,265,455 ML/yr). This is equivalent to an average rate of 5.8 mm/yr over the 219,010 km^2 modelled area of this basin.

Reported modelled water balance results suggest that approximately 93 % of the applied water table recharge exits the model locally via shallow groundwater and/or surface water systems (i.e. discharges via modelled drain and river cells). Net recharge to the deeper confined aquifer systems of the GAB is therefore significantly less than the applied water table recharge. Model results suggest a net recharge volume of 343 ML/d (or 125,265 ML/yr) to the GAB aquifer systems within the Surat CMA (Table 4).

GHD (2012) note that the OGIA Surat CMA Groundwater Model included a relatively simple representation of shallow groundwater systems, which was considered to be consistent with the regional scale and the overall aims of the model. In particular losses from near-surface evapotranspiration and groundwater extraction were not represented in the model. Estimates of modelled discharge to river and drain boundary cells shown in Table 3 therefore exclude these losses and should not be taken as estimates of baseflow to surface water courses in the area. Where evapotranspiration and groundwater extraction from shallow systems were included then a potentially significant proportion of the 93 % of water table recharge that is rejected from the current model would be subsequently lost via groundwater extractions and/or evapotranspiration from near surface systems.

Extraction from groundwater bores in the consolidated GAB units and the Main Range Volcanics was found to be the next most significant water balance component and accounted for approximately 6 % of the applied water table recharge.

Interaction with adjacent areas was reported to represent a relatively minor component of the modelled water balance. Inflow via the modelled general head boundary cells was predominantly from the Clarence-Moreton Basin to the east and constitutes only approximately 0.6 % of the modelled water table recharge. Outflow via general head boundary cells was predominantly to the remainder of the GAB to the south and constitutes only approximately 0.9 % of modelled water table recharge.

A steady-state water balance error for the OGIA Surat CMA Groundwater Model of 0.0 % was reported which corresponds to a disparity between input flows and output flows of -3.3×10^{-03} m^3/d.

Table 3 OGIA Surat CMA Groundwater Model, Long Term Average Modelled Water Balance

Component	Flow IN (ML/d)	Flow OUT (ML/d)	IN-OUT (ML/d)
Water table recharge	5,209.1	0.0	+5,209.1
River boundary cells	0.0	218.1	-218.1
Drain boundary cells	0.0	4,647.8	-4,647.8
Groundwater extraction	0.0	329.2	-329.2
General Head Boundary cells	33.6	47.6	-14
Total	**5,242.7**	**5,242.7**	**0.0**

Discussion of Calibration Results

Based on the values shown in Table 4 then modelled net recharge to the confined GAB aquifer systems in the Surat CMA was 125,267 ML/yr. This total volume was reported as being equivalent to a long-term average recharge rate of 0.4 mm/yr over the entire modelled Surat CMA or 1.9 mm/yr on average over the modelled outcrop area of the contributing aquifers. As expected given their low hydraulic conductivity modelled net recharge to the various aquitard units present within the area approached zero.

Modelled water table recharge values suggested generally increasing recharge within aquifer units towards the north and east and this pattern was considered to be consistent with the topographically driven spatial variation in long-term average rainfall. A similar pattern of variation was also observed by Kellett et al.(2003) who describe generally higher rates of recharge of up 20 mm/yr to older units such as the Hutton and Precipice Sandstone which occur at outcrop towards the north and east of the area. Model calibrated water table recharge rates for these layers were both approximately 20 mm/yr.

GHD (2012) noted that the work of Kellett et al. (2003) was limited to the aquifer units of the Surat Basin and hence few points of comparison were available for the aquitards. However, the relatively high water table recharge modelled to a number of aquitard layers including the WCM Upper Aquitard (model layer 9) and the Moolayember Formation (model layer 15), were reported as seeming somewhat anomalous and potentially related to the relatively small number of groundwater level observations in these layers. Reported net recharge to all of these aquitard layers, however, approached zero which confirmed that almost all of this applied recharge was rejected locally via the modelled drains. The apparent tendency for the OGIA Surat CMA Groundwater Model to over-estimate water table recharge to these aquitard layers was therefore considered, by GHD (2012), unlikely to affect the ability of the model to predict groundwater level impacts related to extraction from the WCM.

Calibrated hydraulic conductivity values are summarised in Table 5 and Table 6.

Reference to Table 5 and Table 6 suggests that average modelled values are typically consistent with the general hydrogeological characteristics of each unit. Hence the calibrated average values for the main aquifer units (i.e. layers 3,5,7,12,14 and 16) are typically higher than those for the aquitard layers. Given the wide range of permissible values adopted for the OGIA Surat CMA Groundwater Model calibration, this outcome, although expected, was not necessarily assured and was therefore considered to be a positive indicator of the reliability of the calibration (GHD, 2012).

Furthermore, while modelled values did in some cases reach either the lower or upper bounds, this typically occurred over only a small percentage of the modelled area. This was presented as evidence that the adopted upper and lower bounds were realistic and consistent with the head observations (GHD, 2012).

For those layers where the initial hydraulic conductivity distribution was derived using a depth relationship, the calibrated distributions were reported to tend to maintain the original pattern of spatial variability, even in areas where substantial numbers of target bores are available. This was presented as evidence by GHD (2012) that the conceptual model of declining conductivity with depth in the deeper units within the CMA was not inconsistent with the available calibration data.

Table 4 OGIA Surat CMA Groundwater Model, Calibrated Values – Recharge

Dominant Unit	Model Layer	Water Table Recharge (mm/yr)	Water Table Recharge (ML/yr)	Net Recharge[1] (mm/yr)	Net Recharge (ML/yr)
Condamine Alluvium	1	0.0	0	0.0	0
Main Range Volcanics	1	20.0	158,910	5.2	41,373
Alluvium outside Condamine area	1	1.1	28,120	0.0	72
Rolling Downs Group	2	3.2	303,512	0.0	2,028
Bungil Formation/Mooga Sandstone	3	2.5	23,176	1.7	15,280
Orallo Formation	4	1.0	8,929	0.0	188
Gubberamunda Sandstone	5	6.1	58,510	2.7	26,346
Westbourne Formation	6	1.0	5,684	0.0	23
Springbok Sandstone	7/8	1.0	7,751	0.6	3,626
WCM (Upper Aquitard)	9	30.0	278,126	0.0	0
WCM (Productive Coal)	10	2.1	19,529	1.1	10,360
WCM (Lower Aquitard)	11	5.8	2,117	0.2	89
Hutton Sandstone	12	19.2	251,773	1.3	17,265
Evergreen Formation	13	7.6	34,374	0.0	0
Precipice Sandstone	14	20.7	85,012	1.3	5,388
Moolayember Formation	15	30.0	304,184	0.0	445
Clematis Sandstone	16	30.0	177,408	0.4	2,540
Rewan Group	17	6.7	126,191	0.0	115
Bandanna Formation	18	1.0	27,196	0.0	130
Pre-Bandanna Age Units	19	14.7	729	0.0	0
TOTAL	NA	6.8	1,901,331	0.4	125,267

[1] Net Recharge = modelled water table recharge – modelled discharge to local shallow groundwater systems + net inflow from adjacent layers

Table 5 OGIA Surat CMA Groundwater Model, Calibrated Values – Horizontal Hydraulic Conductivity

Dominant Unit	Model Layer	Kh (m/d) – Min	Kh (m/d) – Avg	Kh (m/d) – Max
Condamine Alluvium	1	$1.9x10^{+00}$	$1.6x10^{+01}$	$4.0x10^{+01}$
Main Range Volcanics	1	$3.7x10^{-04}$	$1.1x10^{-01}$	$1.7x10^{+00}$
Alluvium outside Condamine area	1	$3.7x10^{-04}$	$1.8x10^{+01}$	$5.0x10^{+01}$
Rolling Downs Group	2	$5.5x10^{-03}$	$2.1x10^{-02}$	$9.4x10^{-02}$
Bungil Formation/Mooga Sandstone	3	$3.3x10^{-01}$	$1.5x10^{+00}$	$5.0x10^{+00}$
Orallo Formation	4	$1.0x10^{-02}$	$3.2x10^{-02}$	$3.7x10^{-01}$
Gubberamunda Sandstone	5	$4.9x10^{-02}$	$6.9x10^{-01}$	$5.0x10^{+00}$
Westbourne Formation	6	$2.5x10^{-04}$	$1.4x10^{-03}$	$2.8x10^{-02}$
Springbok Sandstone	7/8	$1.7x10^{-03}$	$6.5x10^{-01}$	$5.0x10^{+00}$
WCM (Upper Aquitard)	9	$4.0x10^{-07}$	$6.1x10^{-04}$	$4.0x10^{-03}$
WCM (Productive Coal)	10	$2.1x10^{-05}$	$3.1x10^{-02}$	$1.0x10^{+00}$
WCM (Lower Aquitard)	11	$1.7x10^{-06}$	$2.2x10^{-03}$	$8.5x10^{-03}$
Hutton Sandstone	12	$1.0x10^{-04}$	$5.2x10^{-01}$	$5.0x10^{+00}$
Evergreen Formation	13	$2.3x10^{-05}$	$1.3x10^{-04}$	$8.8x10^{-04}$
Precipice Sandstone	14	$9.8x10^{-03}$	$3.4x10^{-01}$	$5.0x10^{+00}$
Moolayember Formation	15	$3.7x10^{-06}$	$1.4x10^{-03}$	$1.4x10^{+00}$
Clematis Sandstone	16	$7.6x10^{-04}$	$2.0x10^{-01}$	$5.0x10^{+00}$
Rewan Group	17	$1.0x10^{-04}$	$5.4x10^{-02}$	$1.4x10^{+00}$
Bandanna Formation	18	$1.0x10^{-05}$	$3.2x10^{-02}$	$1.0x10^{+00}$
Pre-Bandanna Age Units	19	$5.0x10^{-07}$	$8.5x10^{-06}$	$5.0x10^{-03}$

Table 6 OGIA Surat CMA Groundwater Model, Calibrated Values – Vertical Hydraulic Conductivity

Dominant Unit	Model Layer	Kv (m/d) – Min	Kv (m/d) – Avg	Kv (m/d) – Max
Condamine Alluvium	1	$1.9x10^{+00}$	$1.6x10^{+01}$	$4.0x10^{+01}$
Main Range Volcanics	1	$1.5x10^{-06}$	$4.4x10^{-04}$	$6.9x10^{-03}$
Alluvium outside Condamine area	1	$1.5x10^{-06}$	$2.7x10^{+00}$	$4.0x10^{+01}$
Rolling Downs Group	2	$5.5x10^{-06}$	$2.1x10^{-05}$	$9.4x10^{-05}$
Bungil Formation/Mooga Sandstone	3	$1.8x10^{-02}$	$8.1x10^{-02}$	$2.7x10^{-01}$
Orallo Formation	4	$1.0x10^{-05}$	$3.2x10^{-05}$	$3.7x10^{-04}$
Gubberamunda Sandstone	5	$3.9x10^{-03}$	$5.5x10^{-02}$	$3.9x10^{-01}$
Westbourne Formation	6	$1.0x10^{-06}$	$5.7x10^{-06}$	$1.1x10^{-04}$
Springbok Sandstone	7/8	$2.9x10^{-04}$	$1.1x10^{-01}$	$8.4x10^{-01}$
WCM (Upper Aquitard)	9	$1.0x10^{-08}$	$1.5x10^{-05}$	$1.0x10^{-04}$
WCM (Productive Coal)	10	$1.0x10^{-08}$	$6.0x10^{-06}$	$1.0x10^{-04}$
WCM (Lower Aquitard)	11	$2.0x10^{-08}$	$2.6x10^{-05}$	$1.0x10^{-04}$
Hutton Sandstone	12	$5.4x10^{-06}$	$2.8x10^{-02}$	$2.7x10^{-01}$
Evergreen Formation	13	$1.0x10^{-07}$	$5.7x10^{-07}$	$3.9x10^{-06}$
Precipice Sandstone	14	$7.4x10^{-04}$	$2.6x10^{-02}$	$3.8x10^{-01}$
Moolayember Formation	15	$3.6x10^{-07}$	$1.3x10^{-04}$	$1.1x10^{-01}$
Clematis Sandstone	16	$1.0x10^{-04}$	$2.7x10^{-02}$	$6.9x10^{-01}$
Rewan Group	17	$1.0x10^{-07}$	$9.7x10^{-05}$	$1.1x10^{-01}$
Bandanna Formation	18	$2.0x10^{-09}$	$6.4x10^{-06}$	$2.0x10^{-04}$
Pre-Bandanna Age Units	19	$5.0x10^{-08}$	$8.5x10^{-07}$	$5.0x10^{-04}$

Calibrated vertical anisotropy values are summarised in Table 7.

GHD (2012) report that the calibrated values for the majority of the aquitard layers (i.e. except the upper and lower aquitards of the WCM (model layers 9 and 11) and the Moolayember Formation (model layer 15)), show a significant increase in vertical anisotropy in comparison to the initial values adopted. Calibrated values are therefore typically characterised by elevated ratios between horizontal and vertical hydraulic conductivity. This is consistent with the often highly variable nature of these aquitard units, many of which include significant permeable sandstone units.

Conversely, calibrated vertical anisotropy for the aquifer units are reported to have typically remained around the initial value of 10, suggesting less significant vertical heterogeneity within the main aquifer units. Given that the aquifer units in the Surat CMA are also typically considered to be highly heterogeneous (Section 2.2.3) then this result was considered to be somewhat surprising and attributed to an 'artefact' of the model calibration rather than a real feature. Other modelling studies undertaken in the area have also resulted in higher vertical anisotropy factors for aquitard layers and this is reflected in the hydraulic conductivity values proposed by USQ (2011).

The relatively low modelled vertical anisotropy of the upper and lower WCM aquitards (model layers 9 and 11) was reported as being consistent with the relatively limited thickness of these units and hence the reduced potential for heterogeneity compared to other thicker aquitard layers.

Anisotropy values for the composite coal layers were reported to have increased during the calibration from an initial value of 1,000 to a final calibrated value of 5,000 in both the WCM and the Bandanna Formation. These relatively high values were considered to be consistent with the highly stratified and variable nature of the productive coal units present in both basins (GHD, 2012).

Table 7 OGIA Surat CMA Groundwater Model, Calibrated Values – Anisotropy

Dominant Unit	Model Layer	Anisotropy – Calibrated
Condamine Alluvium	1	1
Main Range Volcanics	1	244
Alluvium outside Condamine area	1	97
Rolling Downs Group	2	1,000
Bungil Formation/Mooga Sandstone	3	18
Orallo Formation	4	1,000
Gubberamunda Sandstone	5	13
Westbourne Formation	6	254
Springbok Sandstone	7/8	6
WCM (Upper Aquitard)	9	40
WCM (Productive Coal)	10	5,000
WCM (Lower Aquitard)	11	85
Hutton Sandstone	12	18
Evergreen Formation	13	225
Precipice Sandstone	14	13
Moolayember Formation	15	10
Clematis Sandstone	16	7
Rewan Group	17	1,000
Bandanna Formation	18	5,000
Pre-Bandanna Age Units	19	10

Comparison of Observed and Modelled Groundwater Levels

Scatter plots of modelled against observed average groundwater levels for all head targets used to calibrate the steady-state OGIA Surat CMA Groundwater Model are shown in Appendix A, Figure 18. Calibration statistics are summarised in Table 8 and Appendix A, Figure 19.

Steady state calibration results indicate a scaled root mean square (SRMS) error of 3.7 % overall (Table 8). Considering the variable lithology of the Surat CMA, the regional size of the model and the resulting relatively coarse cell sizes adopted, the fit achieved between modelled and observed head targets was considered to be good (GHD, 2012).

The results presented suggested a particularly good calibration performance (i.e. a SRMS of around 5 % or lower) was achieved for the Bungil Formation/Mooga Sandstone (model layer 3), the Precipice Sandstone (model layer 14) and the Bandanna Formation (model layer 18). Relatively poor calibration performance is achieved for the Orallo Formation (model layer 4), the Westbourne Formation (model layer 6) and the Moolayember Formation (model layer 15) (Table 8).

Modelled groundwater levels were within 20 m of observed at approximately 66 % of the locations for which groundwater level data were available and within 30 m at approximately 83 % of the targets (see Appendix A, Figure 19). This result was considered to be satisfactory for a model of this size and complexity (GHD, 2012).

Table 8 OGIA Surat CMA Groundwater Model, Regional Steady State Model – RMS Errors

Dominant Unit	Model Layer	Scaled RMS Error	Residual Mean Error (m)	Number of Head Targets
Condamine Alluvium	1	NA	NA	NA
Main Range Volcanics	1	NA	NA	NA
Alluvium outside Condamine area	1	NA	NA	NA
Rolling Downs Group	2	6.2%	-10.1	214
Bungil Formation/Mooga Sandstone	3	5.2%	7.1	362
Orallo Formation	4	19.5%	5.5	24
Gubberamunda Sandstone	5	8.3%	2.5	160
Westbourne Formation	6	12.2%	0.2	39
Springbok Sandstone	7/8	7.7%	-5.6	47
WCM	9/10/11	6.5%	-3.1	198
Hutton Sandstone	12	7.6%	-3.6	225
Evergreen Formation	13	9.3%	-0.8	28
Precipice Sandstone	14	4.6%	2.0	43
Moolayember Formation	15	10.9%	-24.9	6
Clematis Sandstone	16	7.9%	13.4	10
Rewan Group	17	6.6%	-17.8	14
Bandanna Formation	18	4.5%	-8.4	14
Pre-Bandanna Age Units	19	7.7%	-19.0	21
Non-Outcrop Targets		**4.0%**	**0.63**	**917**
Outcrop Targets		**4.1%**	**-4.17**	**488**
All Targets		**3.7%**	**1.0**	**1405**

Comparison of Observed and Modelled Groundwater Flows

Total calibrated modelled inflow to the Condamine Alluvium was 29.4 ML/d (or 10,731 ML/yr) so the model was unable to match the calibration target of 16.2 ML/d (or 5,913 ML/yr) as estimated based on a pre-modelling water balance assessment undertaken by KCB (2010c). GHD (2012) noted, however, that this flow target is itself significantly uncertain. A precise match between this ‘observed’ target and modelled flows was not therefore necessarily expected, or required, as an outcome of the calibration process. Nevertheless the ‘observed’ and modelled flows were reported to be of the same order of magnitude so modelled inflows to the Condamine Alluvium were considered to be consistent with previous studies (GHD, 2012).

2.2.7 OGIA Surat CMA Groundwater Model - Initial Predictive Setup

Following completion of the model calibration work summarised in Section 2.2.6 further work was undertaken by GHD and the QWC (GHD, 2012) to develop and test a predictive model of the Surat CMA for subsequent use by the QWC for assessing the impacts of CSG related water extraction activities.

CSG Production Estimates

GHD (2012) reported, based on feedback from the CSG companies that, in the majority of areas within the Surat Basin optimal conditions for gas flow are typically achieved when groundwater levels in the CSG well-fields are at approximately 40 m above the top of the productive coal seams. Hence it was assumed that each well-field is operated such that groundwater levels are gradually drawn down to, and held at or around, this target groundwater level or target pressure. This process of drawing down groundwater to the target pressure usually occurs gradually over a five year period and the water produced from each well during this period typically declines exponentially over this period.

Estimates of total water production from each well-field were available to the QWC from each of the CSG companies and these could have been used as input data for predictive runs of the OGIA Surat CMA Groundwater Model. However, these water production estimates are themselves typically based on detailed local scale reservoir models, usually one model per CSG company. Given that different projects were at different stages of development the maturity of these models also varied from CSG company to company. Estimates from different CSG companies operating adjacent fields were therefore not necessarily consistent. Furthermore, output from these models was difficult to verify independently due to confidentiality and other constraints.

Rather than rely on these estimates, the QWC instead developed an independent estimate of water production from each field, derived from historical production data and development plans provided by the CSG companies. This independent water production estimate formed a key input parameter to the OGIA Surat CMA Groundwater Model predictive simulations.

Predictive Model Description

The ‘predictive’ version of the OGIA Surat CMA Groundwater Model was required to simulate the cumulative impact of both existing and proposed CSG extraction within the Surat CMA including the recovery period. Previous modelling has indicated an extended recovery period of up to 3,000 years. Consequently, the predictive model was set up to simulate a 3,000 year period from the commencement of CSG extraction in the Surat Basin during early 1995, through the main extraction period to 2050 before tracking the subsequent gradual recovery in groundwater levels.

Starting conditions for the predictive simulation were therefore extracted from the OGIA Surat CMA Groundwater Model steady state calibration run which included simulation of groundwater extraction from stock and domestic use, volumetric entitlements and conventional gas activities operational in 1995.

The simulation period was split into 259 modelled stress periods.

For the ‘predictive’ part of the run (i.e. from January 2011 onwards) all modelled boundary conditions including recharge (Table 4) were assumed to be as derived from the steady state calibration and so were assumed to be constant through time.

In the area of overlap between the OGIA Surat CMA Groundwater Model and the Condamine Alluvium Groundwater Model a zero recharge rate was assumed for the purposes of the predictive simulations. This was considered to be a conservative assumption from a CSG impact assessment point of view and is premised on the idea that groundwater levels in the Condamine Alluvium are currently low enough that disconnection of the Condamine River and the Condamine Alluvium has occurred. Under such conditions, any further reduction in groundwater levels in the Condamine Alluvium would not induce any additional recharge from surface water systems. In practice, while disconnection is considered likely in the central parts of the Condamine Alluvium, additional recharge could be induced around the margins of the alluvium. The assumption of zero recharge was therefore considered likely to represent an underestimate of actual recharge and expected to lead to over-estimation of CSG related impacts the Condamine Alluvium (GHD, 2012).

Predictive Model Parameterisation

Hydraulic conductivity and vertical anisotropy values for predictive modelling purposes were taken from the final calibration run of the steady-state OGIA Surat CMA Groundwater Model (Table 4, Table 5, Table 6, and Table 7).

Final specific storage values which were adopted for predictive modelling purposes are summarised in Table 9.

Specific storage for the productive zone of the WCM (model layer 10) was initially taken from the average of the calibrated values output from the transient sub-model calibration (i.e. 2.0×10^{-05} m^{-1}). Similarly specific storage for the Bandanna Formation (model layer 18) was taken from a previous transient calibration undertaken by Santos (2010). However, based on initial predictive modelling results alternative spatially variable specific storage values were developed for the WCM and the Bandanna Formation (Section 2.2.6). These were based on similar depth relationships to those developed for hydraulic conductivity. The distributions were developed such that consistency with the calibrated storage values estimated by Santos and by the transient sub-model were maintained. For example, calibration of the transient sub-model indicated a specific storage of 2.0×10^{-05} m^{-1} for the WCM in the Daandine field and consistency with this value was maintained by ensuring that the modelled depth relationship gives values of approximately 2.0×10^{-05} m^{-1} in this area.

Specific storage for the remaining model layers was assumed to be 5.0×10^{-05} m^{-1}. Storage values based on the specific yield (i.e. unconfined storage) were adopted in outcrop areas.

Table 9 OGIA Surat CMA Groundwater Model – Adopted Storage Values

Dominant Unit	Model Layer	Specific Storage (m^{-1})	Specific Yield (dimensionless)
Condamine Alluvium	1	NA	Variable ($1.0x10^{-03}$ – $1.0x10^{-01}$)
Main Range Volcanics	1	NA	$5.0x10^{-03}$
Alluvium outside Condamine area	1	NA	$7.0x10^{-03}$
Rolling Downs Group	2	$5.0x10^{-05}$	$5.0x10^{-03}$
Bungil Formation/Mooga Sandstone	3	$5.0x10^{-05}$	$5.0x10^{-03}$
Orallo Formation	4	$5.0x10^{-05}$	$5.0x10^{-03}$
Gubberamunda Sandstone	5	$5.0x10^{-05}$	$5.0x10^{-03}$
Westbourne Formation	6	$5.0x10^{-05}$	$5.0x10^{-03}$
Springbok Sandstone	7/8	$5.0x10^{-05}$	$5.0x10^{-03}$
WCM (Upper Aquitard)	9	$5.0x10^{-05}$	$5.0x10^{-03}$
WCM (Productive Coal)	10	Variable ($1.0x10^{-07}$ – $3.4x10^{-05}$)	$5.0x10^{-03}$
WCM (Lower Aquitard)	11	$5.0x10^{-05}$	$5.0x10^{-03}$
Hutton Sandstone	12	$5.0x10^{-05}$	$5.0x10^{-03}$
Evergreen Formation	13	$5.0x10^{-05}$	$5.0x10^{-03}$
Precipice Sandstone	14	$5.0x10^{-05}$	$5.0x10^{-03}$
Moolayember Formation	15	$5.0x10^{-05}$	$5.0x10^{-03}$
Clematis Sandstone	16	$5.0x10^{-05}$	$5.0x10^{-03}$
Rewan Group	17	$5.0x10^{-05}$	$5.0x10^{-03}$
Bandanna Formation	18	Variable ($1.0x10^{-07}$ – $3.4x10^{-05}$)	$5.0x10^{-03}$
Pre-Bandanna Age Units	19	$5.0x10^{-05}$	$5.0x10^{-03}$

Simulation of CSG Extractions

Given that the aim of CSG water extraction is to achieve a target pressure, rather than a particular water flow rate, CSG extractions were simulated in both the historic calibration and predictive versions of the OGIA Surat CMA Groundwater Model using the MODFLOW EVT package. This package provided a convenient means by which user defined water volumes could be removed from the model but subject to an additional level control (GHD, 2012).

The MODFLOW EVT package requires four input datasets for each model stress period as described below.

Information on historic and predicted future production rates, corresponding to evapotranspiration rates in the EVT package, was required. Actual extraction data provided by

CSG companies were used for the historic period, while the QWC derived estimates of future production rates were used for the predictive part of the simulation (i.e. January 2011 onwards).

User-defined evaporation surface and extinction depths were both required for the MODFLOW EVT package. Where modelled heads are above the evaporation surface then evaporation (or extraction in this case) continues at the full modelled rate. In the event that modelled heads fall below this surface the modelled evaporation (or extraction rate) decrease linearly from 100 % of the modelled rate at the evaporation surface to zero at the evaporation surface minus the extinction depth. The following evaporation and extinction depths were adopted for the OGIA predictive simulations:

- Based on discussions between QWC and Arrow, for the Arrow tenements a lower target pressure of 20 m above the uppermost productive coal seam was assumed. This translated into an upper evaporation surface for predictive modelling purposes of 15 m above the top of layer 9, or around 30 m above the top of model layer 10, since layer 9 is 15 m thick on average;
- Based on discussions with other CSG companies a target pressure of 40 m above the uppermost productive coal seam was assumed outside of the Arrow tenements. For the WCM, this translated into an upper evaporation surface for predictive modelling purposes of 35 m above the top of layer 9, or around 50 m above the top of model layer 10. For the Bandanna Formation this translated into an upper evaporation surface for predictive modelling purposes of 50 m above the top of layer 18;
- No de-rating of historic actual quantities was considered to be required and so an elevated extinction depth of 50 m was adopted such that little or no reduction of historic extraction occurs; and
- For all predictive periods and well-fields, an extinction depth of 20 m below the evaporation surface was assumed.

Based on the parameter set-ups described above, the intention for the historical part of the simulation was that little or no de-rating of the actual extraction quantities was undertaken. Conversely during the predictive part of the simulations, it was intended that modelled production rates would begin to be de-rated once the head reaches 10 m above the target pressure and reduced gradually to zero at 10 m below the target pressure.

GHD (2012) note that within the Surat Basin, the modelled evaporation surface was calculated relative to the top of the WCM (i.e. the top of model layer 9) rather than the top of the productive coals (i.e. the top of model layer 10). This approach was adopted because the top of the WCM was considered to be a less noisy and a more reliable surface.

Extraction was assumed to be from the Bandanna Formation (model layer 18) or the WCM (model layer 10) depending on whether the proposed well-field will extract gas and water from the coals of the Bowen or Surat basins.

2.2.8 OGIA Surat CMA Groundwater Model Test Predictions

A number of test predictive runs of the OGIA Surat CMA Groundwater Model were undertaken by GHD (2012) and predictions of total production rates and modelled drawdowns extracted from the model. Based on analysis of this output data a number of changes were made to the initial predictive model set-up as described below.

Changes to the Initial Predictive Model Set-up

Initial runs of the predictive model resulted in predicted total extraction volumes that significantly exceeded other estimates, and groundwater levels in many tenements that remained well above target pressures. In some tenements this problem was considered to be related to erroneously high hydraulic conductivity values and was addressed through re-calibration of the regional steady-state model using revised initial values. However, in most areas, and considering that the hydraulic conductivity values were calibrated, attention was instead focused on the modelled storage values. Storage values for both the WCM and the Bandanna Formation were considered to be relatively poorly calibrated since only limited transient calibrations had been possible at the time.

The constant values for specific storage initially adopted for the WCM (model layer 10) and the Bandanna Formation (model layer 18) were therefore reviewed and modified to introduce a decline in specific storage with depth. This was considered to be consistent the conceptual model for these composite coal and aquitard units and with similar relationships which were adopted for hydraulic conductivity (GHD, 2012). Furthermore the introduction of depth based storage relationships significantly improved the performance of the predictive model by:

- Reducing predicted total extraction volumes such that they were considered to be reasonably consistent with other estimates; and
- Reducing modelled groundwater levels such that they approached target pressures in the majority of tenements within realistic timeframes.

Given the lack of actual test data available for specific storage, the derived depth relationships were developed ensuring that:

- Average specific storage for layer 10 in the area of North Kogan and Daandine was approximately equal to 2.0×10^{-05} m^{-1}, this being the value obtained through the transient sub-model calibration process;
- Average specific storage for layer 18 in the Fairview CSG tenements was approximately equal to 4.0×10^{-06} m^{-1}, this being the value obtained thorough calibration of the Bowen Basin groundwater model developed by Santos (2010); and
- A minimum value of specific storage of 1.0×10^{-07} m^{-1} was assumed to apply at depths exceeding 1,000 m. This minimum value was calculated based on the equations and approach suggested by Younger (1993) assuming an aquifer compressibility of 1×10^{-11} $m\ s^2/kg$ and porosity of 0.01. While it was recognised that the result is a very low value it was considered to be consistent with the conceptual idea that the permeability of the WCM and the Bandanna Formation also approaches zero at these extreme depths.

Alternative ‘Dummy’ Layer Parameterisation Approach

The Condamine Alluvium is an example of an area where the need to maintain continuous layers within the OGIA Surat CMA Groundwater Model represented a potentially significant limitation. As shown in Appendix A, Figure 13 and discussed in Section 2.2.3 in parts of this area the productive zones of the WCM (model layer 10) may directly underlie the Condamine Alluvium (model layer 1). However, sub-cropping model layers are not permitted to ‘pinch out’ in MODFLOW (and many other packages) and hence layers 2, 3, 4, 5, 6, 7, 8 and 9 were defined as active within the OGIA Surat CMA Groundwater Model in the area beneath the Condamine Alluvium, although these layers are not present in reality. Collectively these layers are often referred to as ‘dummy’ layers and are usually parameterised by copying hydraulic conductivity values from over or underlying ‘real’ layers and assuming minimal thicknesses. In the case of the OGIA Surat CMA Groundwater Model these ‘dummy’ layers were assigned a thickness of 1 m and given the properties of the underlying WCM (i.e. they were effectively modelled as part of the underlying coal measures rather than the overlying alluvium). This was seen as the best way of proceeding to maintain consistency with the estimated actual thickness of the Condamine Alluvium as extracted from the Condamine Model (KCB, 2011). However, given the relatively low vertical hydraulic conductivity of the WCM, and to evaluate whether this approach might tend to under-estimate impacts on the overlying Condamine Alluvium, an alternative parameterisation approach was trialled. In the alternative approach the ‘dummy’ layers separating the Condamine Alluvium and the WCM were assigned the properties of the overlying, and relatively high hydraulic conductivity, Condamine Alluvium.

The predictive model was then re-run, adopting this alternative parameterisation approach, and a revised set of model predictions developed. Comparison of the two sets of predictions suggested that that the predicted impacts on the Condamine Alluvium were insensitive to the ‘dummy’ layer parameterisation approach (GHD, 2012).

2.3 OGIA Surat CMA Groundwater Model – Predictive Results

2.3.1 Introduction

The initial set-up of the initial predictive model as described above in Section 2.2.7 represents the final task reported by GHD (2012). Subsequent predictive model runs and an associated uncertainty analysis were undertaken by Watermark Numerical Computing (2012)

This section provides a brief outline of the scope of work undertaken by Watermark Numerical Computing (2012). Final output from this study in the form of predicted long-term drawdown predictions and definition of the long-term affected area for each of the aquifers within the Surat CMA were also presented in the Underground Water Impact Report (QWC, 2012).

2.3.2 Methodology

The uncertainty analyses undertaken by Watermark Numerical Computing (2012), “Employed the so-called “null space Monte Carlo” (NSMC) methodology (Tonkin and Doherty, 2009). The "null space" refers to those model parameter combinations that are not estimable from the information content of the conditioning data. This Monte Carlo procedure was undertaken to produce many different realisations of model parameters that represent both realistic complexity and are constrained by the calibration dataset. Firstly, 200 sets of parameters were randomly generated on the basis of an adopted parameter covariance matrix that respected current hydrogeological understanding and “professional intuition and experience. Mathematical techniques (i.e. subspace methods) were then employed to excise the "solution space" component of each such parameter vector and replaced it with that of the calibrated model; the “solution space” refers to the parameter combinations which are informed by the calibration dataset (but which are contaminated by measurement “noise”).”

The following model parameters were considered as part of this analysis:

- Modelled water table recharge
- Horizontal hydraulic conductivity
- Vertical hydraulic conductivity
- Vertical anisotropy; and
- Specific storage/specific yield

In the case of the OGIA Surat CMA Groundwater Model Watermark Numerical Computing (2012) reported that, “NSMC was applied to a model simulation of two future extractive scenarios over a 3000-year period (1995–4995), namely:

(i) a continuation of current activities; and

(ii) progressive expansion and contraction of CSG operations over the next 50-60 years.

The simulation of current activities provided a spatio-temporal baseline for water level and interlayer flux response from which the comparative responses to CSG operations were subtracted to determine "impact". Cell based and site-specific outputs of predictive uncertainty (in the form of probability distributions and common statistical measures) were then able to be determined empirically on the basis of model outputs representing predictions of interest."

2.3.3 Results and Discussion

Output Measures

Watermark Numerical Computing (2012) reported that, "The NSMC approach produces a significantly larger quantity of information than from a traditional modelling process; there are effectively 200 "calibrated" models which have been used to simulate groundwater responses (or processed versions thereof) over time that must be synthesised into a form for clear communication of uncertainty limits. To illustrate this point, at each active grid cell in each of 19 model layers there are 200 sets of piezometric head responses extending over 259 stress periods of quarterly to decadal duration that need to be evaluated.

To interpret this abundance of outputs a statistical approach was adopted, whereby the 5th and 95th percentiles of a given output at every grid cell (or interpolated to points of interest) were computed from the 200 realisations. The values outside the 5th and the 95th percentile are considered 'outliers'. Such an approach is common practice in probabilistic risk assessments, where a range of outcomes are produced that meet a prescribed set of risk criterion for a representative sample population. A percentile is the value of a variable (e.g. a water level) below which a given percentage of values for that variable fall. So the 95th percentile is the value below which 95% of the values for that variable may be found (and 5% are greater). Similarly, the 5th percentile represents the value below which only 5% of the values for that variable reside (and 95% are greater). Mean and median values were also computed."

Uncertainty of Simulated Impact Drawdown

One of the primary purposes of the uncertainty analysis was to determine drawdown resulting from conventional P&G and future CSG operations, as separate from current non-P&G activities (irrigated agriculture, stock watering and town water supplies as well as for commercial and other agricultural purposes).

The results of the 200 NSMC simulations, including the maximum predicted value of drawdown in each model cell over the 3000 year simulation period were used to produce a series of contour maps. Contours of the 95th percentile, median, mean and 5th percentile of maximum impact drawdown in every active model cells for each aquifer unit were presented. These are provided in Appendix B, Figures 5-1 to 5-9. Conceptually, there is approximately a 5% probability that the maximum impact drawdown will be lower than the values illustrated for the 5th percentile, and approximately a 95% probability that the maximum impact drawdown will be less than the values illustrated for the 95th percentile. As expected, the contours indicated that the maximum impact drawdown is focused around CSG well fields and impacts extend over the largest area in the Walloon Coal Measures (Layer 10) and Bandanna Formation (Layer 18) where extractions are directly applied (Watermark Numerical Computing, 2012).

Watermark Numerical Computing (2012) reported that, "An alternative approach was adopted for determining the maximum impact drawdown over time for the Condamine Alluvium. Firstly, the maximum case was determined from the highest simulated peak change in flow (4,100 m^3/d) from the Condamine Alluvium to the Walloon Coal Measures that occurred throughout the 200 NSMC predictions using the QWC regional model (see Appendix B, Figure 5-100). The corresponding time series of the change in flow from the Condamine Alluvium to the Walloon Coal Measures was simulated as an extractive loss (via the WELL package) from all active cells in the alluvial aquifer (layer 2) of the KCB (2011) model. Spatial and temporal interpolation of the exported flow dataset from the regional model scale to that of the KCB

(2011) model scale was therefore required. The predictive simulation for the KCB (2011) model spanned approximately 120 years of monthly stress periods, spanning 1 July, 2009 to 1 June, 2127. This period captures the peak change in flow from the Condamine Alluvium to the Walloon Coal Measures and is about 70 years along the recession slope. Also, other simulated extractions (i.e. non-CSG and non-P&G) involved 605 bores at 50 % of authorised use for the year 2009 cycled continually. A 30-year historical period of recharge and river stage was cycled across the simulation period." The resulting predicted drawdowns in the Condamine Alluvium were reported in the Surat CMA UWIR (QWC, 2012).

3. Predictive Modelling Methods

3.1 Introduction

As discussed previously in Section 1.1 the footprint of the current Arrow Surat Gas Project (SGP) development plan which is being assessed in the SREIS represents production from a smaller area than the plan previously assessed by the:

- Arrow Surat Gas Project EIS using a groundwater flow model developed by Schlumberger Water Services (SWS, 2011); and
- The OGIA using the OGIA Surat CMA Groundwater Model (GHD, 2012; Watermark Numerical Computing, 2012) and Condamine Alluvium Groundwater Model (KCB, 2011) described in Sections 2.1, 2.2 and 2.3.

Of these two modelling assessments the combined use of the OGIA Surat CMA Groundwater Model and Condamine Alluvium Groundwater Model and the probabilistic modelling approach described in Section 2.3 is seen as the most advanced methodology for assessing the groundwater impacts of the current development plan. The method described in the remainder of this section therefore effectively represents a repeat of the groundwater modelling and uncertainty analysis previously completed by/on the behalf of the OGIA but based on the current development plan data provided by Arrow. Rather than produce a single impact estimate based on a single calibrated parameter set, the results presented in Section 4 therefore also reference output from 200 different realisations (or parameter sets).

Predictions of future CSG production were input to the OGIA Surat CMA Groundwater model via the MODFLOW EVT package, as described in Section 2.2.7. The EVT input file for the OGIA Surat CMA Groundwater Model has been modified, as described in Section 3.4.1, in order to assess the impacts of the current development plan. No other changes have been made to the OGIA Surat CMA Groundwater Model. In all other respects the model is therefore identical to that described in Section 2.2.

Groundwater level impacts in the Condamine Alluvium area have been assessed by simulating induced leakage from the Condamine Alluvium Groundwater Model area (calculated using the OGIA Surat CMA Groundwater Model) using the MODFLOW WEL package as described in Section 2.3.3. The WEL package input file for the Condamine Alluvium Groundwater Model has been modified, as described in Section 3.4.2, in order to assess the impacts of Arrow's current SGP development plan. The Fracture Well Package (FWL) input file for the Condamine Alluvium Groundwater Model has also been modified, as described in Section 3.4.3, in order to assess net groundwater level impacts post-substitution. No other changes have been made to the Condamine Alluvium Groundwater Model. In all other respects the Condamine Alluvium Groundwater Model is therefore identical to that described in Section 2.1.

3.2 OGIA Surat CMA Groundwater Model 'Benchmarking'

Prior to using the OGIA Surat CMA Groundwater Model for the current study a series of checks were undertaken to confirm that it was possible to re-produce a selection of model results and calculated impacts previously reported by Watermark Numerical Computing (2012) or in the Surat CMA UWIR (QWC, 2012). The results of this 'benchmarking' analysis are provided as Appendix D.

A comparison of cumulative modelled flow volumes, as recorded in MODFLOW record (or .OUT) files, for both the 'baseline' and 'cumulative impact' runs provided by the OGIA and reported in the Surat CMA UWIR (QWC, 2012) was undertaken initially. Both of these runs were repeated using the input files provided to confirm that the same results could be independently generated using different computing hardware. As shown in Appendix D cumulative volumes are identical (to 4 decimal places) which was taken as confirmation that modelled groundwater levels and flows calculated using the same model but run on different PCs were unlikely to be significantly different.

As a further check of the accuracy of model output processing undertaken for the current study Condamine flux impacts for the maximum impact realisation were also recalculated, as shown in Appendix D, based on a re-run of the OGIA Surat CMA Groundwater Model files for comparison with Figure 5-100 previously produced by Watermark Numerical Computing (2012). The maximum impact realisation was selected for this test since output from this run was previously used to assess maximum impacts on the Condamine Alluvium. It should be noted at this point that the Watermark Numerical Computing (2012) figure also shows output from individual 'realisations' which result in the minimum and maximum predicted impacts. The figure does not therefore show the 5^{th} to 95^{th} percentile envelope as suggested in the title. This has been confirmed by the authors of the report (pers comm Mark Gallagher 15 April 2013). Visual comparison of the results of this analysis (see Appendix D) suggests that the predicted maximum impacts on the Condamine Alluvium have been successfully reproduced.

3.3 Predictive Scenarios

Four predictive scenarios were simulated as follows:

- Non CSG Scenario. Referred to as the 'Base Run' in the Surat CMA UWIR report (QWC, 2012). This scenario models non-Petroleum & Gas (P&G) industry extraction only from 1995 onward;
- Base Case. This scenario models current and proposed CSG water extraction by QGC, Santos and Origin and other petroleum activities from 1995 onward. Extraction related to current and proposed Arrow CSG activities is therefore excluded from this scenario;
- Cumulative Case. Referred to as the 'P&G Production Run' in the Surat CMA UWIR report (QWC, 2012). This scenario models all current and proposed water extraction from P&G activities from 1995 onwards. Extraction by QGC, Santos, Origin and Arrow are therefore all included in this scenario, in addition to non-P&G extraction;
- Substitution Case. This scenario has been run to quantify net impacts on groundwater levels in the Condamine Alluvium with and without substitution of selected current entitlements in the Condamine Alluvium.

Further details on average extraction quantities over the next 100 years modelled in each scenario are provided in Table 10 for the calibrated parameter set. Time series of modelled CSG extraction rates for the Base and Cumulative cases for the calibrated parameter set are shown in Figure 5. It should be noted that predicted CSG related extraction quantities vary to some extent based on the modelled hydraulic parameters and hence vary from realisation to realisation. This is discussed further in Section 4.

Table 10 Predictive Scenarios – Average Extraction Quantities (ML/d)

Scenario	Arrow CSG	Other CSG	Total CSG	Total Other	Total
Non CSG	0.0	0.0	0.0	458.3	458.3
Base Case	0.0	107.4	107.4	458.3	673.0
Cumulative Case	22.4	107.2	129.6	458.3	717.5

A further breakdown of modelled CSG extraction from each of the proposed Arrow drainage areas based on Arrow's current development plan is shown in Table 11.

Table 11 Modelled CSG Water Production (ML/d) by Drainage Area – Arrow Current Development Plan, Calibrated Model "Realisation"

Elapsed Time (Years from 1995)	Notional Year	DA1	DA2	DA5	DA7	DA8	DA9	DA10	DA11	Sum (ML/d)	Sum (GL/yr)
16	2011	0.0	0.0	0.0	6.3	0.8	0.9	0.0	0.0	7.9	3
17	2012	0.0	0.0	0.0	6.2	0.8	0.9	0.0	0.0	7.8	3
18	2013	0.0	0.0	0.0	6.1	0.8	0.9	0.0	0.0	7.7	3
19	2014	0.0	0.0	0.0	6.0	0.8	0.9	0.0	0.0	7.6	3
20	2015	0.0	0.0	0.0	1.8	1.8	1.2	0.0	0.0	4.8	2
21	2016	0.4	0.0	0.0	0.5	4.7	6.3	0.0	0.0	11.9	4
22	2017	0.5	0.7	0.0	0.2	10.9	11.3	0.0	0.0	23.6	9
23	2018	5.1	5.4	1.5	14.4	32.8	31.9	0.3	2.8	94.1	34
24	2019	12.5	11.8	4.0	18.5	32.4	19.1	0.4	9.2	107.9	39
25	2020	6.3	4.8	11.3	15.7	13.6	39.8	1.9	17.9	111.3	41
26	2021	5.0	3.2	3.7	8.2	48.0	33.7	1.0	36.0	138.9	51
27	2022	6.1	5.6	2.0	11.4	30.3	34.1	0.7	53.3	143.5	52
28	2023	7.9	8.4	15.3	10.3	29.8	29.9	0.5	38.3	140.4	51
29	2024	8.6	9.0	16.5	11.5	33.3	25.9	6.6	28.2	139.7	51
30	2025	9.4	9.6	13.5	10.1	18.9	28.5	11.7	21.5	123.3	45
31	2026	7.4	9.3	14.4	10.8	21.4	25.6	9.9	16.5	115.3	42
32	2027	4.4	8.5	10.2	6.8	18.6	26.5	6.9	13.3	95.3	35
33	2028	2.5	7.2	8.1	7.5	16.0	24.8	6.2	11.5	83.7	31
34	2029	1.6	7.1	8.5	7.4	15.5	24.1	6.2	10.3	80.8	30
35	2030	1.2	3.5	7.4	6.4	14.8	28.4	6.0	9.4	77.1	28
36	2031	0.9	2.4	7.5	4.2	20.5	16.5	3.6	8.7	64.2	23
37	2032	0.7	1.7	6.9	6.6	16.5	10.2	3.8	8.1	54.5	20
38	2033	0.6	1.4	6.3	3.2	10.1	7.4	6.2	7.6	42.7	16
39	2034	0.5	1.1	6.8	1.8	5.7	5.9	4.8	7.2	33.8	12
40	2035	0.4	0.9	4.3	1.3	4.2	4.9	2.7	6.7	25.5	9
41	2036	0.4	0.8	2.1	1.1	3.4	4.2	1.9	6.4	20.2	7
42	2037	0.3	0.7	1.4	0.9	2.9	3.6	1.6	6.0	17.5	6
43	2038	0.3	0.6	1.0	0.8	2.5	3.2	1.3	5.7	15.6	6
44	2039	0.3	0.6	0.9	0.7	2.3	2.9	1.1	5.4	14.2	5
45	2040	0.3	0.5	0.7	0.7	2.1	2.7	0.9	5.1	13.0	5
46	2041	0.3	0.5	0.7	0.6	1.9	2.5	0.8	4.9	12.1	4
47	2042	0.2	0.5	0.6	0.5	1.8	2.3	0.7	4.6	11.3	4
48	2043	0.2	0.5	0.5	0.5	1.7	2.1	0.6	4.4	10.6	4
49	2044	0.2	0.4	0.5	0.5	1.6	2.0	0.5	4.1	9.9	4
50	2045	0.2	0.4	0.5	0.5	1.5	1.9	0.5	3.9	9.3	3
51	2046	0.2	0.4	0.5	0.4	1.4	1.8	0.5	3.7	8.8	3
52	2047	0.2	0.4	0.4	0.4	1.3	1.6	0.4	3.5	8.3	3
53	2048	0.2	0.3	0.4	0.4	1.2	1.4	0.4	3.4	7.6	3
54	2049	0.2	0.3	0.4	0.3	1.0	1.3	0.4	3.1	6.9	3
55	2050	0.2	0.3	0.3	0.3	1.0	1.1	0.3	2.4	5.9	2
56	2051	0.2	0.3	0.3	0.2	0.8	1.0	0.3	1.3	4.3	2
57	2052	0.1	0.2	0.3	0.2	0.6	0.9	0.3	0.6	3.2	1
TOTAL	**-**	**86**	**109**	**160**	**192**	**432**	**476**	**92**	**375**	**1922**	**702**

Impacts calculated through comparison of the four predictive scenarios are described in Section 4. In addition to reporting on the predicted impacts of the current Arrow SGP development plan (with and without substitution) results are also presented on the predicted cumulative impacts of CSG related extraction by Arrow, QGC, Santos and Origin (with and without substitution). Modelled extraction rates relating to QGC, Santos and Origin tenures are based on data included in the original EVT file provided by the OGIA and hence have been adopted unaltered for the current study.

Arrow SGP and Cumulative impacts have been calculated by comparing modelled groundwater levels and flows extracted from pairs of 'baseline' and 'impact' scenarios as described in Table 12. Since modelled groundwater levels are generally lower in the various 'impact' scenarios than in the related 'baseline' scenario then a reduction in groundwater level (i.e. drawdown) is returned as a positive value. Conversely groundwater level recovery, which can occur in the post substitution runs of the Condamine Alluvium Groundwater Model, result in negative drawdowns. Flow impacts are calculated in exactly the same way, although in many instances CSG extraction acts to induce additional flows, for example increasing flow to the Walloon Coal Measures from adjacent strata. This is further complicated by the fact that MODFLOW records inflow as positive values whilst outflow is negative. Flow impacts can therefore be positive or negative depending on:

- Whether flows are increased or decreased in the 'impact' scenario relative to the 'baseline' scenario; and
- Whether there is a net inflow or outflow to, for example, a model layer.

Careful interpretation of modelled impacts is therefore required.

This method of calculating impacts based on pairs of 'baseline' and 'impact' runs and by subtraction of impacted groundwater levels from the baseline run is identical to that used for previous report relating to the OGIA Surat CMA Groundwater Model (Watermark Numerical Computing, 2012; and OGIA, 2012).

Table 12 Impact Calculation

Impact	'Baseline' Scenario	'Impact' Scenario	Impact Calculation
Arrow Surat Gas Project – Pre-Substitution	Base Case	Cumulative Case	Base Case – Cumulative Case
Cumulative P&G Impact – Pre-Substitution	Non CSG	Cumulative Case	Non CSG – Cumulative Case
Arrow Surat Gas Project – Post-Substitution	Base Case	Cumulative Case with Substitution	Base Case – Cumulative Case with Substitution
Cumulative P&G Impact – Post-Substitution	Non CSG	Cumulative Case with Substitution	Non CSG – Cumulative Case with Substitution

3.4 Scenario Setup in Numerical Model

3.4.1 OGIA Surat CMA Groundwater Model

As mentioned previously in Section 3.1, predictions of future CSG production are input to the current OGIA Surat CMA Groundwater Model via the MODFLOW EVT package, as described in Section 2.2.7. The OGIA Surat CMA Groundwater Model EVT input file used for the Cumulative and Substitution Cases has therefore been modified as necessary, such that the modelled EVT rates are consistent with Arrow's current development plans for the Surat Basin. A second revised EVT file was also required for the Base Case with all Arrow extractions removed. These two files were generated as described below:

1. Current OGIA Surat CMA Groundwater Model MODFLOW EVT file provided by the OGIA;
2. All EVT rate entries which fall within Arrow tenements revised to zero.
3. Revised EVT file for use in the Base Case scenario generated;
4. In some cases the proposed current Arrow development plan areas extend beyond those previously modelled and hence the current OGIA modelled EVT surface and EVT extinction depth entries were also revised in some locations based on the same methodology previously applied for the OGIA modelling work;
5. EVT rate entries within current Arrow development plan areas were initially re-populated with revised rates based on production estimates provided by Arrow;
6. Modelled EVT rates were then further adjusted as necessary, on a block by block basis, to ensure target pressures are approached in each of the proposed development blocks; and
7. Revised EVT file for use in the Cumulative and Substitution Cases generated.

Further detail on the changes made to the modelled EVT or production rates and modelled EVT surfaces or target pressures (i.e. steps 4, 5 and 6) are provided below.

No other changes have been made to the OGIA Surat CMA Groundwater Model. In all other respects the model used for the current study is therefore identical to that described in Section 2.2.

Modelled Target Pressures (Step 4)

As outlined in Step 4 above, in some cases Arrow's current development plan areas extend beyond those previously modelled and hence the current OGIA modelled EVT surface and EVT extinction depth entries were also revised in some locations. The current surfaces were revised using the same methodology previously applied for the OGIA modelling work, as described in Section 2.2.7. The modelled EVT surface for all Arrow production areas was therefore set to 15 m above the top of model layer 9 or 30 m above the top of model layer 10 (i.e. around 30 m above the uppermost modelled coal in the WCM). An EVT extinction depth of 20 m below the evaporation surface has also been assumed as per the previous modelling.

Modelled Production Rates (Steps 5 and 6)

As outlined in Step 5 above, EVT rate entries within Arrow's current development plan areas were based initially on estimates provided by Arrow. These estimates are understood to have been derived from predicted water production curves for each of the proposed development blocks and detailed information on the timing of development in each block. A single run of the OGIA model, based on the calibrated parameters, was then undertaken initially using the rates provided by Arrow. Outputs from this model run were then processed to produce time series plots of:

- Modelled groundwater levels at the centre of each proposed development block compared to the modelled EVT surface or target pressure at the same location; and
- Total modelled input and output extraction quantities for each proposed production block. For blocks where modelled groundwater levels fall below the modelled EVT surface or target pressure, there should be some de-rating, or difference between the input and output extraction quantities.

Based on these plots modelled extraction rates were then progressively increased until groundwater levels at the centre of each block approached the EVT surface and/or some difference was observed between input and output extraction rates. This iterative approach mirrors similar checks which were undertaken by the OGIA during development of the OGIA Surat CMA Groundwater Model. The overall intent of the process being to ensure that modelled groundwater levels in the majority of the proposed development blocks approach target pressures in a timeframe considered to represent operation of a CSG field. Detailed block-by-block output generated based on the final modelled extraction rates included in the Cumulative Case and on calibrated model parameters can be found in Appendix E.

One outcome of this process of gradually increasing extraction rates is that the final modelled rates of water production applied to the revised OGIA Surat CMA Groundwater Model exceed those expected by Arrow Energy within the current development plan areas (Table 13). This apparent tendency for the OGIA model to over-predict total extraction was noted in the Surat CMA UWIR (QWC, 2012) and it was proposed by QWC (2012) that this may be related to processes such as dual phase flow which cannot be simulated precisely in numerical models such as MODFLOW (or other regional scale groundwater flow models).

Table 13 Total Arrow Surat Gas Project Water Production Volumes

Estimate	Total Extraction (GL)
Current SREIS Case - Expected (2011-2052)	510
Current SREIS Case - Modelled (2011-2052)	702

It should be stressed that this process of increasing modelled extraction rates until modelled groundwater levels approach target pressures, whilst accepting some potential over-simulation of total extraction volumes, is considered likely to be conservative from an impact assessment point of view. A number of the potential impacts of CSG developments, including the time taken for groundwater to recover to pre-development levels, will be related to the total volume of water extracted which is likely to be over predicted using the adopted approach.

3.4.2 Condamine Alluvium Groundwater Model – Pre-Substitution Scenarios

As mentioned previously in Section 3.1 groundwater level impacts in the Condamine Alluvium have been calculated by simulating induced leakage from the Condamine Alluvium Groundwater Model using the MODFLOW WEL package as described in Section 2.3.2. This approach was adopted due to the availability of the more localised and hence detailed Condamine Alluvium Groundwater Model.

Three additional runs of the Condamine Alluvium Groundwater Model were previously undertaken by Watermark Numerical Computing (2012) as described in Section 2.2.3, based on induced leakage (or interlayer flux) estimates extracted from the following OGIA Surat CMA Groundwater Model realisations (i.e. parameter sets):

- A maximum impact realisation (No. 69);
- The calibrated model ‘realisation’; and
- A minimum impact realisation (No. 143);

Net modelled interlayer fluxes between the Condamine Alluvium and the underlying strata (i.e. modelled fluxes between Layer 1 and 2) were initially extracted from the OGIA Surat CMA Groundwater Model for each of these three realisations and for each of the three pre-substitution scenarios summarised in Section 4.2 (i.e. nine sets of model output in total). These modelled flows were then used to calculate modelled P&G and non-P&G related impacts (or additional stresses on the Condamine Alluvium) which were interpolated as necessary for input into the Condamine Alluvium Groundwater Model. The procedure followed here is summarised below and replicates the approach previously adopted by Watermark Numerical Computing (2012, see Section 2.3.3.).

1. Extract modelled cell by cell flow values from the OGIA Surat CMA Groundwater Model for the maximum, minimum and calibrated impact ‘realisations’ of the Base Case, Non CSG and Cumulative Case Scenarios (nine model runs in total);
2. Convert OGIA Surat CMA Groundwater Model cell-by-cell flow values into surfaces, one surface for each stress period where the OGIA Surat CMA Groundwater Model and Condamine Alluvium Groundwater Model time periods overlap (i.e. stress periods 60 to 153 of the OGIA Surat CMA Groundwater Model);
3. Interpolate OGIA Surat CMA Groundwater Model flux surface values onto the Condamine Alluvium Groundwater Model grid using bi-linear interpolation;
4. Calculate modelled Cumulative and Arrow Surat Gas Project impacts at each Condamine Alluvium Groundwater Model cell by comparing pairs of Scenarios (Table 12);
5. Re-set any positive flux impacts to zero (i.e. ignore areas where model results suggest a net positive impact). This is considered to be a conservative adjustment since including these areas would tend to reduce the modelled impact;
6. The OGIA Surat CMA Groundwater Model uses a scheme of gradually increasing stress periods during the predictive period whilst the Condamine Alluvium Groundwater Model uses a 30 year simulation period and monthly stress periods. Further temporal interpolation was therefore required to map the OGIA Surat CMA Groundwater Model impacts onto the Condamine Alluvium Groundwater Model stress periods. This was undertaken relatively simply by assuming that the calculated impacts change in a stepwise fashion from one OGIA stress period to the next. Hence in a period when there are 12 Condamine Alluvium Groundwater Model monthly stress periods corresponding to one annual OGIA Surat CMA Groundwater Model stress period then the input to the Condamine model comprises 12 equal values;
7. Generate six MODFLOW input well files relating to calculated pre-substitution Cumulative and Arrow Surat Gas Project impacts for the minimum, maximum and calibrated ‘realisations’. Each well file comprises a time series of flux values for each of the Condamine Alluvium Groundwater Model cells which comprise the Condamine alluvial aquifer;
8. Complete six additional pre-substitution runs of the Condamine Alluvium Groundwater Model representing a 120 year CSG impact period and assuming that non-CSG extraction from the Condamine Alluvium continues at 50% of 2009 authorised use (see Section 2.1.8 for further discussion on what this scenario represents). In order to extend the 30 year Condamine Model simulation period it was also necessary to cycle the historical recharge and river stage quantities across the simulation period.

No other changes have been made to the Condamine Alluvium Groundwater Model as part of the current scope of work. In all other respects the model developed for the current study is therefore identical to that described in Section 2.1.

3.4.3 Condamine Model – Substitution Scenarios

Two further runs of the Condamine Alluvium Groundwater Model were also undertaken, based on the calibration 'realisation', to assess net impacts on the Condamine Alluvium with and without substitution. In this case, substitution involves providing appropriately treated CSG water to existing holders of groundwater allocations from the Condamine Alluvium such that they are able to reduce extraction from their existing groundwater bores. The substitution scenario undertaken involved reducing a sub-set of the existing allocations in the Condamine Alluvium Groundwater Model to offset predicted flux impacts using the methodology described below.

1. Based on the calculations of flux impact described in Steps 4 and 5 in Section 3.4.2 above, the net interlayer flux impact on the Condamine Alluvium as a result of the current Arrow development case was calculated based on the calibration 'realisation'. This volume represents the adopted offset target.
2. Identify extraction wells in the 50% of 2009 authorised use scenario of the Condamine Alluvium Groundwater Model Fracture Well Package (FWL) within the maximum predicted impact area;
3. Generate a revised FWL package input file where bores identified in Step 2 were reduced such that the reduction in each stress period is equal to the offset target (i.e. the predicted Arrow component of flux impacts on the Condamine Alluvium for the calibration 'realisation').

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4. Predictive Modelling Results

4.1 Arrow Project Impacts

4.1.1 Introduction

Section 4.1 summarises the predicted impacts of the Arrow SGP only. These impacts have been calculated as described in Section 3.2 by subtracting predicted groundwater levels and flows for the Cumulative Case from the Base Case. The predicted cumulative impacts of CSG operations currently proposed by Arrow, Origin, QGC and Santos within the Surat CMA are presented and discussed separately in Section 4.2.

4.1.2 Simulated CSG Water Production

Modelled extraction rates for Arrow's current development plan, based on the calibrated parameter set are shown in Figure 5, Table 11 and Table 13. Total modelled Arrow SGP extraction over the period 2011 to 2052 is 702 GL (Table 13). Model predictions indicate a peak extraction rate of around 140 ML/d is likely to occur between around 2021 to 2024, or 26 to 29 years into the 'predictive' simulation period which runs from 1995 onwards.

Modelled CSG extraction rates relating to Arrow's operations for all 200 model realisations are shown in Figure 7 and suggest peak extractions will fall between 110 and 150 ML/d.

4.1.3 Spatial Assessment

Maximum predicted impact drawdowns due to Arrow's current development plan alone are shown in Figure 8 to Figure 17. The modelled outputs presented in these figures are based on the calculated maximum impact drawdown i.e. the maximum simulated drawdown in each modelled cell. This maximum drawdown calculation has been undertaken for impacts calculated using the calibration 'realisation' (Figure 8) and also using each of the alternative 200 model realisations developed as part of the uncertainty analysis work (Watermark Numerical Computing, 2012). Combining results from the 200 alternative realisations allows a statistical analysis to be undertaken, the results of which are summarised in Figure 9 to Figure 16. For the Condamine Alluvium, in line with previous work undertaken by Watermark Numerical Computing (2012) and reported in the Surat CMA UWIR (QWC, 2012), a slightly different approach has been adopted whereby drawdowns at the end of the extended 120 year Condamine Alluvium Model simulation period have been calculated through reference to an individual maximum impact realisation. Predicted maximum drawdowns in the Condamine Alluvium Groundwater Model area are shown in Figure 17.

GAB Consolidated Aquifers

Figure 8 identifies areas where the predicted maximum impact drawdowns exceed 5 m in each of the affected GAB consolidated aquifers based on the calibration realisation. Table 14 presents the same predictions in tabular form. Five metre contours have been plotted since this is the trigger threshold for consolidated aquifers as specified in the Water Act 2000. Similar maps are presented in the Surat CMA UWIR report (QWC, 2012).

As expected, the predicted impacted area is greatest in the Walloon Coal Measures and gradually reduces in the various underlying and overlying aquifers. Results for the calibration 'realisation' suggest predicted maximum drawdown impacts of more than 5 m in the:

- Springbok Sandstone;
- Walloon Coal Measures; and
- Hutton Sandstone;

Conversely maximum drawdown impacts of less than 5 m are anticipated in the:

- Minor alluvial deposits (i.e. excluding the Condamine Alluvium which has been assessed separately, see below);
- Main Range Volcanics;
- Mooga Formation;
- Bungil Sandstone;
- Gubberamunda Sandstone;
- Precipice Sandstone; and
- Clematis Sandstone.

Table 14 also provides useful information on the potential uncertainty associated with these estimates. 95th percentile results are also shown in Figure 9 and suggest that the same three aquifers will be impacted by more than 5 m at some point in the future, although as would be expected the areas affected are more extensive than predicted based on the calibrated 'realisation'. 5th percentile results suggest that impacts of more than 5 m may be largely limited to the Walloon Coal Measures (Table 14).

Table 14 Area Bounded by the 5 m Maximum Arrow Surat Gas Project Impact Drawdown Contour

Model Layer	Area (km^2) 5th Percentile	Area (km^2) Calibration Realisation	Area (km^2) 95th Percentile
1 – Main Range Volcanics / Alluvium (outside the Condamine alluvial aquifer)	0	0	0
3 – Bungil Sandstone / Mooga Formation	0	0	0
5 – Gubberamunda Sandstone	0	0	0
7 – Springbok Sandstone	21	295	1,819
10 – Walloon Coal Measures	6,289	7,518	8,361
12 – Hutton Sandstone	0	873	950
14 – Precipice Sandstone	0	0	0
16 – Clematis Sandstone	0	0	0

Contours of the 95th percentile, 50th percentile, mean and 5th percentile of the maximum Arrow SGP related drawdown in individual aquifers are shown in Figure 10 to Figure 16. As per the calibration 'realisation' 5 m drawdown contours shown in Figure 8, these figures suggest that maximum impacts are focused around the proposed Arrow extraction areas and the Walloon Coal Measures (model layer 10).

Condamine Alluvium

Figure 17 shows predicted Arrow SGP related drawdown in the Condamine Alluvium at the end of the 120 year Condamine Alluvium Model simulation period for the maximum impact realisation. Drawdowns of up to around 0.6 m are predicted in central parts of the Condamine Alluvium south west of Dalby. However, predicted average Arrow SGP related drawdown over the full Condamine Alluvium Groundwater Model area for the maximum impact realisation is only 0.20 m.

Predicted Arrow SGP related maximum drawdowns are therefore below the 2 m trigger threshold specified in the Water Act 2000 for unconsolidated aquifers such as the Condamine Alluvium.

As discussed in Sections 3.4.2 and 2.3.2 it should be noted that impacts on the Condamine Alluvium have been assessed in a slightly different manner by:

- Estimating the maximum predicted flux impact using the OGIA Surat CMA Groundwater model; and
- Using the Condamine Alluvium Groundwater Model to assess the impact of this flux impact on groundwater levels in the Condamine Alluvium

Due to the more involved nature of this process only selected realisations were run by Watermark Numerical Computing (2012) as part of the Surat CMA UWIR work (QWC, 2012) and have therefore been repeated for the current study. Since impacts on the Condamine Alluvium have only been calculated for selected realisations it is currently not possible to fully assess the uncertainty associated with this set of predictions. However, given the minor impacts calculated in the Condamine Alluvium based on the maximum impact realisation then this is not considered to be a significant limitation.

Predicted Arrow SGP related drawdowns within the Condamine Alluvium with and without substitution and based on the calibration ‘realisation’, rather than the maximum impact realisation results described above, for the purposes of assessing the potential benefits of substitution are presented separately in Section 4.3.2.

4.1.4 Temporal Assessment

Predicted drawdown time series at the centre of each of the proposed extraction blocks (i.e. the hydrograph locations shown in Figure 3 and Figure 4), have also been extracted for each of the 200 realisations. Plots showing the 95th percentile, 50th percentile, mean and 5th percentile drawdowns at each location for the Springbok Sandstone, Walloon Coal Measures, Hutton Sandstone and the Precipice Sandstone are included as Appendix F. Reference to these plots indicate that time lags between extraction in the Walloon Coal Measures and impacts in the adjacent aquifers gradually increase with separation. Hence, peak impacts typically occur:

- Between around 2021 and 2024 in the WCM (i.e at or around the same time as peak extraction);
- Up to around 100 years later in Springbok and Hutton Sandstones; and
- Up to around 1000 years later in the Precipice Sandstone.

4.1.5 Interaction with Adjacent Aquifers

GAB Consolidated Aquifers

Peak net interlayer flux impacts for the calibration realisation are summarised in Table 15. Pre-CSG interlayer fluxes with the Surat CMA are predominantly upward, outside of the main recharge areas, and hence negative interlayer flux impacts in this case indicate a reduction in net upward flow. Conversely positive values indicate increased net upward flow. The Arrow SGP net interlayer flux results shown in Table 15 suggest:

- Peak reductions of up to 7.2 ML/d in net upward flow from the productive coal horizons of the WCM (model layer 10) to the overlying upper WCM aquitard unit (model layer 9);
- Gradually reducing net upward peak flow reductions in each of the overlying layers. Interlayer fluxes between model layers 1 and 2 are reduced by around 2.5 ML/d;
- Increases of up to around 9 ML/d in net upward flow through the lower WCM aquitard unit (model layer 11) to the overlying WCM coal (model layer 10);
- Gradually reducing net upward flow increases in each of the underlying layers. Only very minor increases in upward flow of up to 0.1 ML/d are predicted from model layers 14 and below (i.e. the Precipice Sandstone and below);

Given that modelled Arrow SGP extractions are expected to peak at around 140 ML/d then the predicted peak reductions in net flow to overlying layers and increased upflow from underlying units are expected to provide a relatively minor component of the CSG water balance. In the short term the majority of the remainder of the water balance is likely to come from storage, induced recharge or reduced discharge to near surface water systems in outcrop areas.

Table 15 Predicted Arrow SGP Net Interlayer Flux Impacts GAB Consolidated Aquifers– Calibration Realisation

From Model Layer	To Model Layer	Peak Net Interlayer Flux Impact (ML/d)
1 – Main Range Volcanics / Alluvium (outside the Condamine alluviual aquifer)	2	-2.5
2 – Rolling Downs Group	3	-2.5
3 – Bungil Sandstone / Mooga Formation	4	-2.5
4 – Orallo Formation	5	-2.6
5 – Gubberamunda Sandstone	6	-2.8
6 – Westbourne Formation	7	-3.2
7 – Springbok Sandstone, upper	8	-4.9
8 – Springbok Sandstone, lower	9	-5.8
9 – WCM (Upper Aquitard)	10	-7.2
10 – WCM (Productive Coal)	11	9.0
11 – WCM (Lower Aquitard)	12	5.6
12 – Hutton Sandstone	13	0.2
13 –Evergreen Formation	14	0.1
14 – Precipice Sandstone	15	0.0
15 – Moolayember Formation	16	0.0
16 – Clematis Sandstone	17	0.0
17 – Rewan Group	18	0.0
18 – Bandanna Formation	19	0.0
Total Modelled Extraction from the WCM	-	143.5

Note: In this case negative flow impacts indicate a reduction in net upward flow. Conversely positive values indicate an increase in net upward flow.

It should be noted that, due to the apparent tendency for the OGIA Surat CMA Groundwater Model to over-predict total extraction (Section 3.4.1), the flux impacts shown in Table 15 and discussed in the text above are considered likely to represent over-estimates.

A tendency for peak net interlayer flux impacts calculated using the calibrated 'realisation' set of the OGIA Surat CMA Groundwater Model to plot outside the NSMC envelope interlayer flux impacts for four model layers was noted. The four model layers apparently affected were; the Orallo Formation to the upper part of the Springbok Sandstone (i.e. model layers 7 to 4). It should be noted that in all other layers predicted interlayer flux impacts calculated based on the calibration 'realisation' are less than the 95th percentile, as would normally be expected suggesting that predicted interlayer flux for other layers, including layers 1 and 2, were not affected.

Condamine Alluvium

Predicted net flux impacts on the Condamine Alluvium for the 5th and 95th percentiles and the maximum impact and calibration realisations (see Section 3.4.2) are shown in Figure 18 and in

Table 16. Predicted net interlayer fluxes for the Non CSG scenario are into the Condamine Alluvium (i.e. upward flow). This is consistent with the conceptual understanding of the Condamine Alluvium. Model predictions suggest that net interlayer fluxes to the Condamine Alluvium will remain upward following CSG development and hence the impact in this case is a reduced upward flow to the Condamine Alluvium, compared to modelled flows prior to CSG development. As described above, negative interlayer flux impacts therefore indicate a reduction in net upward flow. Conversely positive values indicate increased net upward flow.

It should also be noted that the strata immediately underlying the Condamine Alluivum varies from west to east, in line with the general dip of the strata, and the OGIA Surat CMA Groundwater Model reflects this. Towards the west of the area the Condamine Alluvium is underlain by the Westbourne Formation (model layer 6) whilst further east it is underlain by the Springbok Sandstone (model layers 7 and 8) and the WCM (model layers 9, 10 and 11). The impacts described in this section relate to the total impact on net interlayer fluxes to the Condamine Alluvium. There is no differentiation of the individual contribution of the various underlying layers to this total.

Results suggest relatively minor peak impacts on flow to the Condamine Alluvium (compared to the simulated 143.5 ML/d Arrow SGP peak extraction rate) peaking at between 1.3 and 2.8 ML/d).

Predicted long term flux impacts on the Condamine Alluvium over the next 100 years are also shown in Table 16 and indicate total impacts of between 34 and 73 GL over the next 100 years. Predictions based on the calibration 'realisation' suggest total net interlayer fluxes to the Condamine Alluvium of 619 GL over the next 100 years in the Base Case Scenario reducing to 556 GL over the same period in the Cumulative Case. This results in a predicted Arrow SGP net interlayer flux impact of 63 GL (or around 10% of the baseline flux) as shown Table 16. As stated previously model predictions therefore suggest that a significant component of upward flow to the Condamine will remain post development.

Table 16 Predicted Arrow SGP Net Interlayer Flux Impacts Condamine Alluvium

Net Interlayer Flux Impact	5th Percentile	Calibration Realisation	95th Percentile	Maximum Realisation
Peak (ML/d)	-1.3	-2.5	-2.6	-2.8
Total 100 years (i.e. 2011 to 2111) (GL)	-34	-63	-71	-73

Note: In this case negative flow impacts indicate a reduction in net upward flow. Conversely positive values indicate an increase in net upward flow.

4.2 Cumulative Impacts

4.2.1 Introduction

This section summarises the predicted cumulative impacts of CSG projects to be operated by Arrow, Origin, QGC and Santos within the Surat CMA. All impacts have been calculated as described in Section 3.2 by subtracting predicted groundwater levels and flows for the Cumulative Case from the Non CSG Scenario.

4.2.2 Simulated CSG Water Production

Total modelled extraction from CSG projects to be operated by Arrow, Origin, QGC and Santos with the Surat CMA are shown in Figure 5 and suggest a cumulative peak extraction of around 550 ML/d in 2015, or around 20 years into the 'predictive' simulation which runs from 1995 onwards. Modelled total CSG extraction rates for all 200 model realisations are shown in Figure 6 and suggest peak extractions will fall between 500 and 600 ML/d.

4.2.3 Spatial Assessment

Maximum predicted cumulative impact drawdowns are shown in Figure 19 to Figure 27.

GAB Consolidated Aquifers

Figure 19 identifies areas where the predicted cumulative maximum impact drawdowns based on the calibration 'realisation' exceed 5 m in each of the affected aquifers. Table 17 presents the same predictions in tabular form. As expected the impacted area is greatest in the WCM and gradually reduces in the various underlying and overlying aquifers. Calibration 'realisation' results suggest predicted maximum cumulative drawdown impacts of more than 5 m in the:

- Gubberamunda Sandstone;
- Springbok Sandstone;
- Walloon Coal Measures;
- Hutton Sandstone;
- Precipice Sandstone; and
- Clematis Sandstone.

Conversely impacts of less than 5 m are anticipated in the:

- Minor alluvial deposits (i.e. excluding the Condamine Alluvium which has been assessed separately, see below)
- Main Range Volcanics
- Mooga Formation; and
- Bungil Sandstone.

95th percentile results are shown in Figure 20 and Table 17 and suggest the same six aquifers will be impacted by more than 5 m at some point in the future, although as would be expected the areas affected are more extensive than predicted based on the calibrated 'realisation' results.

Contours of the 95th percentile, 50th percentile, mean and 5th percentile of the maximum predicted cumulative impact drawdown in individual aquifers are shown in Figure 21 to Figure 27. As per the Arrow SGP impacts, these figures also suggest maximum impacts that are focused around the proposed CSG tenures and the WCM (model layer 10). As would be expected, given that the Arrow SGP extractions account for only around 20% of long term average total modelled CSG extraction from the Surat CMA (Table 10), the predicted cumulative drawdown impacts substantially exceed the Arrow SGP impacts reported in Section 4.1.

Condamine Alluvium

Figure 28 shows the maximum predicted cumulative impact in the Condamine Alluvium and suggests drawdowns of up to around 1.3 m south east of Chinchilla. However, predicted average cumulative drawdown over the full Condamine Alluvium Groundwater Model area for the maximum impact realisation is only 0.28 m.

Predicted cumulative maximum drawdowns are therefore below the 2 m trigger threshold specified in the Water Act 2000 for unconsolidated aquifers such at the Condamine Alluvium.

Although still relatively minor, predicted cumulative drawdowns are higher than those predicted for the Arrow SGP on its own (Section 4.1.2) which suggests that other proposed CSG operations in the Surat CMA will also contribute to groundwater level impacts particularly in central and northern parts of the Condamine Alluvium.

Comparison with Previous Studies

The results shown in Figure 20 to Figure 28 and Table 17 are similar to comparable outputs reported in the Surat CMA UWIR (QWC 2012, see Appendix I) and by Watermark Numerical Computing (2012, see Appendix B). The extent of the 95^{th} percentile 5 m impact drawdown contours and Condamine impacts shown in Figure 20 and Figure 28 are slightly reduced compared to those previously reported. This is consistent with the current Arrow SGP development area, and hence total extraction, being smaller than previously assessed in the Surat CMA UWIR. The similarity of these two sets of output suggests that the current study has been successful in repeating the processing methodologies adopted by the OGIA and Watermark Numerical Computing (QWC, 2012; Watermark Numerical Computing, 2012). When comparing these plots it should also be noted that the version of the Surat CMA Groundwater Model provided by the OGIA at the start of the current SREIS modelling process included some other minor revisions to the ‘original’ EVT file used to assess the impacts reported in the Surat CMA UWIR (QWC, 2012). Not all of the differences between Figure 20 to Figure 28 and the equivalent plots shown in Appendix B and Appendix I can therefore attributed to the revised Arrow SGP development plan.

Table 17 Area Bounded by the 5 m Maximum Cumulative Impact Drawdown Contour

Model Layer	Area (km^2) 5th Percentile	Area (km^2) Calibration Realisation	Area (km^2) 95th Percentile
1 – Main Range Volcanics / Alluvium (outside the Condamine alluviual aquifer)	0	0	0
3 – Bungil Sandstone / Mooga Formation	0	0	0
5 – Gubberamunda Sandstone	0	1.2	109
7 – Springbok Sandstone	6,675	8,329	15,466
10 – Walloon Coal Measures	27,720	30,088	31,417
12 – Hutton Sandstone	304	4,640	6,562
14 – Precipice Sandstone	76	185	509
16 – Clematis Sandstone	43	124	169

4.2.4 Temporal Assessment

Predicted cumulative drawdown time series, at the centre of each of the proposed extraction blocks (i.e. the hydrograph locations shown in Figure 3 and Figure 4) have also been extracted for each of the 200 model realisations. Plots showing the 95th percentile, 50th percentile, mean and 5th percentile cumulative drawdowns at each location for the Springbok Sandstone, Walloon Coal Measures, Hutton Sandstone and Precipice Sandstone are included as Appendix G. As expected, given the substantially higher CSG extraction modelled in the cumulative scenario, these plots show more impact than those predicted for the Arrow SGP project only. In particular, cumulative results (Appendix G) suggest drawdown impacts of more than 0.1 m in the Precipice Sandstone at almost all locations, whilst most sites showed impacts of less than 0.1 m based on calculated drawdowns from the Arrow SGP only (Appendix F).

4.2.5 Interaction with Adjacent Aquifers

GAB Consolidated Aquifers

Peak cumulative net interlayer flux impact envelopes are presented in Table 18. Pre-CSG interlayer fluxes with the Surat CMA are predominantly upward outside of the main recharge areas and hence negative interlayer flux impacts in this case indicate a reduction in net upward flow. Conversely positive values indicate increased net upward flow. The cumulative net interlayer flux results shown in Table 18 suggest:

- Reductions of up to around 49.7 ML/d in net upward flow from the productive coal horizons of the WCM (model layer 10) to the overlying upper WCM aquitard unit (model layer 9);

- Gradually reducing net upward flow reductions in each of the overlying layers. Interlayer fluxes between model layers 1 and 2 are reduced to around 4.9 ML/d;
- Increases of up to around 49.9 ML/d in net upward flow through the lower WCM aquitard unit (model layer 11) to the overlying WCM coal (model layer 10); an
- Gradually reducing net upward flow increases in each of the underlying Surat Basin layers (i.e. model layers 11 to 14 inclusive).

Table 18 Predicted Cumulative Net Interlayer Flux Impacts GAB Consolidated Aquifers– Calibration Realisation

From Model Layer	To Model Layer	Peak Net Interlayer Flux Impact (ML/d)
1 – Main Range Volcanics / Alluvium (outside the Condamine alluvial aquifer)	2	-4.9
2 – Rolling Downs Group	3	-5.0
3 – Bungil Sandstone / Mooga Formation	4	-5.3
4 – Orallo Formation	5	-6.4
5 – Gubberamunda Sandstone	6	-9.1
6 – Westbourne Formation	7	-15.8
7 – Springbok Sandstone, upper	8	-31.5
8 – Springbok Sandstone, lower	9	-41.5
9 – WCM (Upper Aquitard)	10	-49.7
10 – WCM (Productive Coal)	11	49.9
11 – WCM (Lower Aquitard)	12	29.0
12 – Hutton Sandstone	13	0.7
13 –Evergreen Formation	14	0.2
14 – Precipice Sandstone	15	-1.6
15 – Moolayember Formation	16	-2.4
16 – Clematis Sandstone	17	-2.6
17 – Rewan Group	18	-23.2
18 – Bandanna Formation	19	20.0

Note: In this case negative flow impacts indicate a reduction in net upward flow. Conversely positive values indicate an increase in net upward flow.

Condamine Alluvium

Pre-CSG interlayer flux is predominantly upwards, outside of recharge areas and hence negative interlayer flux impacts in this case indicate a reduction in net upward flow. Conversely positive values indicate increased net upward flow.

Predicted cumulative net flux impacts on the Condamine Alluvium for the 5th and 95th percentiles and the maximum impact and calibration realisations (see Section 3.4.2) are shown in Figure 29 and Table 19. Results suggest relatively minor impacts (compared to the 550 ML/d cumulative peak extraction rate) peaking at between 1.8 and 3.8 ML/d.

Predicted long term flux impacts on the Condamine Alluvium over the next 100 are shown in Table 19 and indicate total impacts of between 44 and 101 GL over the next 100 years. Predictions based on the calibration 'realisation' suggest total net interlayer fluxes to the Condamine Alluvium of 635 GL over the next 100 years in the Non CSG Scenario reducing to 556 GL over the same period in the Cumulative Case. This results in a predicted cumulative net interlayer flux impact of 79 GL (or around 12% of the baseline flux) as shown in Table 19. As stated previously model predictions therefore suggest that a significant component of upward flow to the Condamine will remain post development.

Table 19 Predicted Cumulative Net Interlayer Flux Impacts Condamine Alluvium

Net Interlayer Flux Impact	5th Percentile	Calibration Realisation	95th Percentile	Maximum Realisation
Peak (ML/d)	-1.8	-3.0	-3.4	-3.8
Total 100 years (i.e. 2011 to 2111) (GL)	-44	-79	-90	-101

Note: In this case negative flow impacts indicate a reduction in net upward flow. Conversely positive values indicate an increase in net upward flow.

4.3 Impacts with Substitution

4.3.1 Introduction

As previously described in Section 3.4.3, two further runs of the Condamine Alluvium Groundwater Model were also undertaken based on the calibration 'realisation'. This involved re-running the Condamine Alluvium Groundwater Model with the 50% of 2009 authorised use extraction scenario to assess net impacts on the Condamine Alluvium with and without substitution. In this case substitution involves providing appropriately treated CSG water to existing holders of groundwater allocations from the Condamine Alluvium such that they are able to reduce extraction from their existing groundwater bores. The potential beneficial impact of substitution has been modelled by identifying a number of existing extractions which are included in the Condamine Alluvium Groundwater Model and are located in and around the area of maximum predicted drawdown in the Condamine Alluvium as a result of coal seam gas extraction (see Figure 28). As shown in Figure 28 the area of maximum predicted drawdown in the Condamine Alluvium occurs to the west of Dalby.

It has been assumed that Arrow will undertake substitution in this area in order to offset the predicted likely net flux impacts on the Condamine Alluvium as a result of the current Arrow development case (Table 16). The likely net flux impacts are defined as those calculated based on the calibrated 'realisation' of the OGIA Surat CMA Groundwater Model occurring over the period referred to in the Surat CMA UWIR (QWC, 2012) i.e. the next 100 years. It has been assumed that Arrow can supply water for substitution over a 25 year period, and this scenario has been modelled over that period. The volume supplied for 'virtual injection' into the Condamine Alluvium via substitution is therefore equal to 63 GL over 25 years (or 6.9 ML/d). The total quantities extracted from the Condamine Alluvium Groundwater Model (with and without substitution) are shown in Table 20 and confirm that the total volume offset is equal to 63 GL.

It should be noted that the pre-substitution or baseline run in this case is the 50% of 2009 authorised use scenario previously undertaken using the Condamine Alluvium Groundwater Model by KCB (2011). Historically extraction from the Condamine Alluvium has approached 100% of entitlement levels and hence the pre-substitution baseline volume of 881 GL (or 35.24

GL/yr) quoted in Table 20 therefore represents around half of the long term average rate of 202.94 ML/d (or 74.07 GL/yr) simulated in the historic Condamine Alluvium Groundwater Model (see Table 1).

Table 20 Condamine Alluvium Groundwater Model – Total Modelled Extraction Substitution Case

Scenario	Total Extraction (GL), period 2018 – 2043
Without substitution	881
With substitution	818
Total Quantity Offset	**63**

4.3.2 Arrow Surat Gas Project Impacts

Figure 30 and Figure 31 show predicted Arrow SGP related groundwater level drawdown in the Condamine Alluvium based on the calibration 'realisation' before and after substitution.

Without substitution (Figure 30) predicted drawdowns in the Condamine Alluvium to the west of Dalby are up to around 0.5 m. However, predicted average Arrow SGP related drawdown over the entire Condamine Alluvium Groundwater Model area for the calibration 'realisation' is only 0.18 m.

With substitution, the calibration 'realisation' results suggest:

- Average drawdowns over the full Condamine Alluvium Groundwater Model area are reduced from 0.18 to 0.03 m;
- Net groundwater level increases of up to 0.2 m in the modelled substitution area (Figure 31); and
- Net positive impacts (i.e. groundwater level increases, shown as green colours in Figure 31) which extend over a zone around 70 km in length around Jandowae.

Predicted Arrow SGP related drawdowns with and without substitution are therefore substantially less than the 2 m trigger threshold specified in the Water Act 2000 for unconsolidated aquifers such at the Condamine Alluvium.

Predicted drawdown time series with and without substitution for each of the hydrograph locations shown in Figure 30 and Figure 31 are presented in Appendix H.

4.3.3 Cumulative Impacts

Figure 32 and Figure 33 show predicted cumulative groundwater level impacts in the Condamine Alluvium based on the calibration 'realisation' before and after substitution. As previously discussed, the modelled substitution scenario is based around the predicted Arrow SGP Condamine flux impacts for the calibration 'realisation' (Figure 18), rather than the estimated cumulative impacts shown in Figure 29. Nevertheless, the proposed substitution also has a positive effect on the predicted cumulative impacts.

Without substitution (Figure 32) predicted cumulative drawdowns in the Condamine Alluvium to the west of Dalby are up to around 0.9 m. However, predicted average cumulative drawdown across the entire Condamine Alluvium Groundwater Model area for the calibration 'realisation' is only 0.24 m.

With substitution, based on the calibration 'realisation' results suggest:

- Average drawdowns across the entire Condamine Alluvium Groundwater Model area are reduced from 0.24 to 0.09 m;
- Net groundwater level increases of up to 0.2 m in the modelled substitution area (Figure 33); and
- Net positive impacts (i.e. groundwater level increases, shown as green colours in Figure 33) which extend over a zone around 70 km in length around Jandowae.

Predicted cumulative drawdowns with and without substitution are therefore substantially less than the 2 m trigger threshold specified in the Water Act 2000 for unconsolidated aquifers such at the Condamine Alluvium.

Predicted cumulative drawdown time series with and without substitution for each of the hydrograph locations shown in Figure 32 and Figure 33 are also presented in Appendix H.

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5. Conclusions

Ongoing exploration and improved knowledge of coal seam gas reserves has resulted in a number of parcels of land within Arrow's original project development area being relinquished. The footprint of the current development case and proposed CSG wellfields is therefore smaller than that previously assessed in the Arrow SGP EIS and by the OGIA.

Predictive groundwater flow modelling and uncertainty analysis work previously undertaken by GHD, Watermark Numerical Computing and the OGIA (formerly part of the QWC) has been repeated and updated based on the current Arrow SGP development case.

Following successful 'benchmarking' against selected output from the OGIA Surat CMA Groundwater Model, revised impact predictions were developed based on Arrow's current development case only and for a cumulative case (including all CSG developments by Arrow, Origin, QGC and Santos within the Surat CMA).

Due to the smaller footprint of the current Arrow SGP development case, predicted cumulative groundwater level and flow impacts are typically slightly reduced compared to those previously reported in the Surat CMA Underground Water Impact Report (QWC, 2012).

5.1 Arrow Project Impacts

Revised modelled extraction rates for Arrow's current SGP development case are predicted to peak at around 140 ML/d between around 2021 and 2024 and total water production throughout the lifetime of the project is predicted to be around 702 GL.

Revised predictions for groundwater level impact, under the Arrow only case and based on the calibration 'realisation', indicate maximum drawdowns of greater than 5 m in parts of the Springbok Sandstone, Walloon Coal Measures and the Hutton Sandstone. Impacts of less than 5 m are anticipated in minor alluvial deposits, the Main Range Volcanics, Mooga Formation, Bungil Sandstone, Gubberamunda Sandstone, Precipice Sandstone and the Clematis Sandstone.

In the Condamine Alluvium predictions for the Arrow only case suggest upflow from underlying strata, which include the Walloon Coal Measures, are most likely to be reduced by up to around 2.5 ML/d (or 63 GL in total over the next 100 years) leading to further groundwater level drawdowns in the Condamine Alluvium of up to 0.5 m. However, on average and based on output generated using the OGIA Surat CMA Groundwater Model calibrated parameter set impacts of 0.18 m are expected. With substitution modelled average predicted impacts are reduced from 0.18 to 0.03 m. Predicted Arrow SGP related drawdowns in the Condamine Alluvium, with and without substitution, are therefore substantially less than the 2 m trigger threshold specified in the Water Act 2000.

5.2 Cumulative Impacts

Revised modelled extraction for the Cumulative case is predicted to peak at around 550 ML/d in 2015.

Revised predictions for groundwater level impact, under the cumulative case and based on the calibration 'realisation', indicate maximum drawdowns of greater than 5 m in parts of the Springbok Sandstone, Walloon Coal Measures, Hutton Sandstone, Precipice Sandstone and the Clematis Sandstone. Impacts of less than 5 m are anticipated in minor alluvial deposits, the

Main Range Volcanics, Mooga Formation, Bungil Sandstone and the Gubberamunda Sandstone.

In the Condamine Alluvium cumulative predictions suggest upflow from underlying strata are most likely to be reduced by up to around 3.0 ML/d (or 79 GL in total over the next 100 years) leading to groundwater level drawdowns of up to 0.9 m. However, on average and based on output generated using the calibrated OGIA Surat CMA Groundwater Model parameter set impacts of 0.24 m are predicted. With substitution average modelled impacts are reduced from 0.24 to 0.09 m. Predicted cumulative drawdowns in the Condamine Alluvium, with and without substitution, are therefore substantially less than the 2 m bore trigger threshold specified in the Water Act 2000.

6. Glossary

Acronym	Definition
CCRA	Central Condamine River Alluvium
CGPF	Arrow Surat Gas Project Central Gas Processing Facility
CMA	Cumulative Management Area
Condamine Alluvium Groundwater Model	Central Condamine River Alluvium Groundwater Model (KCB, 2011)
CSG	Coal Seam Gas
CSIRO	Commonwealth Scientific and Industrial Research Organization
DA	Arrow Surat Gas Project Drainage Area
DEM	Digital Elevation Model
DERM	Department of Environment and Resource Management
DNRM	Department of Natural Resources and Mines
EIS	Environmental Impact Statement
EVT	MODFLOW Evaporation or EVT Package
FWL	MODFLOW SURFACT Fracture WEL Package
GAB	Great Artesian Basin
GHB	MODFLOW GHB or General Head Boundary Package
GL	Gigalitres
GL/yr	Gigalitres per year
GWDB	Groundwater Database
K	Hydraulic Conductivity
Kh	Horizontal Hydraulic Conductivity
Kv	Vertical Hydraulic Conductivity
KCB	Khlon Crippen Berger
km	Kilometres
km^2	Square kilometres
m	Metre
m/d	Metres per day
m^2/d	Square metres per day
ML/d	Megalitres per day
ML/yr	Megalitres per year
mm	Millimetres

Acronym	Definition
mm/yr	Millimetres per year
mAHD	Metres above Australian Height Datum
MDBC	Murray-Darling Basin Commission
NSMC	Null Space Monte Carlo
OGIA	Office of Groundwater Impact Assessment (formerly part of the Queensland Water Commission)
PEST	Model Independent Parameter Estimation and Uncertainty Analysis software
P&G	Petroleum and Gas (industry)
%	Per cent
PSC	Project Steering Committee
QPED	Queensland Petroleum Exploration Database
QWC	Queensland Water Commission
R^2	Coefficient of determination or correlation
SEWPAC	Department of Sustainability, Environment, Water, Population and Communities
SREIS	Supplementary Report to the Environmental Impact Statement
SGP	Surat Gas Project
SRMS	Scaled Root Mean Square
OGIA Surat CMA Groundwater Model	Surat CMA groundwater flow model and associated uncertainty analysis (GHD, 2012; Watermark Numerical Computing, 2012; and QWC, 2012)
SVDA	Singular Value Decomposition Assist
SWS	Schlumberger Water Services
T	Transmissivity
TAG	Technical Advisory Group
UWIR	Underground Water Impact Report
WCM	Walloon Coal Measures
WEL	MODFLOW Well or WEL Package
WNC	Watermark Numerical Computing

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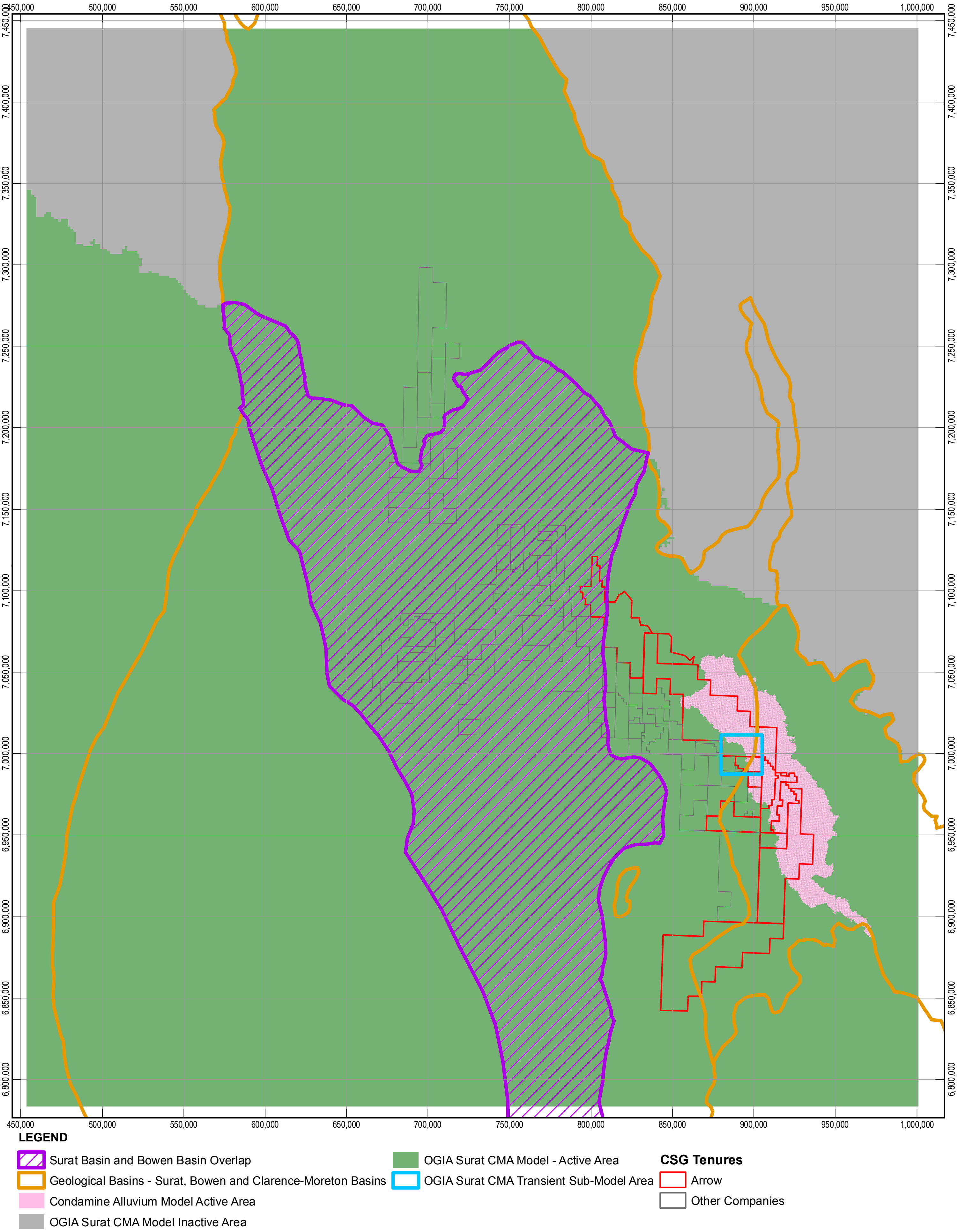

Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Job Number	41-26392
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Date	18 Jun 2013

OGIA and Condamine Model Domains

Figure 1

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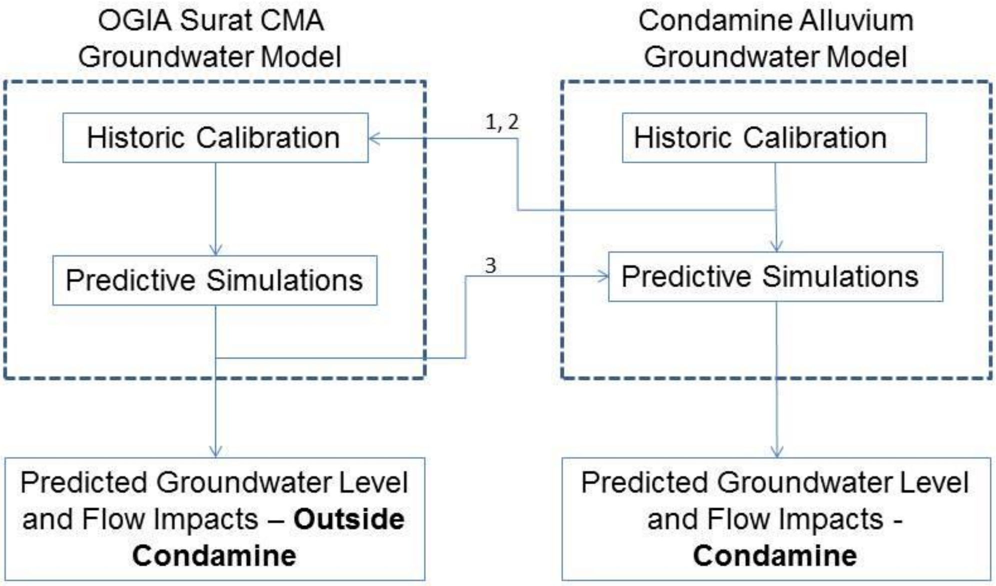
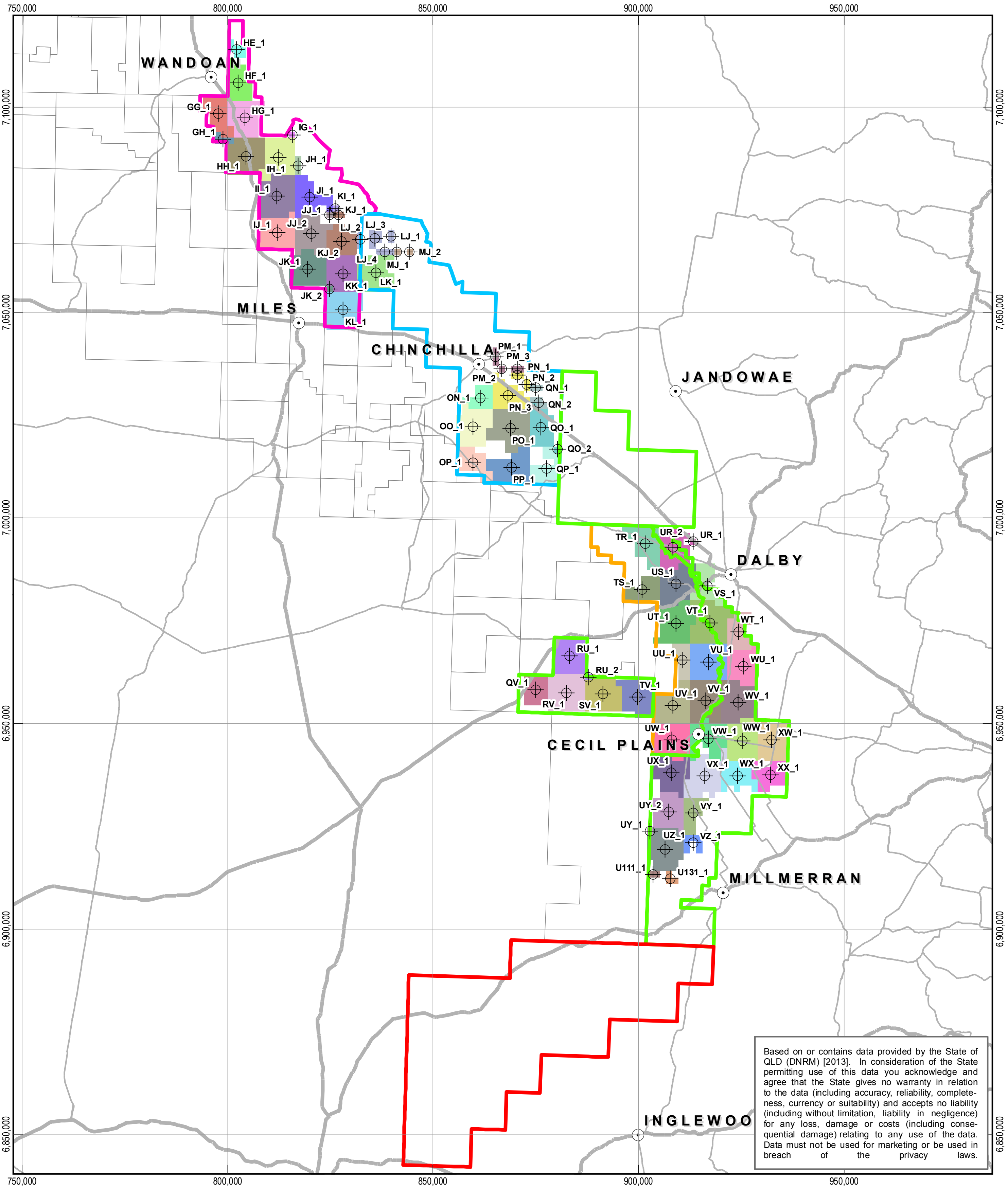
145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013). Created by: LT

Figure 2 OGIA and Condamine Model Inter-Relationship



#1: Condamine Alluvium properties – thickness and calibrated hydraulic conductivity and specific yield
#2: Modelled groundwater levels
#3: Predicted maximum flux impacts on the Condamine Alluvium



LEGEND

Hydrograph Locations
Populated Places
Highway
Main Road
Arrow Development Regions
Dalby
Goondiwindi
Millmerran/Kogan
Wandoan
Chinchilla
CSG Tenures
Other Companies

Paper Size A4
0 5 10 20 30 40 50
Kilometres
Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

Arrow Energy
Assessment of Regional Impacts from OGIA Model

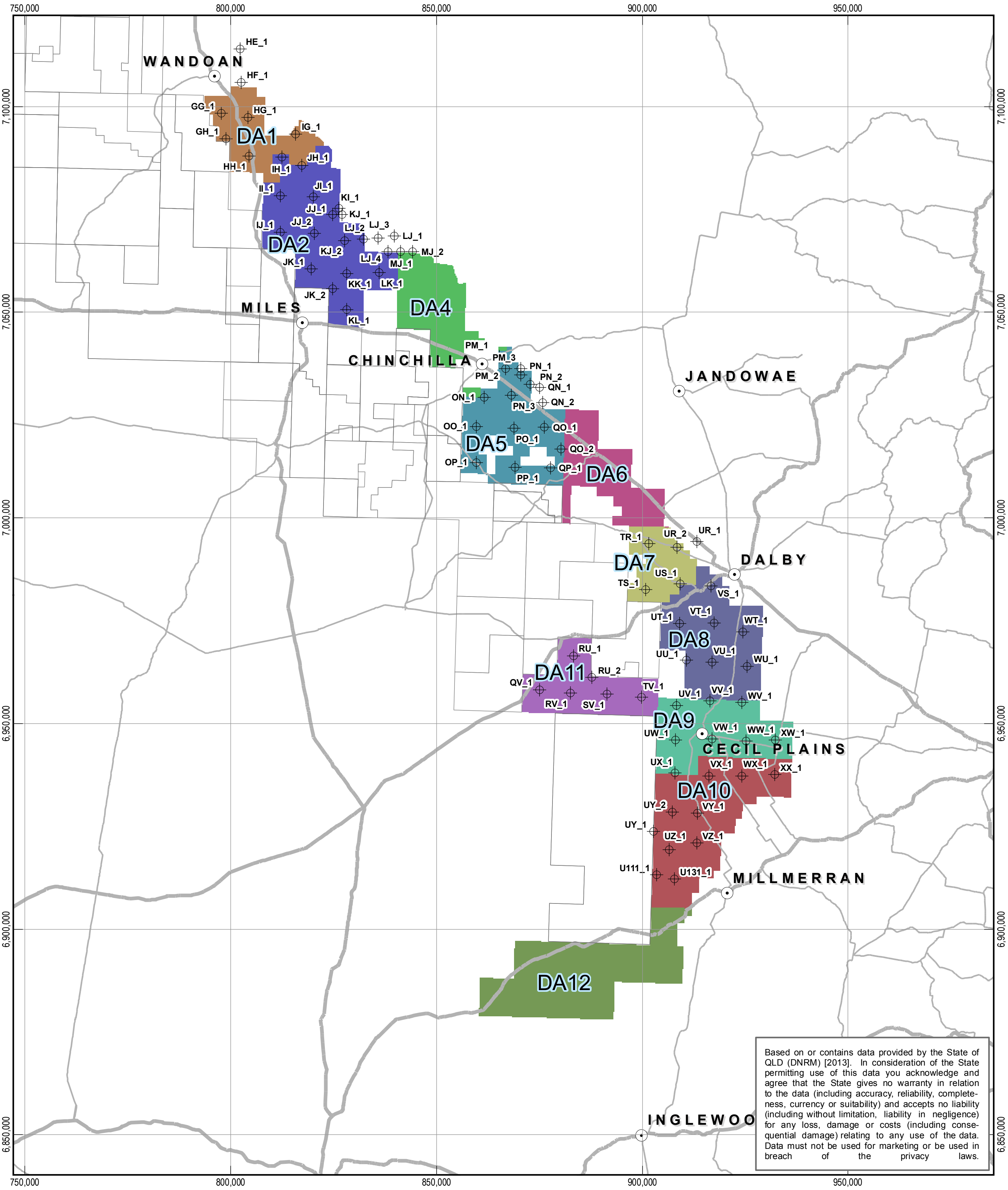
Arrow Surat Gas Project Current Development Plan - Development Regions

Job Number	41-26392
Revision	0
Date	18 Jun 2013

Figure 3

G:\41\26392\GIS\Maps\MXD\Fig 3_4126392_TenureMap_Rev0.mxd
145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Hydrograph Locations (2013); Arrow: Arrow Development Regions (2013); GA: Populated Places (2007); DNRM: Roads (2010) Created by: LT



LEGEND

Hydrograph Locations	Highway	Drainage Areas: 1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12	CSG Tenures	Other Companies
Populated Places	Main Road			

Paper Size A4

0 5 10 20 30 40 50

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Arrow Energy
Assessment of Regional Impacts from OGIA Model

Job Number 41-26392
Revision 0
Date 18 Jun 2013

Arrow Surat Gas Project Current Development Plan - Drainage Areas

Figure 4

G:\41\26392\GIS\Maps\MXD\Fig 4_4126392_DrainageAreas_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (21-01-2013); GHD: Hydrograph Locations (2013); Arrow: Drainage Area (2013); GA: Populated Places (2007); DNRM: Roads (2010) Created by: LT

Figure 5 Modelled CSG and Other Extraction, Calibrated Model “Realisation”

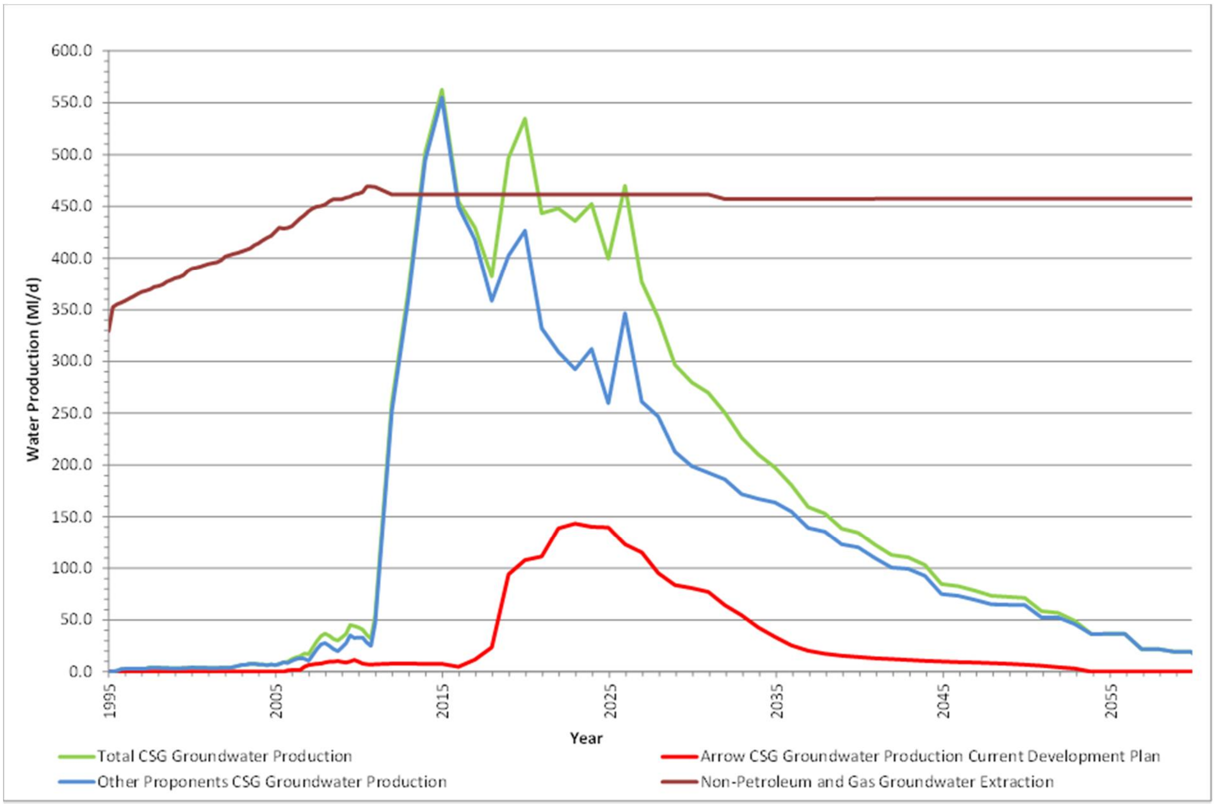


Figure 6 Modelled Cumulative CSG Extraction, All Model Realisations

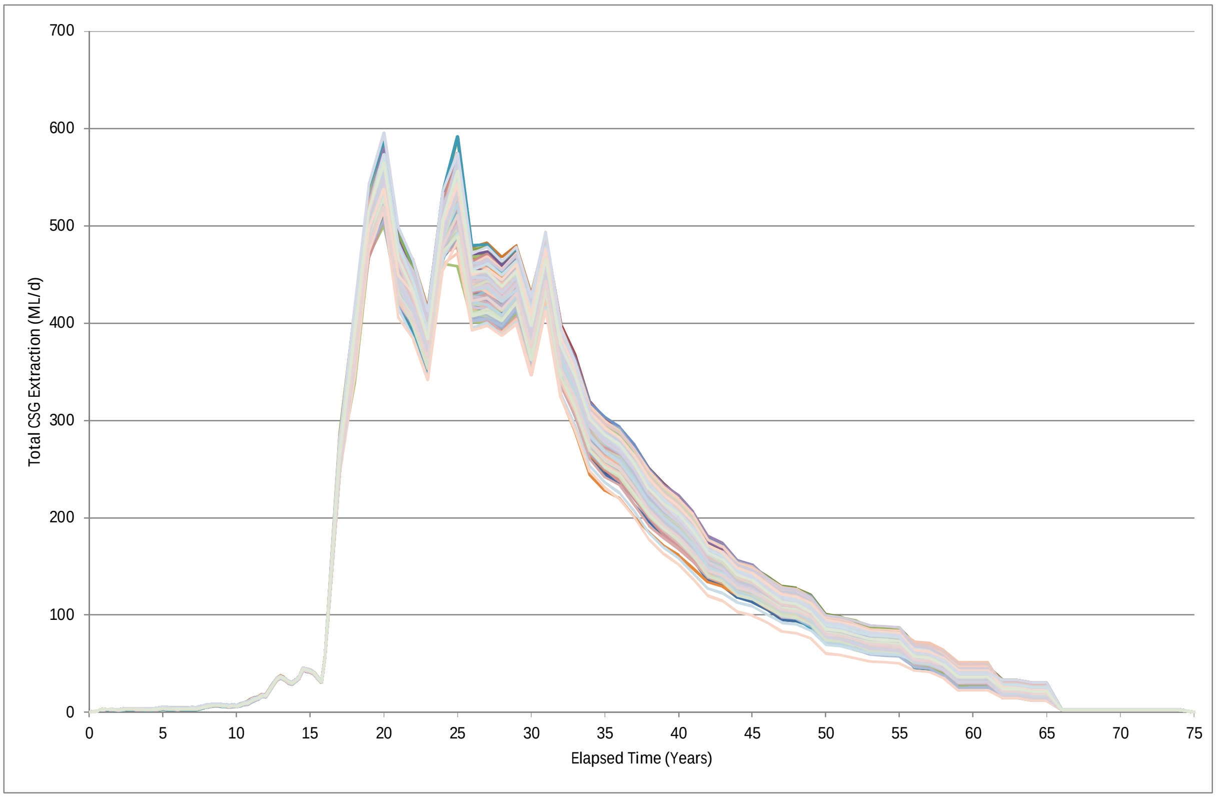
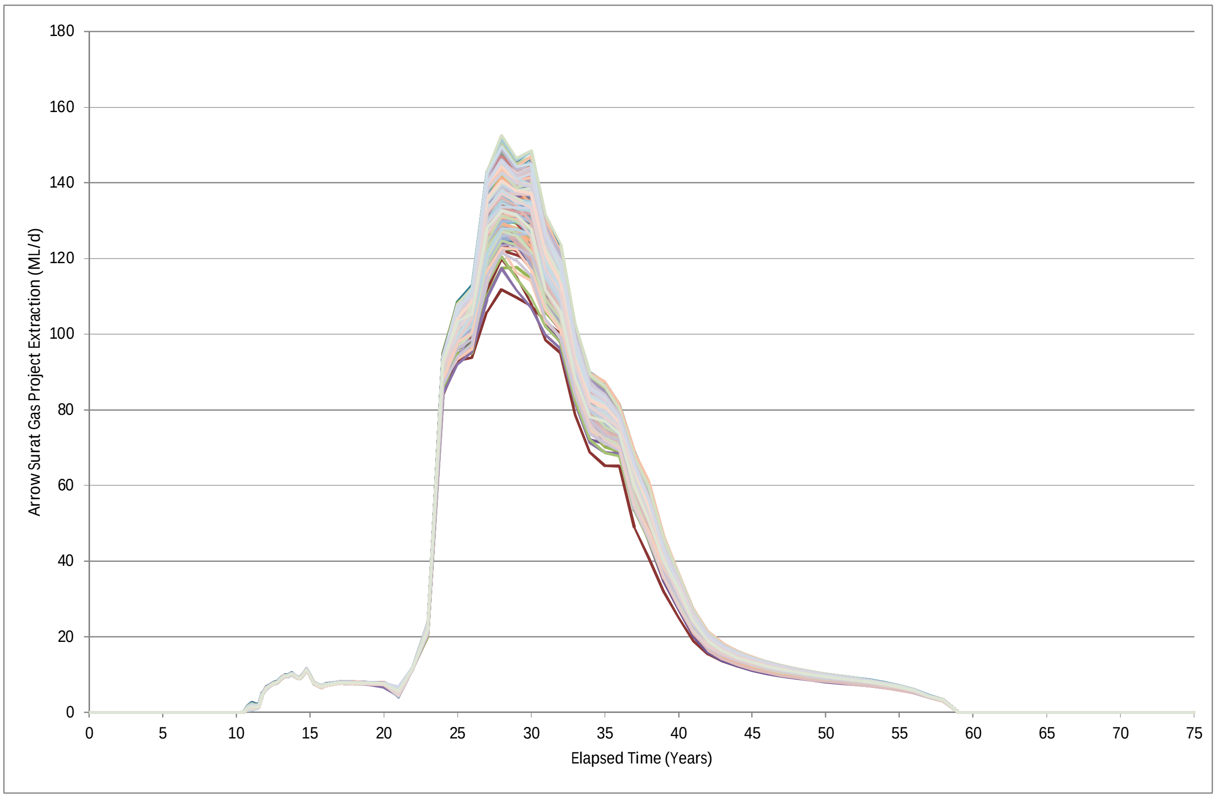
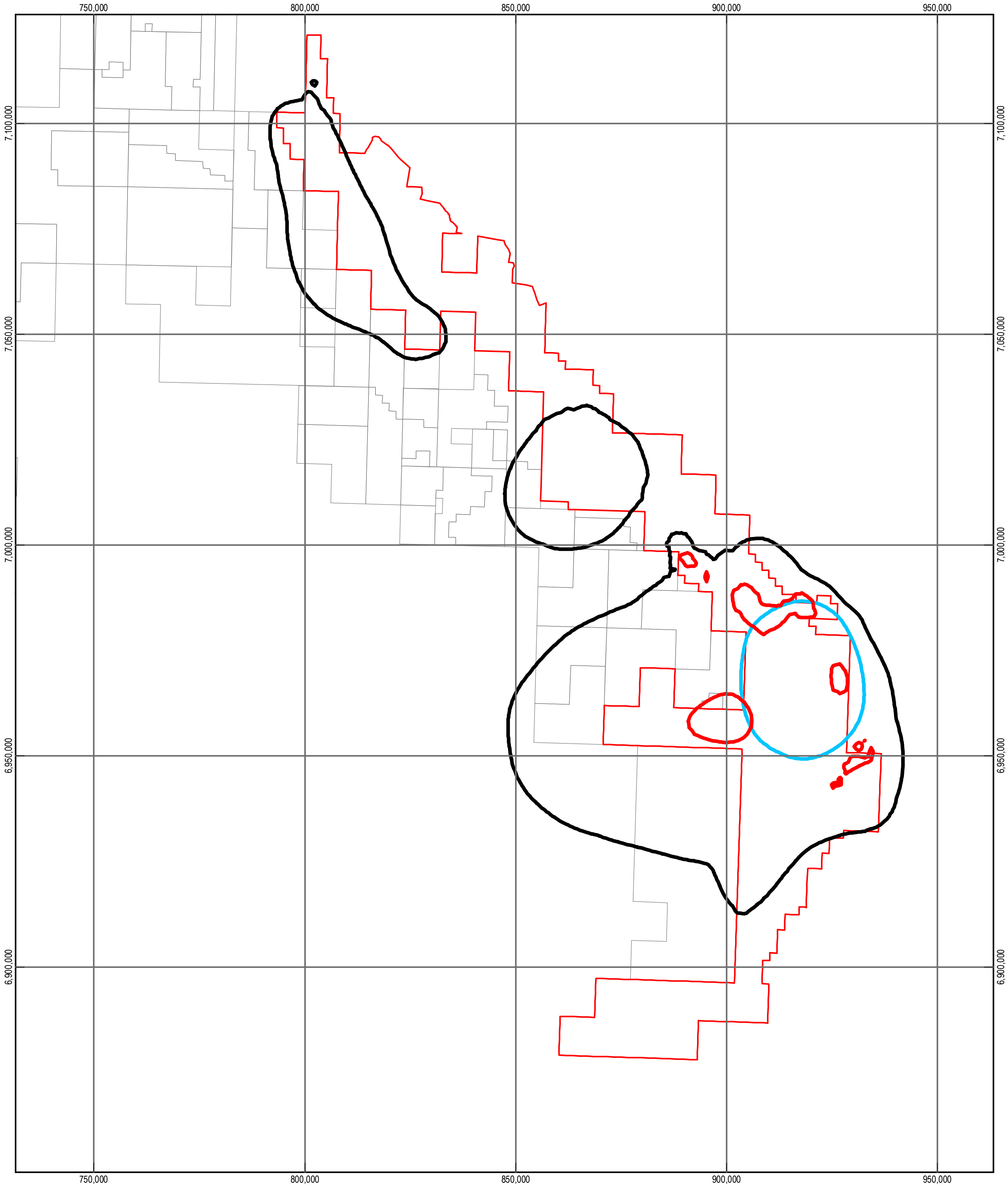


Figure 7 Modelled Arrow Surat Gas Project Extraction, All Model Realisations





LEGEND

Springbok Sandstone	**CSG Tenures**
Walloon Coal Measures	Other Companies
Hutton/Marburg Sandstone	Arrow

Paper Size A4

0 5 10 20 30 40 50

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Job Number | 41-26392
Revision | 0
Date | 18 Jun 2013

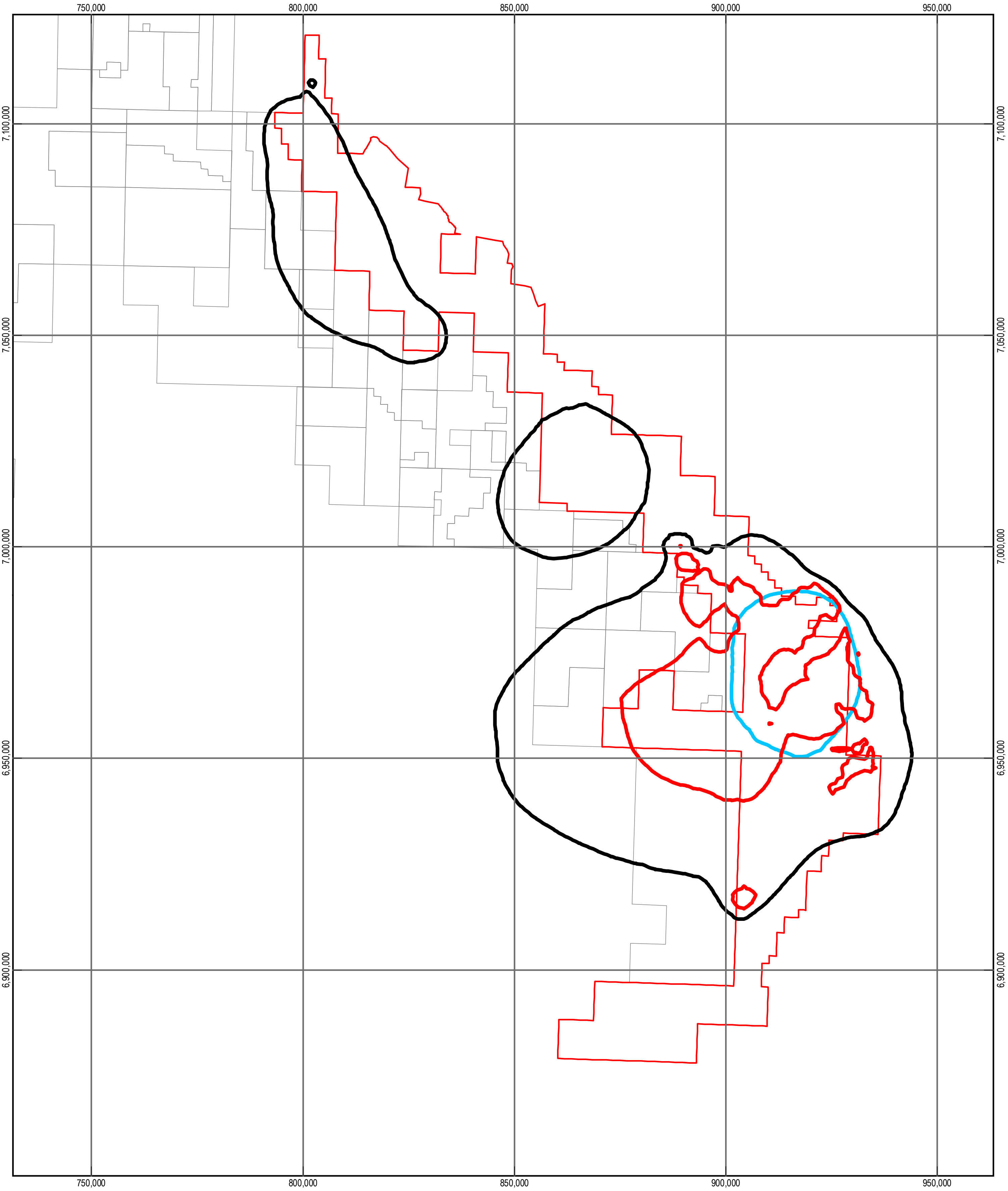
5.0m Maximum Arrow Gas Project
Impact Drawdown Contours, Calibration Realisation

Figure 8

G:\41\26392\GIS\Maps\MXD\Fig 8_4126392_maxddn_Calib_ArrCase_AllLayers_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: Tenure Boundaries (23-05-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013). Created by: LT



LEGEND

Springbok Sandstone
Walloon Coal Measures
Hutton/Marburg Sandstone

CSG Tenures

Other Companies
Arrow

Paper Size A4
0 5 10 20 30 40 50
Kilometres
Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Job Number	41-26392
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Date	18 Jun 2013

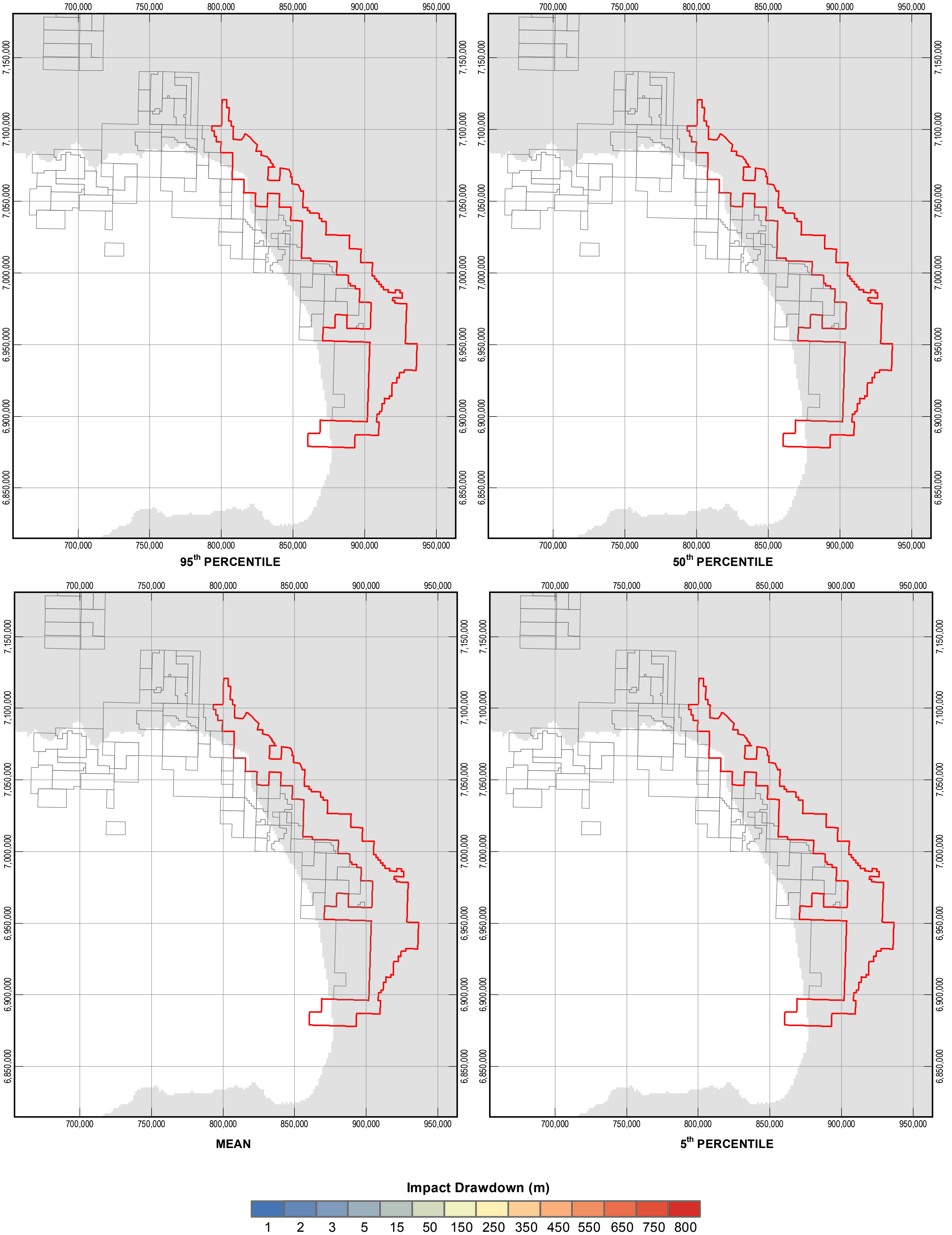
5.0m Maximum Arrow Surat Gas Project
Impact Drawdown Contours, 95th Percentile

Figure 9

G:\41\26392\GIS\Maps\MXD\Fig 9_4126392_maxddn_95th_ArrCase_AllLayers_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: Tenure Boundaries (21-01-2013); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013). Created by: LT



Paper Size A4

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Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Predicted Arrow Surat Gas Project Impact Drawdown, Mooga and Bungil Units

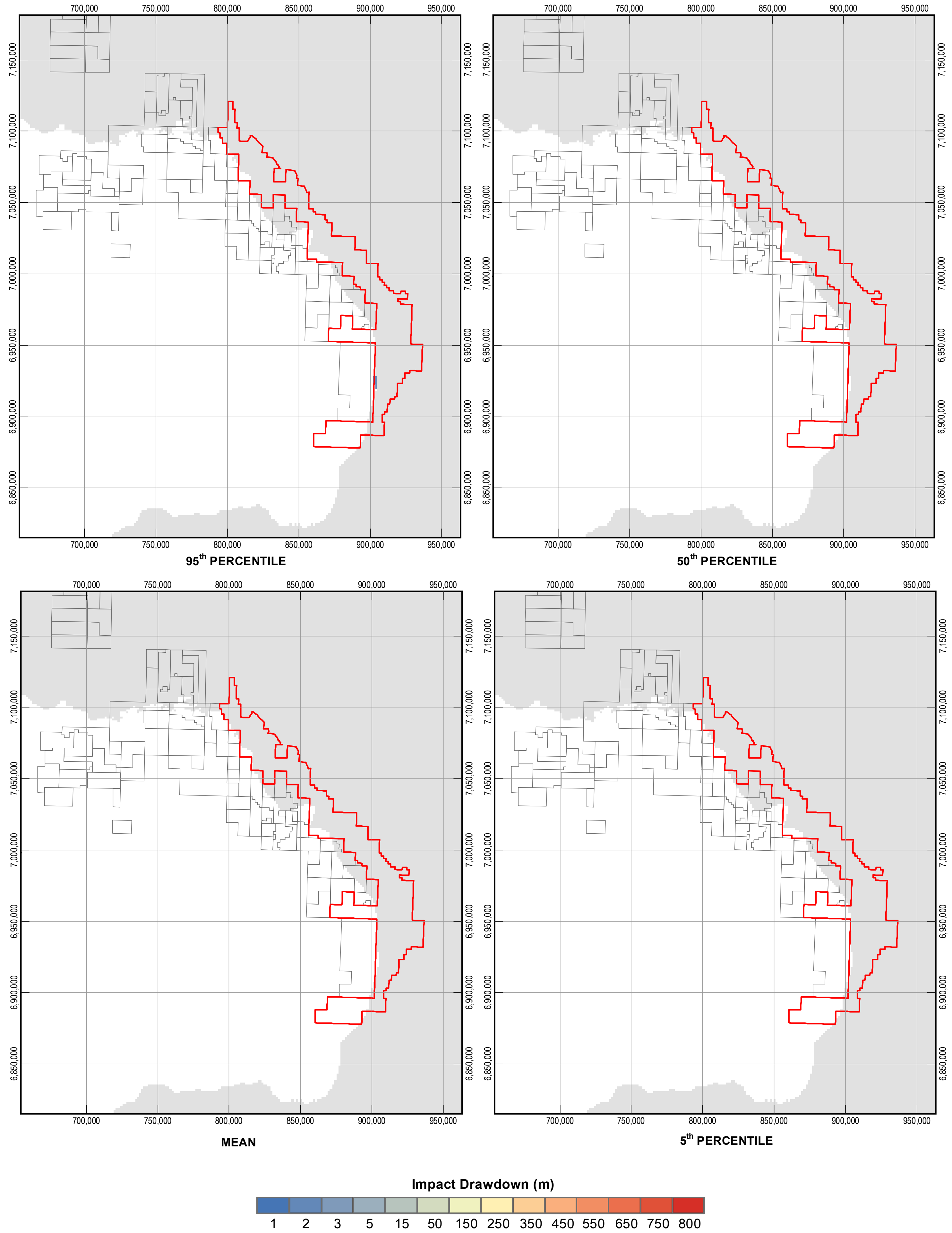
Job Number	41-26392
Revision	0
Date	18 Jun 2013

Figure 10

G:\41\26392\GIS\Maps\MXD\Fig 10_4126392_maxddn_Mean_ArrowCase_lay3_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: QWC: CSG Tenures (21-01-2013); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by: LT



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Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Predicted Arrow Surat Gas Project Maximum Impact Drawdown, Gubberamunda Sandstone

Job Number | 41-26392
Revision | 0
Date | 18 Jun 2013

Figure 11

G:\41\26392\GIS\Maps\MXD\Fig 11_4126392_maxddn_Mean_ArrowCase_lay5_Rev0.mxd

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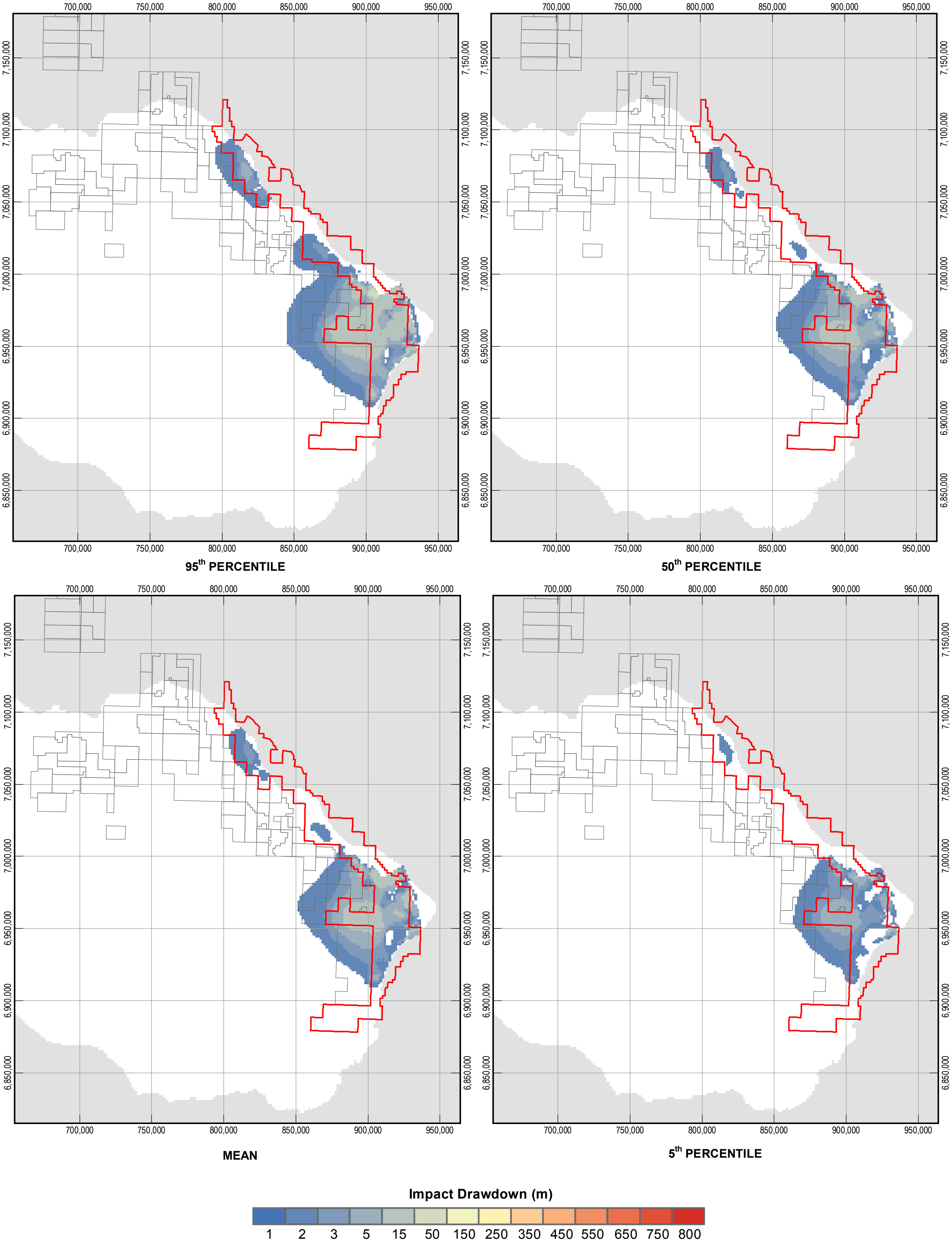
Data source: QWC: CSG Tenures (21-01-2013); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by: LT



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Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Job Number 41-26392
Revision 0
Date 18 Jun 2013

Predicted Arrow Surat Gas Project Maximum Impact Drawdown, Springbok Sandstone

Figure 12

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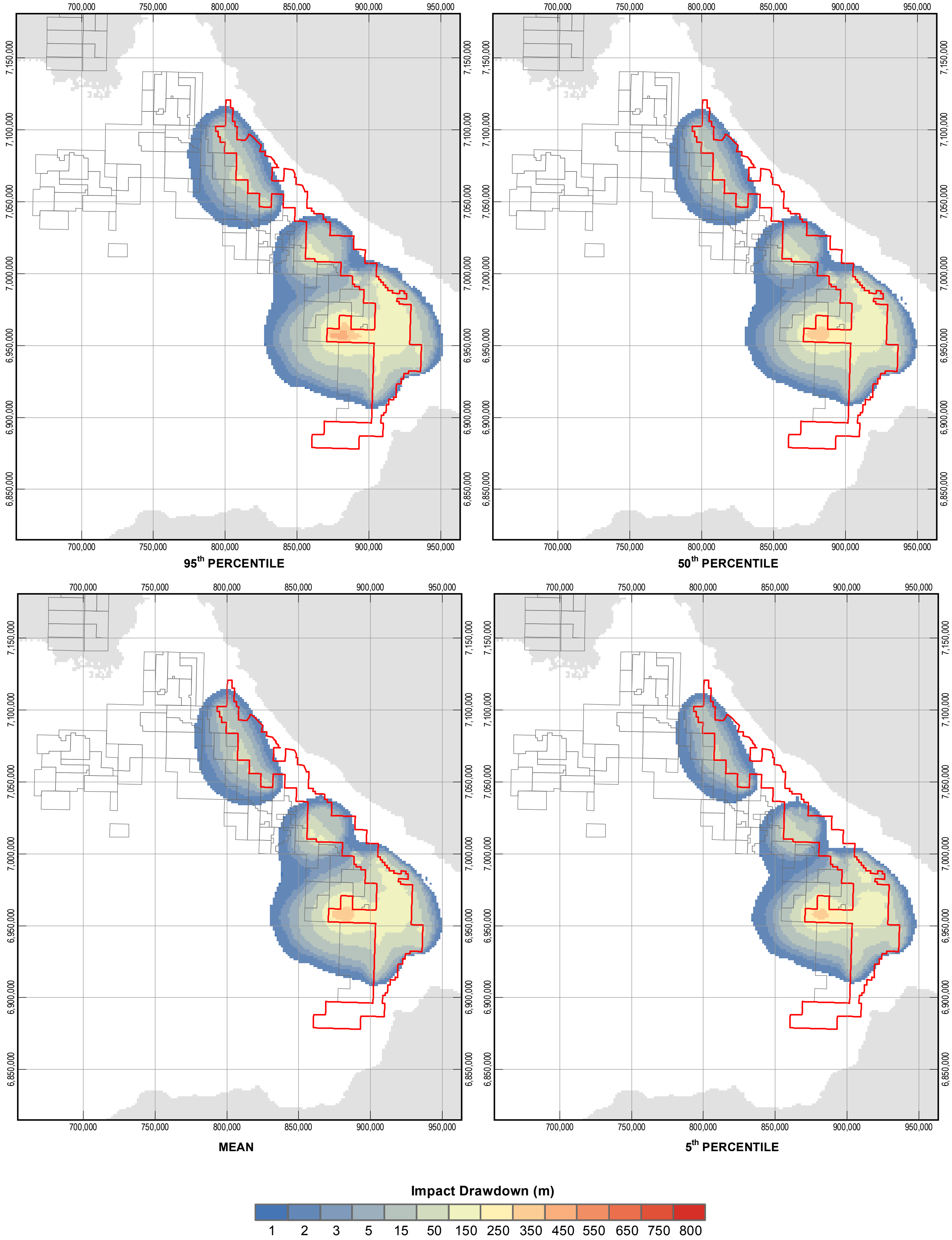
145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: Tenure Boundaries (21-01-2013); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by: LT



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Kilometres

Map Projection: Transverse Mercator

Horizontal Datum: GDA 1994

Grid: GDA 1994 MGA Zone 55

N

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Arrow Energy Surat Gas Project

Assessment of Regional Impacts

Predicted Arrow Surat Gas Project

Impact Drawdown, Walloon Coal Measures

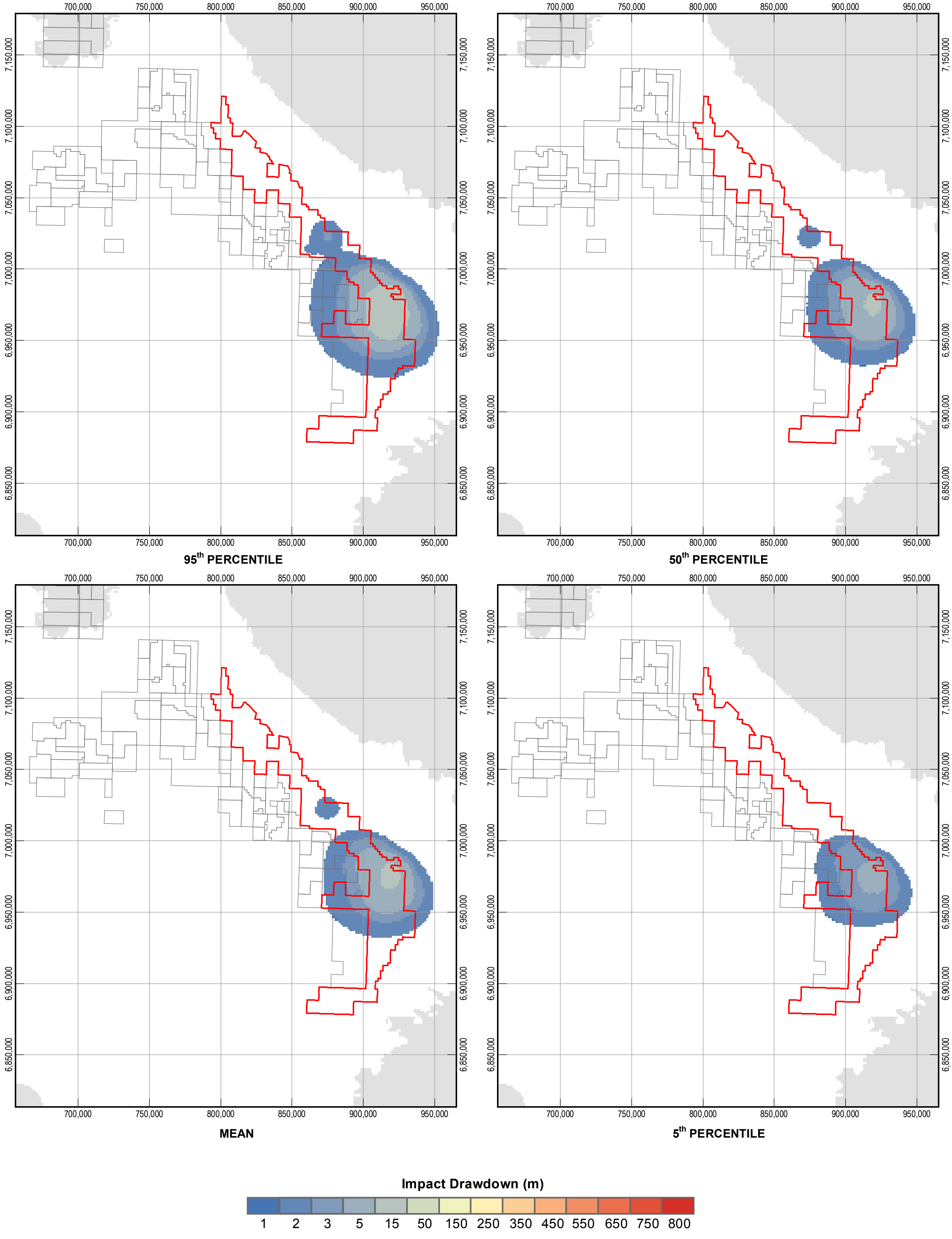
Job Number	41-26392
Revision	0
Date	18 Jun 2013

Figure 13

G:\41\26392\GIS\Maps\MXD\Fig 13_4126392_maxddn_Mean_ArrowCase_lay10_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: QWC: CSG Tenures (21-01-2013); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by: LT



Paper Size A4

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Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Job Number 41-26392
Revision 0
Date 18 Jun 2013

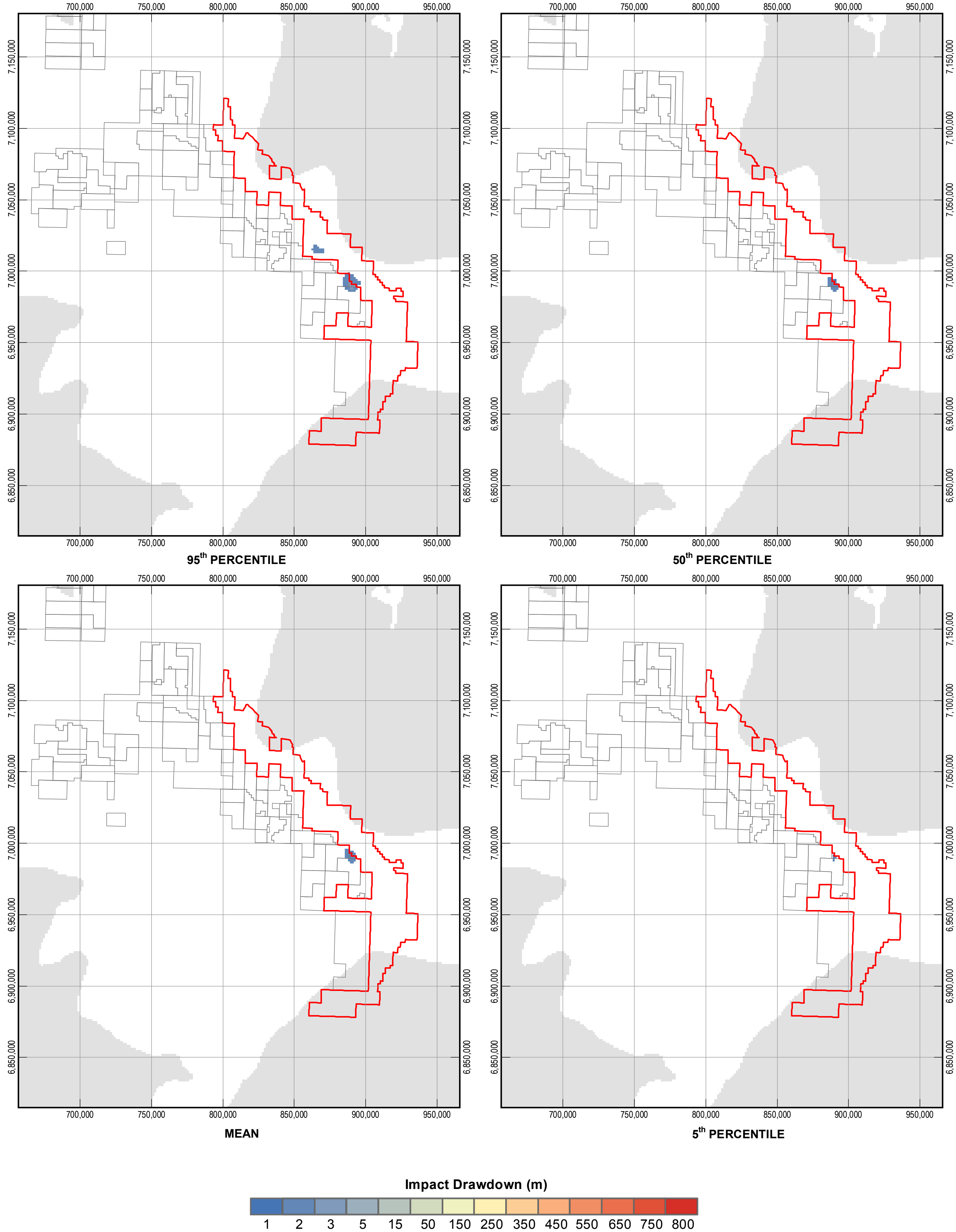
Predicted Arrow Surat Gas Project Maximum Impact Drawdown, Hutton Sandstone

Figure 14

G:\41\26392\GIS\Maps\MXD\Fig 14_4126392_maxddn_Mean_ArrowCase_lay12_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (21-01-2013); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by: LT



Paper Size A4

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Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Job Number 41-26392
Revision 0
Date 18 Jun 2013

Predicted Arrow Surat Gas Project Maximum Impact Drawdown, Precipice Sandstone

Figure 15

G:\41\26392\GIS\Maps\MXD\Fig 15_4126392_maxddn_Mean_ArrowCase_lay14_Rev0.mxd

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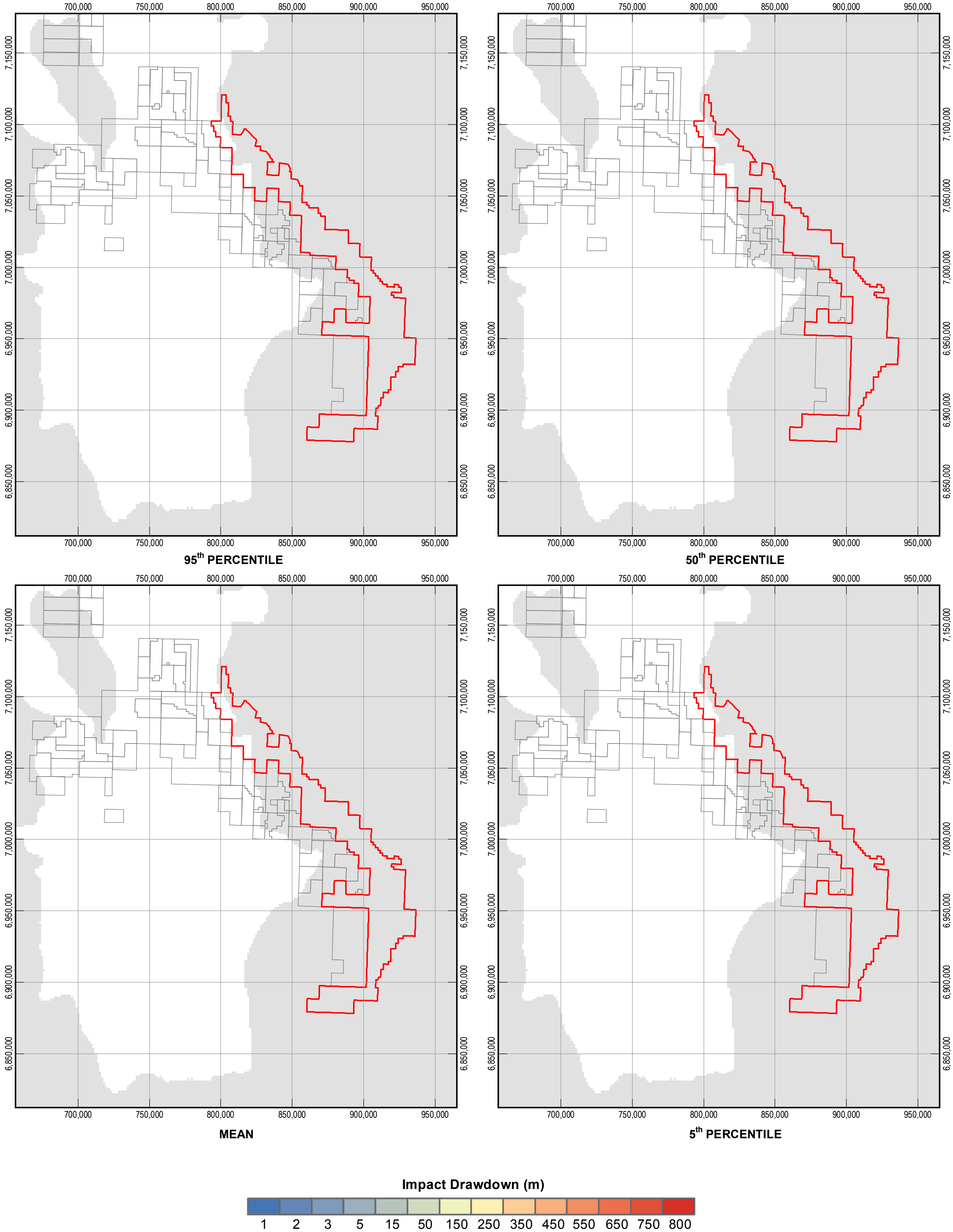
Data source: QWC: Tenure Boundaries (21-01-2013); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by: LT



Paper Size A4

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Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Predicted Arrow Surat Gas Project Maximum Impact Drawdown, Clematis Sandstone

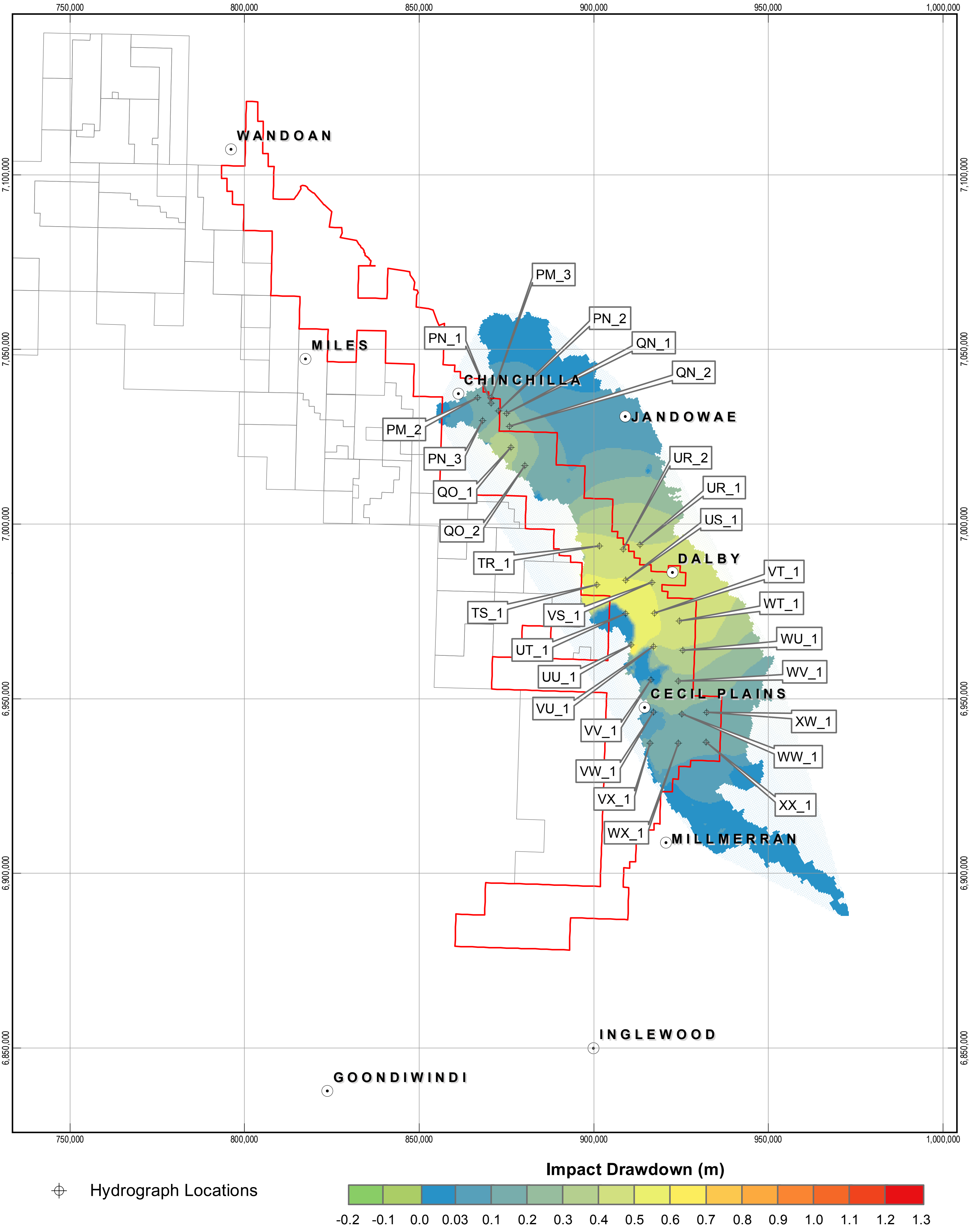
Job Number	41-26392
Revision	0
Date	18 Jun 2013

Figure 16

G:\41\26392\GIS\Maps\MXD\Fig 16_4126392_maxddn_Mean_ArrowCase_lay16_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (21-01-2013); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by: LT



Paper Size A4

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Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Maximum Predicted Arrow Surat Gas Project
Impact Drawdown, Condamine Alluvium

Job Number	41-26392
Revision	0
Date	18 Jun 2013

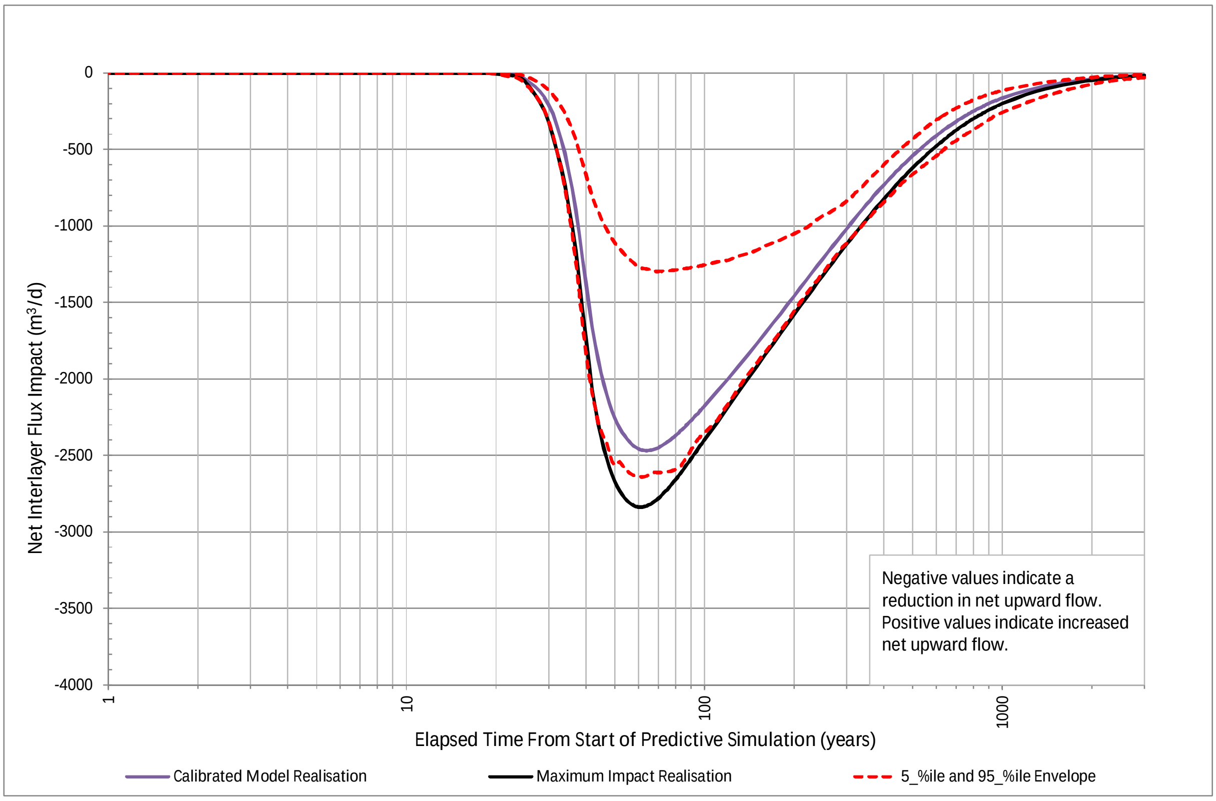
Figure 17

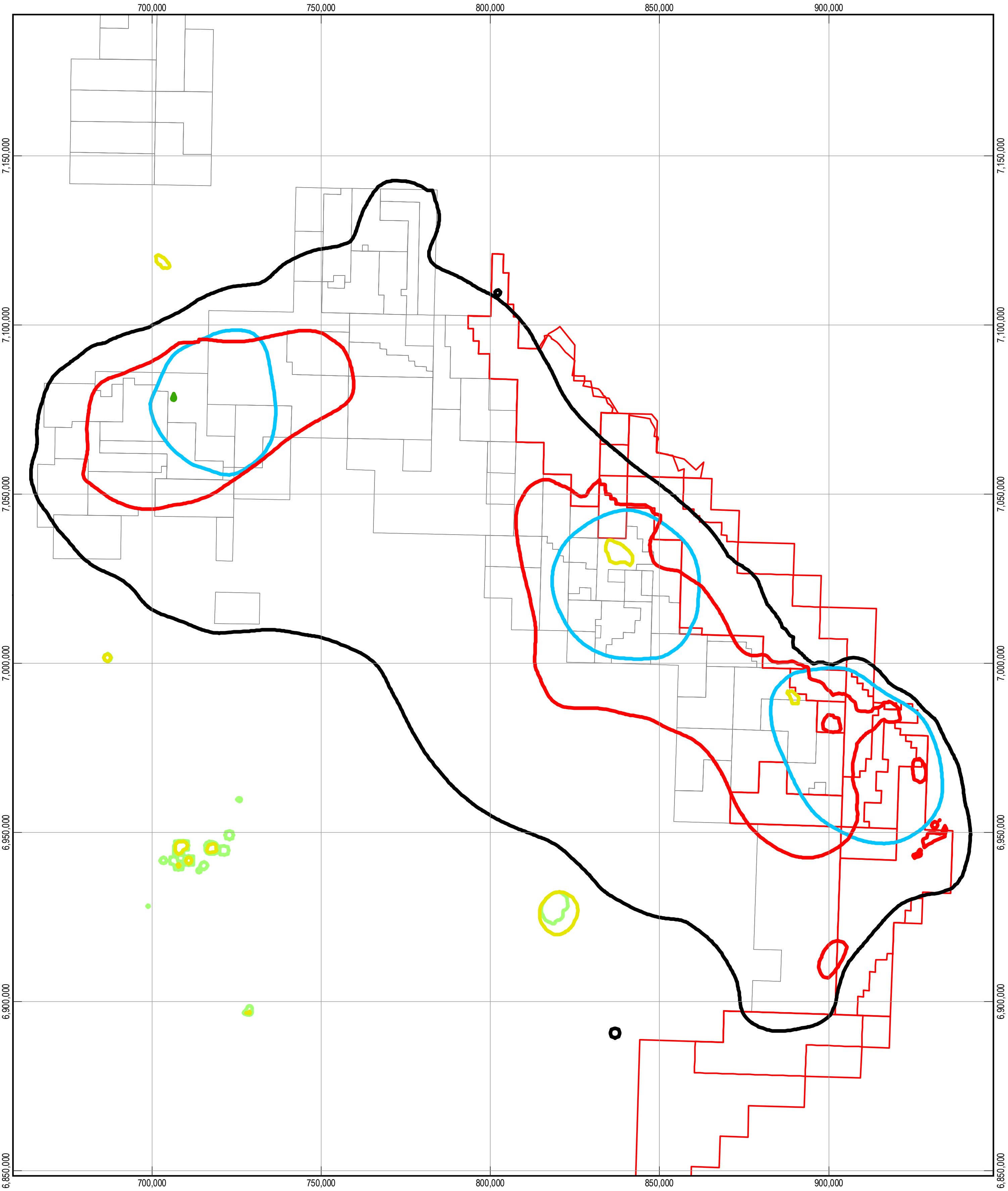
G:\41\26392\GIS\Maps\MXD\Fig 17_4126392_maxddn_Condamine_arrcase_r69_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:mstanley

Figure 18 Interlayer Flux Arrow Surat Gas Project Impact Envelopes, Condamine Alluvium





LEGEND

- Gubberamunda Sndstone
- Springbok Sandstone
- Walloon Coal Measures
- Hutton/Marburg Sandstone
- Precipice Sandstone
- Clematis/Showgrounds Sandstone

CSG Tenures

- Other Companies
- Arrow

Paper Size A4

0 5 10 20 30 40 50

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Arrow Energy Surat Gas Project
Assessment of Regional Impacts

5.0m Maximum Cumulative
Impact 5m Drawdown Contours, Calibration Realisation

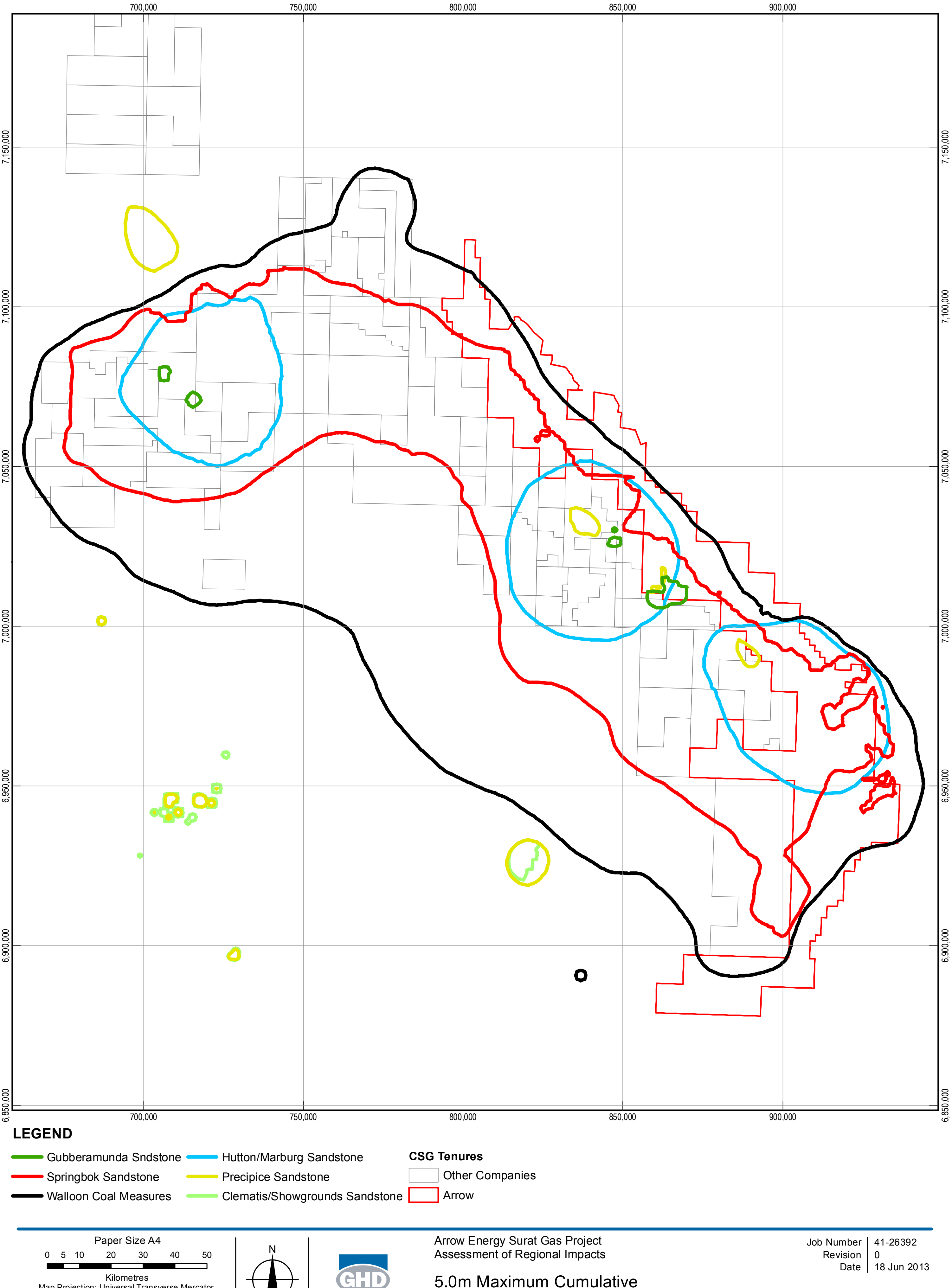
Job Number 41-26392
Revision 0
Date 18 Jun 2013

Figure 19

G:\41\26392\GIS\Maps\MXD\Fig 19_4126392_maxddn_Calib_Cum_AllLayers_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: Tenure Boundaries (23-05-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:afeeney



Arrow Energy Surat Gas Project
Assessment of Regional Impacts

5.0m Maximum Cumulative Impact Drawdown Contours, 95th Percentile

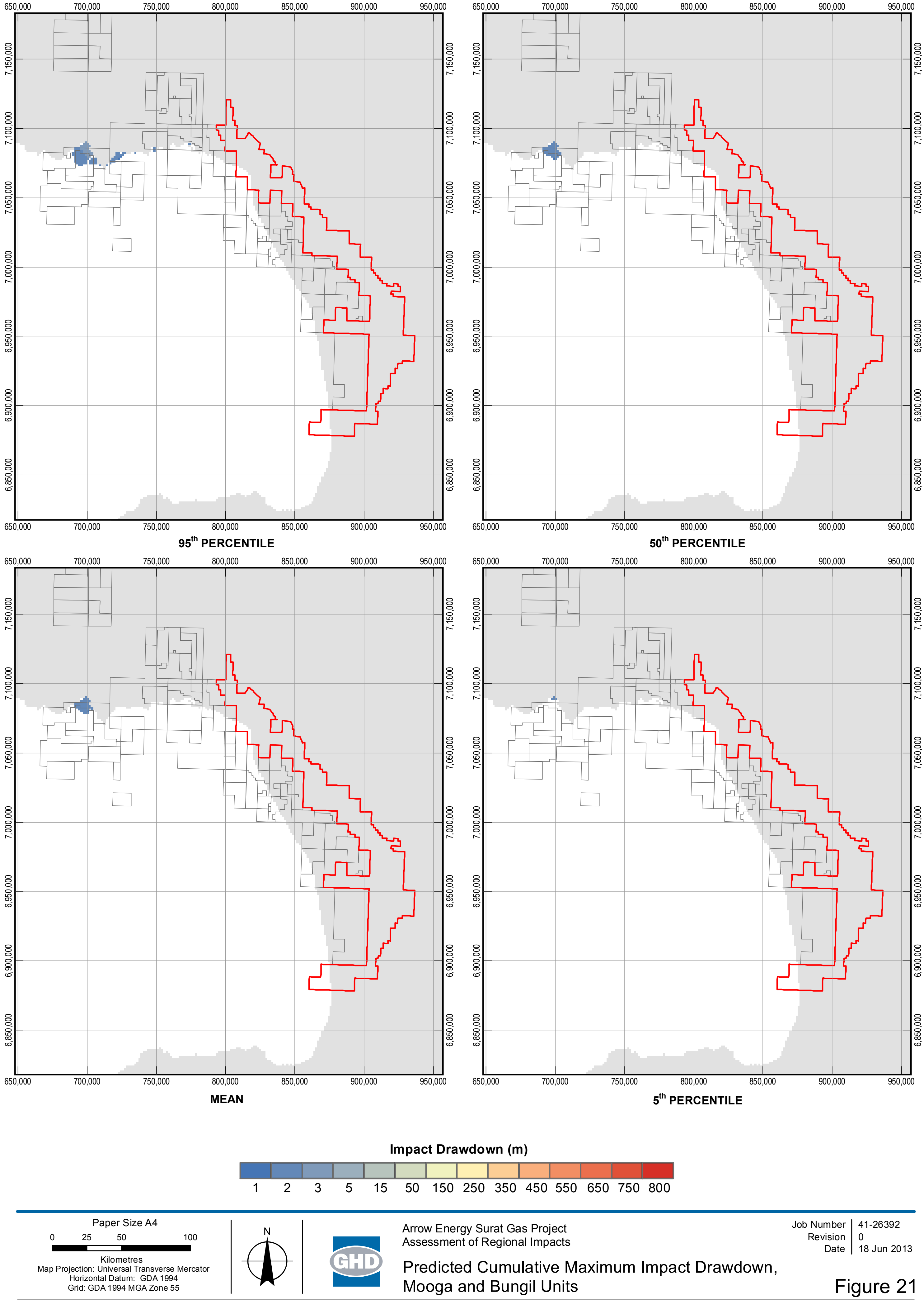
Job Number 41-26392
Revision 0
Date 18 Jun 2013

Figure 20

G:\41\26392\GIS\Maps\MXD\Fig 20_4126392_maxddn_95th_Cum_AllLayers_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: Tenure Boundaries (23-05-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:afeeney



Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Job Number	41-26392
Revision	0
Date	18 Jun 2013

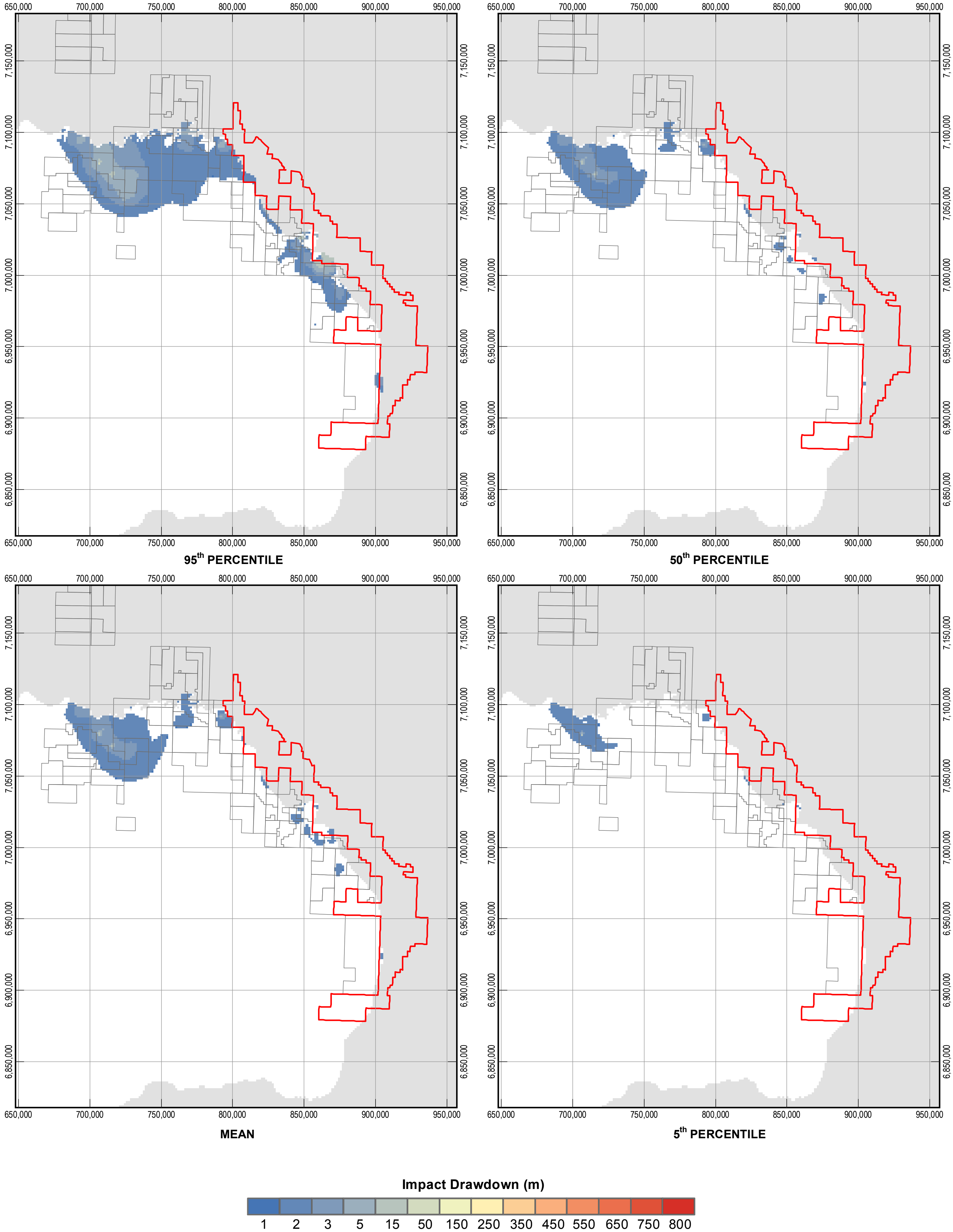
Predicted Cumulative Maximum Impact Drawdown, Mooga and Bungil Units

Figure 21

G:\41\26392\GIS\Maps\MXD\Fig 21_4126392_maxddn_Mean_Cumulative_lay3_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:afeeney



Paper Size A4

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Kilometres

Map Projection: Universal Transverse Mercator

Horizontal Datum: GDA 1994

Grid: GDA 1994 MGA Zone 55

N

GHD

Arrow Energy Surat Gas Project

Assessment of Regional Impacts

Job Number | 41-26392

Revision | 0

Date | 18 Jun 2013

Predicted Cumulative Maximum Impact Drawdown, Gubberamunda Sandstone

Figure 22

G:\41\26392\GIS\Maps\MXD\Fig 22_4126392_maxddn_Mean_Cumulative_lay5_Rev0.mxd

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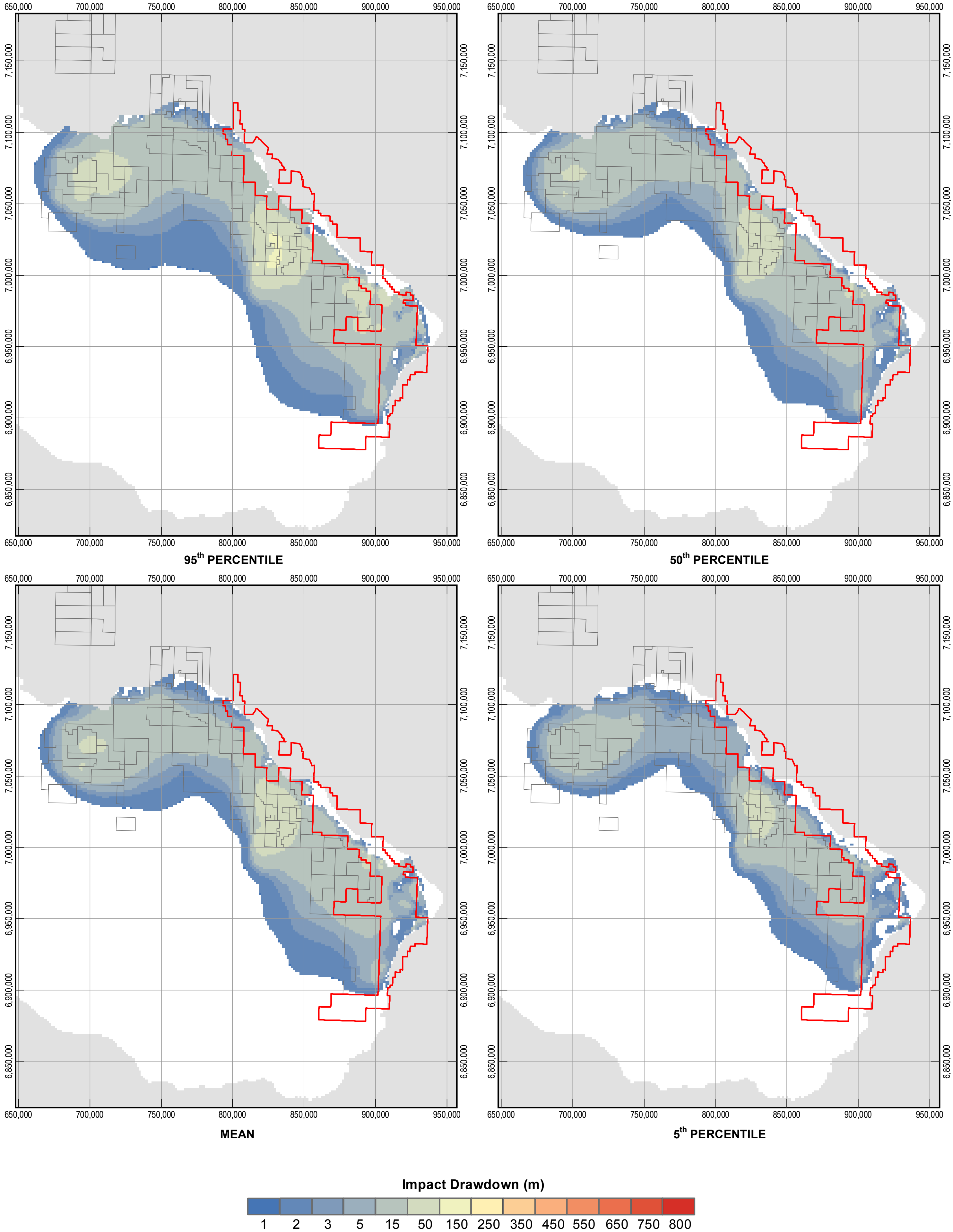
Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:afeeney



Paper Size A4

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Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Predicted Cumulative Maximum Impact Drawdown, Springbok Sandstone

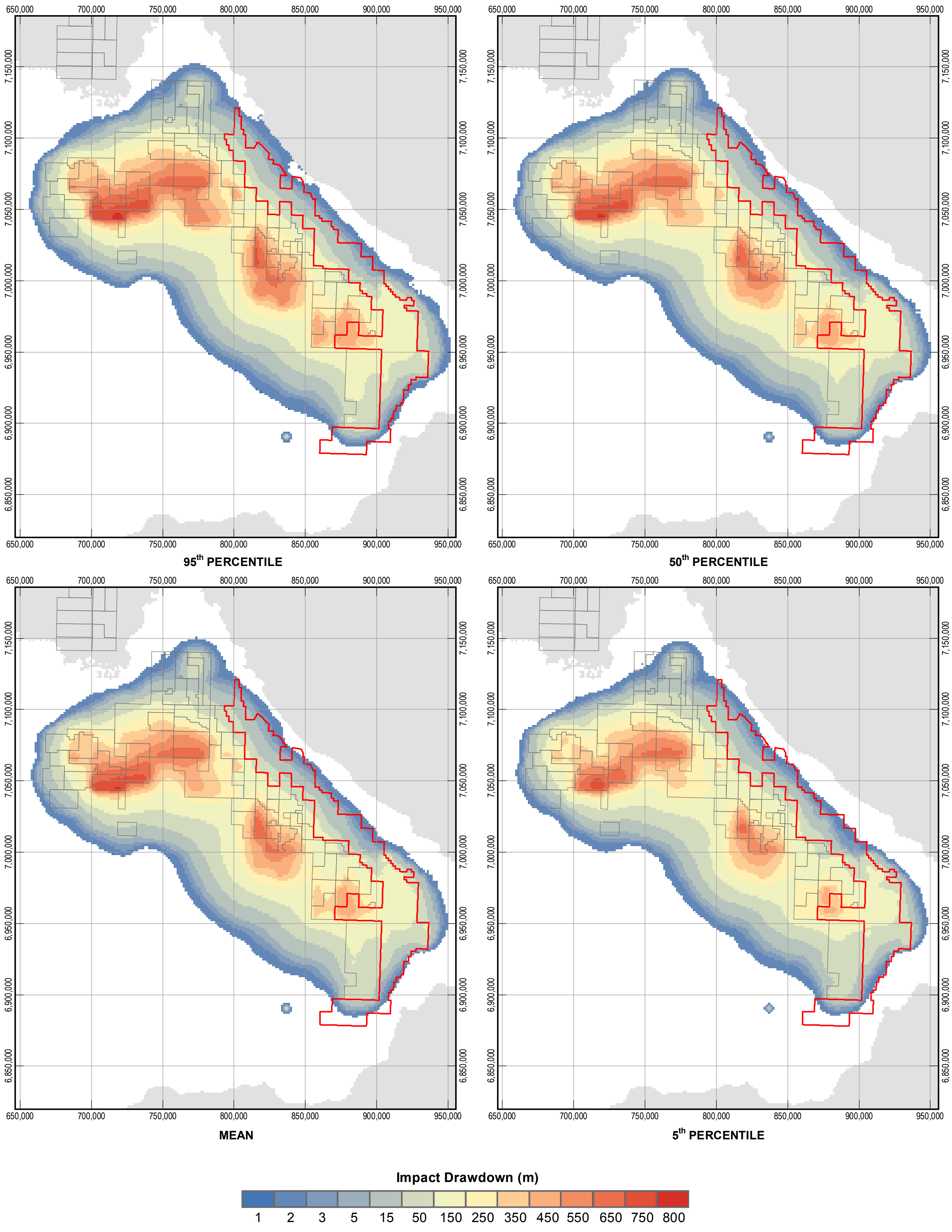
Job Number	41-26392
Revision	0
Date	18 Jun 2013

Figure 23

G:\41\26392\GIS\Maps\MXD\Fig 23_4126392_maxddn_Mean_Cumulative_lay7_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:afeeney



Paper Size A4

0 25 50 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Job Number	41-26392
Revision	0
Date	18 Jun 2013

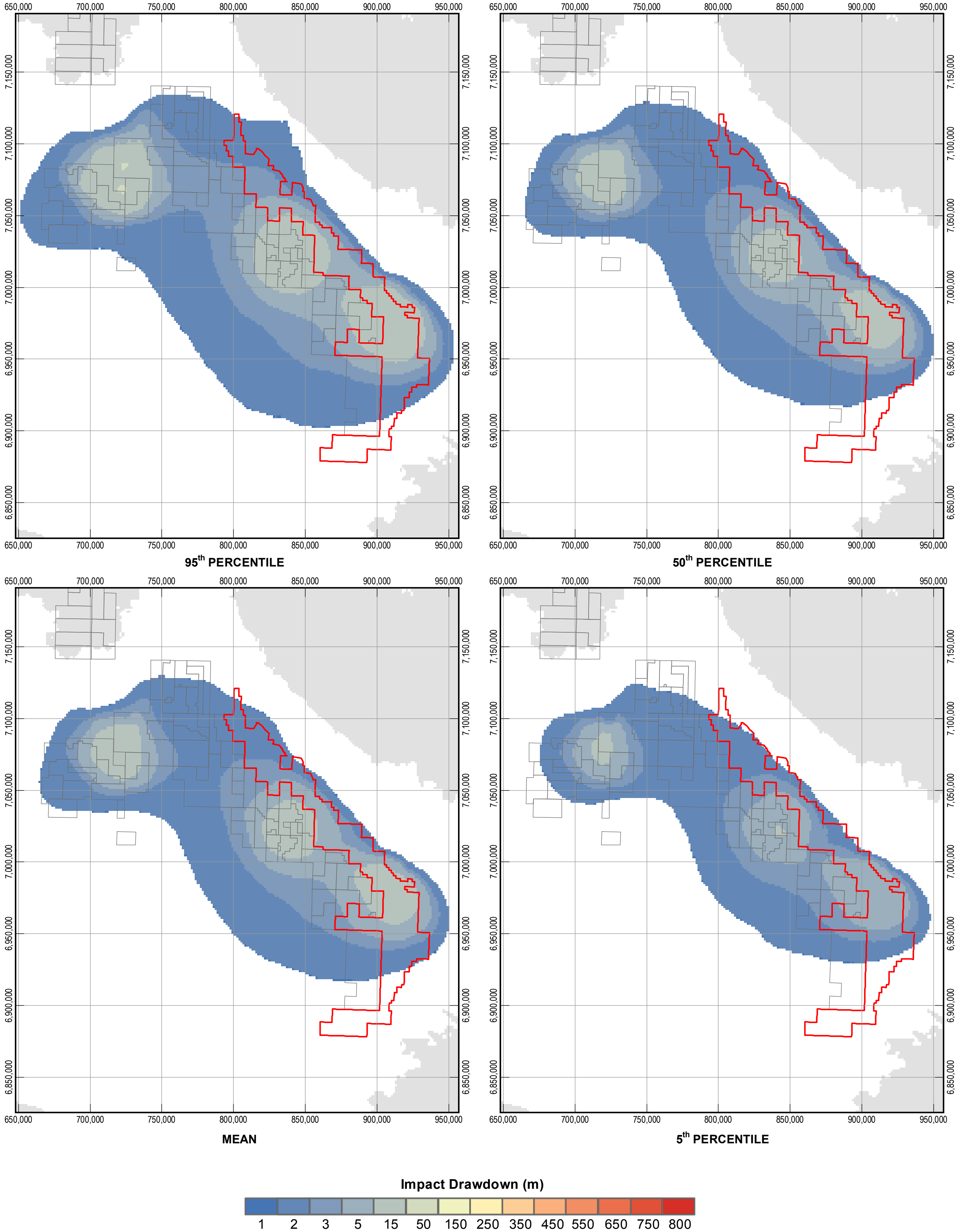
Predicted Cumulative Maximum Impact Drawdown, Walloon Coal Measures

Figure 24

G:\41\26392\GIS\Maps\MXD\Fig 24_4126392_maxddn_Mean_Cumulative_lay10_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:afeeney



Paper Size A4

0 25 50 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Job Number | 41-26392
Revision | 0
Date | 18 Jun 2013

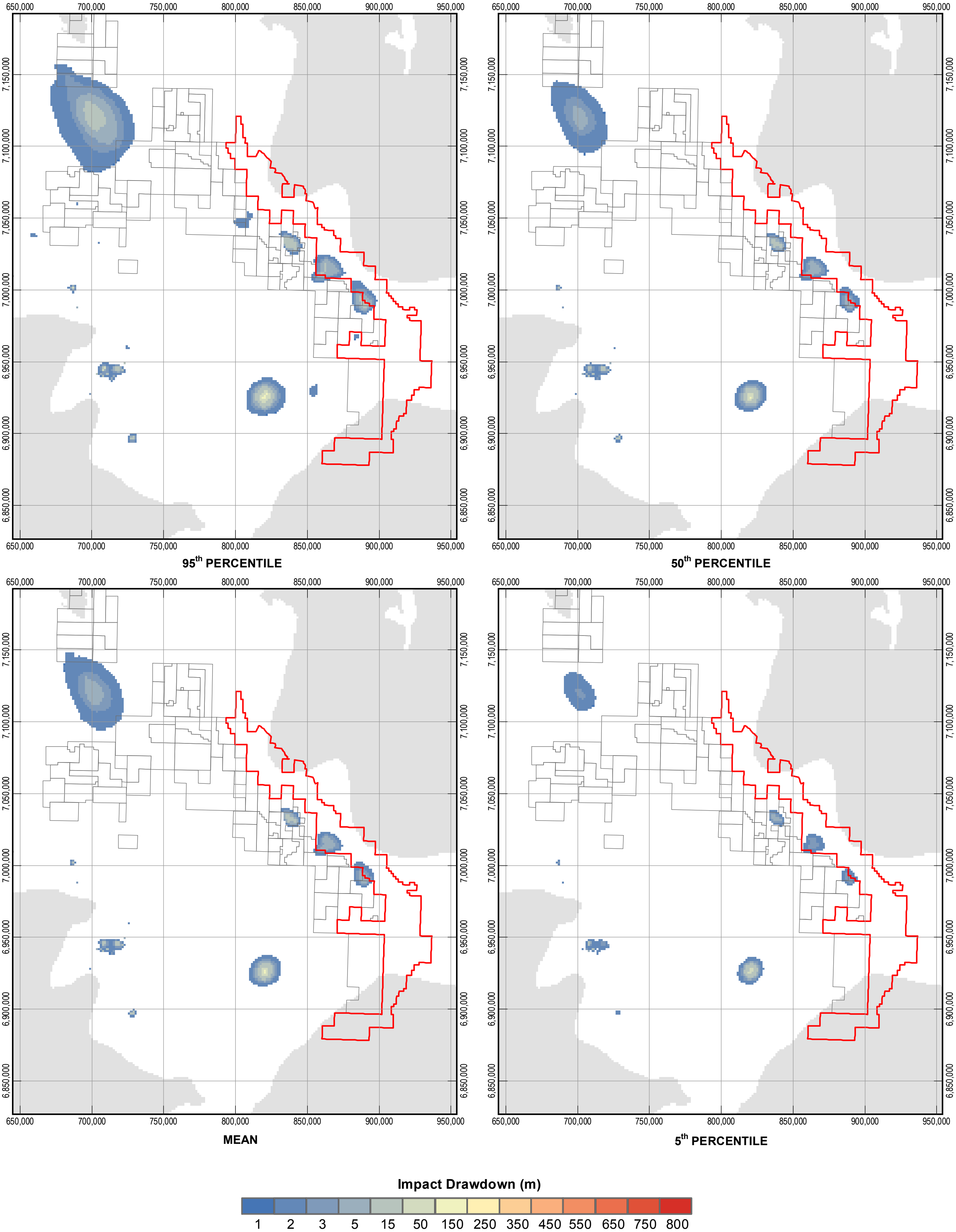
Predicted Cumulative Maximum Impact Drawdown, Hutton Sandstone

Figure 25

G:\41\26392\GIS\Maps\MXD\Fig 25_4126392_maxddn_Mean_Cumulative_lay12_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:afeeney



Paper Size A4

0 25 50 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Predicted Cumulative Maximum Impact Drawdown, Precipice Sandstone

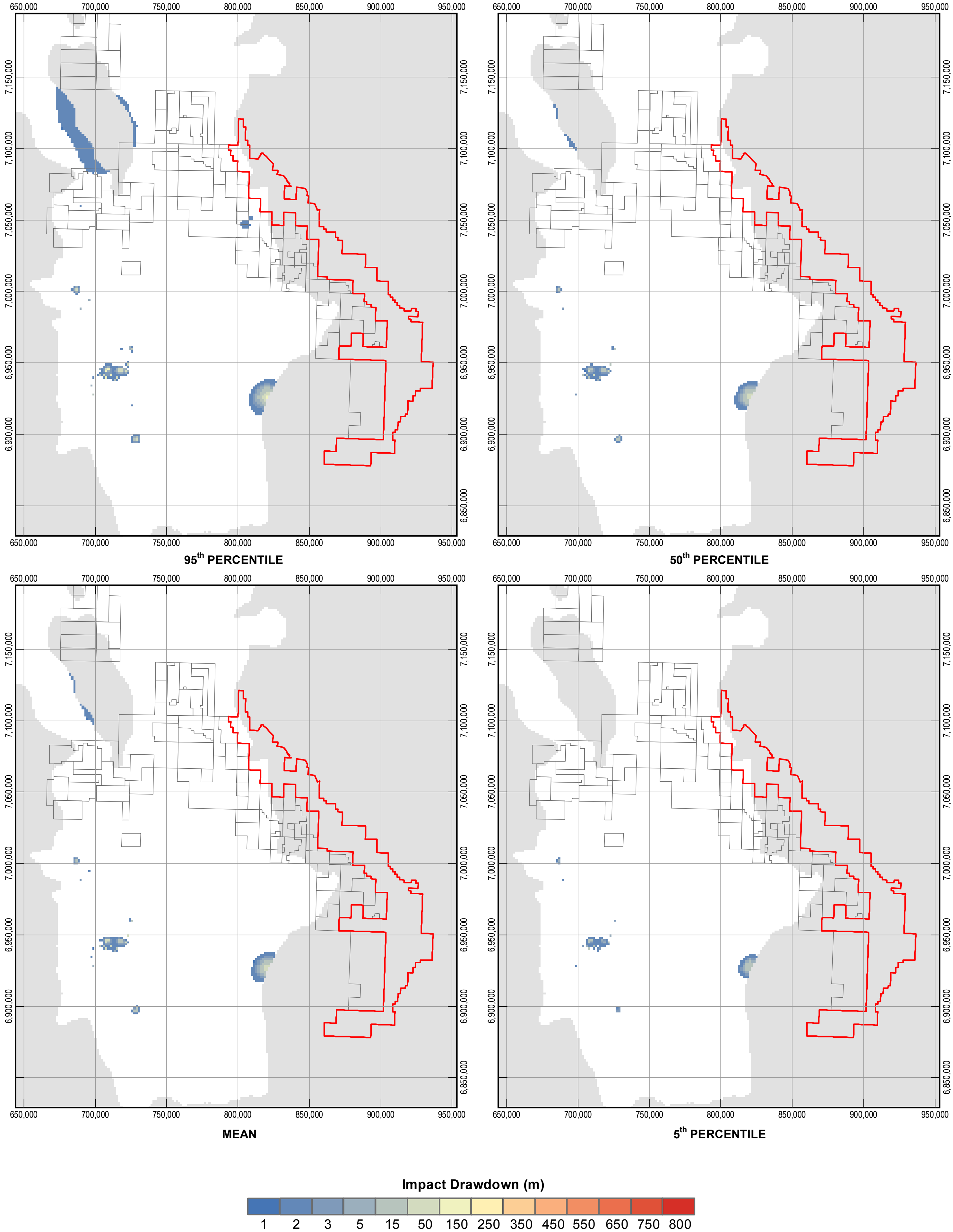
Job Number	41-26392
Revision	0
Date	18 Jun 2013

Figure 26

G:\41\26392\GIS\Maps\MXD\Fig 26_4126392_maxddn_Mean_Cumulative_lay14_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:afeeney



Paper Size A4
0 25 50 100
Kilometres
Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Predicted Cumulative Maximum Impact Drawdown, Clematis Sandstone

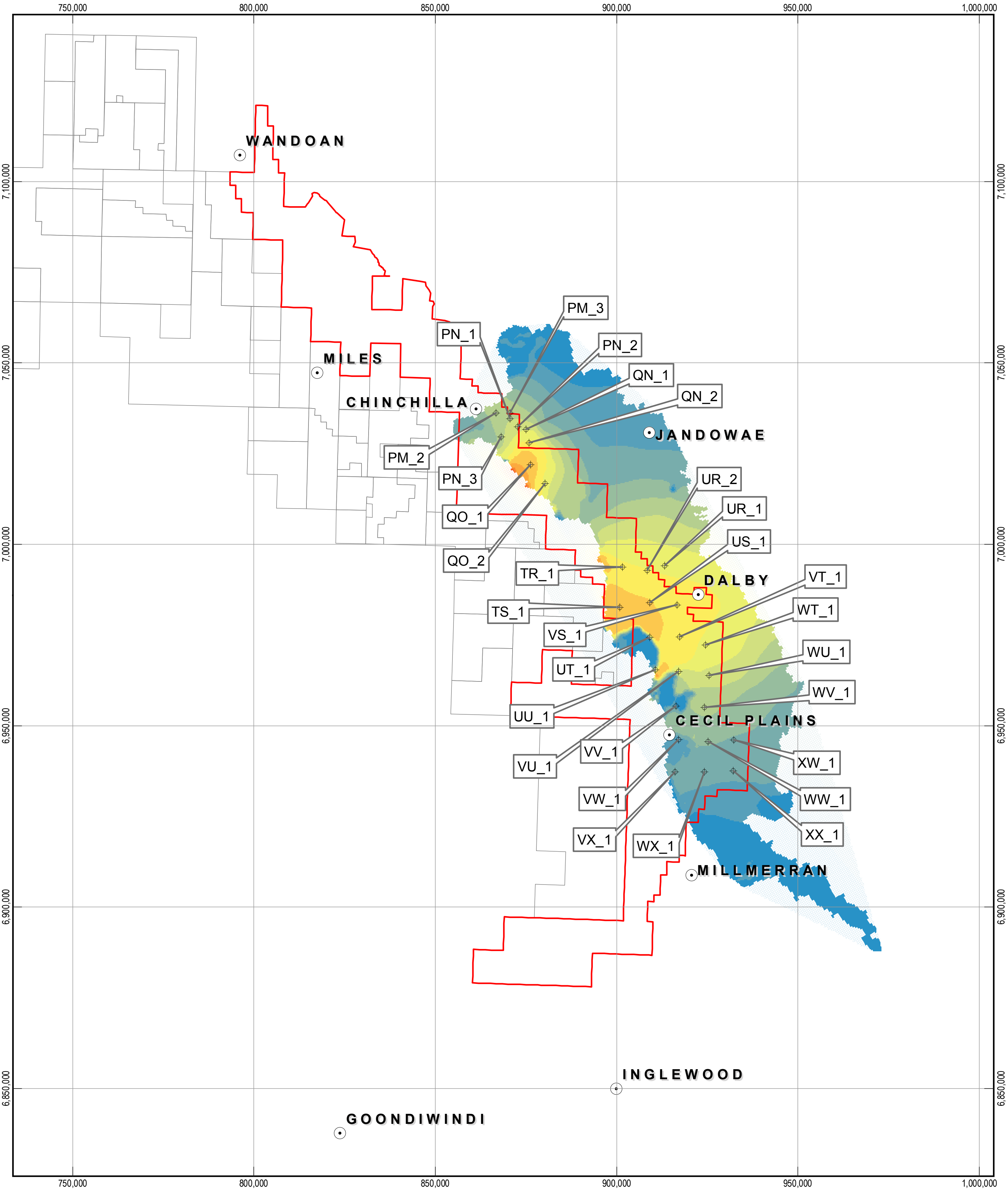
Job Number	41-26392
Revision	0
Date	18 Jun 2013

Figure 27

G:\41\26392\GIS\Maps\MXD\Fig 27_4126392_maxddn_Mean_Cumulative_lay16_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:afeeney



Hydrograph Locations

Impact Drawdown (m)

-0.2 -0.1 0.0 0.03 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3

Paper Size A4
0 5 10 20 30 40 50
Kilometres
Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Job Number 41-26392
Revision 0
Date 18 Jun 2013

Maximum Predicted Cumulative
Impact Drawdown, Condamine Alluvium

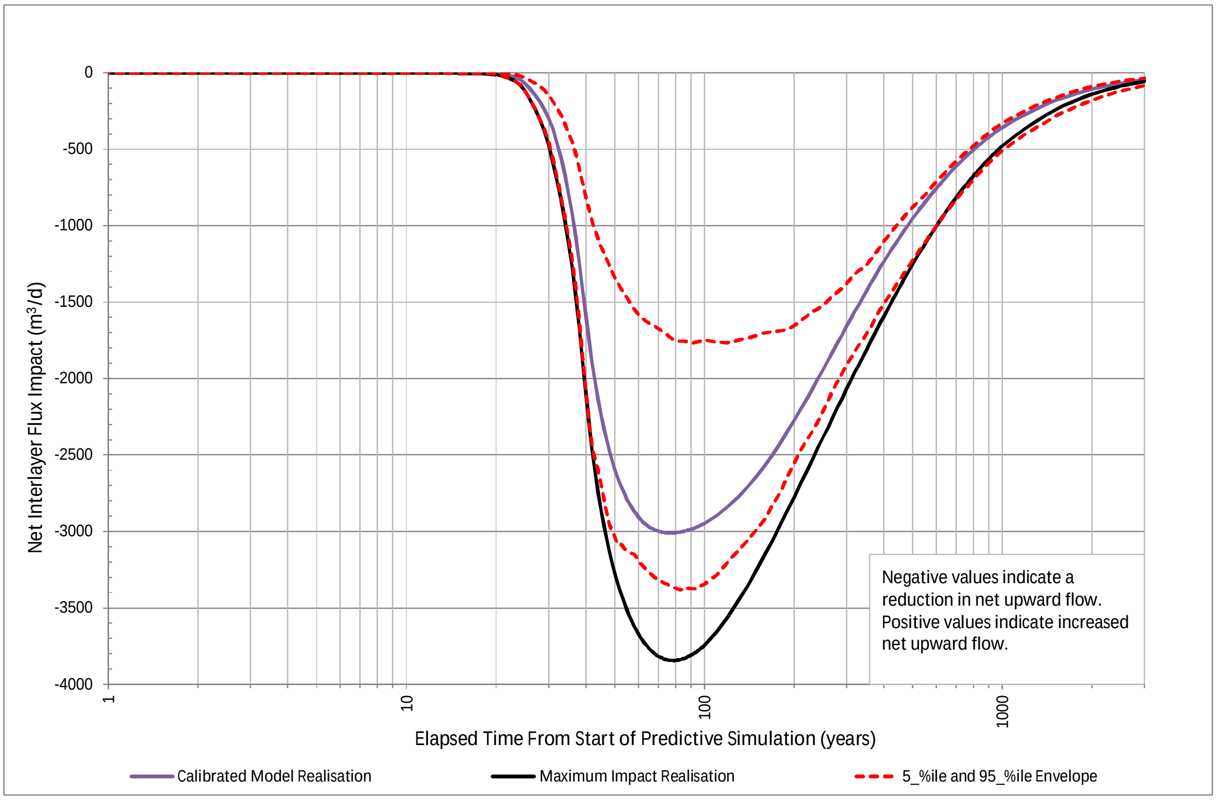
Figure 28

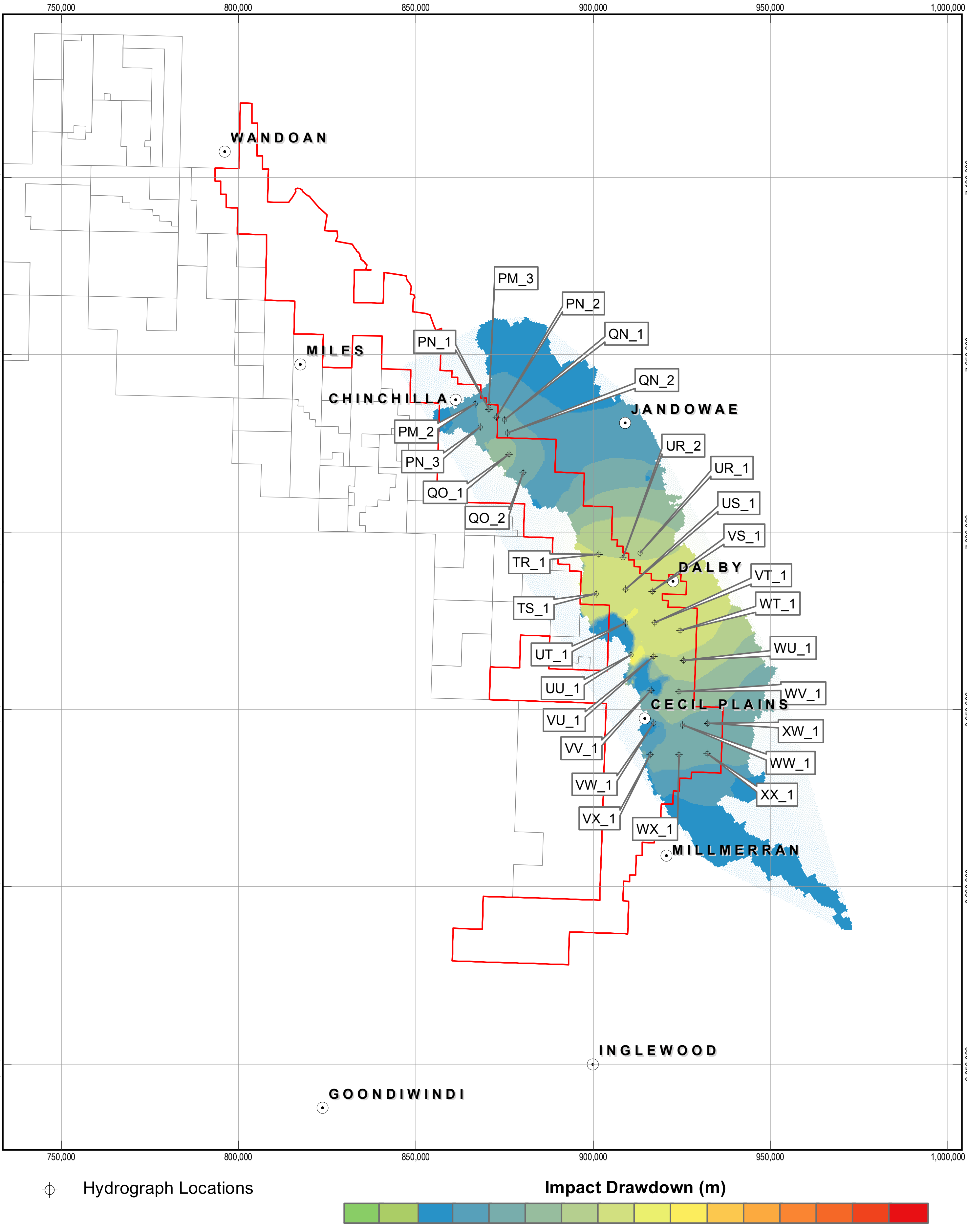
G:\41\26392\GIS\Maps\MXD\Fig 28_4126392_maxddn_Condamine_Cum_r69_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:mstanley

Figure 29 Interlayer Flux Cumulative Impact Envelopes, Condamine Alluvium





Paper Size A4

0 5 10 20 30 40 50

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Job Number	41-26392
Revision	0
Date	18 Jun 2013

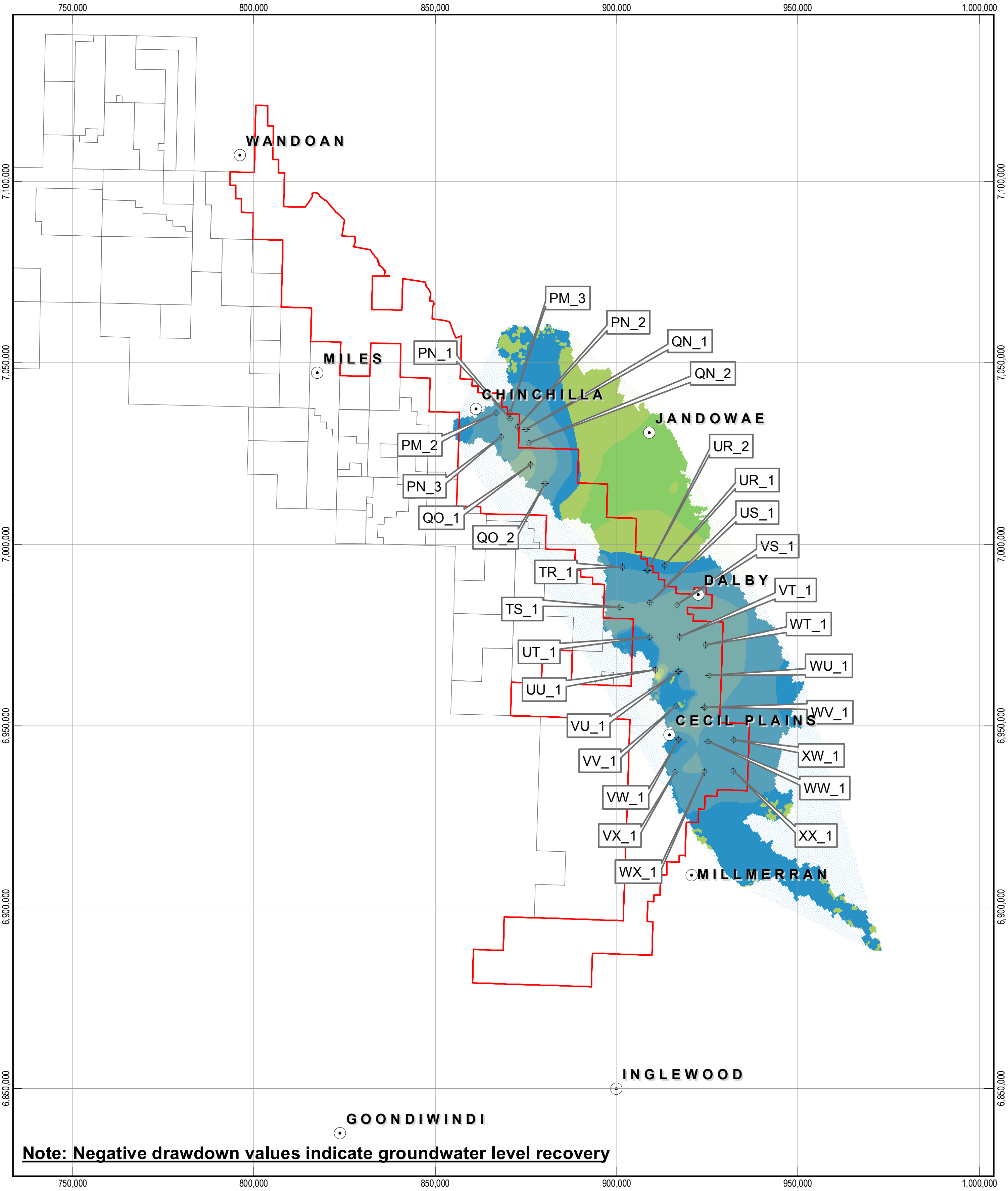
Predicted Arrow Surat Gas Project Drawdown
after 120 Years, Condamine Alluvium, Calibration Realisation

Figure 30

G:\41\26392\GIS\Maps\MXD\Fig 30_4126392_maxddn_Condamine_arrcase_rC_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:mstanley



Hydrograph Locations

Impact Drawdown (m)

-0.2 -0.1 0.0 0.03 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3

Paper Size A4

0 5 10 20 30 40 50

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Job Number 41-26392
Revision 0
Date 18 Jun 2013

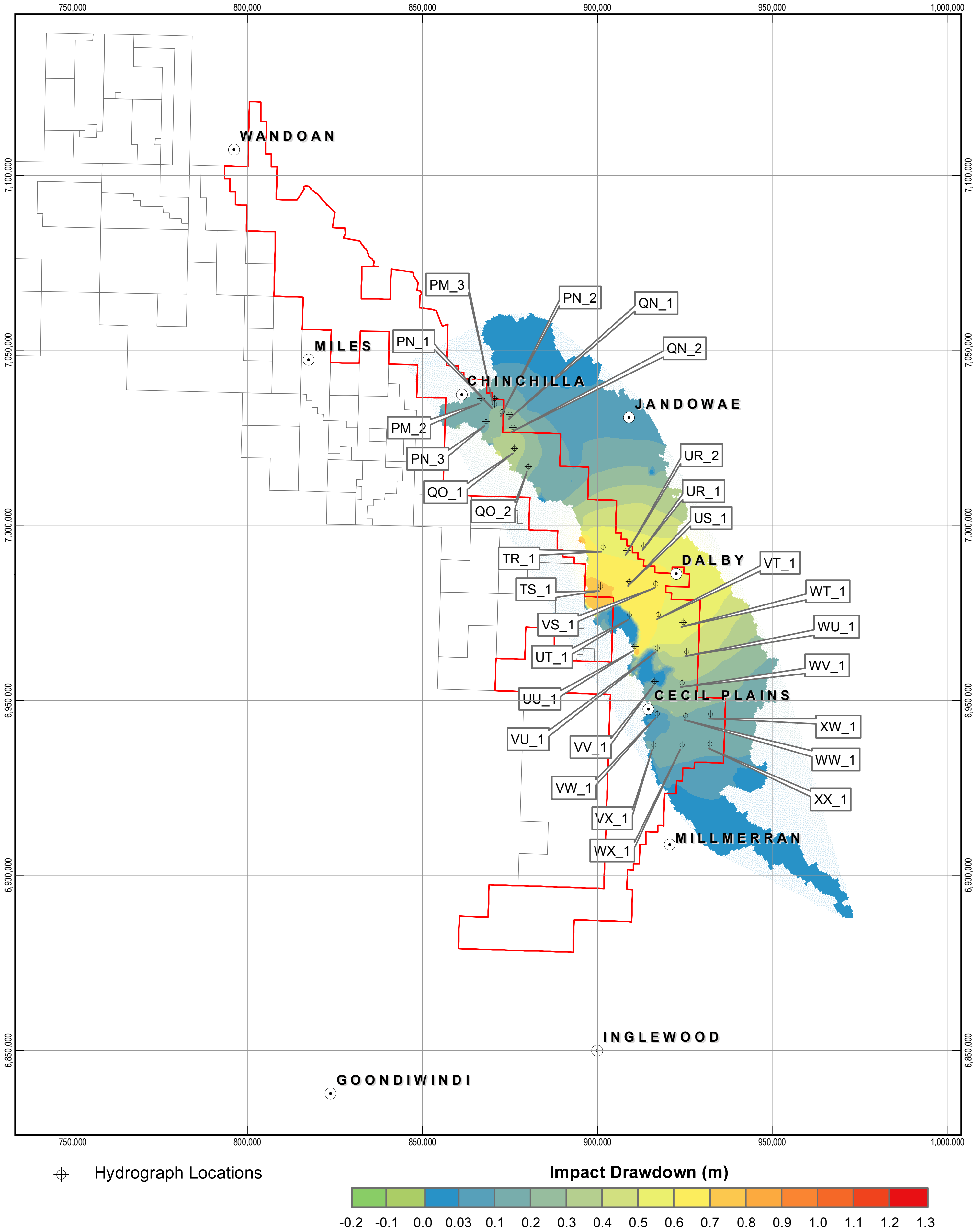
Predicted Arrow Surat Gas Project Impact Drawdown after 120 Years, Condamine Alluvium with Substitution, Calibration Realisation

Figure 31

G:\41\26392\GIS\Maps\MXD\Fig 31_4126392_maxddn_Condamine_arrcase_rC_mit_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:mstanley



Paper Size A4

0 5 10 20 30 40 50

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Job Number 41-26392
Revision 0
Date 18 Jun 2013

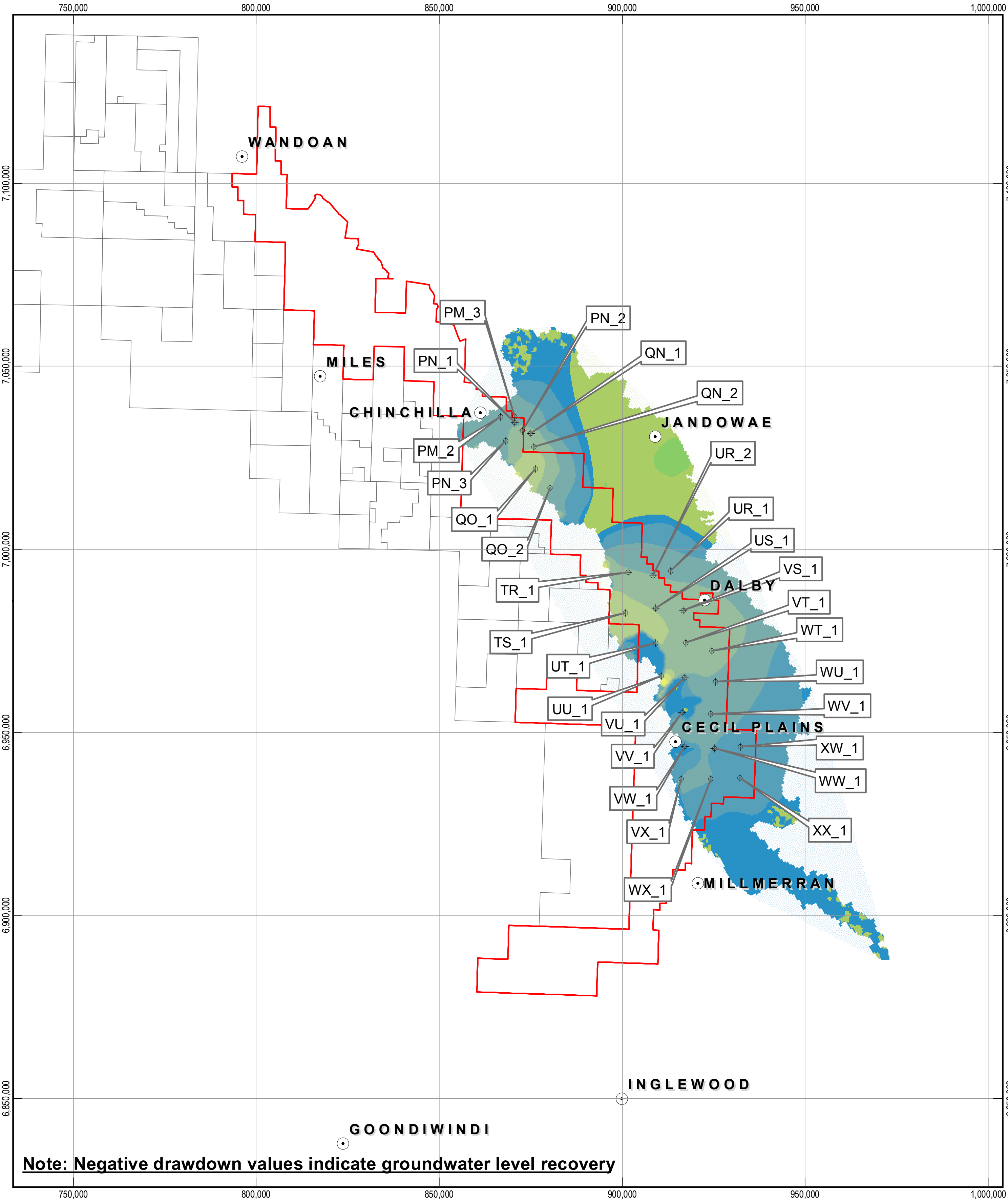
Predicted Cumulative Impact Drawdown
after 120 Years, Condamine Alluvium, Calibration Realisation

Figure 32

G:\41\26392\GIS\Maps\MXD\Fig 32_4126392_maxddn_Condamine_Cum_rC_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:mstanley



Hydrograph Locations

Impact Drawdown (m)

-0.2 -0.1 0.0 0.03 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3

Paper Size A4

0 5 10 20 30 40 50

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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Arrow Energy Surat Gas Project
Assessment of Regional Impacts

Predicted Cumulative Impact Drawdown after 120 Years, Condamine Alluvium with Substitution, Calibration Realisation

Job Number 41-26392
Revision 0
Date 18 Jun 2013

Figure 33

G:\41\26392\GIS\Maps\MXD\Fig 33_4126392_maxddn_Condamine_Cum_rC_mit_Rev0.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Modelled Cumulative Maximum Drawdown Statistics (2013) Created by:mstanley

Appendices

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Appendix A – Surat Cumulative Management Area Groundwater Modelling Report, May 2012, Figures

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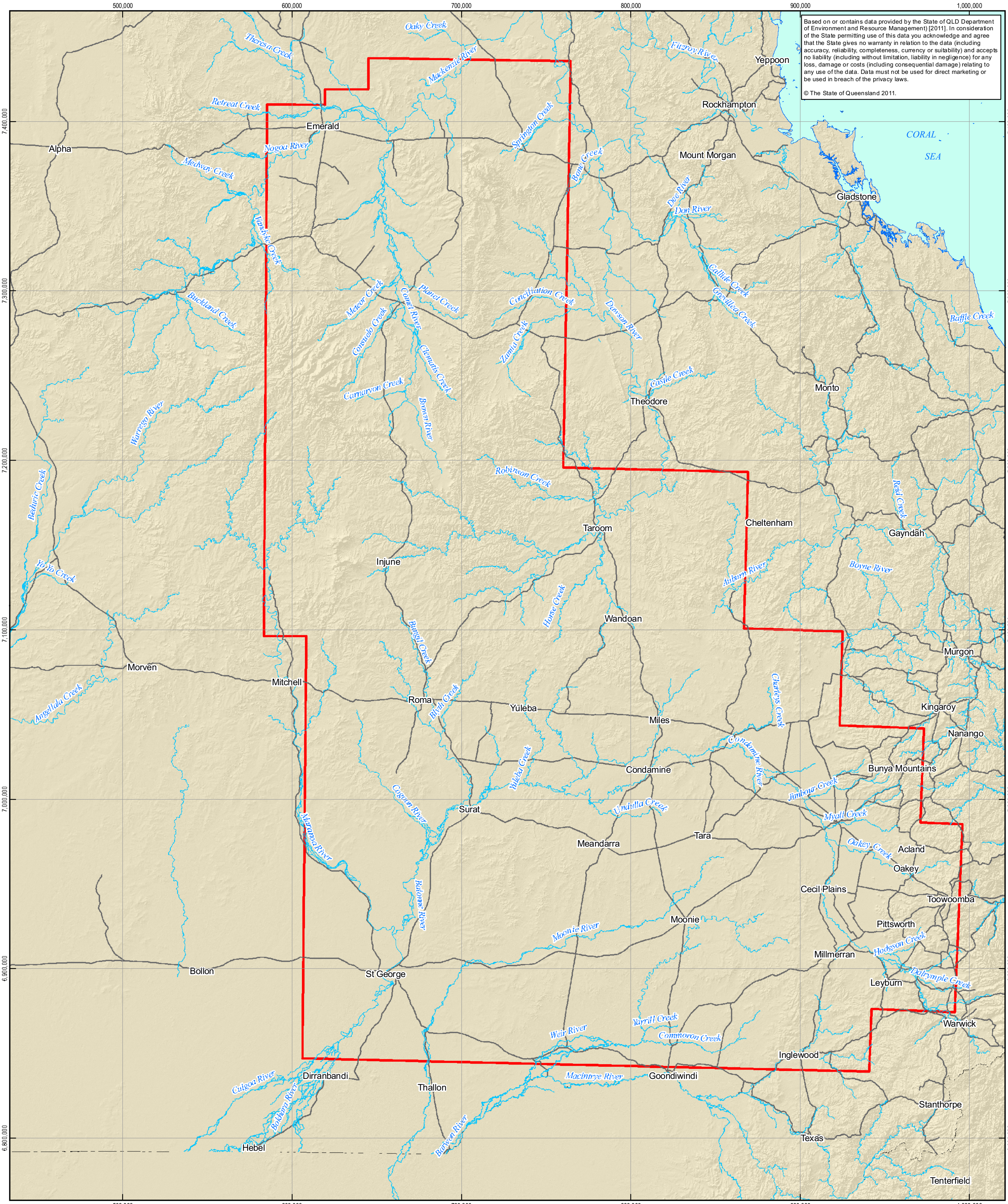

LEGEND

State Controlled Roads

Major Watercourses

Surat Cumulative Management Area

1:2,100,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Surat Cumulative Management Area Groundwater Model Report

Job Number	41-23918
Revision	0
Date	08 DEC 2011

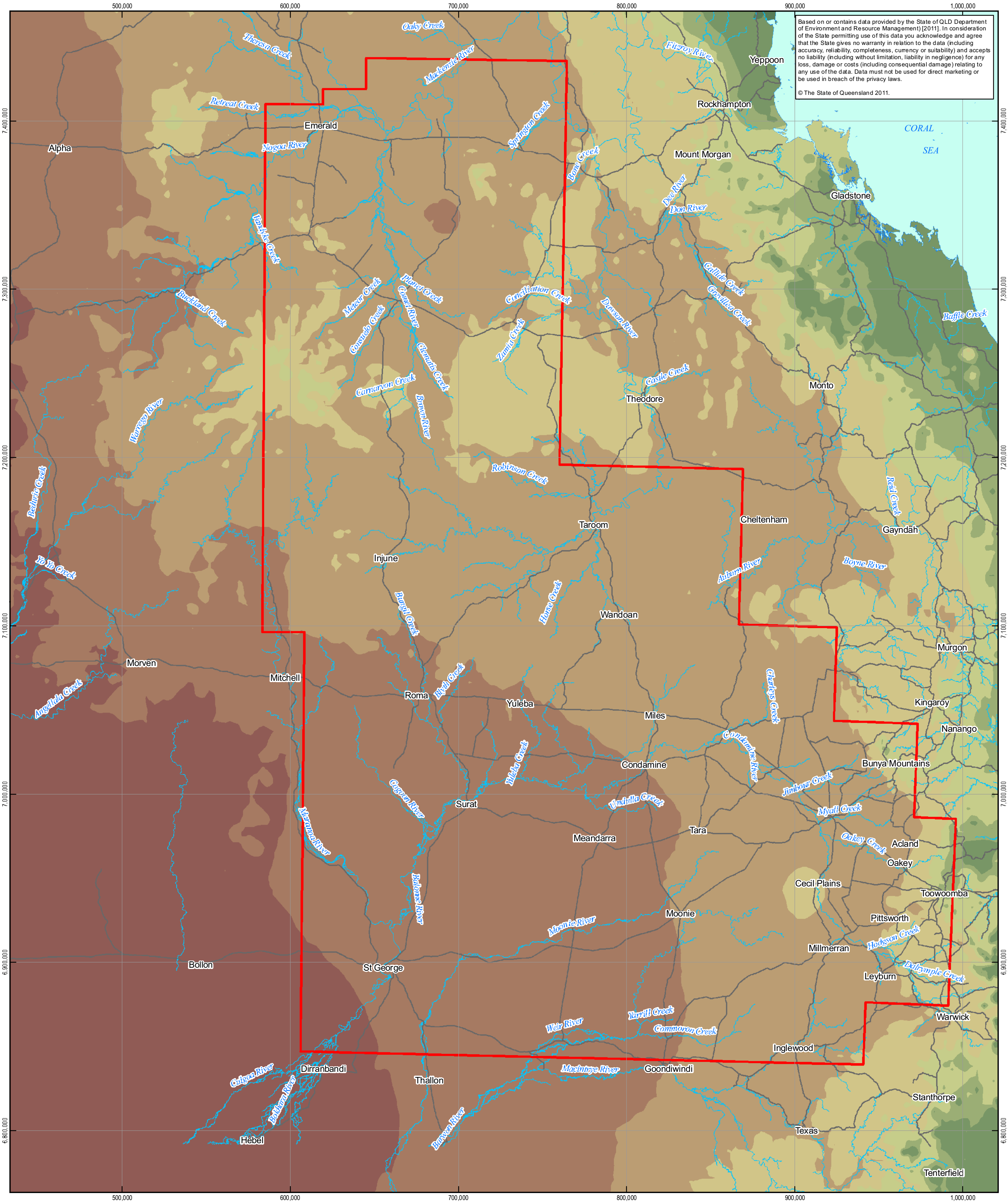
Study Area Locality Map

Figure 1

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_01.mxd

201 Charlotte Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: DERM - Waterways (2011). DTMR - State Controlled Roads (2010). Navteq - Place Names, Land Mass (2008). ESRI - SRTM (2009). GHD - Ocean, Surat Cumulative Management Area (2011). Created by: CM



LEGEND

State Controlled Roads	
Major Watercourses	
Surat Cumulative Management Area	

Average Rainfall (mm)

400 - 500	600 - 700	900 - 1000
500 - 600	700 - 800	1000 - 1500
	800 - 900	1500 - 2000

1:2,100,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Date	08 DEC 2011

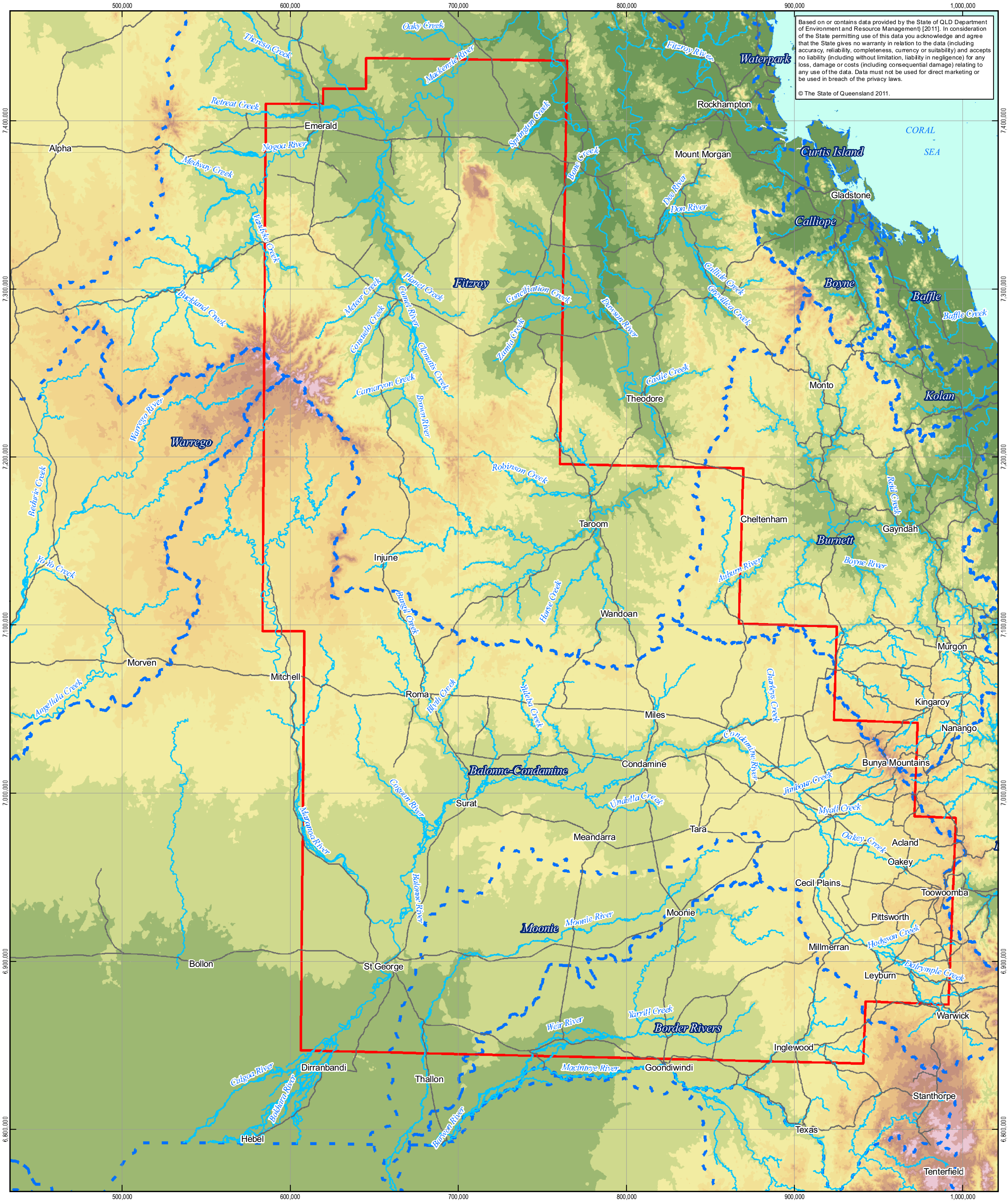
Long Term Average Rainfall

Figure 2

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_02.mxd

201 Charlotte Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: DERM - Waterways (2011). DTMR - State Controlled Roads (2011). Navteq - Place Names, Land Mass (2008). BOM - Average Rainfall (2007). GHD - Ocean, Surat Cumulative Management Area (2011). Created by: CM



LEGEND

- State Controlled Roads
- Major Watercourses
- Surat Cumulative Management Area
- Drainage Basins

Ground Elevation (Metres)

-12 - 100	400 - 500	700 - 800	1000 - 1500
100 - 200	500 - 600	800 - 900	1500 - 2000
200 - 300	600 - 700	900 - 1000	
300 - 400			

1:2,100,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Job Number 41-23918
Revision 0
Date 08 DEC 2011

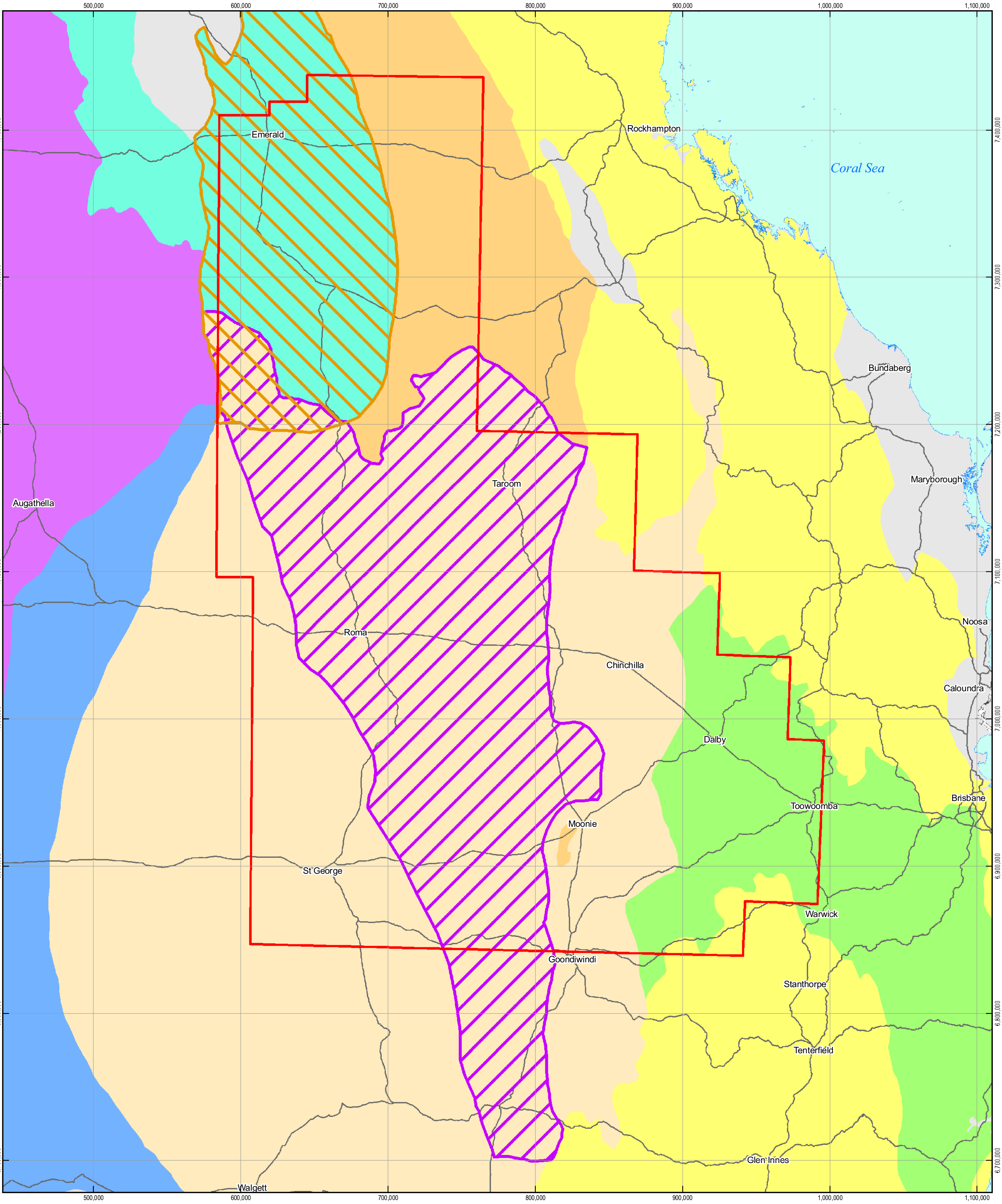
Main Rivers

Figure 3

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_03.mxd

201 Charlotte Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: DERM - Waterways, Drainage Basins (2011). DTMR - State Controlled Roads (2011). Navteq - Place Names, Land Mass (2008). GHD - Ocean, Surat Cumulative Management Area (2011). Created by: CM



LEGEND

- Major Roads
- Surat Cumulative Management Area
- Bowen Basin and Drummond Basin Overlap
- Surat Basin and Bowen Basin Overlap

Geological Basins

- No Data
- Bowen Basin
- Clarence-Moreton Basin
- Drummond Basin
- Eromanga Basin
- Galilee Basin
- New England Fold Belt
- Surat Basin

1:2,400,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Surat Cumulative Management Area Groundwater Model Report

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Revision 0
Date 08 DEC 2011

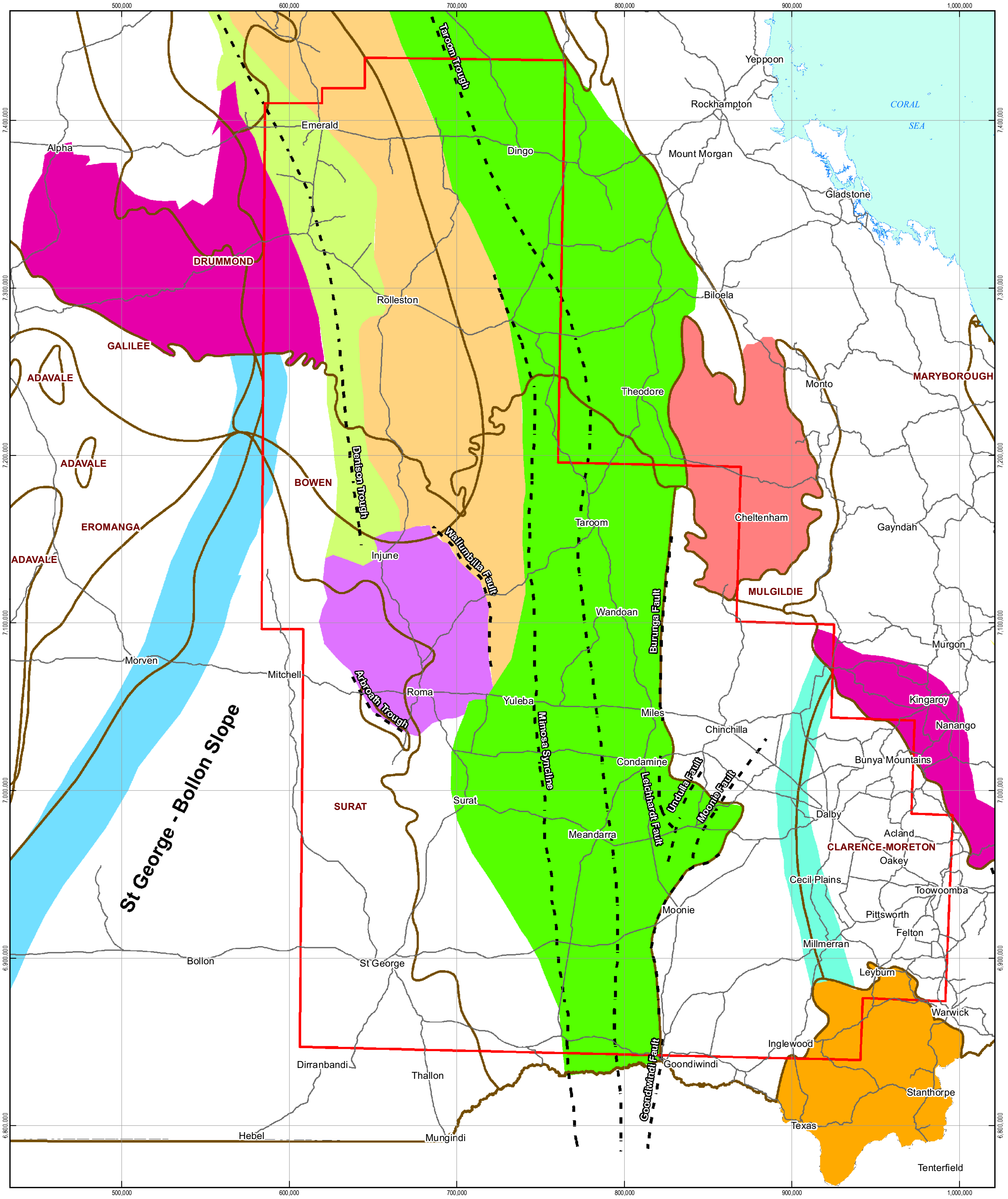
Geological Basin Boundaries

Figure 4

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_04.mxd

201 Charlotte Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: DTMR - State Controlled Roads (2010). Navteq - Place Names, Land Mass (2008). GA - Geological Basins. GHD - Ocean, Surat Cumulative Management Area V2 (2011). Created by: CM



LEGEND

- State Controlled Roads
- Geological Structures
- Surat Cumulative Management Area
- Sedimentary Basin Boundaries

Troughs

- Auburn Arch
- Comet Platform - Collinsville Shelf
- D'Aguilar Block
- Denison Trough
- Kumbarilla Ridge
- Nebine Ridge
- Roma Shelf
- Springsure Shelf
- Taroom Trough
- Texas Block
- Yarramin Block

1:2,100,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Date 26 MAR 2012

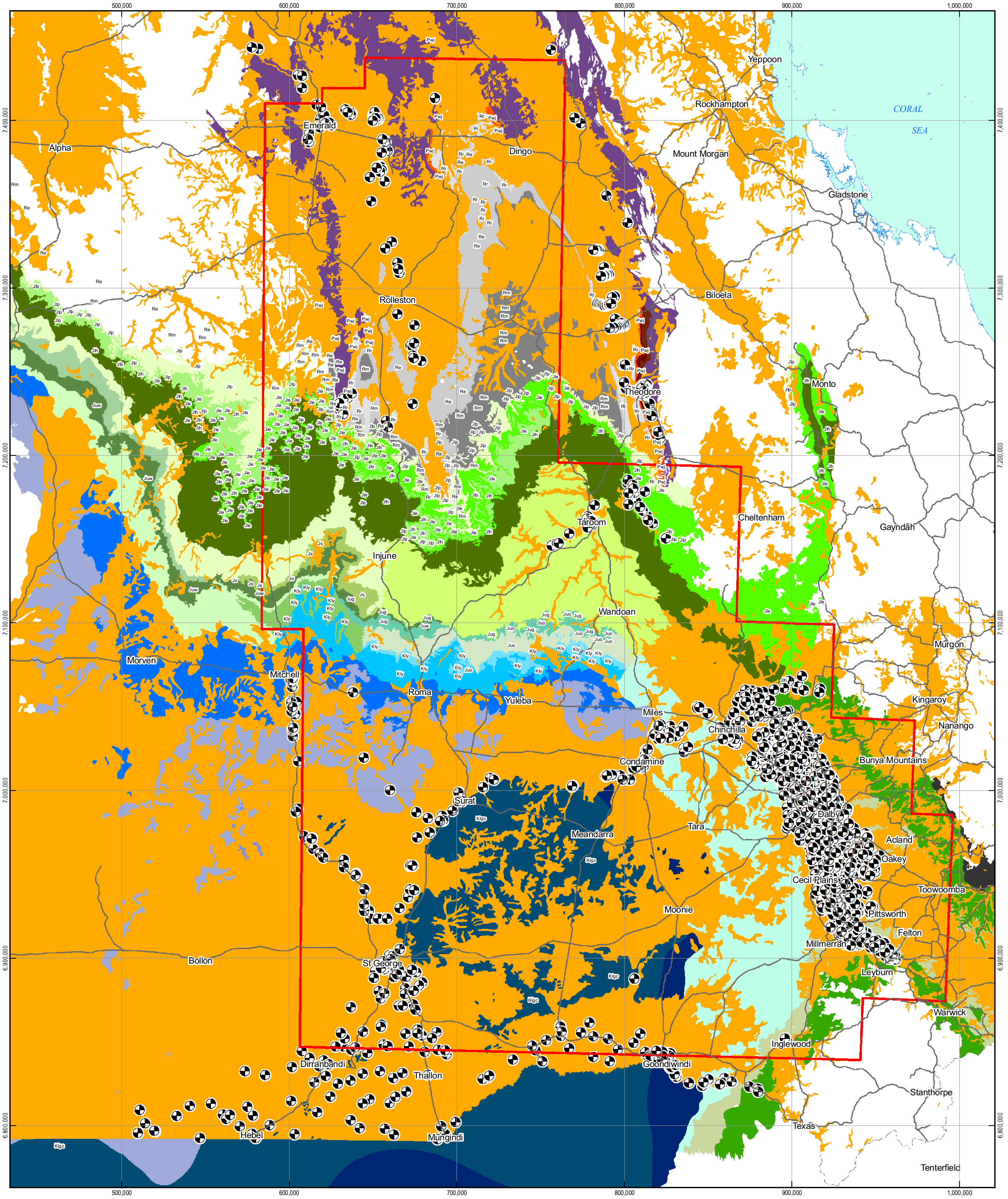
Geological Structures

Figure 5

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_05.mxd

201 Charlotte Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: DTMR - State Controlled Roads (2010). Navteq - Place Names, Land Mass (2008). GA - Geological Structures, Sedimentary Basin Boundaries, Troughs. GHD - Surat Cumulative Management Area, Ocean (2011). Created by: CM



LEGEND

- Boreholes used to Define Thickness of Superficial Deposits
- State Controlled Roads
- Surat Cumulative Management Area V2
- Quaternary and Tertiary Age Superficial Deposits

Cretaceous

- Griman Creek Formation (Klgc)
- Surat Siltstone
- Coreena Member
- Doncaster Member
- Wallumbilla Formation
- Bungil Formation (Kly)
- Mooga Sandstone
- Kumbarilla Beds

Jurassic

- Orallo Formation (Juo)
- Southlands Formation
- Hooray Sandstone
- Gubberamunda Sandstone (Jug)
- Westbourne Formation (Juw)
- Adori Sandstone
- Springbok Sandstone (Js)
- Birkhead Formation
- Walloon Coal Measures
- Injune Creek Beds
- Hutton Sandstone (Jlh)
- Evergreen Formation (Jle)
- Boxvale Sandstone Member
- Marburg Sandstone
- Precipice Sandstone (Jlp)

Triassic

- Helidon Sandstone - Woogaroo Subgroup

Triassic

- Moolayember Formation (Rm)
- Clematis Group (Re)
- Lower Clematis Group
- Rewan Formation (Rr)

Permian

- Kaloola Member
- Bandana Formation
- Pre-Bandana Age Units (inc Pwj)
- Wiseman Formation

1:2,100,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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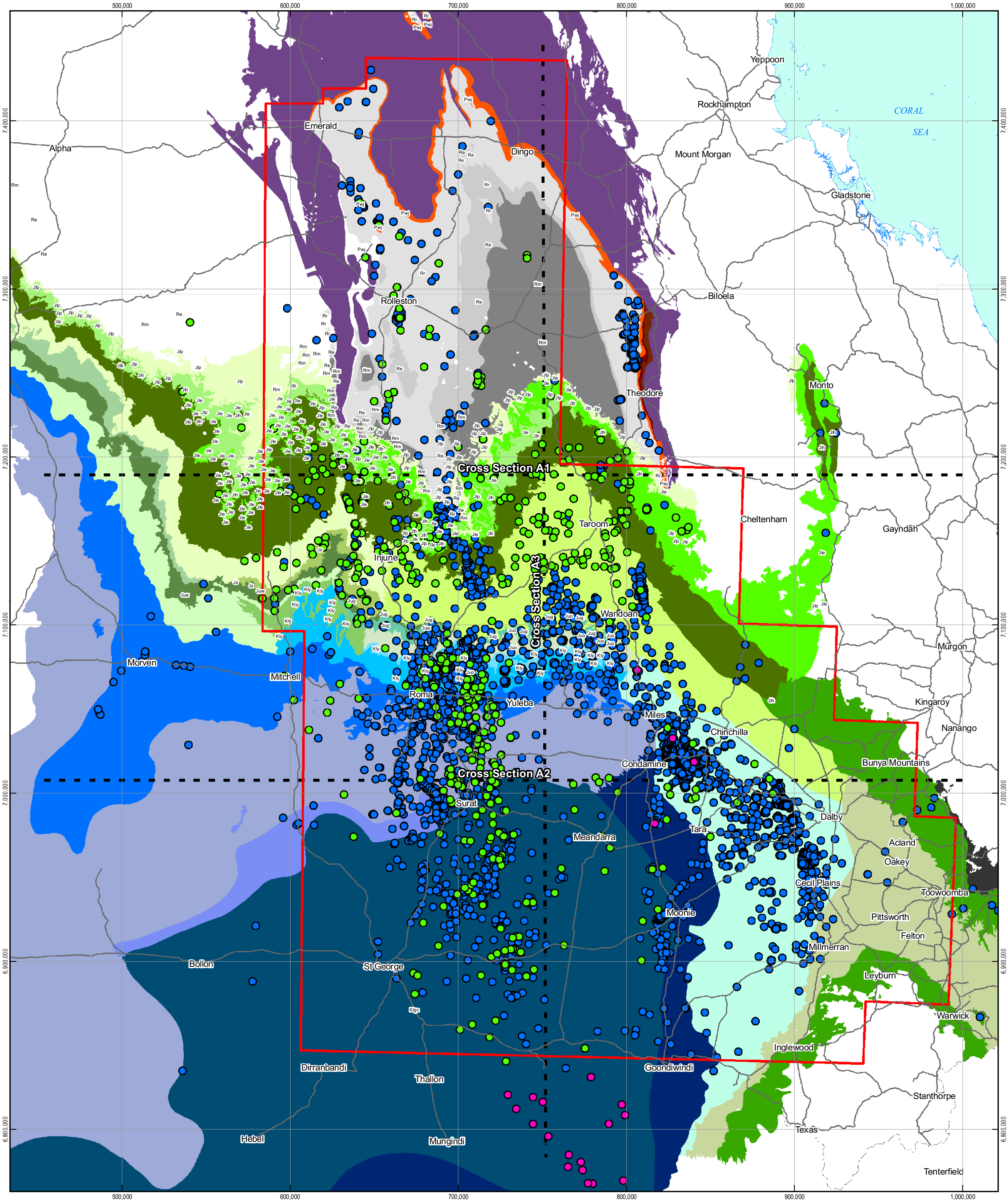
Outcrop Geology

Figure 6

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_06.mxd

201 Charlotte Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: DTMR - State Controlled Roads (2010). Navteq - Place Names, Land Mass (2008). GA - Bowen Geology, Surat Geology (2011). GA/GHD - Quaternary and Tertiary Age Superficial Deposits, Boreholes used to Define Thickness of Superficial Deposits (2011). GHD - Ocean, Surat Cumulative Management Area (2011). Created by: CM



LEGEND

- State Controlled Roads
- Surat Cumulative Management Area
- Vitrinite Bores
- Queensland Groundwater Database Bores
- QPED and CSG Company Bores
- Cross Sections

Cretaceous
- Griman Creek Formation (Klgc)
- Surat Siltstone
- Coreena Member
- Doncaster Member
- Wallumbilla Formation
- Bungil Formation (Kly)
- Mooga Sandstone
- Kumbarilla Beds

Jurassic
- Orallo Formation (Juo)
- Southlands Formation
- Hooray Sandstone
- Gubberamunda Sandstone (Jug)
- Westbourne Formation (Juw)
- Adori Sandstone
- Springbok Sandstone (Js)
- Birkhead Formation
- Walloon Coal Measures
- Injune Creek Beds
- Hutton Sandstone (Jlh)
- Evergreen Formation (Jle)
- Boxvale Sandstone Member
- Marburg Sandstone
- Precipice Sandstone (Jlp)

Triassic
- Helidon Sandstone - Woogaroo Subgroup

Triassic
- Moolayember Formation (Rm)
- Clematis Group (Re)
- Lower Clematis Group
- Rewan Formation (Rr)

Permian
- Kaloola Member
- Bandana Formation
- Pre-Bandana Age Units (inc Pwj)
- Wiseman Formation

1:2,100,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Solid Geology

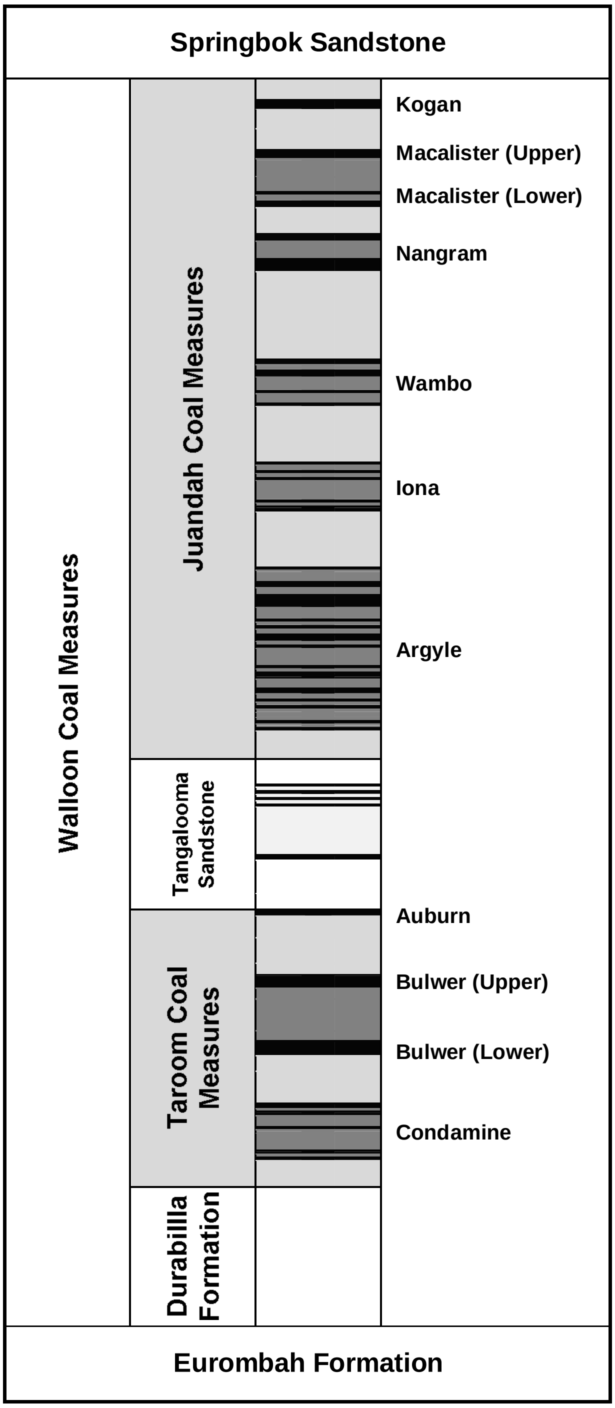
Figure 7

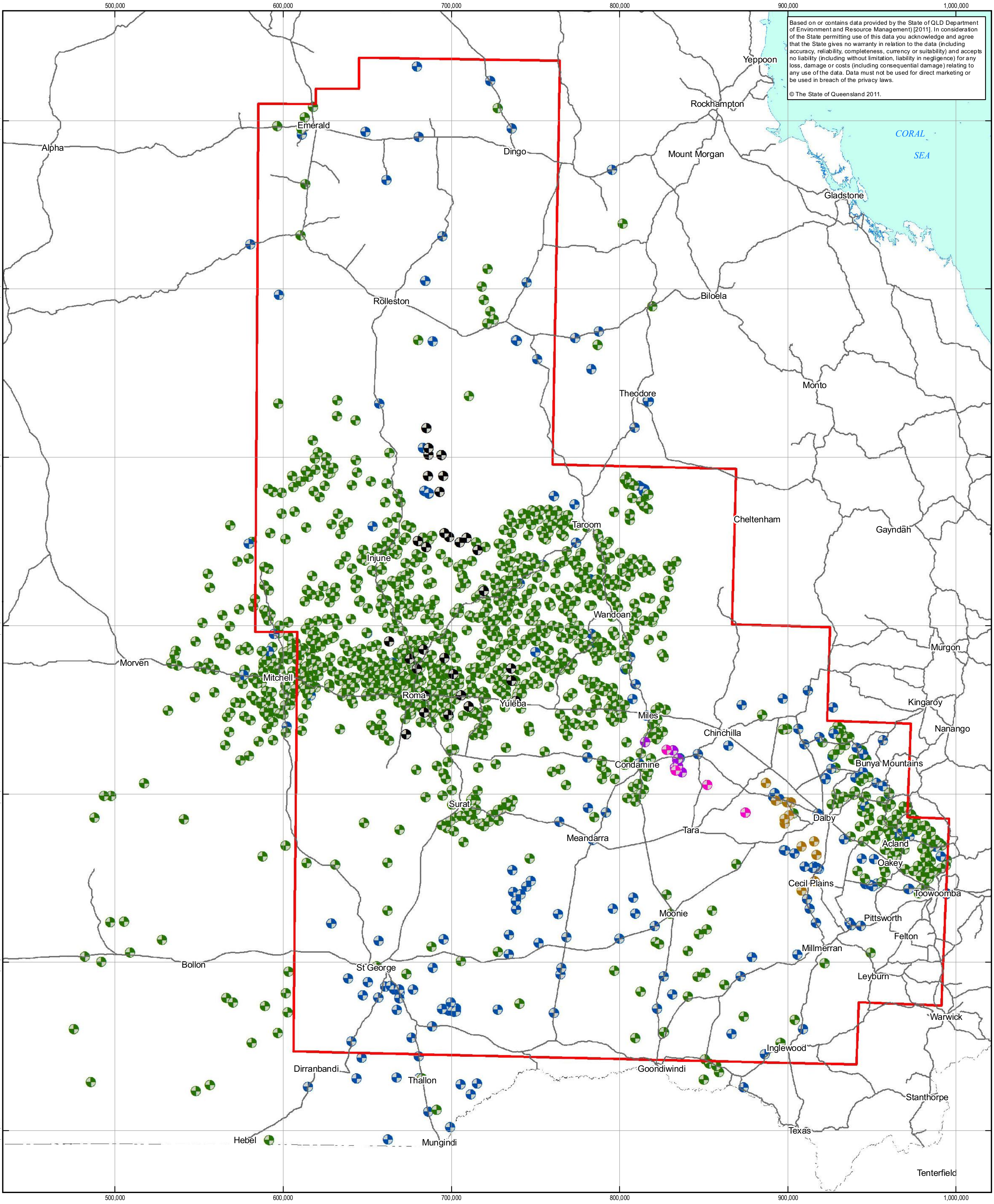
N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_07.mxd

201 Charlotte Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: DTMR - State Controlled Roads (2010). Navteq - Place Names, Land Mass (2008). Unknown - Vitrinite Bores, Queensland Groundwater Database Bores, QPED and CSG Company Bores (2011). GHD - Ocean, Surat Cumulative Management Area (2011). Created by: CM

Figure 8 Stratigraphy of the Walloon Coal Measures





LEGEND

- State Controlled Roads
- Surat Cumulative Management Area
- State Monitoring Network Bores
- Arrow Monitoring Bore
- Origin Monitoring Bore
- QGC Monitoring Bore
- Santos Monitoring Bore
- Other Registered Bores with Groundwater Level Data

1:2,100,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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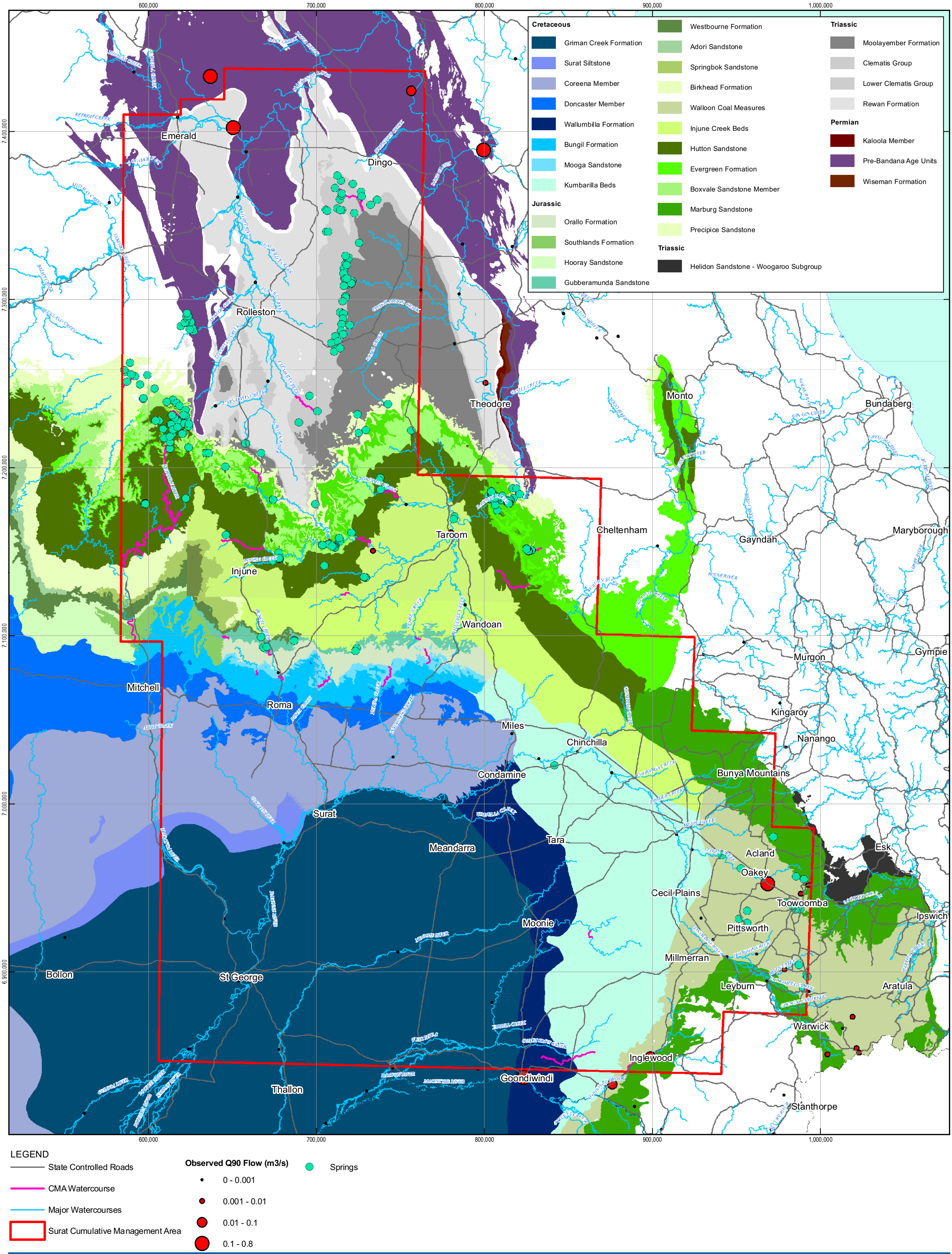
Groundwater Level Monitoring Boreholes

Figure 9

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_09.mxd

201 Charlotte Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: DTMR - State Controlled Roads (2010). Navteq - Place Names, Land Mass (2008). DERM/Origin/Arrow/QGC/Santos/DERM - Groundwater Level Monitoring Boreholes (2011). GHD - Surat Cumulative Management Area, Ocean (2011). Created by: CM



1:2,000,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Surat Cumulative Management Area Groundwater Model Report

Job Number	41-23918
Revision	0
Date	02 APR 2012

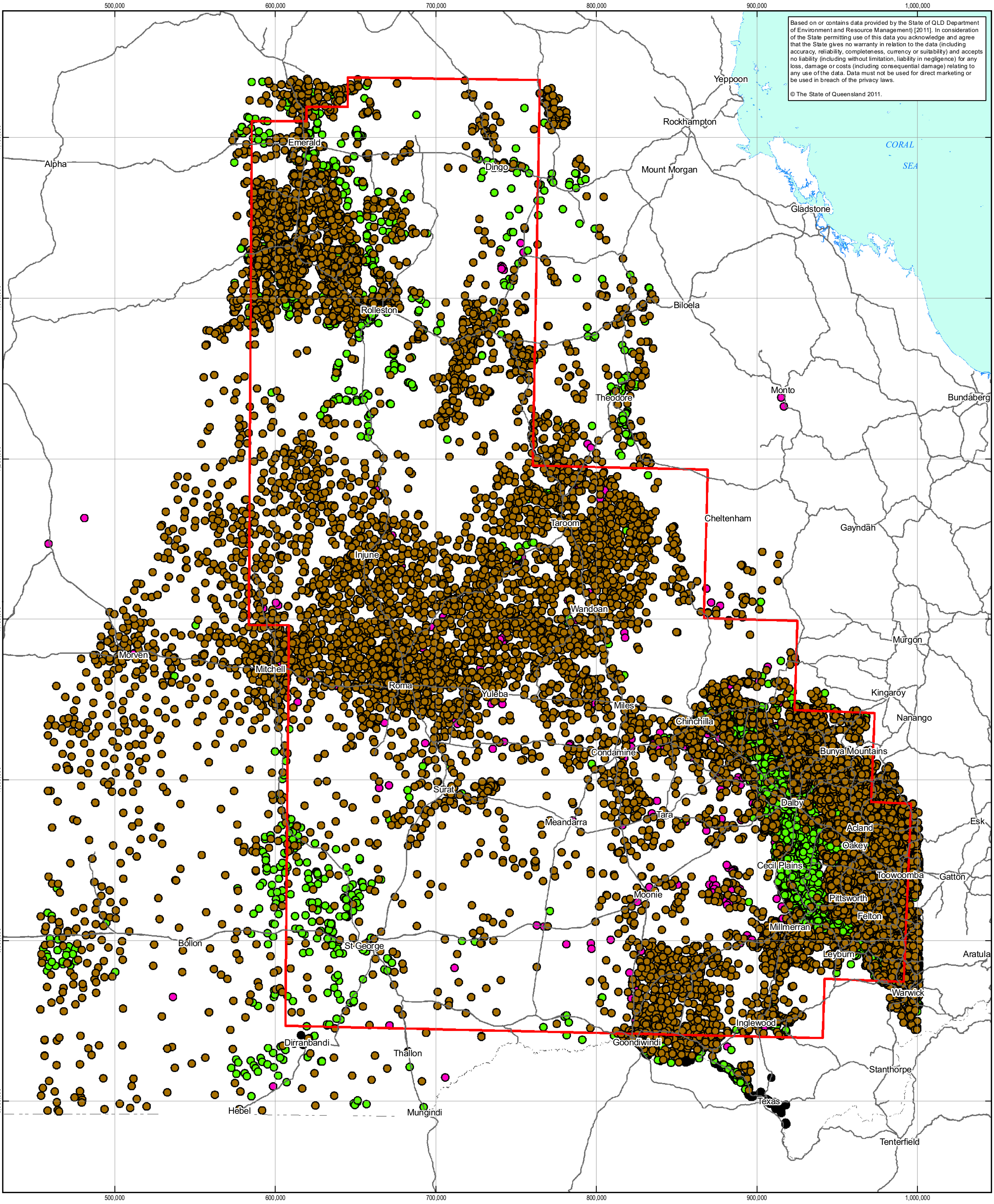
Surface Water Groundwater Interaction

Figure 10

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_11.mxd

201 Charlotte Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: DTMR - State Controlled Roads (2010). Navteq - Place Names, Land Mass (2008). DERM - Observed Q90 Flow (m3/s), Springs, CMA Watercourse (2011). Geoscience Australia - Bowen Geology, Surat Geology (2011). GHD - Ocean, Surat Cumulative Management Area (2011). Created by: CM



LEGEND

- State Controlled Roads
- Surat Cumulative Management Area
- Licensed Entitlements - Superficial Deposits
- Licensed Entitlements - Other Formations
- Stock & Domestic Extractions - Superficial Deposits
- Stock & Domestic Extractions - Other Formations

1:2,200,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Surat Cumulative Management Area Groundwater Model Report

Job Number 41-23918
Revision 0
Date 02 ARP 2012

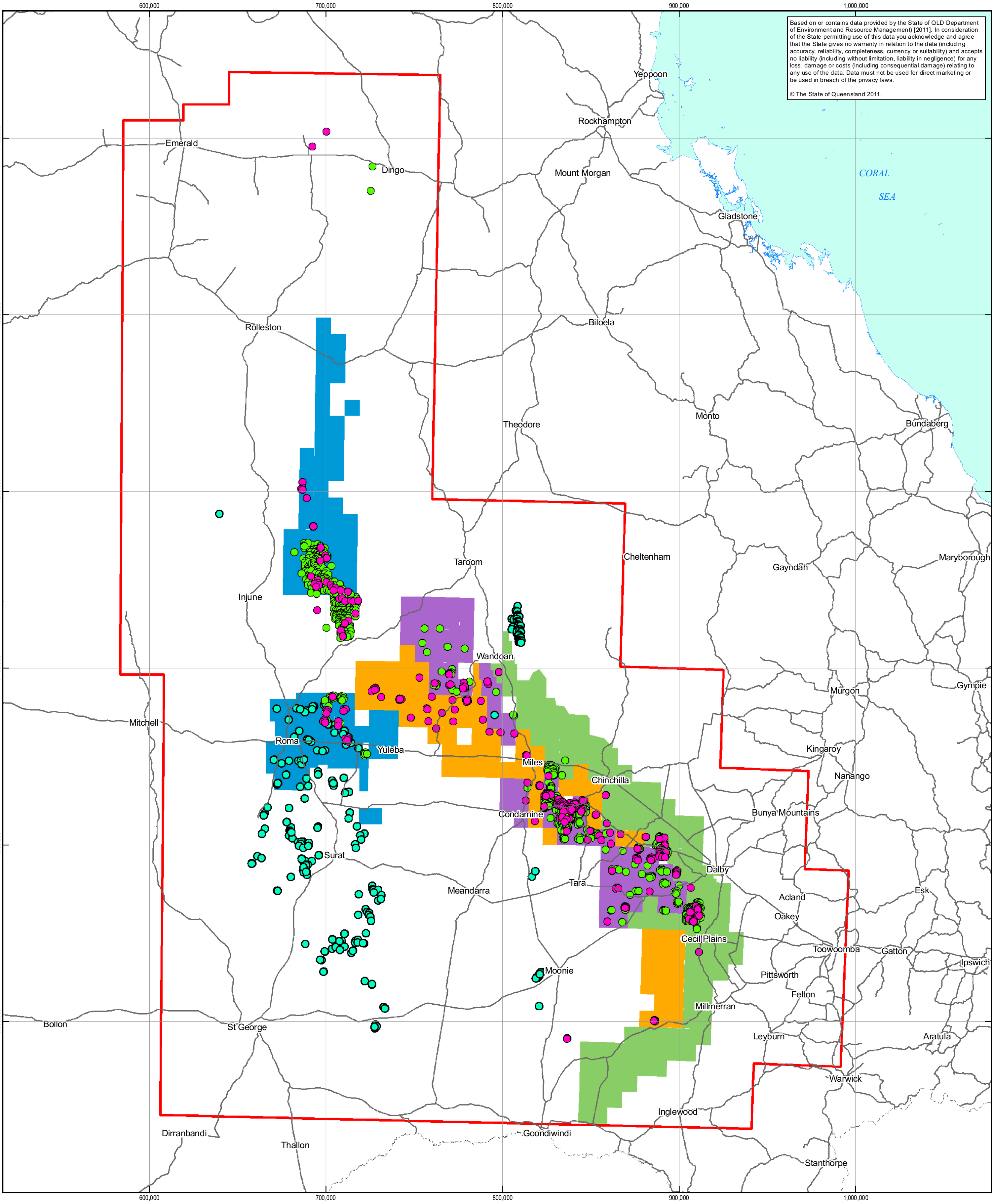
Groundwater Extractions

Figure 11

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_12.mxd

201 Charlotte Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: DTMR - State Controlled Roads (2010). Navteq - Place Names, Land Mass (2008). DERM - Stock & Domestic Extractions, Licensed Entitlements (2011). GHD - Ocean, Surat Cumulative Management Area (2011). Created by: CM



LEGEND

- State Controlled Roads
- Surat Cumulative Management Area
- Existing CSG Test Well
- Existing CSG Production Well
- Existing Conventional Gas Well

EIS CSG Tenements

- QGC
- APLNG
- Santos
- Arrow

1:2,000,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Surat Cumulative Management Area Groundwater Model Report

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Date	02 APR 2012

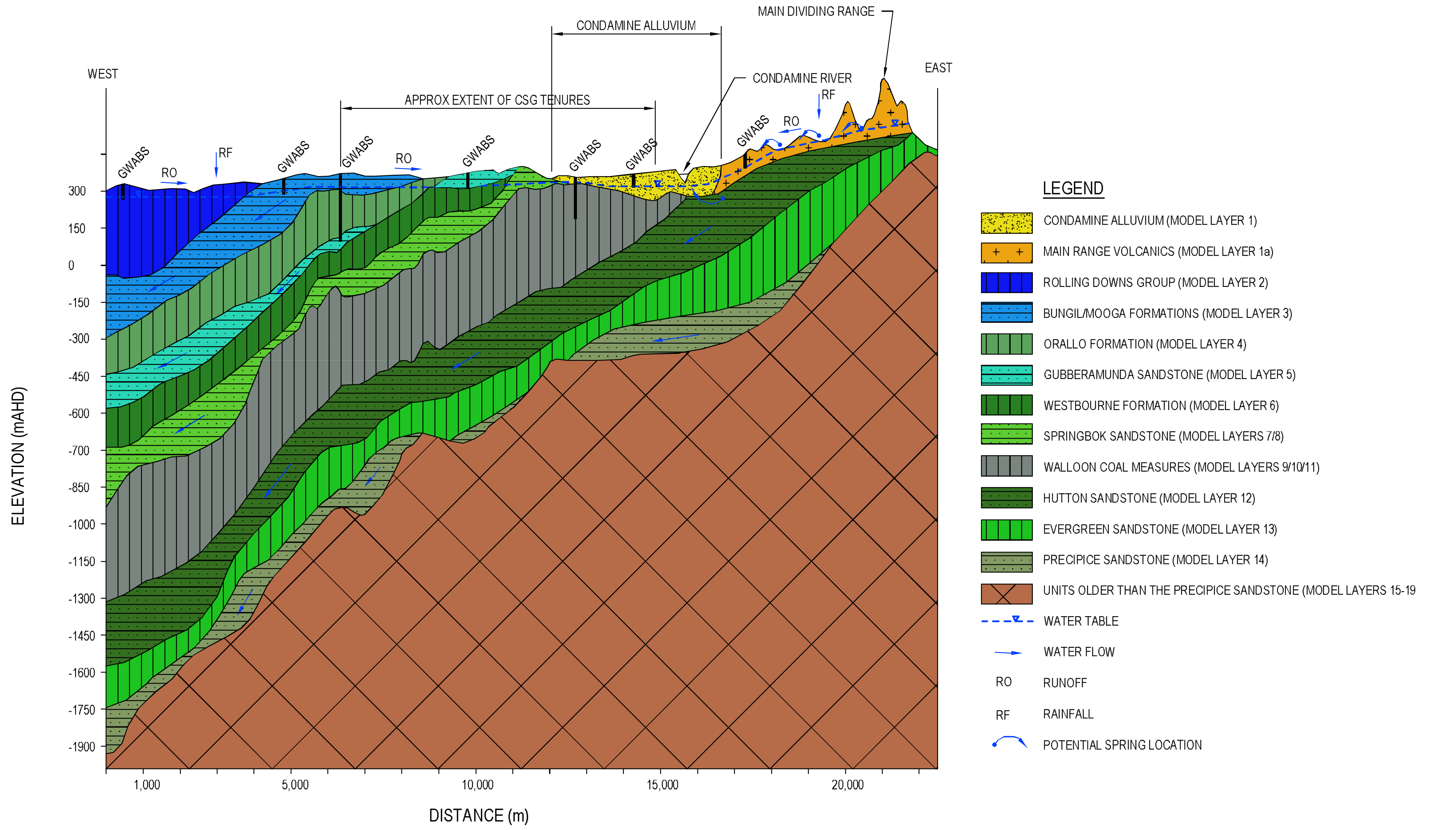
Existing Conventional and Coal Seam Gas Extractions

Figure 12

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_13.mxd

201 Charlotte Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: DTMR - State Controlled Roads (2010). Navteq - Place Names, Land Mass (2008). DERM - Coal Seam Gas Tenements, Existing CSG Test Wells, Existing CSG Production Wells, Existing Conventional Gas Wells (2011). GHD - Ocean, Surat Cumulative Management Area (2011). Created by: CM



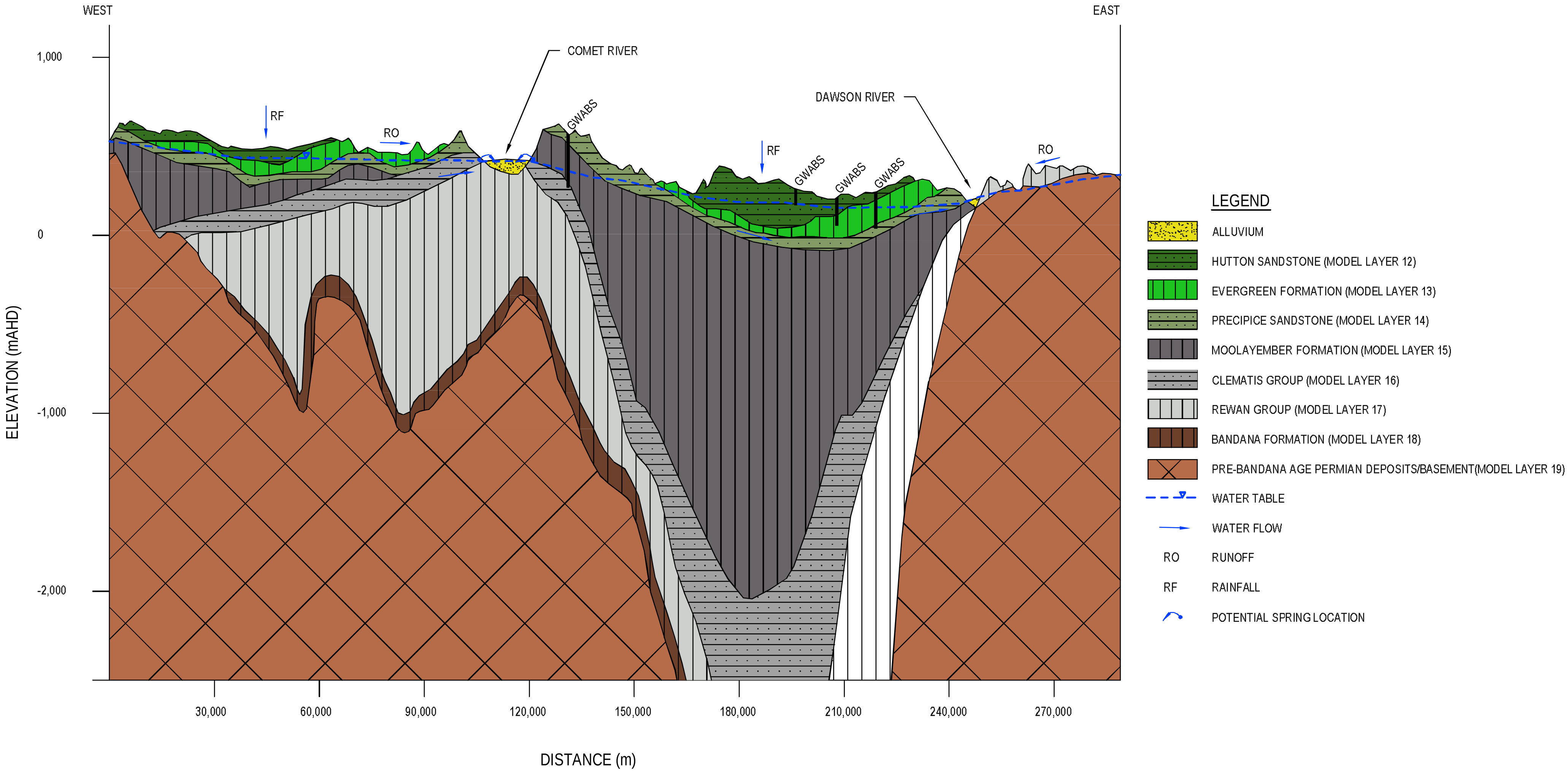
QUEENSLAND WATER COMMISSION
SURAT CUMULATIVE MANAGEMENT AREA
GROUNDWATER MODEL REPORT
CONCEPTUAL MODEL SURAT BASIN

Job Number	41-23918-12
Revision	A
Date	NOV 2011

Figure 13

Level 4, 201 Charlotte St Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Plot Date: 4 April 2012 - 9:49 AM Plotted by: Leanne S Martin/Brisbane/GHD/AU Cad File No: G:\41\23918\CADD\Drawings\41-23918-FIG13.dwg



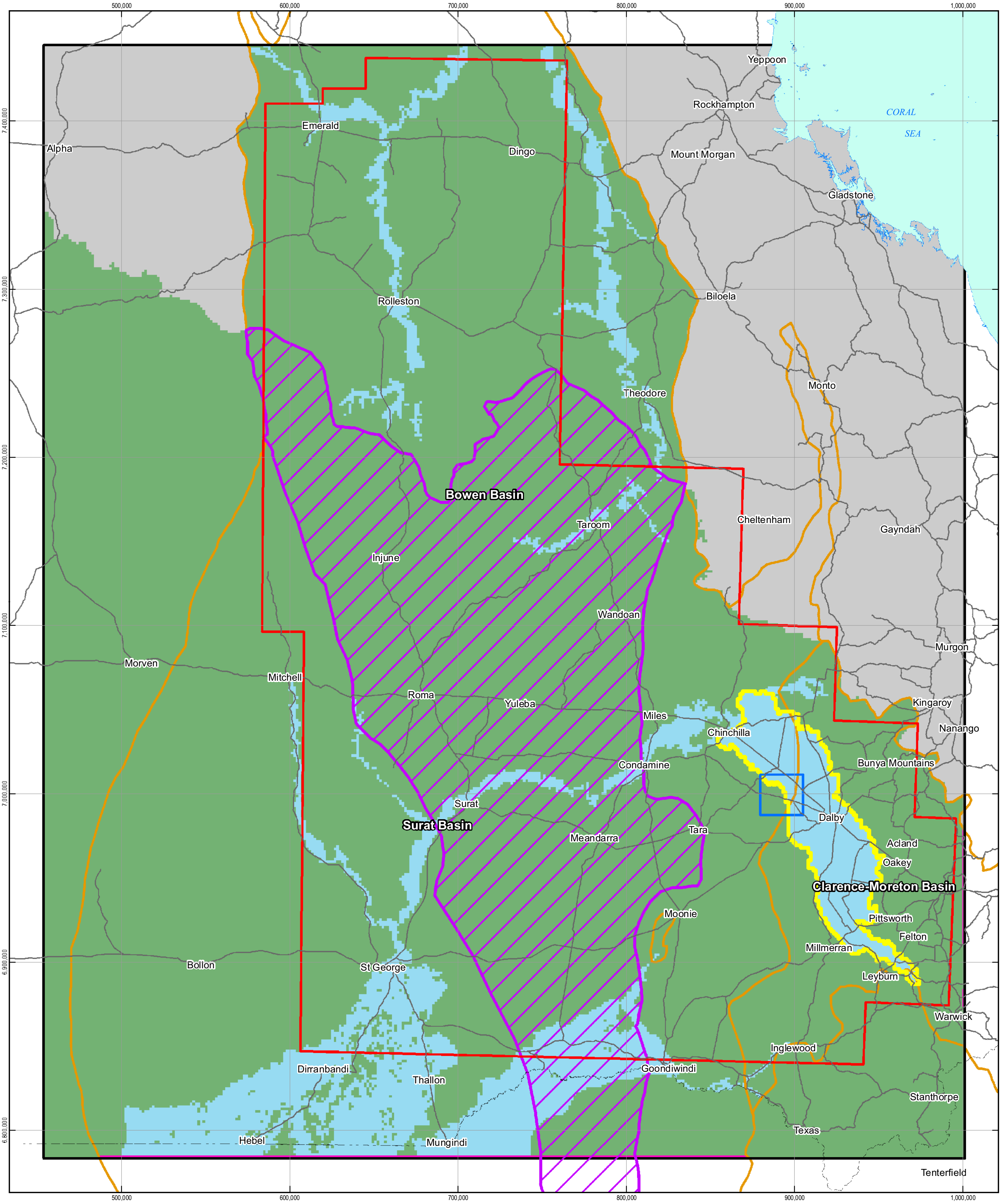
QUEENSLAND WATER COMMISSION
SURAT CUMULATIVE MANAGEMENT AREA
GROUNDWATER MODEL REPORT
CONCEPTUAL MODEL BOWEN BASIN

Job Number 41-23918-12
Revision A
Date NOV 2011

Figure 14

Level 4, 201 Charlotte St Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Plot Date: 4 April 2012 - 9:49 AM Plotted by: Leanne S Martin/Brisbane/GHD/AU Cad File No: G:\41\23918\CADD\Drawings\41-23918-FIG14.dwg



LEGEND

- State Controlled Roads
- Surat Cumulative Management Area
- Transient Sub-Model Area
- Surat Basin and Bowen Basin Overlap
- Condamine Model Area
- Regional Steady State Model Area
- Geological Basins - Surat, Bowen and Clarence-Moreton Basins
- General Head Boundary
- Rivers
- Drains
- No Flow

1:2,100,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Queensland Water Commission
Surat Cumulative Management Area Groundwater Model Report

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Revision 1
Date 02 APR 2012

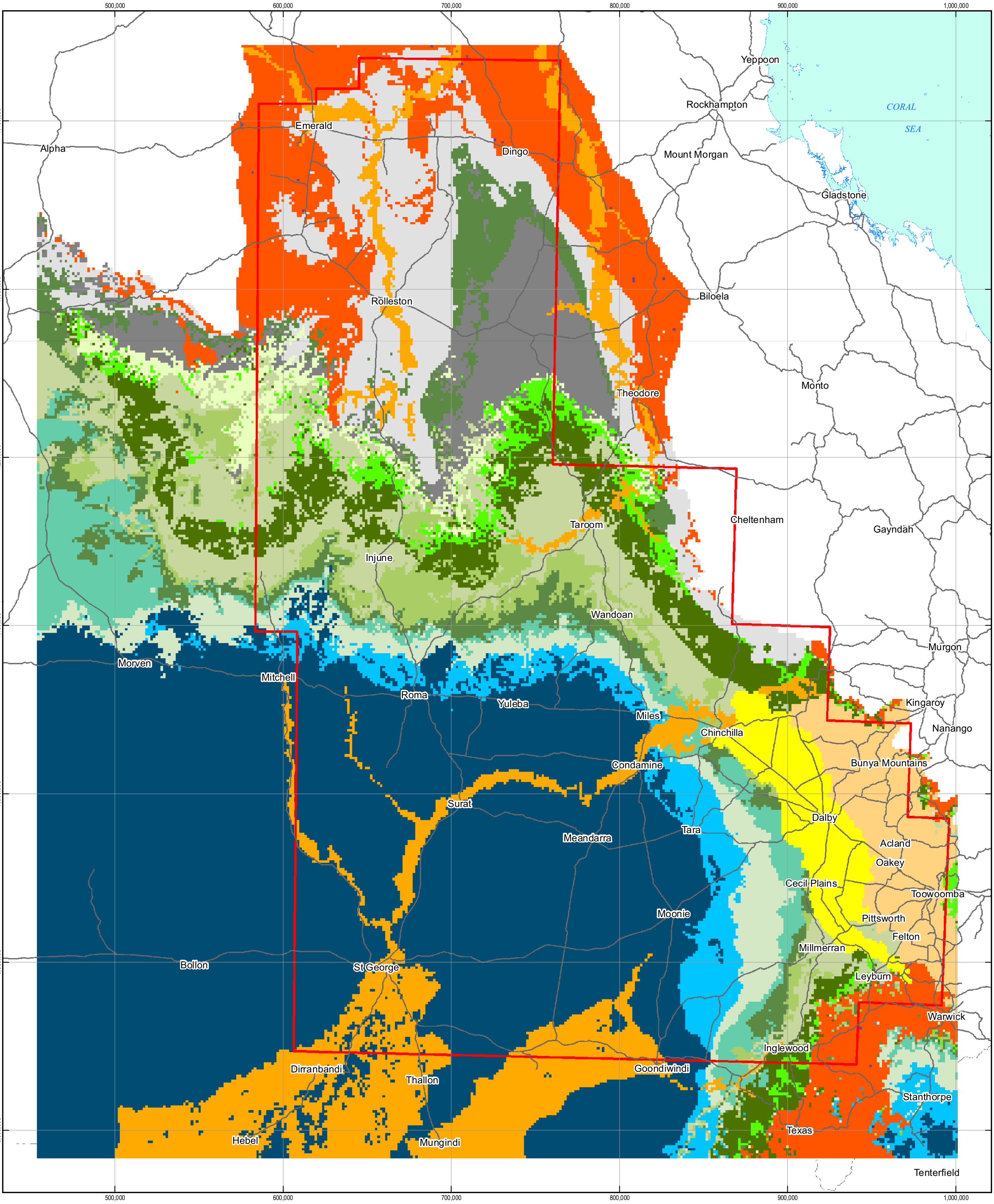
Grid and Boundary Conditions
Steady State Regional Model

Figure 15

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_16.mxd

201 Charlotte Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: DTMR - State Controlled Roads (2010). Navteq - Place Names, Land Mass (2008). GA - Geological Basins (2011). GHD - Ocean, Surat Cumulative Management Area, General Head Boundary, Rivers, Drains, No Flow, Transient Sub-Model Area (2011). Created by: CM



LEGEND

- State Controlled Roads
- Surat Cumulative Management Area V2

Model Layers

- Layer 1 (Alluvium Outside Condamine)
- Layer 2 (Rolling Downs Group)
- Layer 3 (Bungil/Mooga Formation)
- Layer 4 (Orallo Formation)
- Layer 5 (Gubberamunda Sandstone)
- Layer 6 (Westbourne Formation)
- Layer 7/8 (Springbok Sandstone)
- Layer 9/10/11 (Walloon Coal Measures)
- Layer 12 (Hutton Sandstone)
- Layer 13 (Evergreen Formation)
- Layer 14 (Precipice Sandstone)
- Layer 15 (Moolayember Formation)
- Layer 16 (Westbourne Formation)
- Layer 17 (Rewan Group)
- Layer 18 (Bandana Formation)
- Layer 19 (Pre Bandana Age Units)
- Layer 1 (Main Range Volcanics)
- Layer 1 (Condamine Alluvium)

1:2,100,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Surat Cumulative Management Area Groundwater Model Report

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Revision 0
Date 08 DEC 2011

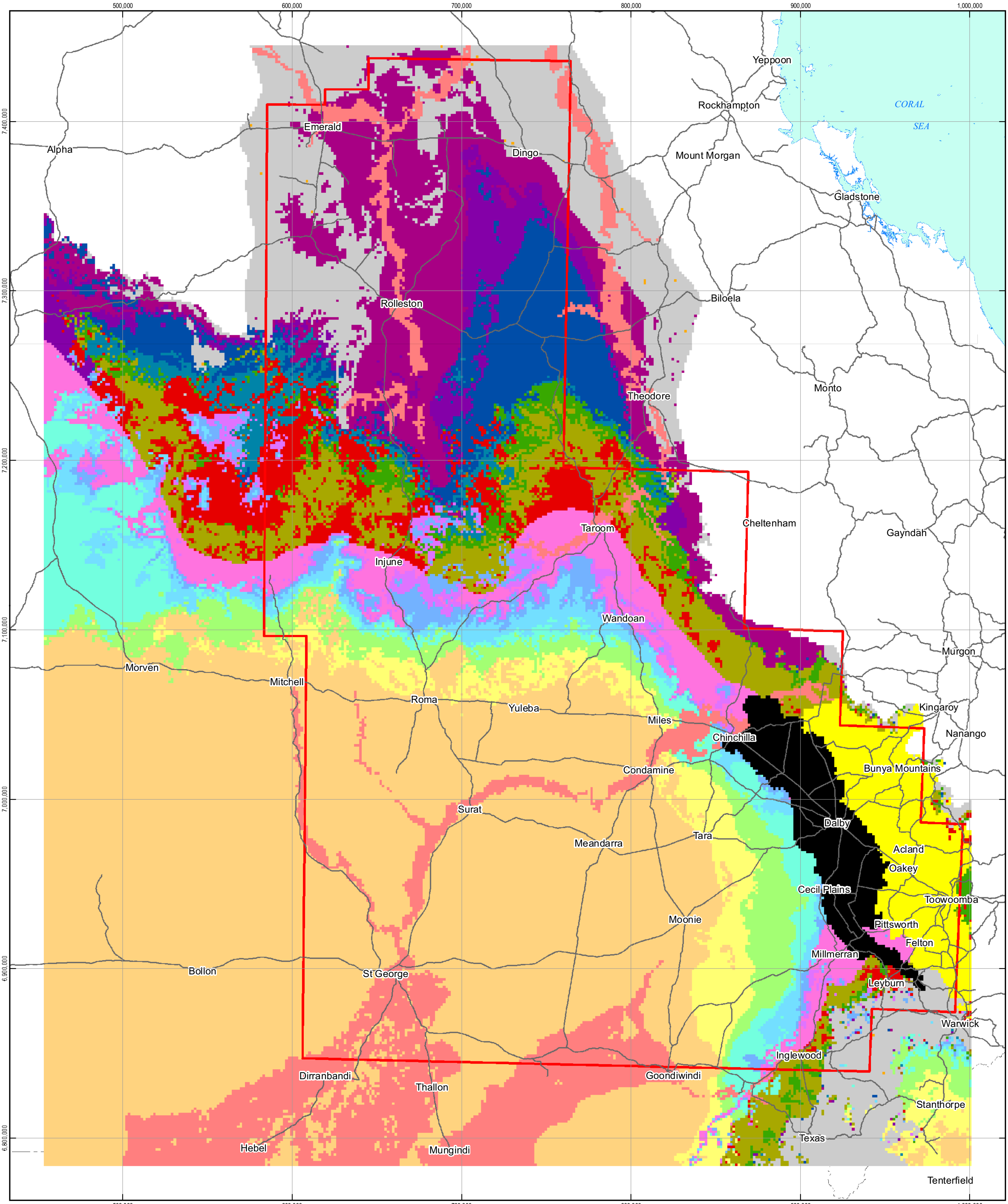
Modelled Outcrop
Steady State Regional Model

Figure 16

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_17.mxd

201 Charlotte Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: DTMR - State Controlled Roads (2010). Navteq - Place Names, Land Mass (2008). GA/GHD - Model Layers (2011). GHD - Ocean, Surat Cumulative Management Area (2011). Created by: CM



LEGEND

State Controlled Roads	
Surat Cumulative Management Area	

Net Recharge

- Layer 1 (Alluvium outside Condamine) - 0 mm/yr
- Layer 1 (Main Range Volcanics) - 5.2 mm/yr
- Layer 1 (Condamine Alluvium) - 0 mm/yr
- Layer 2 - 0 mm/yr
- Layer 3 - 1.7 mm/yr
- Layer 4 - 0 mm/yr
- Layer 5 - 2.7 mm/yr
- Layer 6 - 0 mm/yr
- Layer 7 - 0.6 mm/yr
- Layer 8 - 0.6 mm/yr
- Layer 9 - 0 mm/yr
- Layer 10 - 1.1 mm/yr
- Layer 11 - 0.2 mm/yr
- Layer 12 - 1.3 mm/yr
- Layer 13 - 0 mm/yr
- Layer 14 - 1.3 mm/yr
- Layer 15 - 0 mm/yr
- Layer 16 - 0.4 mm/yr
- Layer 17 - 0 mm/yr
- Layer 18 - 0 mm/yr
- Layer 19 - 0 mm/yr

1:2,100,000 @ A3

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Surat Cumulative Management Area Groundwater Model Report

Job Number	41-23918
Revision	2
Date	02 APR 2012

Modelled Long Term Average Net Recharge

Figure 17

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_10.mxd

201 Charlotte Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: DTMR - State Controlled Roads (2010). Navteq - Place Names, Land Mass (2008). BOM/GHD - Modelled Long Term Average Recharge (2011). GHD - Ocean, Surat Cumulative Management Area (2011). Created by: CM

Figure 18 Simulated v Observed Groundwater Levels – Steady State Regional Model

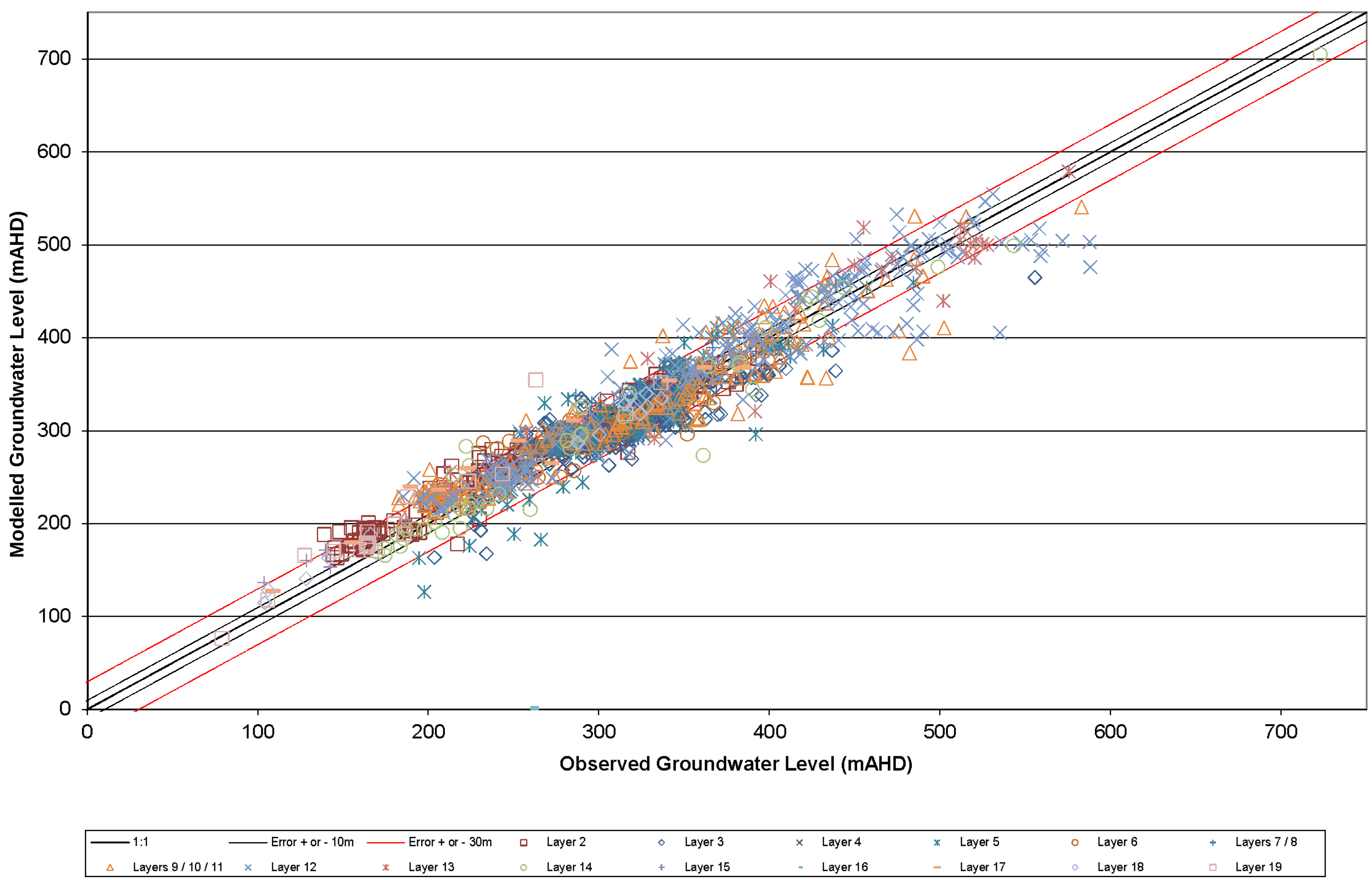
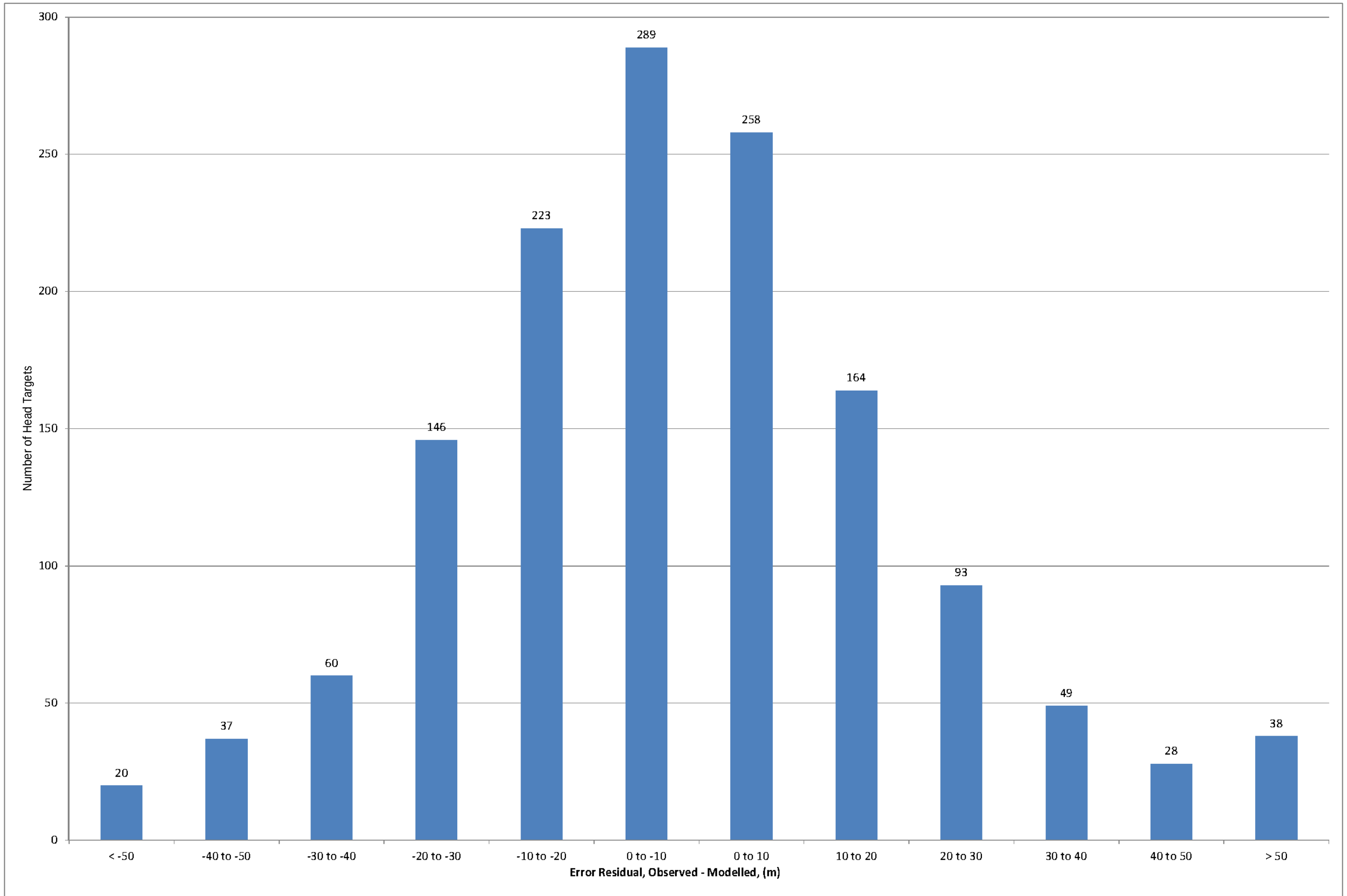
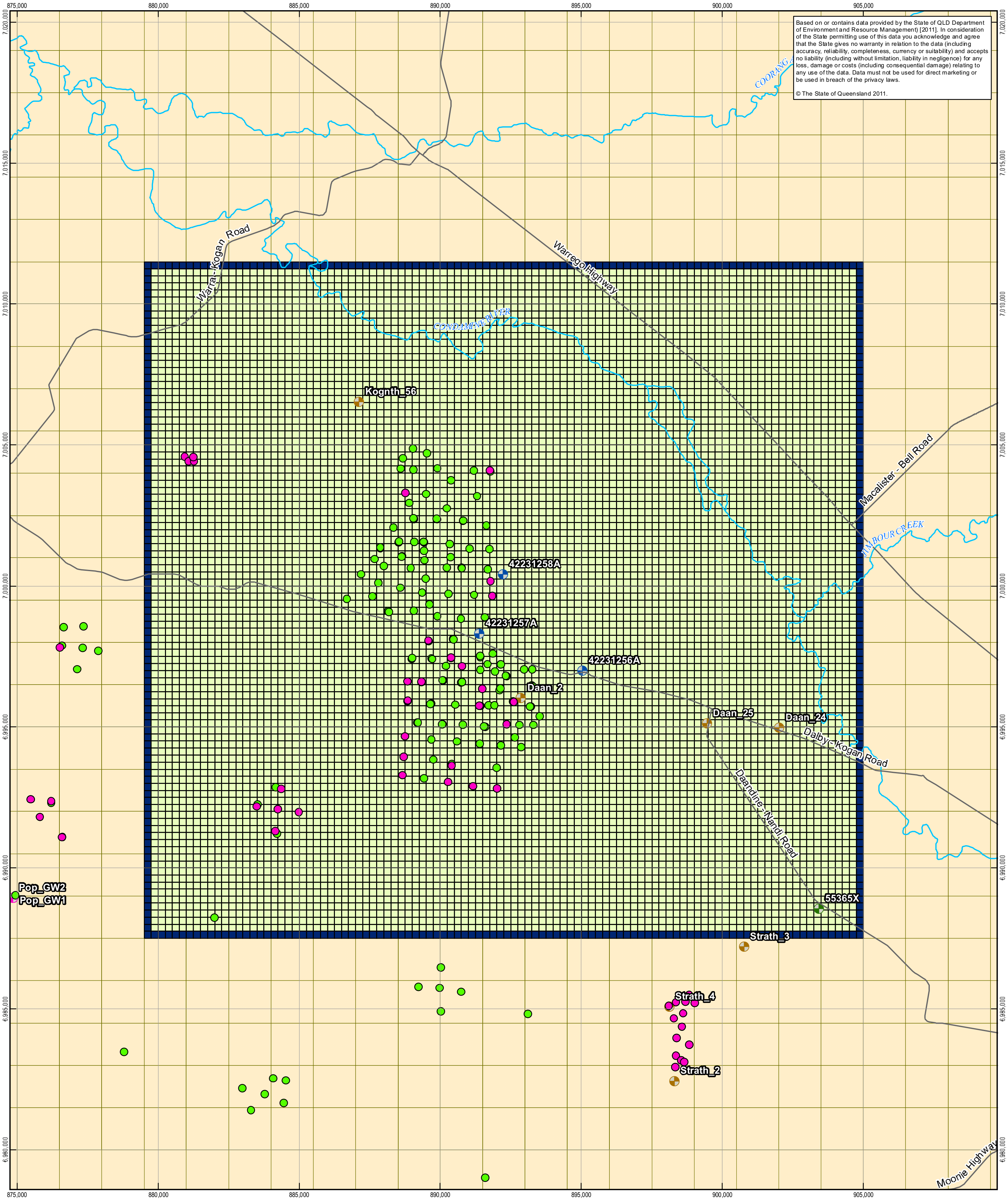


Figure 19 Distribution of Error Residuals – Steady State Regional Model





LEGEND

State Controlled Roads	**Groundwater Level Monitoring Bores**	QGC Monitoring Bore
Major Watercourses	State Monitoring Network Bores	Santos Monitoring Bore
Existing CSG Test Well	Arrow Monitoring Bore	Other Registered Bores with Groundwater Level Data
Existing CSG Production Well	Origin Monitoring Bore	

Sub Model Grid
Regional Model Grid
Constant Head Boundary Cells
Drain Cells

1:125,000 @ A3

0 1 2 3 4 5

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Revision 0
Date 08 DEC 2011

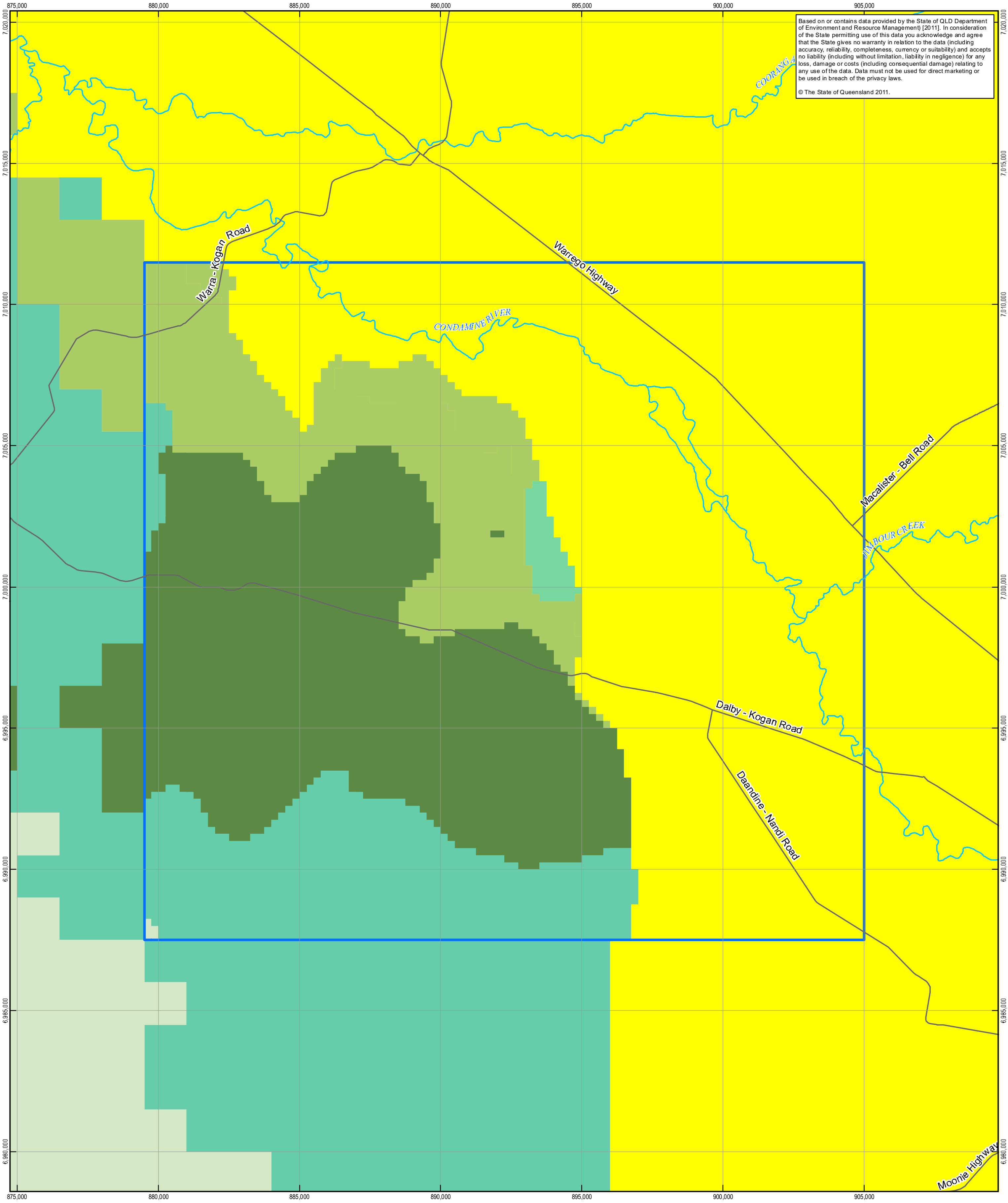
Grid and Boundary Conditions Transient Sub-Model

Figure 20

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_19.mxd

201 Charlotte Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: DTMR - State Controlled Roads (2010). Navteq - Place Names, Land Mass (2008). DERM - Major Watercourses, Existing CSG Production Wells, Existing CSG Test Wells, Groundwater Monitoring Bores (2011).
GHD - Constant Head Boundary, Drain Cells, Sub Model and Regional Model Mesh (2011). Created by: CM



LEGEND

- State Controlled Roads
- Major Watercourses
- Transient Sub-Model Area

Model Layers

- Layer 1 (Condamine Alluvium)
- Layer 4 (Orallo Formation)
- Layer 5 (Gubberamunda Sandstone)
- Layer 6 (Westbourne Formation)
- Layer 7/8 (Springbok Sandstone)
- Layer 9 (Walloon Coal Measures)

1:125,000 @ A3

0 1 2 3 4 5

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 55

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Queensland Water Commission
Surat Cumulative Management Area Groundwater Model Report

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Revision	0
Date	08 DEC 2011

Modelled Outcrop - Transient Sub-Model

Figure 21

N:\AU\Toowoomba\Projects\41\23918\GIS\Maps\4123918_20.mxd

201 Charlotte Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: DTMR - State Controlled Roads (2010). DERM - Major Watercourses (2011). Navteq - Place Names, Land Mass (2008). GA/GHD - Model Layers (2011). GHD - Transient Sub-Model Area (2011). Created by: CM

Appendix B – Predictive Uncertainty of the Regional Scale Groundwater Flow Model for the Surat Cumulative Management Area, Watermark Numerical Computing, 2012, Selected Figures

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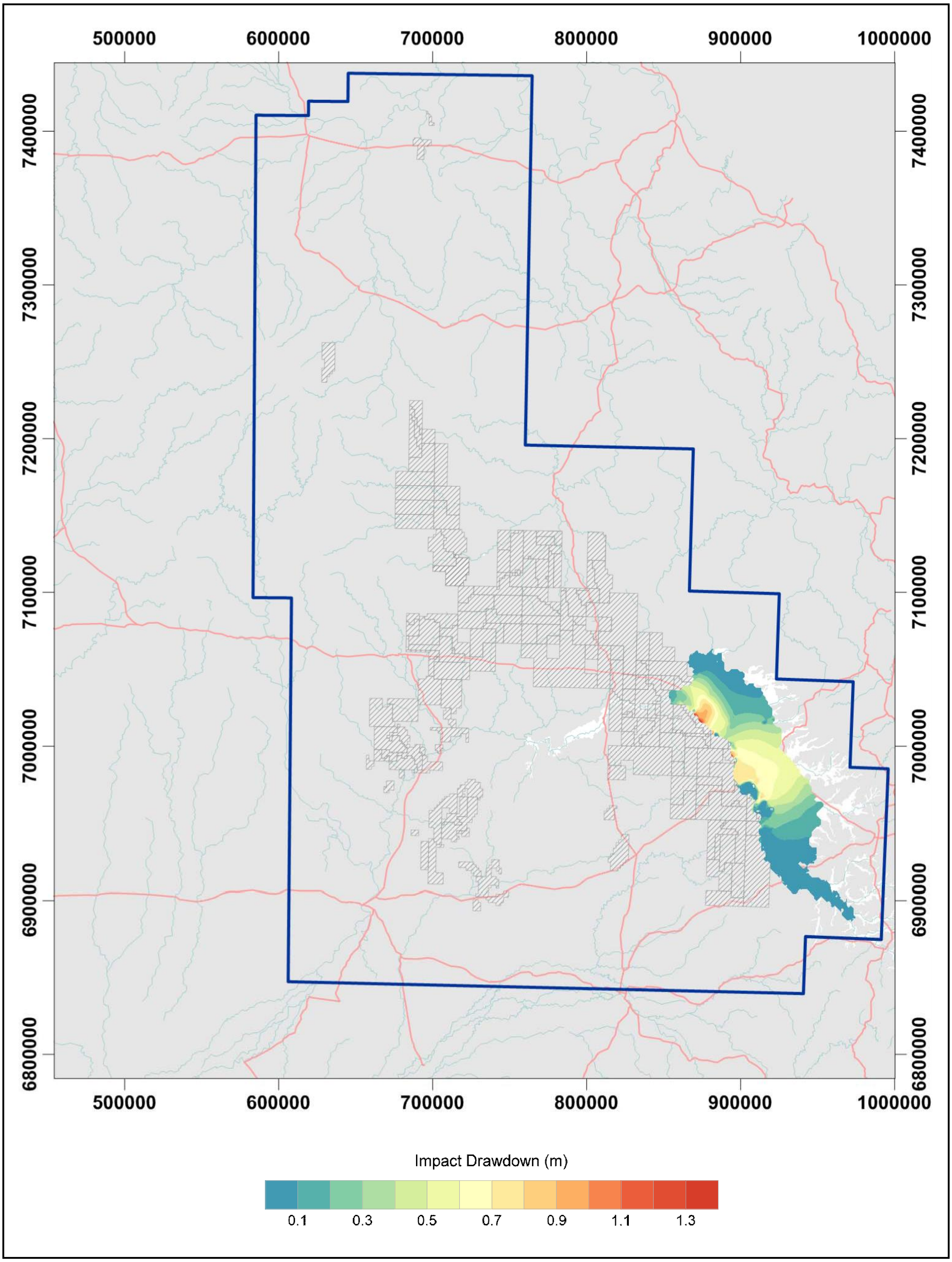


Figure 5-1 Maximum of the maximum "all time" impact drawdown for Condamine Alluvium

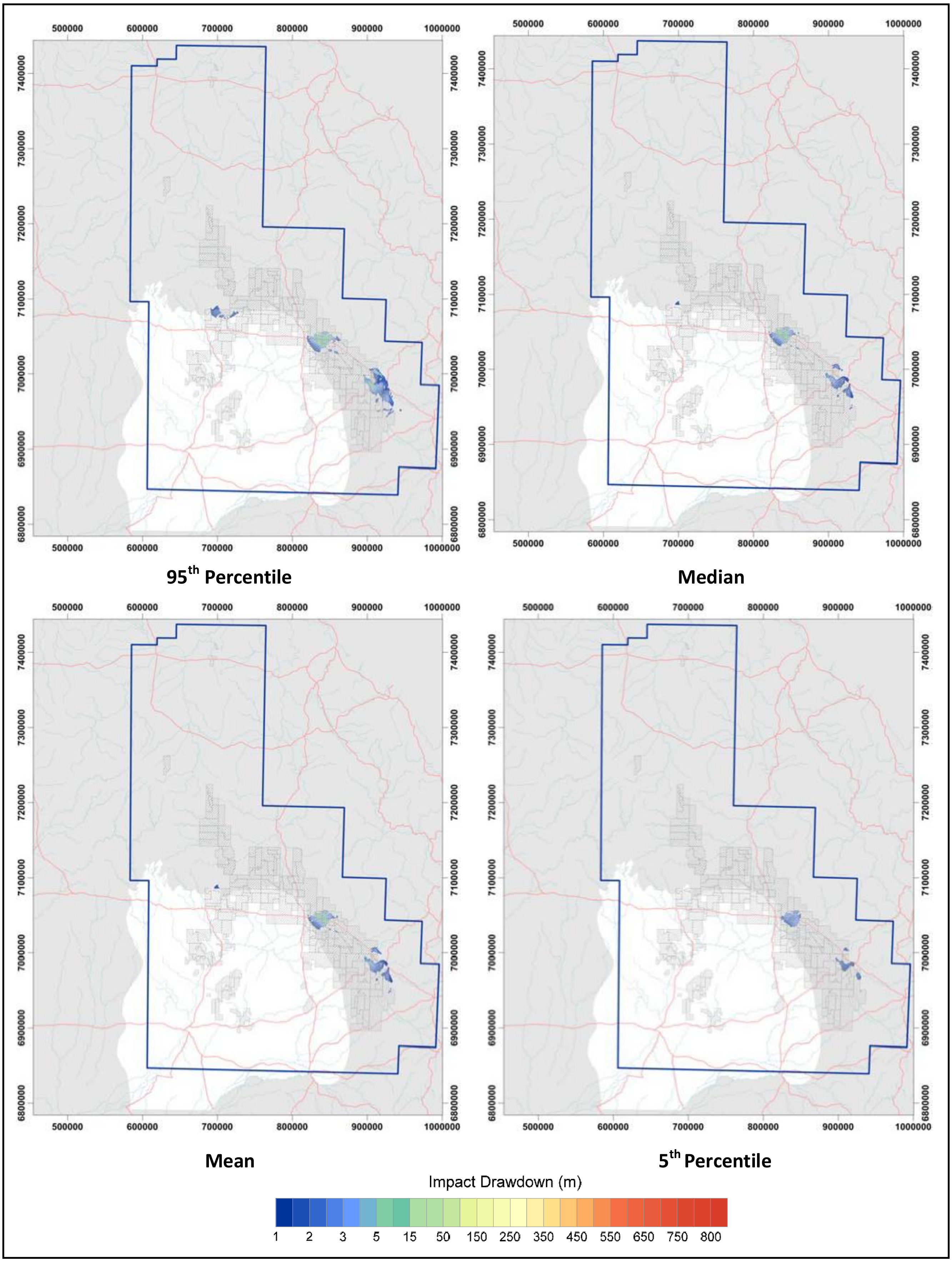


Figure 5-2 Statistics of the maximum "all time" impact drawdown for Mooga and Bungil Units

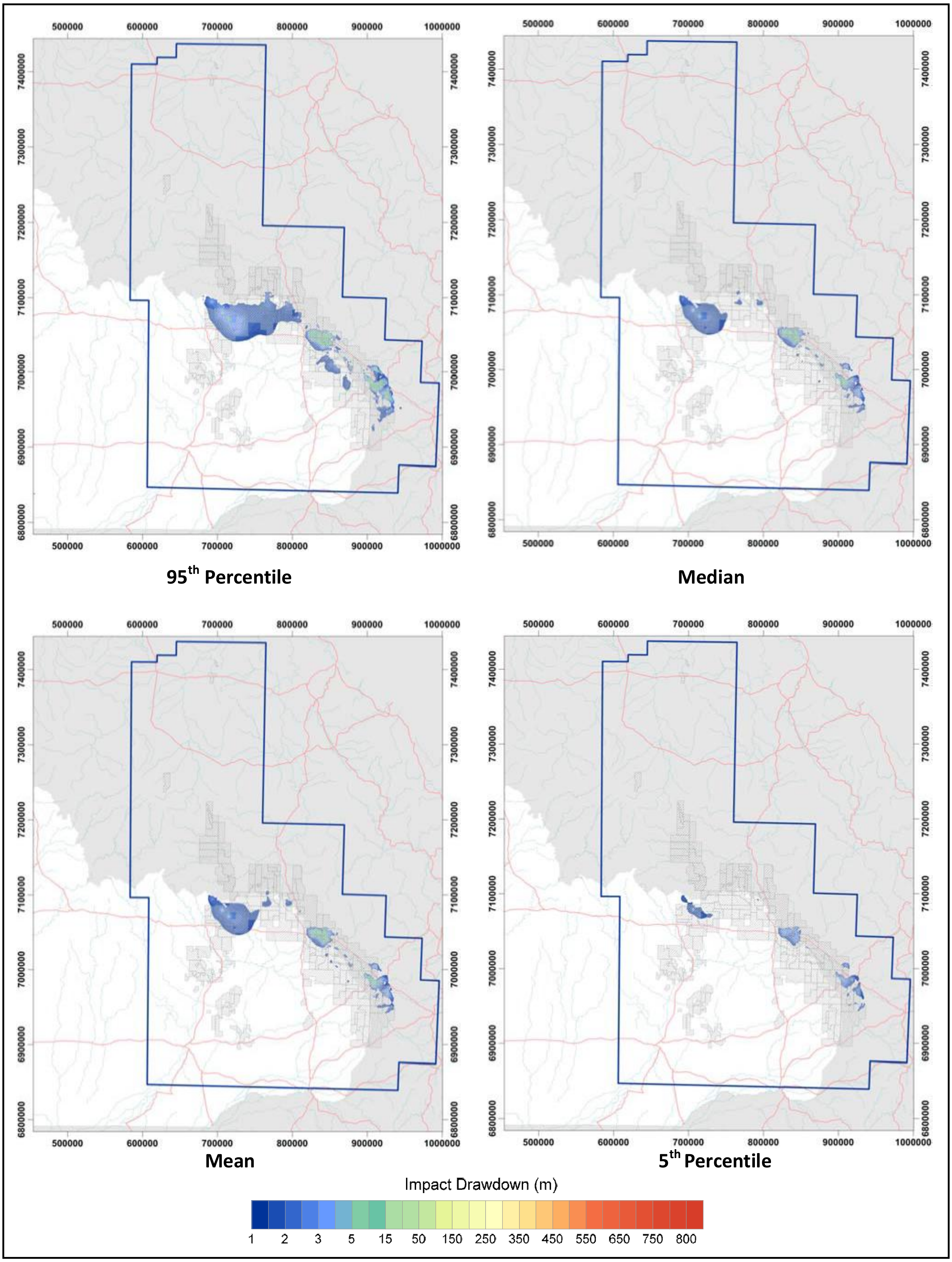


Figure 5-3 Statistics of the maximum "all time" impact drawdown for Gubberamunda Sandstone

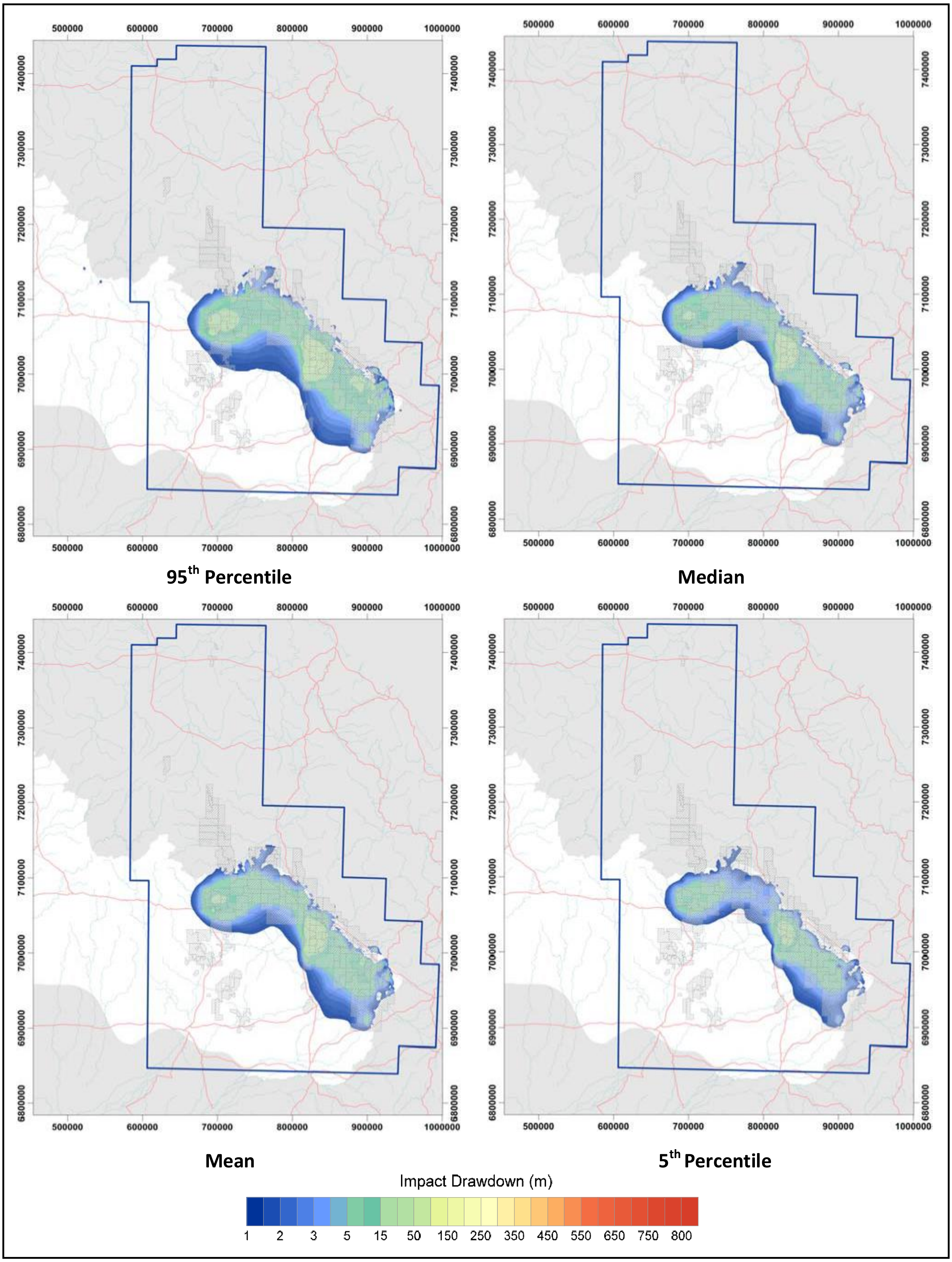


Figure 5-4 Statistics of the maximum "all time" impact drawdown for Springbok Sandstone/Kumbarilla Beds

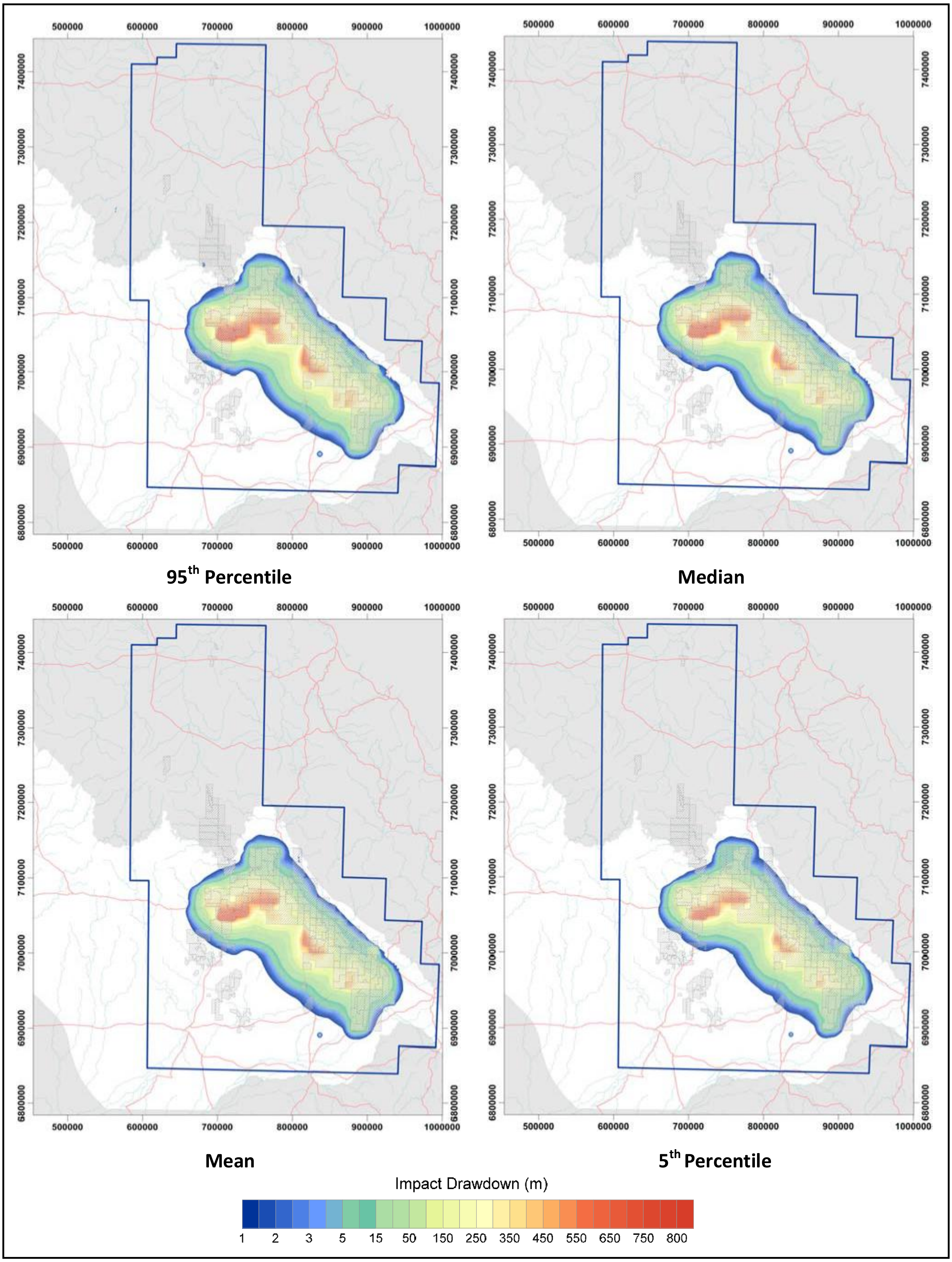


Figure 5-5 Statistics of the maximum "all time" impact drawdown for Walloon Coal Measures

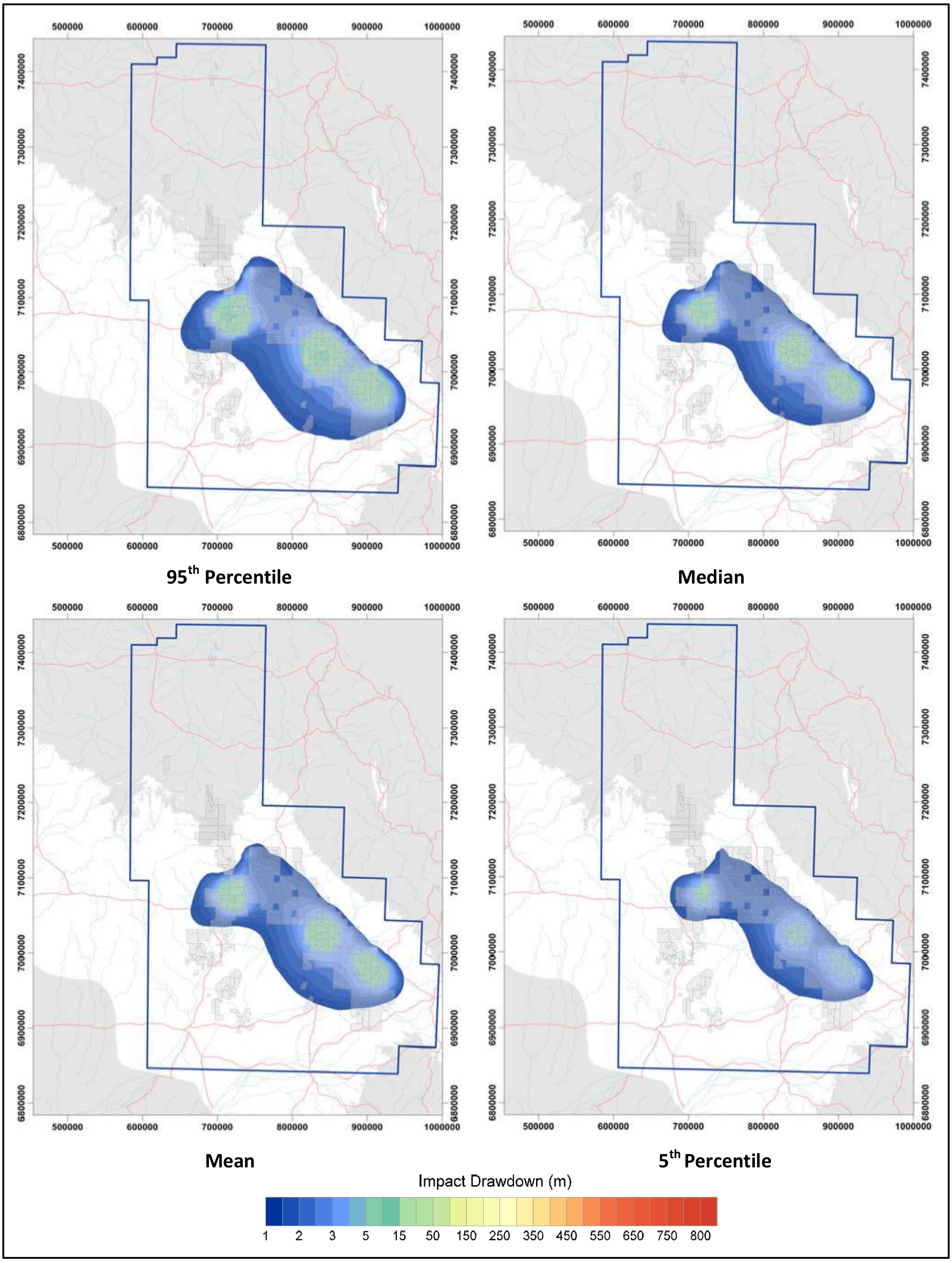


Figure 5-6 Statistics of the maximum "all time" impact drawdown for Hutton Sandstone

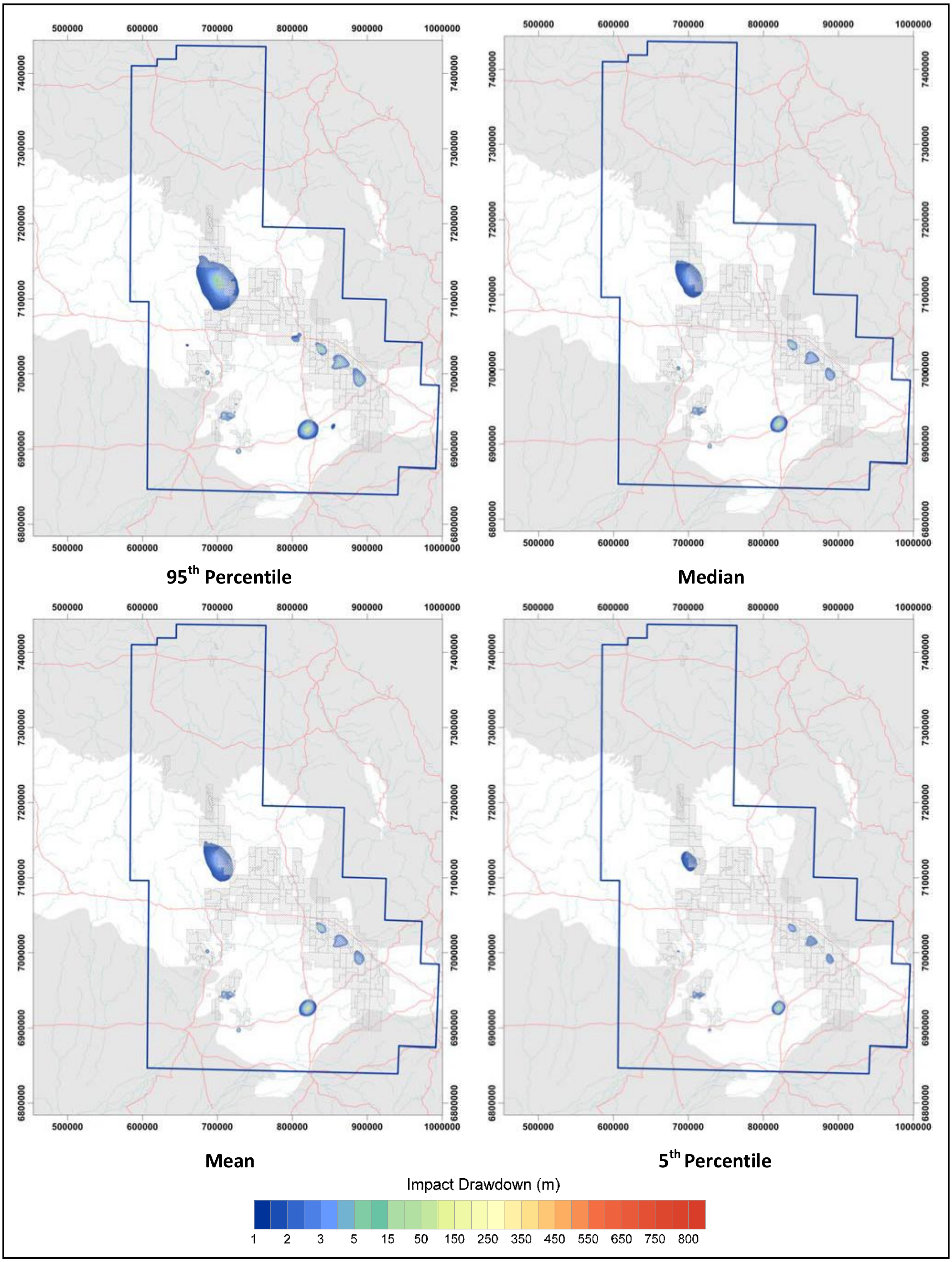


Figure 5-7 Statistics of the maximum "all time" impact drawdown for Precipice Sandstone

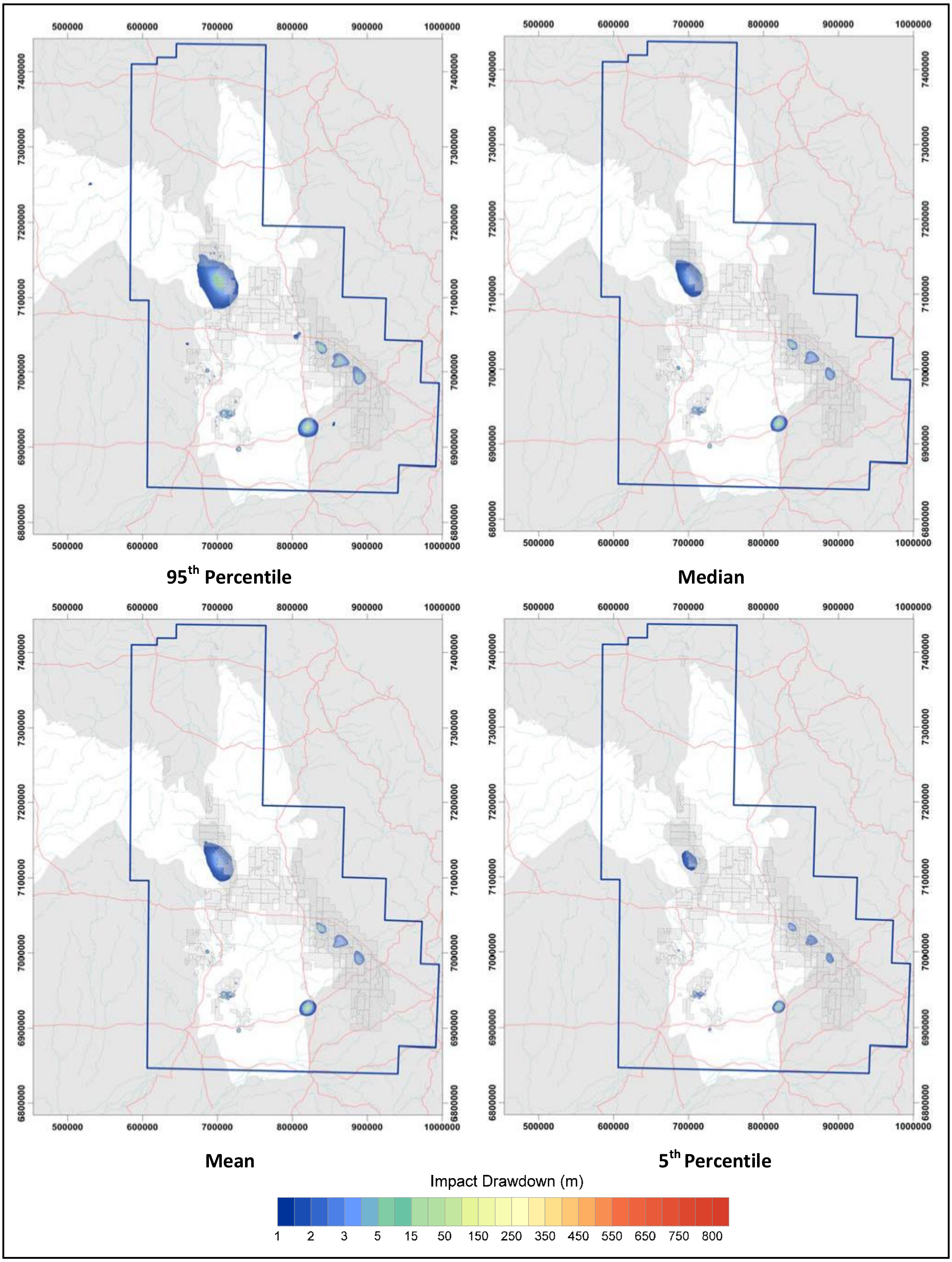


Figure 5-8 Statistics of the maximum "all time" impact drawdown for Clematis Sandstone

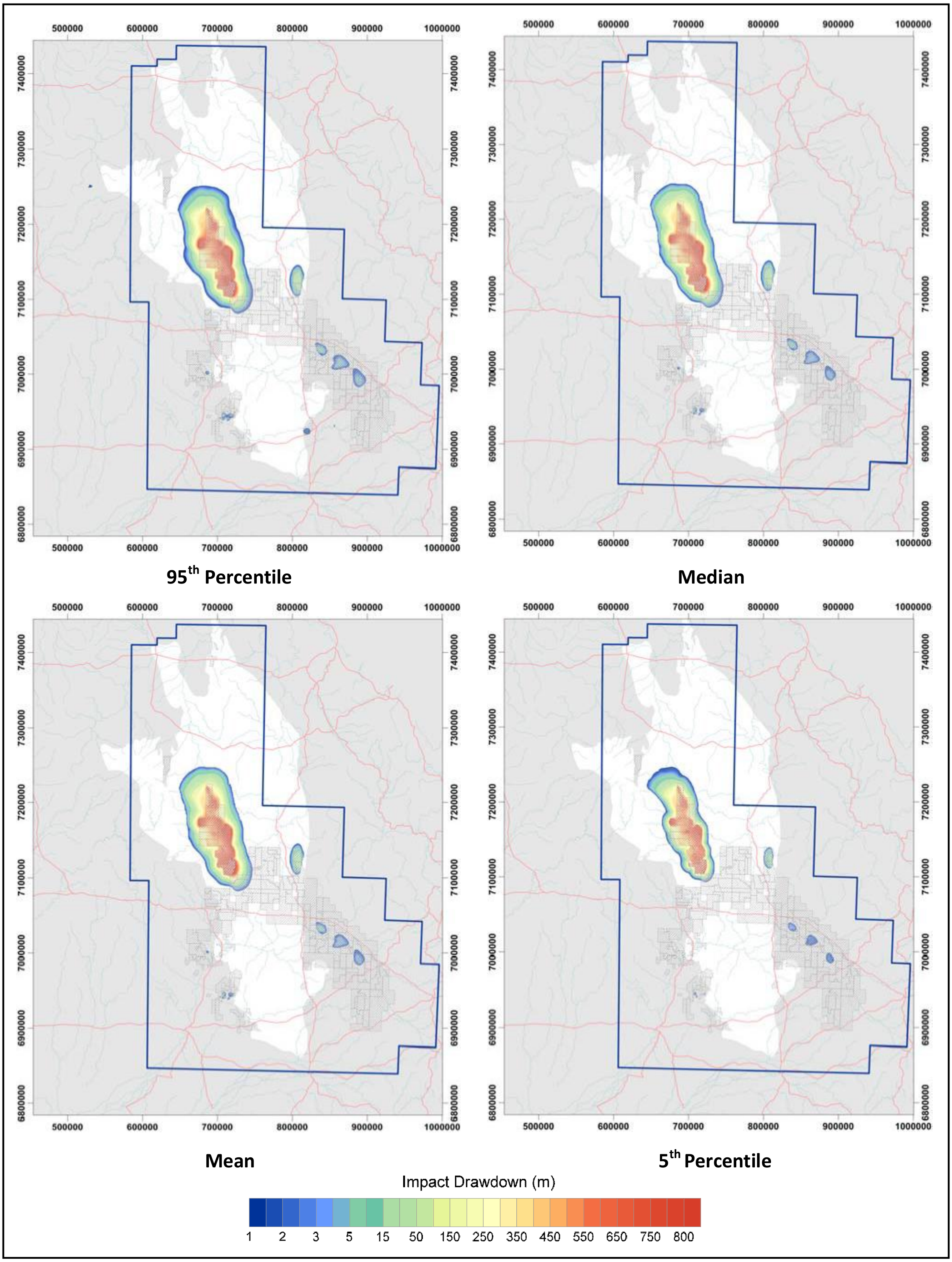


Figure 5-9 Statistics of the maximum "all time" impact drawdown for Bandanna Coal Formation

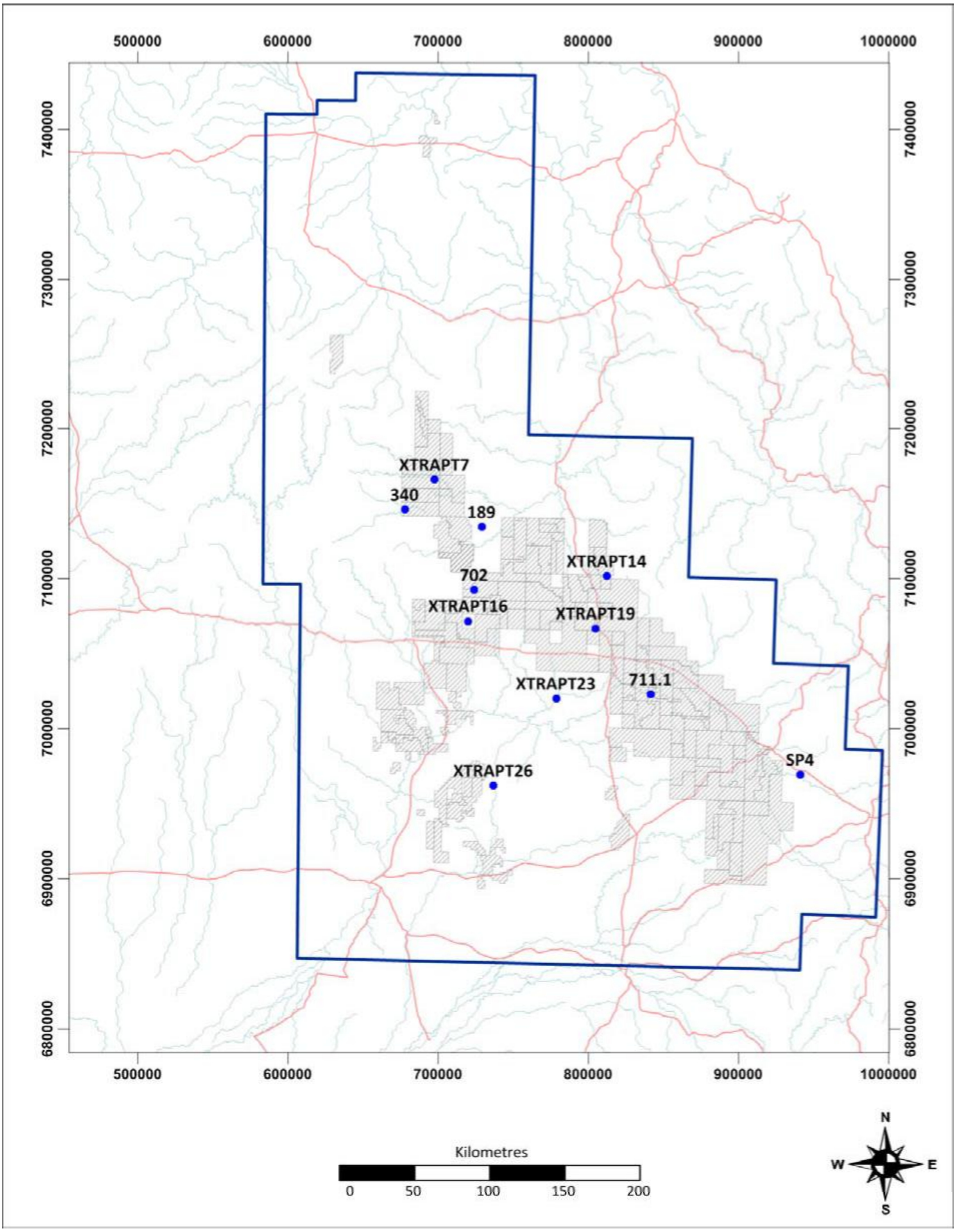


Figure 5-26 Site locations for time series of impact drawdown.

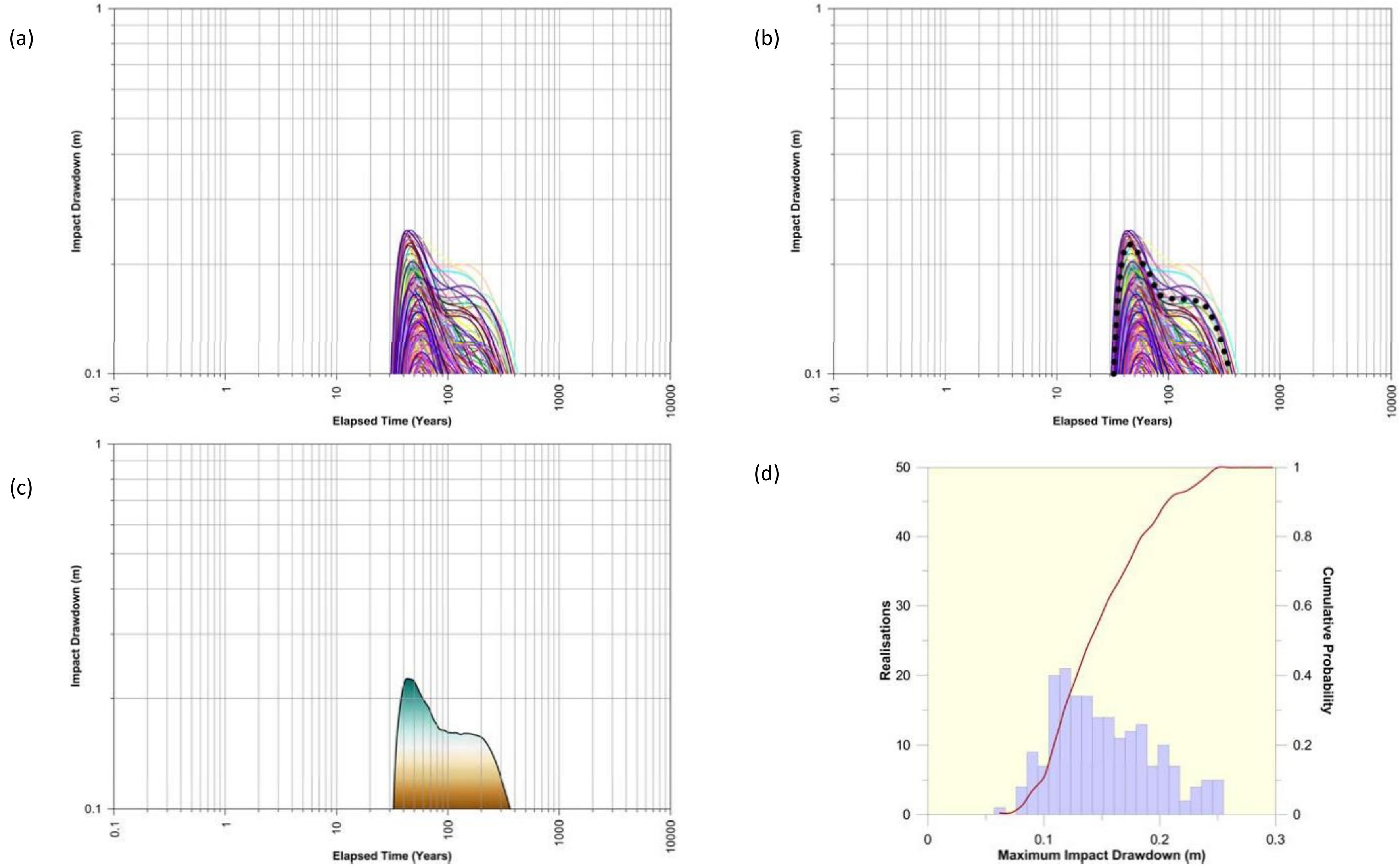


Figure 5-27 Predicted impact drawdown over time at site "189" in layer 12 for (a) all 200 realisations, (b) identification of 5th and 95th percentiles, (c) 5th and 95th percentile envelopes, and (d) histogram and cumulative probability distribution of maximum impact drawdown.

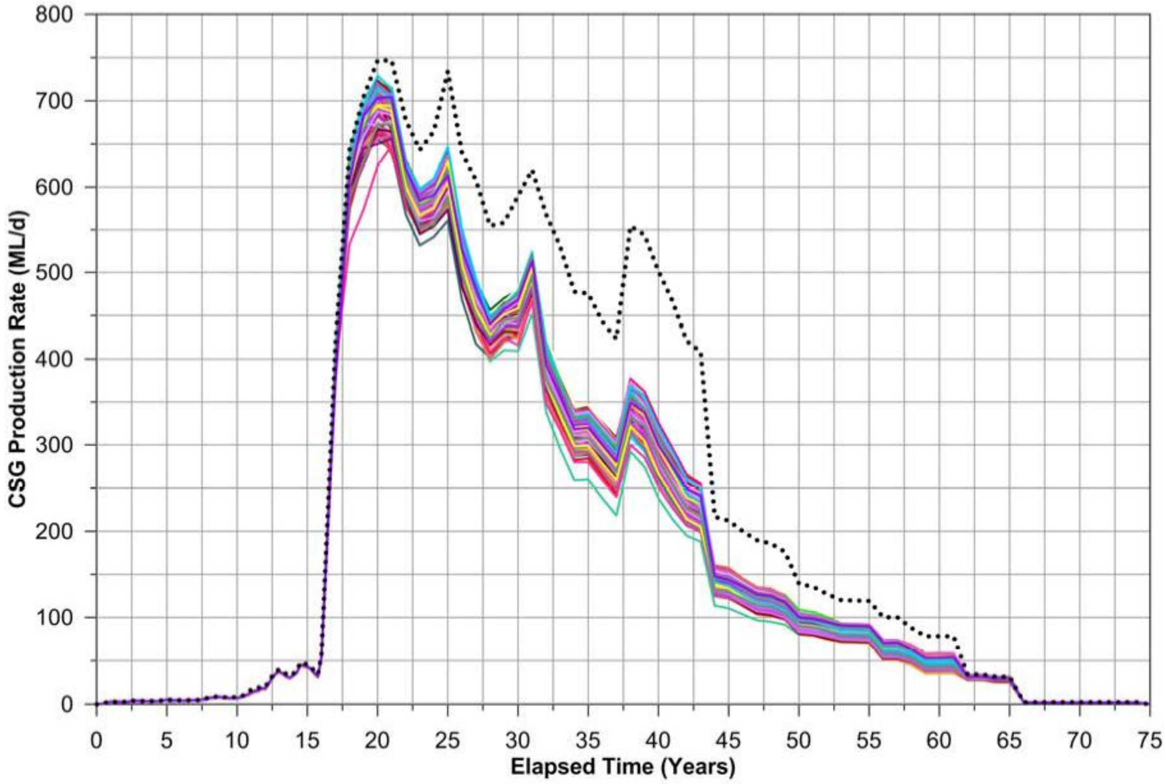


Figure 5-93 Predicted CSG water production rate over time for all 200 realisations. Dotted line indicates maximum input extraction rate and coloured lines indicate actual extraction rate in the model.

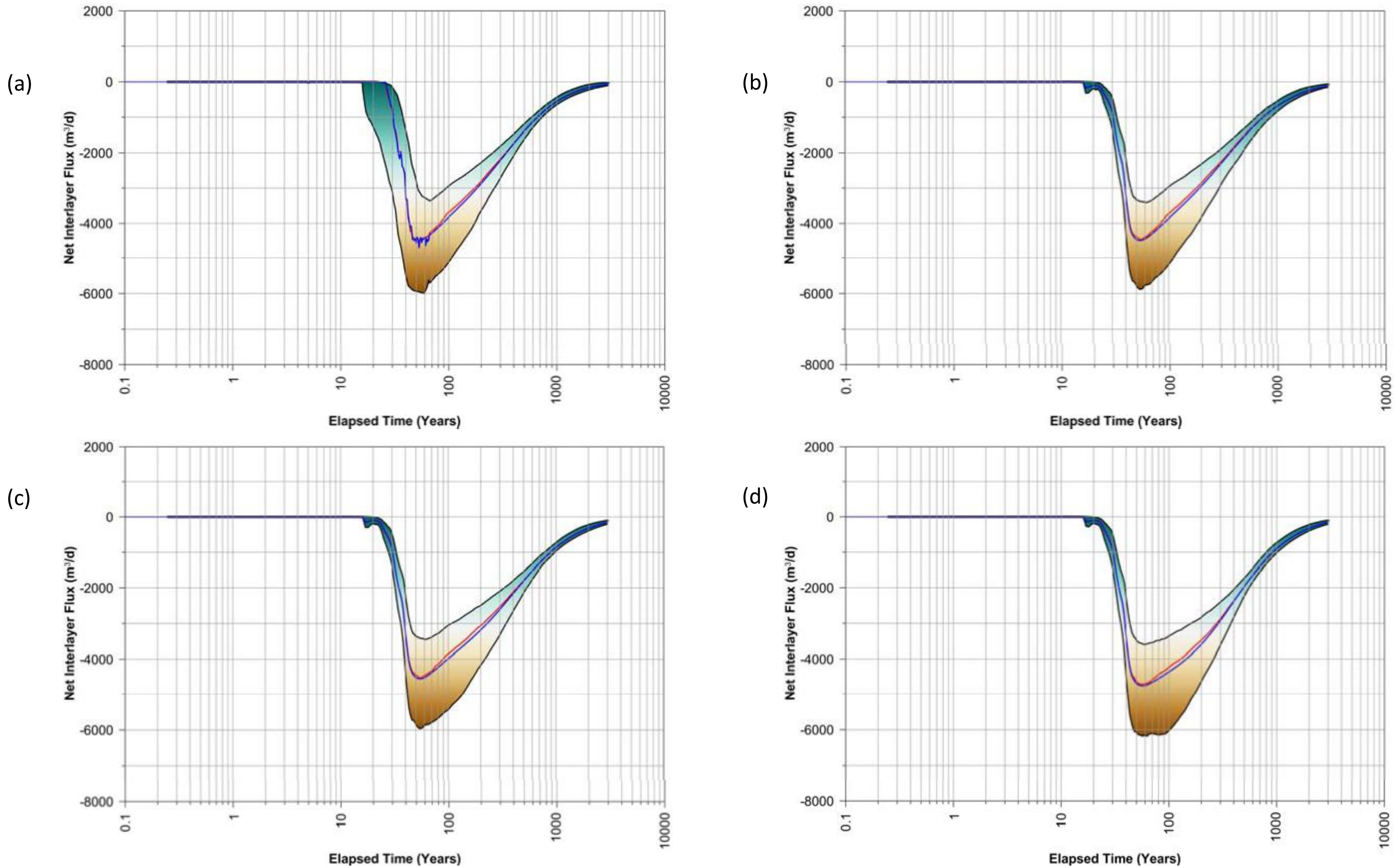


Figure 5-94 The 5th and 95th percentile envelopes of net vertical leakage flux "impact" from (a) layer 1 to 2, (b) layer 2 to 3, (c) layer 3 to 4, and (d) layer 4 to 5. Median and mean responses are also shown as red and blue lines respectively. Positive values indicate an upward net leakage differential between the base case and CSG case.

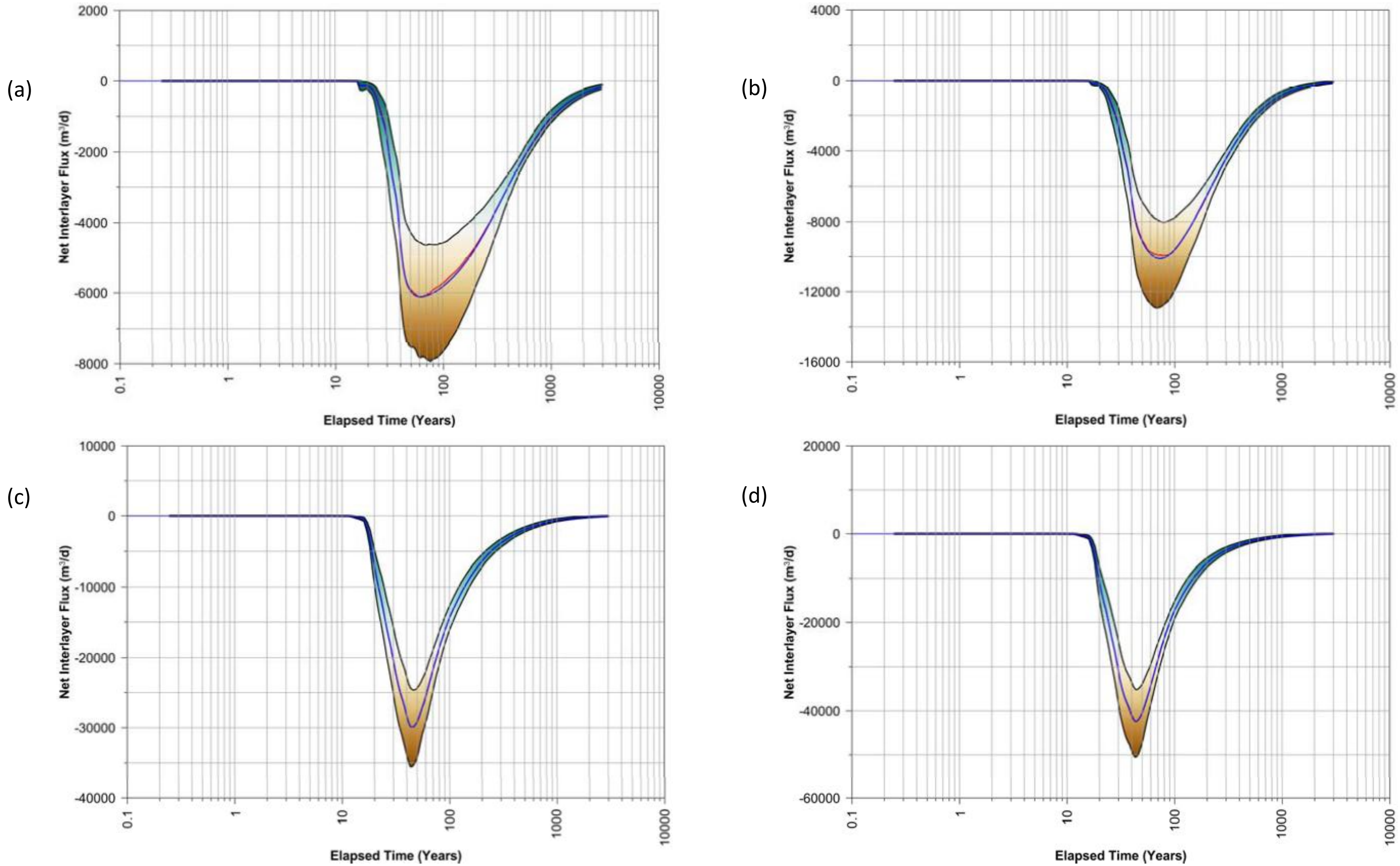


Figure 5-95 The 5th and 95th percentile envelopes of net vertical leakage flux "impact" from (a) layer 5 to 6, (b) layer 6 to 7, (c) layer 7 to 8, and (d) layer 8 to 9. Median and mean responses are also shown as red and blue lines respectively. Positive values indicate an upward net leakage differential between the base case and CSG case.

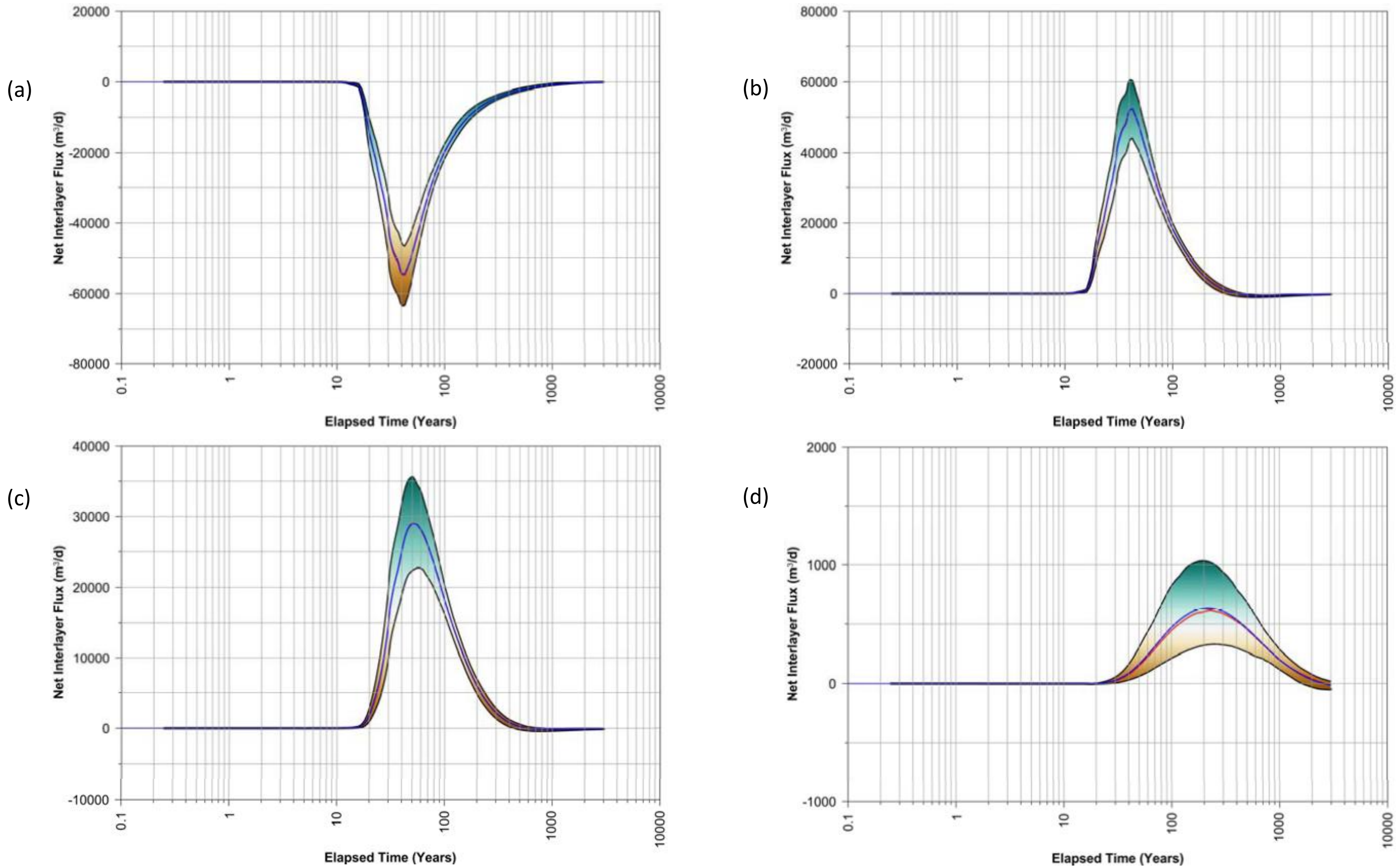


Figure 5-96 The 5th and 95th percentile envelopes of net vertical leakage flux "impact" from (a) layer 9 to 10, (b) layer 10 to 11, (c) layer 11 to 12, and (d) layer 12 to 13. Median and mean responses are also shown as red and blue lines respectively. Positive values indicate an upward net leakage differential between the base case and CSG case.

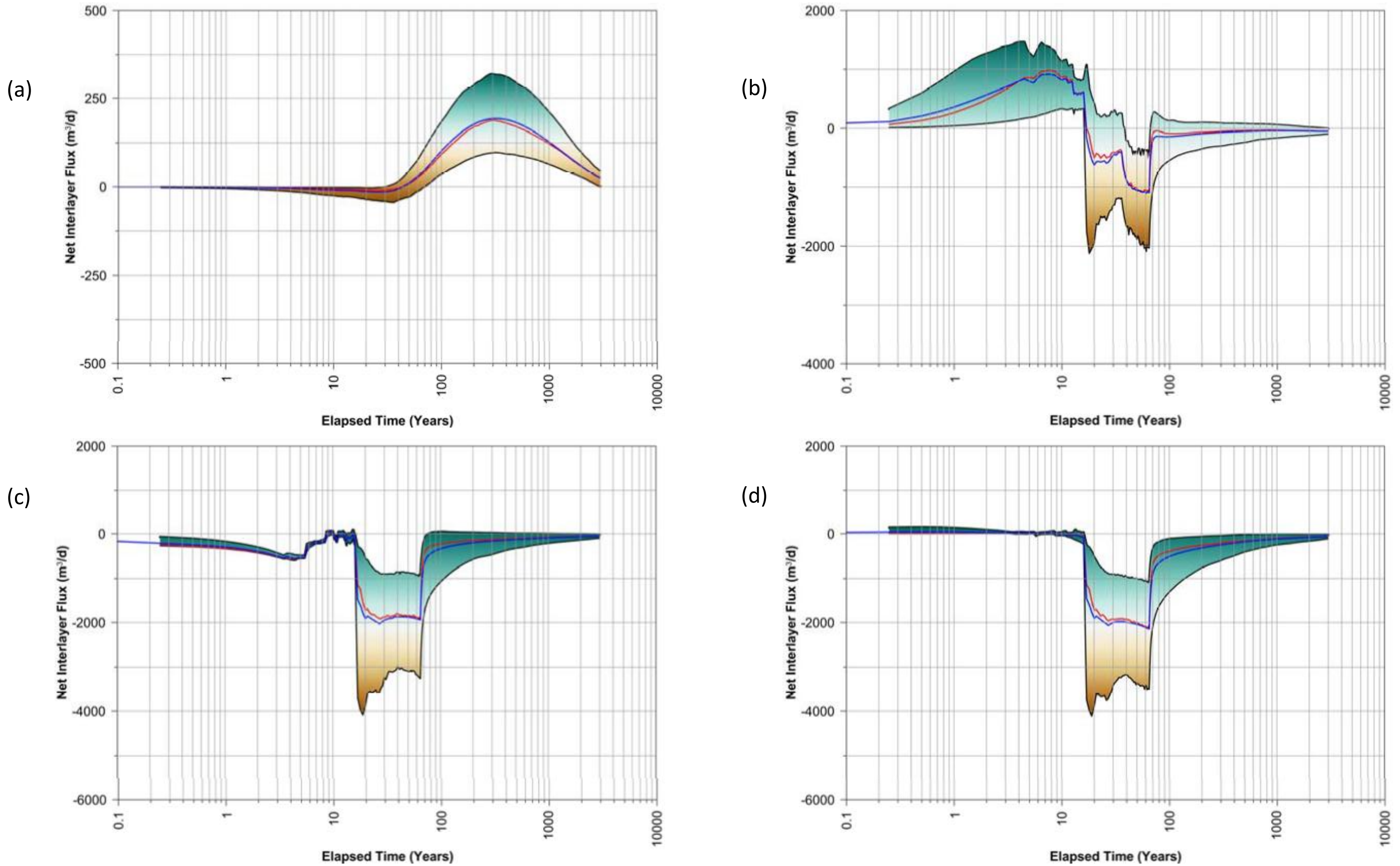
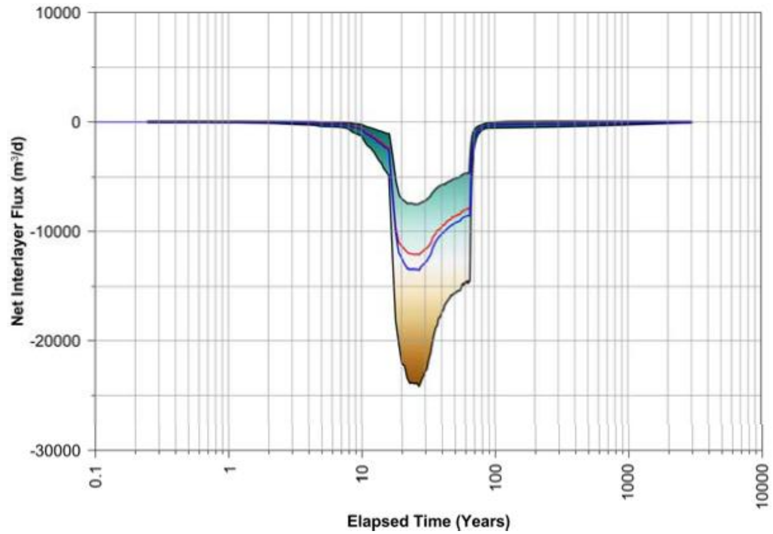


Figure 5-97 The 5th and 95th percentile envelopes of net vertical leakage flux "impact" from (a) layer 13 to 14, (b) layer 14 to 15, (c) layer 15 to 16, and (d) layer 16 to 17. Median and mean responses are also shown as red and blue lines respectively. Positive values indicate an upward net leakage differential between the base case and CSG case.

(a)



(b)

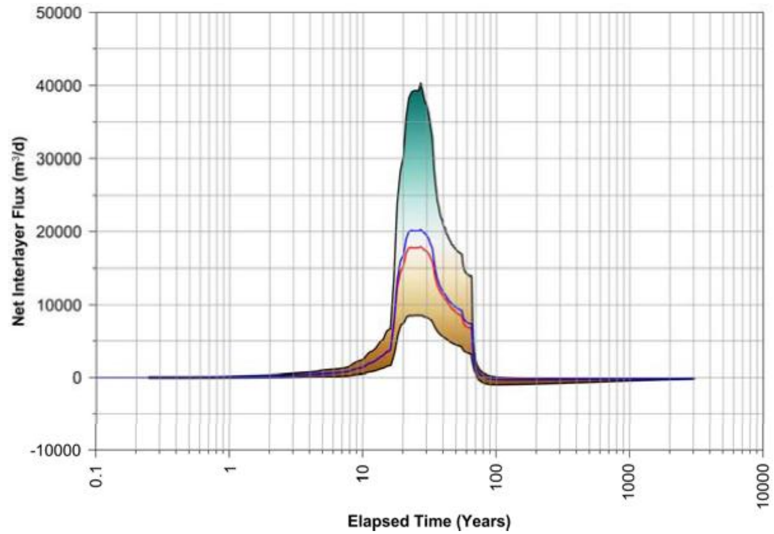


Figure 5-98 The 5th and 95th percentile envelopes of net vertical leakage flux "impact" from (a) layer 17 to 18, and (b) layer 18 to 19. Median and mean responses are also shown as red and blue lines respectively. Positive values indicate an upward net leakage differential between the base case and CSG case.

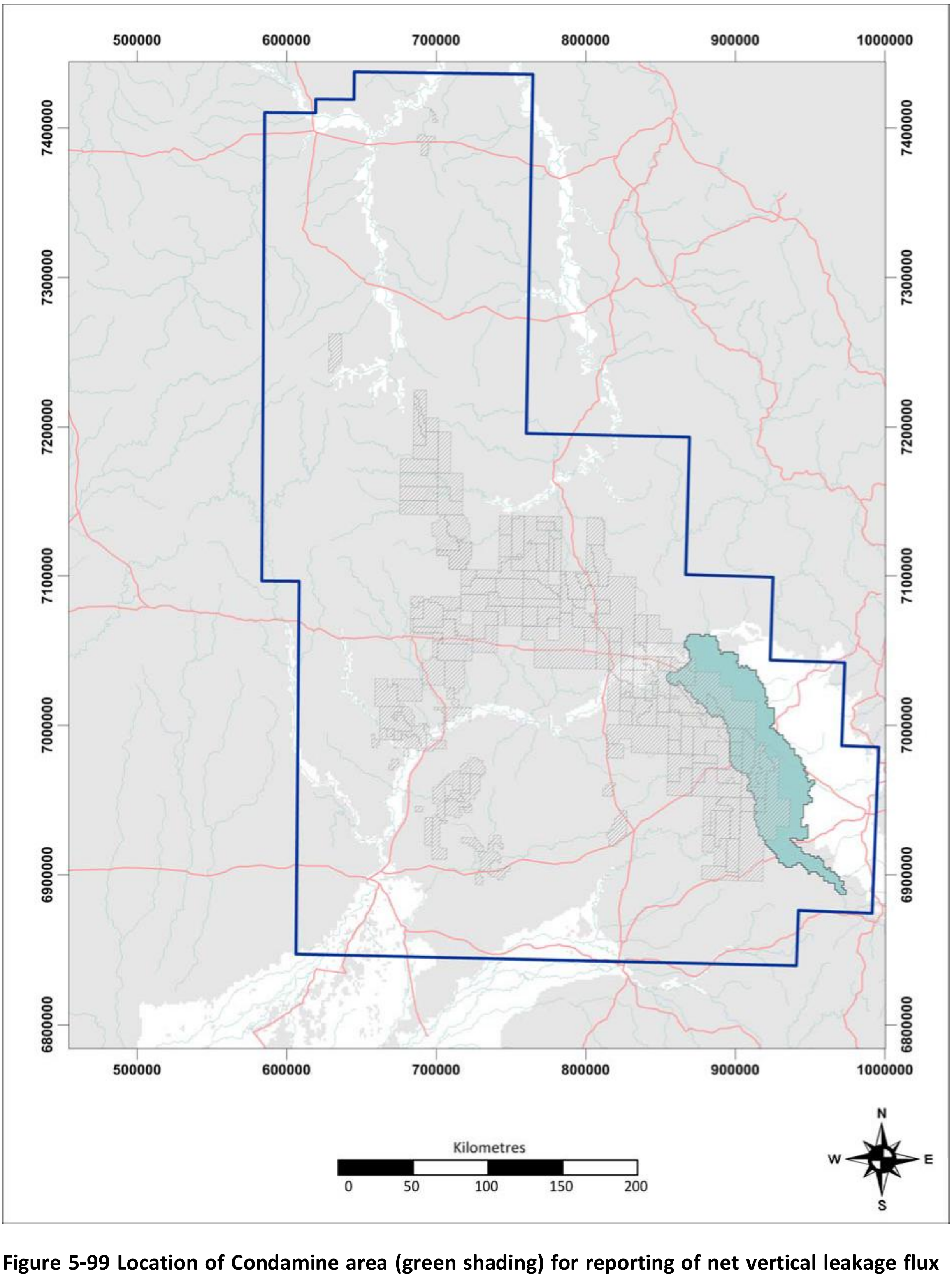


Figure 5-99 Location of Condamine area (green shading) for reporting of net vertical leakage flux "impact" from layer 1 to layer 2

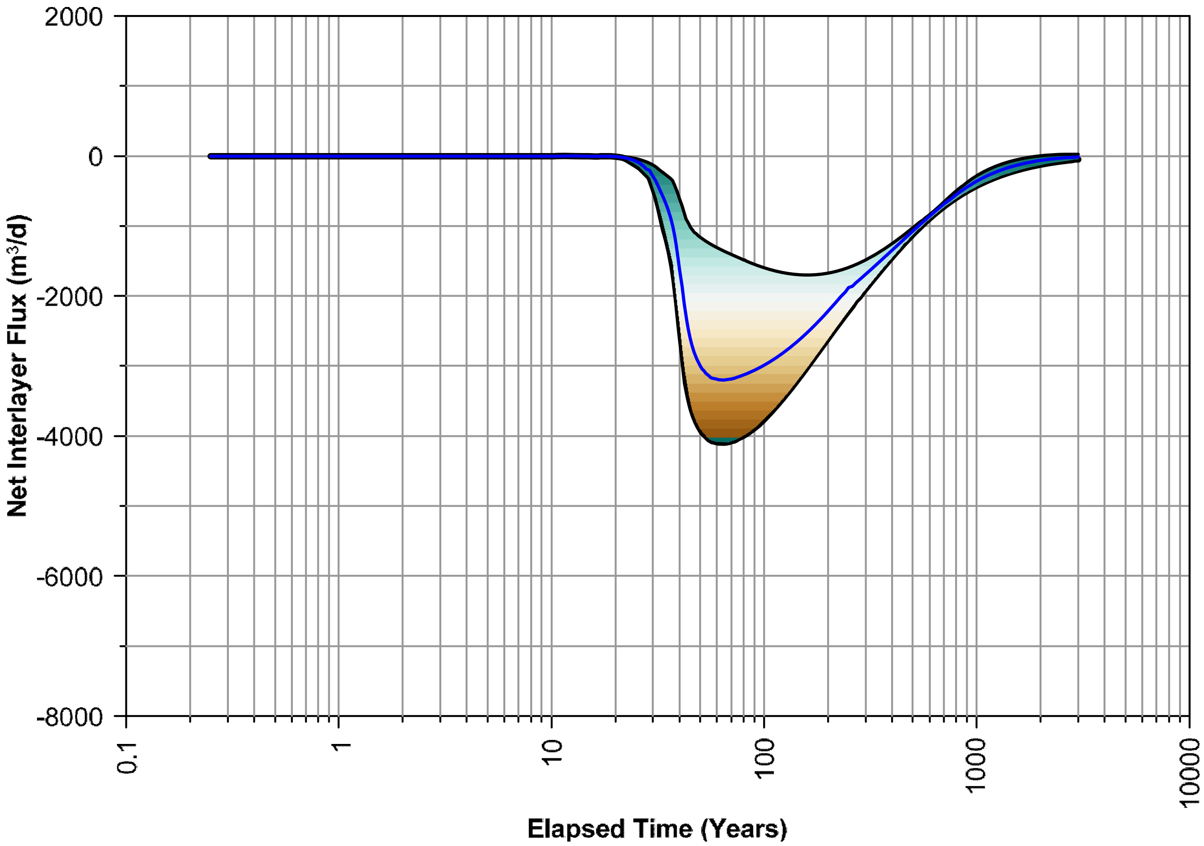


Figure 5-100 The 5th and 95th percentile envelopes of net vertical leakage flux "impact" from layer 1 to 2 in Condamine area. Mean response is also shown as a blue line. Positive values indicate an upward net leakage differential between the base case and CSG case.

Appendix C – Central Condamine Alluvium Stage IV – Numerical Modelling, KCB June 2011, Selected Figures

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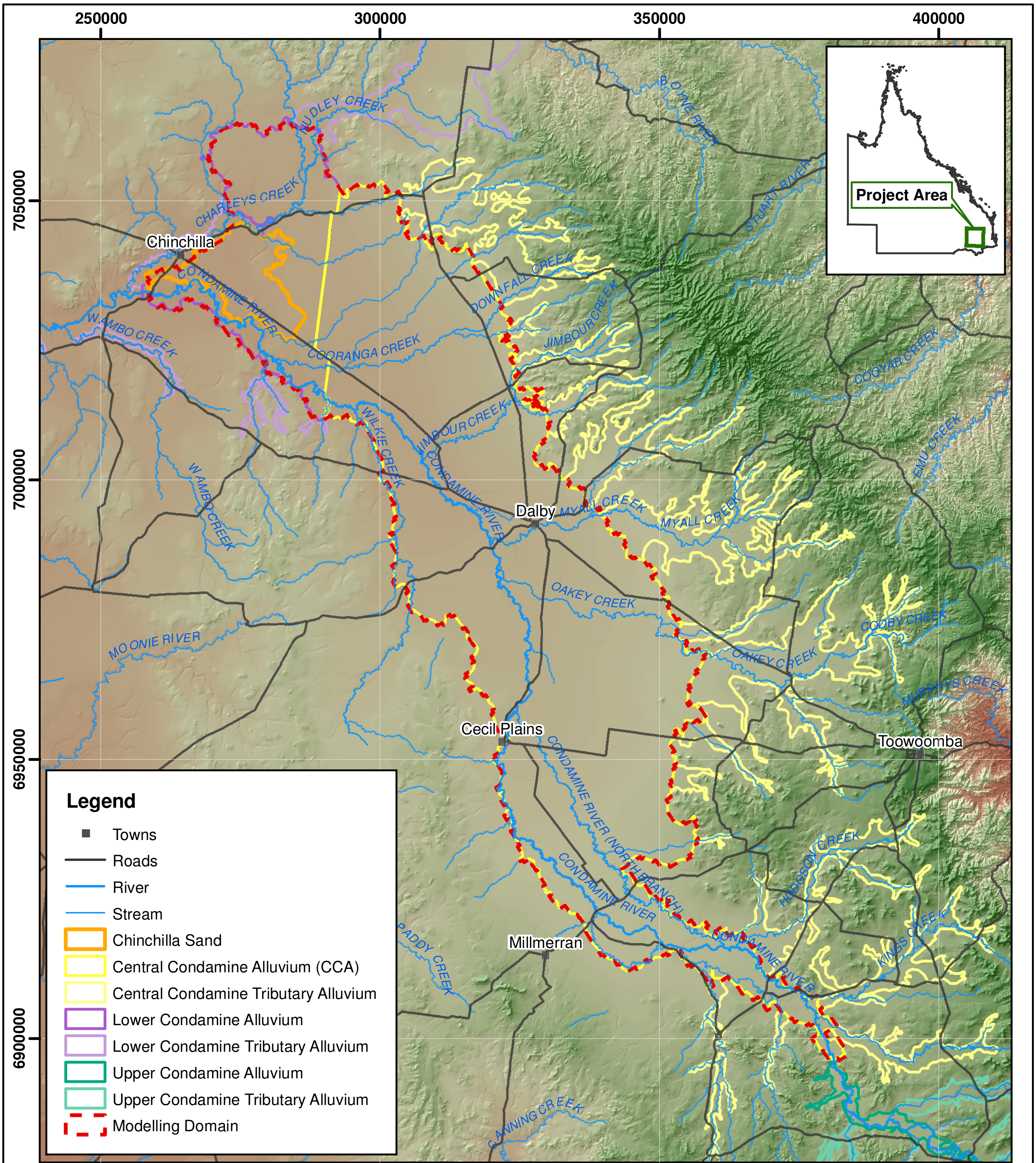

0 10 20 30 40 Kilometers

NOT FOR CONSTRUCTION

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 56
3. Vertical Datum: Mean Sea Level
4. Scale: 1:1,000,000

N

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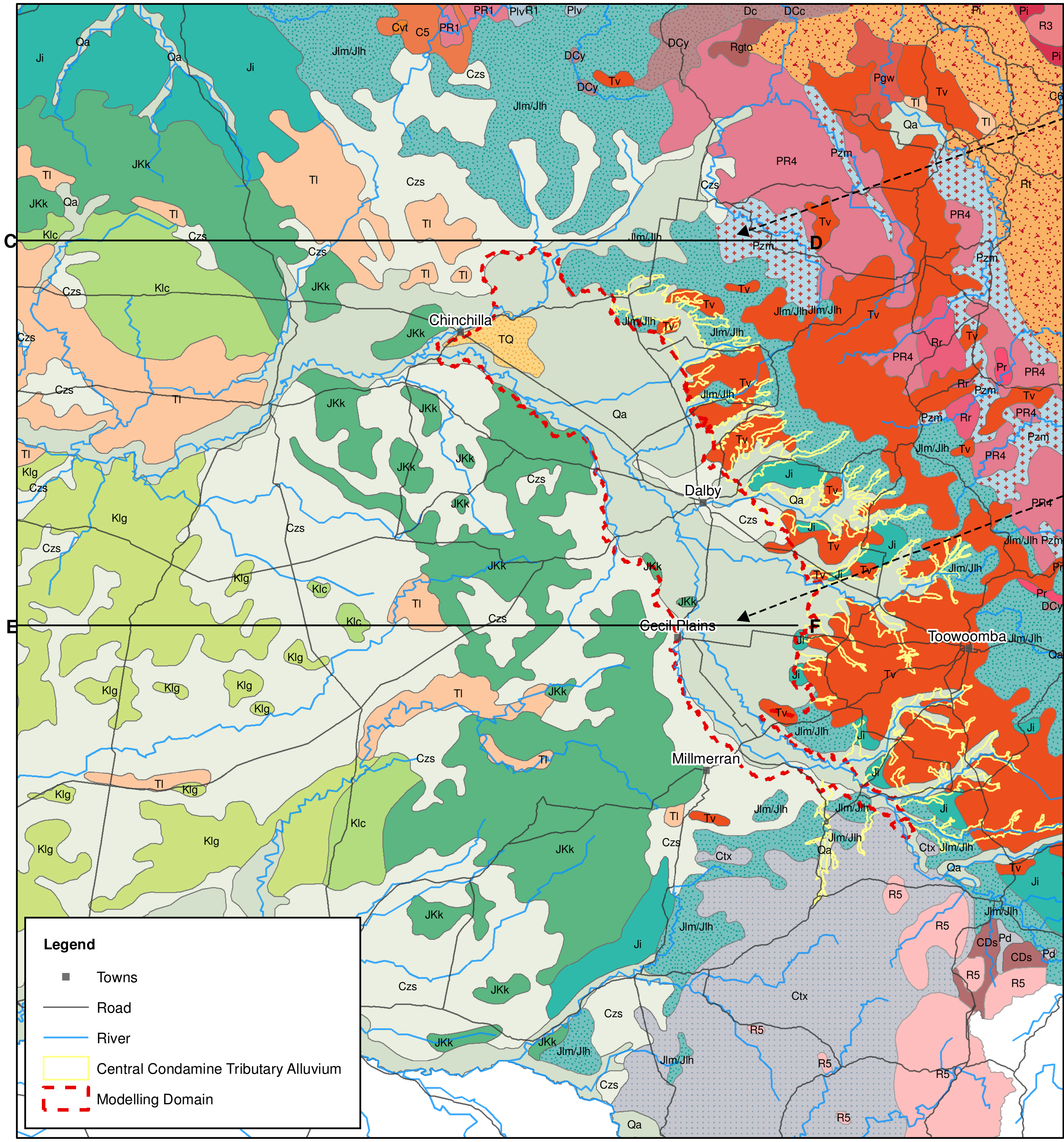
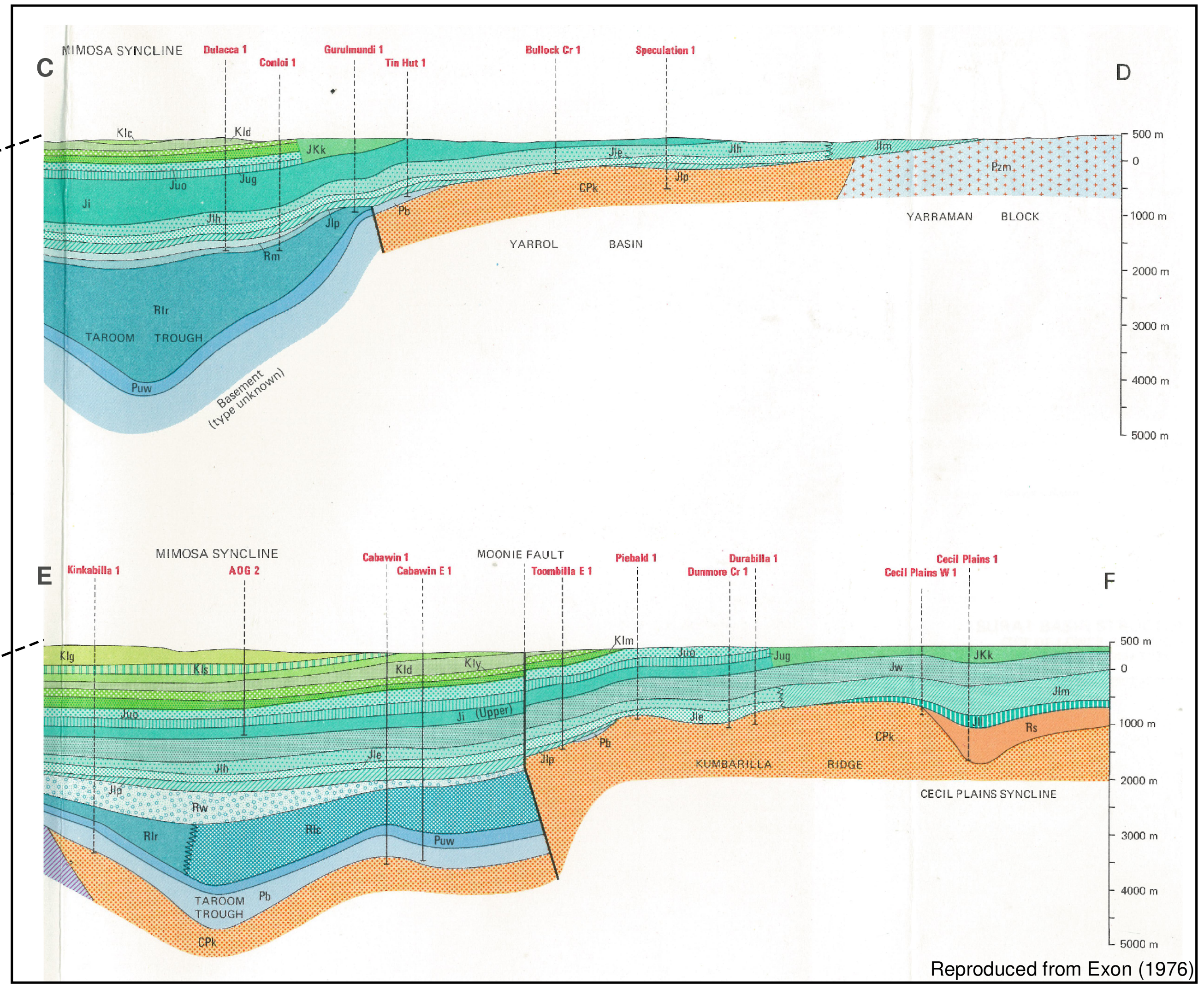
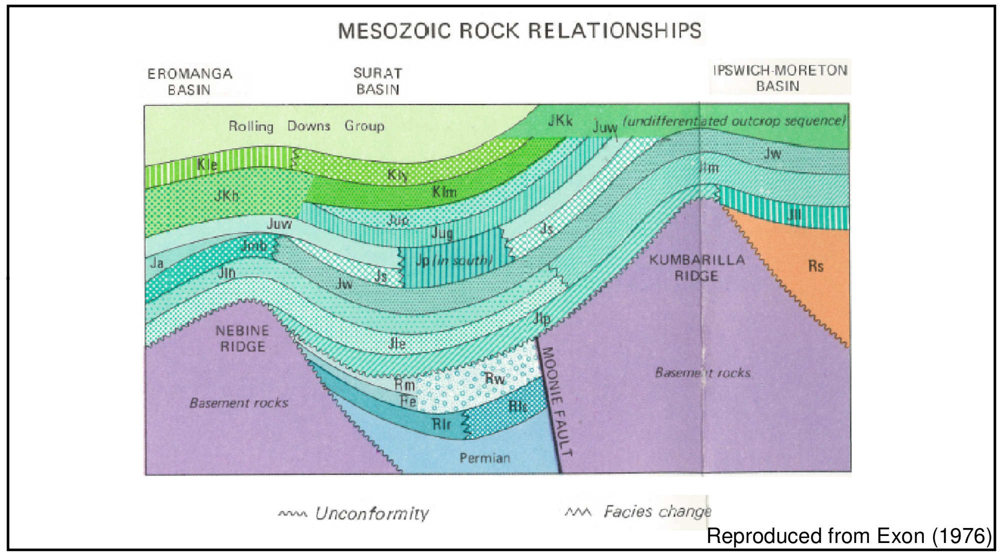
TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED: June 2011

CLIENT	PROJECT
Queensland Government	Department of Environment and Resource Management (DERM)
Klohn Crippen Berger	TITLE: Project Study Limits
	PROJECT No. M09631A02 — FIG No. FIGURE 2.1

Tuesday, June 07, 2011 12:30 PM Z:\MBNE\M09631A02 - Condamine Stages 3 & 4\400 Drawings\Stage_IV_Figures\FinalFigures_110607







Geology

- Qa, Quaternary sediments
- Czs, Late Cainozoic sediments
- Tv, Tertiary volcanics, mainly basalt
- TQ, Pliocene-Pleistocene sediments
- Tl, Paleocene-Oligocene sediments
- Klg, Griman Creek Formation
- Klc, Wallumbilla Formation
- JKk Bungil Formation,Gubberamunda Sandstone,Hooray Sandstone,Kumbarilla beds
- JKi, Mount Bauple Syenite
- Ji, Injune Creek Group,Walloon Subgroup
- Jlm/Jlh, Evergreen Formation,Hutton Sandstone,Marburg Formation,Precipice Sandstone
- R1, Boolgal Granite
- R3, Unnamed intrusions in Gympie Block
- R5, New Englan Batholith
- R7, Enoggera Granite
- Rc, Cynthia beds
- Rgto, Toondahra Granite
- Rr, Tarong beds
- Rt, Agnes Water Volcanics
- Pd, Condamine beds
- PR1, Eulogie Park Gabbro
- PR4, Boondooma Igneous Complex
- Pgw, Wigton Granite
- Pi, Biggenden beds
- Plv, Volcanic units of NE Bowen Basin
- Pr, Cressbrook Creek Group
- Cvt, Torsdale Volcanics
- Ctx, Texas beds
- CDs, Silverwood Group
- C6, Claddagh Granodiorite
- C5, Glandore Granodiorite
- DCc, Curtis Island Group
- Pzm, Maronghi Creek beds
- DCu, Bunya Phyllite
- DCy, Yarrol & Campwyn Blocks
- Dc, Barmundoo beds

0 10 20 40 60 80 100 Kilometers

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 56
3. Vertical Datum: Mean Sea Level
4. Scale 1:1,500,000

N

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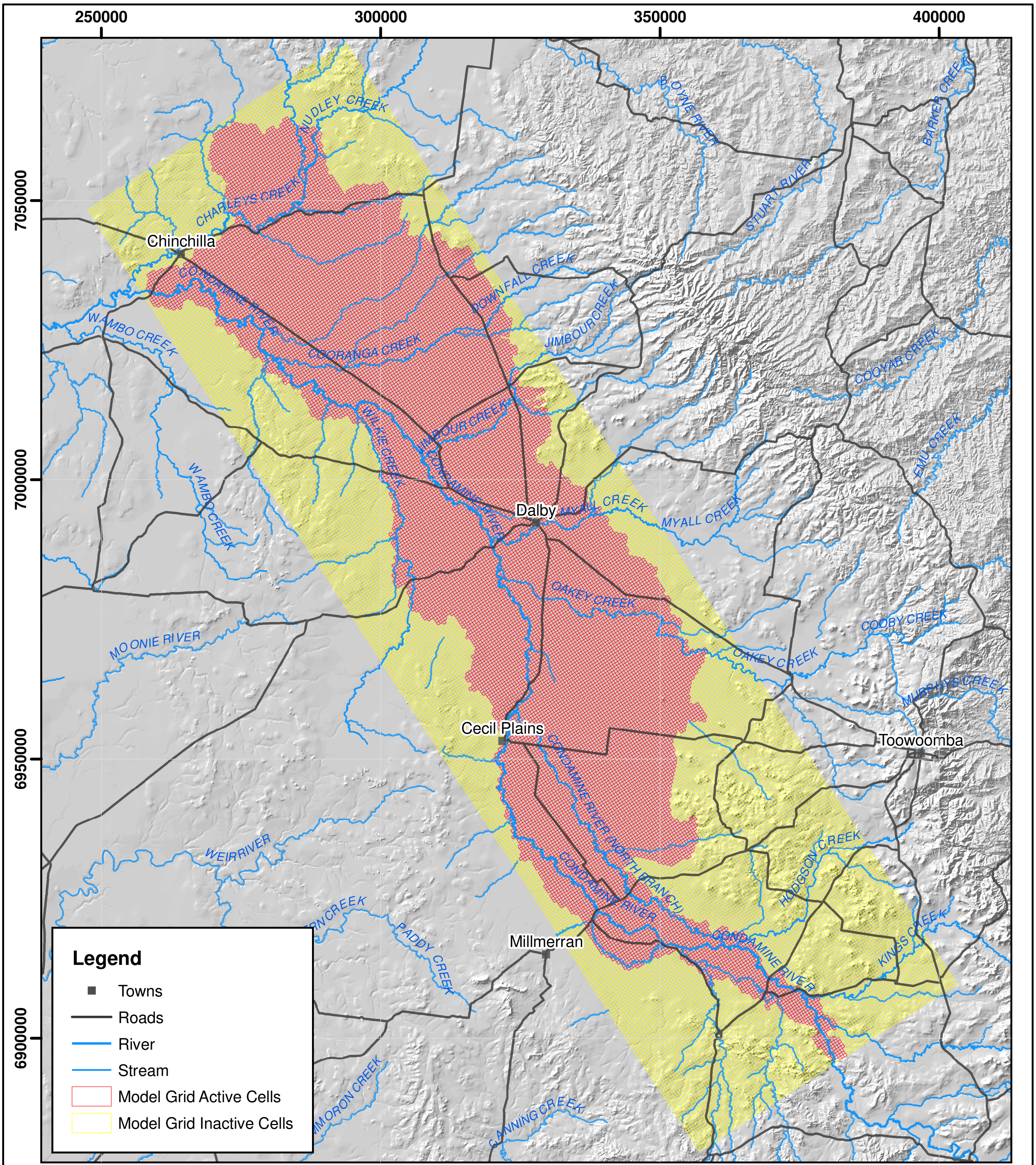
CLIENT
Queensland Government
Klohn Crippen Berger

PROJECT
Department of Environment and Resource Management (DERM)

TITLE
Regional Interpretation, after Exon, 1976

PROJECT No. M09631A02
FIG No. FIGURE 2.3

Tuesday, June 07, 2011 12:30 PM Z:\MBNE\M09631A02 - Condamine Stages 3 & 4\400 Drawings\Stage_IV_Figures\FinalFigures_110607



0 10 20 30 40 Kilometers

NOT FOR CONSTRUCTION

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 56
3. Vertical Datum: Mean Sea Level
4. Scale: 1:1,000,000

N

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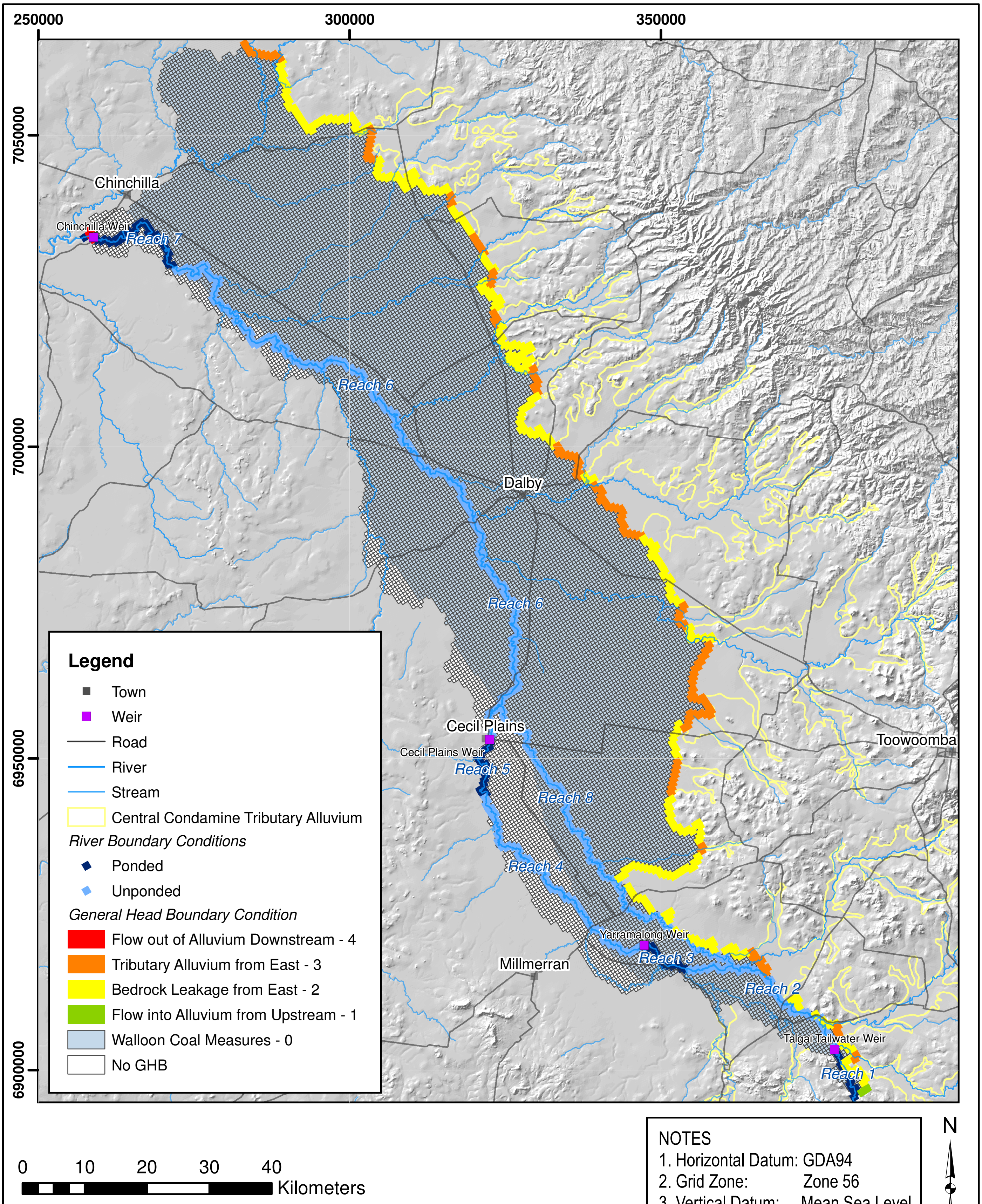
CLIENT Queensland Government	PROJECT Department of Environment and Resource Management (DERM)
Klohn Crippen Berger	TITLE **Model Grid Active Area**
	PROJECT No. M09631A02 — FIG No. FIGURE 3.1

Tuesday, June 07, 2011 12:30 PM Z:\MBNE\M09631A02 - Condamine Stages 3 & 4\400 Drawings\Stage_IV_Figures\FinalFigures_110607



NOT FOR CONSTRUCTION

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 56
3. Vertical Datum: Mean Sea Level
4. Scale: 1:850,000

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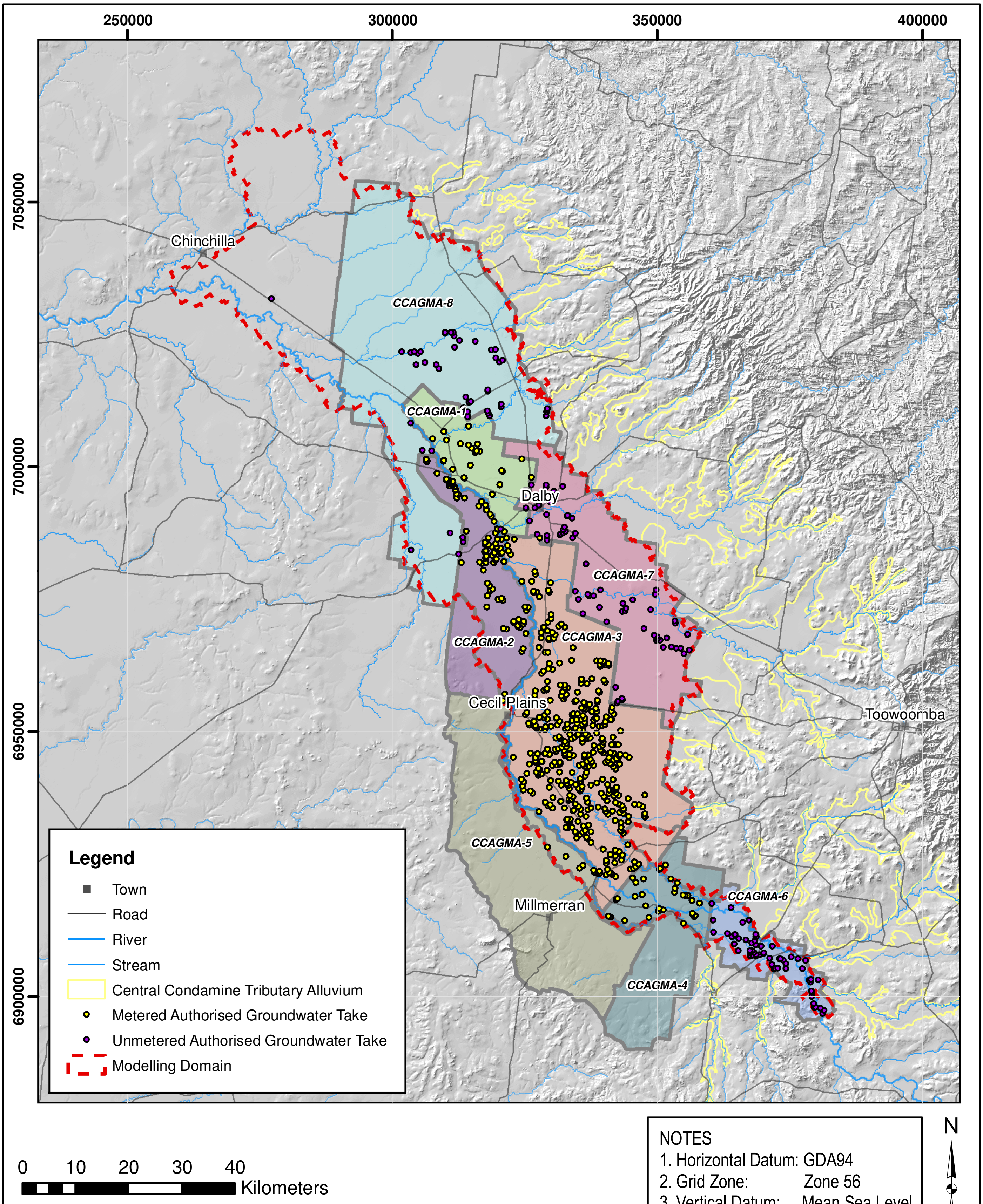
PROJECT
Department of Environment and Resource Management (DERM)

TITLE
Boundary Conditions

PROJECT No. **M09631A02**

FIG No. **FIGURE 3.8**



NOT FOR CONSTRUCTION

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 56
3. Vertical Datum: Mean Sea Level
4. Scale: 1:1,000,000

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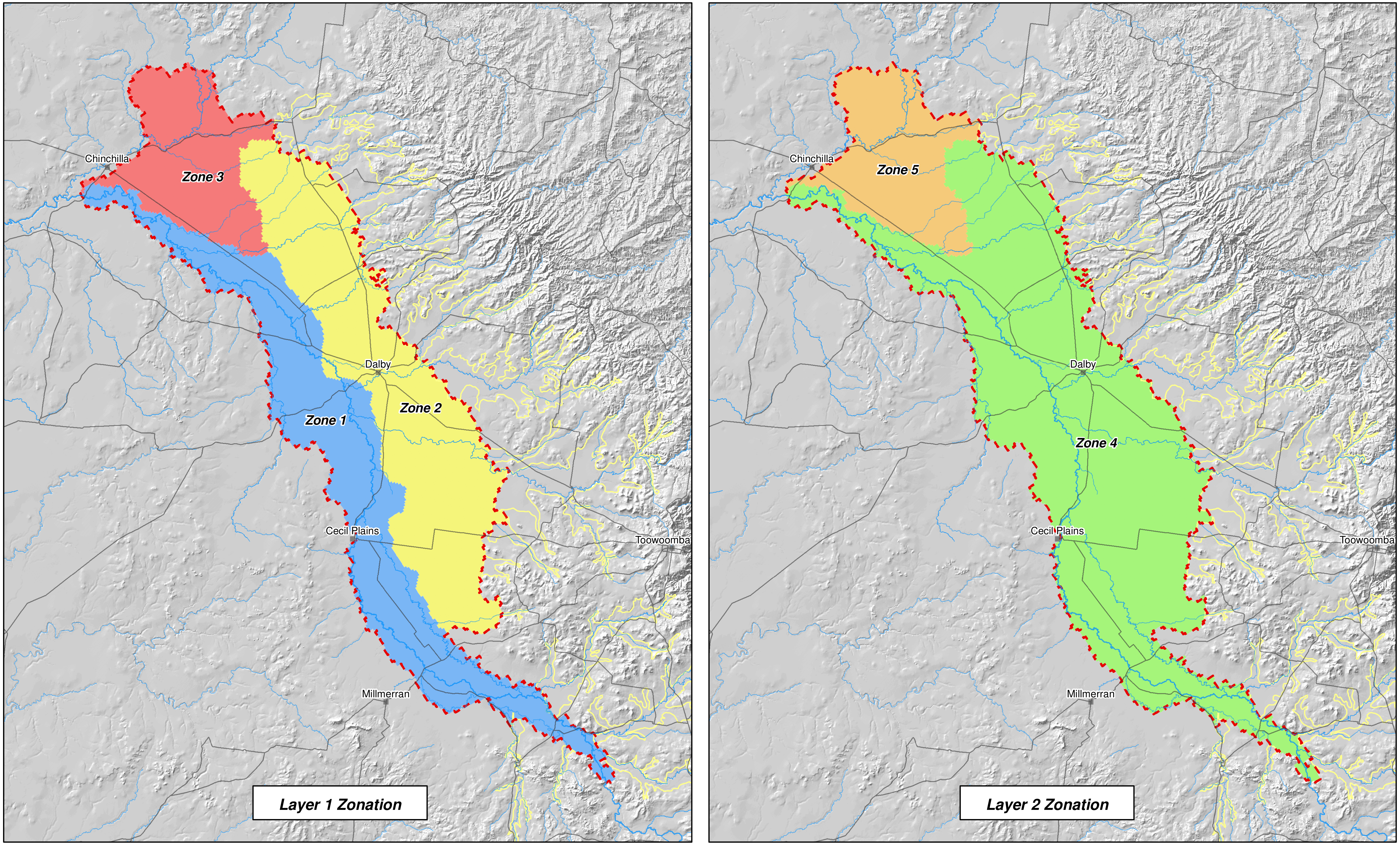
CLIENT Queensland Government	PROJECT Department of Environment and Resource Management (DERM)
Klohn Crippen Berger	TITLE Filtered Metered and Unmetered Abstraction Locations
	PROJECT No. M09631A02 — FIG No. FIGURE 3.9



Legend

- Town
- Road
- River
- Central Condamine Tributary Alluvium
- Stream
- Modelling Domain

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 56
3. Vertical Datum: Mean Sea Level
4. Scale: 1:850,000

NOT FOR CONSTRUCTION

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Klohn Crippen Berger

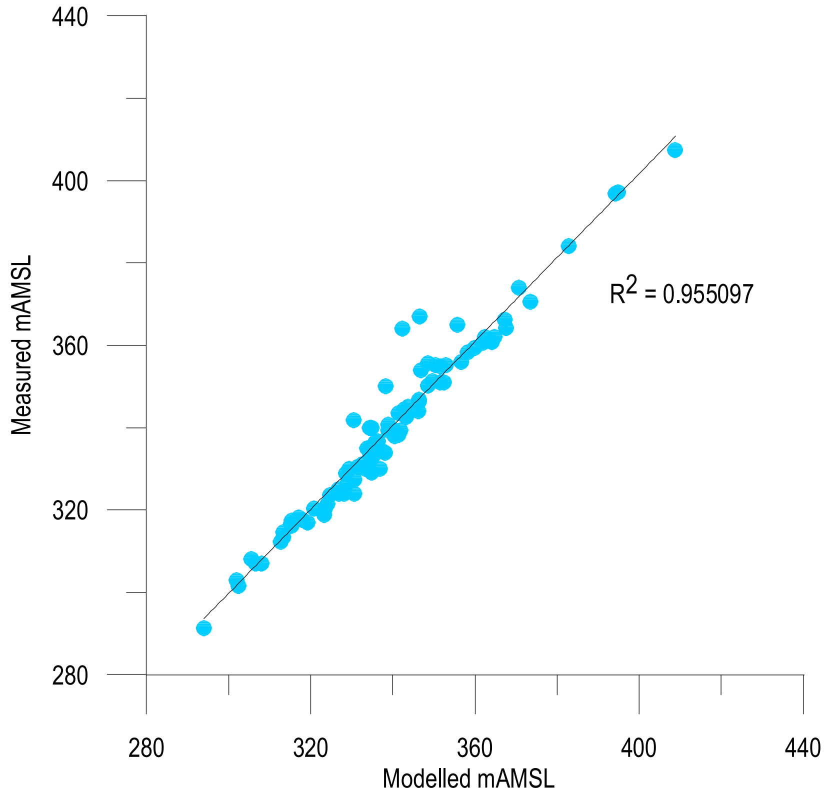
PROJECT: Department of Environment and Resource Management (DERM)

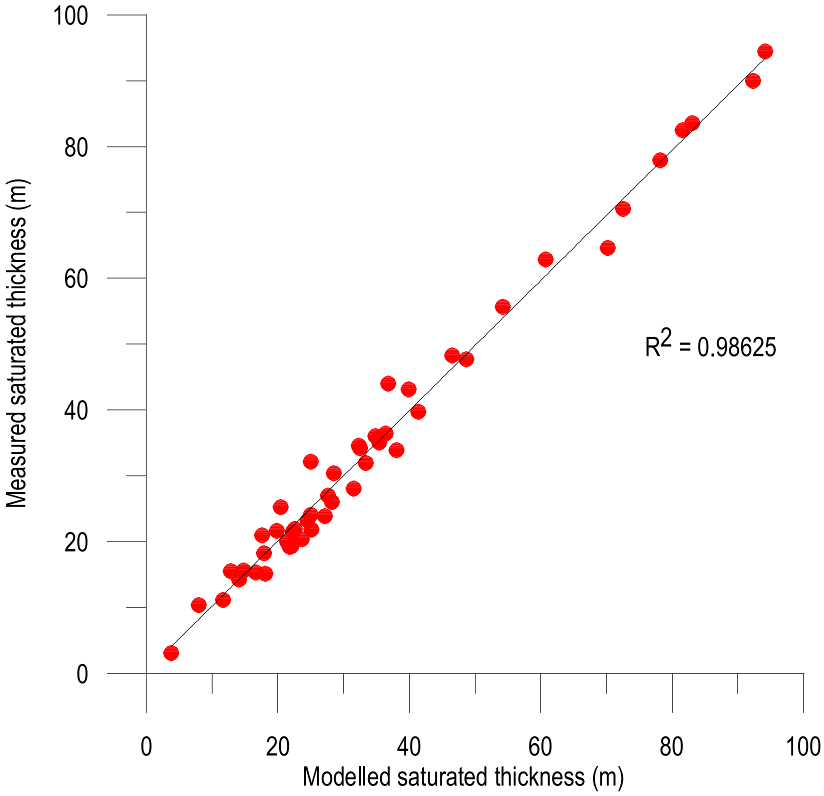
TITLE: Layer 1 and 2 Parameter Zonation

PROJECT No. M09631A02

FIG No. FIGURE 3.14

Tuesday, June 07, 2011 12:30 PM Z:\MBNE\M09631A02 - Condamine Stages 3 & 4\400 Drawings\Stage_IV_Figures\FinalFigures_110607





TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED DECEMBER 2010

CLIENT: Queensland Government

Klohn Crippen Berger

PROJECT: Department of Environment and Resource Management (DERM)

TITLE: **Steady state (1/1/1980) water level scatter mAMSL and Saturated thickness**

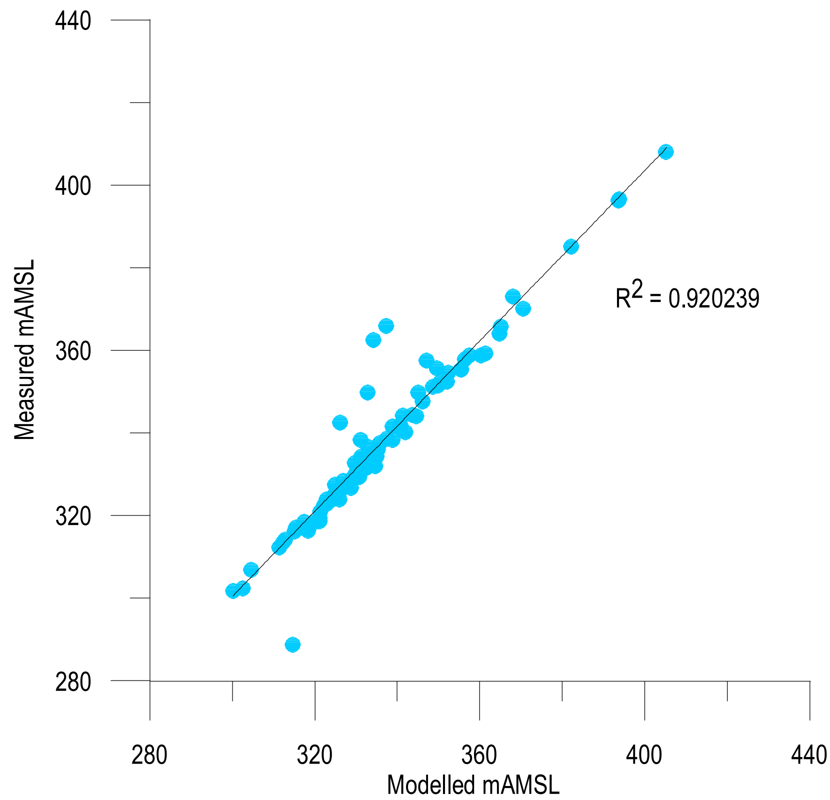
PROJECT NO. M09631A02.400

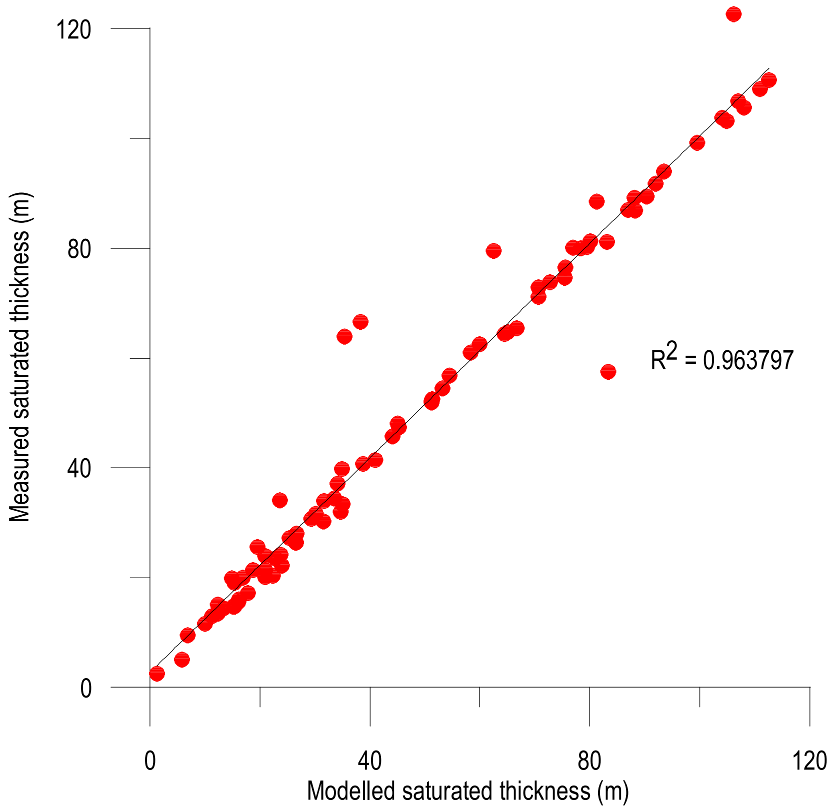
FIGURE NO. **FIGURE 4.3**

Parameter	Calibrated value	Lower Bound	Upper Bound	Parameter	Calibrated value	Lower Bound	Upper Bound
Hydraulic Conductivity horizontal m/day (Kxy)							
kxy1pp01	0.5	0.5	40	kxy2pp01	3.448357	0.5	40
kxy1pp02	40	0.5	40	kxy2pp02	40	0.5	40
kxy1pp03	5.895957	0.5	40	kxy2pp03	17.8447	0.5	40
kxy1pp04	40	0.5	40	kxy2pp04	0.5	0.5	40
kxy1pp05	40	0.5	40	kxy2pp05	0.5	0.5	40
kxy1pp06	40	0.5	40	kxy2pp06	0.5	0.5	40
kxy1pp07	40	0.5	40	kxy2pp07	40	0.5	40
kxy1pp08	40	0.5	40	kxy2pp08	40	0.5	40
kxy1pp09	4.445404	0.5	40	kxy2pp09	40	0.5	40
kxy1pp10	40	0.5	40	kxy2pp10	40	0.5	40
kxy1pp11	40	0.5	40	kxy2pp11	40	0.5	40
kxy1pp12	40	0.5	40	kxy2pp12	0.9637534	0.5	40
kxy1pp13	40	0.5	40	kxy2pp13	40	0.5	40
kxy1pp14	9.205461	0.5	40	kxy2pp14	40	0.5	40
kxy1pp15	5.86E-02	0.05	3	kxy2pp15	40	0.5	40
kxy1pp16	5.00E-02	0.05	3	kxy2pp16	0.5	0.5	40
kxy1pp17	0.1340721	0.05	3	kxy2pp17	40	0.5	40
kxy1pp18	0.4985905	0.05	3	kxy2pp18	0.5	0.5	40
kxy1pp19	0.1246179	0.05	3	kxy2pp19	40	0.5	40
kxy1pp20	0.2751757	0.05	3	kxy2pp20	40	0.5	40
kxy1pp21	0.2691962	0.05	3	kxy2pp21	40	0.5	40
kxy1pp22	0.2720174	0.05	3	kxy2pp22	40	0.5	40
kxy1pp23	0.1001686	0.05	3	kxy2pp23	40	0.5	40
kxy1pp24	5.00E-02	0.05	3	kxy2pp24	40	0.5	40
kxy1pp25	5.03E-02	0.05	3	kxy2pp25	40	0.5	40
kxy1pp26	0.2023173	0.05	3	kxy2pp26	40	0.5	40
kxy1pp27	1.111906	0.5	10	kxy2pp27	5.232285	0.5	40
kxy1pp28	5.517323	0.5	40	kxy2pp28	4.422666	0.5	40
kxy1pp29	4.996948	0.5	10	kxy2pp29	34.60152	0.5	40
kxy1pp30	40	0.5	40	kxy2pp30	40	0.5	40
kxy1pp31	40	0.5	40	kxy2pp31	40	0.5	40
kxy1pp32	40	0.5	40	kxy2pp32	40	0.5	40
kxy1pp33	40	0.5	40	kxy2pp33	2.322619	0.5	40
kxy1pp34	0.8218773	0.5	40	kxy2pp34	40	0.5	40
kxy1pp35	40	0.5	40	kxy2pp35	16.25842	0.5	40
kxy1pp36	1.126758	0.5	40	kxy2pp36	40	0.5	40
kxy1pp37	40	0.5	40	kxy2pp37	40	0.5	40
kxy1pp38	40	0.5	40	kxy2pp38	40	0.5	40
kxy1pp39	40	0.5	40	kxy2pp39	3.277827	0.5	40
kxy1pp40	4.468762	0.5	10	kxy2pp40	40	0.5	40
kxy1pp41	0.4277793	0.05	3	kxy2pp41	40	0.5	40
kxy1pp42	0.1204984	0.05	3	kxy2pp42	40	0.5	40

Parameter	Calibrated value	Lower Bound	Upper Bound	Parameter	Calibrated value	Lower Bound	Upper Bound
kxy1pp43	0.4253595	0.05	3	kxy2pp43	40	0.5	40
kxy1pp44	0.2116779	0.05	3	kxy2pp44	40	0.5	40
kxy1pp45	0.1833643	0.05	3	kxy2pp45	0.5	0.5	40
kxy1pp46	0.1771879	0.05	3	kxy2pp46	40	0.5	40
kxy1pp47	0.4961506	0.05	3	kxy2pp47	40	0.5	40
kxy1pp48	8.93E-02	0.05	3	kxy2pp48	0.5	0.5	40
kxy1pp49	5.00E-02	0.05	3	kxy2pp49	5.966918	0.5	40
kxy1pp50	0.4464504	0.05	3	kxy2pp50	0.5	0.5	40
kxy1pp51	0.1720699	0.05	3	kxy2pp51	40	0.5	40
Hydraulic Conductivity vertical ration Kxy1 to Kxy2							
kz01	7.15E-02	0.01	0.3				
kz02	2.10E-03	0.001	0.3				
Specific Yield Sy1 and Sy2							
sy1pp01	0.1	0.001	0.1	sy2pp01	0.1	0.001	0.1
sy1pp02	1.00E-03	0.001	0.1	sy2pp02	1.00E-03	0.001	0.1
sy1pp03	1.00E-03	0.001	0.1	sy2pp03	1.00E-03	0.001	0.1
sy1pp04	0.1	0.001	0.1	sy2pp04	0.1	0.001	0.1
sy1pp05	0.1	0.001	0.1	sy2pp05	0.1	0.001	0.1
sy1pp06	0.1	0.001	0.1	sy2pp06	0.1	0.001	0.1
sy1pp07	0.1	0.001	0.1	sy2pp07	0.1	0.001	0.1
sy1pp08	0.1	0.001	0.1	sy2pp08	0.1	0.001	0.1
sy1pp09	0.1	0.001	0.1	sy2pp09	0.1	0.001	0.1
sy1pp10	0.1	0.001	0.1	sy2pp10	0.1	0.001	0.1
sy1pp11	0.1	0.001	0.1	sy2pp11	0.1	0.001	0.1
sy1pp12	1.00E-03	0.001	0.1	sy2pp12	1.00E-03	0.001	0.1
sy1pp13	2.58E-02	0.001	0.1	sy2pp13	0.1	0.001	0.1
sy1pp14	1.00E-03	0.001	0.1	sy2pp14	3.05E-03	0.001	0.1
sy1pp15	0.1	0.001	0.1	sy2pp15	4.07E-03	0.001	0.1
sy1pp16	1.00E-03	0.001	0.1	sy2pp16	7.51E-03	0.001	0.1
sy1pp17	1.00E-03	0.001	0.1	sy2pp17	1.00E-03	0.001	0.1
sy1pp18	0.1	0.001	0.1	sy2pp18	0.1	0.001	0.1
sy1pp19	0.1	0.001	0.1	sy2pp19	0.1	0.001	0.1
sy1pp20	0.1	0.001	0.1	sy2pp20	0.1	0.001	0.1
sy1pp21	0.1	0.001	0.1	sy2pp21	0.1	0.001	0.1
sy1pp22	0.1	0.001	0.1	sy2pp22	1.00E-03	0.001	0.1
sy1pp23	0.1	0.001	0.1	sy2pp23	3.62E-03	0.001	0.1
sy1pp24	0.1	0.001	0.1	sy2pp24	0.1	0.001	0.1
sy1pp25	0.1	0.001	0.1	sy2pp25	1.00E-03	0.001	0.1
sy1pp26	0.1	0.001	0.1	sy2pp26	0.1	0.001	0.1
sy1pp27	8.16E-03	0.001	0.1	sy2pp27	0.1	0.001	0.1
sy1pp28	0.1	0.001	0.1	sy2pp28	0.1	0.001	0.1
sy1pp29	0.1	0.001	0.1	sy2pp29	0.1	0.001	0.1
Storage Compressibility Ss1 and Ss2							
ss1pp01	3.94E-05	0.000002	0.02	ss2pp01	2.00E-02	0.000002	0.02
ss1pp02	8.33E-04	0.000002	0.02	ss2pp02	2.00E-06	0.000002	0.02
ss1pp03	3.83E-05	0.000002	0.02	ss2pp03	1.82E-04	0.000002	0.02
ss1pp04	2.00E-02	0.000002	0.02	ss2pp04	2.00E-02	0.000002	0.02

Parameter	Calibrated value	Lower Bound	Upper Bound	Parameter	Calibrated value	Lower Bound	Upper Bound
ss1pp05	2.00E-02	0.000002	0.02	ss2pp05	2.00E-02	0.000002	0.02
ss1pp06	2.00E-02	0.000002	0.02	ss2pp06	2.00E-02	0.000002	0.02
ss1pp07	2.00E-02	0.000002	0.02	ss2pp07	2.00E-02	0.000002	0.02
ss1pp08	2.00E-02	0.000002	0.02	ss2pp08	2.00E-02	0.000002	0.02
ss1pp09	8.52E-05	0.000002	0.02	ss2pp09	2.00E-02	0.000002	0.02
ss1pp10	2.00E-02	0.000002	0.02	ss2pp10	2.00E-02	0.000002	0.02
ss1pp11	2.80E-05	0.000002	0.02	ss2pp11	2.92E-04	0.000002	0.02
ss1pp12	7.18E-06	0.000002	0.02	ss2pp12	5.81E-05	0.000002	0.02
ss1pp13	5.72E-04	0.000002	0.02	ss2pp13	1.90E-04	0.000002	0.02
ss1pp14	5.46E-05	0.000002	0.02	ss2pp14	3.61E-05	0.000002	0.02
ss1pp15	3.68E-04	0.000002	0.02	ss2pp15	2.00E-06	0.000002	0.02
ss1pp16	2.43E-04	0.000002	0.02	ss2pp16	1.04E-04	0.000002	0.02
ss1pp17	3.18E-04	0.000002	0.02	ss2pp17	8.32E-05	0.000002	0.02
ss1pp18	2.00E-02	0.000002	0.02	ss2pp18	2.00E-02	0.000002	0.02
ss1pp19	2.00E-06	0.000002	0.02	ss2pp19	2.00E-02	0.000002	0.02
ss1pp20	1.51E-04	0.000002	0.02	ss2pp20	2.00E-02	0.000002	0.02
ss1pp21	1.32E-04	0.000002	0.02	ss2pp21	2.00E-06	0.000002	0.02
ss1pp22	2.00E-06	0.000002	0.02	ss2pp22	2.00E-02	0.000002	0.02
ss1pp23	2.00E-02	0.000002	0.02	ss2pp23	2.00E-02	0.000002	0.02
ss1pp24	2.00E-06	0.000002	0.02	ss2pp24	1.04E-04	0.000002	0.02
ss1pp25	2.18E-04	0.000002	0.02	ss2pp25	1.20E-03	0.000002	0.02
ss1pp26	5.82E-04	0.000002	0.02	ss2pp26	1.20E-04	0.000002	0.02
ss1pp27	8.01E-05	0.000002	0.02	ss2pp27	2.00E-02	0.000002	0.02
ss1pp28	1.38E-03	0.000002	0.02	ss2pp28	4.37E-05	0.000002	0.02
ss1pp29	4.37E-05	0.000002	0.02	ss2pp29	4.27E-05	0.000002	0.02
River Reach Bed Conductance							
rv01	50	50	300				
rv02	50	50	300				
rv03	300	50	300				
rv04	400	50	400				
rv05	200	20	200				
rv06	20	20	200				
rv07	20	20	200				
rv08	400	20	400				





Wednesday, December 15, 2010 2:11PM Z:\M\BNE\M09631A02 - Condamine Stages 3 & 4\400 Drawings

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CLIENT: Queensland Government

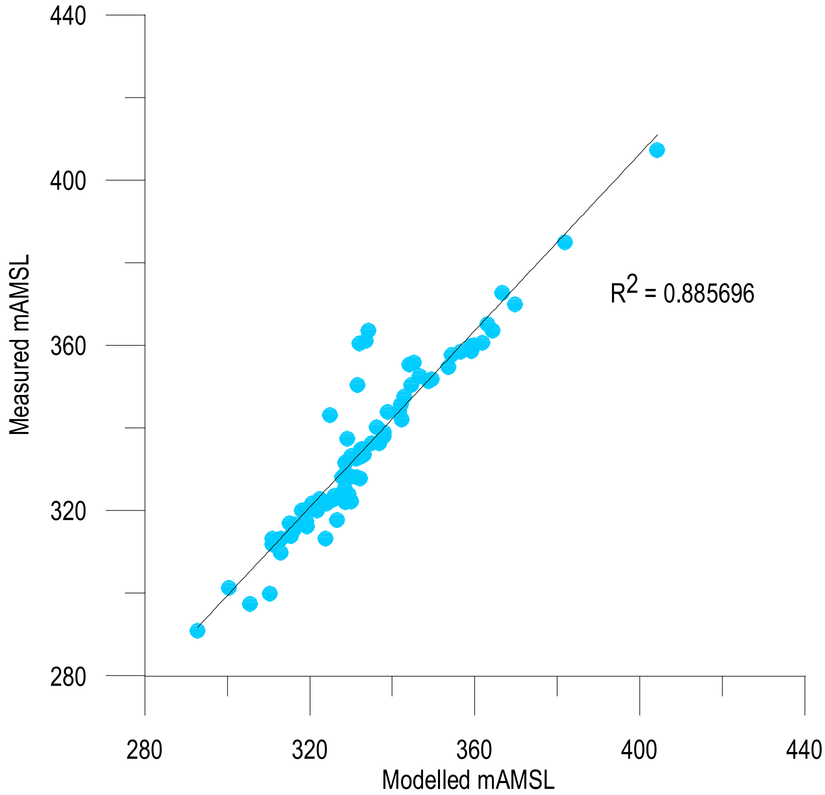
Klohn Crippen Berger

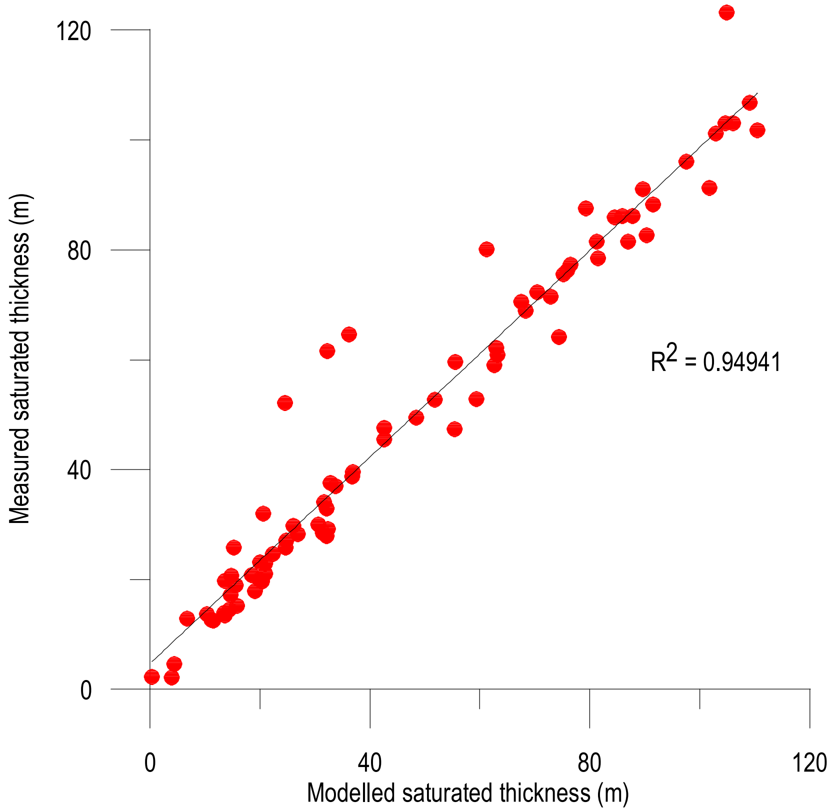
PROJECT: Department of Environment and Resource Management (DERM)

TITLE: Transient state (1/1/1990) water level scatter mAMSL and Saturated thickness

PROJECT NO. M09631A02.400

FIGURE NO. APPENDIX VI-I





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CLIENT: Queensland Government

Klohn Crippen Berger

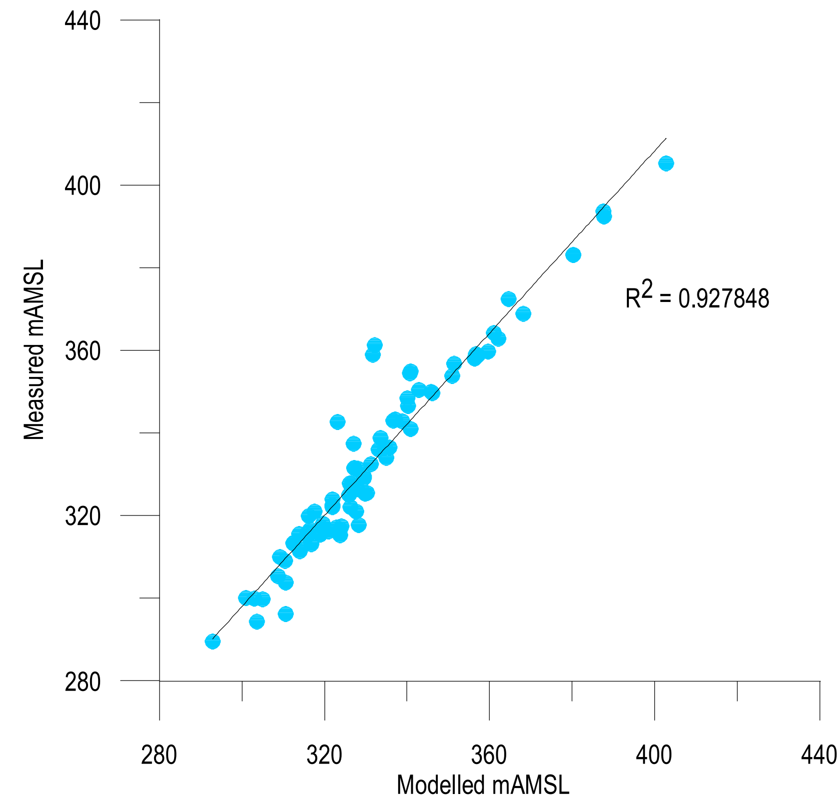
PROJECT: Department of Environment and Resource Management (DERM)

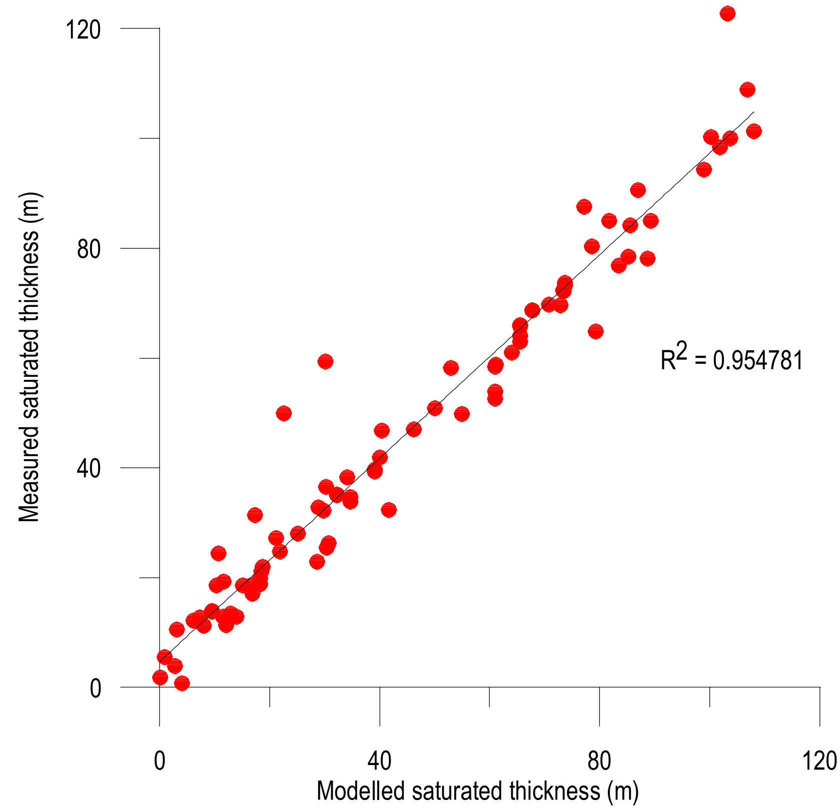
TITLE: **Transient state (1/1/2000) water level scatter mAMSL and Saturated thickness**

PROJECT NO. M09631A02.400

FIGURE NO. APPENDIX VI-II

Wednesday, December 15, 2010 2:11PM Z:\M\BNE\M09631A02 - Condamine Stages 3 & 4\400 Drawings





TO BE READ WITH KLOHN CRIPPEN BERGER REPORT DATED DECEMBER 2010

CLIENT: Queensland Government

Klohn Crippen Berger

PROJECT: Department of Environment and Resource Management (DERM)

TITLE: **Transient state (1/1/2009) water level scatter mAMSL and Saturated thickness**

PROJECT NO. M09631A02.400

FIGURE NO. APPENDIX VI-III

Wednesday, December 15, 2010 2:11PM Z:\M\BNE\M09631A02 - Condamine Stages 3 & 4\400 Drawings

Appendix D – OGIA Surat CMA Groundwater Model 'Benchmarking' Results

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Appendix D - Benchmarking OGIA Surat CMA Groundwater Model

Baseline Scenario

Extract of OGIA Surat CMA Groundwater Model list file (BSv2TRPred022_base.lst) as provided by OGIA

```
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD 259
------------------------------------------------------------------------------

CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
------------------                 ------------------------

IN:                                IN:
---                                ---
STORAGE = 38174843062.0995         STORAGE =      14743.3845
CONSTANT HEAD =         0.0000     CONSTANT HEAD =         0.0000
WELLS =         0.0000             WELLS =         0.0000
DRAINS =         0.0000            DRAINS =         0.0000
RIVER LEAKAGE =         0.0000     RIVER LEAKAGE =         0.0000
HEAD DEP BOUNDS = 43011675213.8120 HEAD DEP BOUNDS =      39842.6316
RECHARGE =     5.8214E+12          RECHARGE =    5312298.6713

TOTAL IN =     5.9026E+12          TOTAL IN =    5366884.6875

OUT:                               OUT:
----                               ----
STORAGE = 11752291779.8203         STORAGE =        673.7993
CONSTANT HEAD =         0.0000     CONSTANT HEAD =         0.0000
WELLS =501460496895.4468           WELLS =     457902.0638
DRAINS =     5.1102E+12            DRAINS =    4656621.5330
RIVER LEAKAGE =228194247917.1004   RIVER LEAKAGE =     205481.1351
HEAD DEP BOUNDS = 50987824890.1030 HEAD DEP BOUNDS =      46206.4275
RECHARGE =         0.0000          RECHARGE =         0.0000

TOTAL OUT =     5.9026E+12         TOTAL OUT =    5366884.9586

IN - OUT =    -152619.8408         IN - OUT =        -0.2711

PERCENT DISCREPANCY =         0.00 PERCENT DISCREPANCY =         0.00


TIME SUMMARY AT END OF TIME STEP   1 IN STRESS PERIOD  259
SECONDS     MINUTES      HOURS       DAYS        YEARS
-----------------------------------------------------------
TIME STEP LENGTH 3.15567E+09 5.25946E+07 8.76576E+05  36524.      99.997
STRESS PERIOD TIME 3.15567E+09 5.25946E+07 8.76576E+05  36524.      99.997
TOTAL TIME 9.46710E+10 1.57785E+09 2.62975E+07 1.09573E+06  2999.9
1

Run end date and time (yyyy/mm/dd hh:mm:ss): 2013/03/07 11:41:22
Elapsed run time:  2 Hours, 20 Minutes, 48 Seconds
```

Extract of OGIA Surat CMA Groundwater Model list file (UWIR2011_BASE_BGT.lst) re-run by GHD

```
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD 259
------------------------------------------------------------------------------

CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
------------------                 ------------------------

IN:                                IN:
---                                ---
STORAGE = 38174843062.0995         STORAGE =      14743.3845
CONSTANT HEAD =         0.0000     CONSTANT HEAD =         0.0000
WELLS =         0.0000             WELLS =         0.0000
DRAINS =         0.0000            DRAINS =         0.0000
RIVER LEAKAGE =         0.0000     RIVER LEAKAGE =         0.0000
HEAD DEP BOUNDS = 43011675213.8120 HEAD DEP BOUNDS =      39842.6316
RECHARGE =     5.8214E+12          RECHARGE =    5312298.6713

TOTAL IN =     5.9026E+12          TOTAL IN =    5366884.6875

OUT:                               OUT:
----                               ----
STORAGE = 11752291779.8203         STORAGE =        673.7993
CONSTANT HEAD =         0.0000     CONSTANT HEAD =         0.0000
WELLS =501460496895.4468           WELLS =     457902.0638
DRAINS =     5.1102E+12            DRAINS =    4656621.5330
RIVER LEAKAGE =228194247917.1004   RIVER LEAKAGE =     205481.1351
HEAD DEP BOUNDS = 50987824890.1030 HEAD DEP BOUNDS =      46206.4275
RECHARGE =         0.0000          RECHARGE =         0.0000

TOTAL OUT =     5.9026E+12         TOTAL OUT =    5366884.9586

IN - OUT =    -152619.8408         IN - OUT =        -0.2711

PERCENT DISCREPANCY =         0.00 PERCENT DISCREPANCY =         0.00


TIME SUMMARY AT END OF TIME STEP   1 IN STRESS PERIOD  259
SECONDS     MINUTES      HOURS       DAYS        YEARS
-----------------------------------------------------------
TIME STEP LENGTH 3.15567E+09 5.25946E+07 8.76576E+05  36524.      99.997
STRESS PERIOD TIME 3.15567E+09 5.25946E+07 8.76576E+05  36524.      99.997
TOTAL TIME 9.46710E+10 1.57785E+09 2.62975E+07 1.09573E+06  2999.9
1

Run end date and time (yyyy/mm/dd hh:mm:ss): 2013/04/08 16:03:22
Elapsed run time:  3 Hours,  1 Minutes, 36 Seconds
```

Appendix D - Benchmarking OGIA Surat CMA Groundwater Model

Impact Scenario

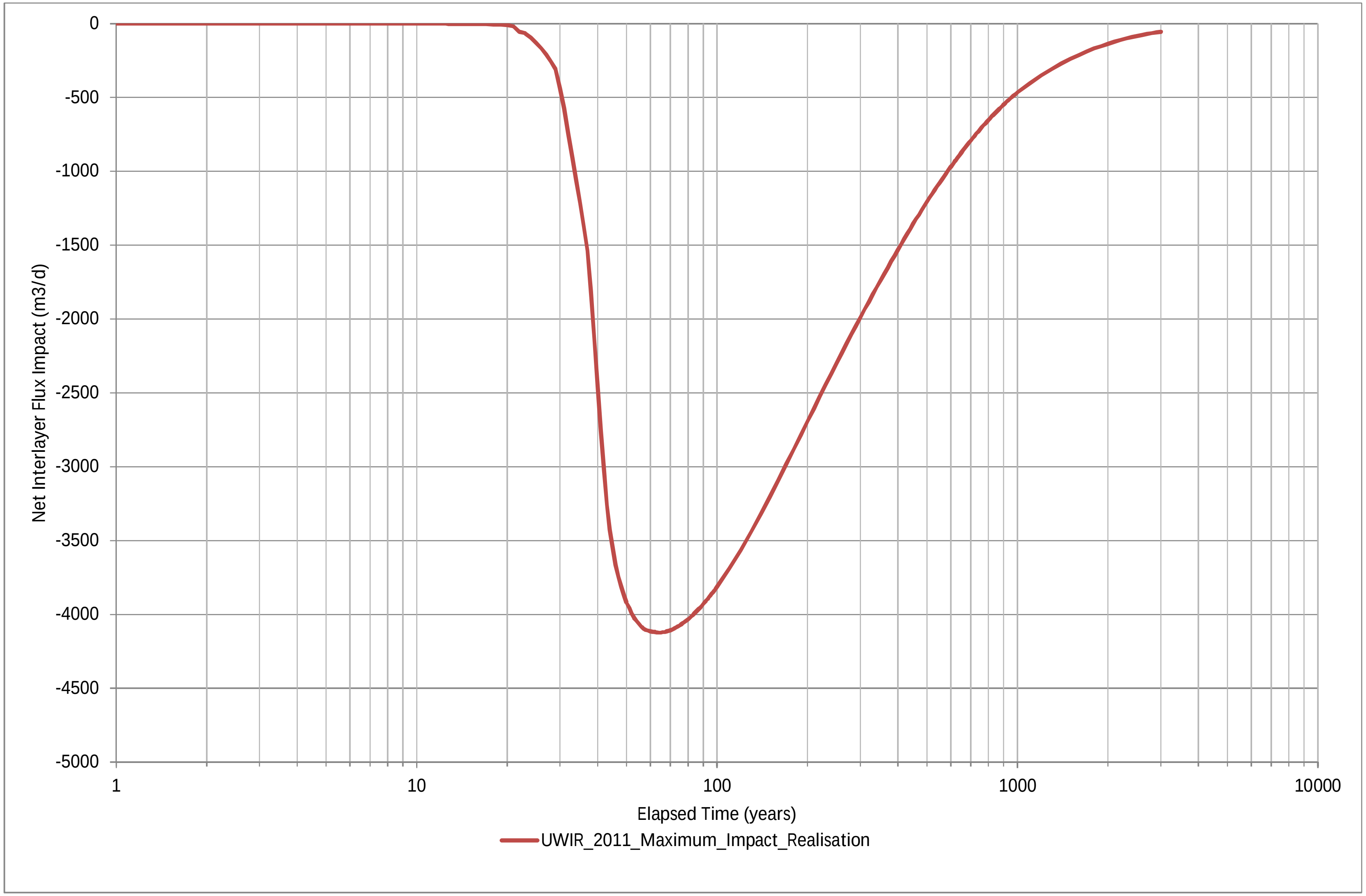
Extract of OGIA Surat CMA Groundwater Model list file (BSv2TRPred022_csg.lst) as provided by OGIA

```
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD 259
------------------------------------------------------------------------------

CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
------------------                 ------------------------

              IN:                                  IN:
              ---                                  ---
       STORAGE = 43480141936.0092            STORAGE =       14303.6758
 CONSTANT HEAD =           0.0000      CONSTANT HEAD =           0.0000
         WELLS =           0.0000              WELLS =           0.0000
        DRAINS =           0.0000             DRAINS =           0.0000
 RIVER LEAKAGE =           0.0000      RIVER LEAKAGE =           0.0000
            ET =           0.0000                 ET =           0.0000
HEAD DEP BOUNDS = 43016225062.5001   HEAD DEP BOUNDS =       39845.8734
      RECHARGE =       5.8214E+12           RECHARGE =     5312298.6713

      TOTAL IN =       5.9079E+12           TOTAL IN =     5366448.2206

             OUT:                                 OUT:
             ----                                 ----
       STORAGE = 16231906345.8156            STORAGE =         817.7160
 CONSTANT HEAD =           0.0000      CONSTANT HEAD =           0.0000
         WELLS =501477235873.6387              WELLS =      457902.0650
        DRAINS =       5.1075E+12             DRAINS =     4656128.4929
 RIVER LEAKAGE =227364446505.2560      RIVER LEAKAGE =      205403.9668
            ET =  4345384405.6012                 ET =           0.0000
HEAD DEP BOUNDS = 50979398074.0830   HEAD DEP BOUNDS =       46196.2409
      RECHARGE =           0.0000           RECHARGE =           0.0000

     TOTAL OUT =       5.9079E+12          TOTAL OUT =     5366448.4816

      IN - OUT =     -179240.3574           IN - OUT =          -0.2610

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00



TIME SUMMARY AT END OF TIME STEP   1 IN STRESS PERIOD  259
          SECONDS     MINUTES      HOURS       DAYS        YEARS
          -----------------------------------------------------------
TIME STEP LENGTH 3.15567E+09 5.25946E+07 8.76576E+05  36524.     99.997
STRESS PERIOD TIME 3.15567E+09 5.25946E+07 8.76576E+05  36524.     99.997
      TOTAL TIME 9.46710E+10 1.57785E+09 2.62975E+07 1.09573E+06  2999.9
1

Run end date and time (yyyy/mm/dd hh:mm:ss): 2013/03/07 19:32:23
Elapsed run time:  2 Hours, 52 Minutes, 27 Seconds
```

Extract of OGIA Surat CMA Groundwater Model list file (UWIR2011_CSG_BGT.lst) re-run by GHD

```
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD 259
------------------------------------------------------------------------------

CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
------------------                 ------------------------

              IN:                                  IN:
              ---                                  ---
       STORAGE = 43480141936.0092            STORAGE =       14303.6758
 CONSTANT HEAD =           0.0000      CONSTANT HEAD =           0.0000
         WELLS =           0.0000              WELLS =           0.0000
        DRAINS =           0.0000             DRAINS =           0.0000
 RIVER LEAKAGE =           0.0000      RIVER LEAKAGE =           0.0000
            ET =           0.0000                 ET =           0.0000
HEAD DEP BOUNDS = 43016225062.5001   HEAD DEP BOUNDS =       39845.8734
      RECHARGE =       5.8214E+12           RECHARGE =     5312298.6713

      TOTAL IN =       5.9079E+12           TOTAL IN =     5366448.2206

             OUT:                                 OUT:
             ----                                 ----
       STORAGE = 16231906345.8156            STORAGE =         817.7160
 CONSTANT HEAD =           0.0000      CONSTANT HEAD =           0.0000
         WELLS =501477235873.6387              WELLS =      457902.0650
        DRAINS =       5.1075E+12             DRAINS =     4656128.4929
 RIVER LEAKAGE =227364446505.2560      RIVER LEAKAGE =      205403.9668
            ET =  4345384405.6012                 ET =           0.0000
HEAD DEP BOUNDS = 50979398074.0830   HEAD DEP BOUNDS =       46196.2409
      RECHARGE =           0.0000           RECHARGE =           0.0000

     TOTAL OUT =       5.9079E+12          TOTAL OUT =     5366448.4816

      IN - OUT =     -179240.3574           IN - OUT =          -0.2610

PERCENT DISCREPANCY =         0.00     PERCENT DISCREPANCY =         0.00



TIME SUMMARY AT END OF TIME STEP   1 IN STRESS PERIOD  259
          SECONDS     MINUTES      HOURS       DAYS        YEARS
          -----------------------------------------------------------
TIME STEP LENGTH 3.15567E+09 5.25946E+07 8.76576E+05  36524.     99.997
STRESS PERIOD TIME 3.15567E+09 5.25946E+07 8.76576E+05  36524.     99.997
      TOTAL TIME 9.46710E+10 1.57785E+09 2.62975E+07 1.09573E+06  2999.9
1

Run end date and time (yyyy/mm/dd hh:mm:ss): 2013/04/08 20:14:58
Elapsed run time:  3 Hours,  1 Minutes,  4 Seconds
```

Appendix D - Benchmarking OGIA Surat CMA Groundwater Model



G:\41\26392\Tech\Design\GWModel\OGIAModel_results\Condam_basal_Flow\

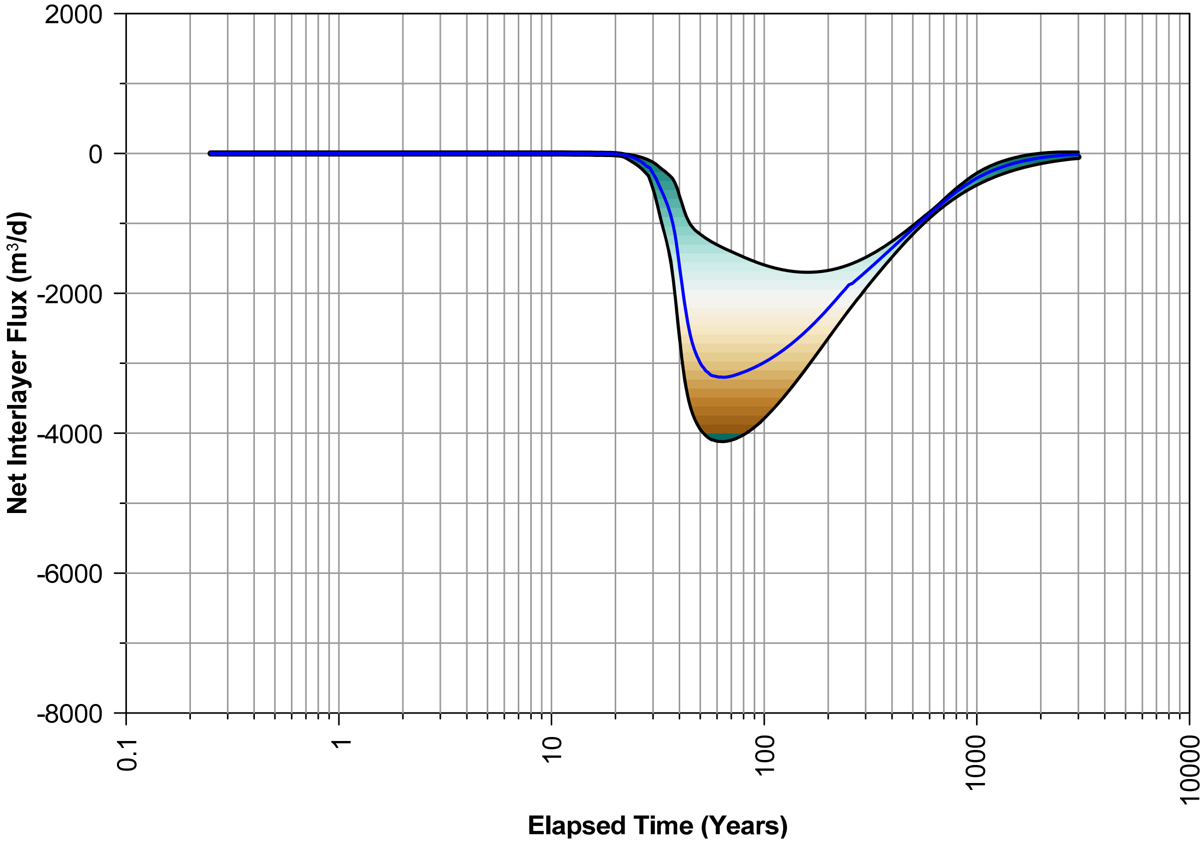


Figure 5-100 The 5th and 95th percentile envelopes of net vertical leakage flux "impact" from layer 1 to 2 in Condamine area. Mean response is also shown as a blue line. Positive values indicate an upward net leakage differential between the base case and CSG case.

Appendix E – Modelled Production Rate Checks

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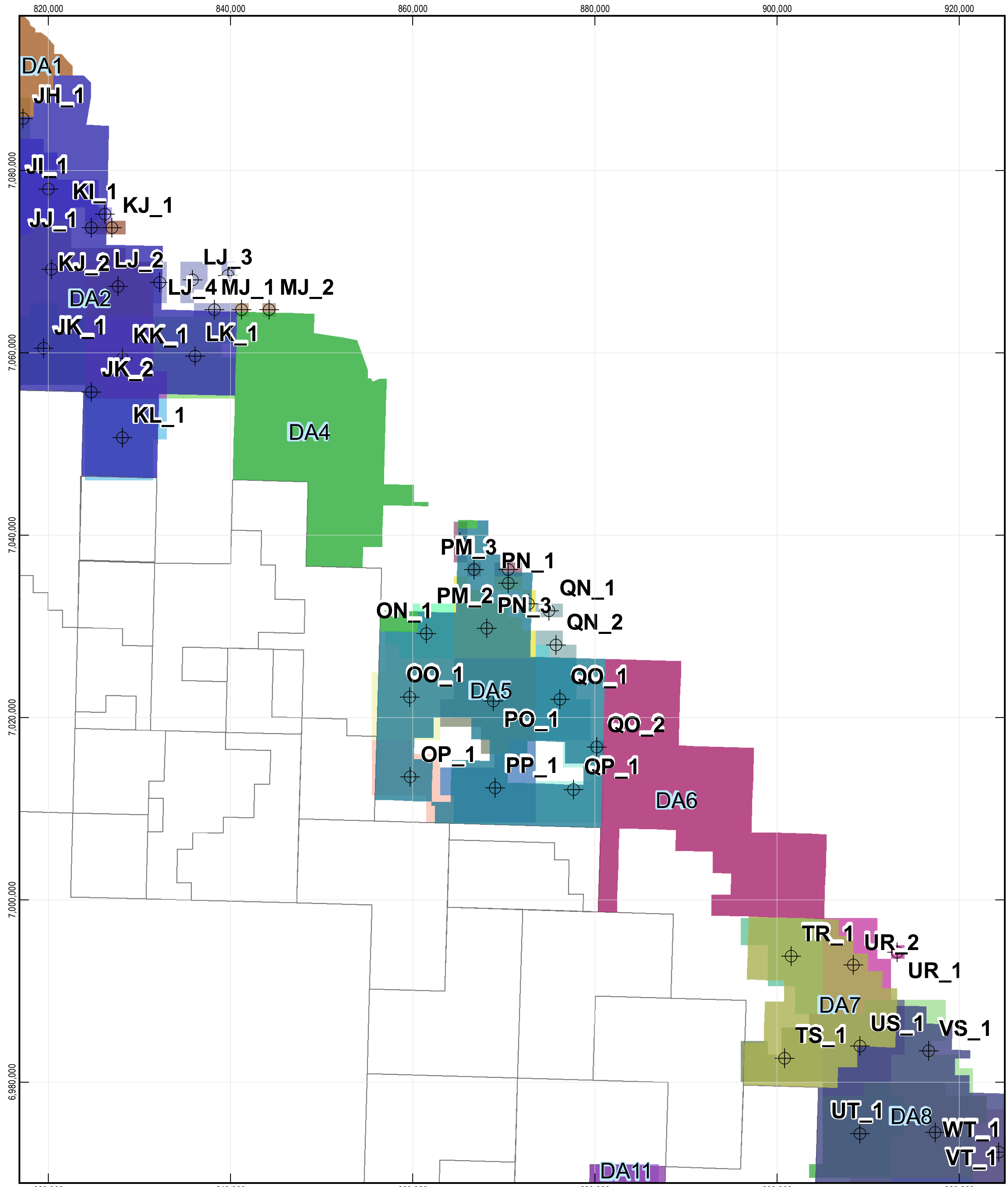


LEGEND

Hydrograph Locations

CSG Tenures

Other Companies

Drainage Areas: 1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12

Paper Size A4

0 2.5 5 10 15 20

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Arrow Energy
Assessment of Regional Impacts from OGIA Model

Job Number	41-26392
Revision	A
Date	18 Jun 2013

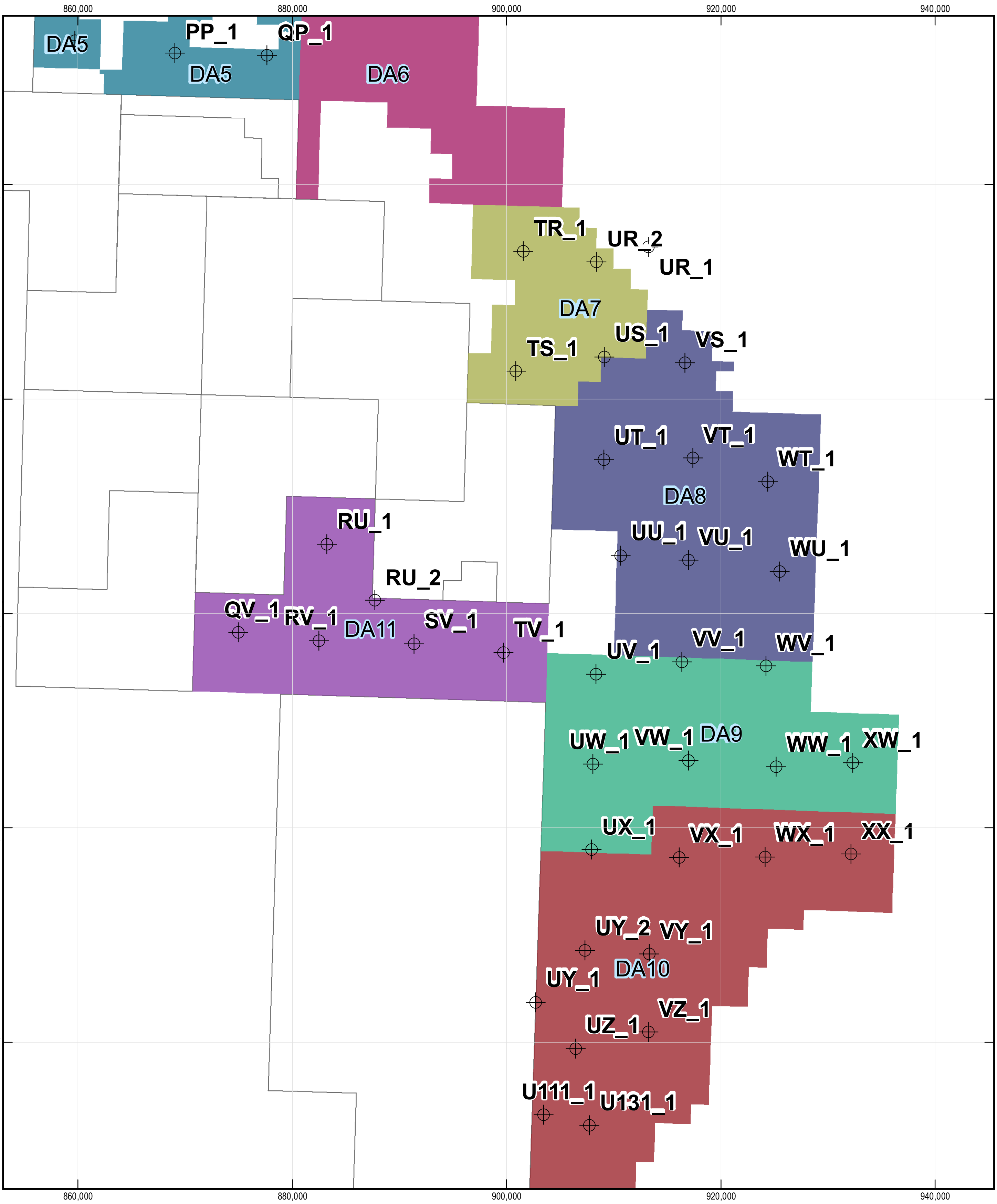
Location of Hydrographs for the Chinchilla Area

Figure E-1

G:\41\26392\GIS\Maps\4126392_AppendixE_Chinchilla.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Hydrograph Locations (2013) Created by:ltraverso



LEGEND

Hydrograph Locations

CSG Tenures

Other Companies

Drainage Areas: 1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12

Paper Size A4

0 2.5 5 10 15 20

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Arrow Energy
Assessment of Regional Impacts from OGIA Model

Location of Hydrographs for the Dalby and Millmerran Areas

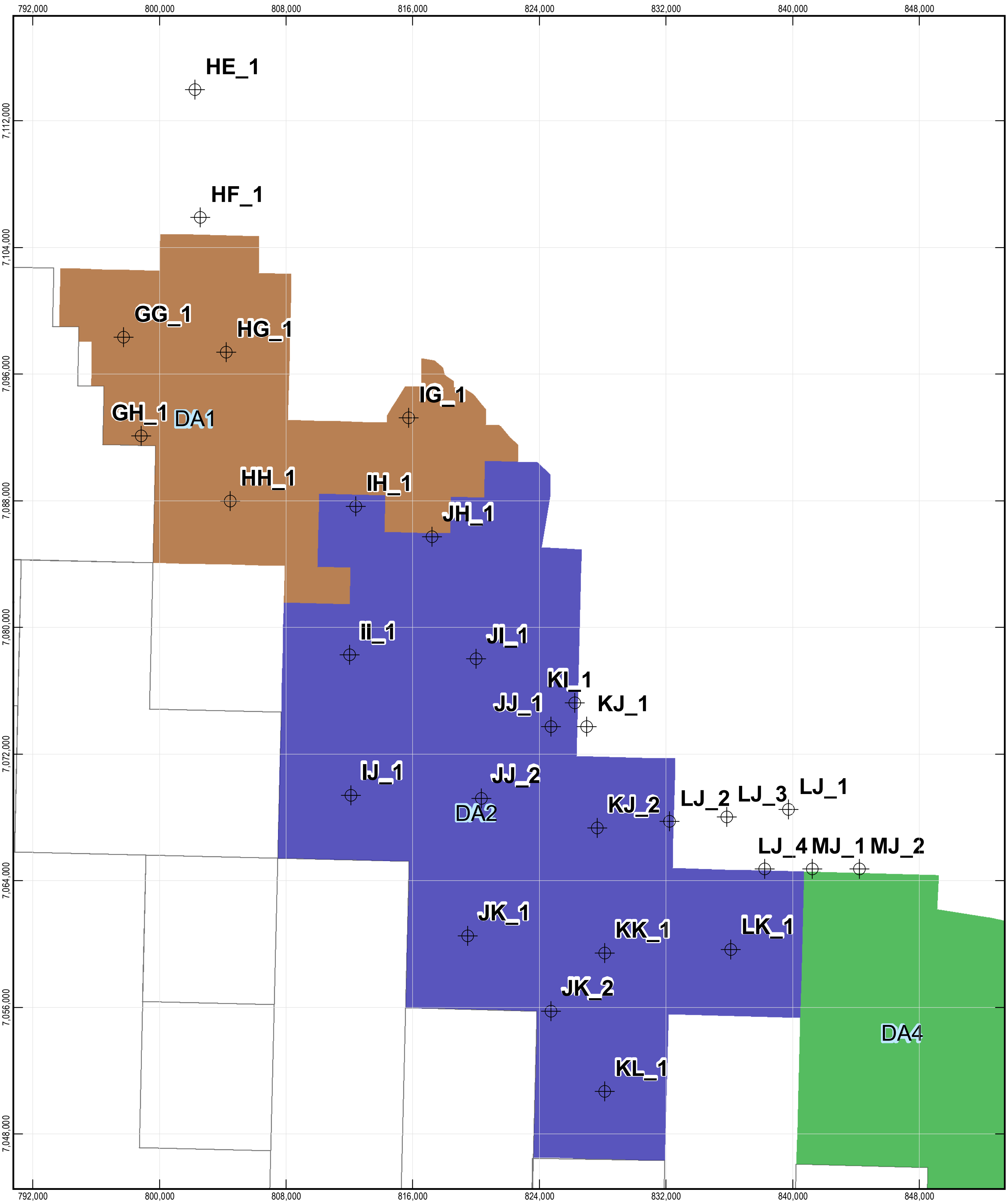
Job Number	41-26392
Revision	A
Date	18 Jun 2013

Figure E-2

G:\41\26392\GIS\Maps\4126392_AppendixE_DalbyMillmerran.mxd

145 Ann Street Brisbane QLD 4000 Australia **T** 61 7 3316 3000 **F** 61 7 3316 3333 **E** bnemail@ghd.com **W** www.ghd.com

Data source: QWC: CSG Tenures (25-03-2011); GHD: Hydrograph Locations (2013) Created by:ltraverso



LEGEND

Hydrograph Locations

CSG Tenures

Other Companies

Drainage Areas

1

2

4

Paper Size A4

0 1 2 4 6 8

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Arrow Energy
Assessment of Regional Impacts from OGIA Model

Job Number	41-26392
Revision	A
Date	18 Jun 2013

Location of Hydrographs for the Wandoan Area

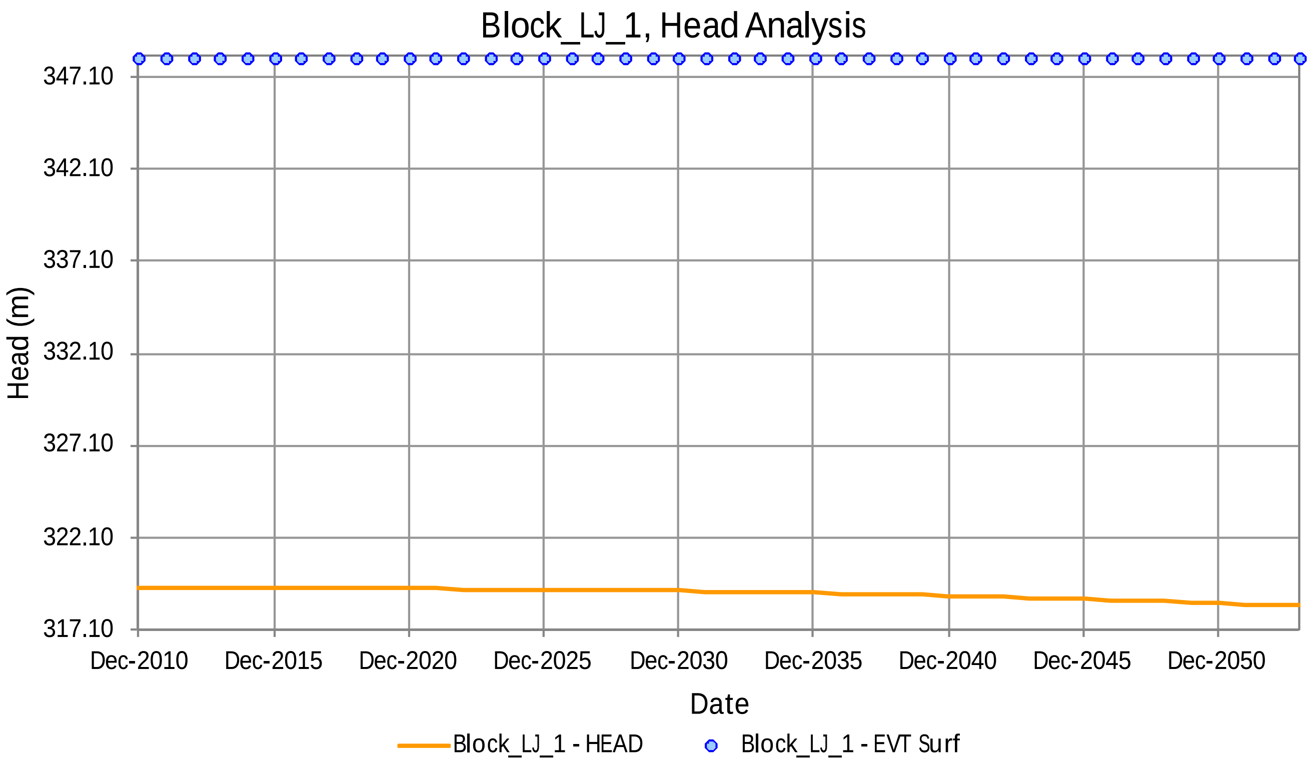
Figure E-3

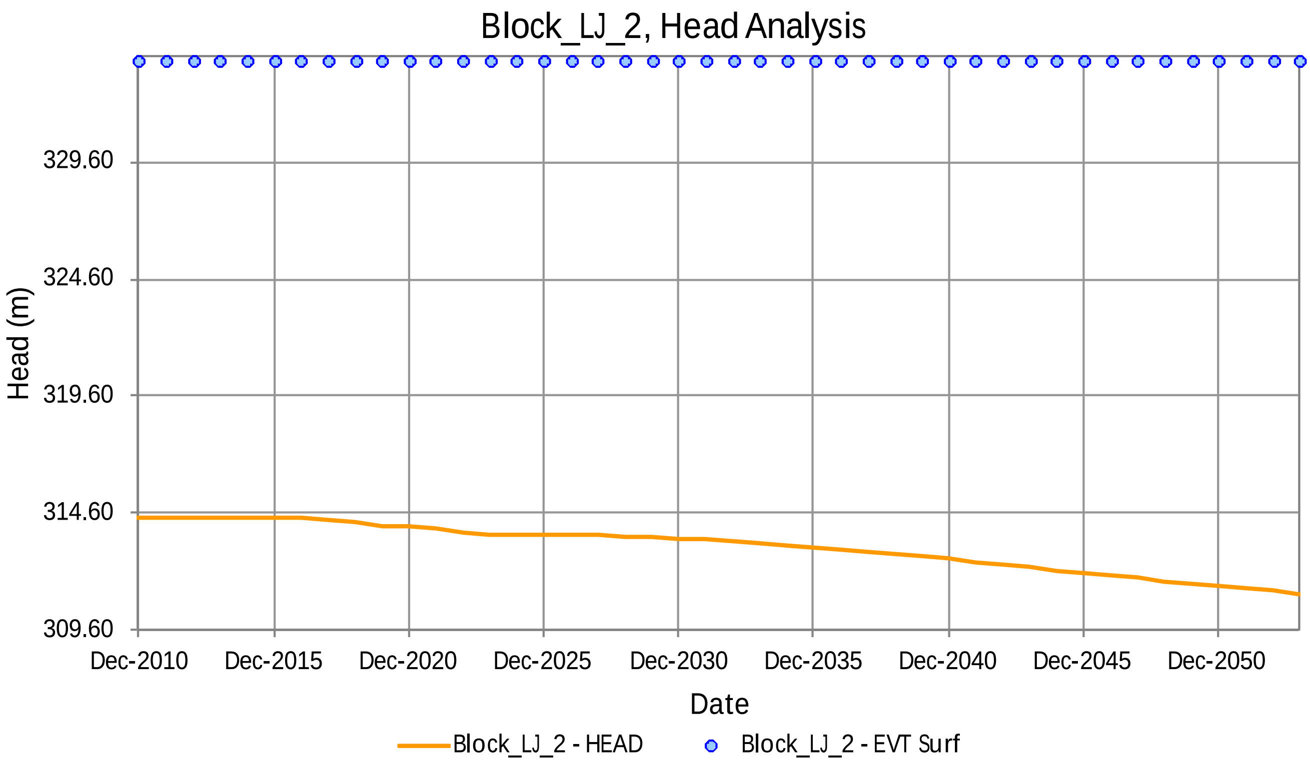
G:\41\26392\GIS\Maps\4126392_AppendixE_Wandoan.mxd

145 Ann Street Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

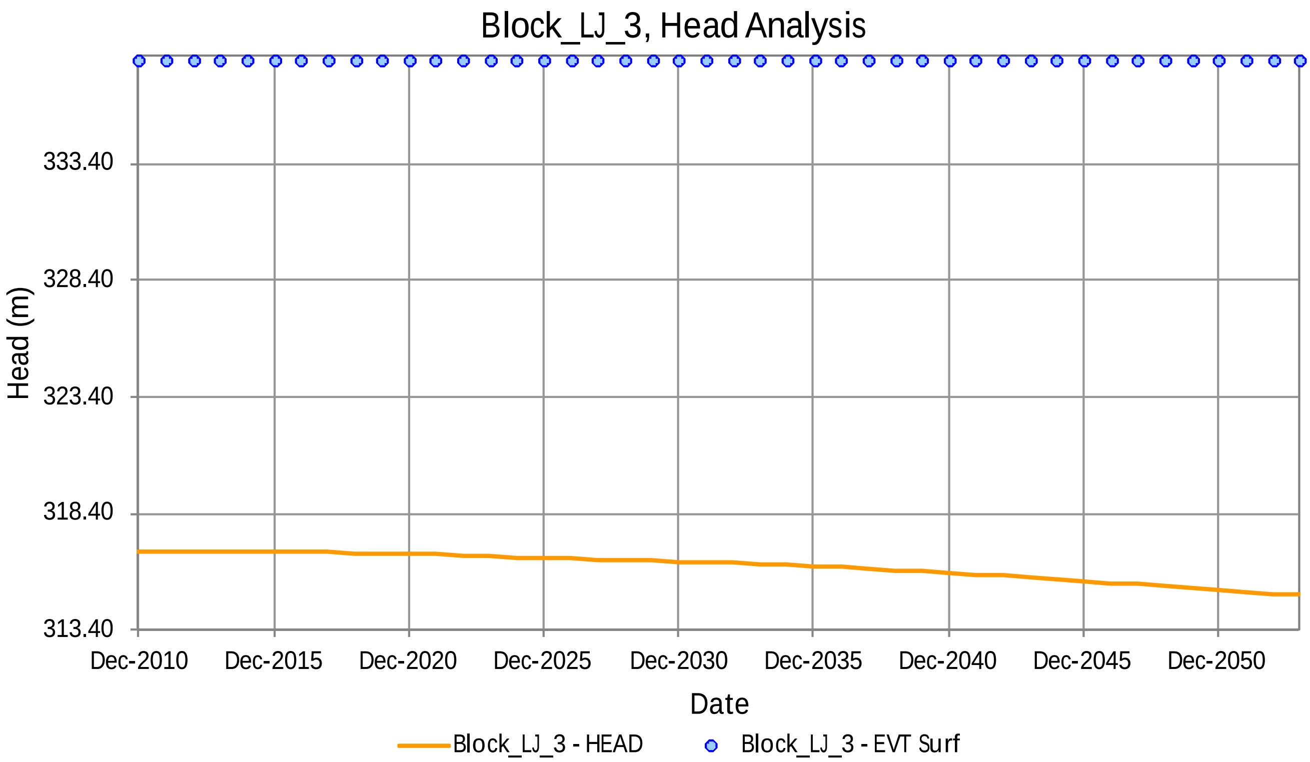
Data source: QWC: CSG Tenures (25-03-2011); GHD: Hydrograph Locations (2013) Created by:ltraverso

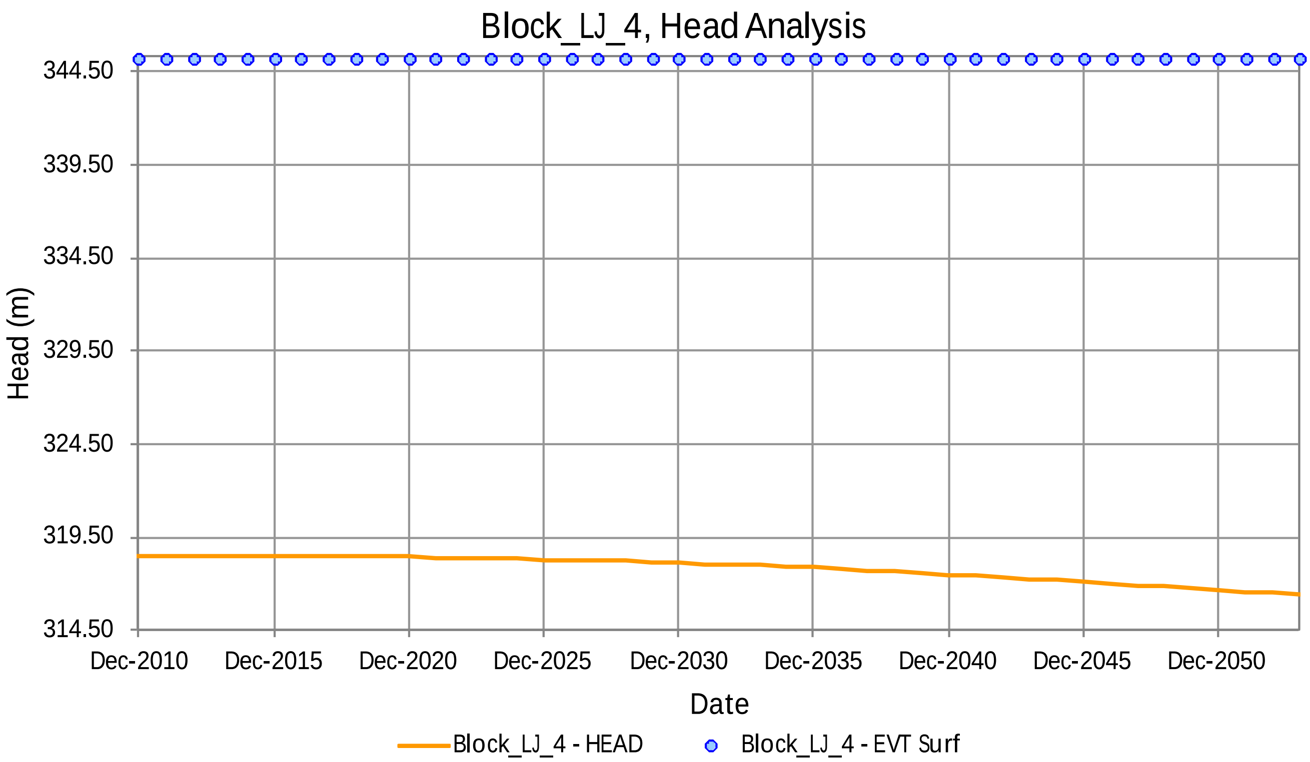
Appendix E - Comparison of Modelled Head and Evaporation Surface - Chinchilla Development Region



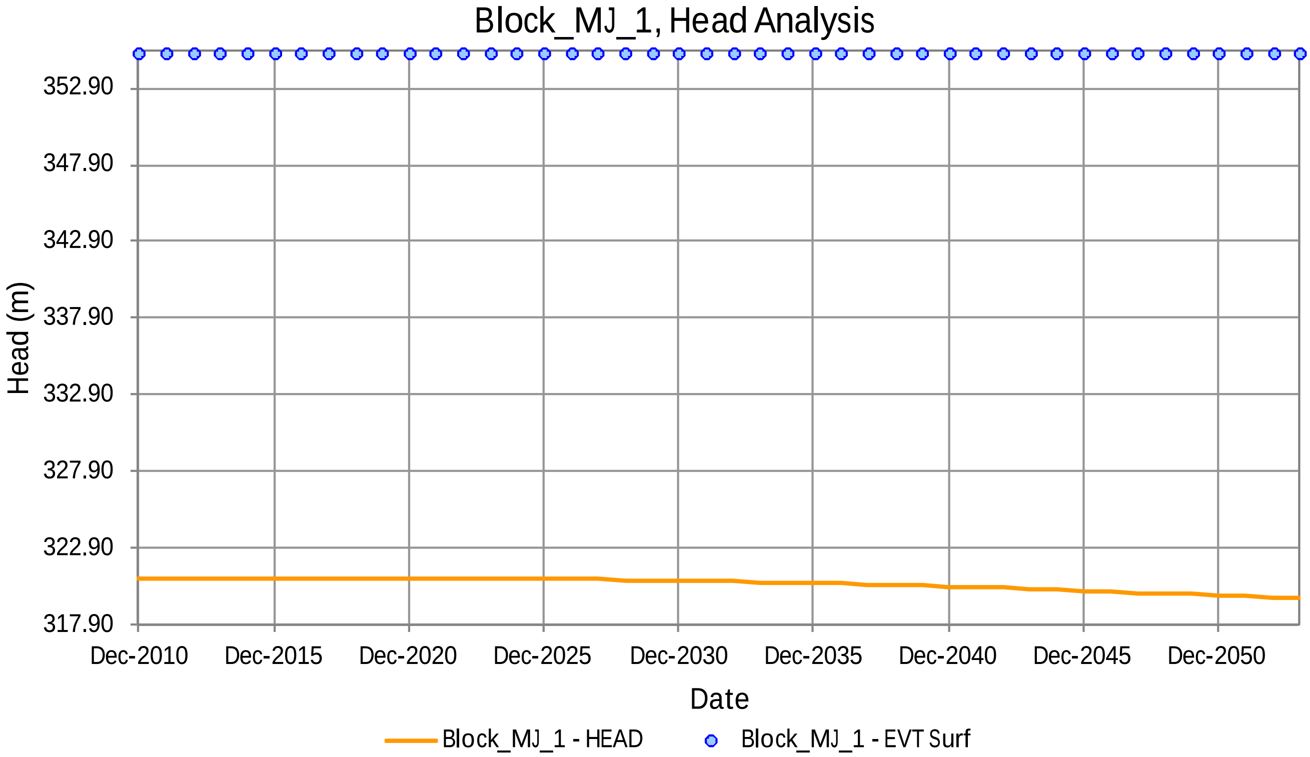


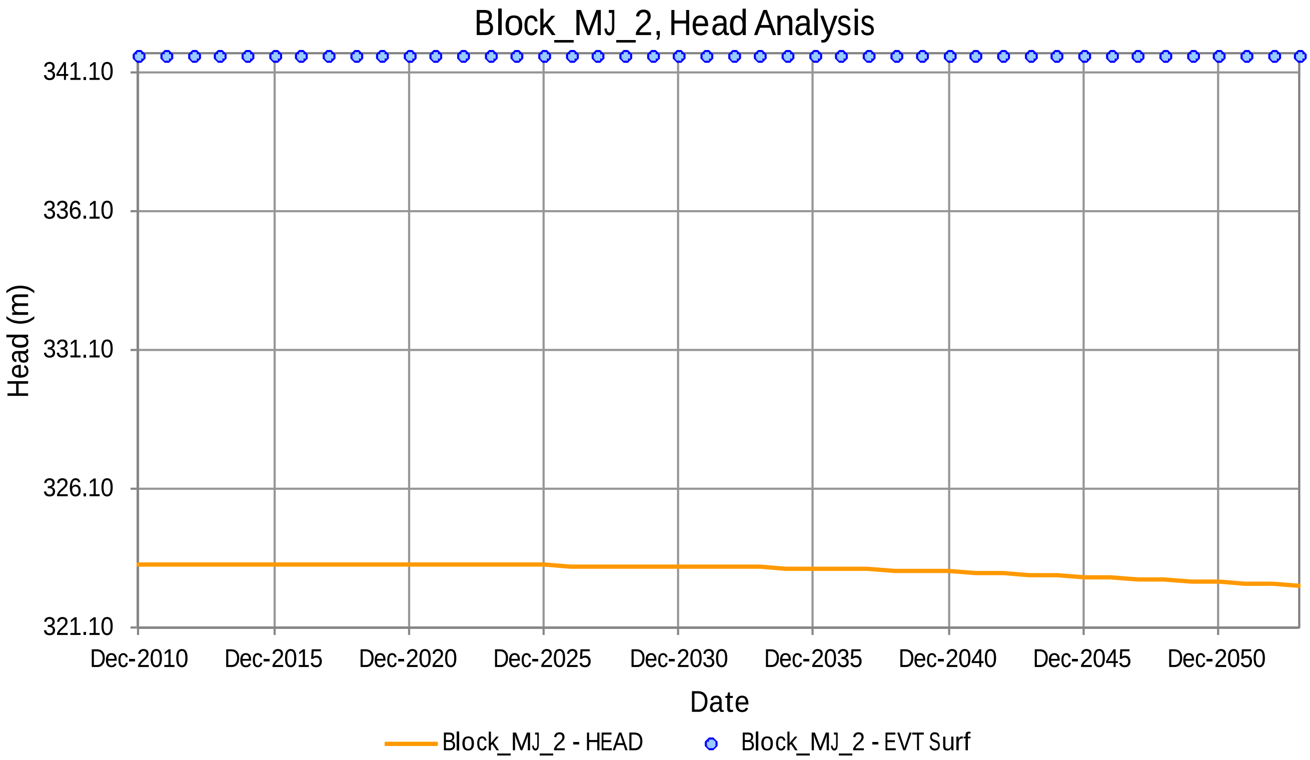
Appendix E - Comparison of Modelled Head and Evaporation Surface - Chinchilla Development Region



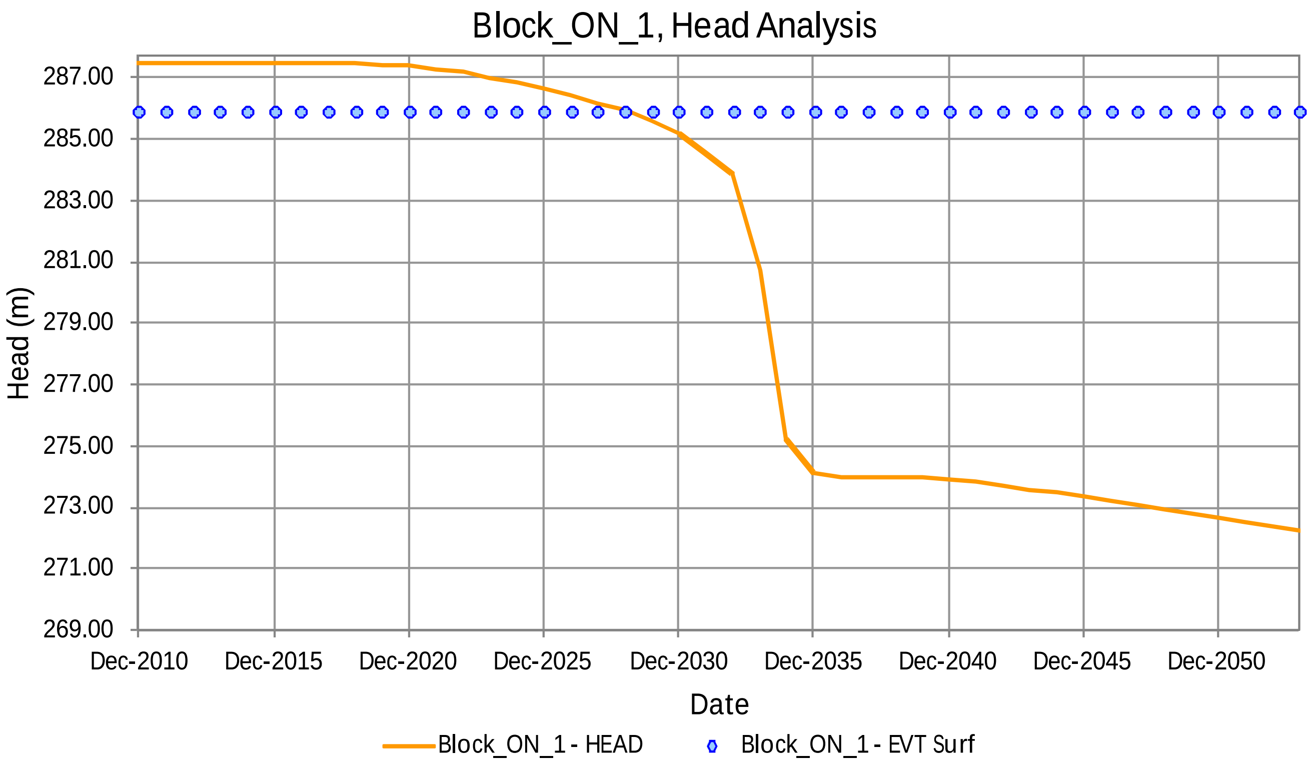


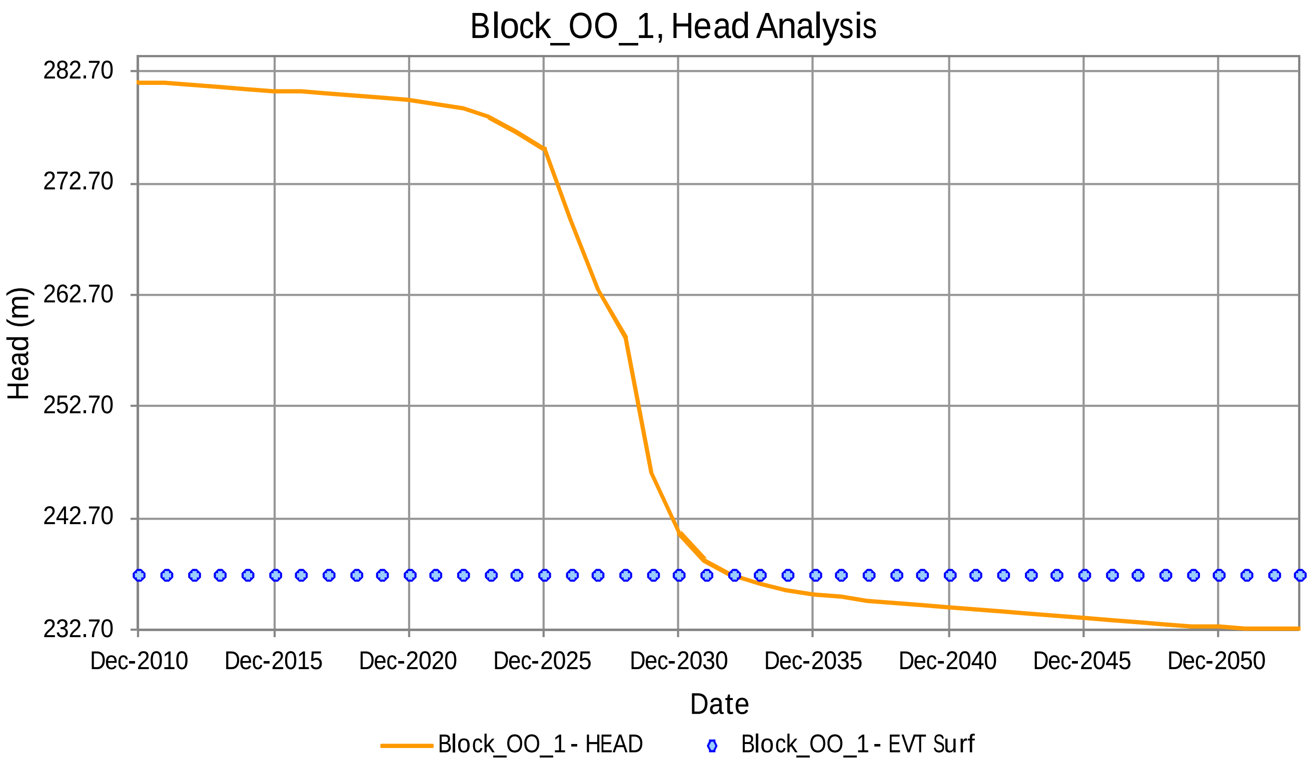
Appendix E - Comparison of Modelled Head and Evaporation Surface - Chinchilla Development Region



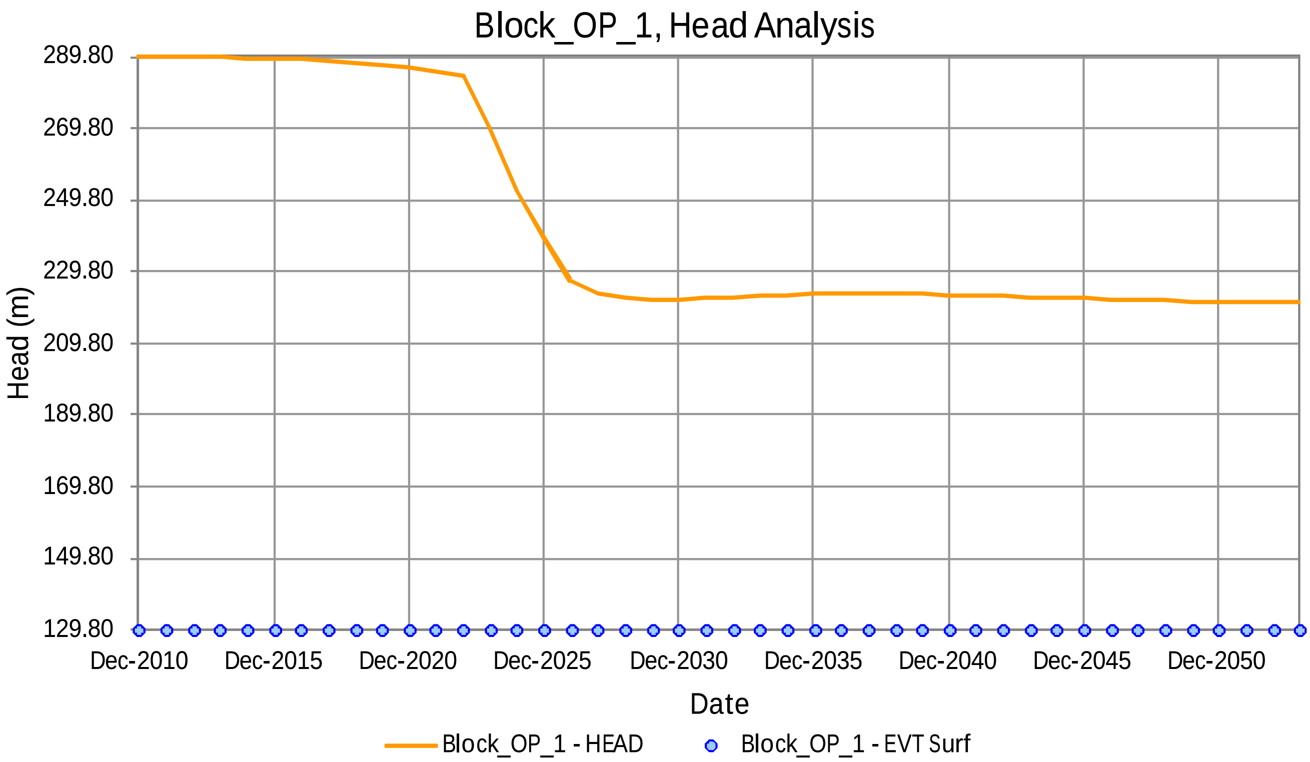


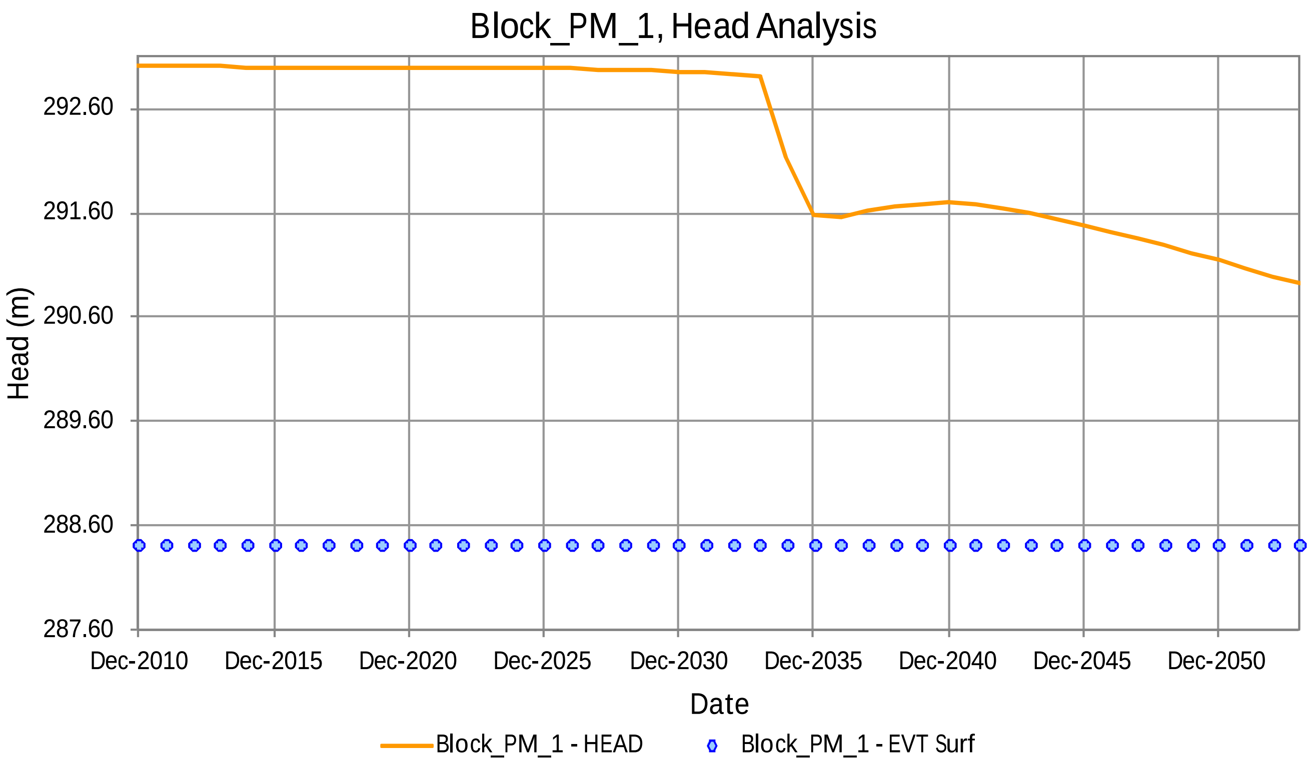
Appendix E - Comparison of Modelled Head and Evaporation Surface - Chinchilla Development Region



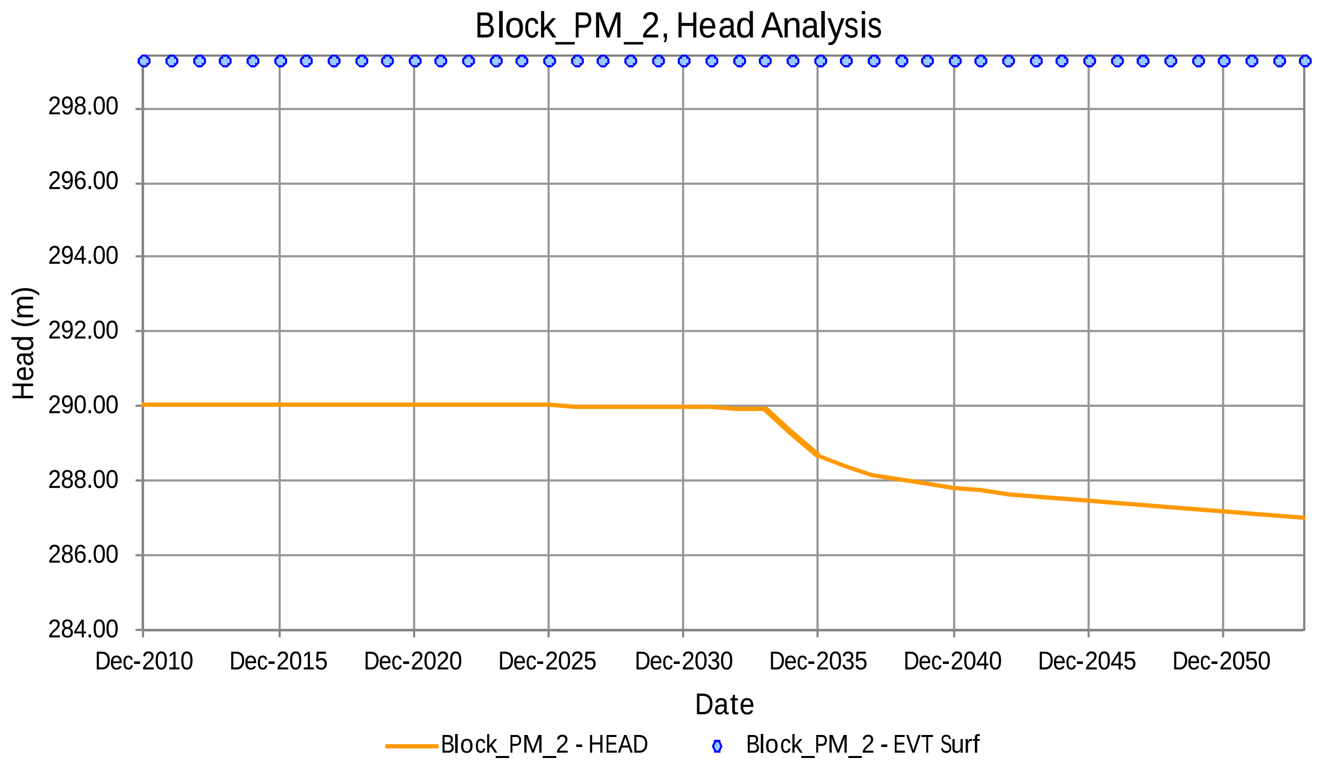


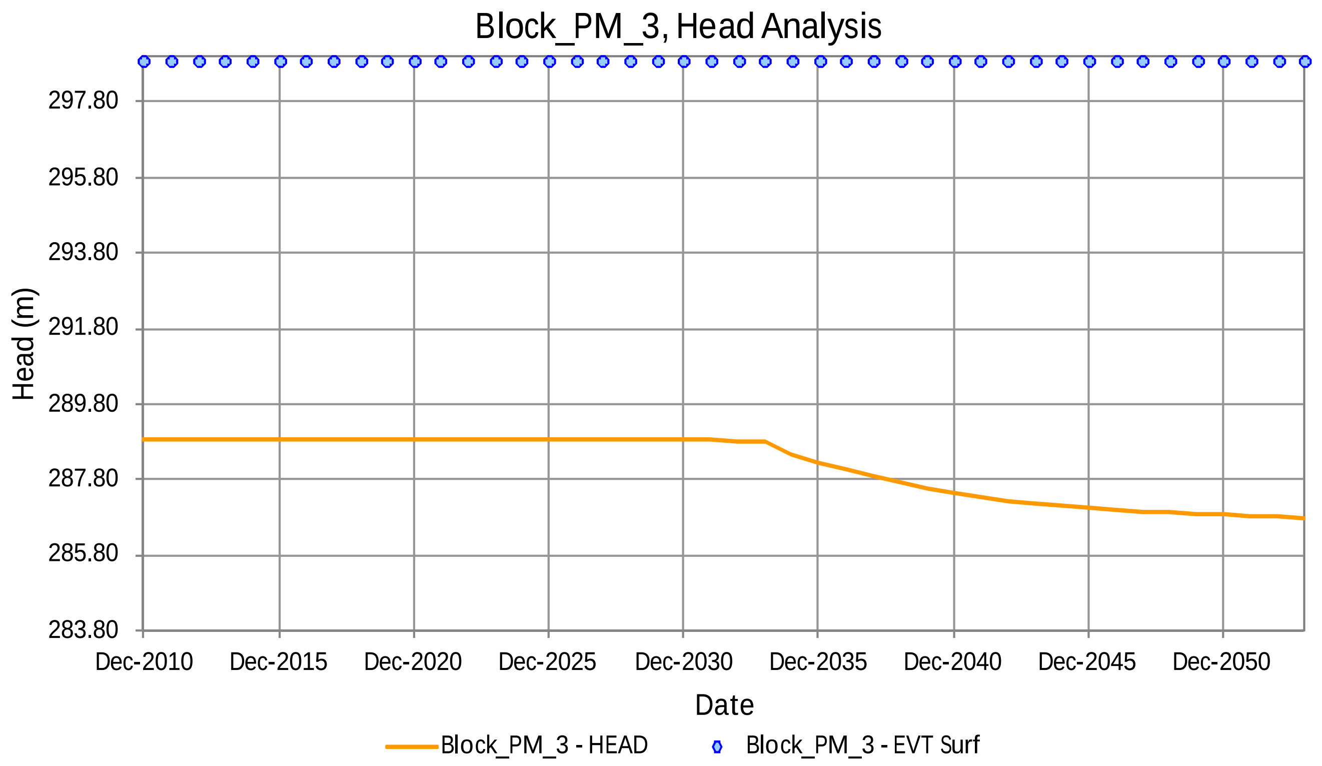
Appendix E - Comparison of Modelled Head and Evaporation Surface - Chinchilla Development Region



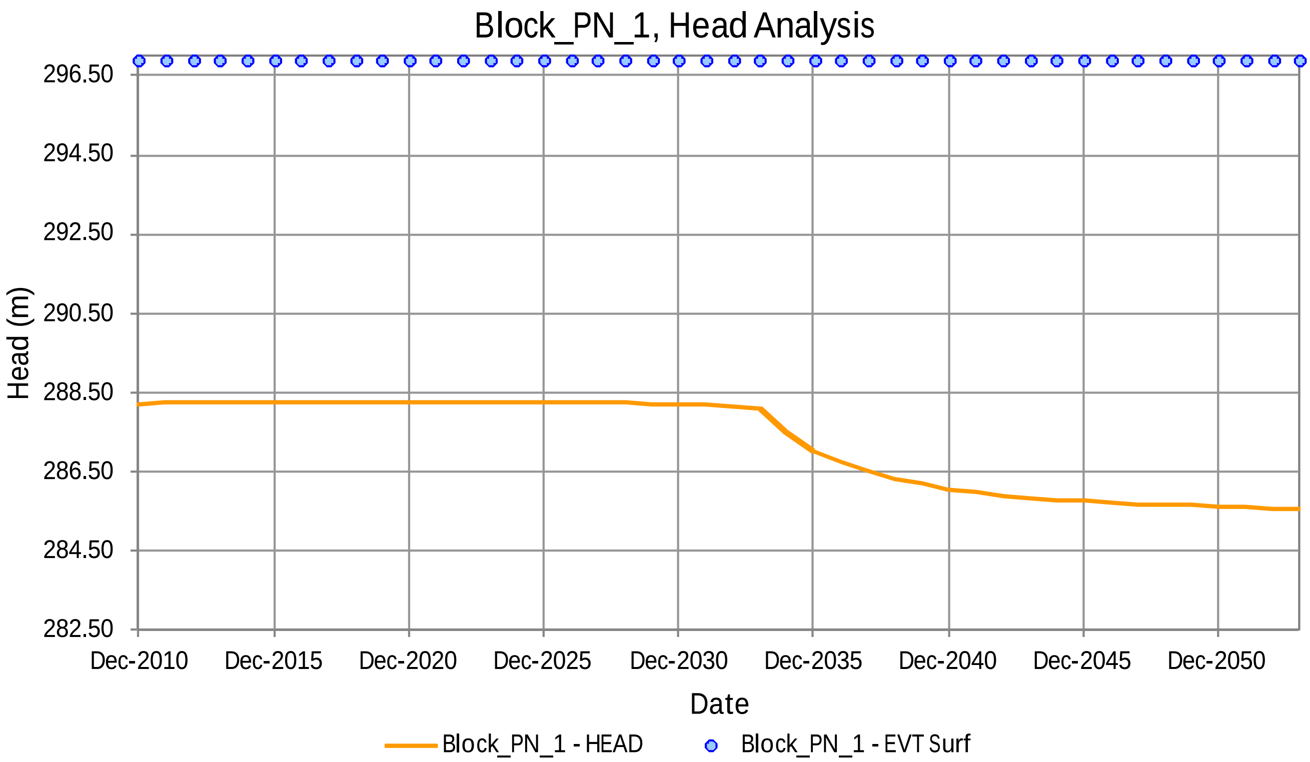


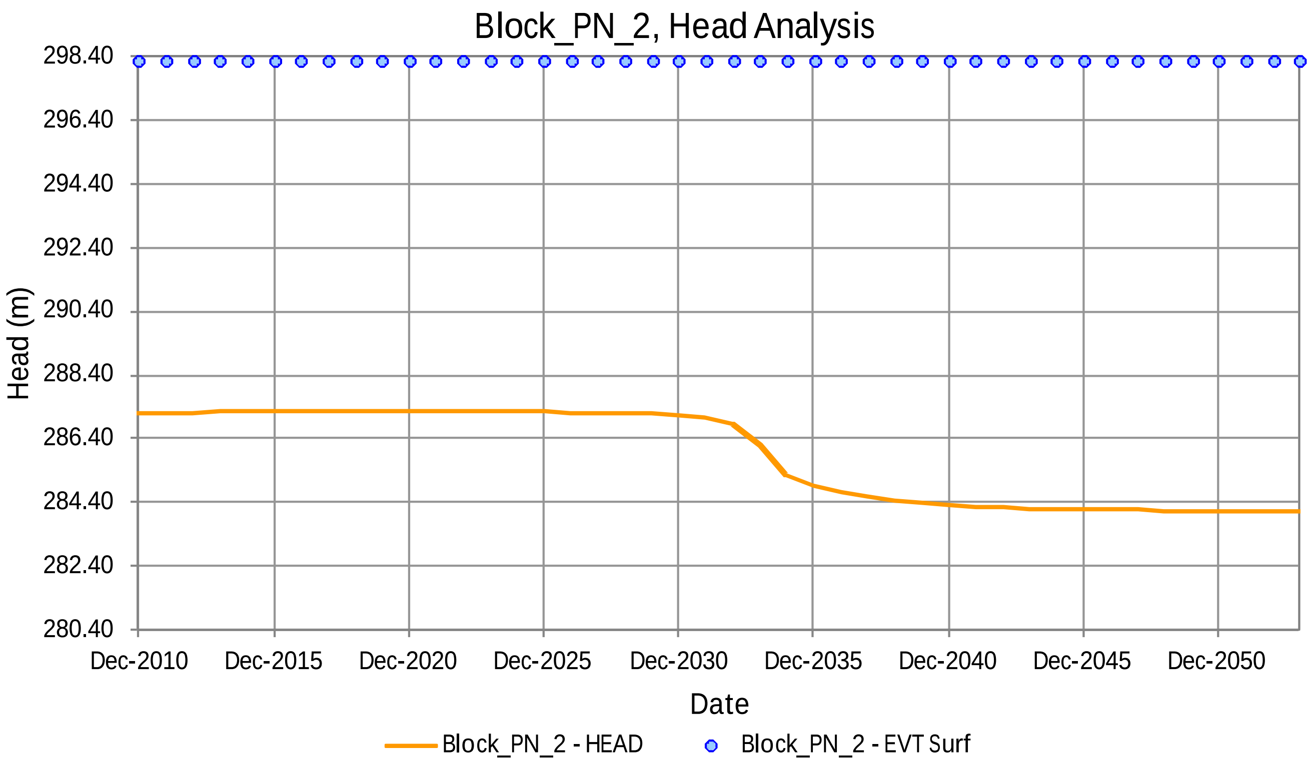
Appendix E - Comparison of Modelled Head and Evaporation Surface - Chinchilla Development Region



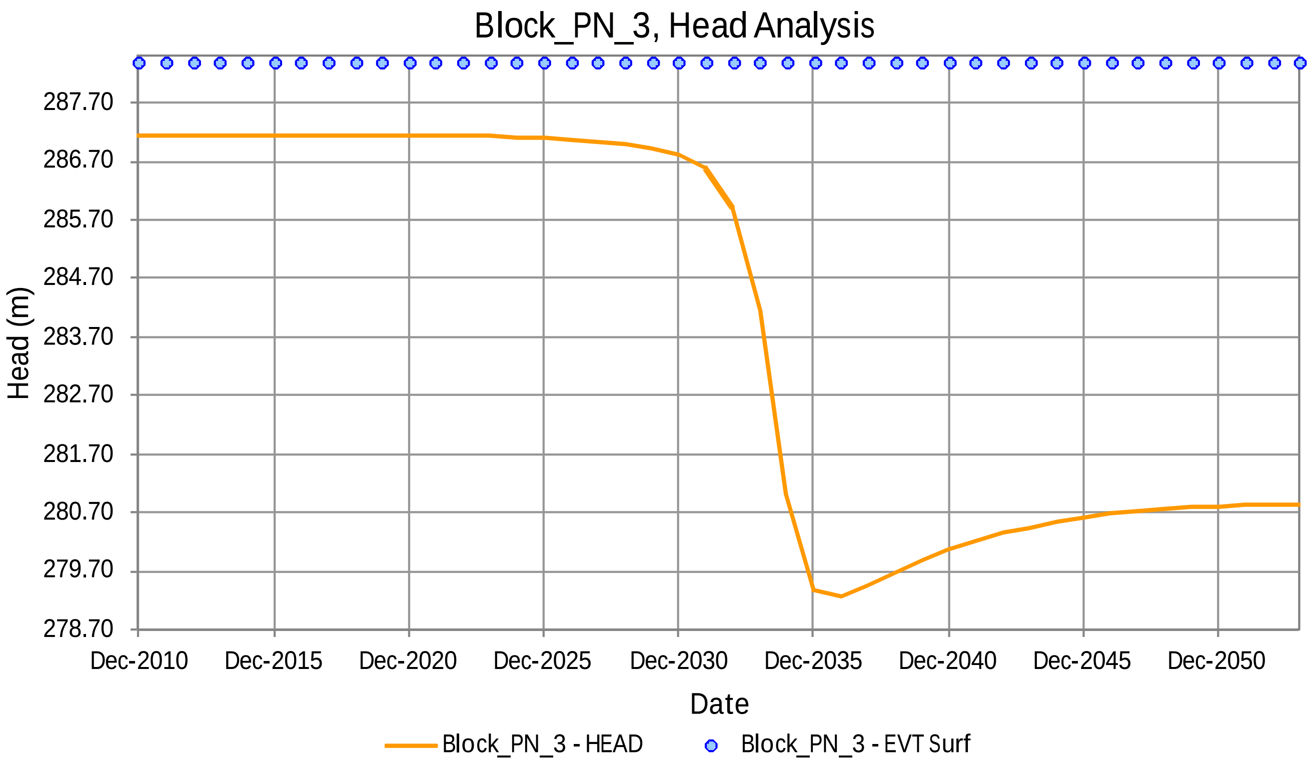


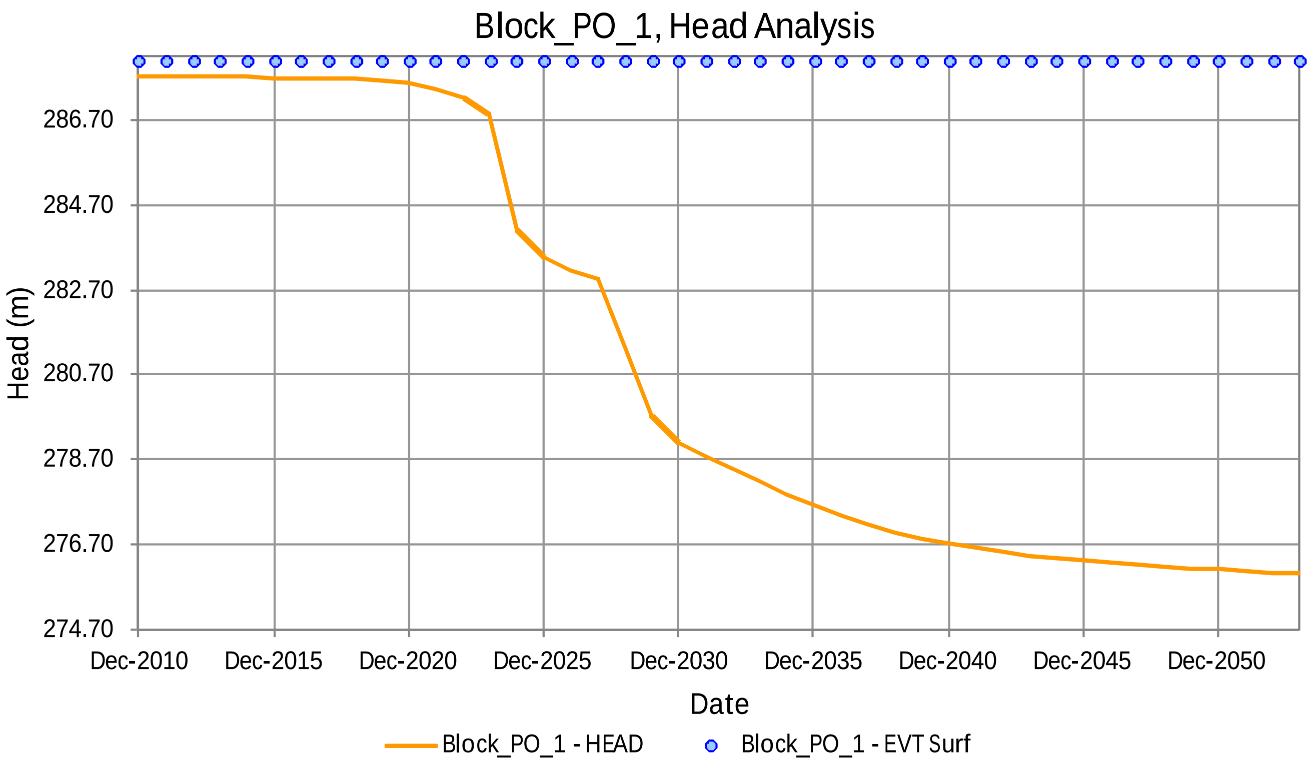
Appendix E - Comparison of Modelled Head and Evaporation Surface - Chinchilla Development Region



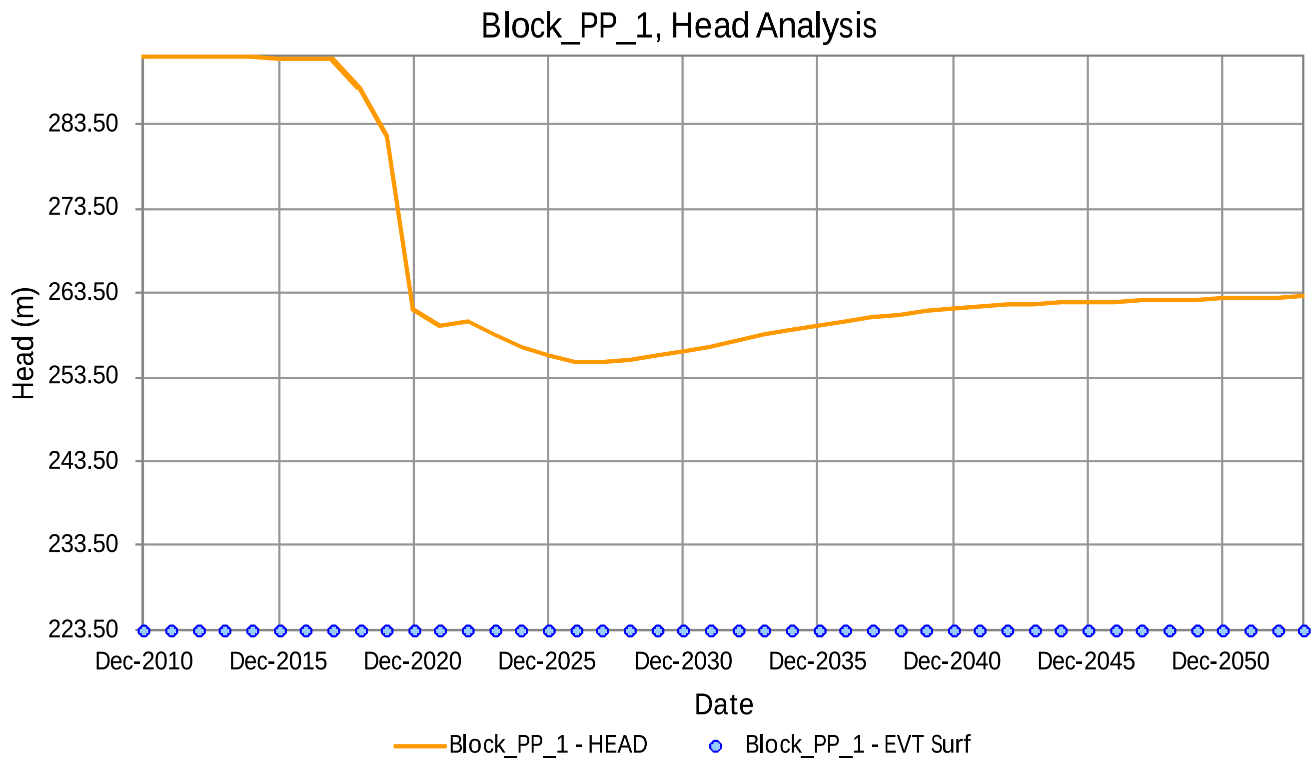


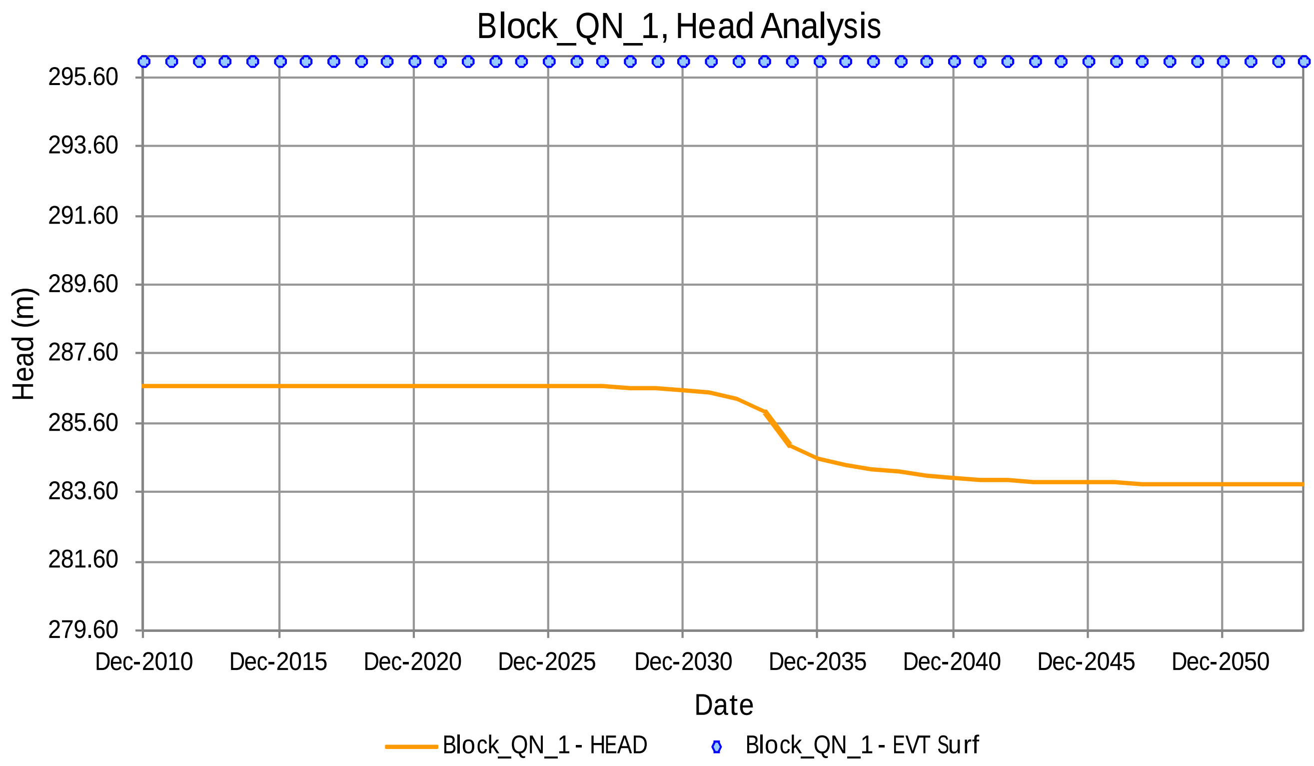
Appendix E - Comparison of Modelled Head and Evaporation Surface - Chinchilla Development Region



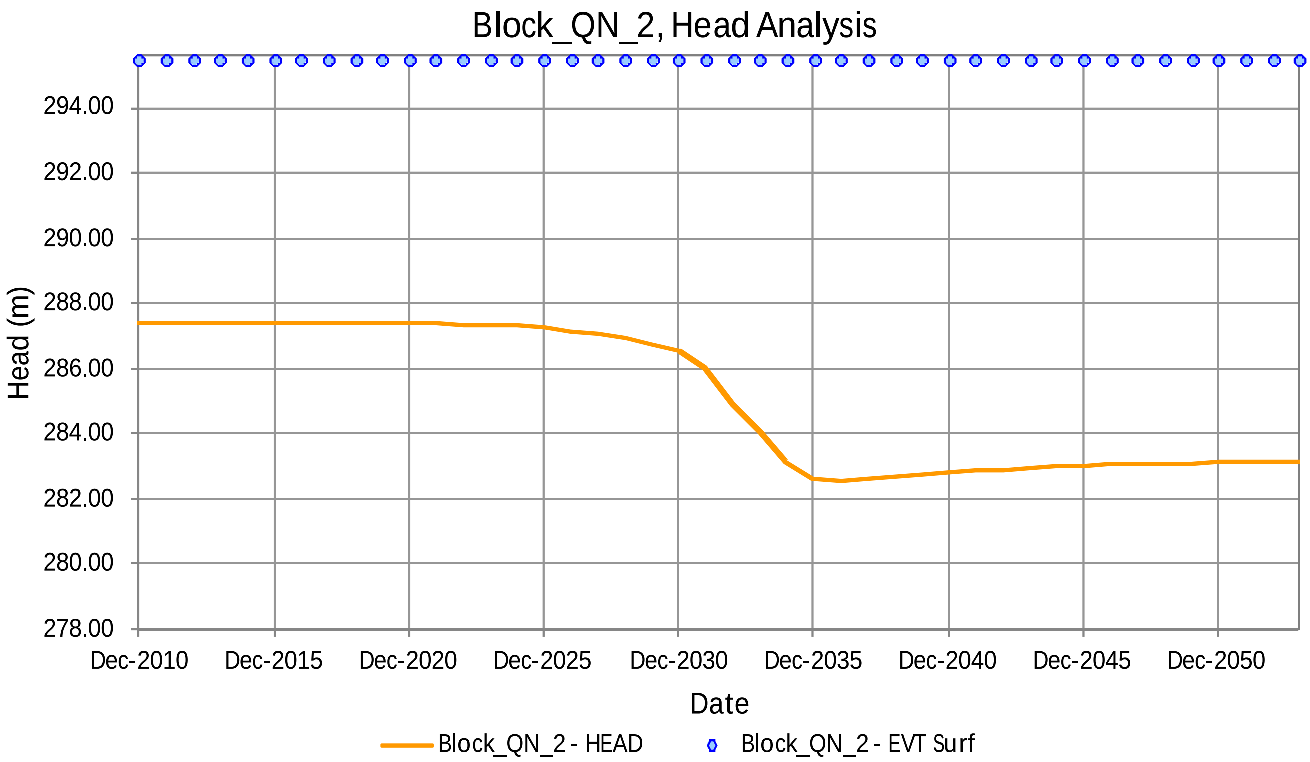


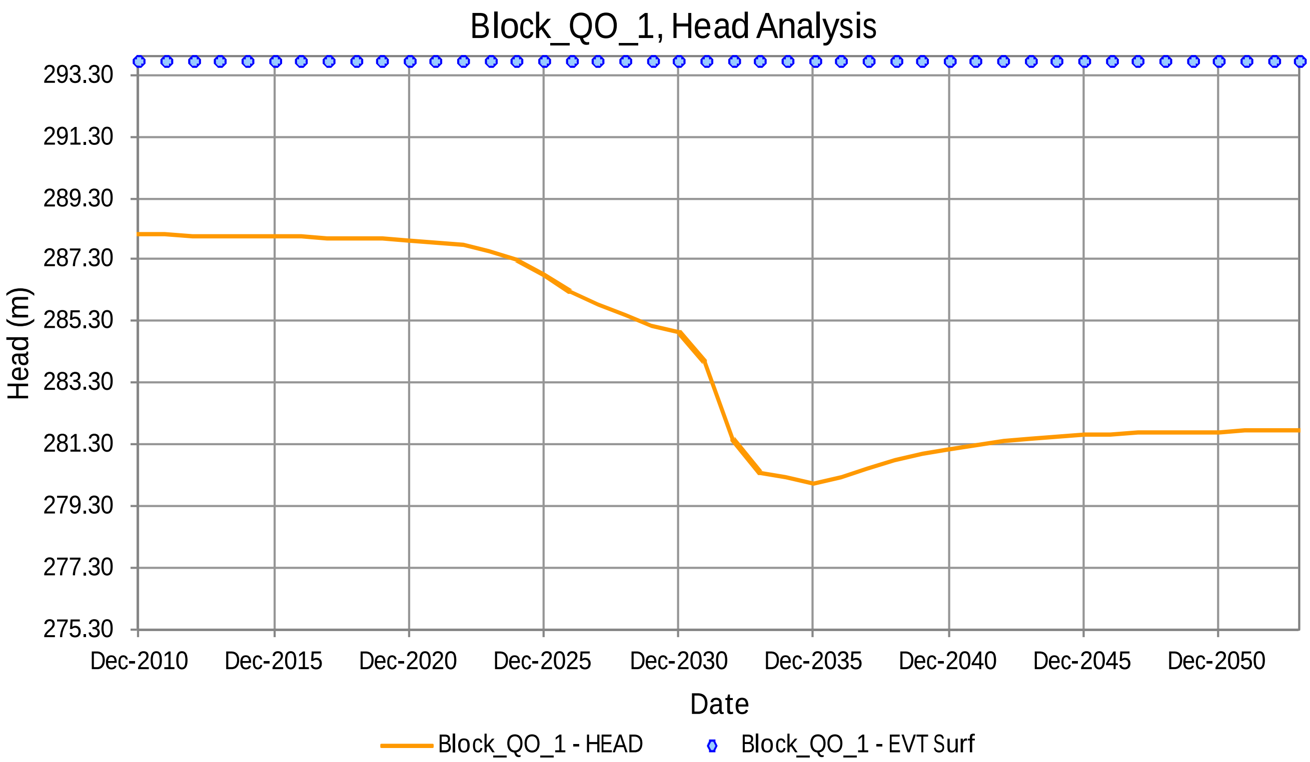
Appendix E - Comparison of Modelled Head and Evaporation Surface - Chinchilla Development Region



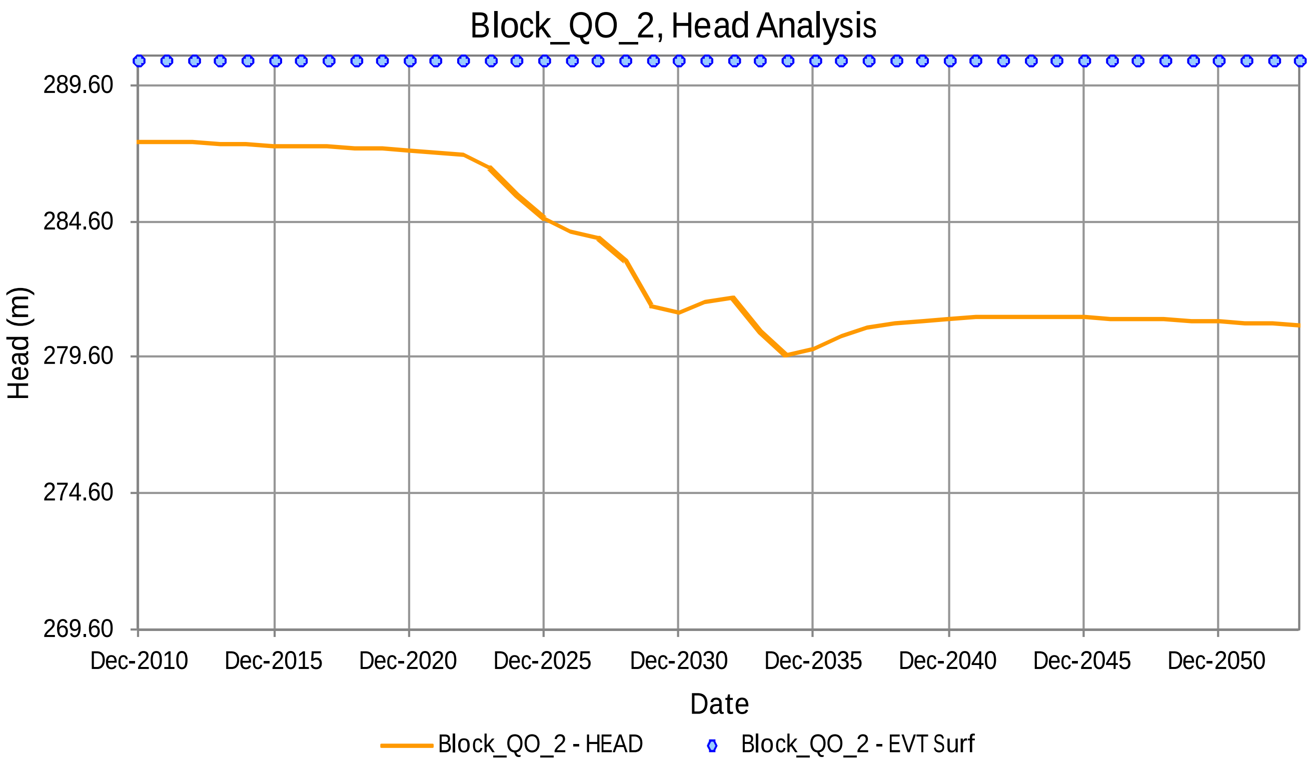


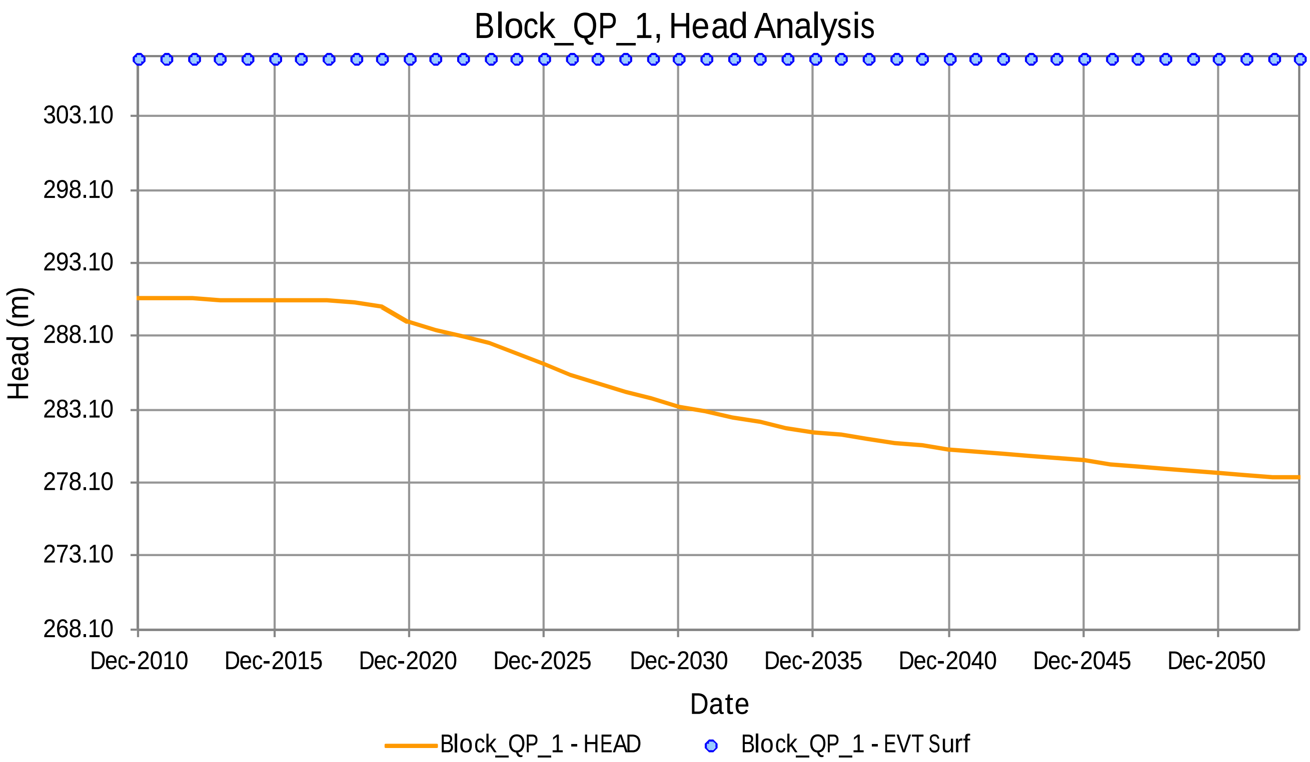
Appendix E - Comparison of Modelled Head and Evaporation Surface - Chinchilla Development Region



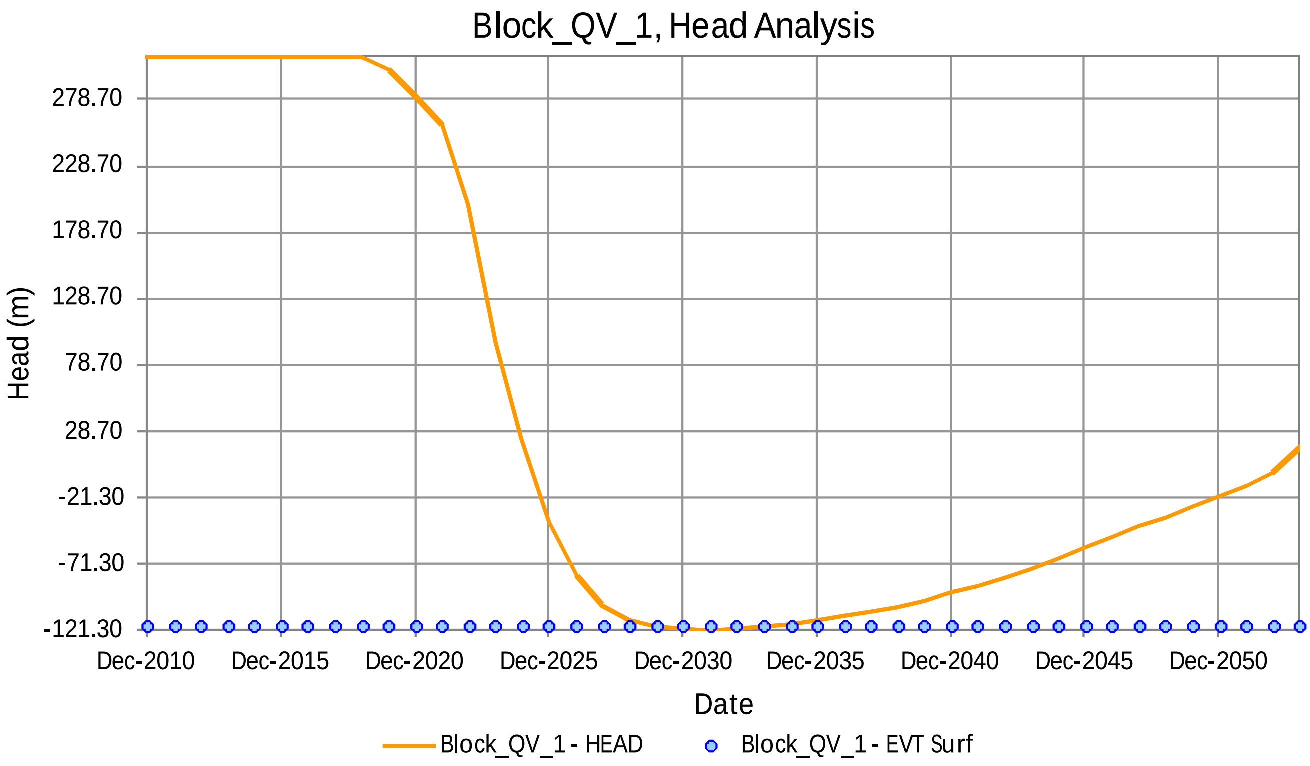


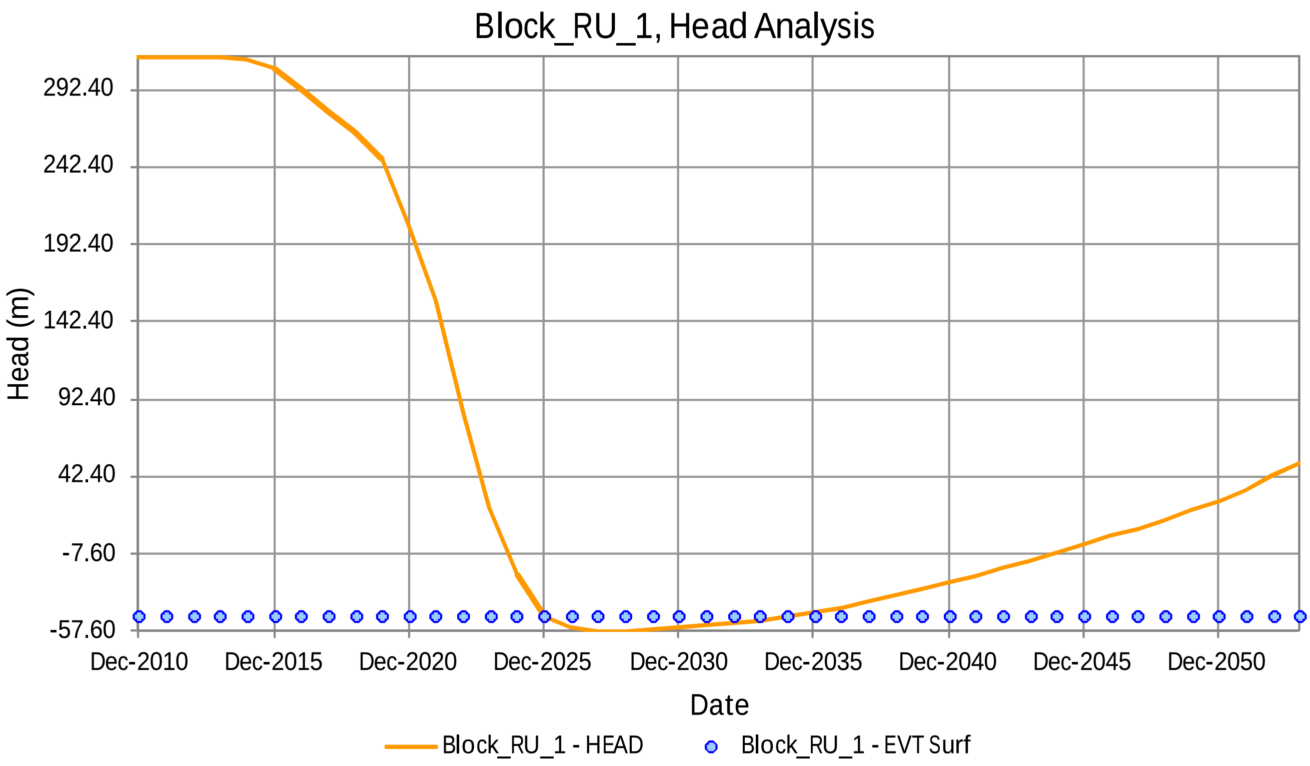
Appendix E - Comparison of Modelled Head and Evaporation Surface - Chinchilla Development Region



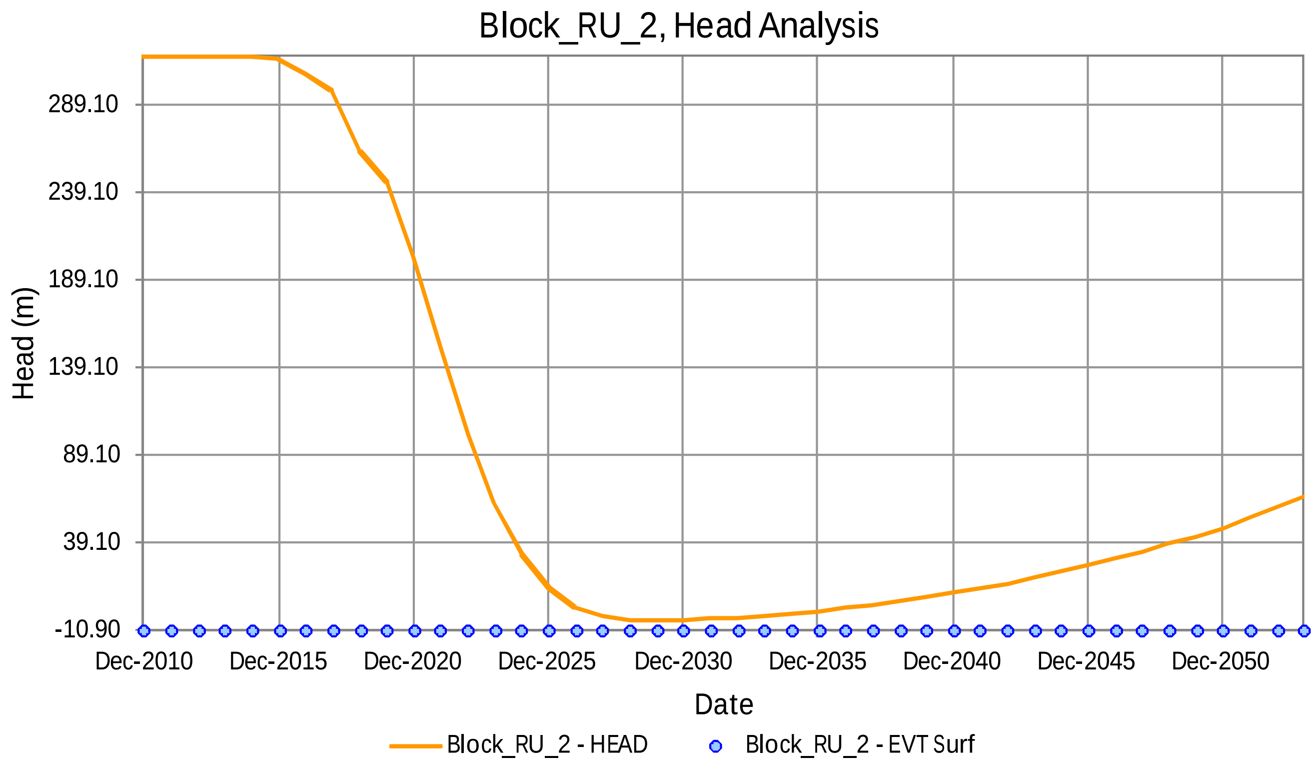


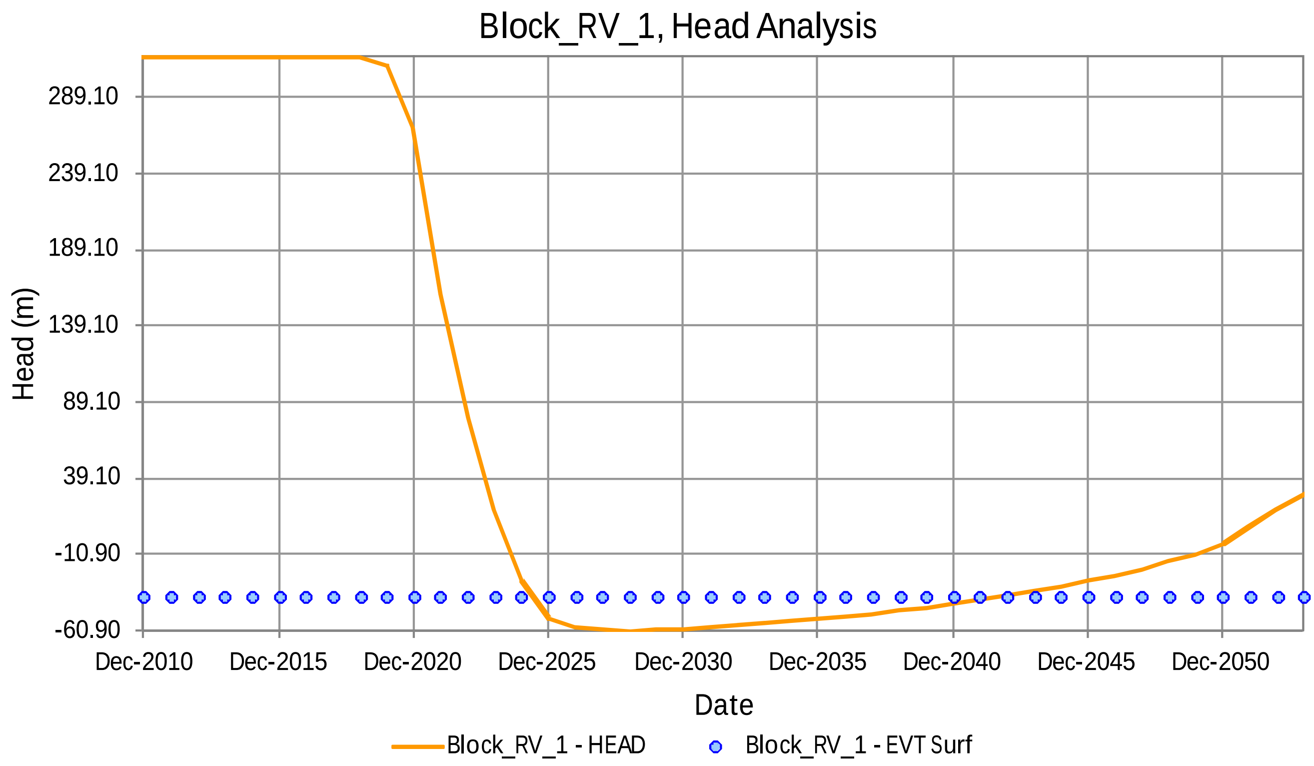
Appendix E - Comparison of Modelled Head and Evaporation Surface - Dalby Development Region



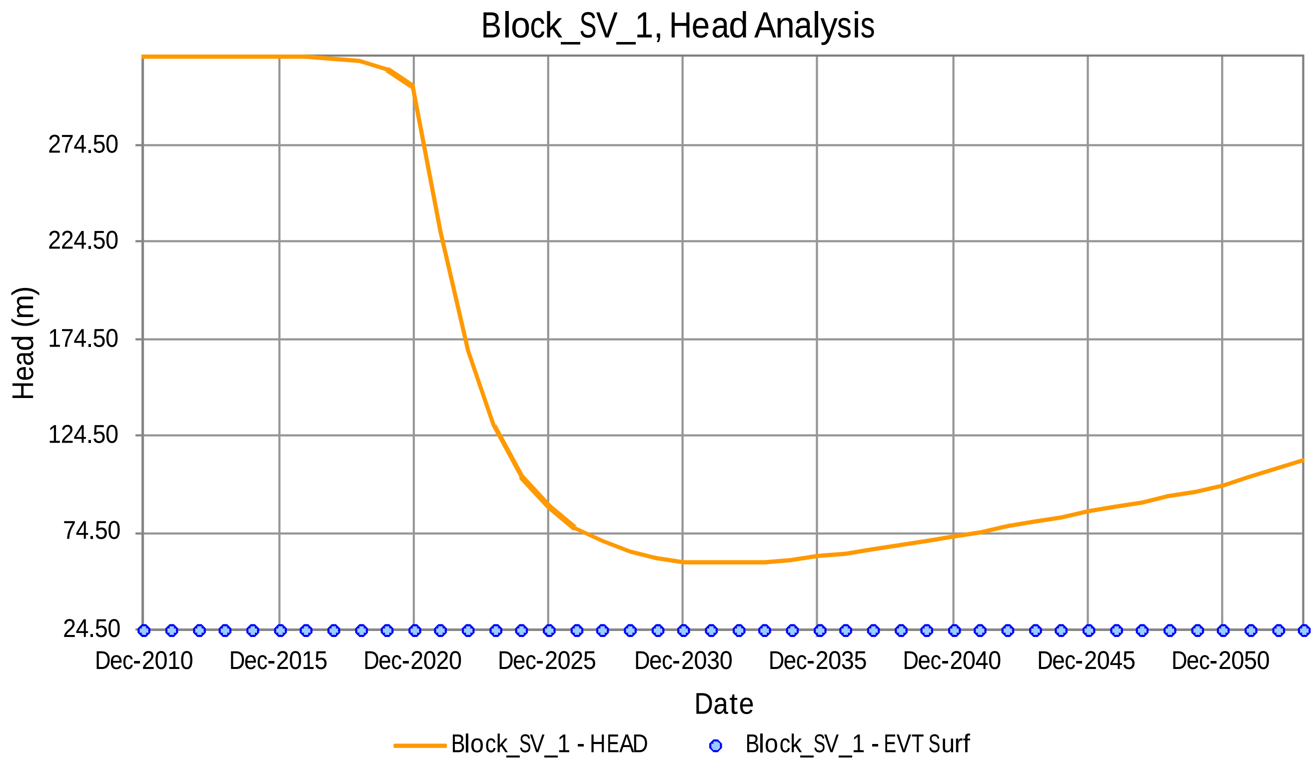


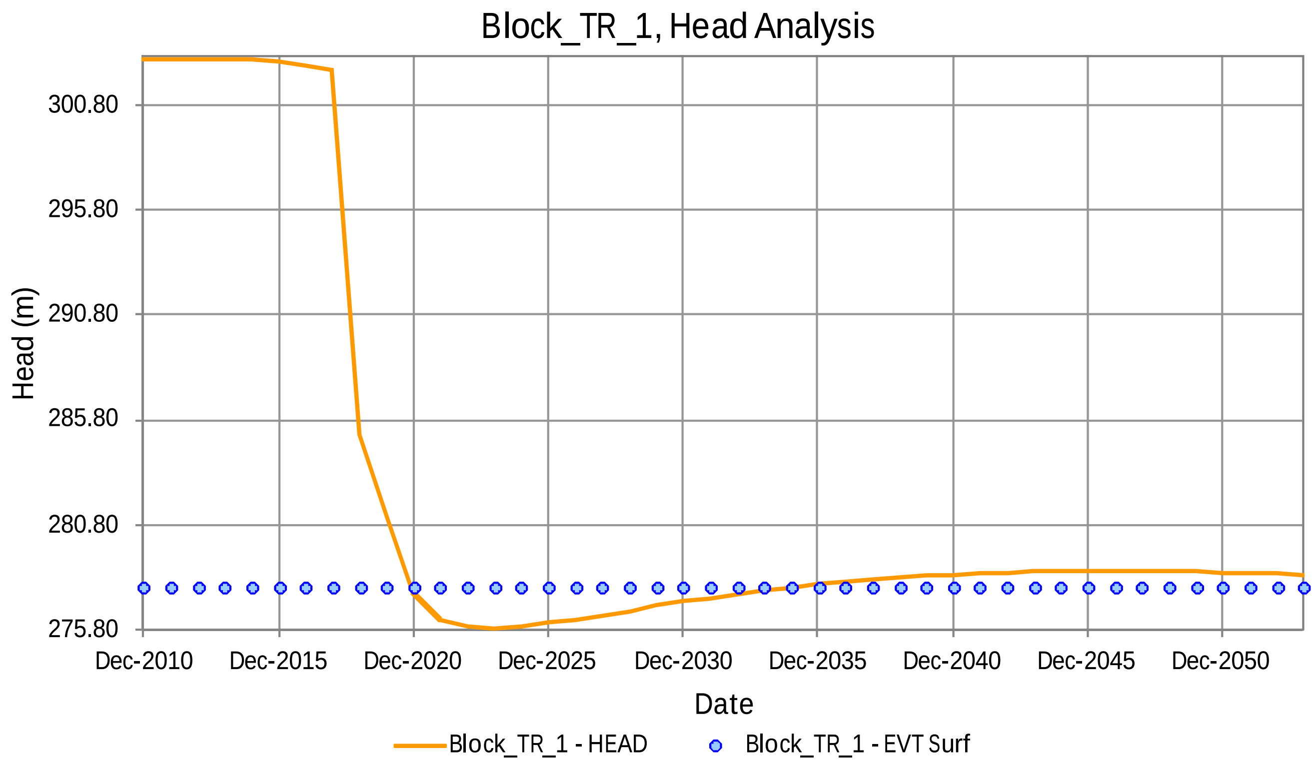
Appendix E - Comparison of Modelled Head and Evaporation Surface - Dalby Development Region





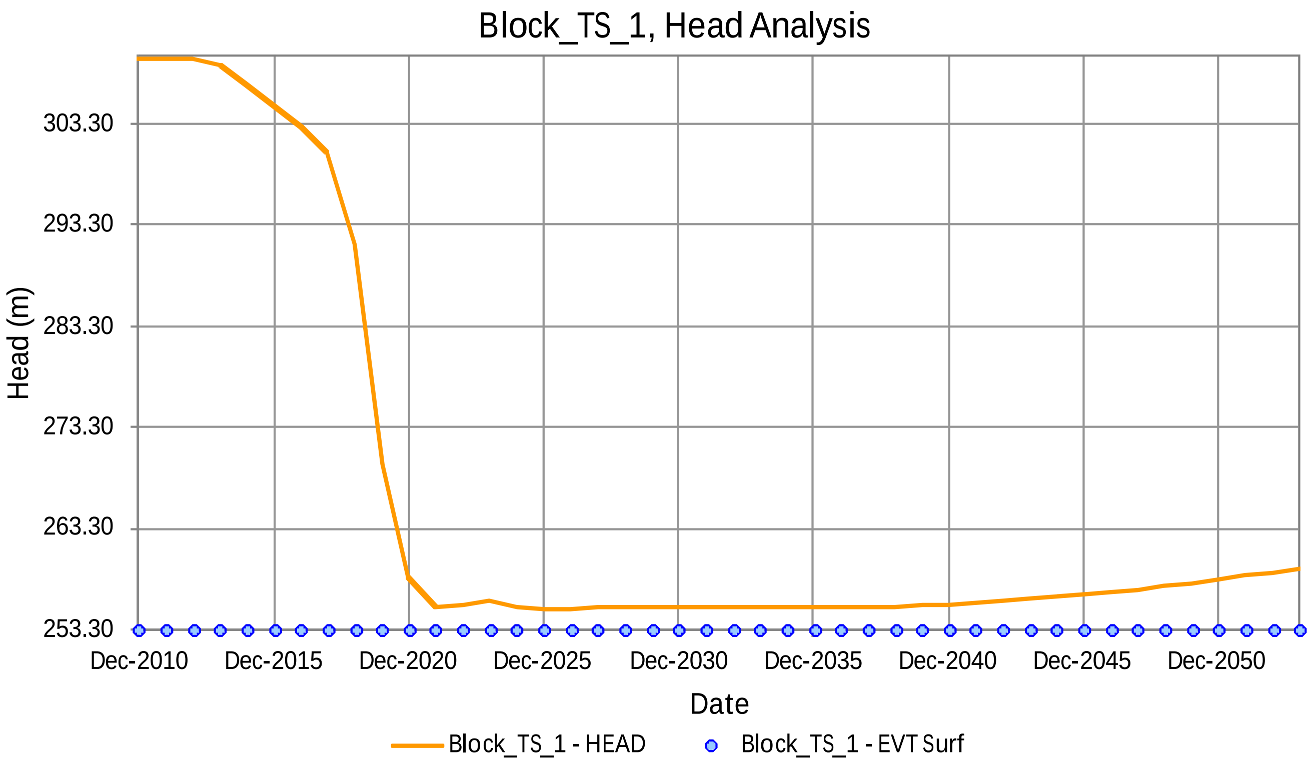
Appendix E - Comparison of Modelled Head and Evaporation Surface - Dalby Development Region

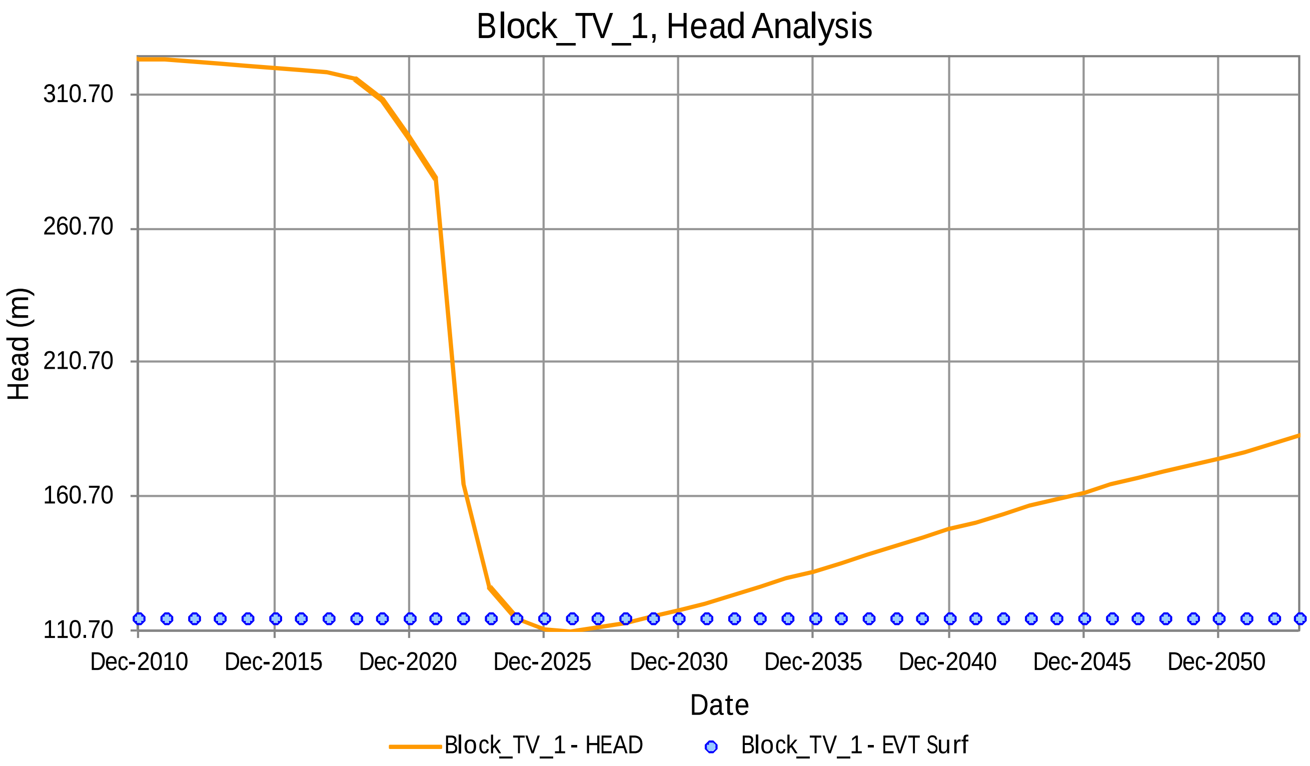




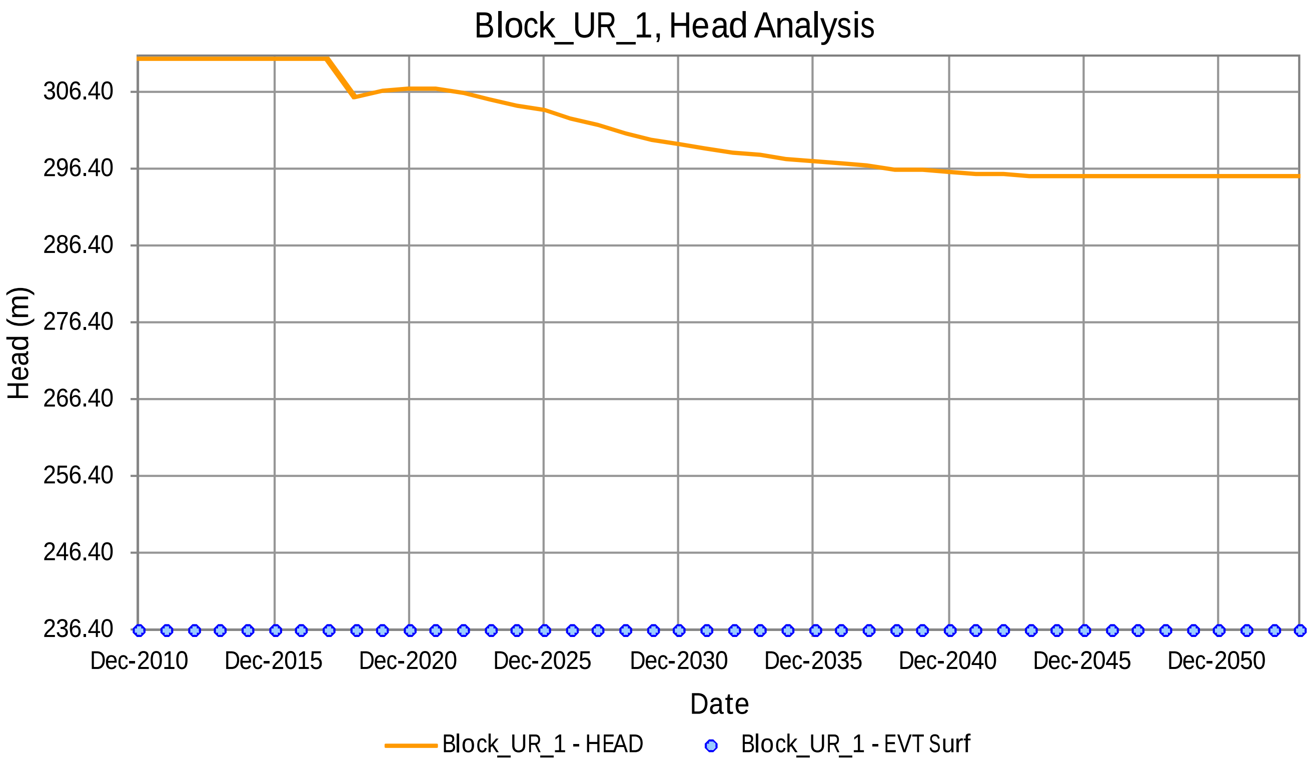
G:\41\26392\Tech\Design\GWModel\OGIAModel_results\mod2smp\Calib_mod2smp_hds_impact1_Arr5xFac2rev5 (Dalby)

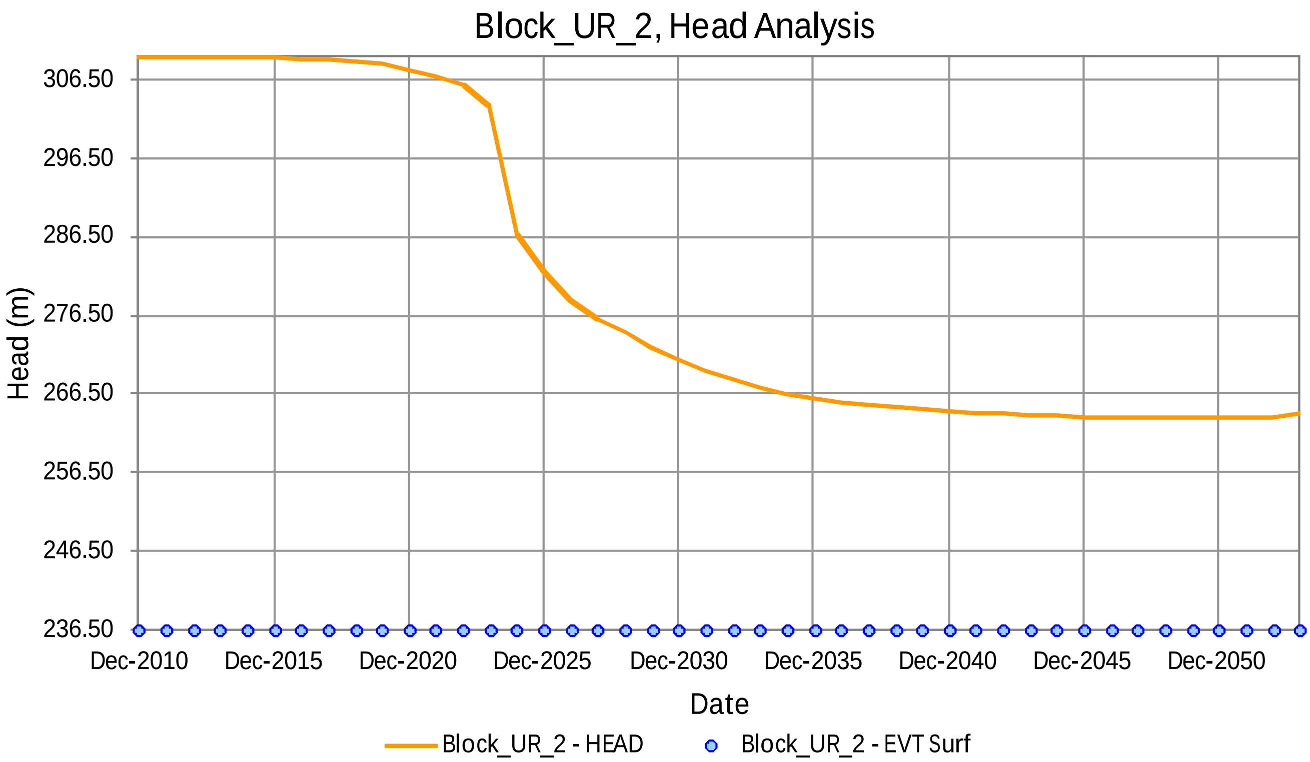
Appendix E - Comparison of Modelled Head and Evaporation Surface - Dalby Development Region



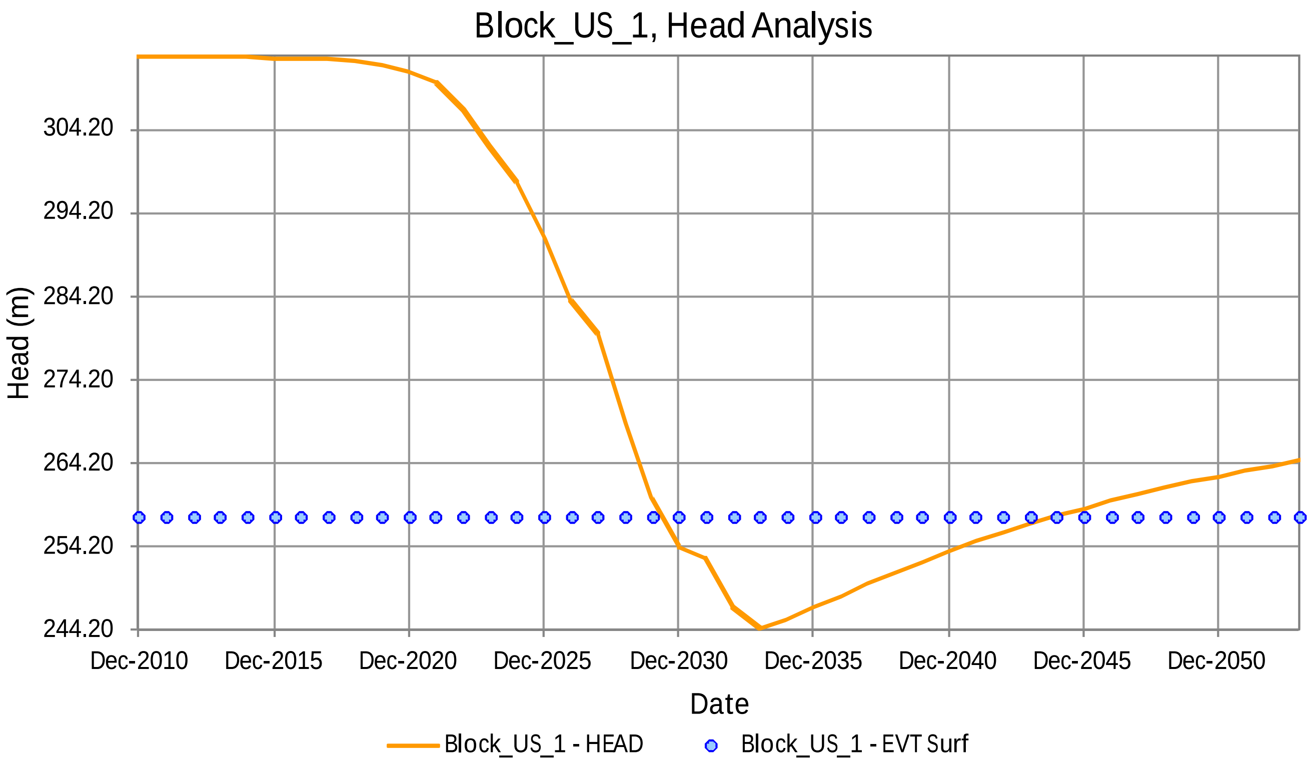


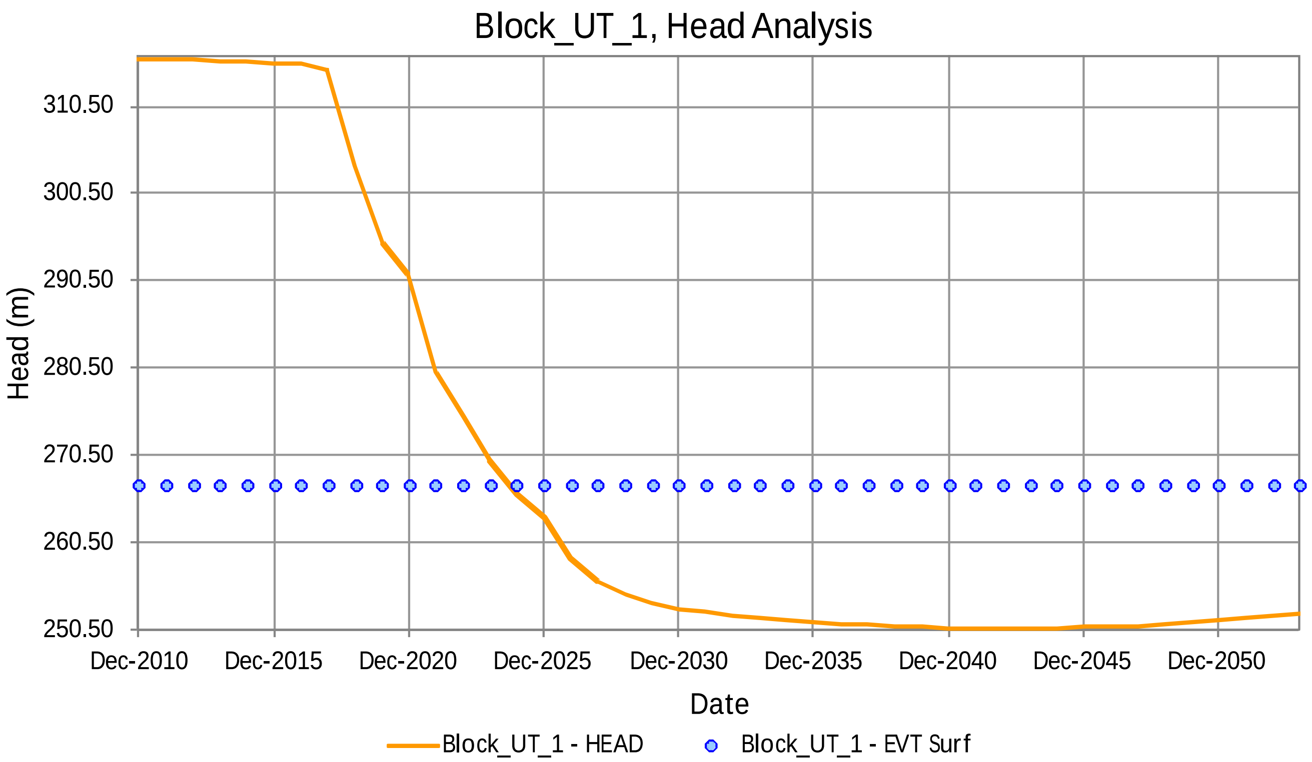
Appendix E - Comparison of Modelled Head and Evaporation Surface - Dalby Development Region



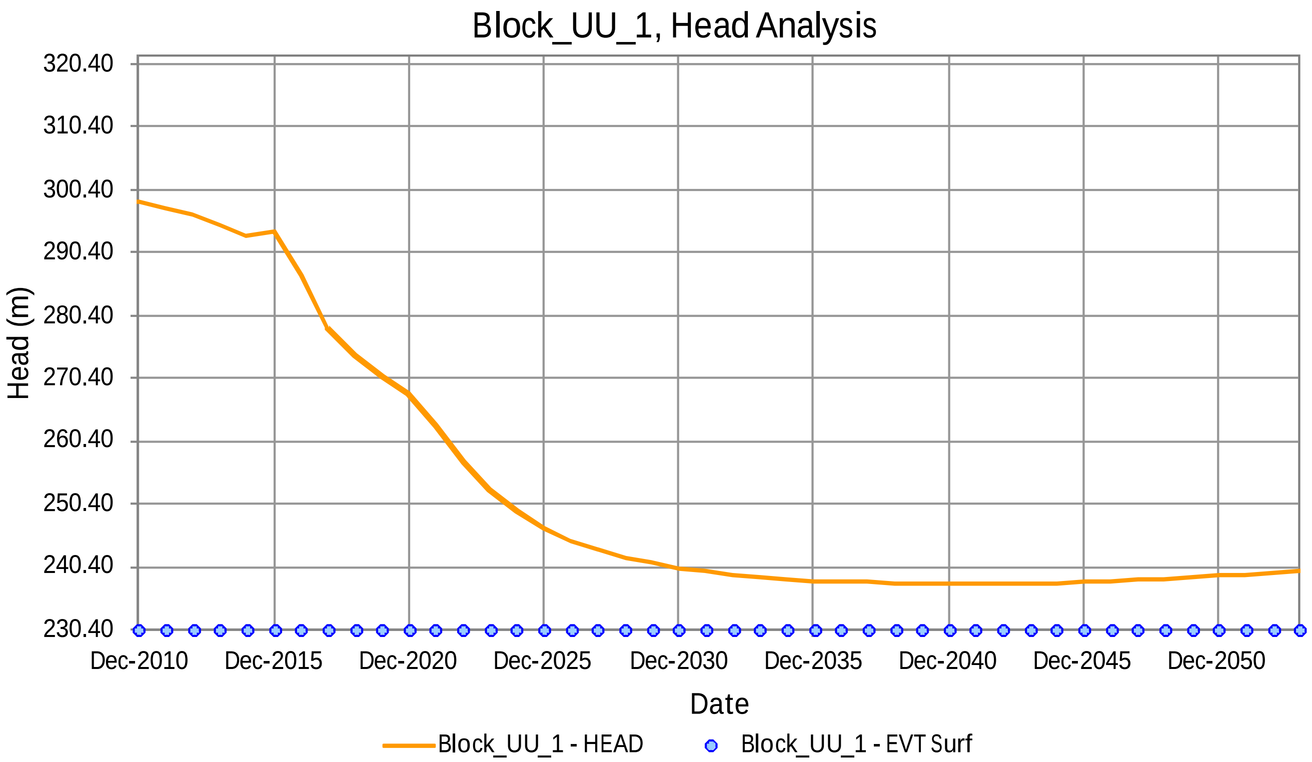


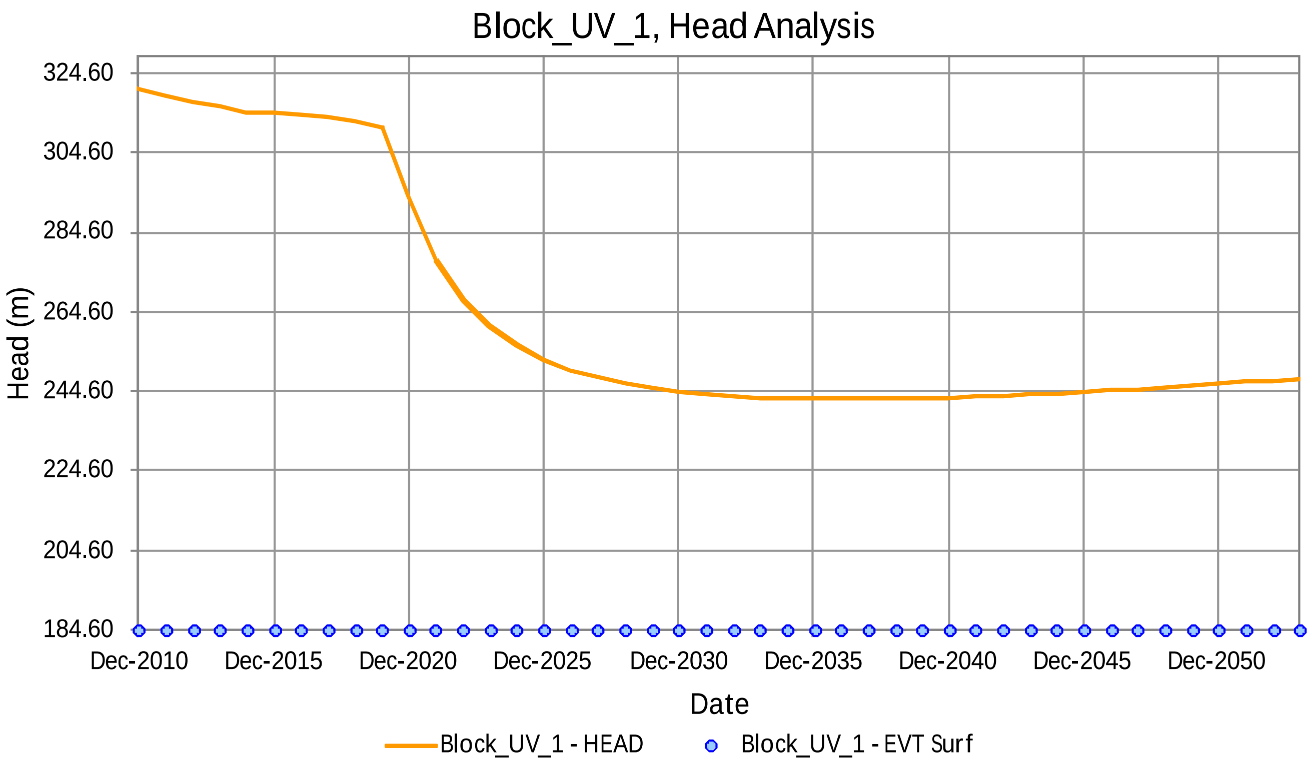
Appendix E - Comparison of Modelled Head and Evaporation Surface - Dalby Development Region



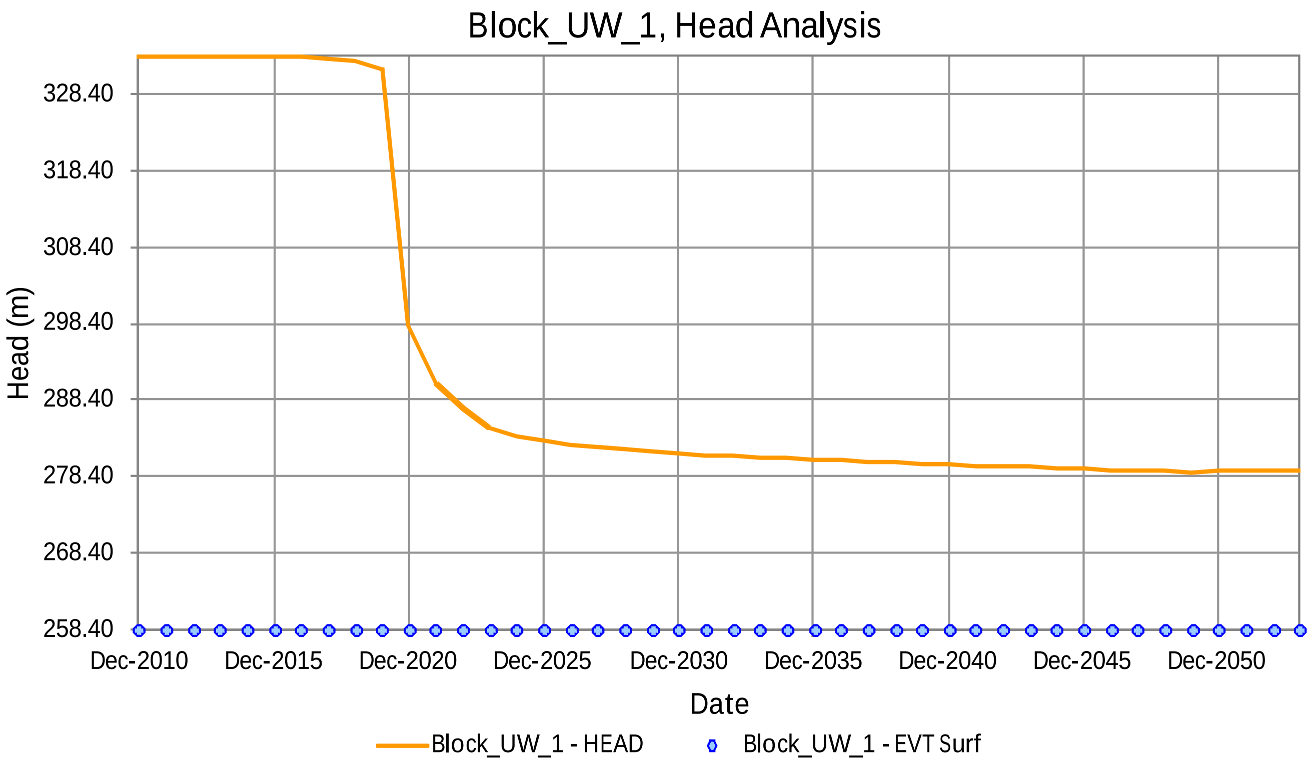


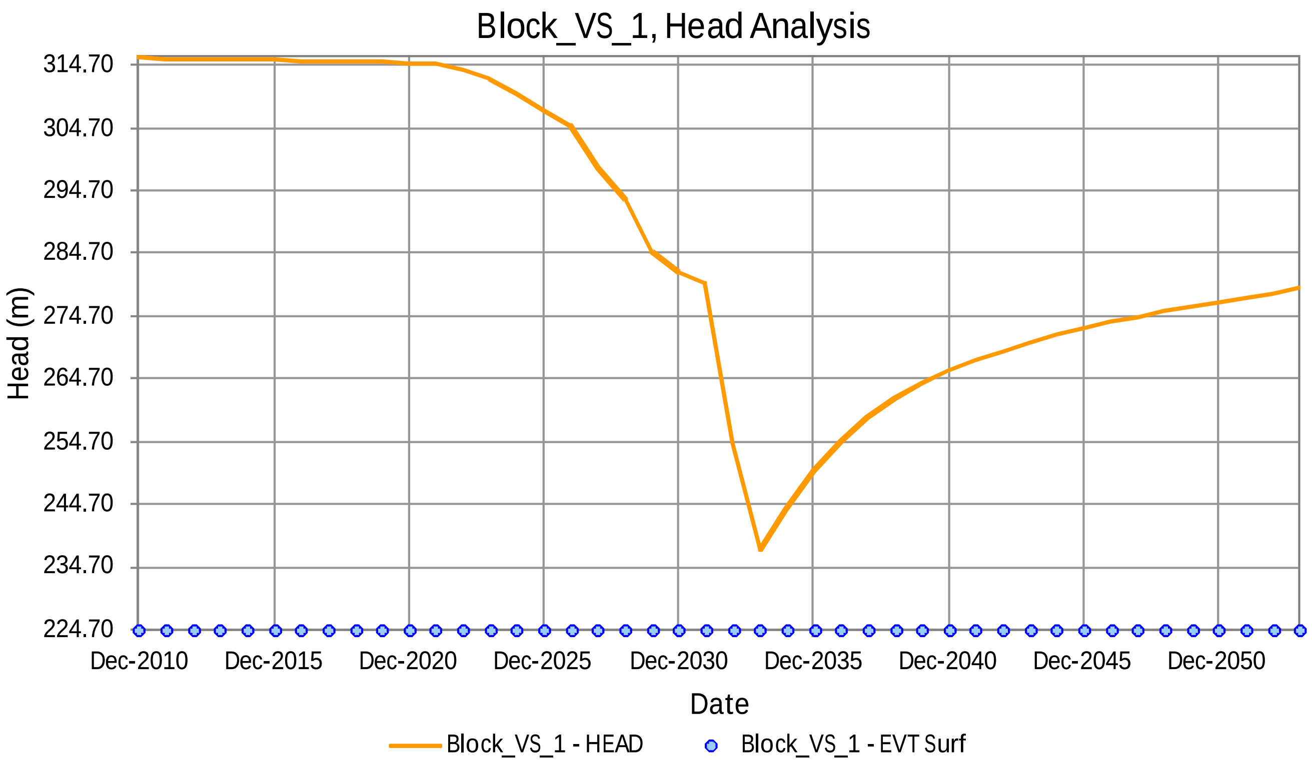
Appendix E - Comparison of Modelled Head and Evaporation Surface - Dalby Development Region



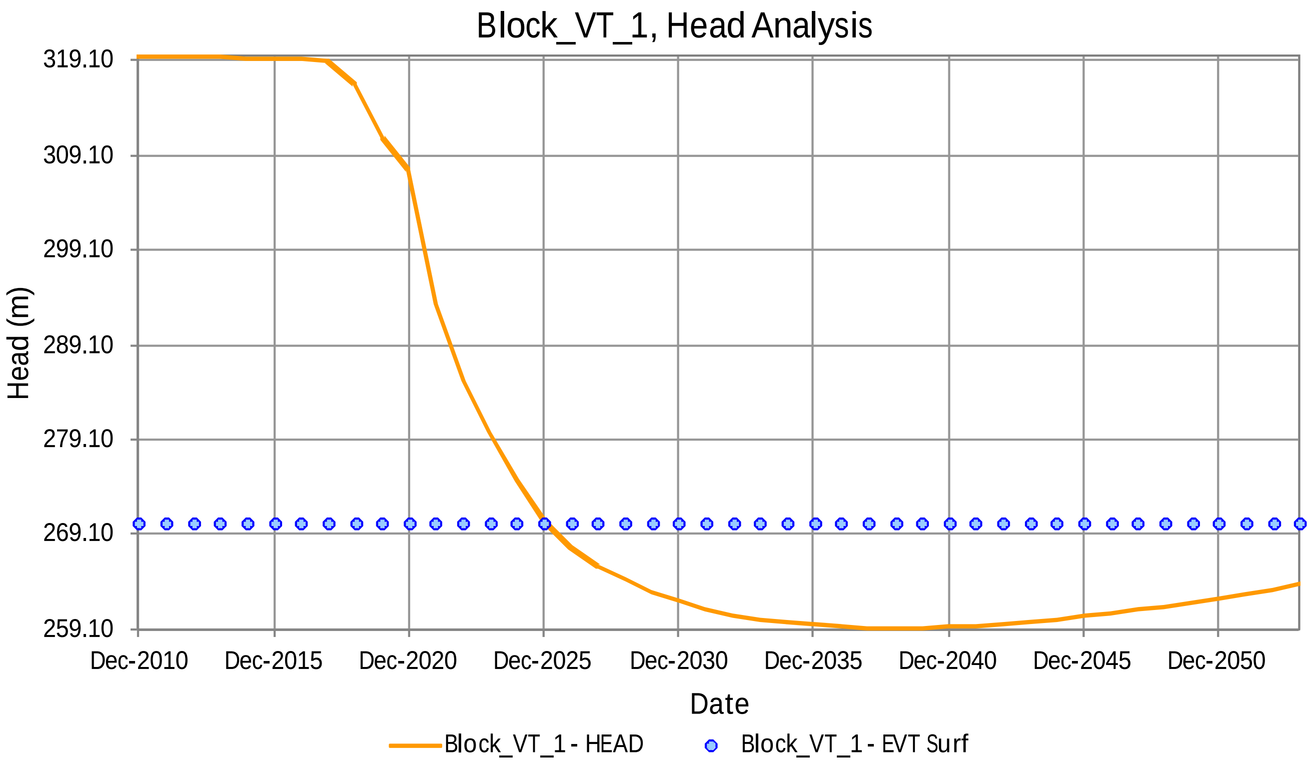


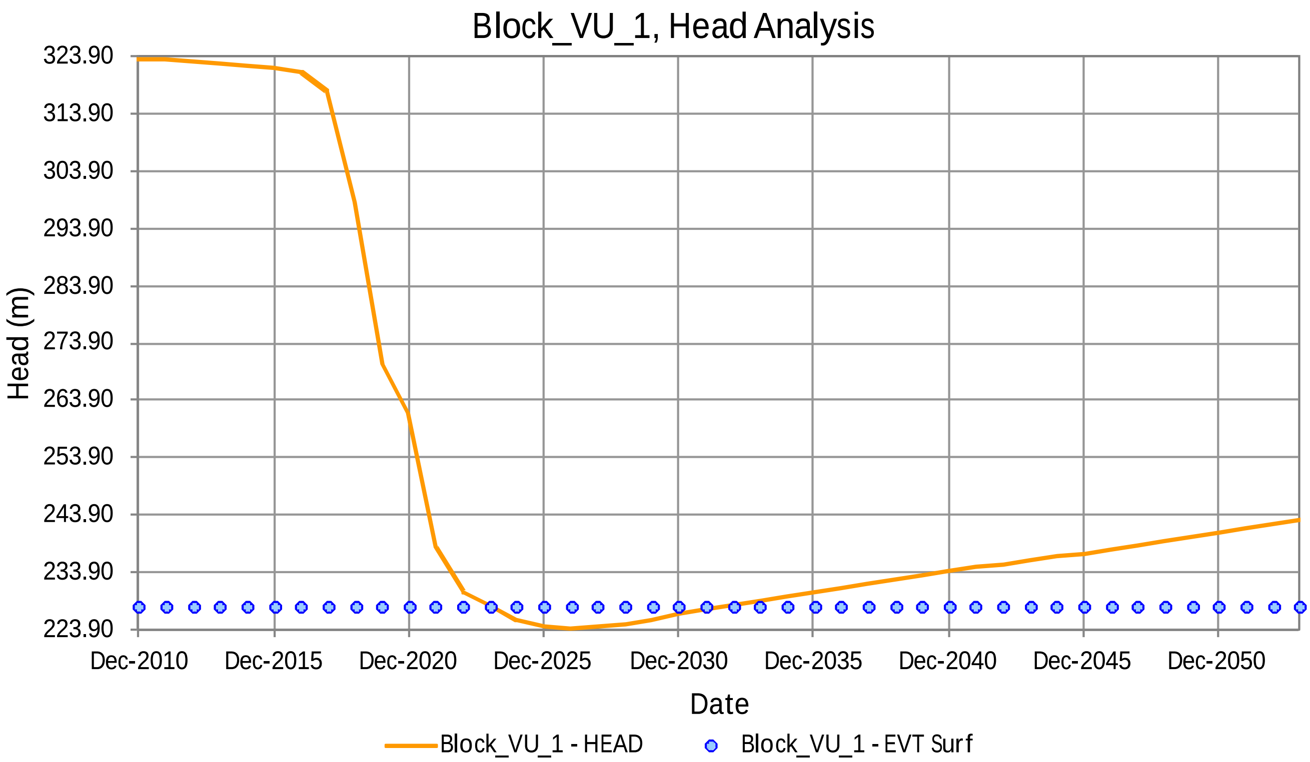
Appendix E - Comparison of Modelled Head and Evaporation Surface - Dalby Development Region



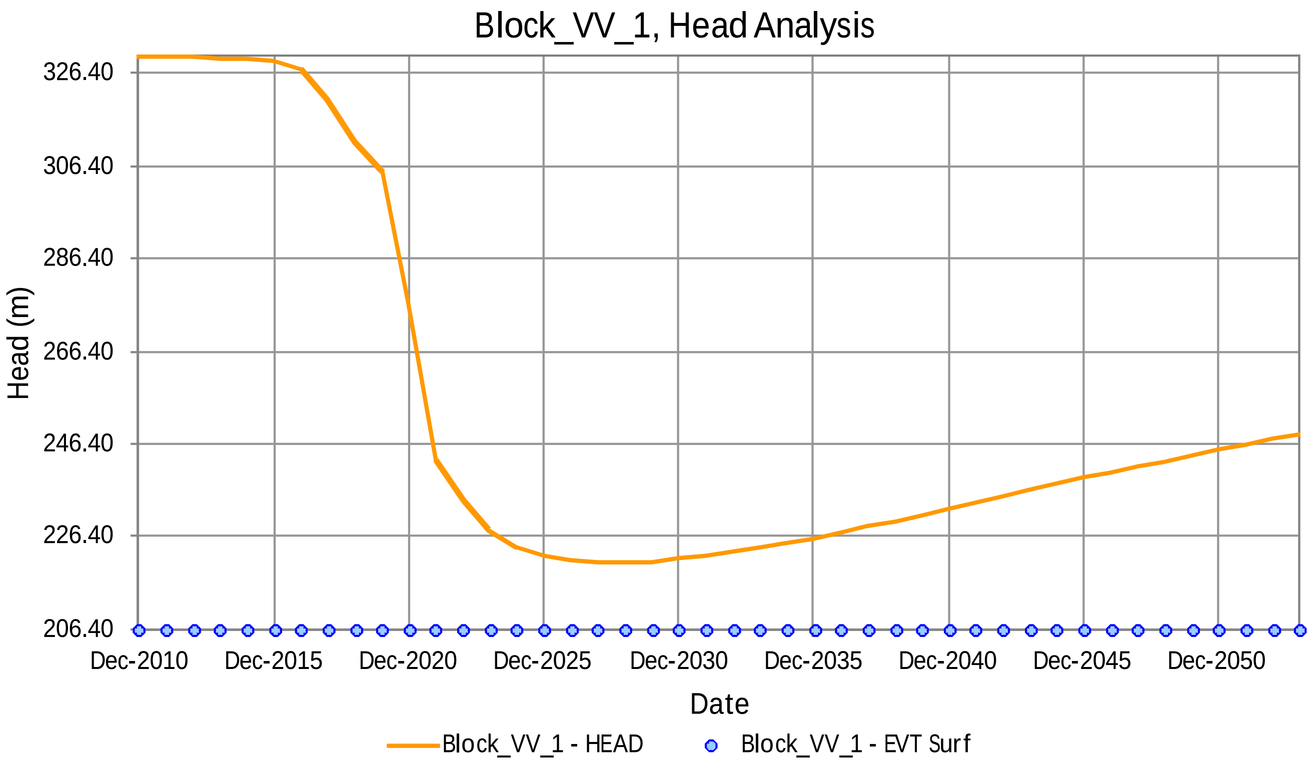


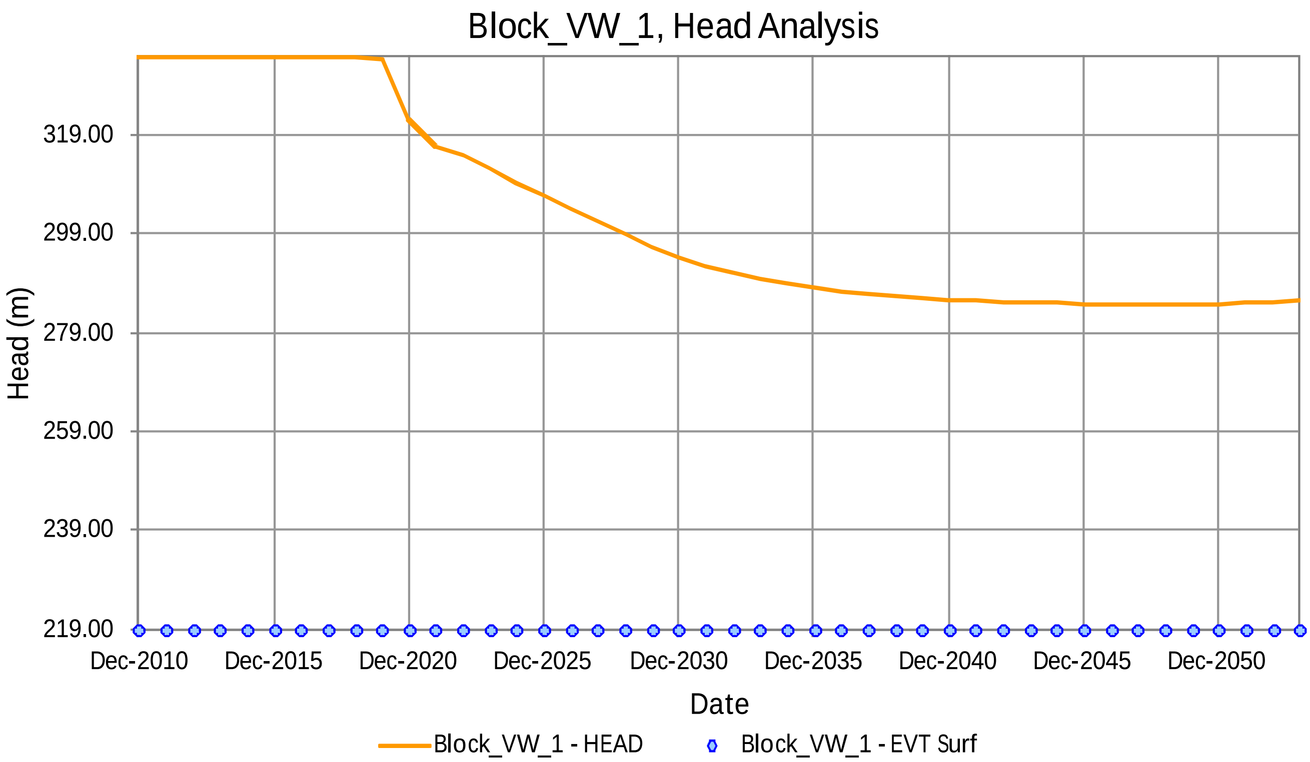
Appendix E - Comparison of Modelled Head and Evaporation Surface - Dalby Development Region



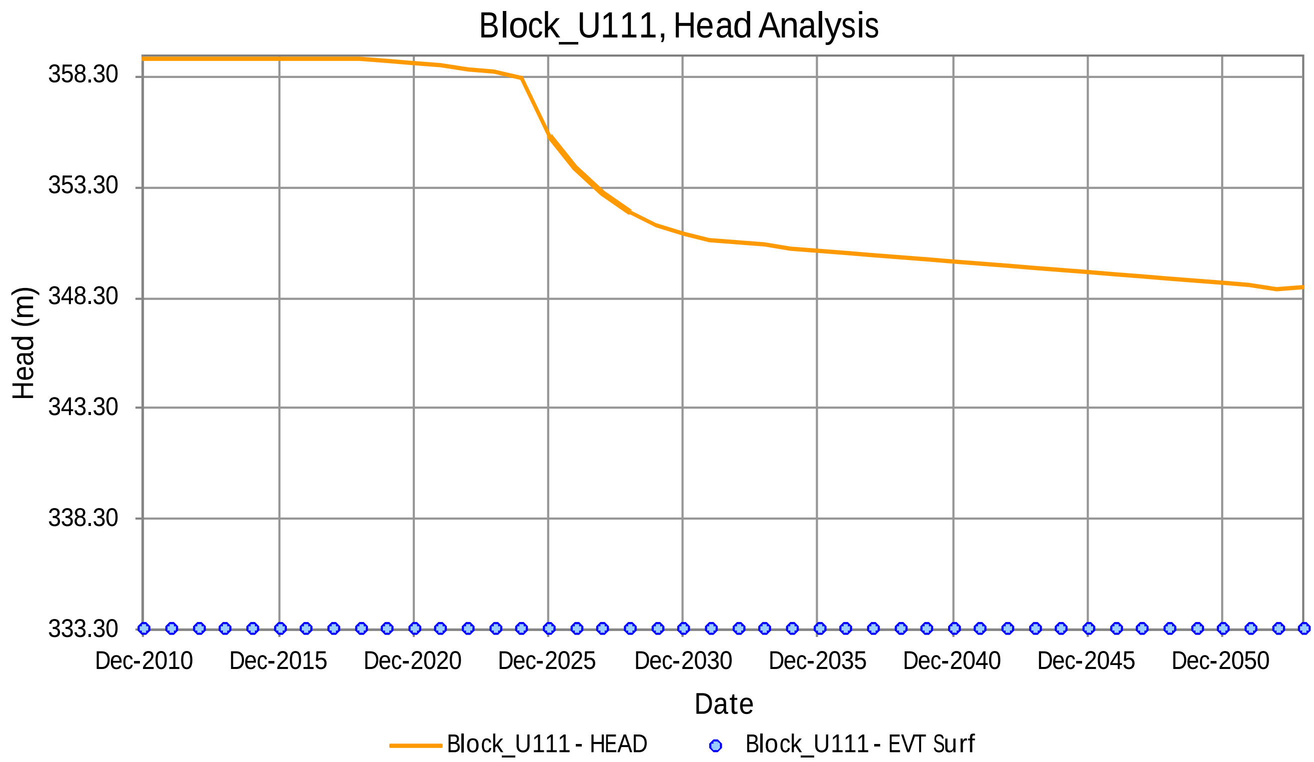


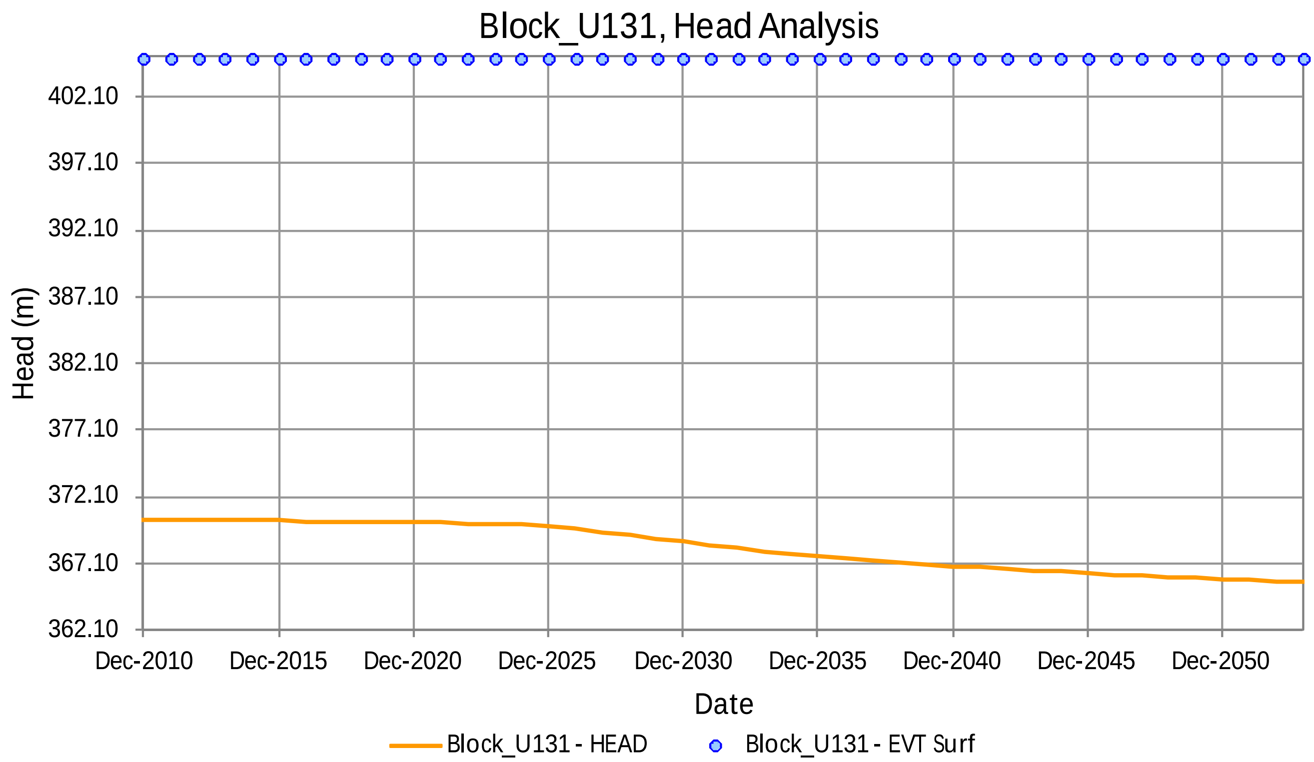
Appendix E - Comparison of Modelled Head and Evaporation Surface - Dalby Development Region





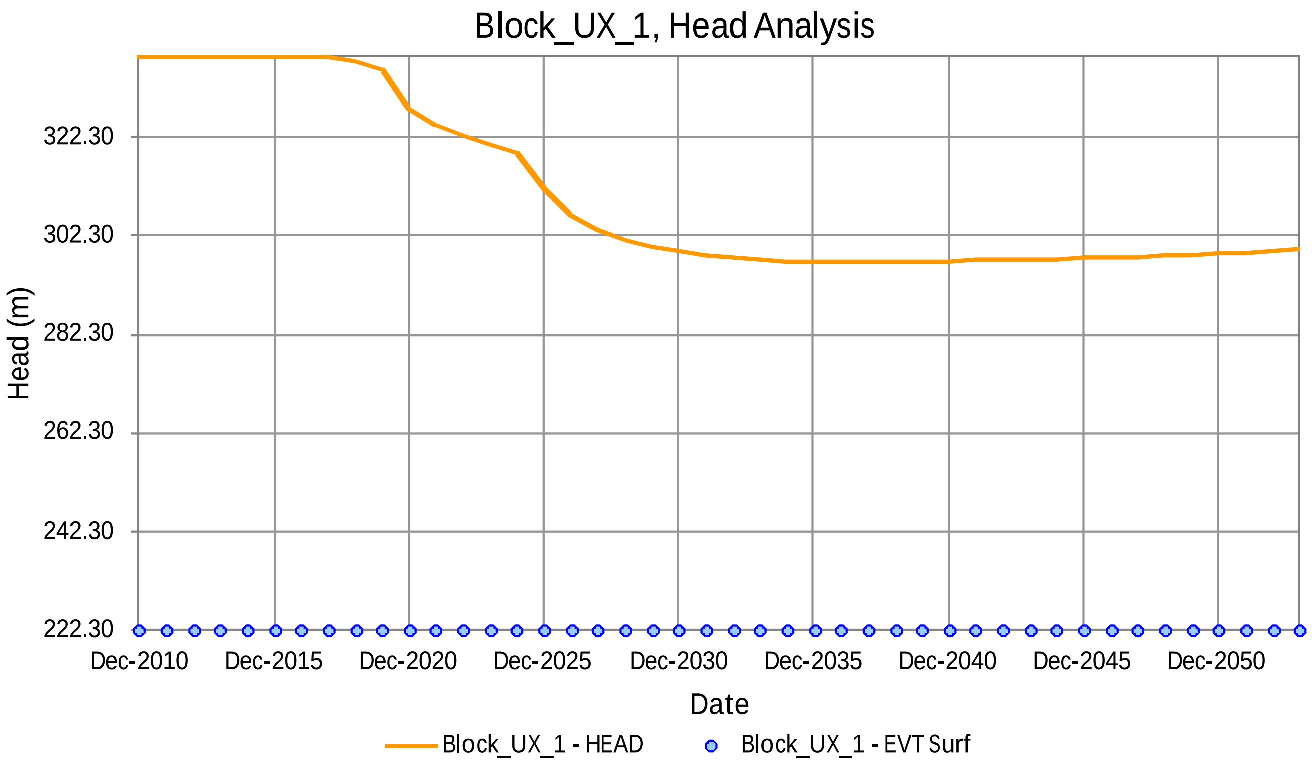
Appendix E - Comparison of Modelled Head and Evaporation Surface - Millmerran Development Region

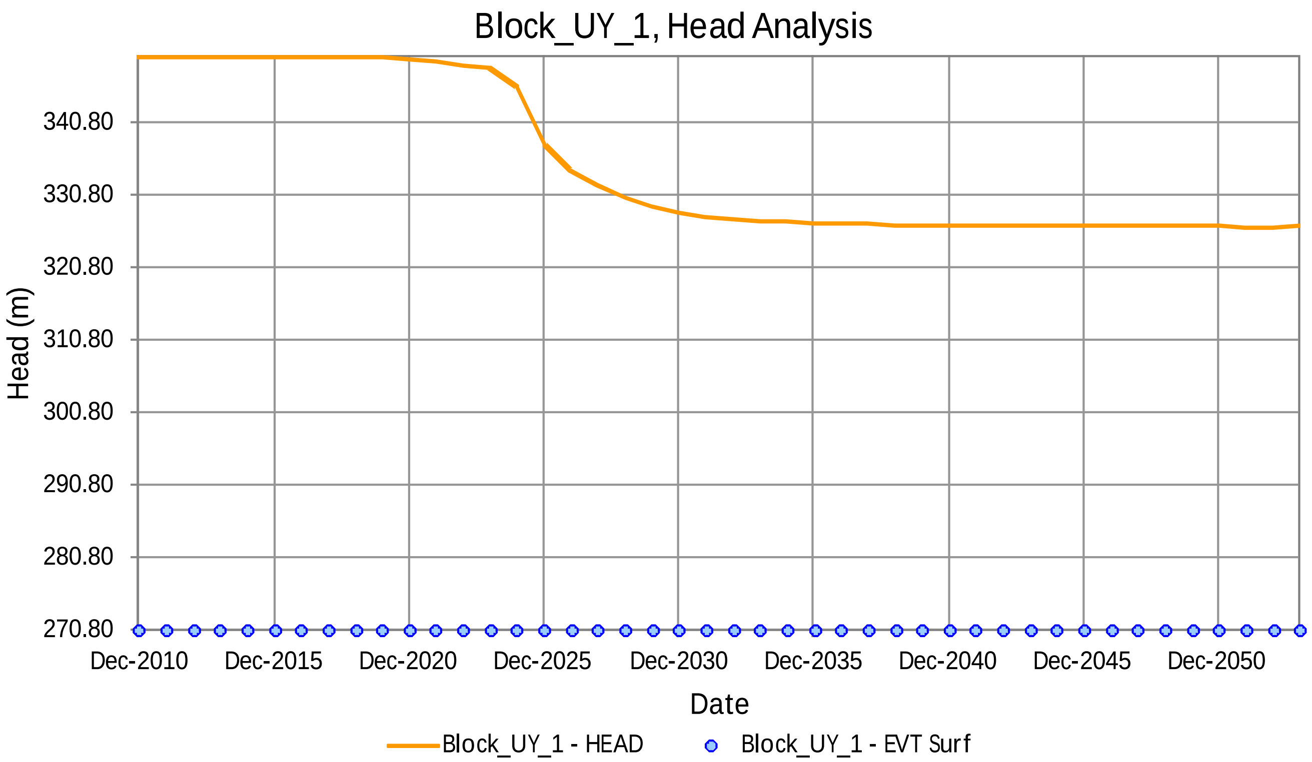




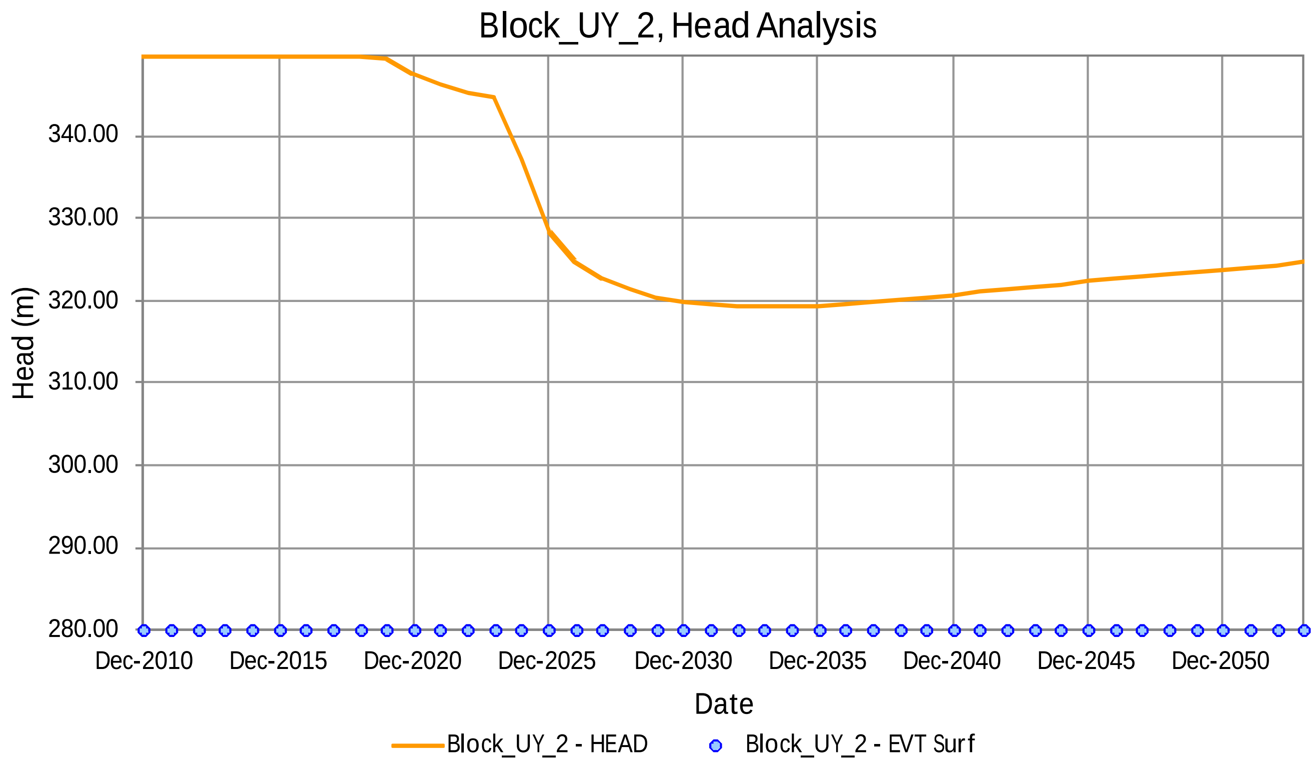
G:\41\26392\Tech\Design\GWModel\OGIAModel_results\mod2smp\Calib_mod2smp_hds_impact1_Arr5xFac2rev5 (Millmerran)

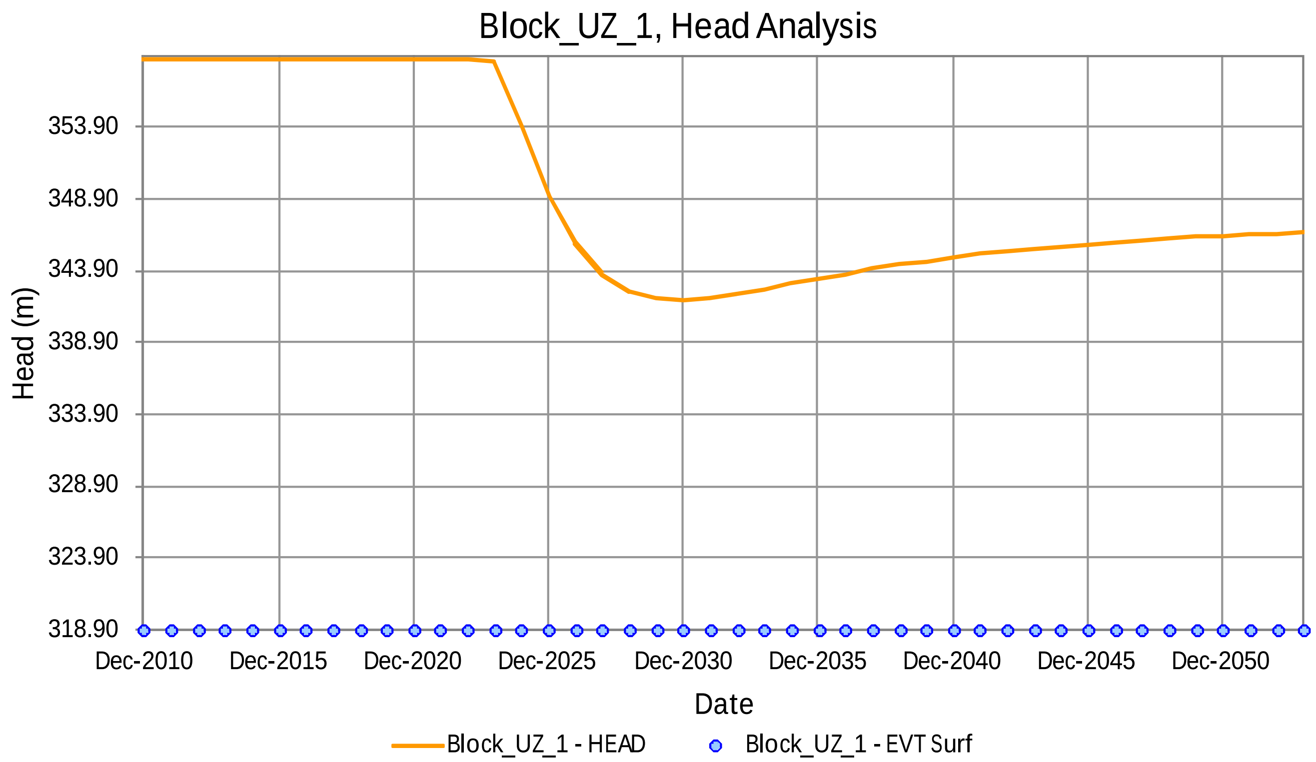
Appendix E - Comparison of Modelled Head and Evaporation Surface - Millmerran Development Region



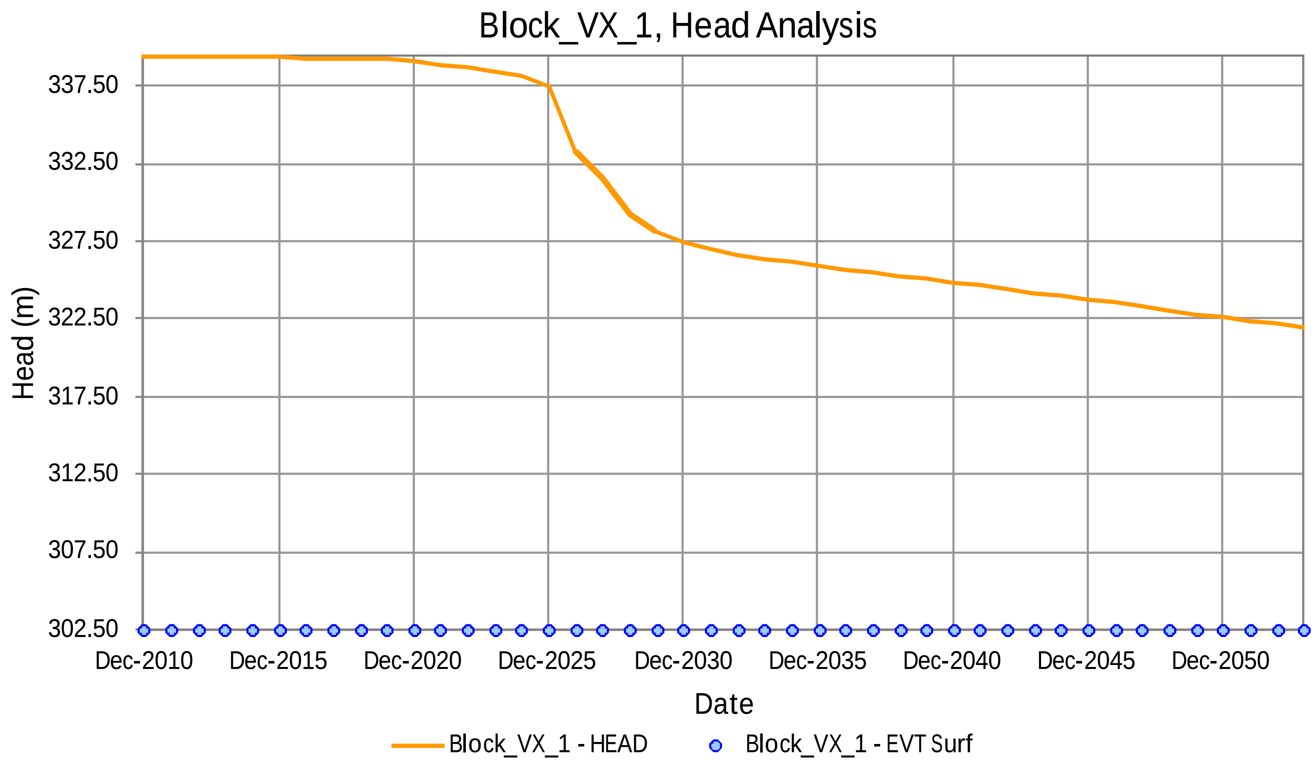


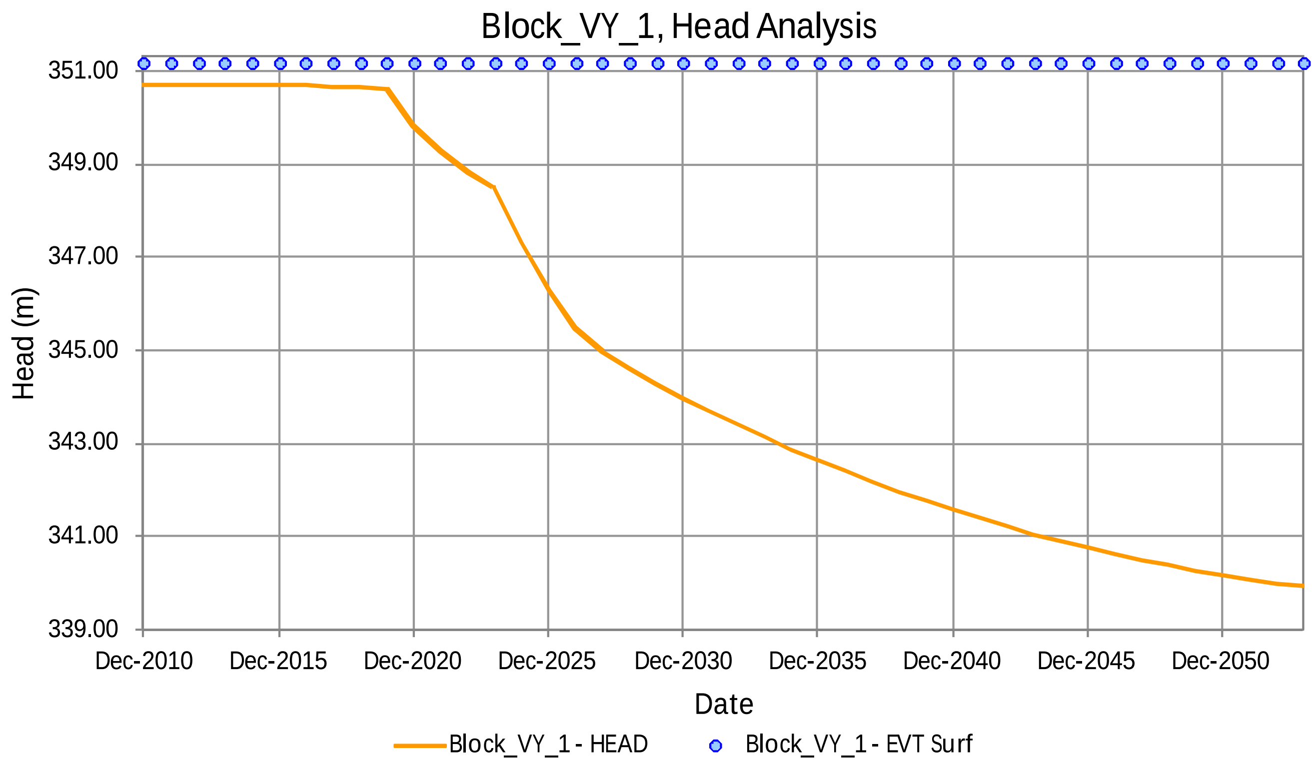
Appendix E - Comparison of Modelled Head and Evaporation Surface - Millmerran Development Region





Appendix E - Comparison of Modelled Head and Evaporation Surface - Millmerran Development Region





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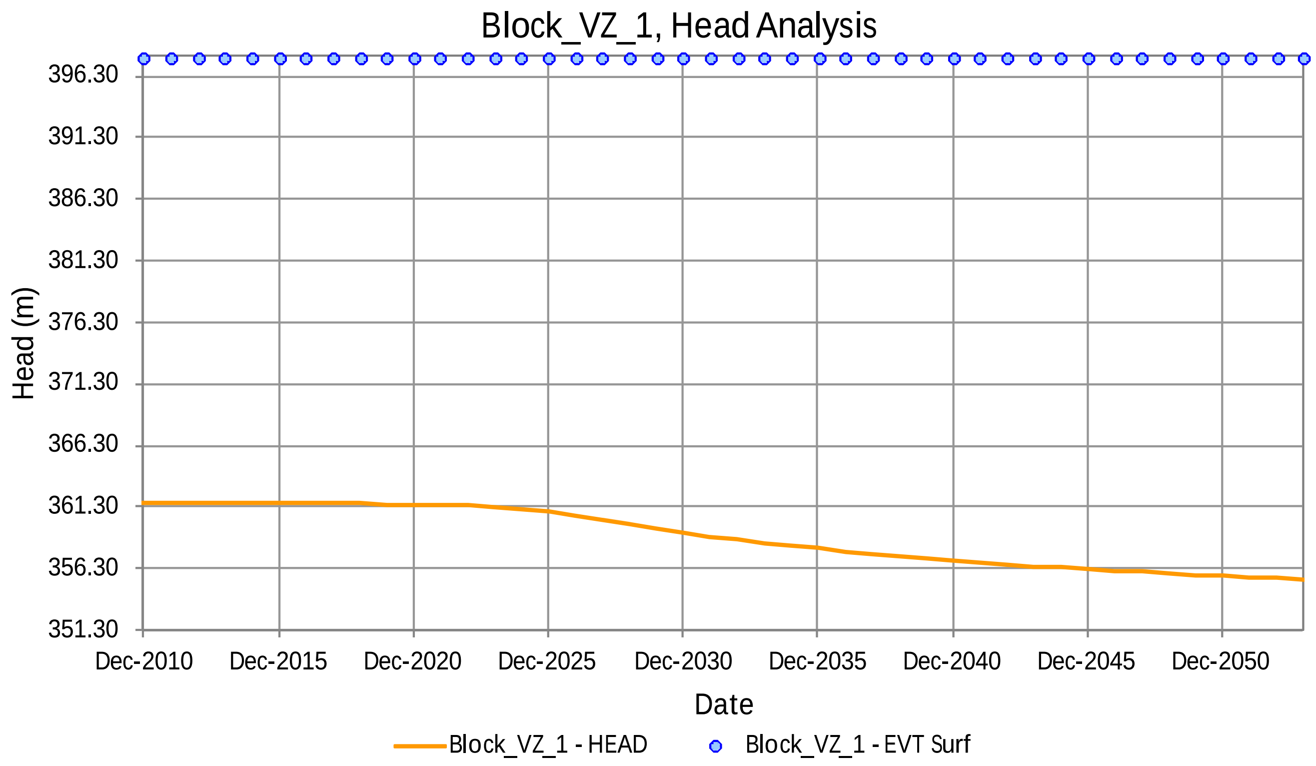
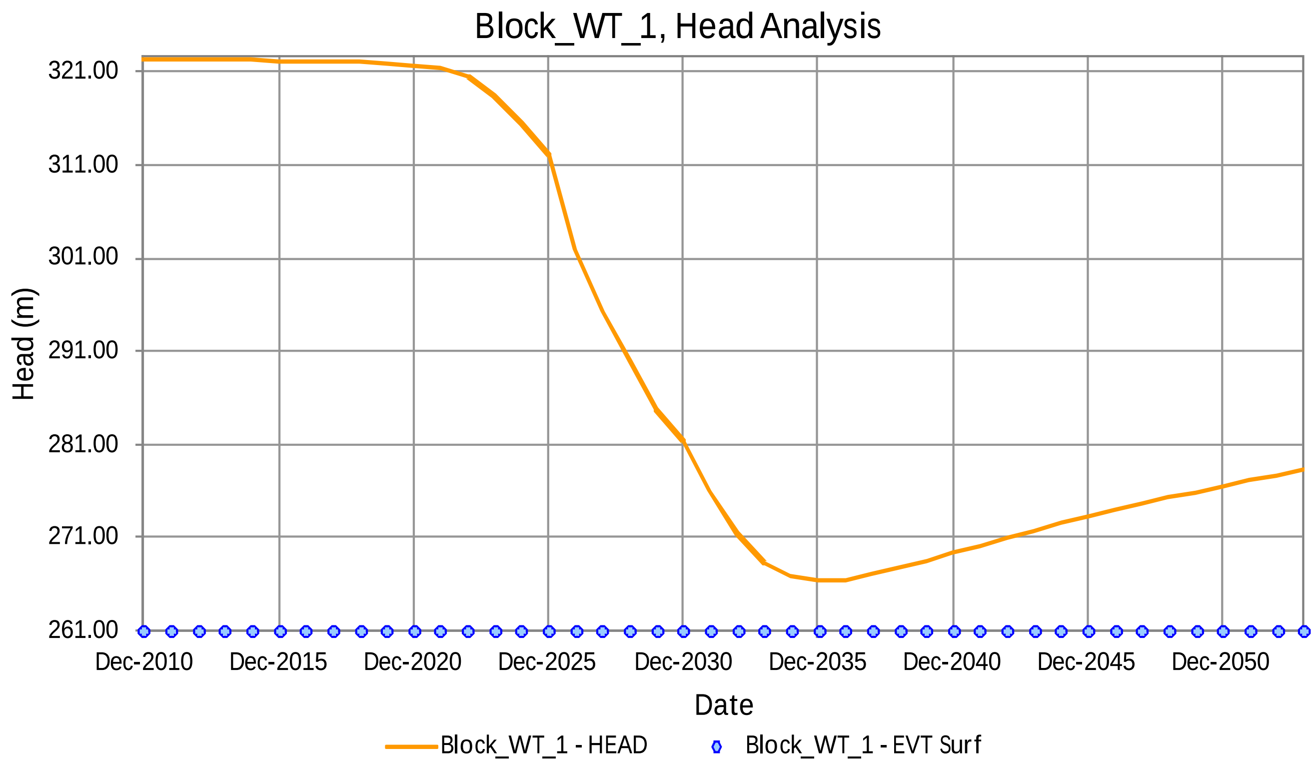
Appendix E - Comparison of Modelled Head and Evaporation Surface - Millmerran Development Region





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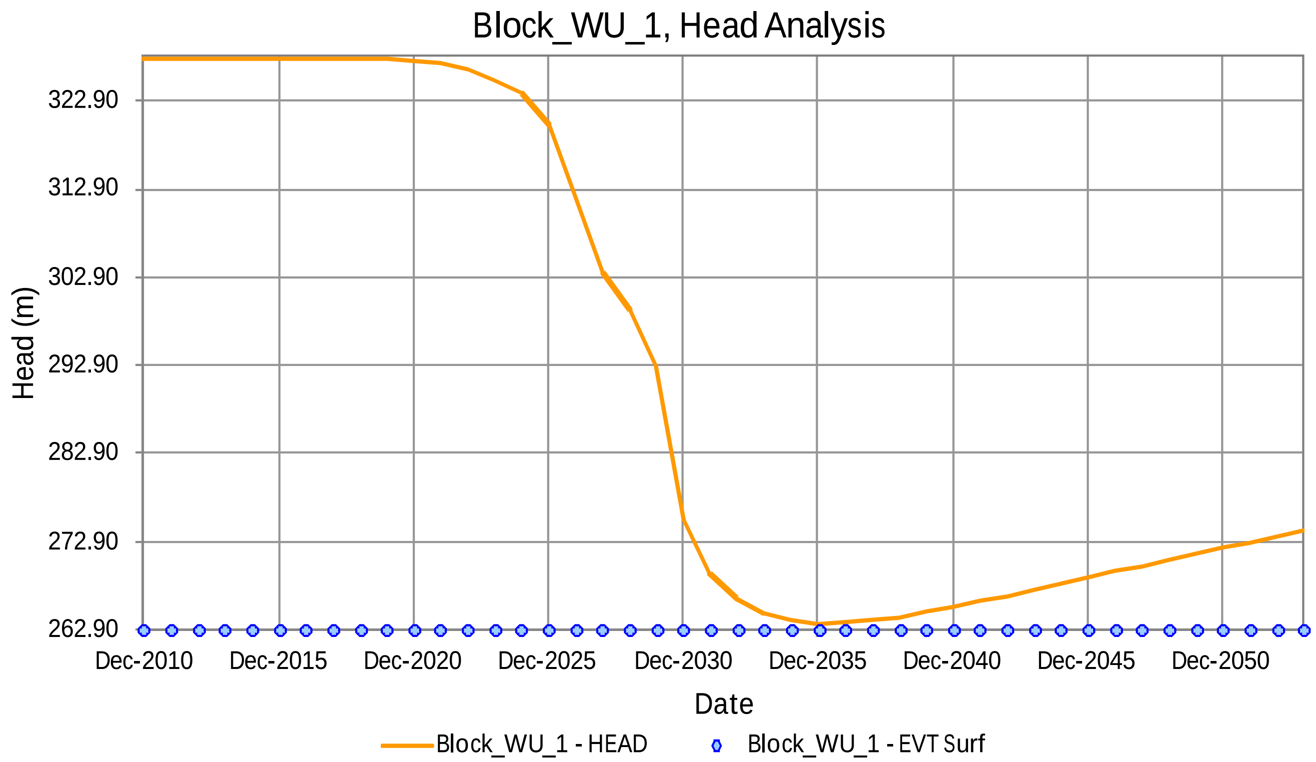
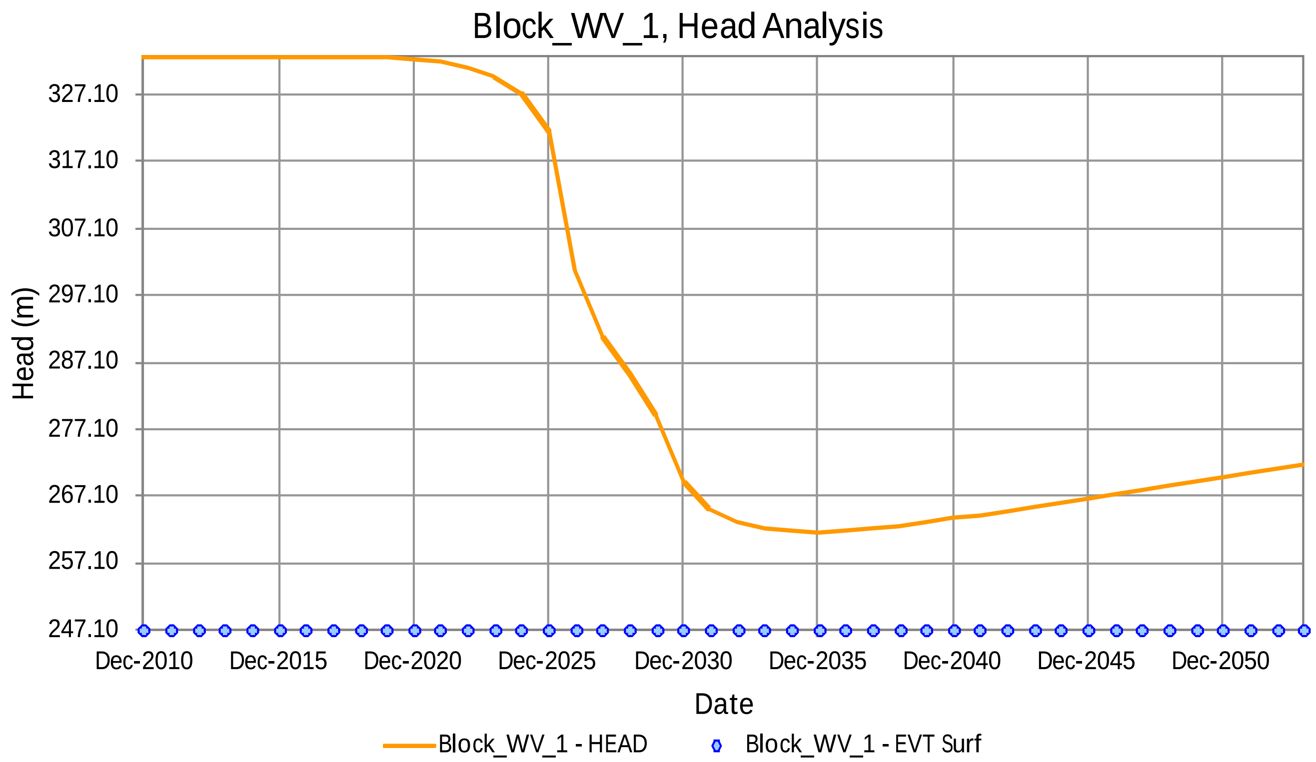
Appendix E - Comparison of Modelled Head and Evaporation Surface - Millmerran Development Region





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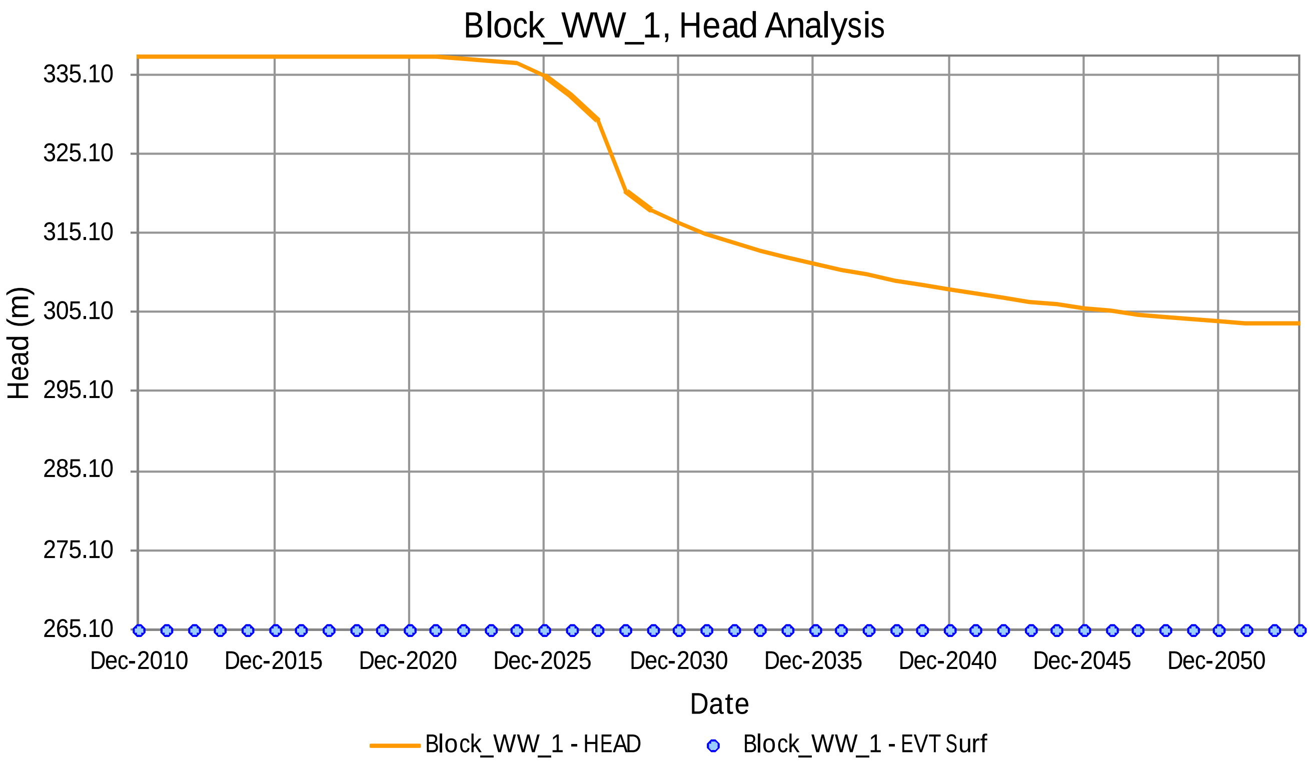
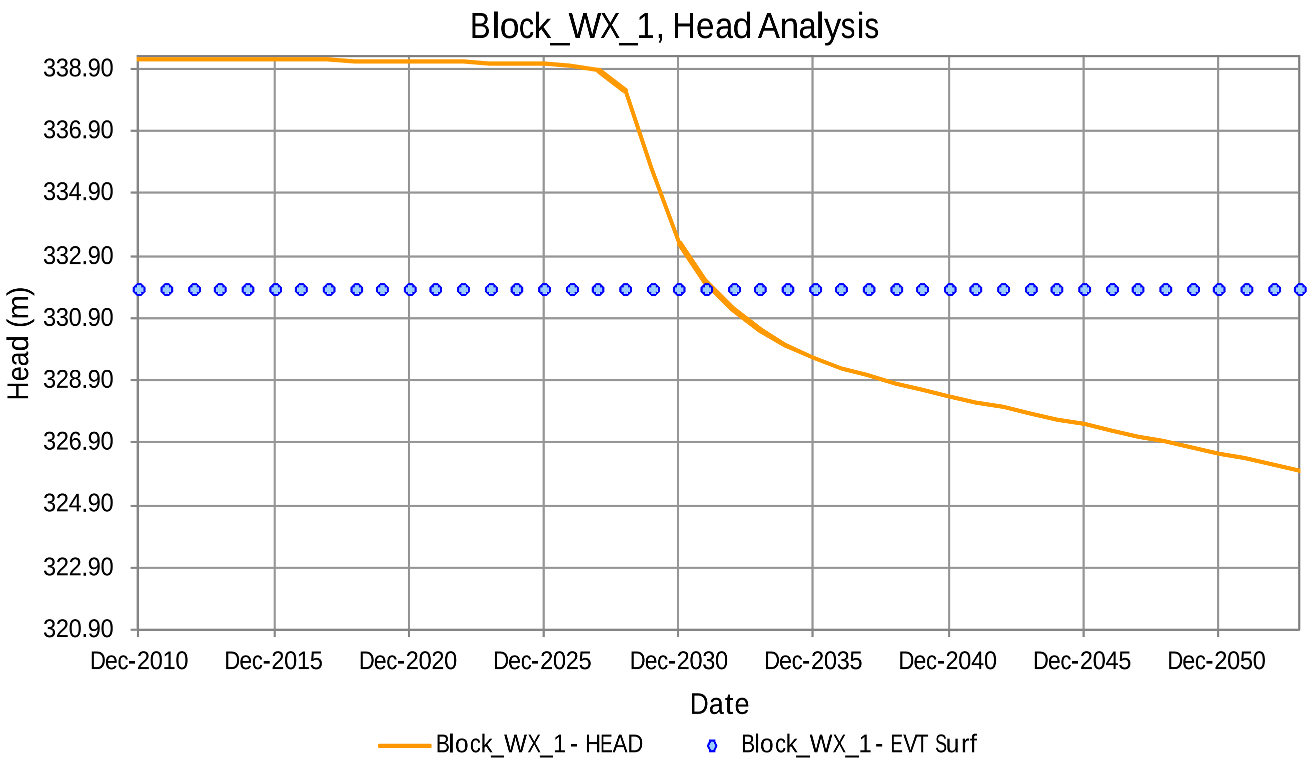
Appendix E - Comparison of Modelled Head and Evaporation Surface - Millmerran Development Region





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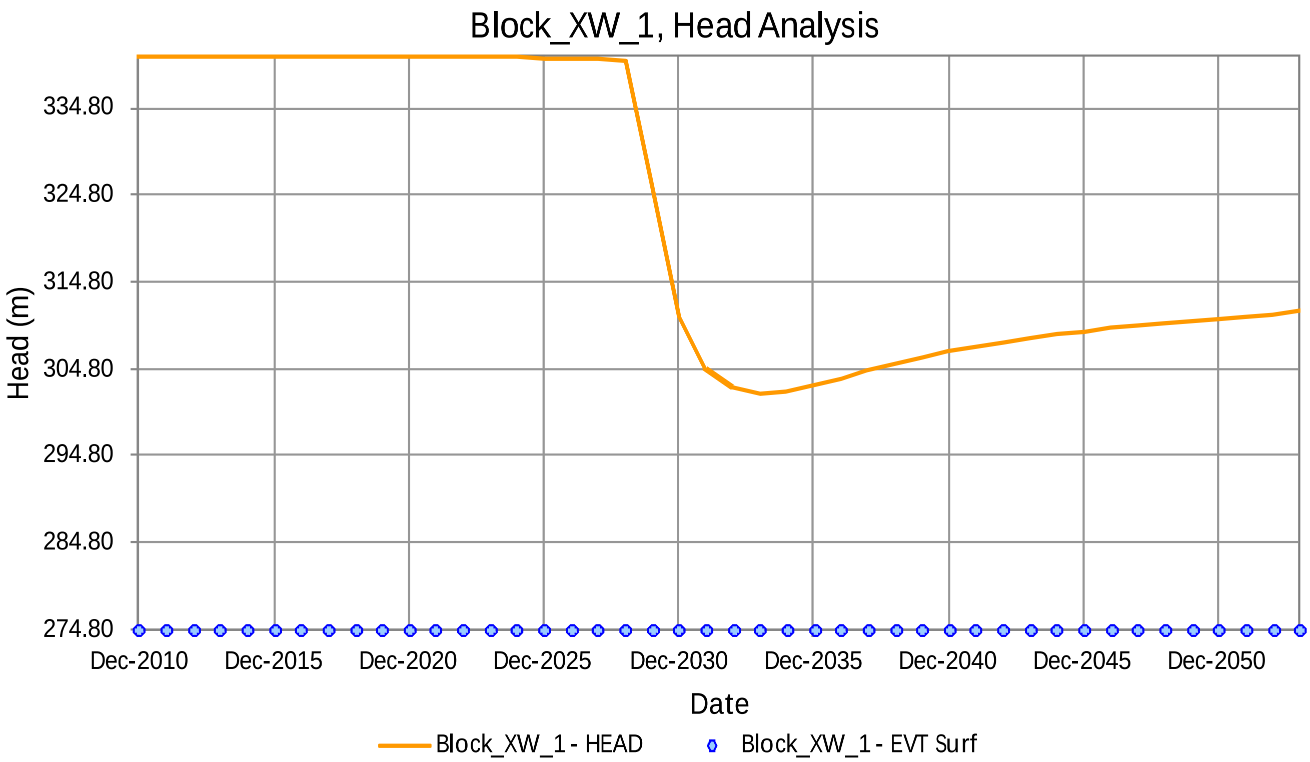
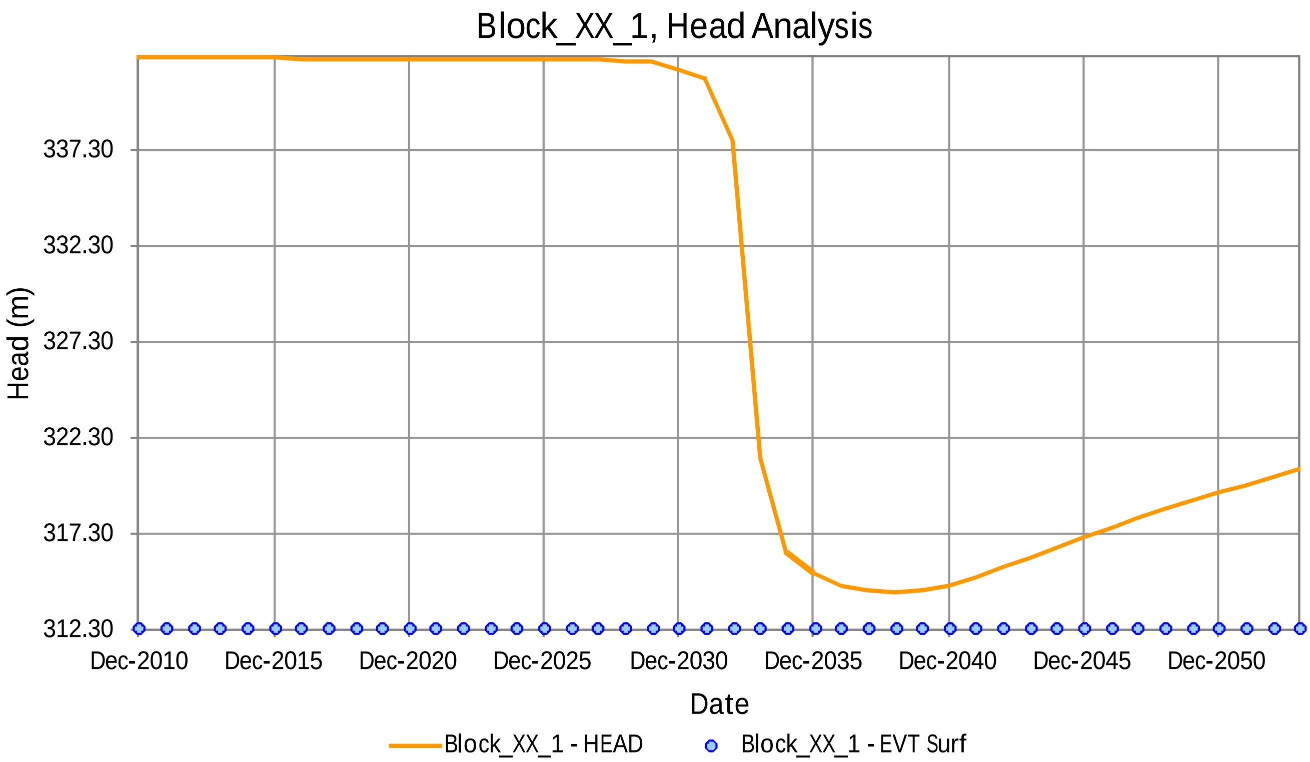
Appendix E - Comparison of Modelled Head and Evaporation Surface - Millmerran Development Region





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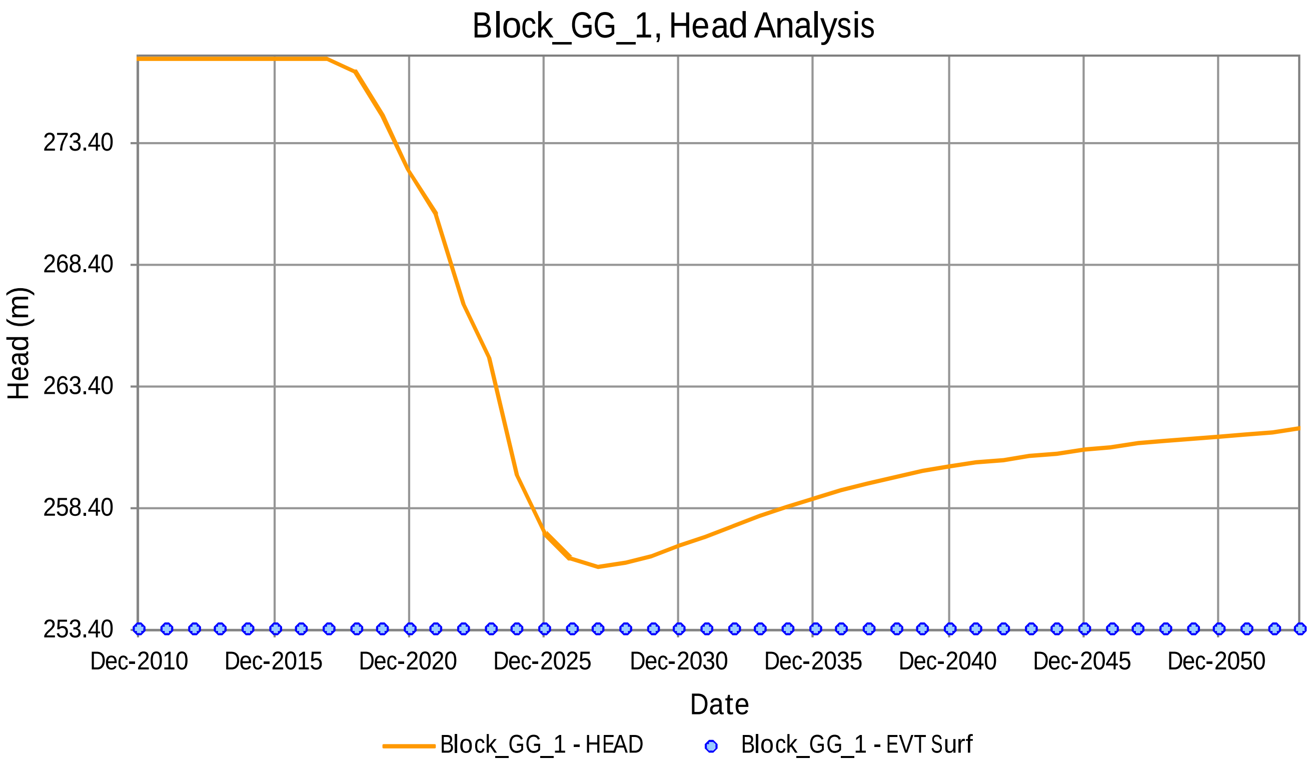
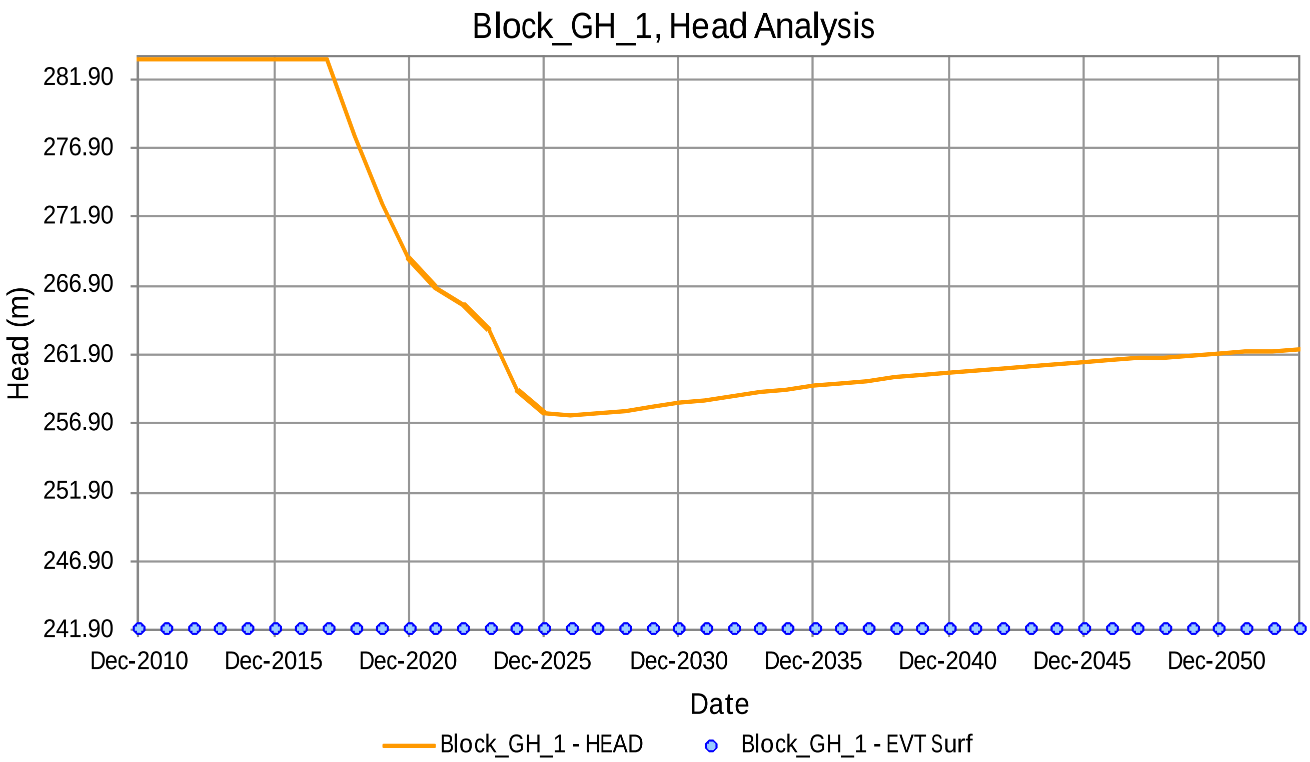
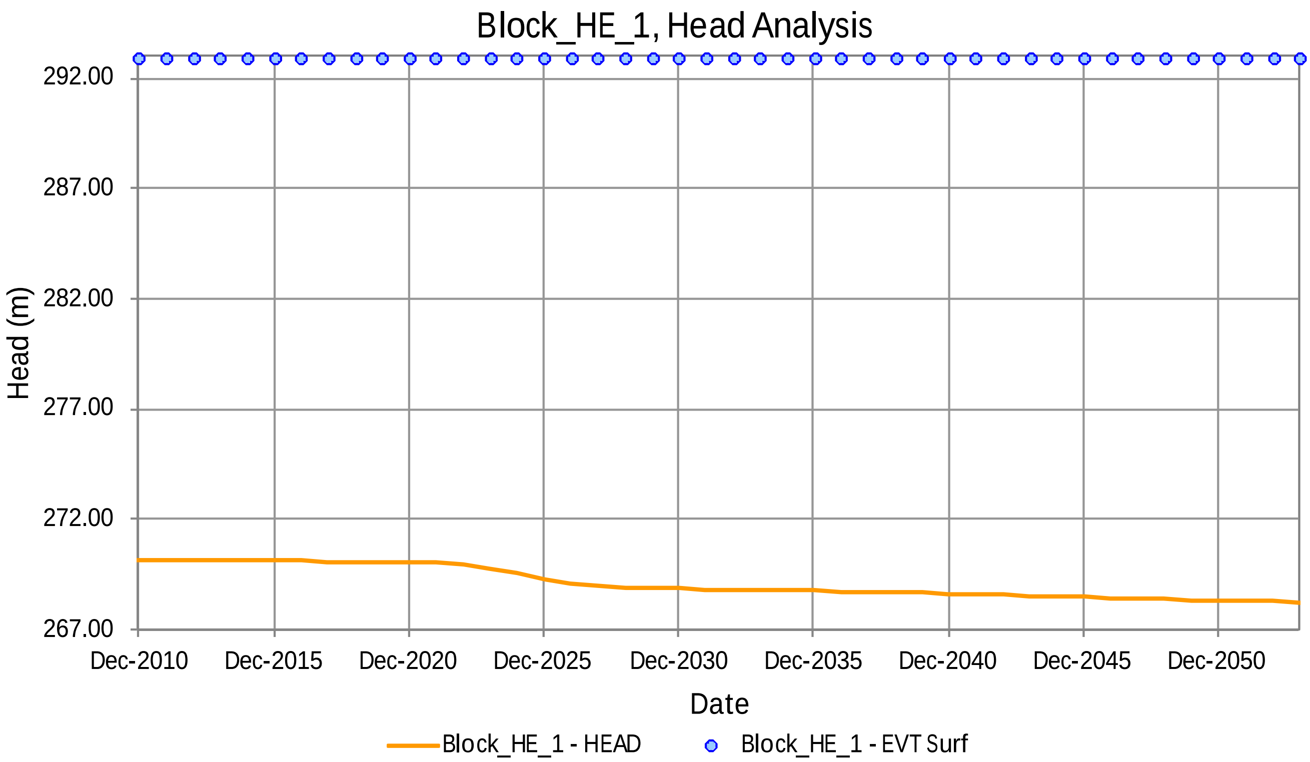
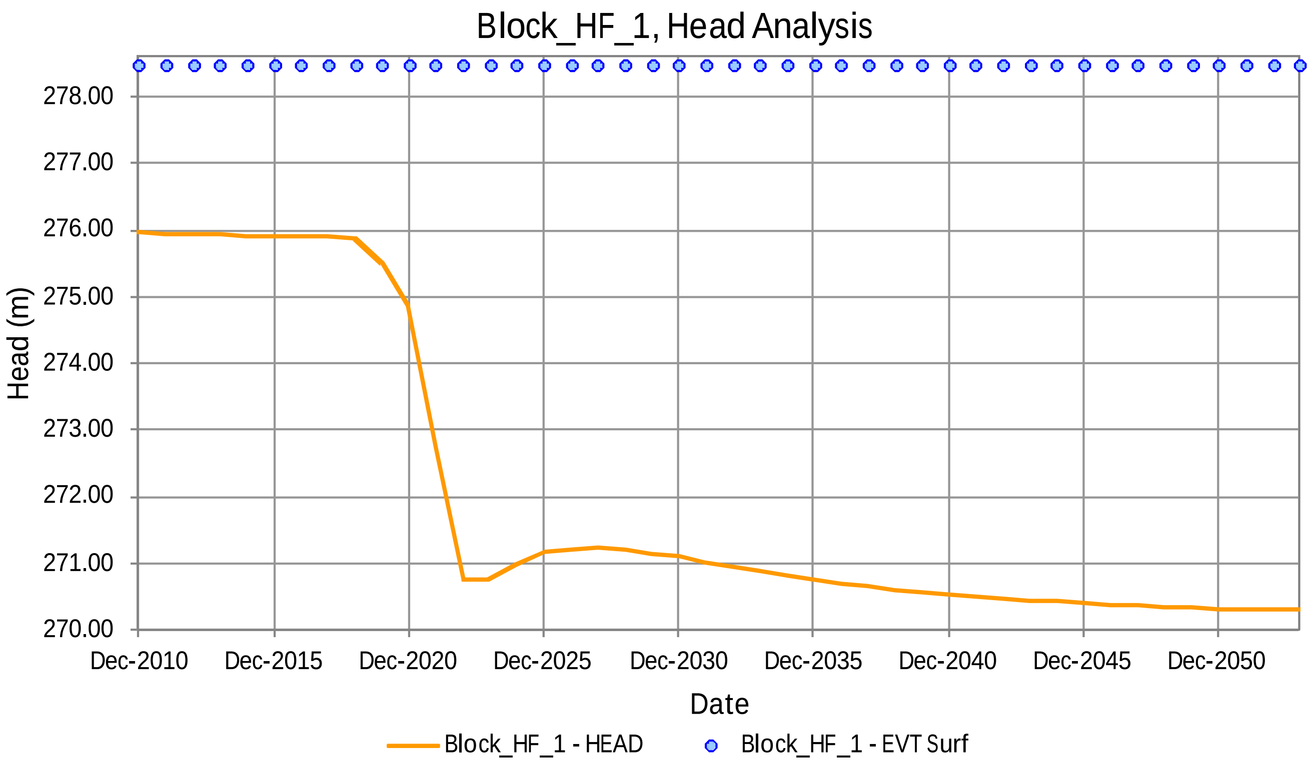
Appendix E - Comparison of Modelled Head and Evaporation Surface - Wandoan Development Region



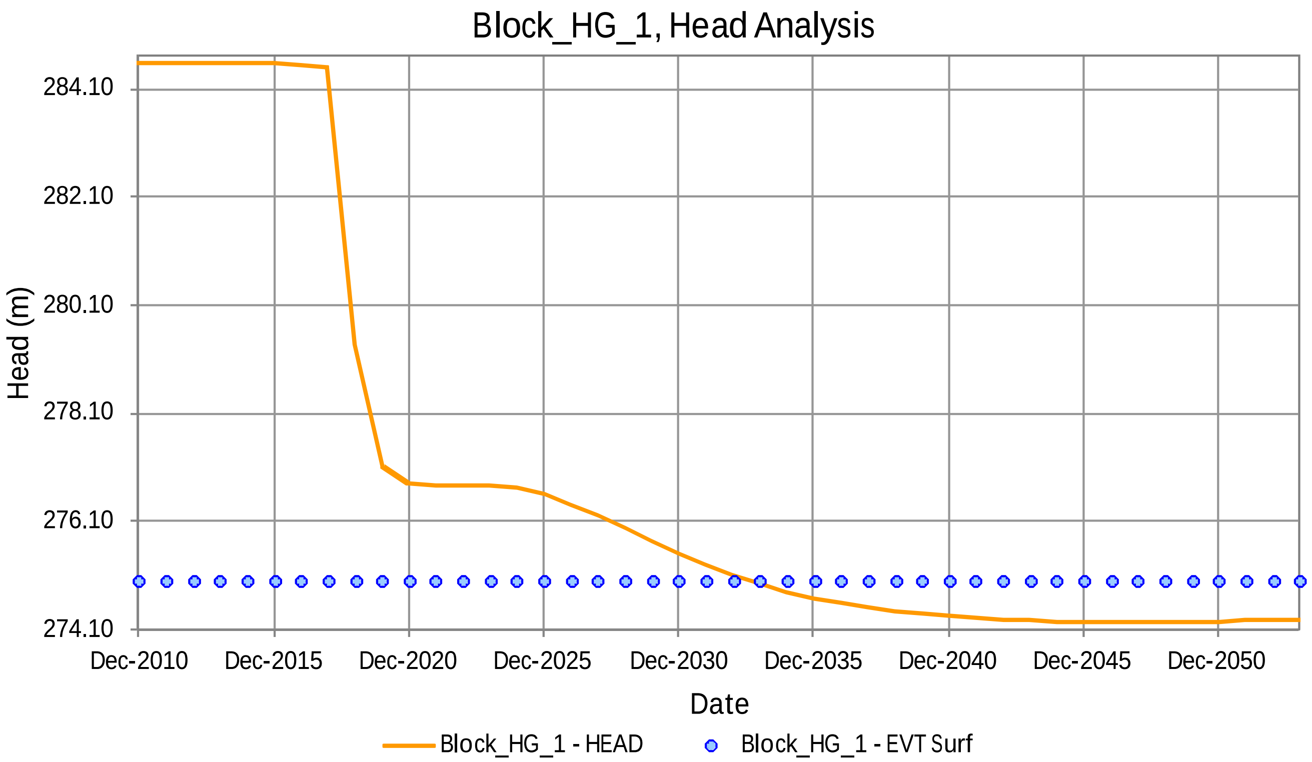


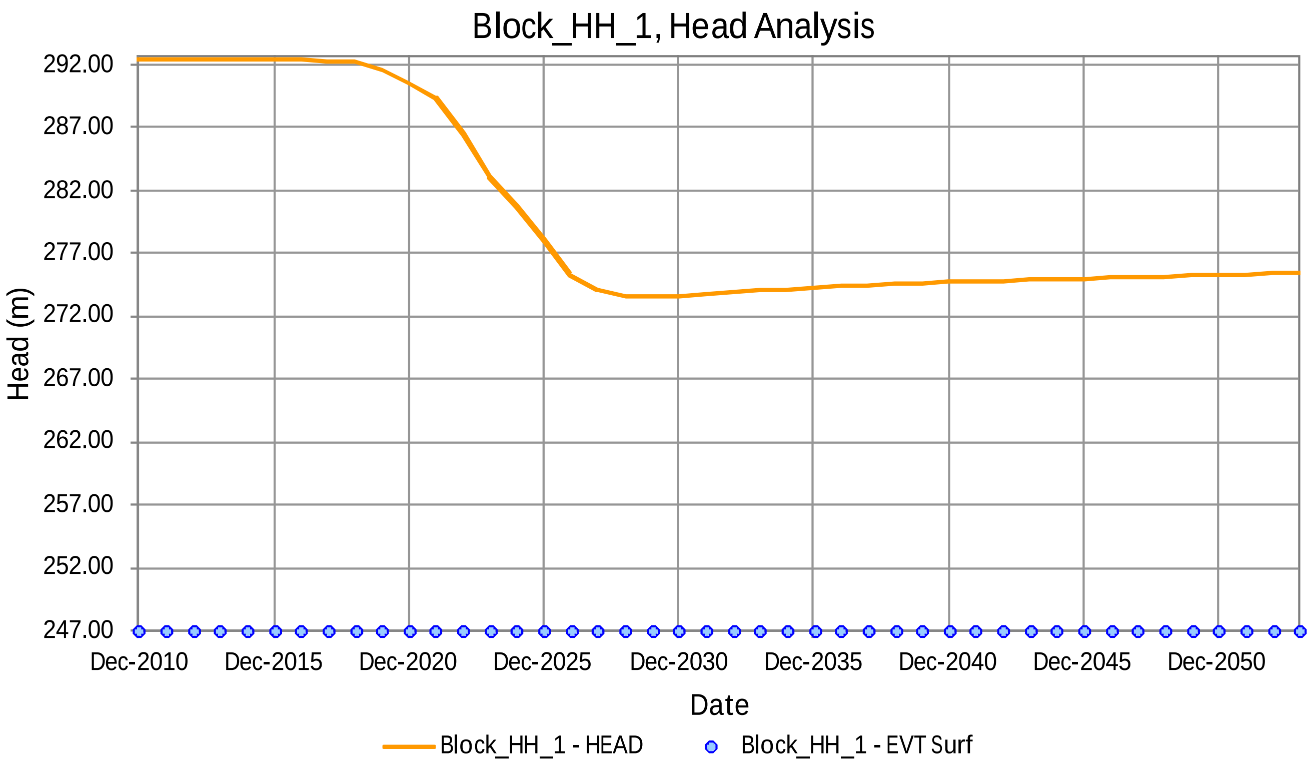
Appendix E - Comparison of Modelled Head and Evaporation Surface - Wandoan Development Region



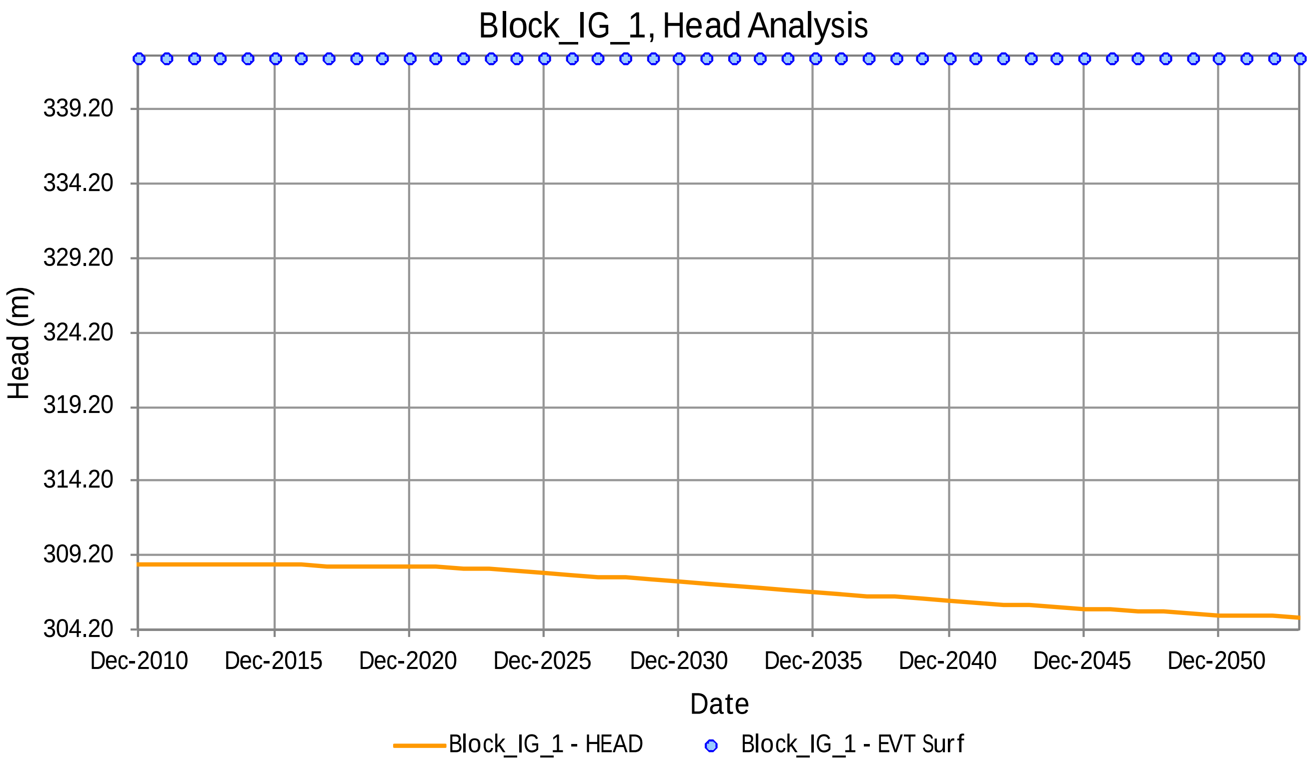


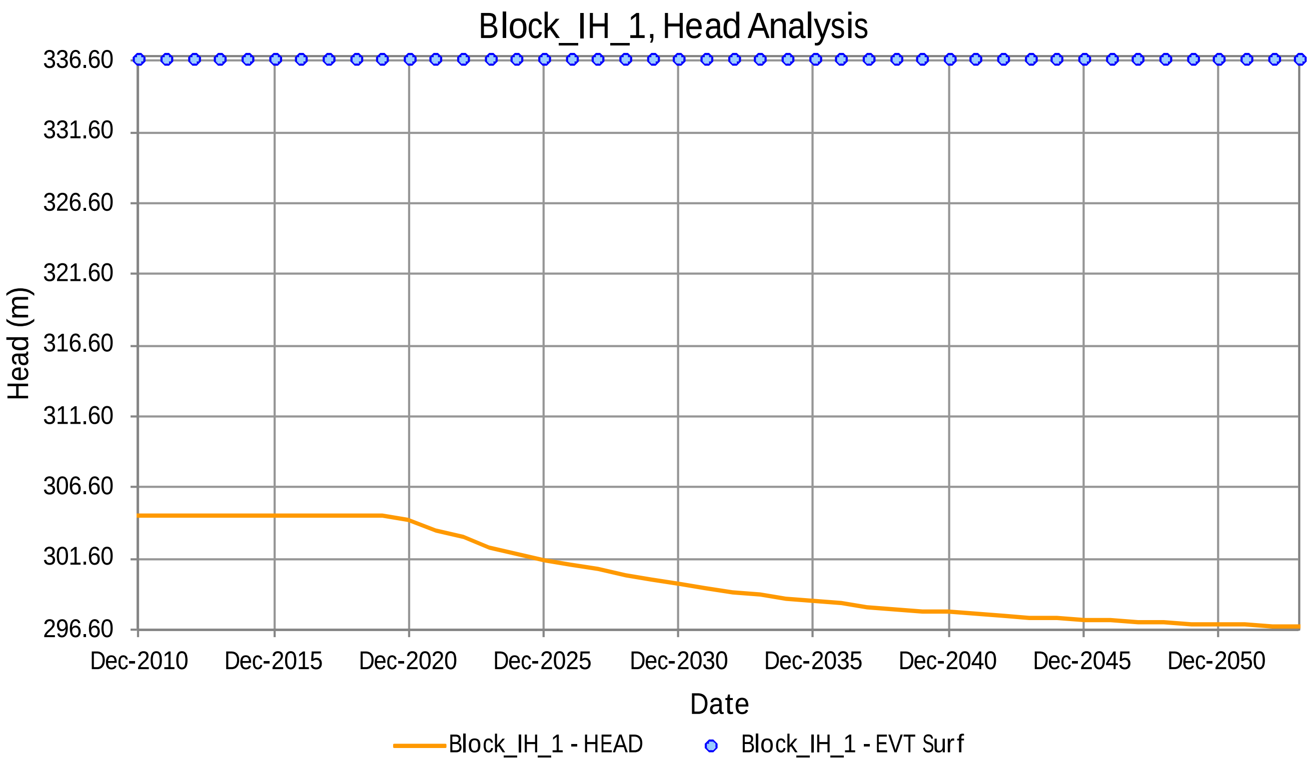
Appendix E - Comparison of Modelled Head and Evaporation Surface - Wandoan Development Region



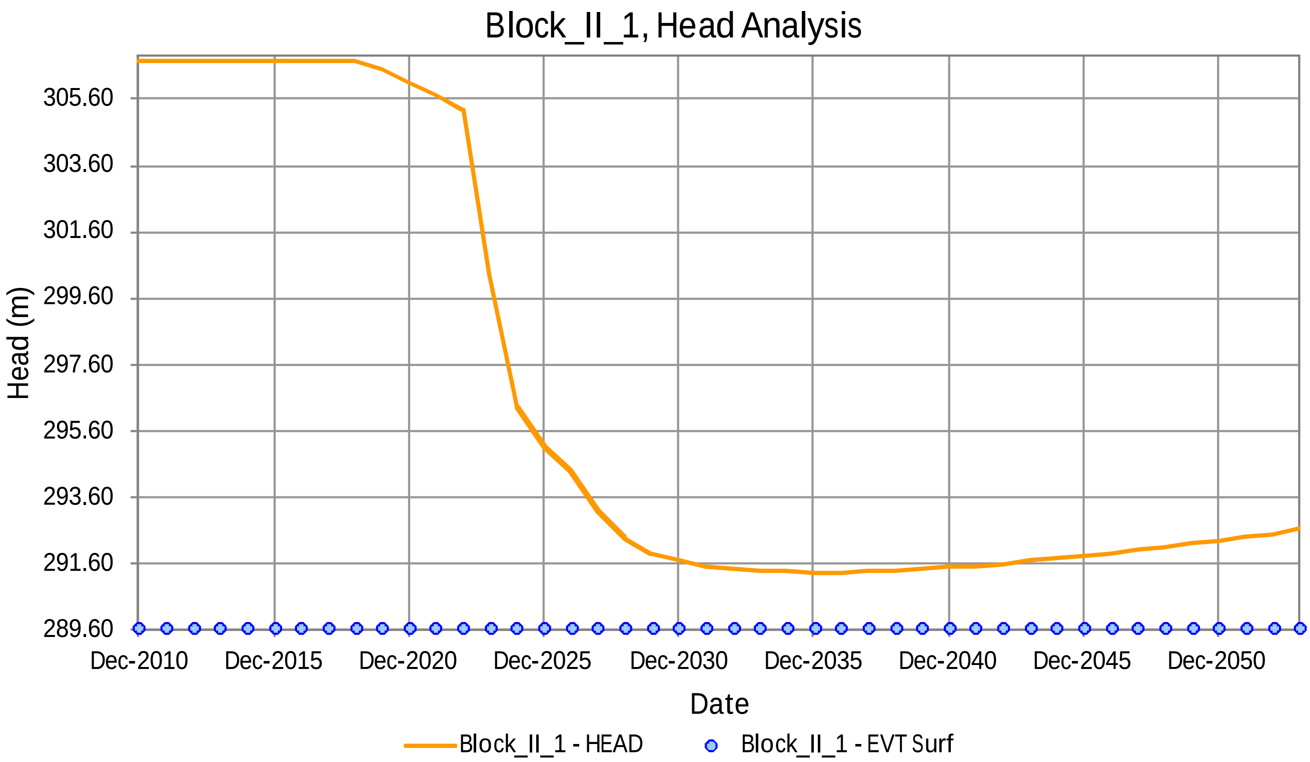


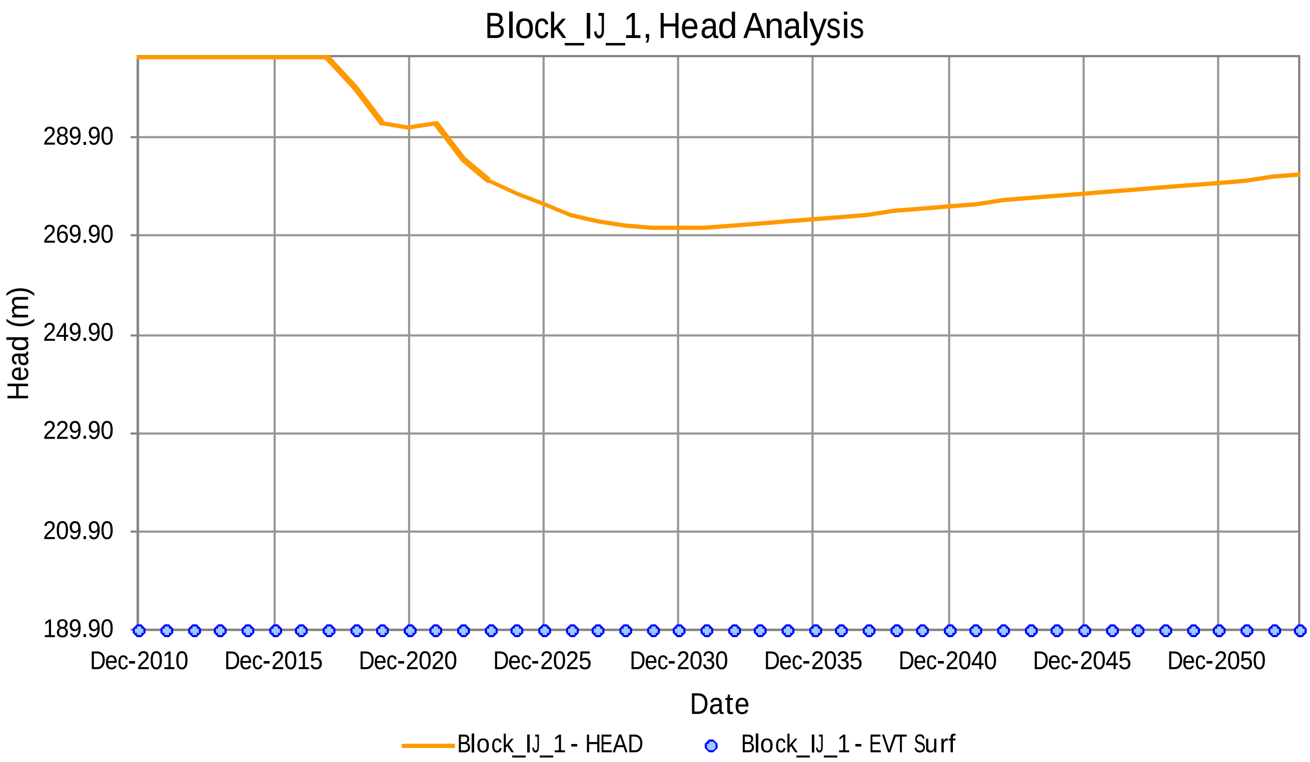
Appendix E - Comparison of Modelled Head and Evaporation Surface - Wandoan Development Region



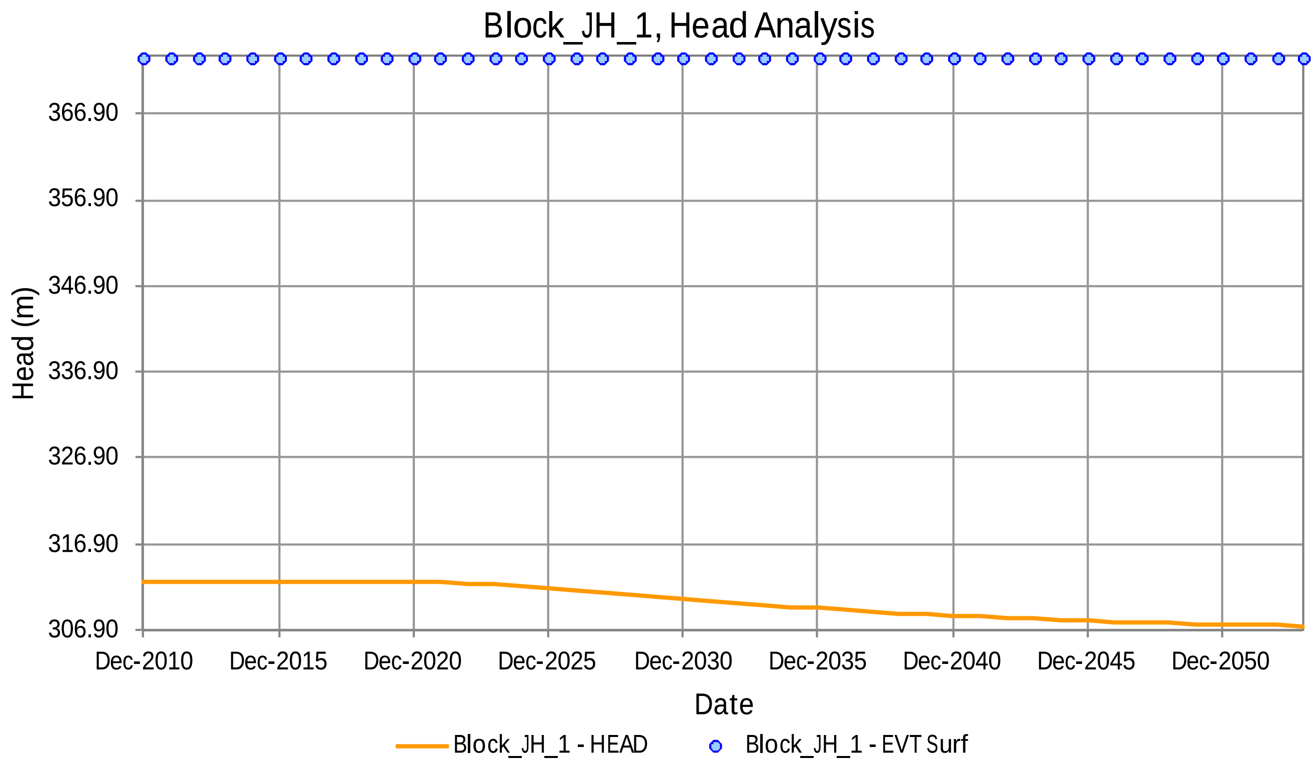


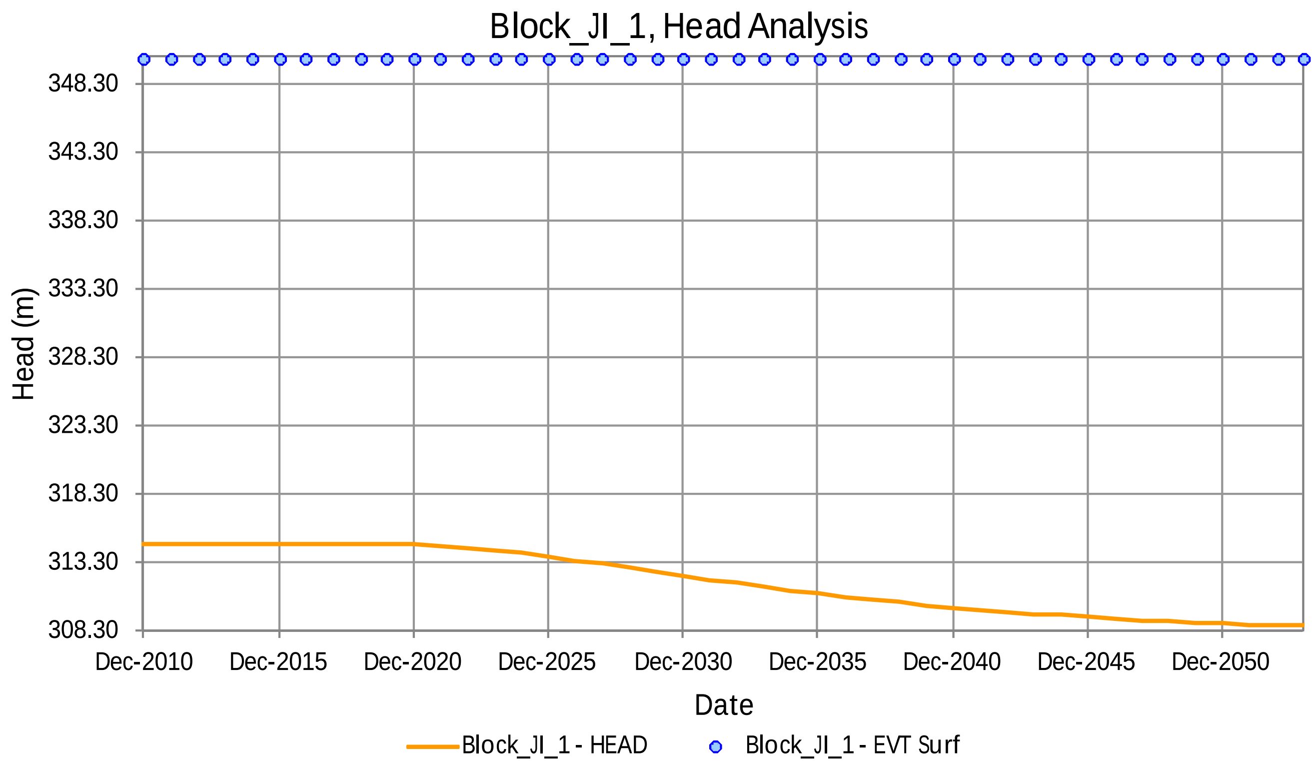
Appendix E - Comparison of Modelled Head and Evaporation Surface - Wandoan Development Region



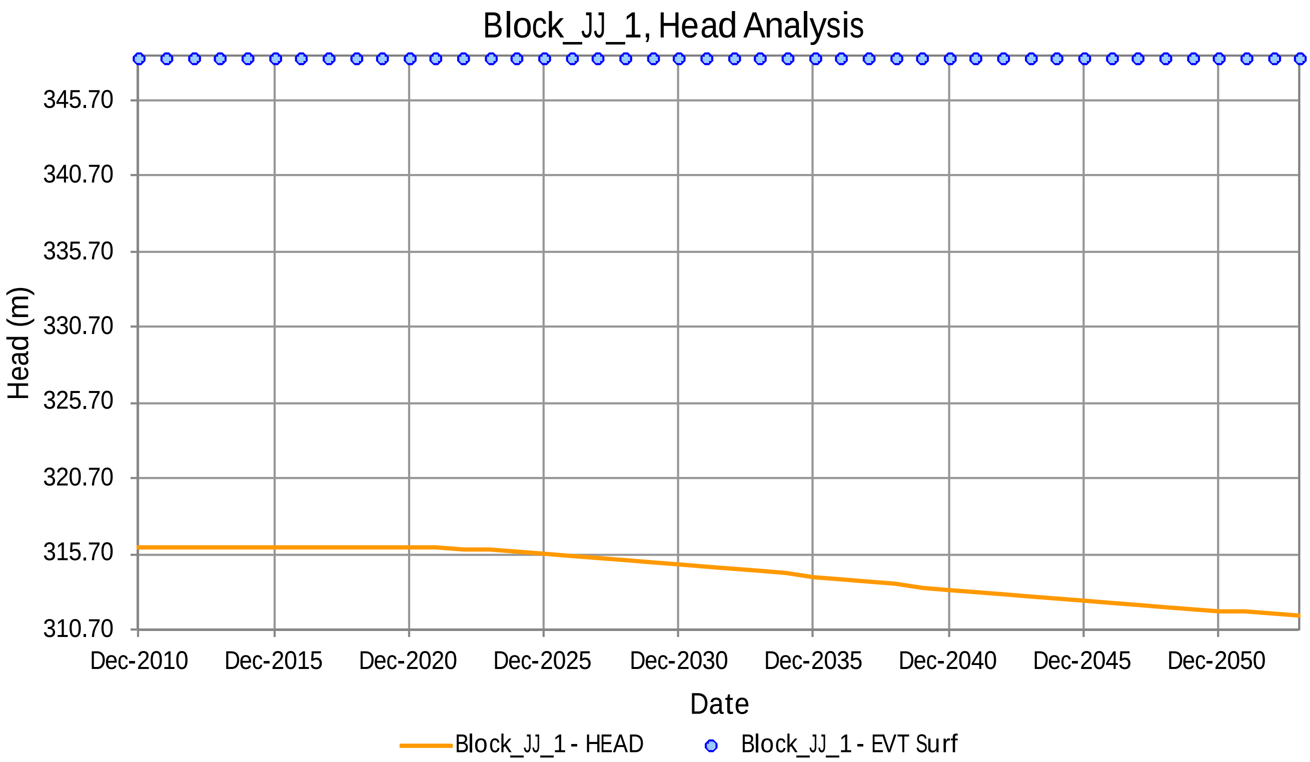


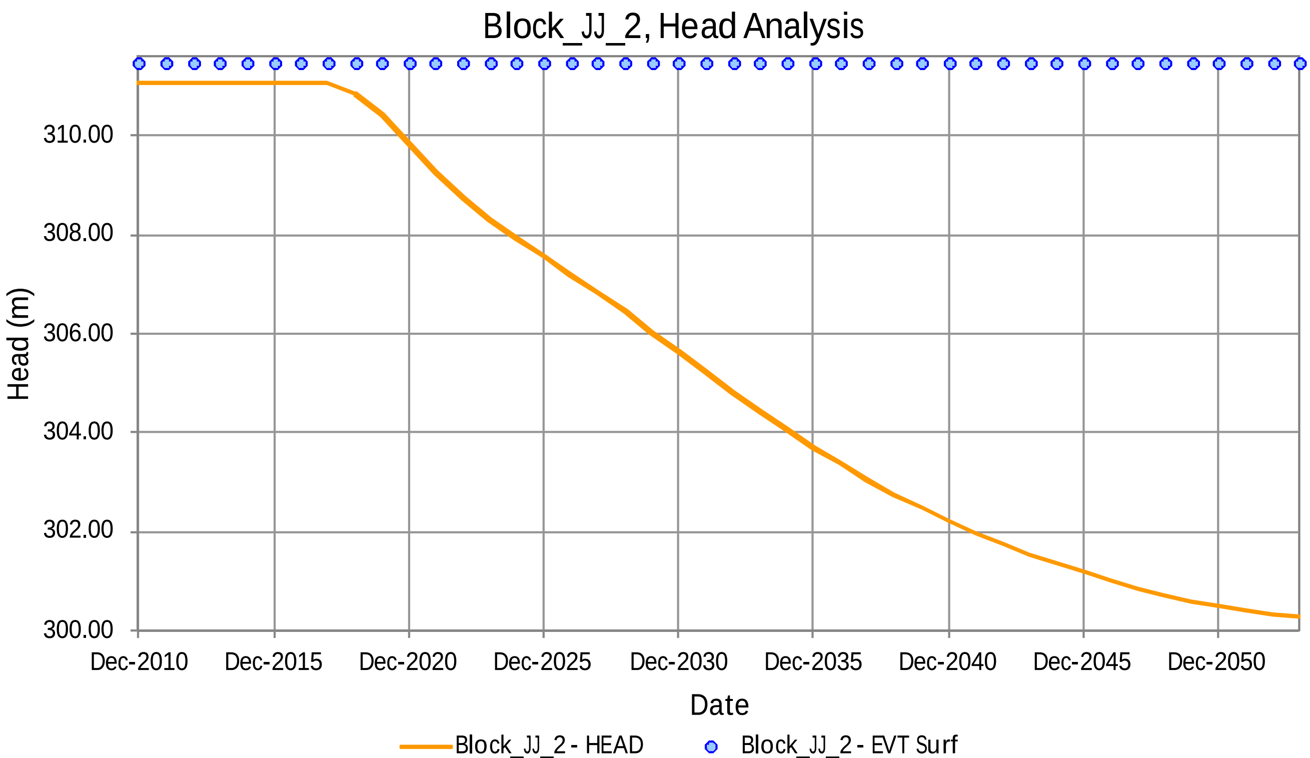
Appendix E - Comparison of Modelled Head and Evaporation Surface - Wandoan Development Region



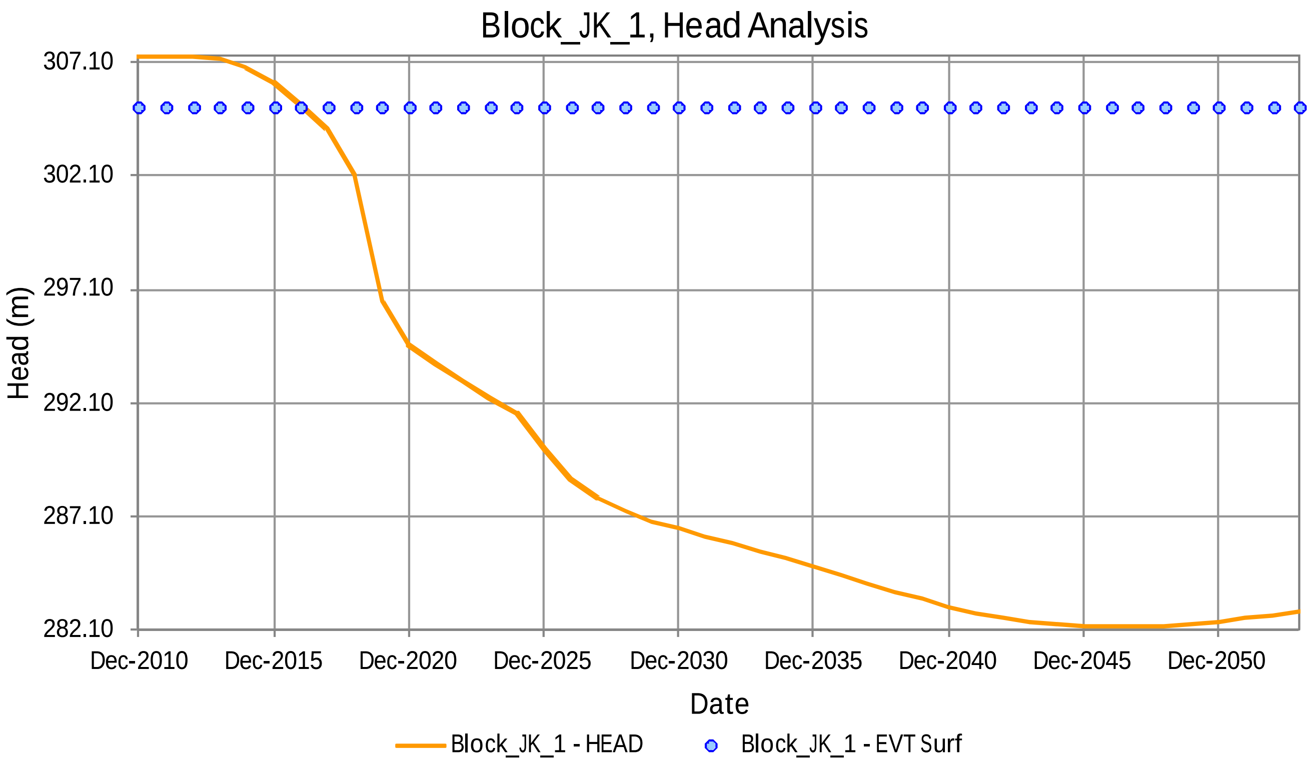


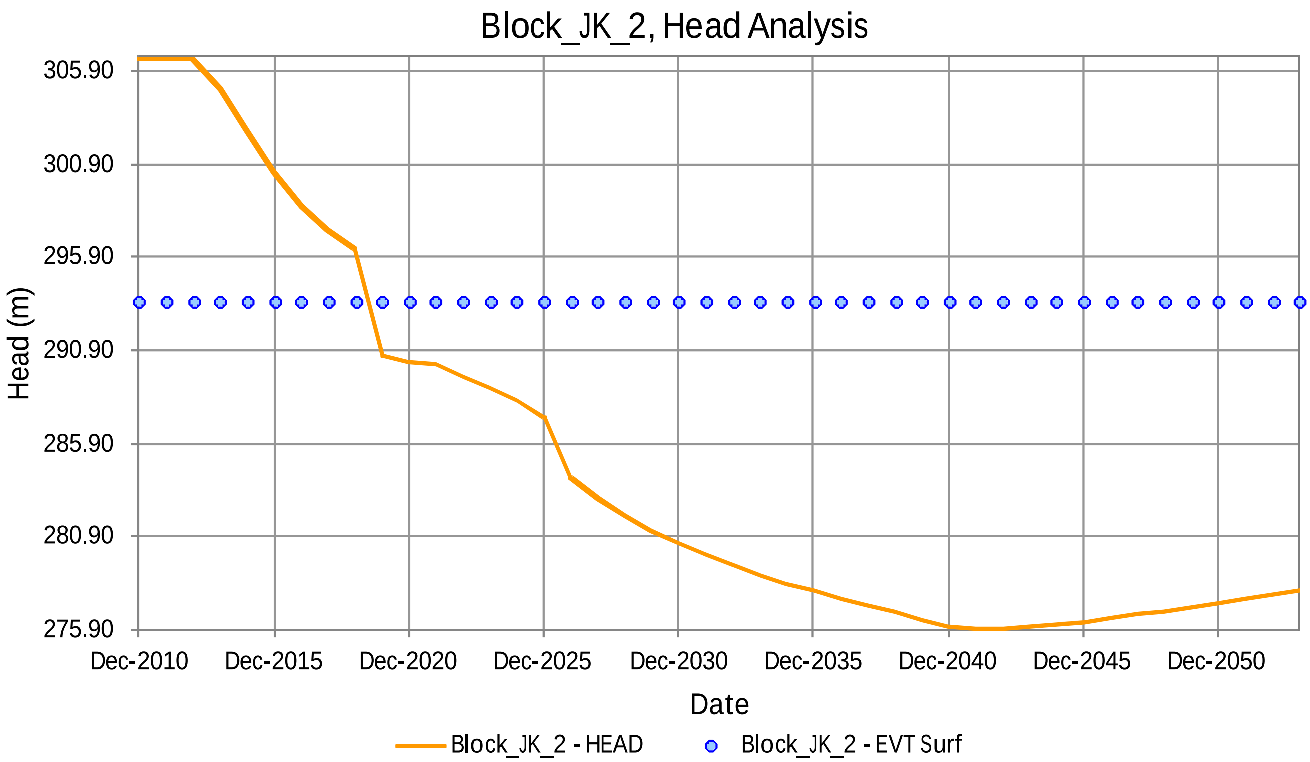
Appendix E - Comparison of Modelled Head and Evaporation Surface - Wandoan Development Region



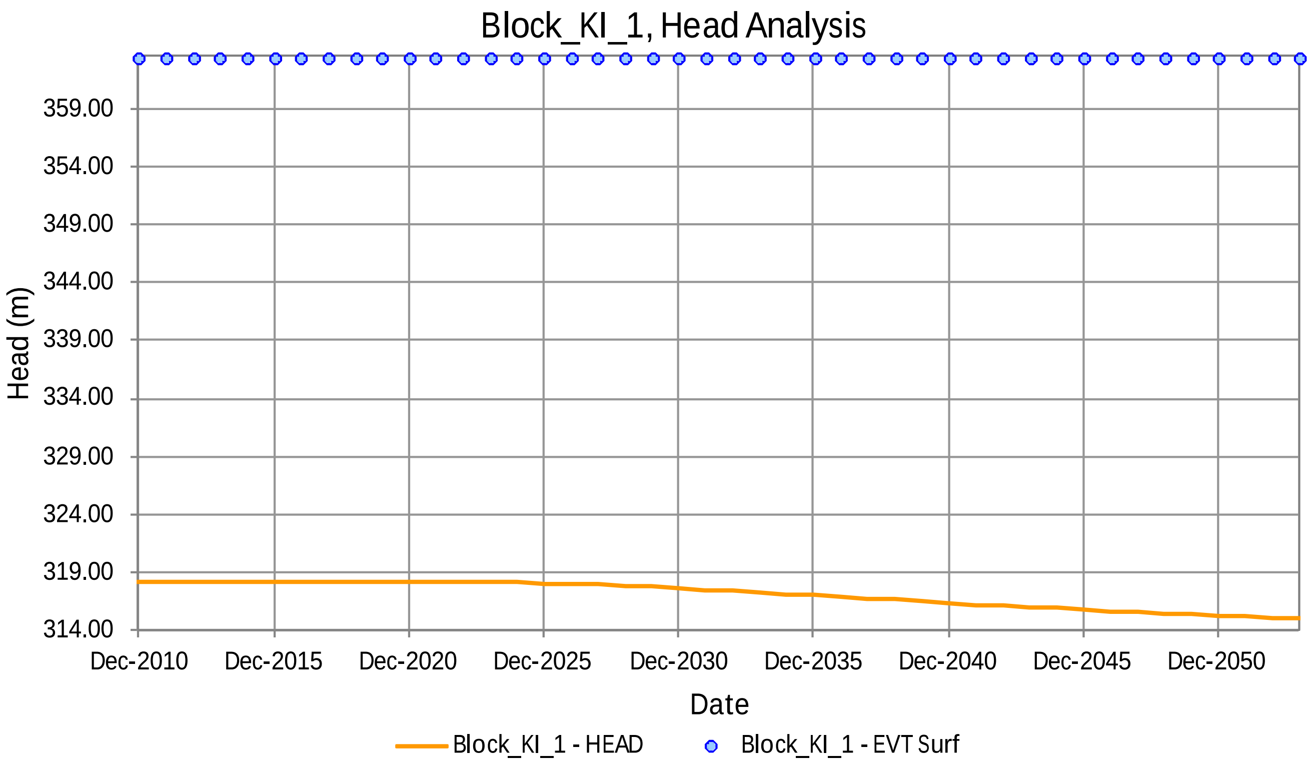


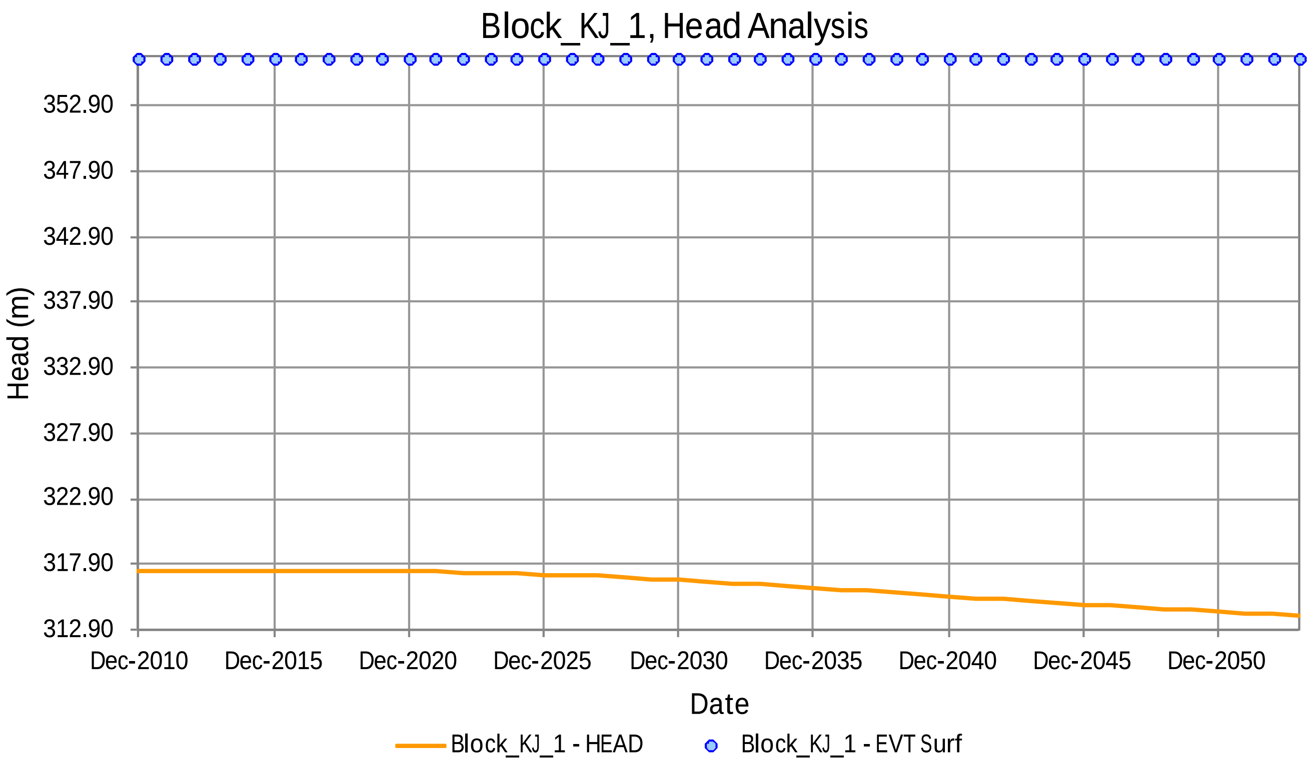
Appendix E - Comparison of Modelled Head and Evaporation Surface - Wandoan Development Region



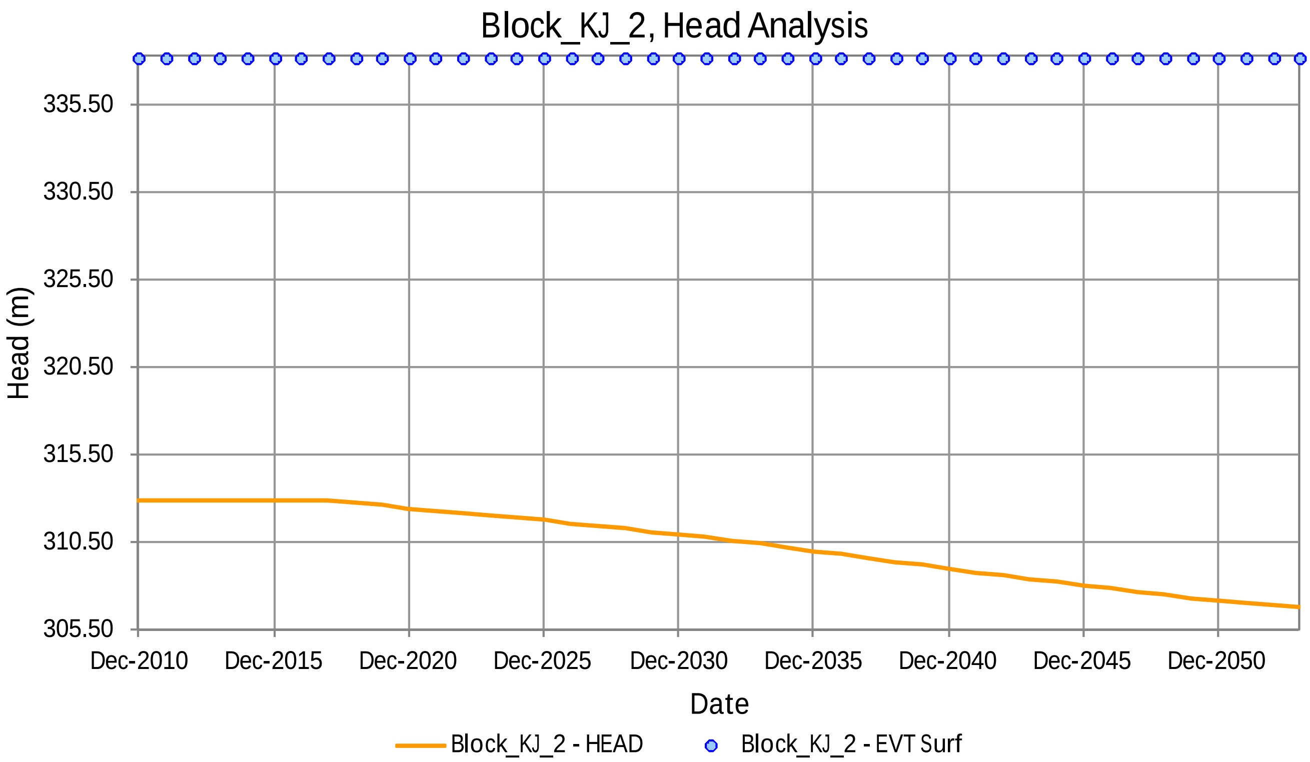


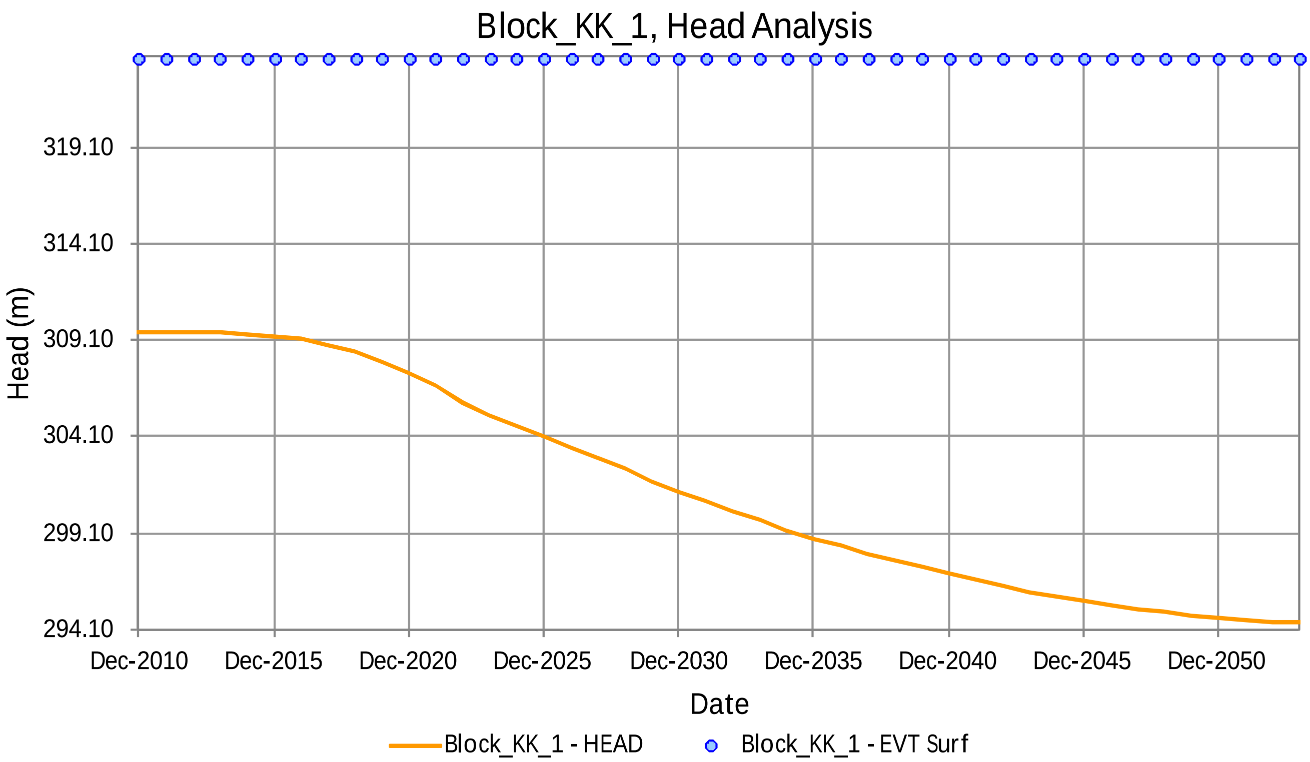
Appendix E - Comparison of Modelled Head and Evaporation Surface - Wandoan Development Region



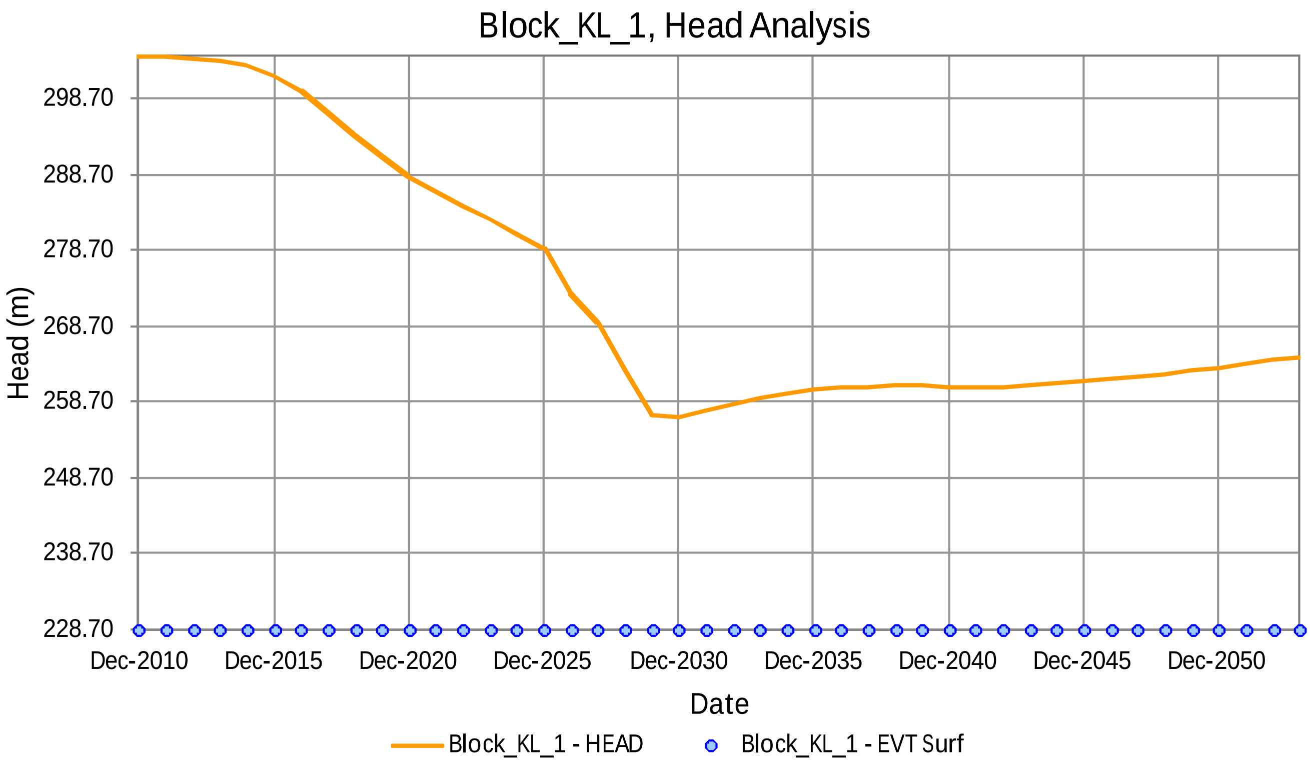


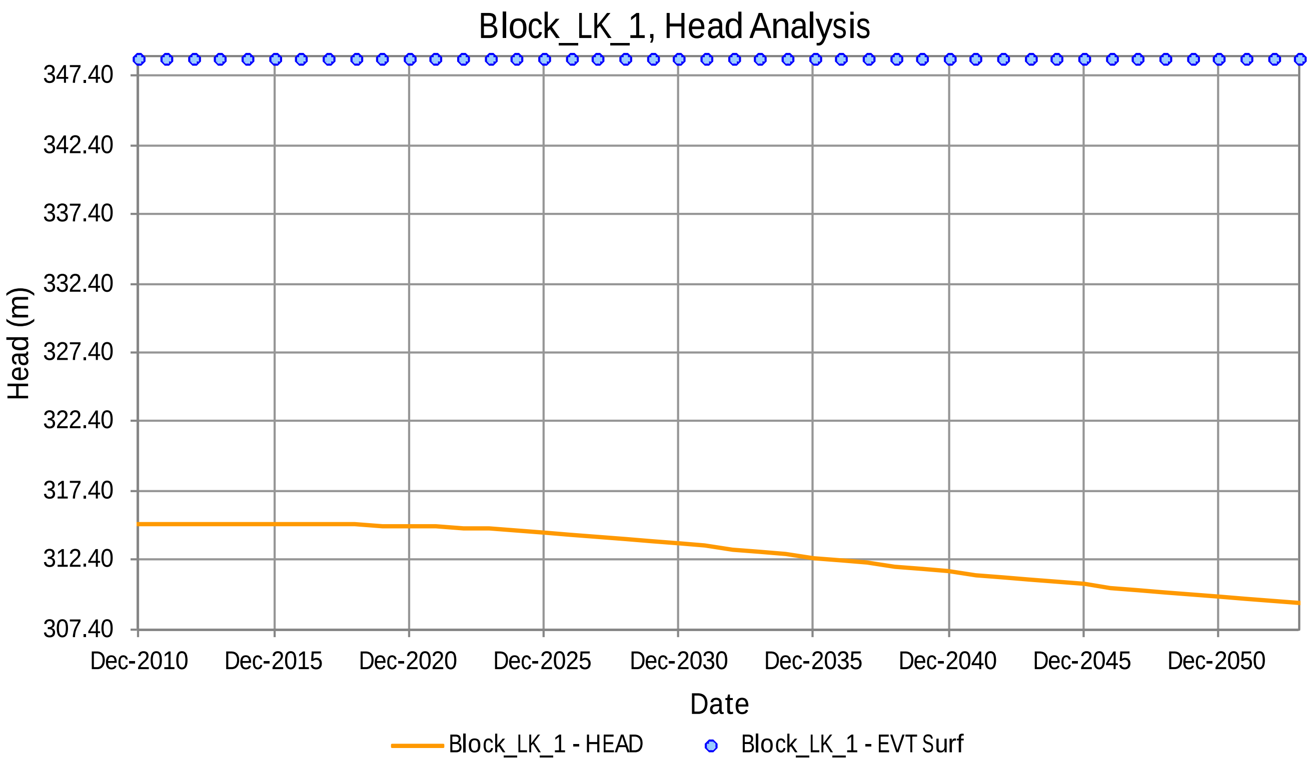
Appendix E - Comparison of Modelled Head and Evaporation Surface - Wandoan Development Region



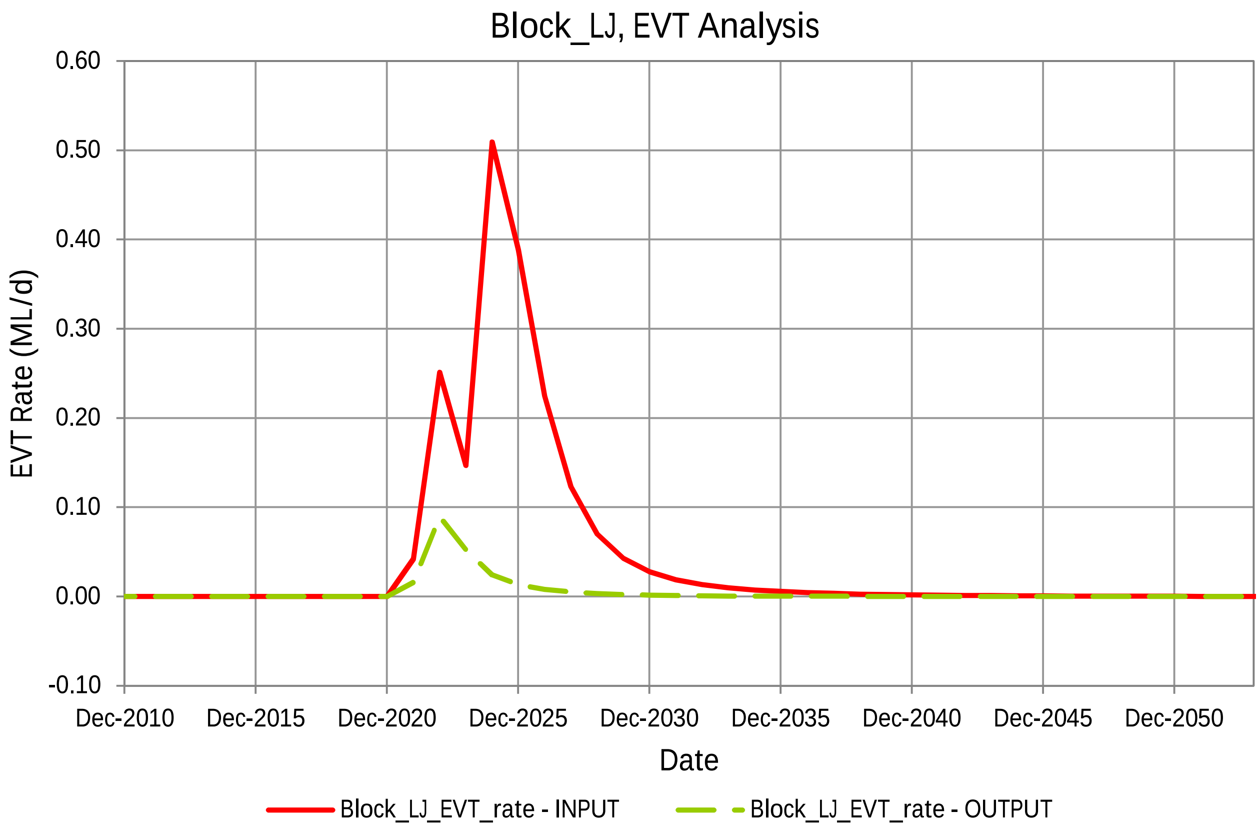


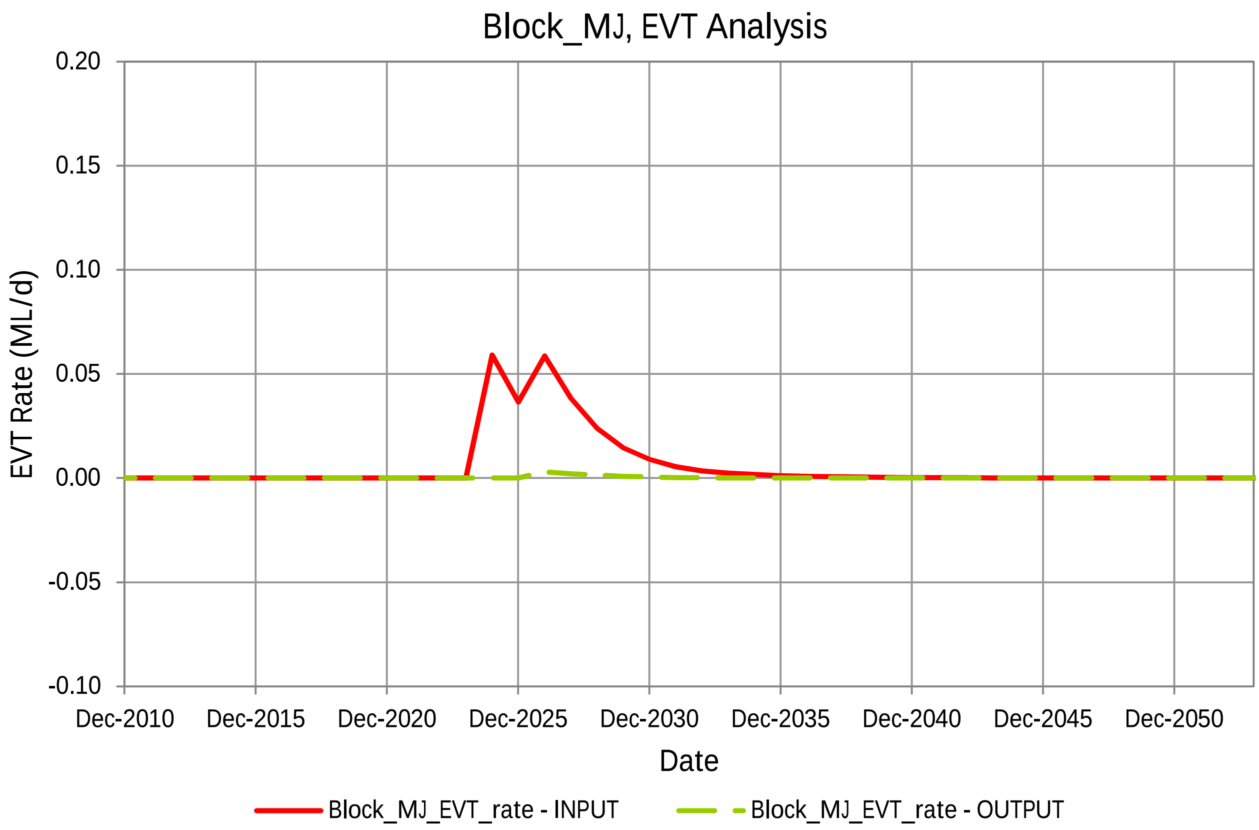
Appendix E - Comparison of Modelled Head and Evaporation Surface - Wandoan Development Region





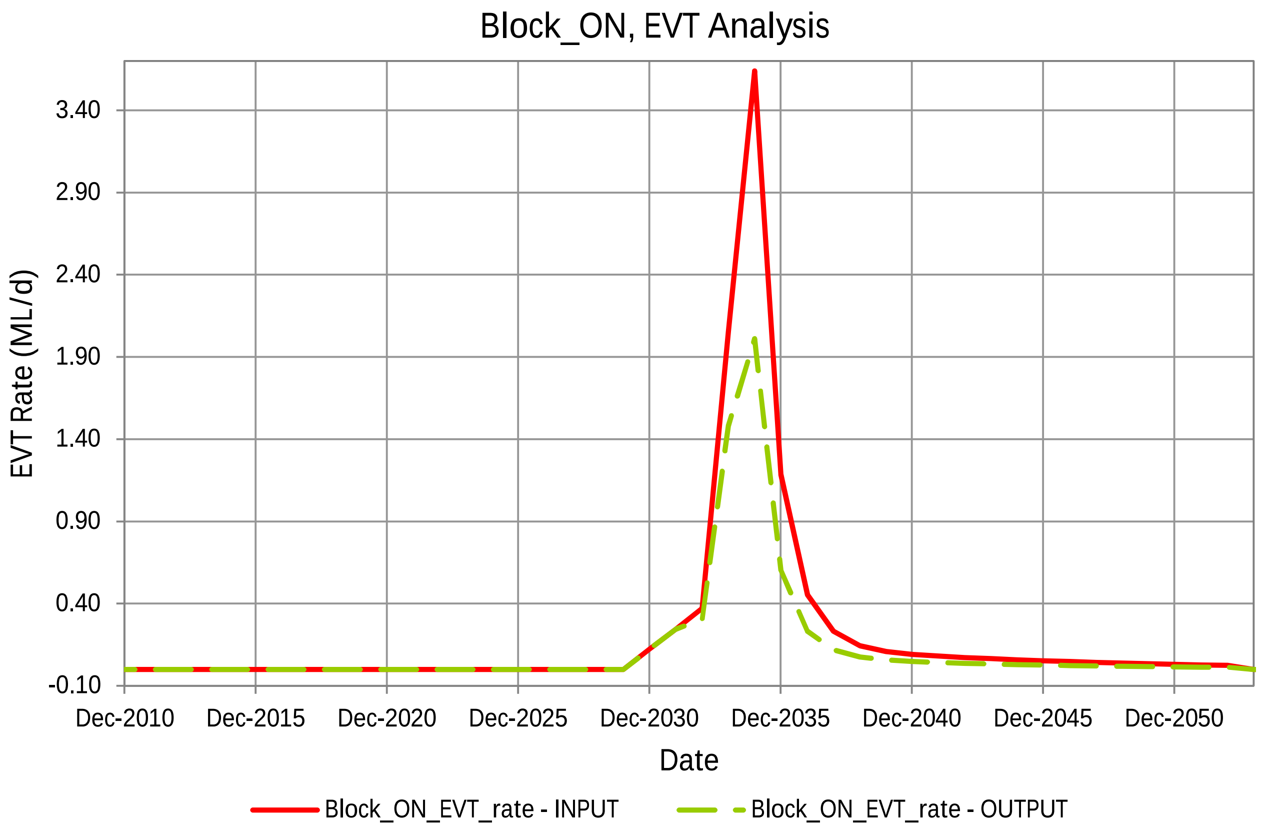
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Chinchilla Development Region

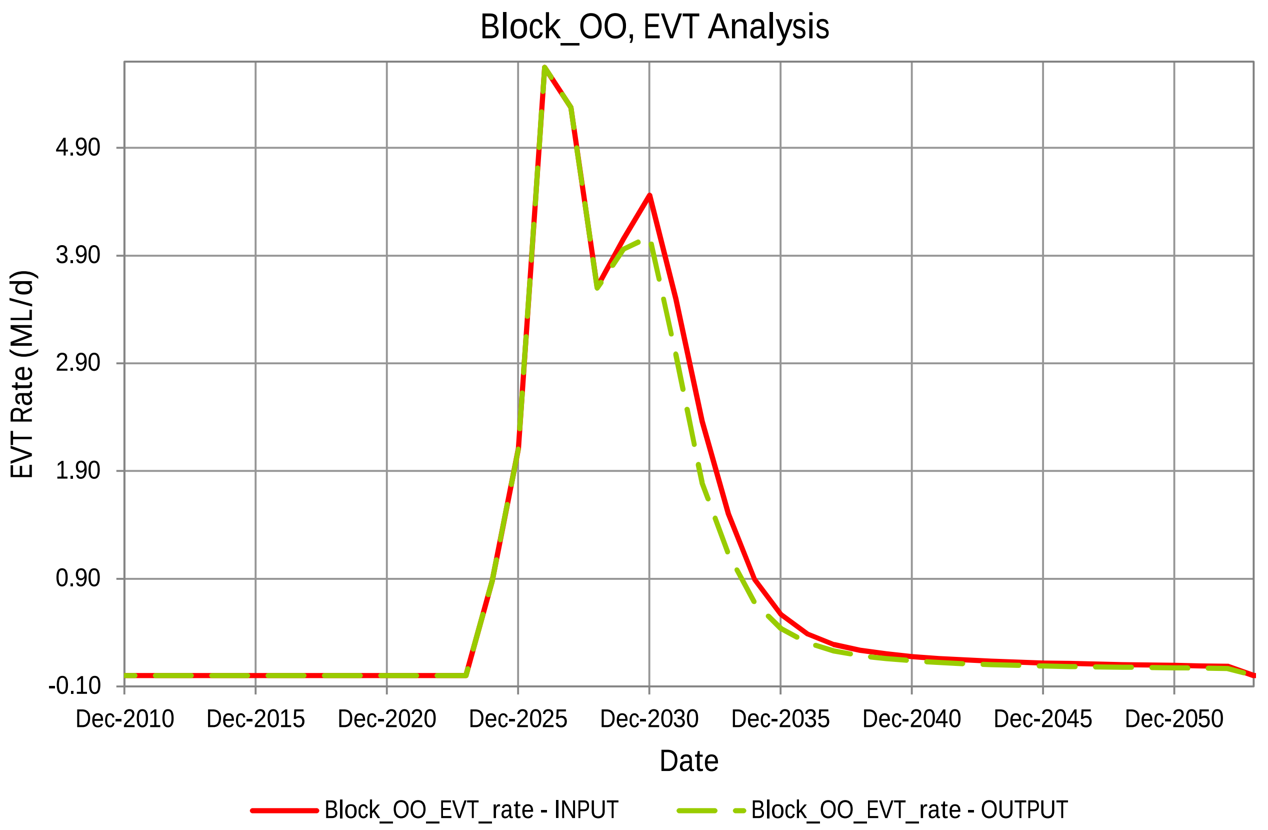




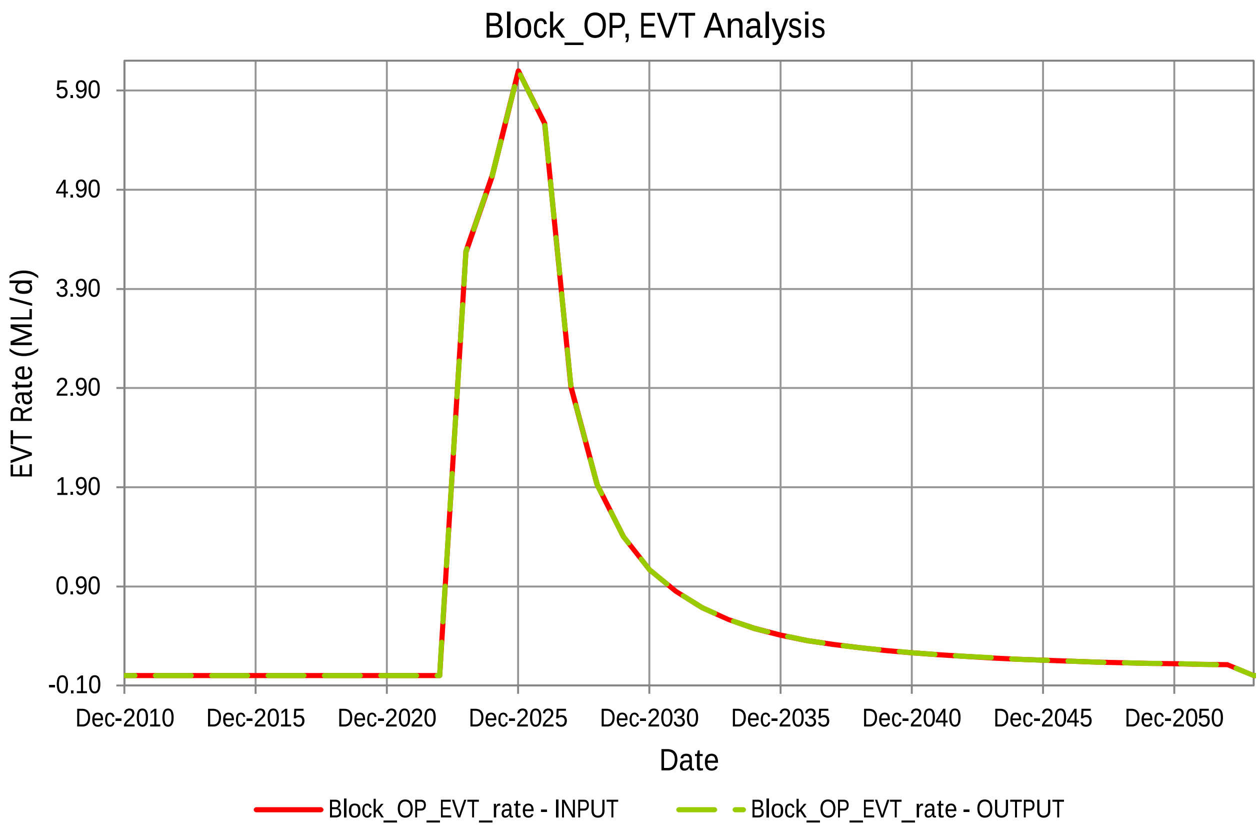
G:\41\26392\Tech\Design\GWModel\OGIAModel_results\EVTproduction\CHECKS\Input_water_production_Arrow5x_fact2rev5 (Chinchilla)

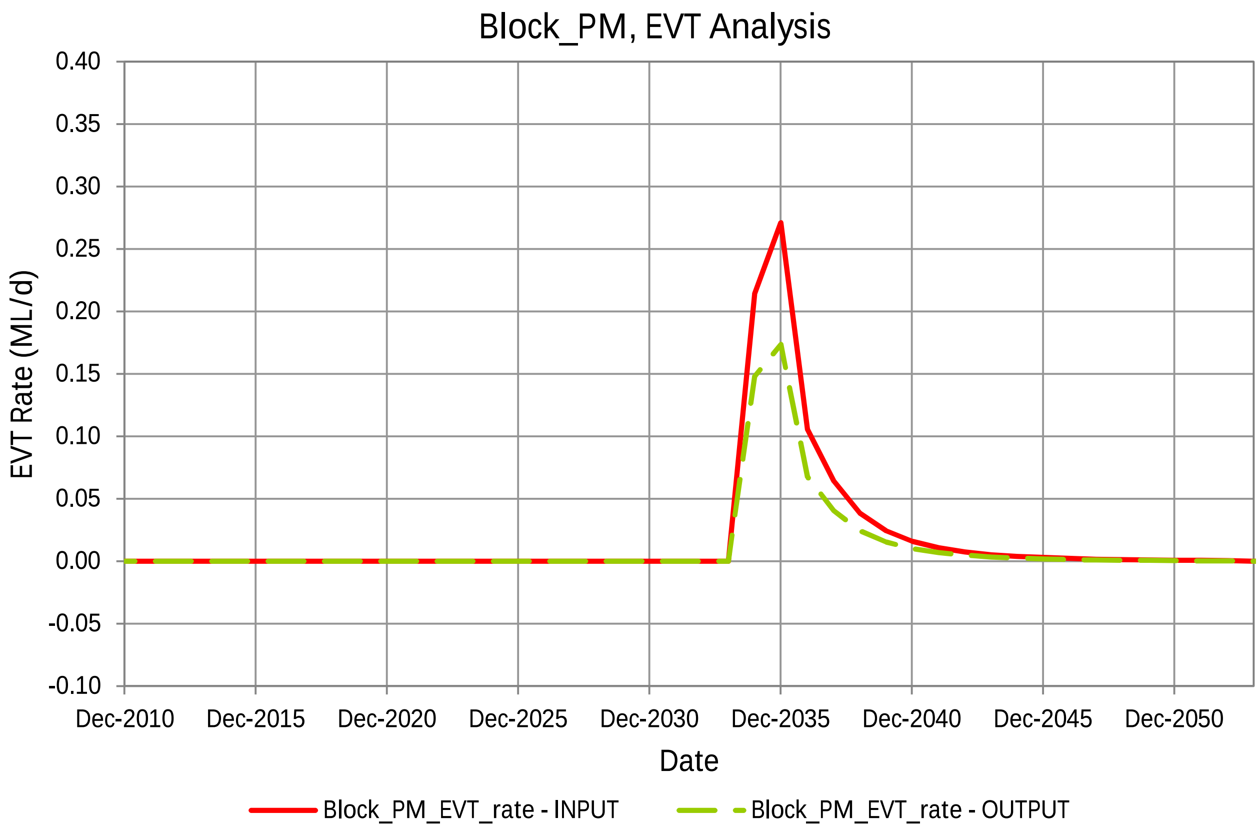
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Chinchilla Development Region





Appendix E - Comparison of Modelled EVT Input and Output Volumes - Chinchilla Development Region





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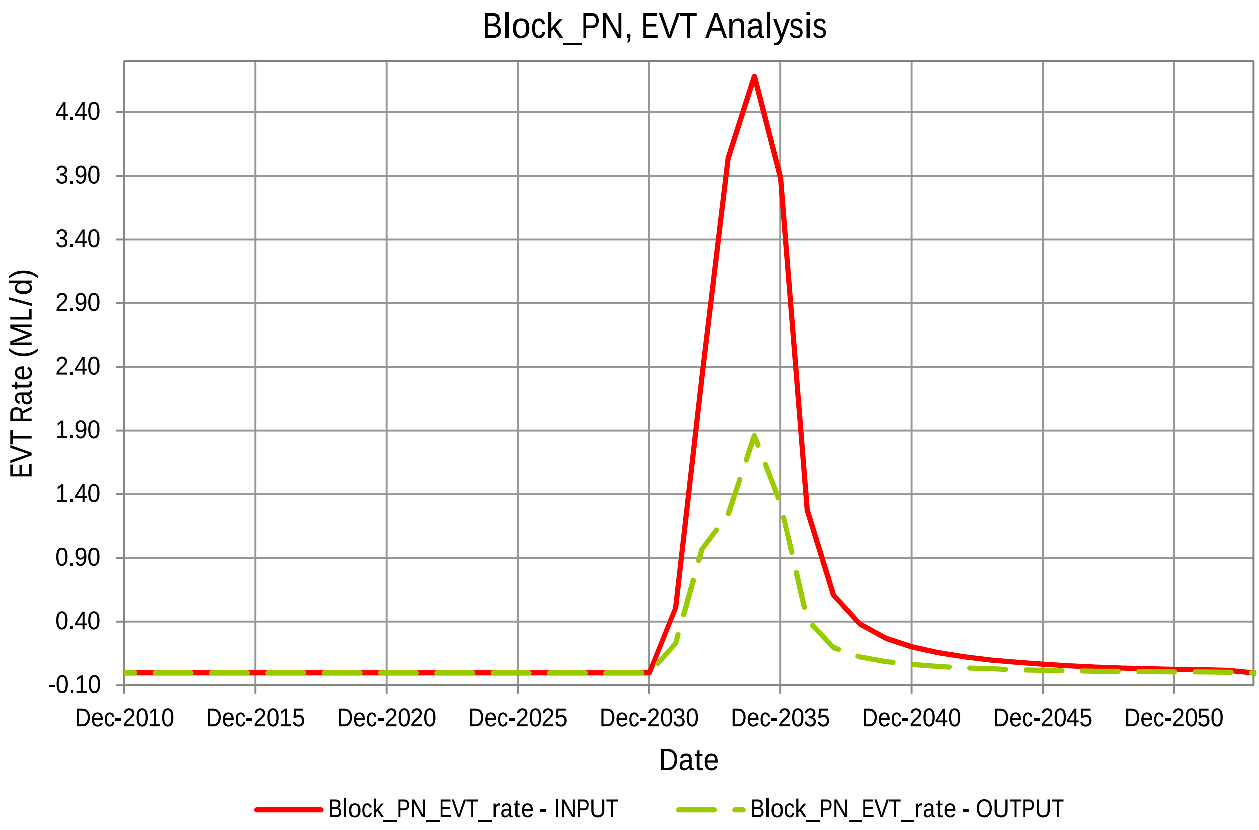
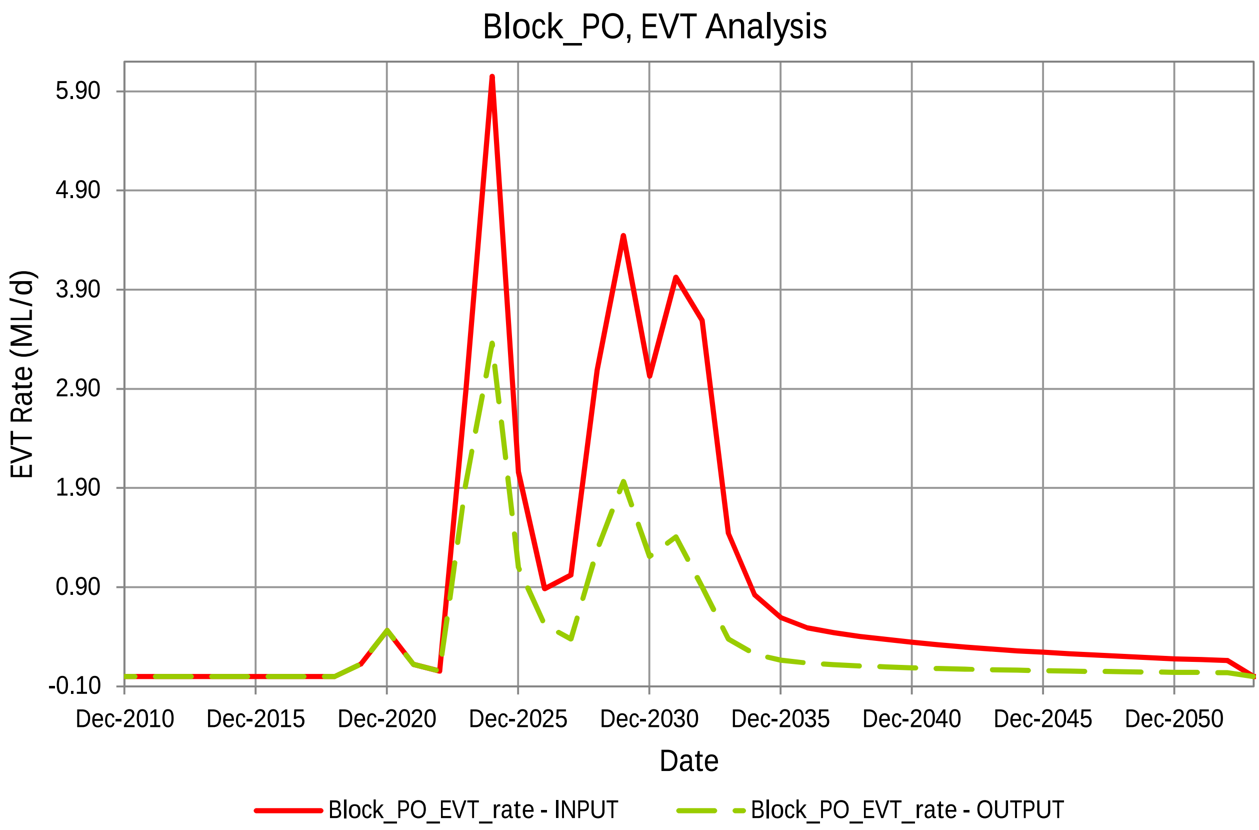
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Chinchilla Development Region





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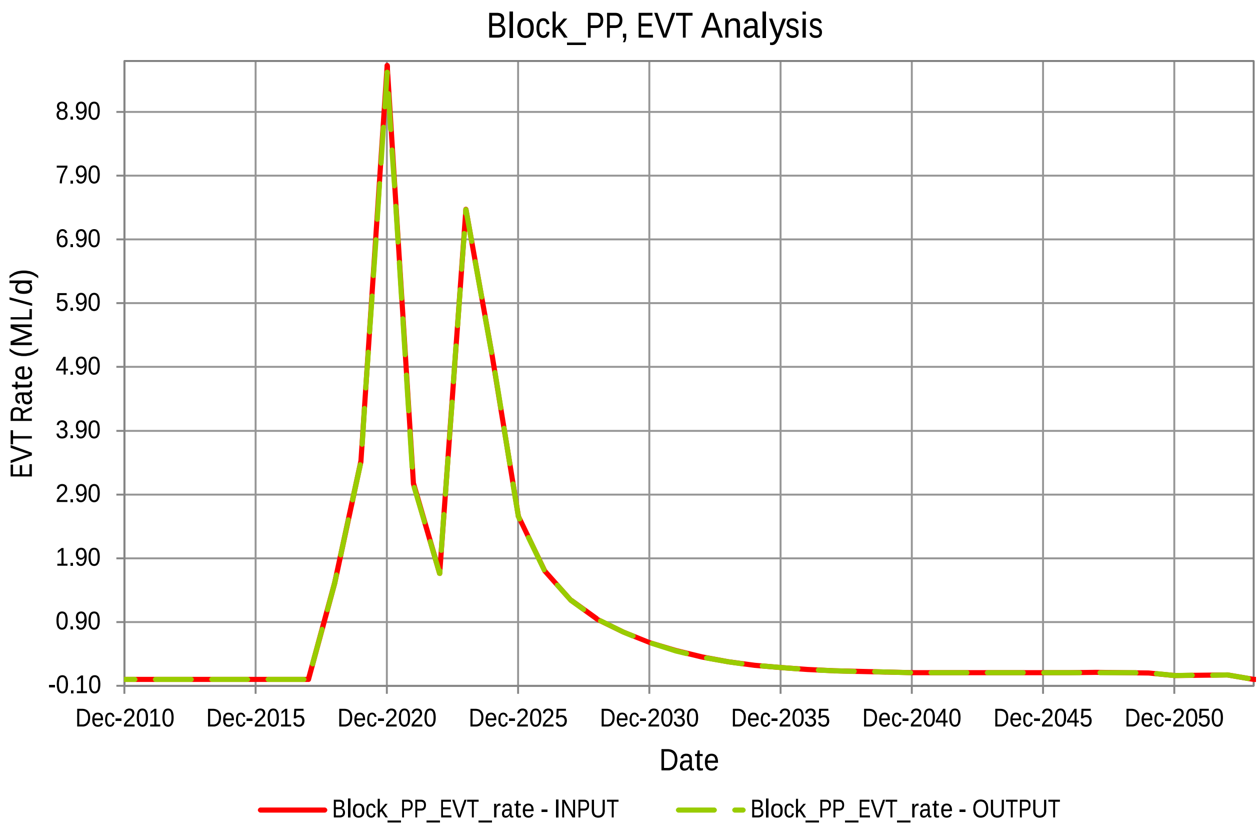
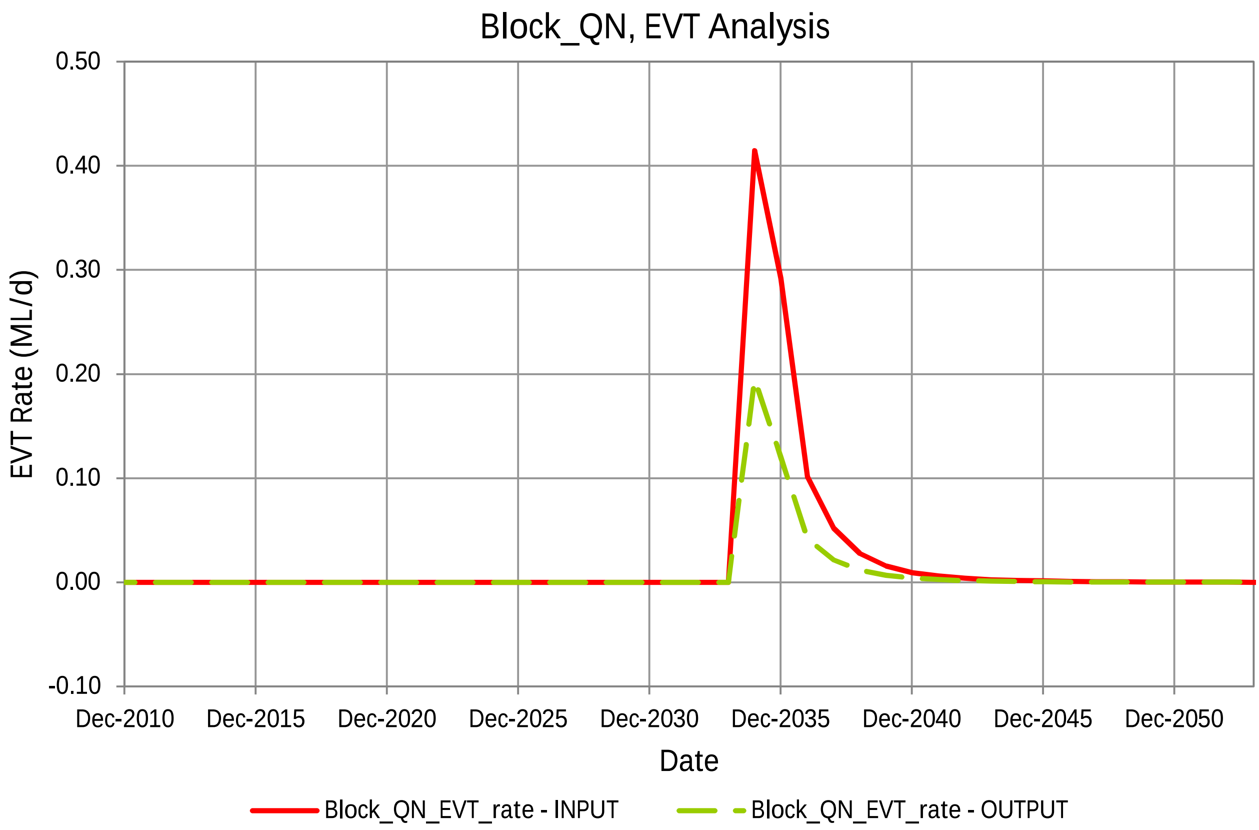
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Chinchilla Development Region





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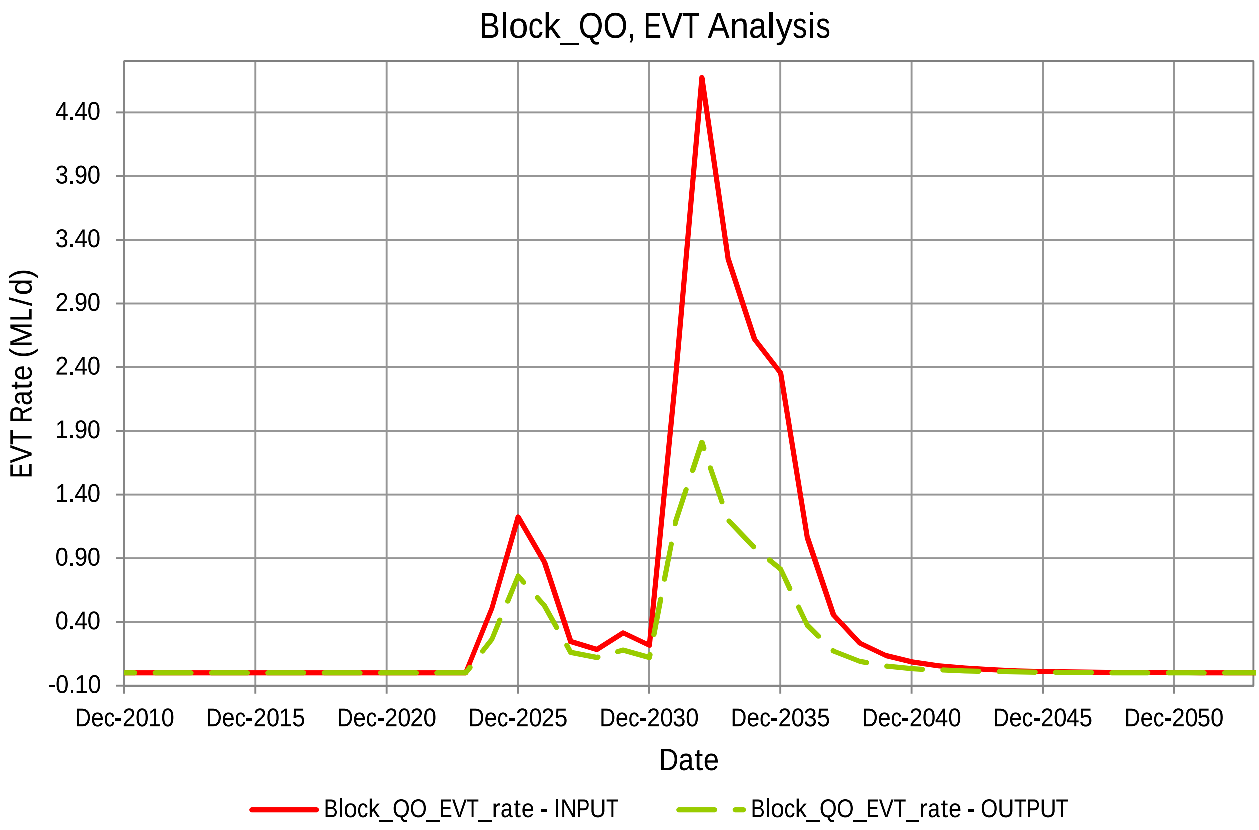
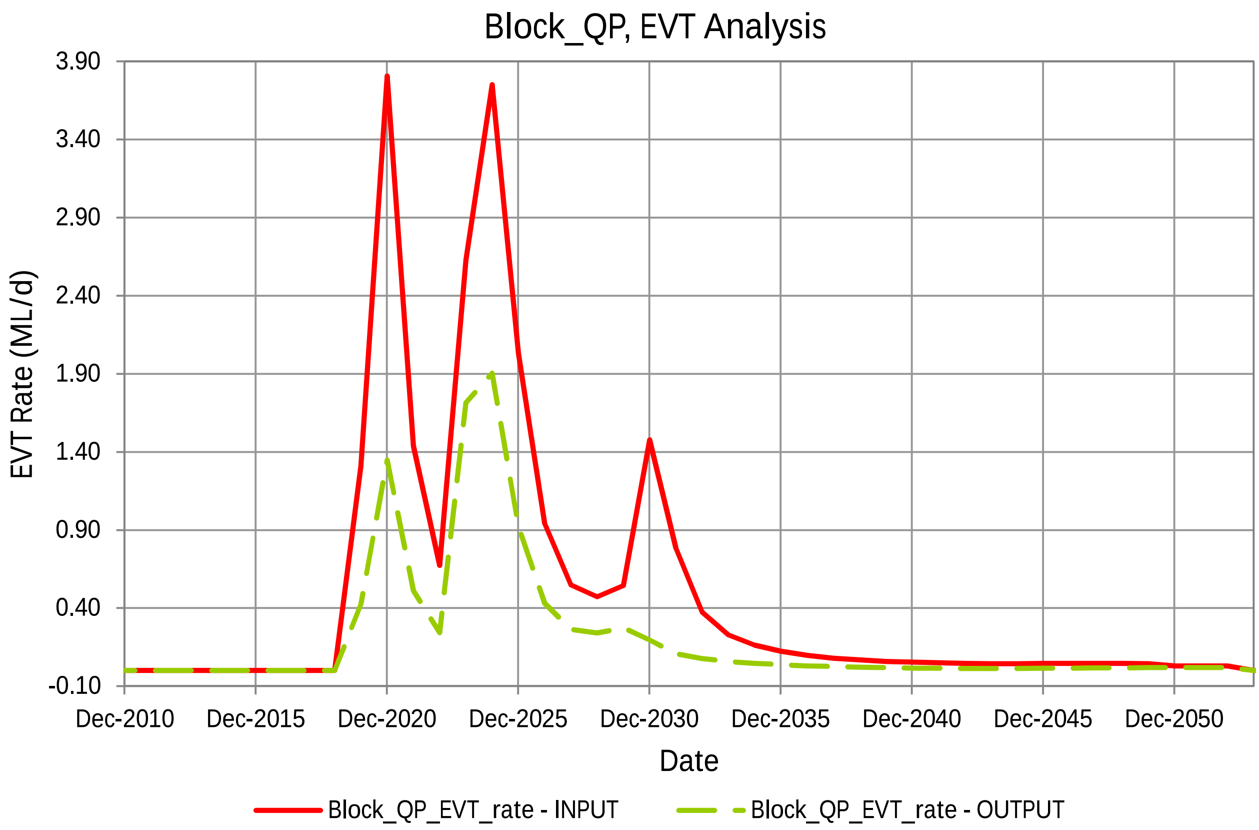
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Chinchilla Development Region





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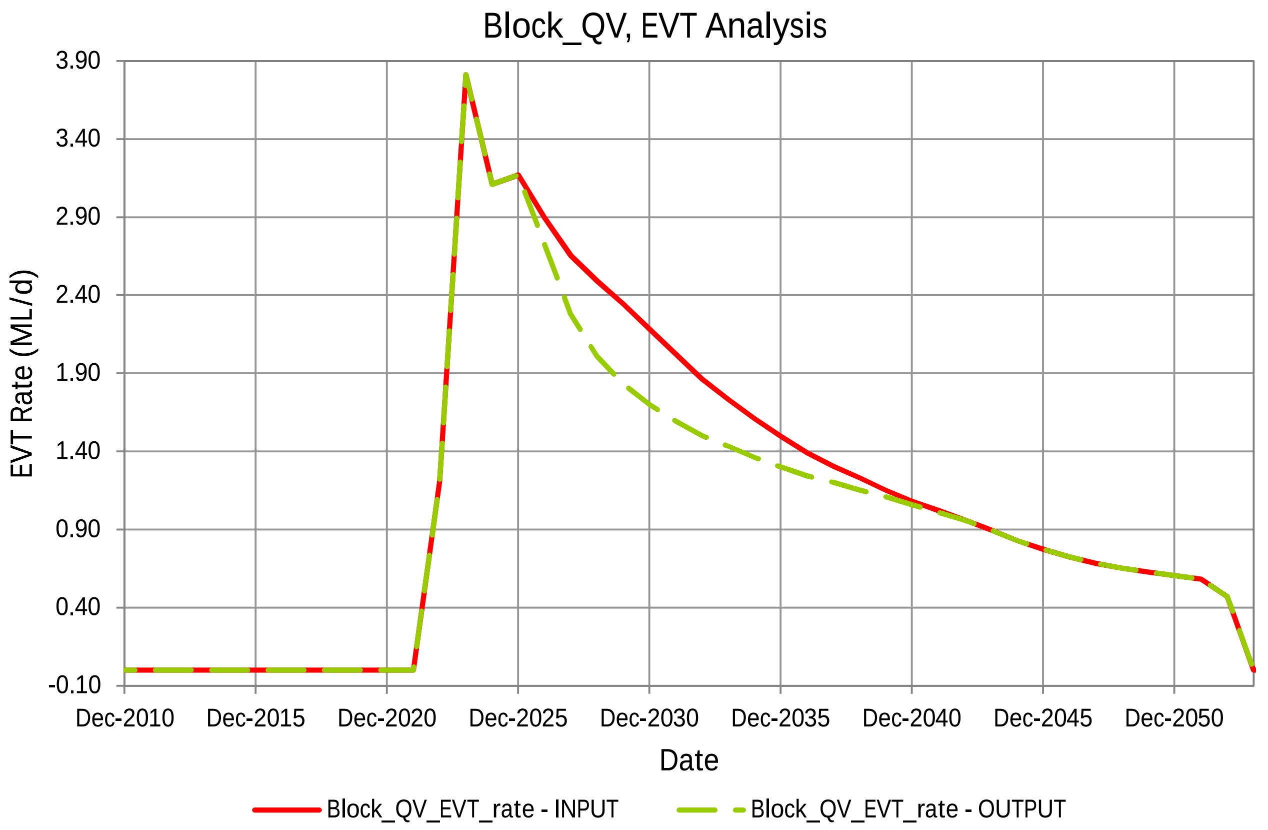
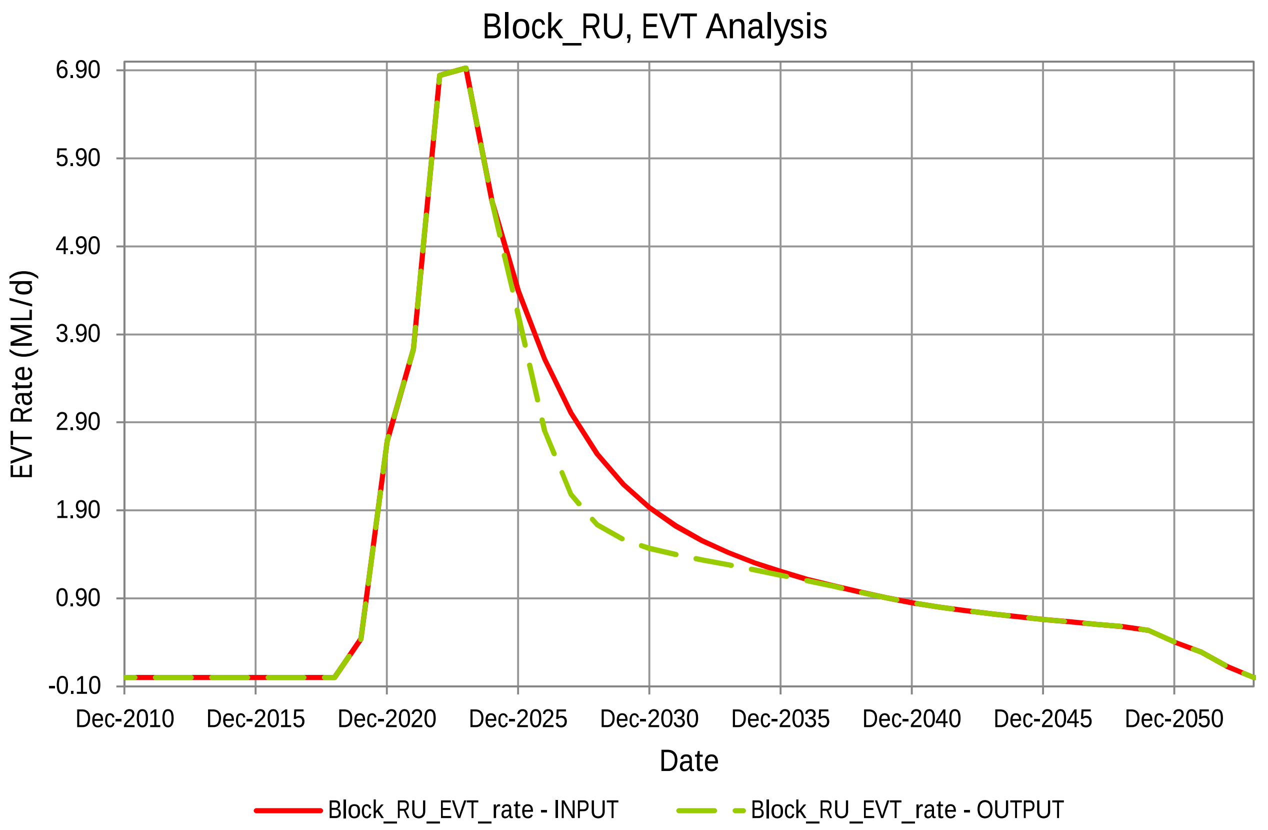
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Dalby Development Region





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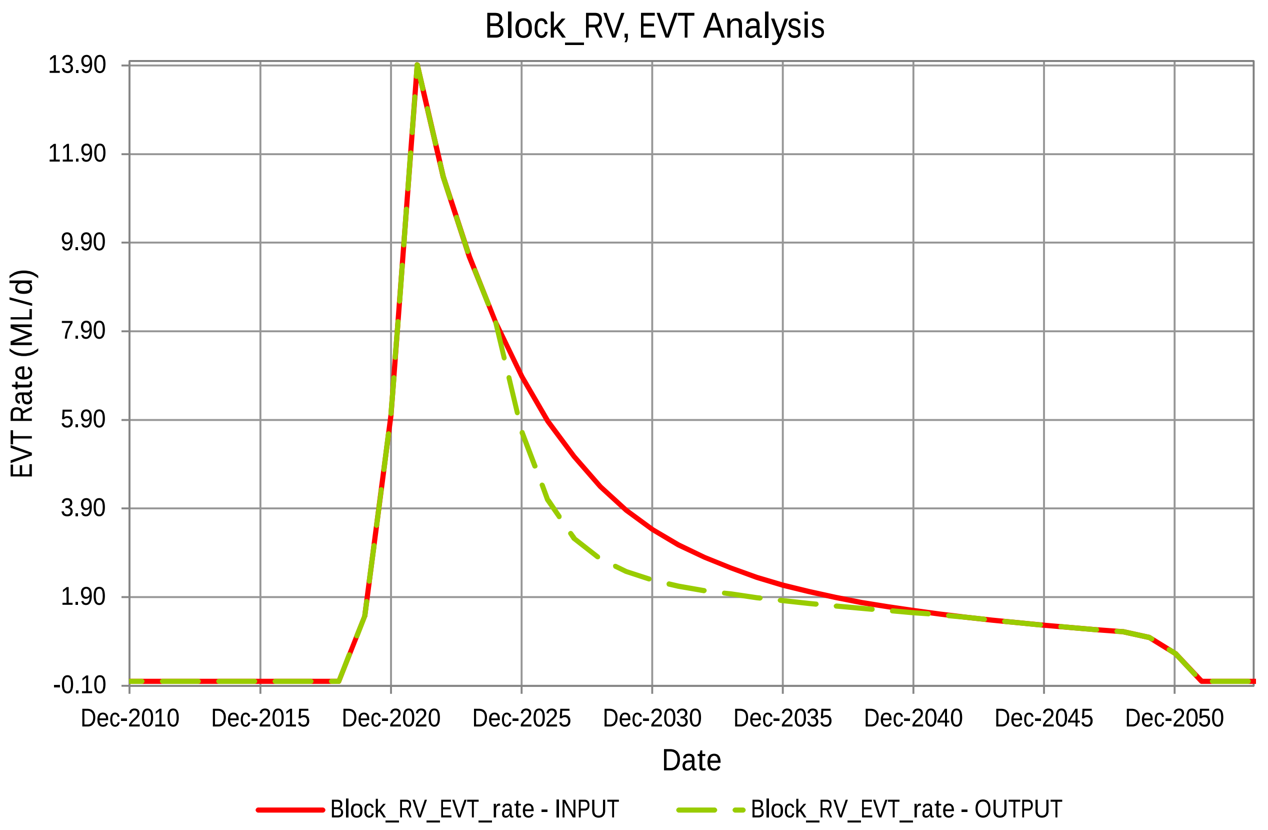
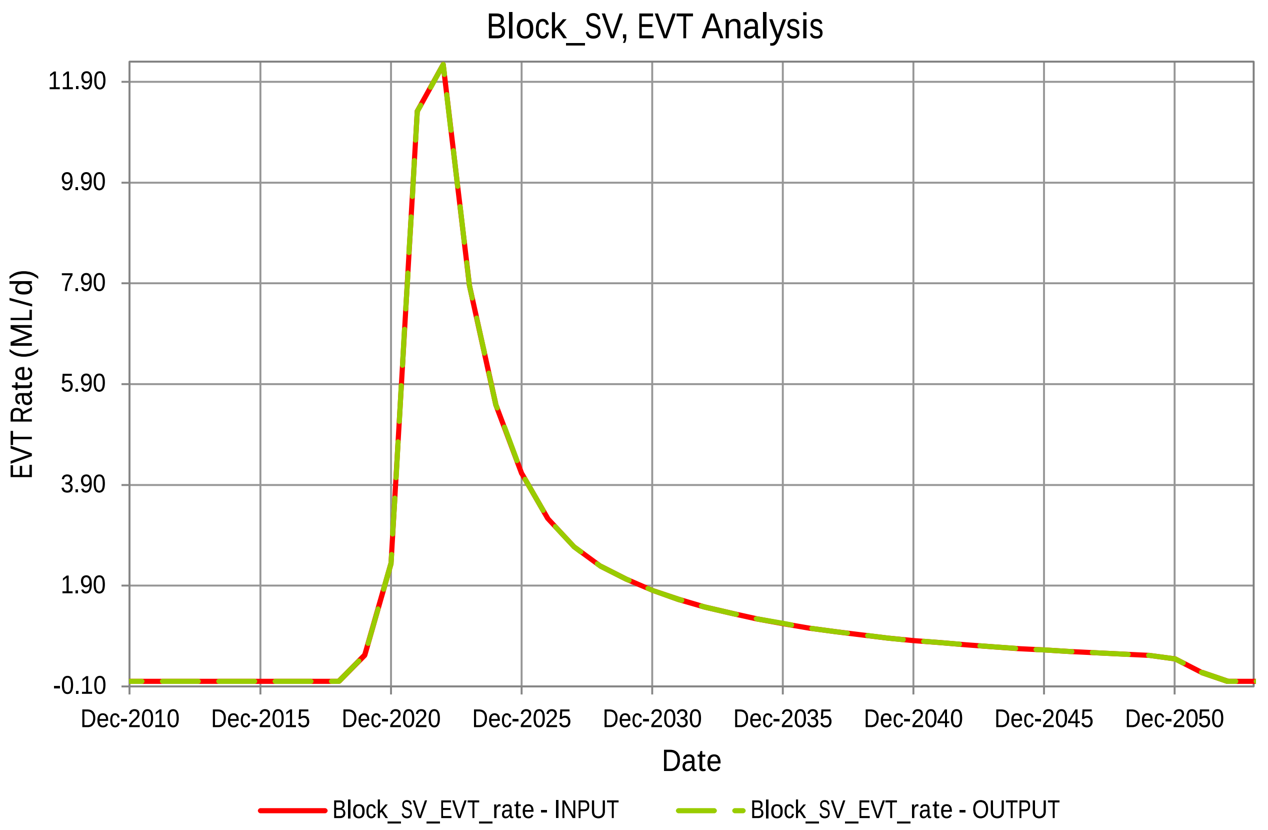
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Dalby Development Region





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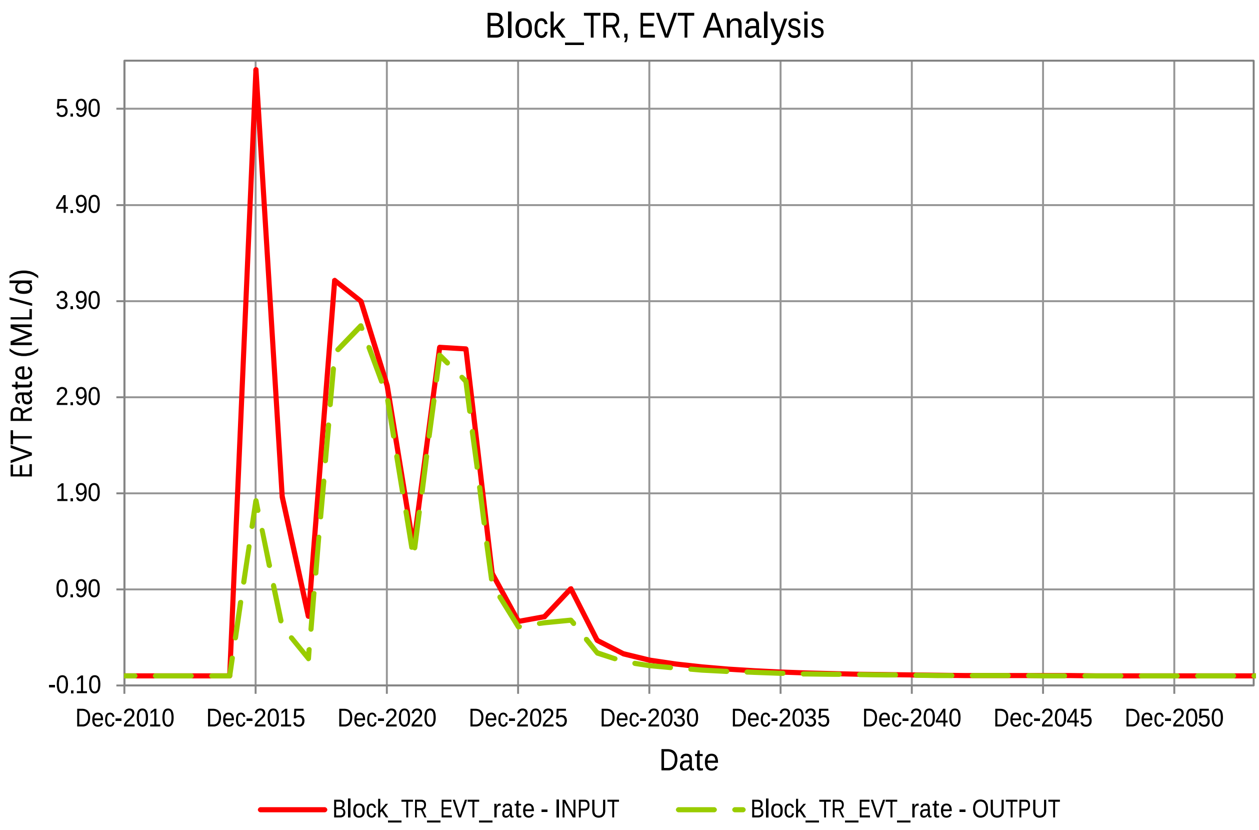
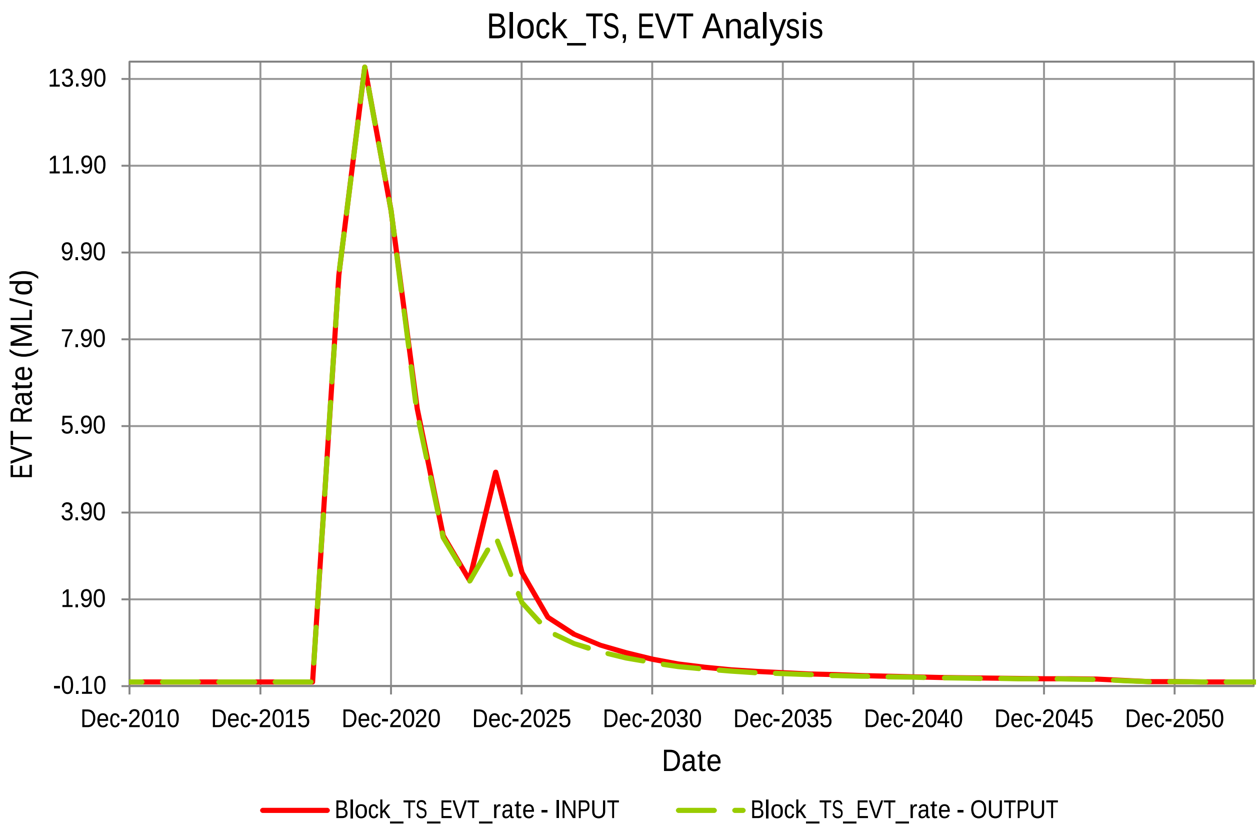
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Dalby Development Region





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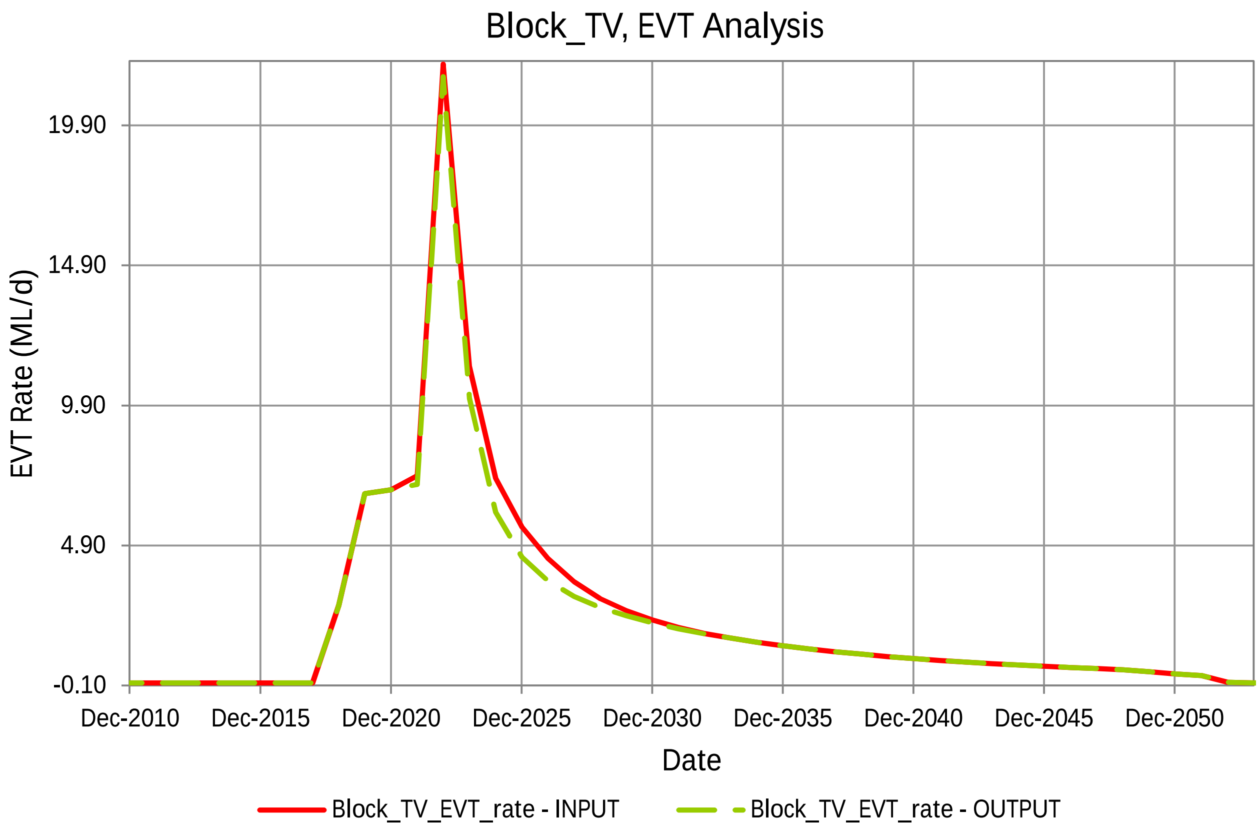

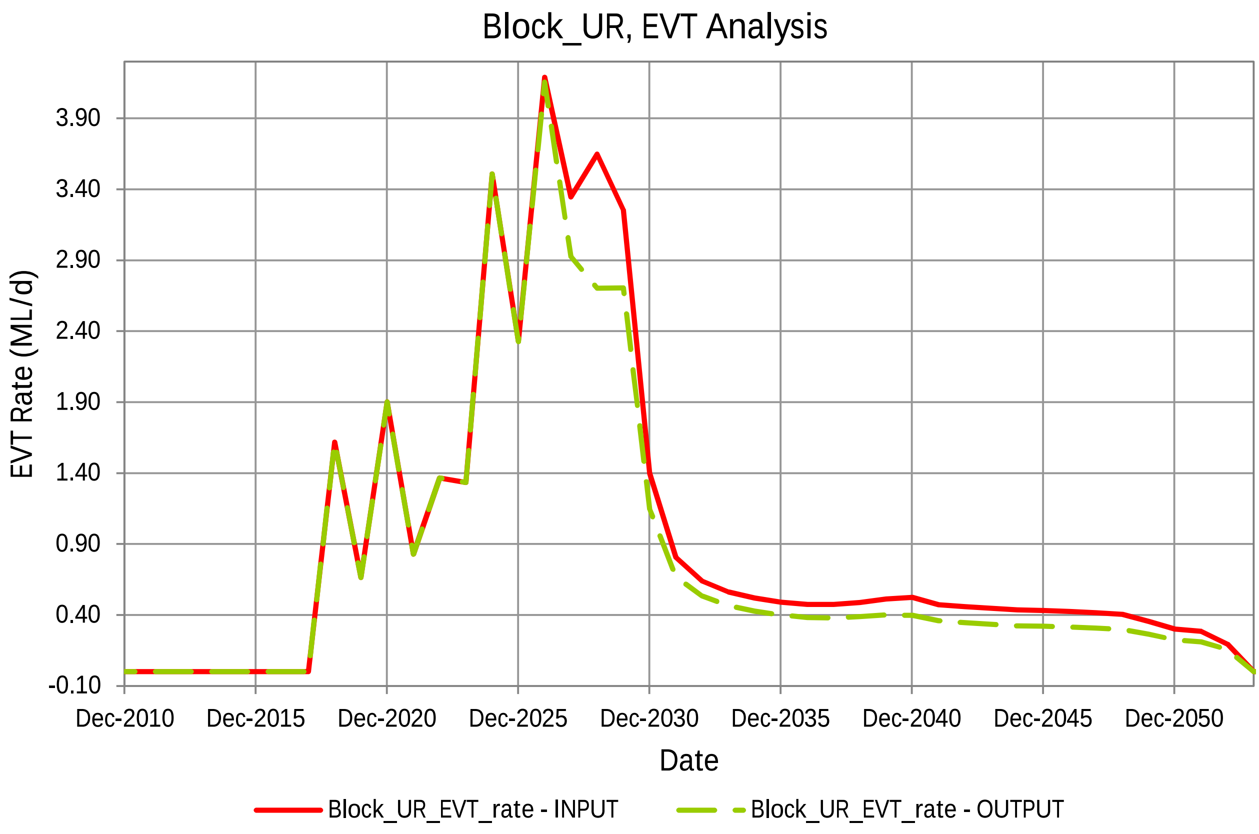

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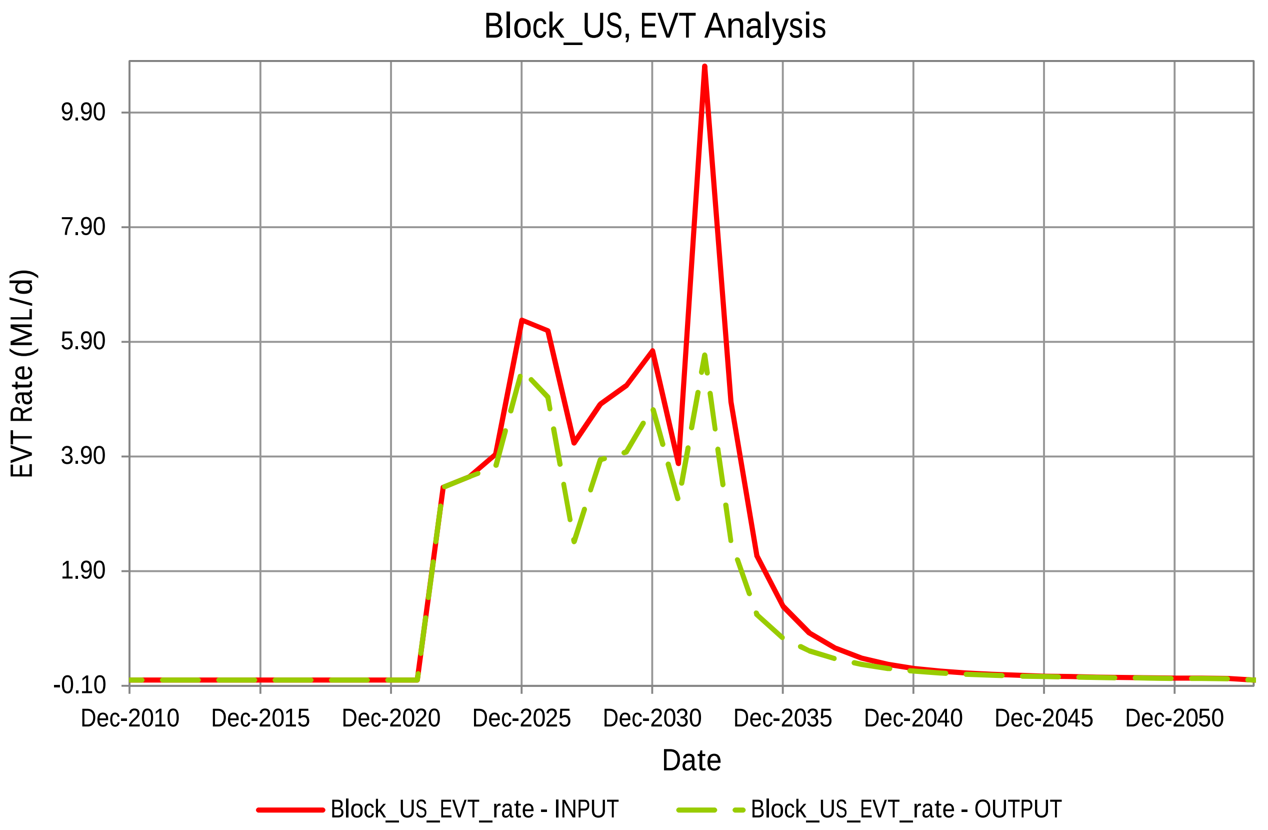

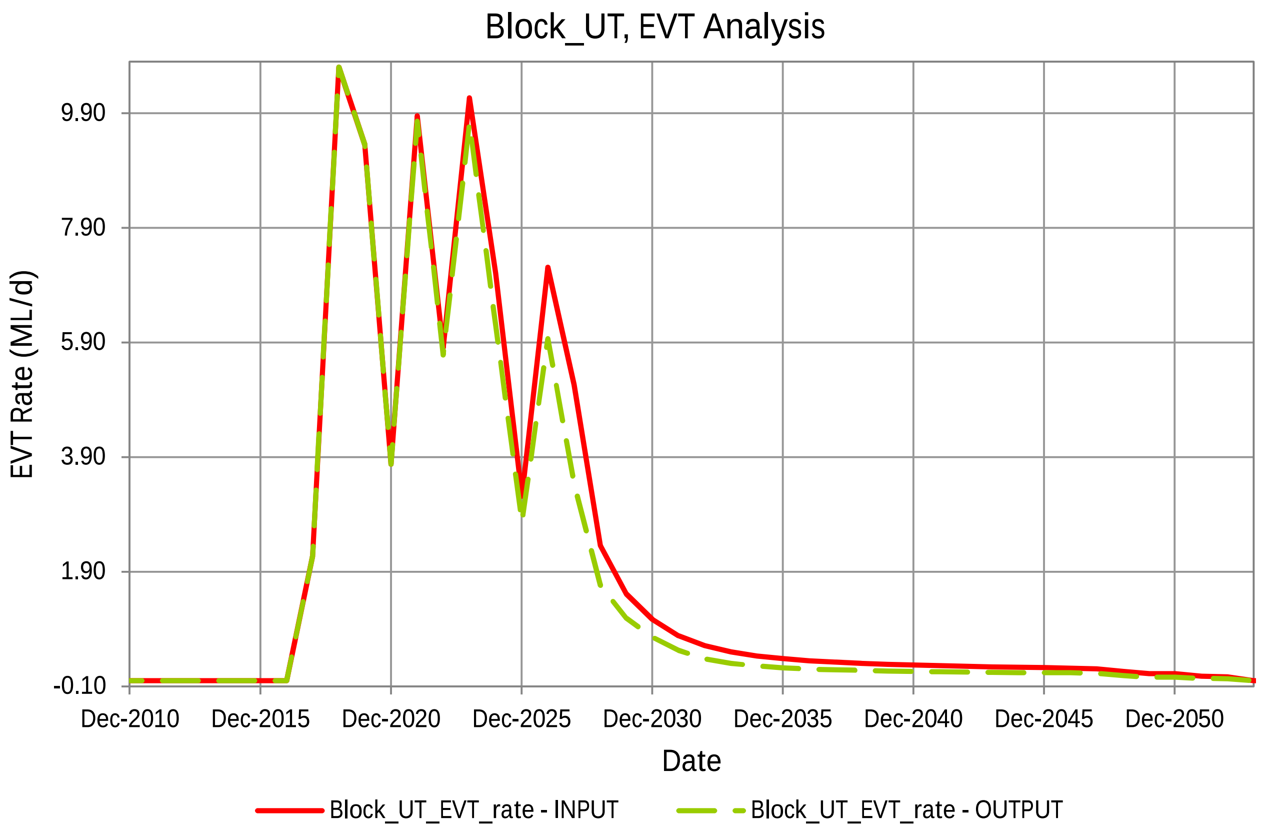

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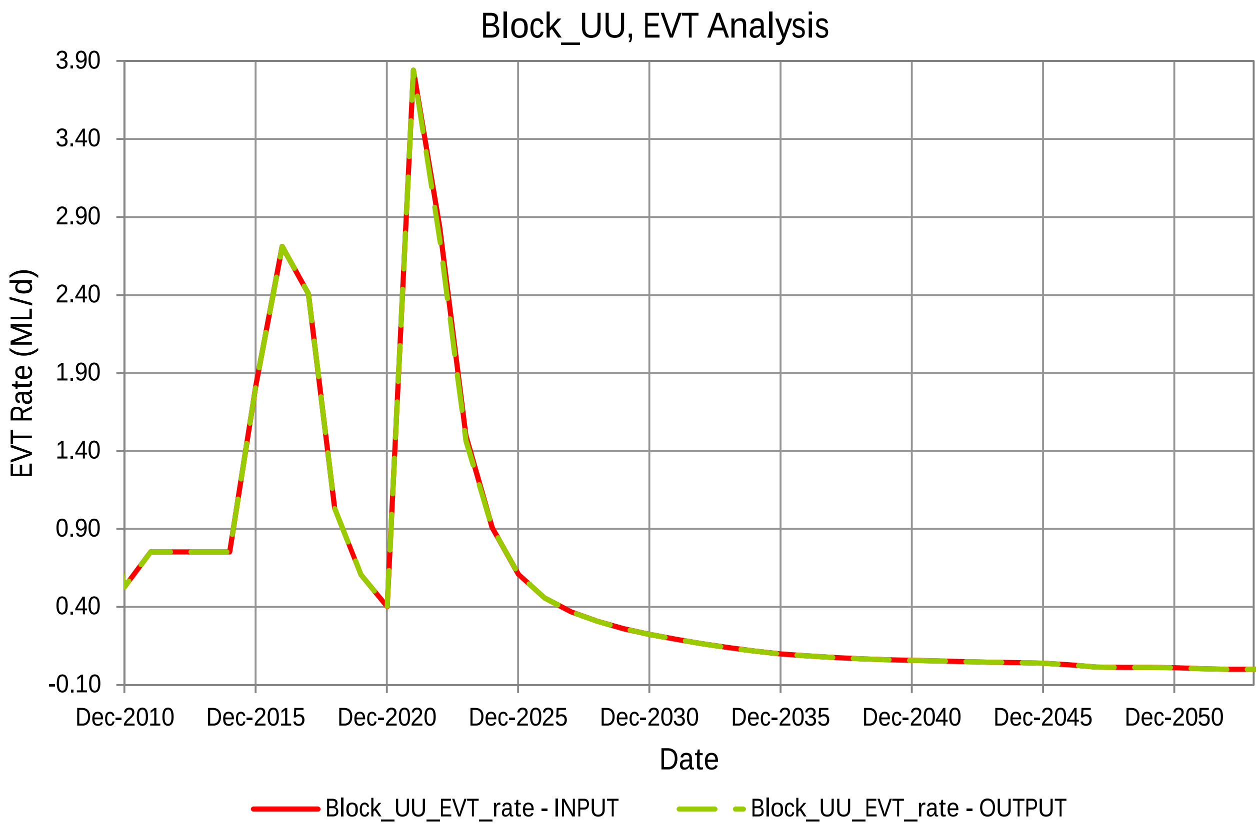

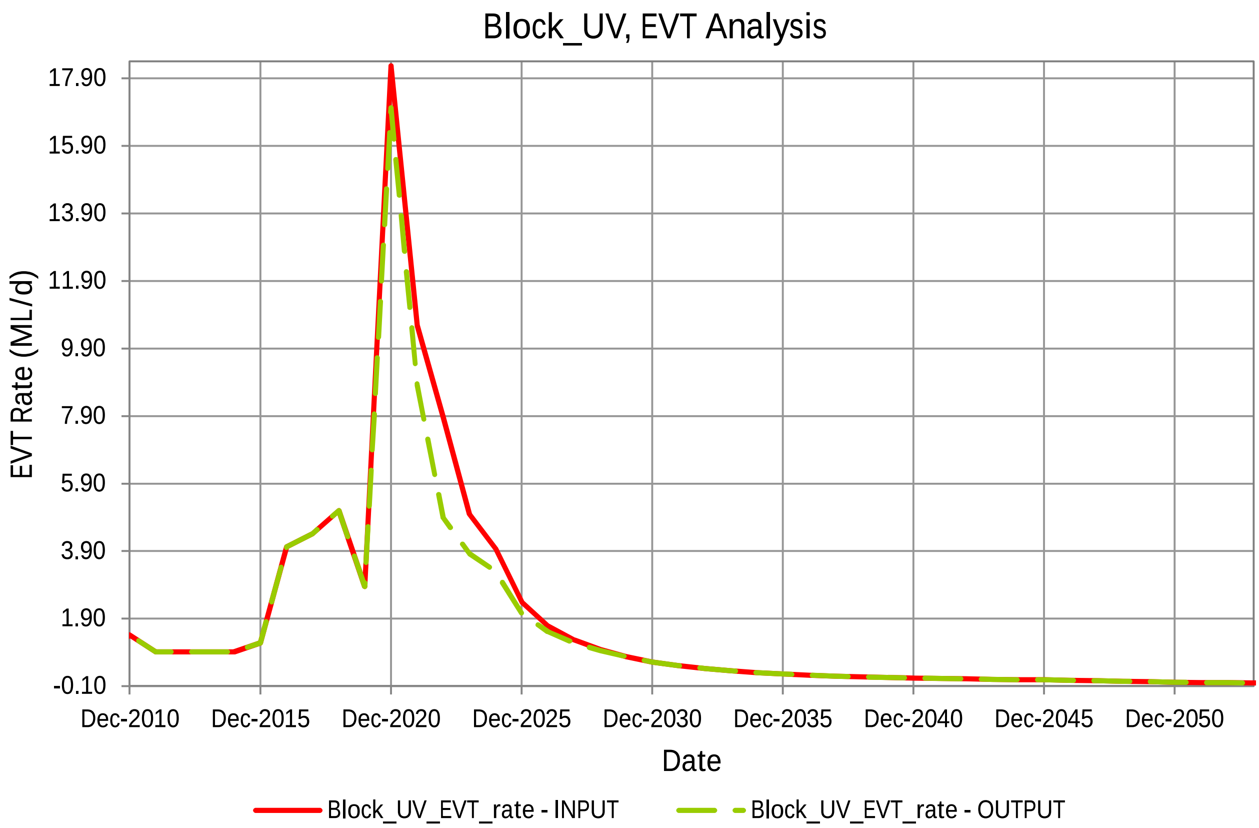

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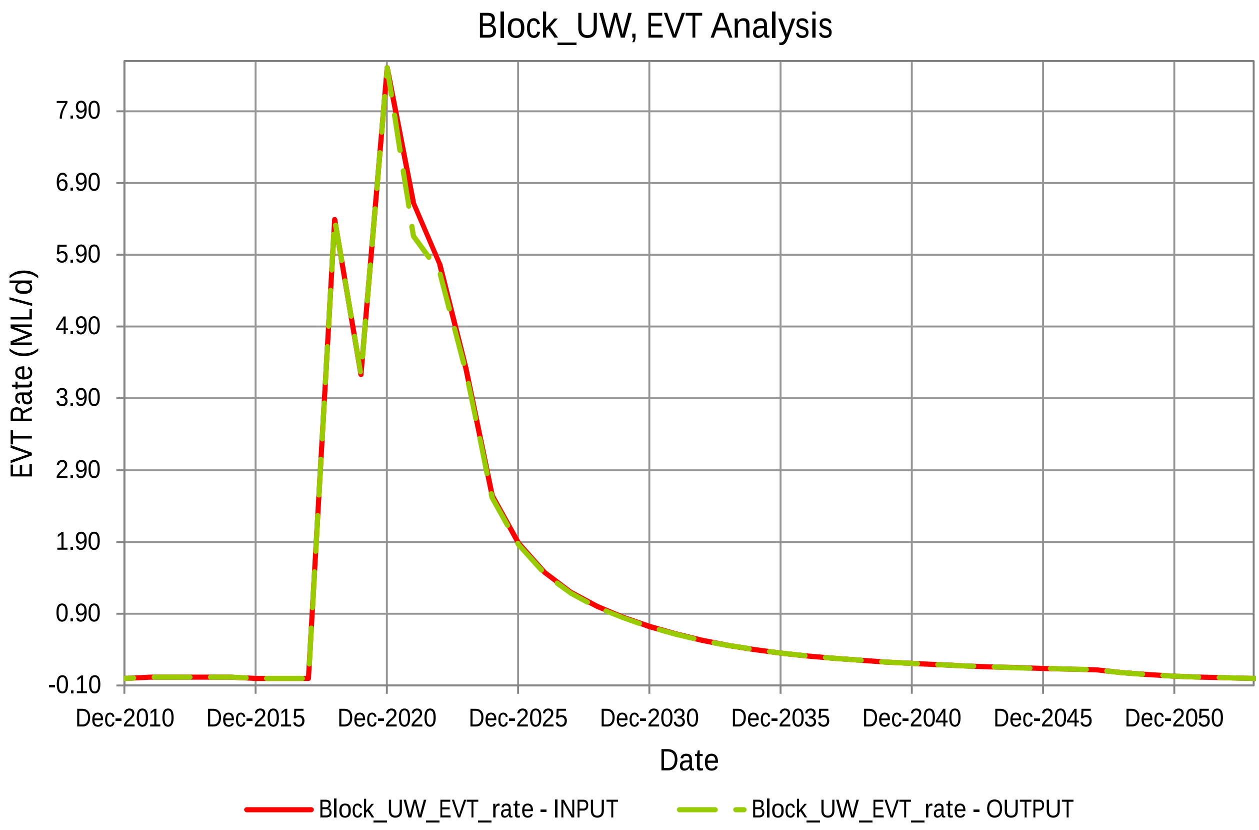
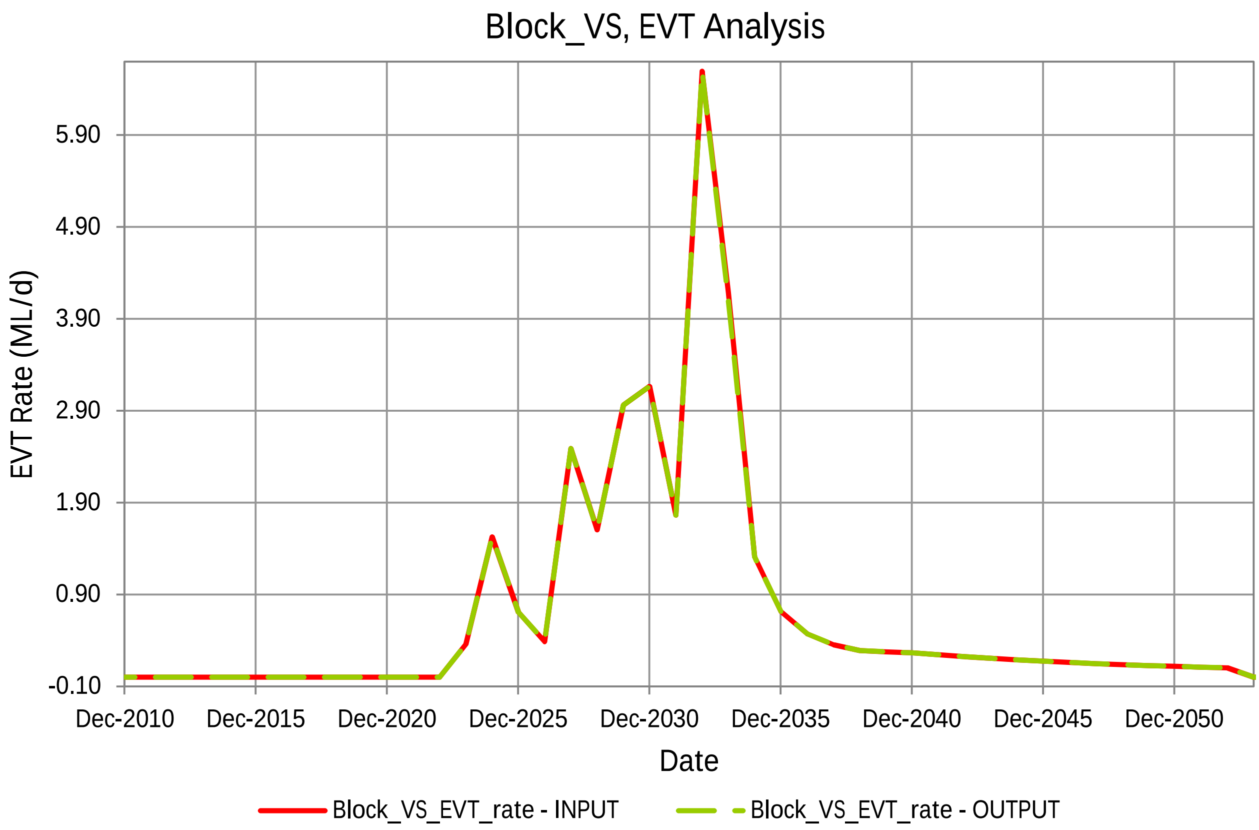
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Dalby Development Region





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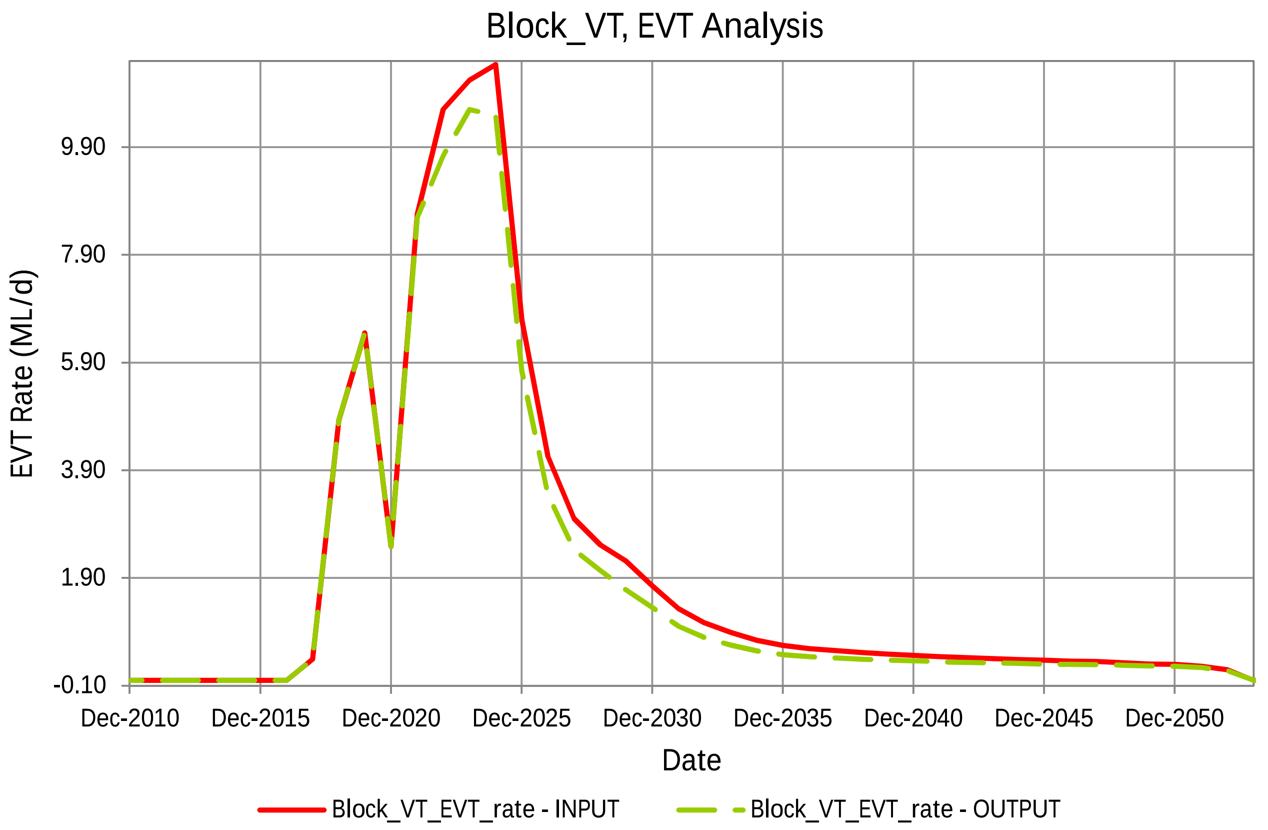

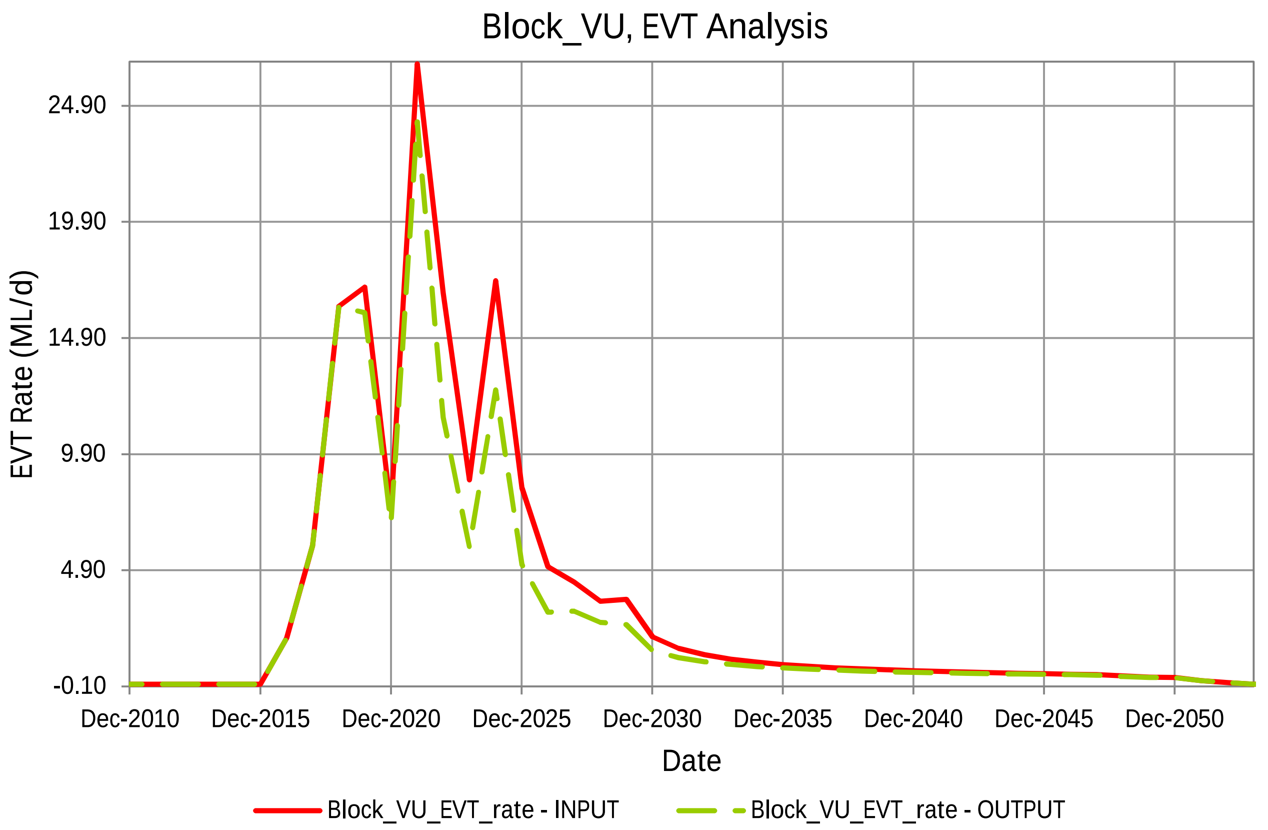

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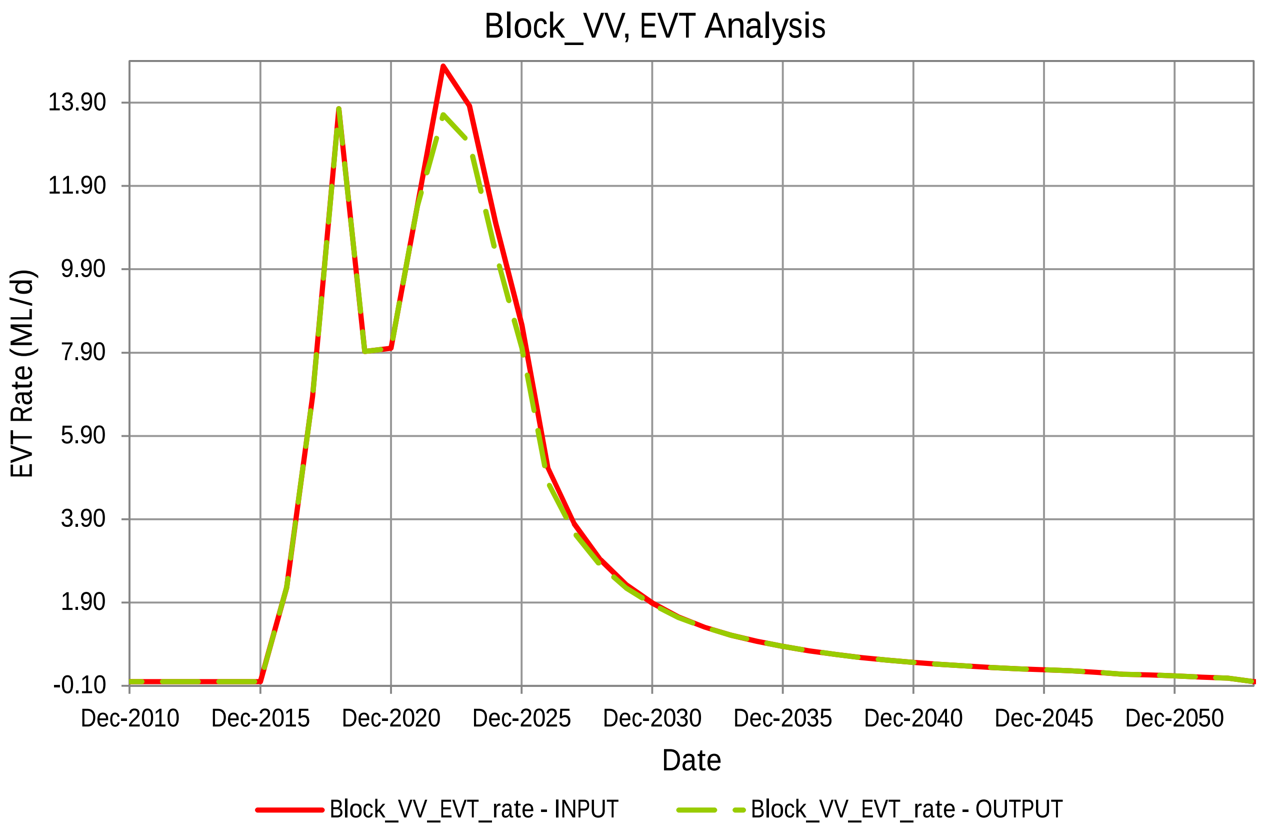
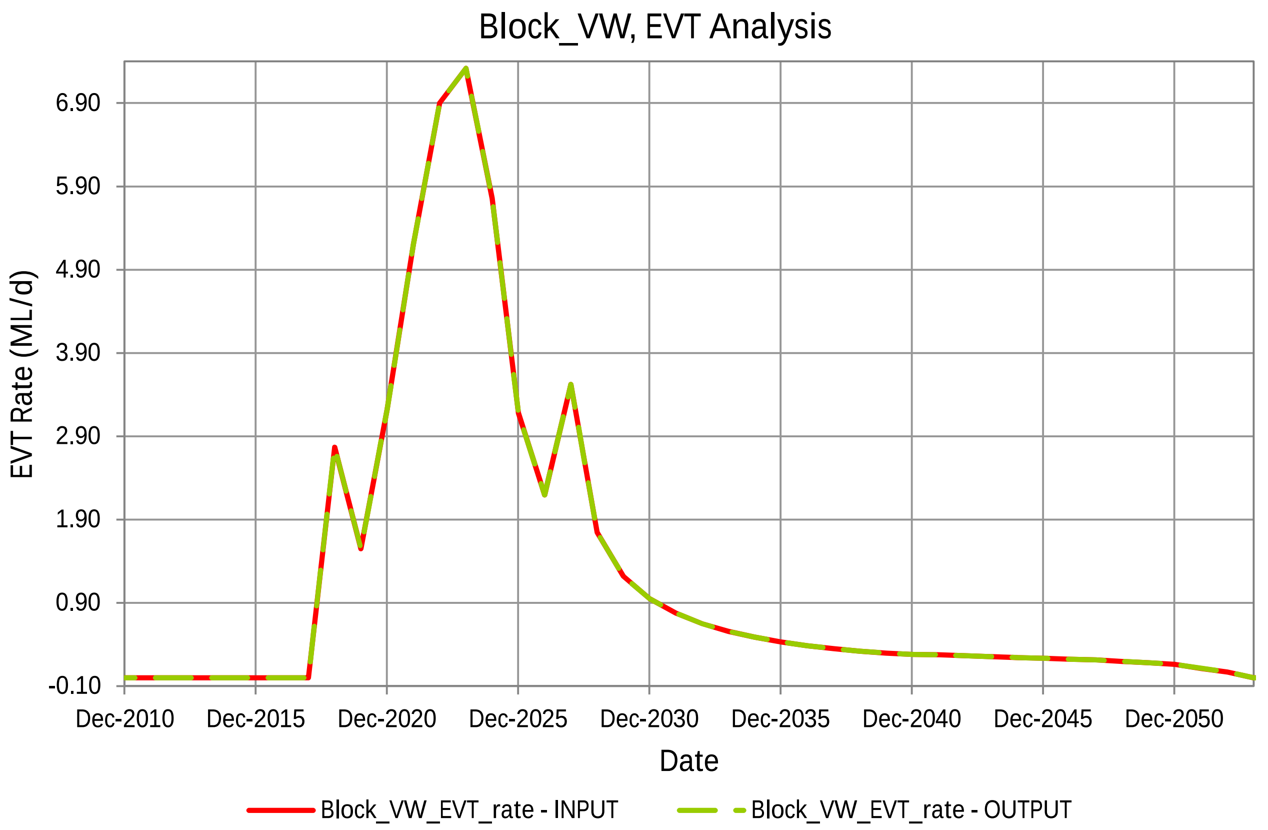
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Dalby Development Region





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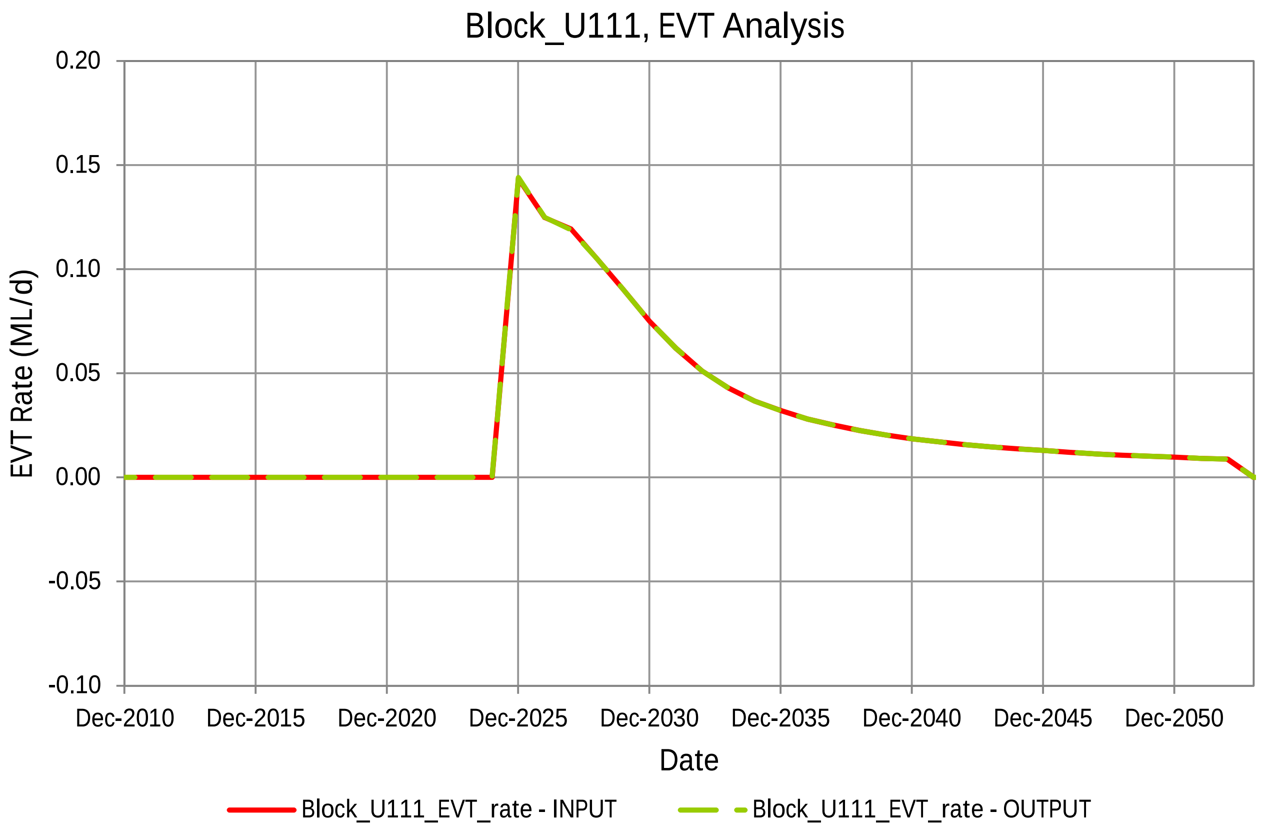
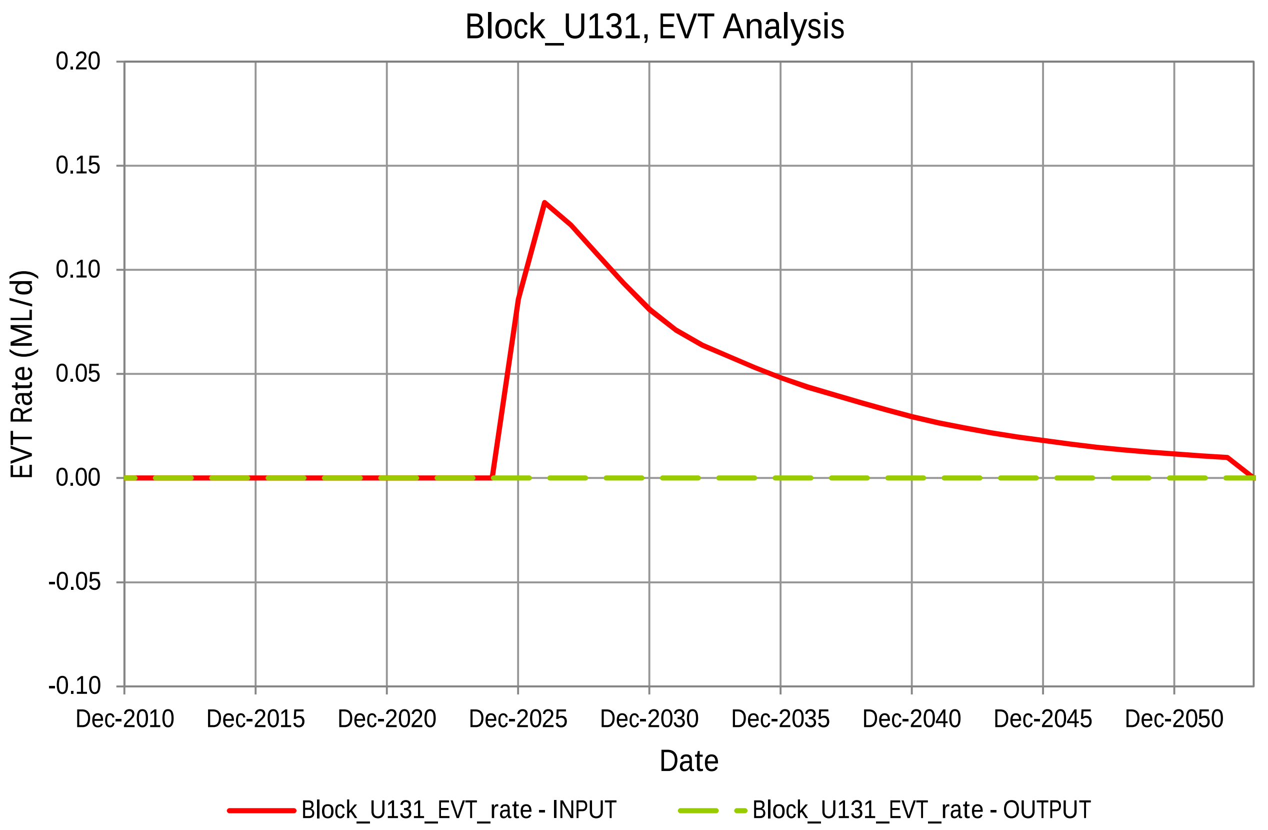
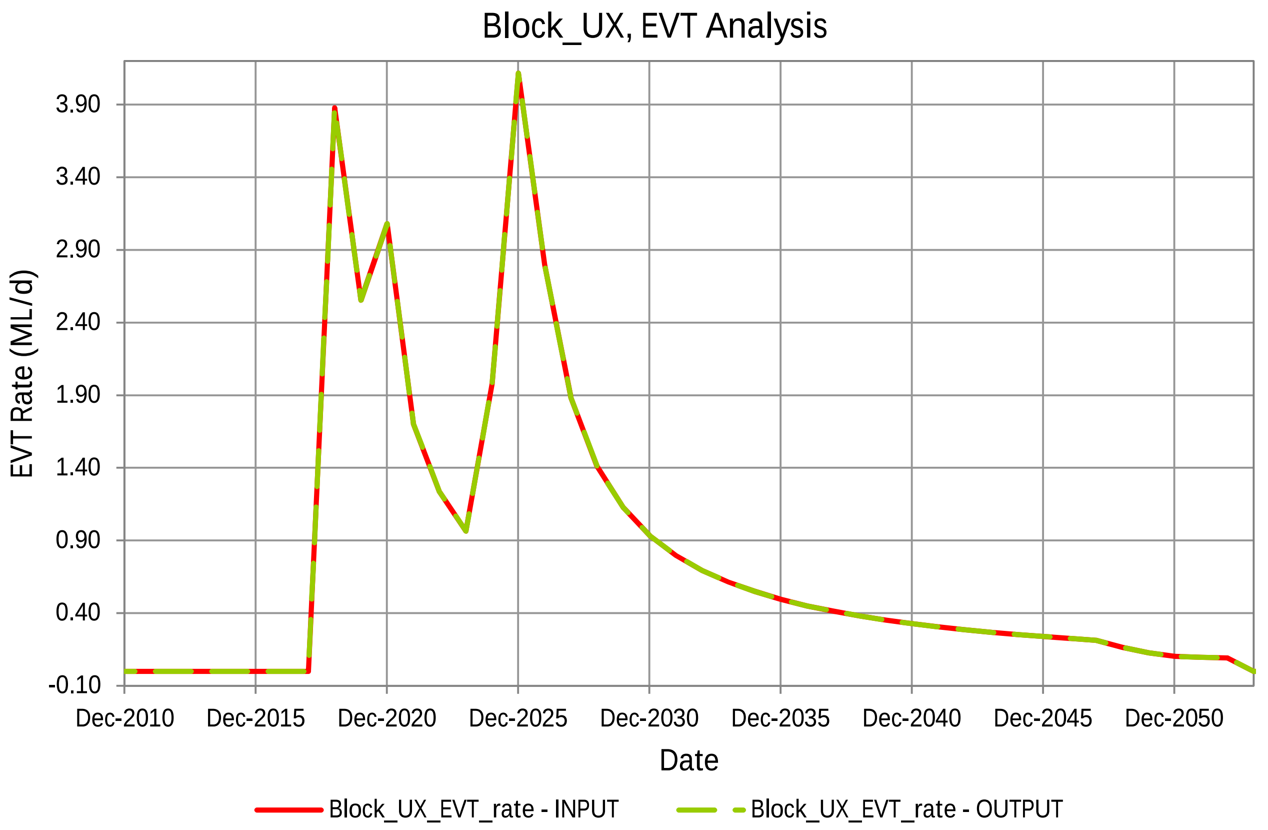
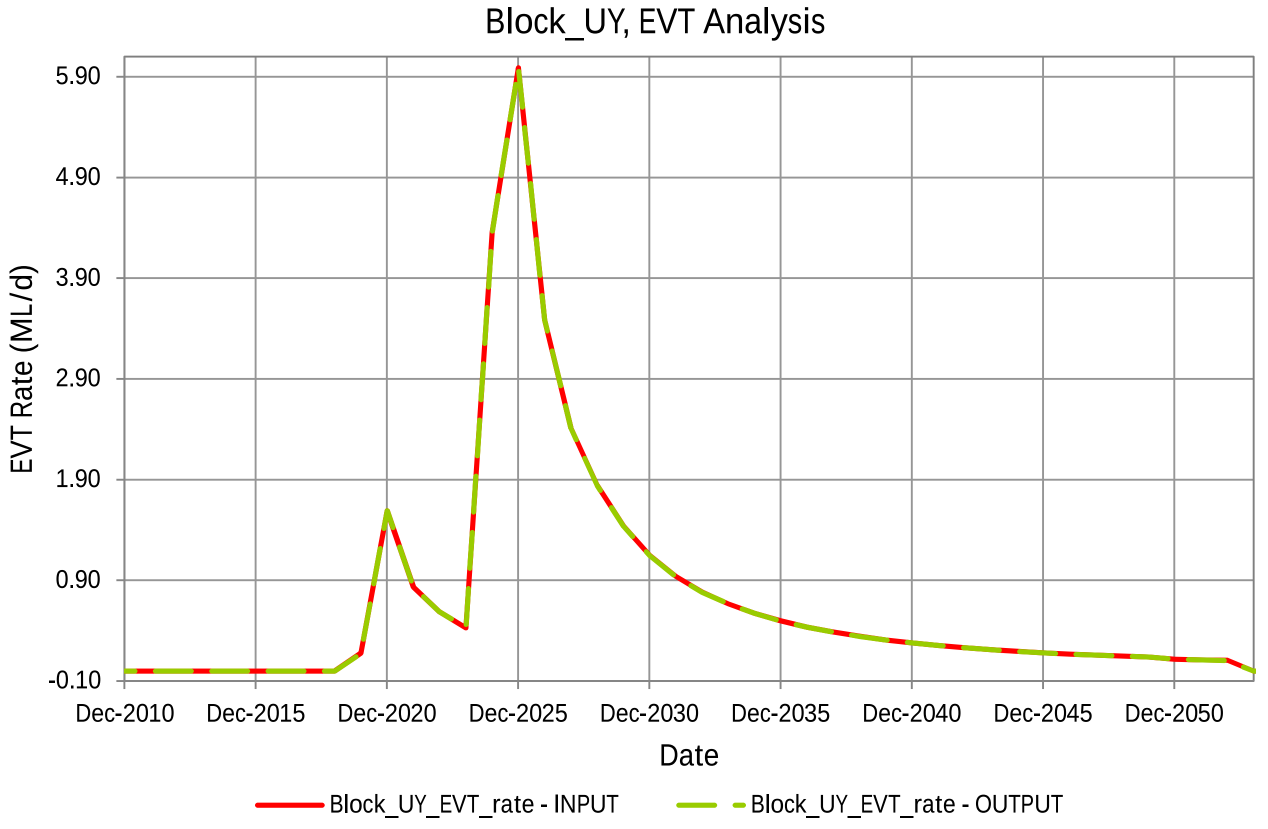
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Millmerran Development Region



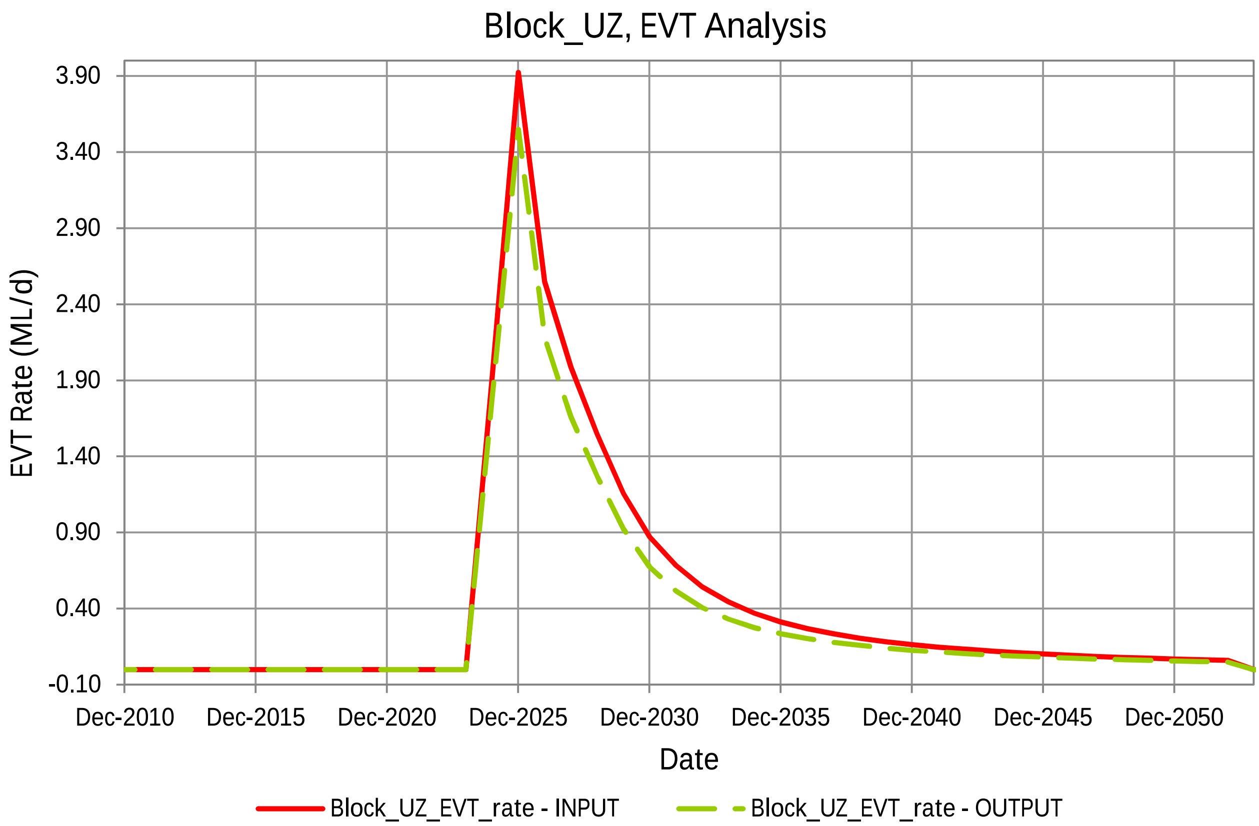


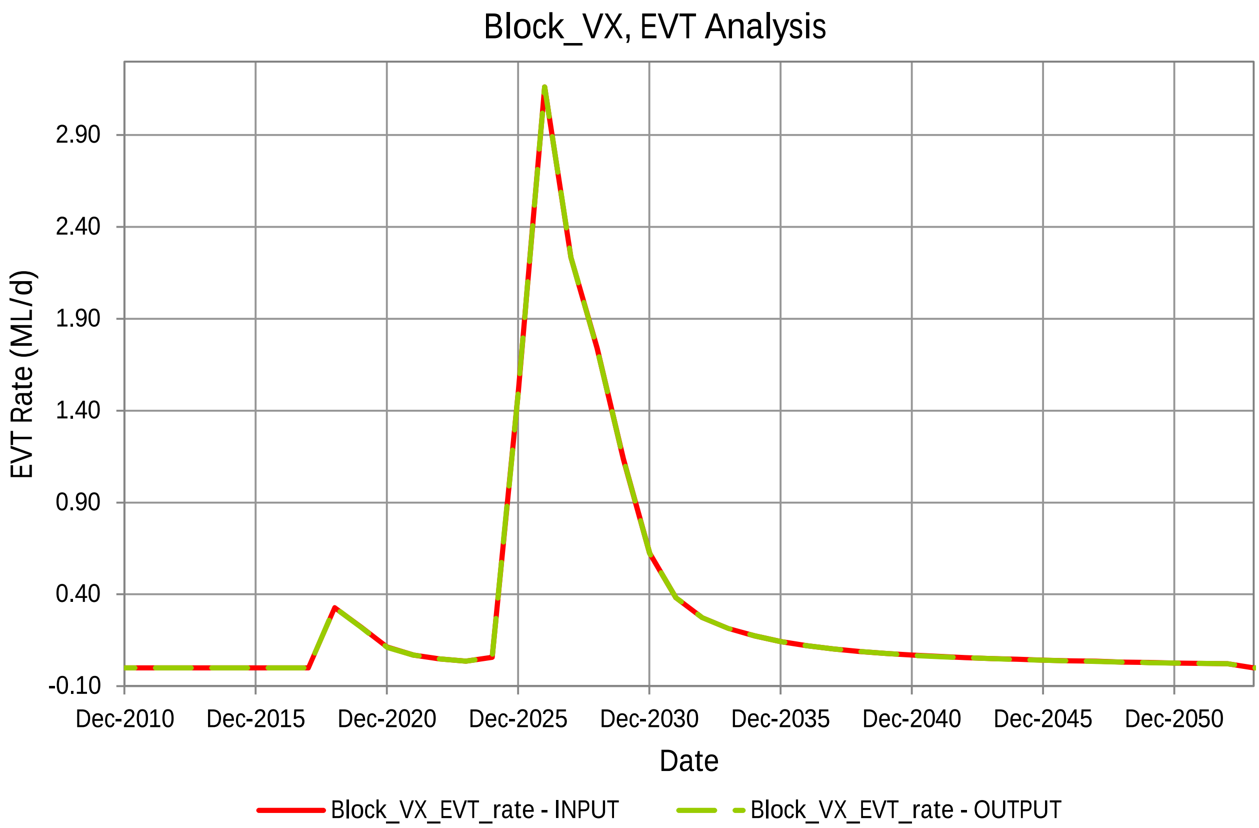
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Millmerran Development Region



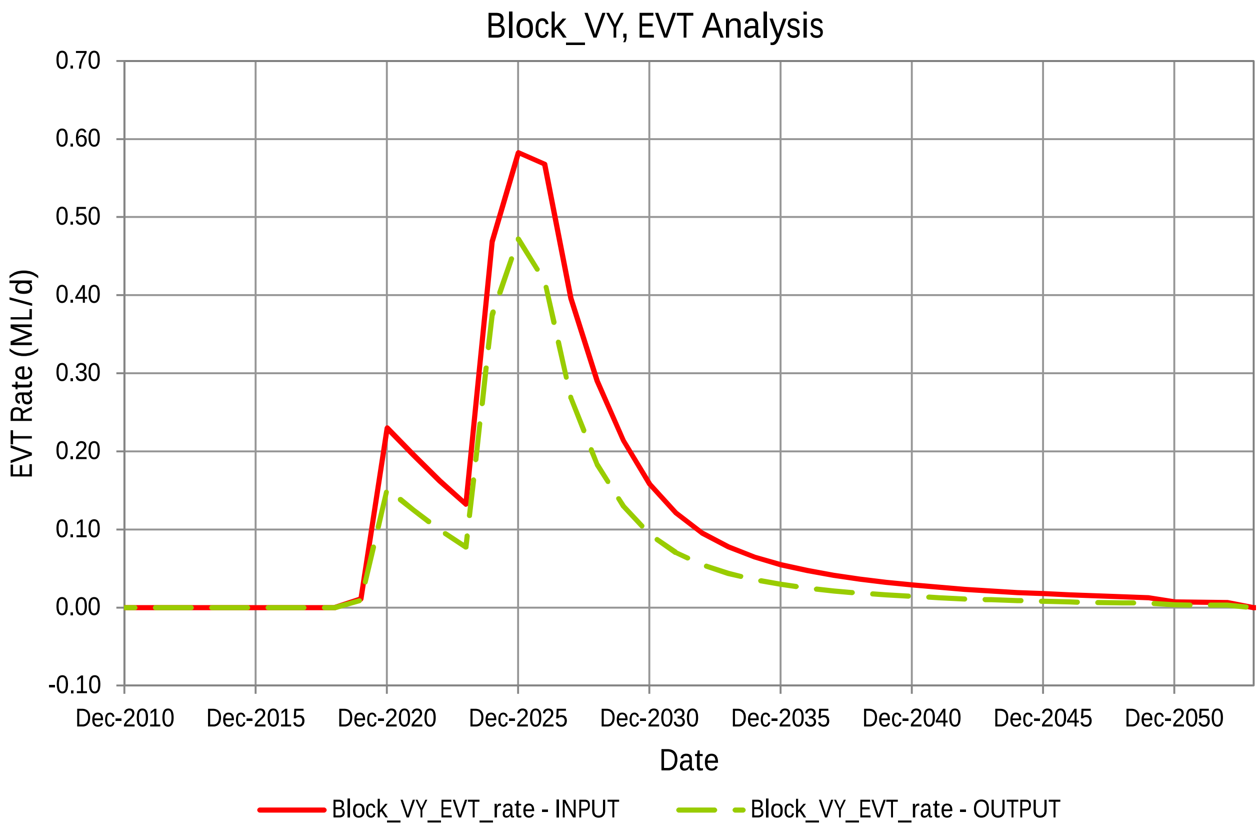


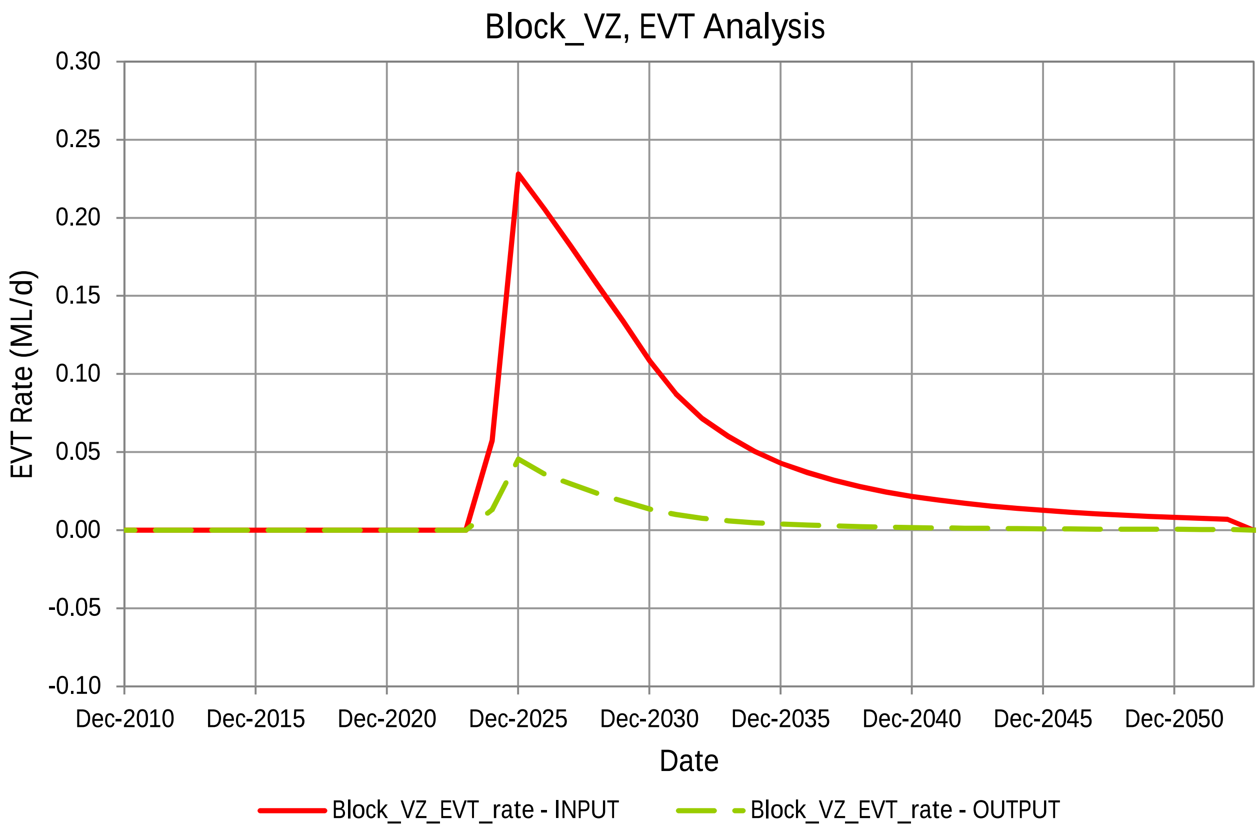
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Millmerran Development Region





Appendix E - Comparison of Modelled EVT Input and Output Volumes - Millmerran Development Region





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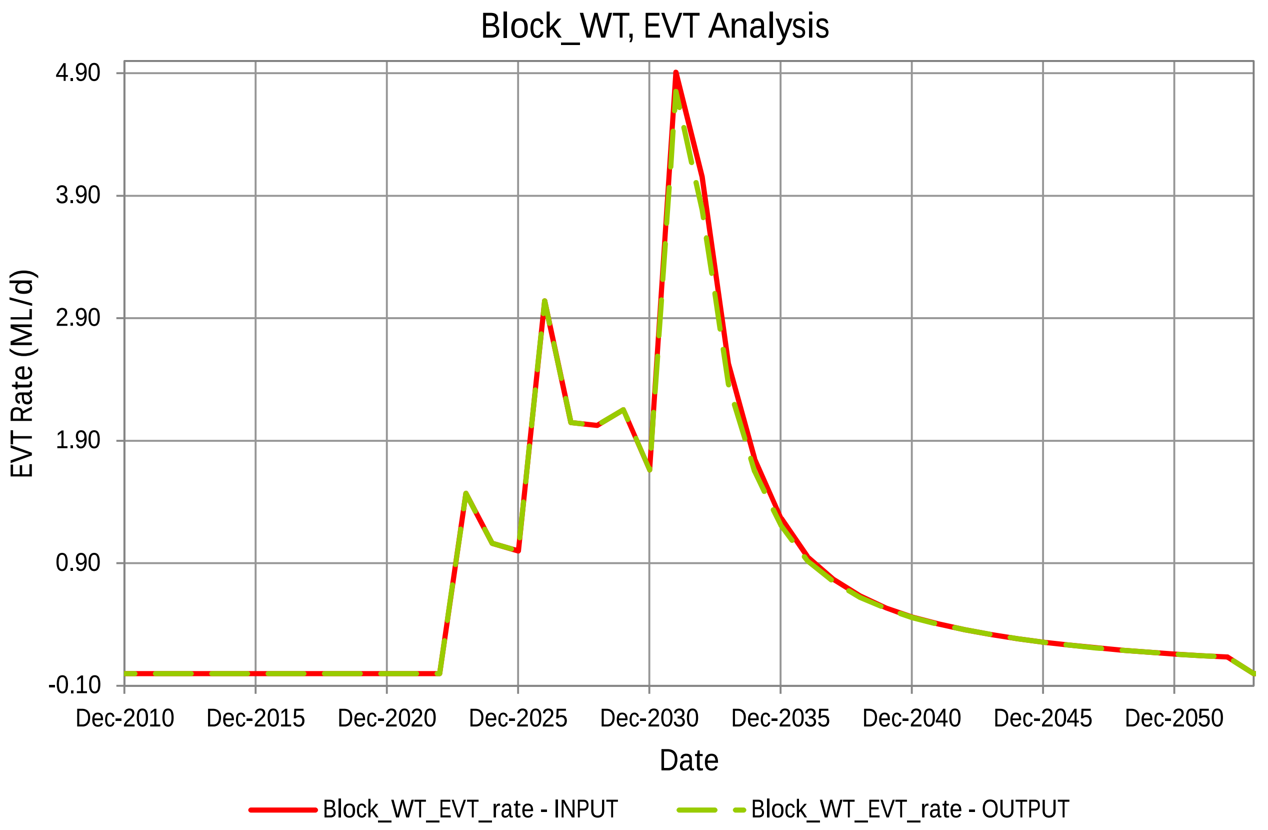
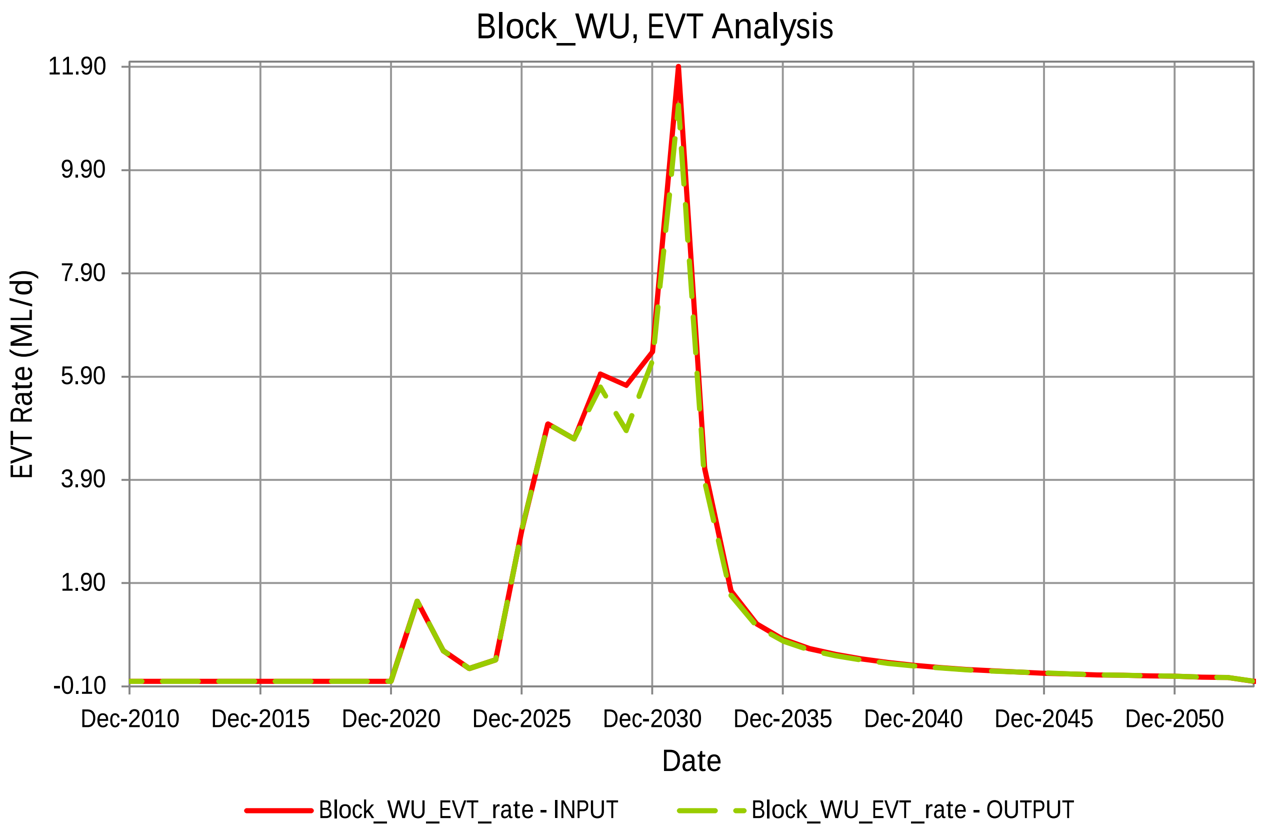
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Millmerran Development Region





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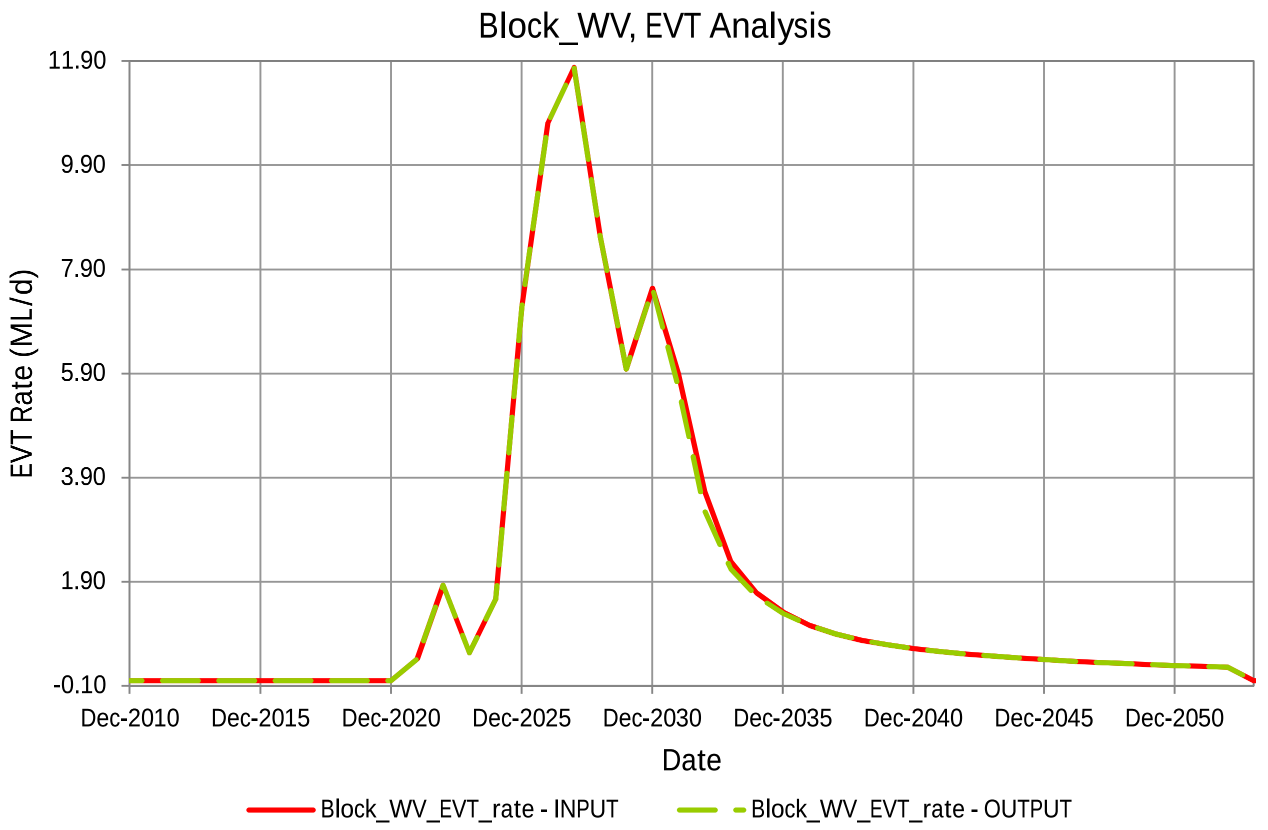
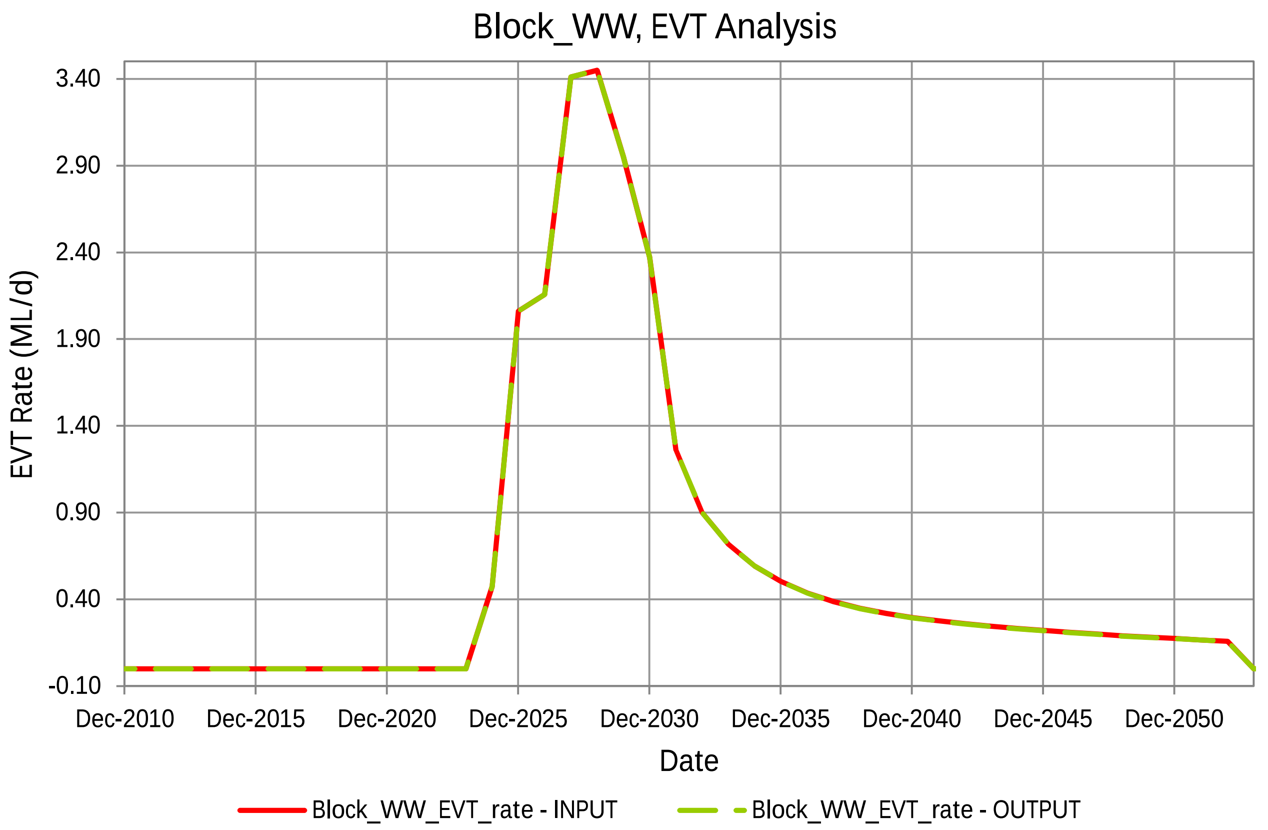
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Millmerran Development Region





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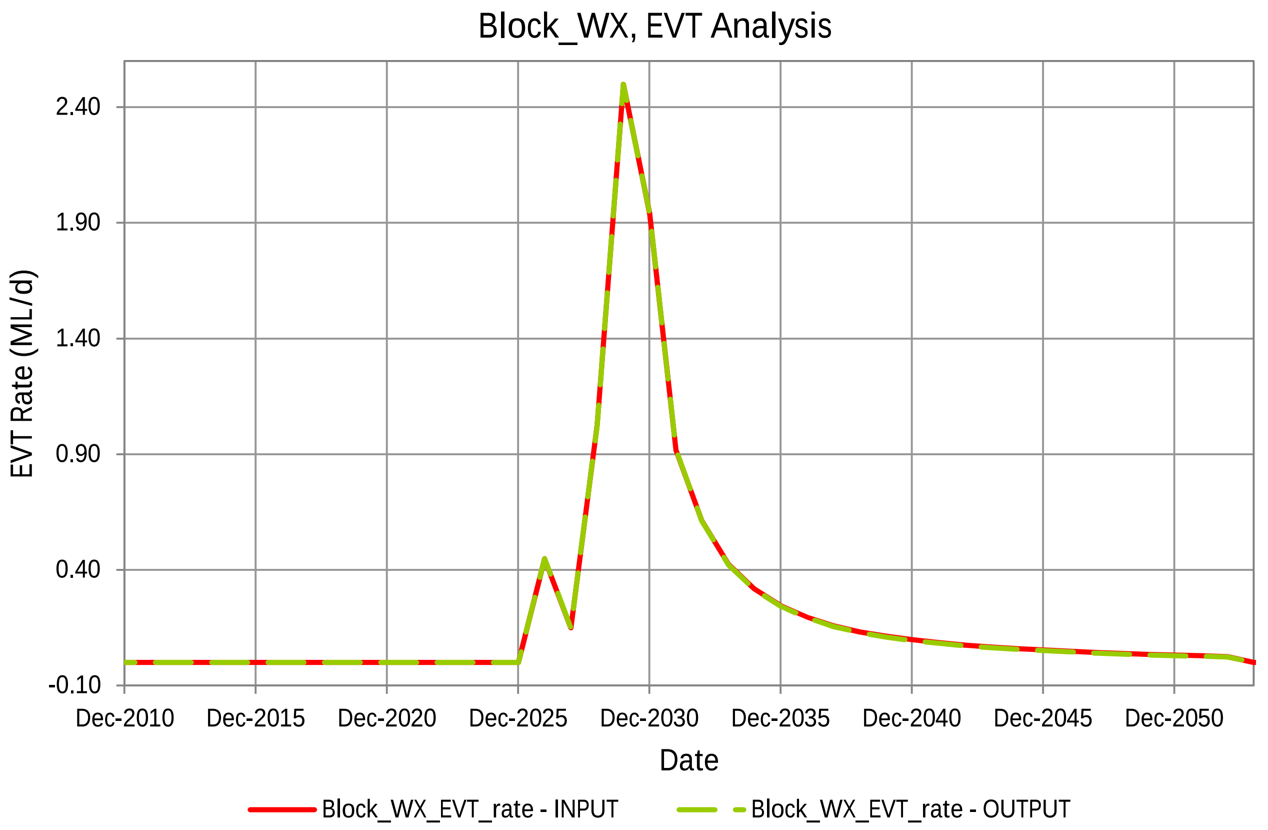
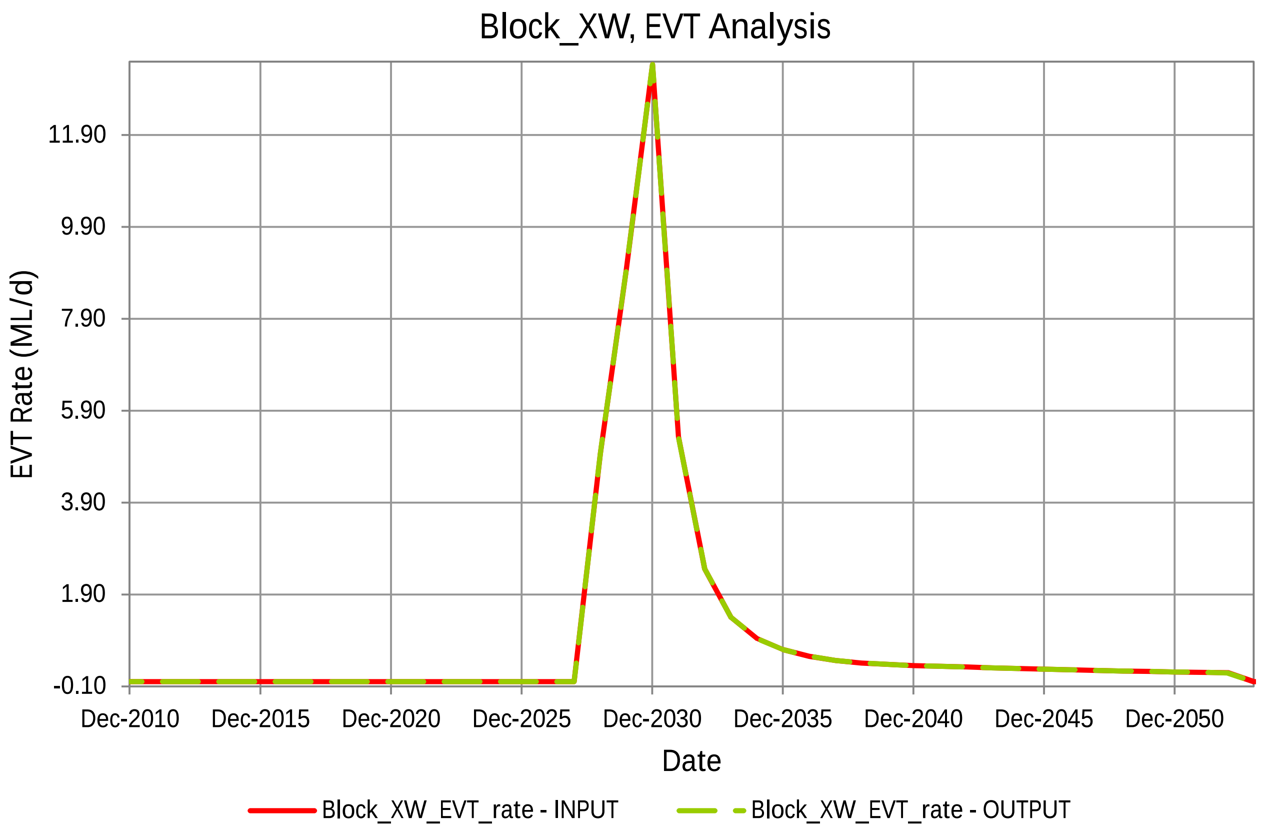
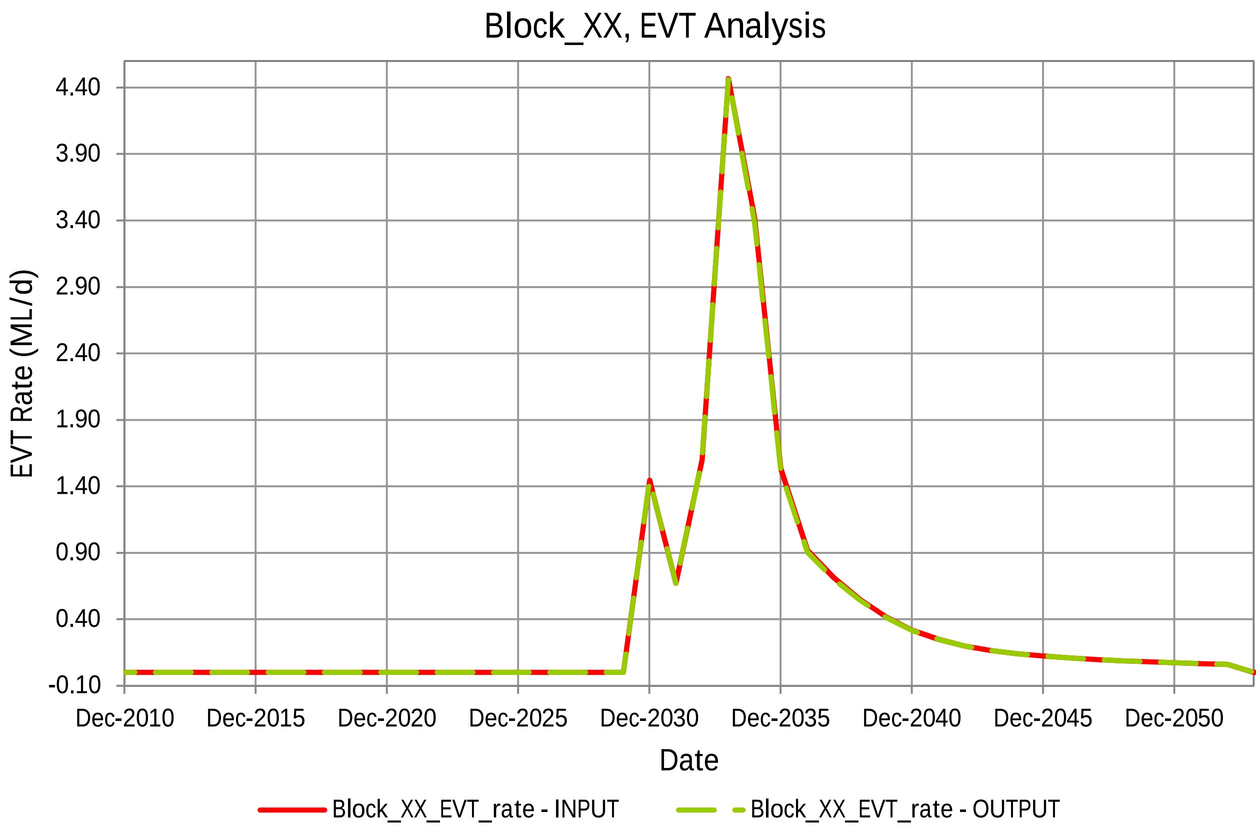
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Millmerran Development Region

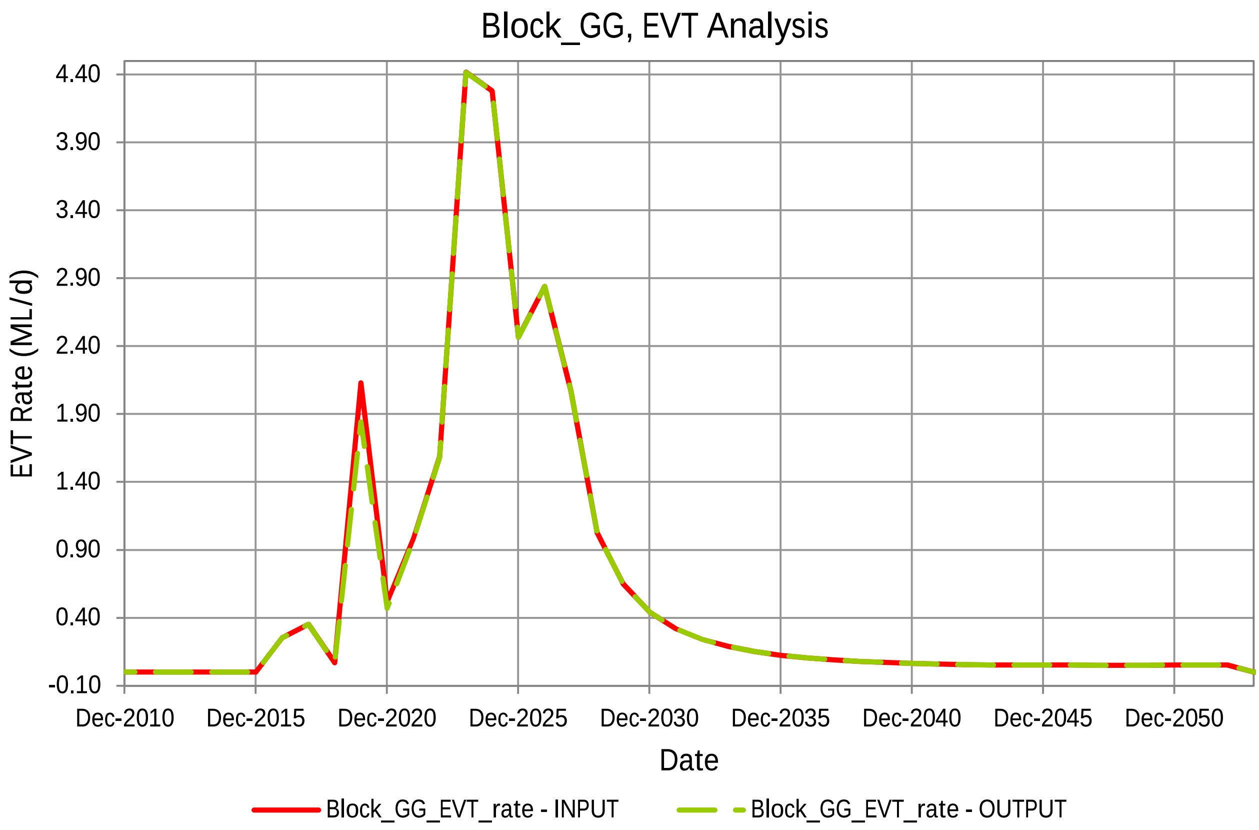


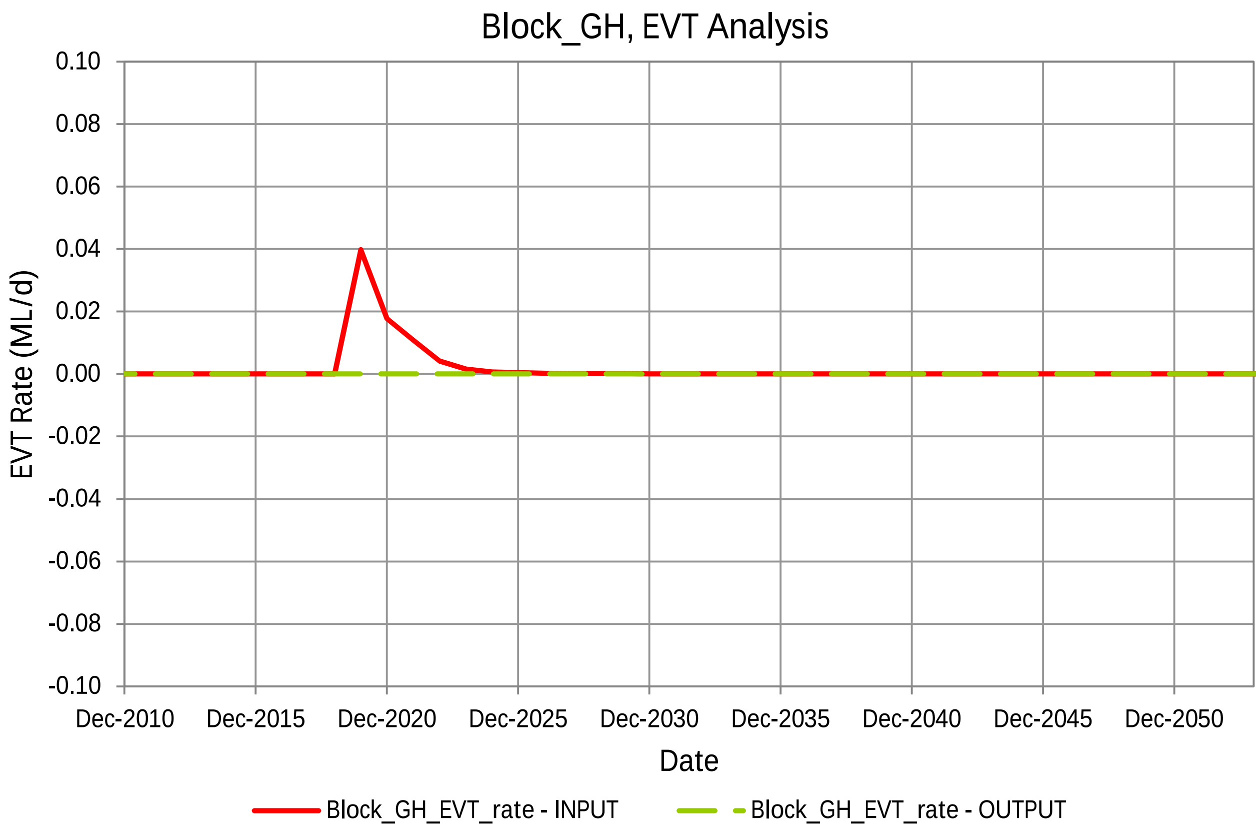


Appendix E - Comparison of Modelled EVT Input and Output Volumes - Millmerran Development Region

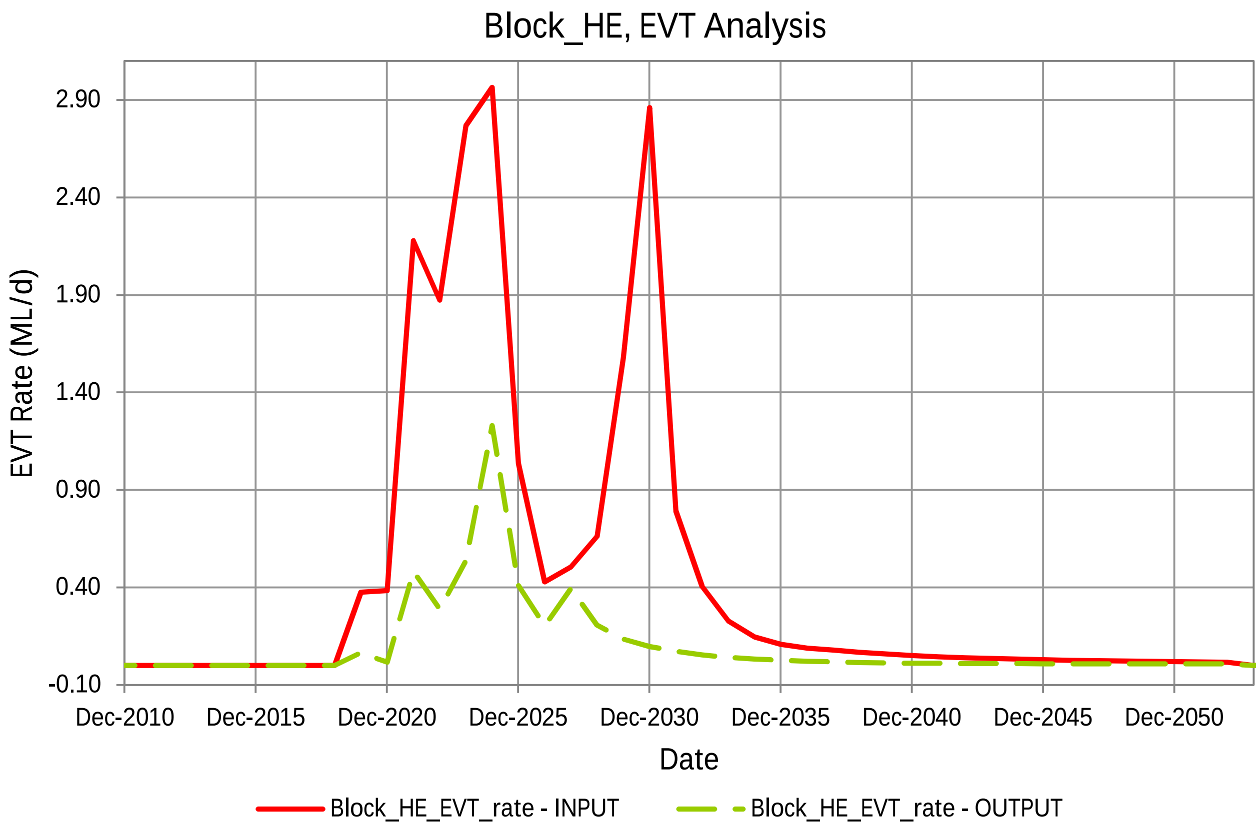


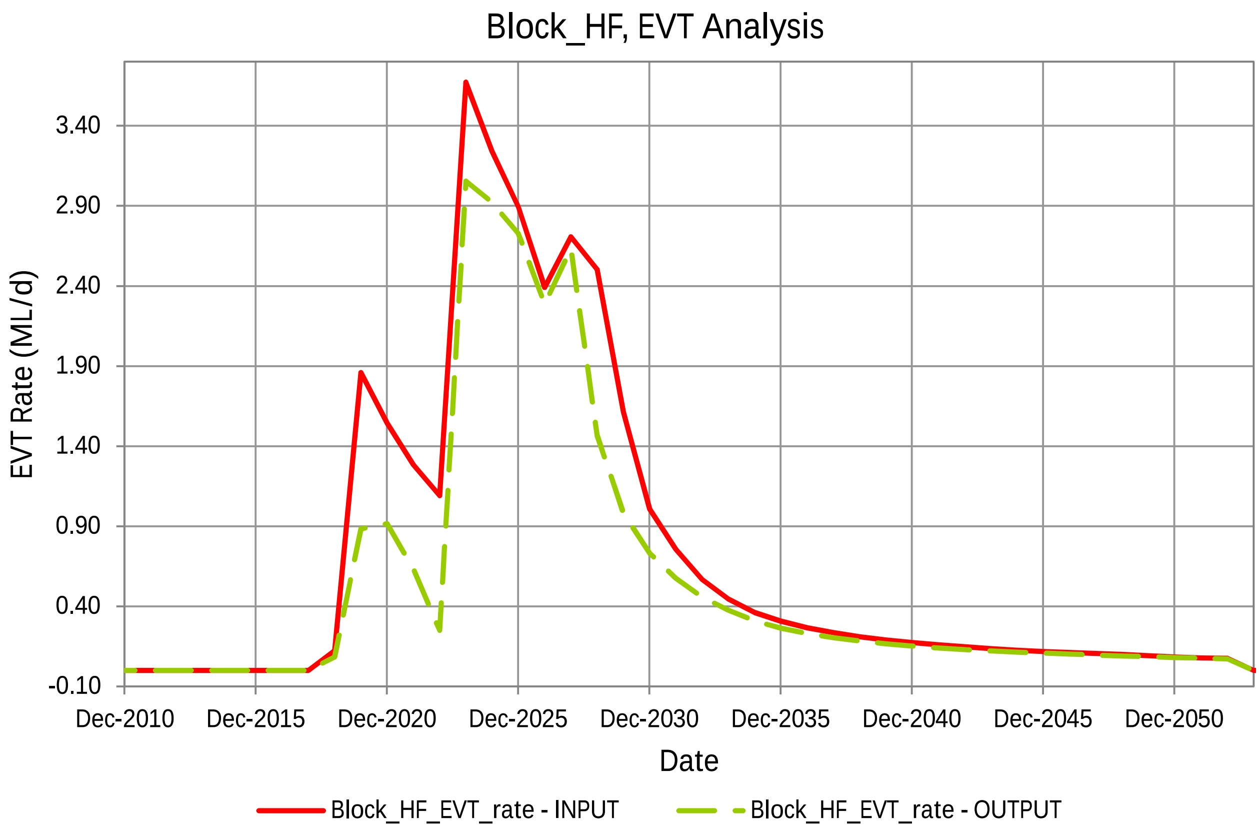
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Wandoan Development Region



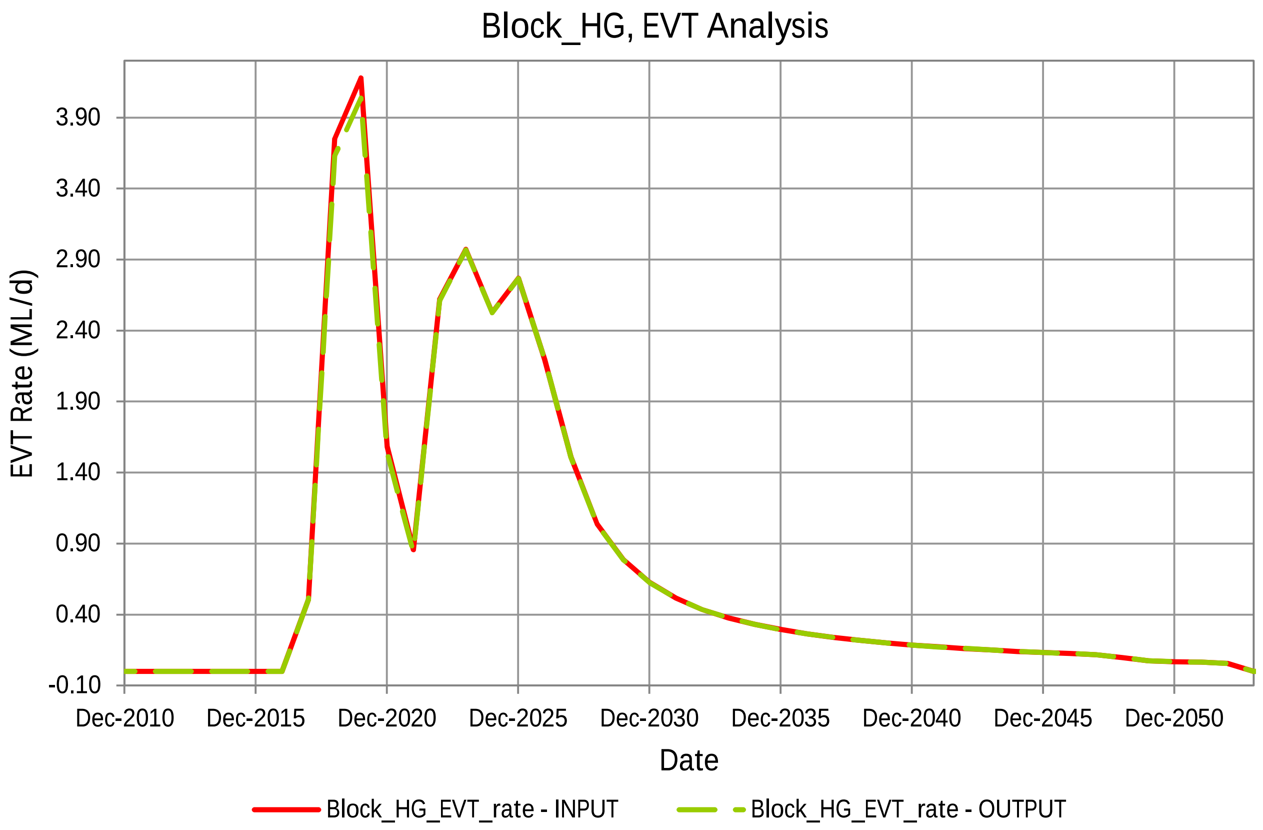


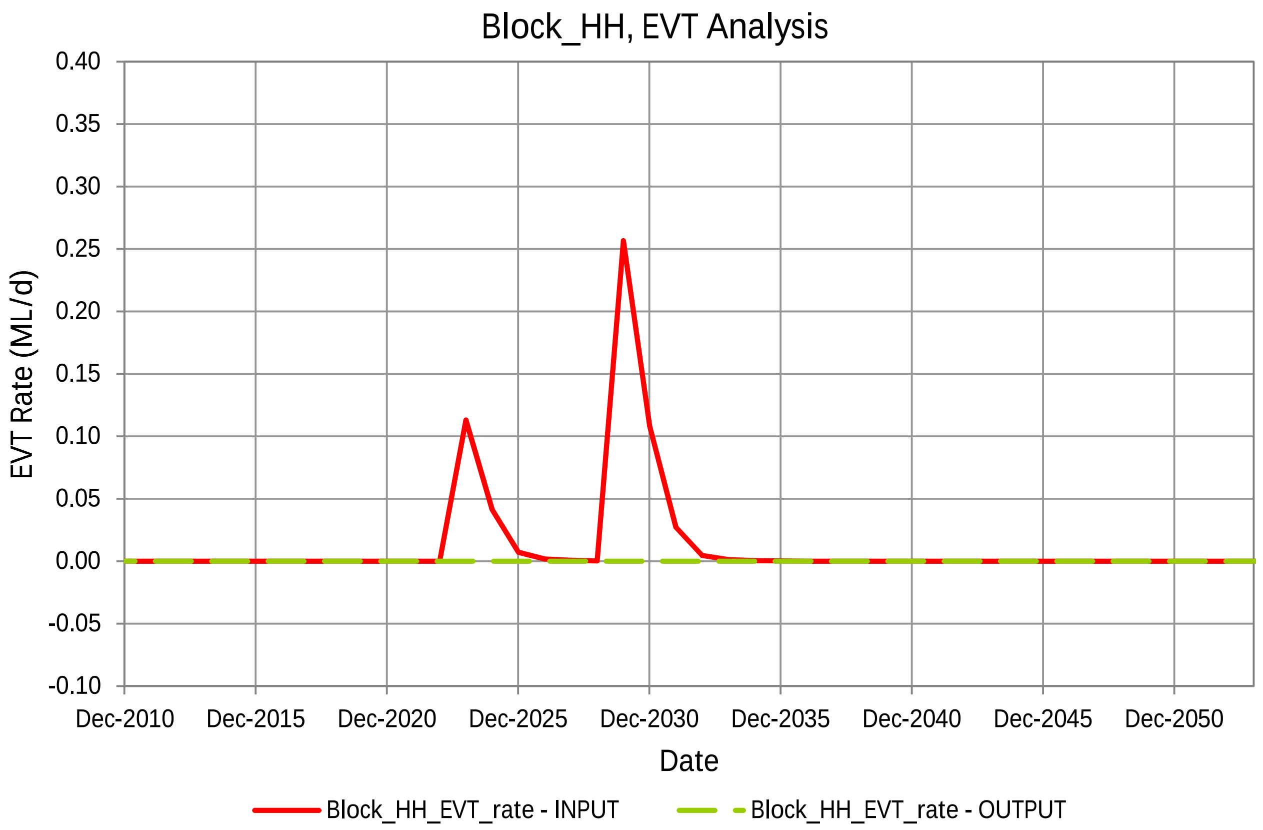
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Wandoan Development Region





Appendix E - Comparison of Modelled EVT Input and Output Volumes - Wandoan Development Region





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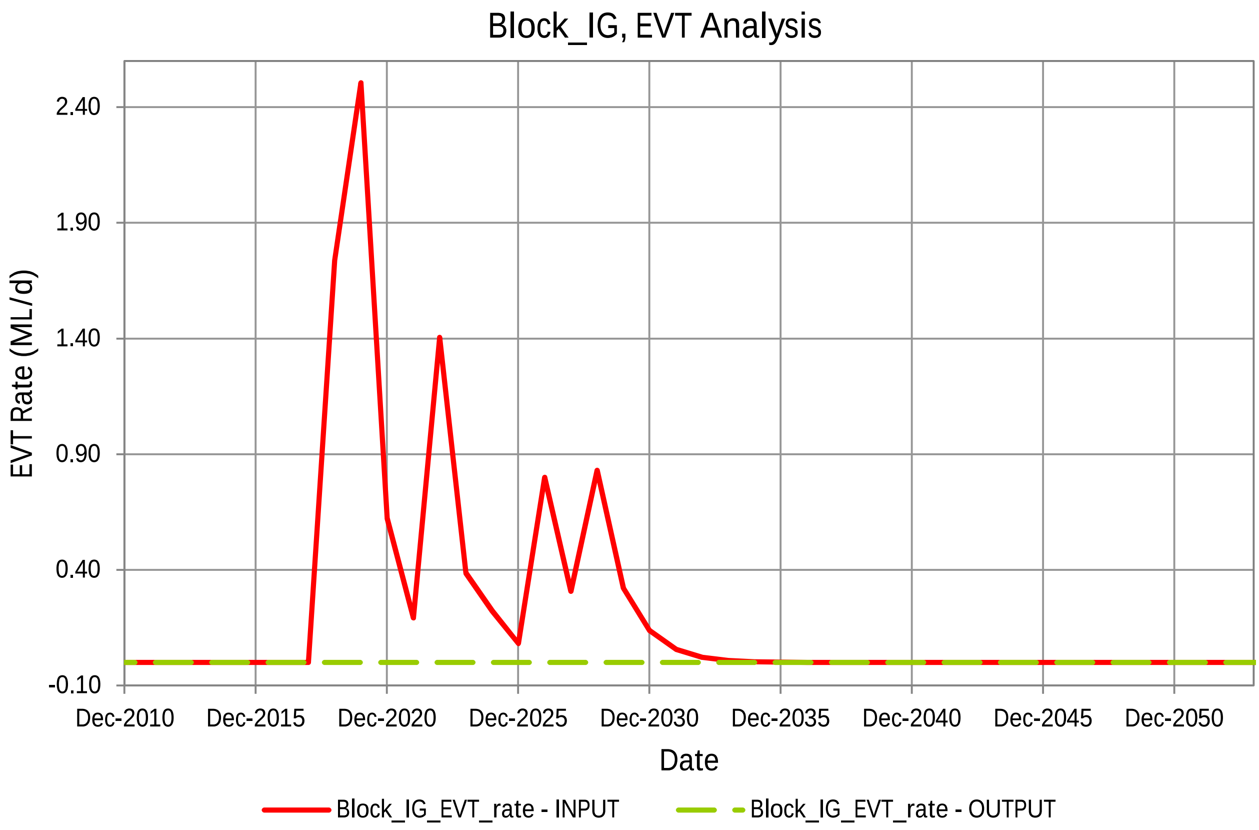
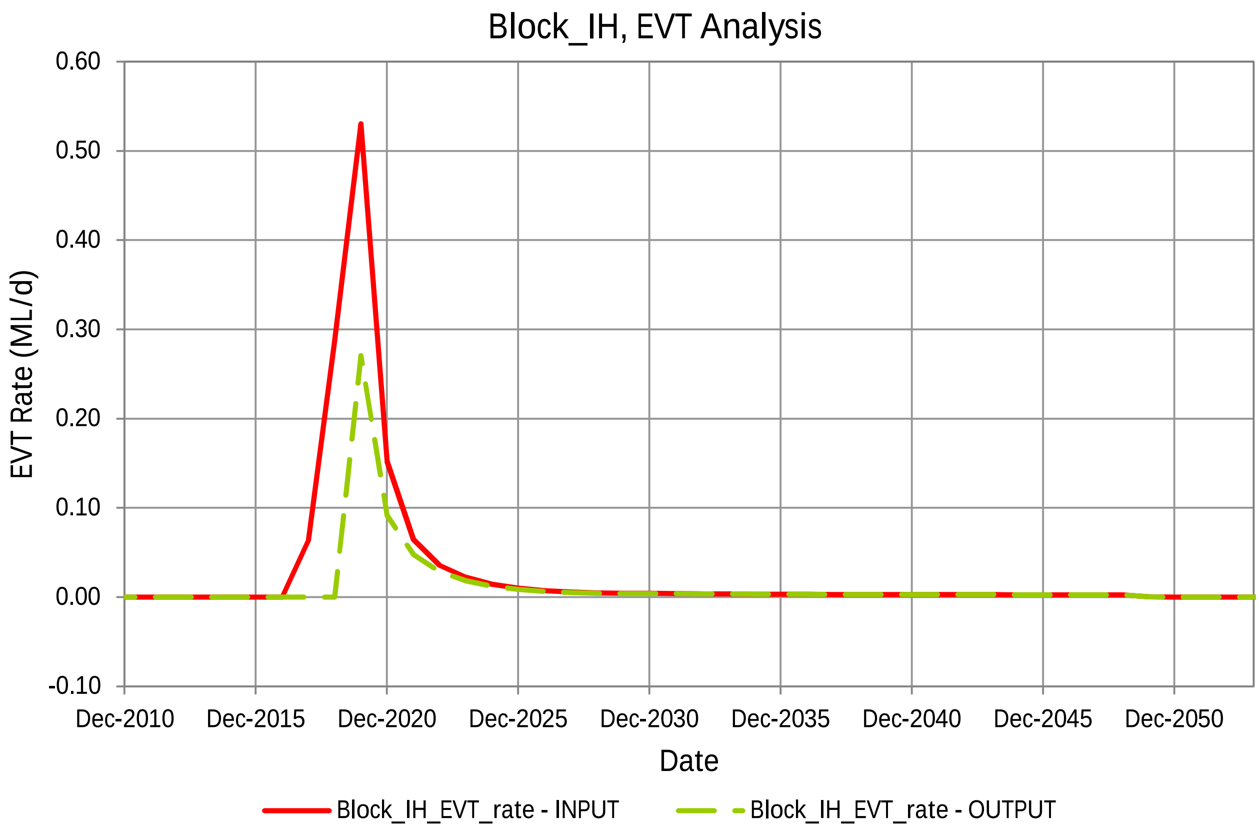
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Wandoan Development Region





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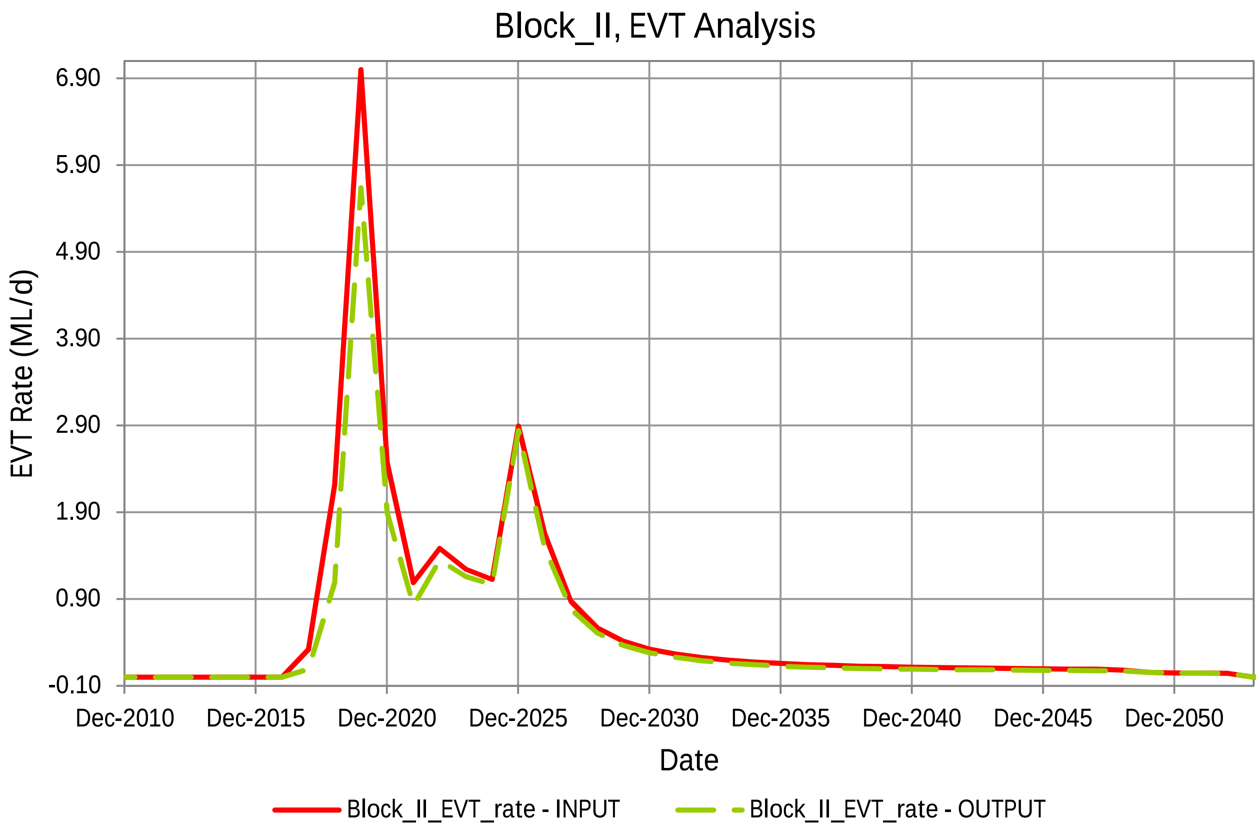
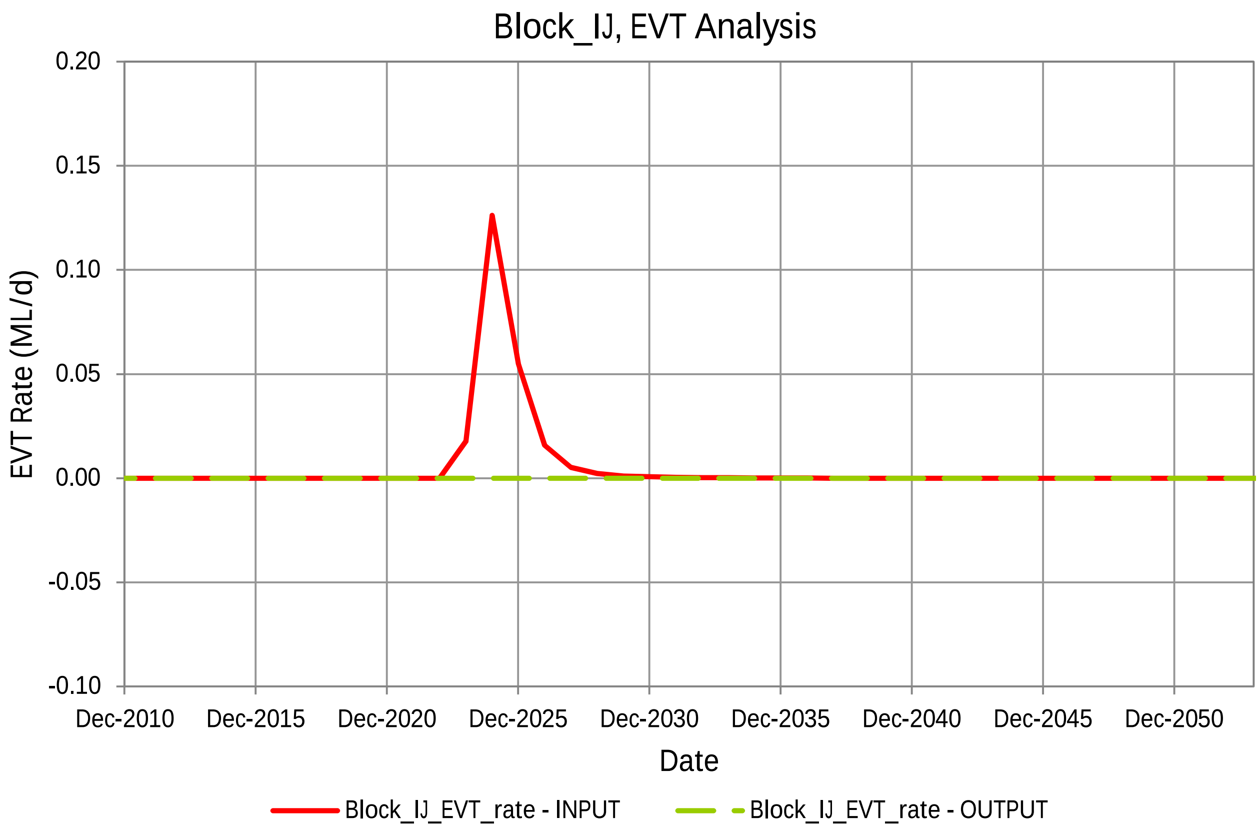
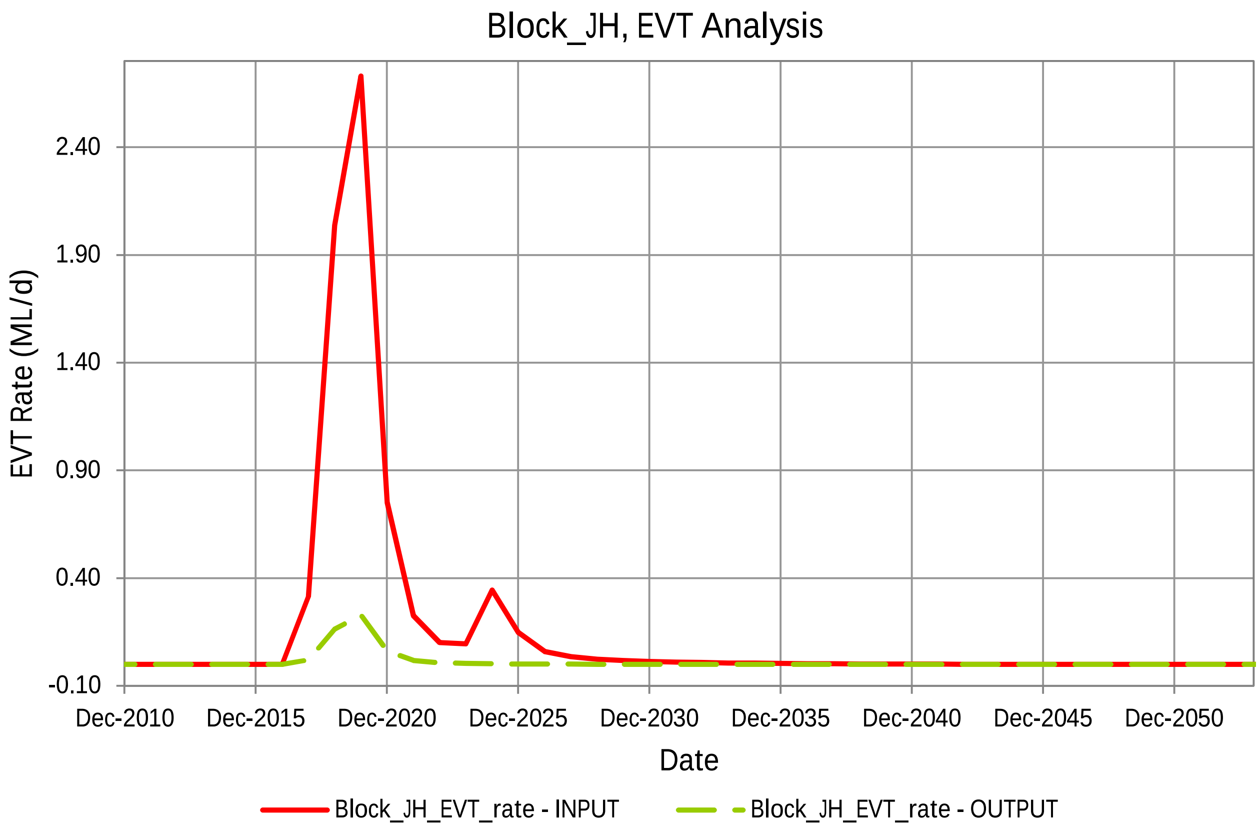
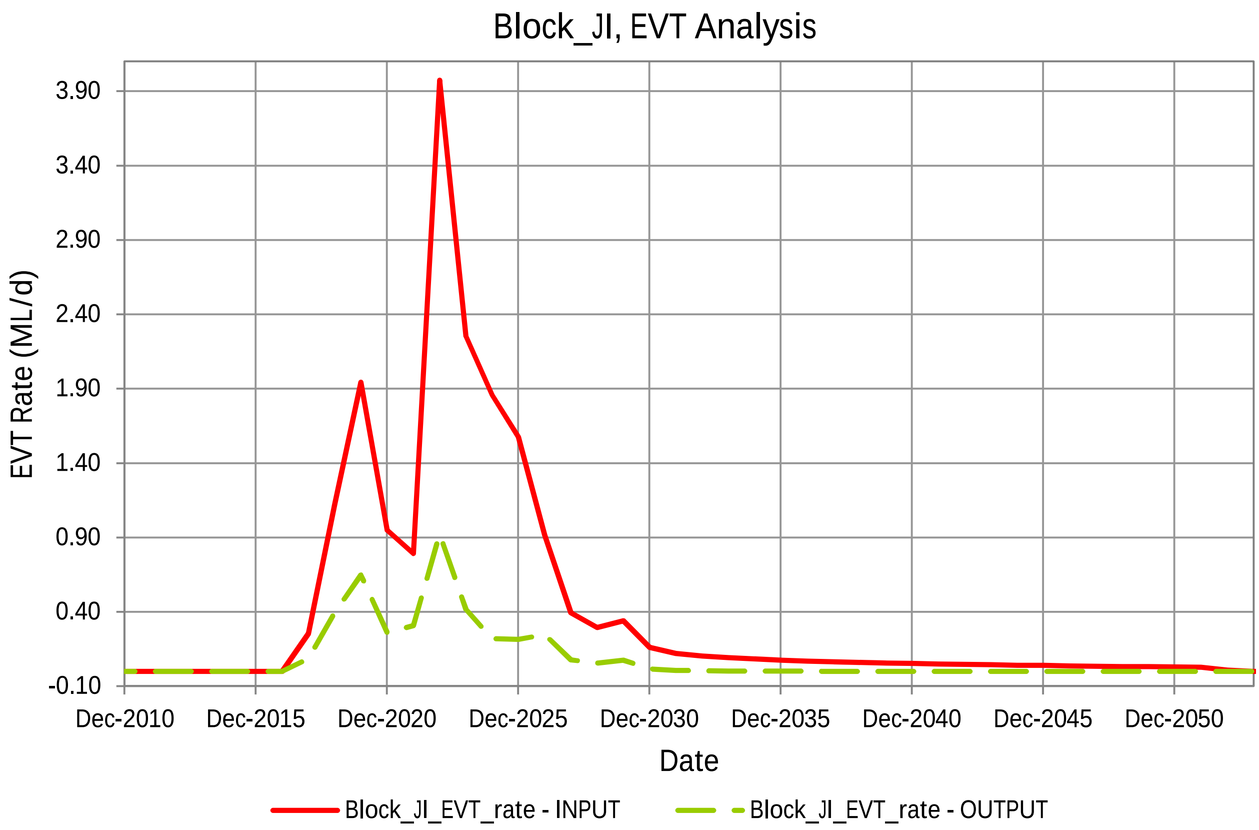




Appendix E - Comparison of Modelled EVT Input and Output Volumes - Wandoan Development Region





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(Wandoan)

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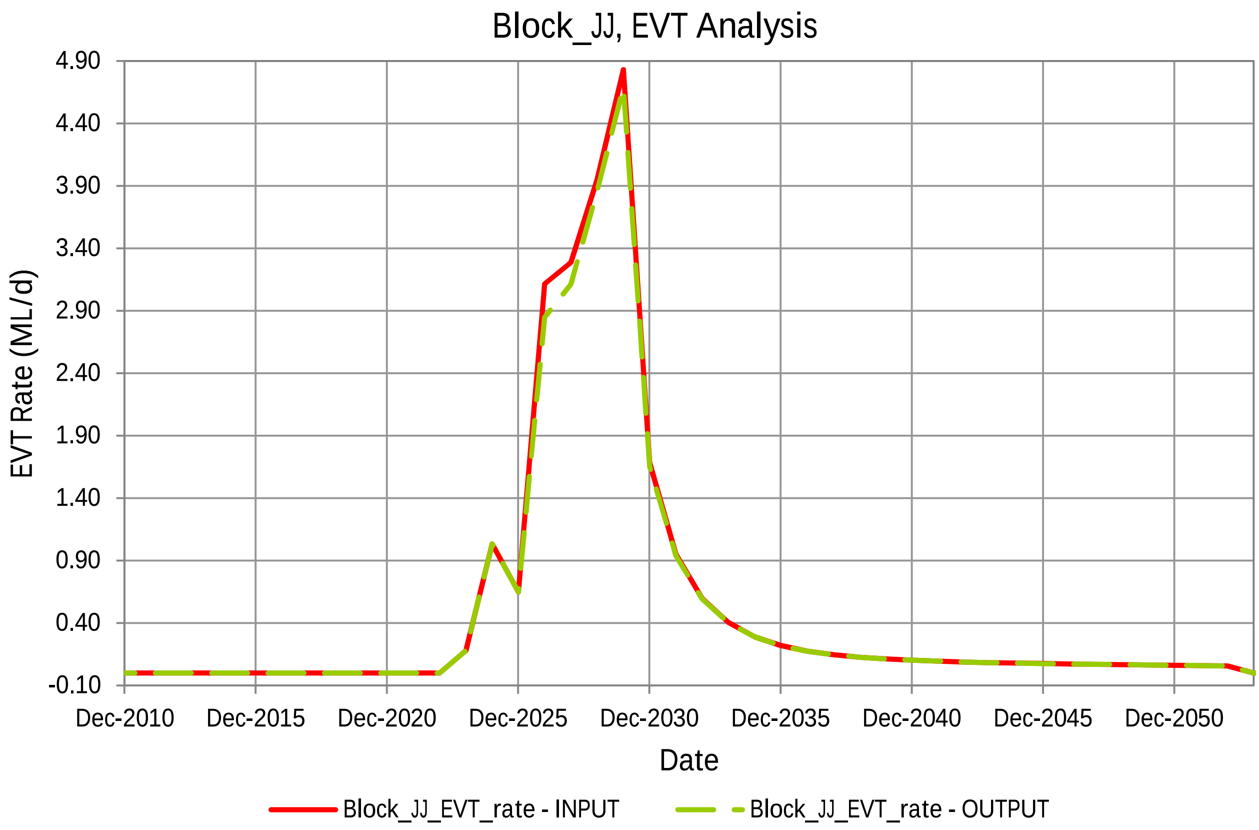

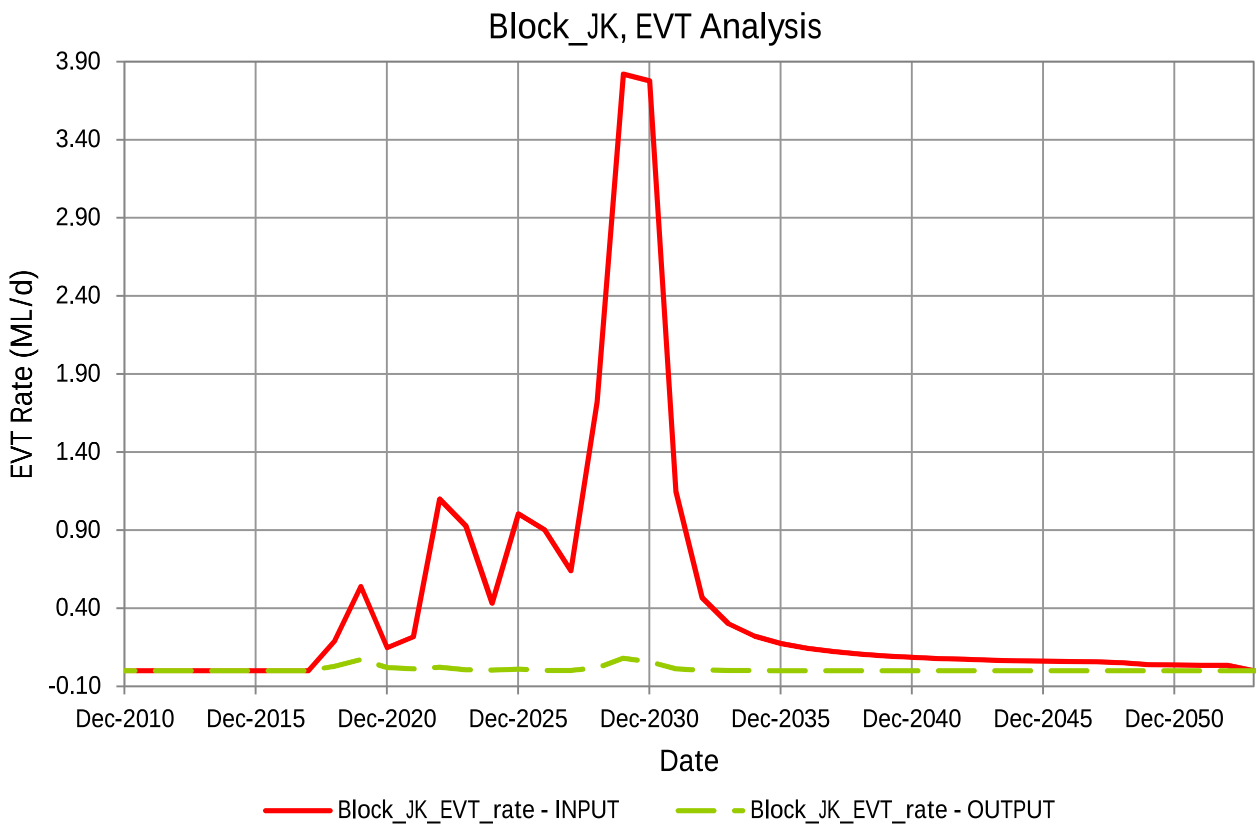

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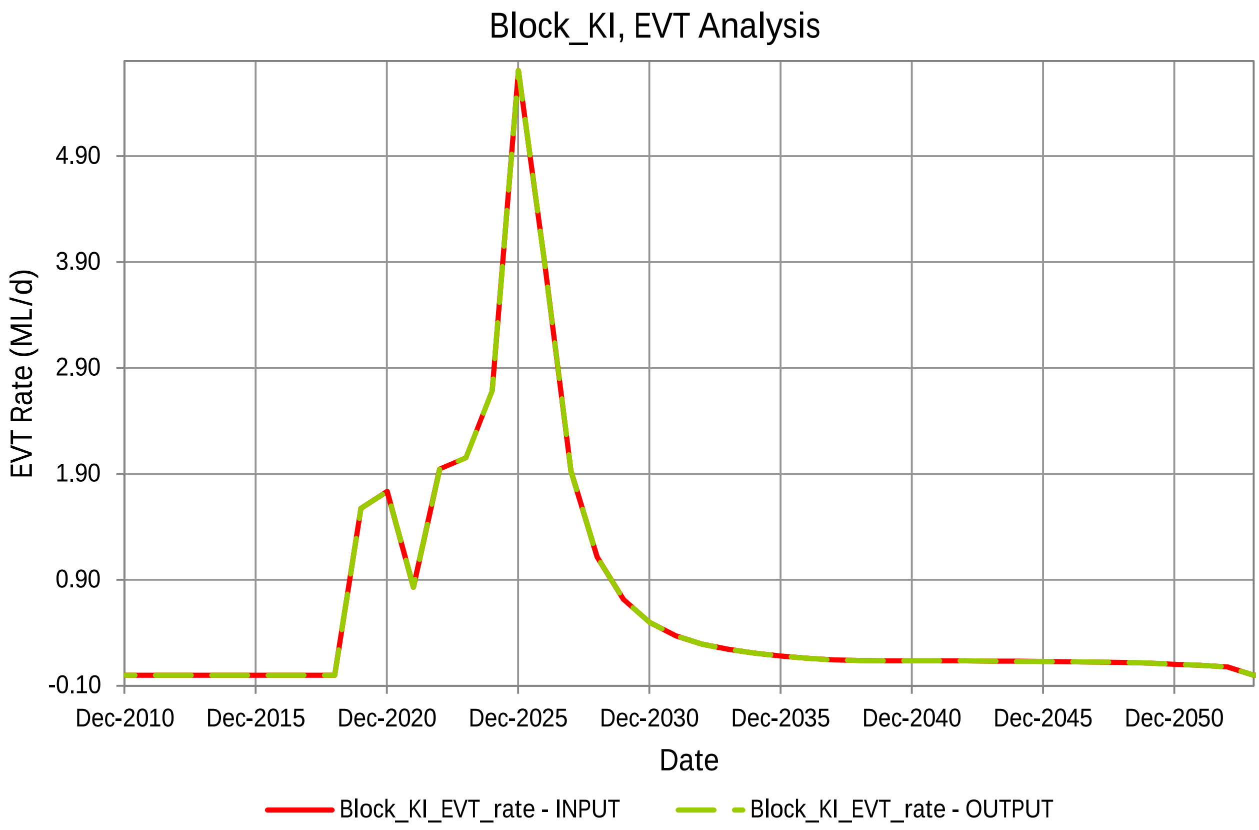
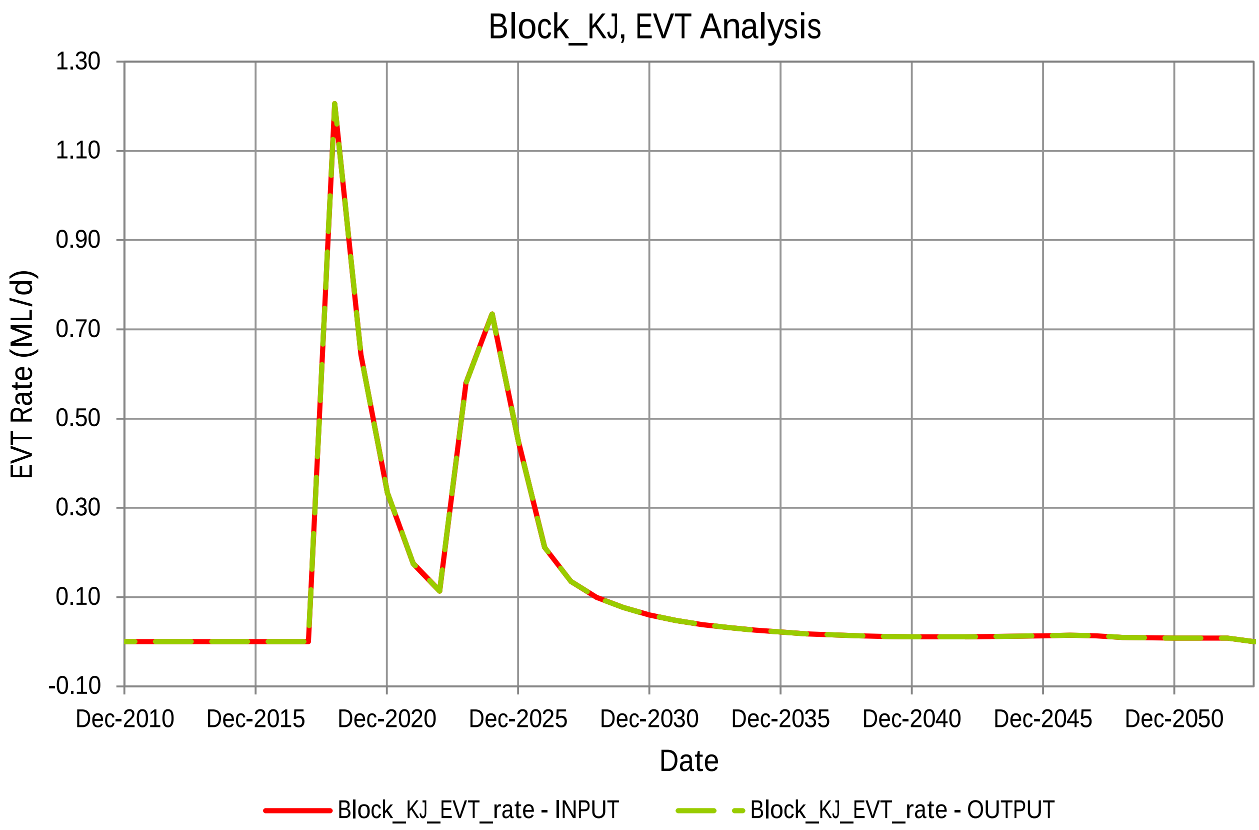
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Wandoan Development Region





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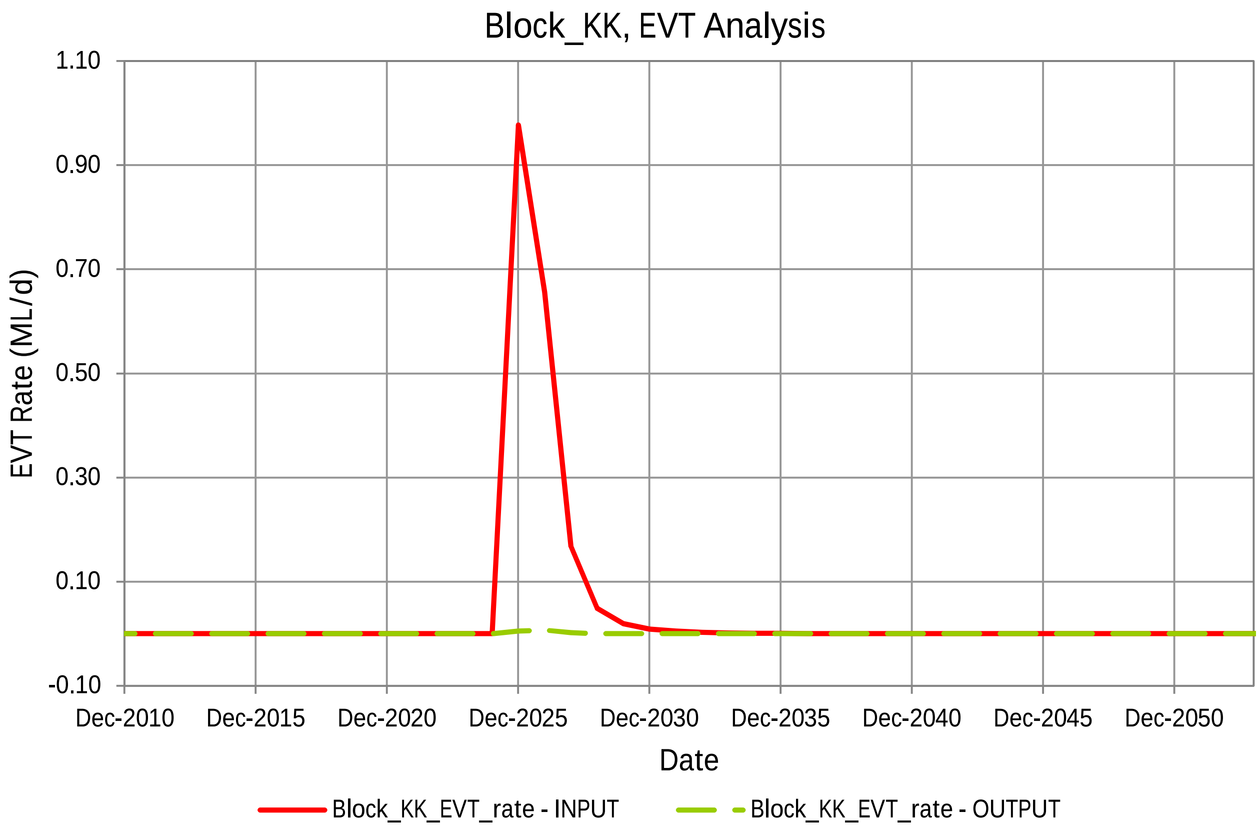

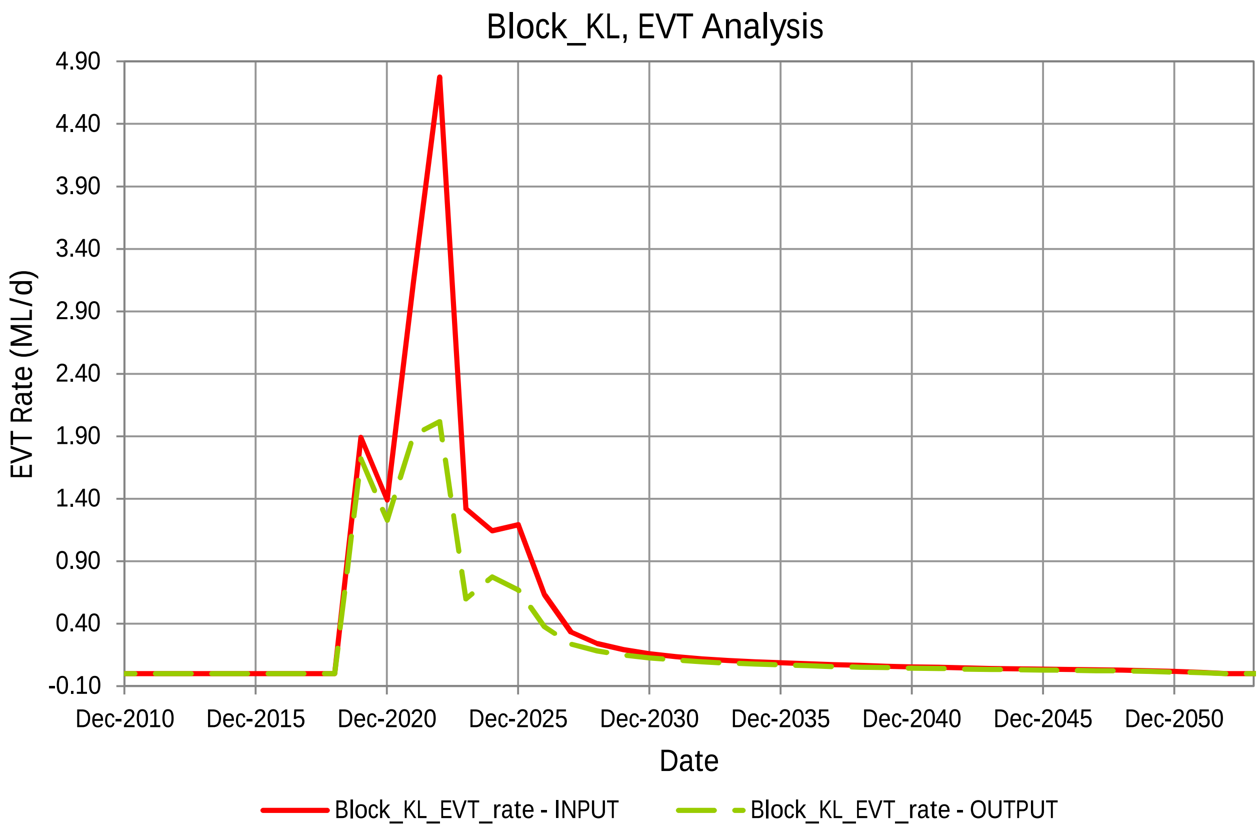

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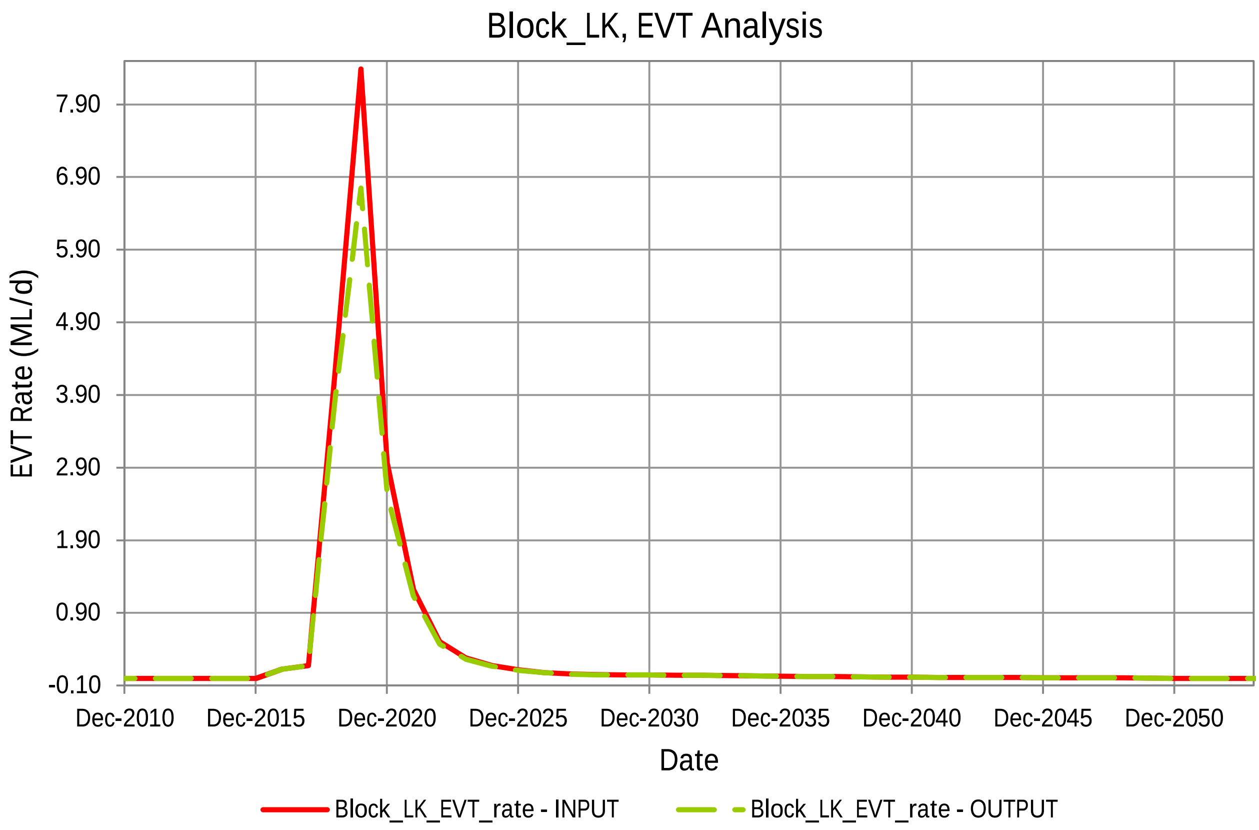
Appendix E - Comparison of Modelled EVT Input and Output Volumes - Wandoan Development Region



Appendix F – Arrow Surat Gas Project Time Series Impact Plots

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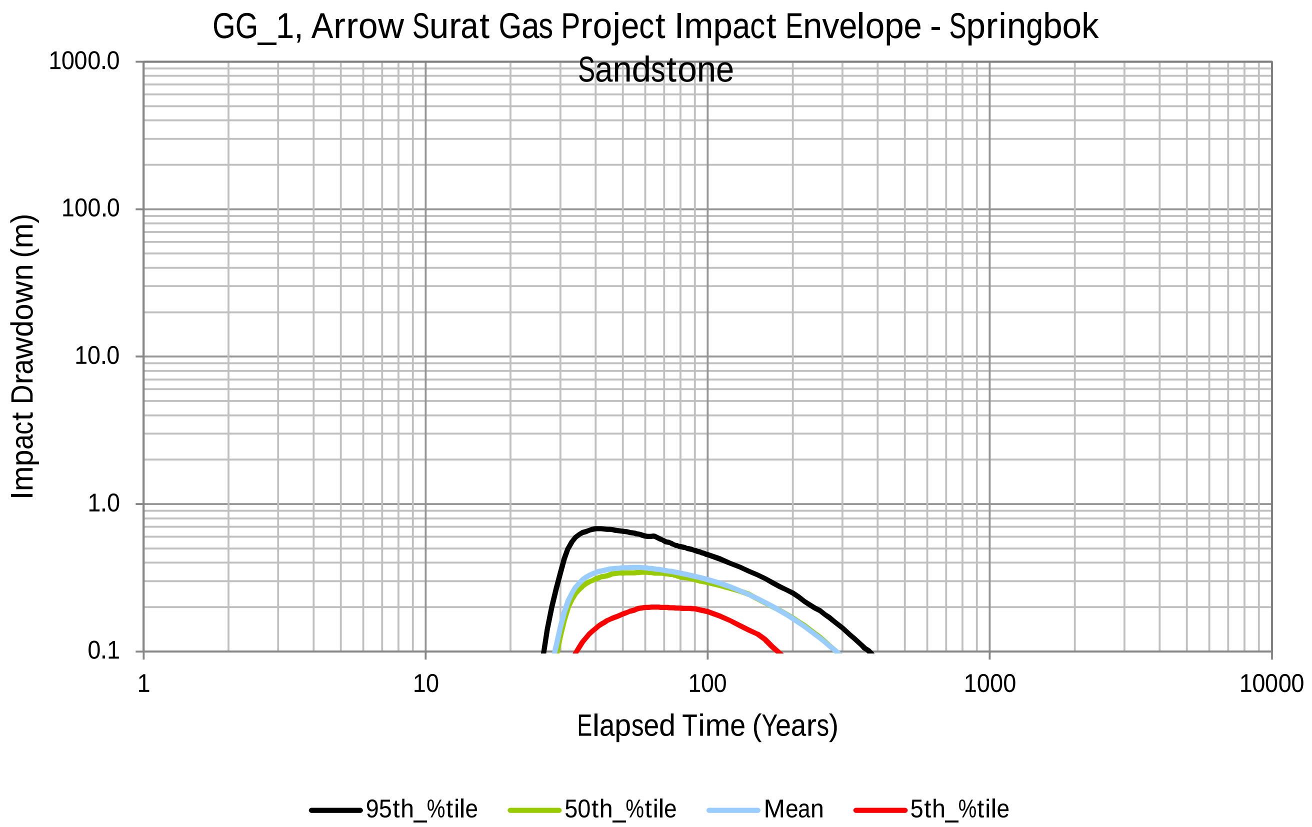
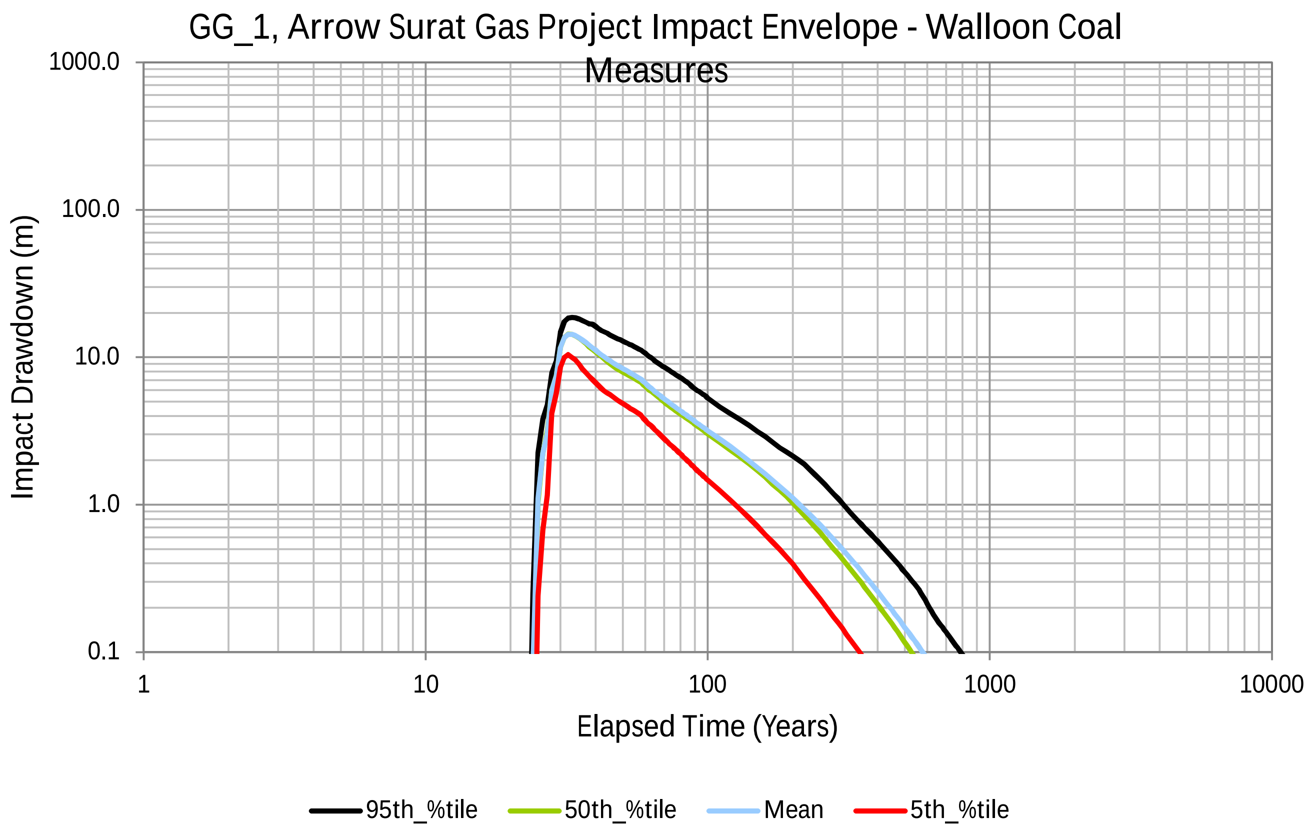
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 1





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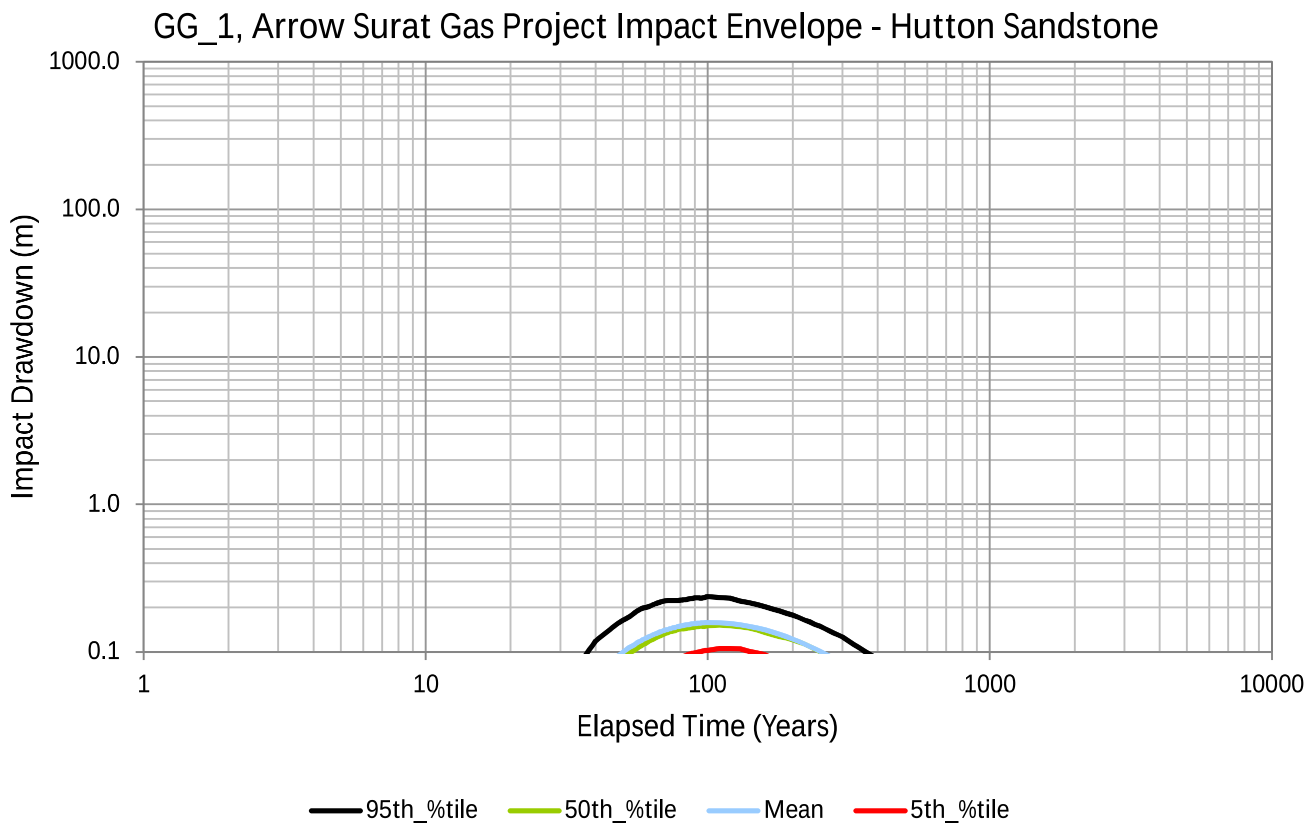

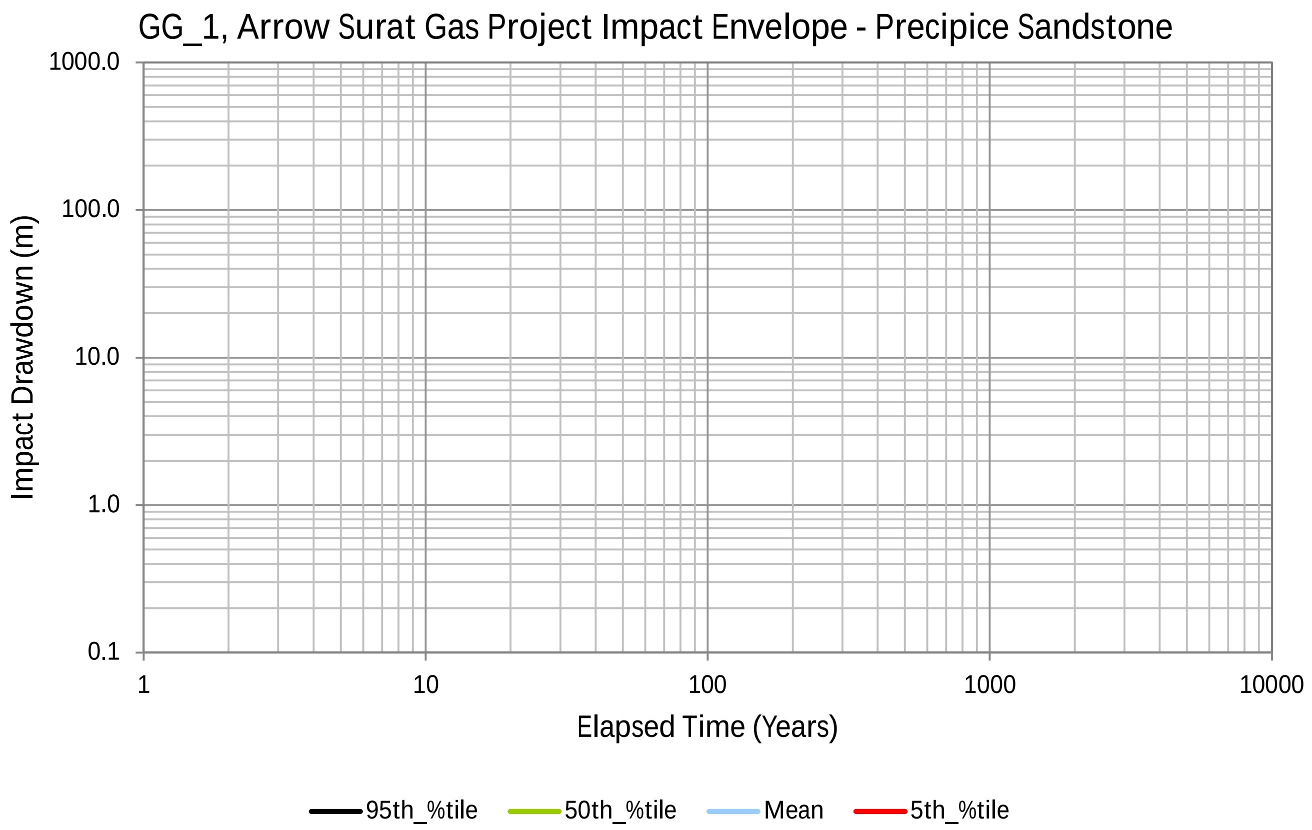

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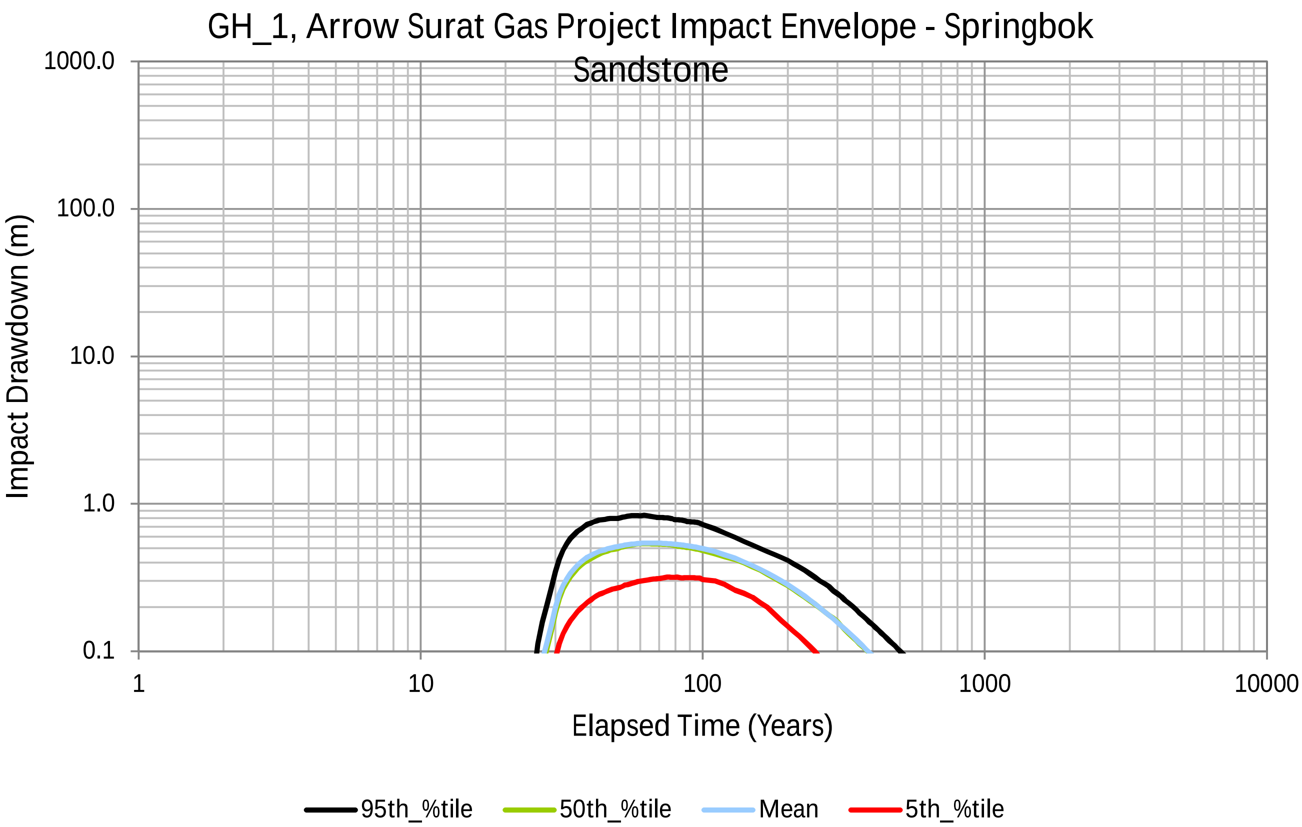
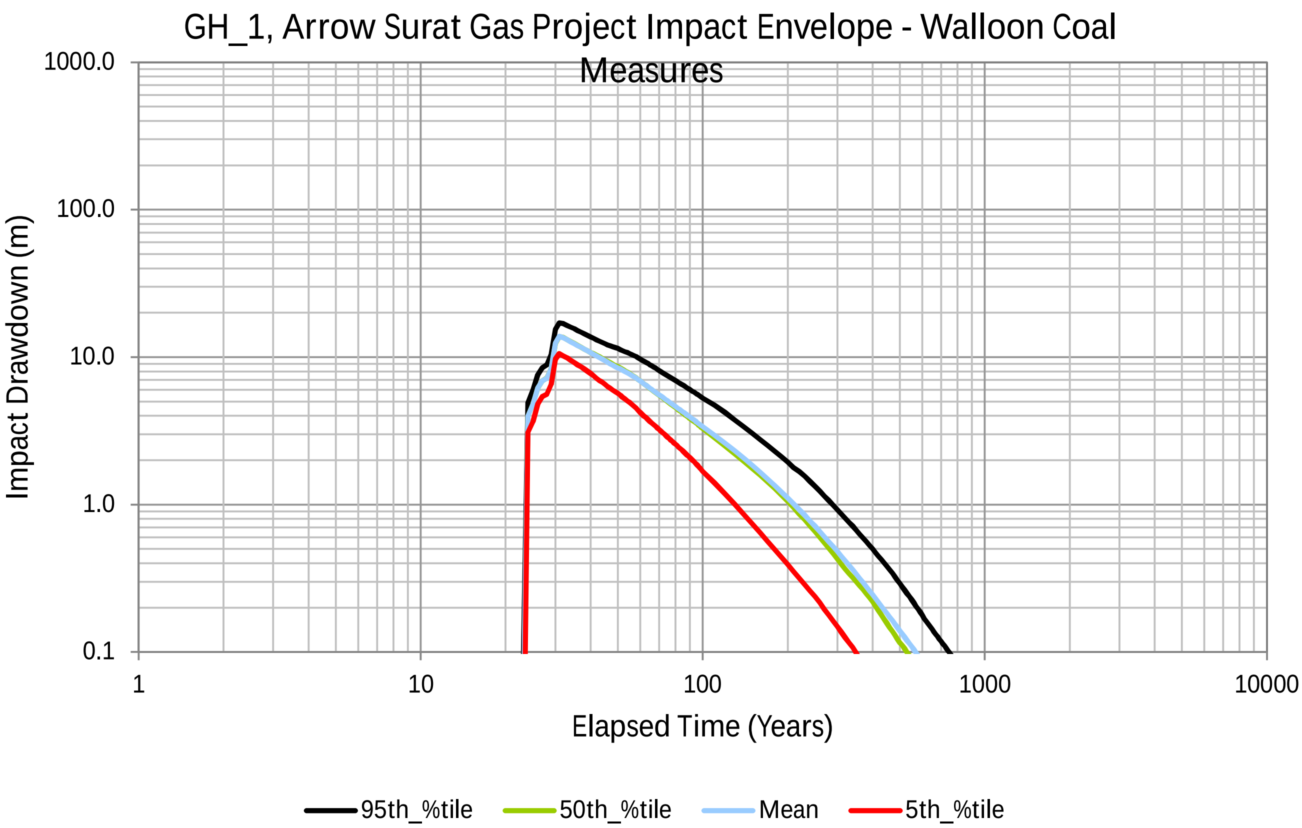
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 1





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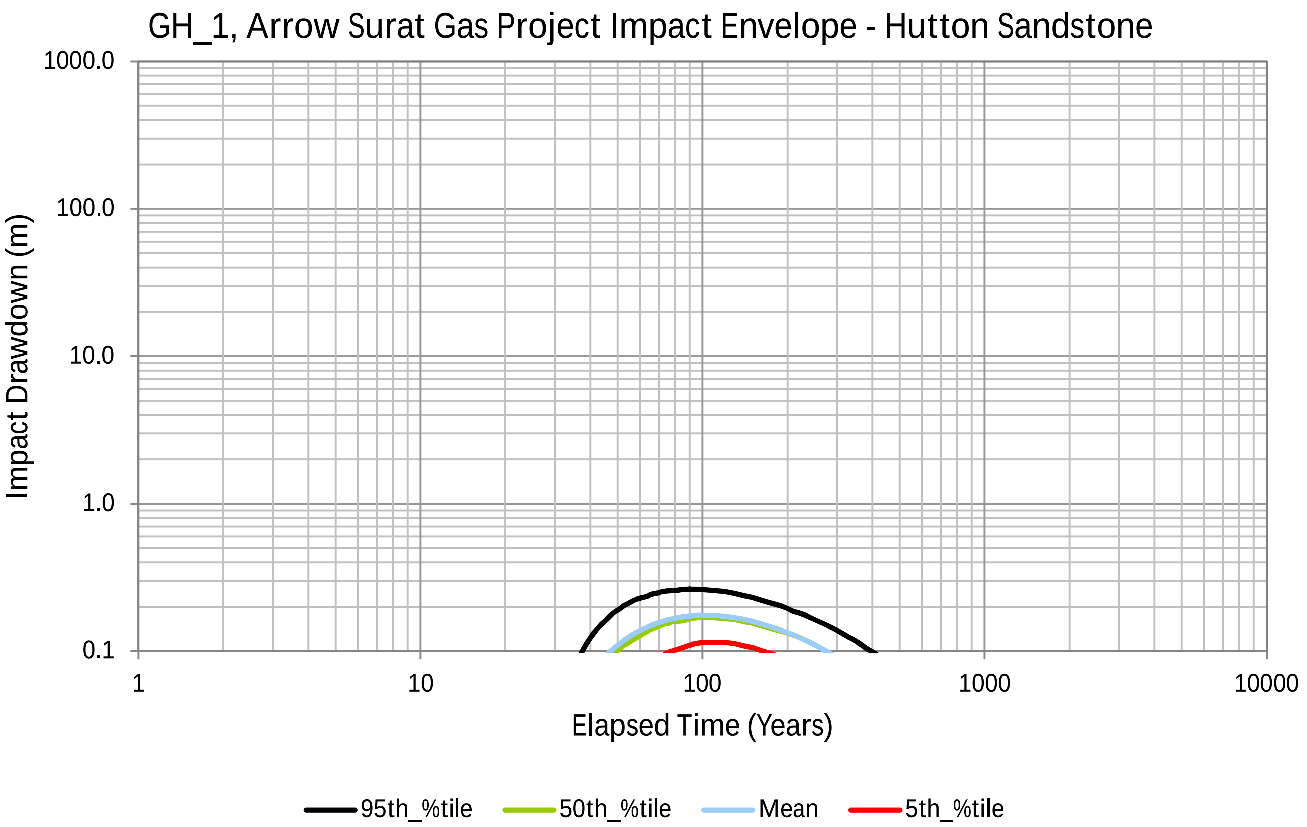
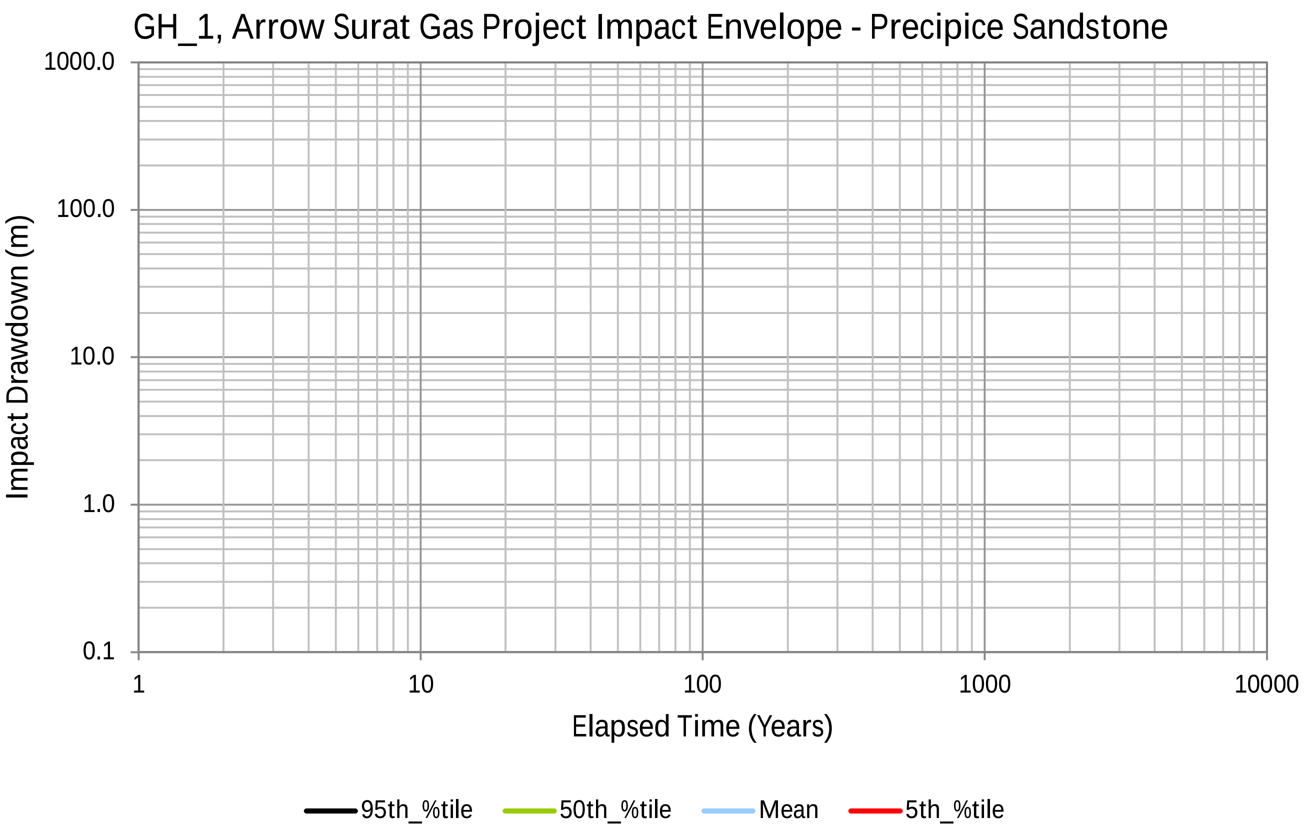
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 1





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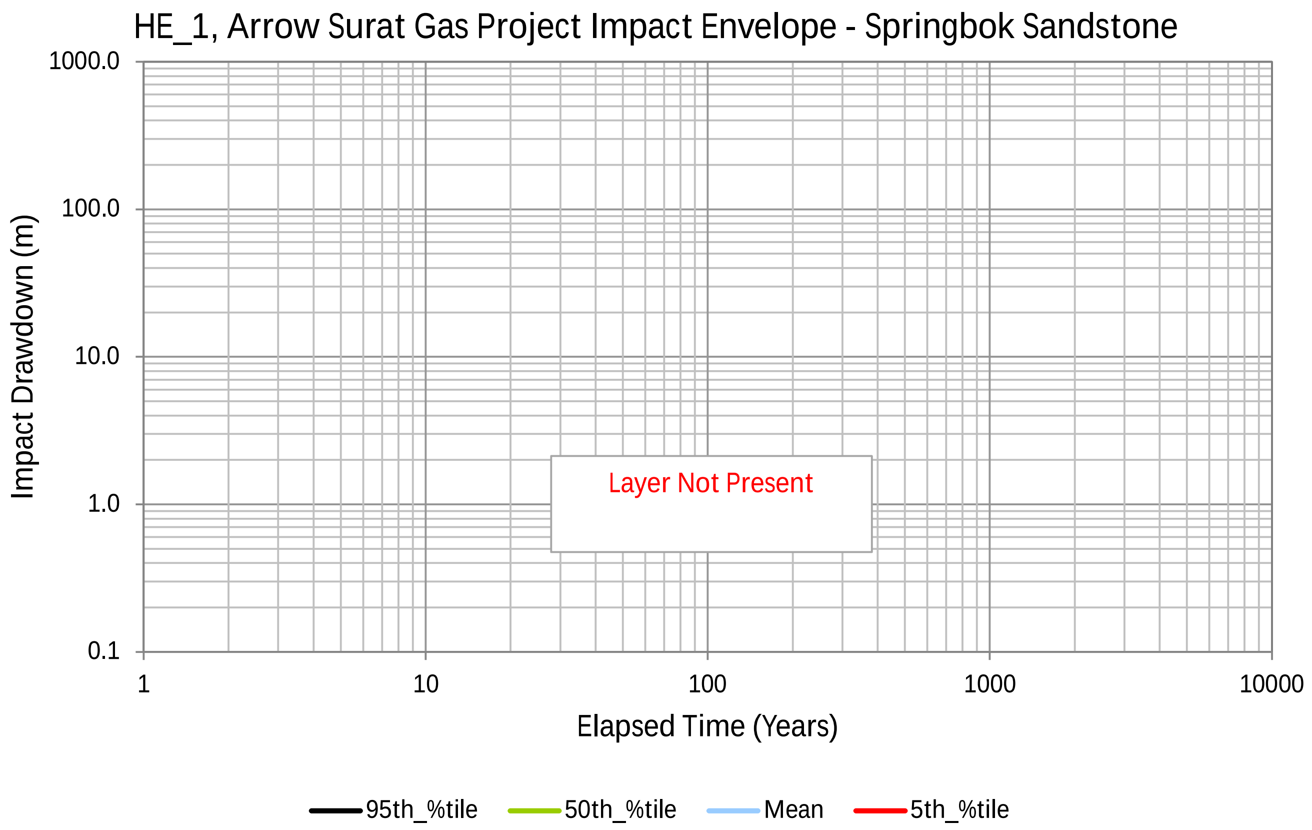
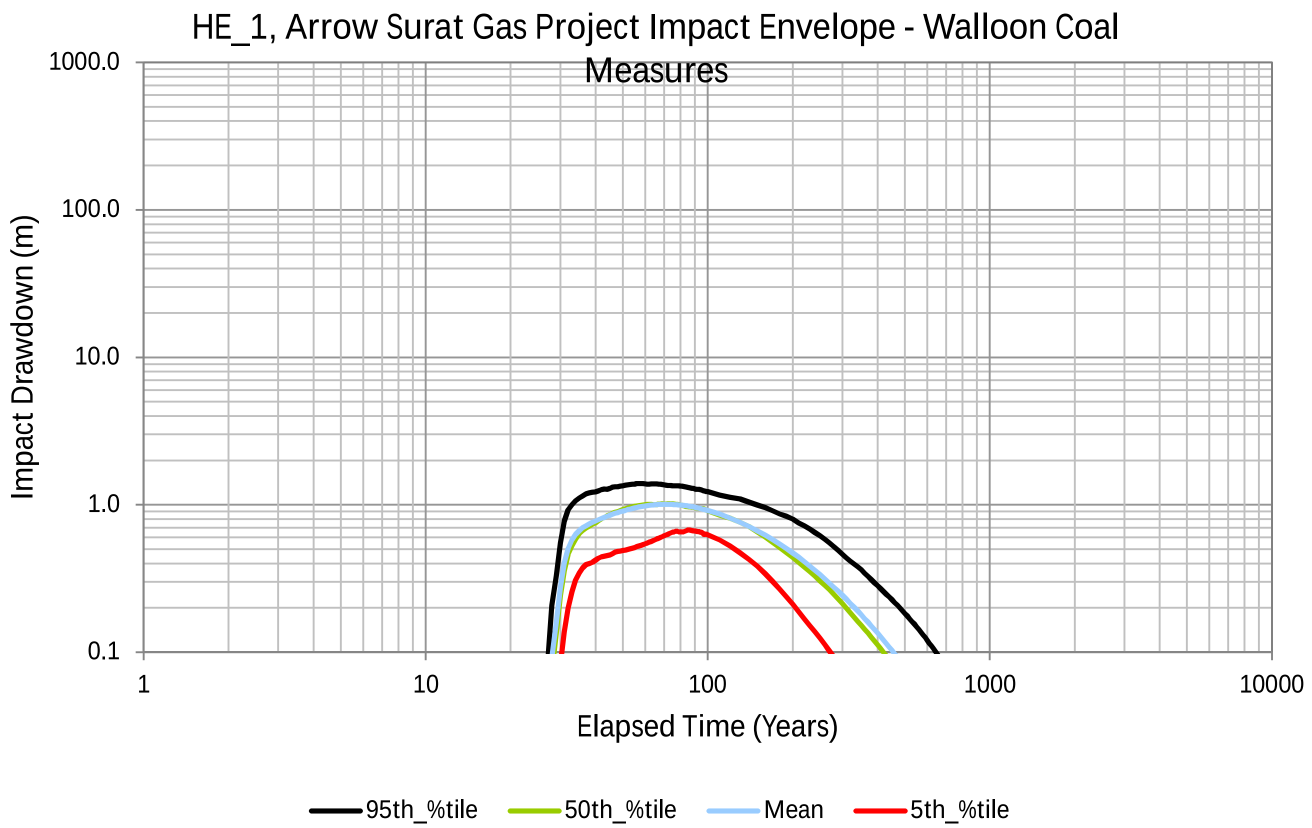
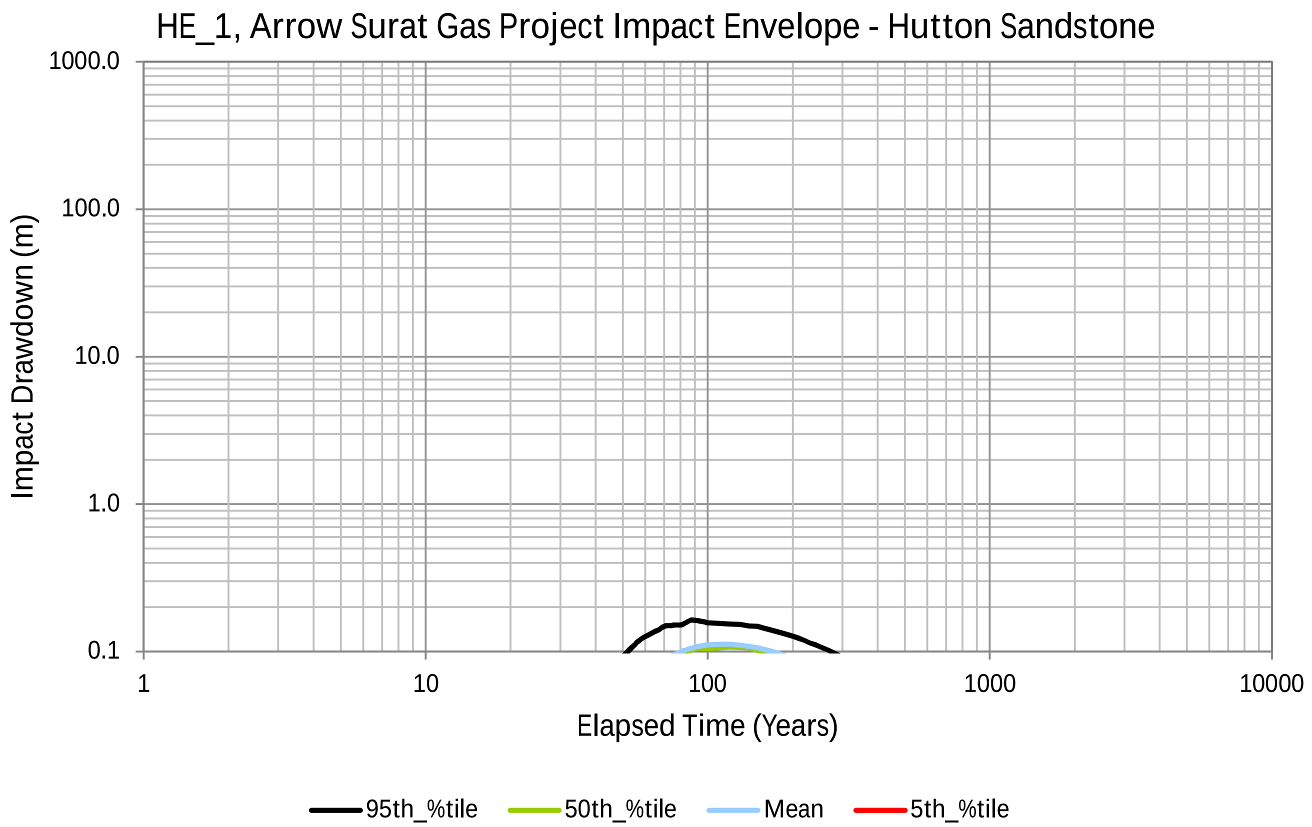
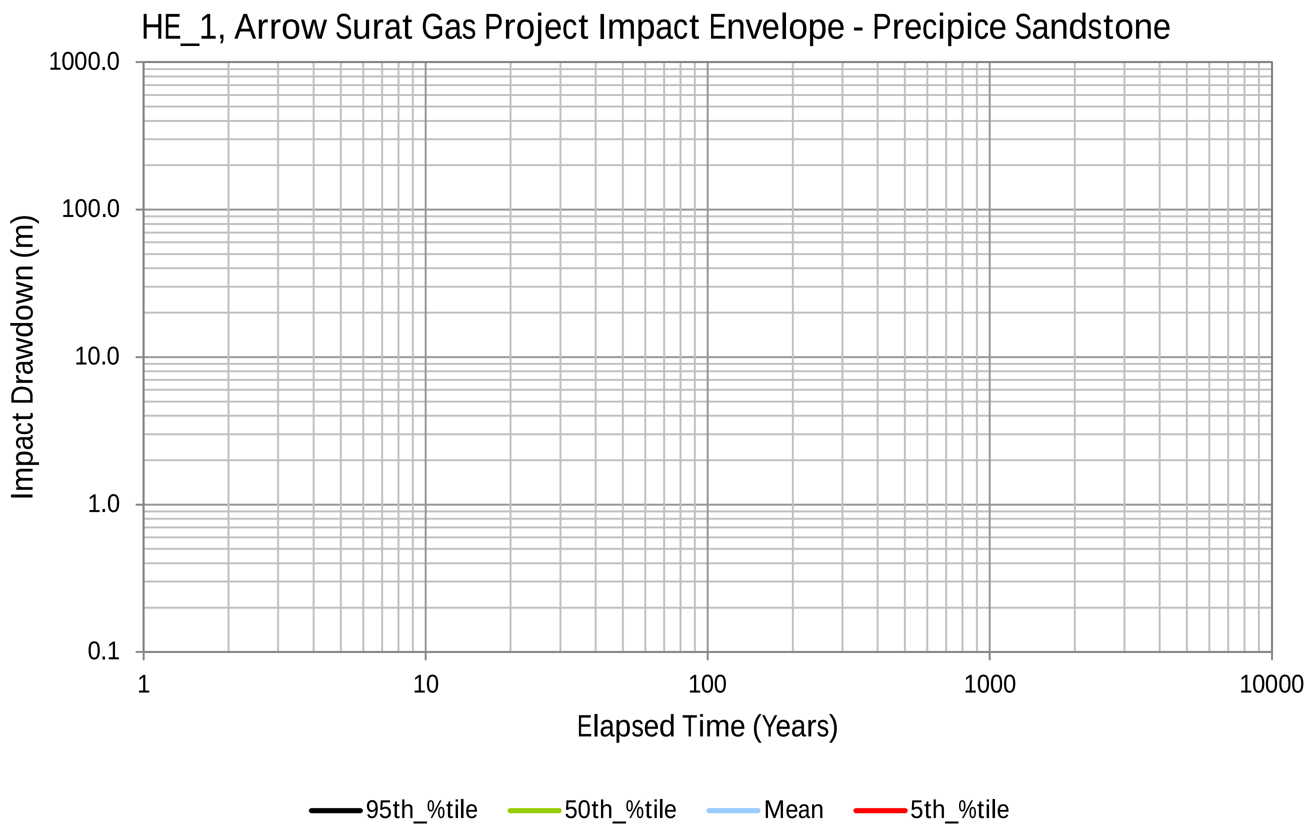
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 1





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 1





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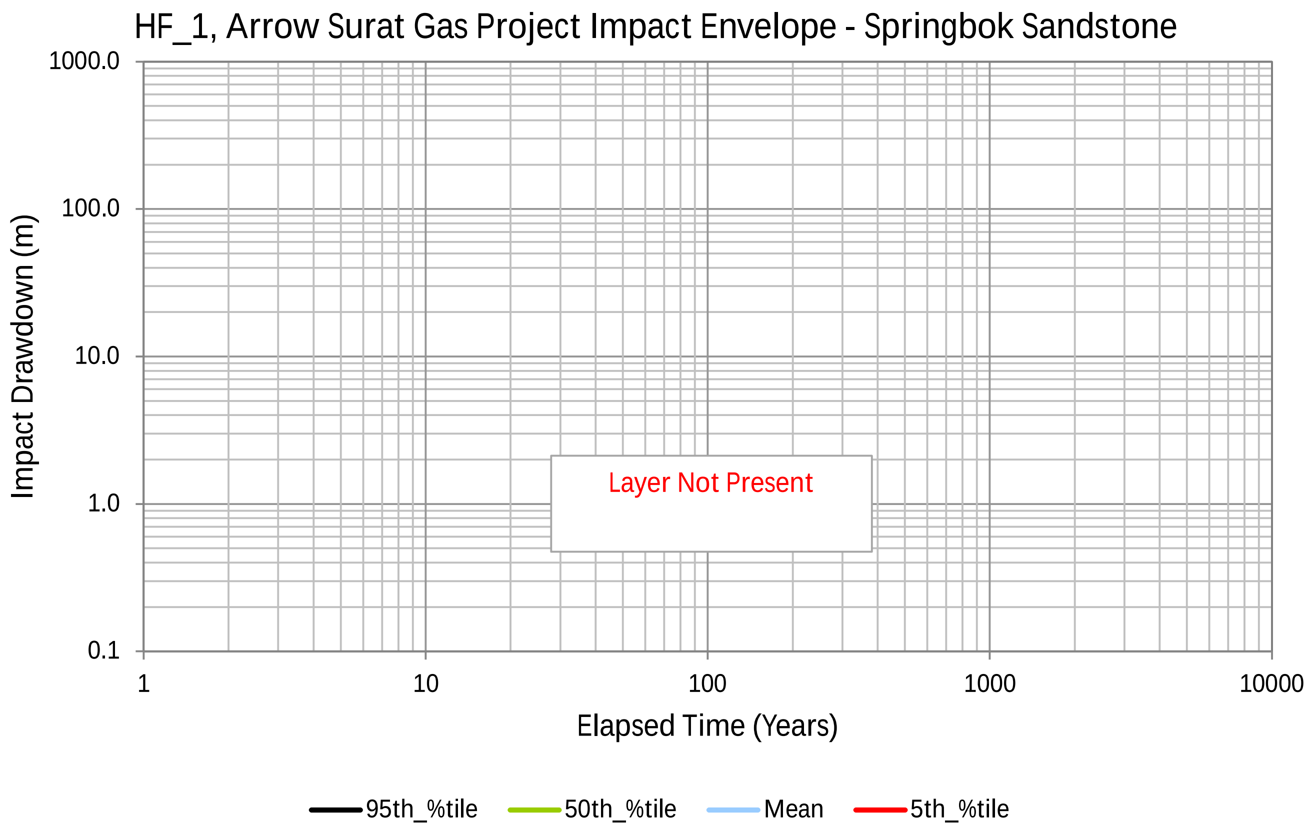

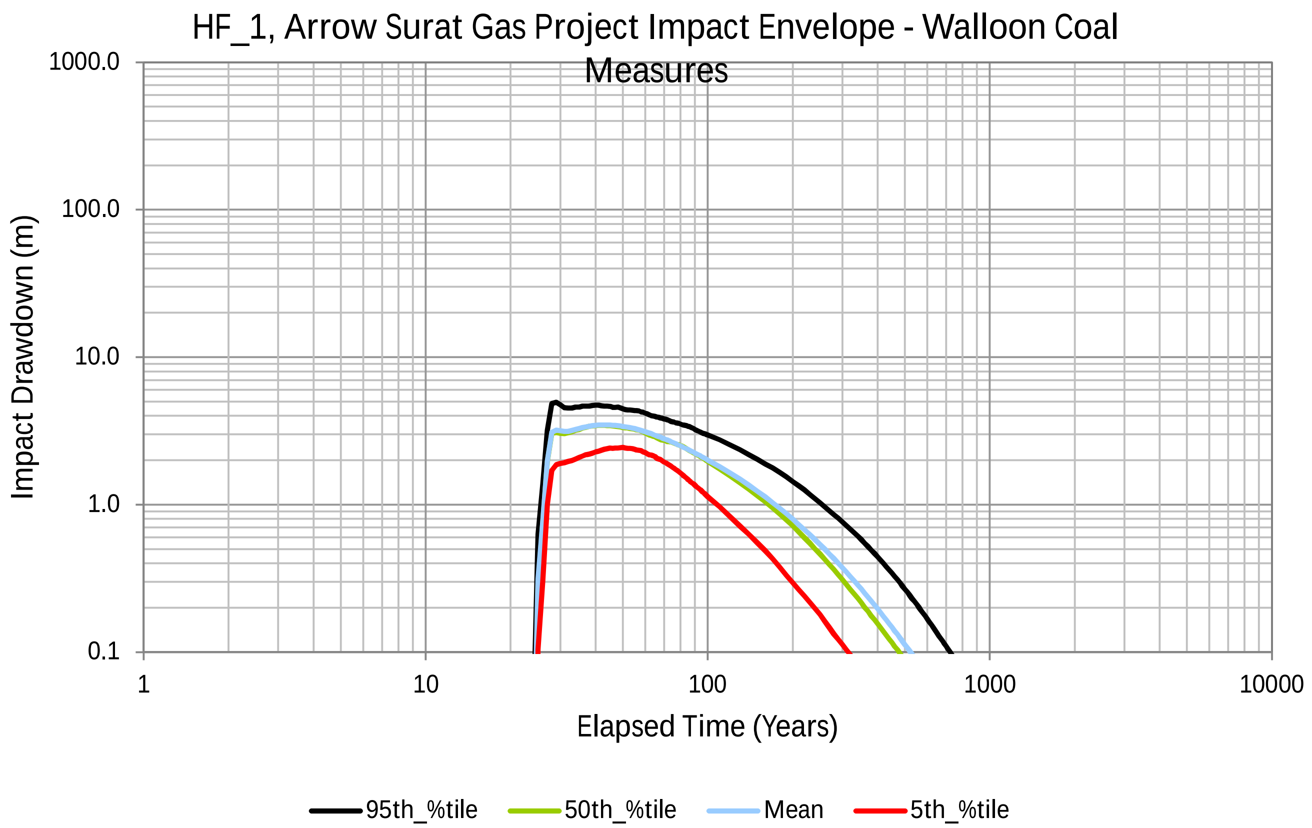

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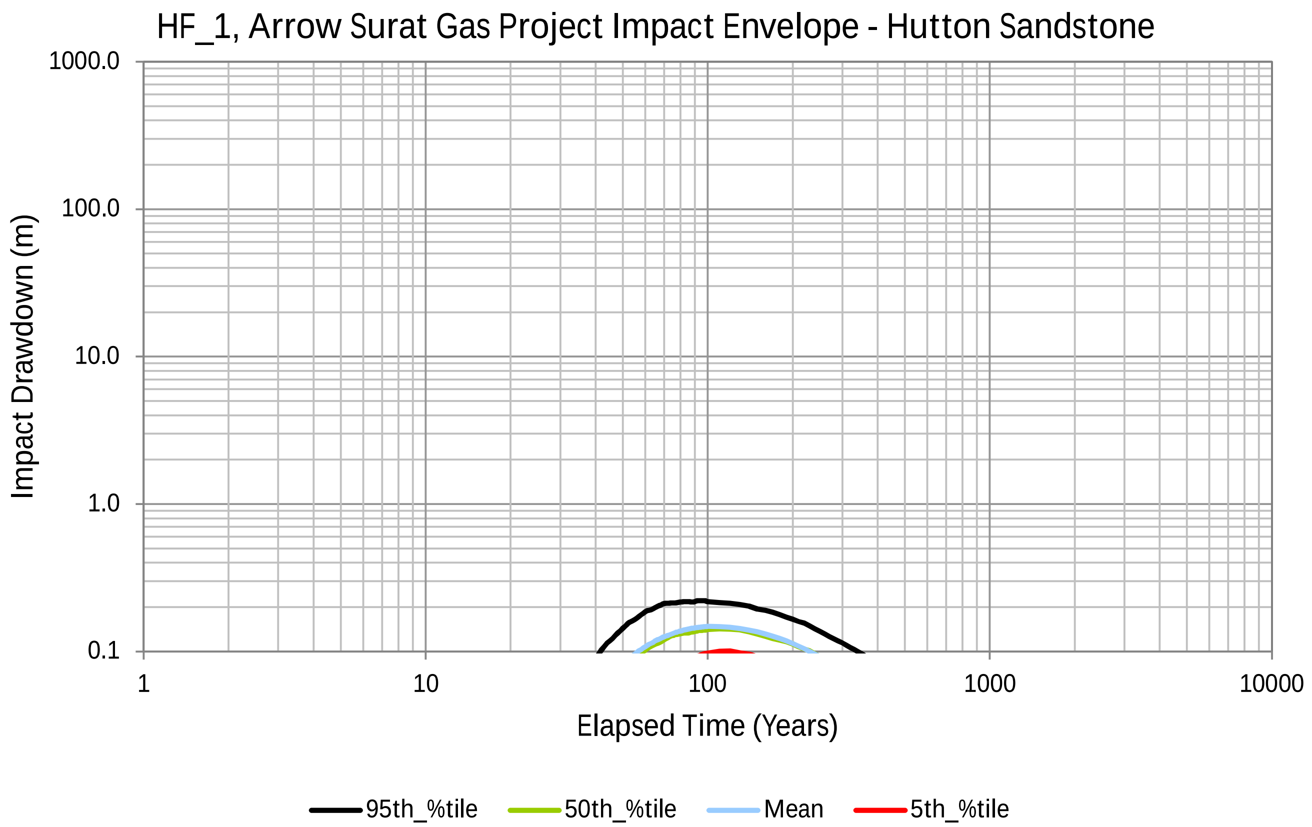
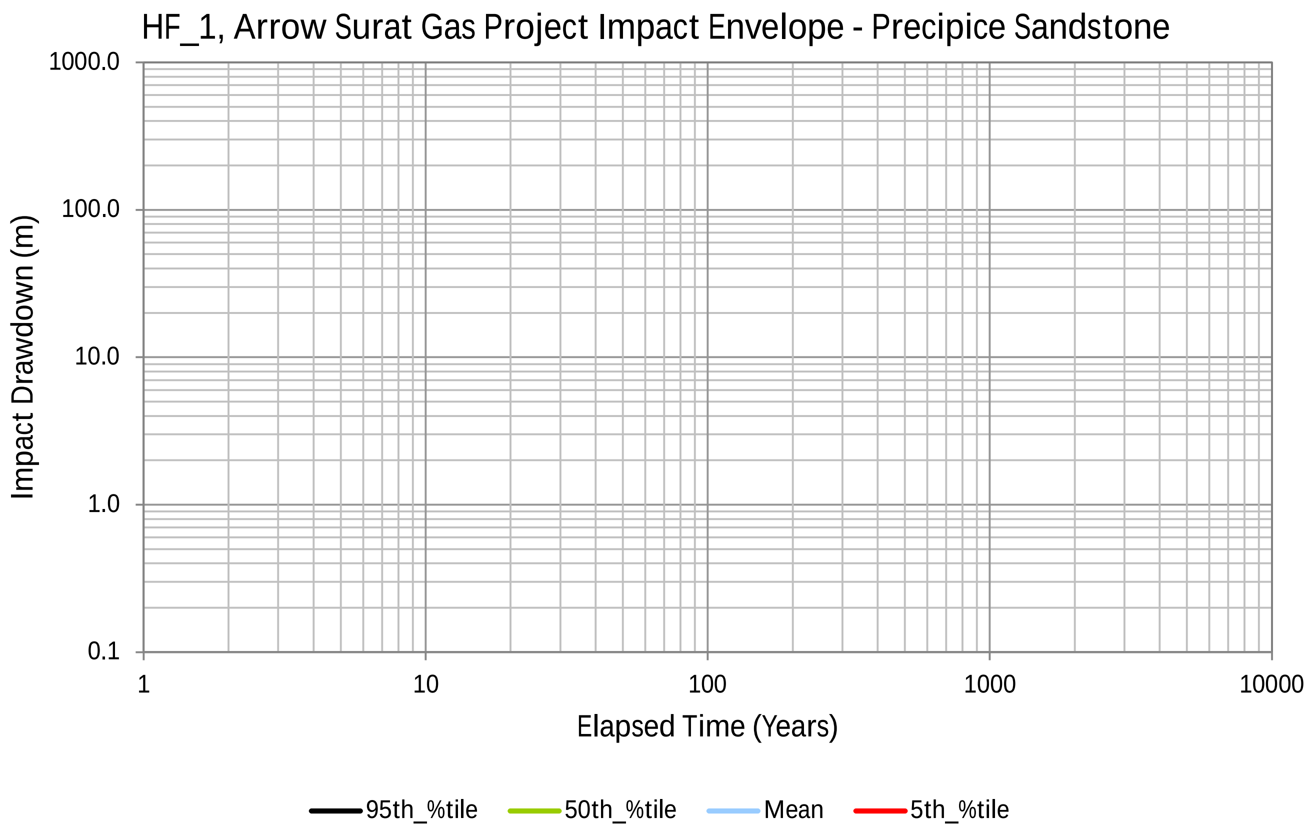
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 1





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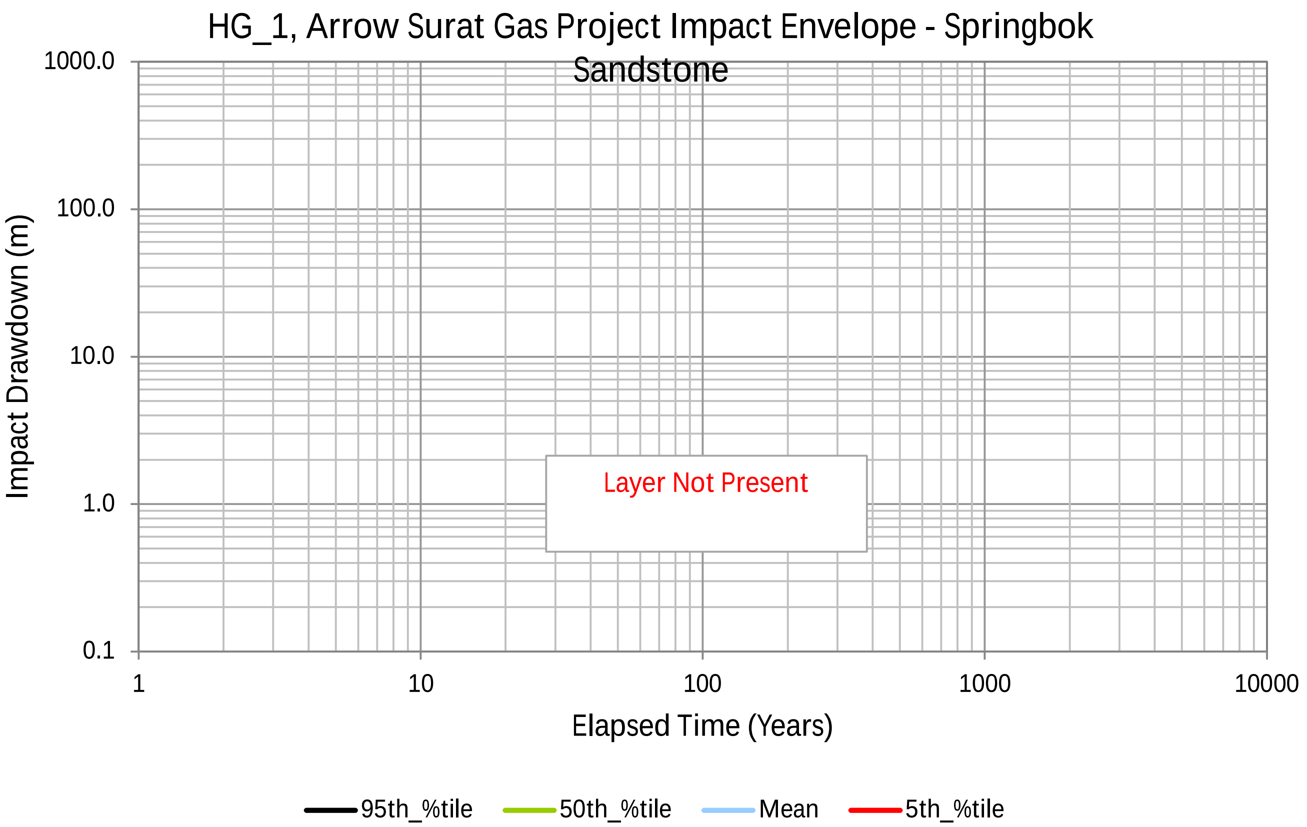
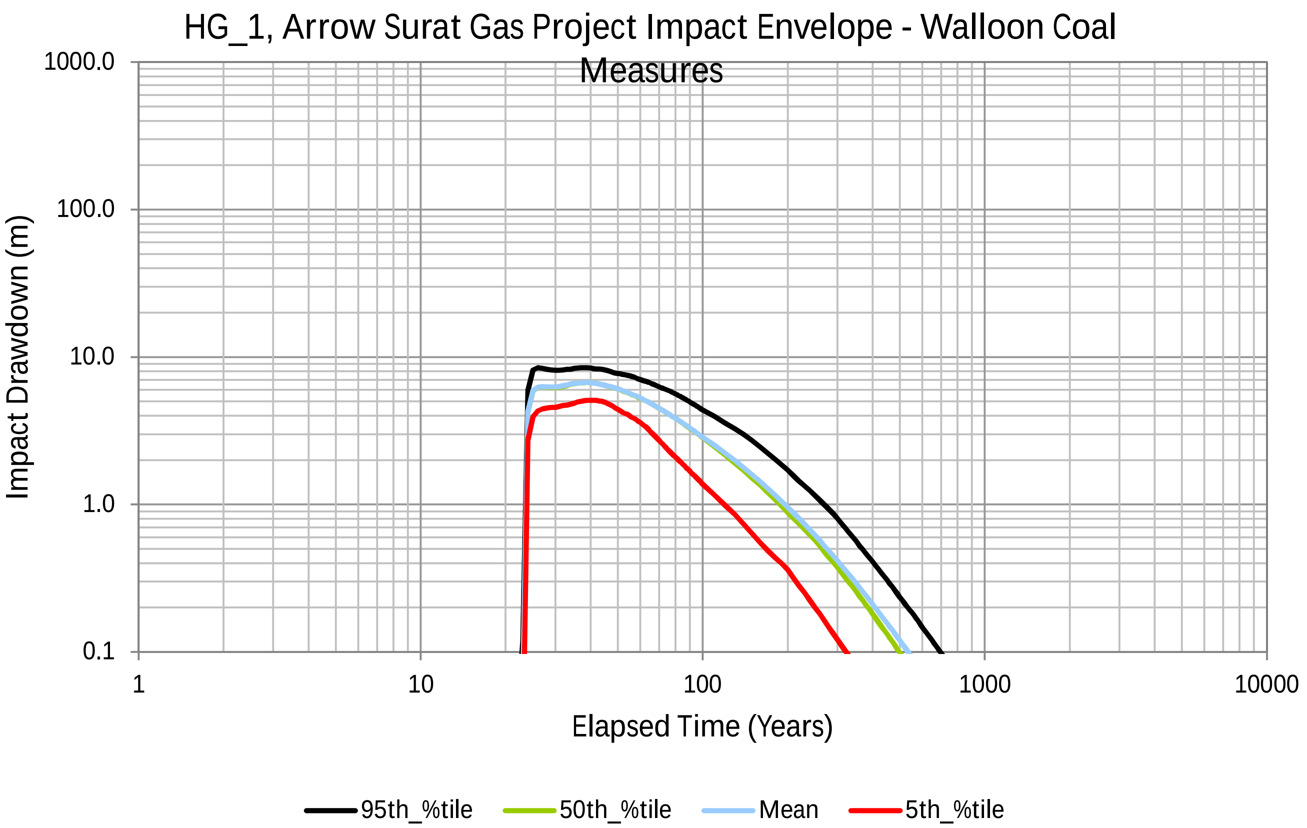
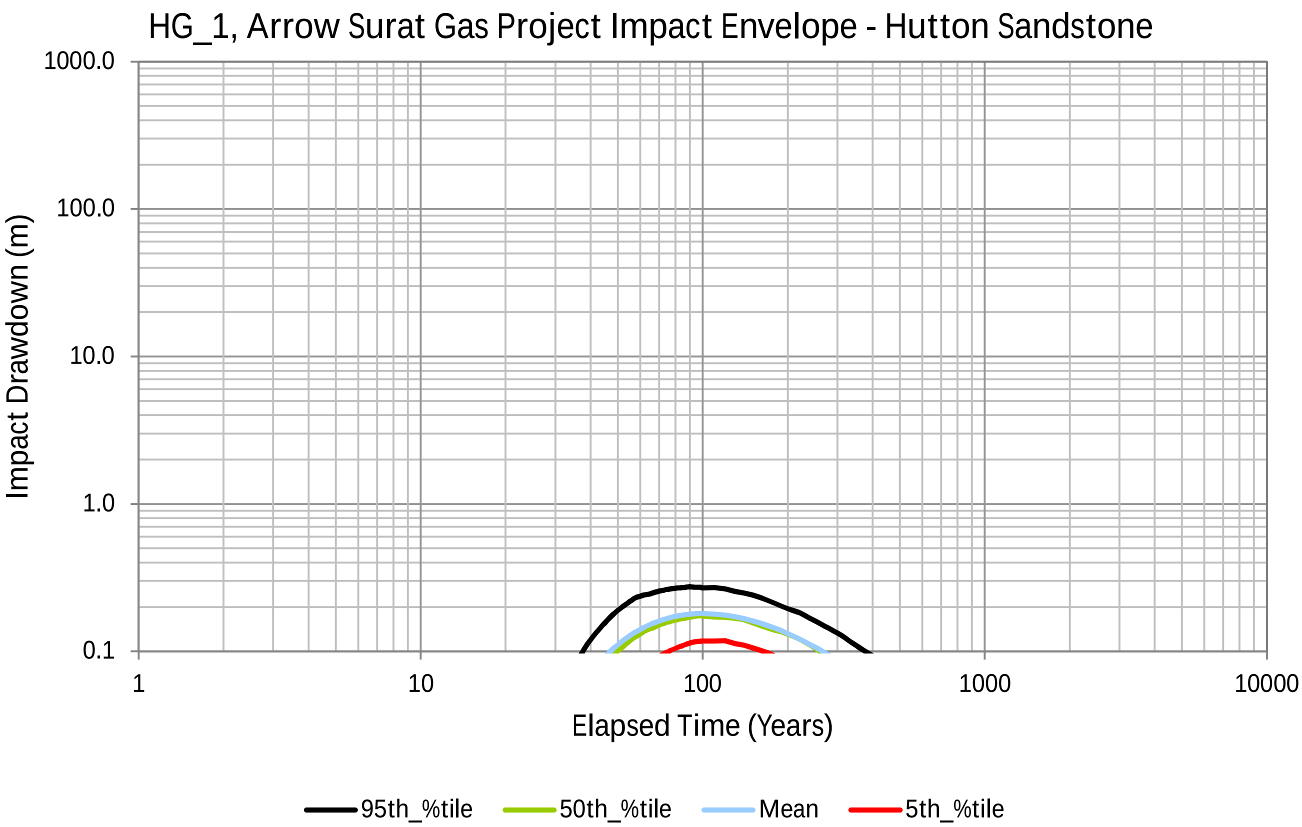
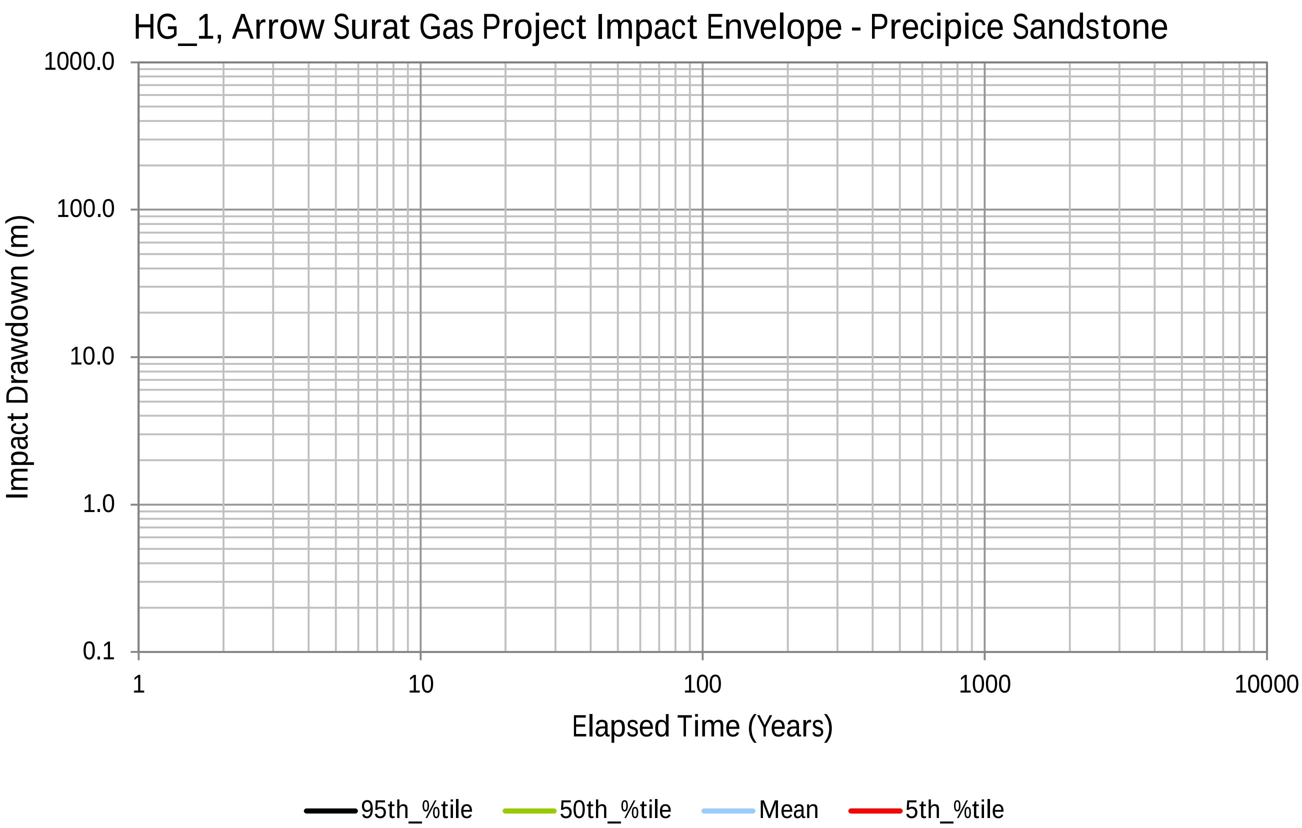
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 1



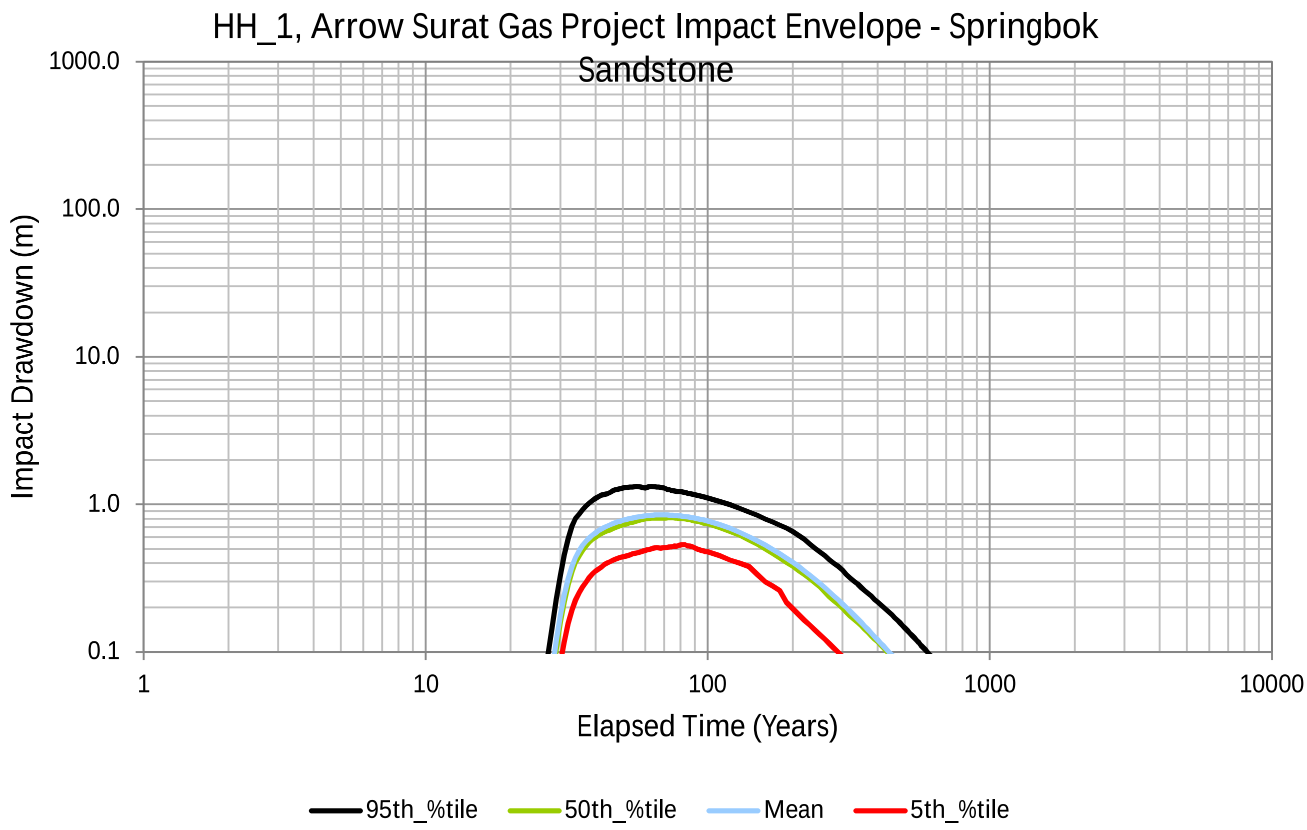


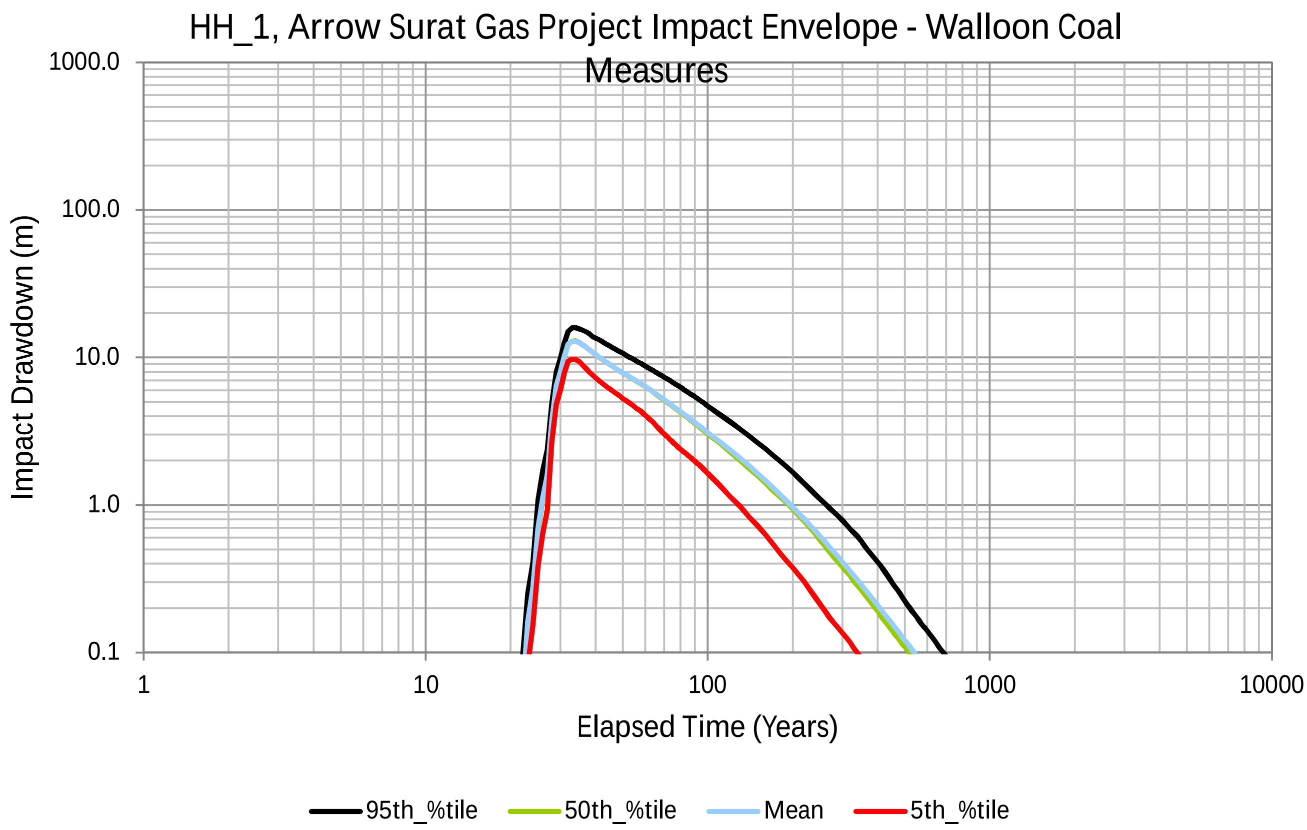
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 1



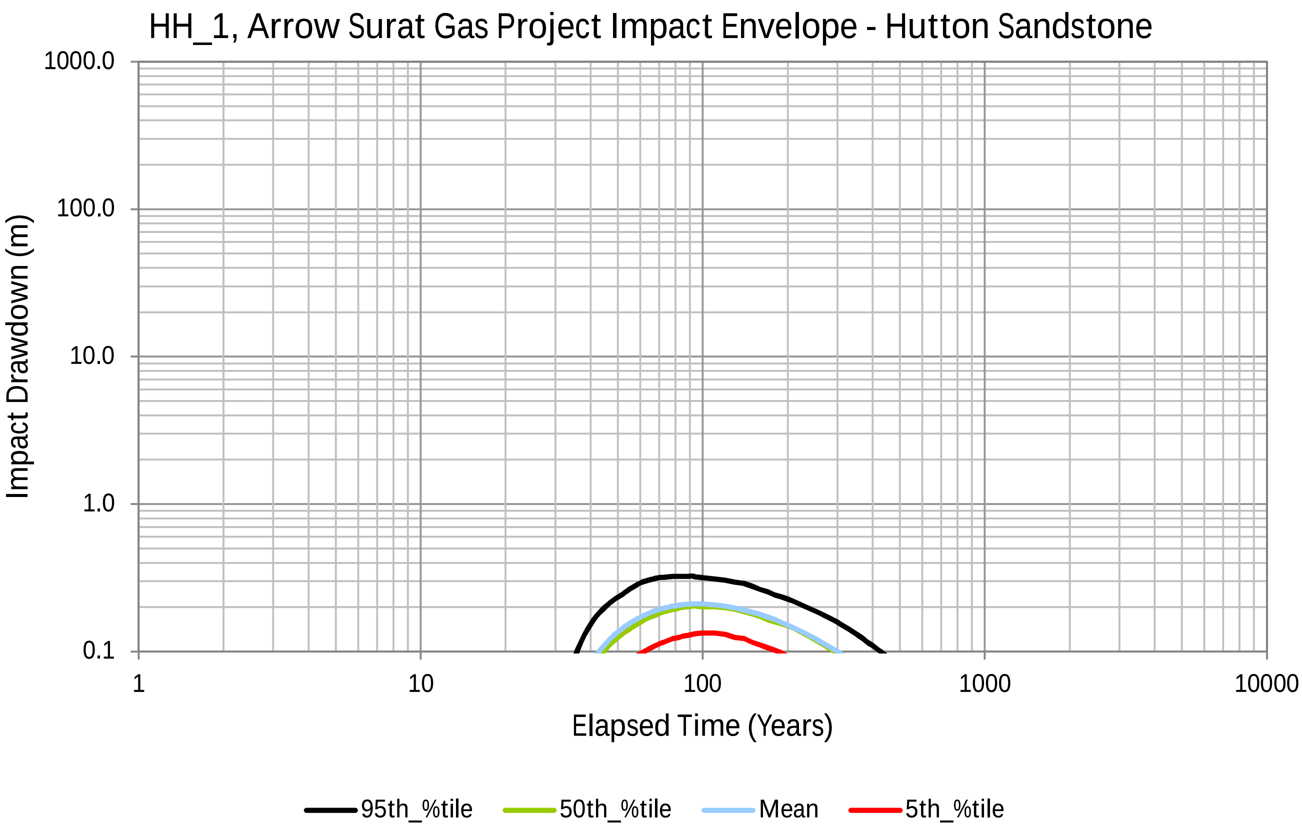


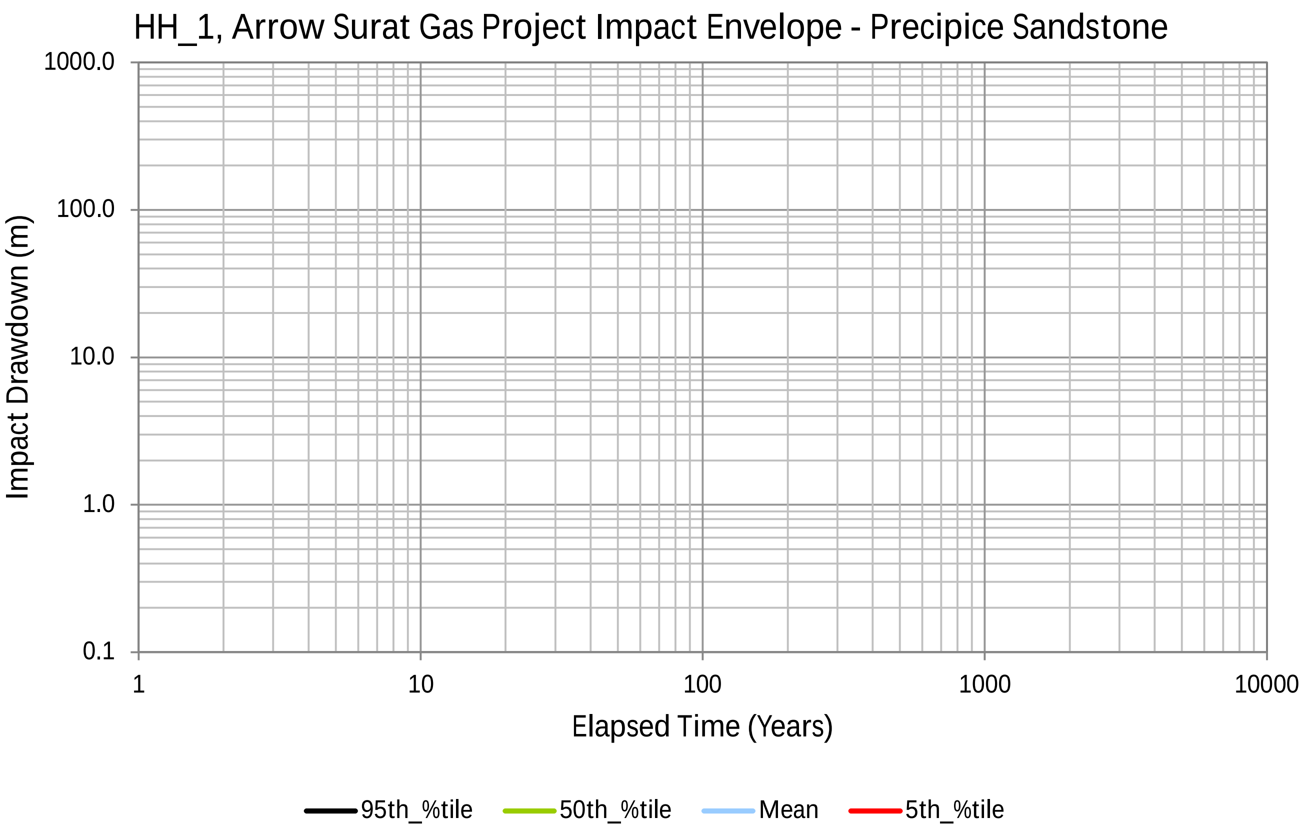
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 1



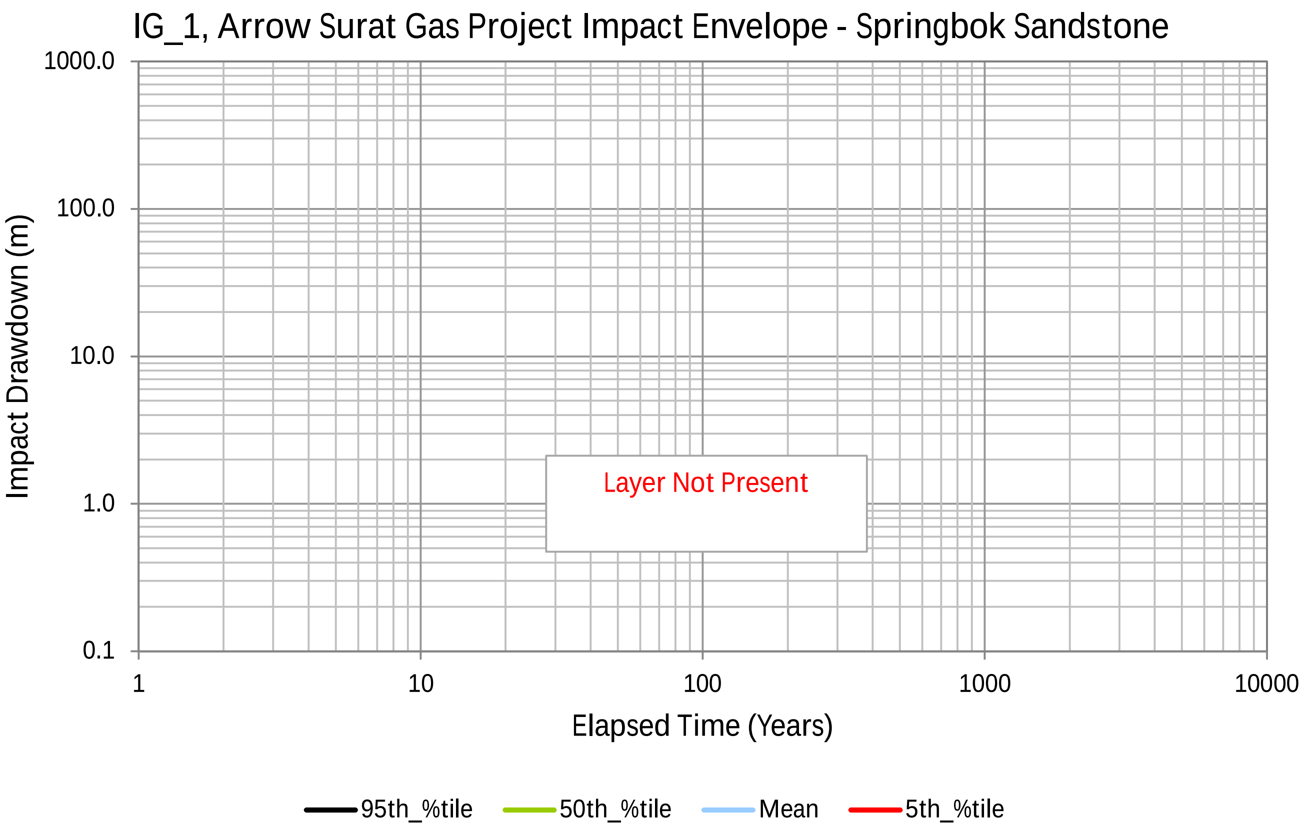


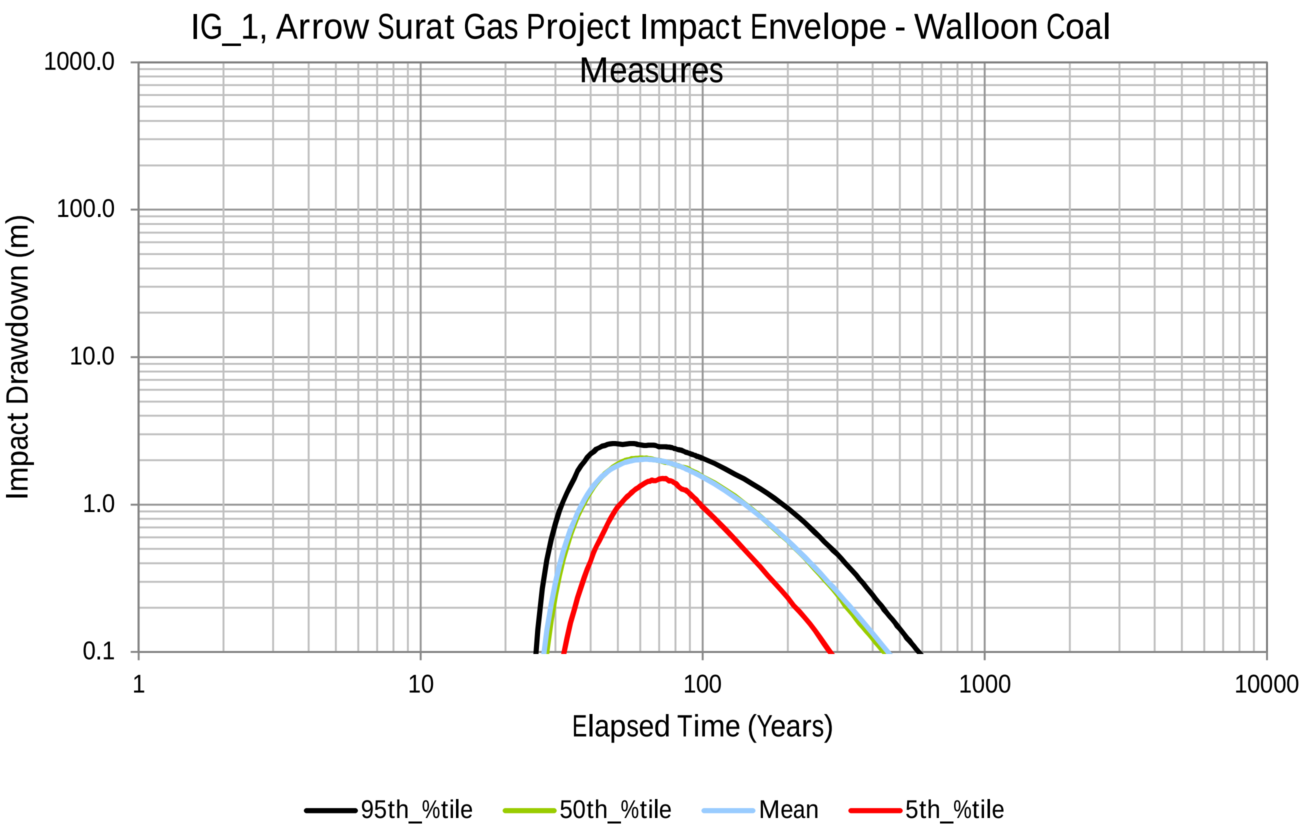
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 1



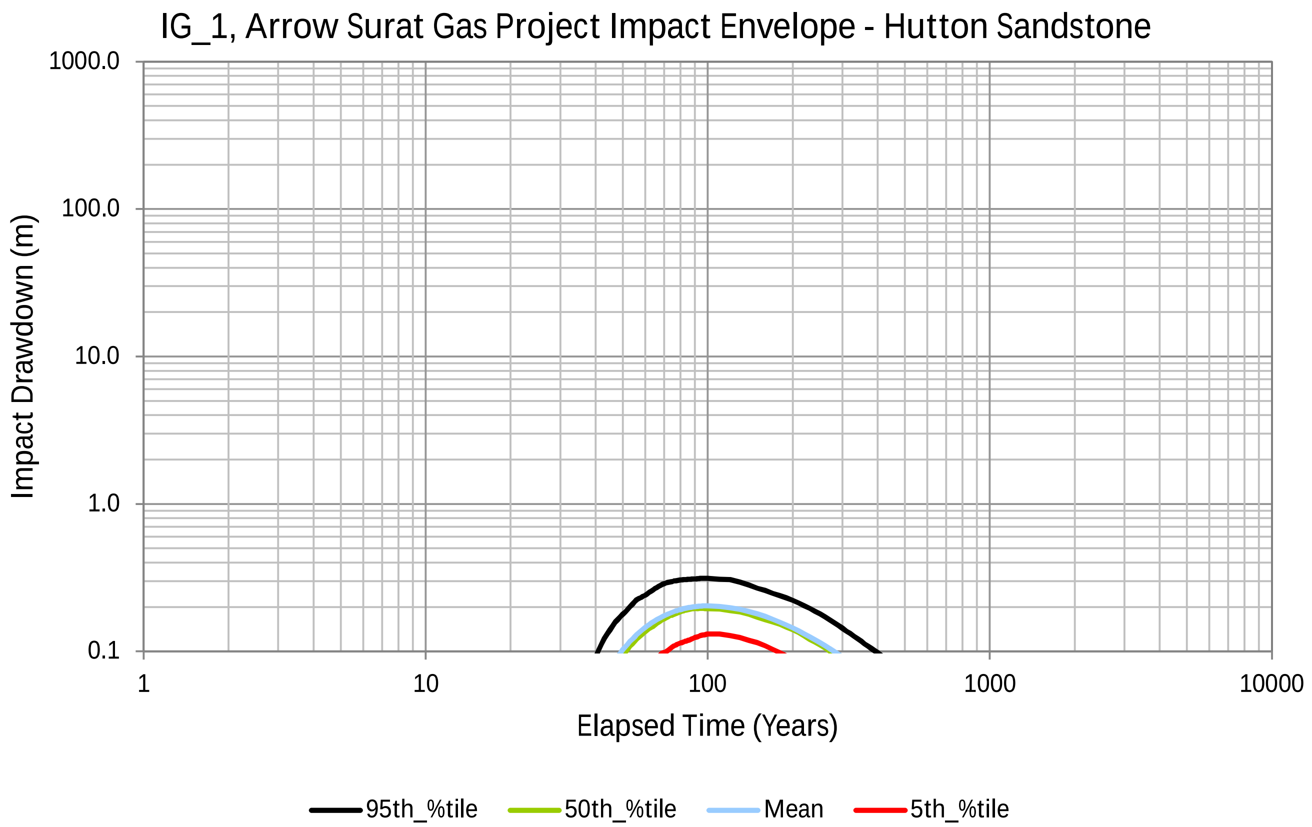


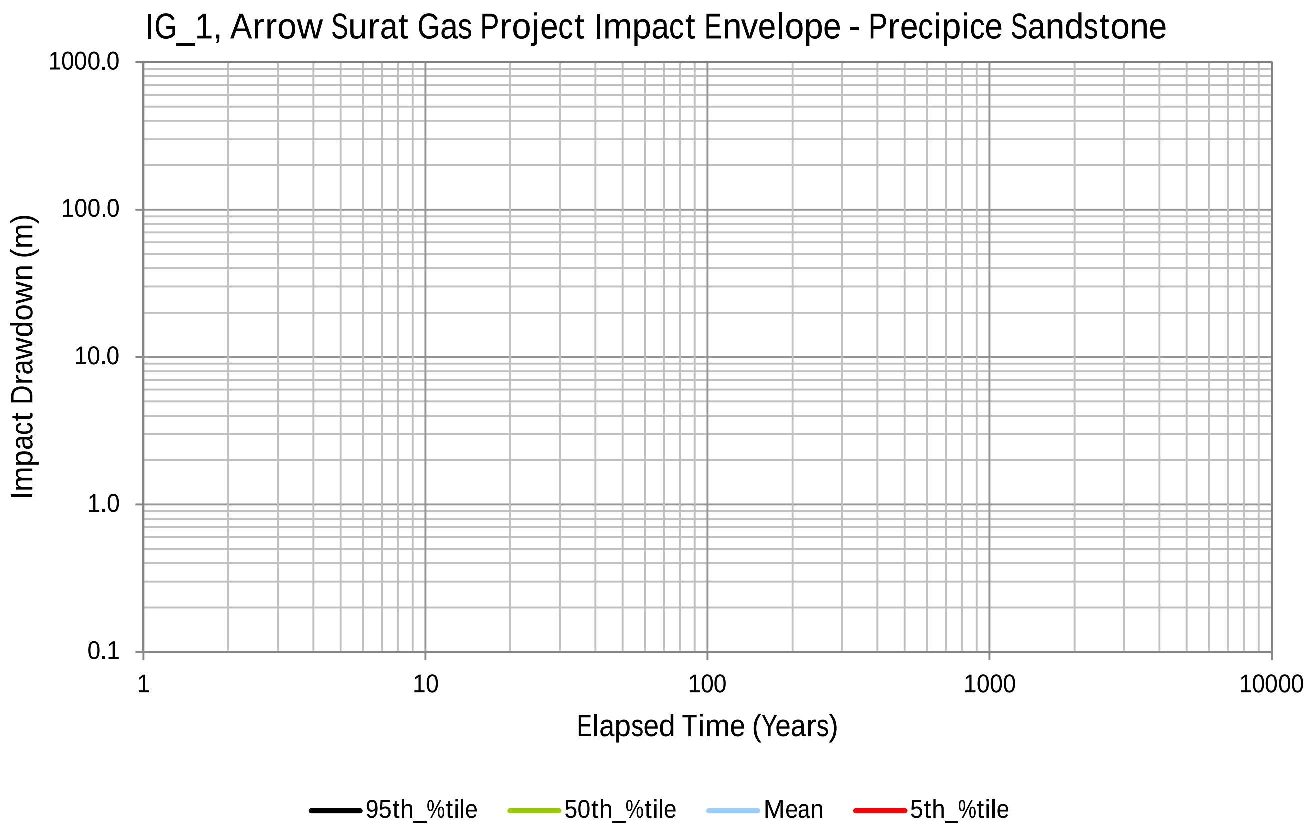
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 1



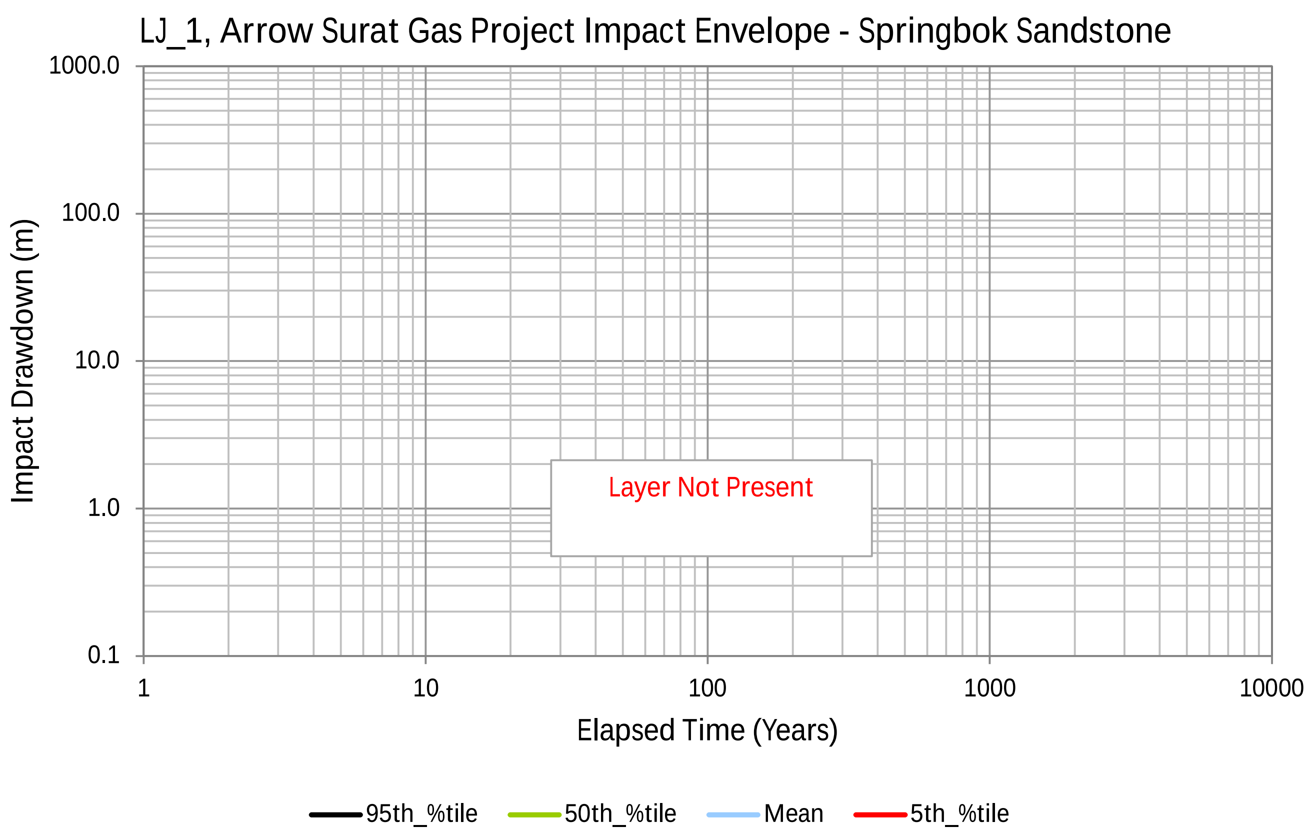


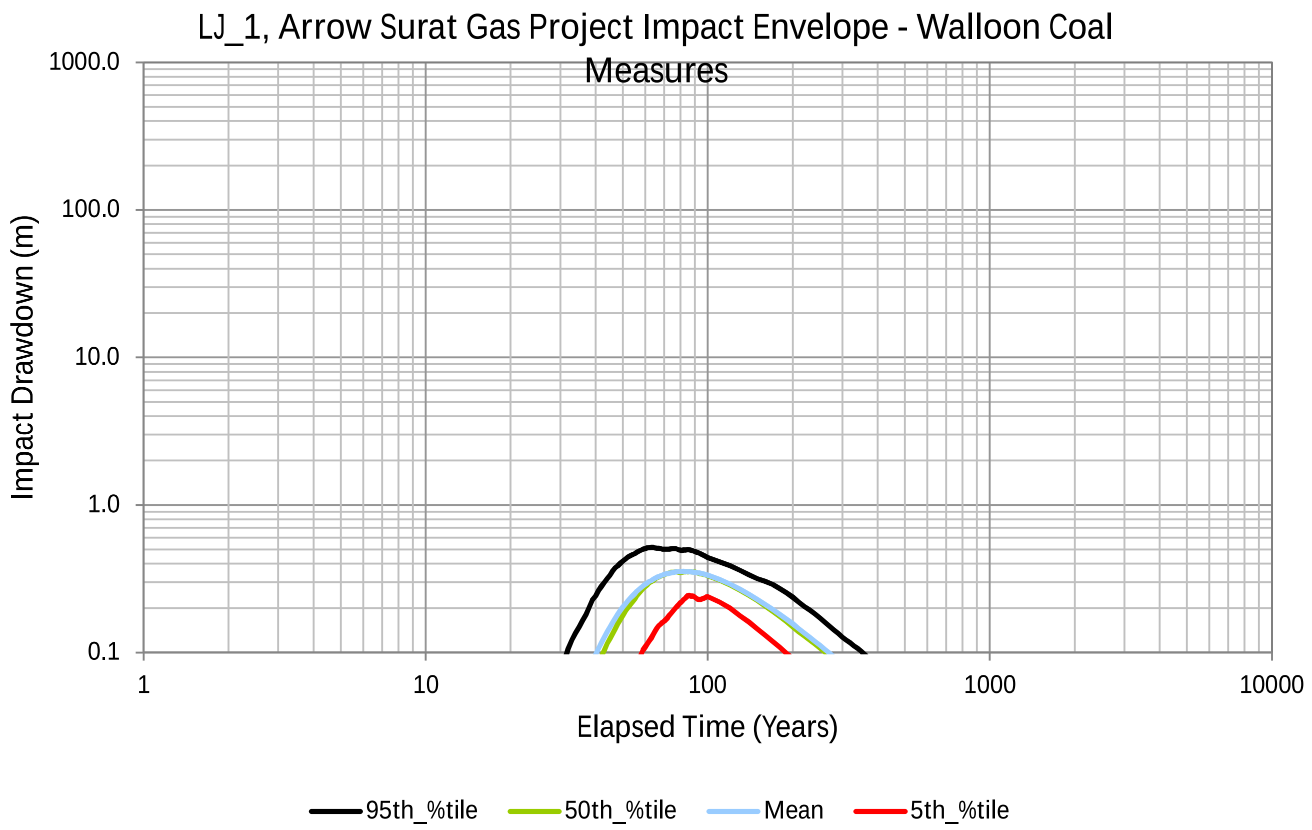
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 1





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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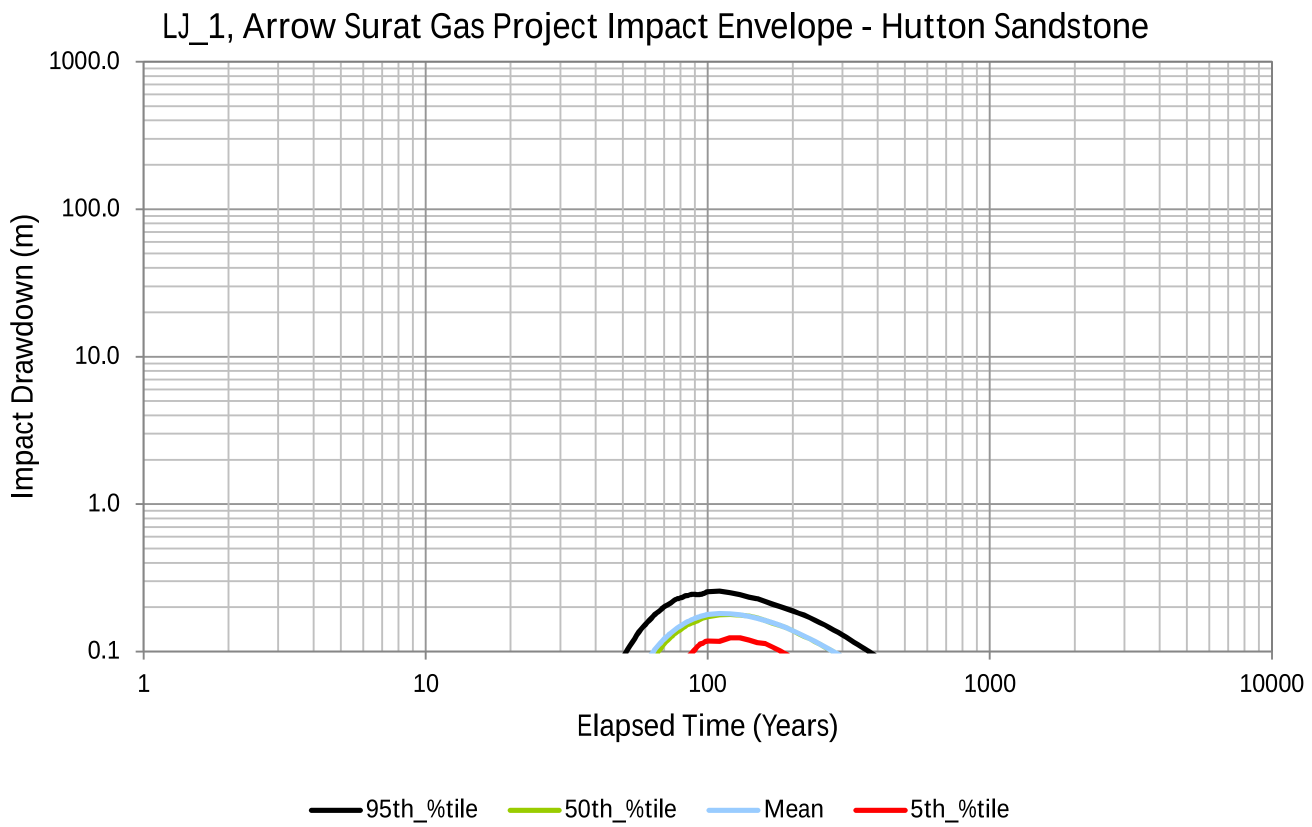
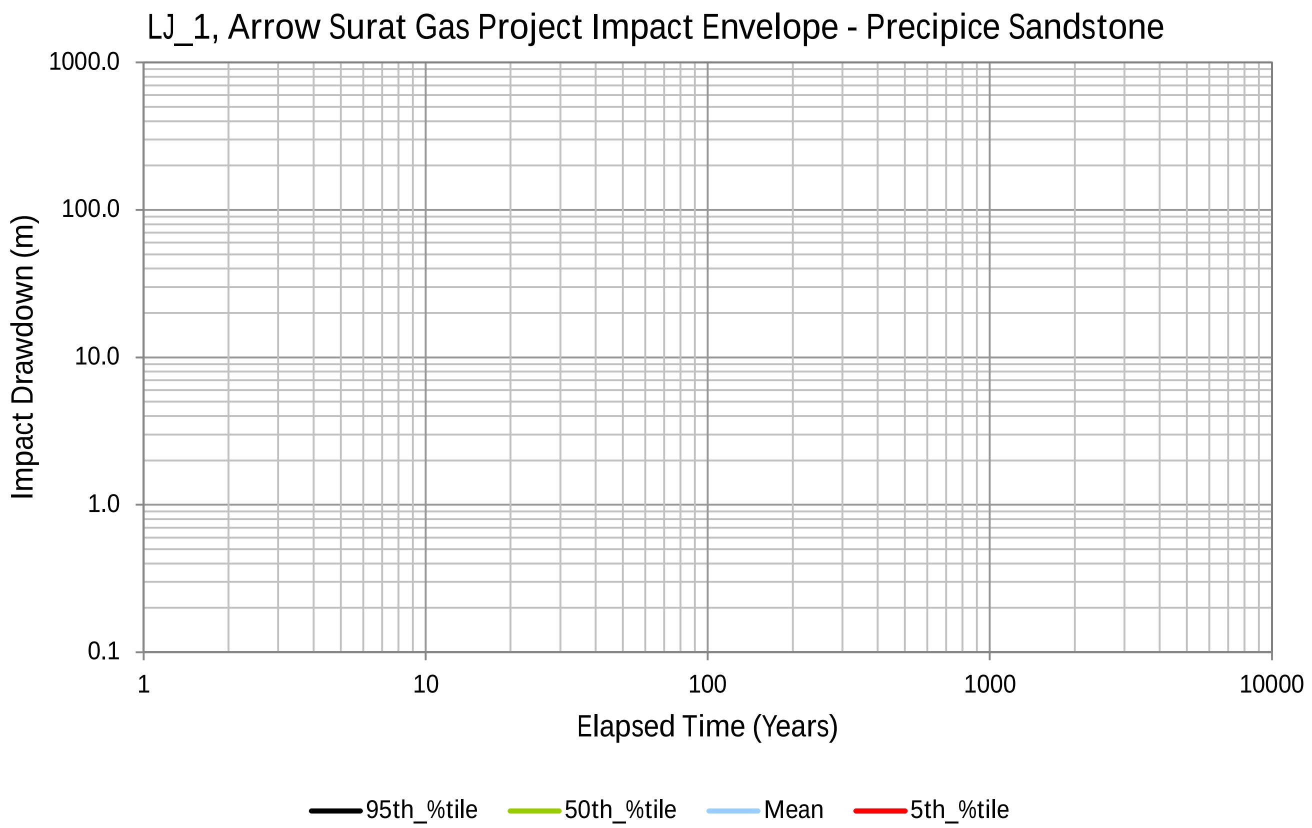
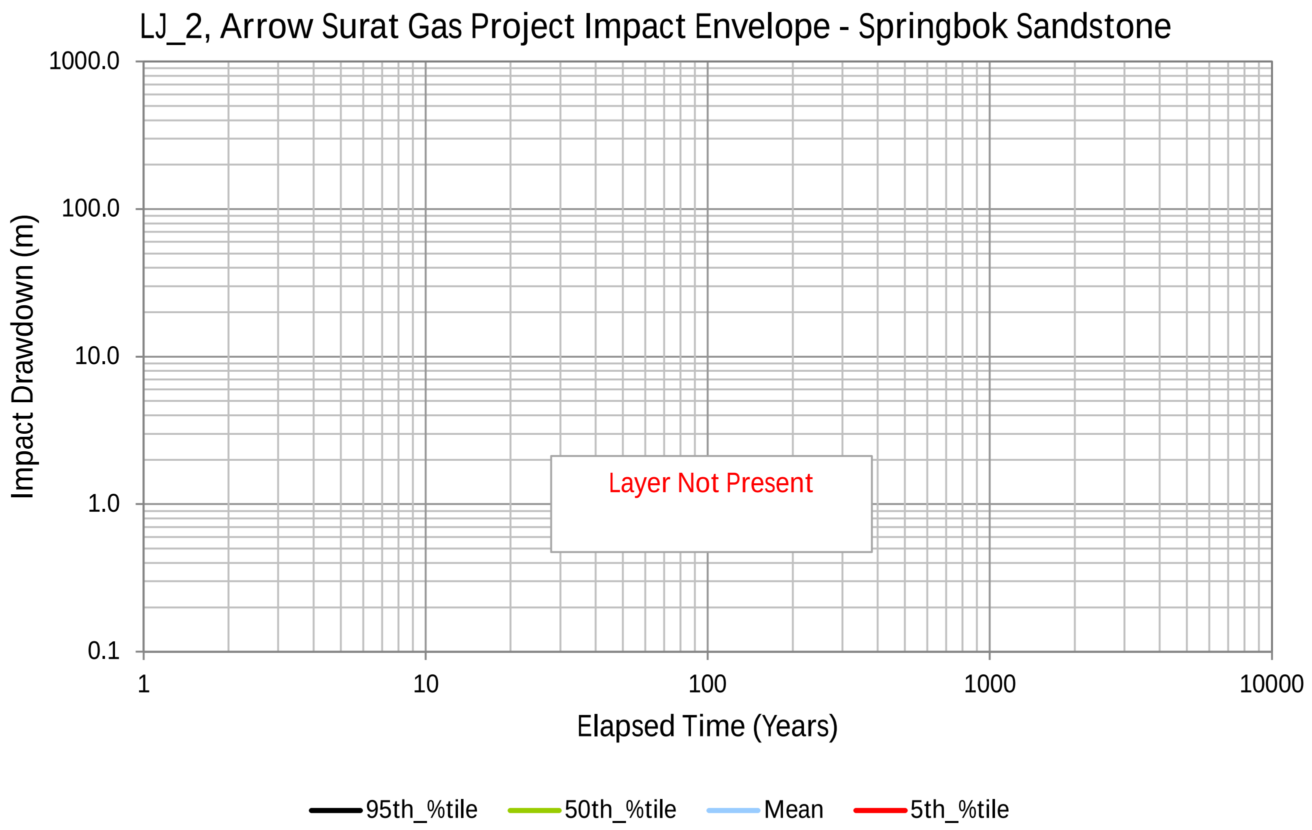
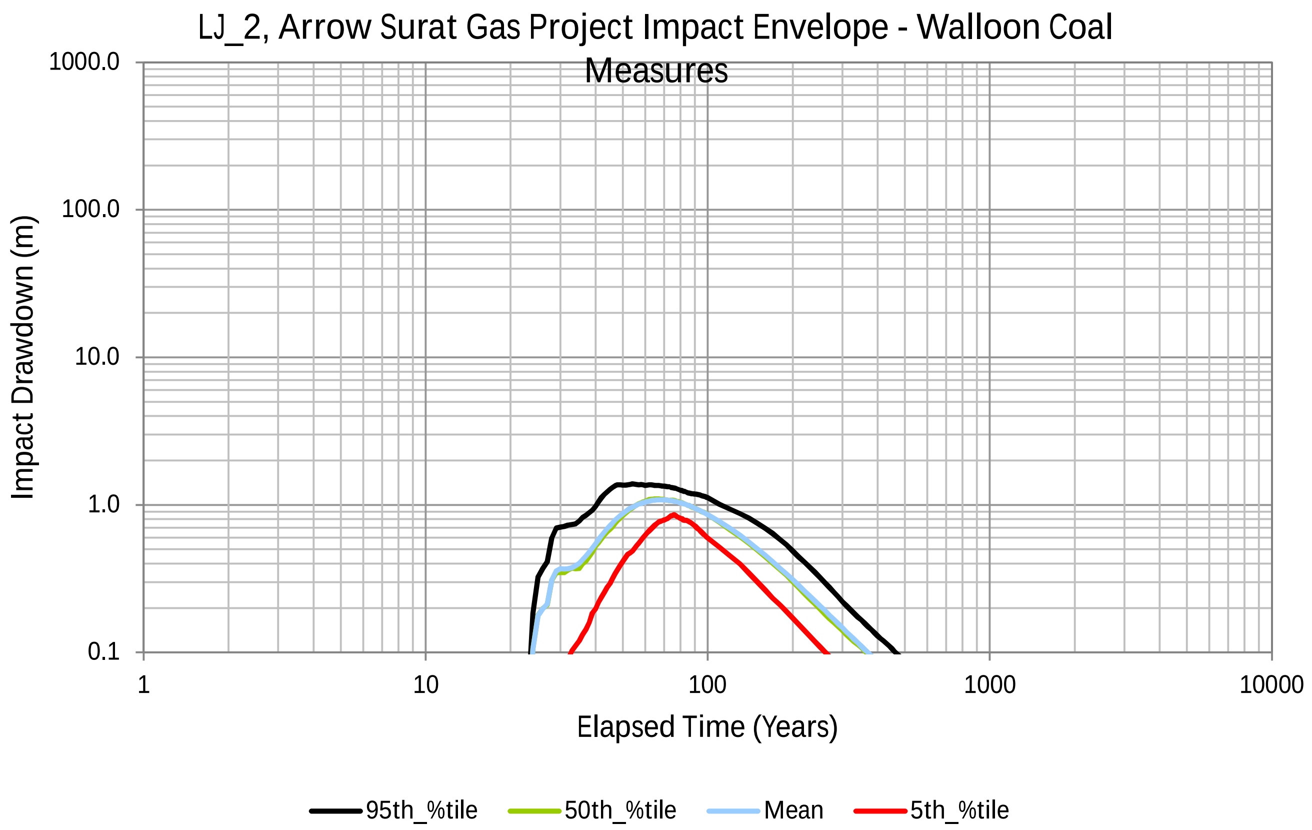
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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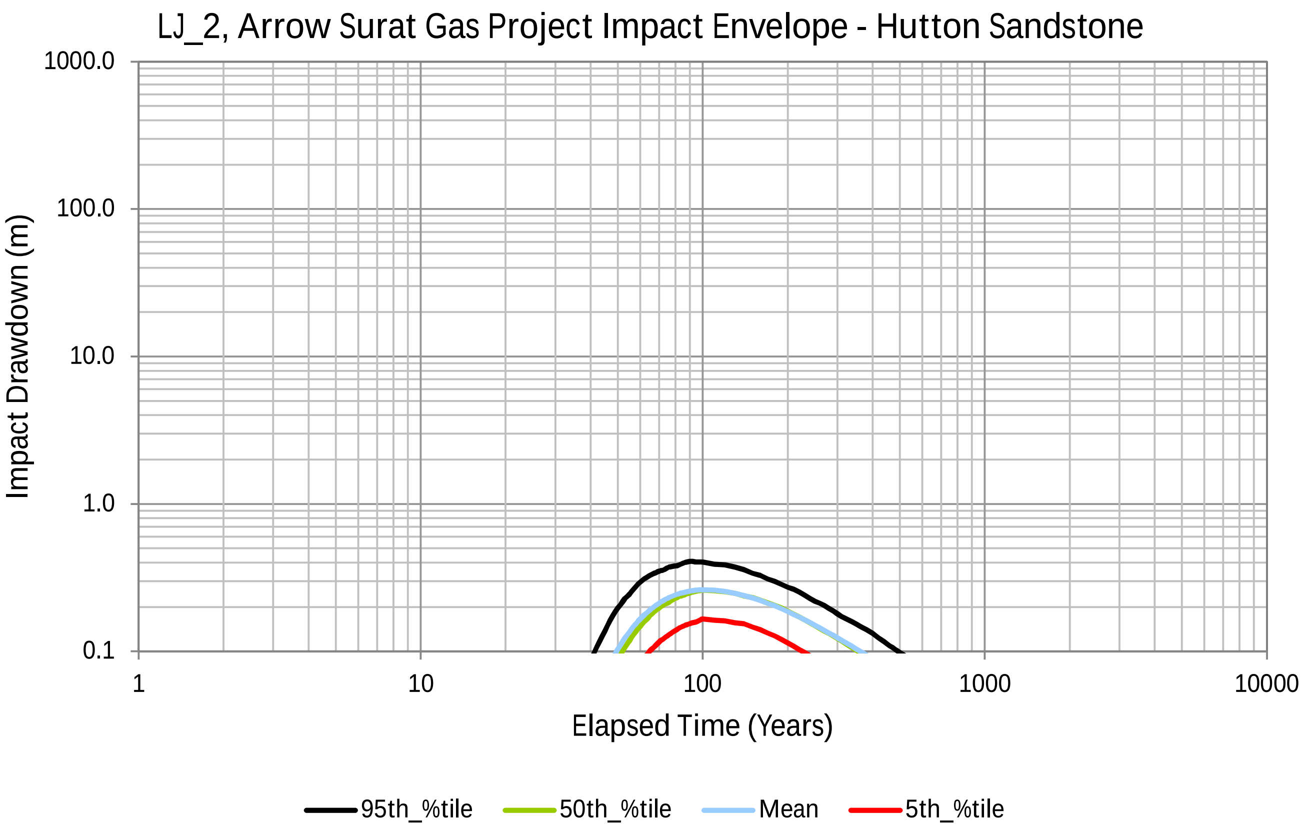
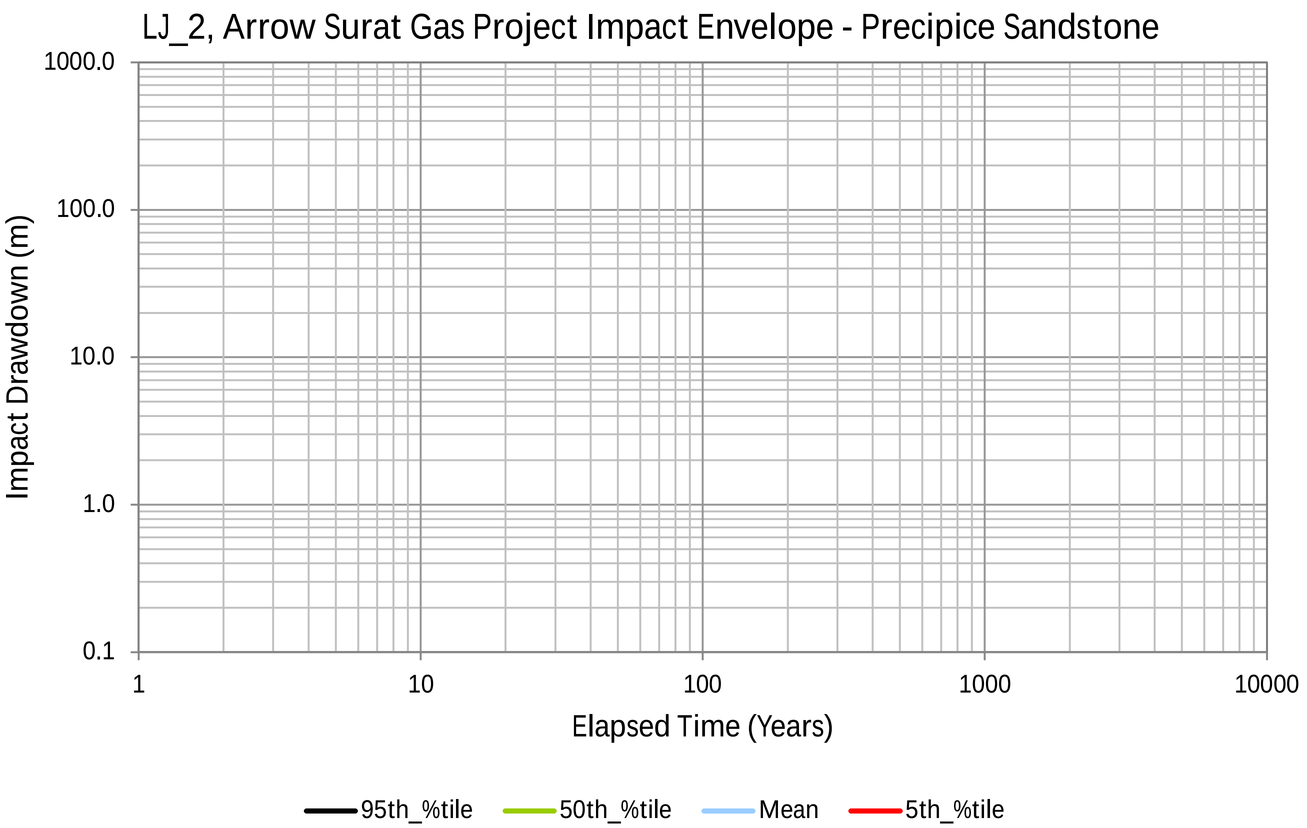
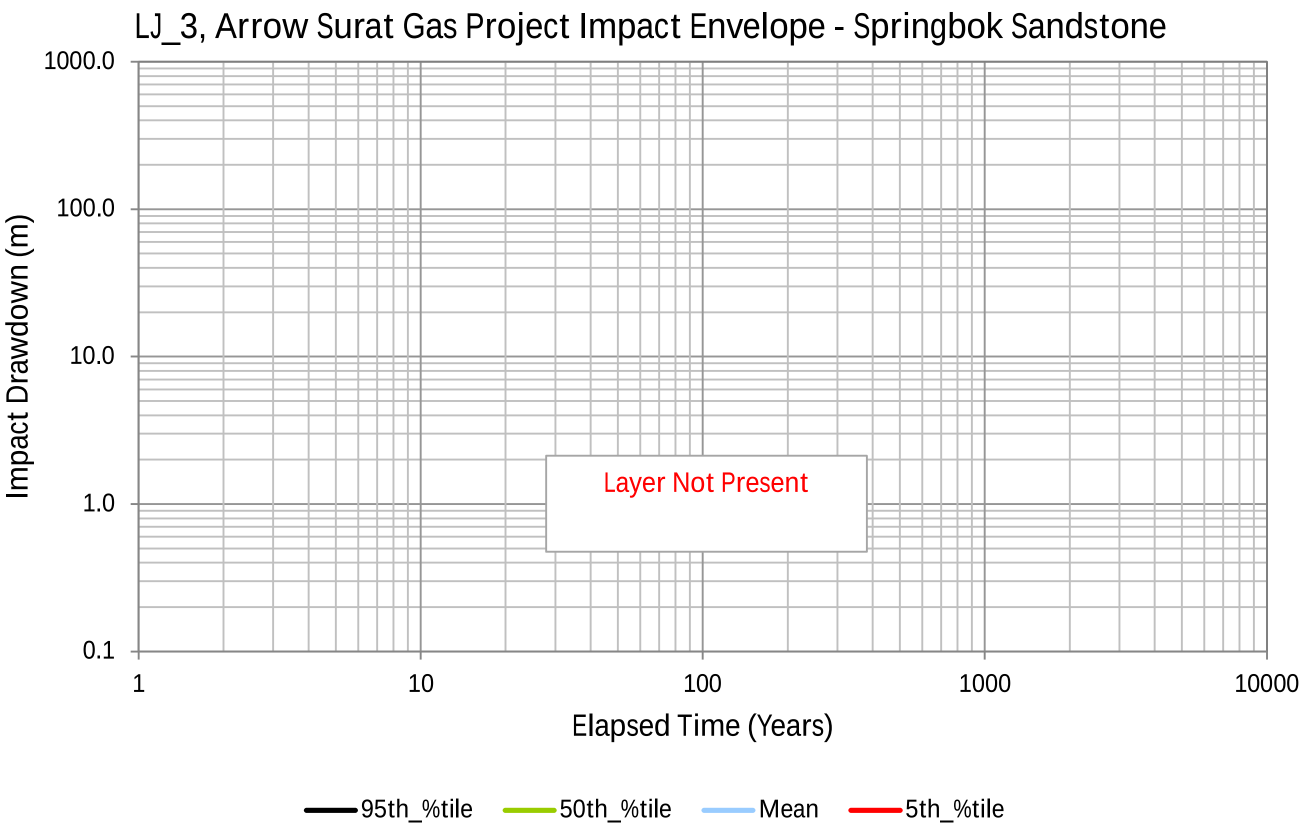
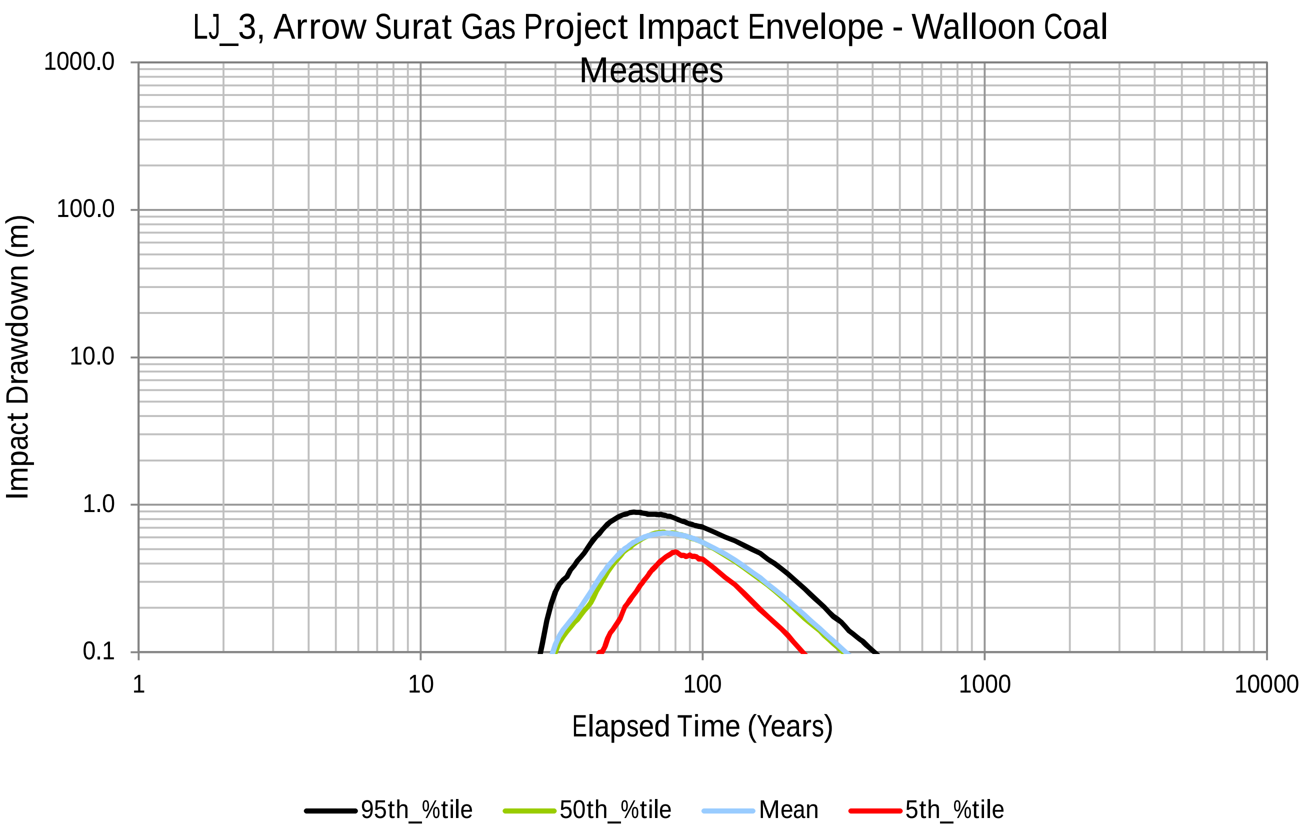
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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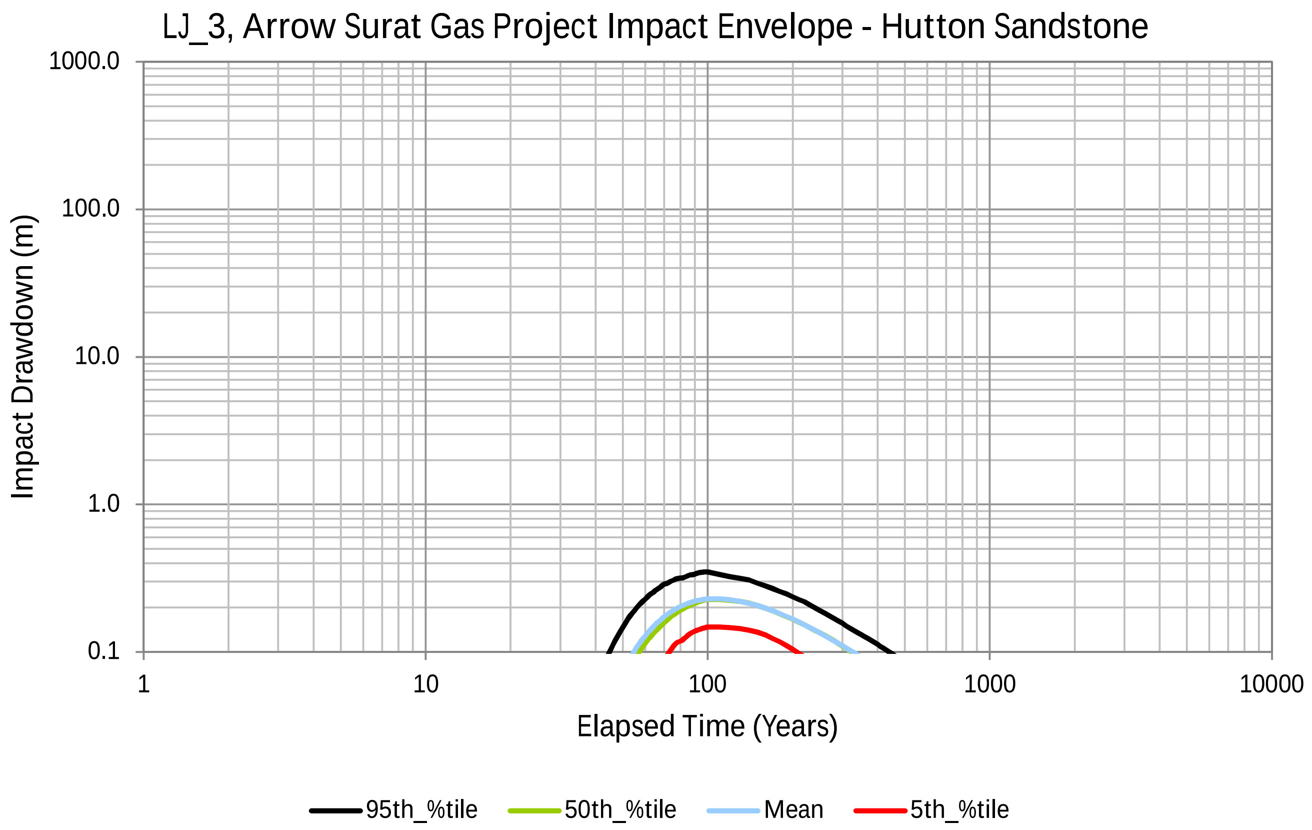
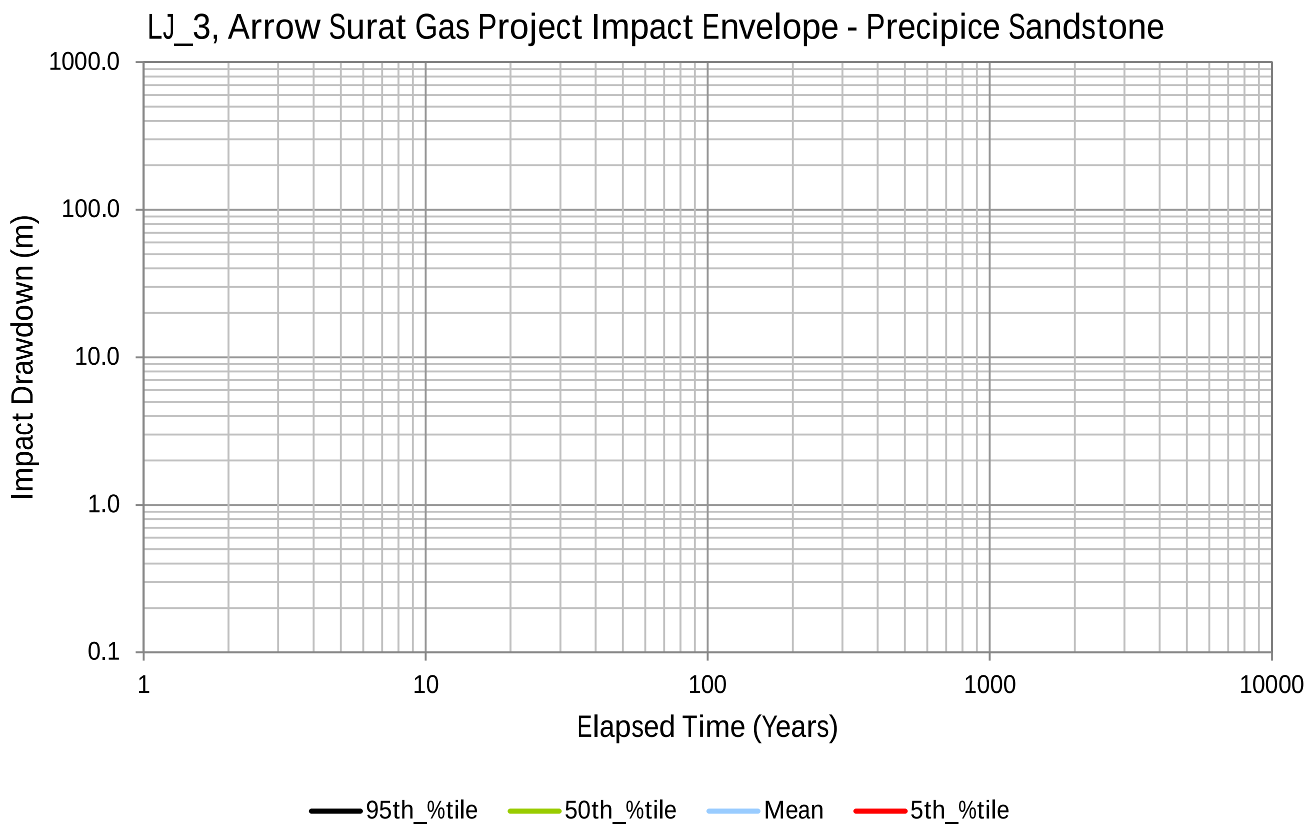
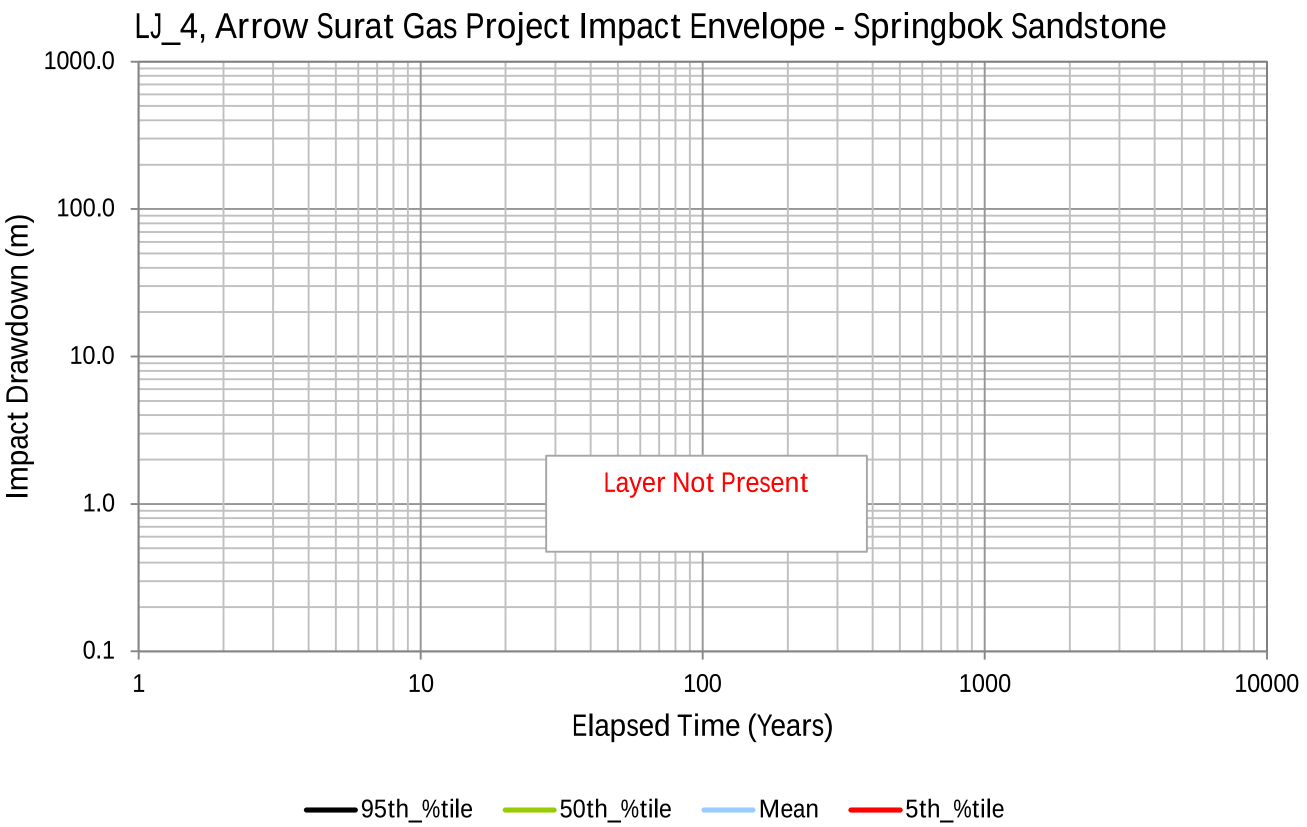
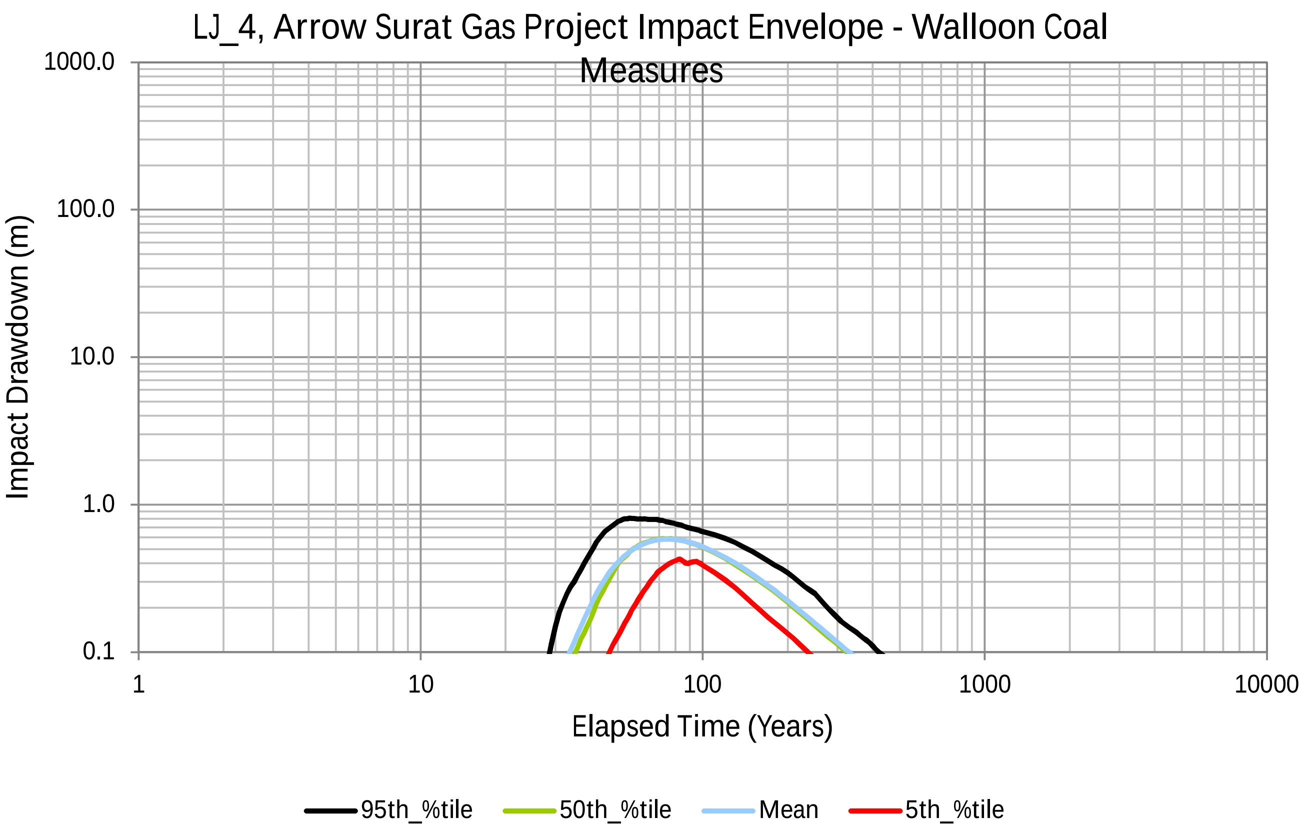

LJ_3, Arrow Surat Gas Project Impact Envelope - Hutton Sandstone
1000.0
100.0
10.0
1.0
0.1
Impact Drawdown (m)
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile


LJ_3, Arrow Surat Gas Project Impact Envelope - Precipice Sandstone
1000.0
100.0
10.0
1.0
0.1
Impact Drawdown (m)
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

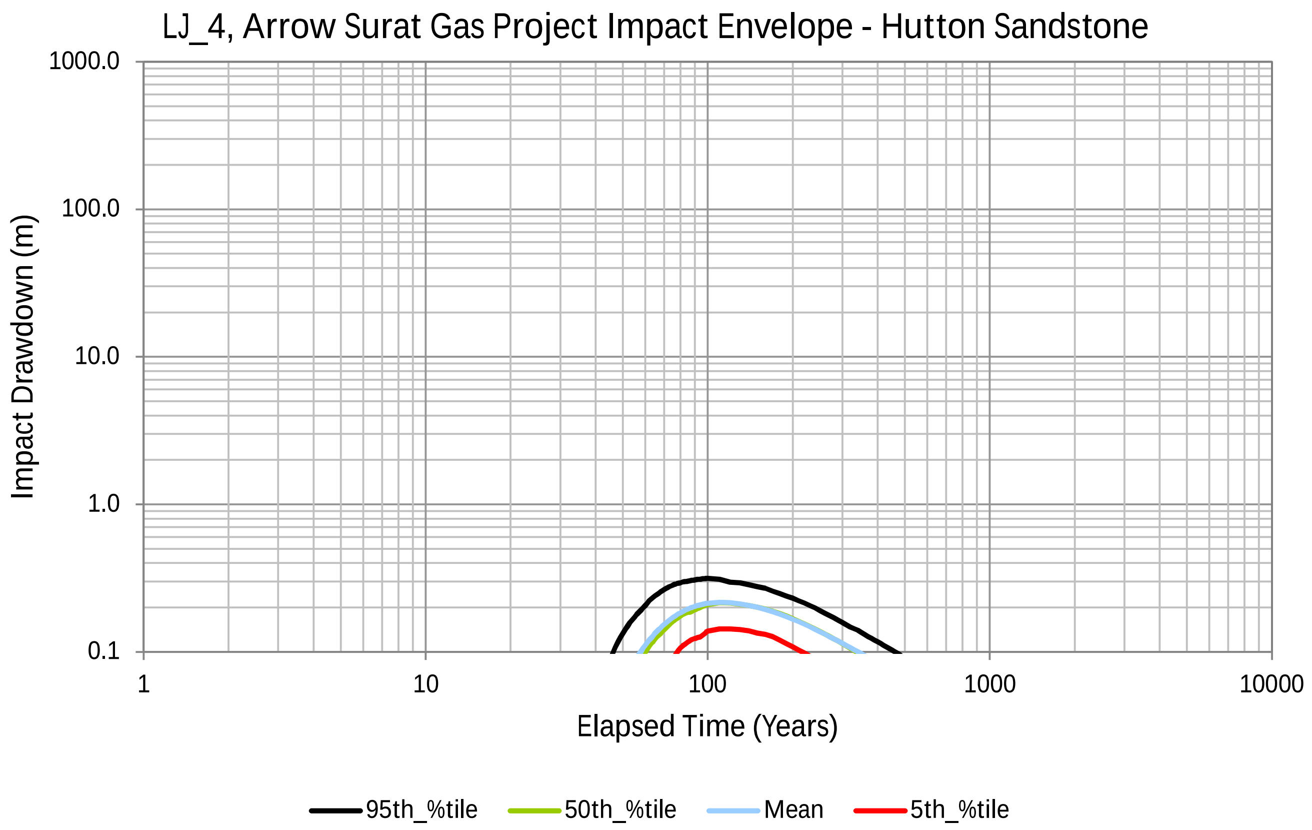
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2

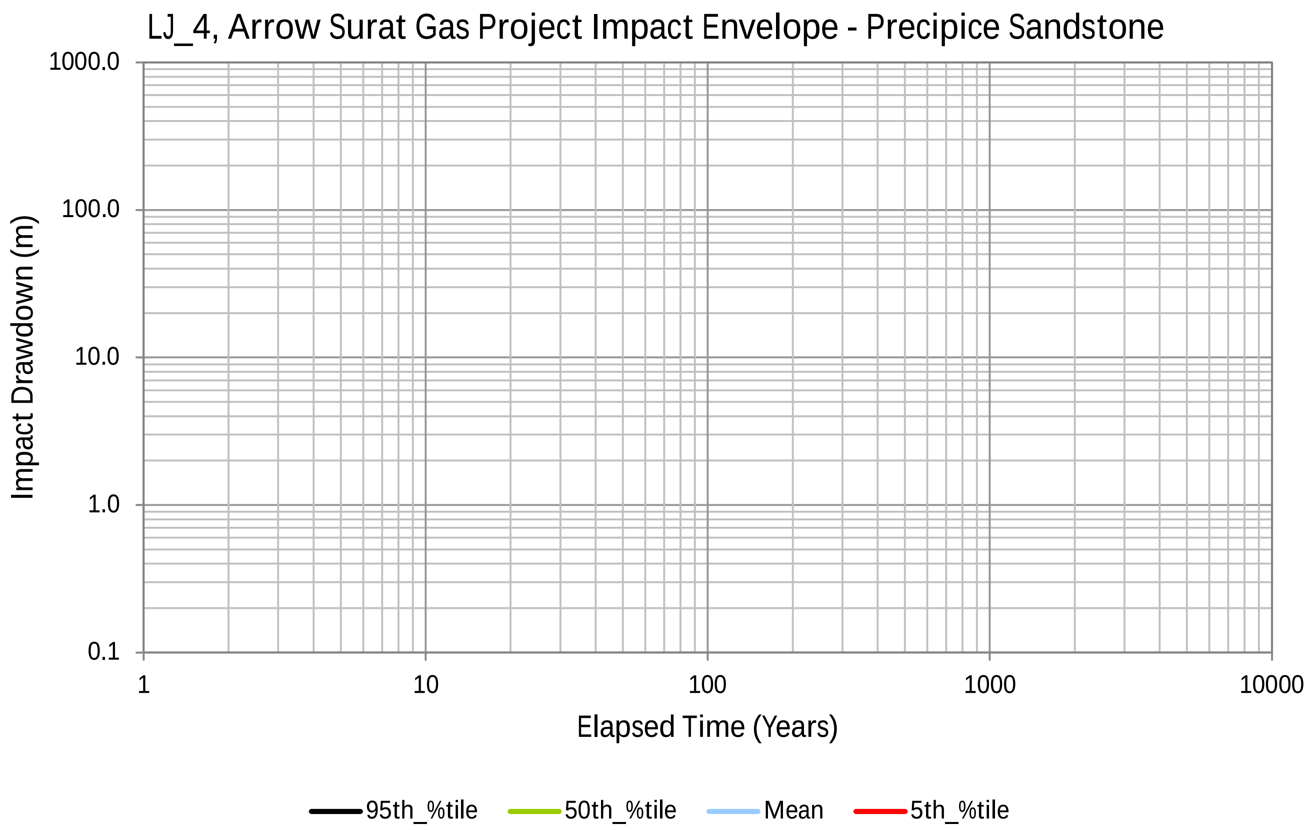




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_2)

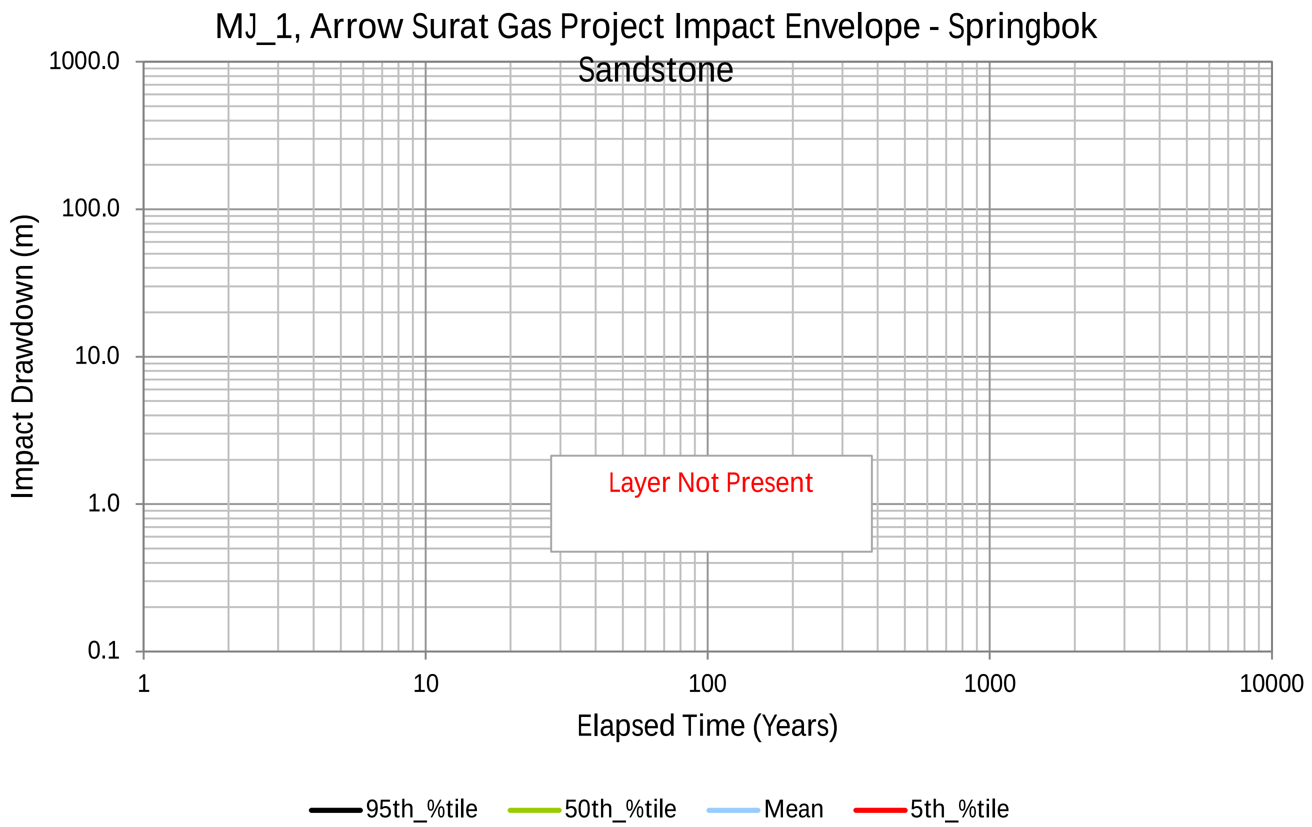
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2

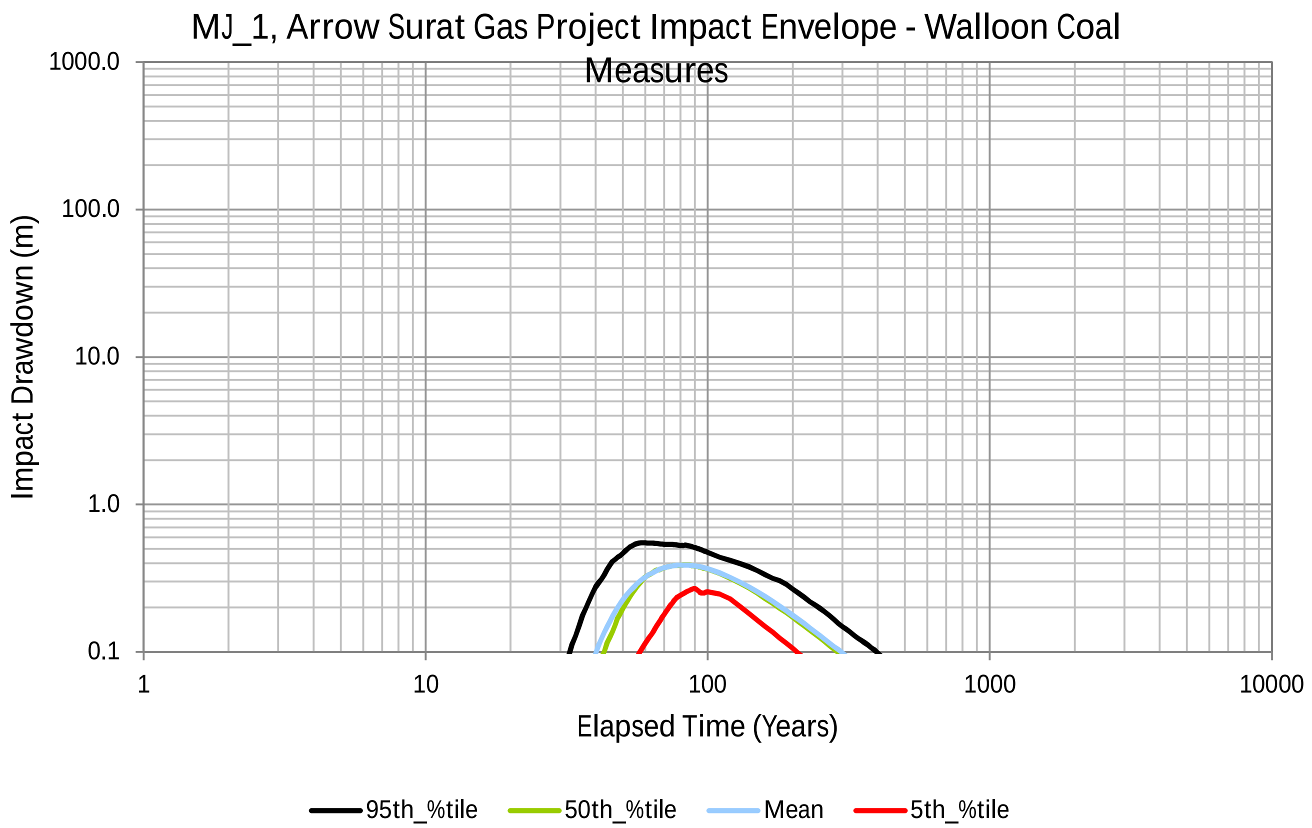




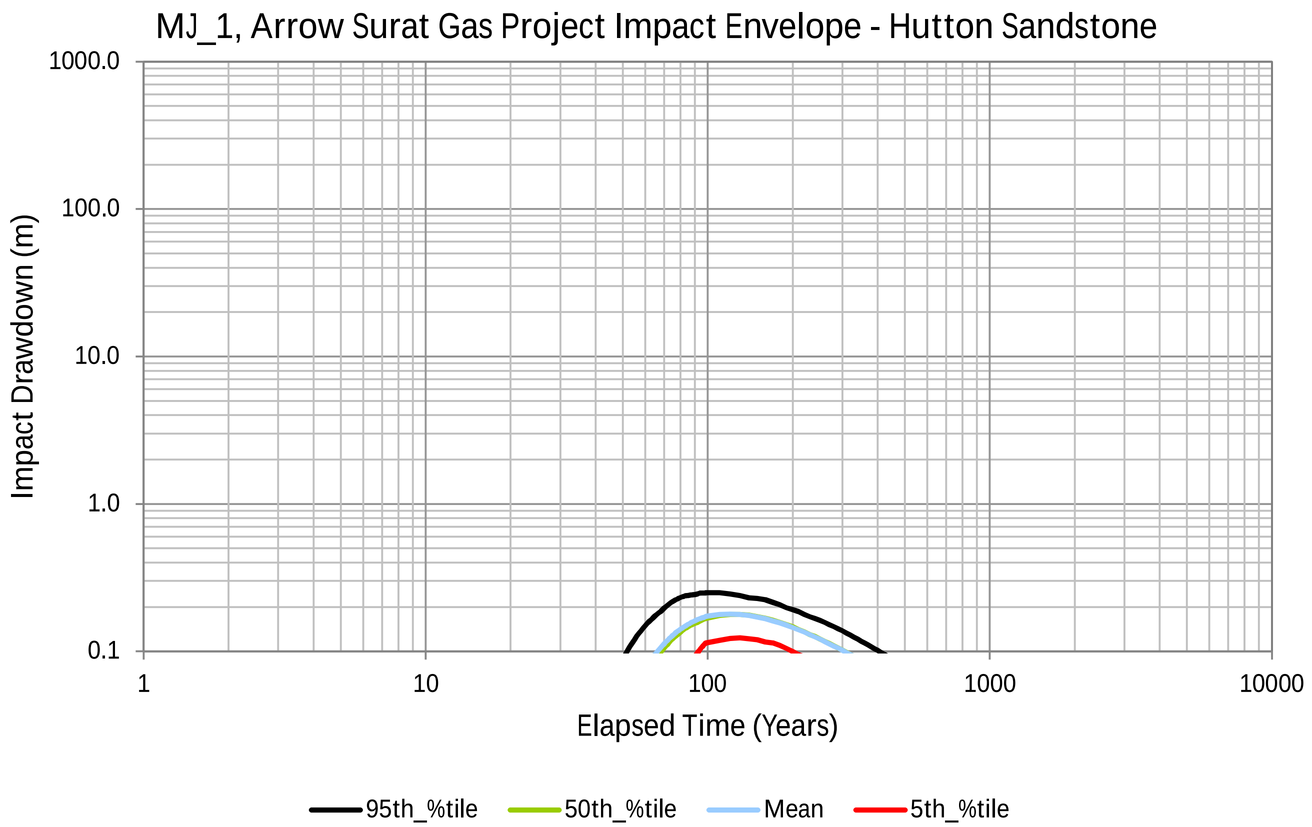
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_2)

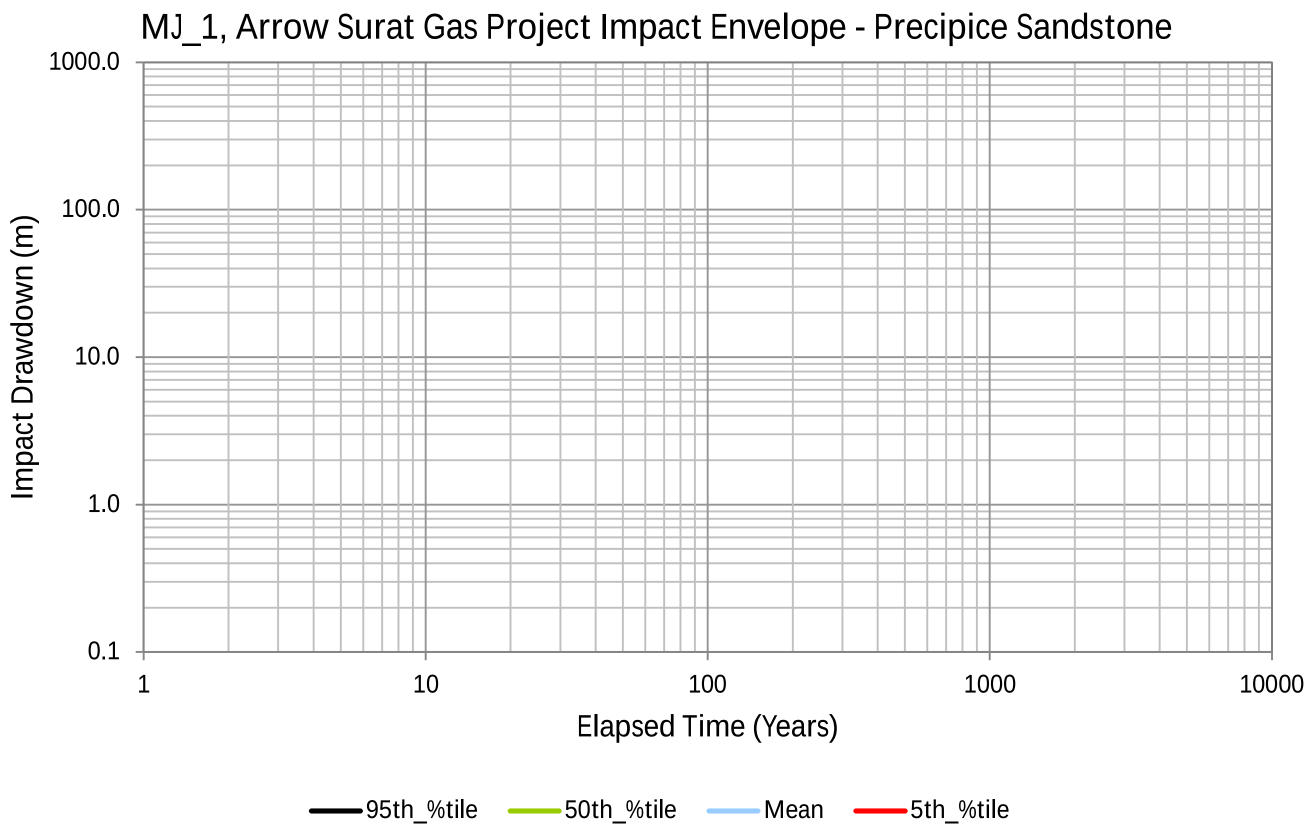
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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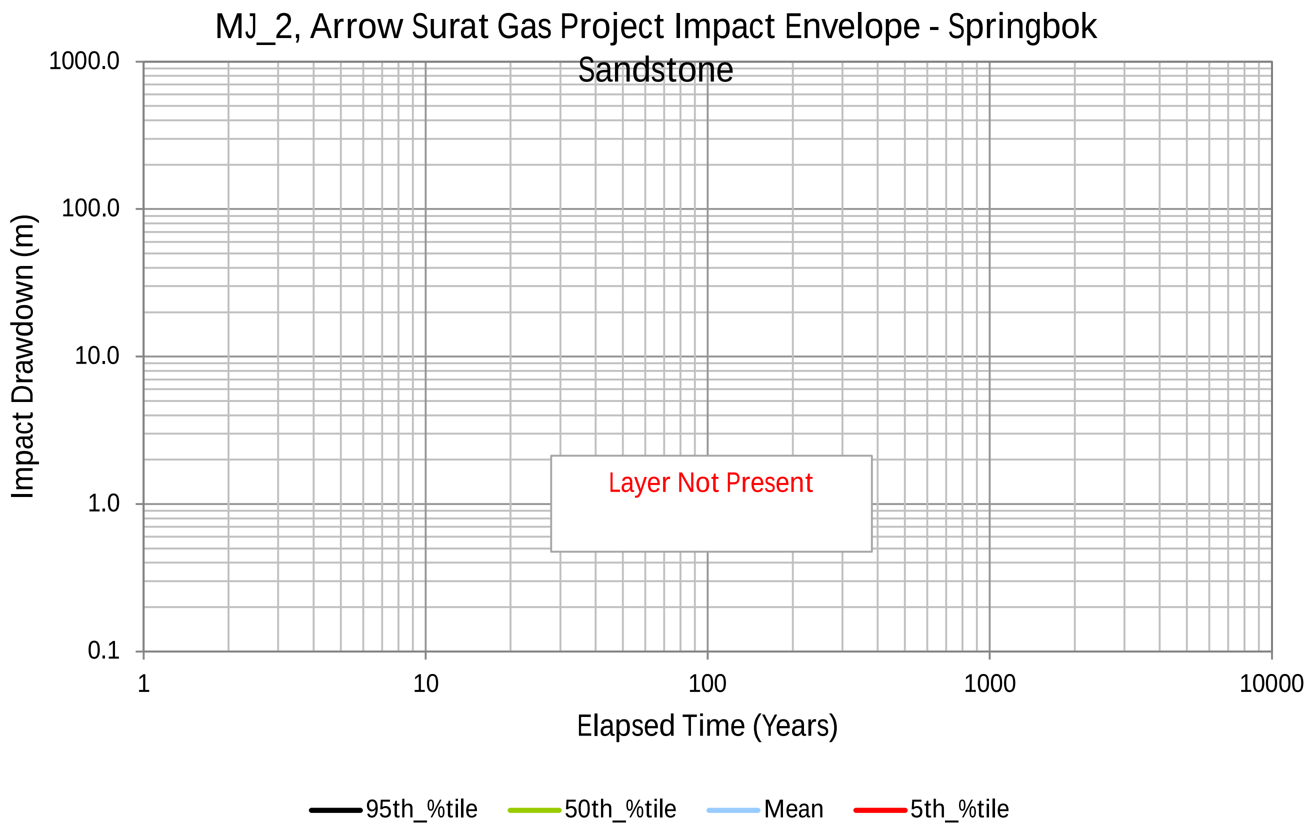
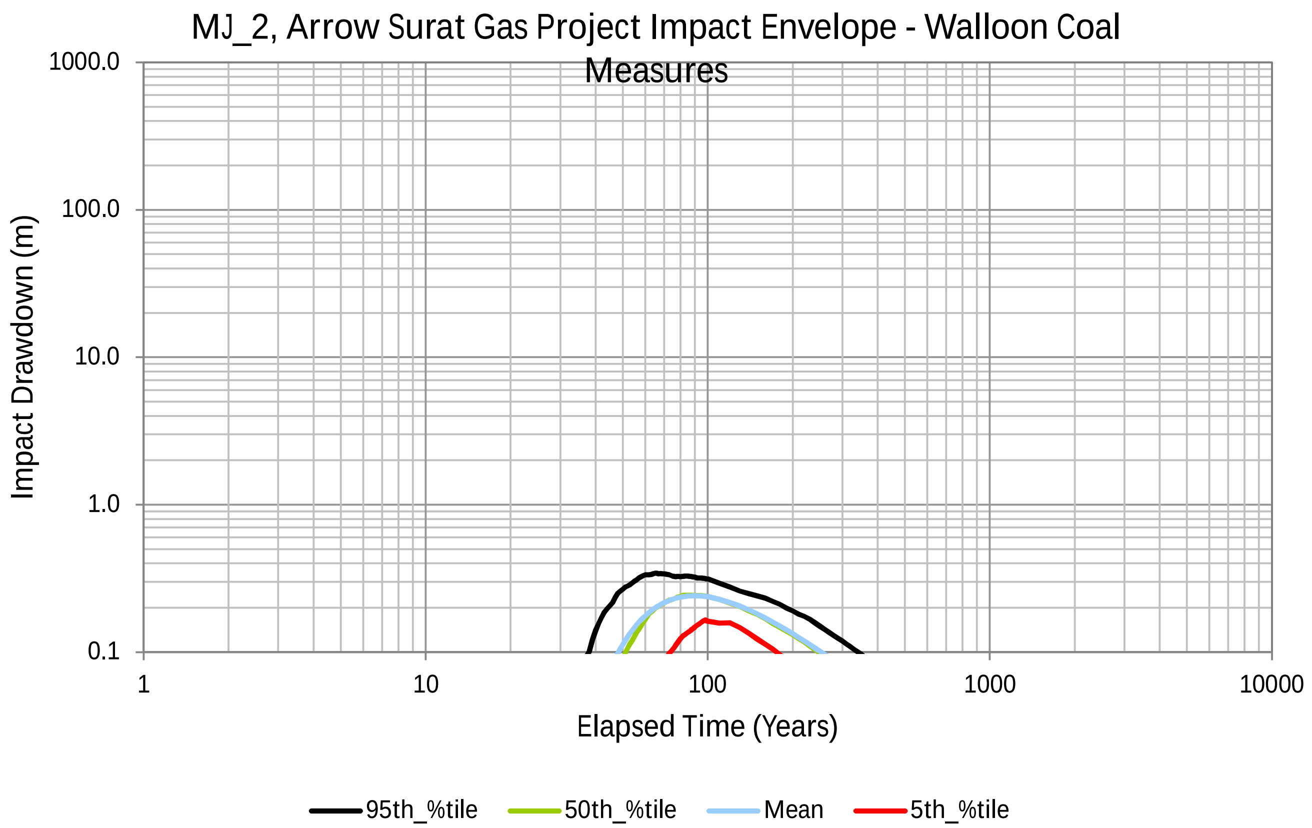
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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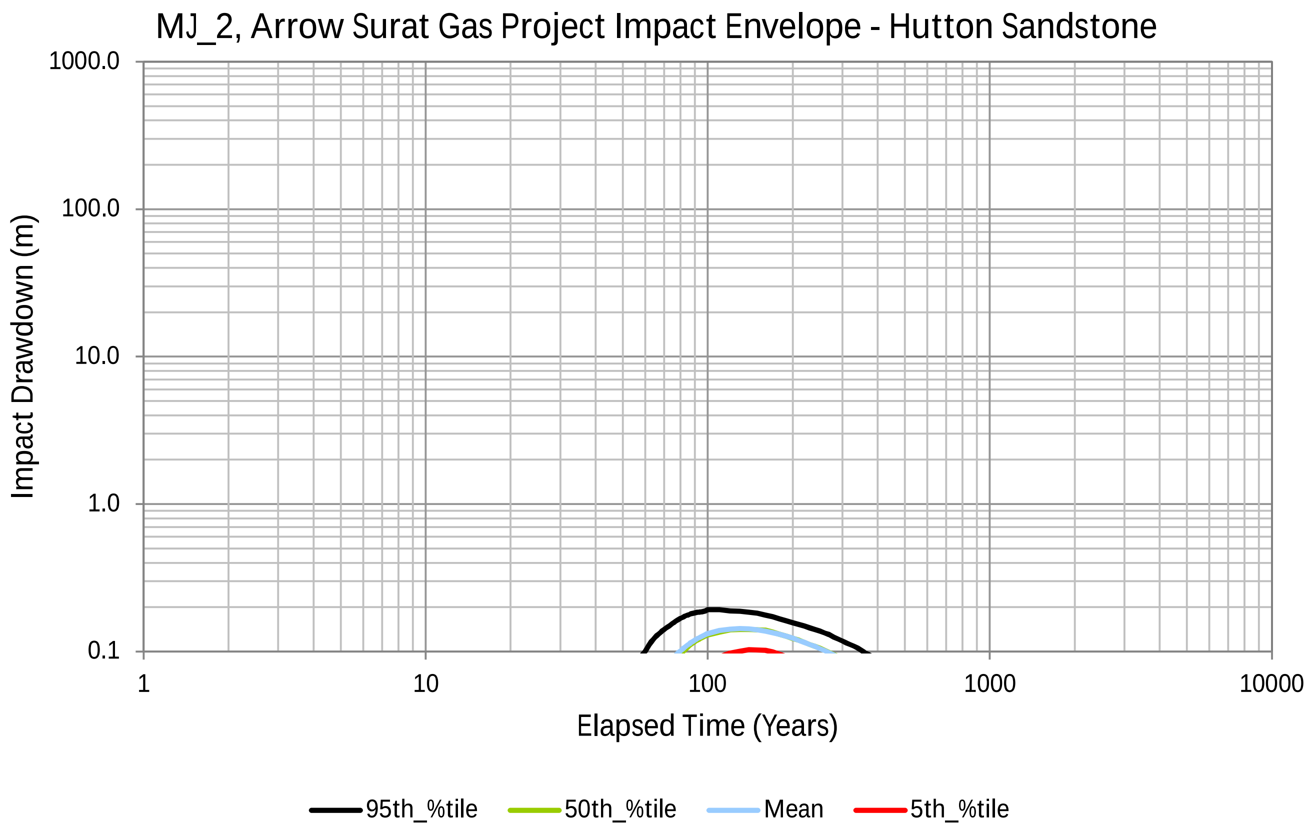
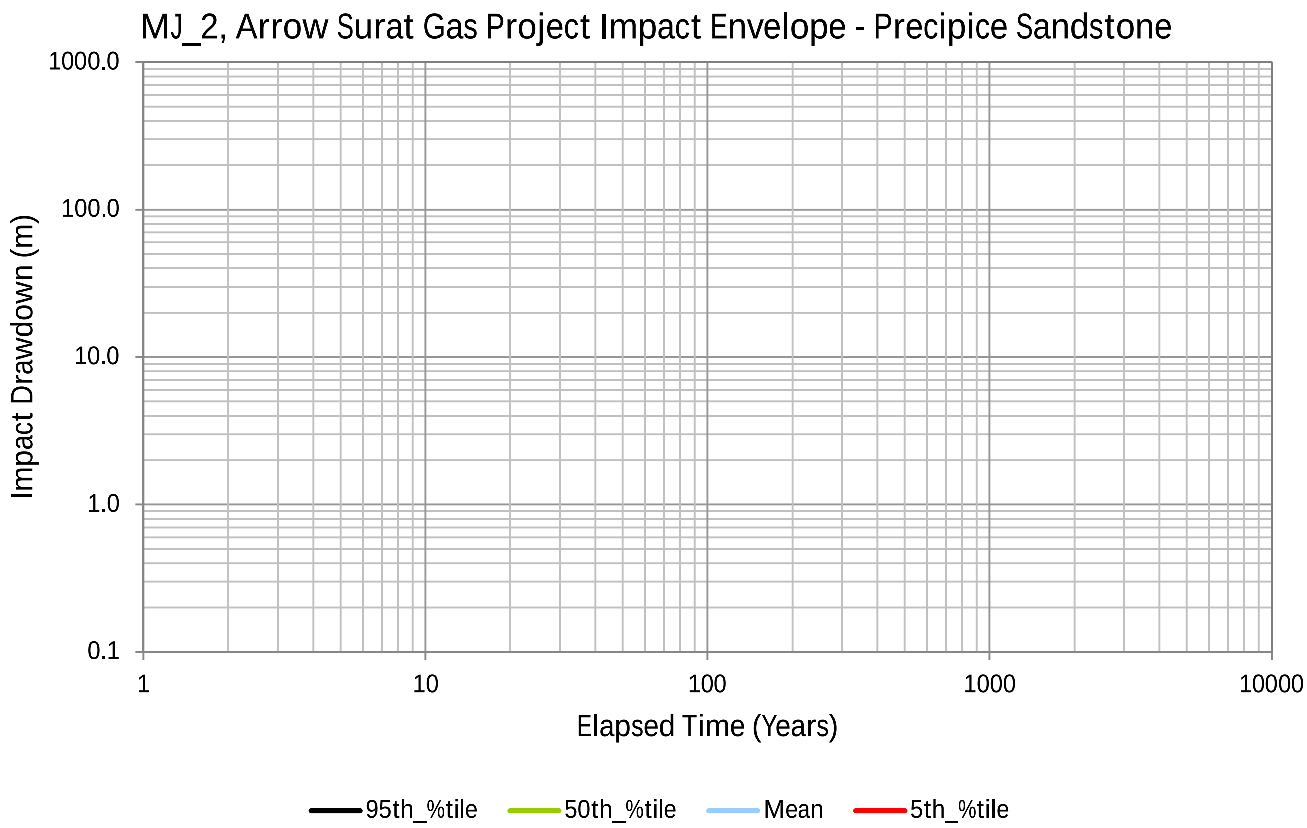
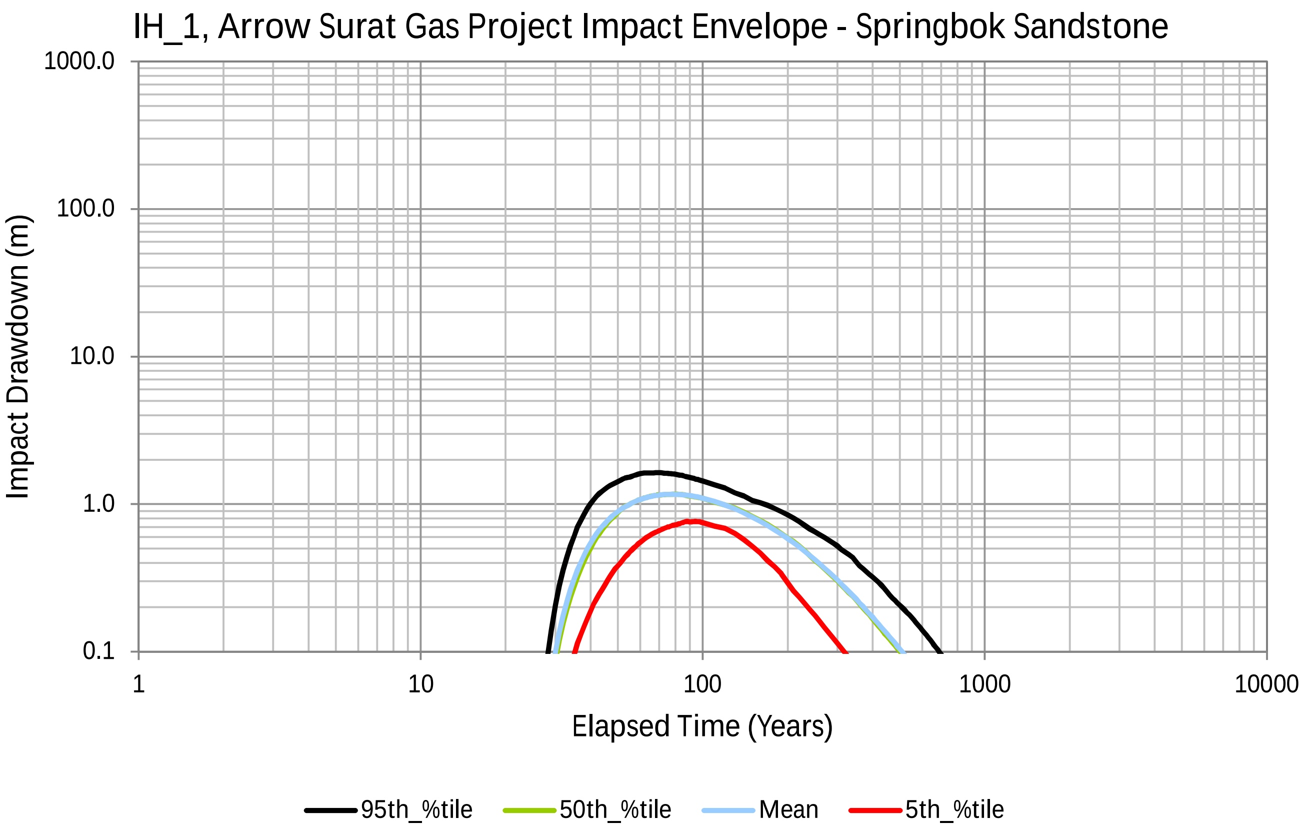
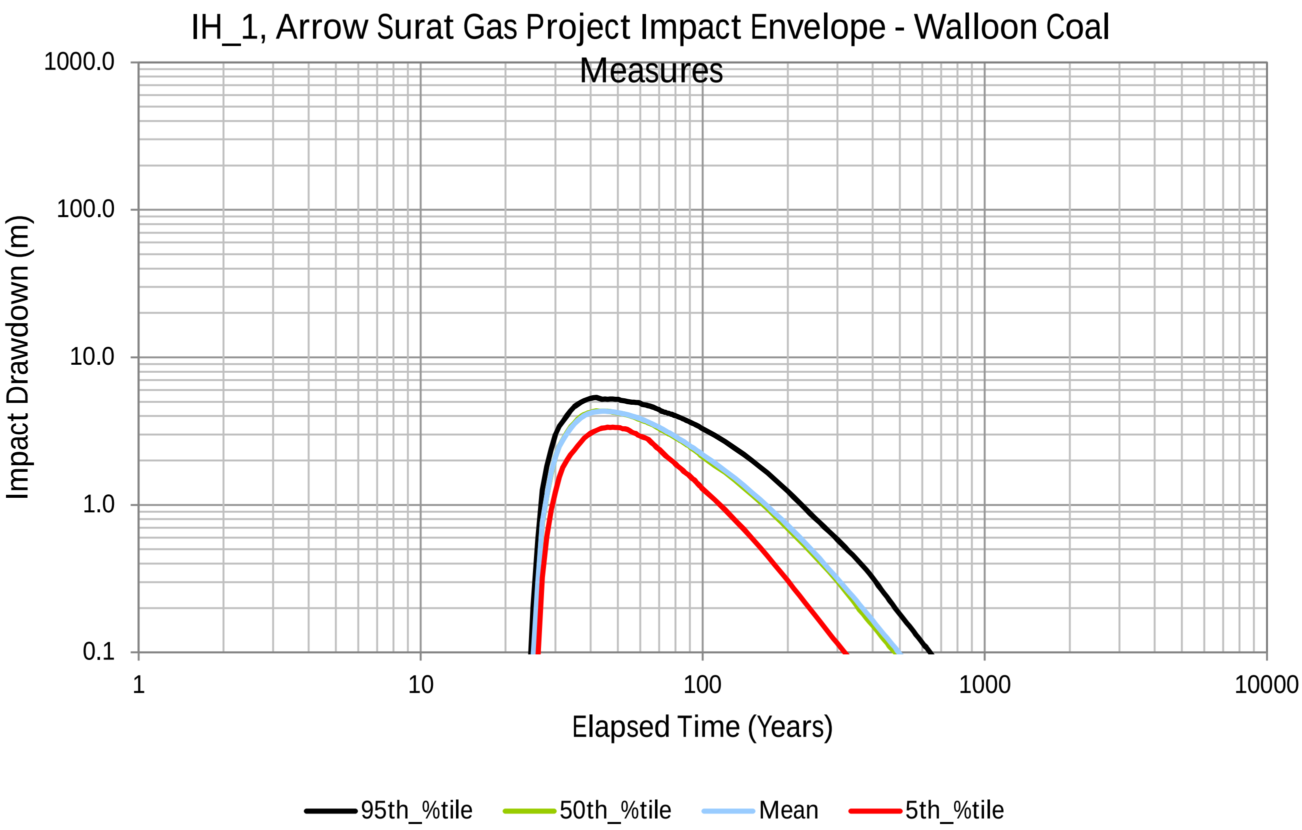
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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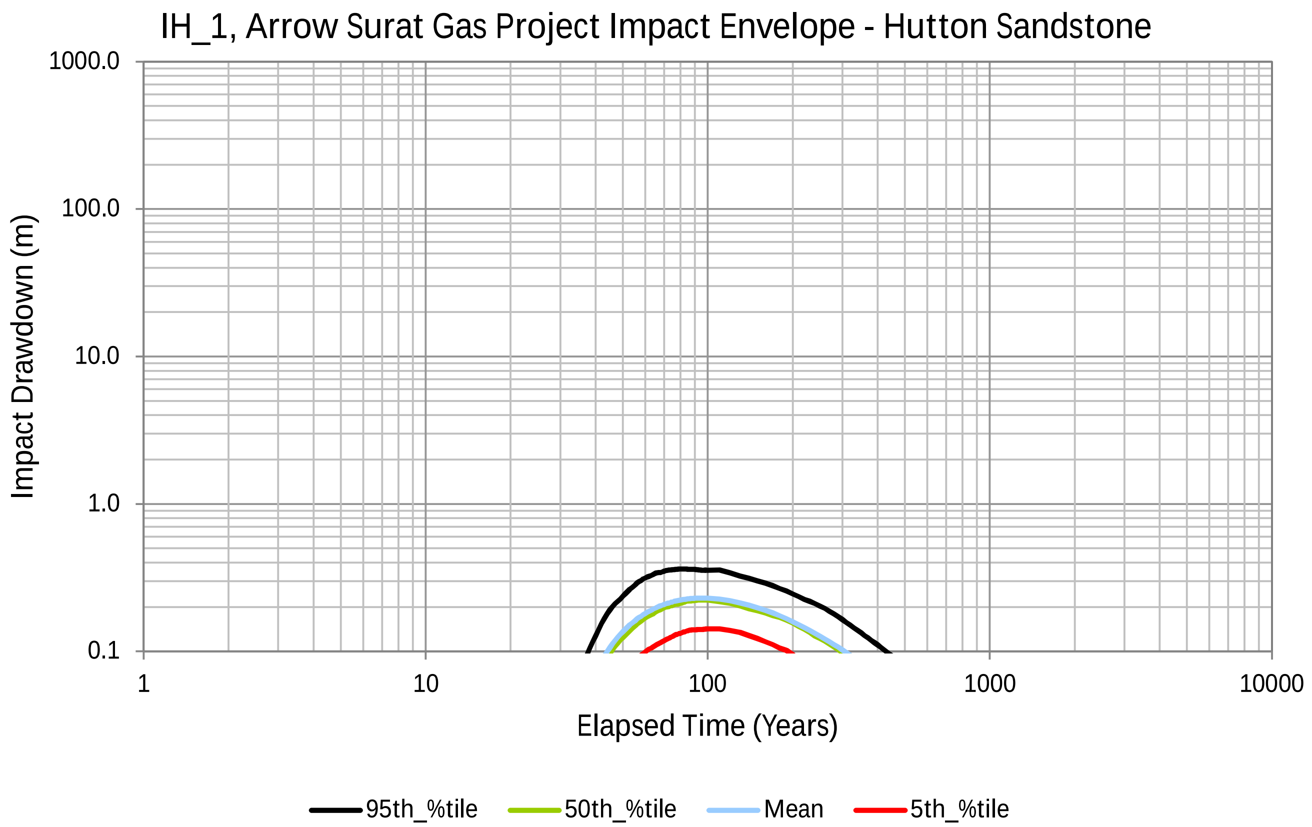
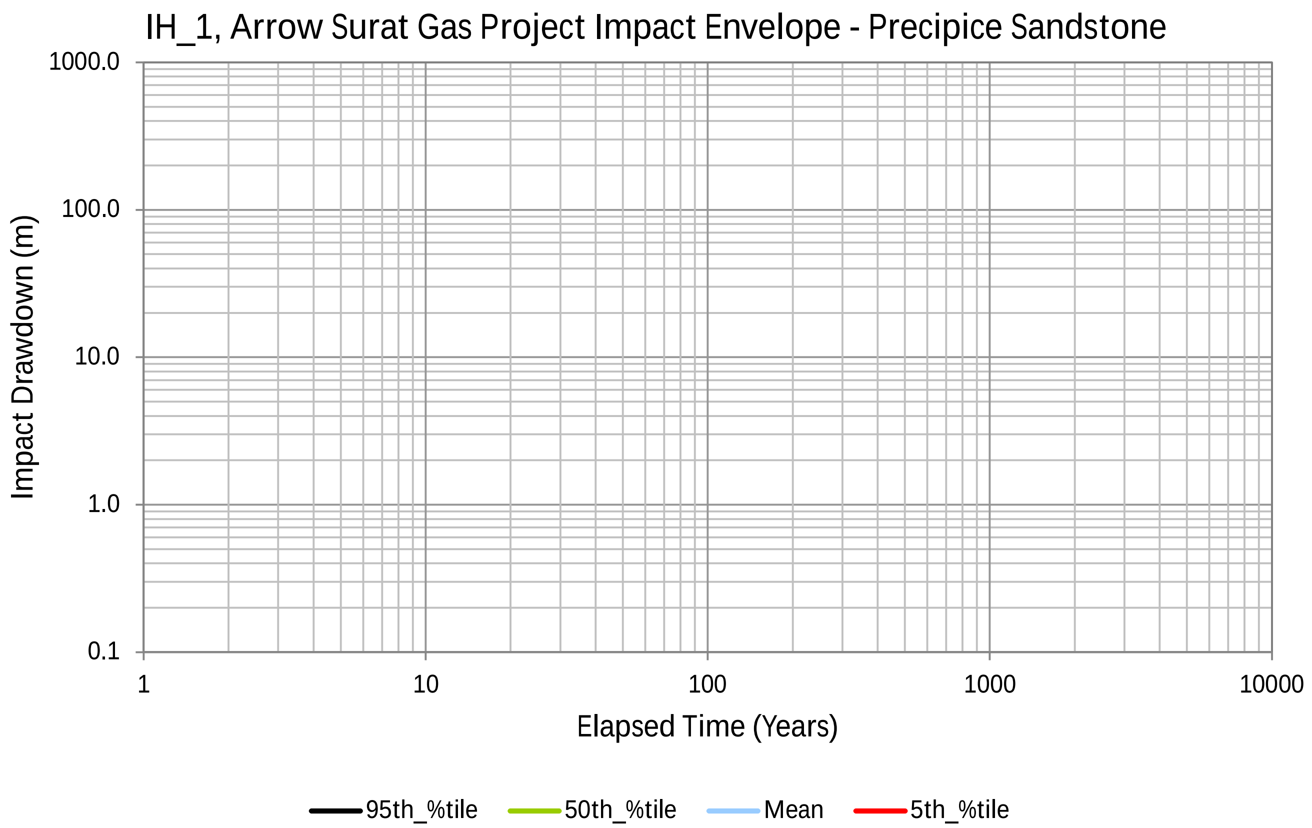
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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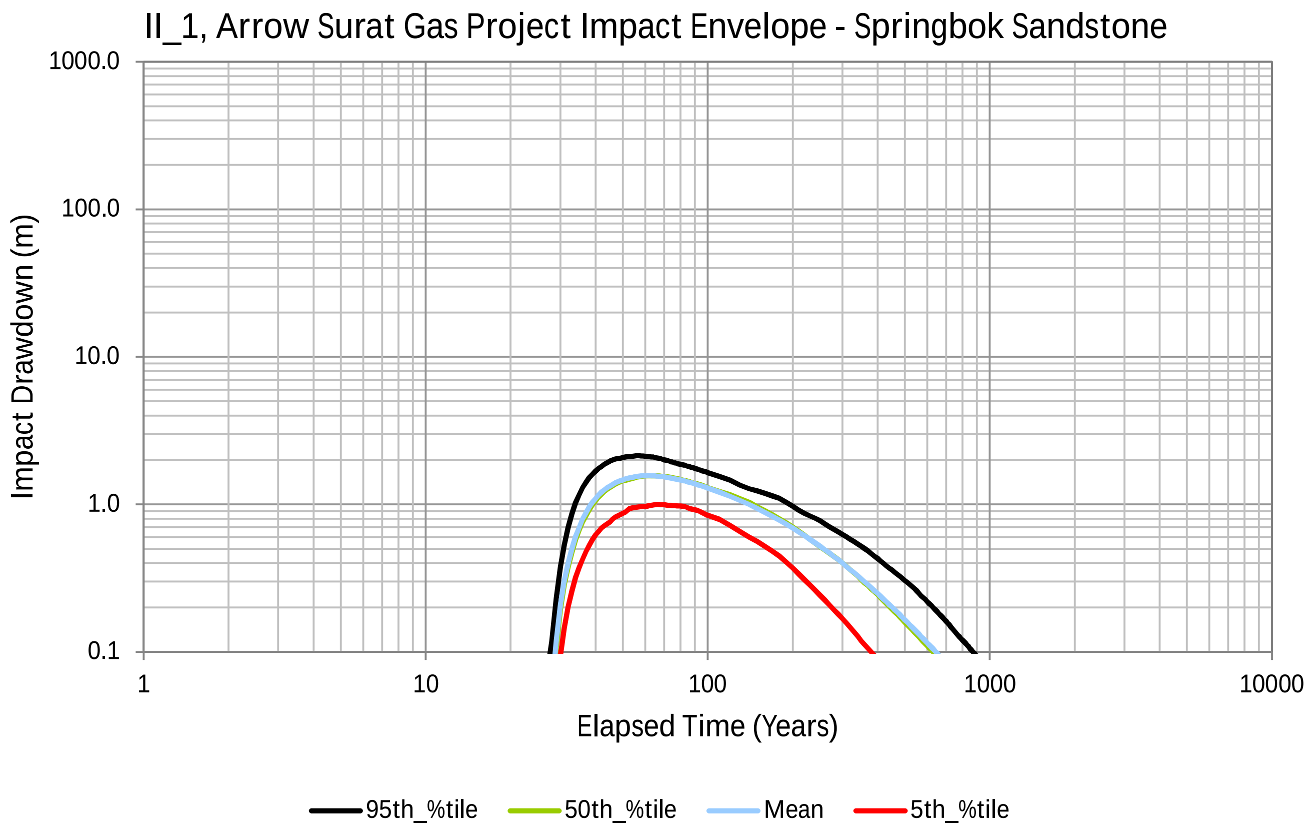
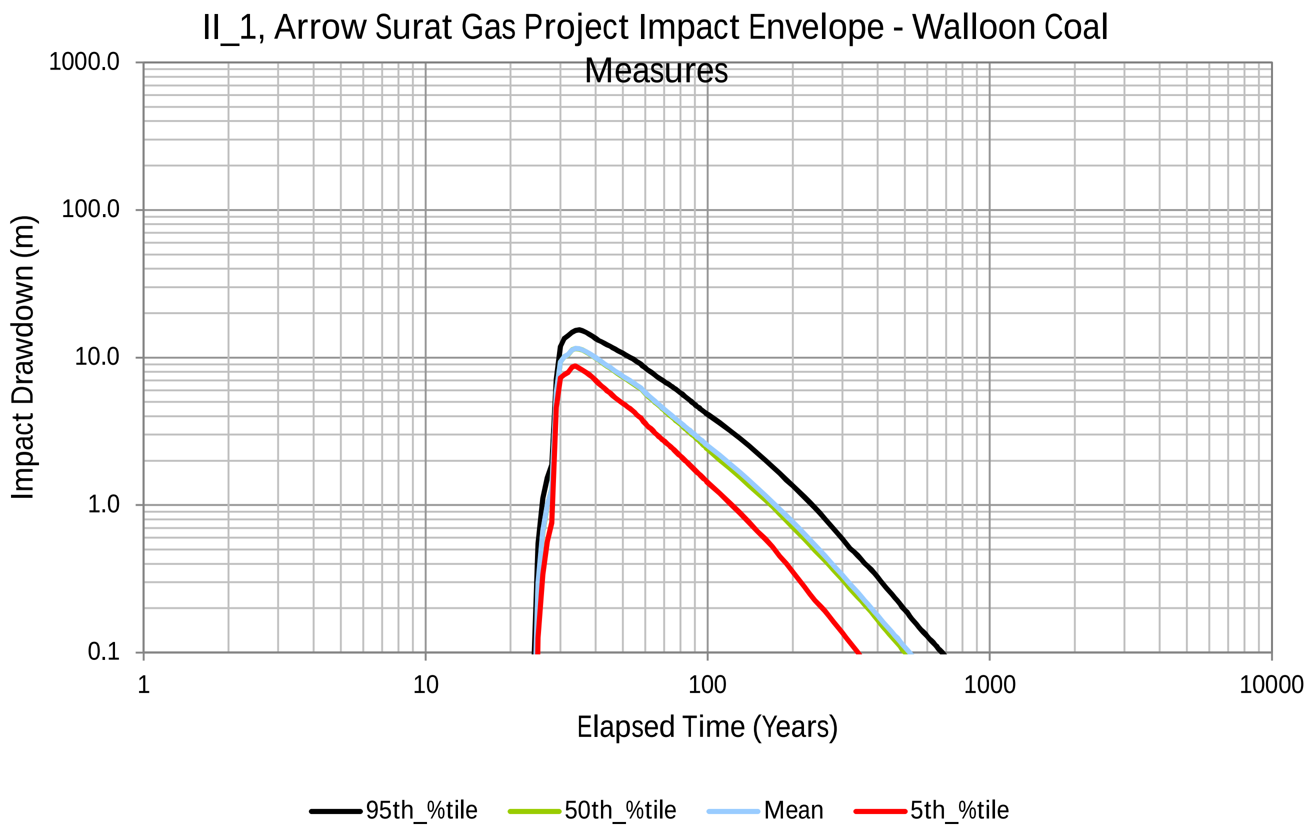
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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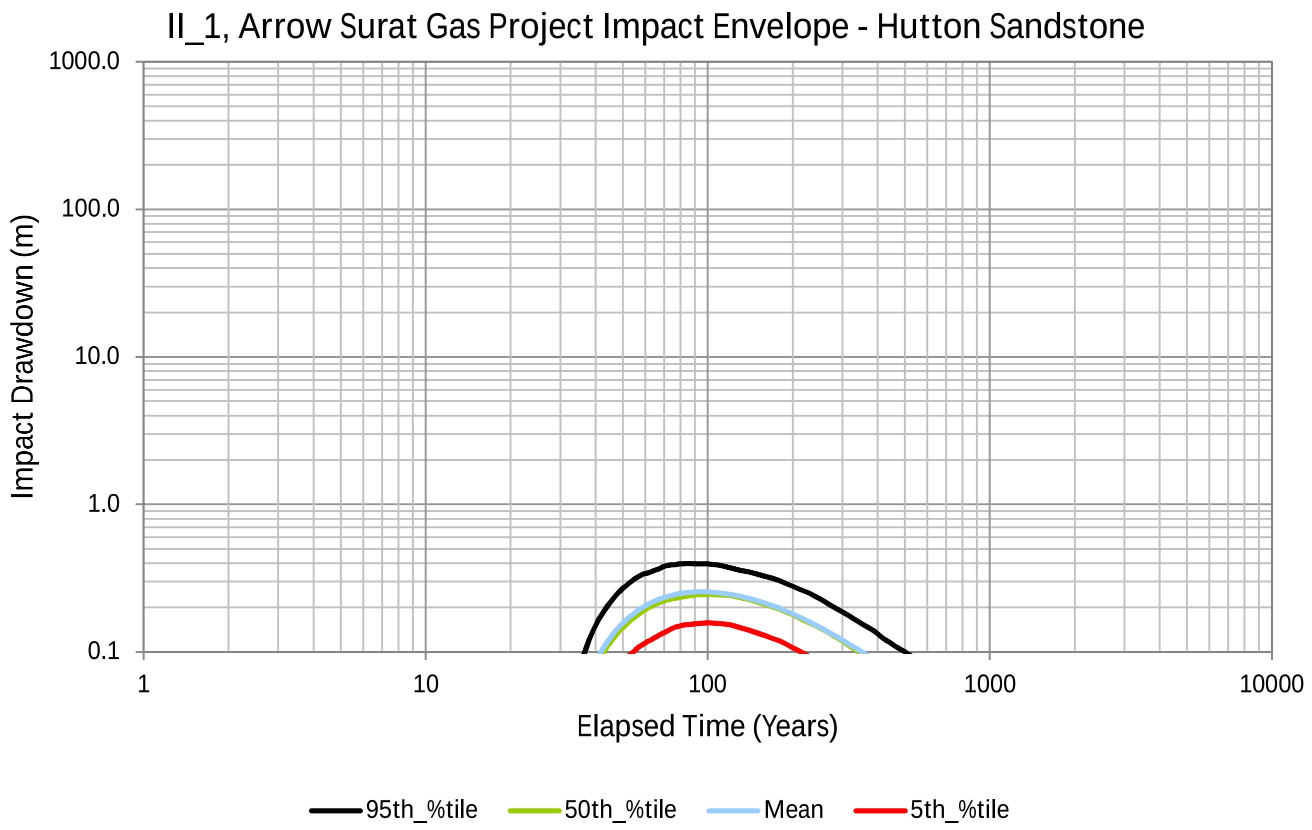
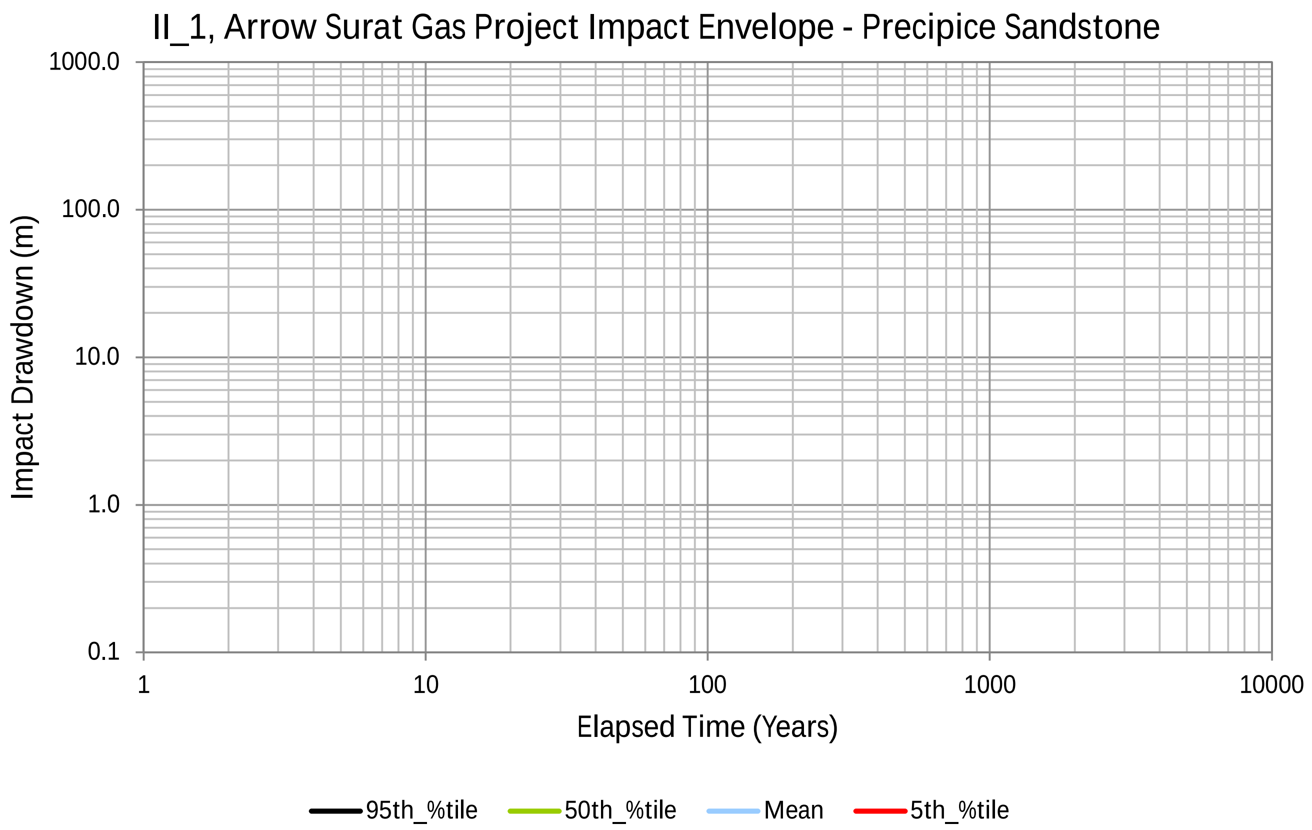
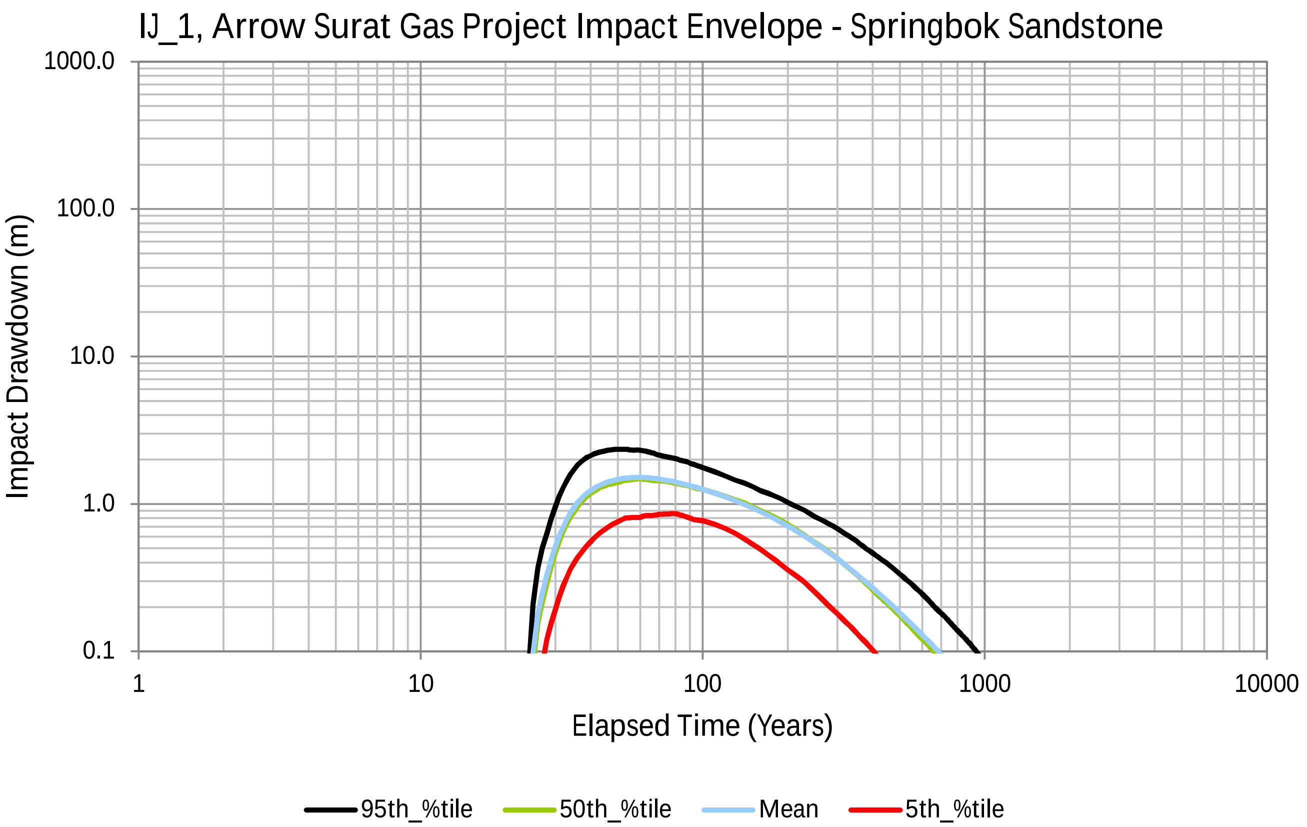
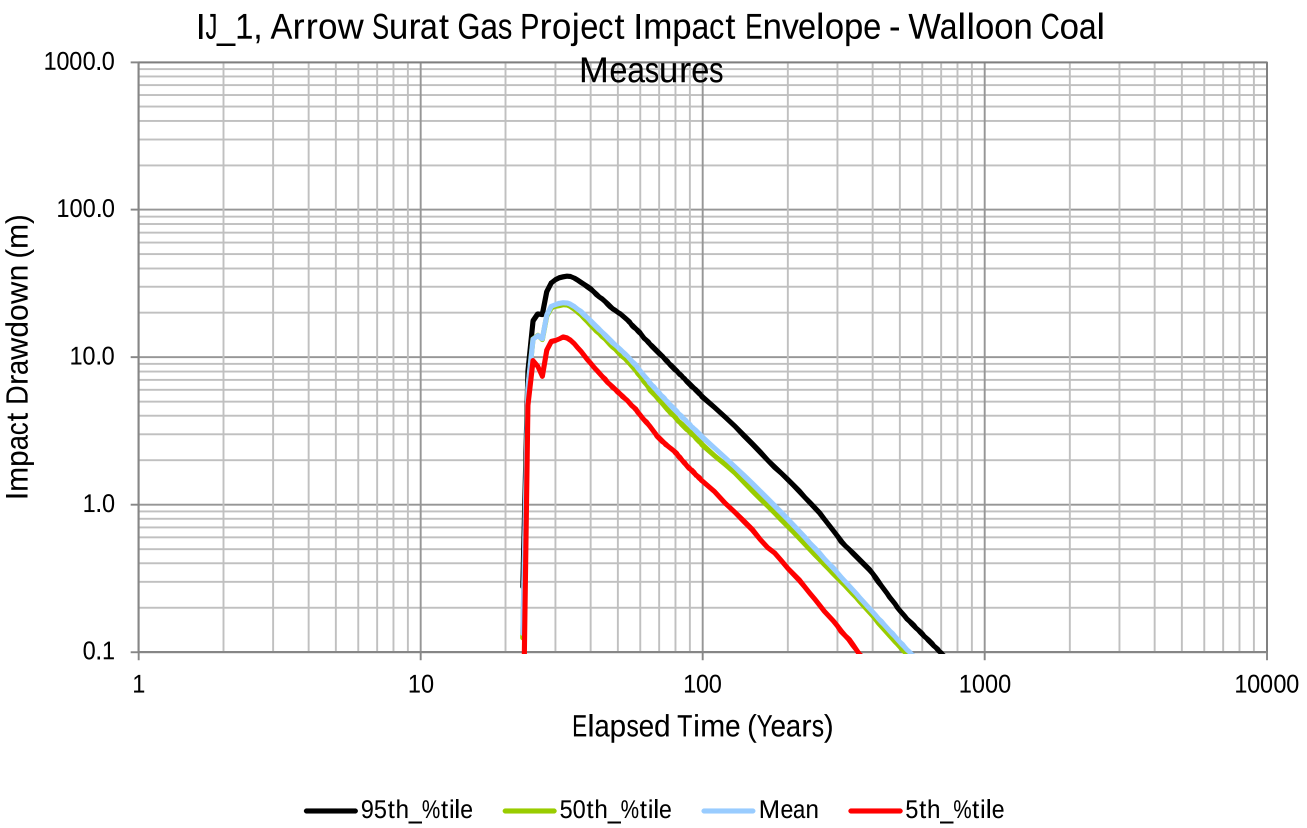
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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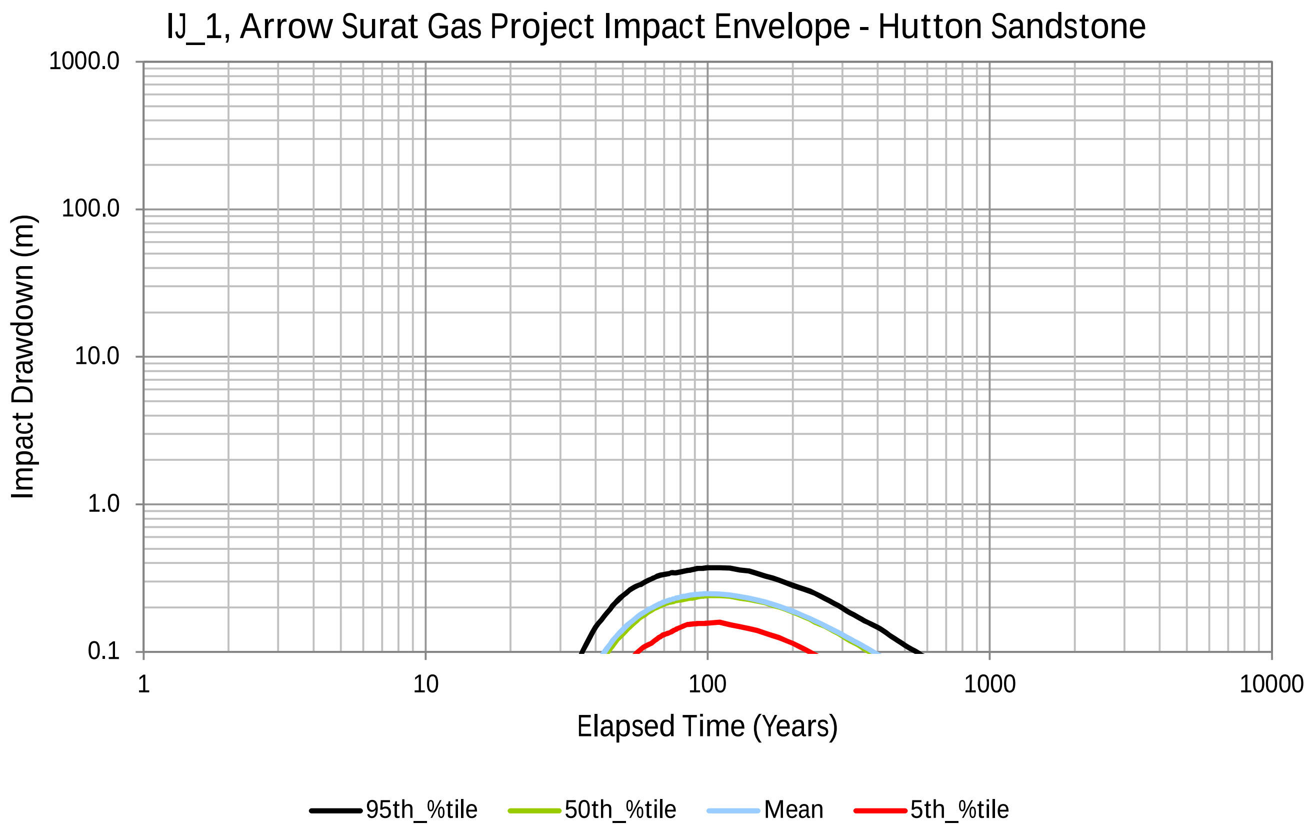
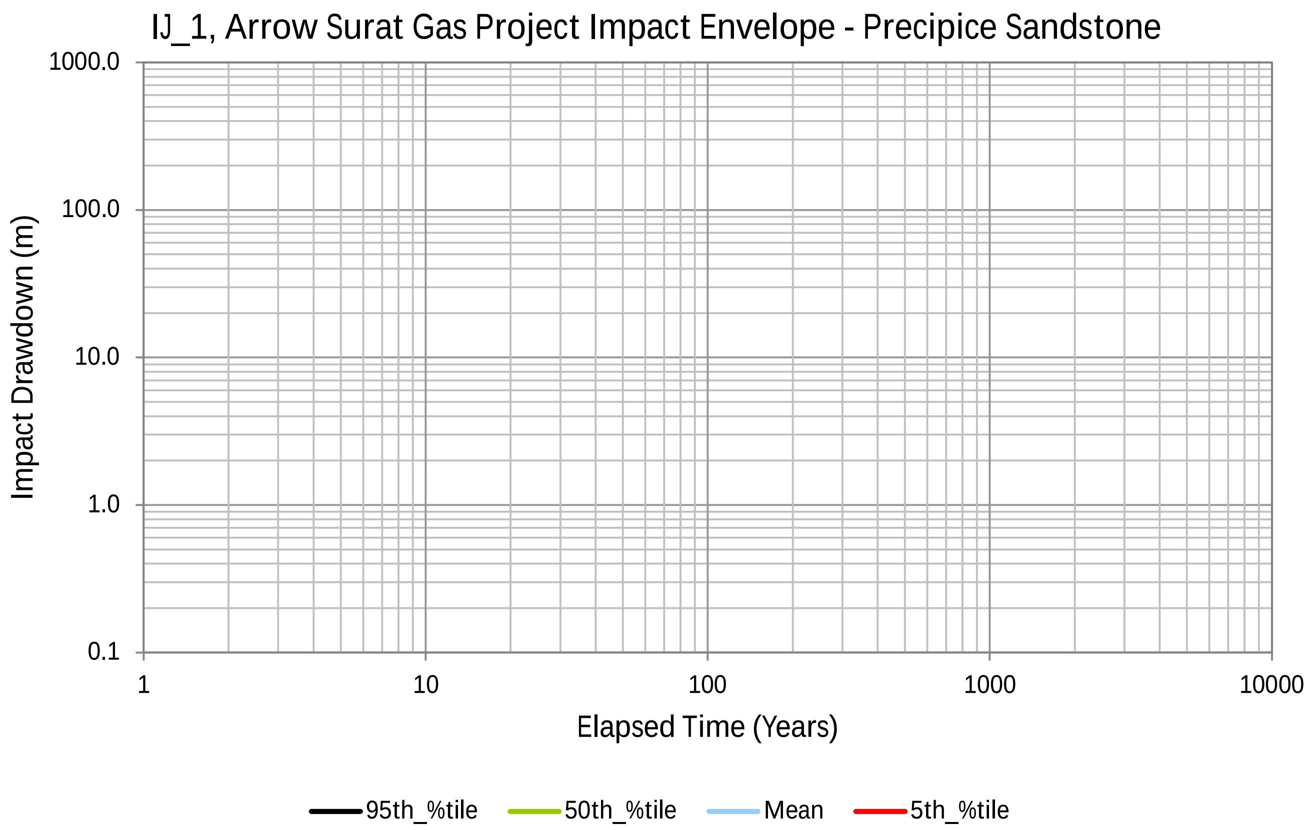
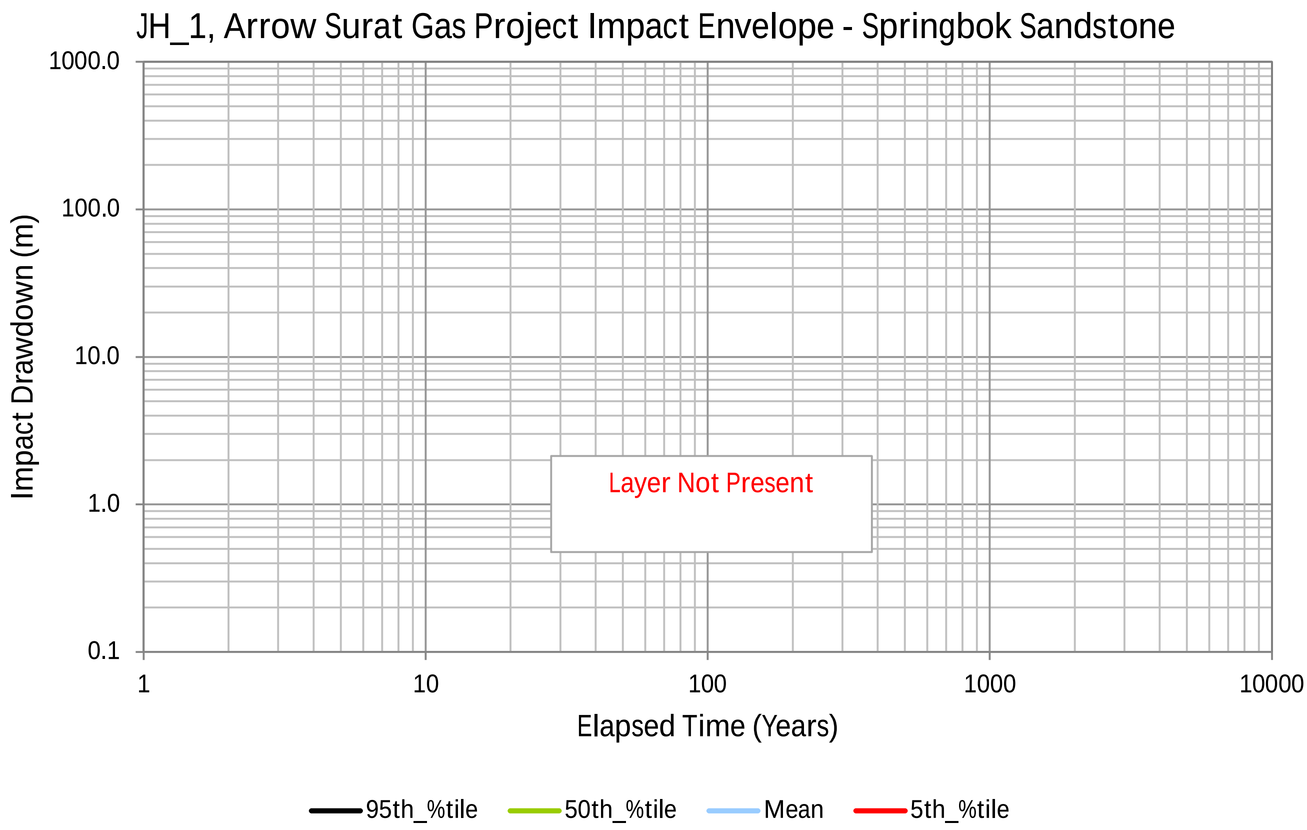
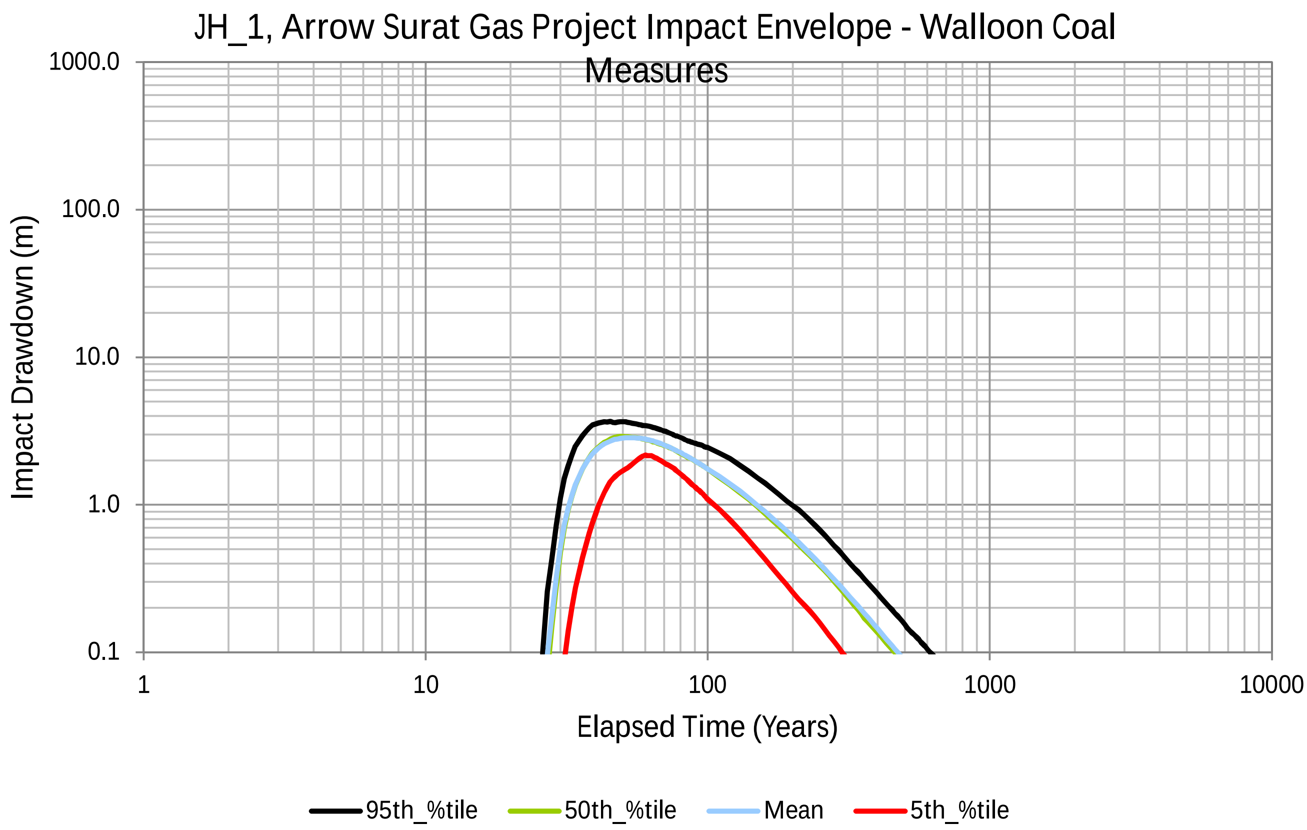
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2



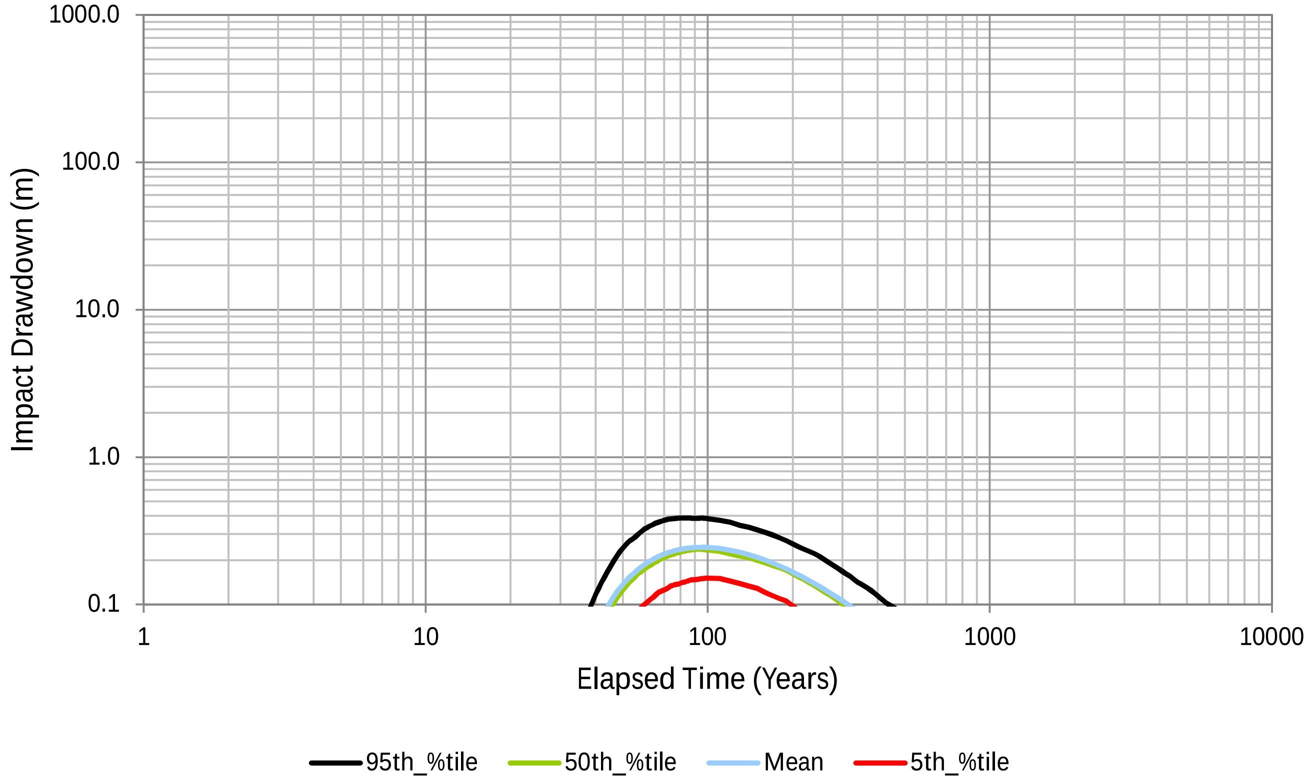


Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2

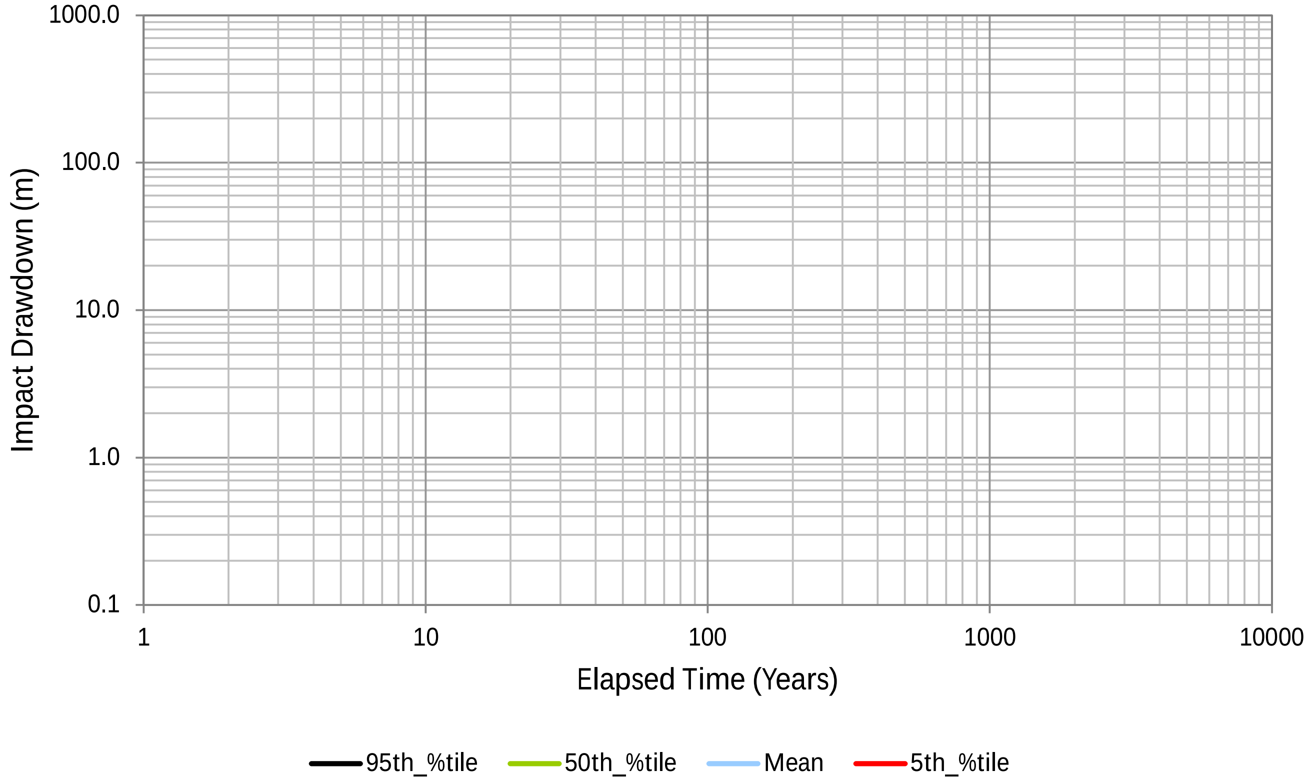




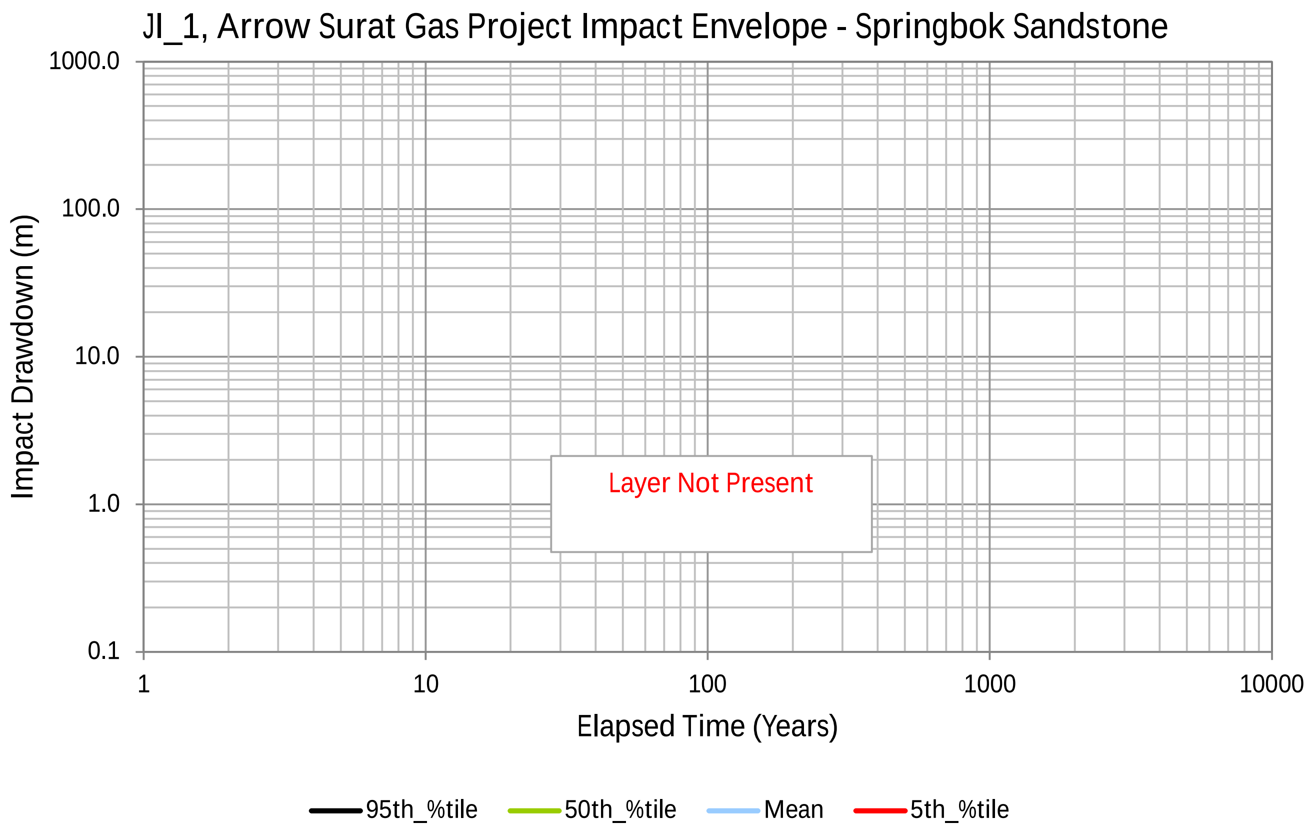
JH_1, Arrow Surat Gas Project Impact Envelope - Hutton Sandstone

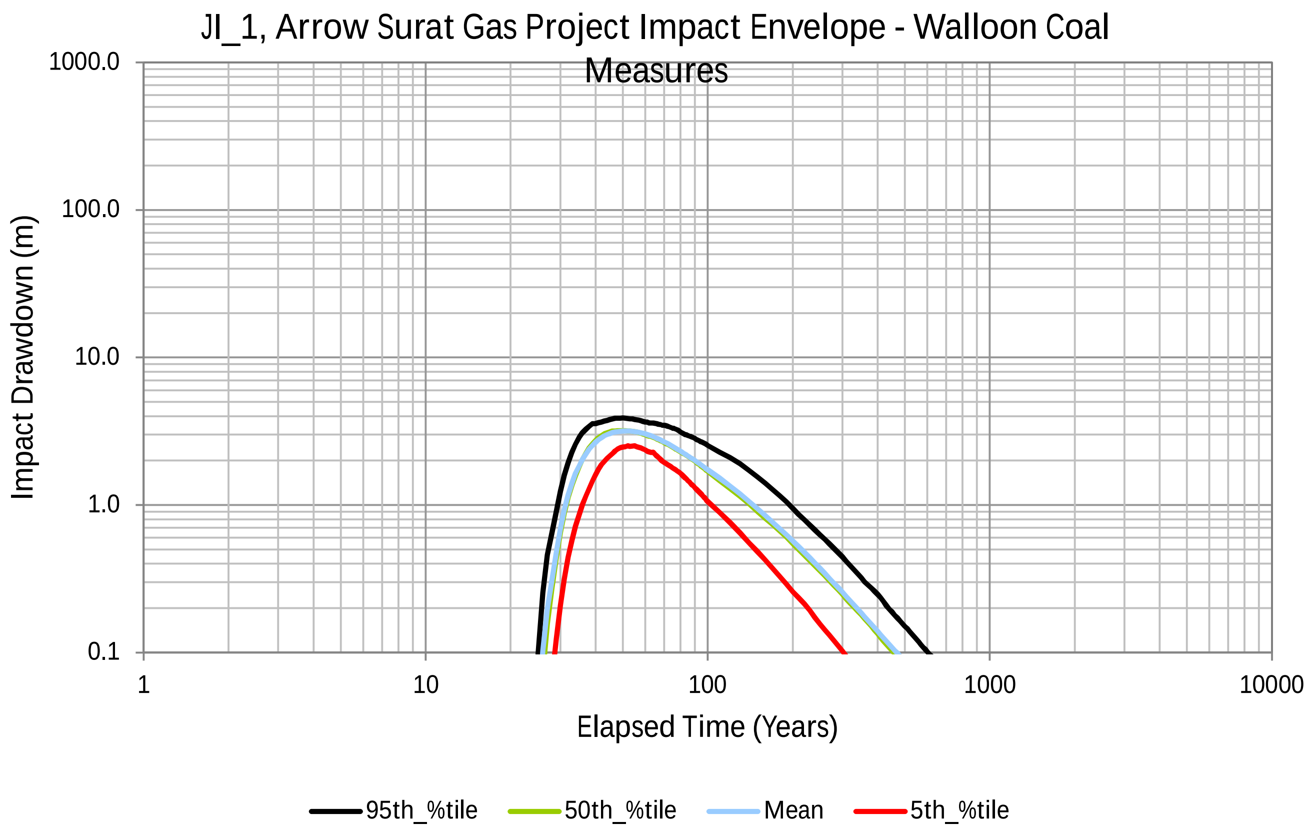


JH_1, Arrow Surat Gas Project Impact Envelope - Precipice Sandstone



Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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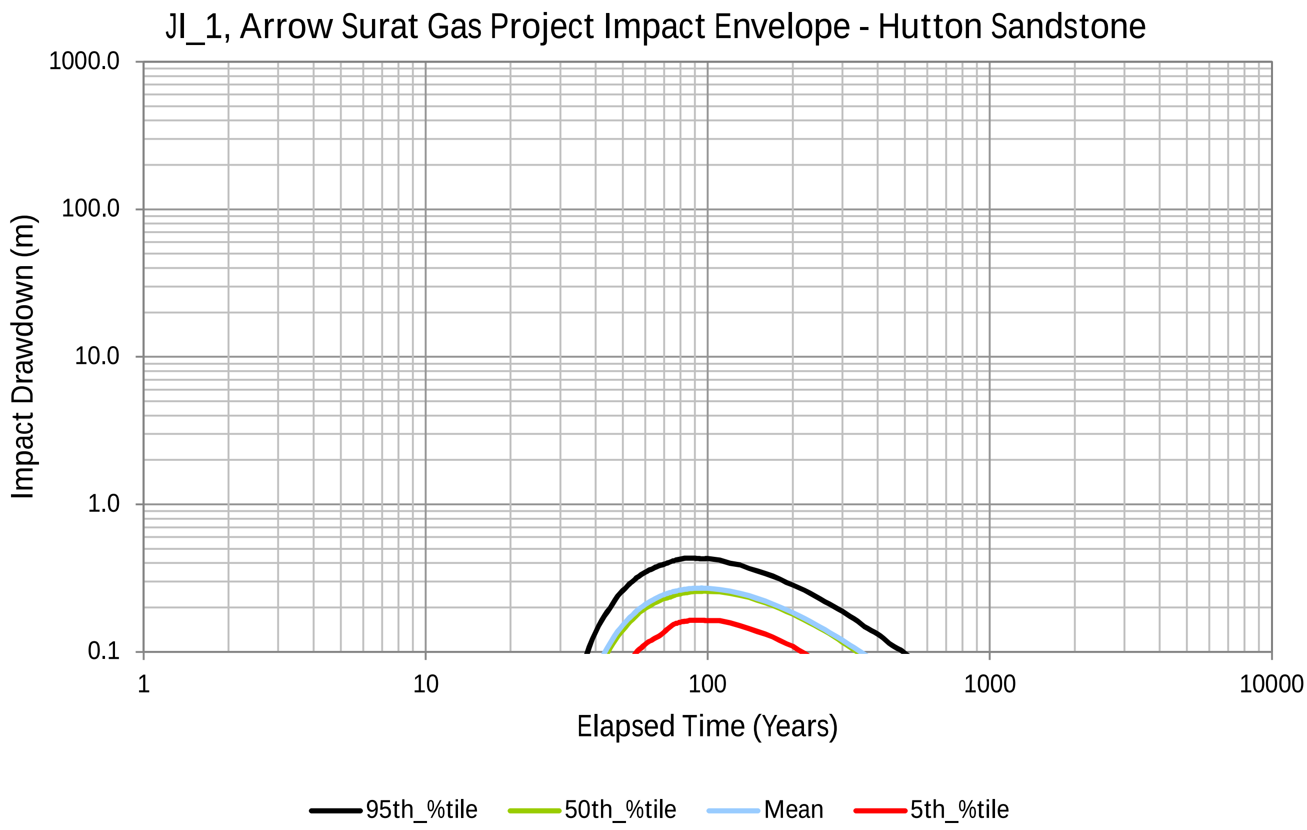
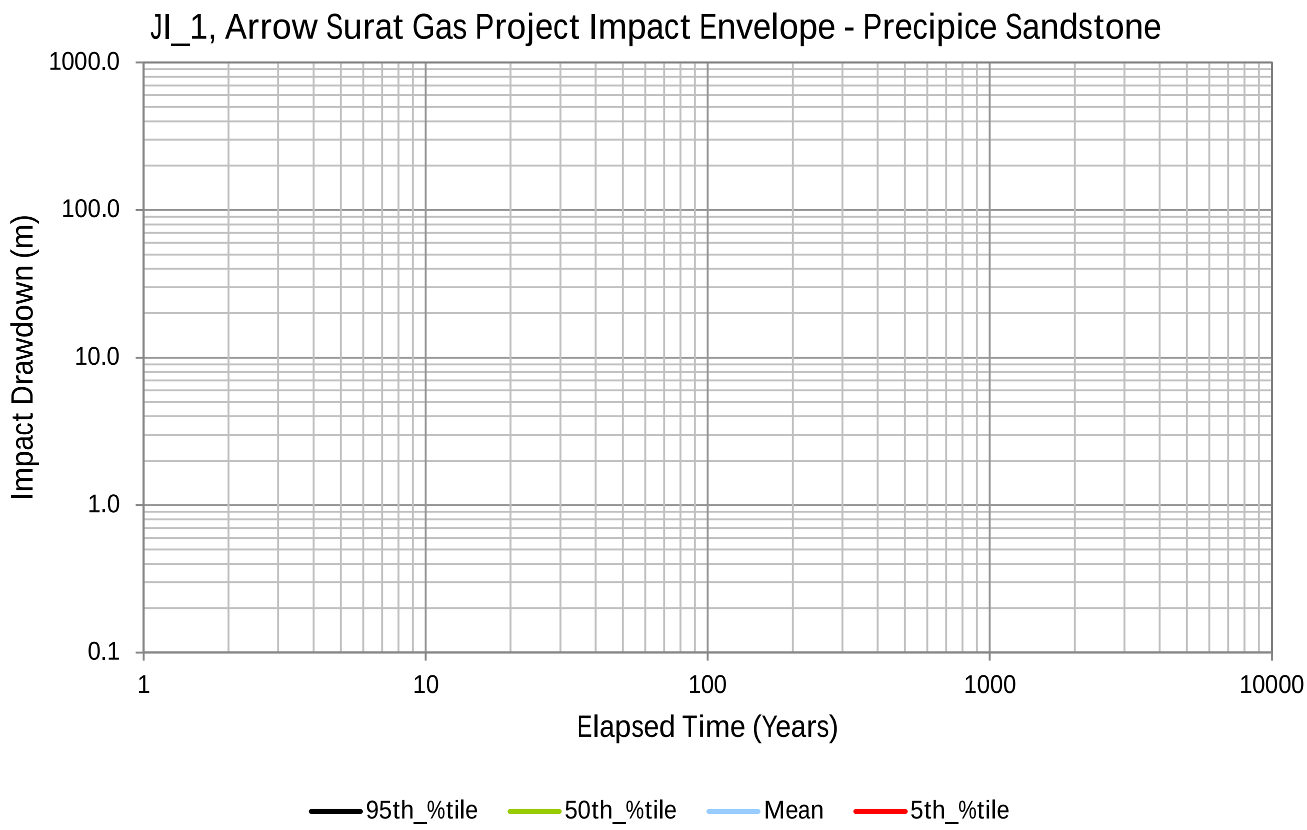
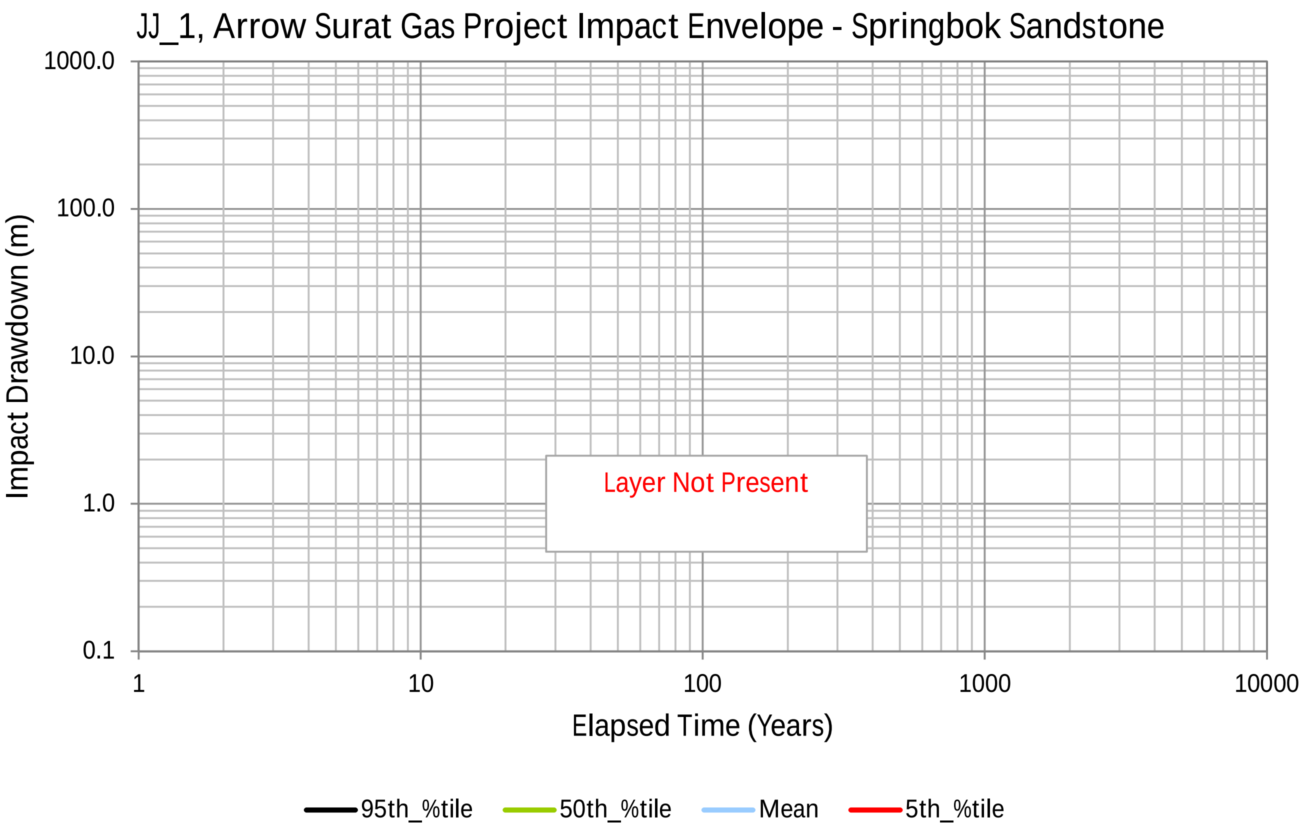
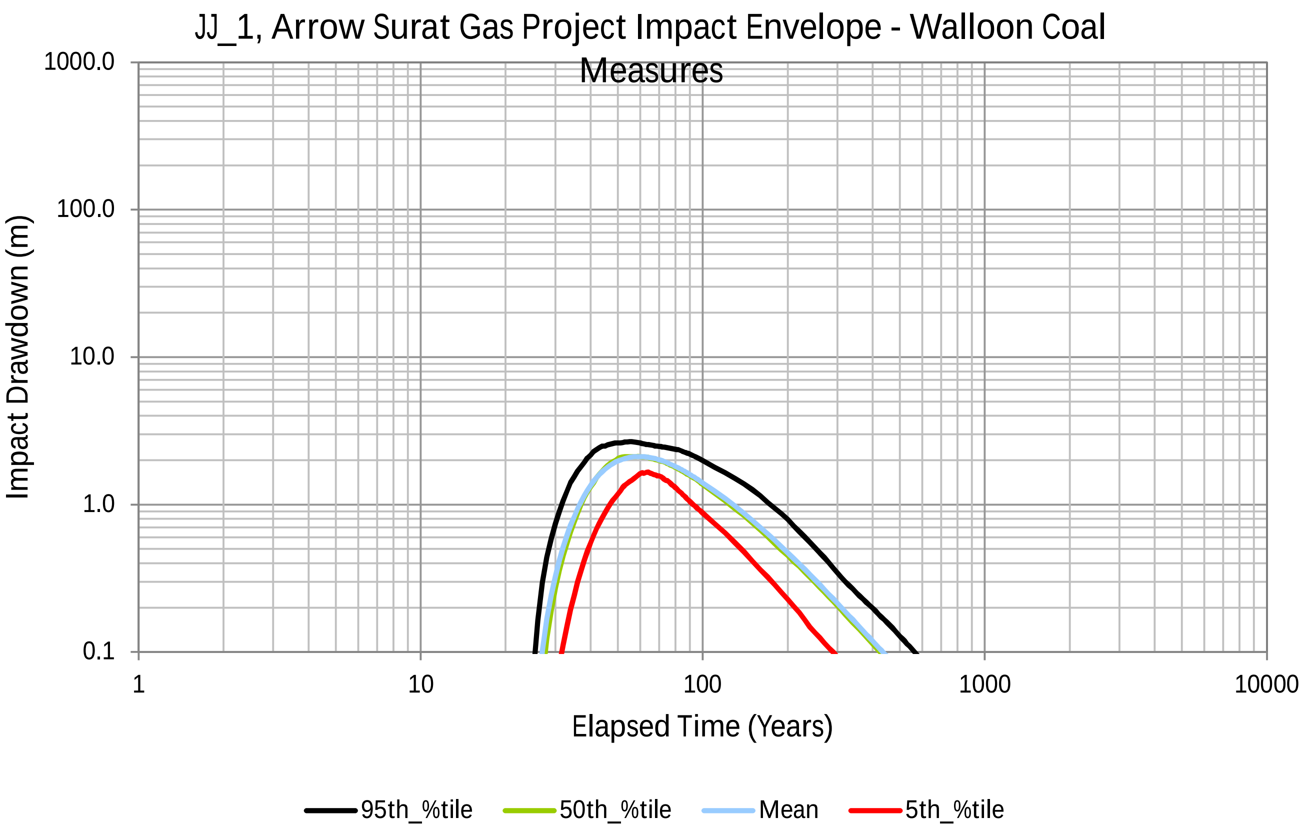

JI_1, Arrow Surat Gas Project Impact Envelope - Hutton Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile


JI_1, Arrow Surat Gas Project Impact Envelope - Precipice Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

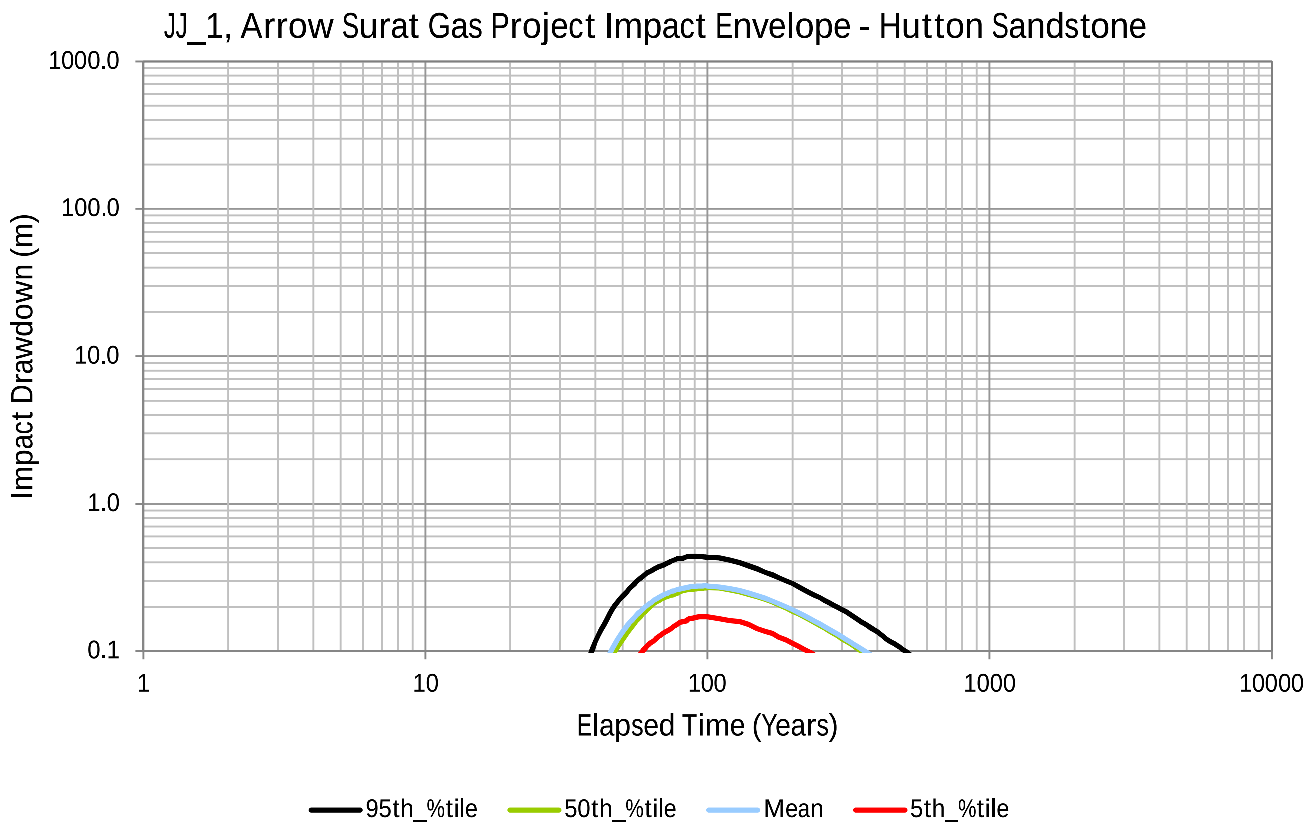
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2

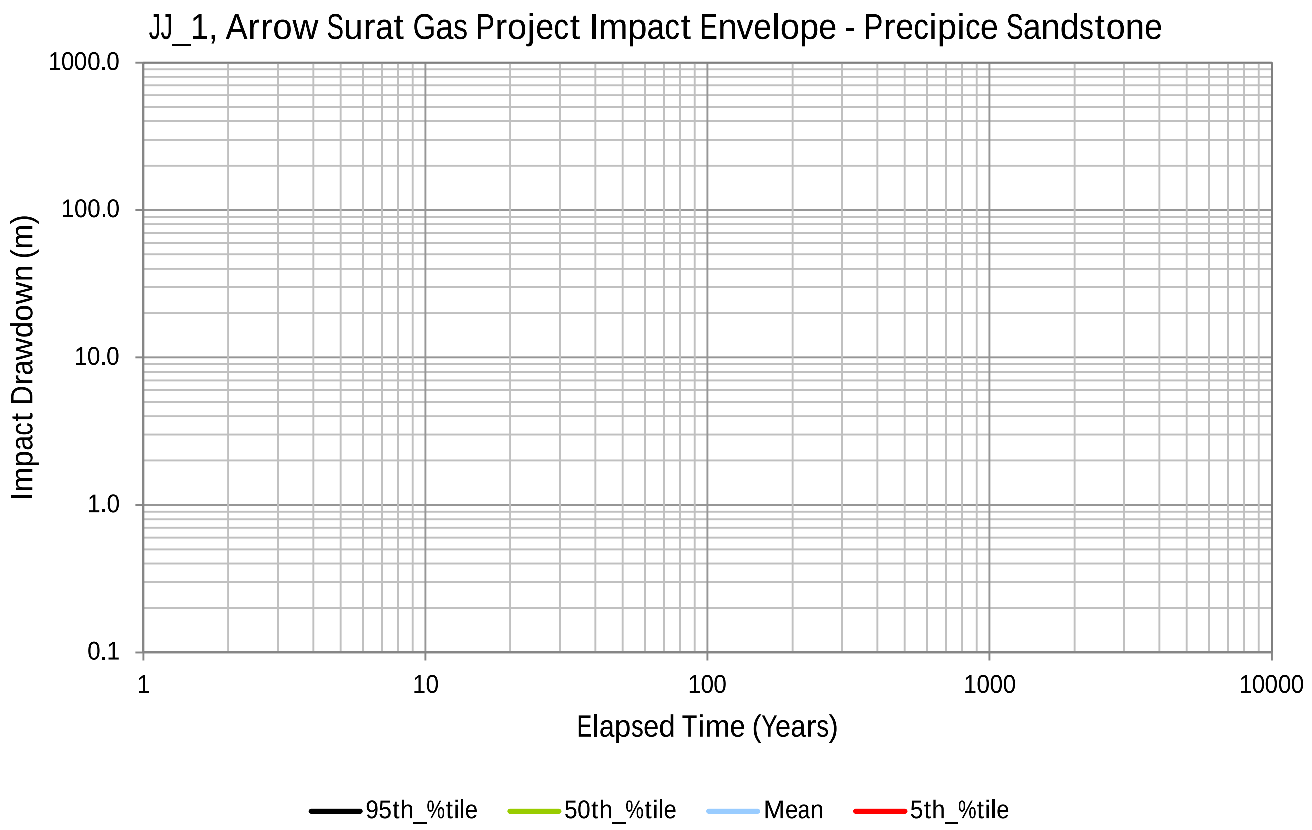




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_2)

Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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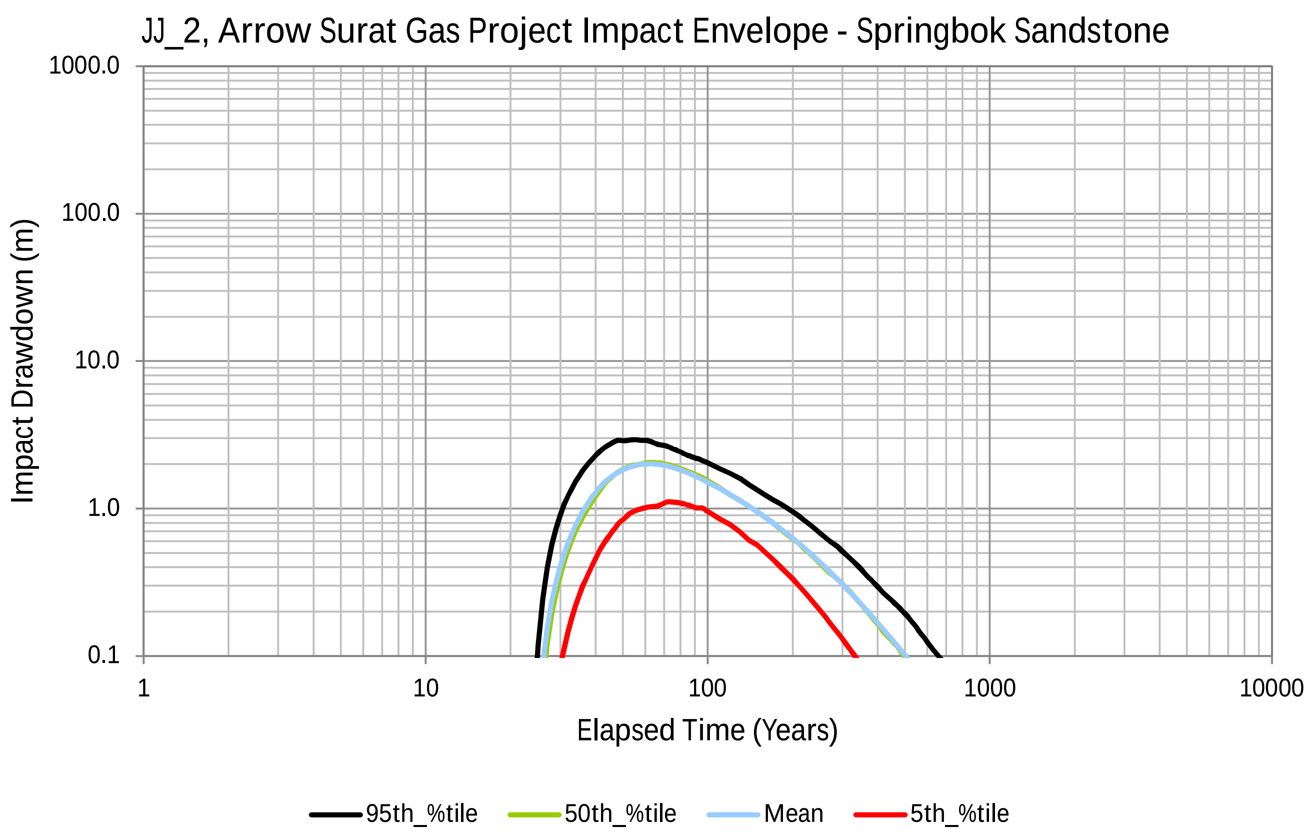
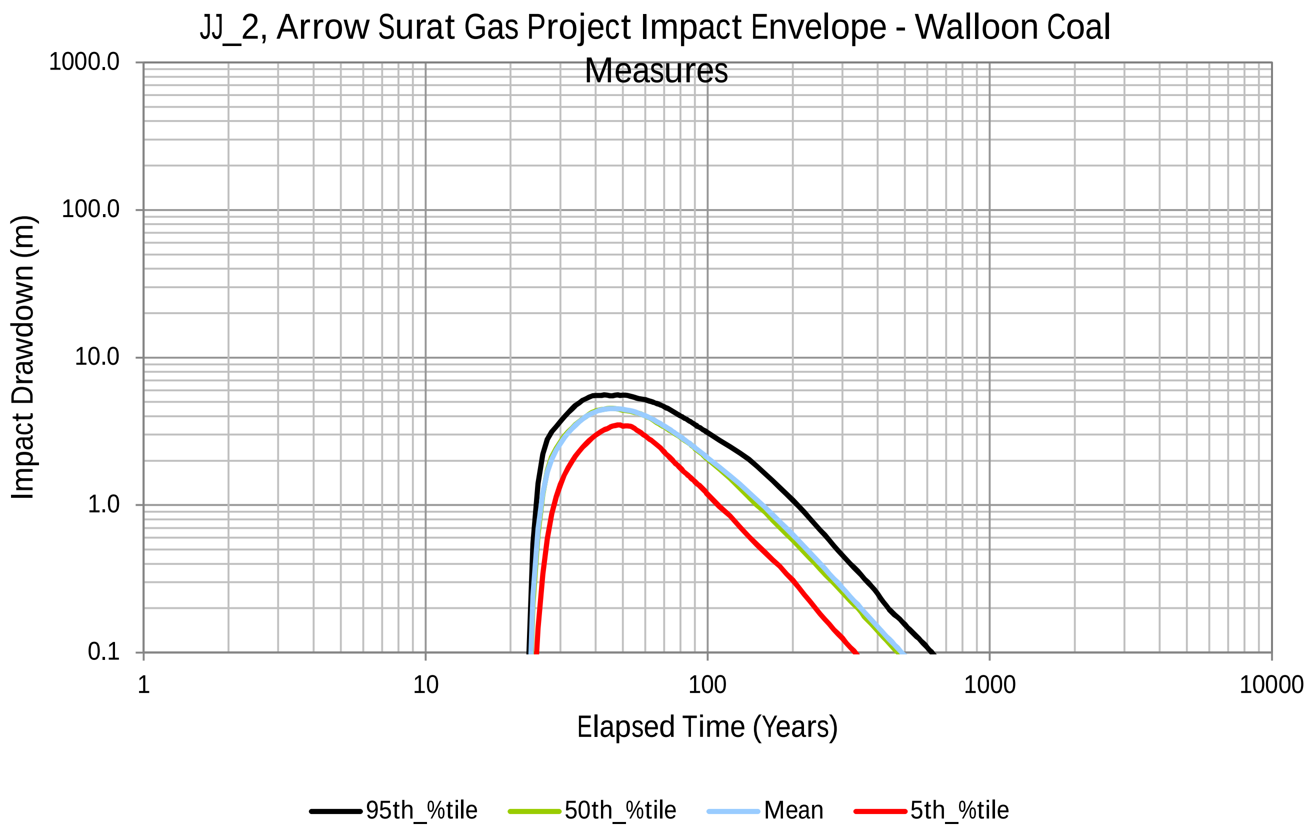
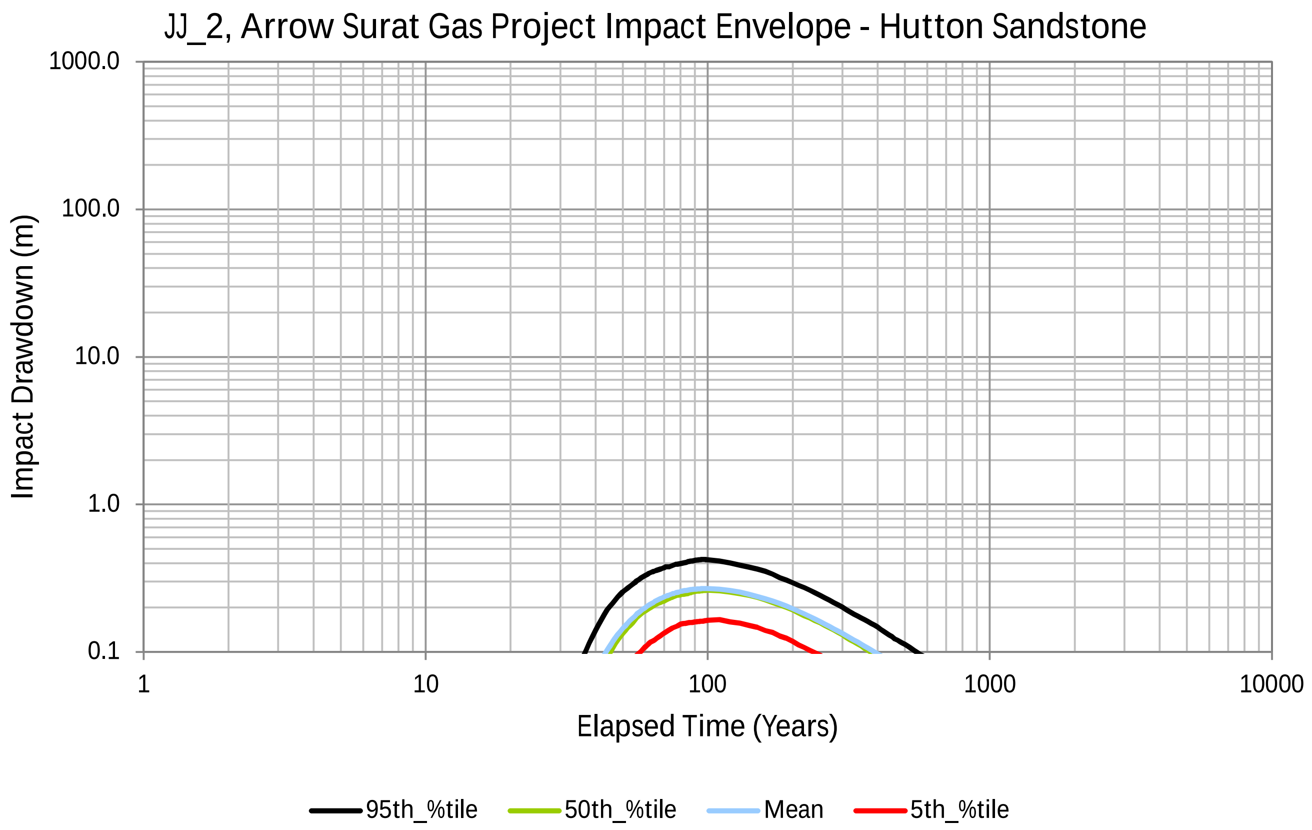
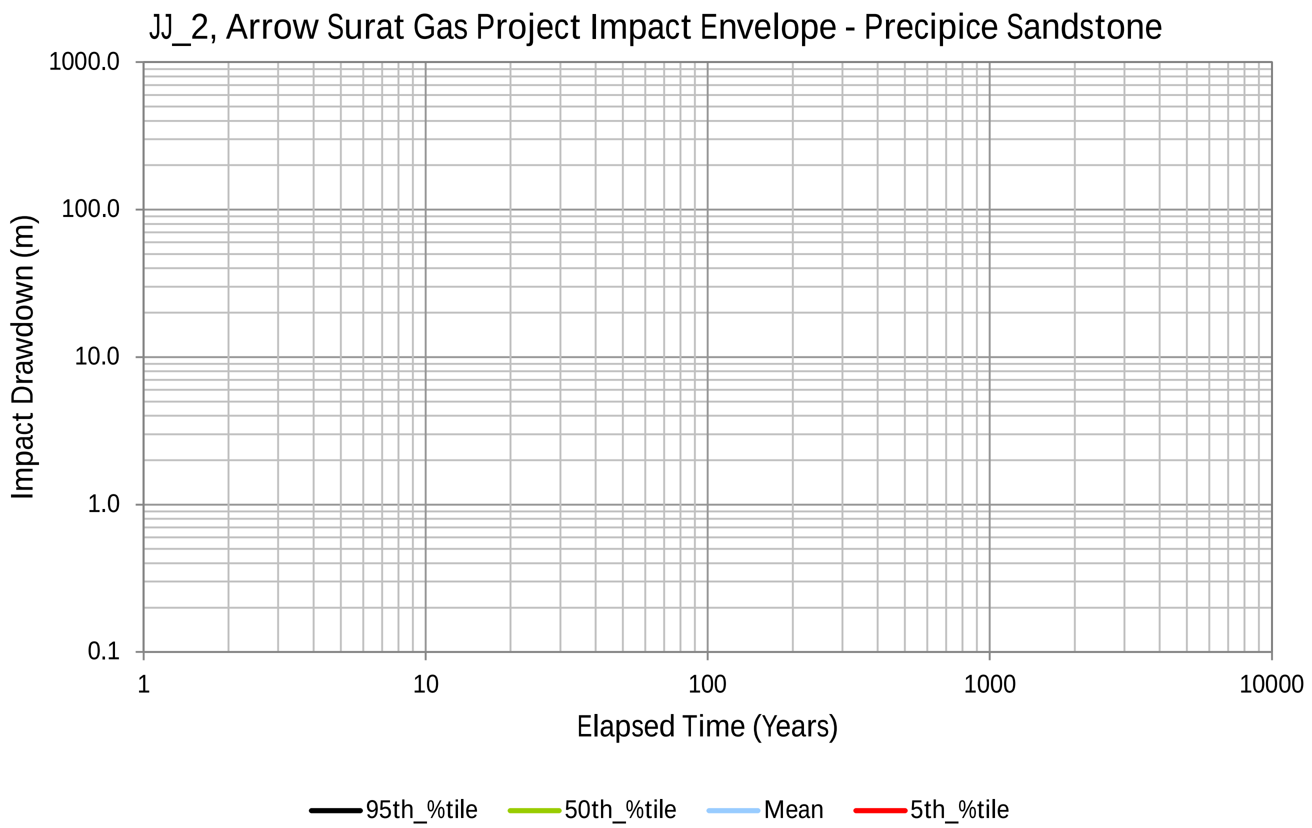
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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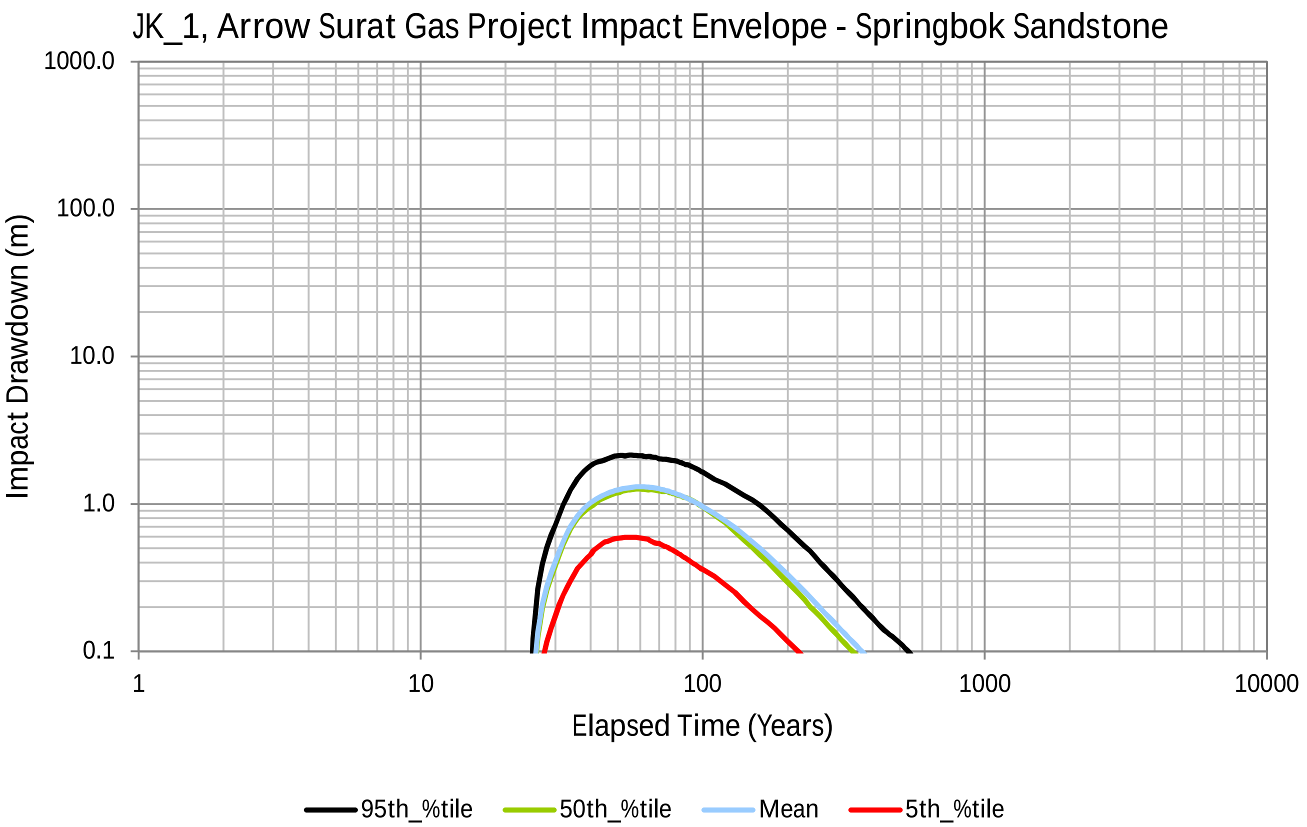
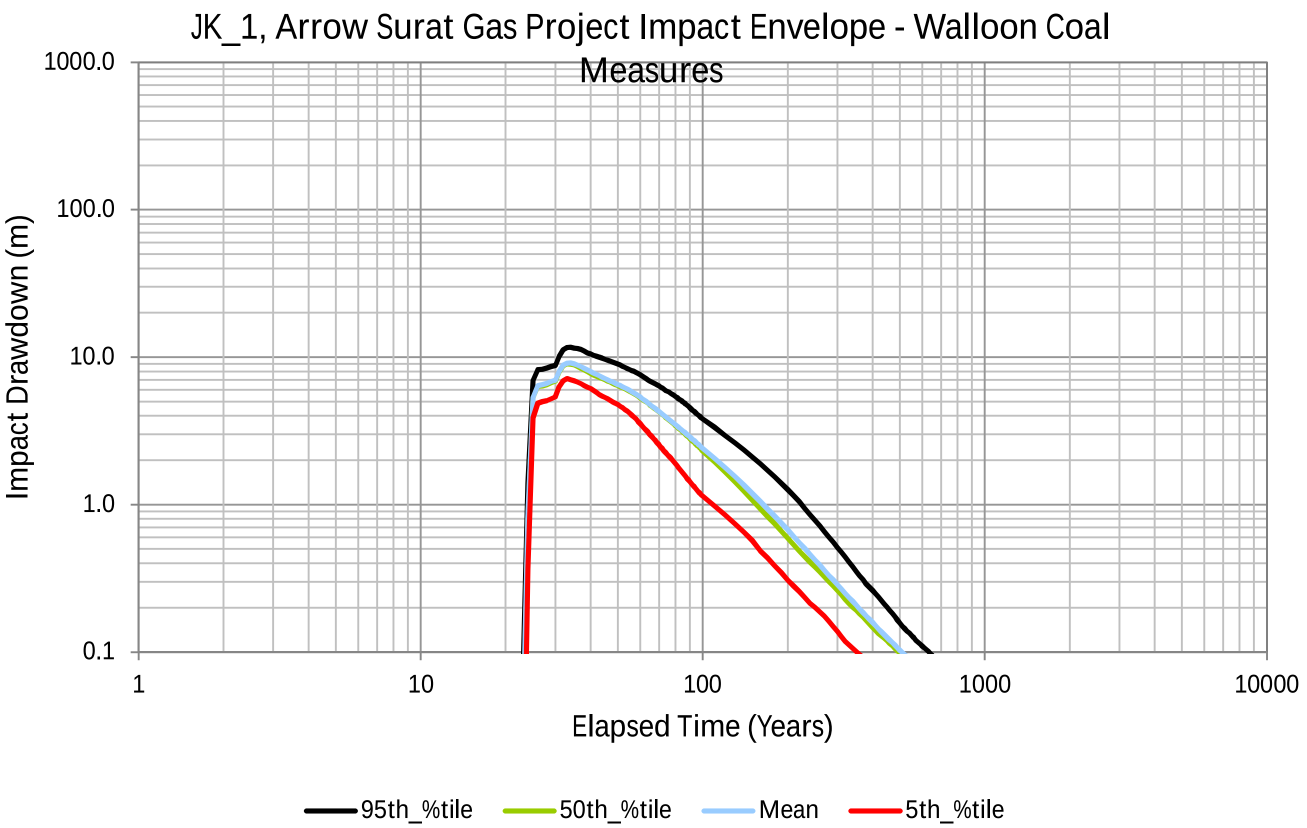
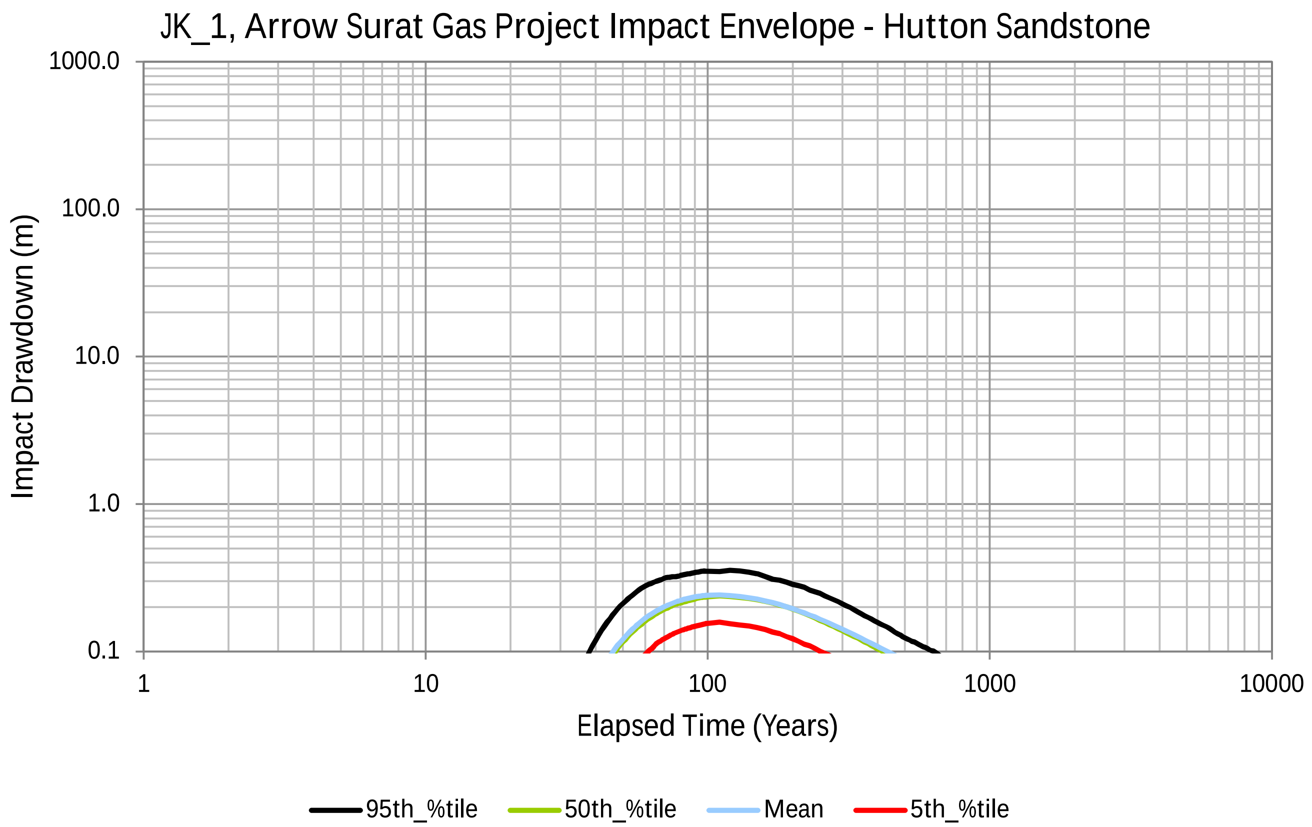
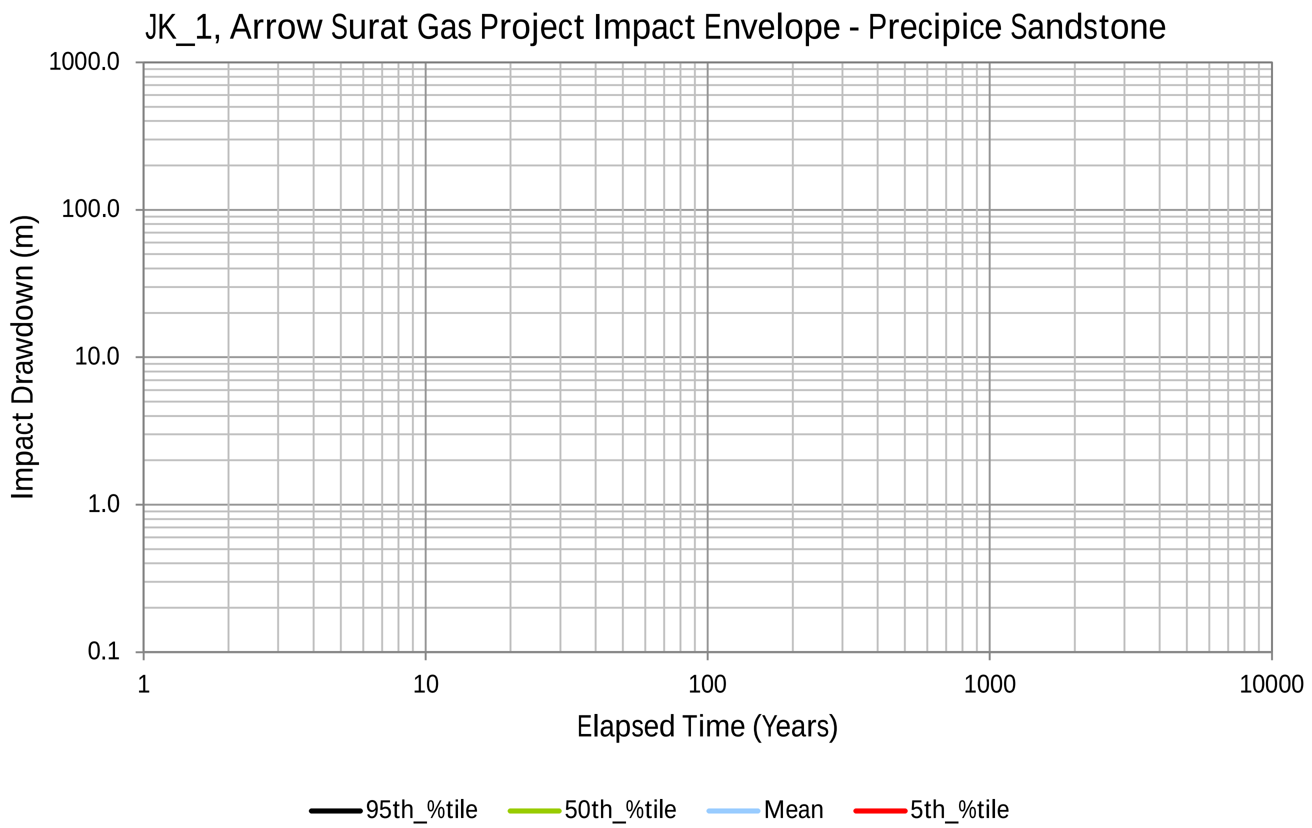
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





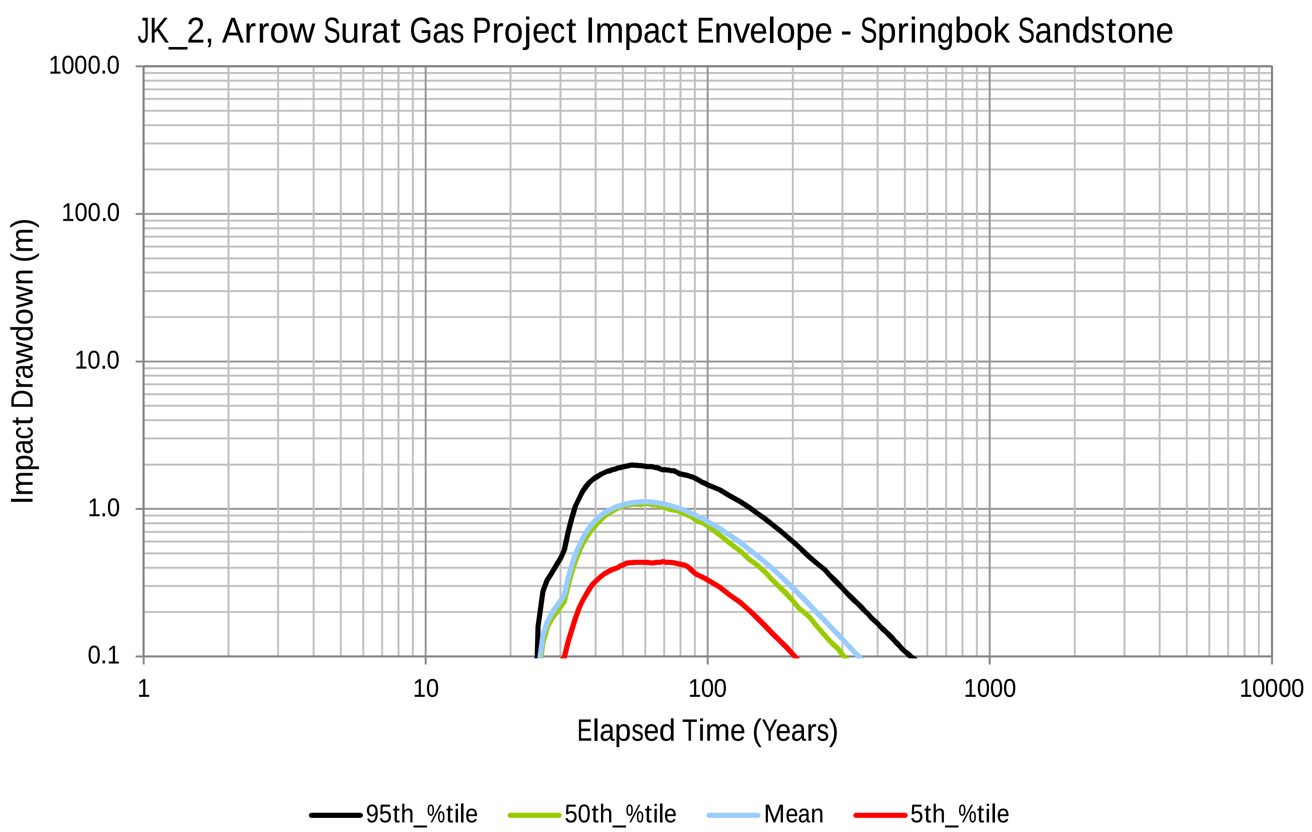
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2

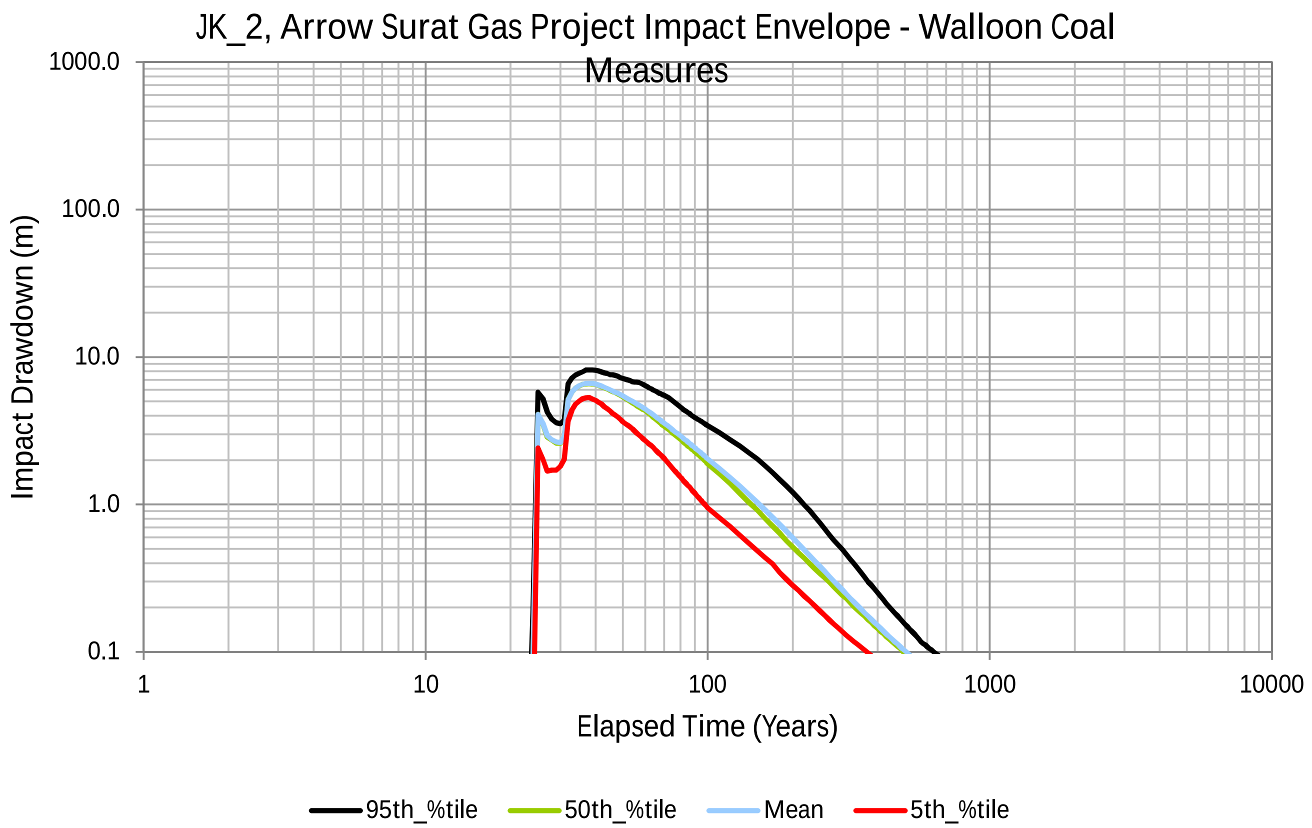




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_2)

Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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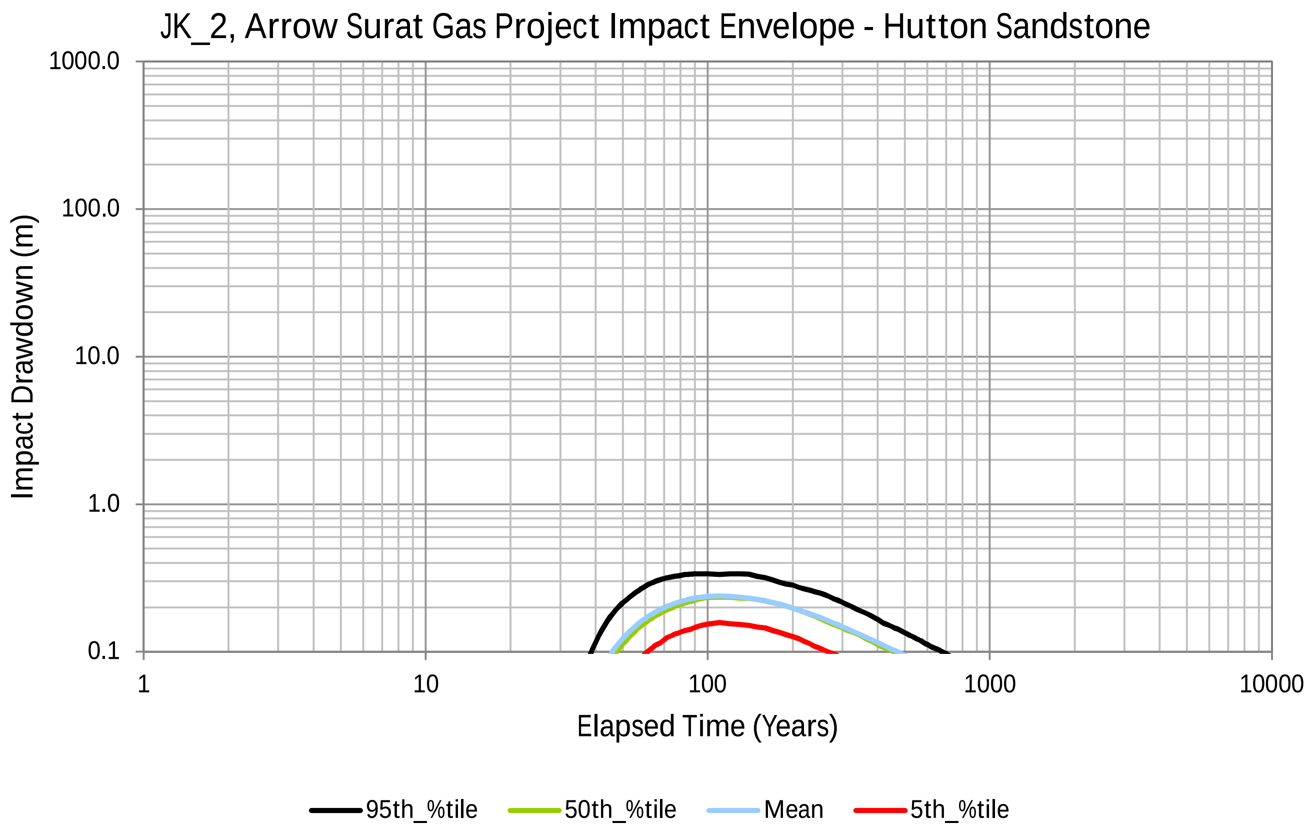
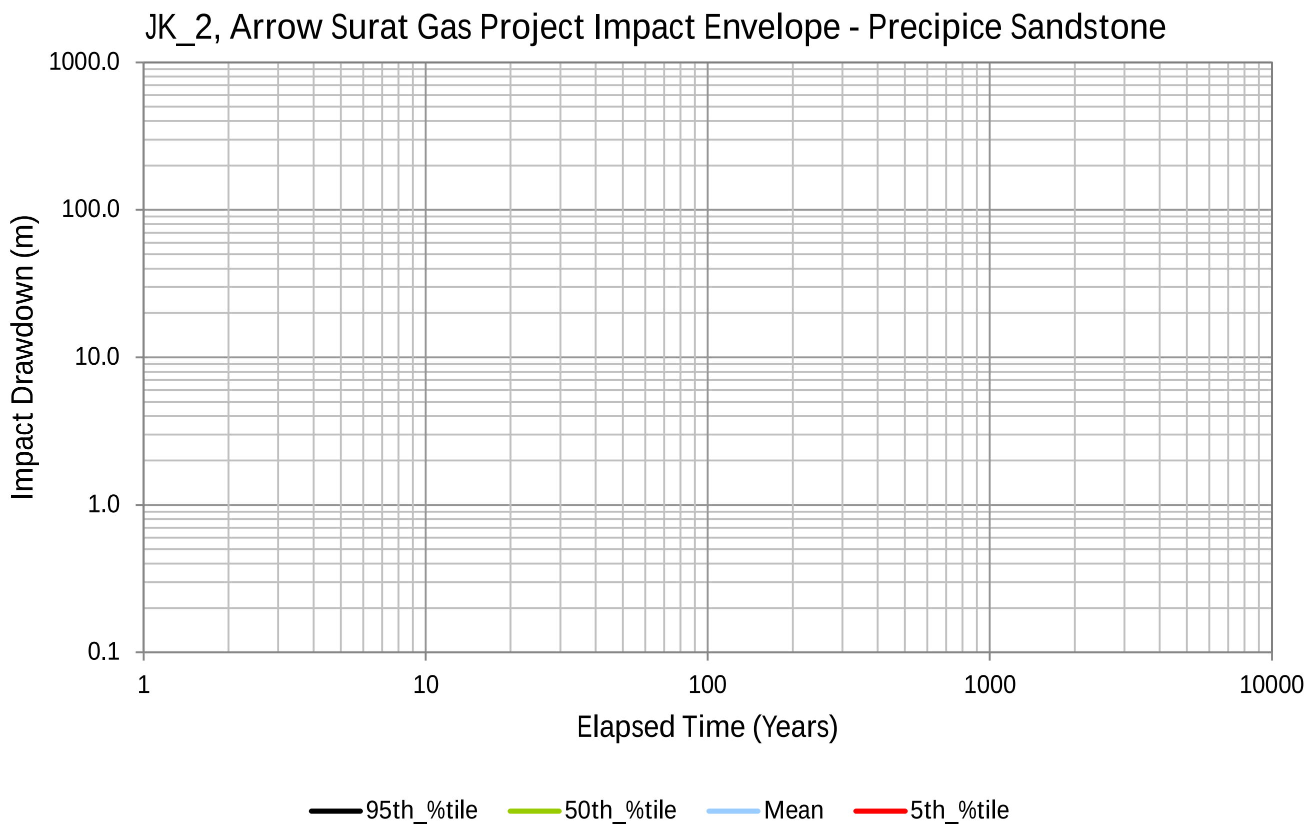
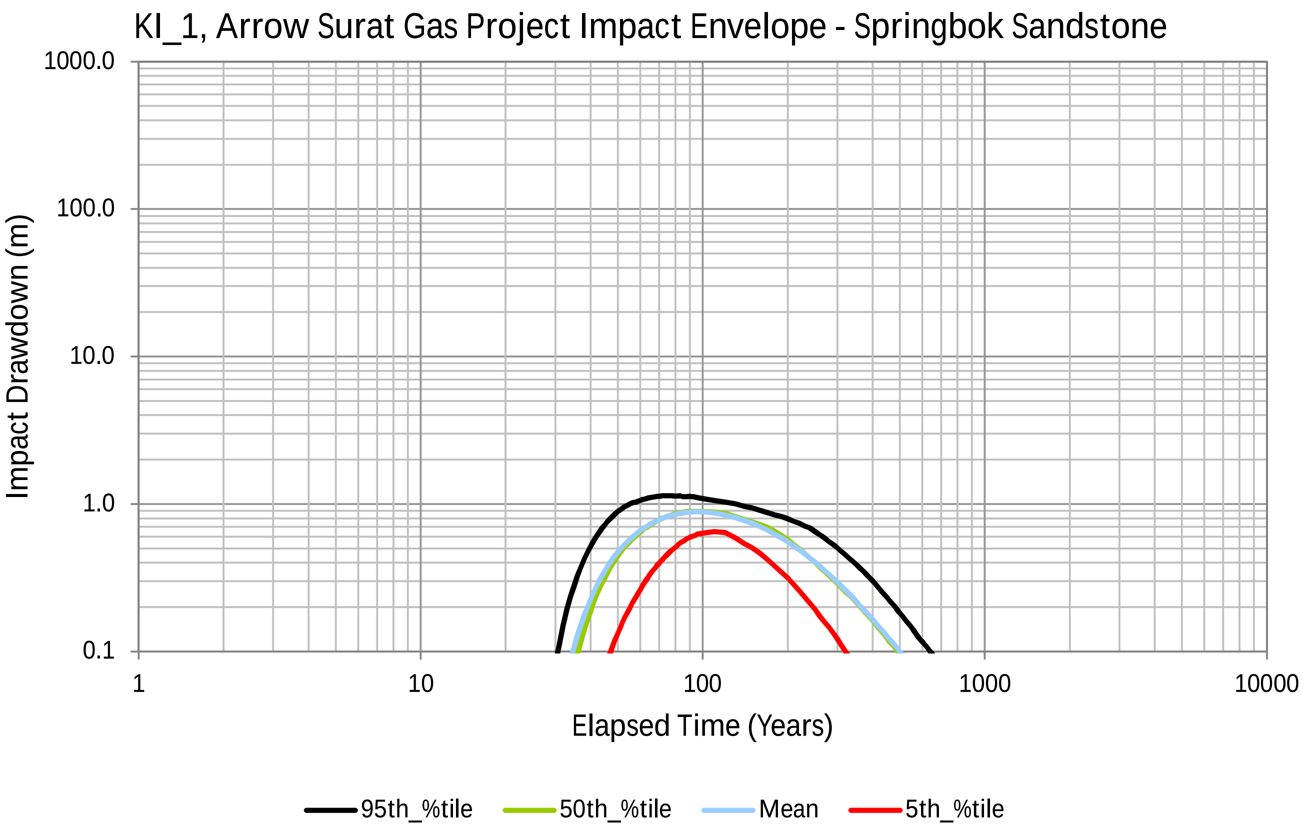
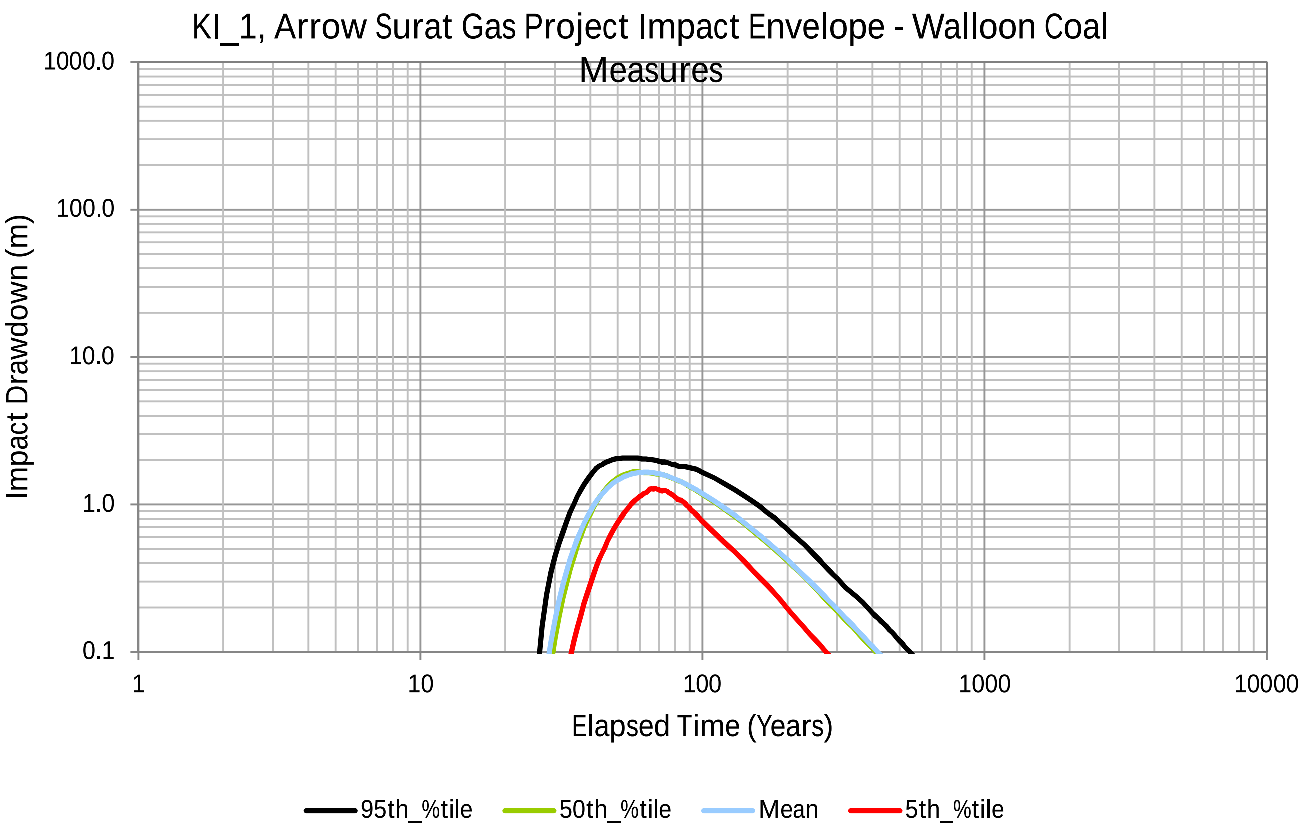
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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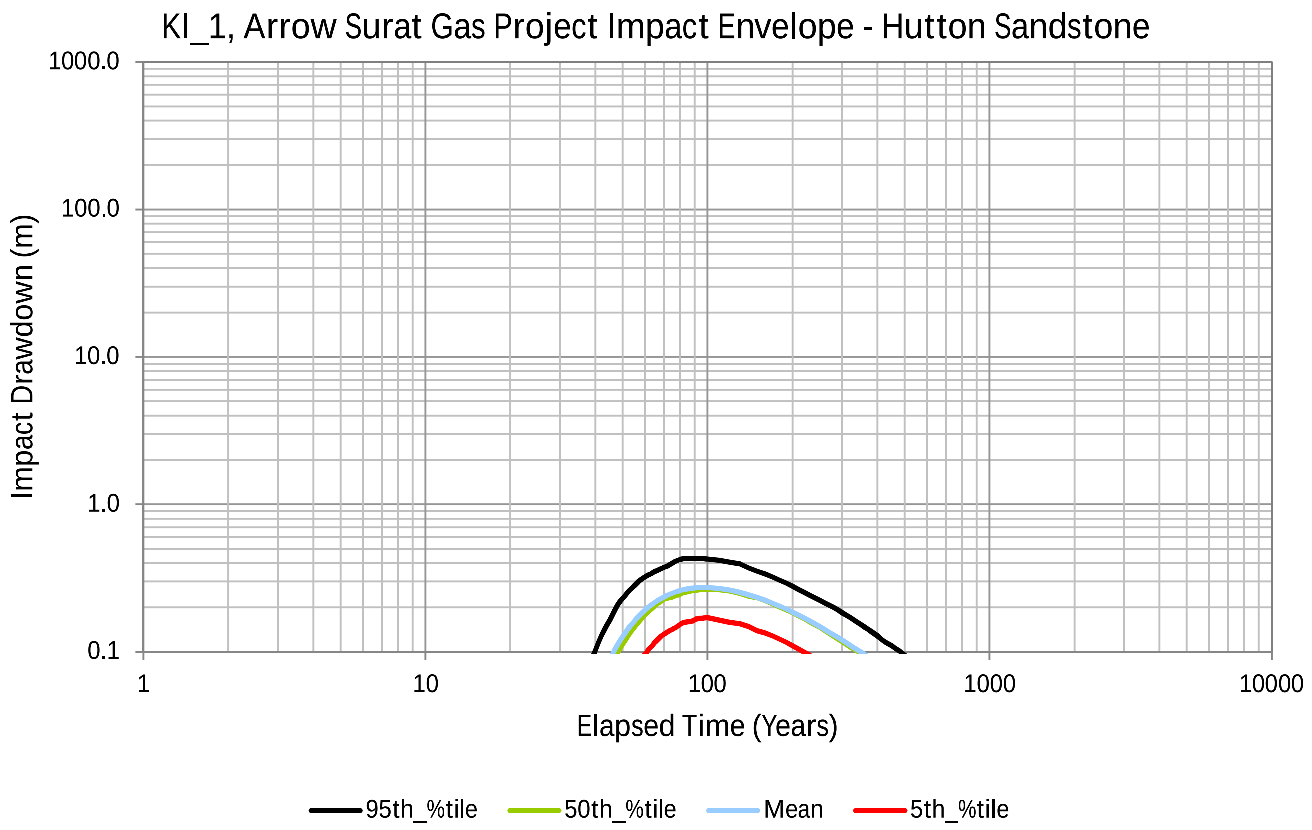
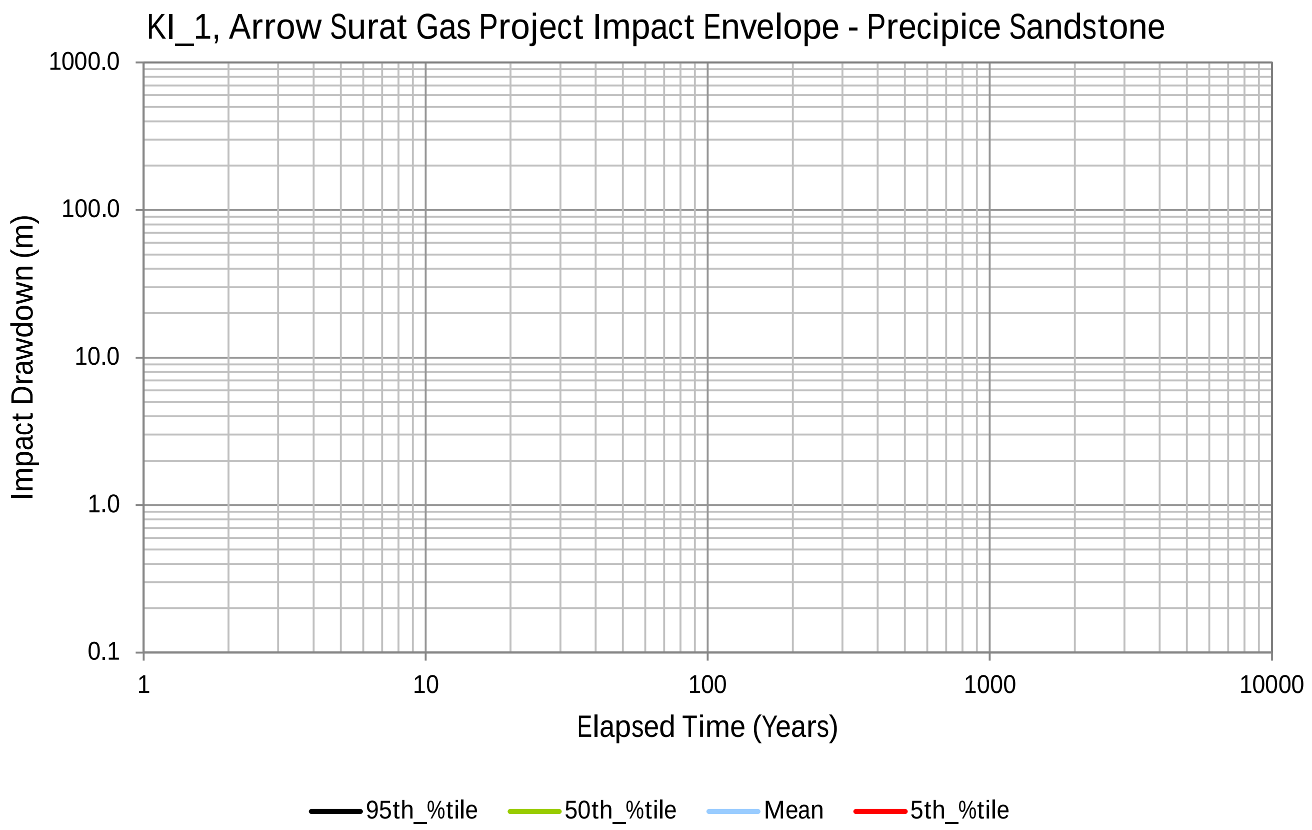
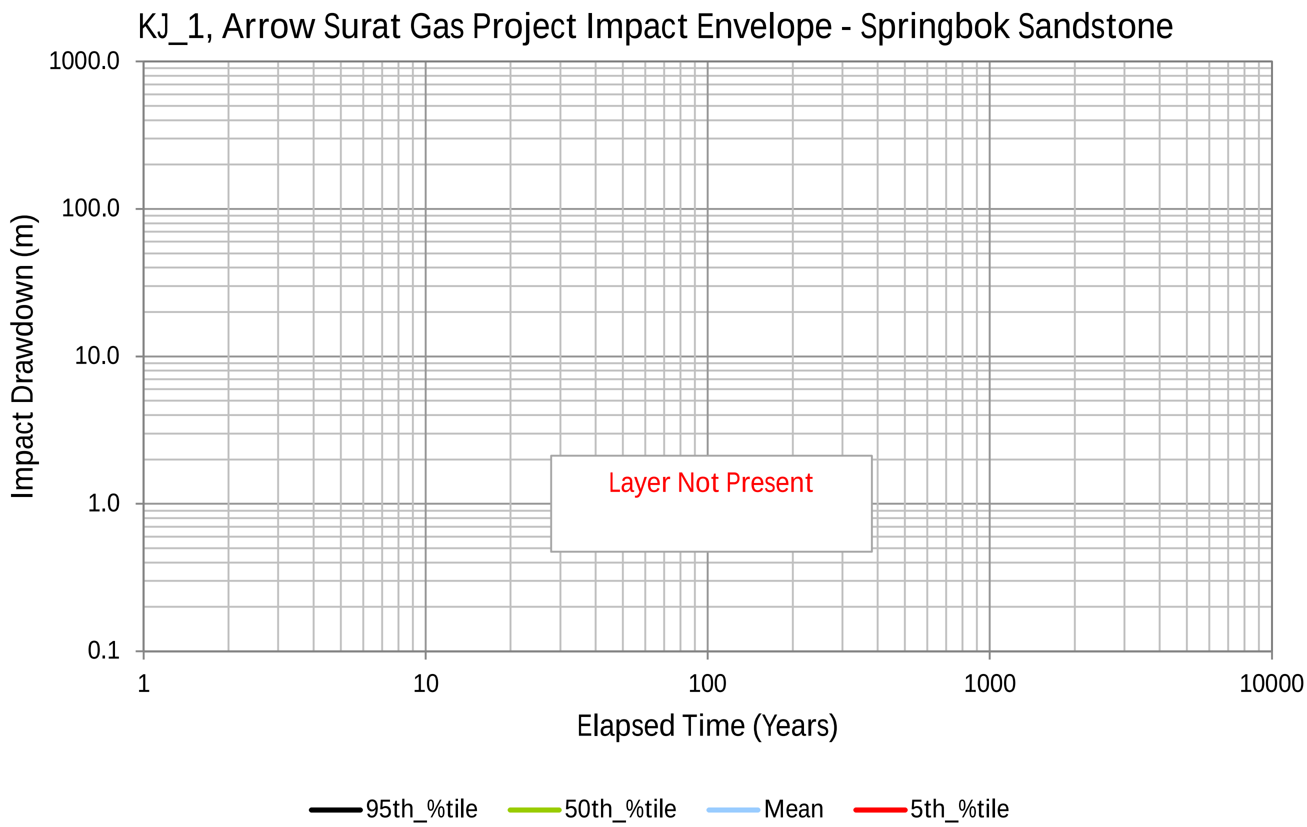
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2

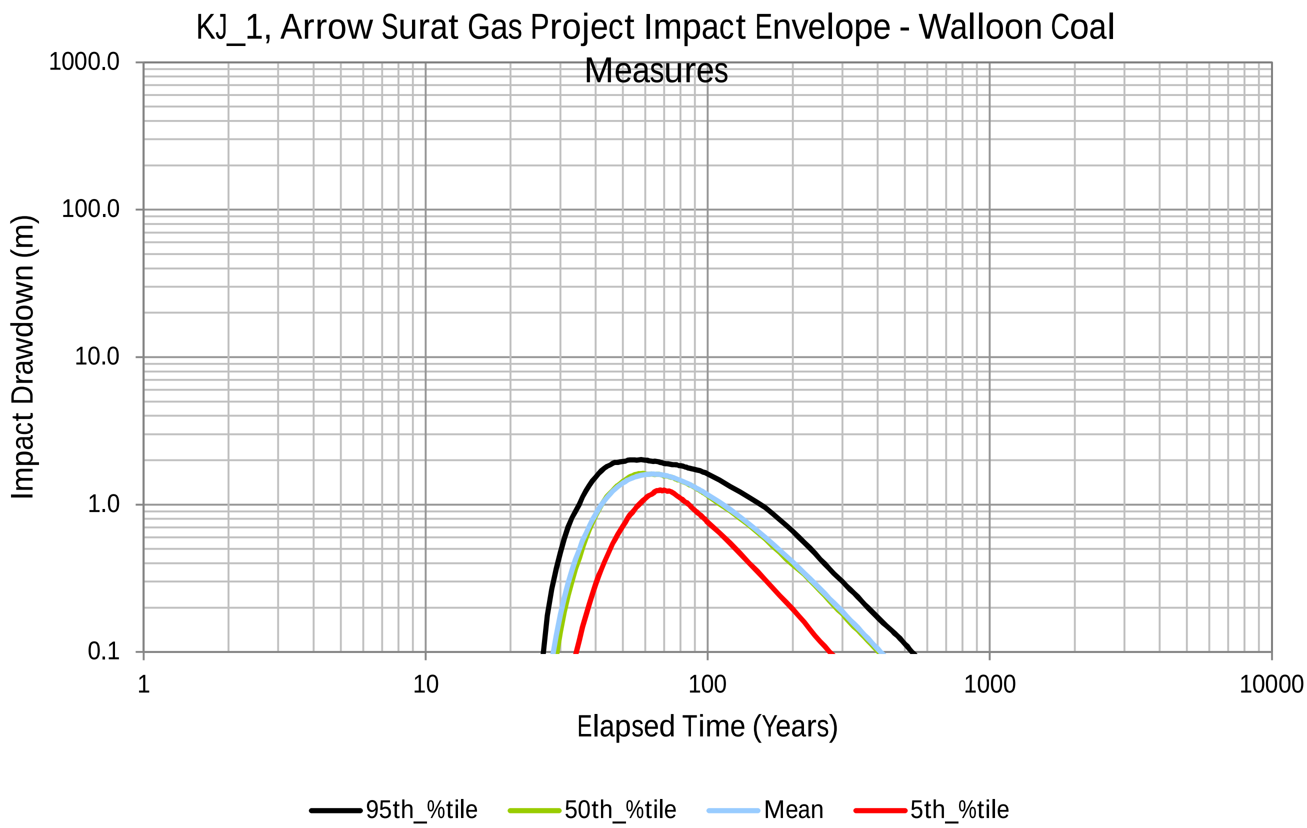




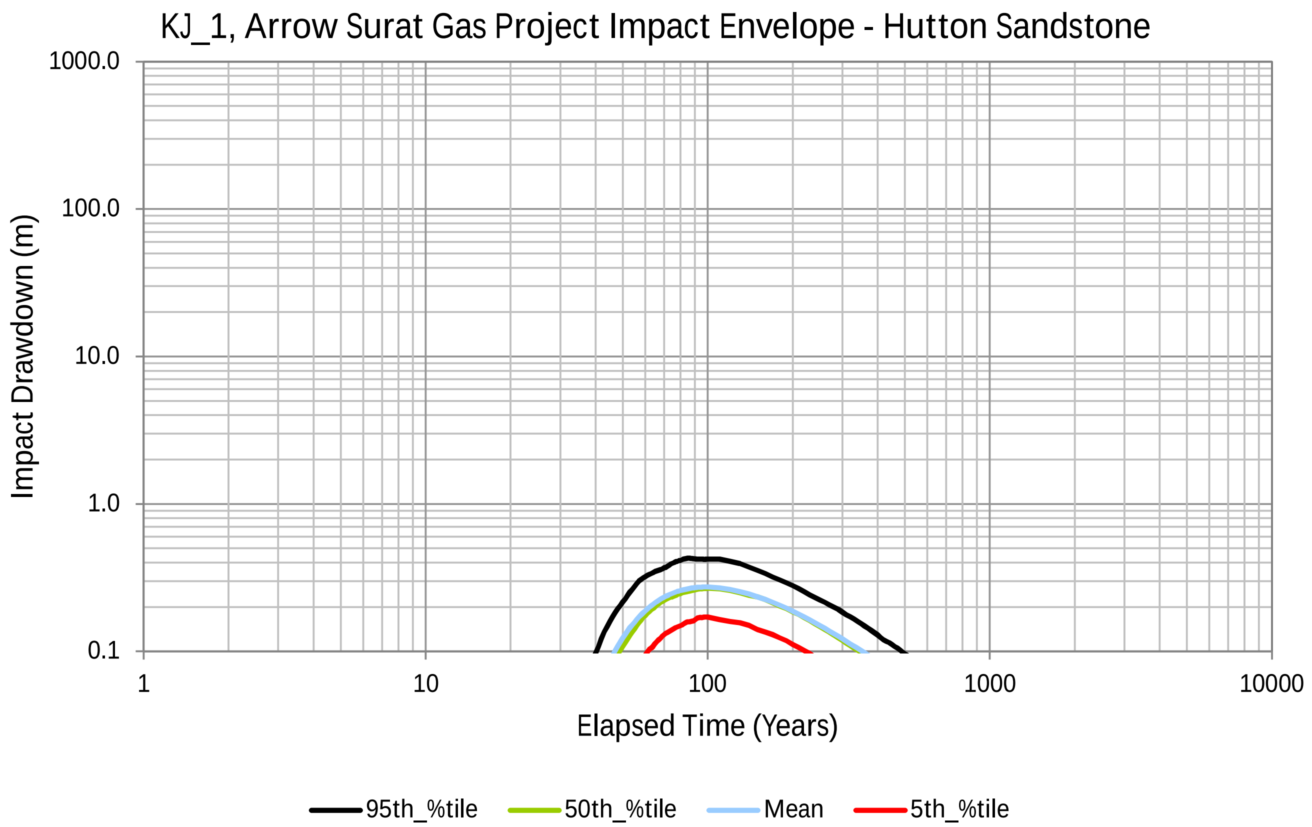
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_2)

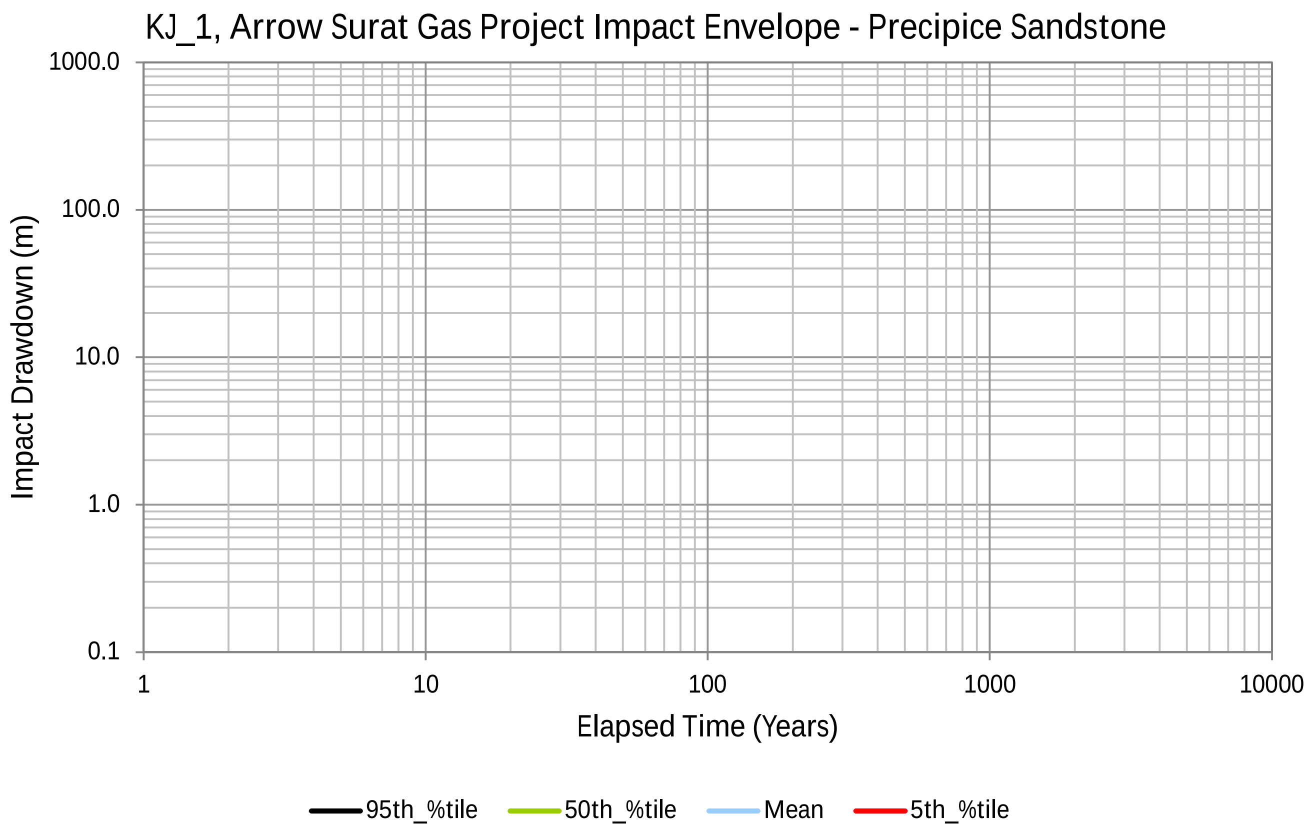
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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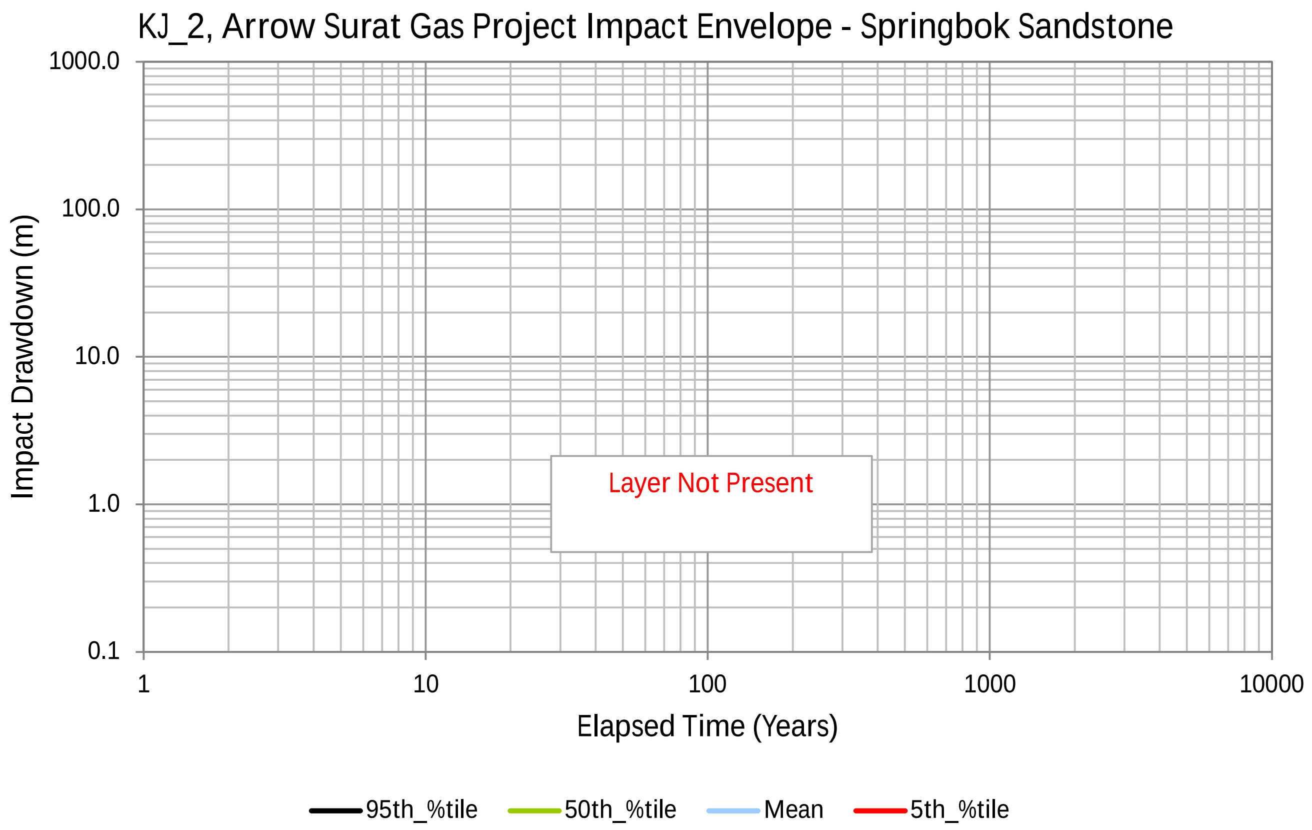
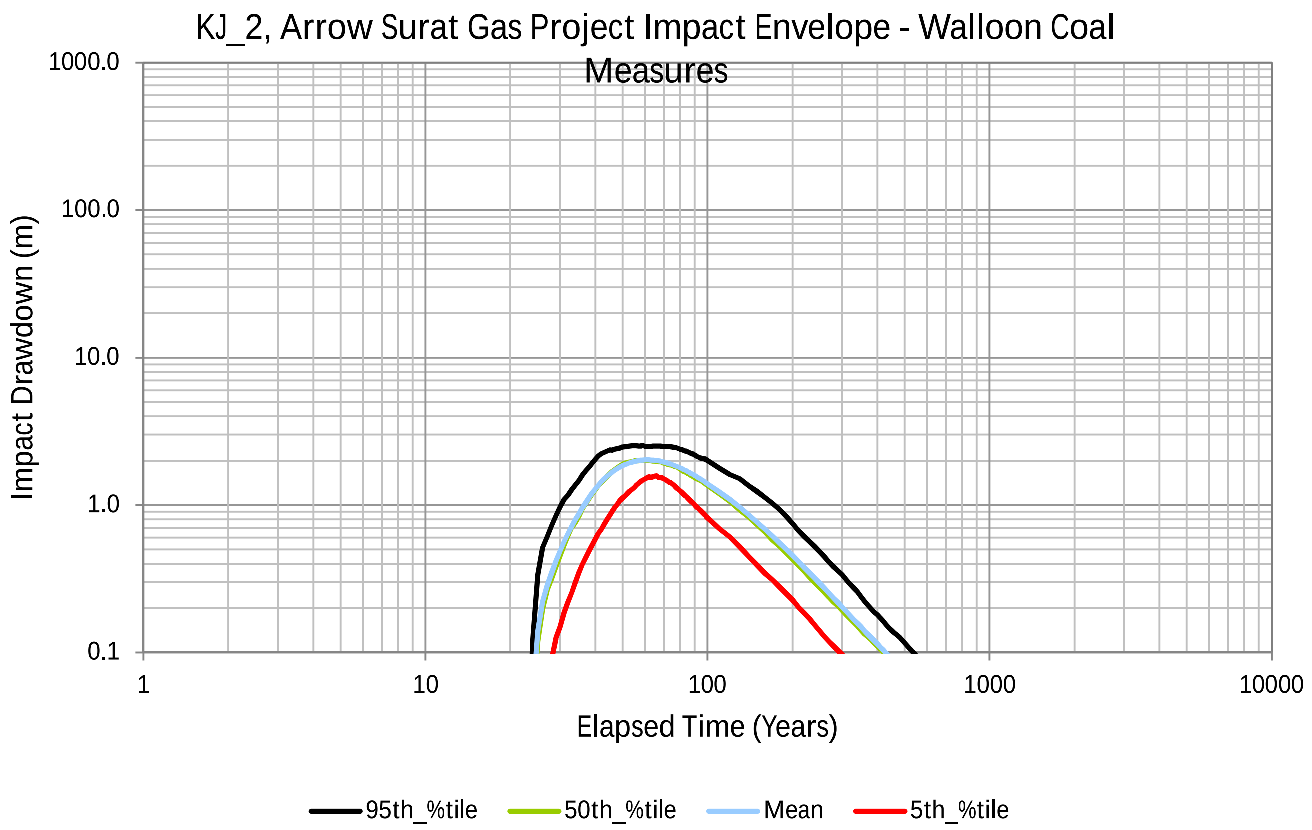
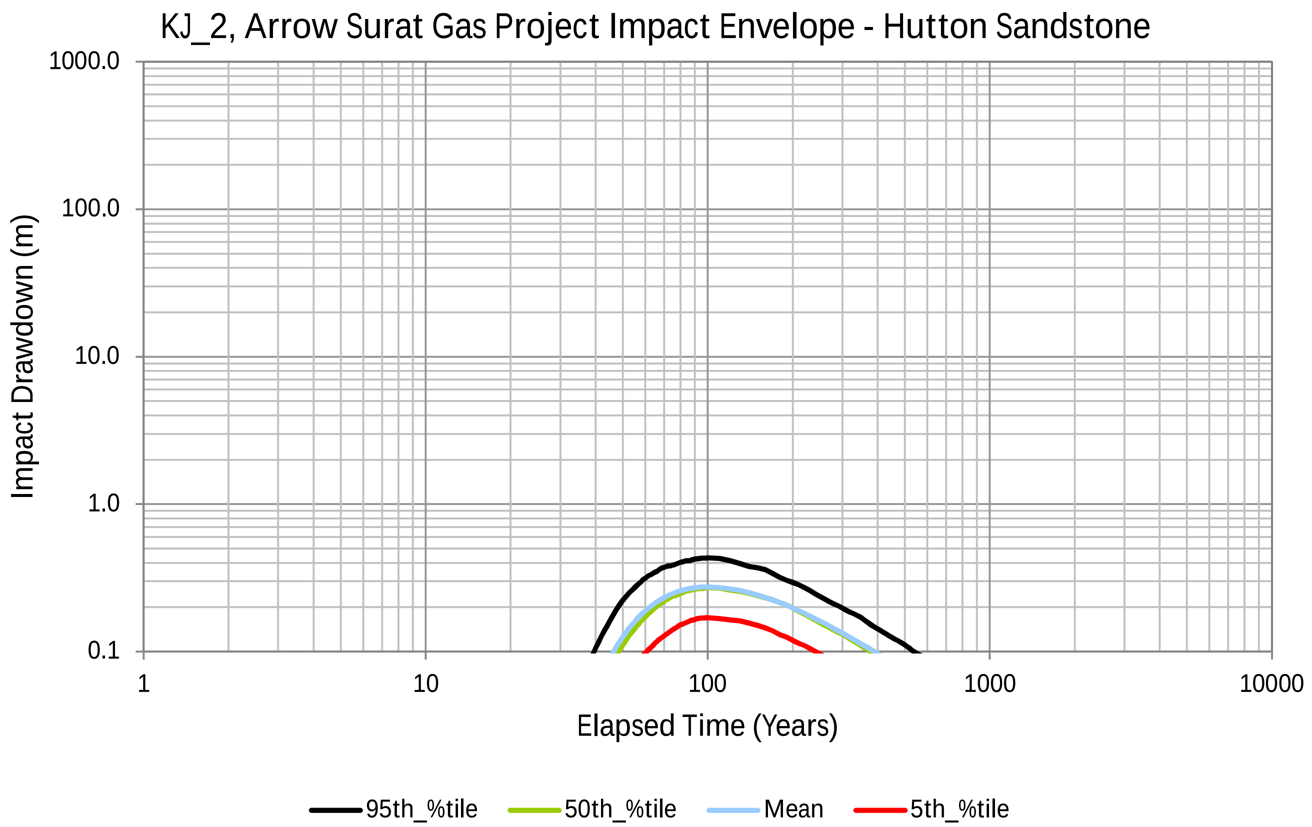
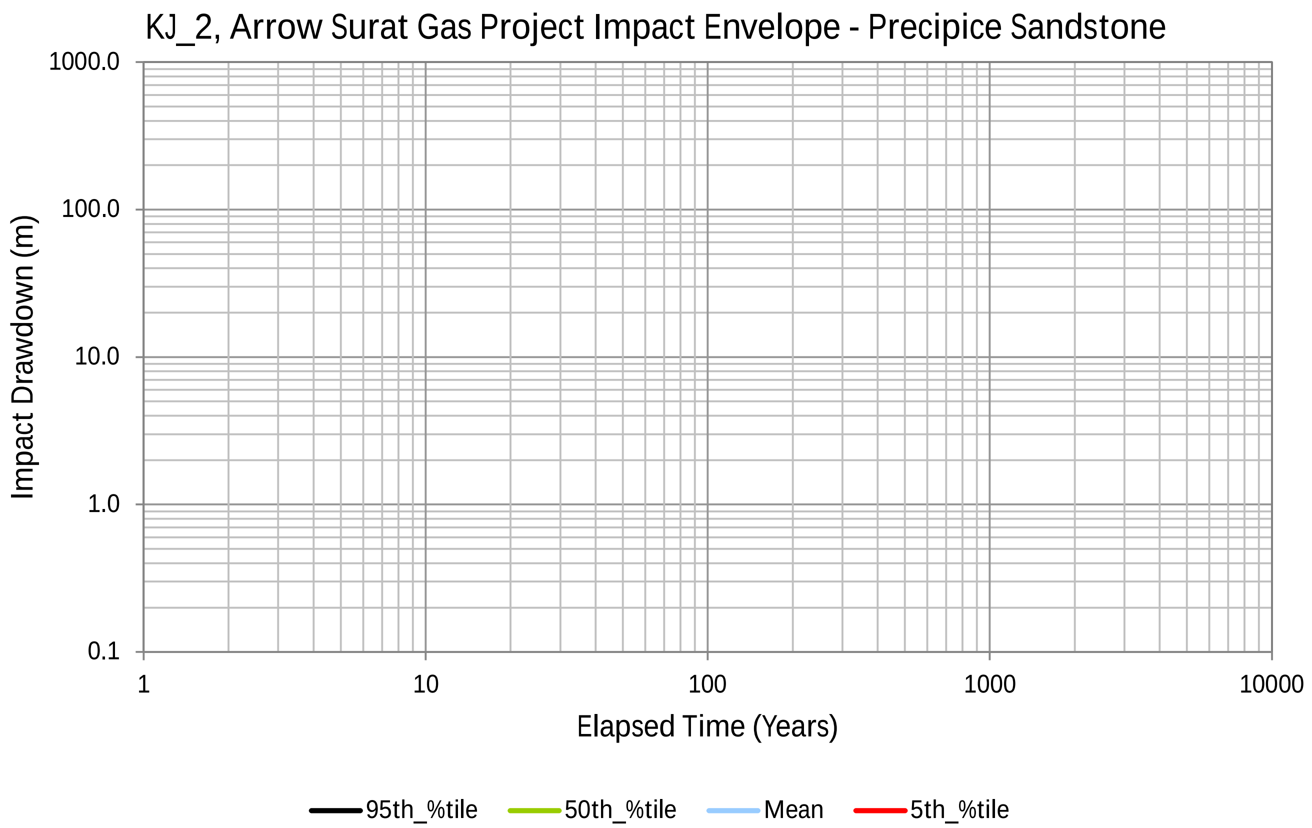

KJ_2, Arrow Surat Gas Project Impact Envelope - Springbok Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
Layer Not Present
95th_%tile
50th_%tile
Mean
5th_%tile

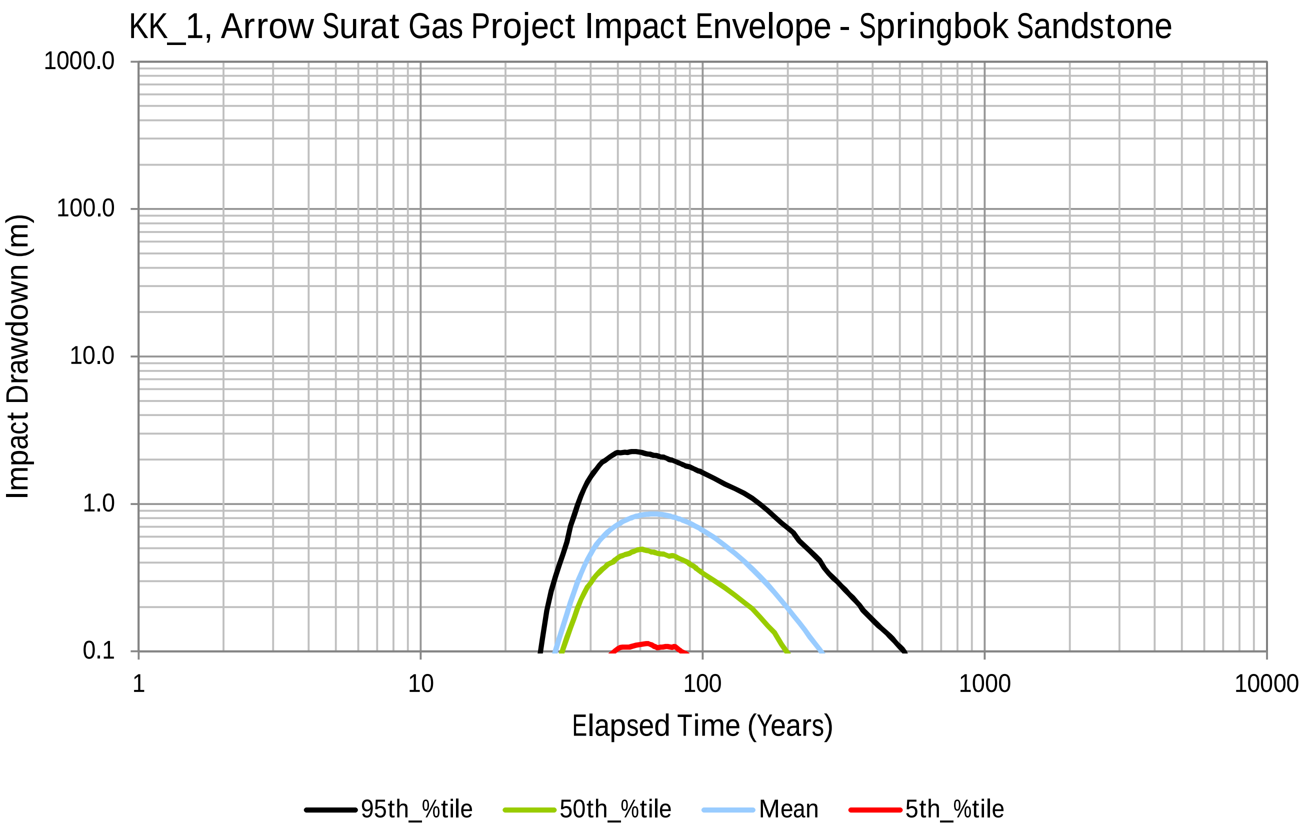

KJ_2, Arrow Surat Gas Project Impact Envelope - Walloon Coal Measures
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

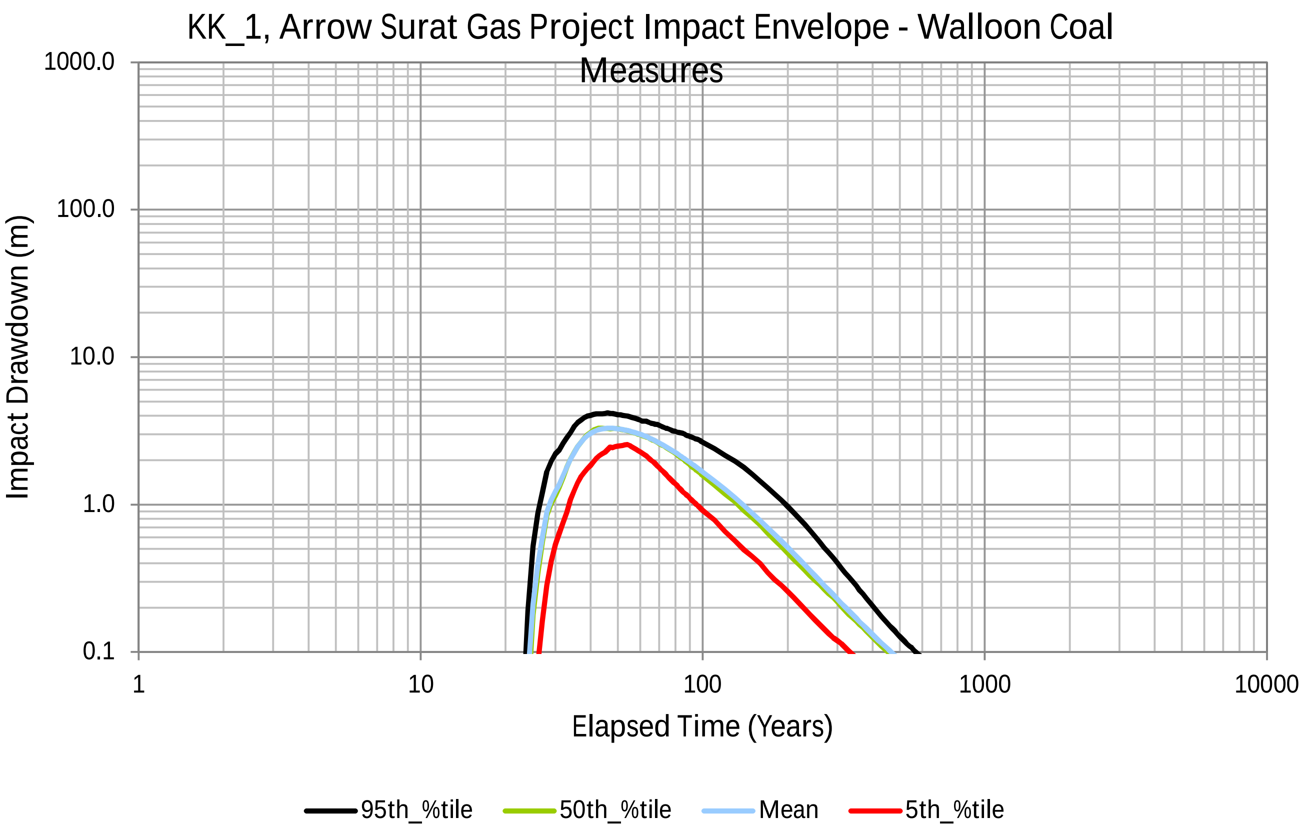
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2



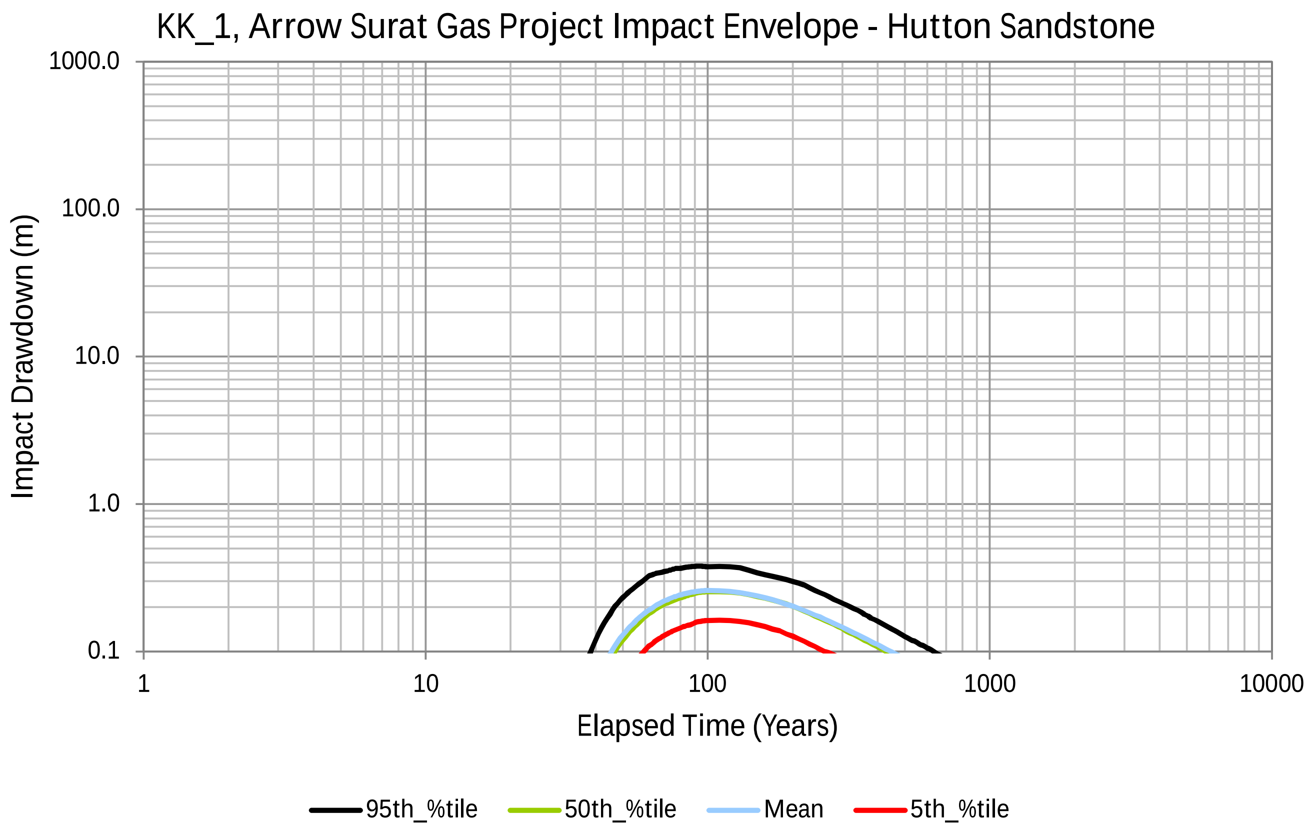


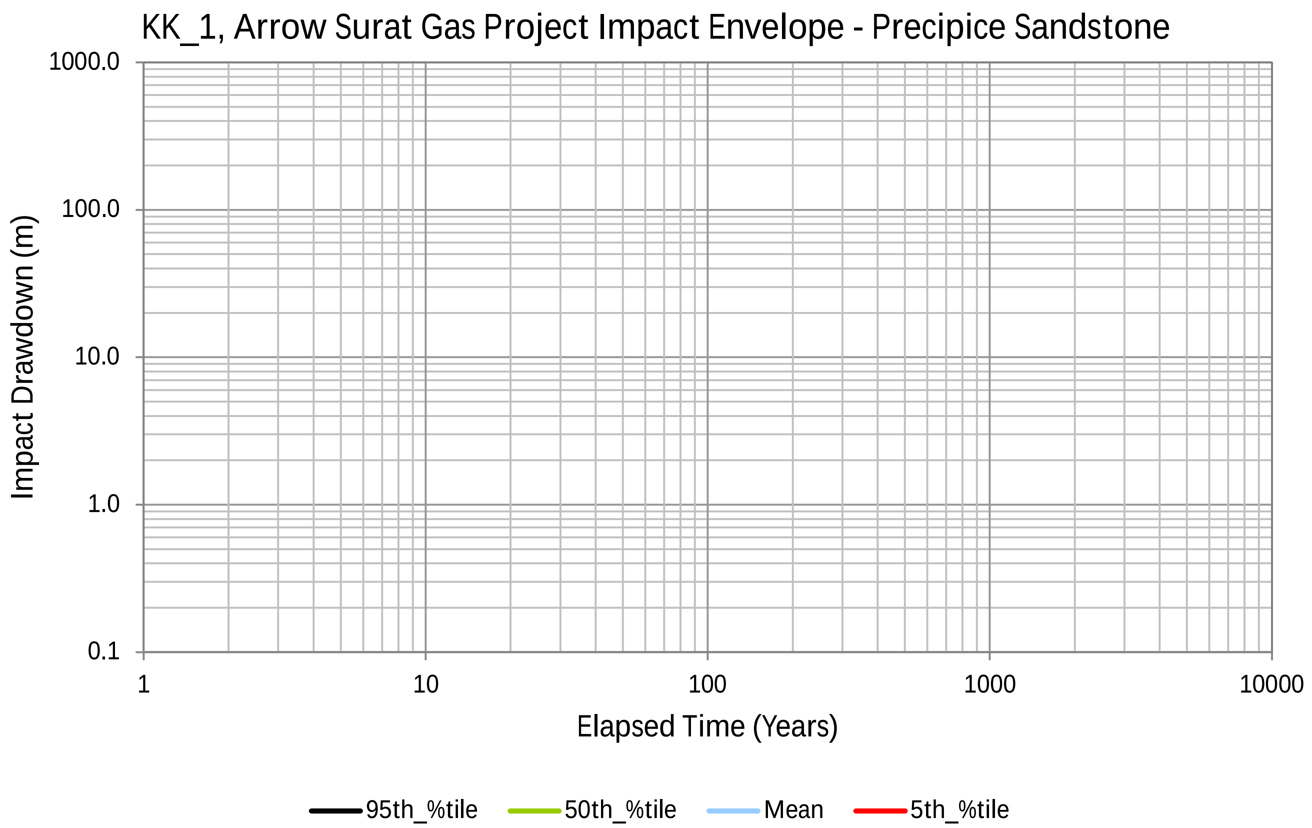
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





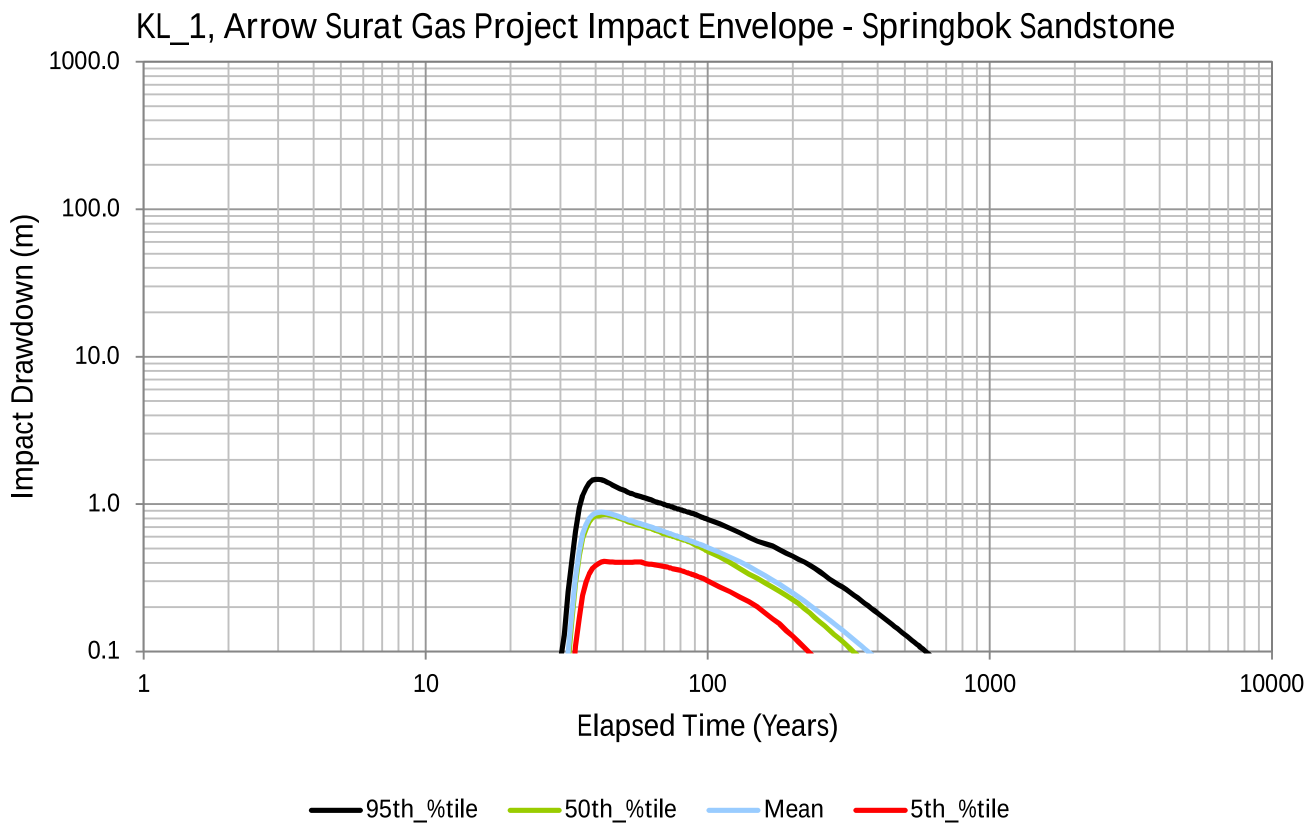
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2



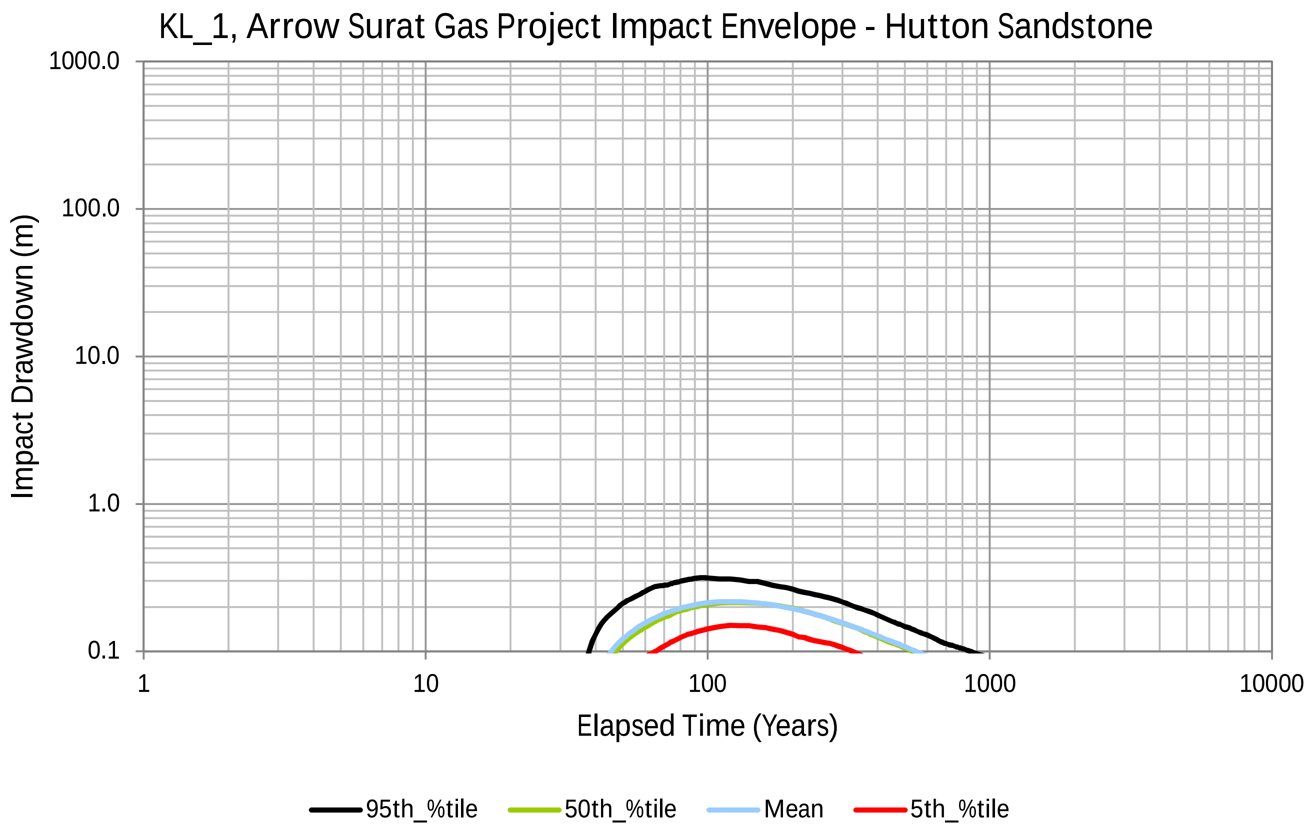


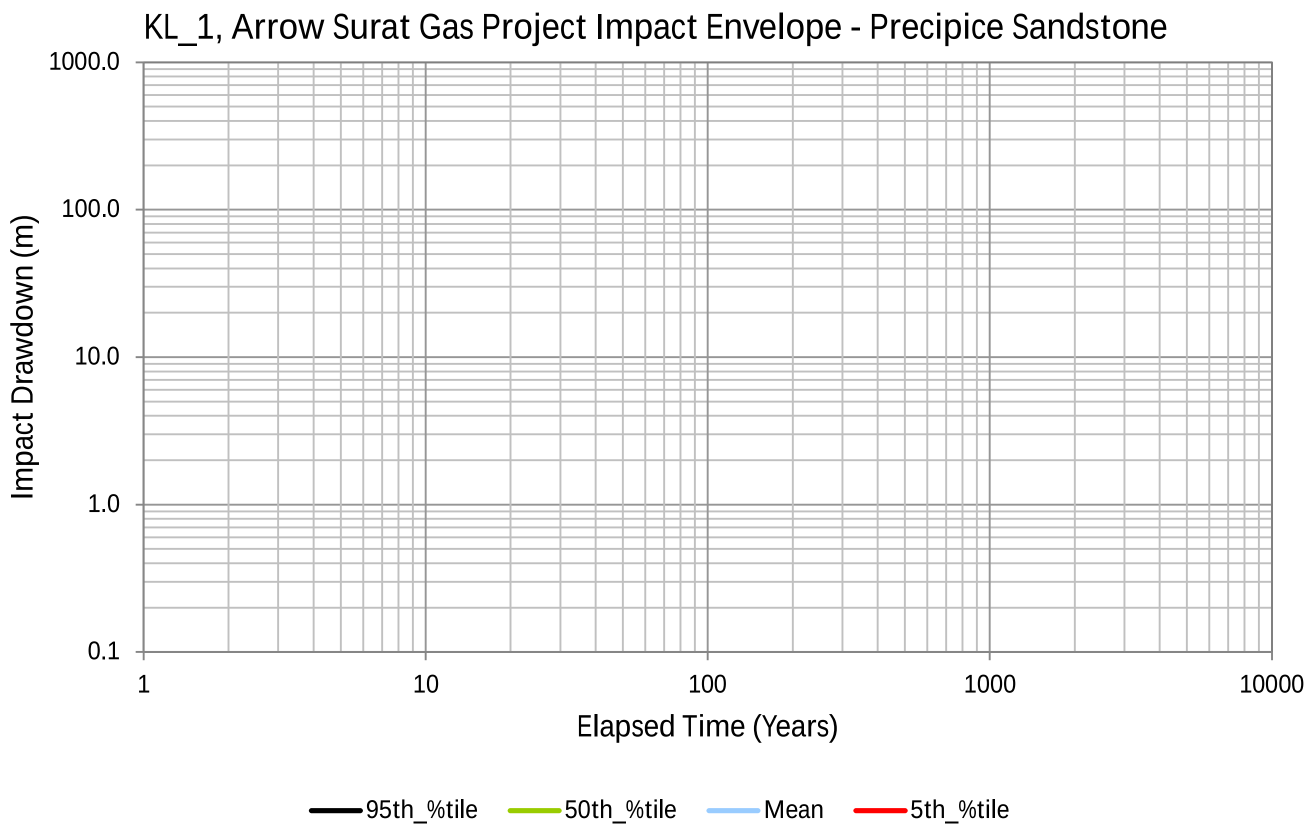
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_2)

Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2



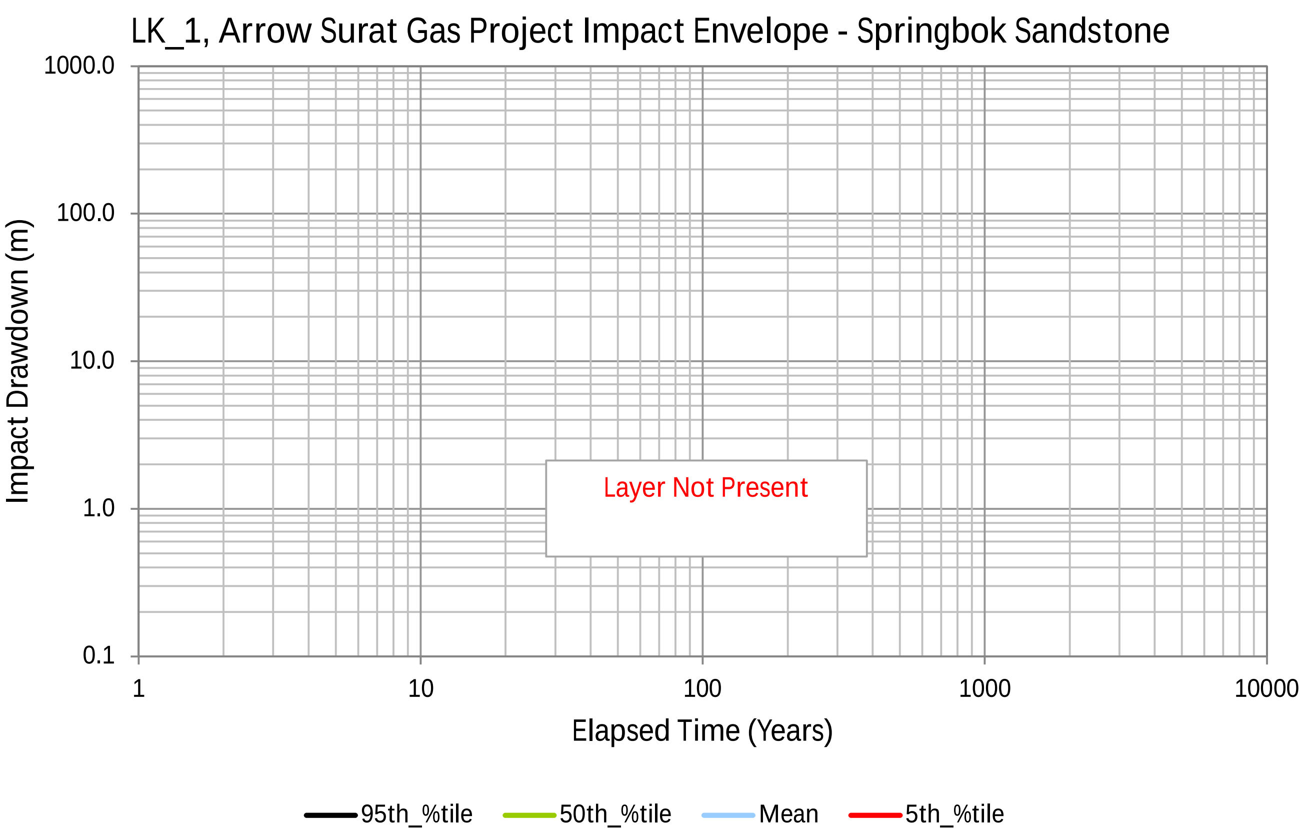
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2

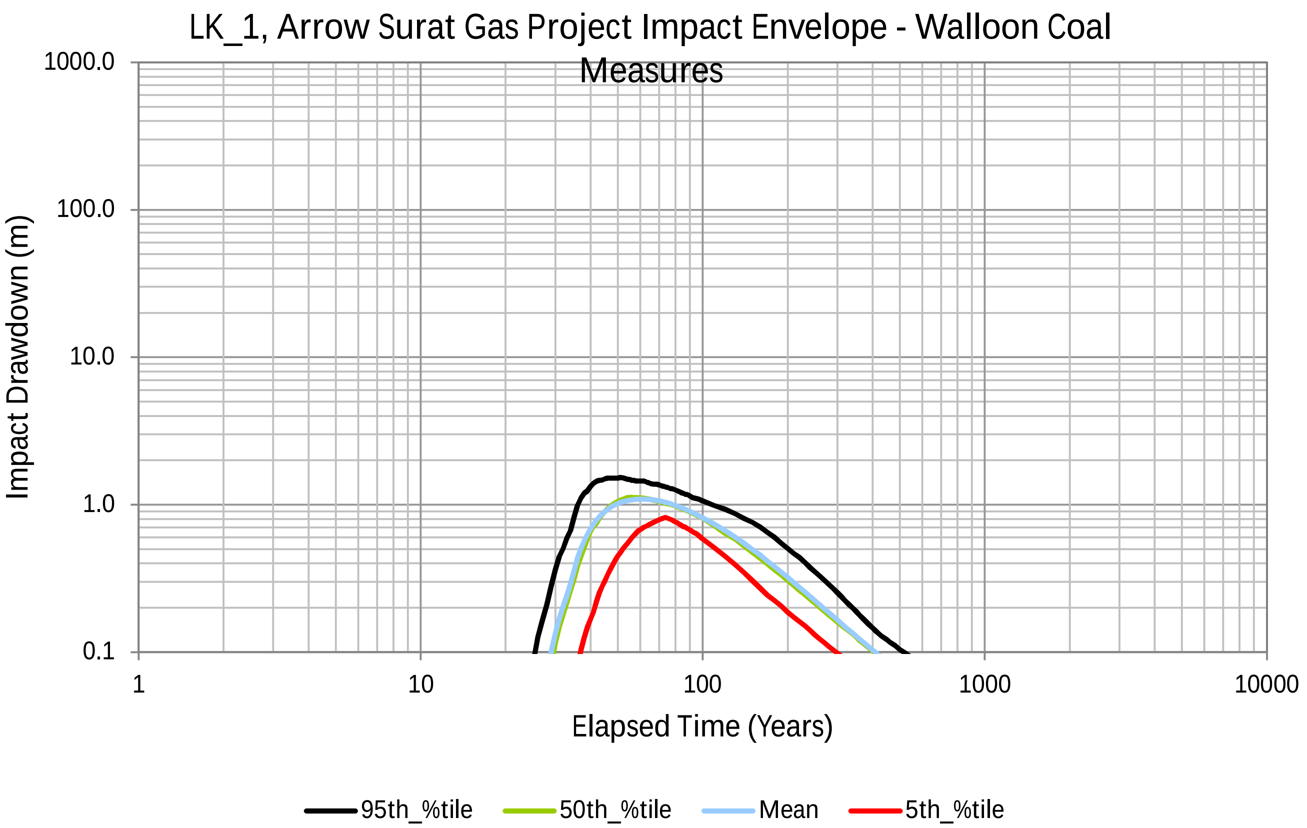




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_2)

Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2





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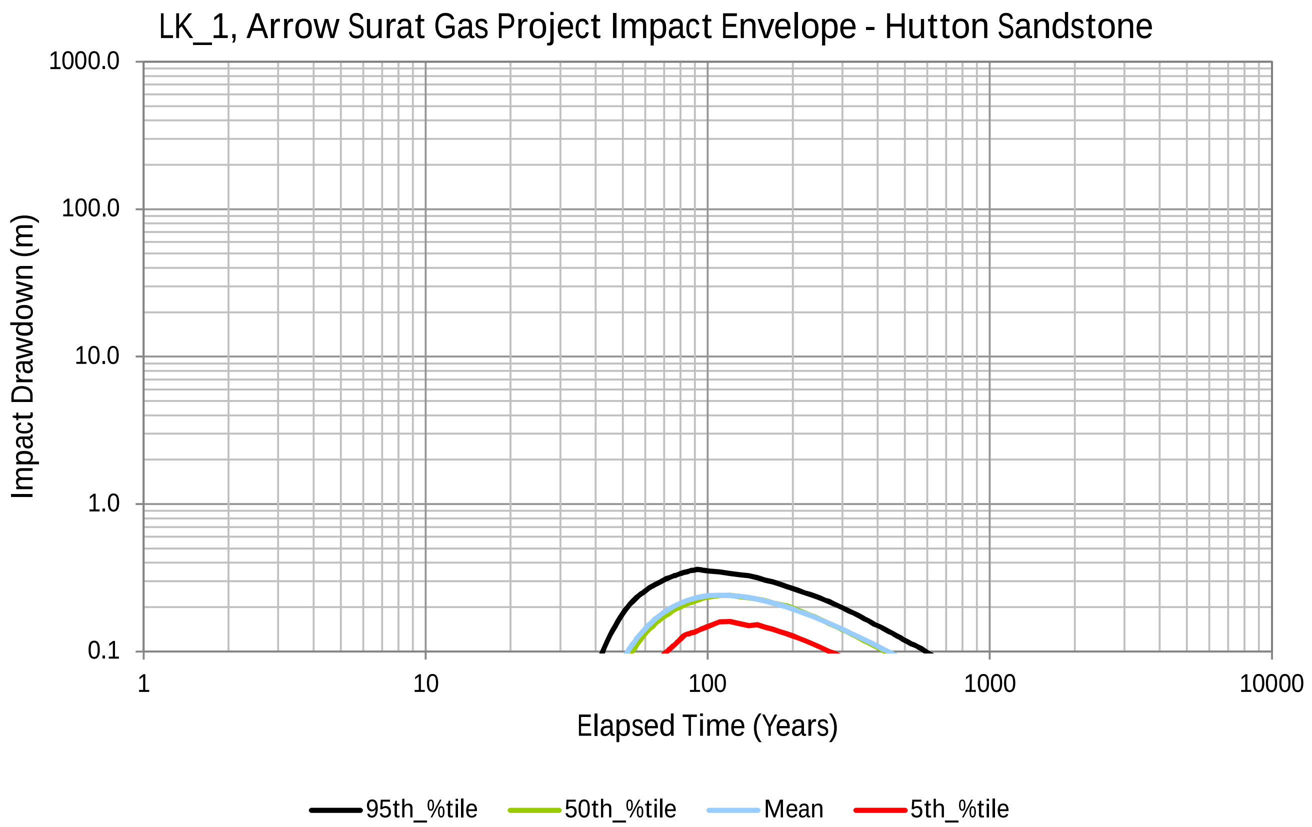
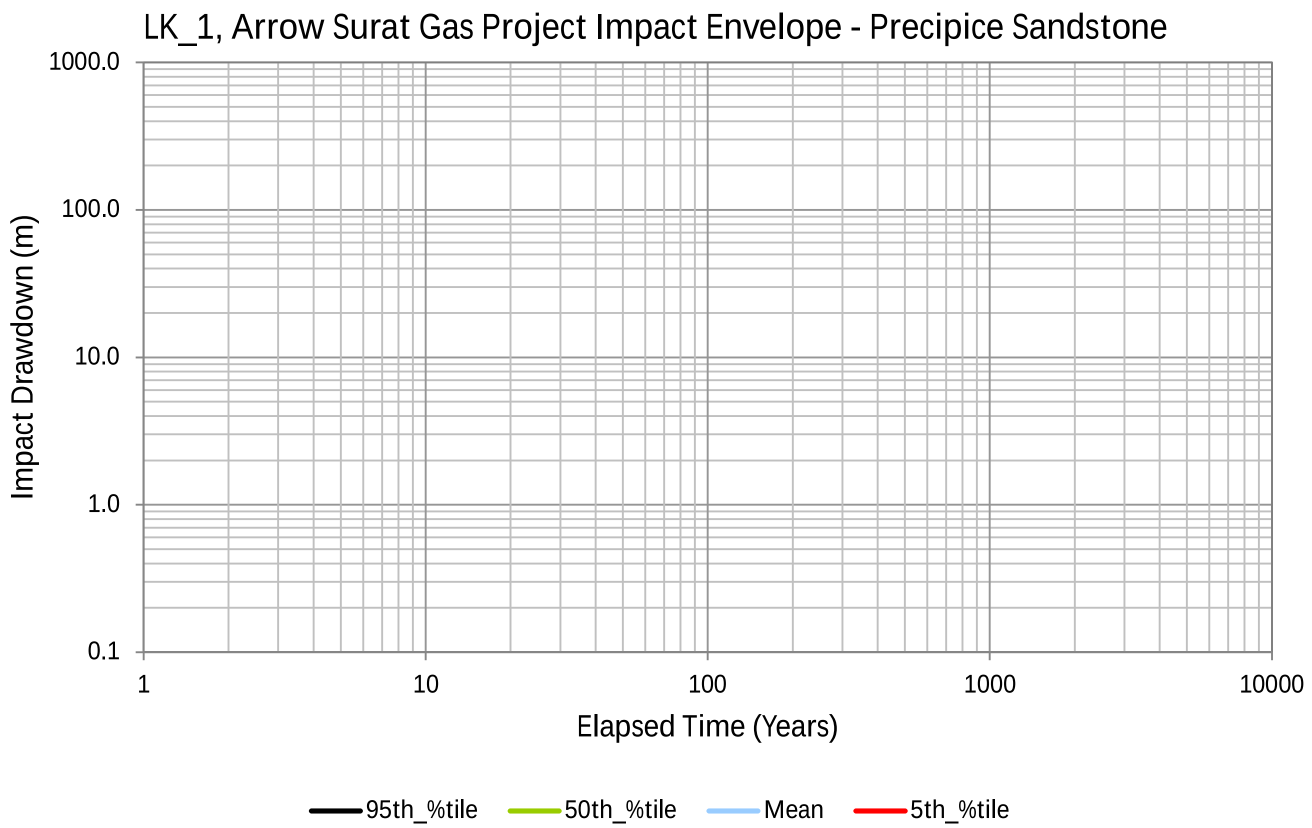
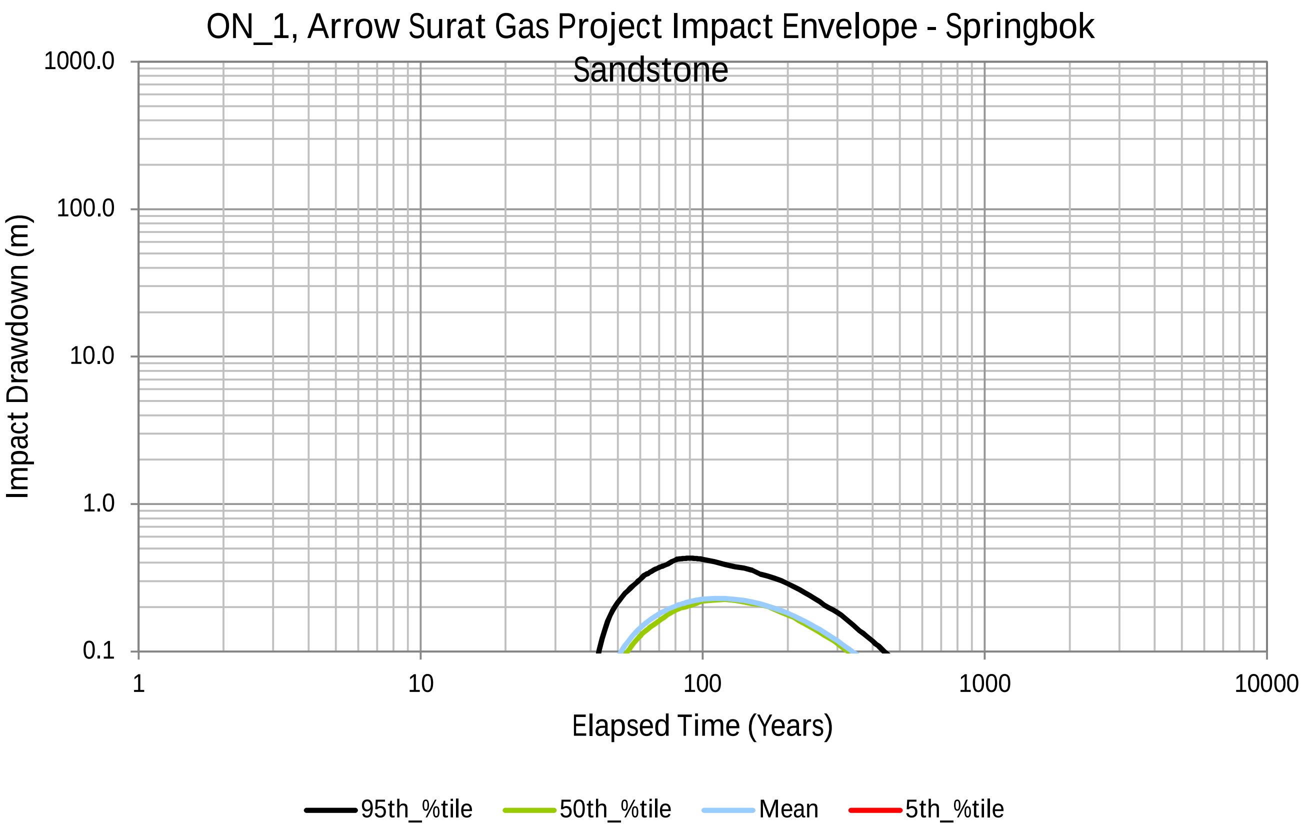
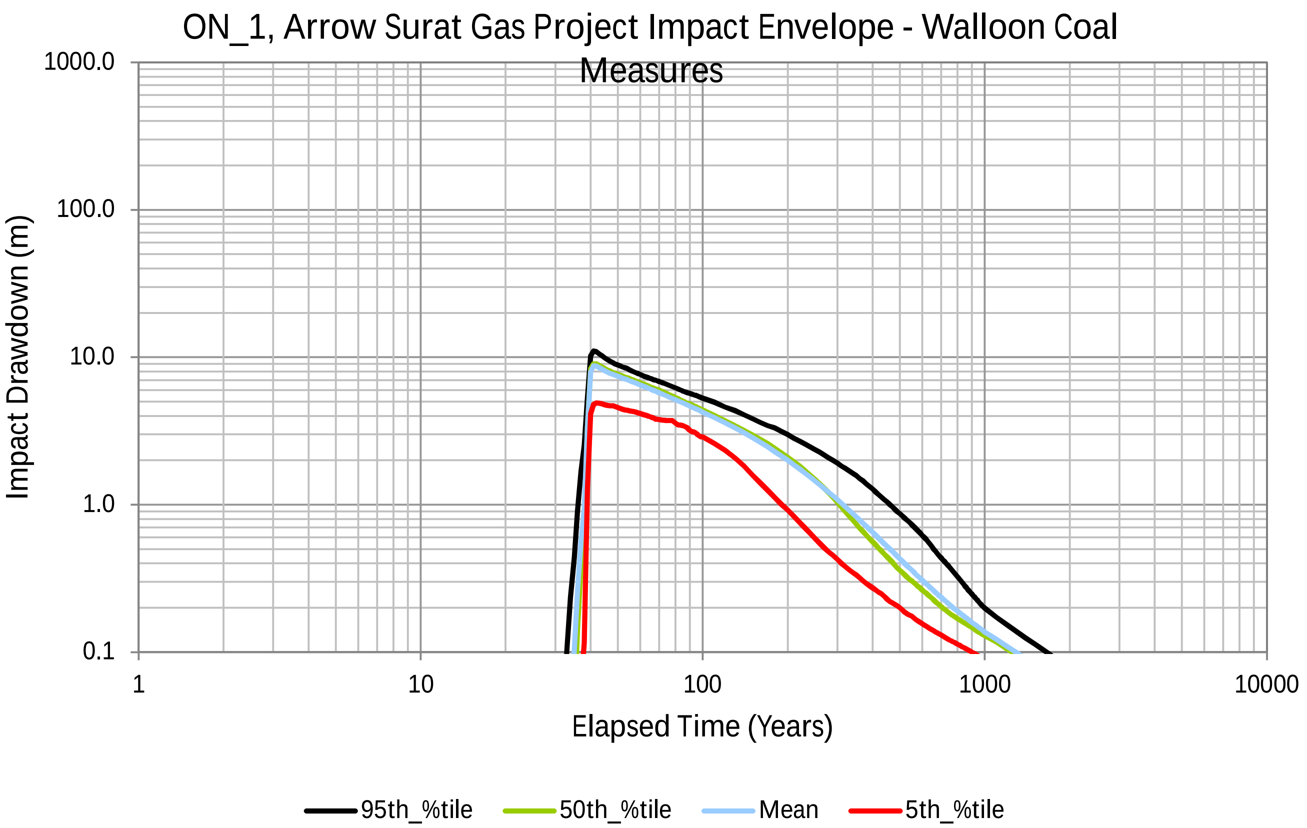
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 2



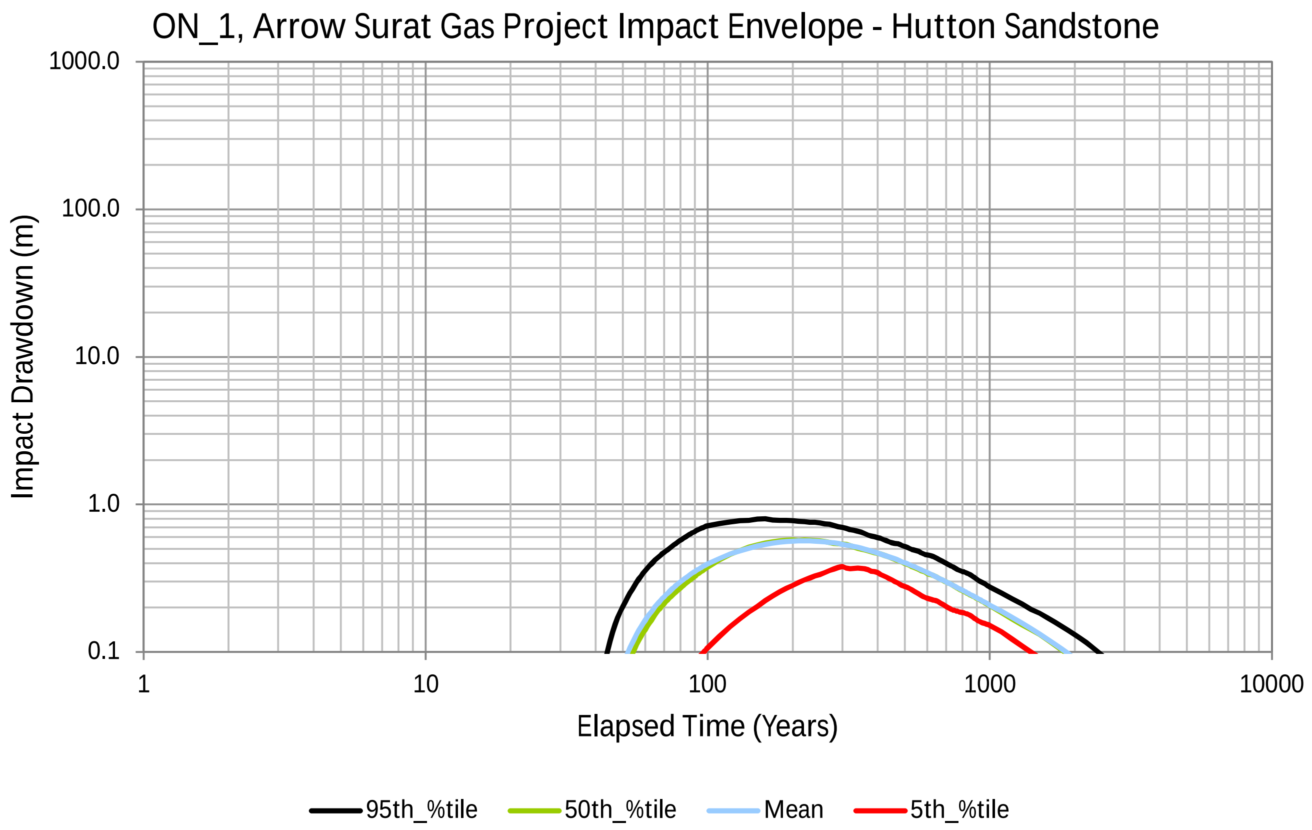


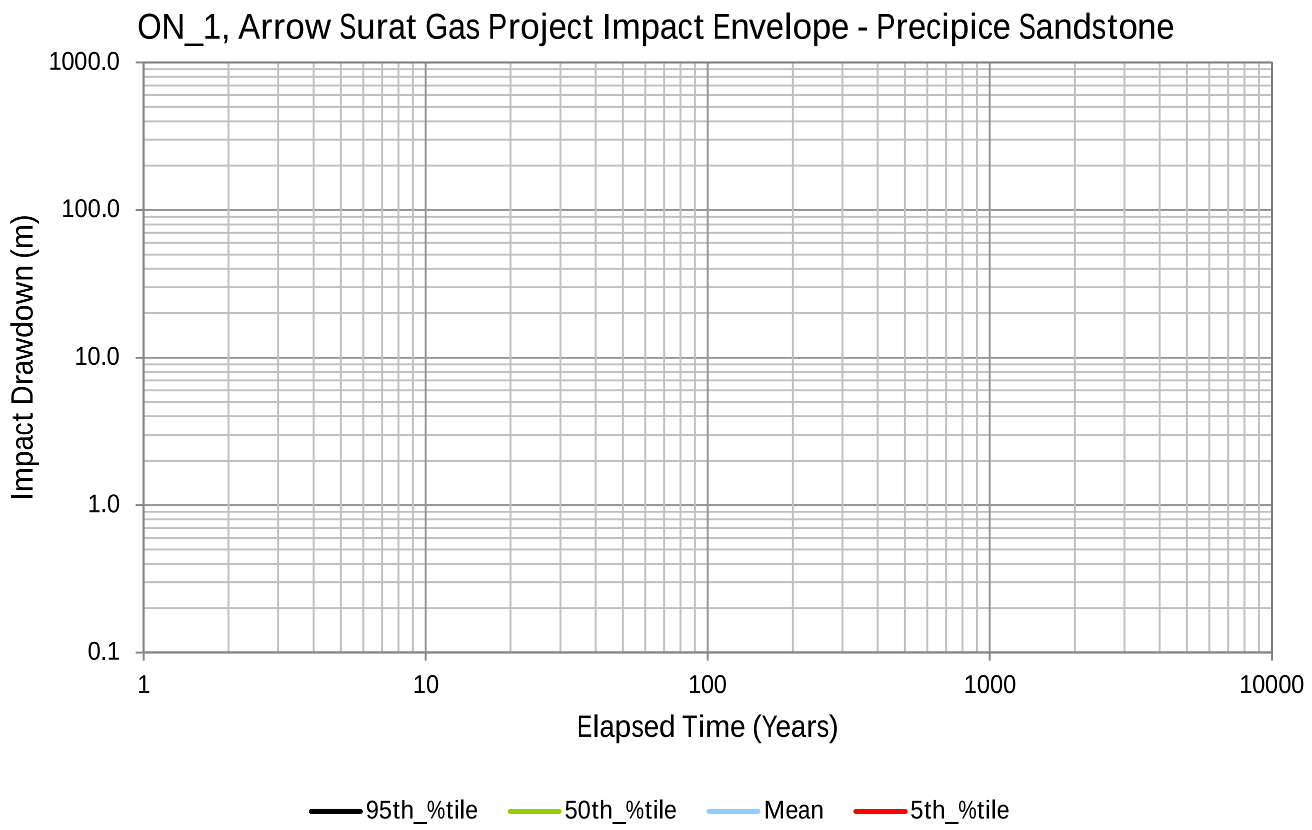
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5





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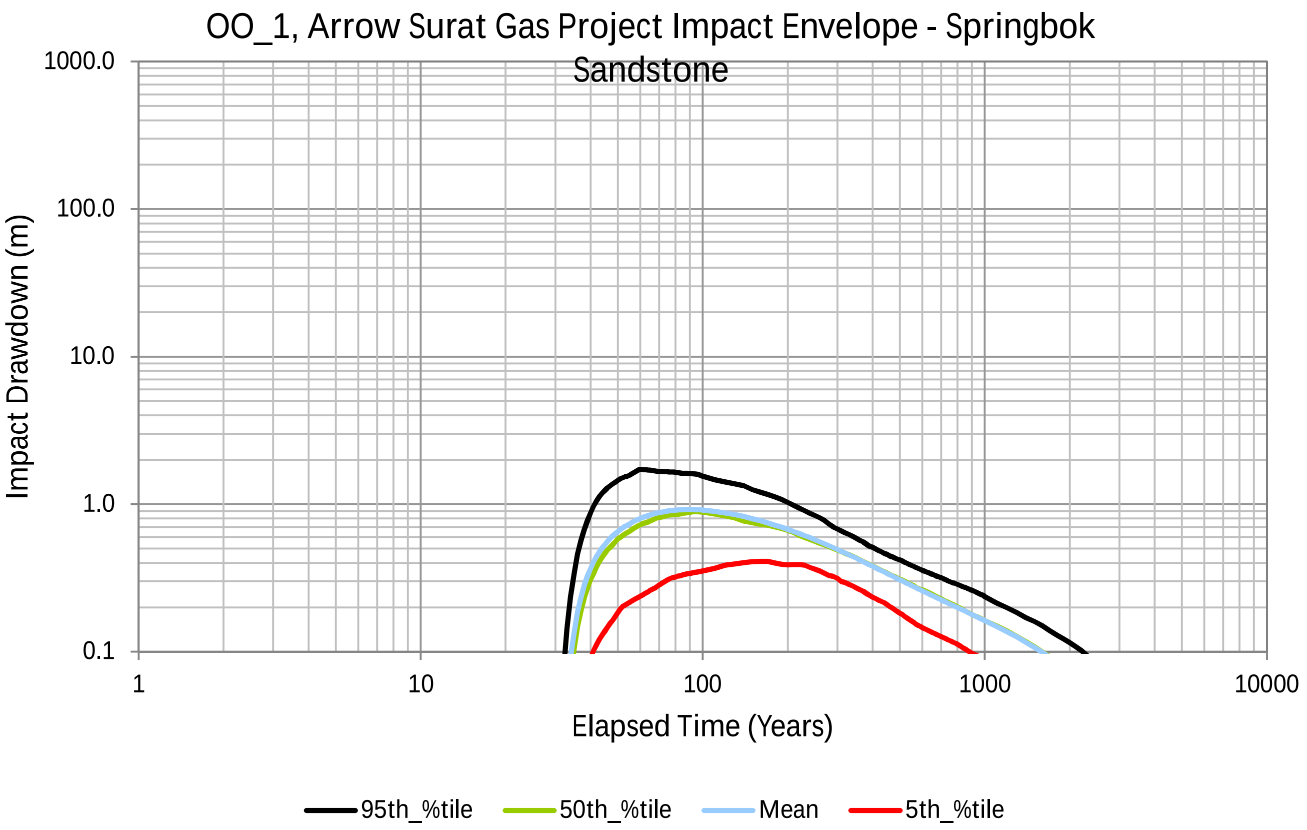
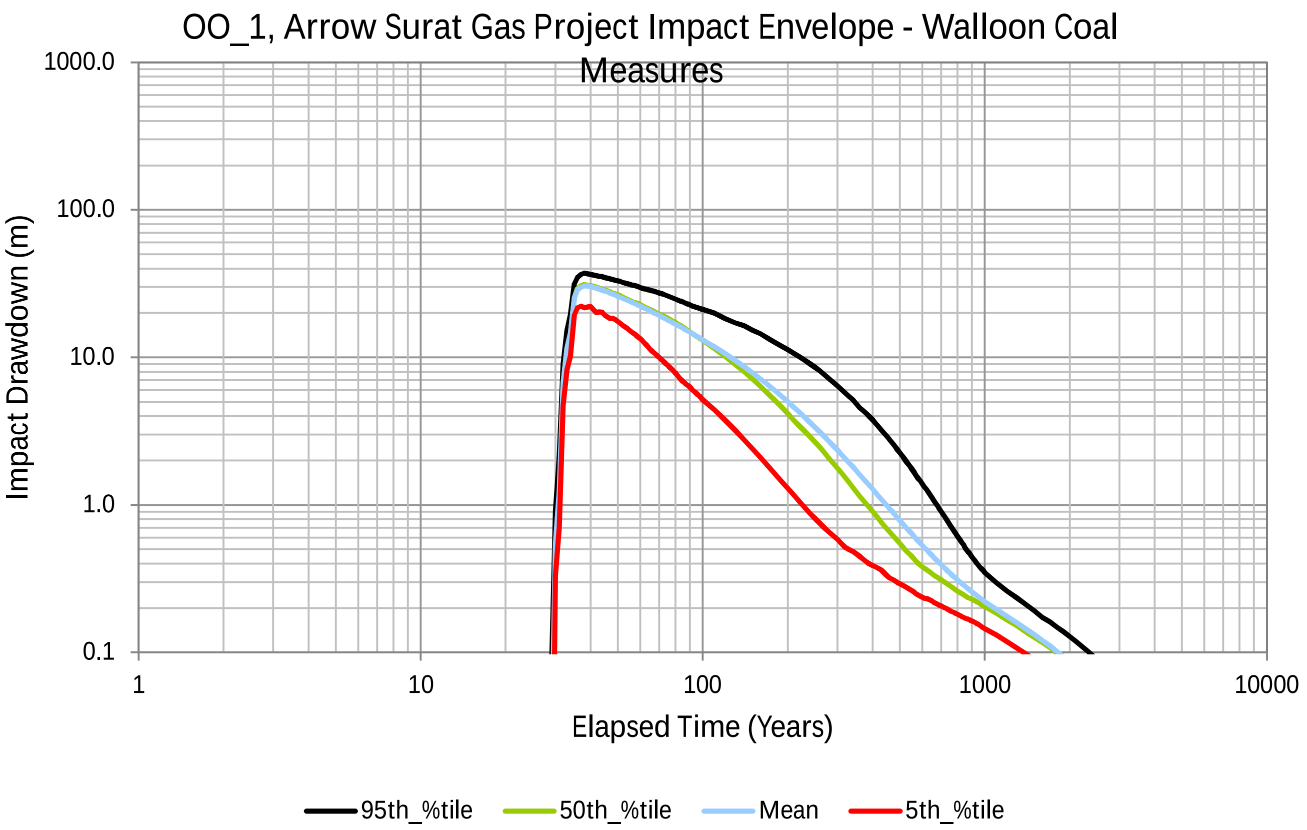
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5





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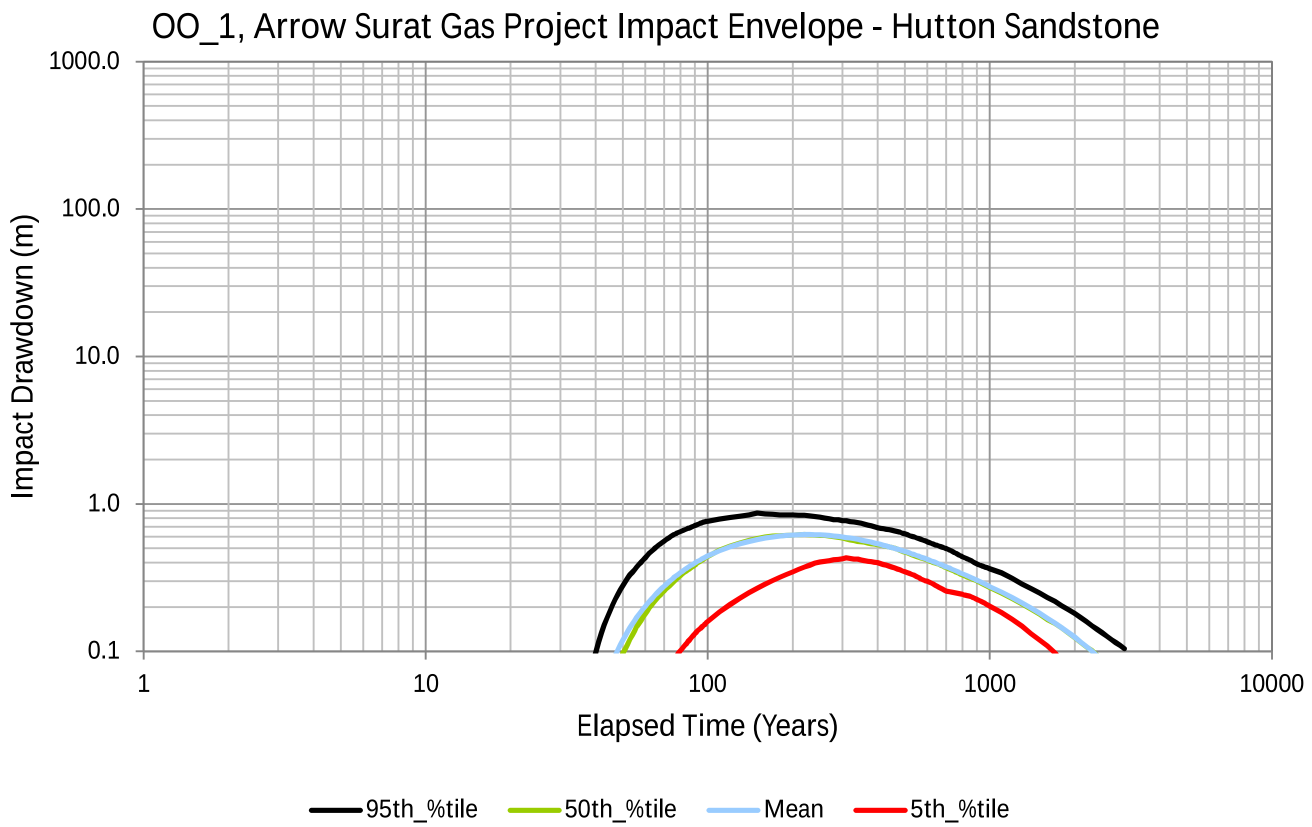
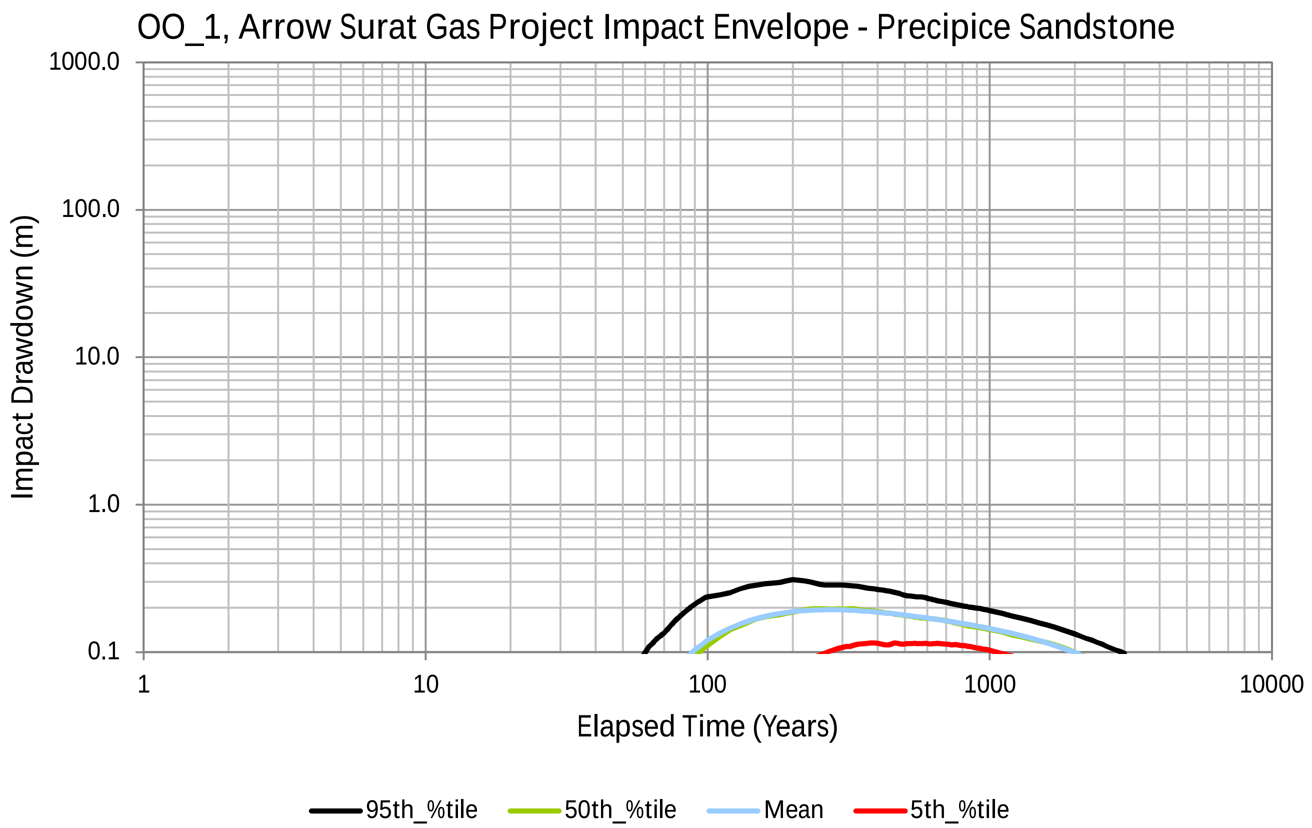
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5





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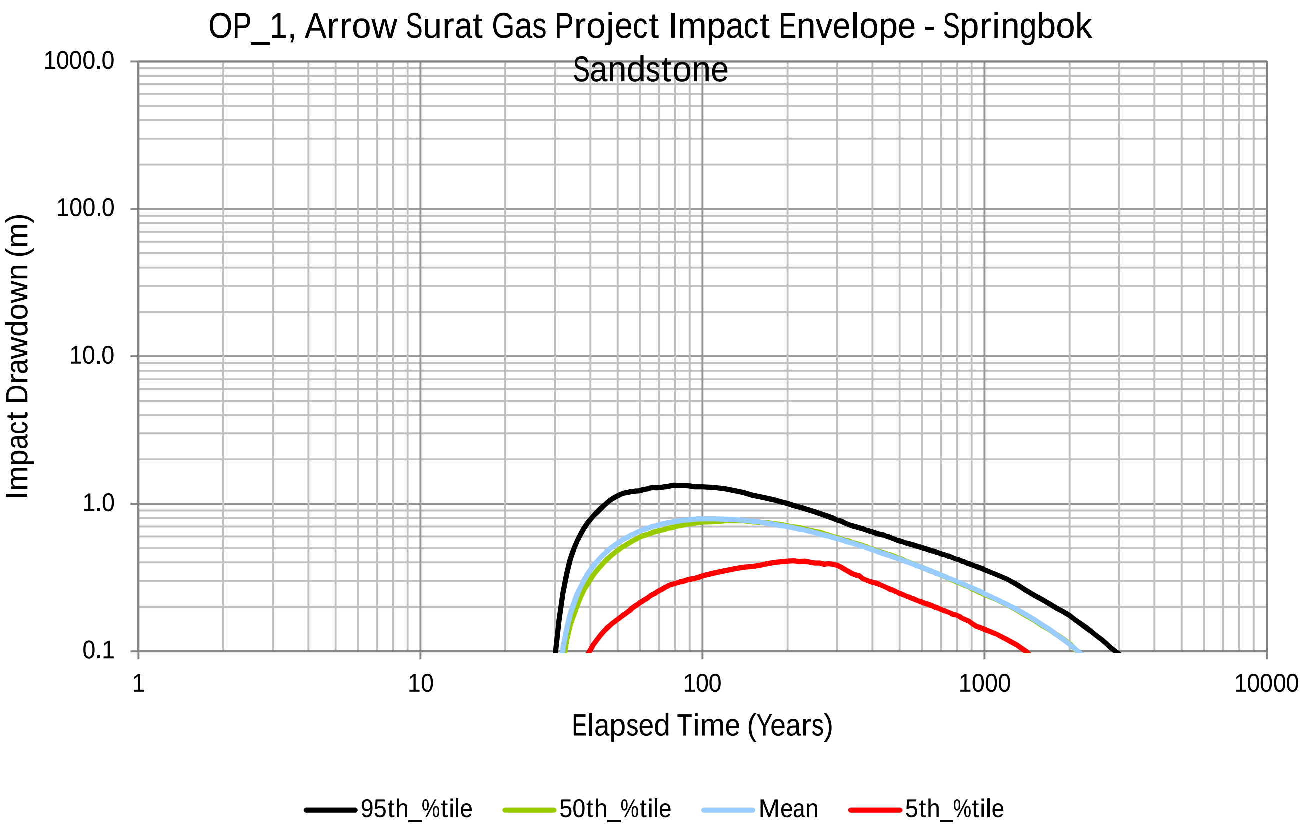
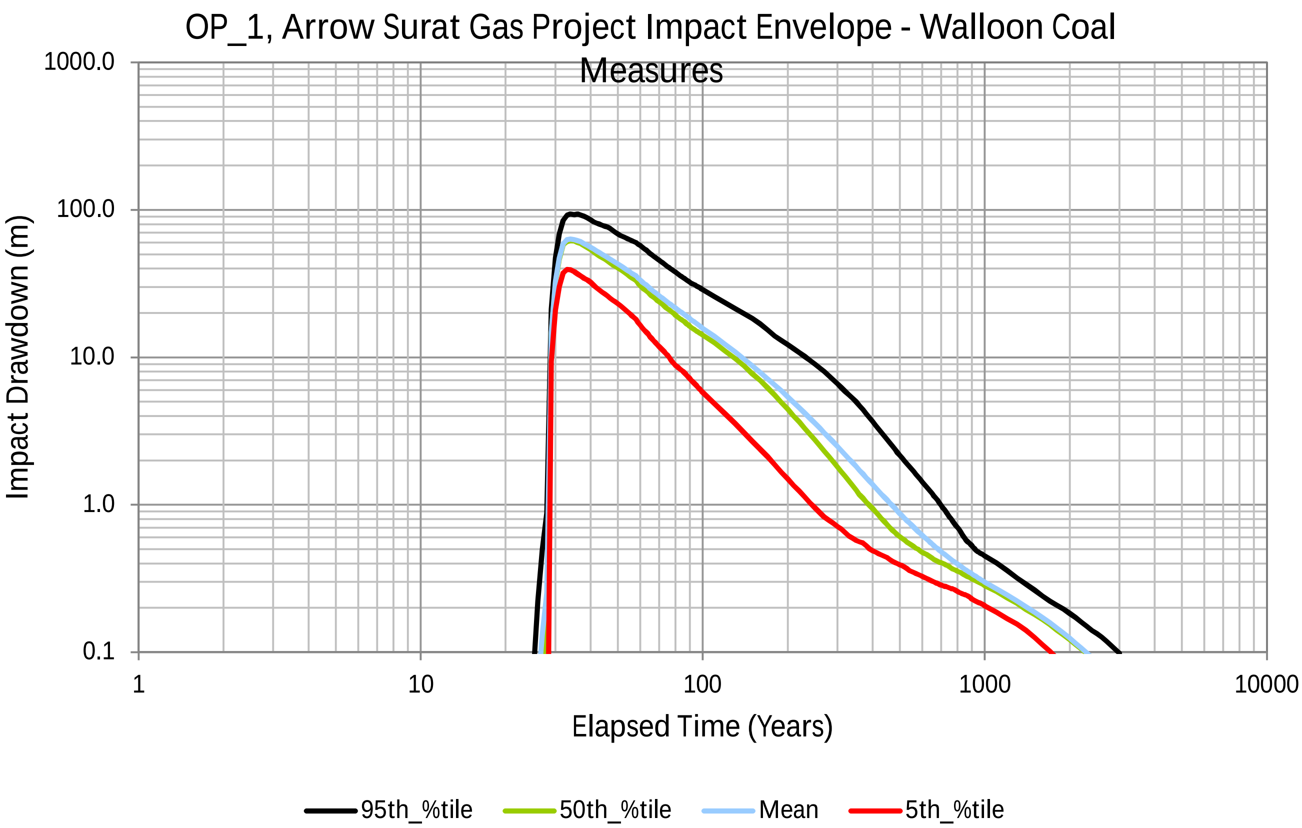
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5





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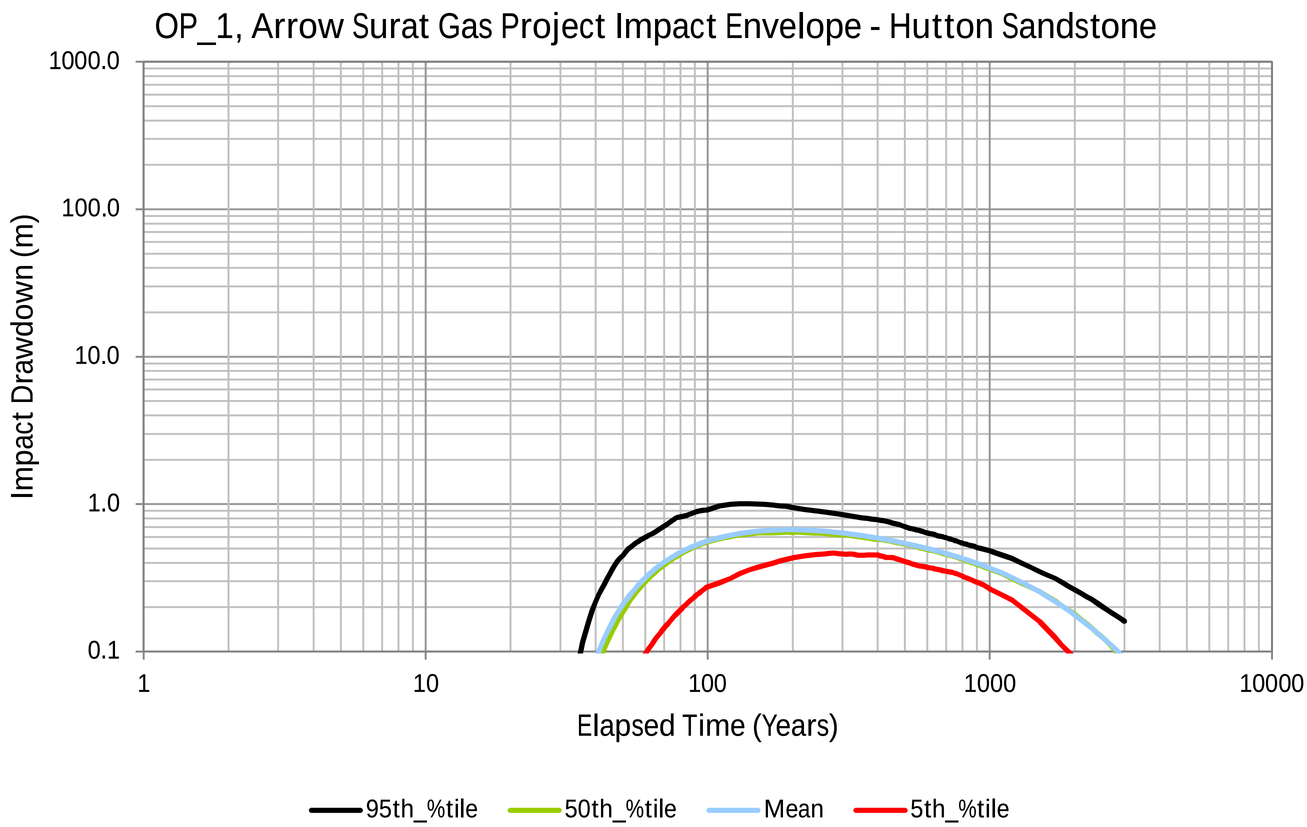
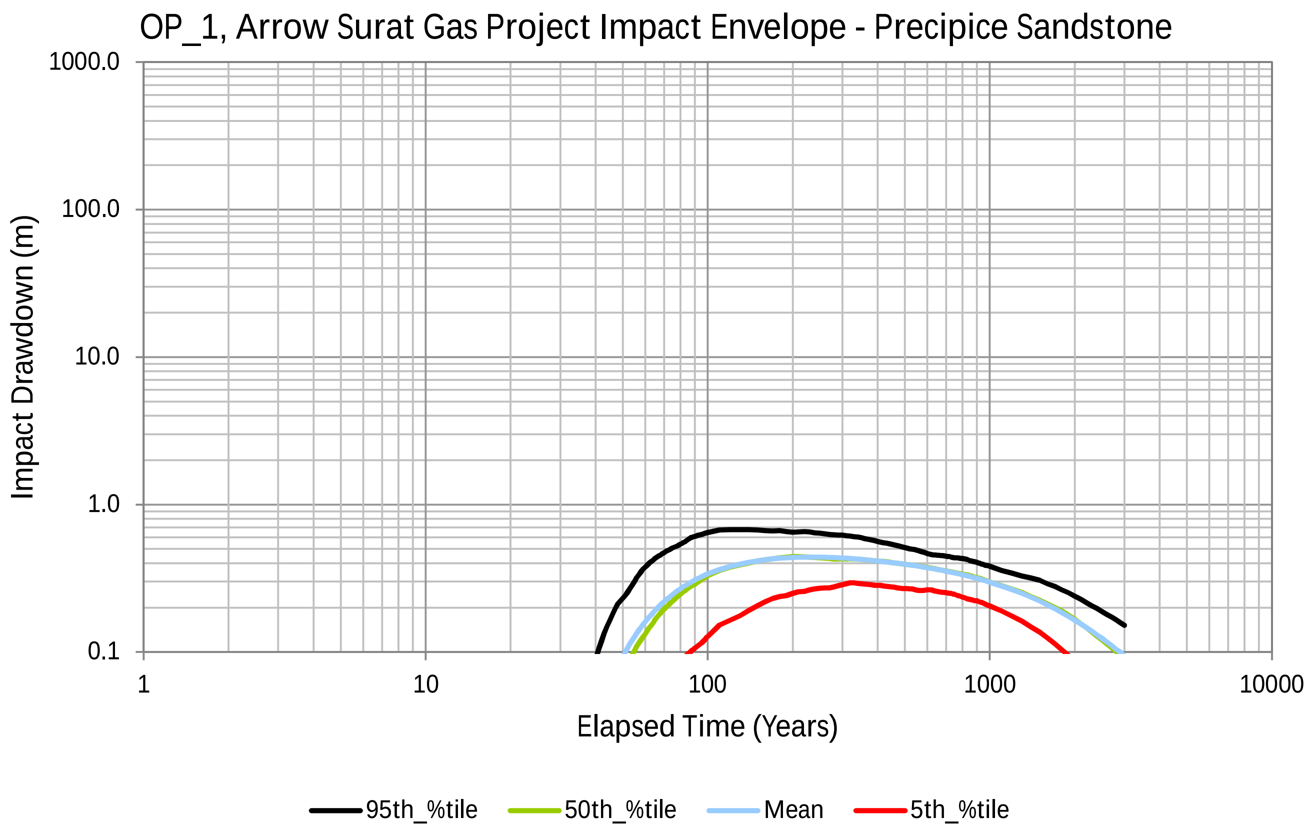
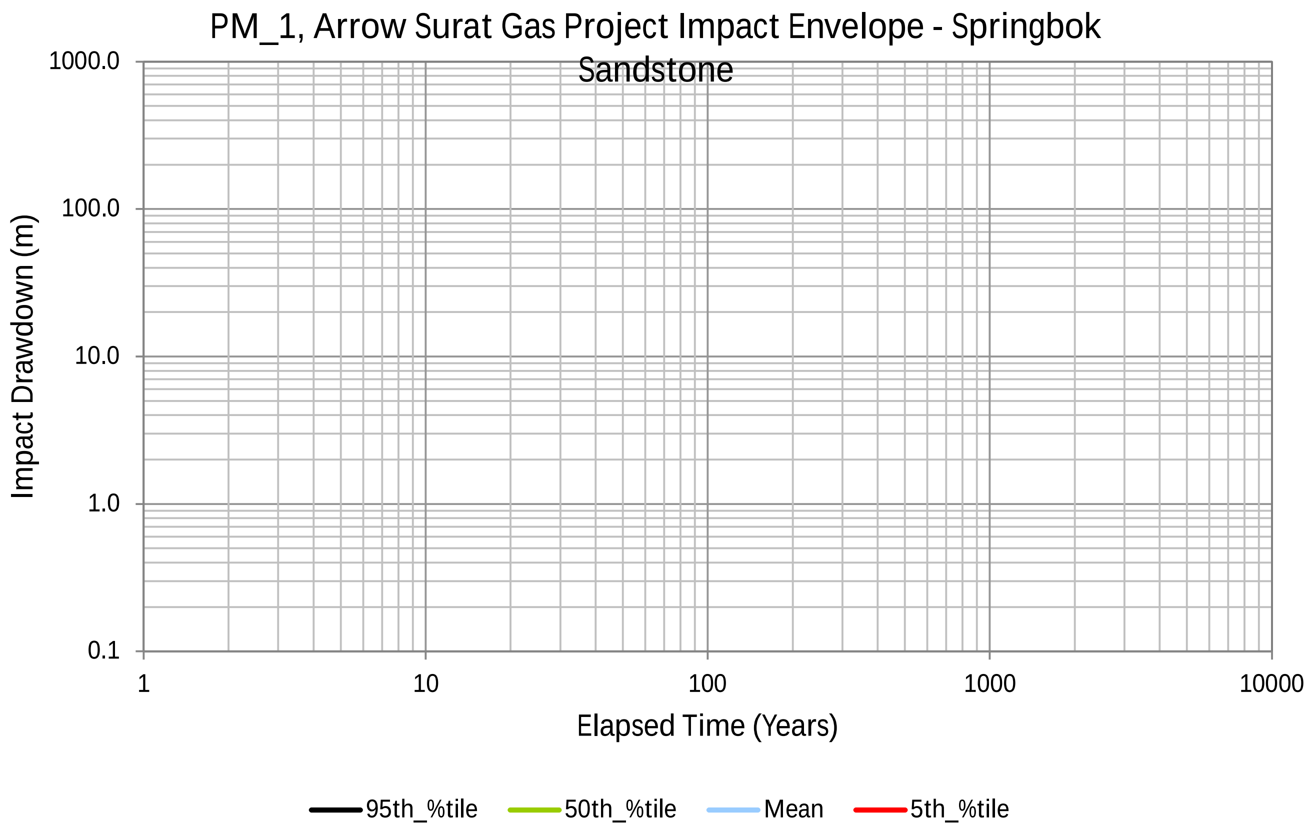
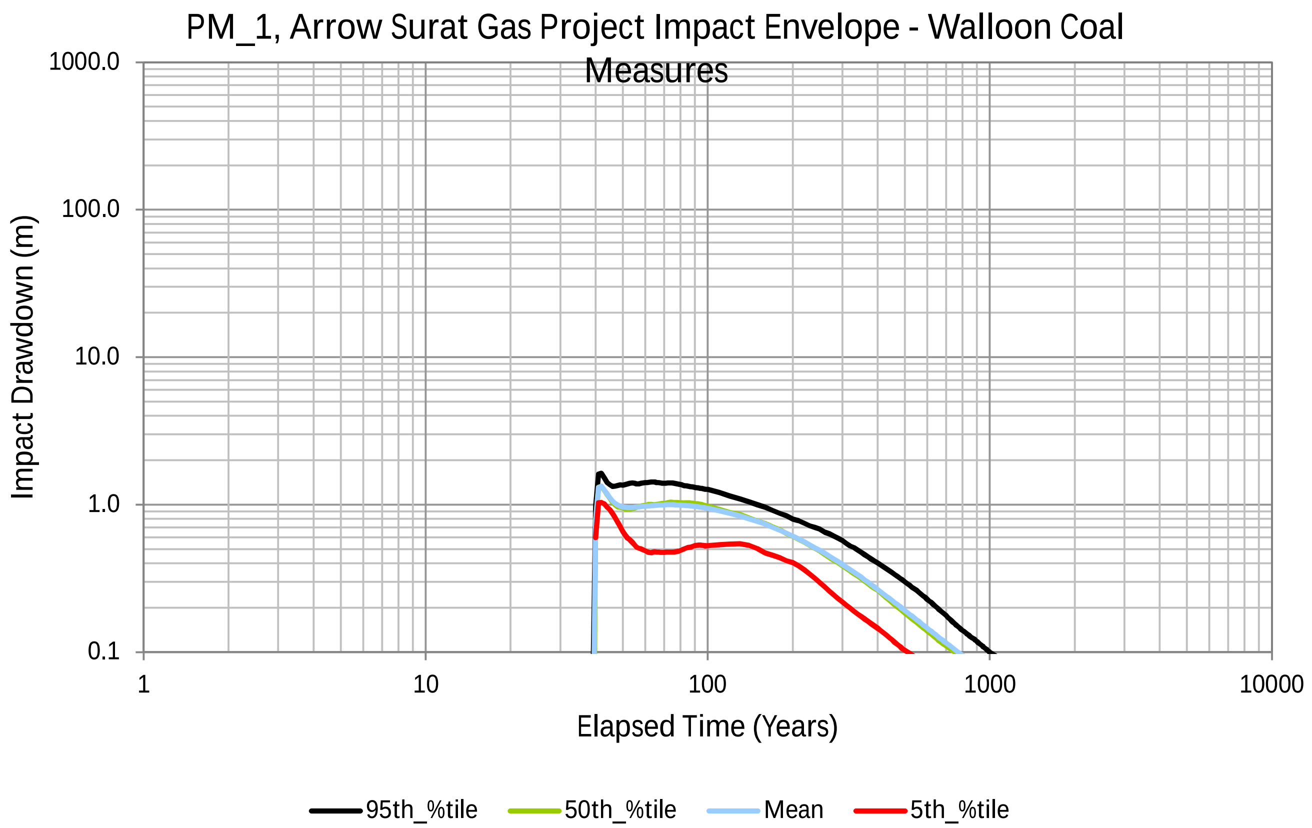
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5

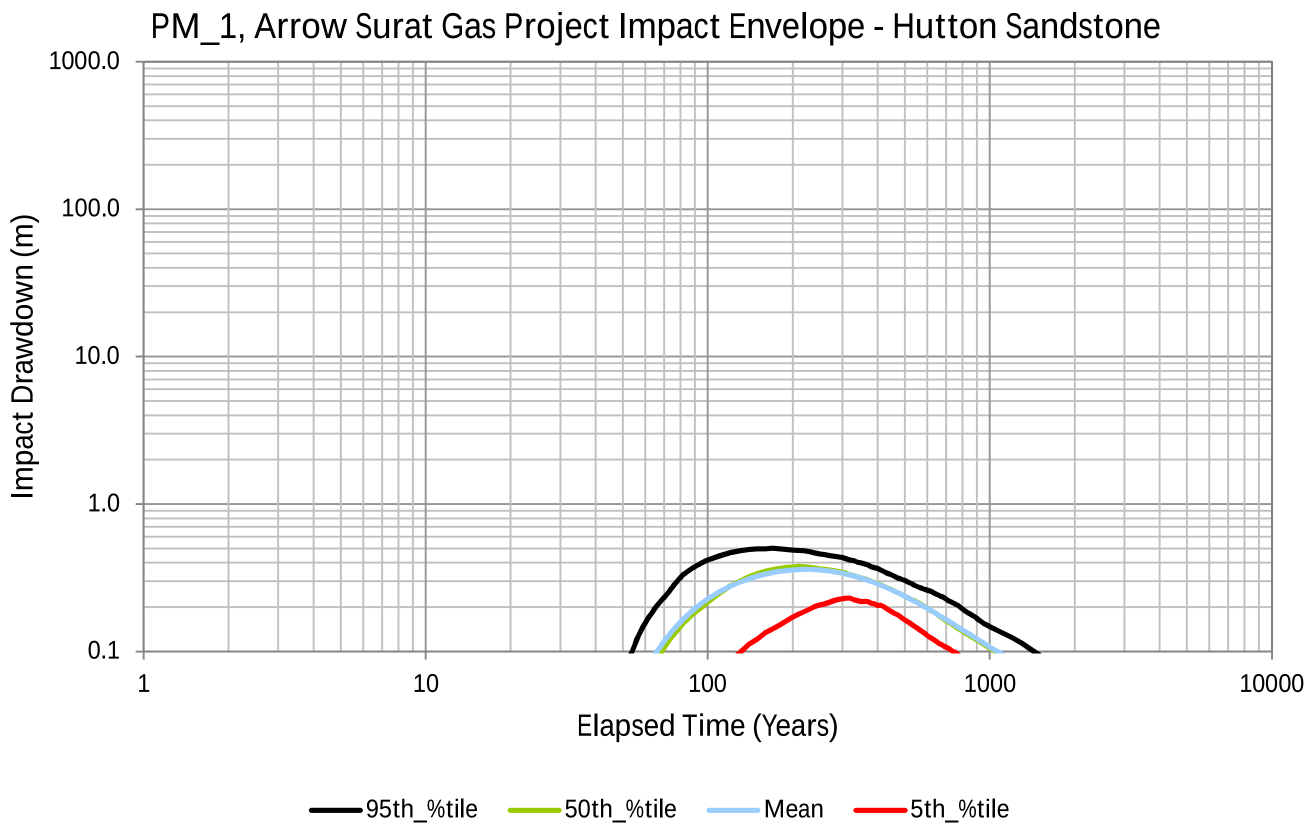


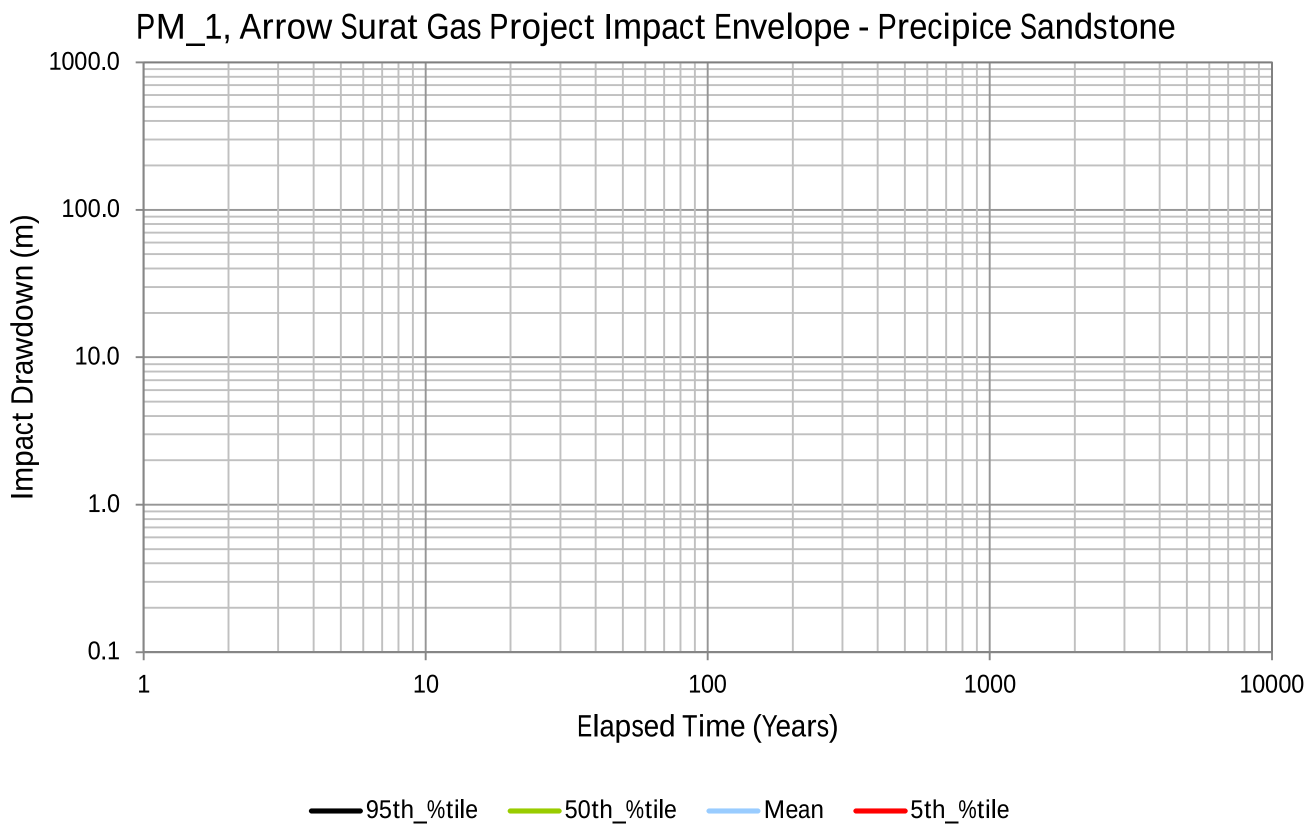



PM_1, Arrow Surat Gas Project Impact Envelope - Springbok Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile


PM_1, Arrow Surat Gas Project Impact Envelope - Walloon Coal Measures
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

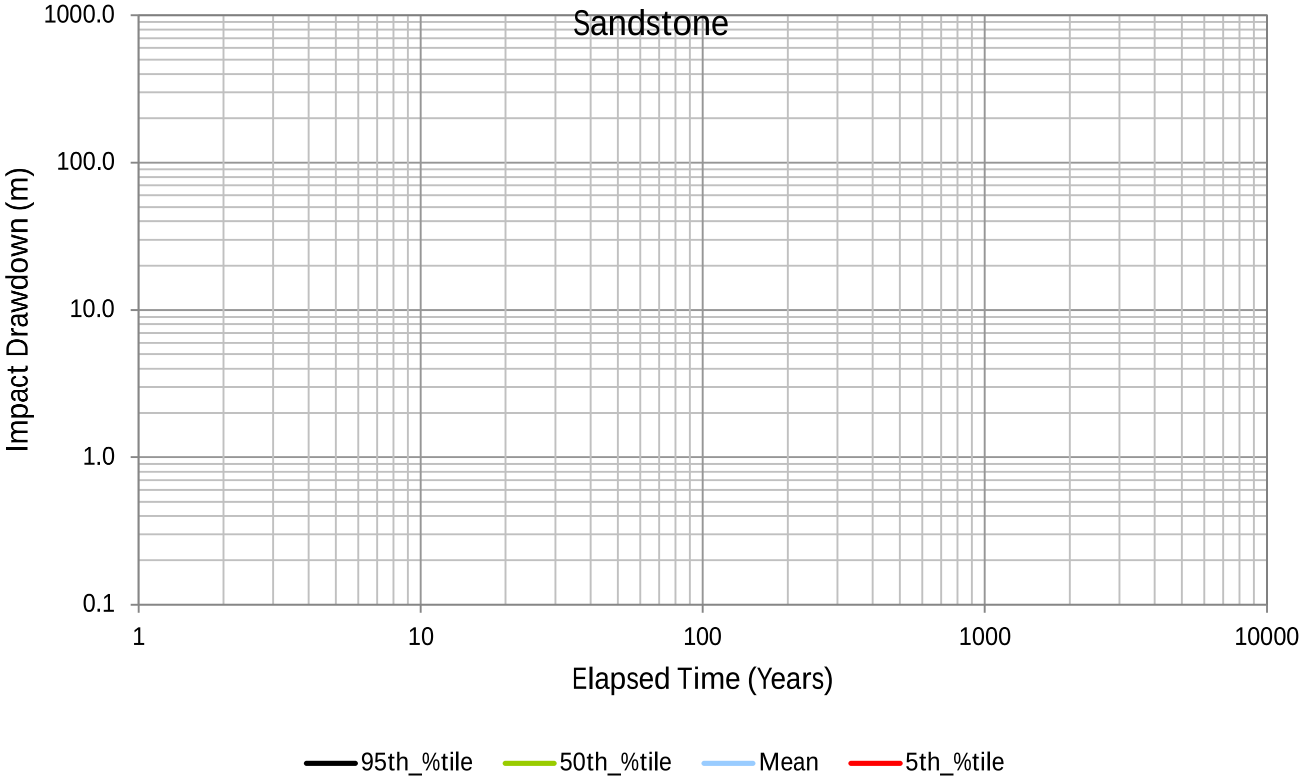
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5



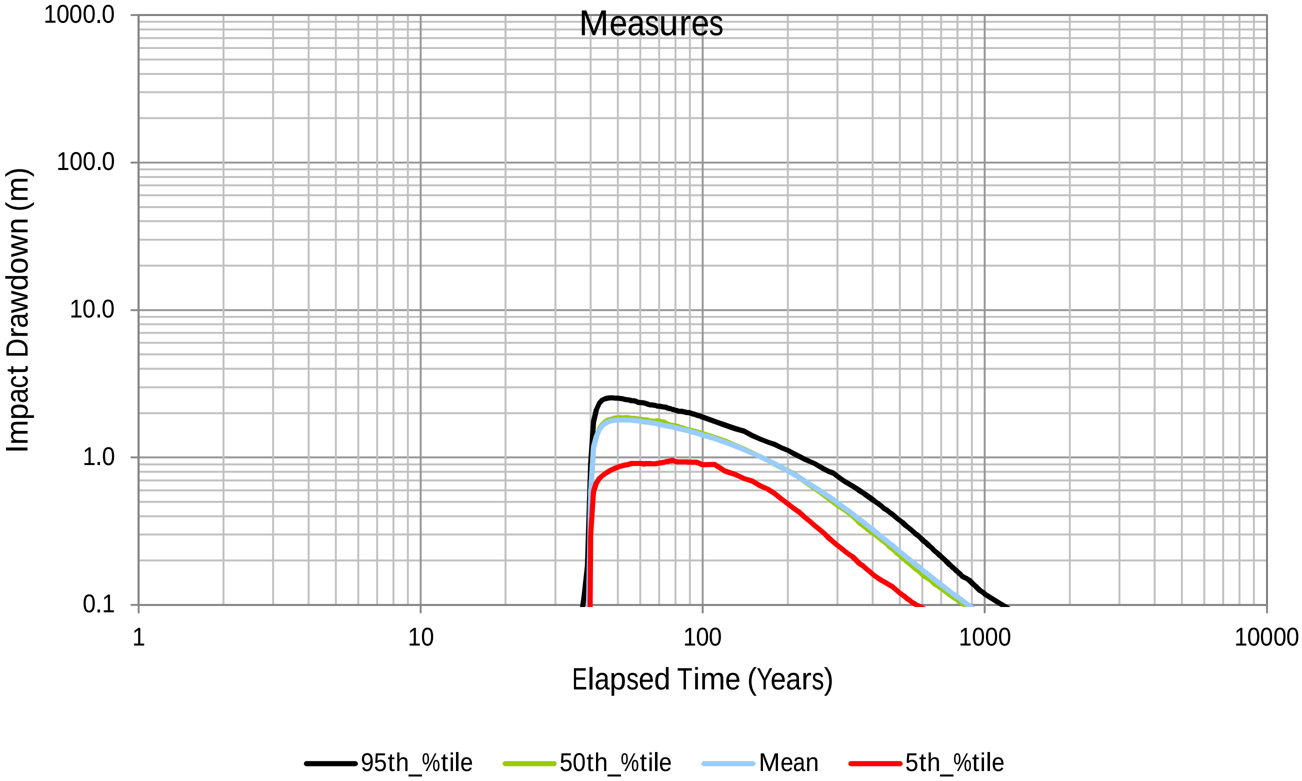


Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5

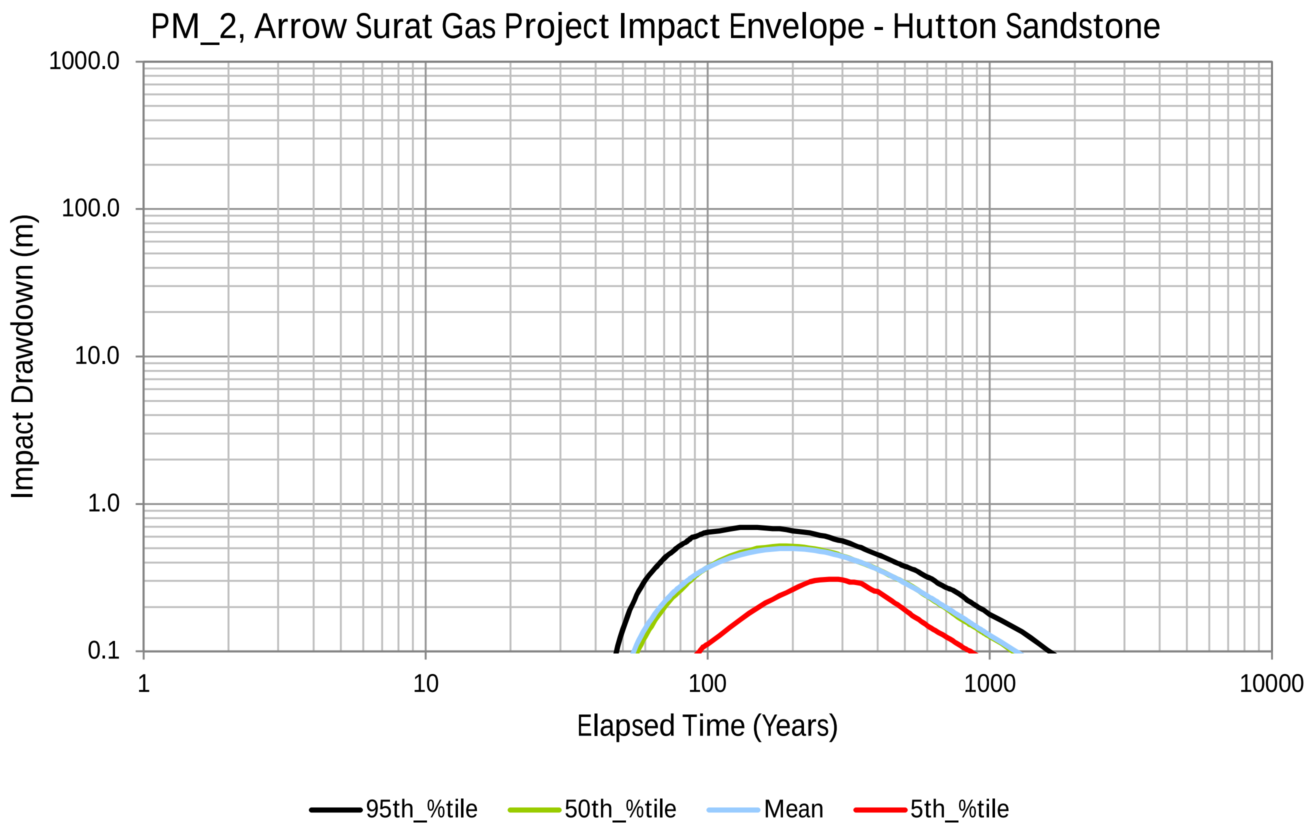
PM_2, Arrow Surat Gas Project Impact Envelope - Springbok Sandstone

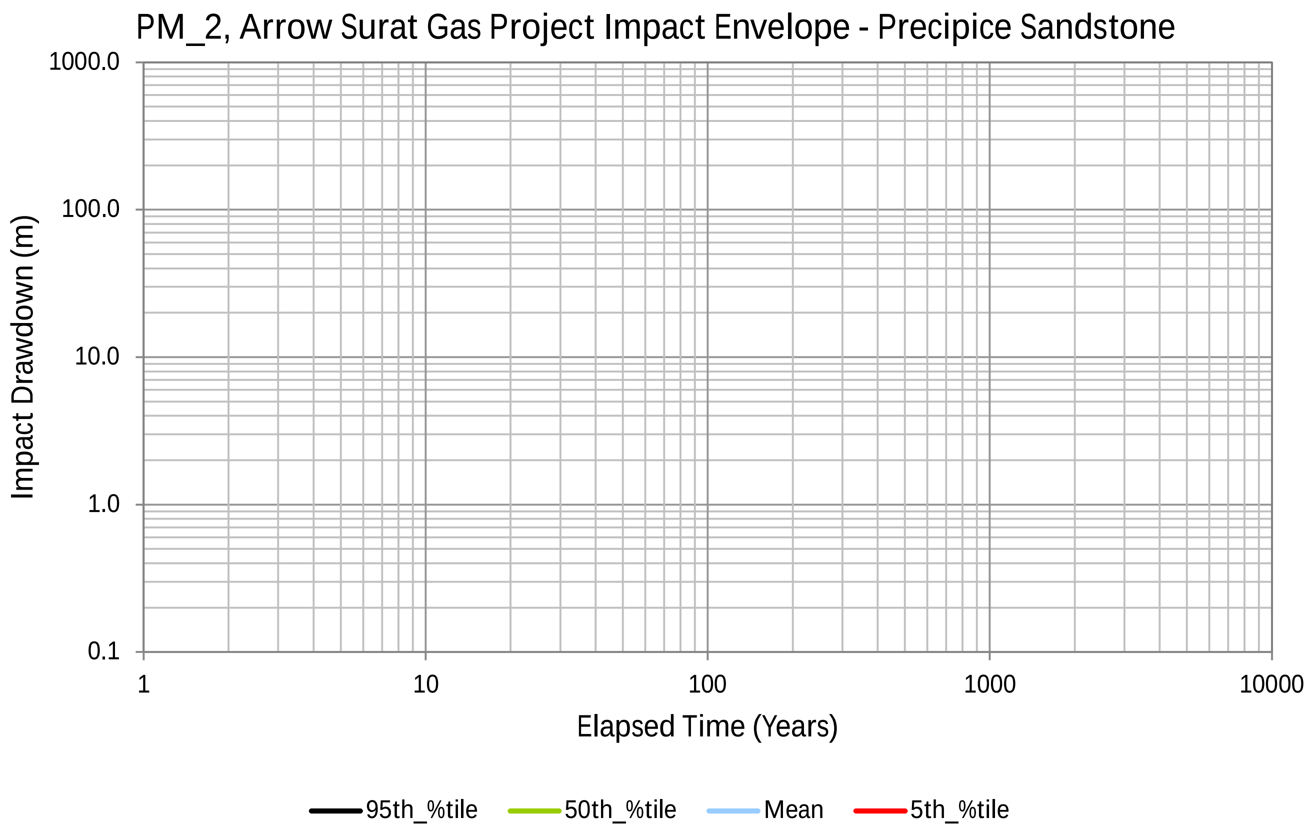


PM_2, Arrow Surat Gas Project Impact Envelope - Walloon Coal Measures



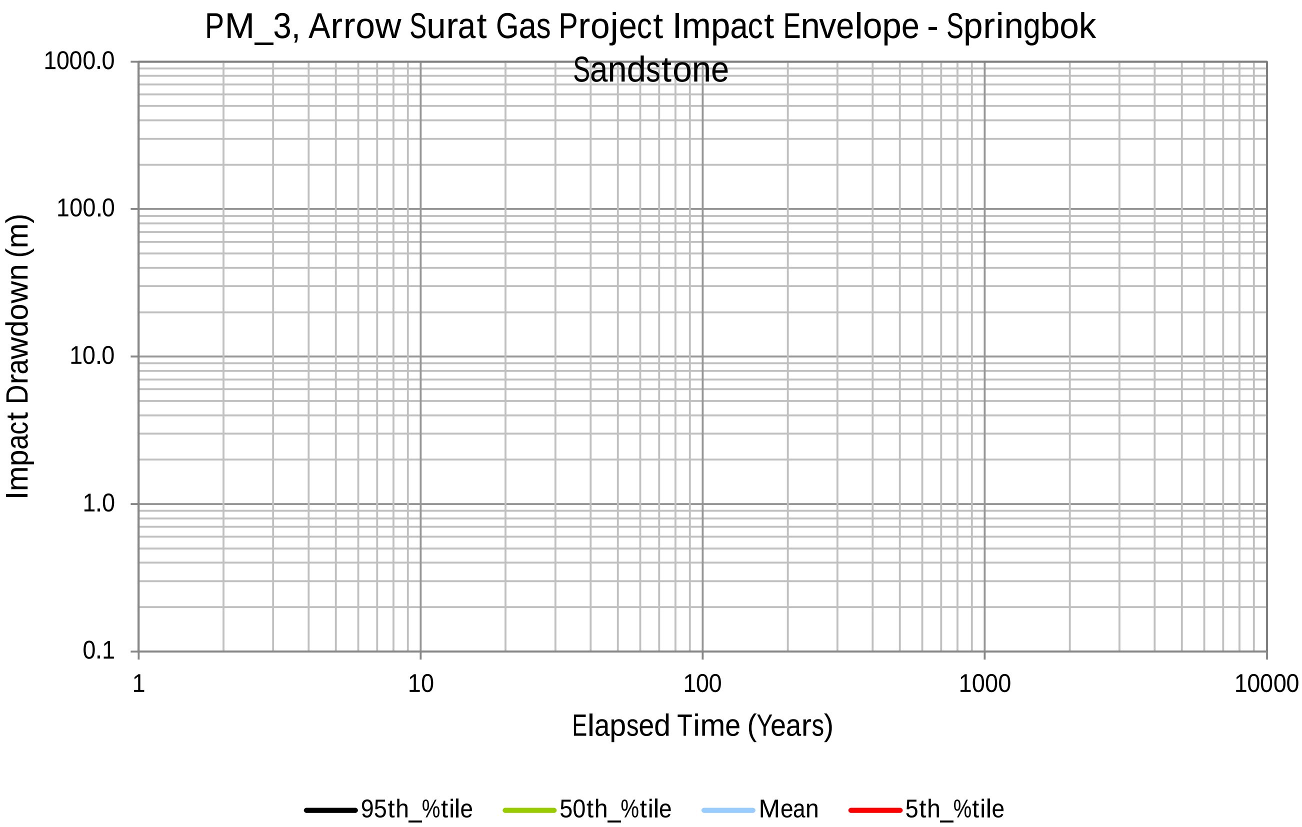
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5

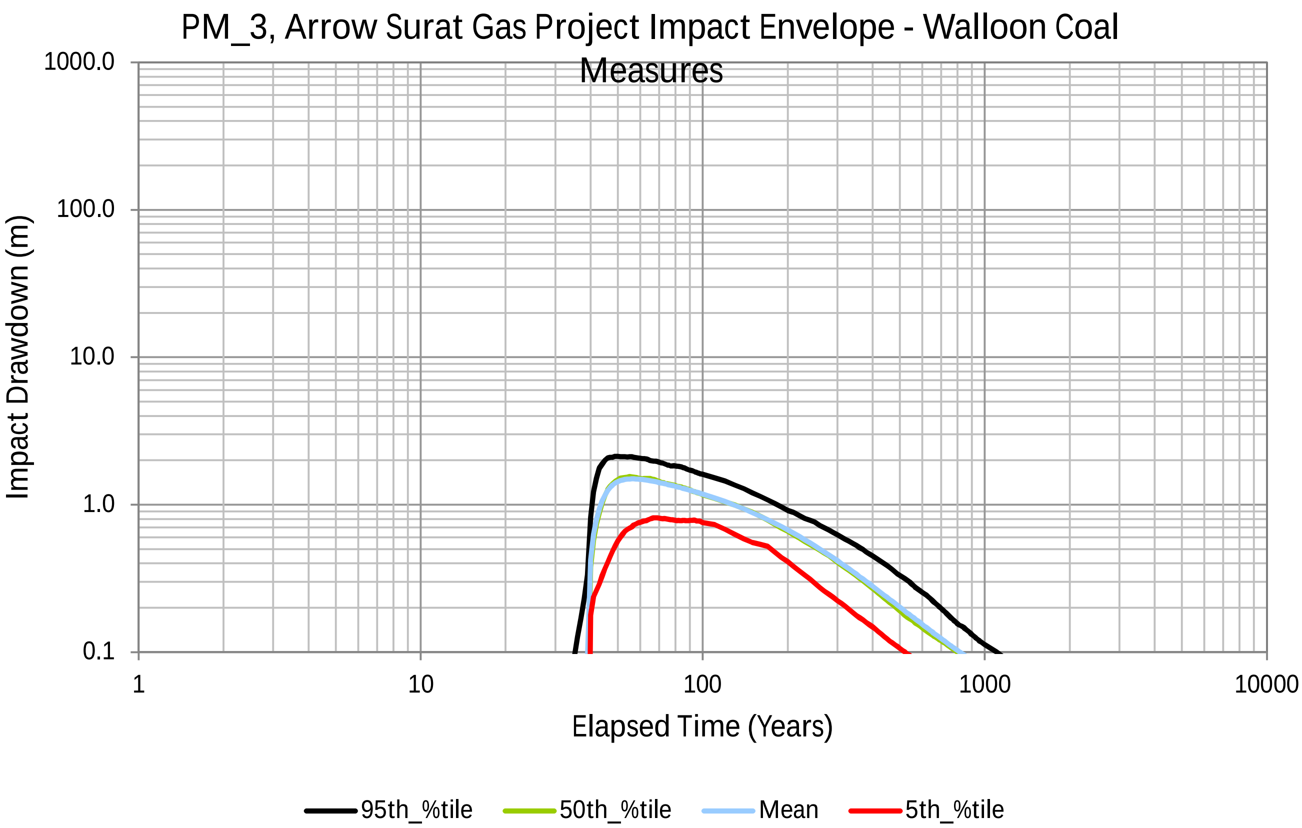




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_5)

Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5





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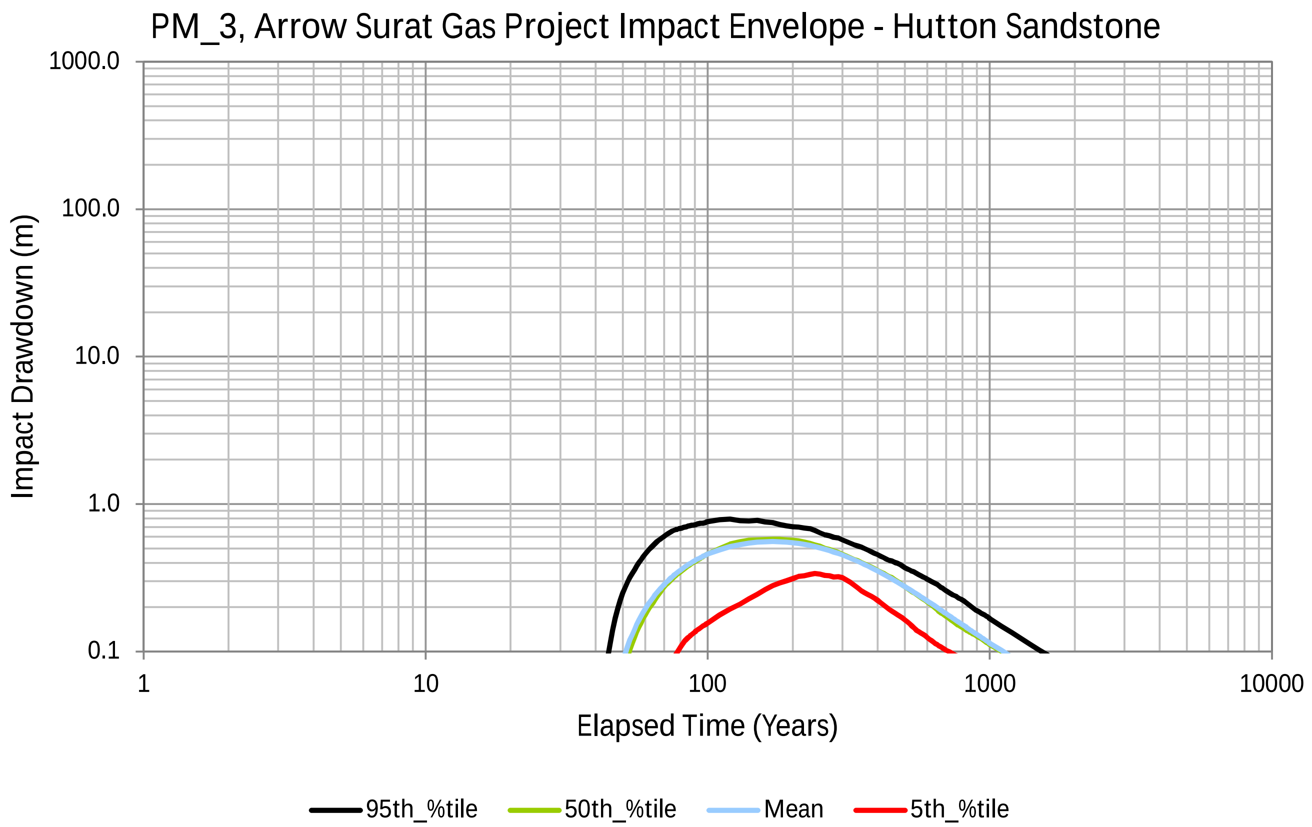
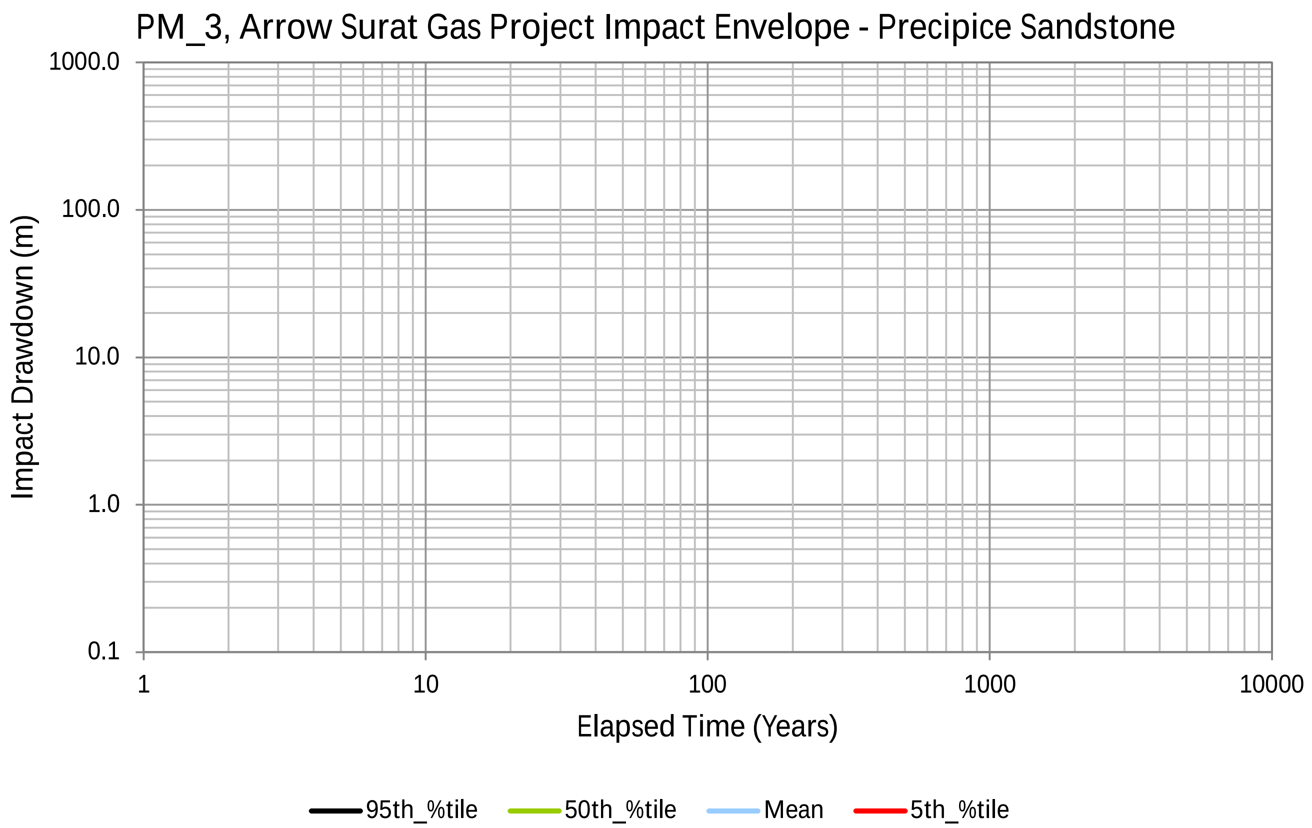
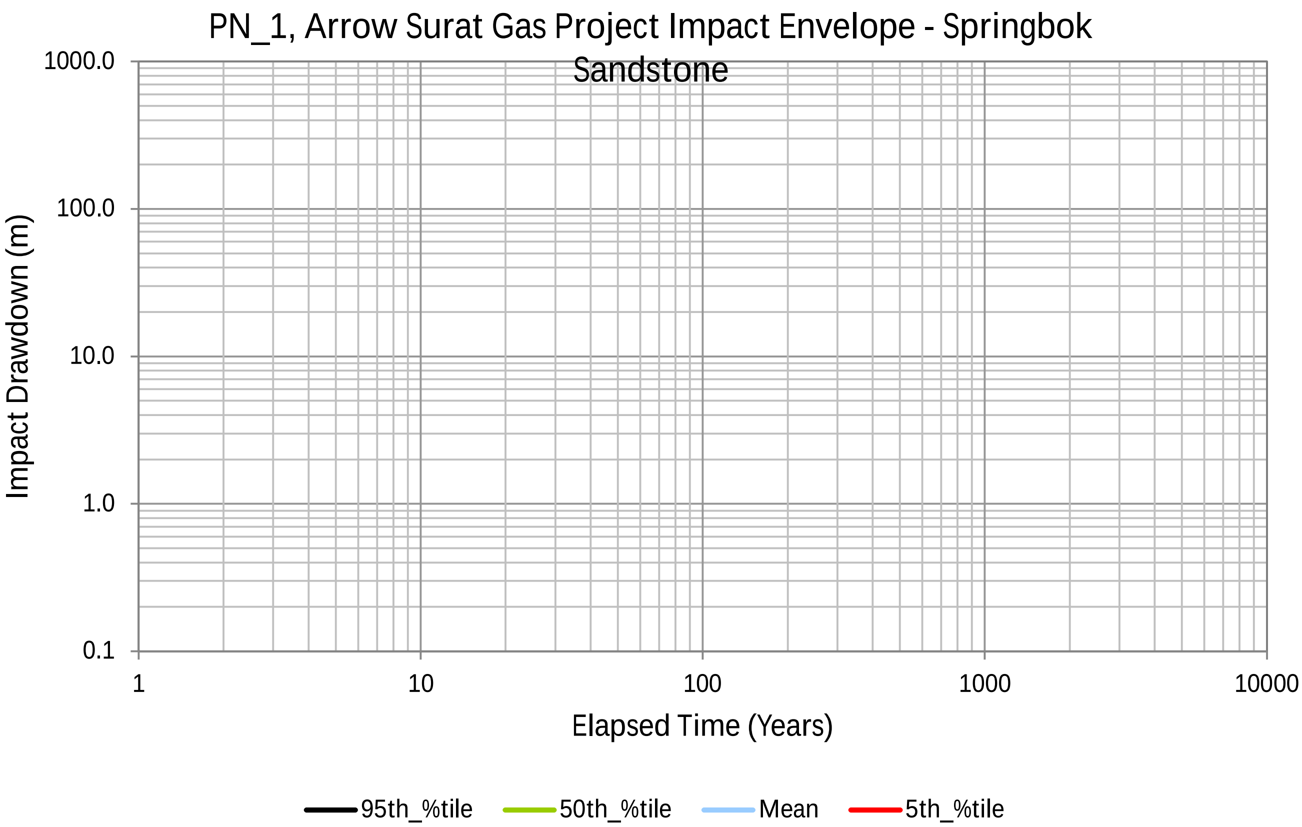
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5

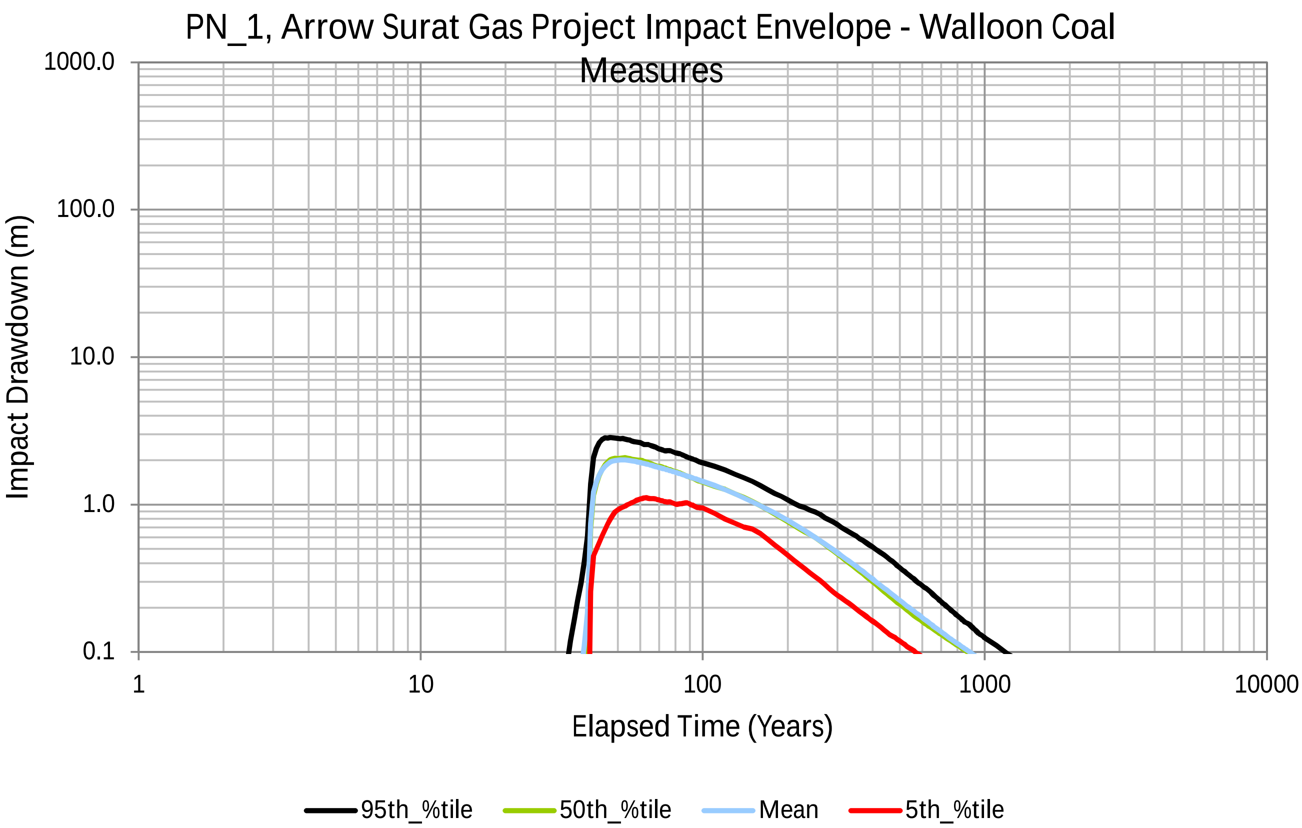




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_5)

Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5





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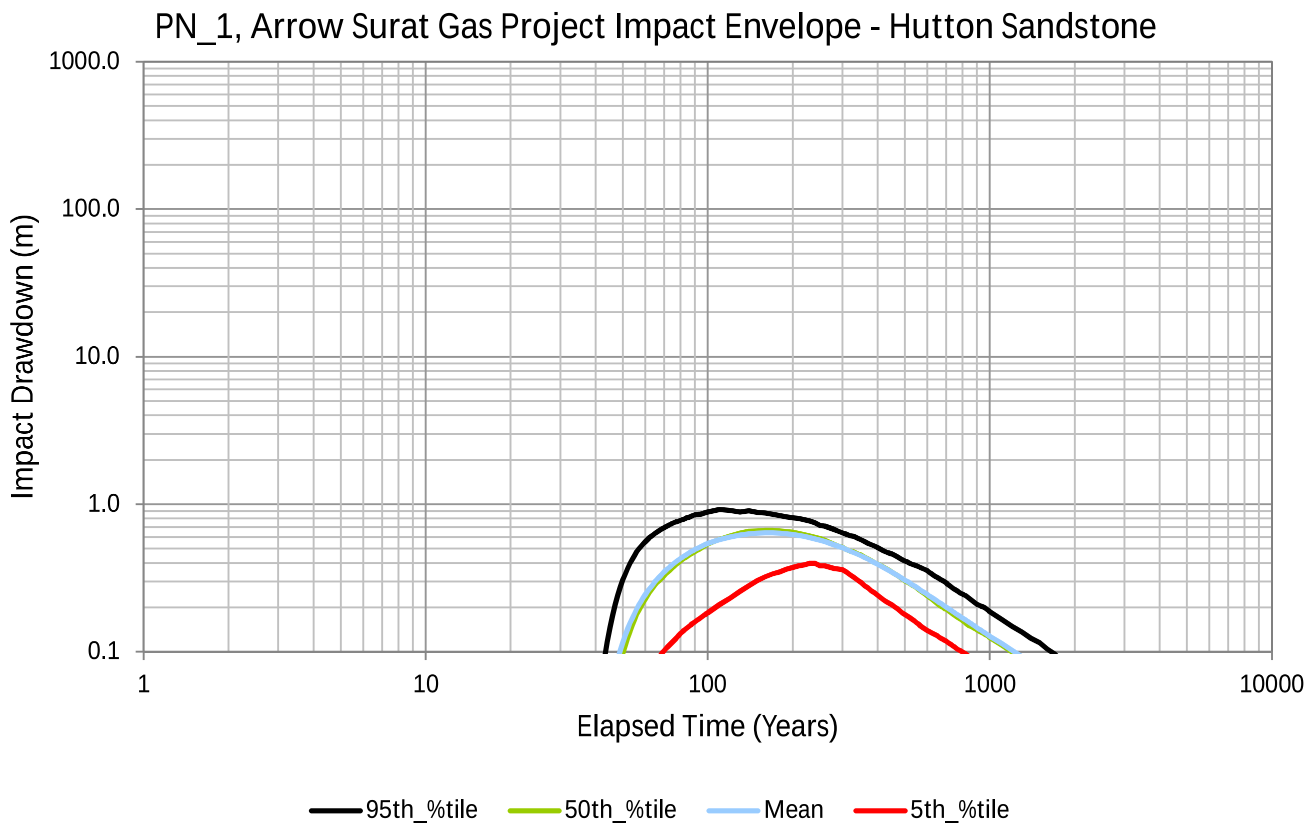
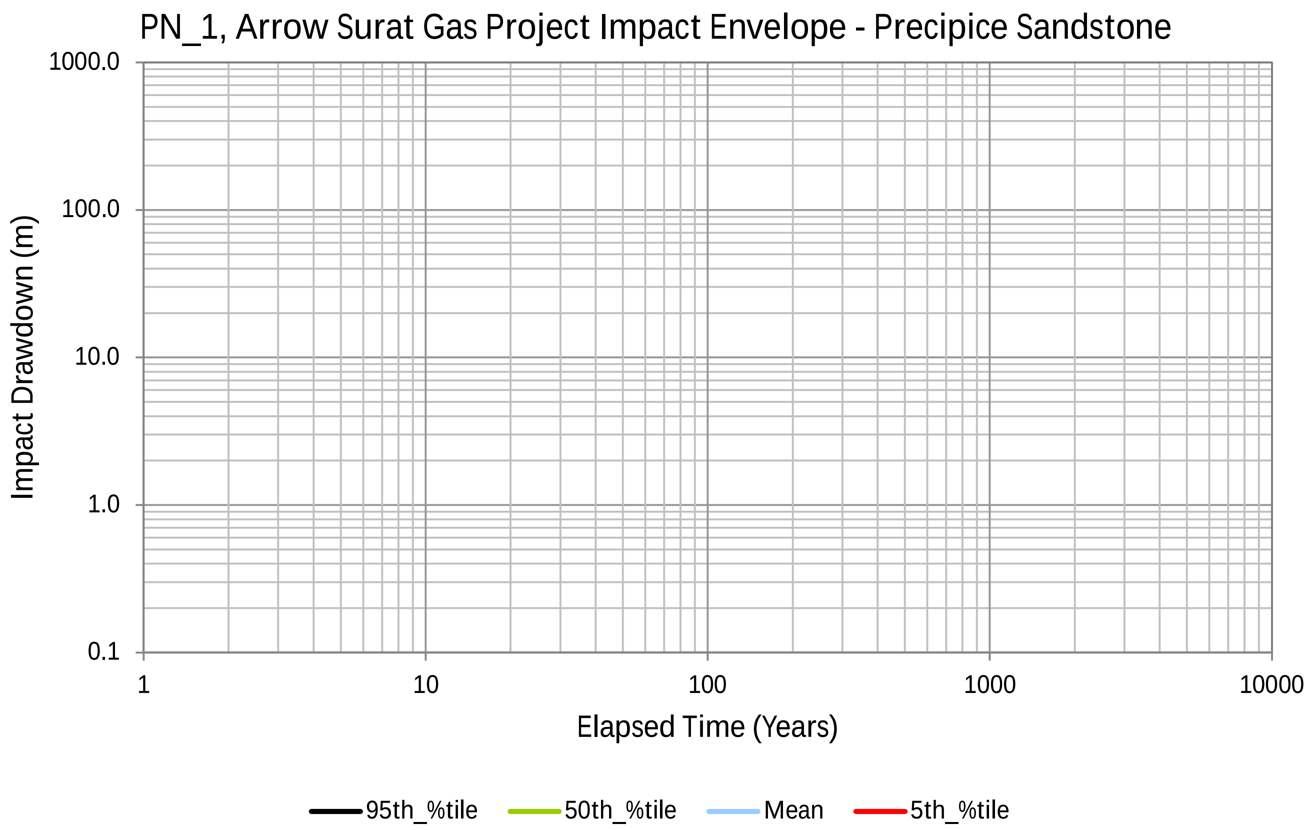
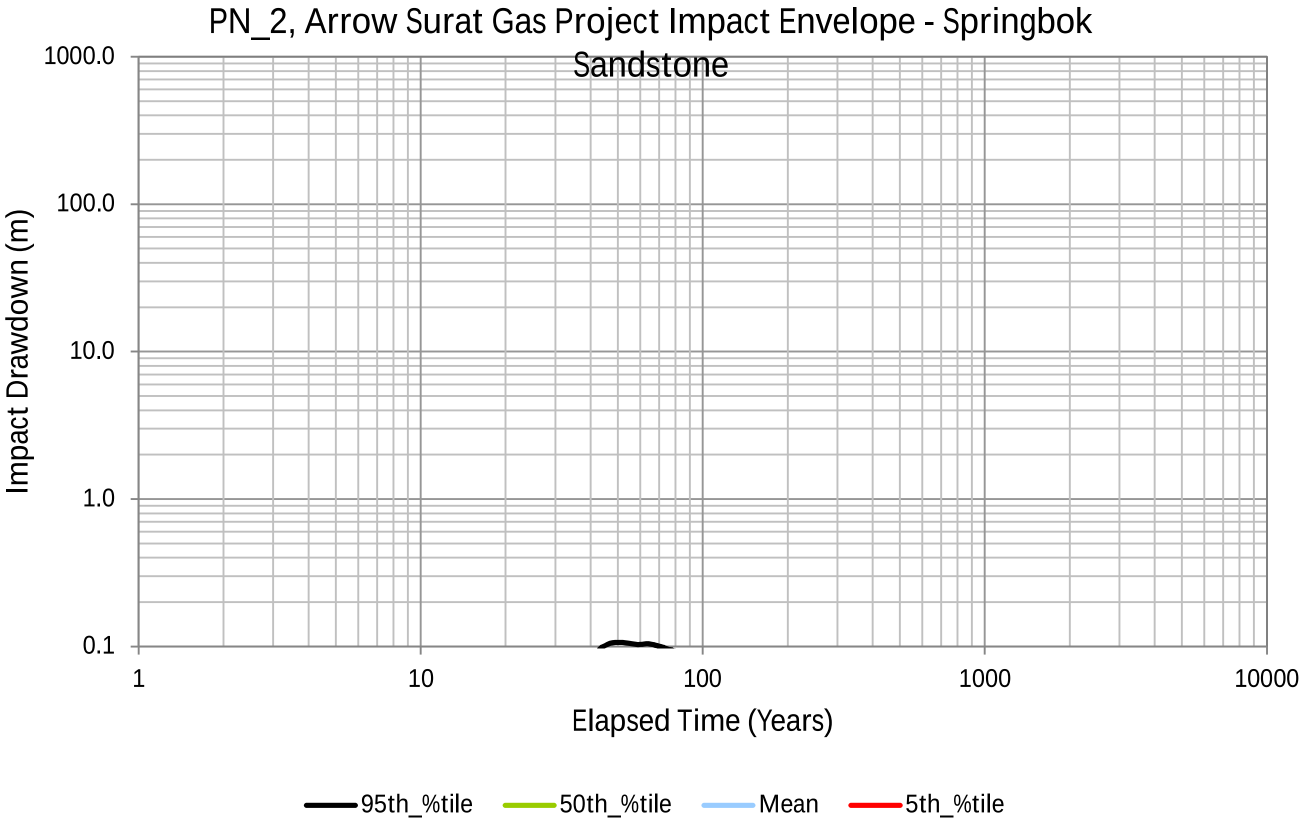
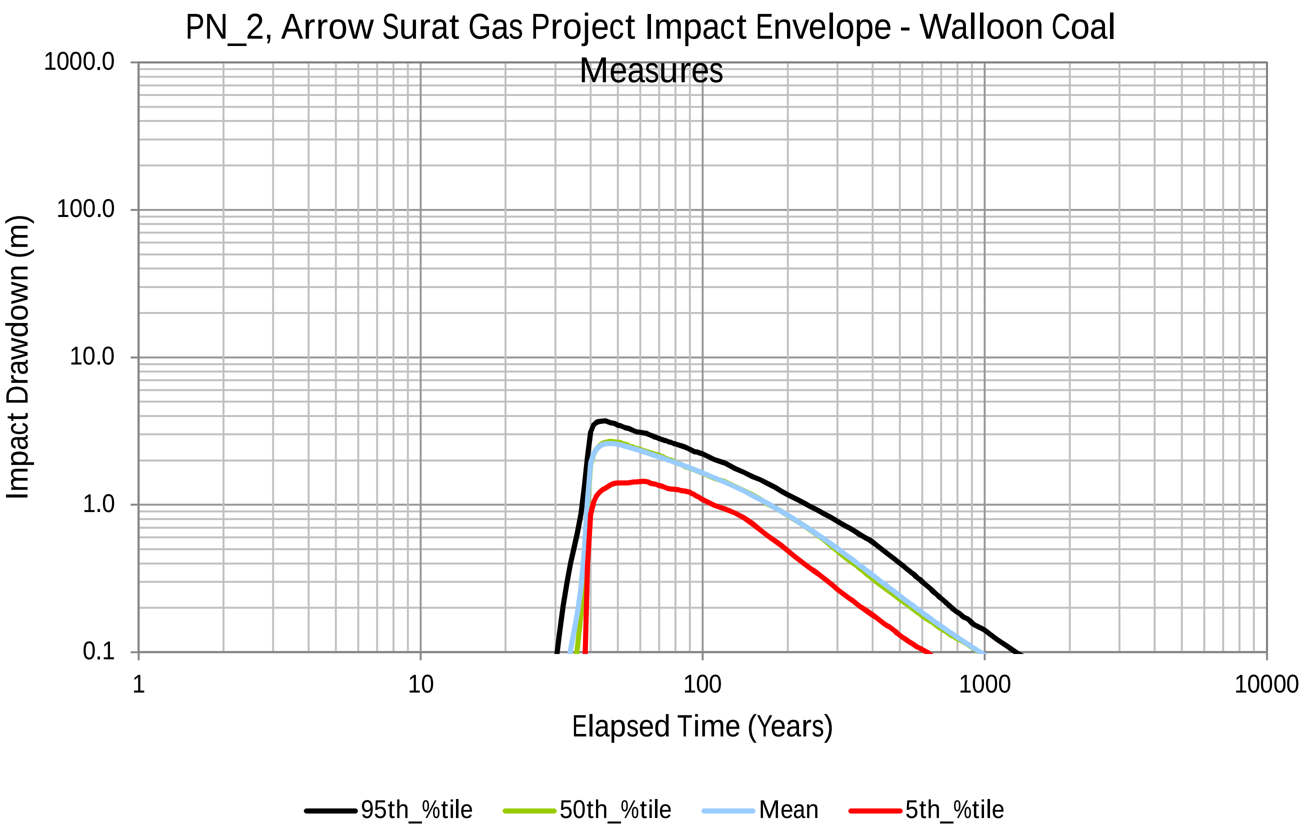

PN_1, Arrow Surat Gas Project Impact Envelope - Hutton Sandstone
1000.0
100.0
10.0
1.0
0.1
Impact Drawdown (m)
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile


PN_1, Arrow Surat Gas Project Impact Envelope - Precipice Sandstone
1000.0
100.0
10.0
1.0
0.1
Impact Drawdown (m)
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

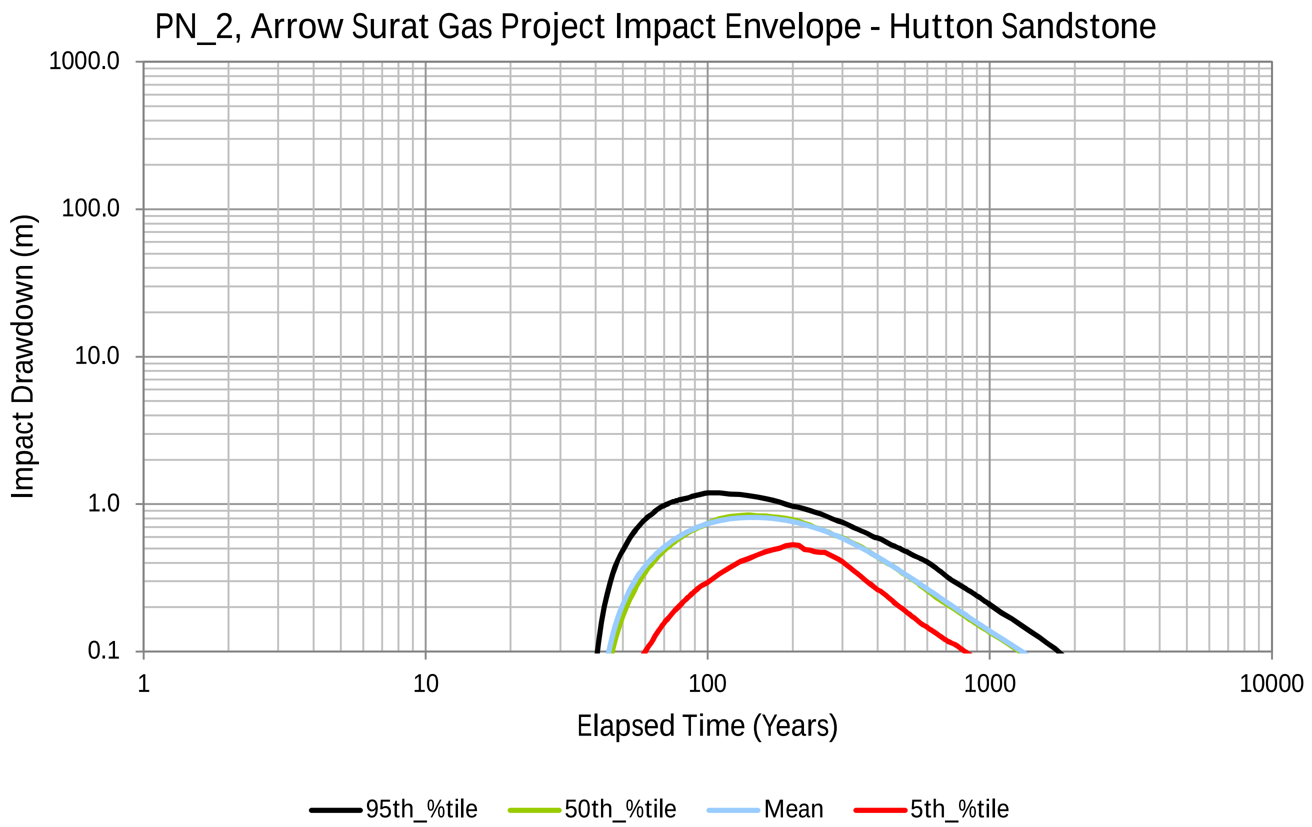
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5

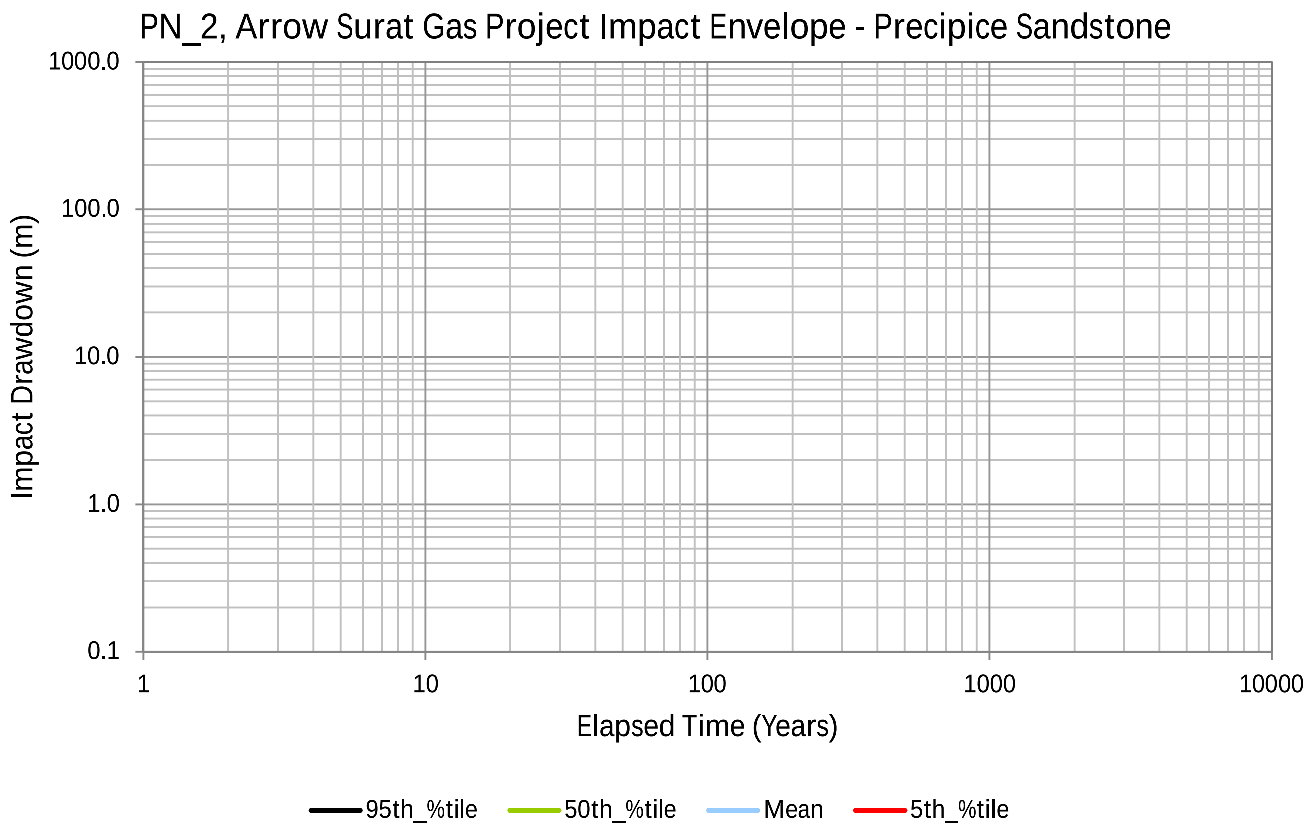




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_5)

Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5





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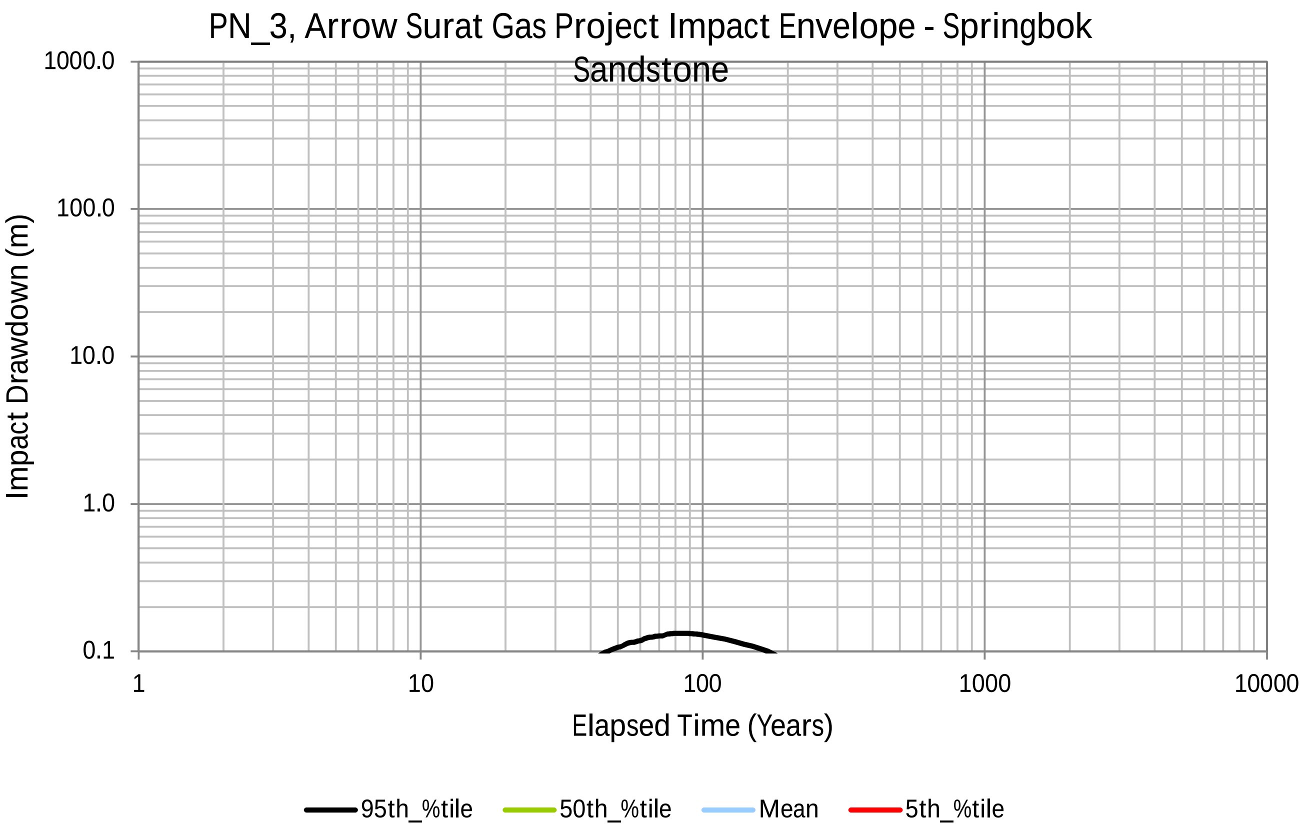
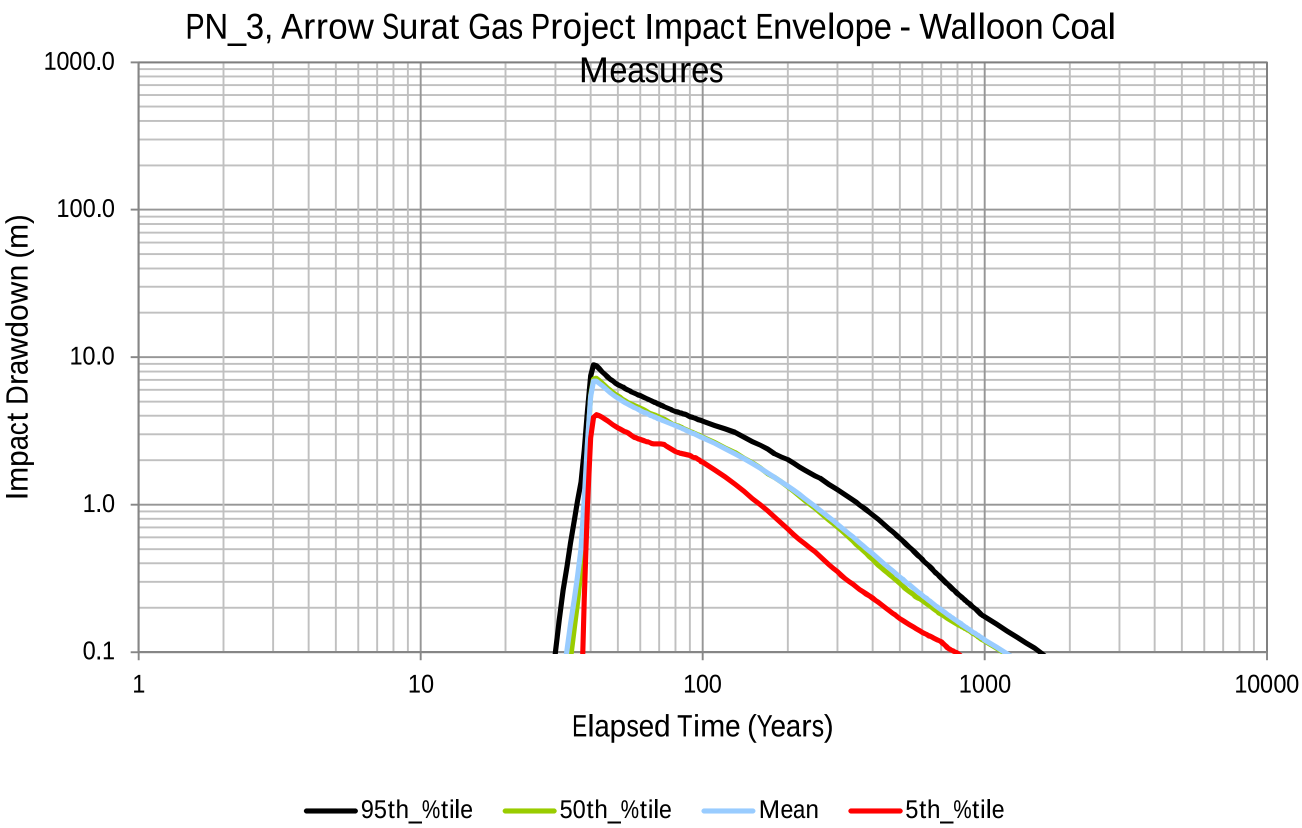
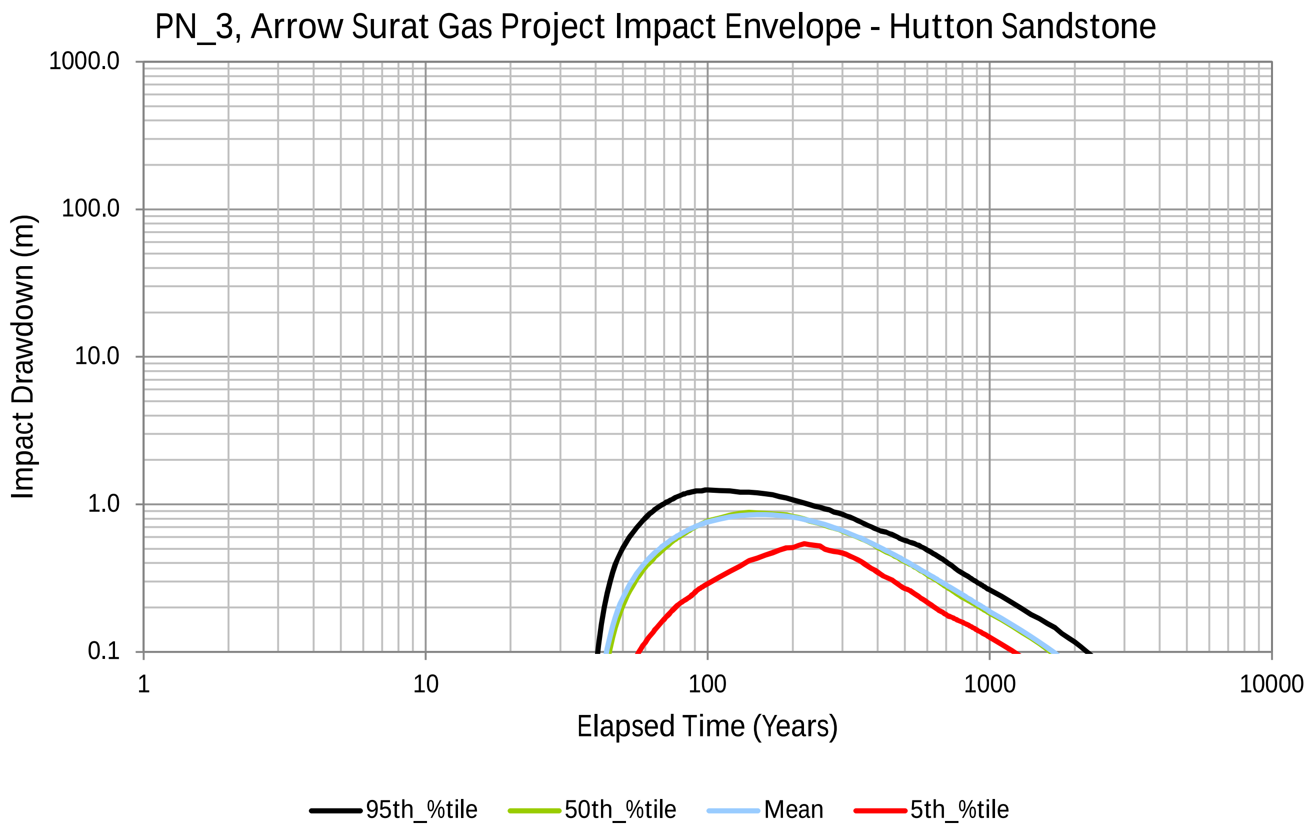
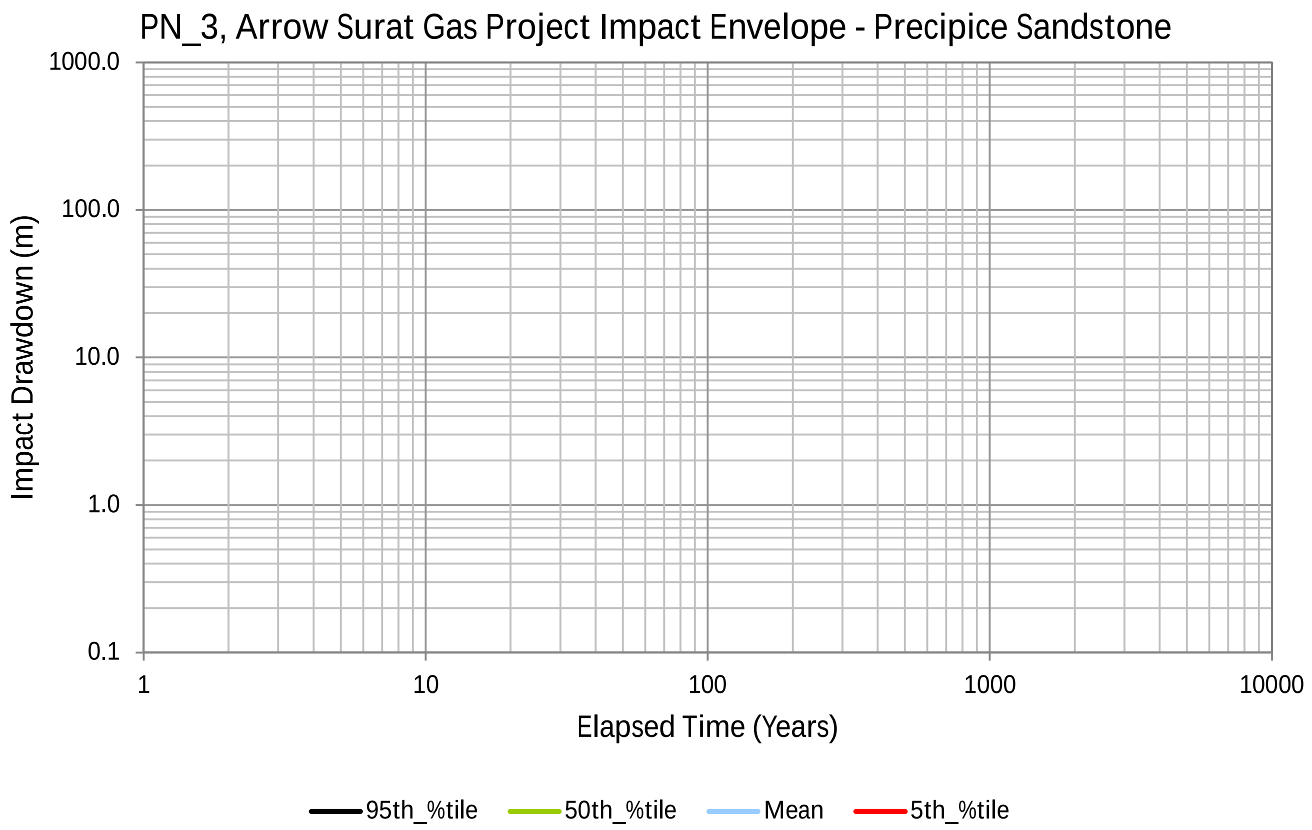
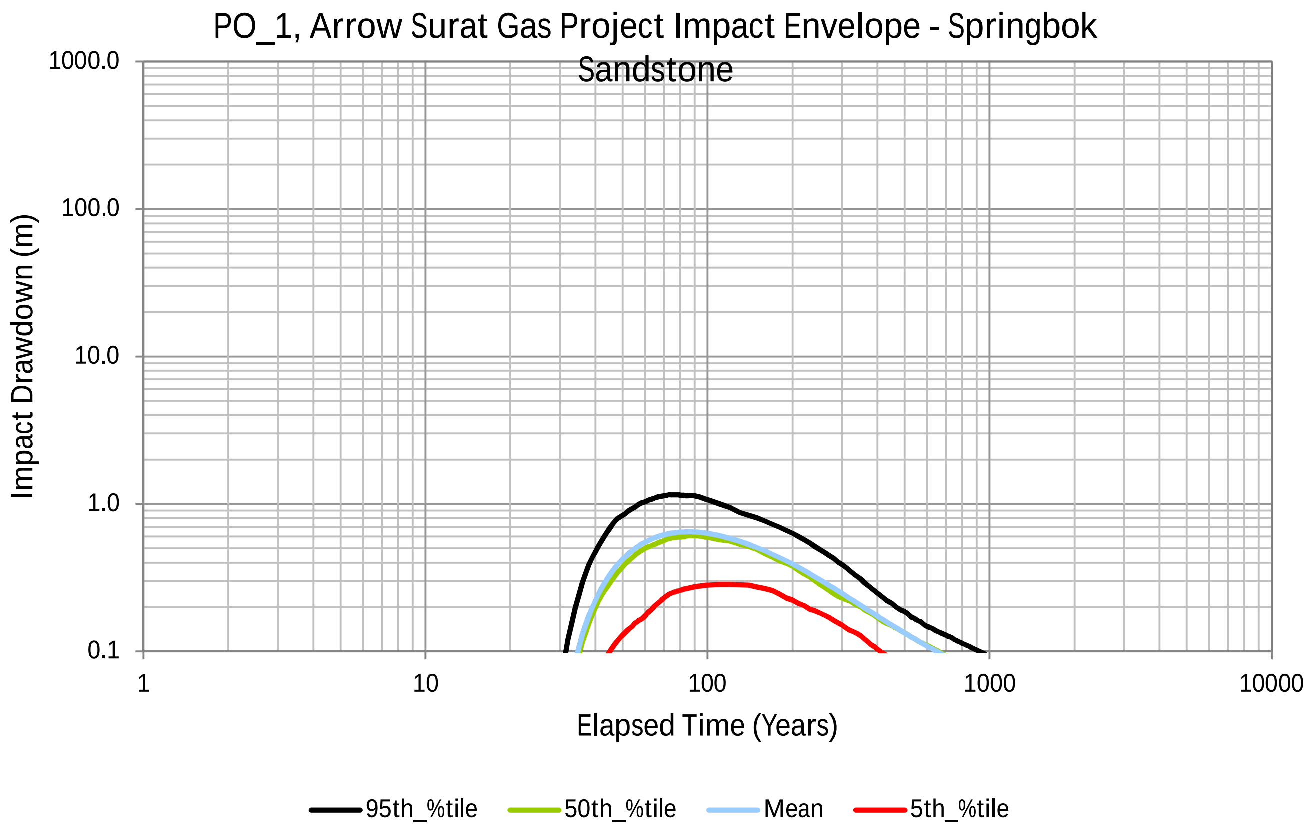

PN_3, Arrow Surat Gas Project Impact Envelope - Springbok Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

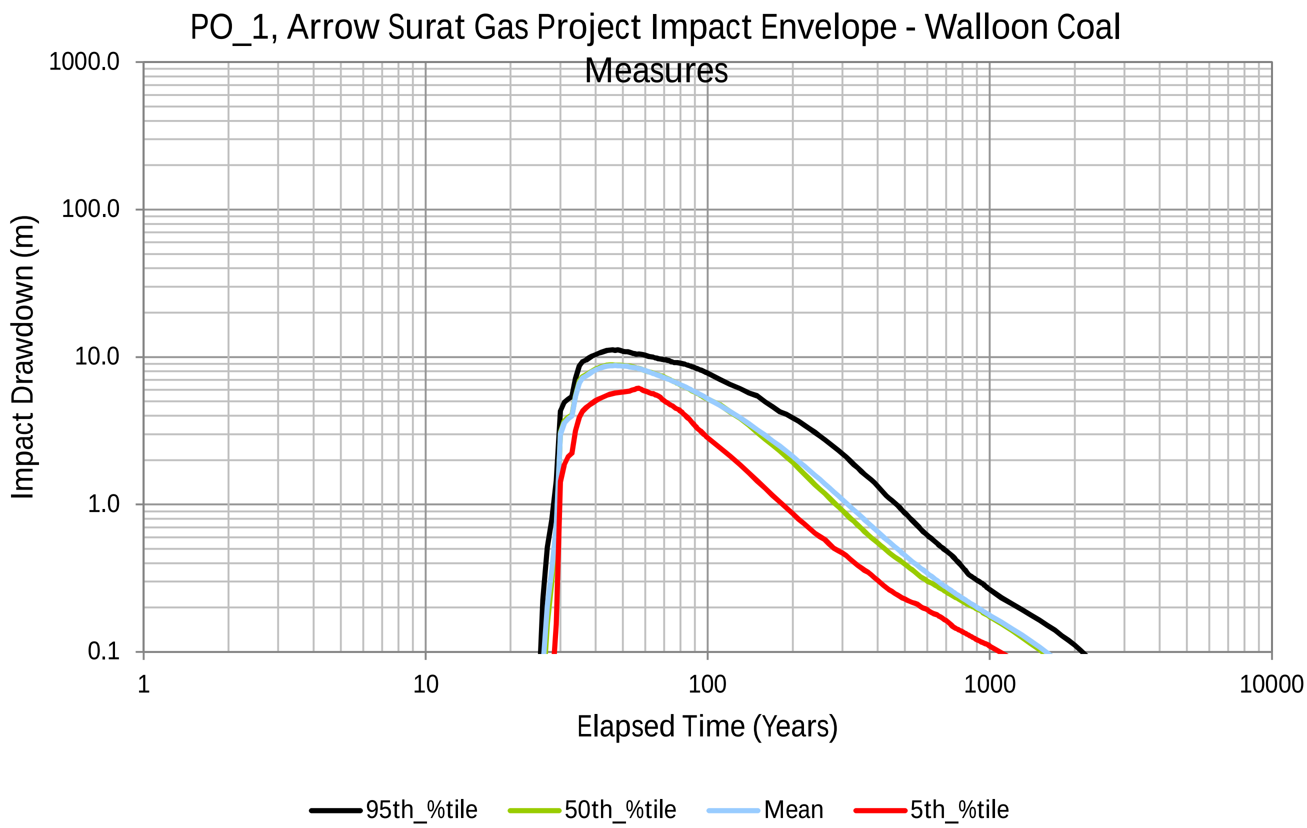

PN_3, Arrow Surat Gas Project Impact Envelope - Walloon Coal Measures
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5

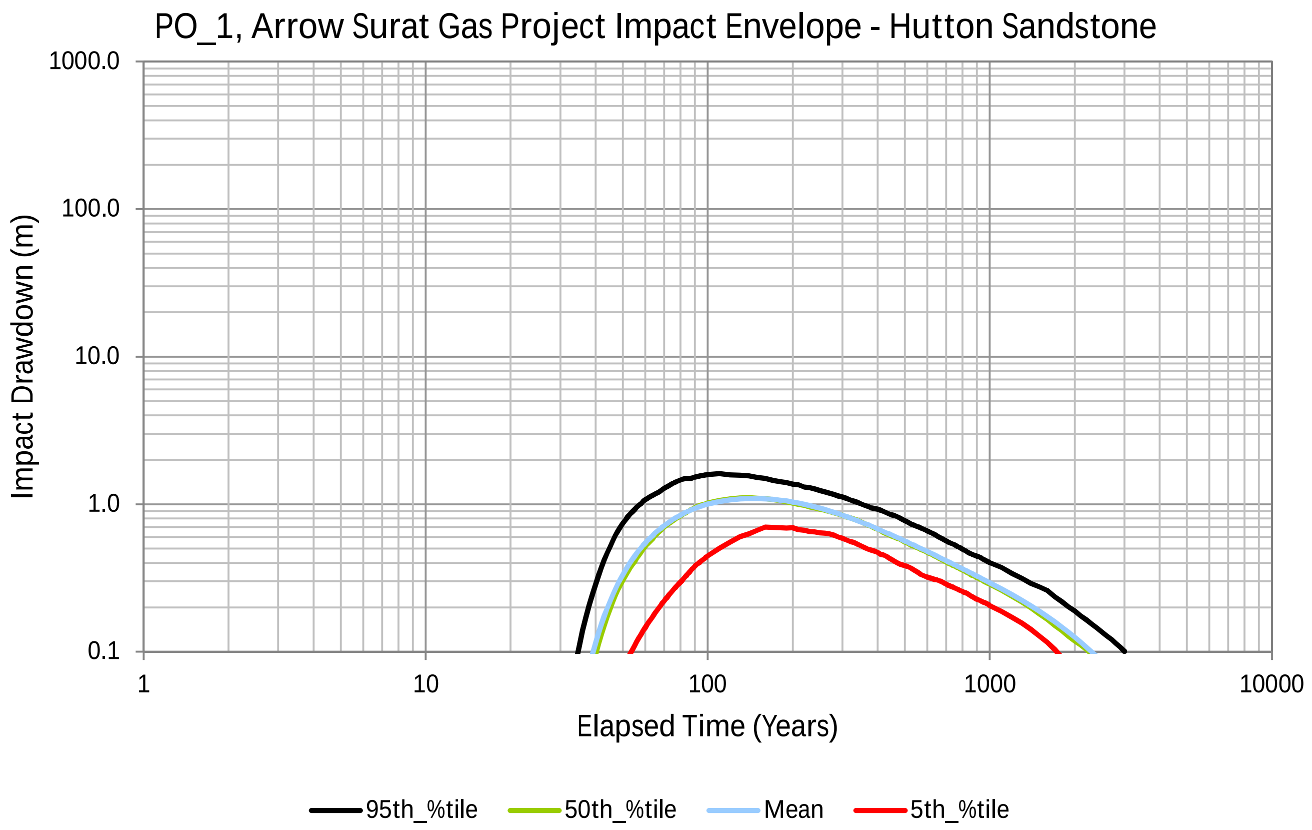


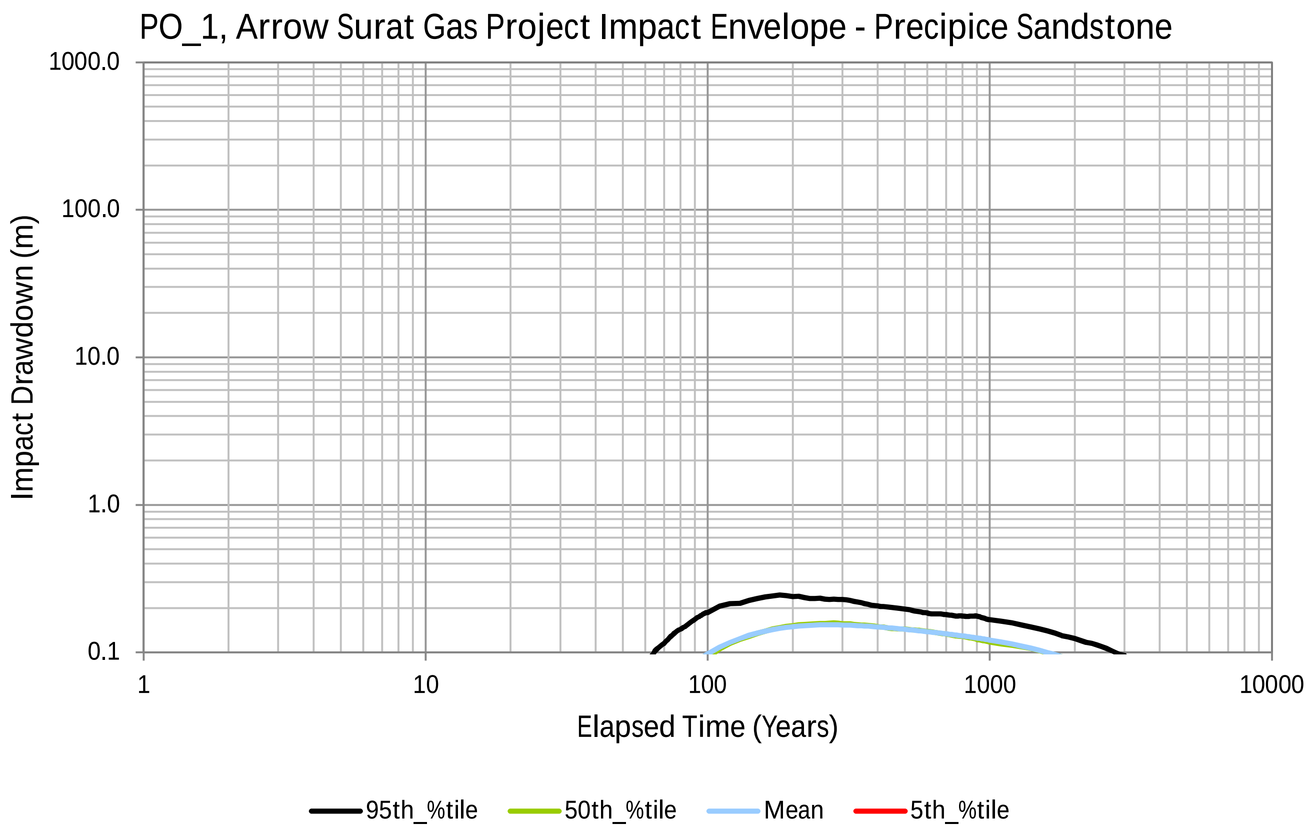



PO_1, Arrow Surat Gas Project Impact Envelope - Springbok Sandstone
1000.0
100.0
10.0
1.0
0.1
Impact Drawdown (m)
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile


PO_1, Arrow Surat Gas Project Impact Envelope - Walloon Coal Measures
1000.0
100.0
10.0
1.0
0.1
Impact Drawdown (m)
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

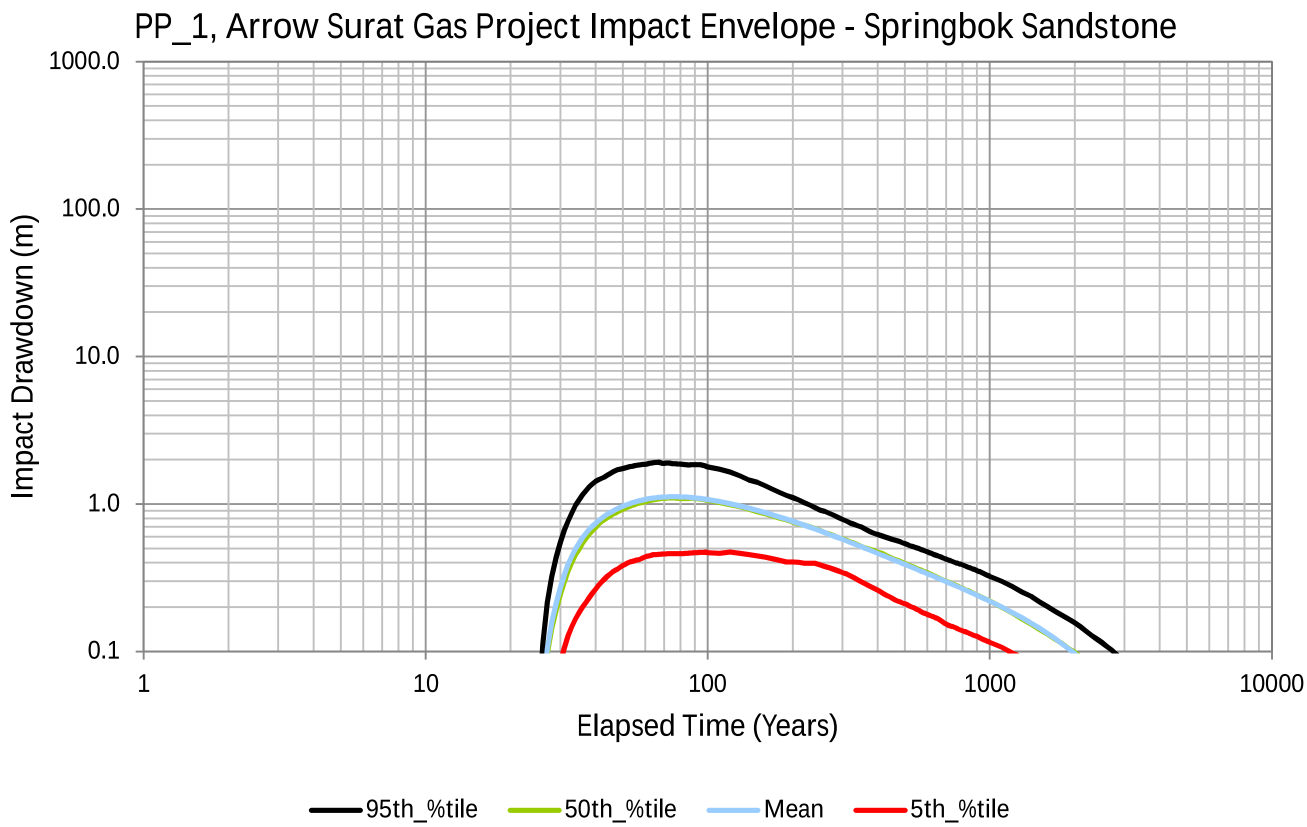
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5

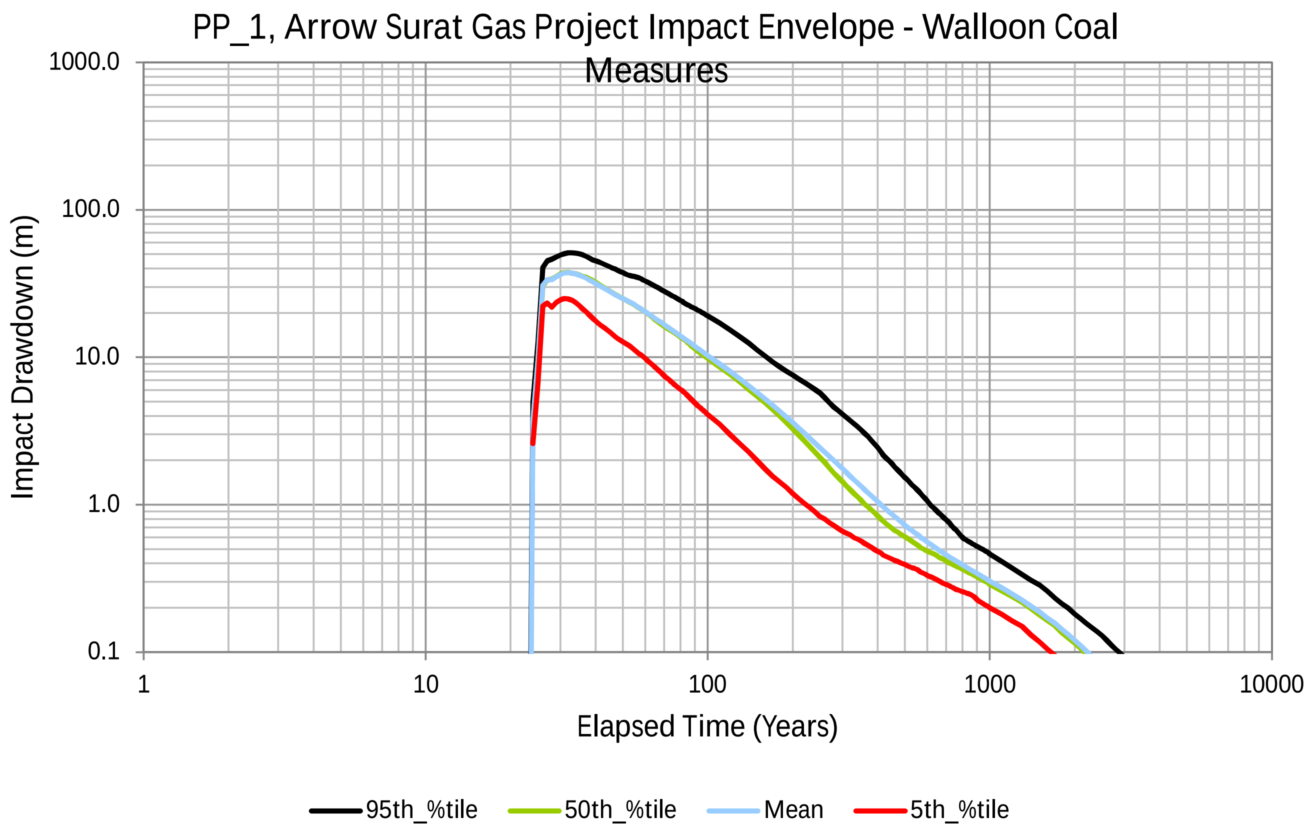




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_5)

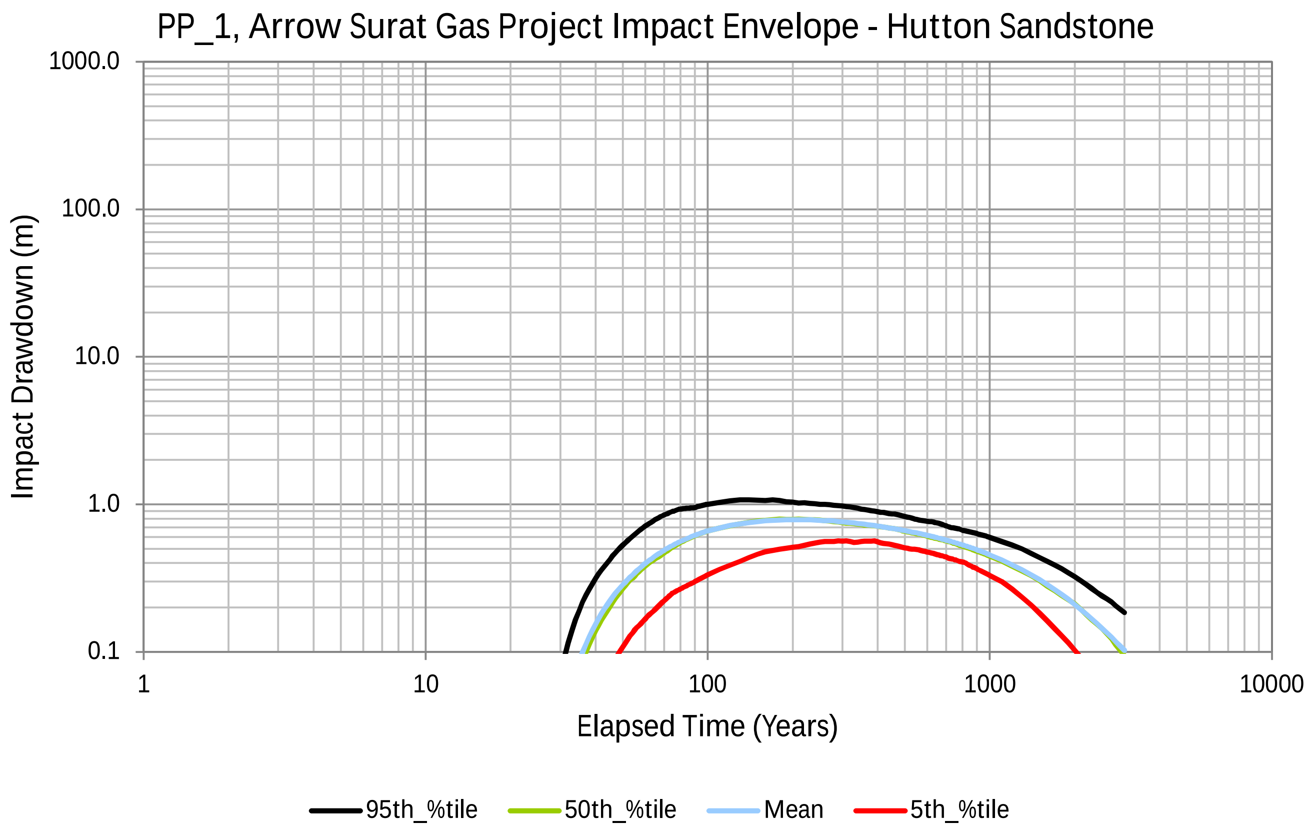
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5

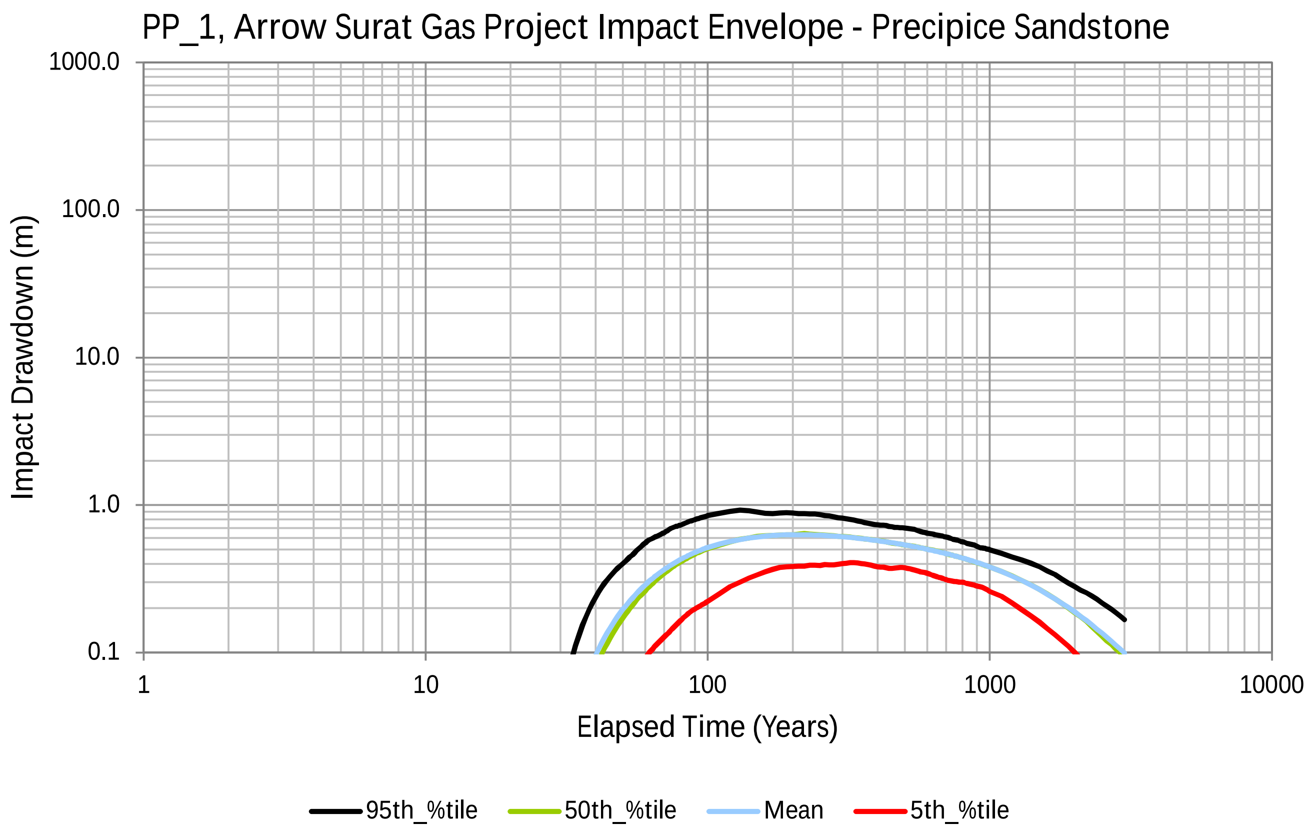




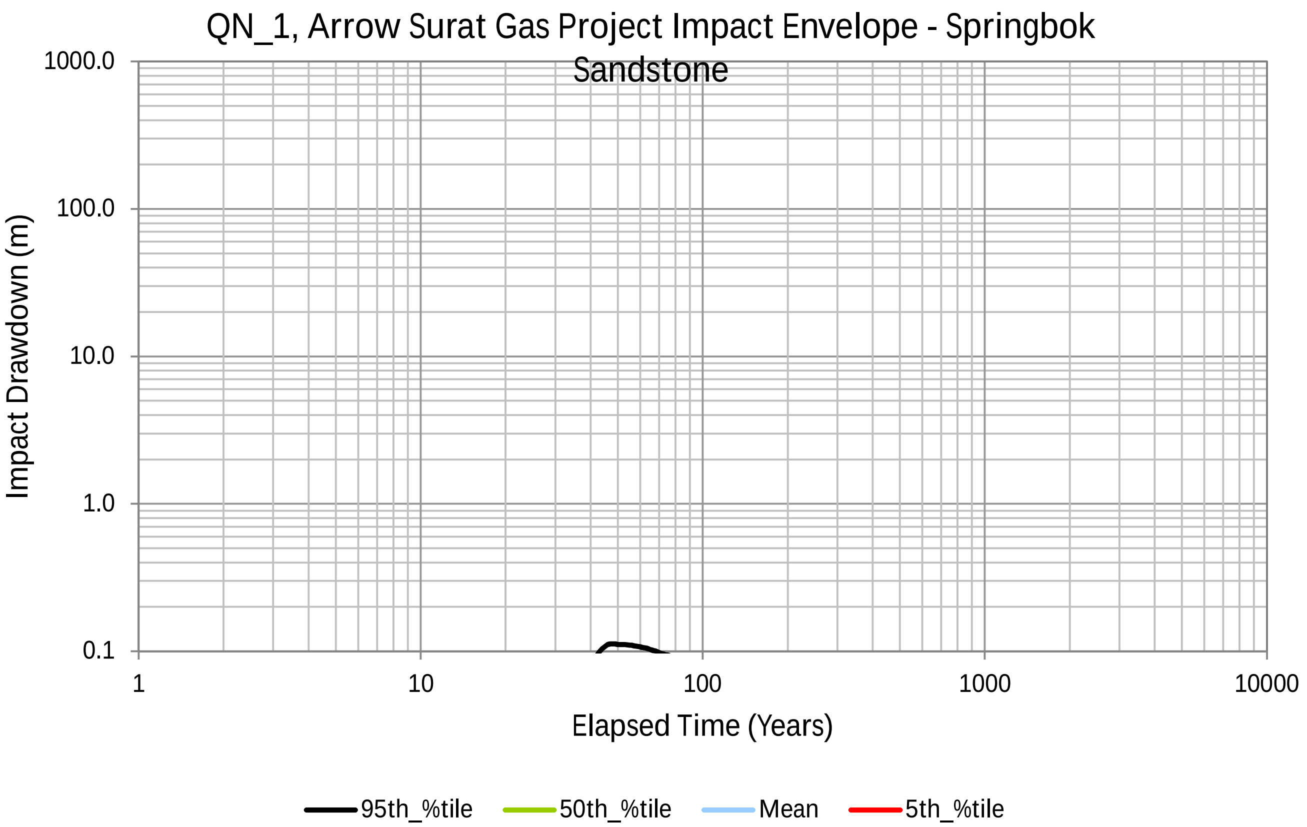
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_5)

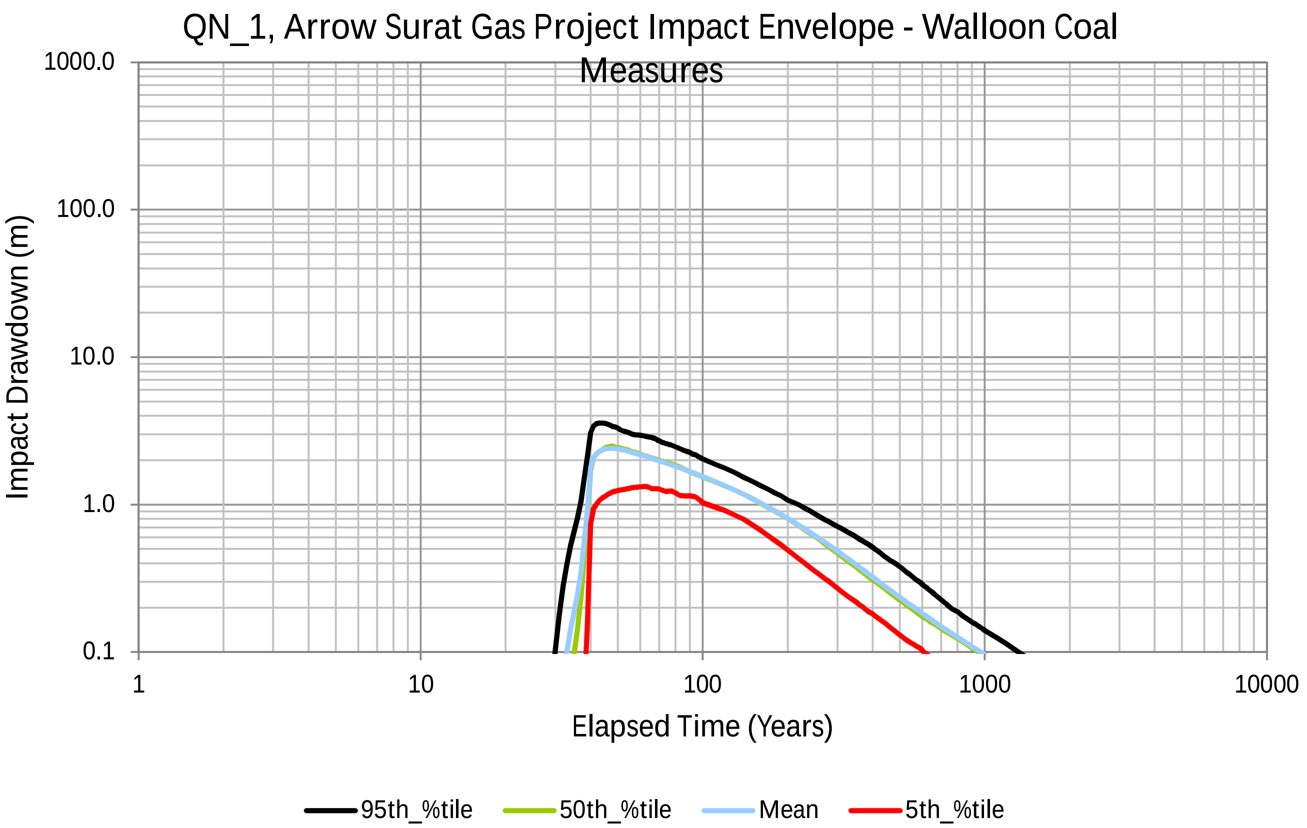
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5





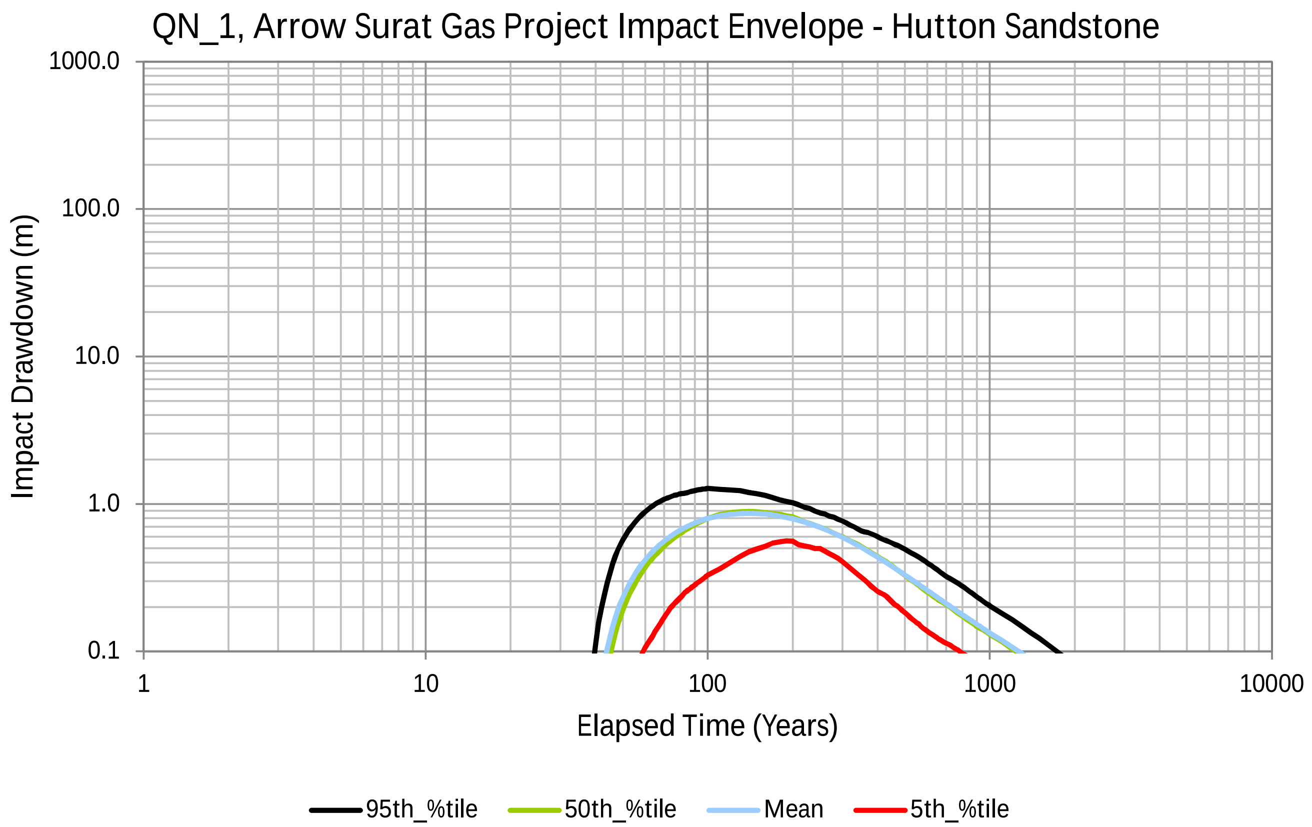
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5

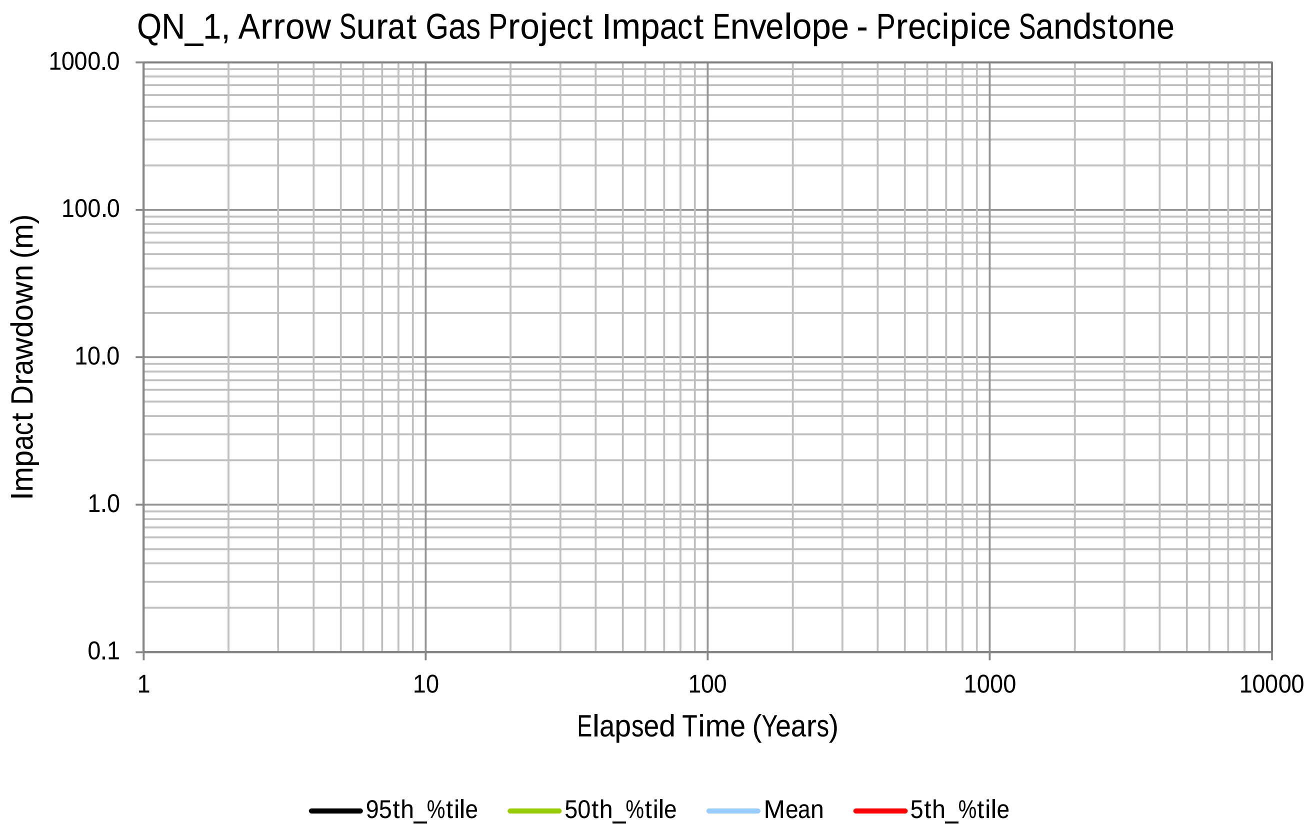




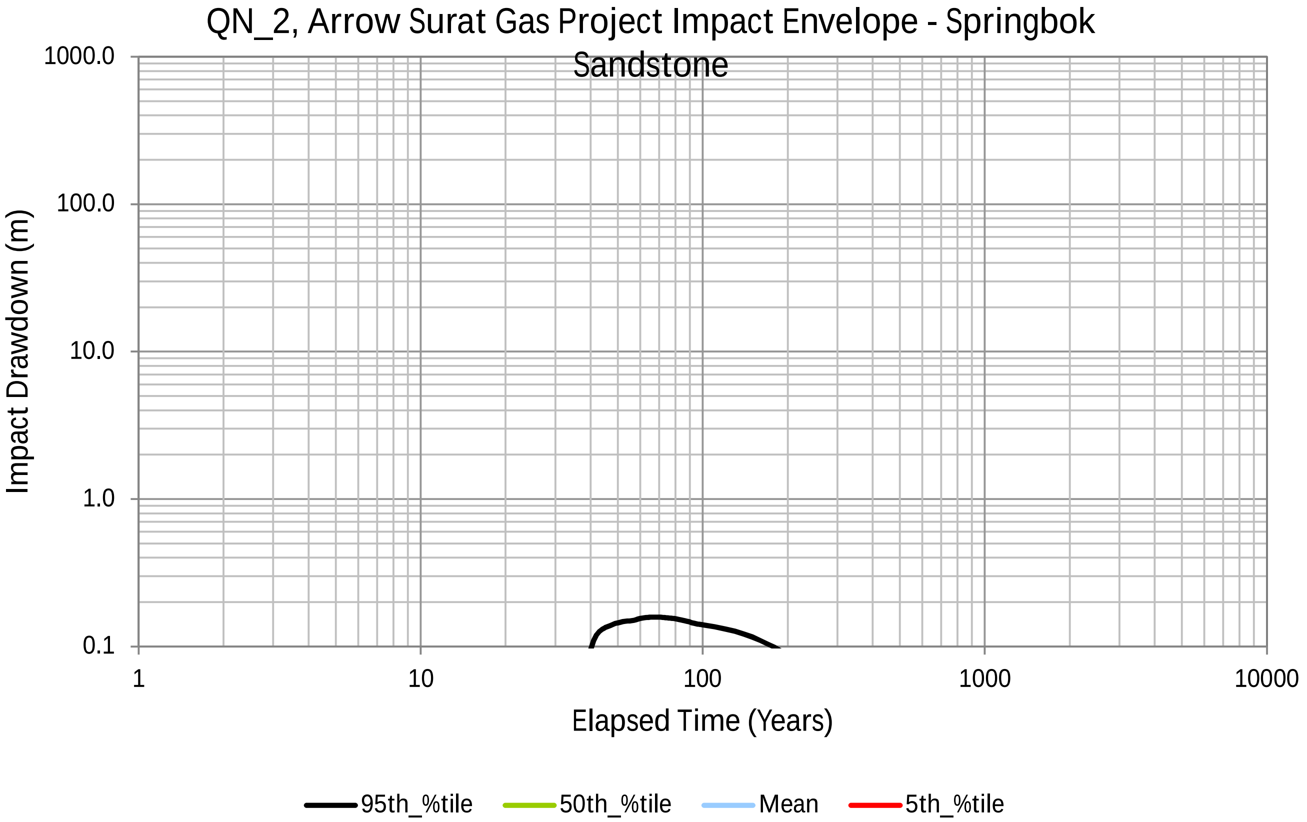
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_5)

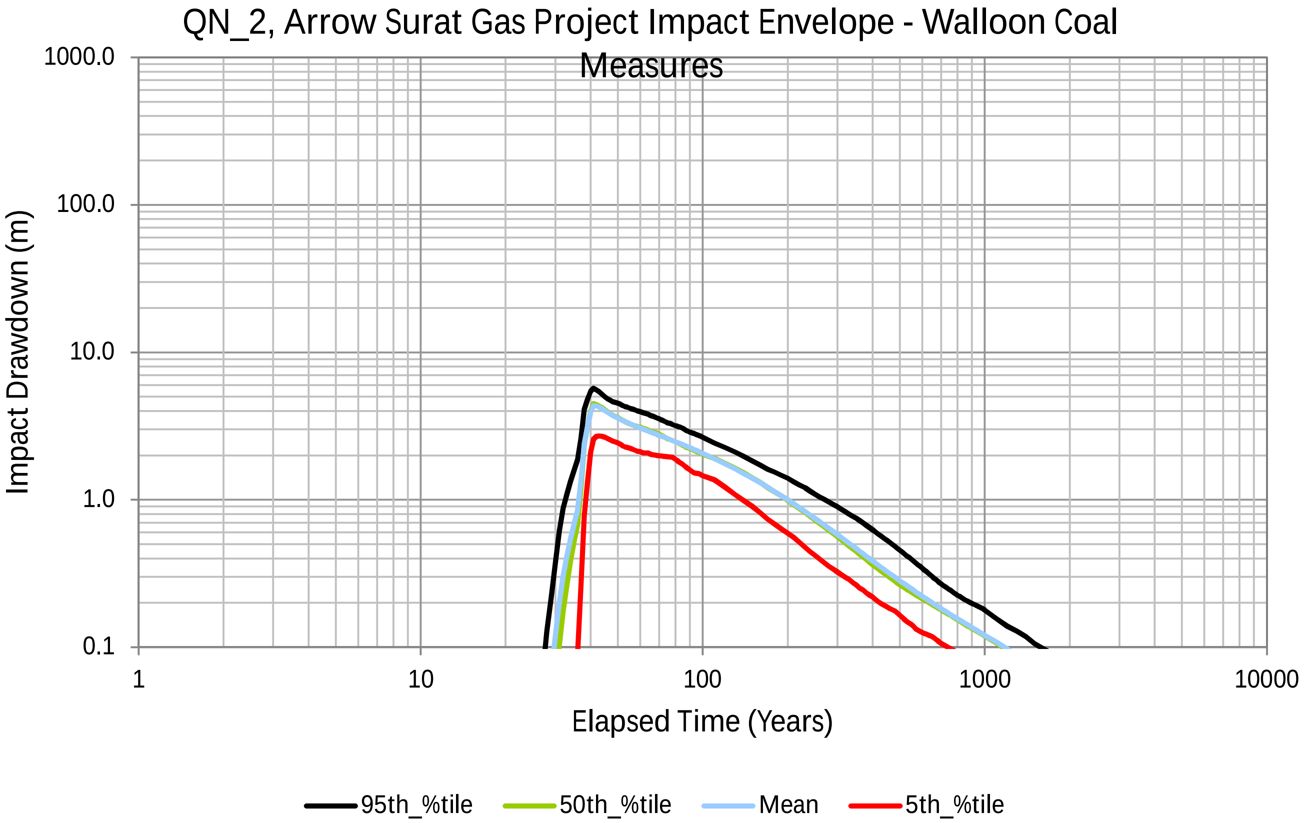
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5



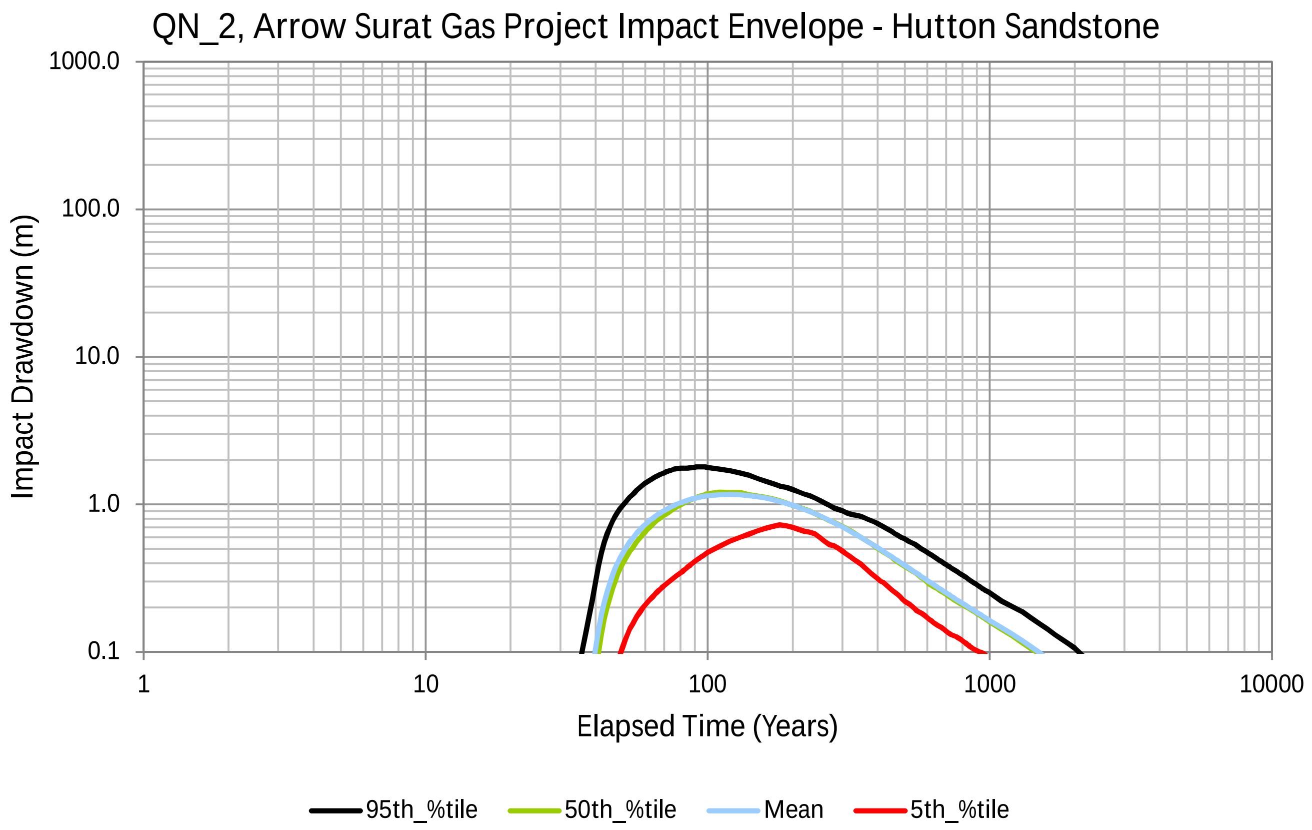


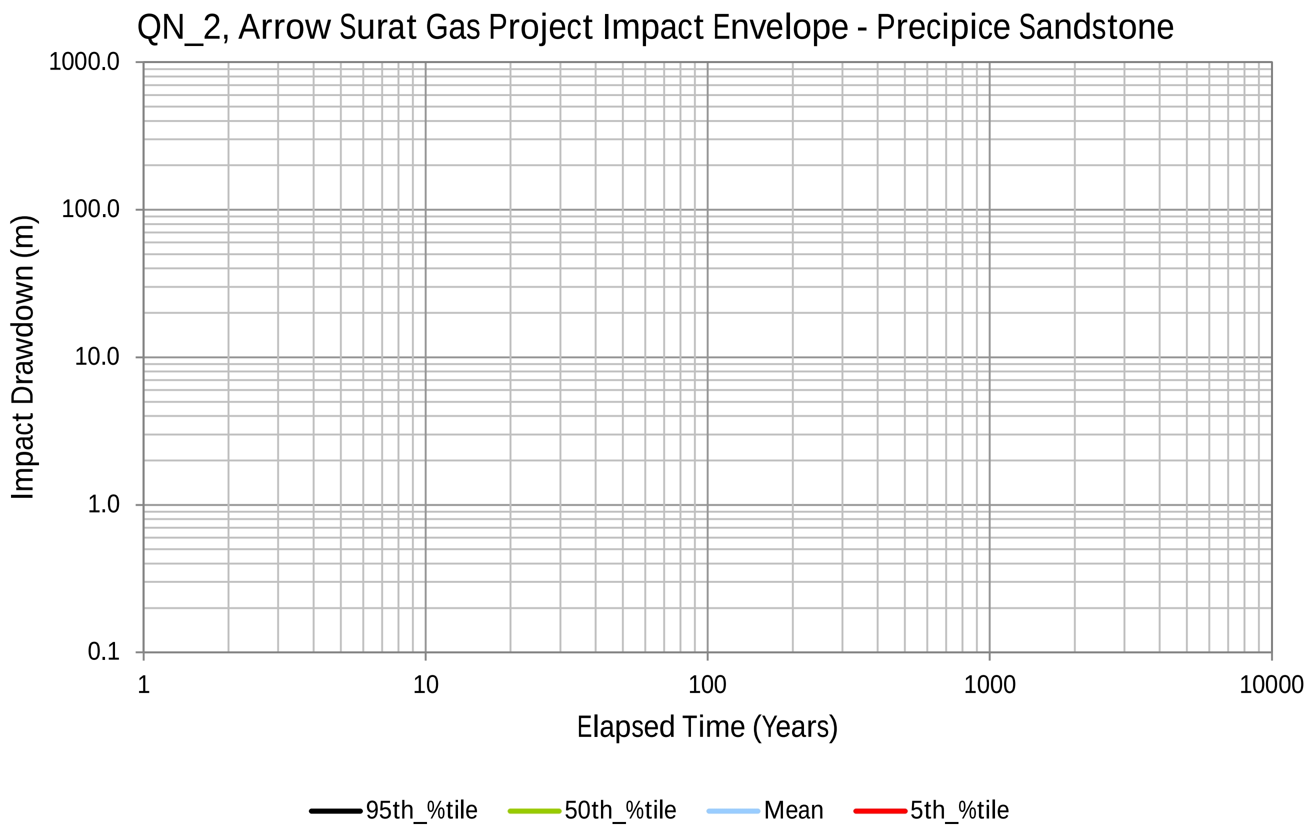
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5



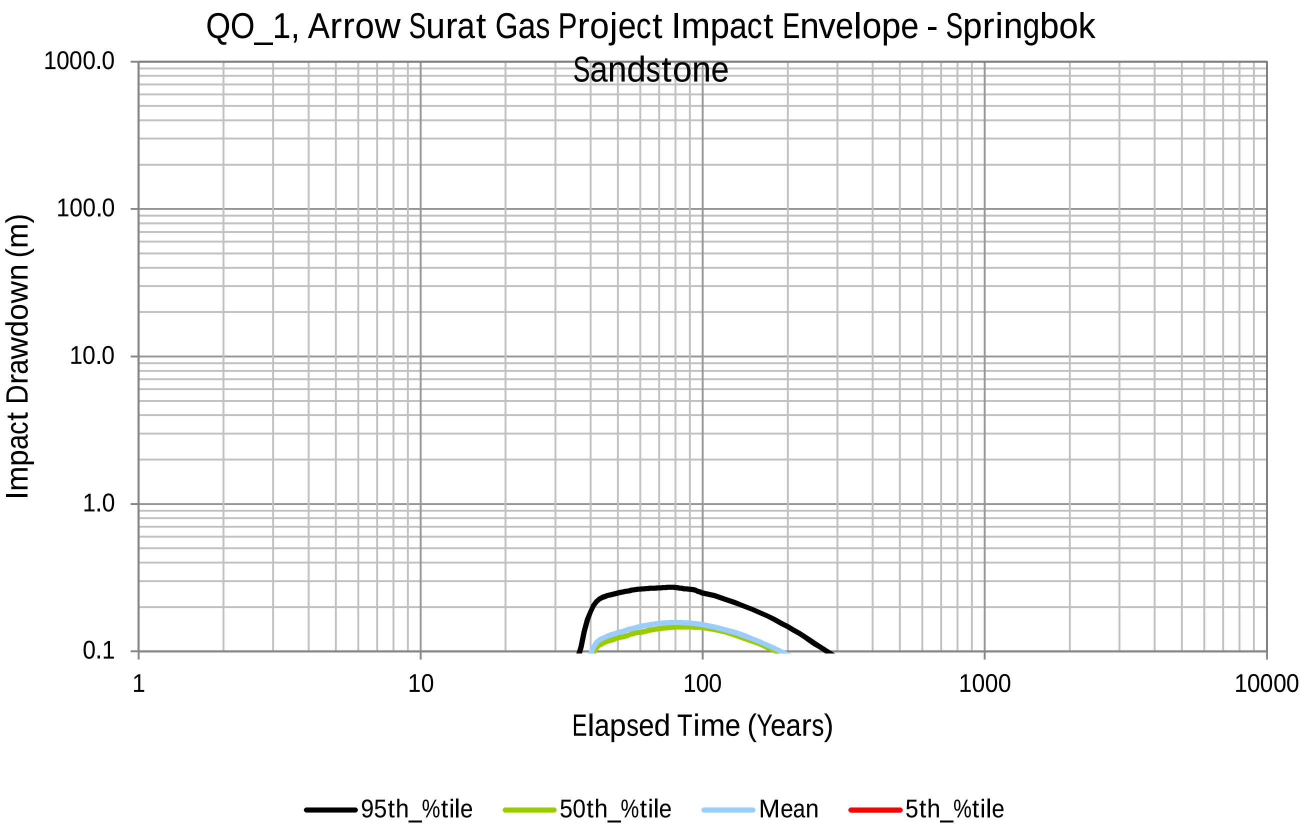


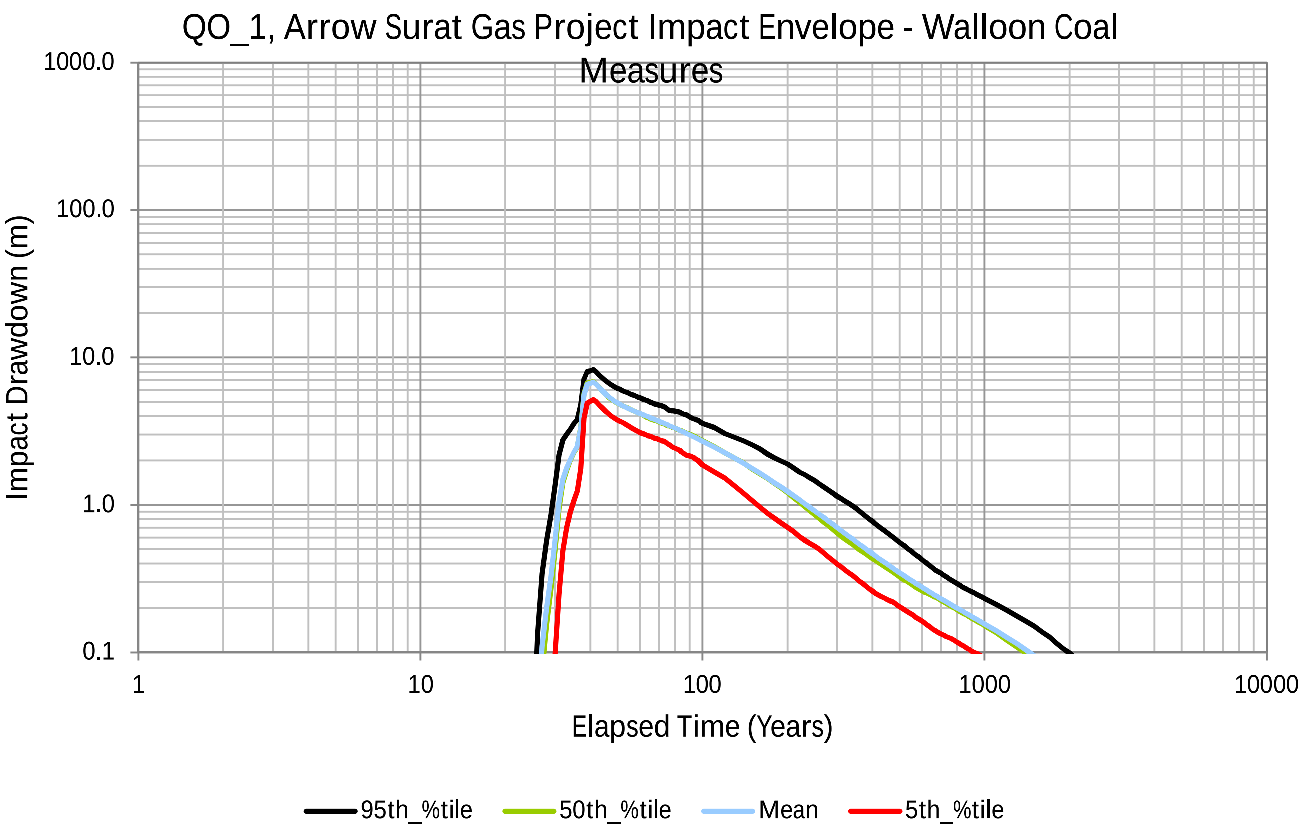
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5

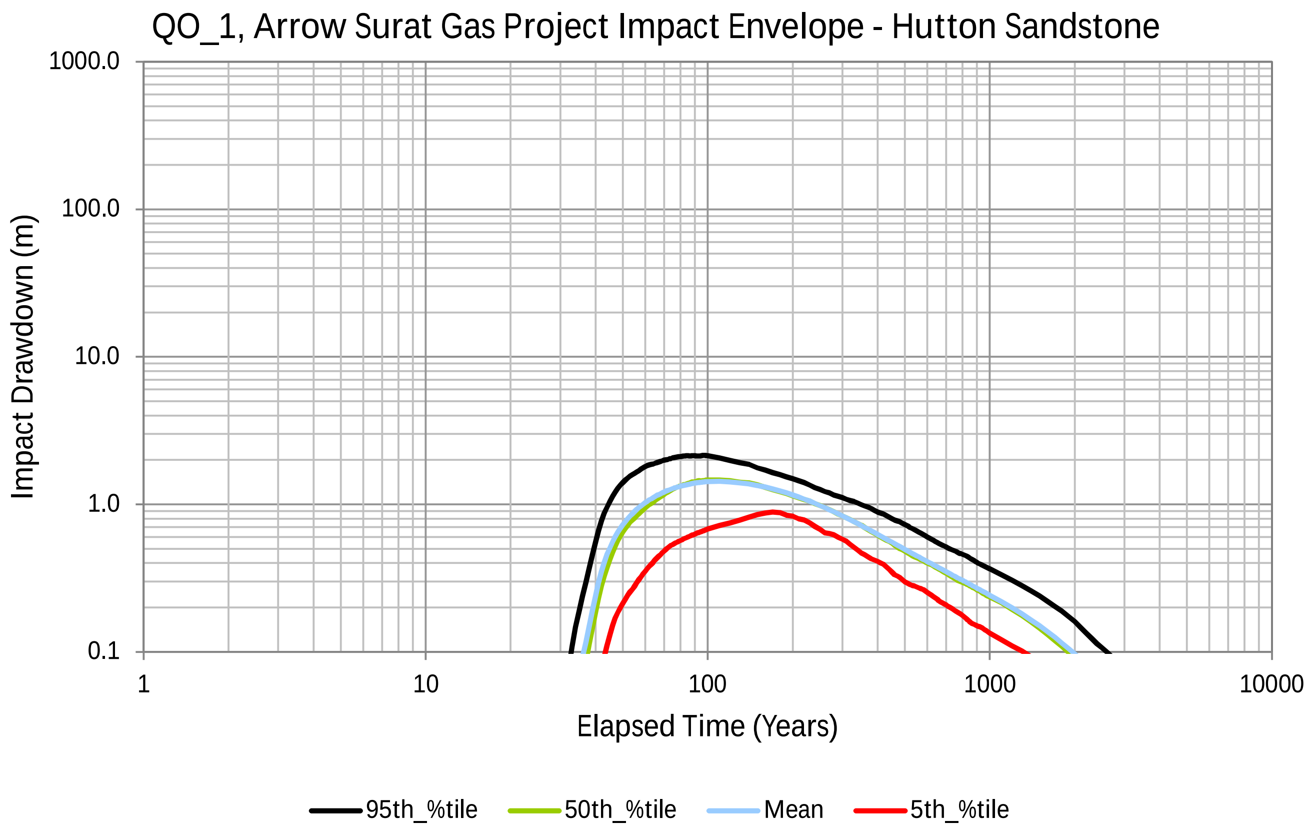


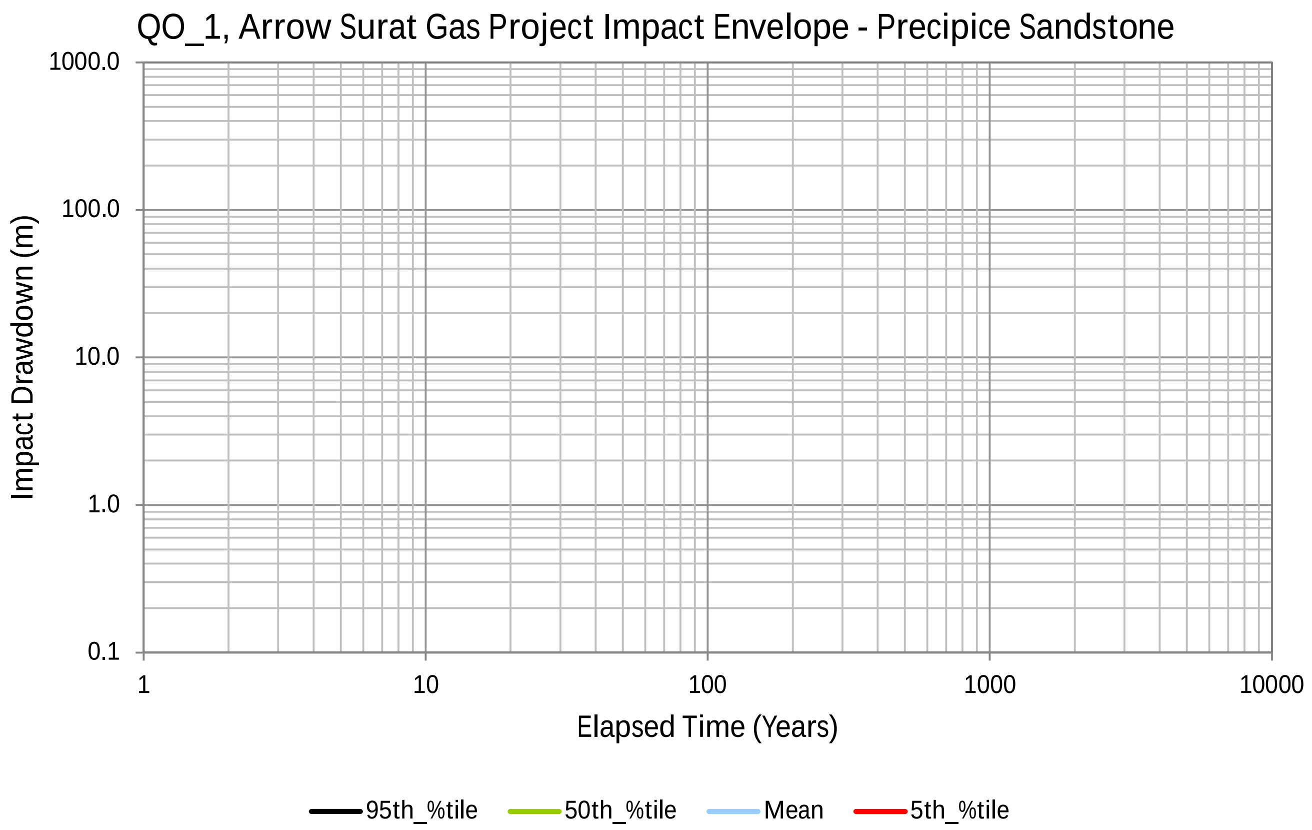


Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5

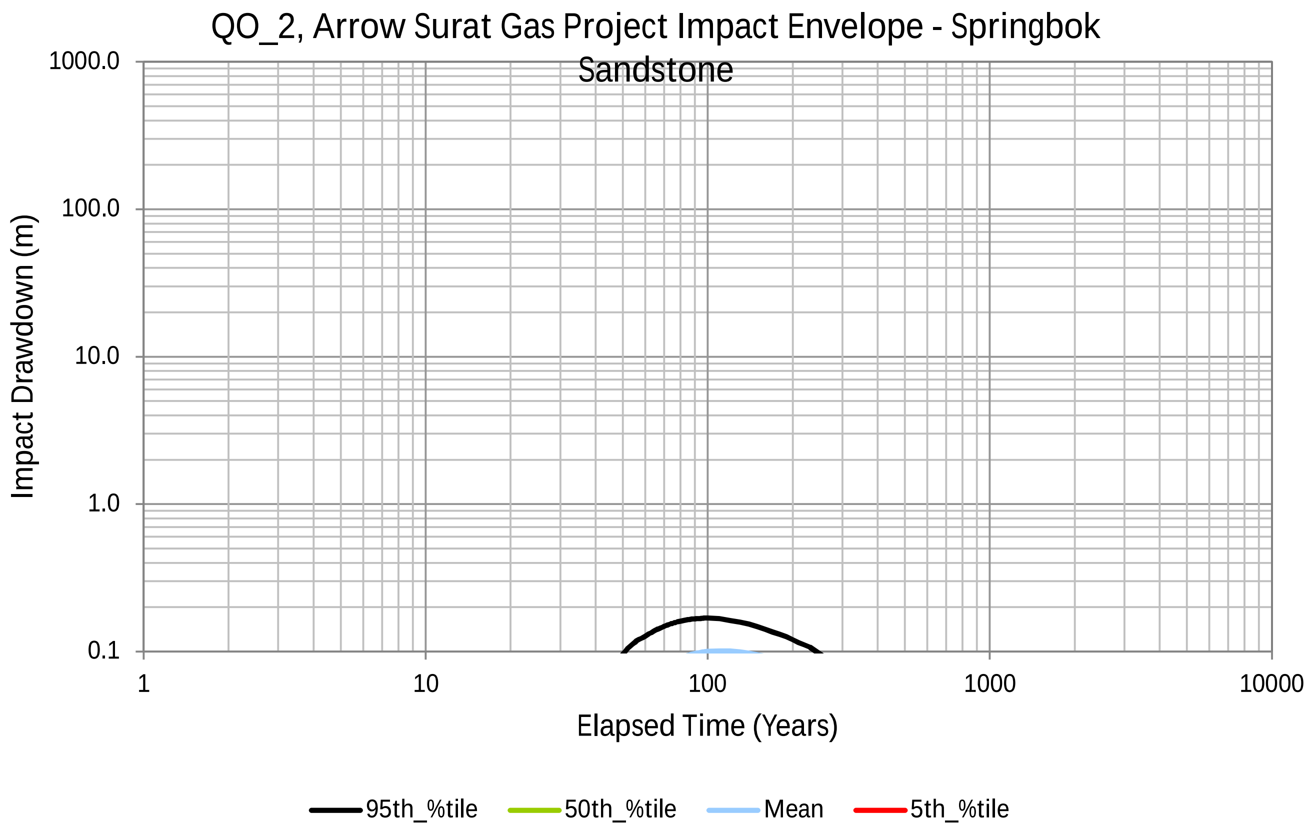


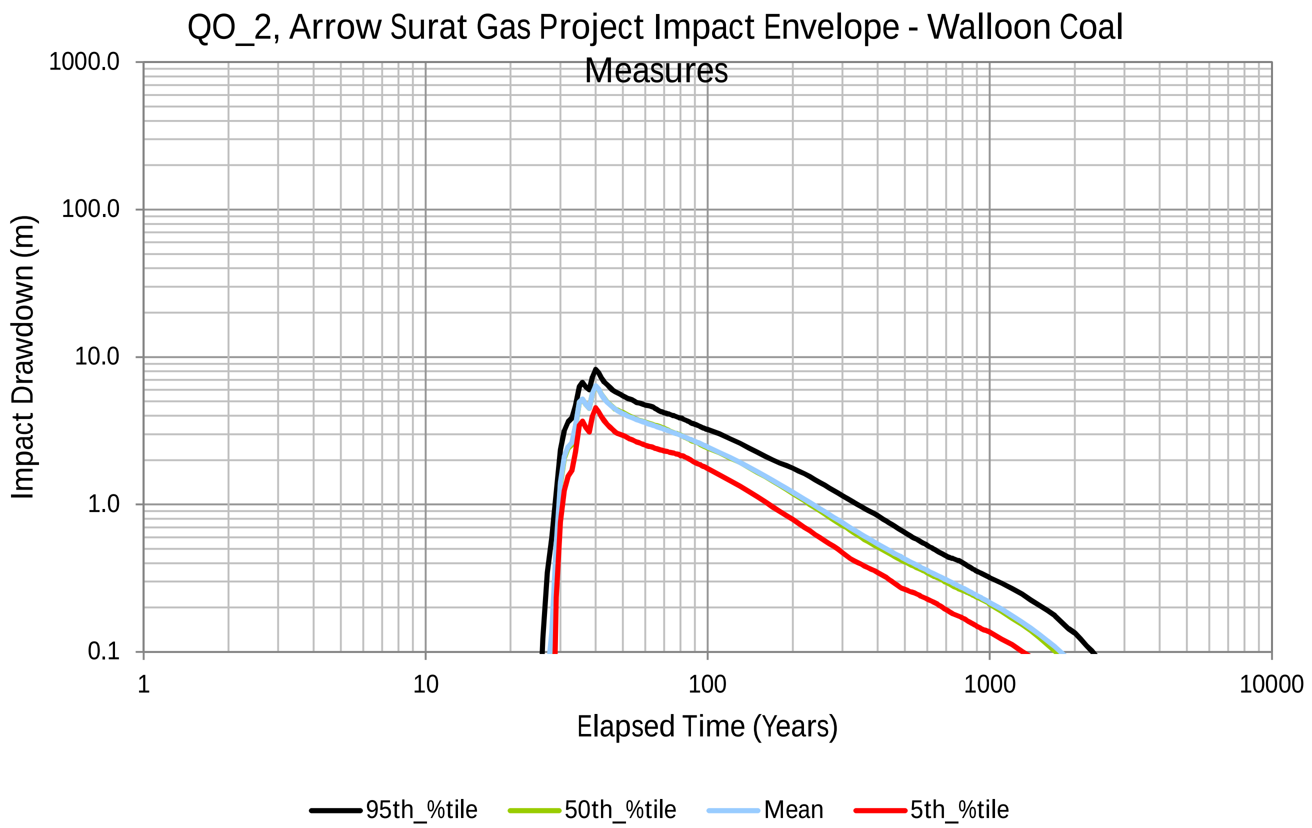



QO_1, Arrow Surat Gas Project Impact Envelope - Hutton Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile


QO_1, Arrow Surat Gas Project Impact Envelope - Precipice Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

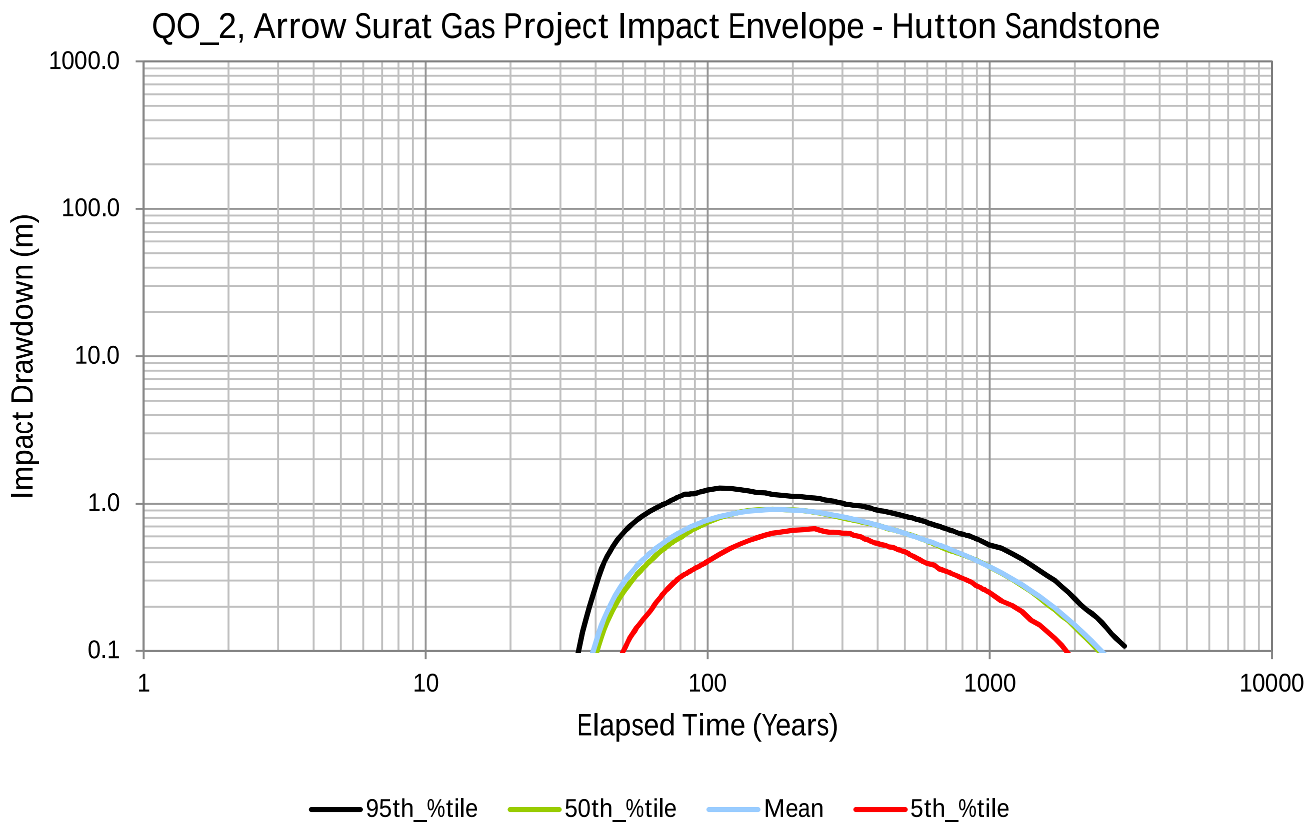
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5

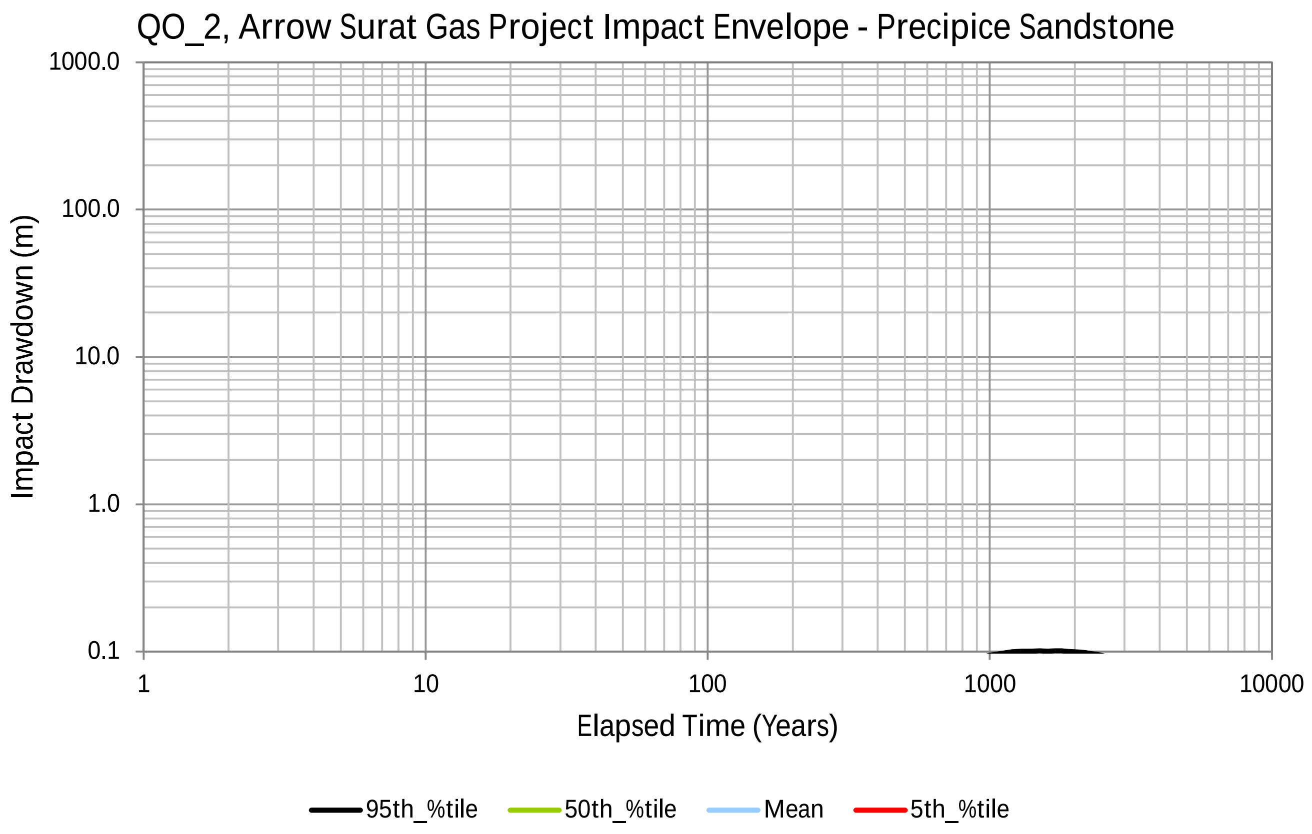




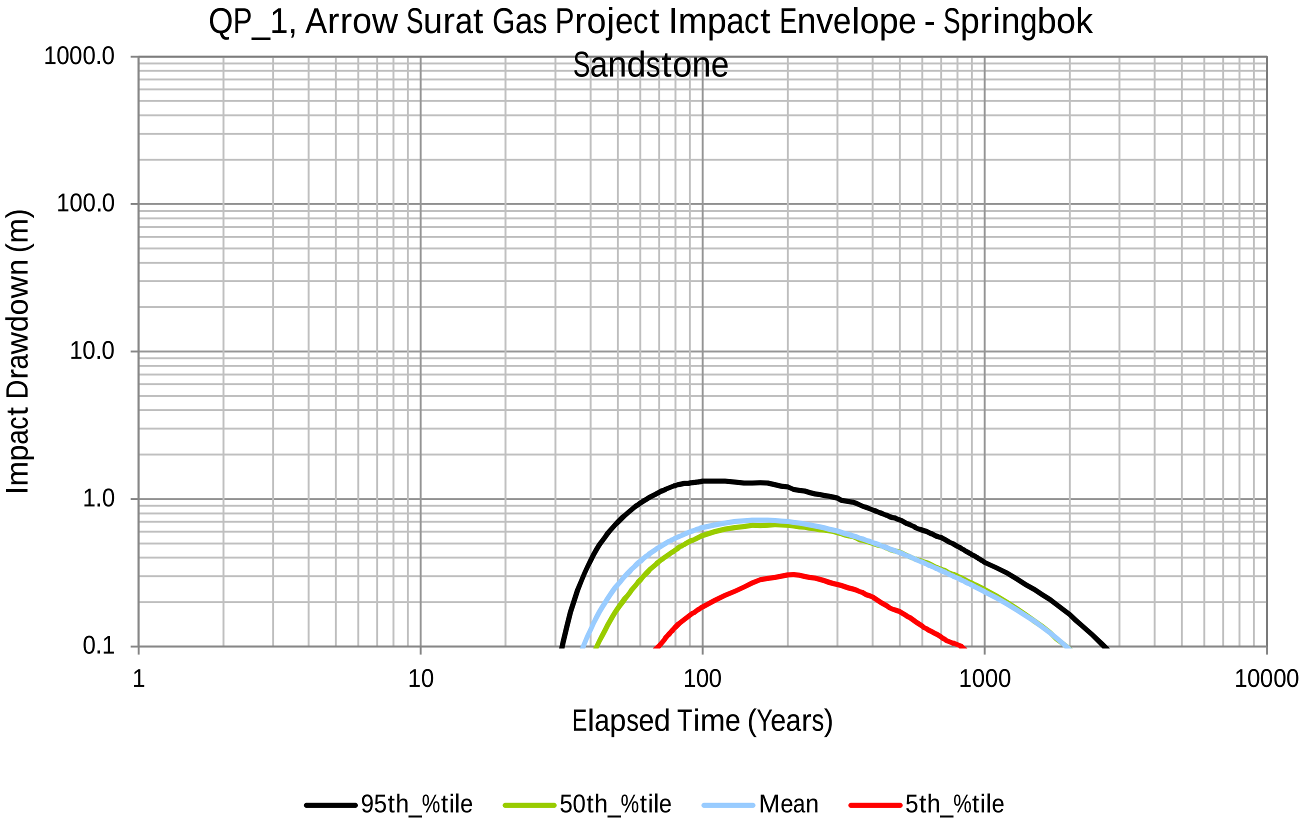
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_5)

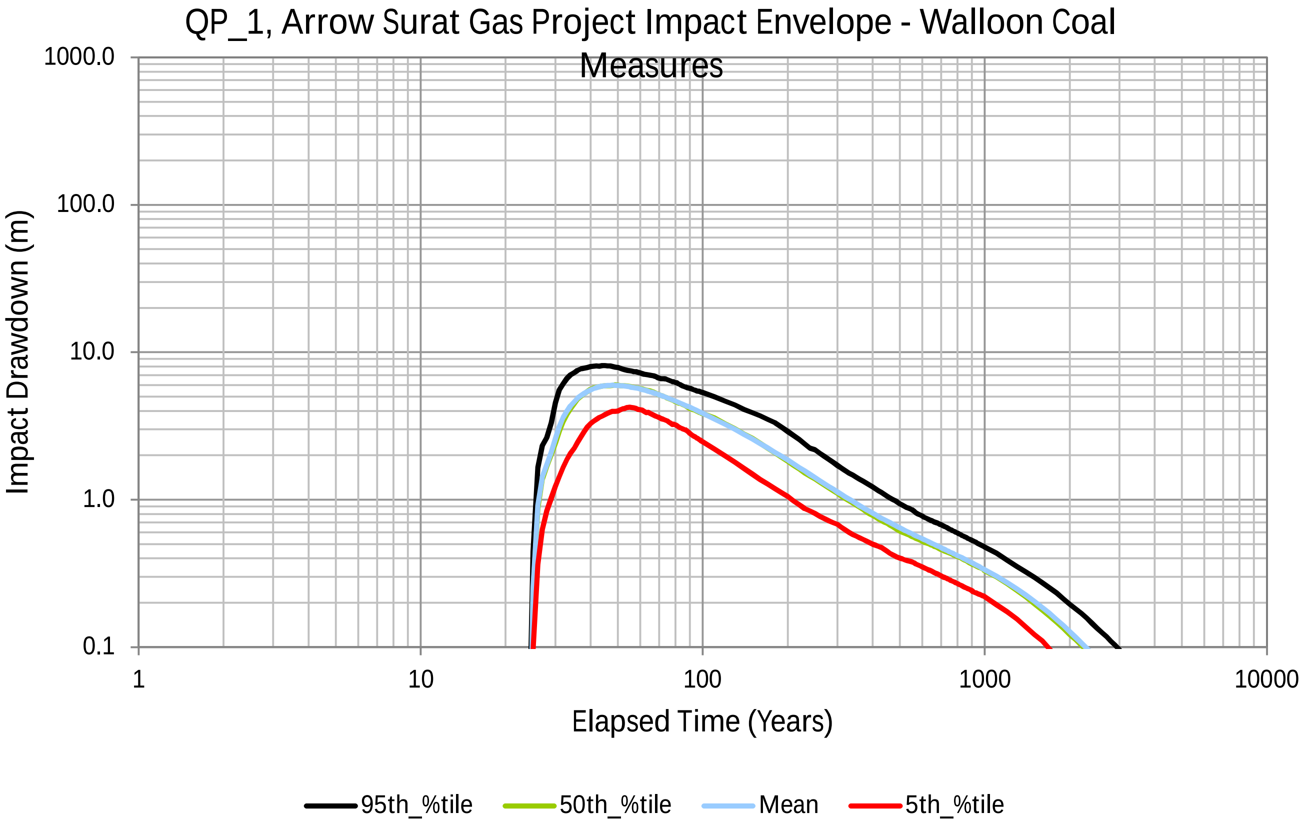
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5





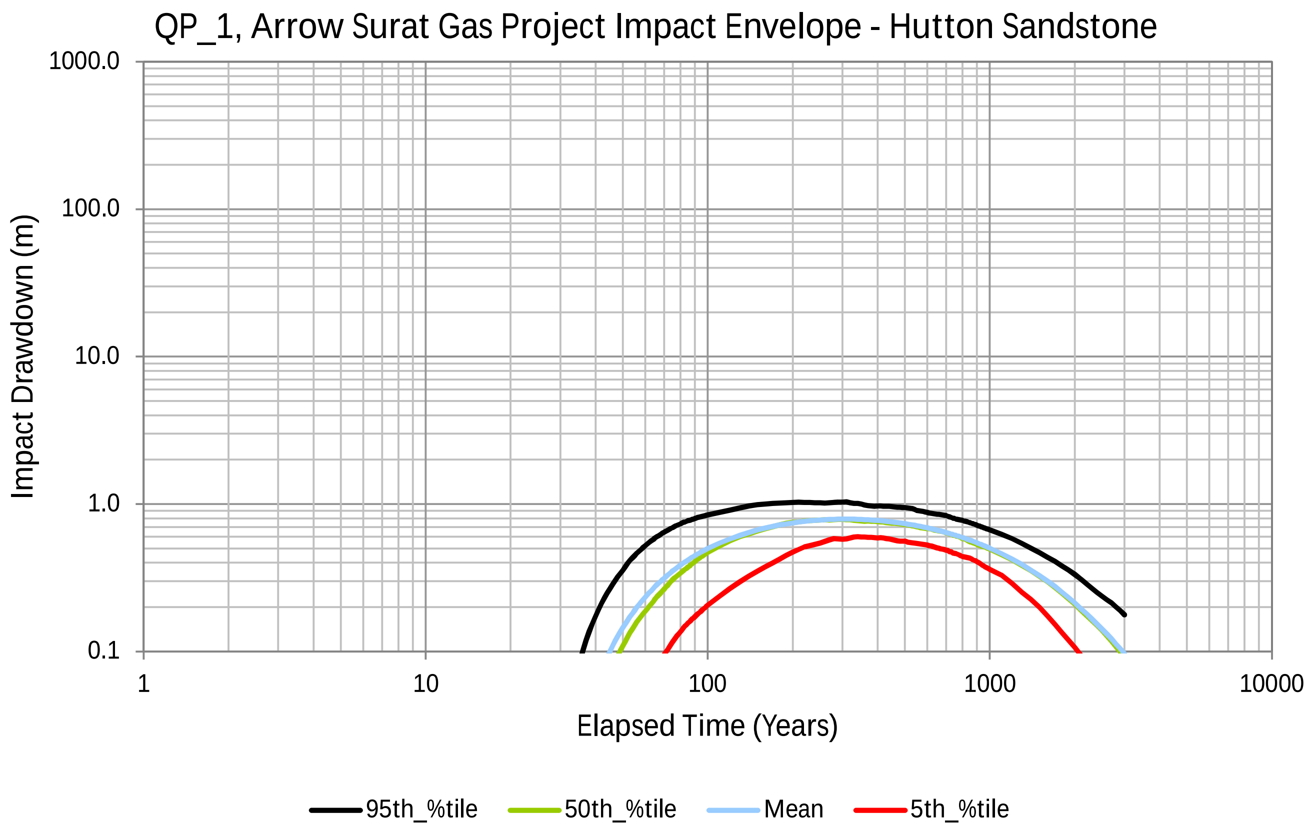
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5

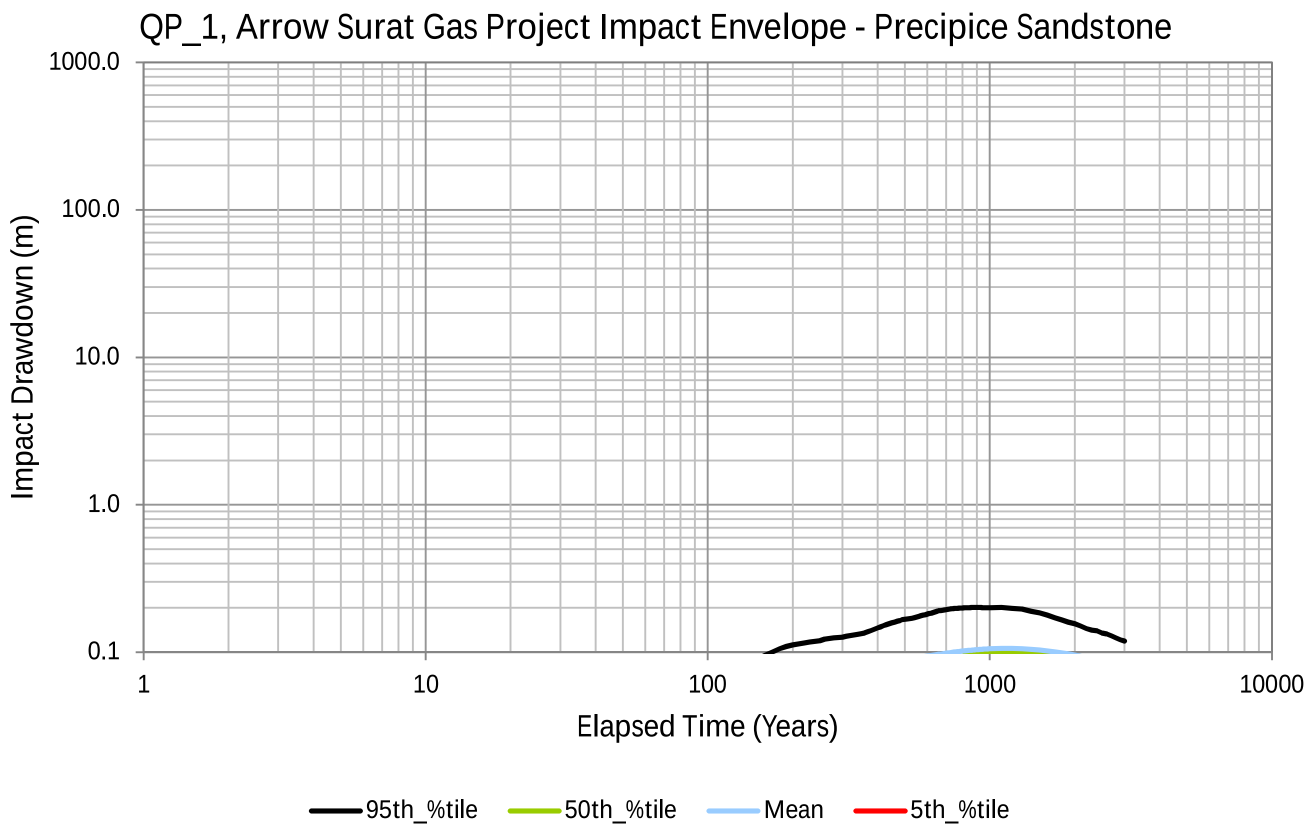




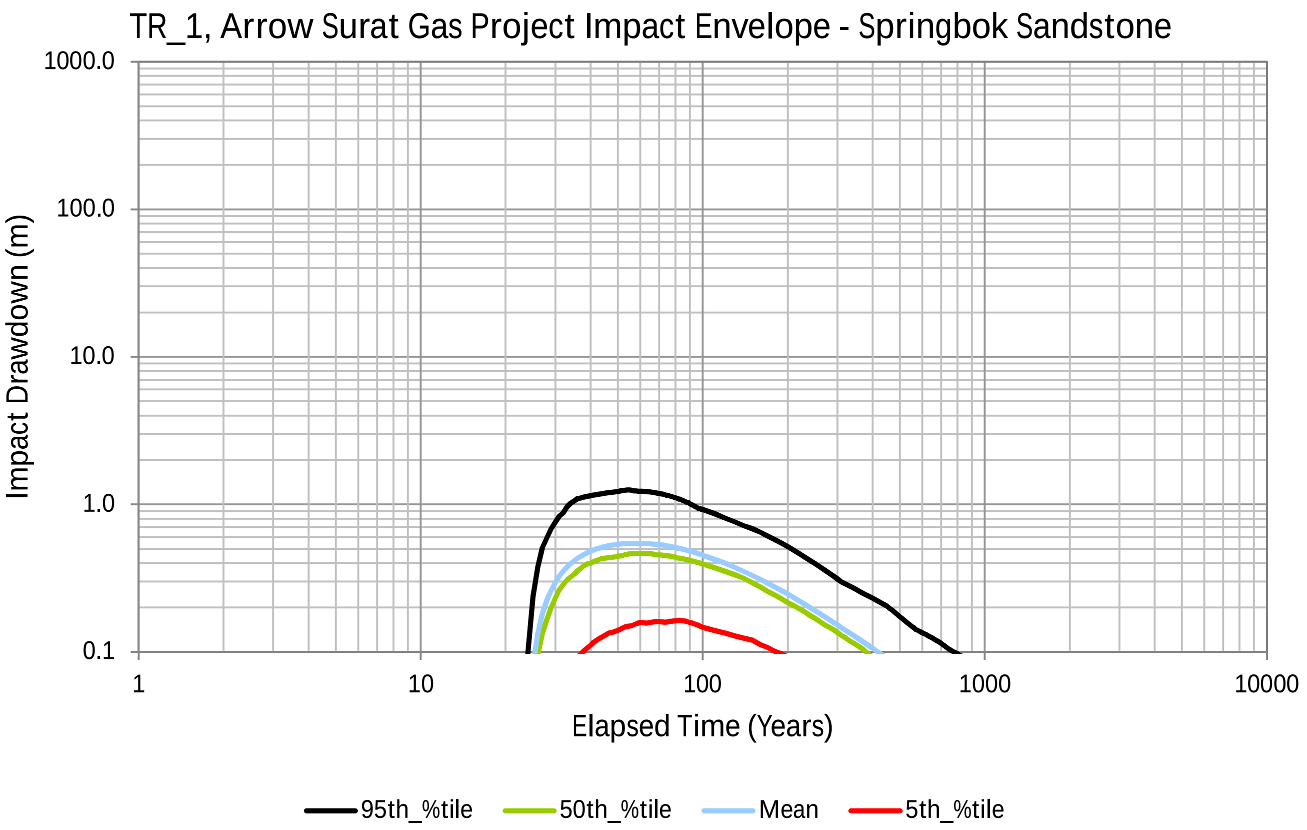
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_5)

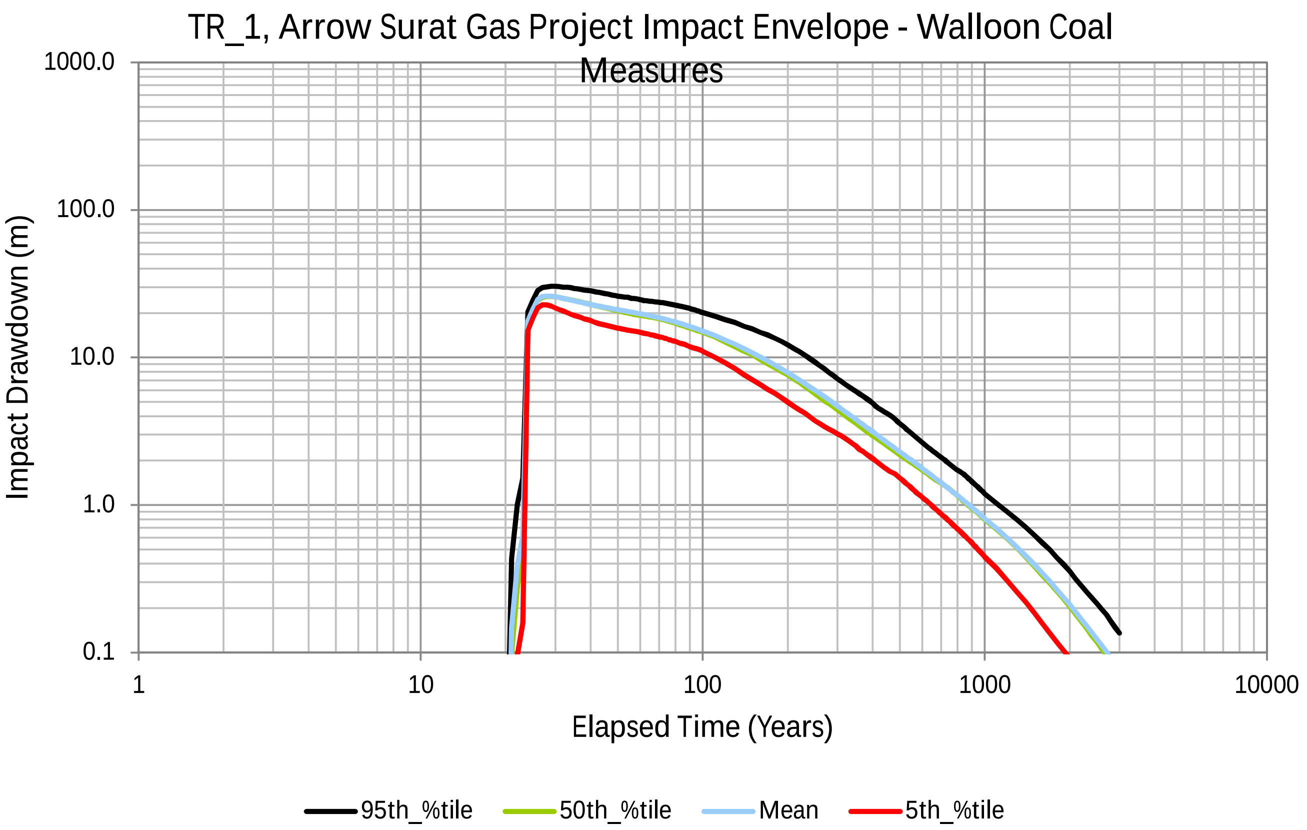
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 5



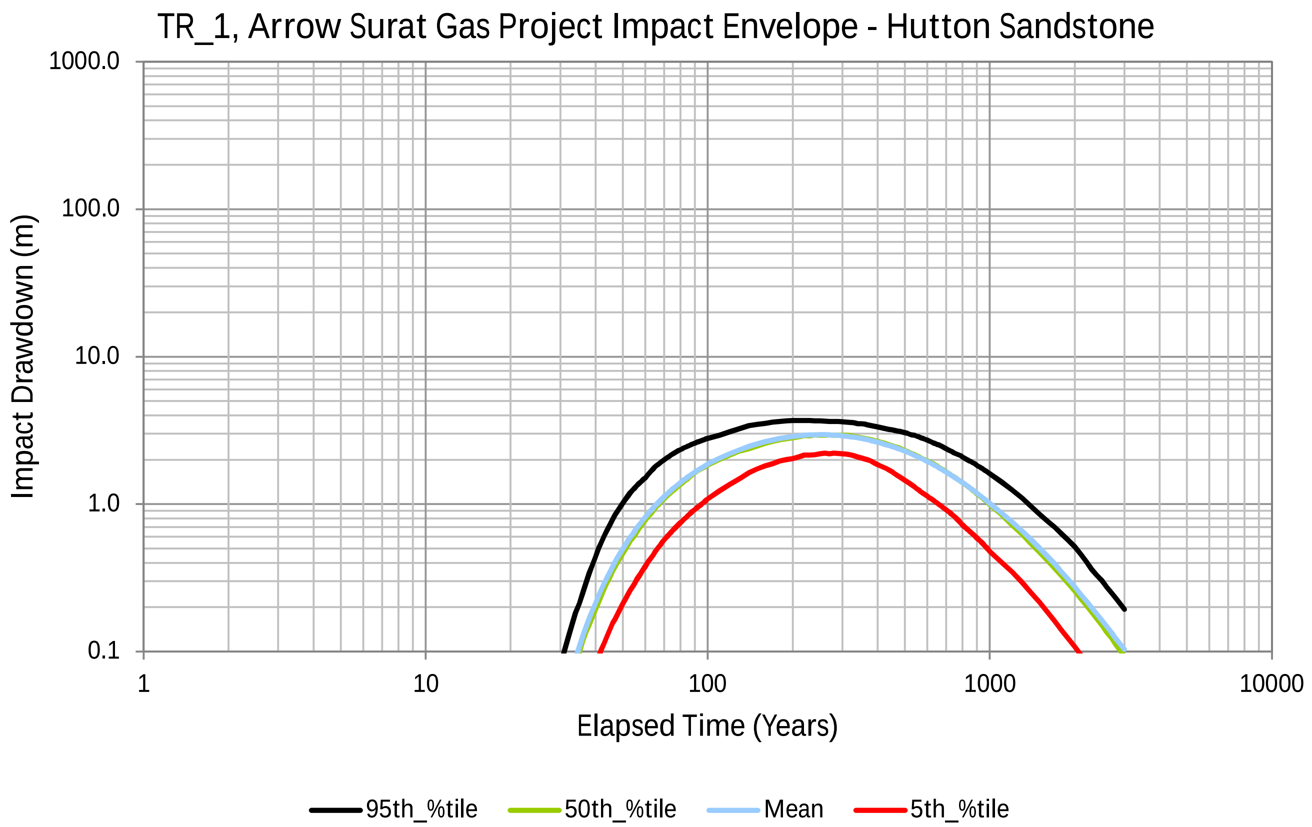


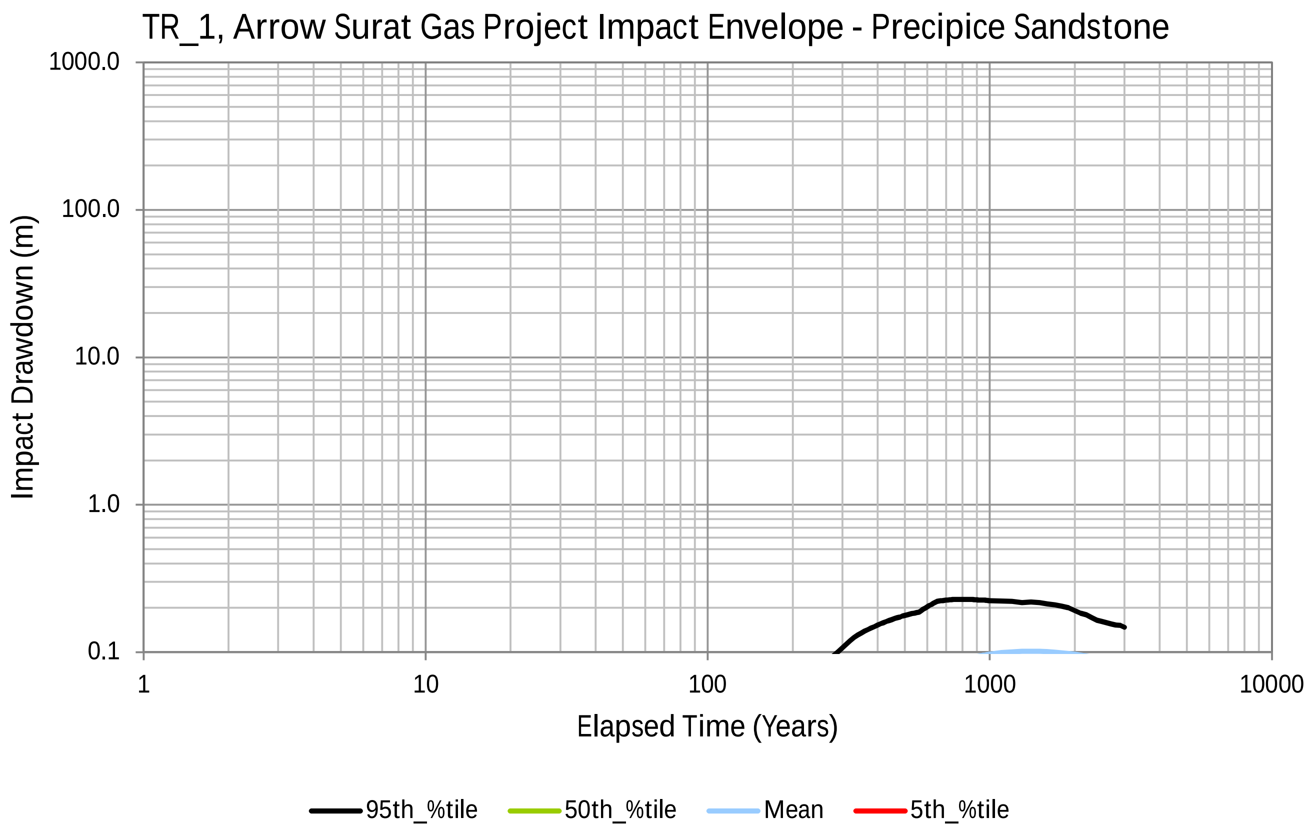
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 7



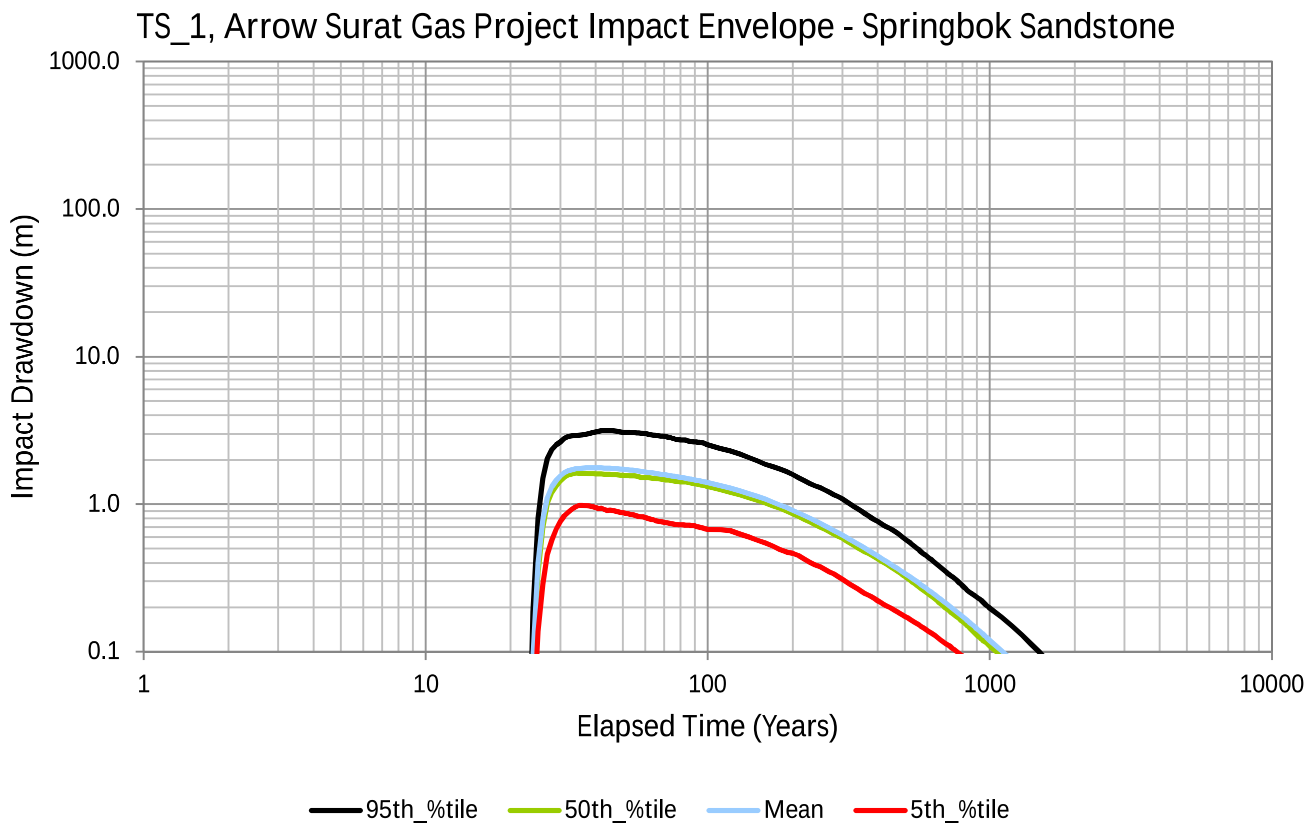


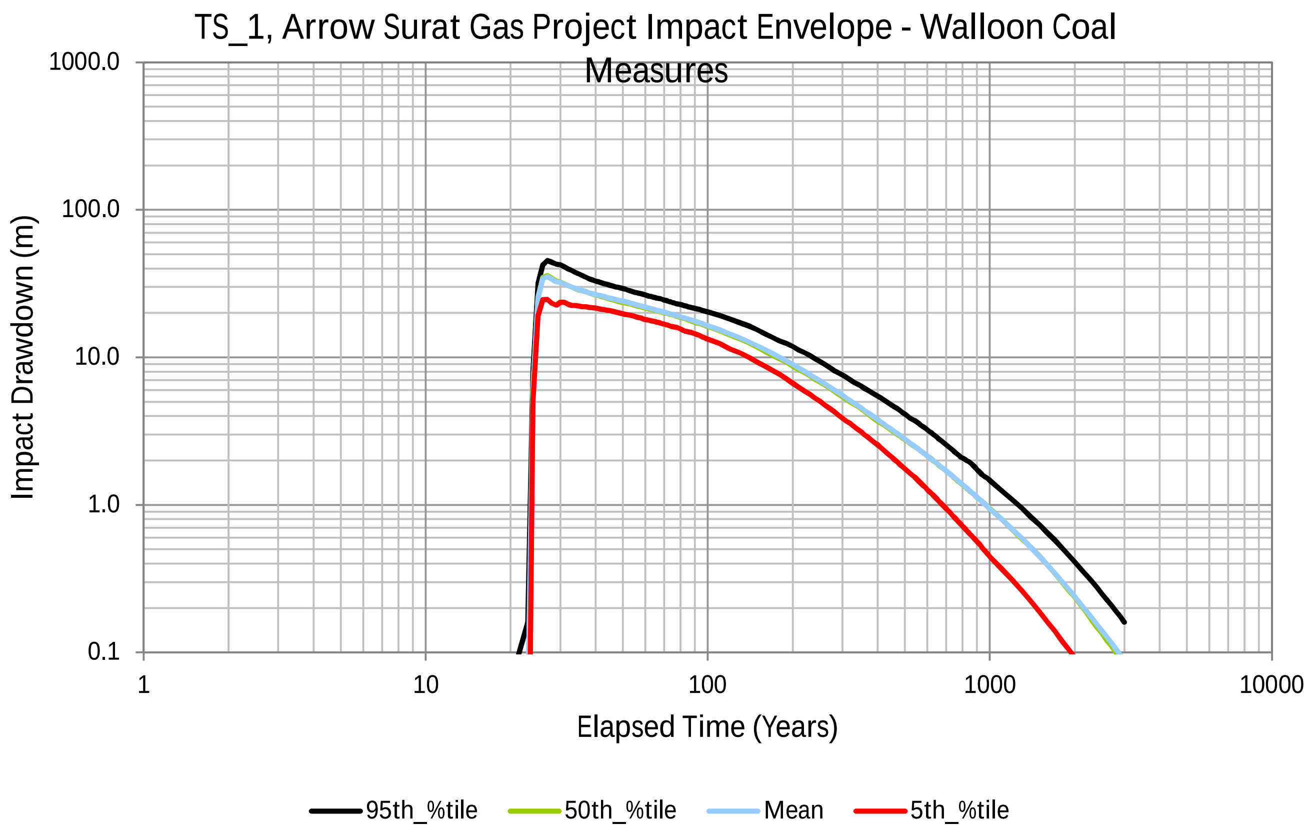
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 7





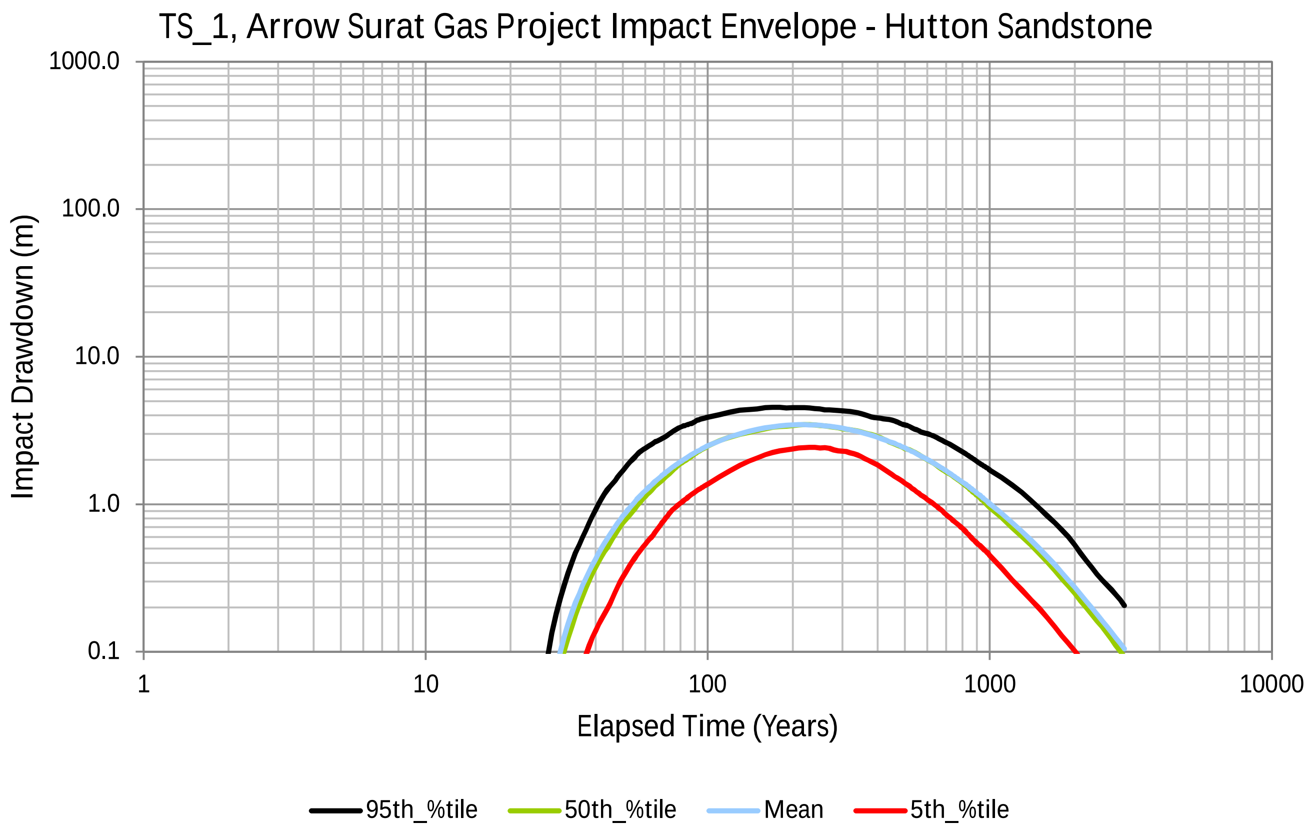
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 7

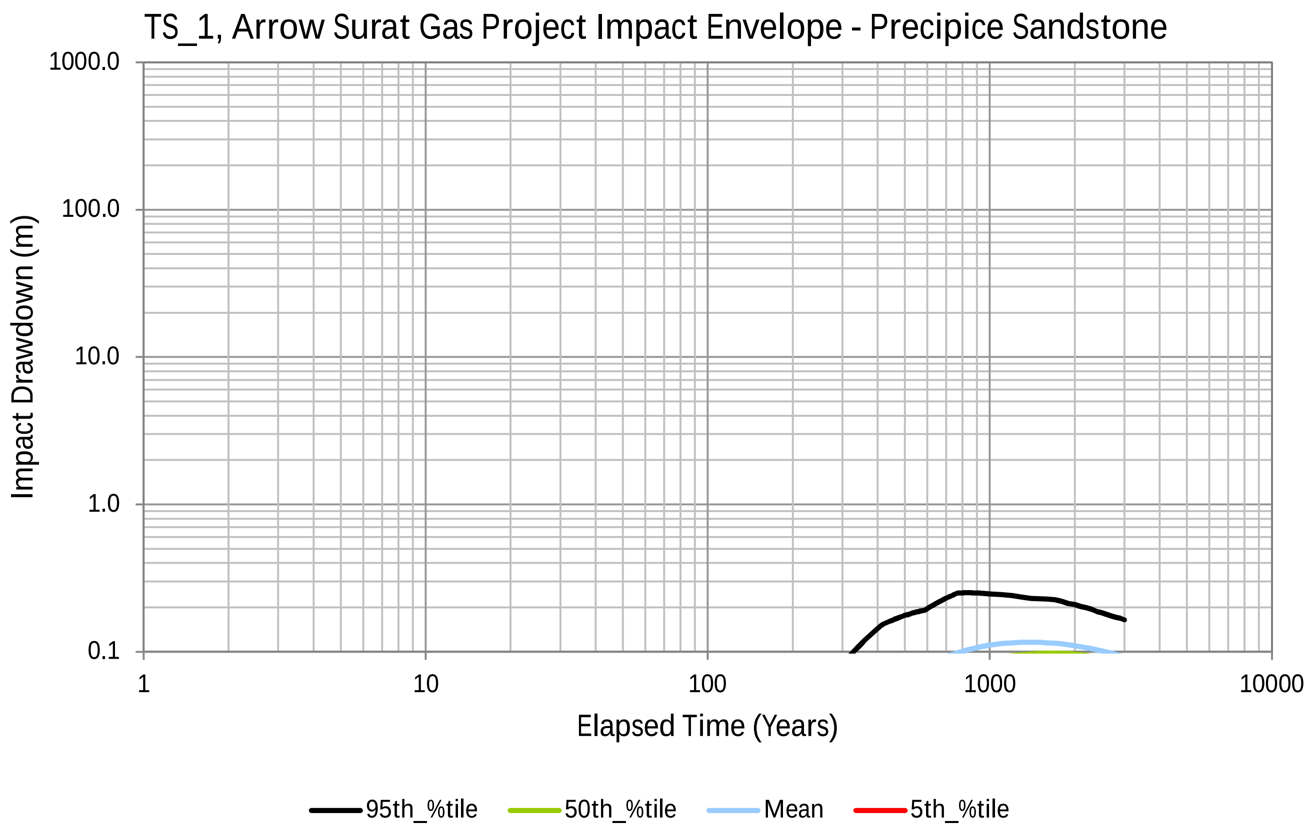




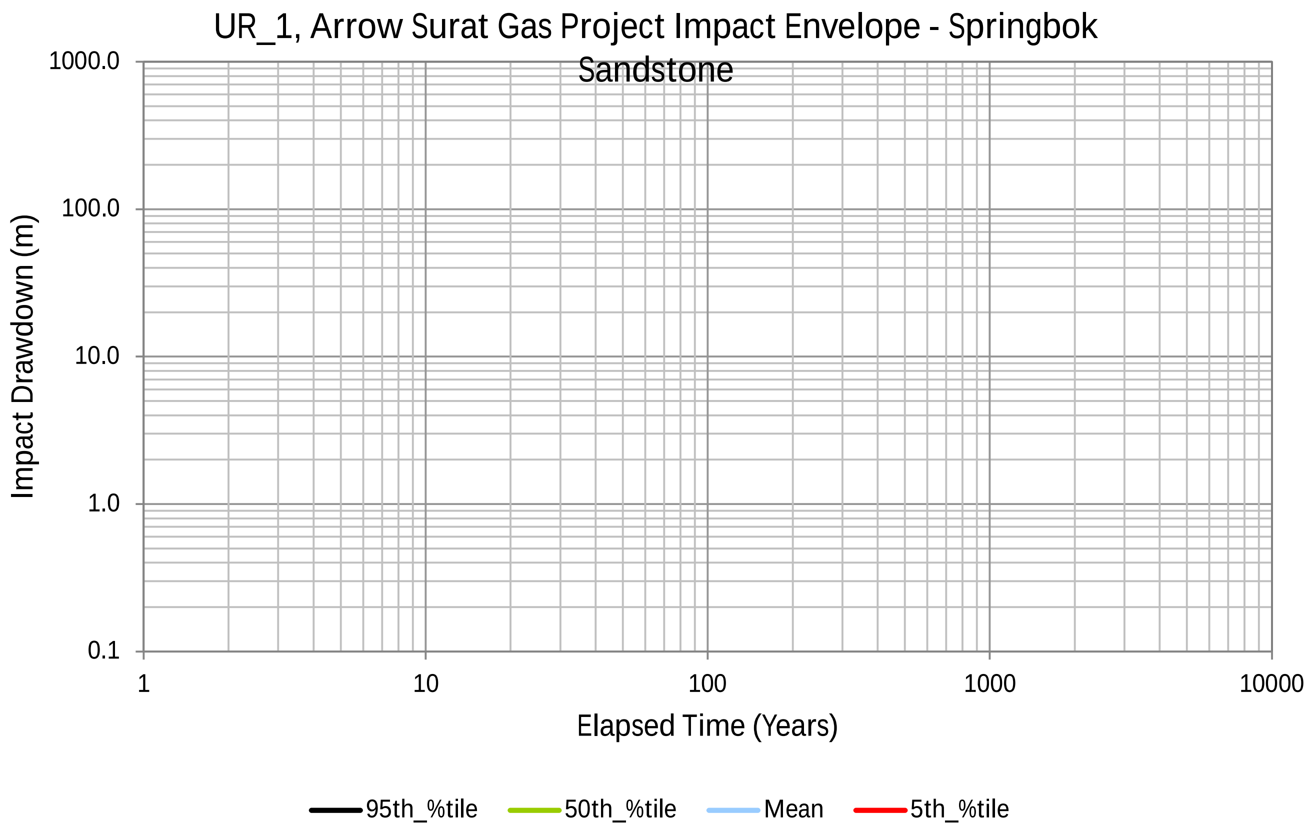
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_7)

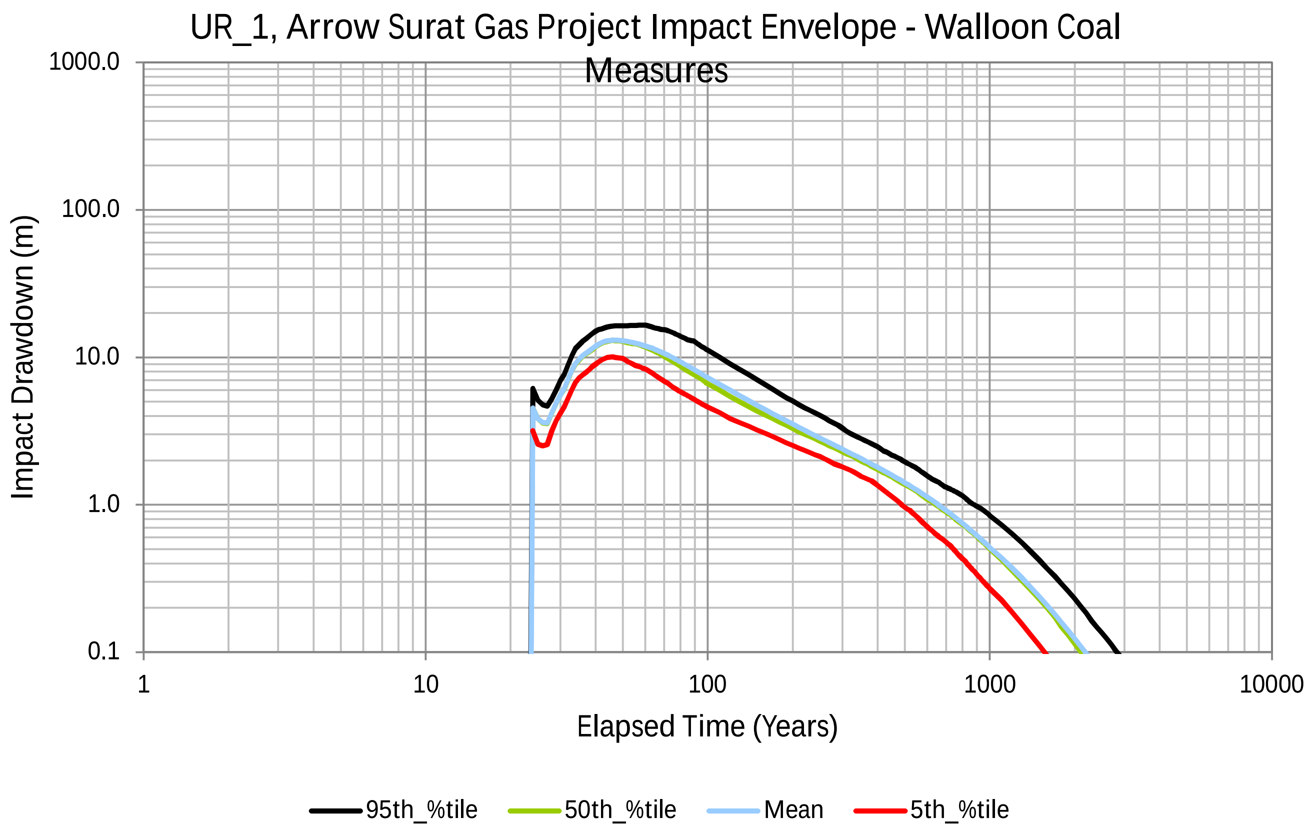
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 7





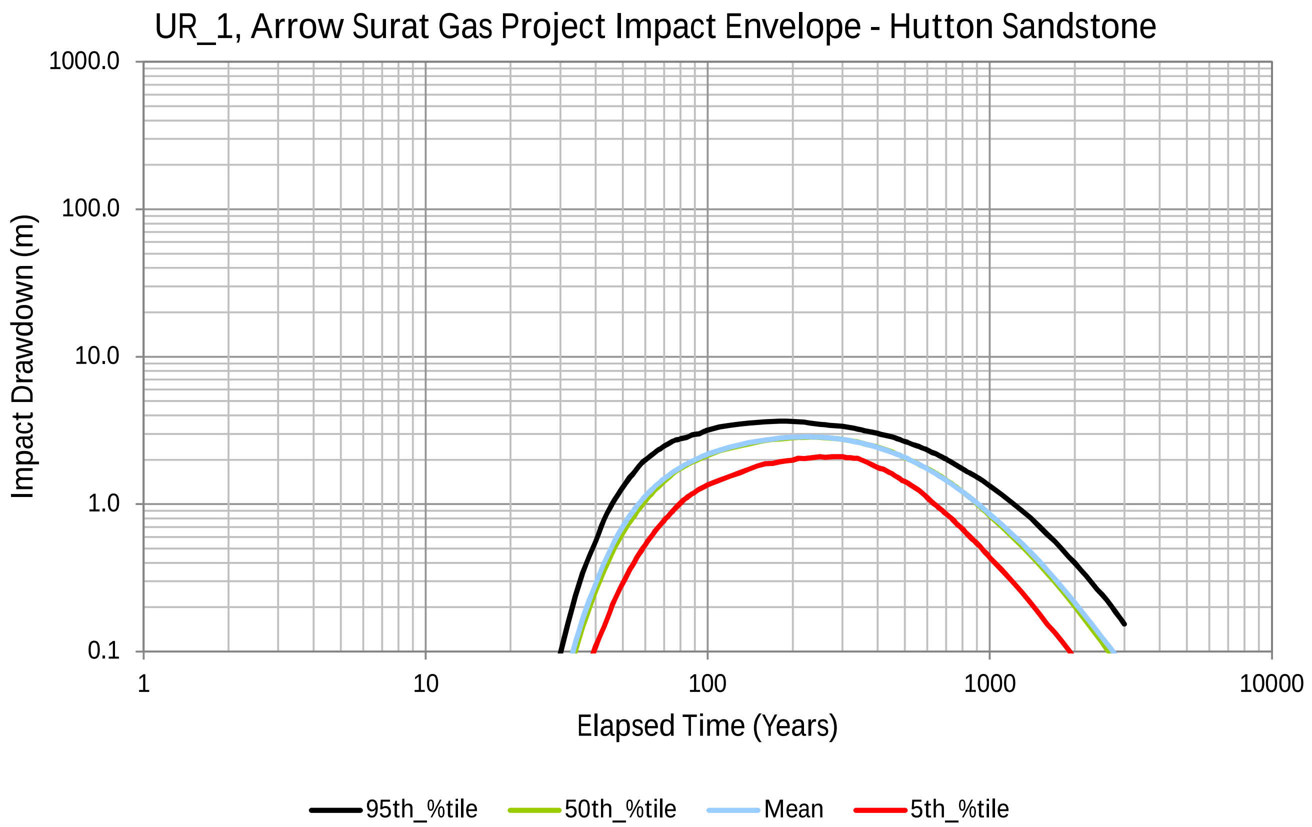
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 7

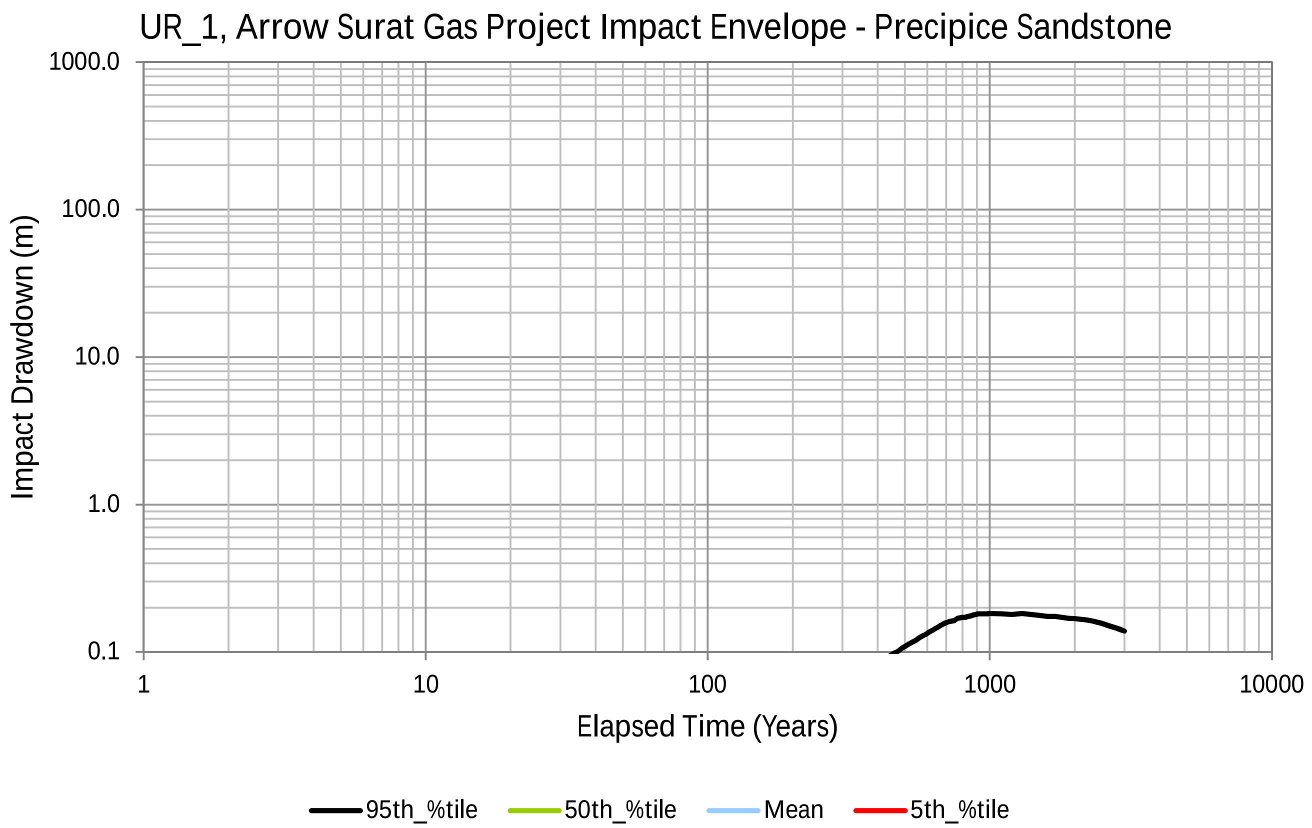




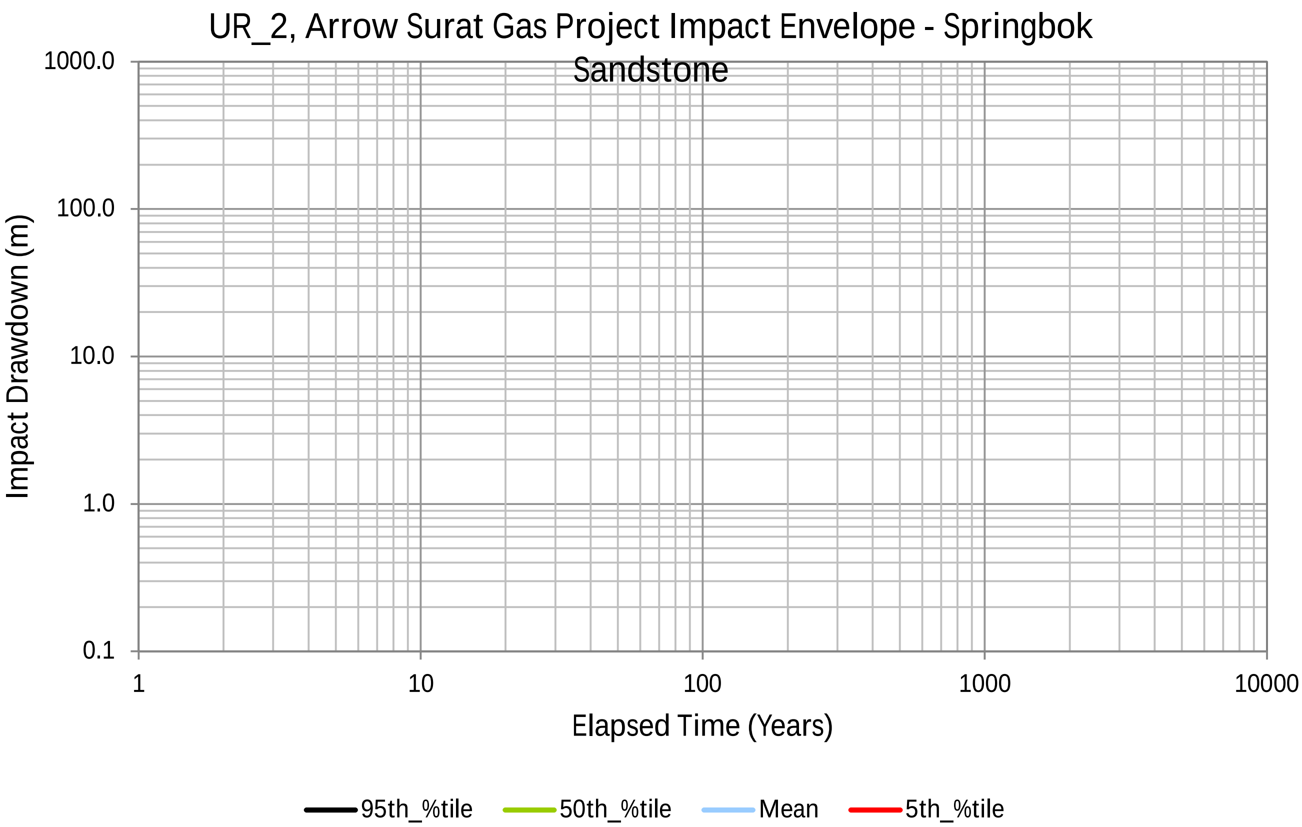
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_7)

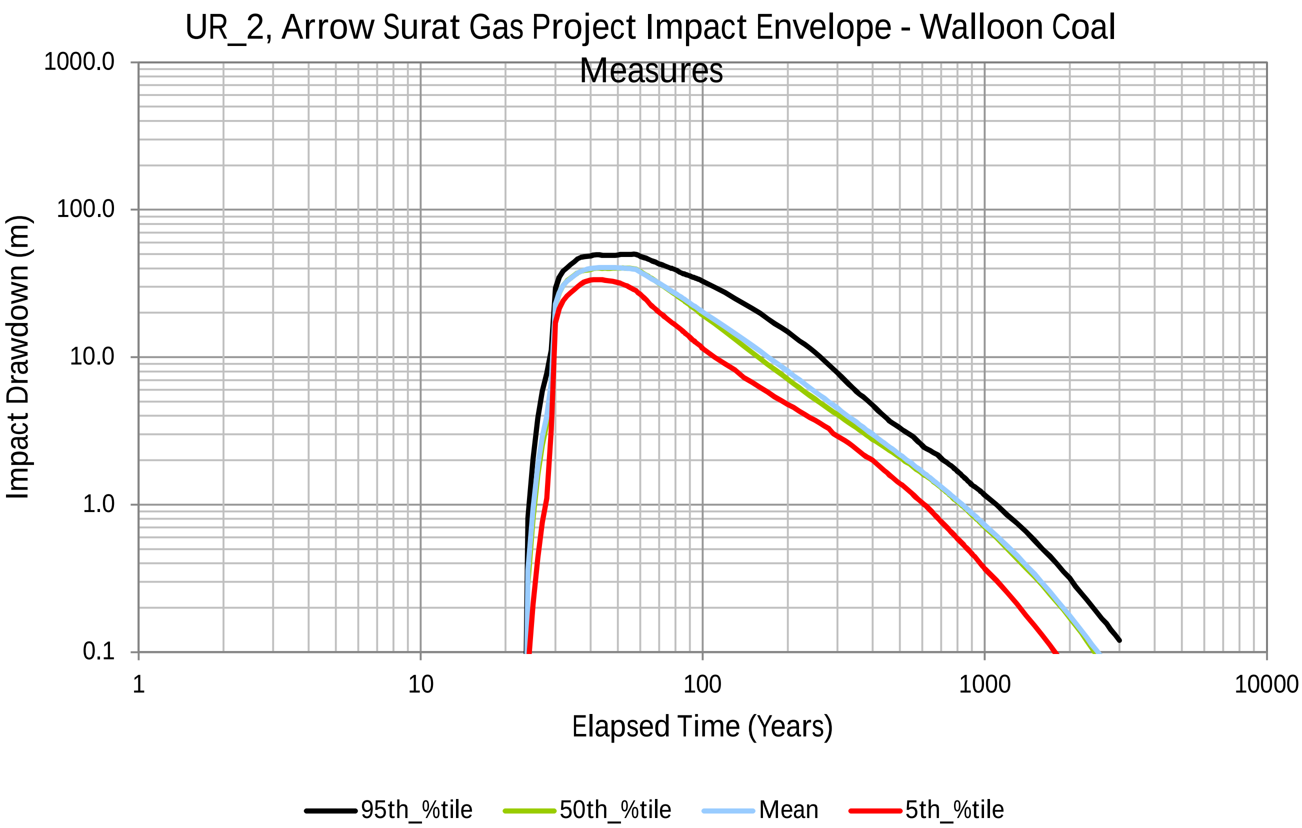
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 7



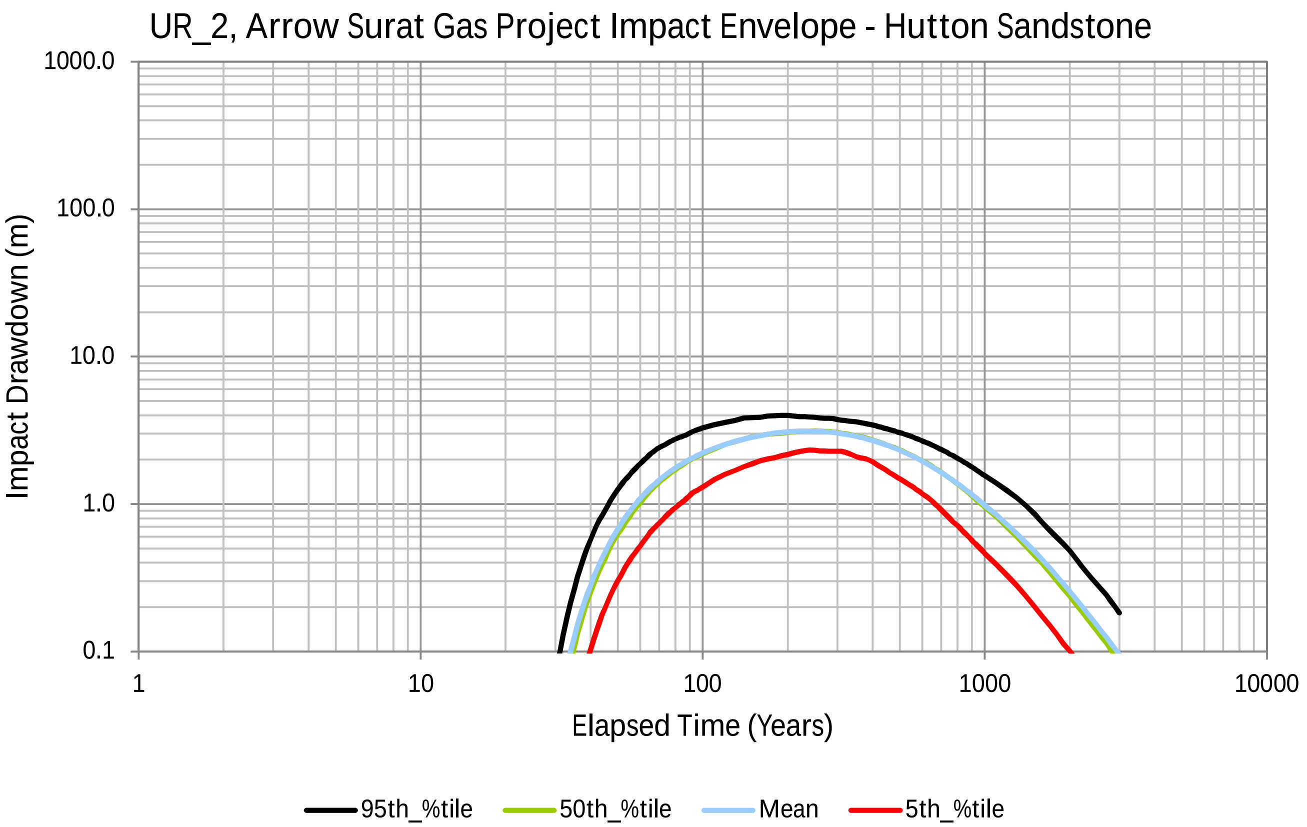


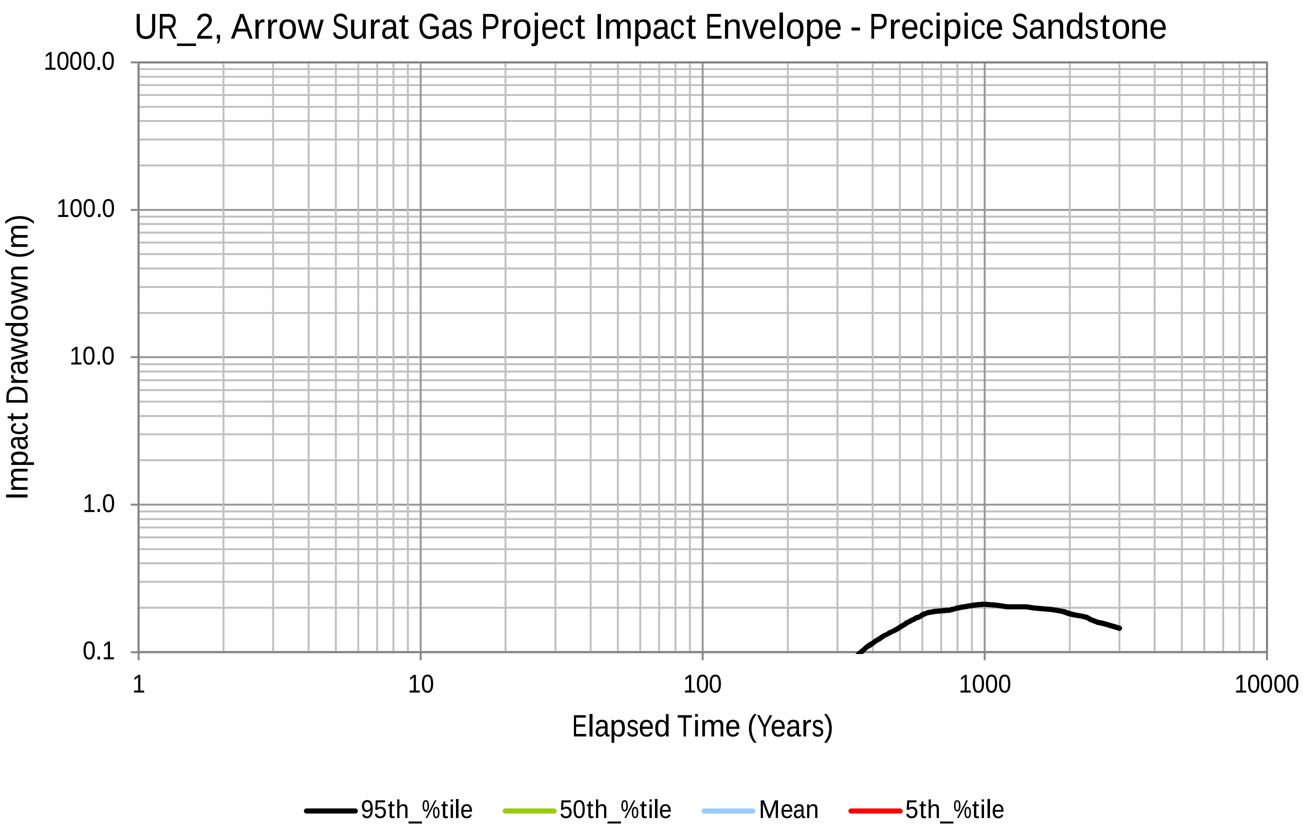
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 7



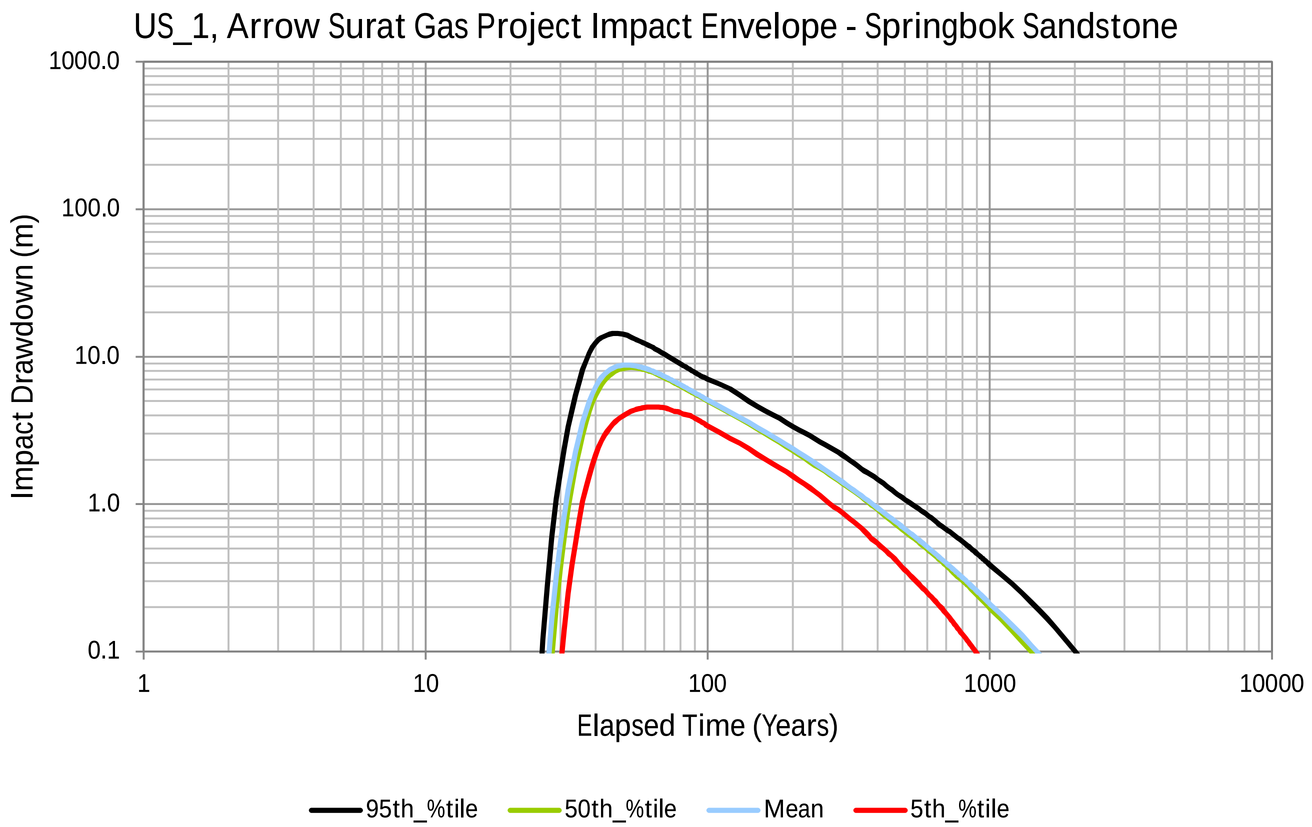


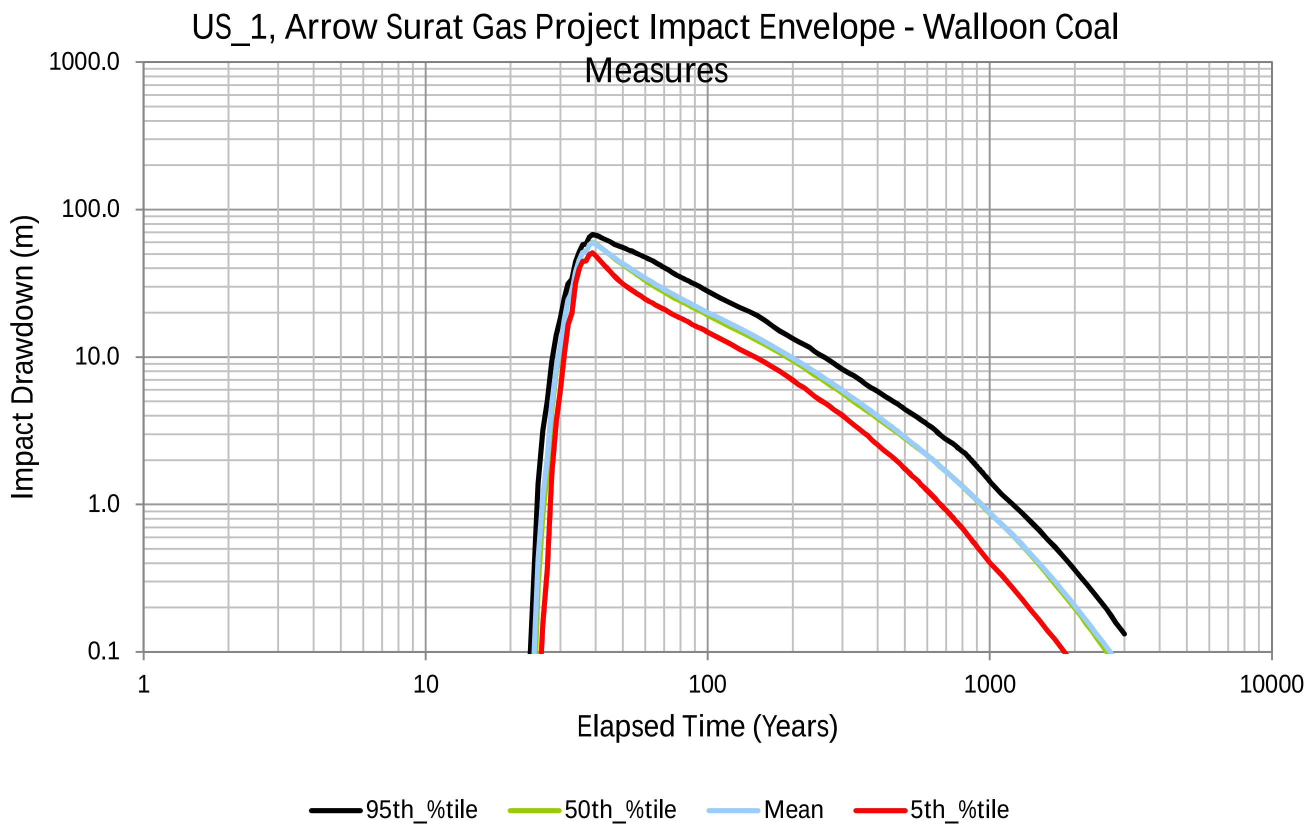
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_7)


UR_2, Arrow Surat Gas Project Impact Envelope - Hutton Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

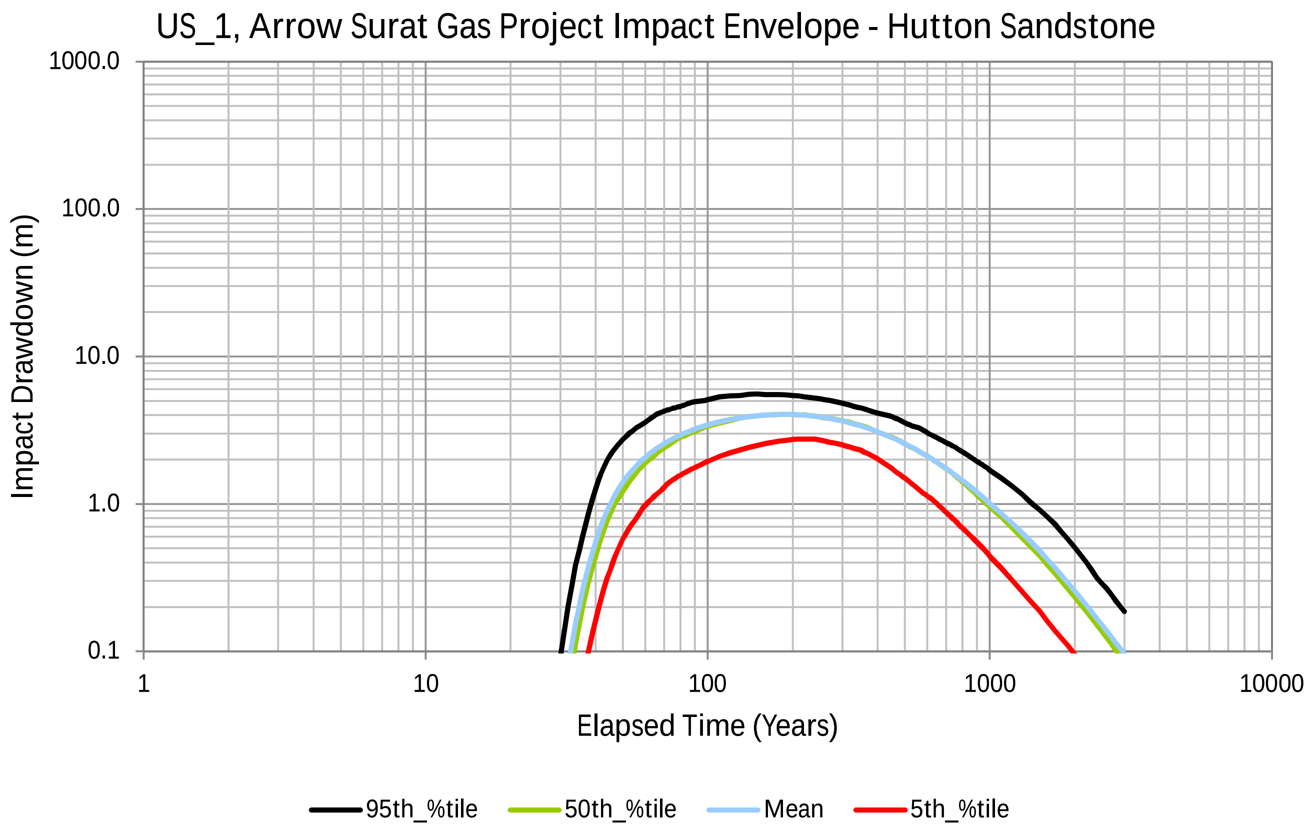

UR_2, Arrow Surat Gas Project Impact Envelope - Precipice Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

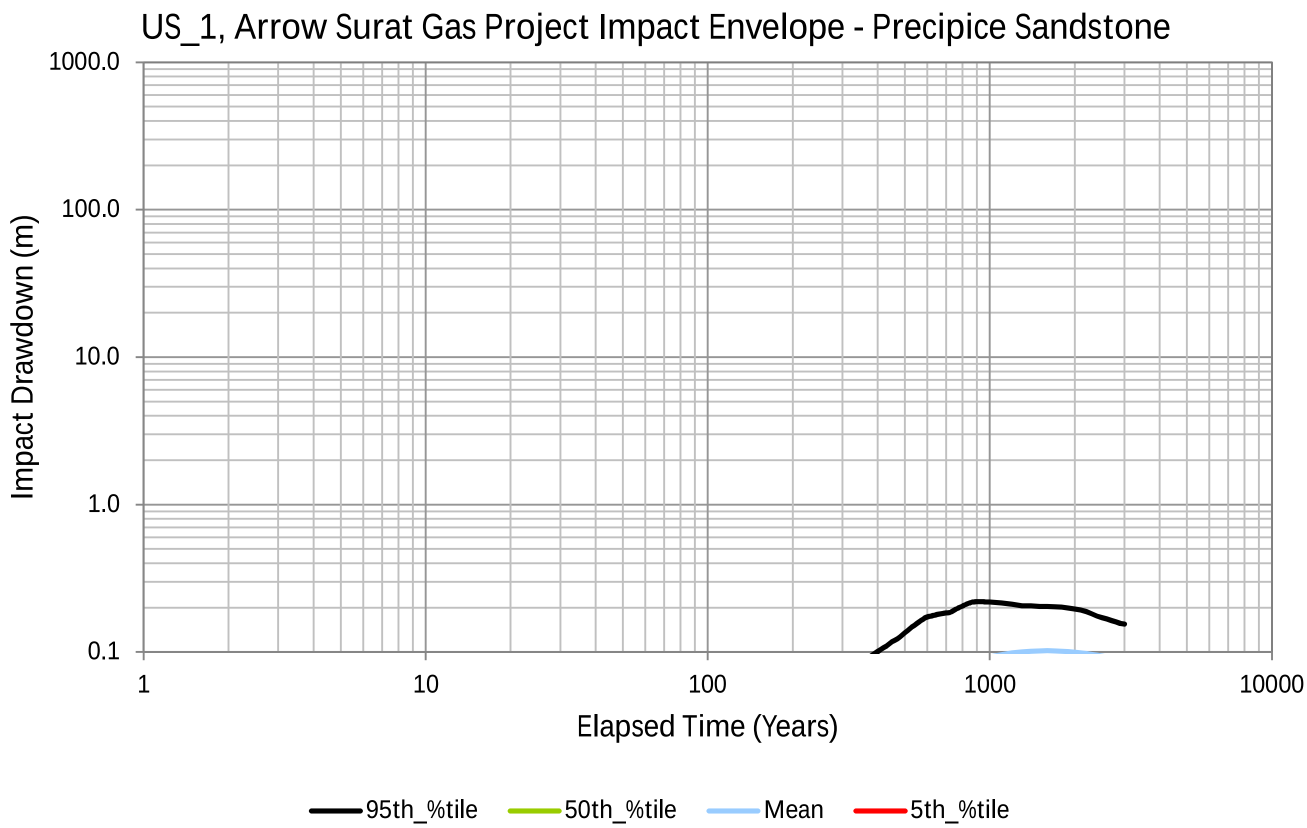
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 7





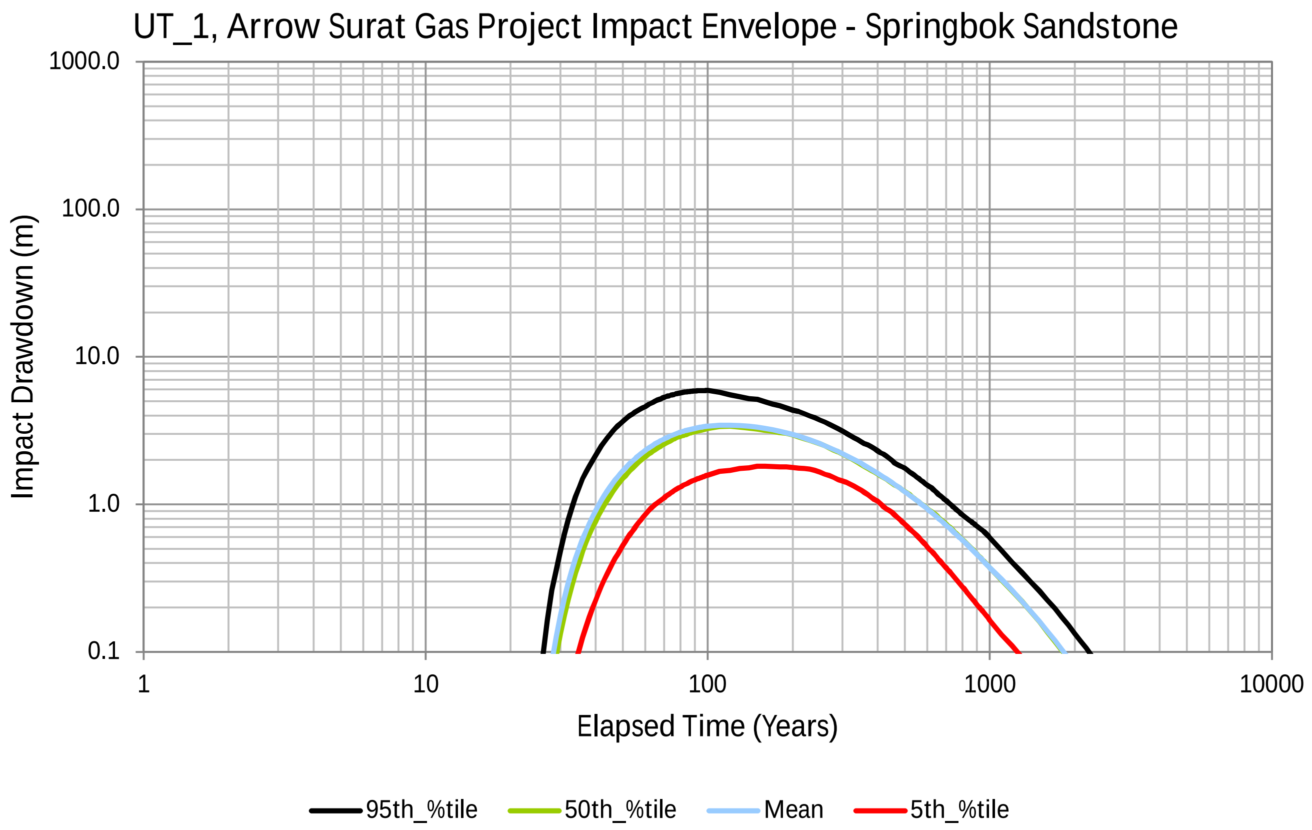
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 7

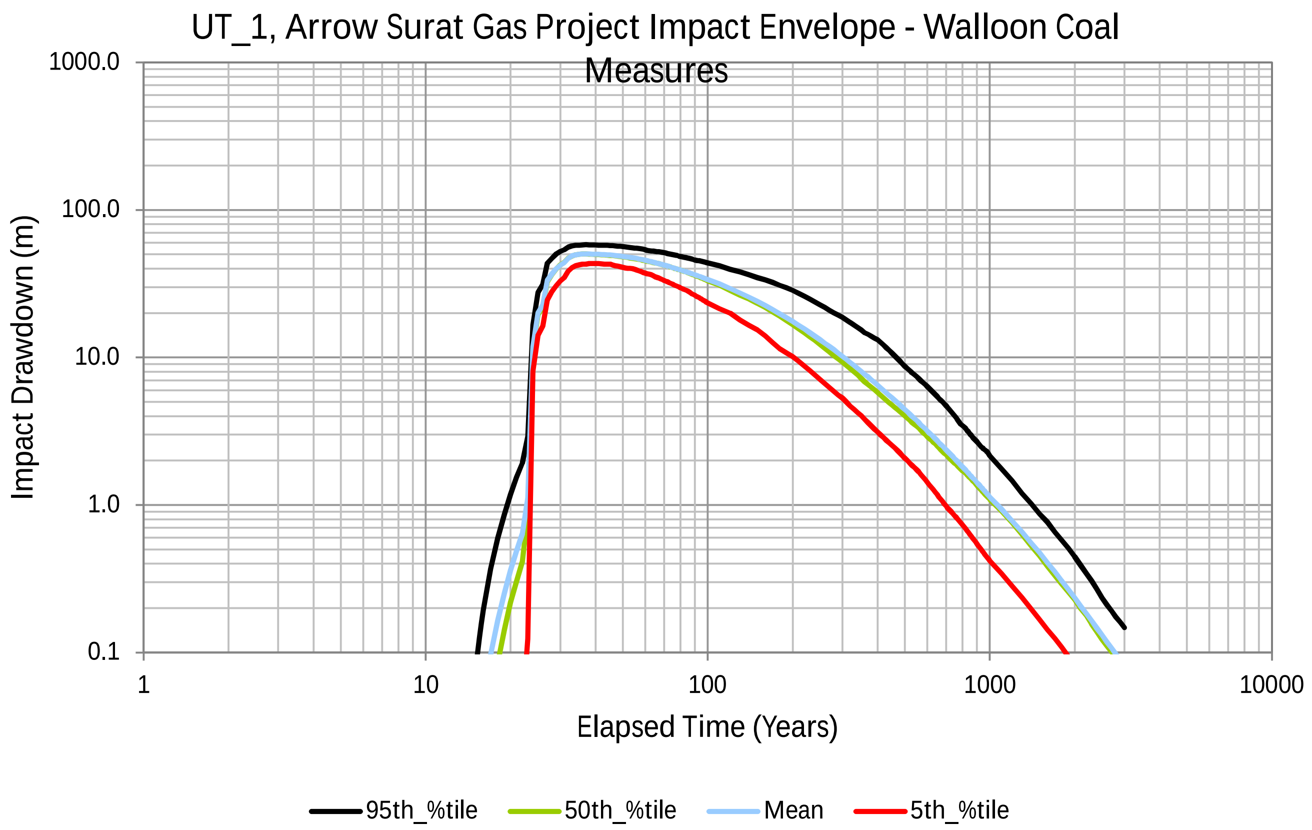




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_7)

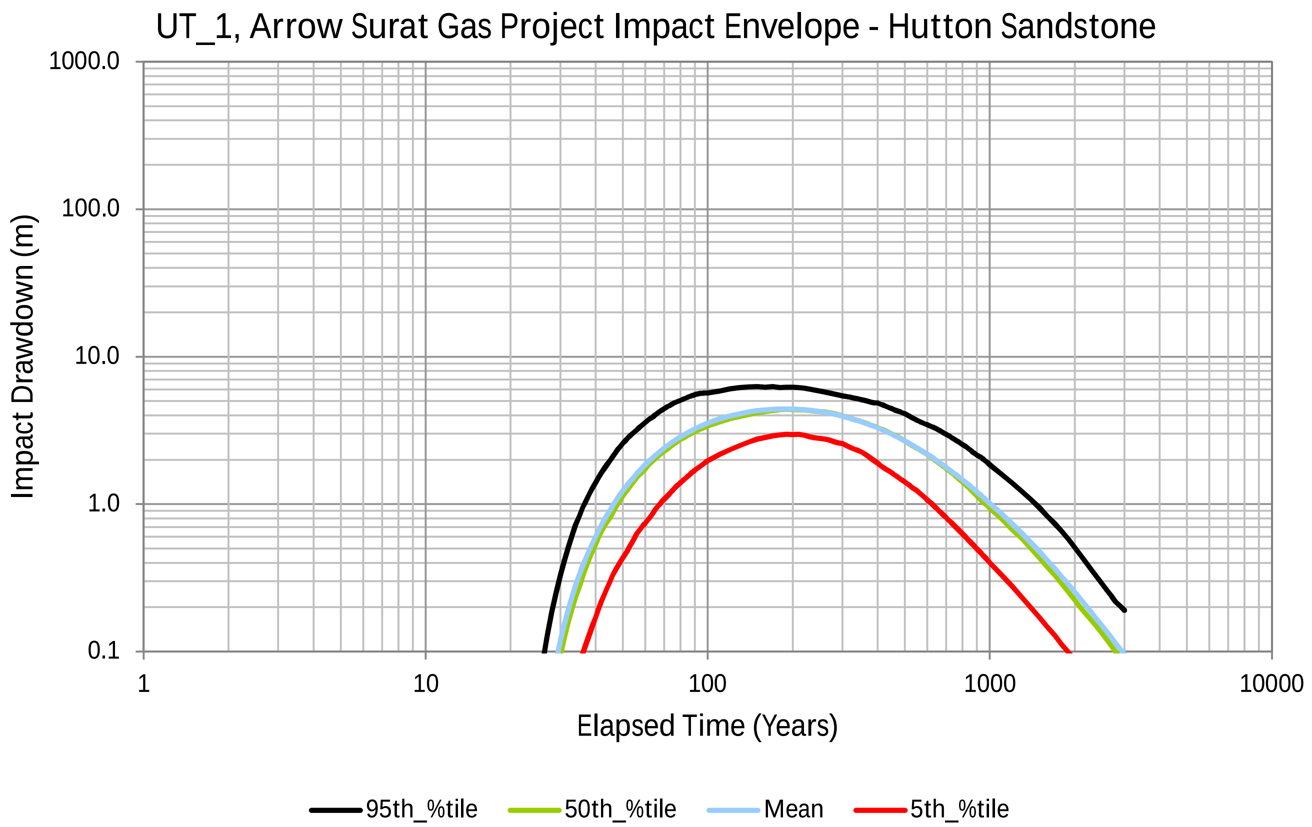
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 8

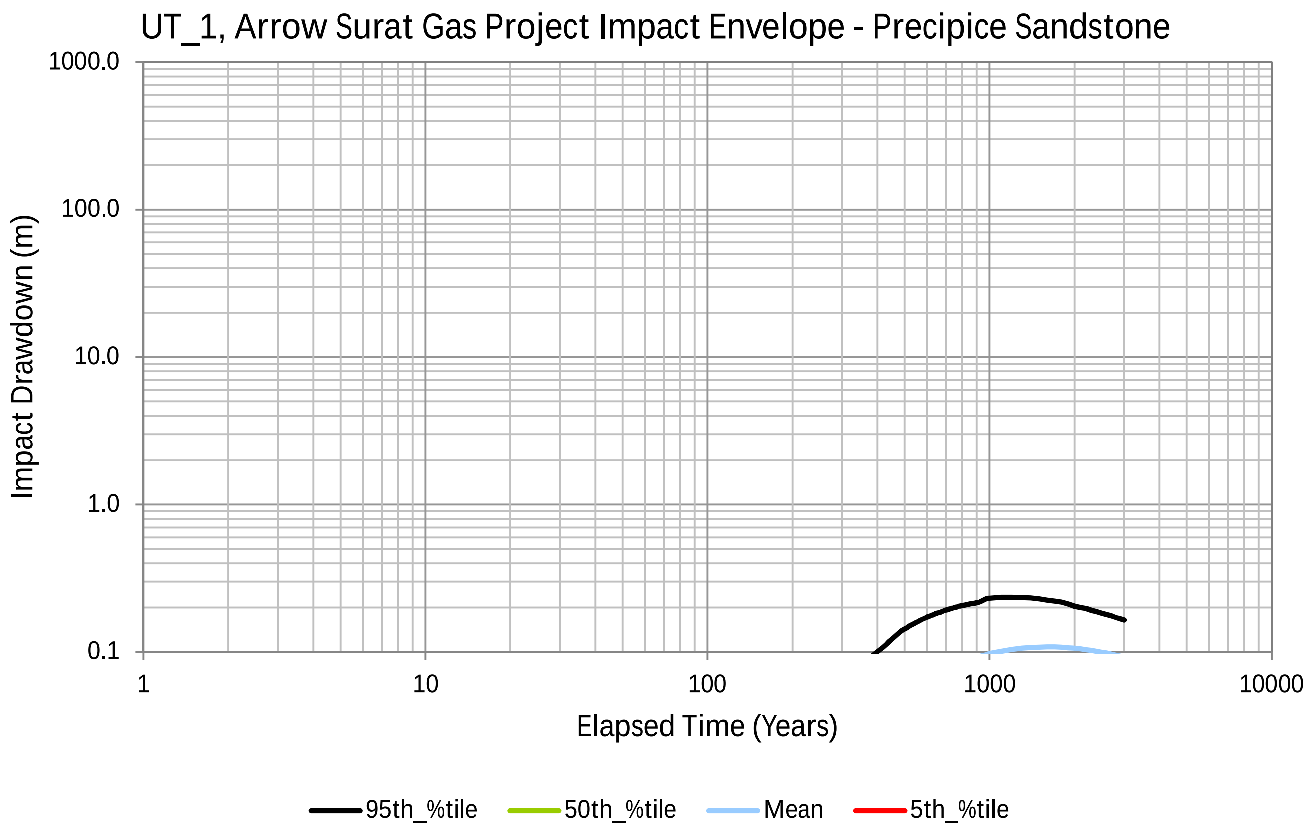




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_8)

Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 8





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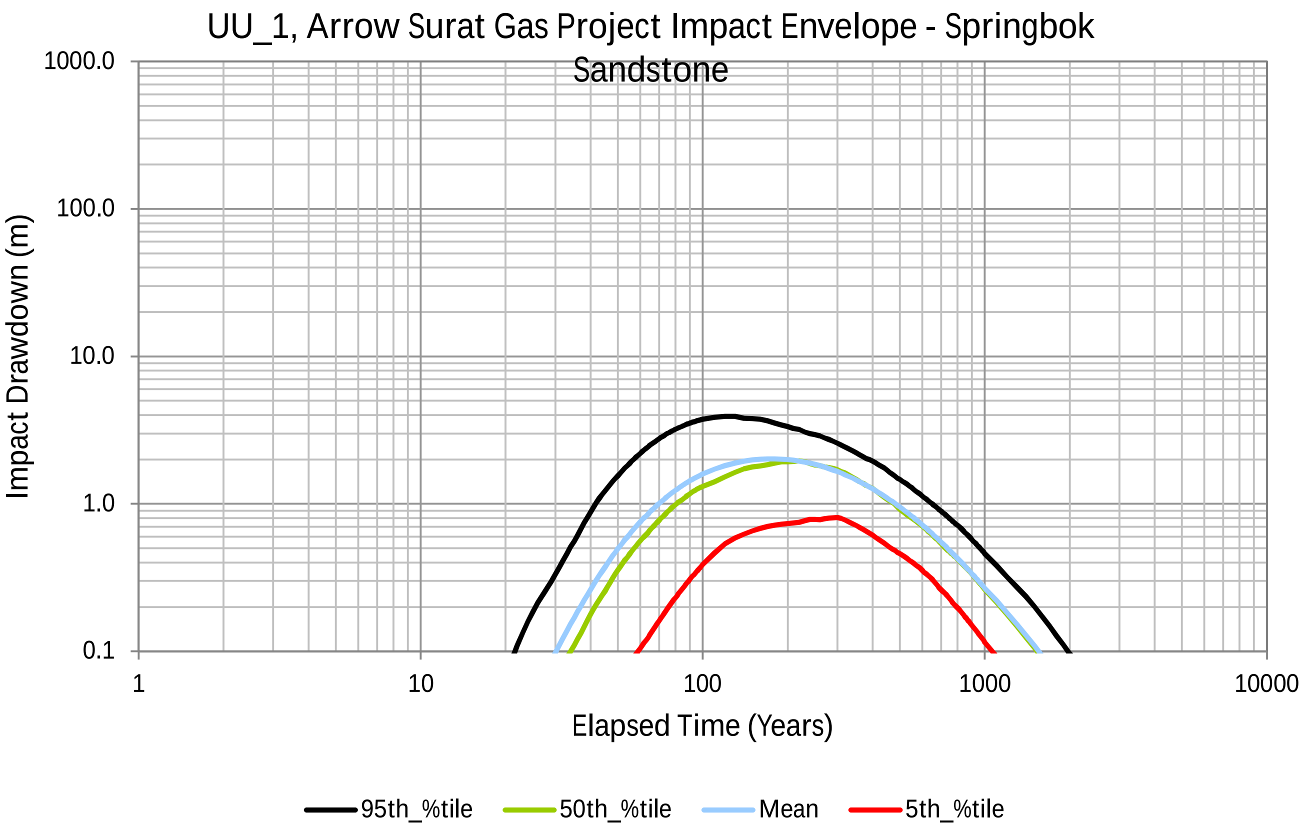
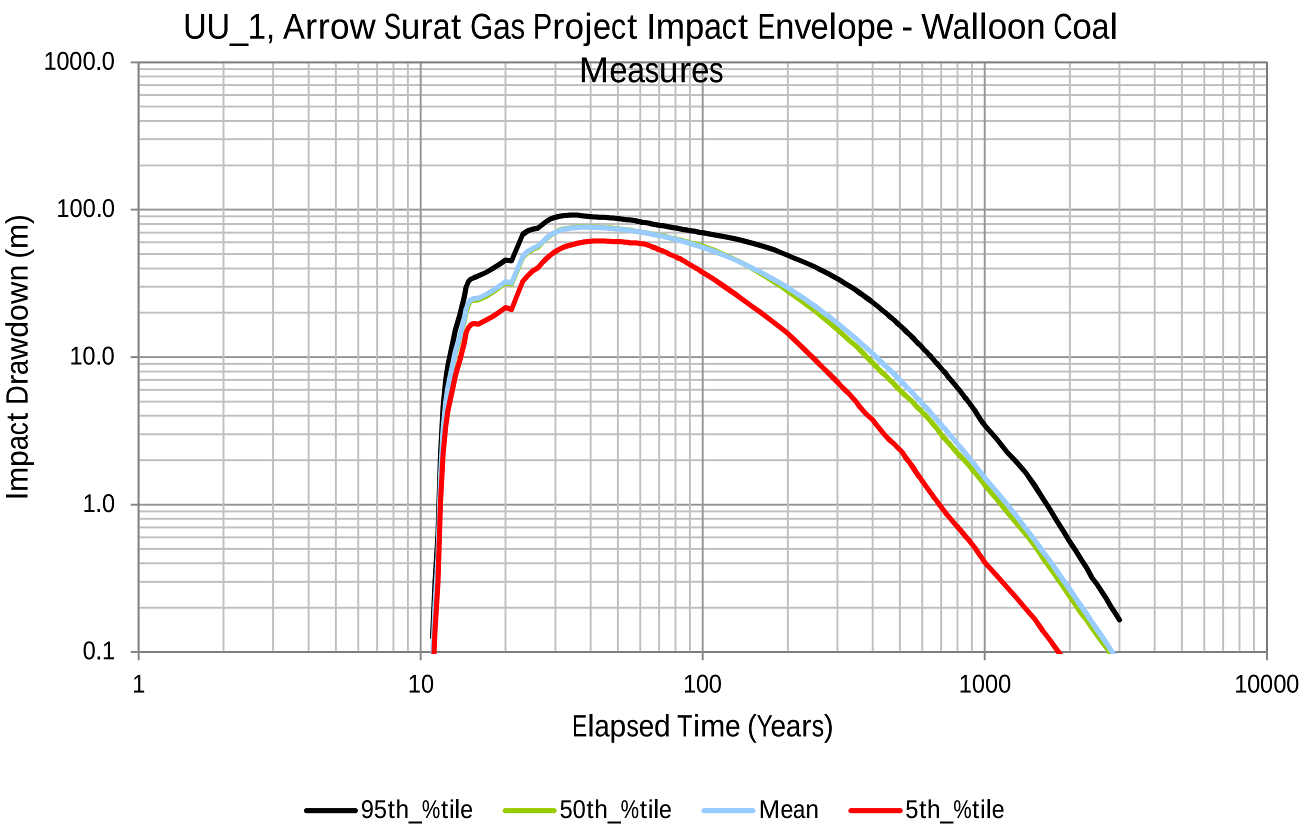
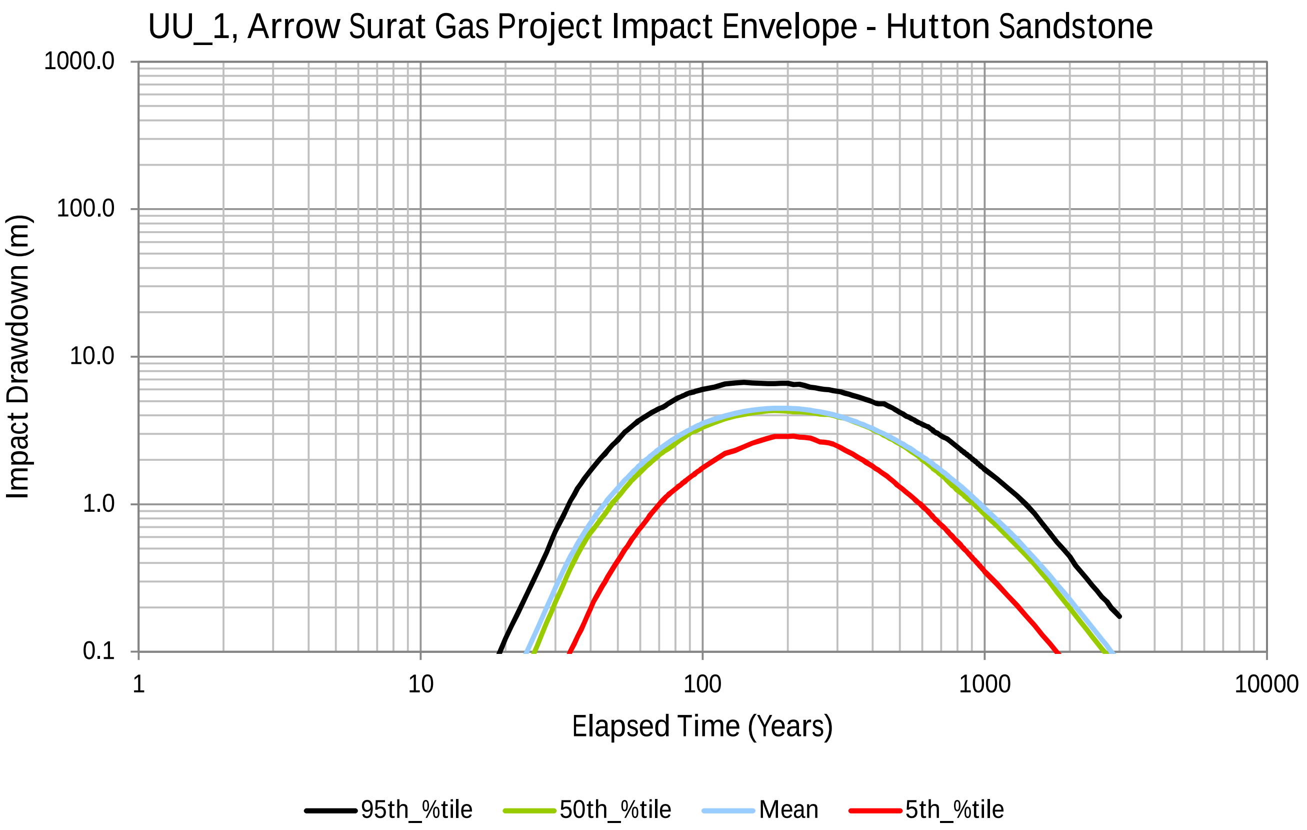
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 8

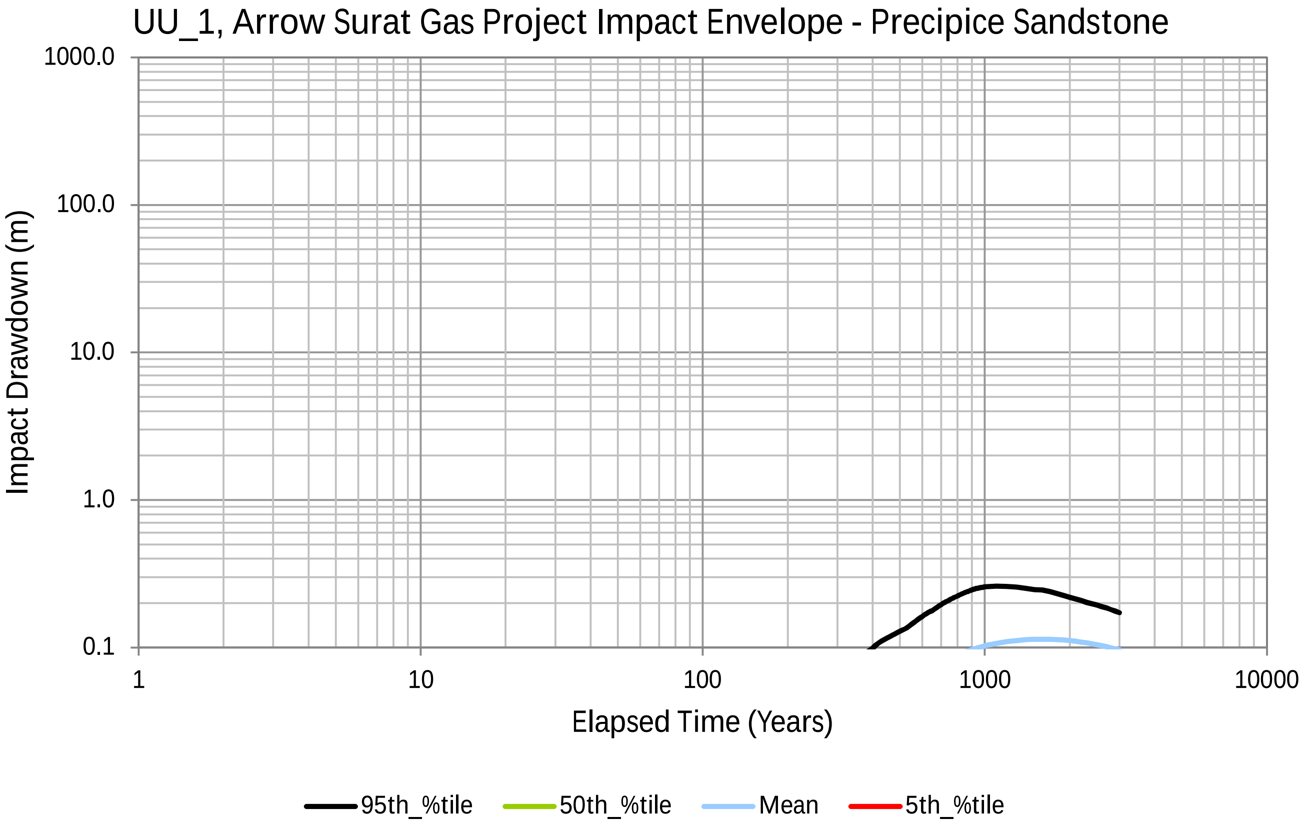




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_8)

Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 8





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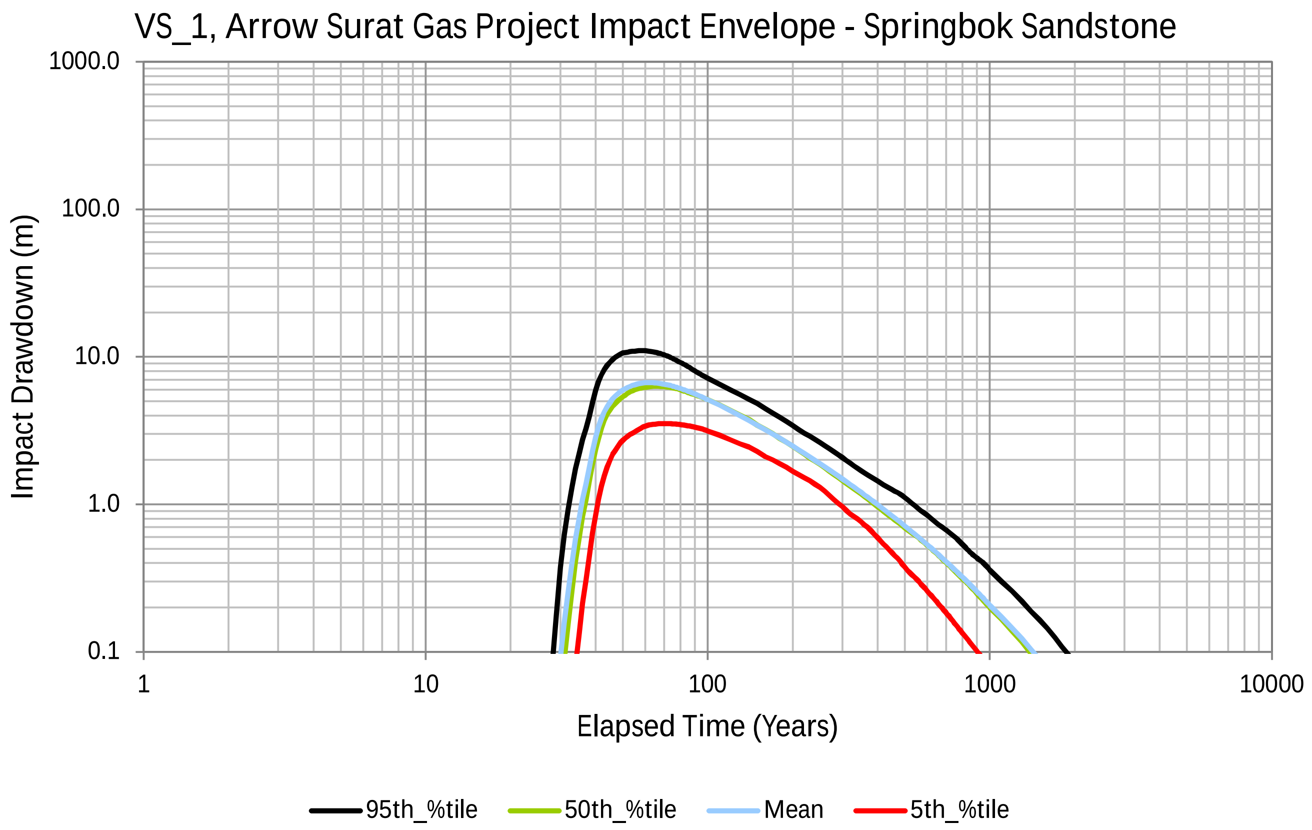
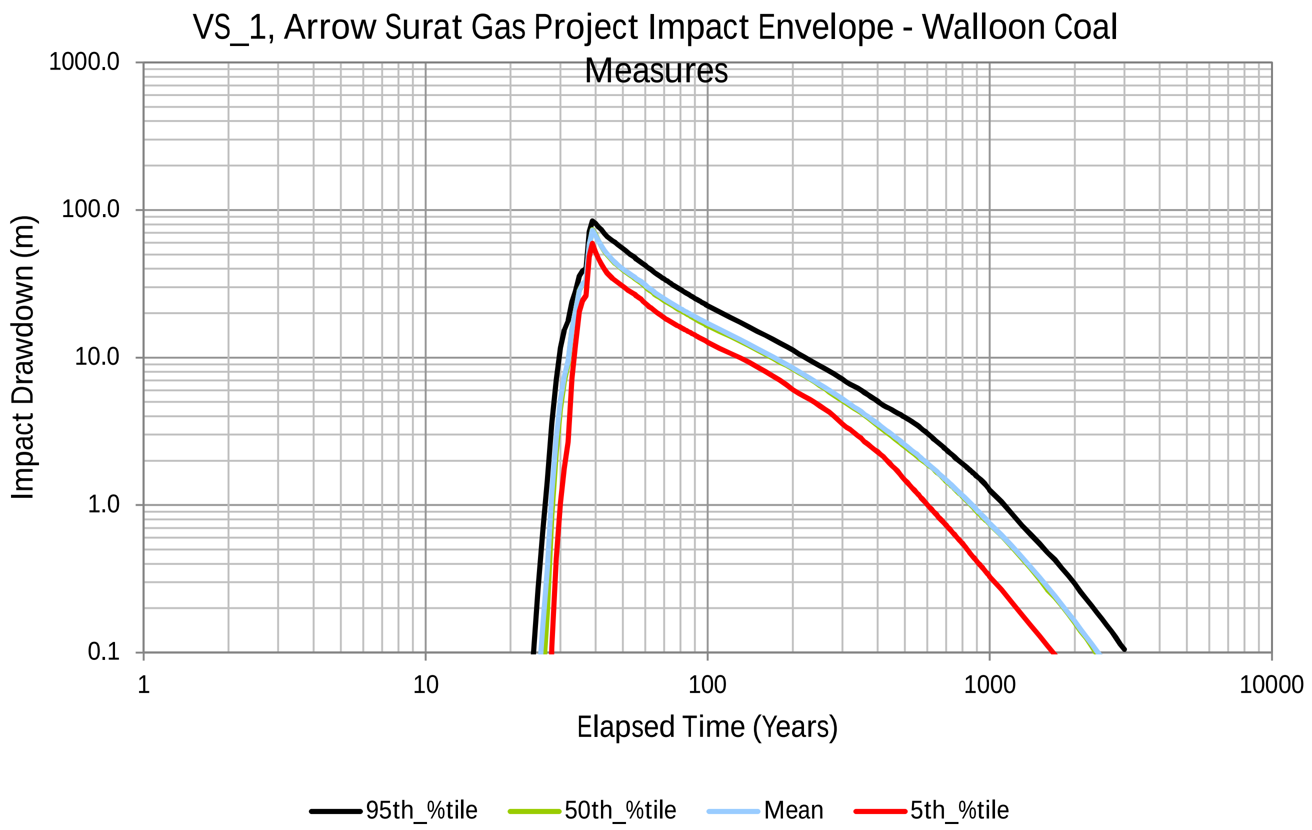
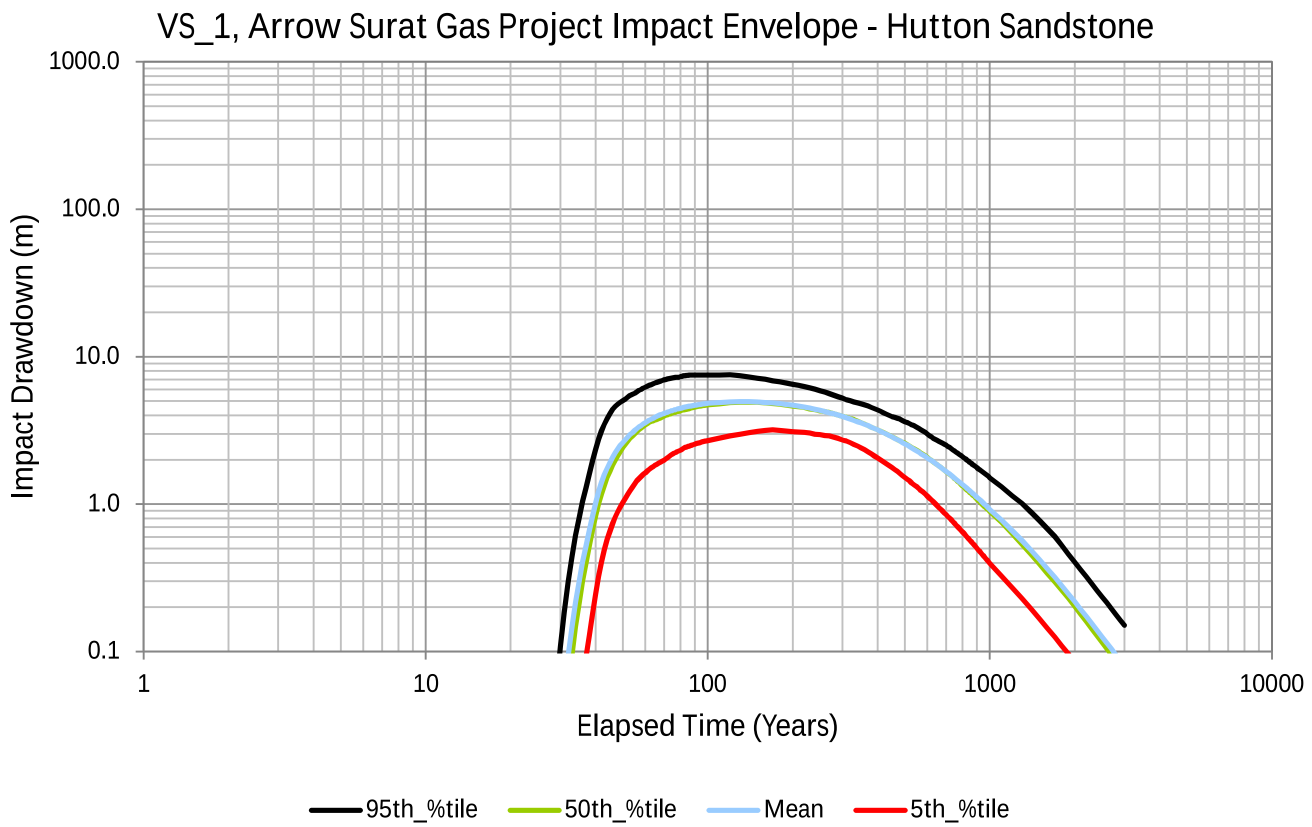
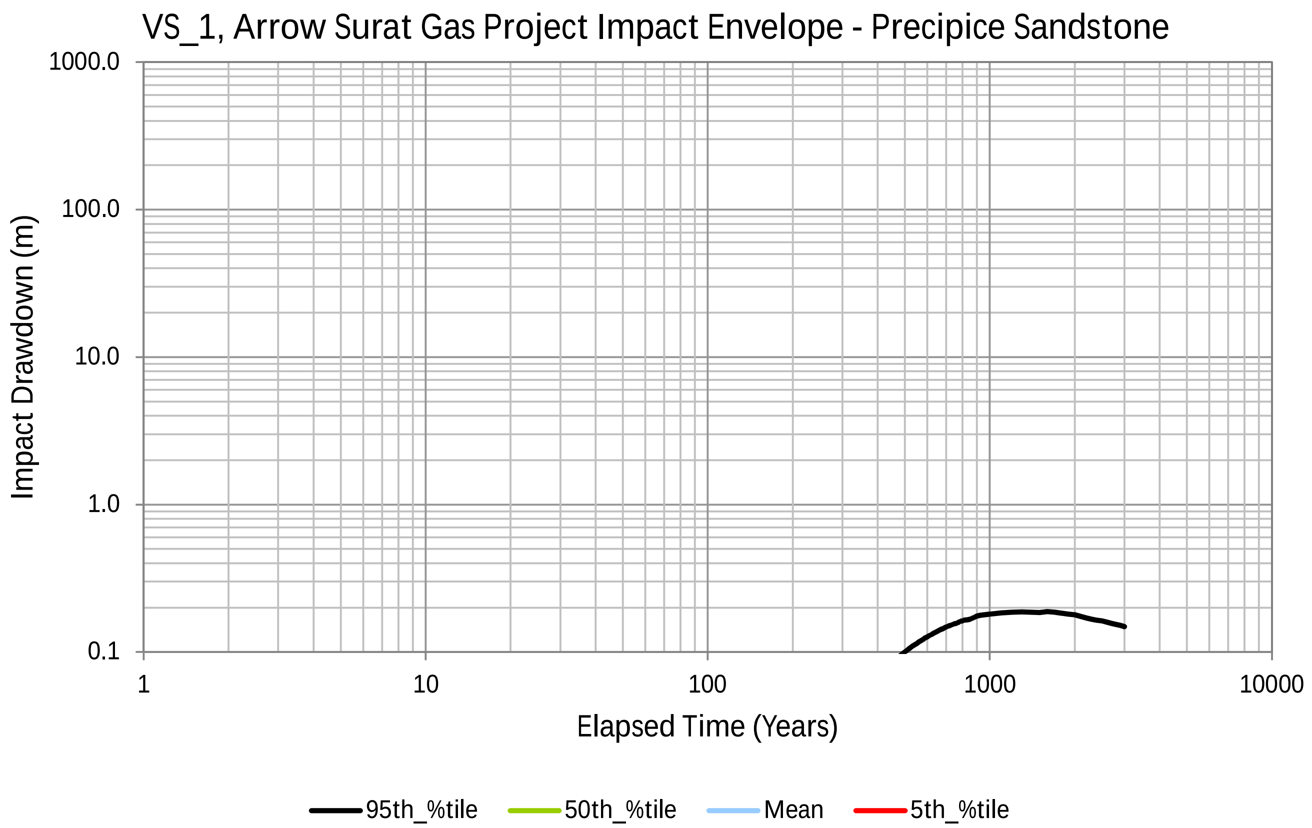

VS_1, Arrow Surat Gas Project Impact Envelope - Springbok Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

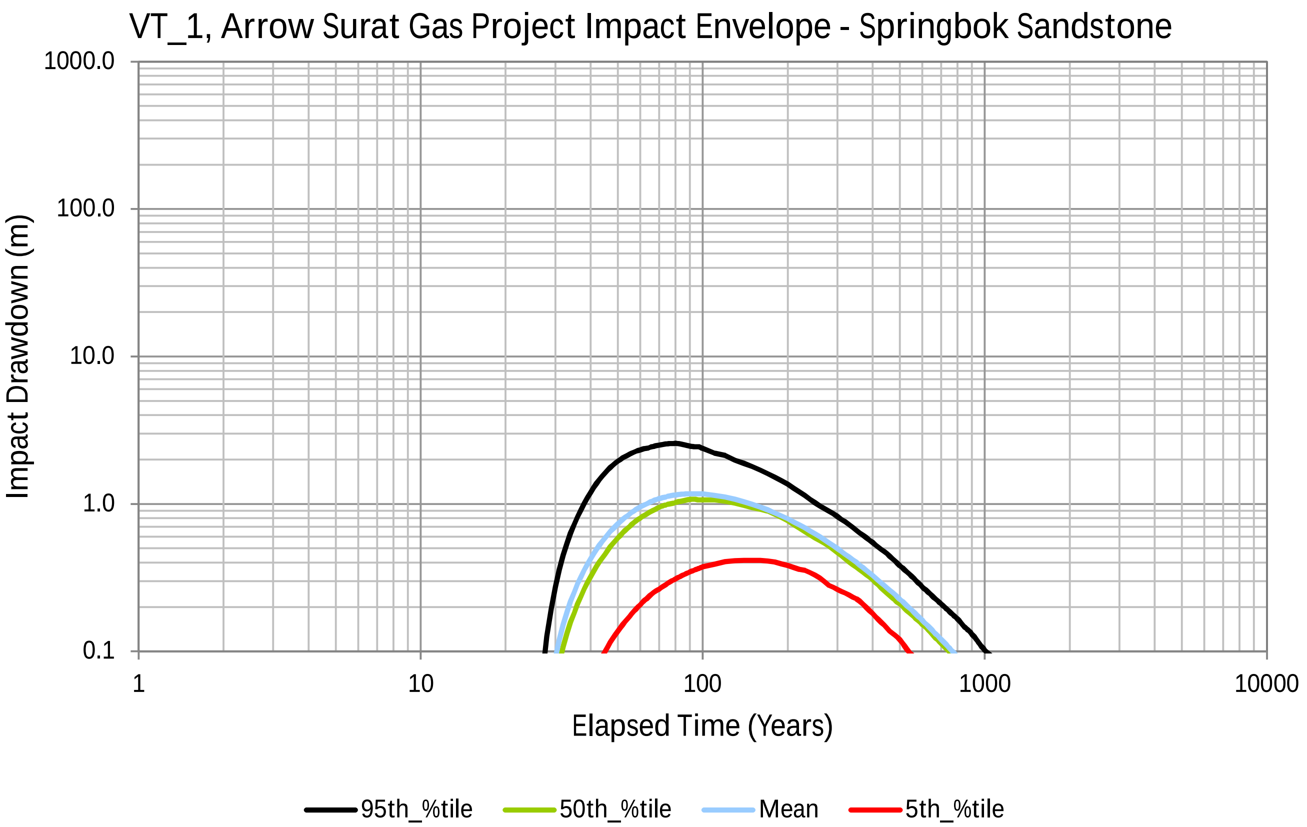

VS_1, Arrow Surat Gas Project Impact Envelope - Walloon Coal Measures
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

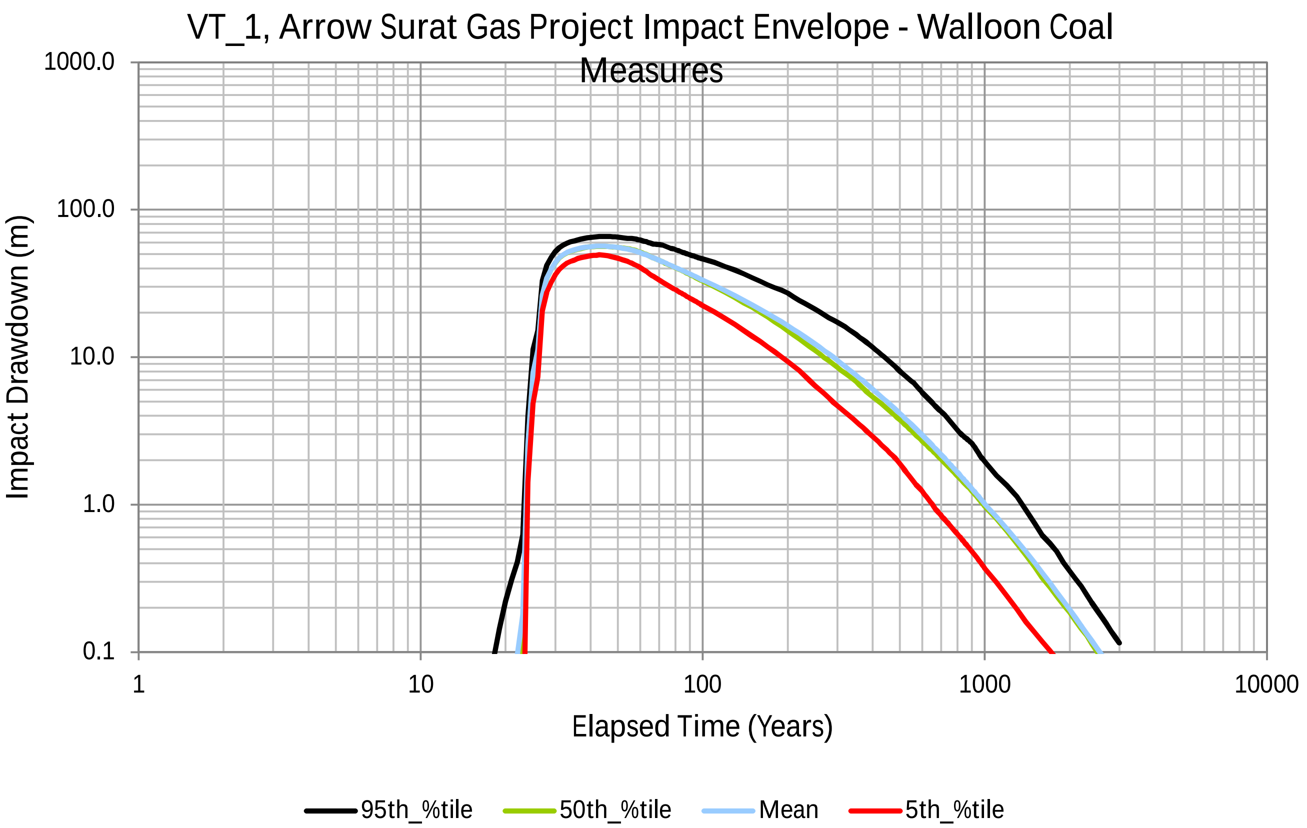
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 8



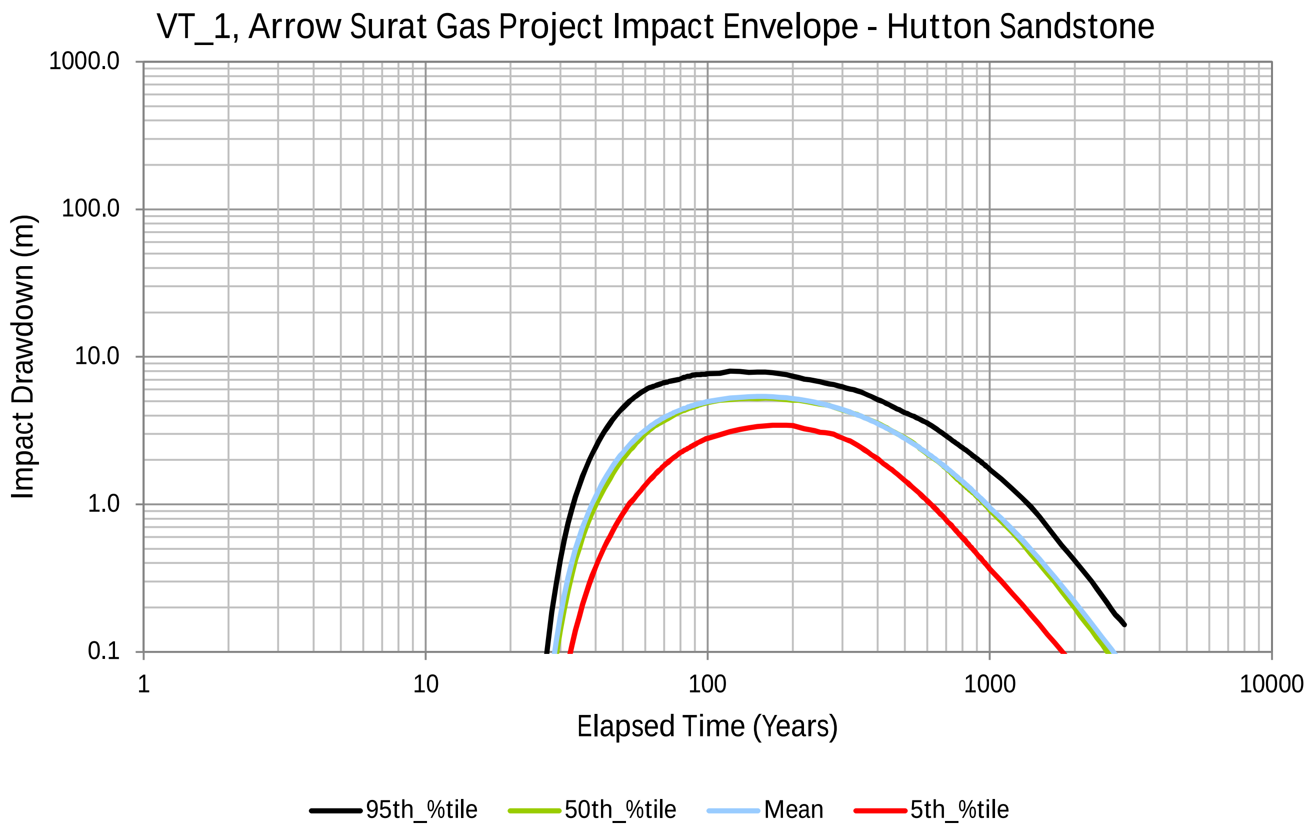


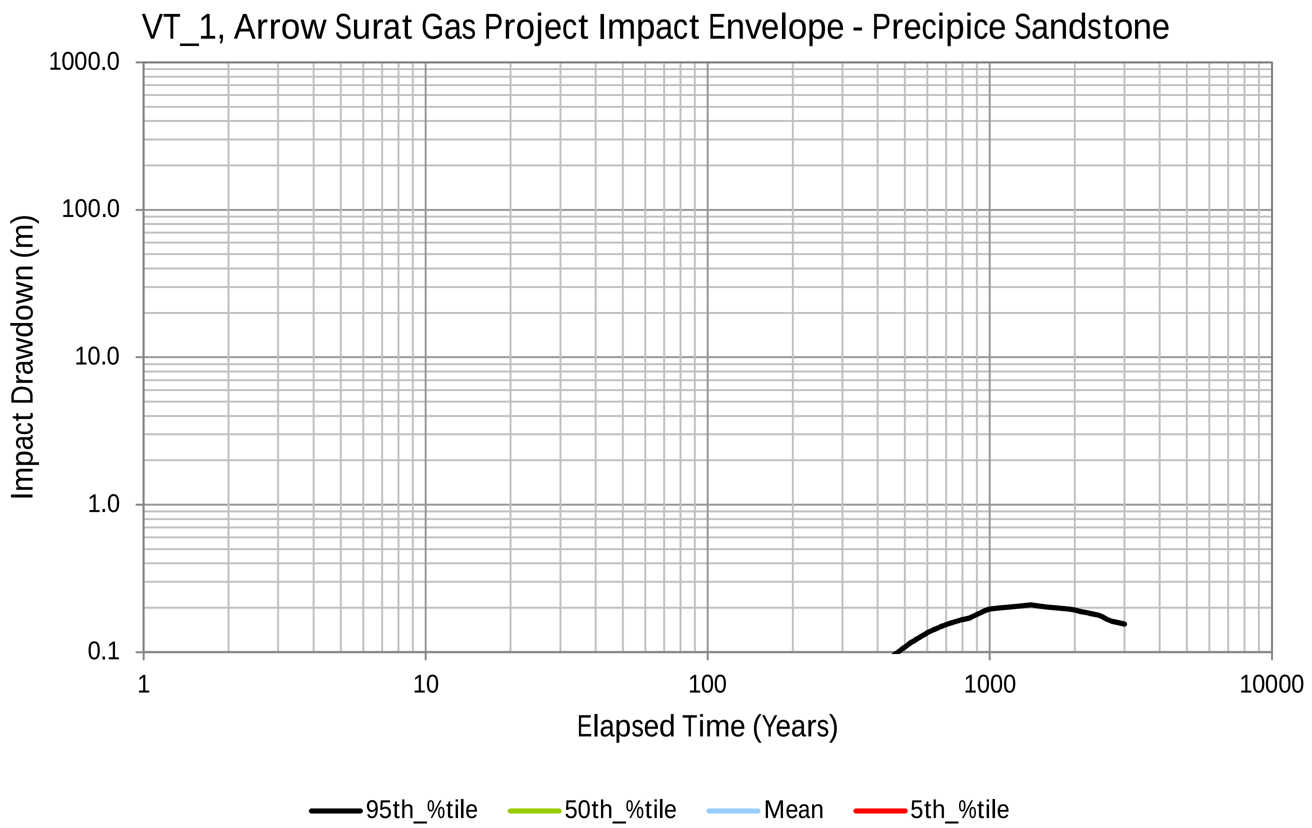
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_8)


VT_1, Arrow Surat Gas Project Impact Envelope - Springbok Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile


VT_1, Arrow Surat Gas Project Impact Envelope - Walloon Coal Measures
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

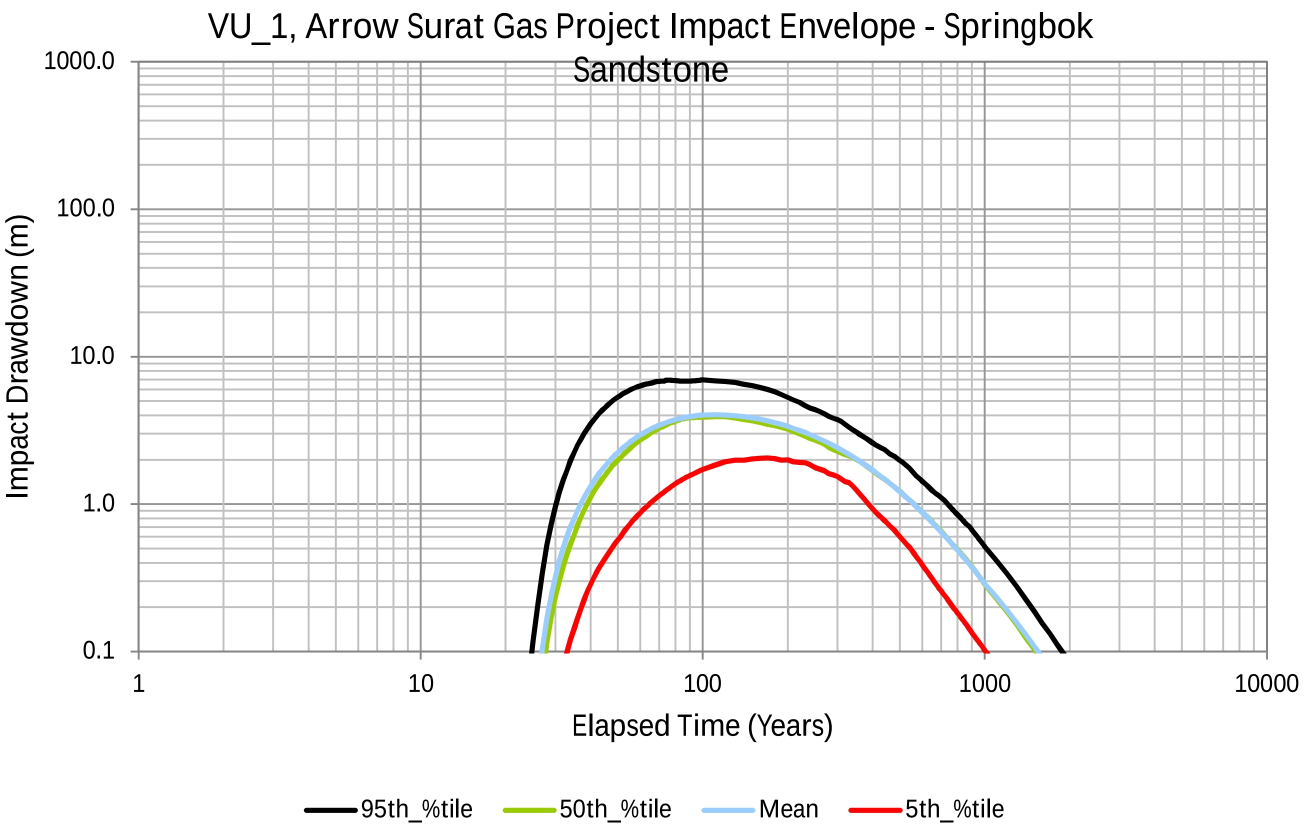
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 8

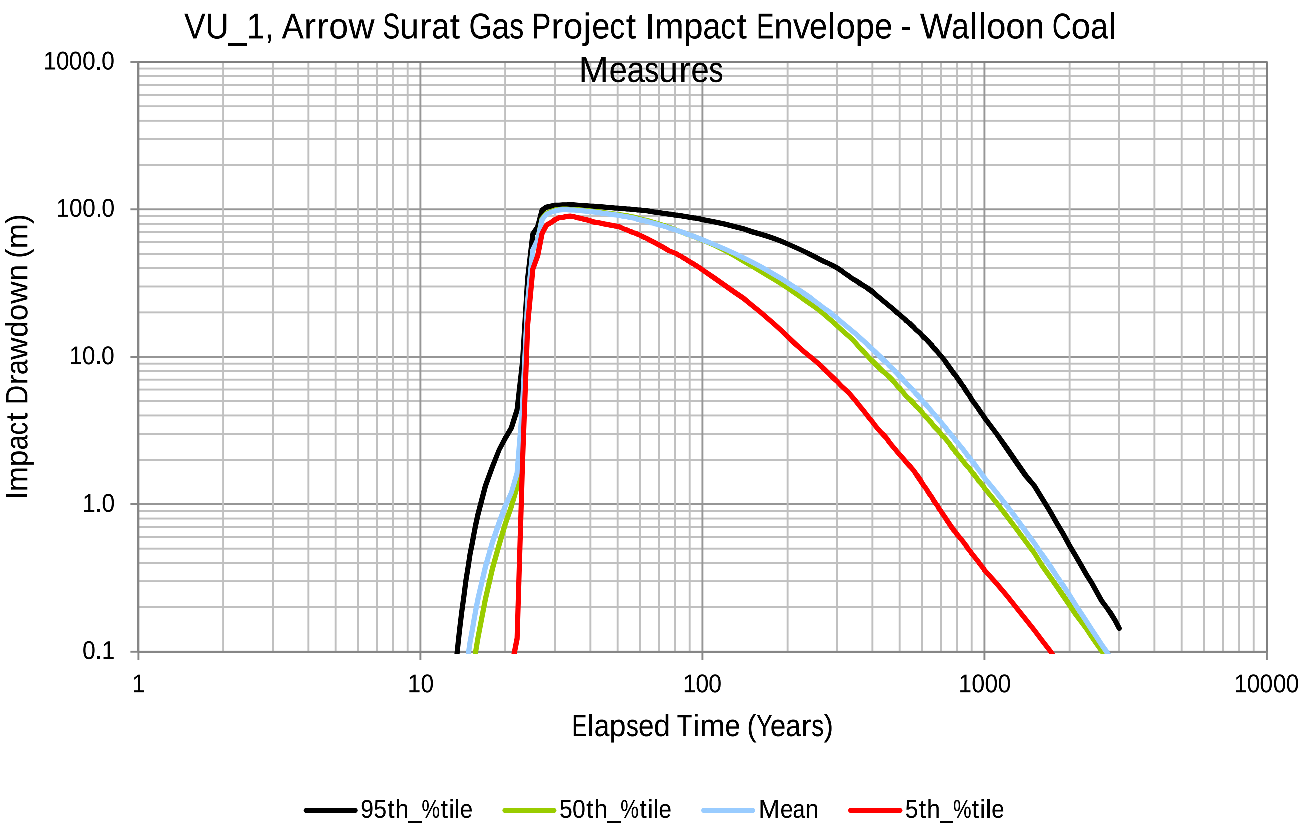


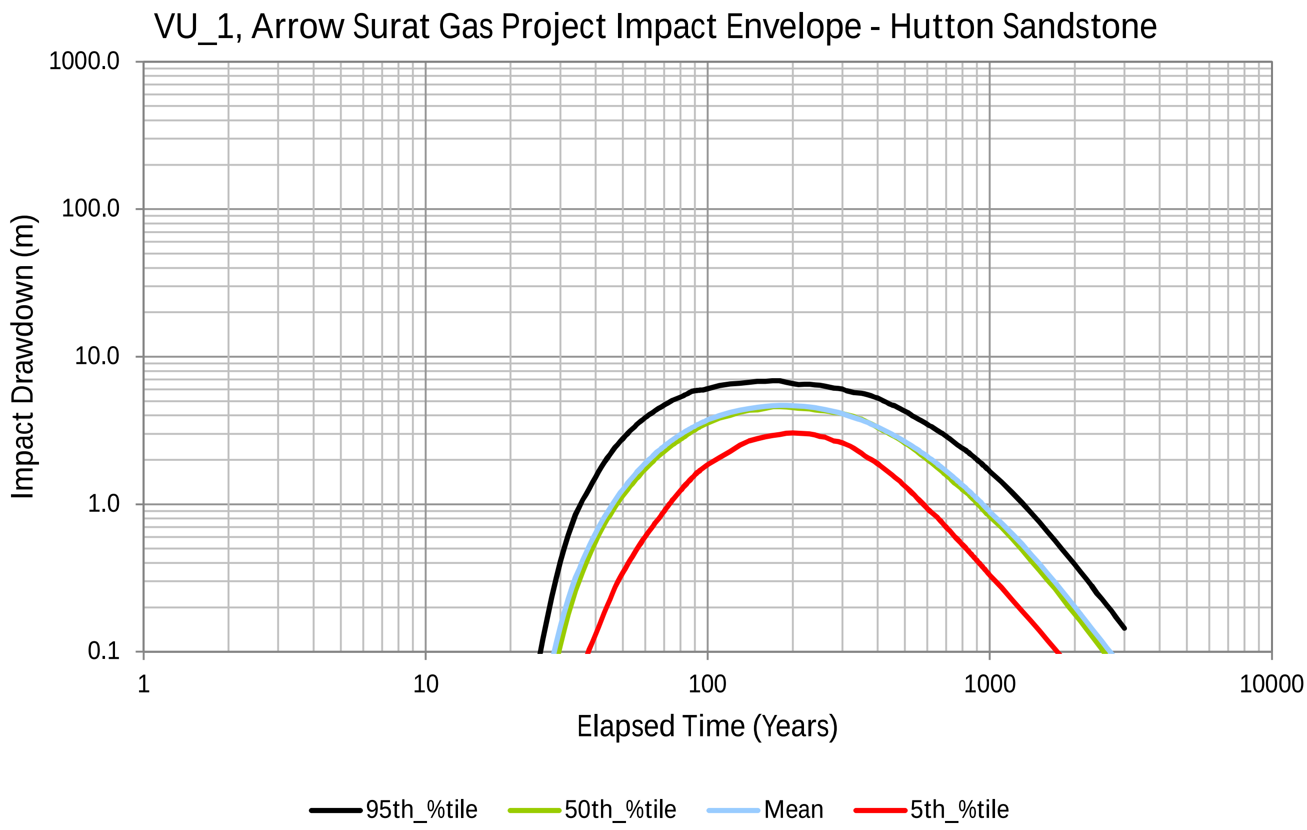


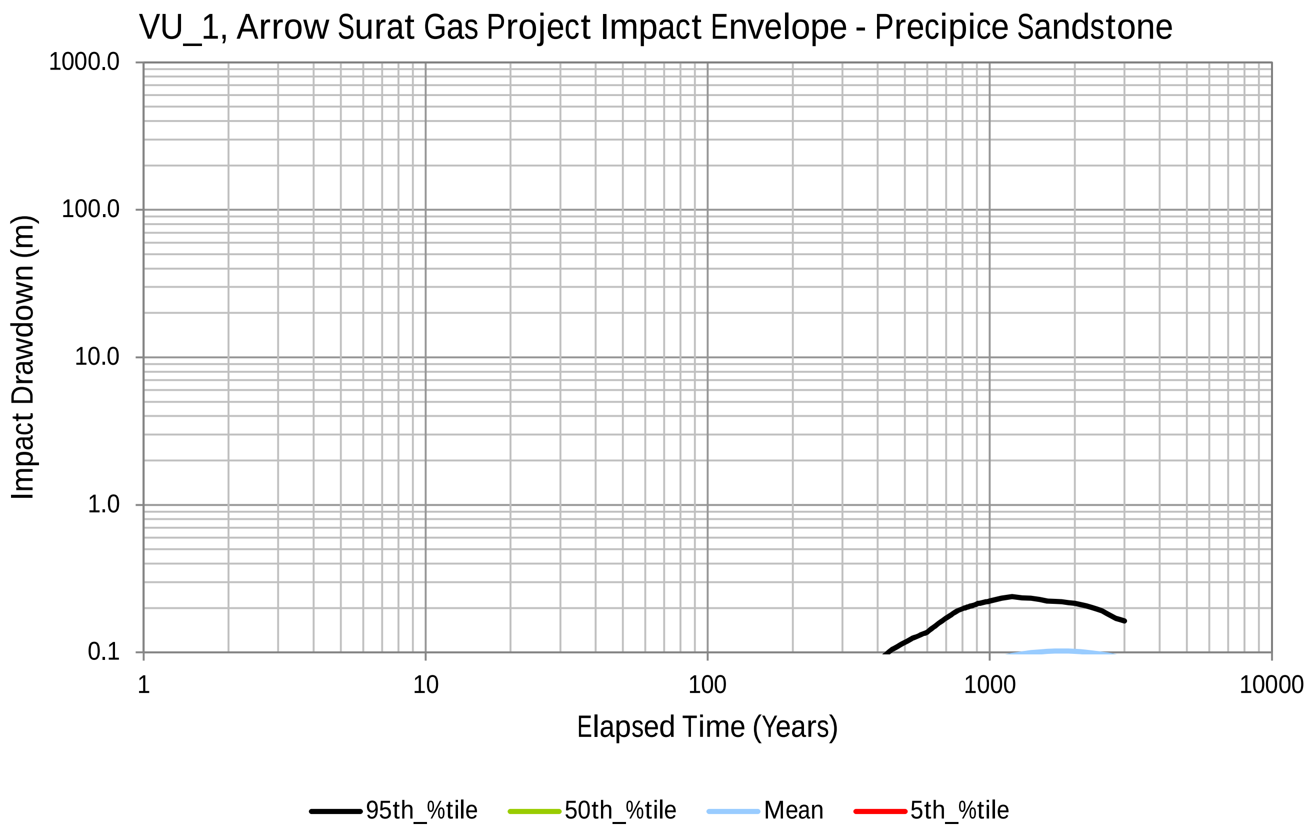
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_8)

Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 8

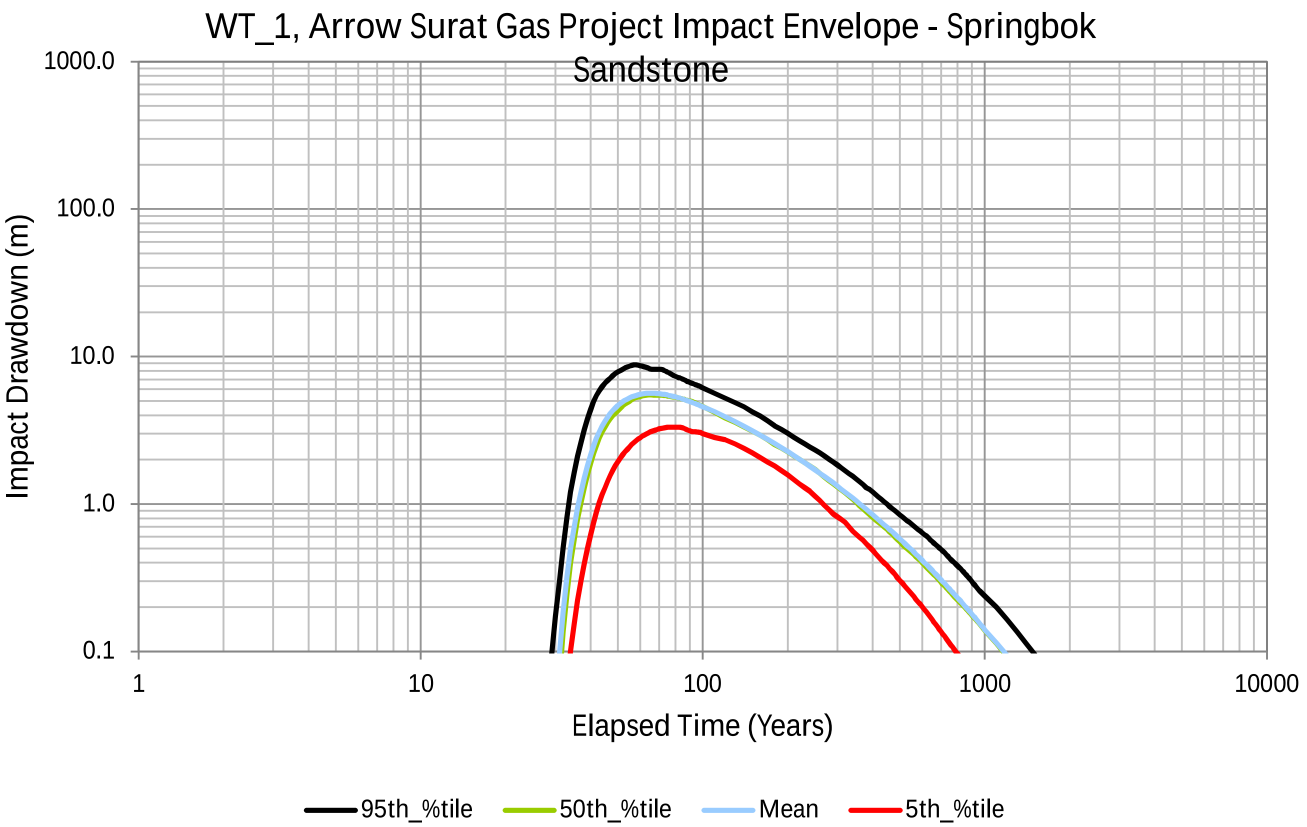


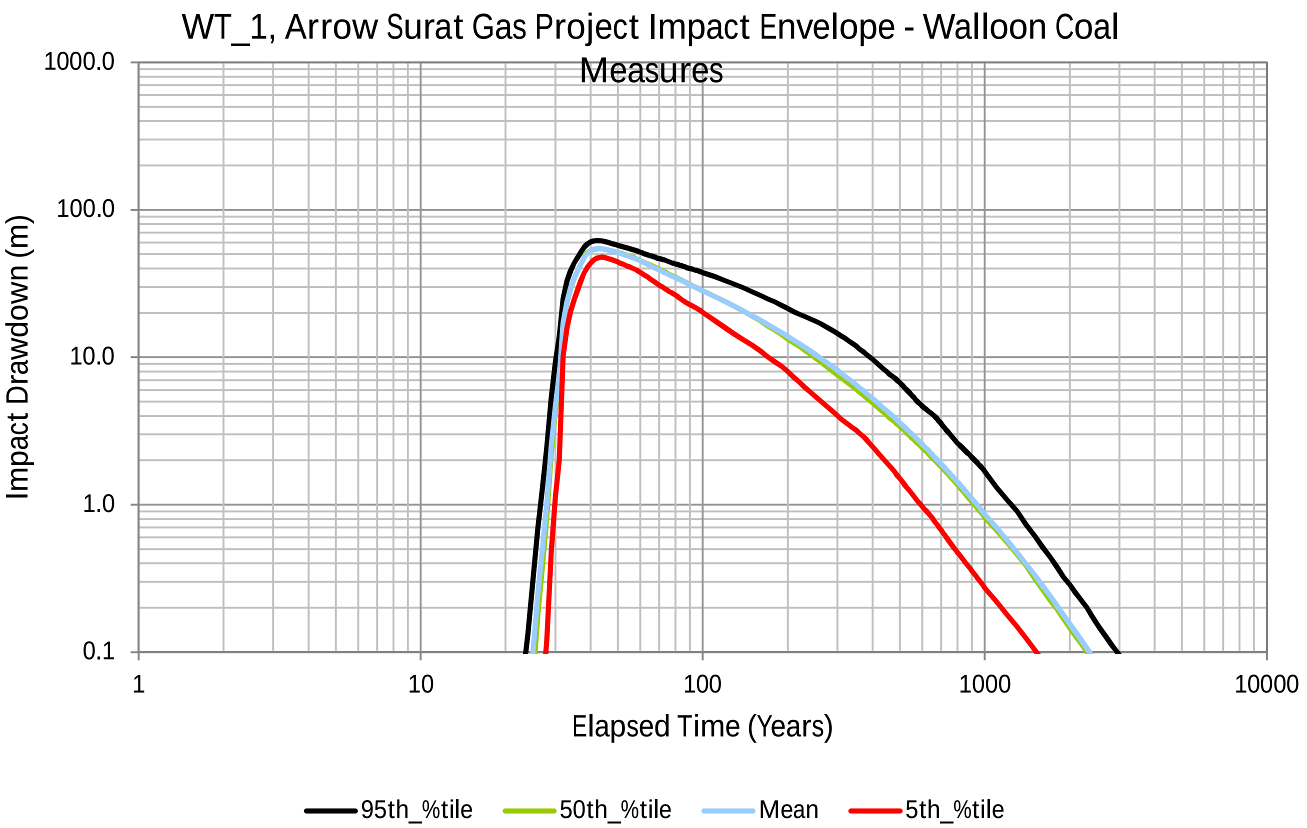



VU_1, Arrow Surat Gas Project Impact Envelope - Hutton Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

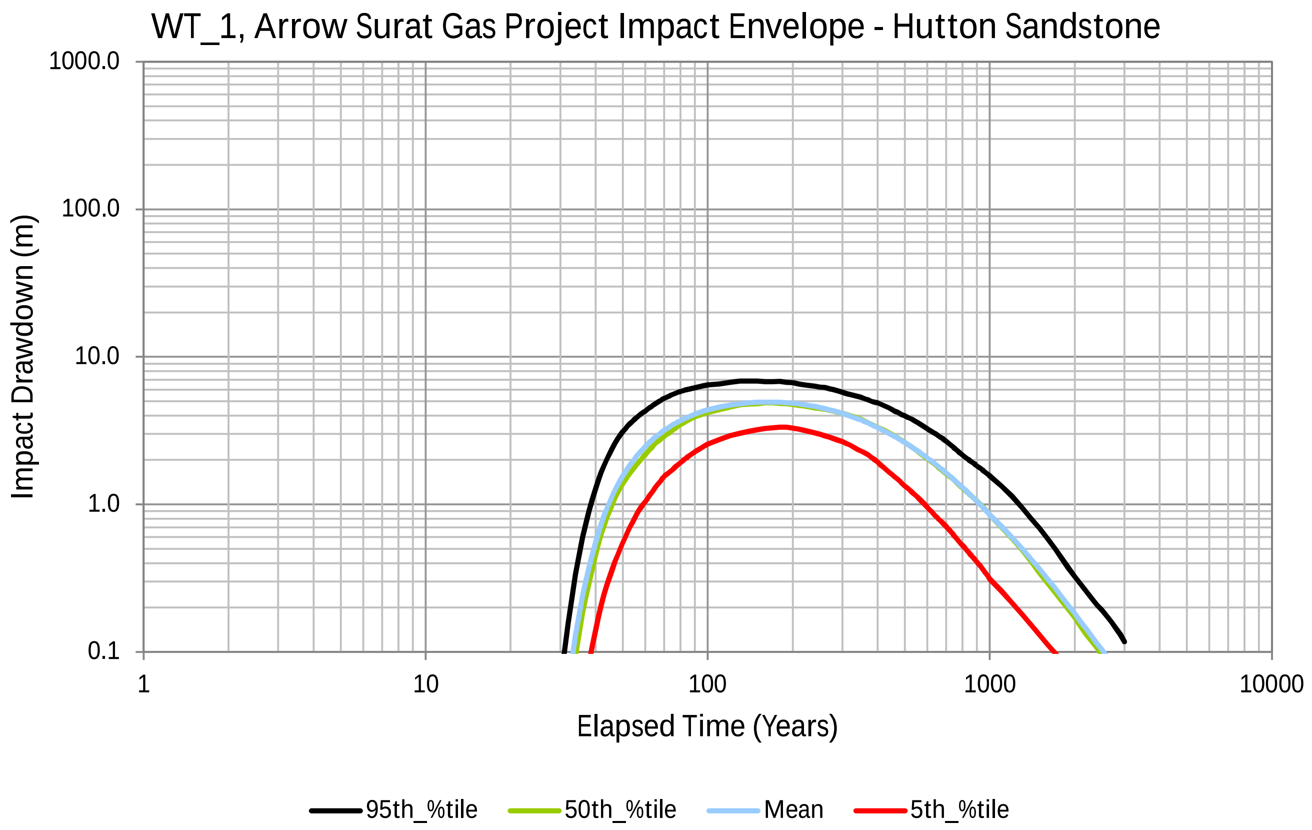

VU_1, Arrow Surat Gas Project Impact Envelope - Precipice Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

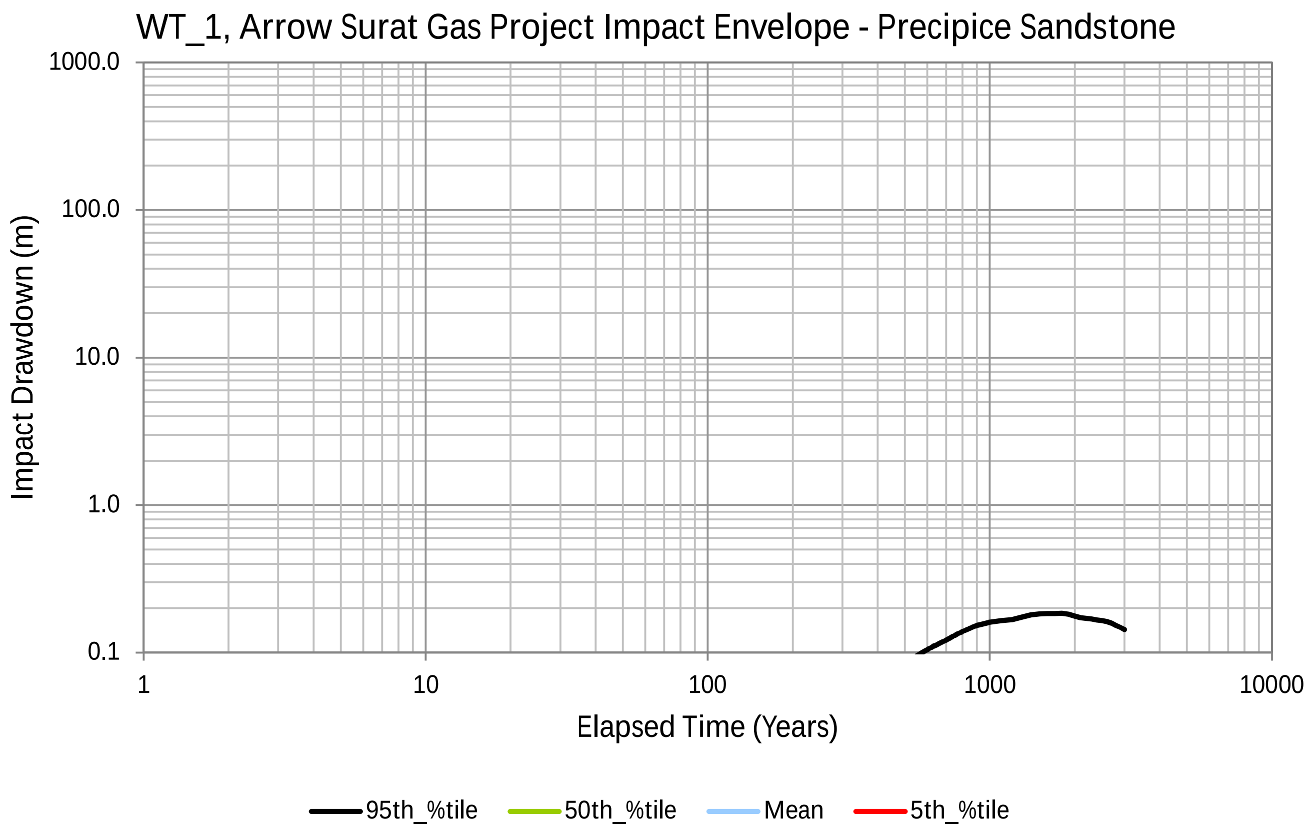
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 8





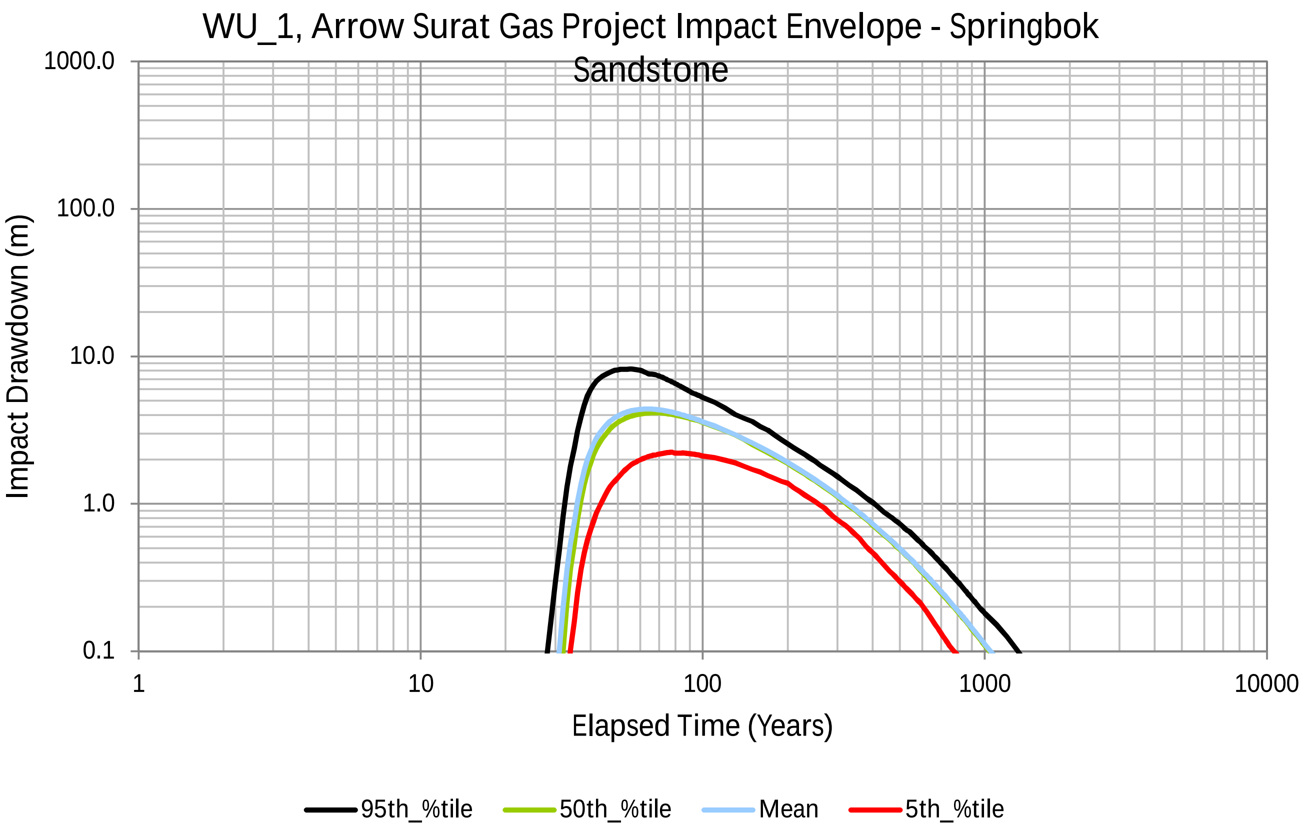
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 8

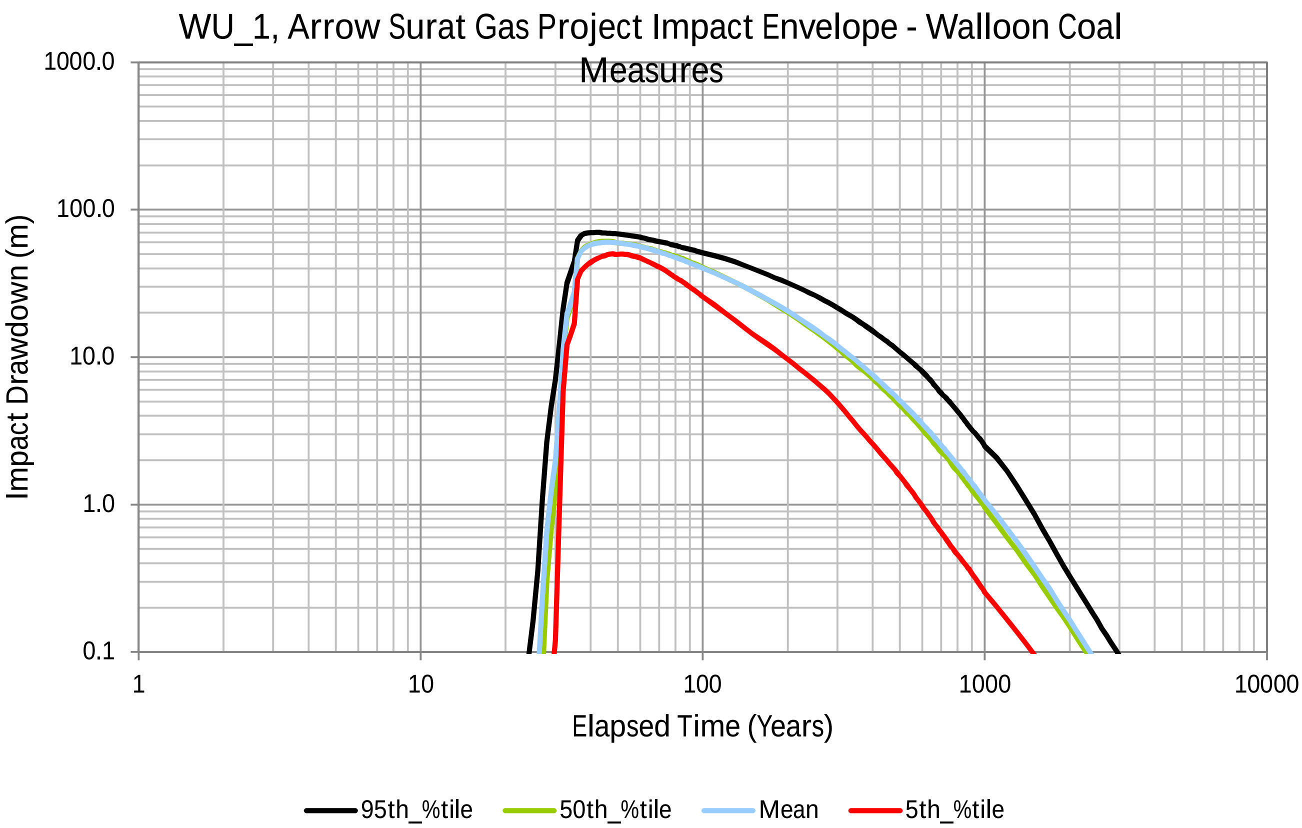




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_8)

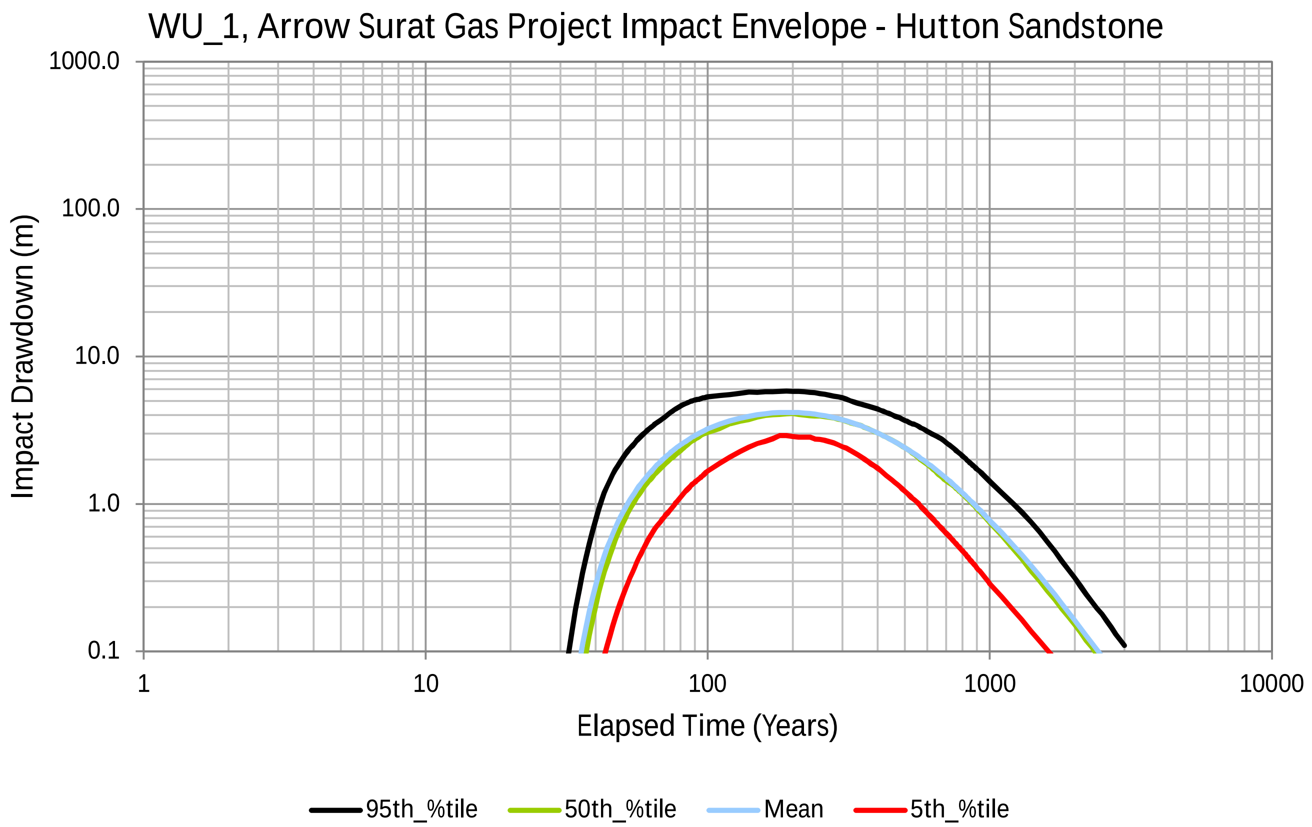
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 8

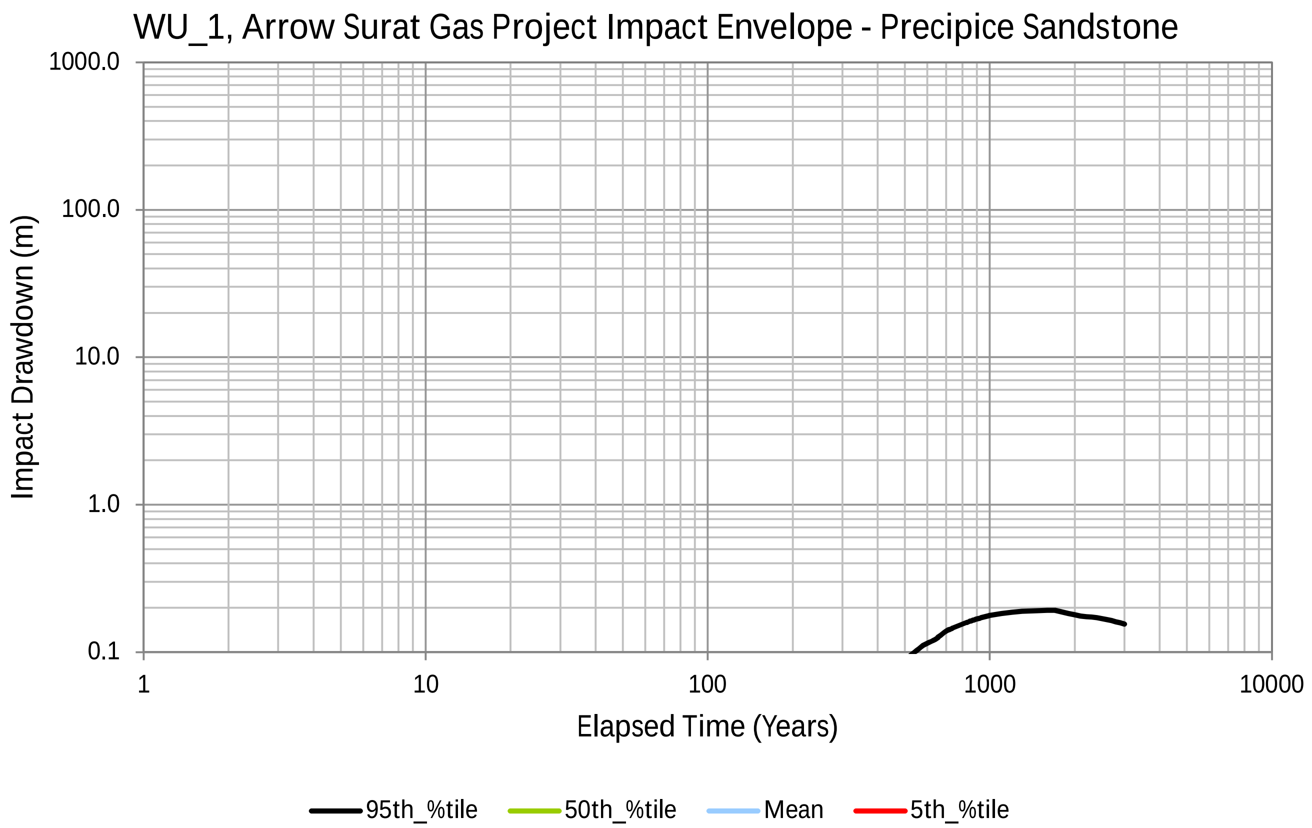




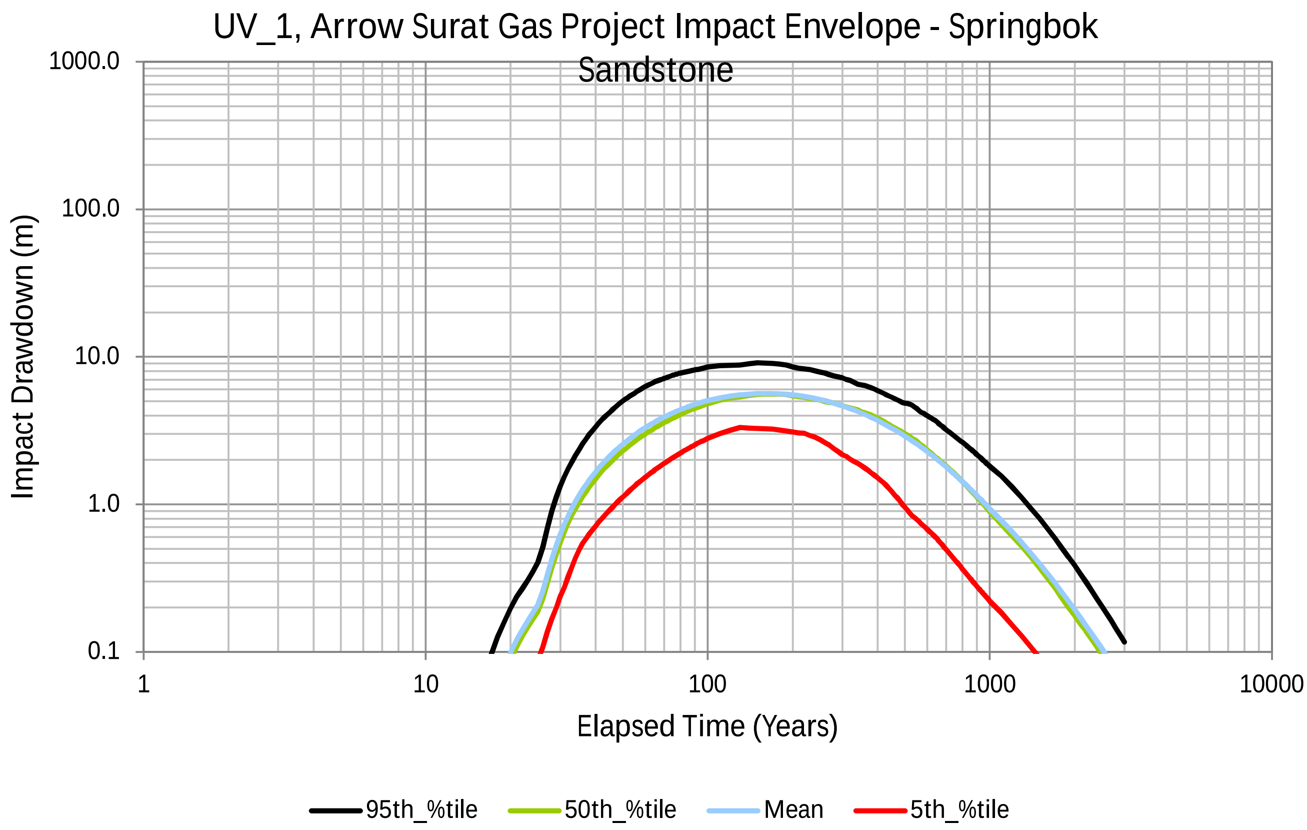
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_8)

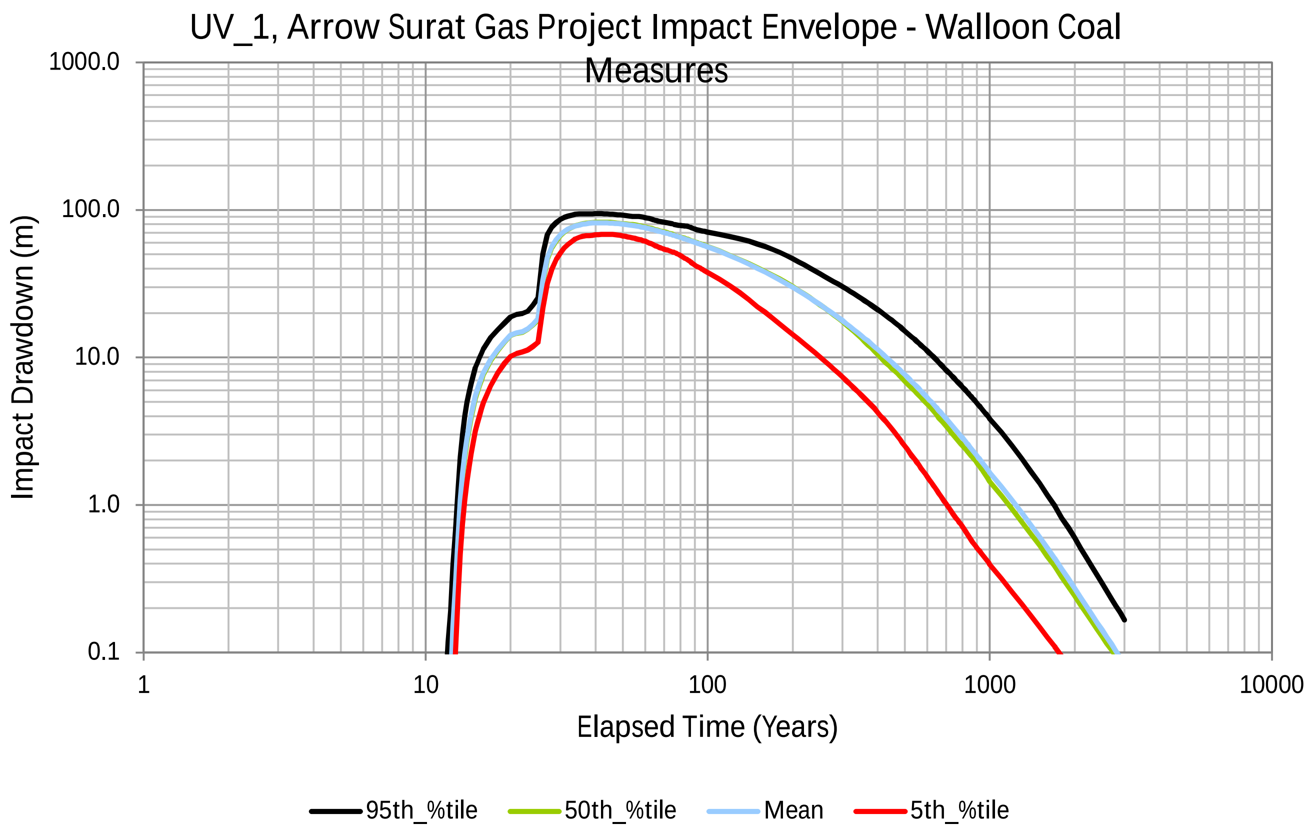
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 8

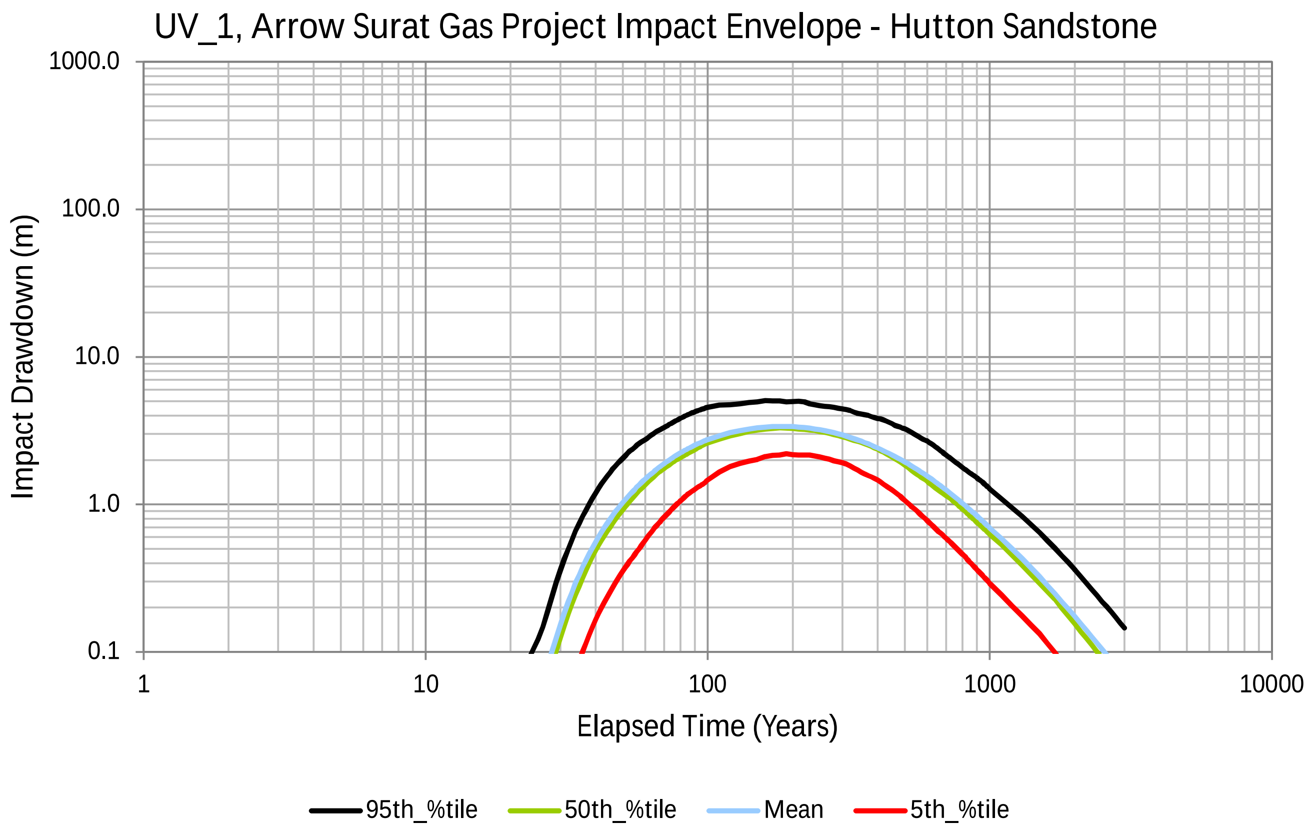


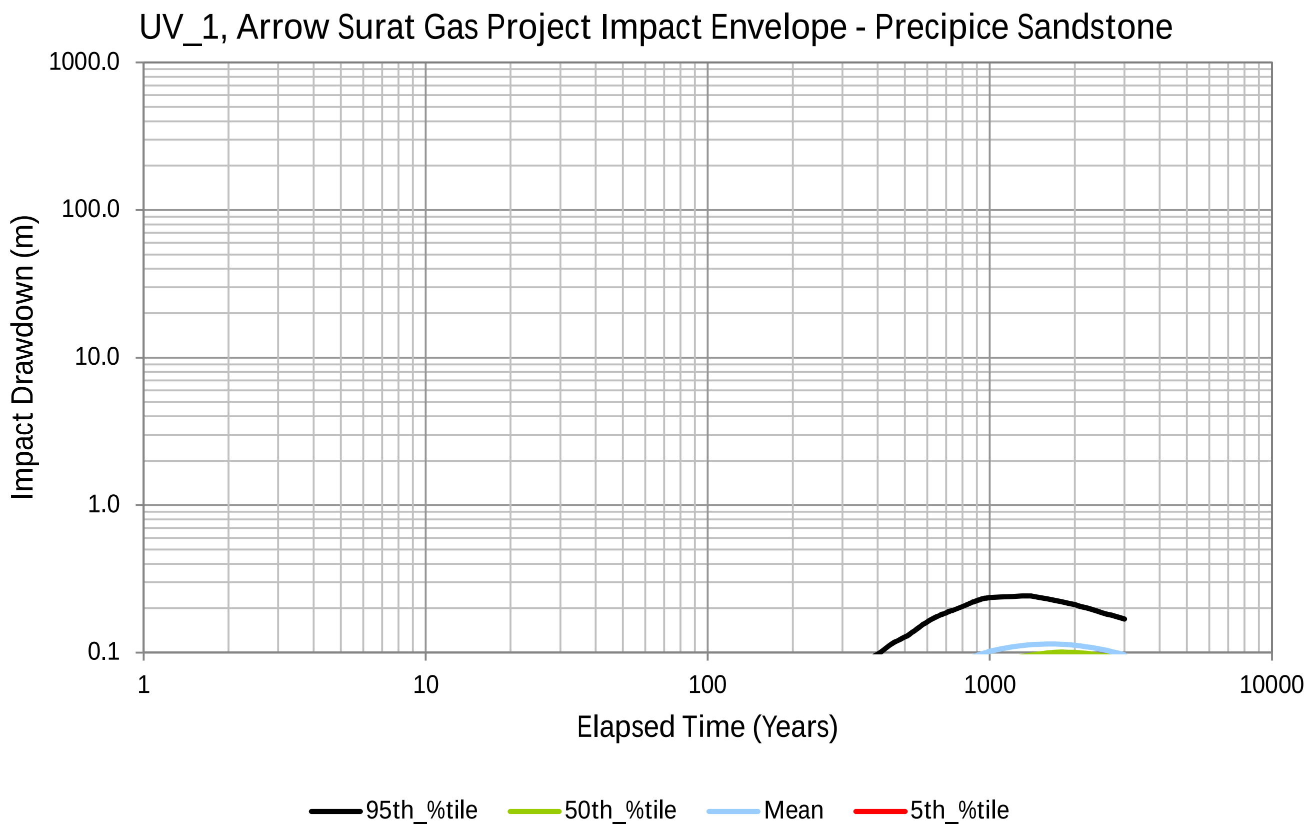


Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9

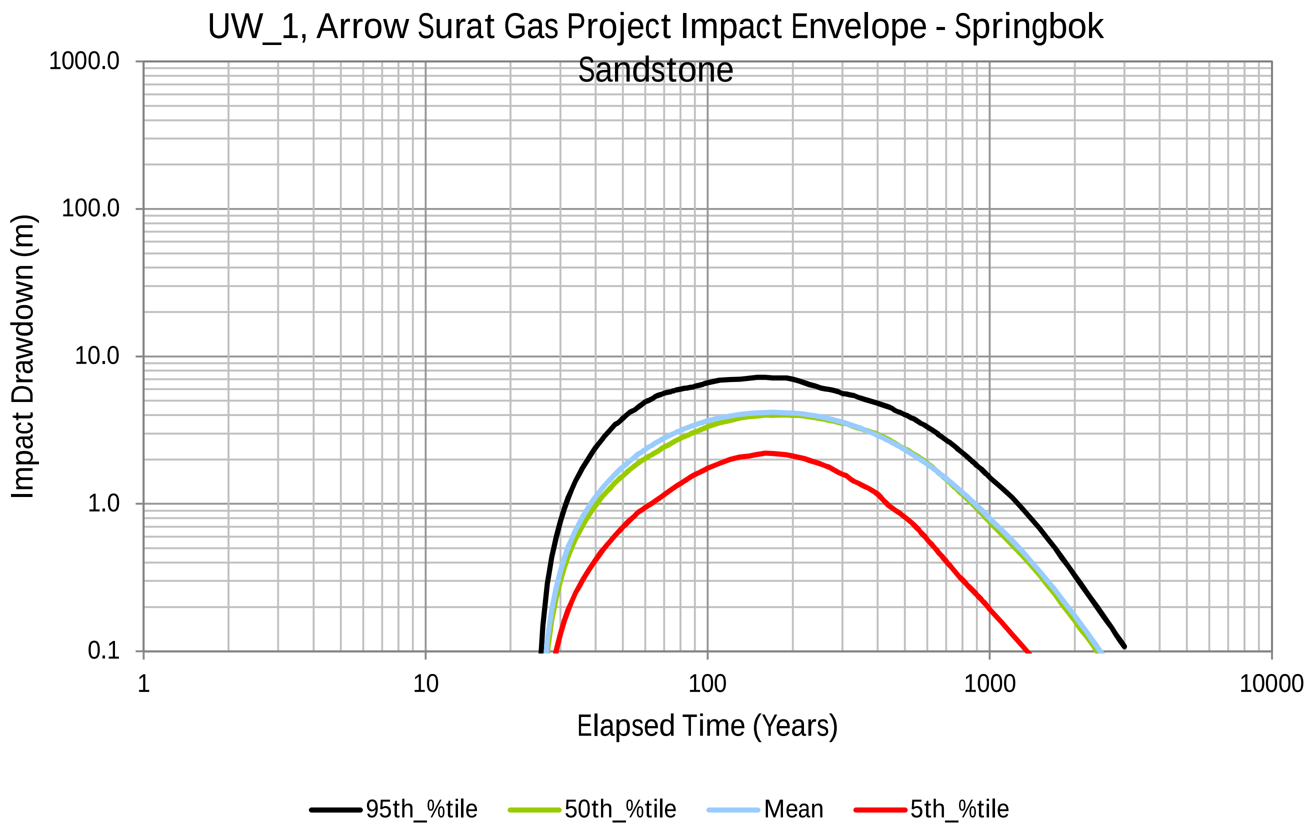


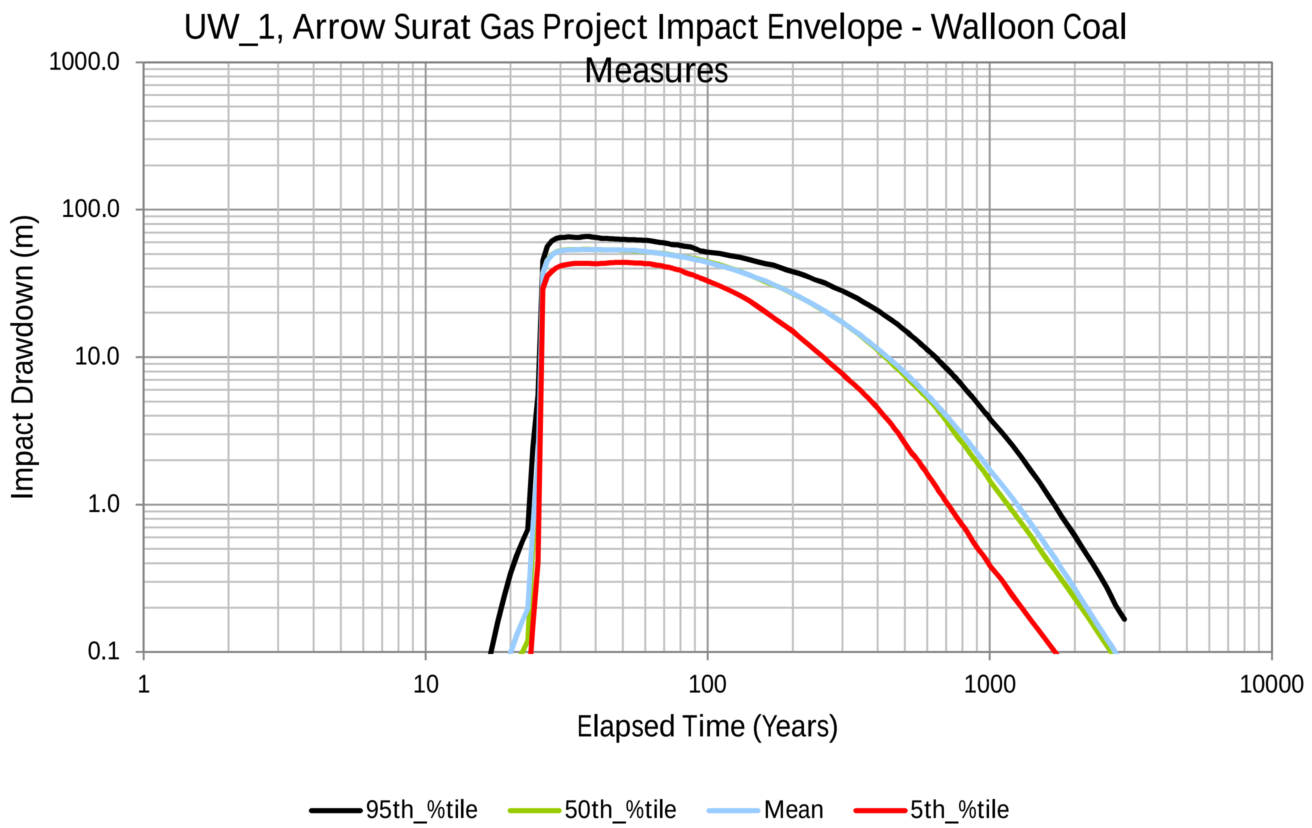



UV_1, Arrow Surat Gas Project Impact Envelope - Hutton Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

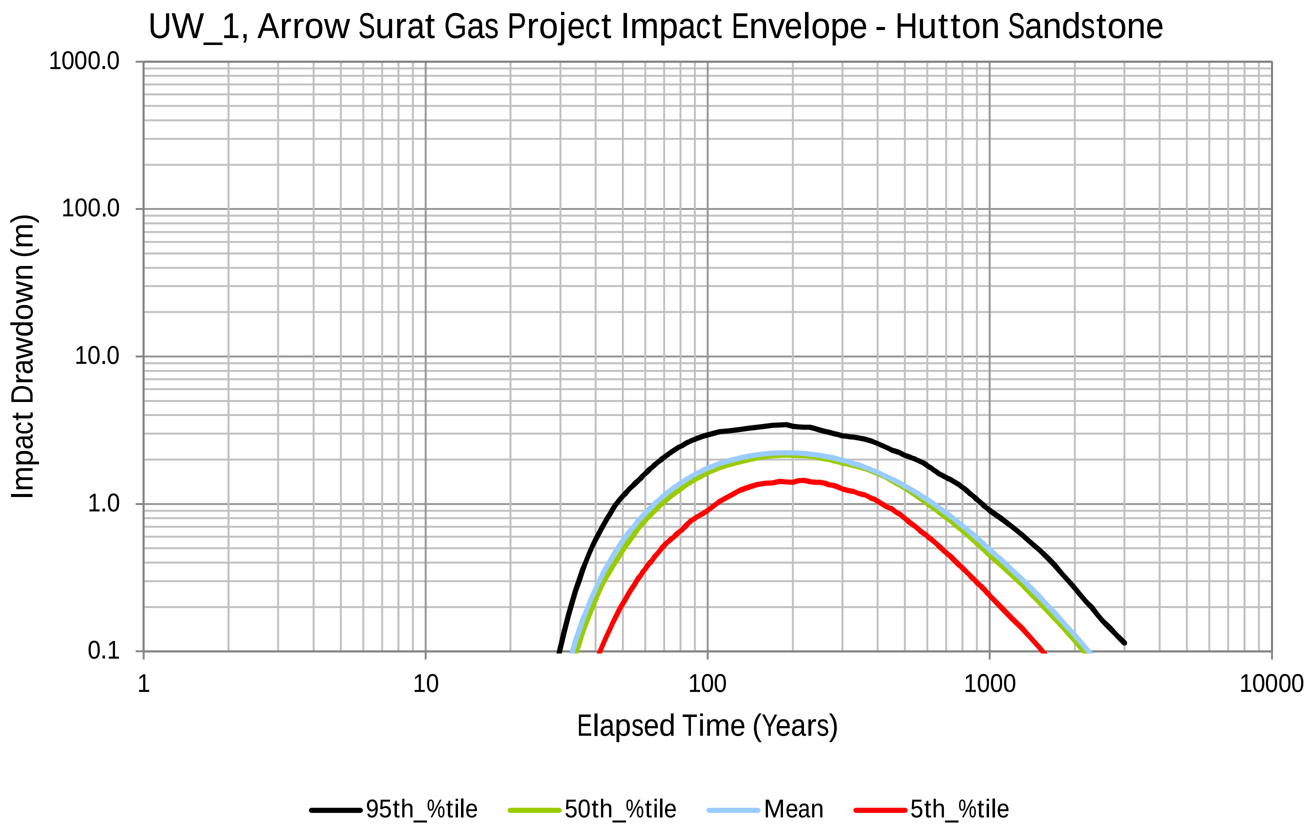

UV_1, Arrow Surat Gas Project Impact Envelope - Precipice Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

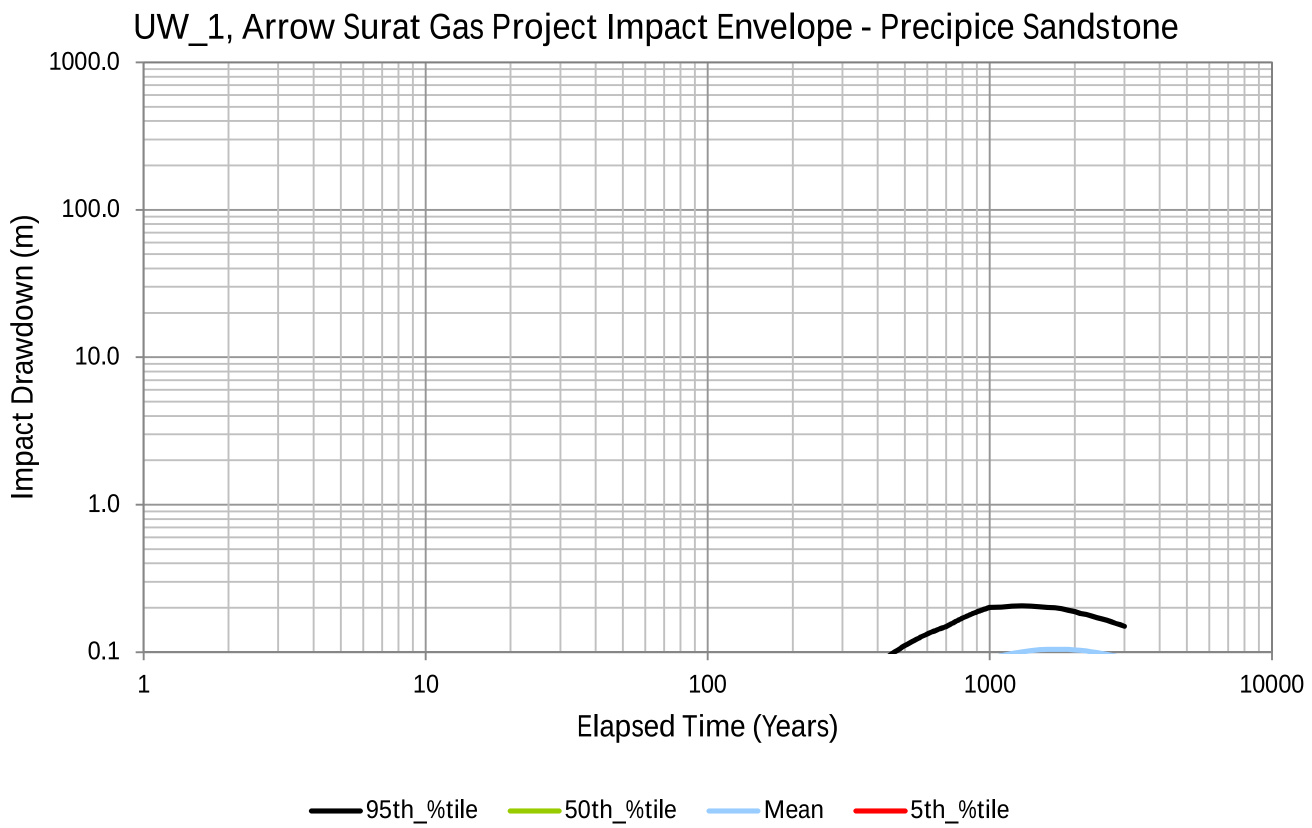
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9



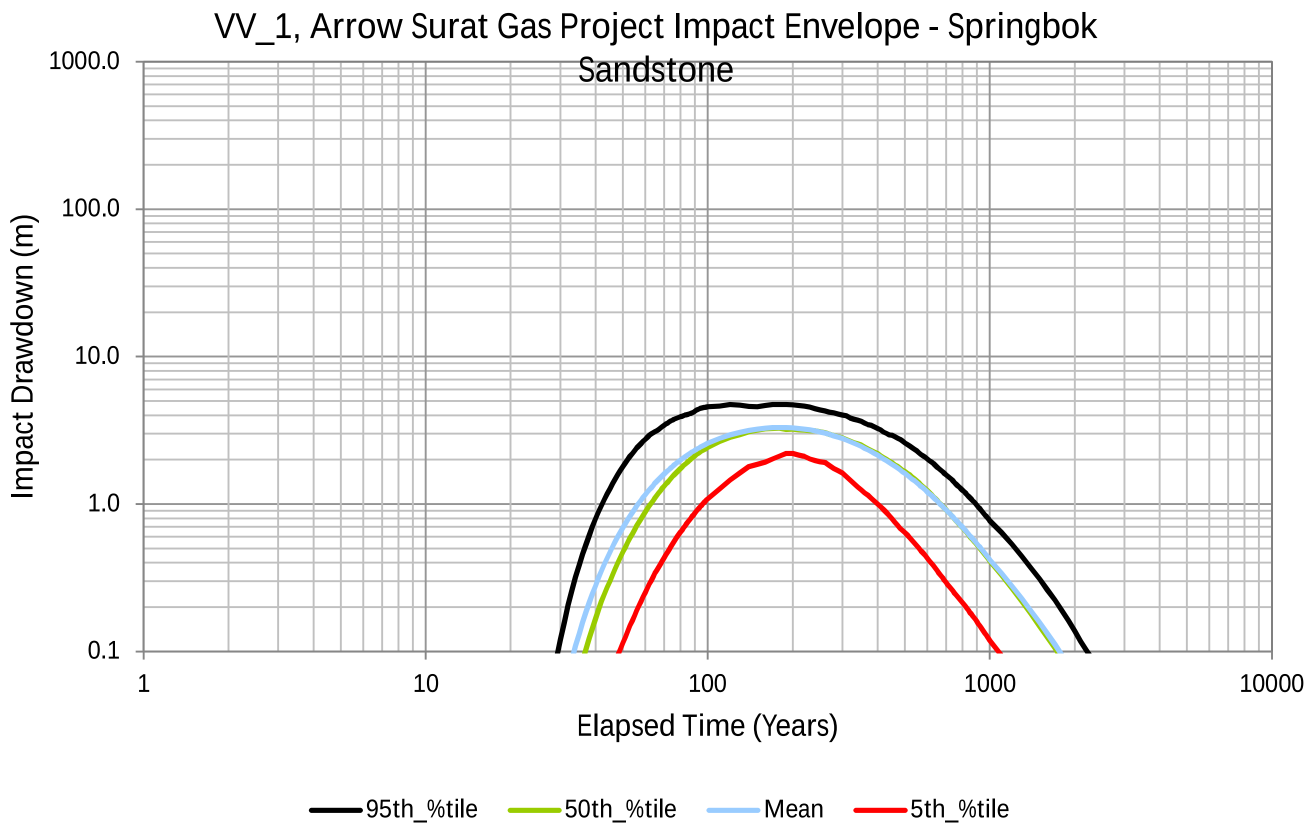


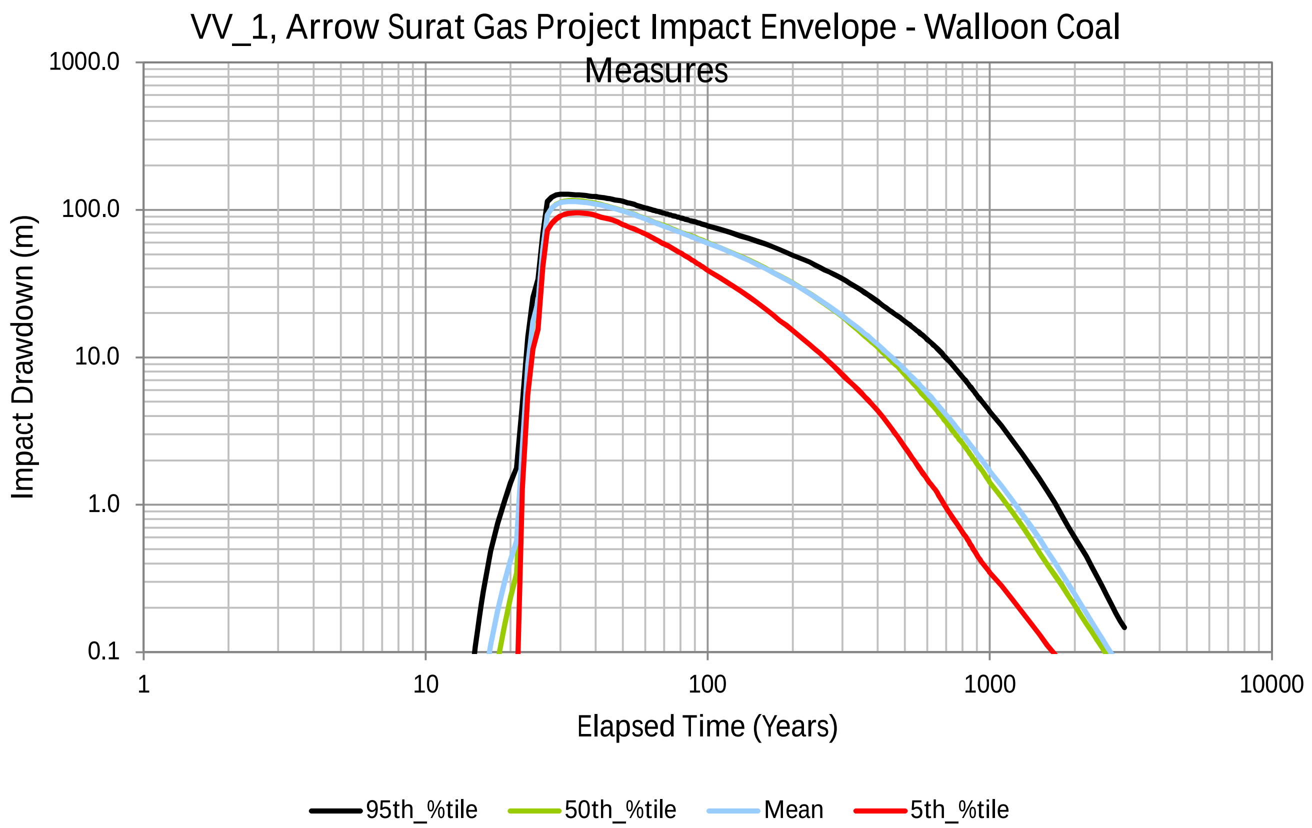
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9





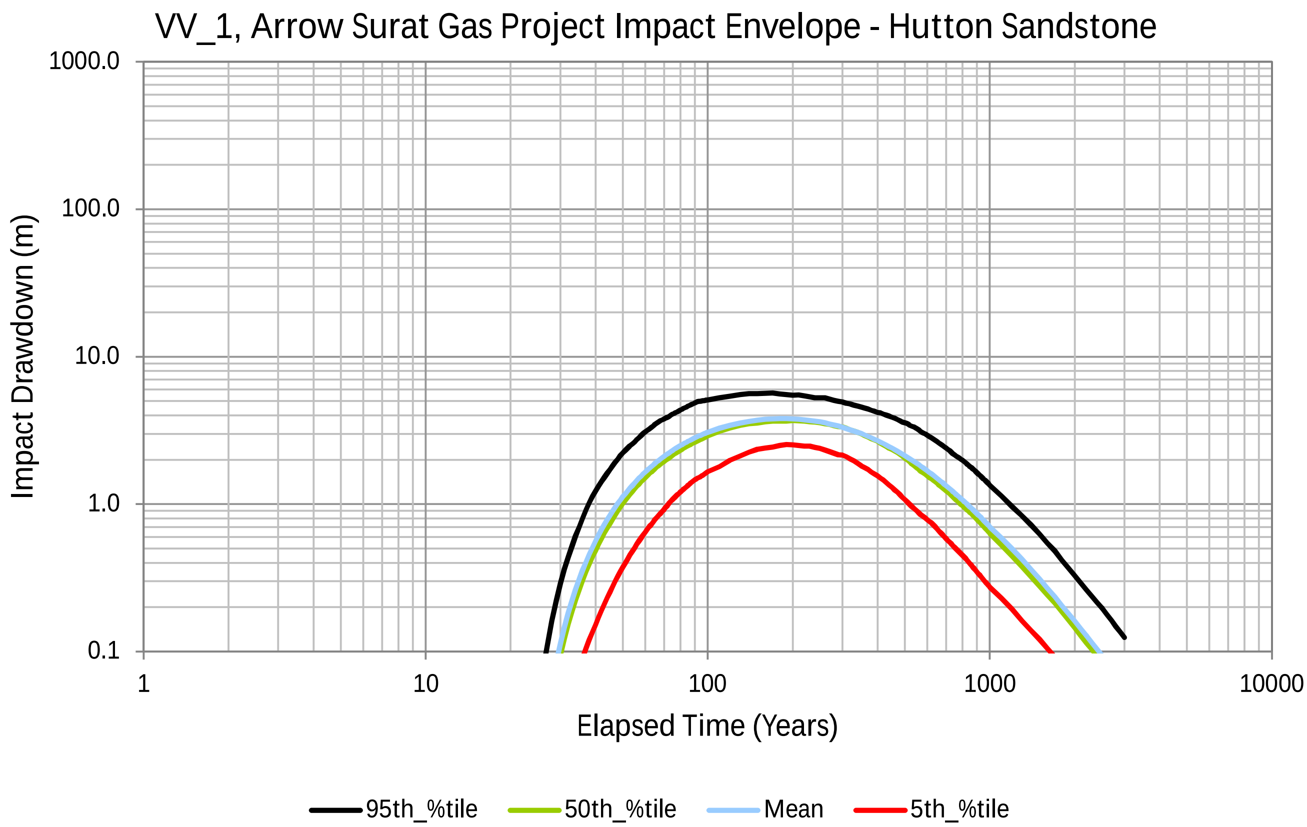
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9

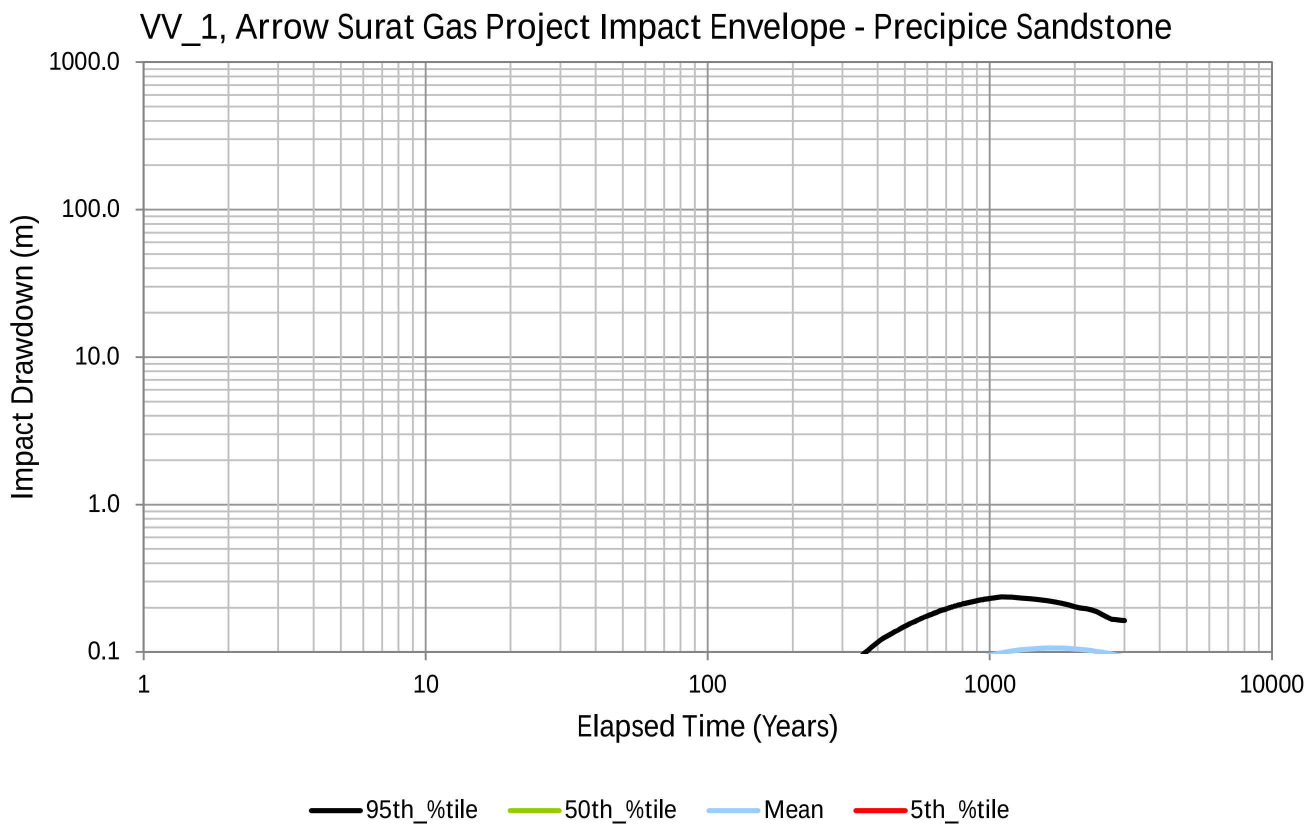




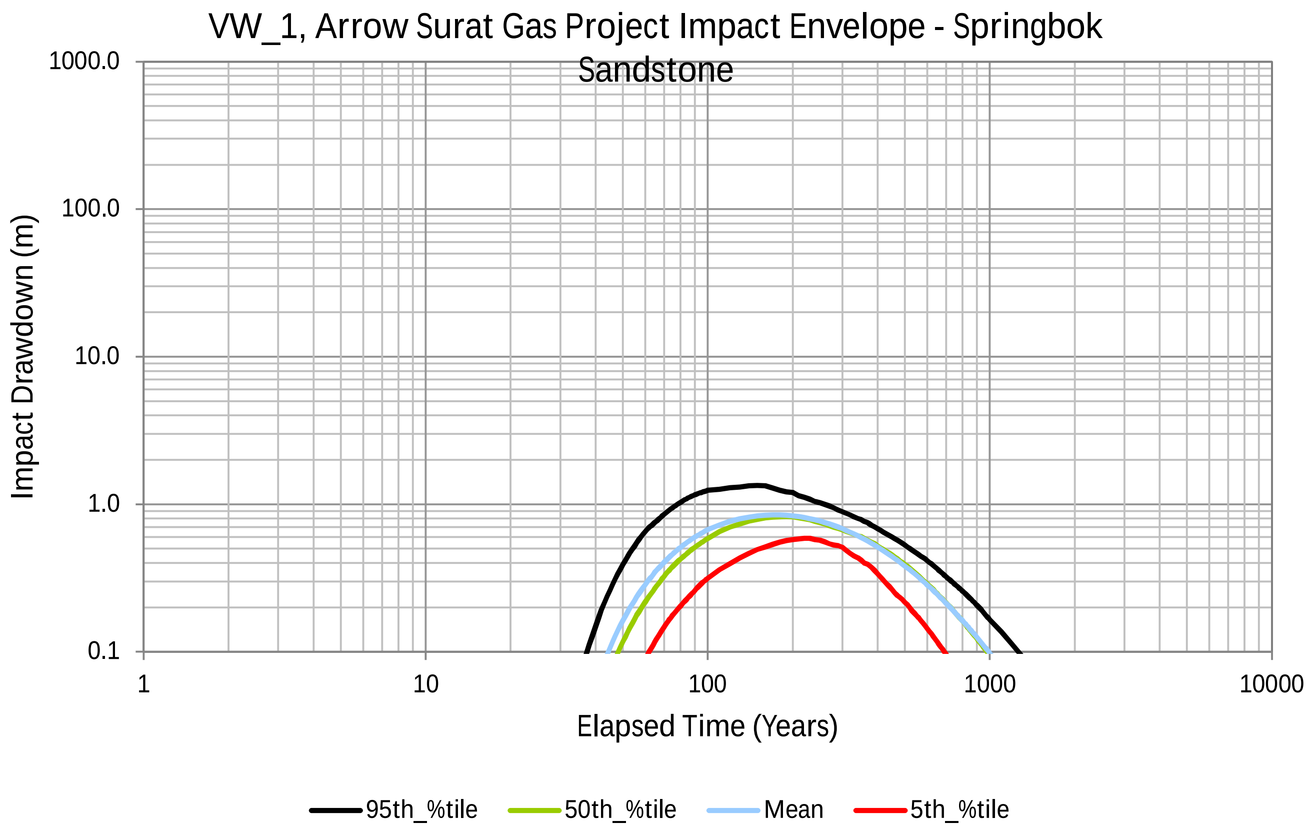
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_9)

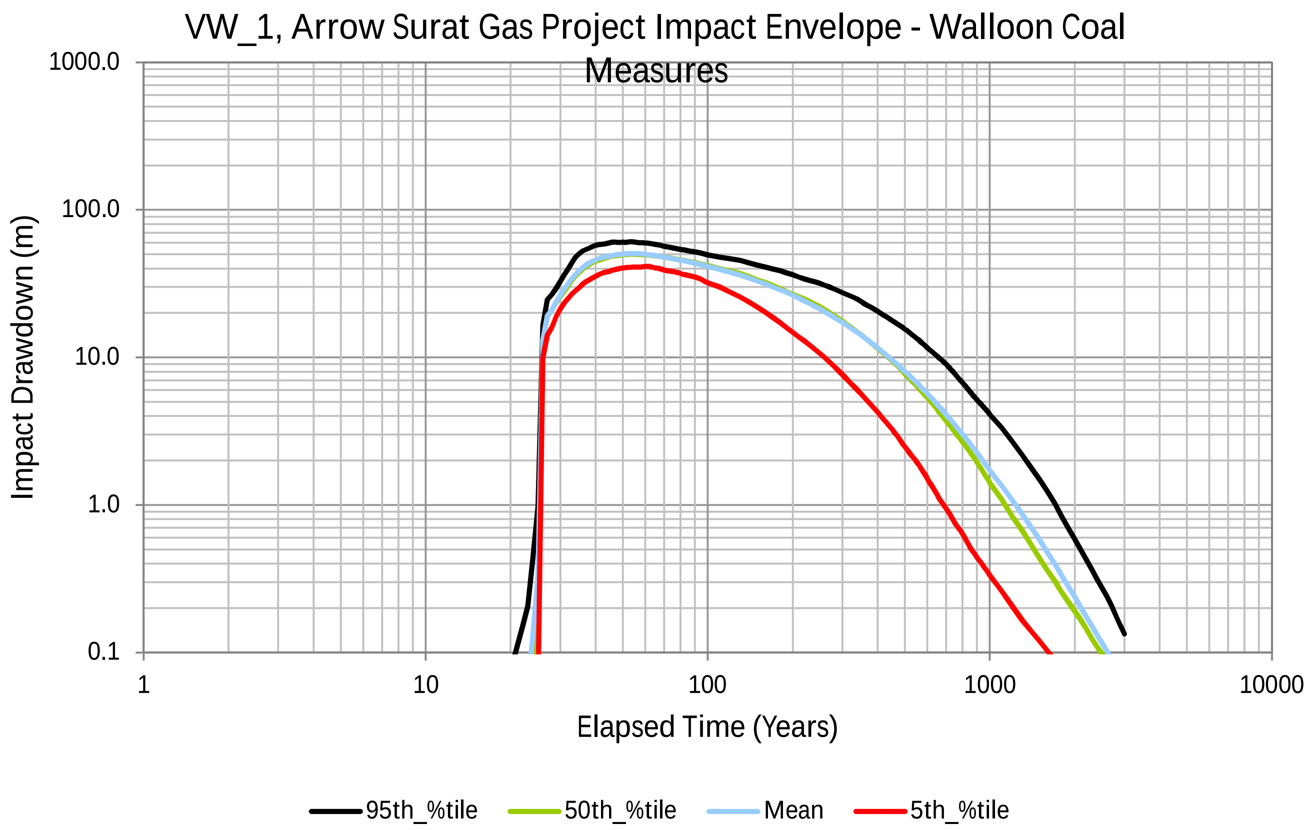
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9



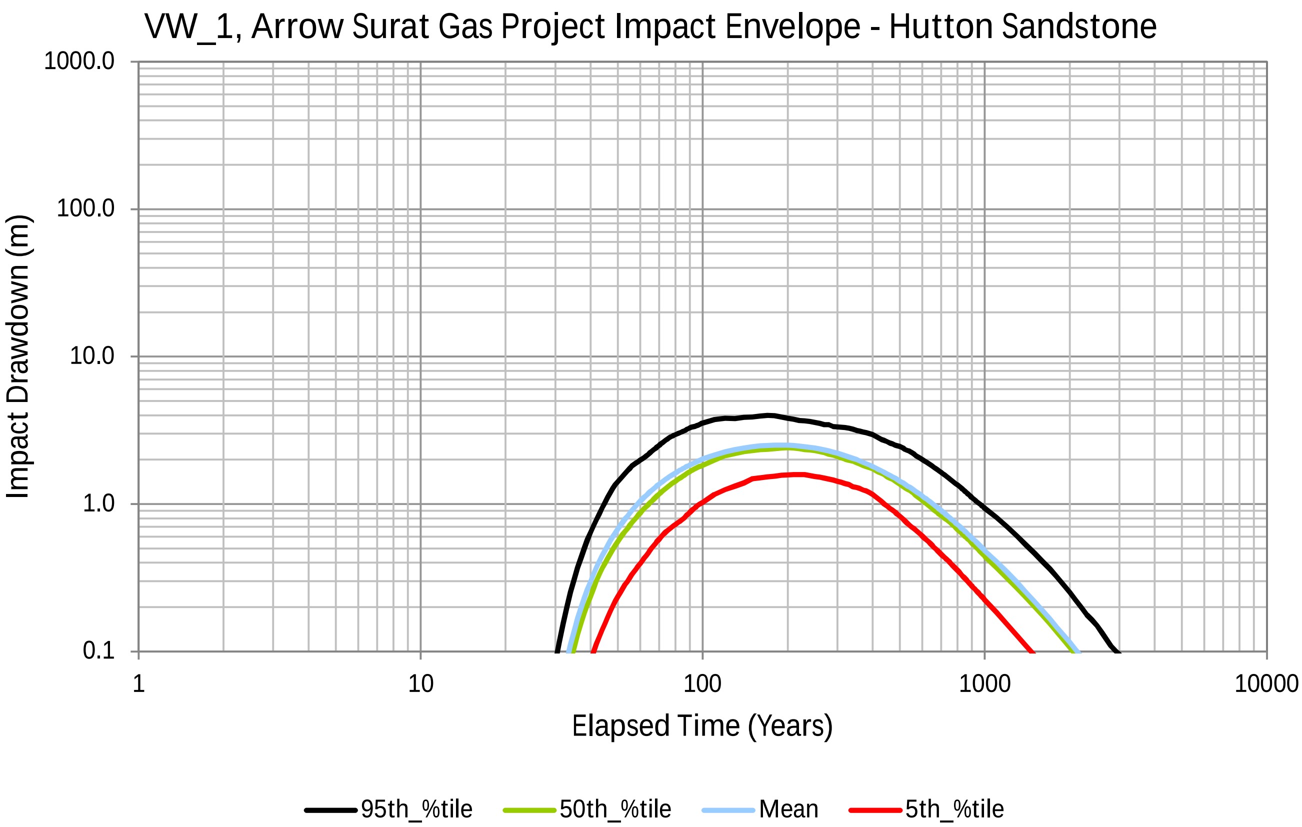


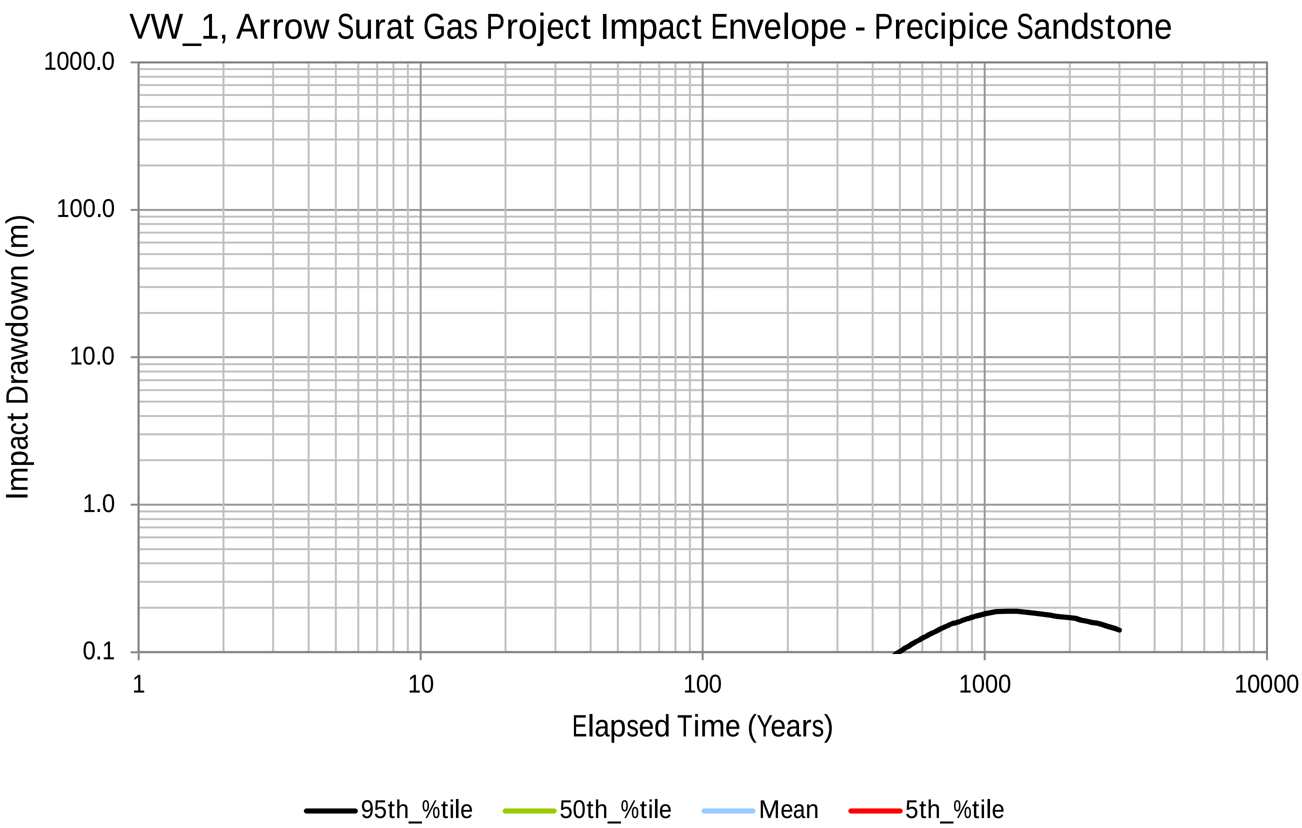
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9



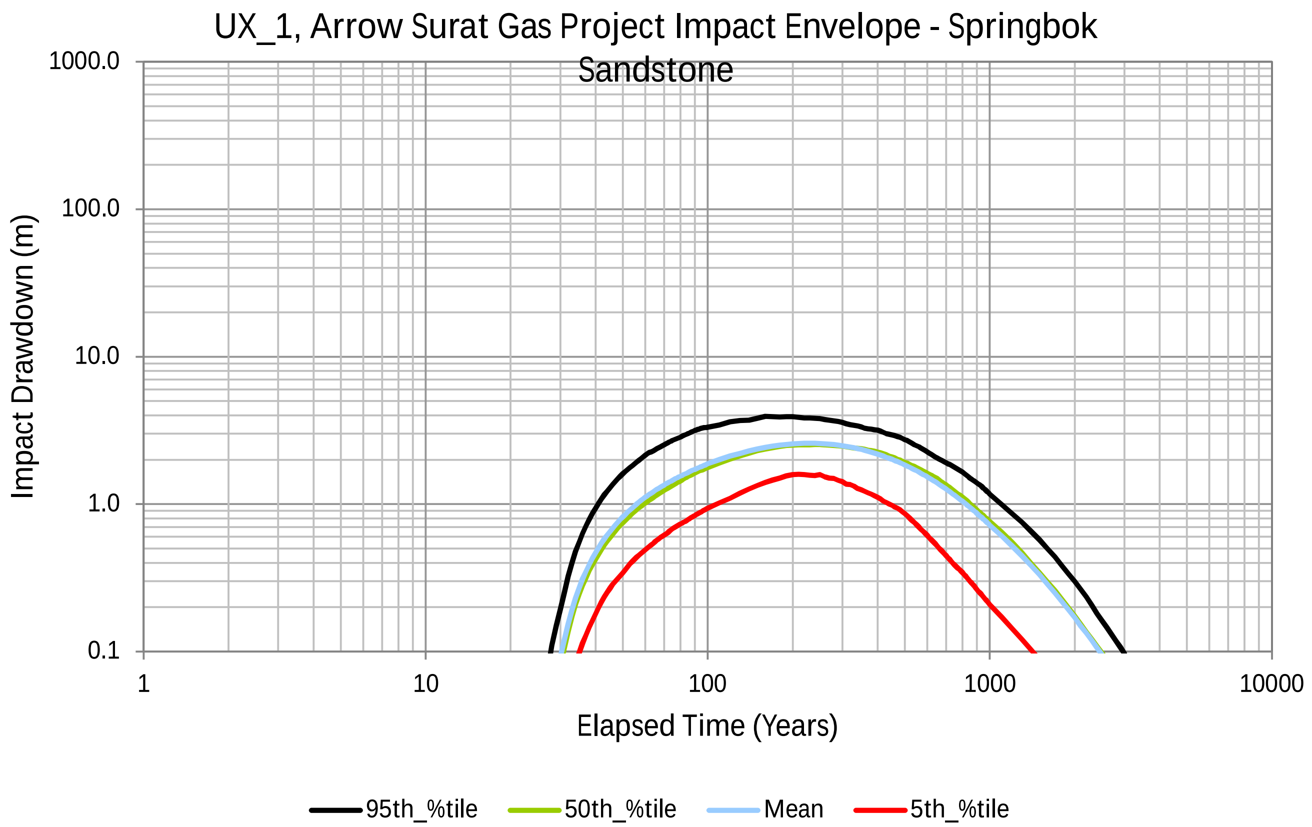


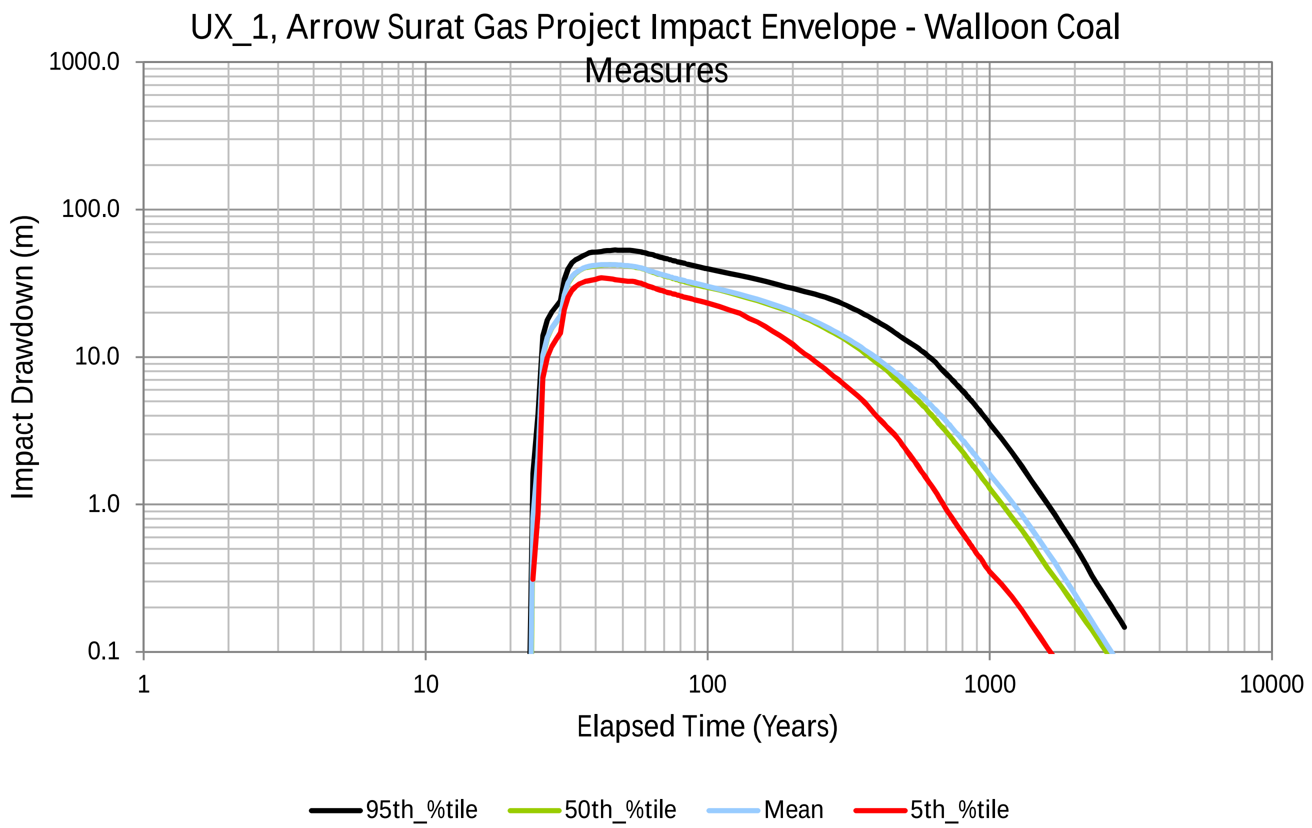
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9





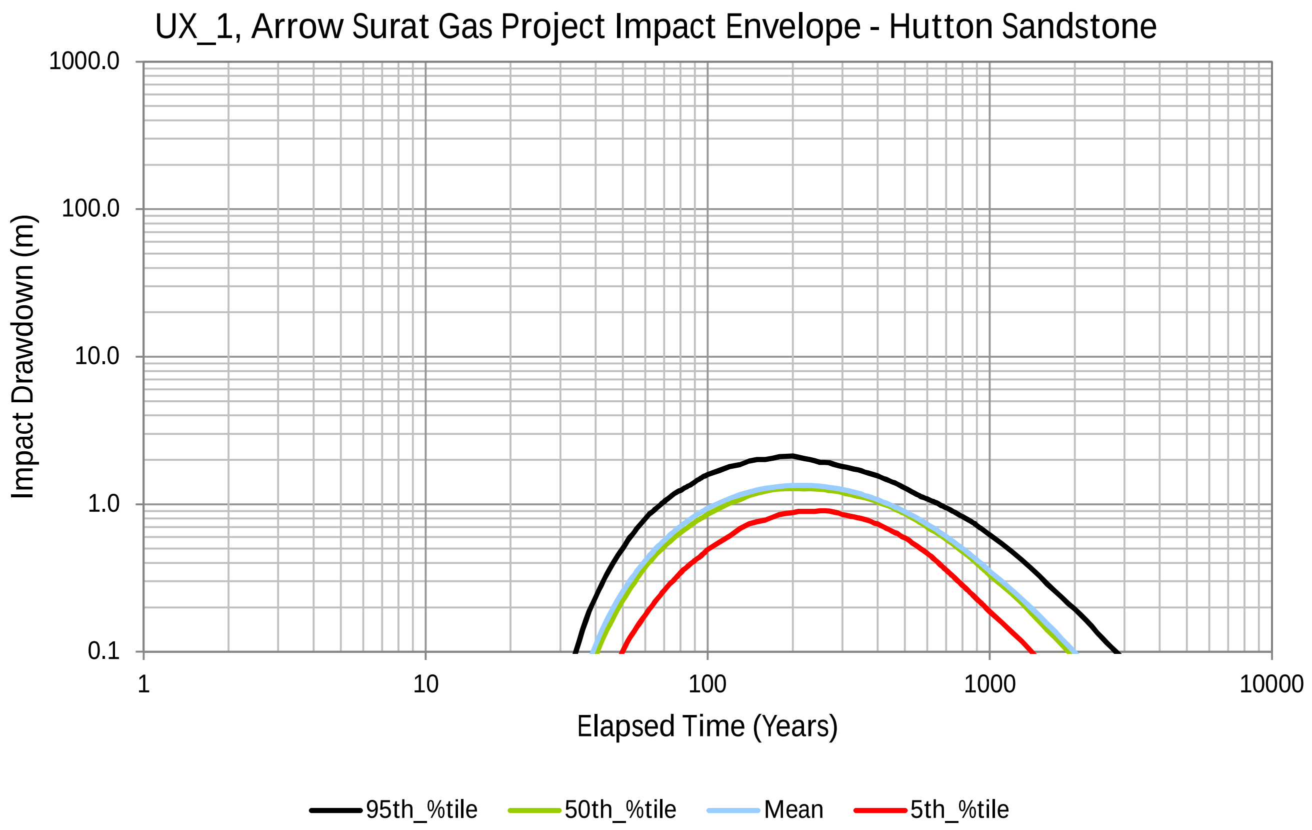
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9

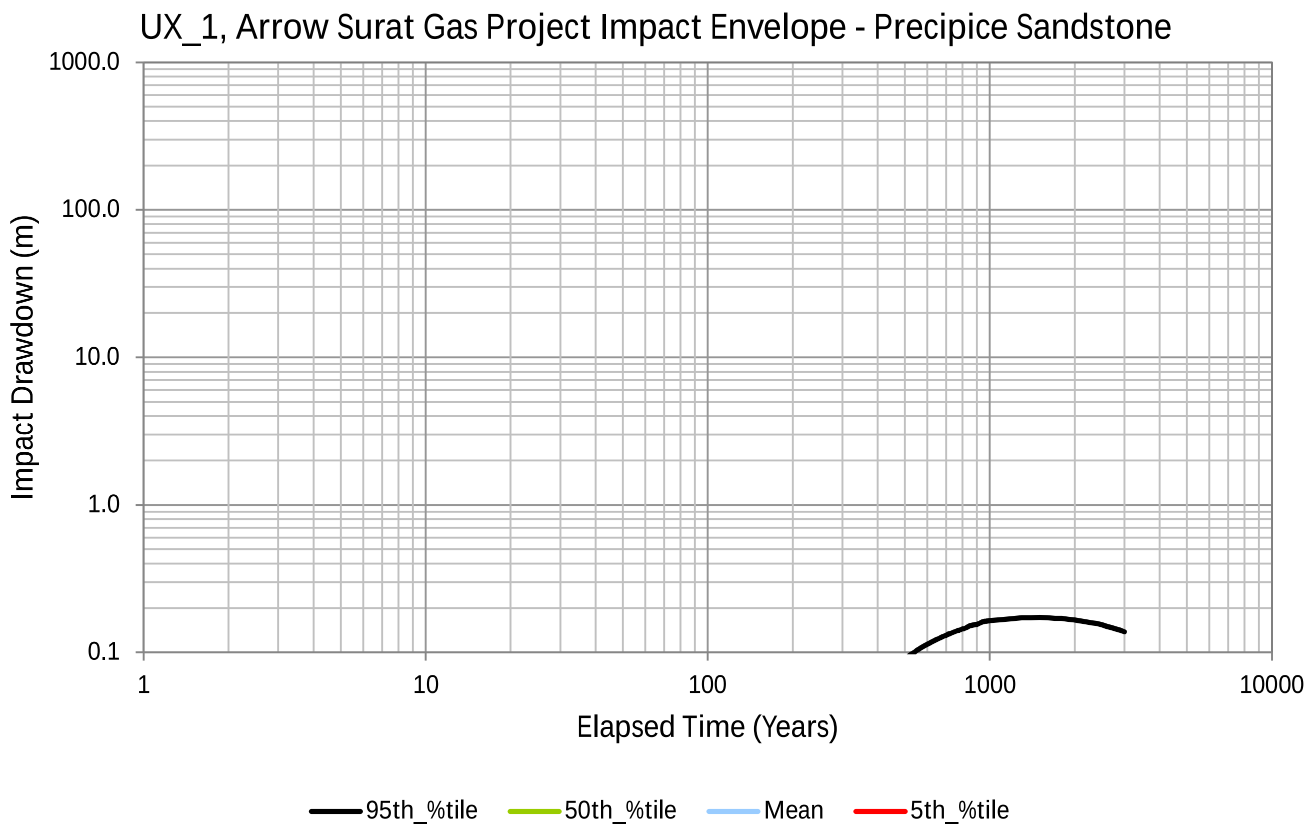




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_9)

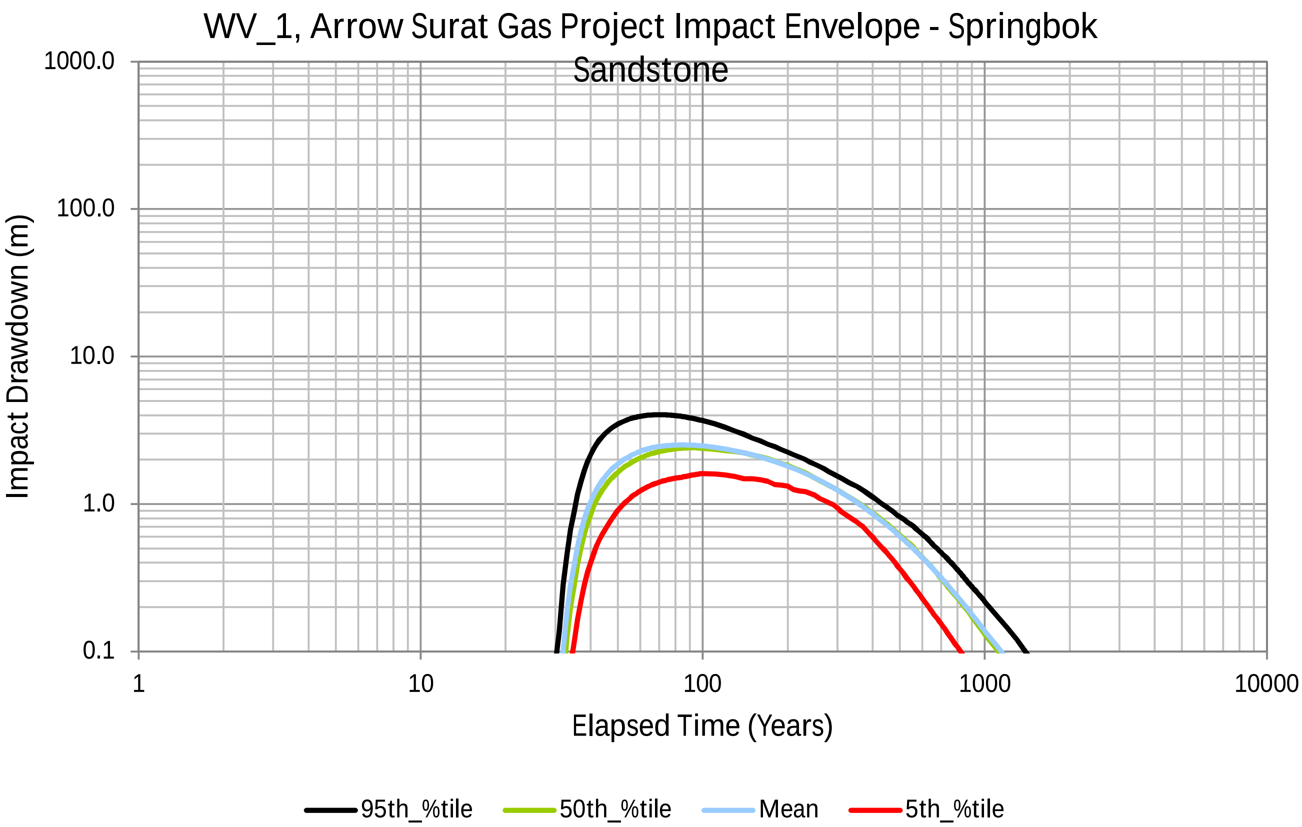
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9

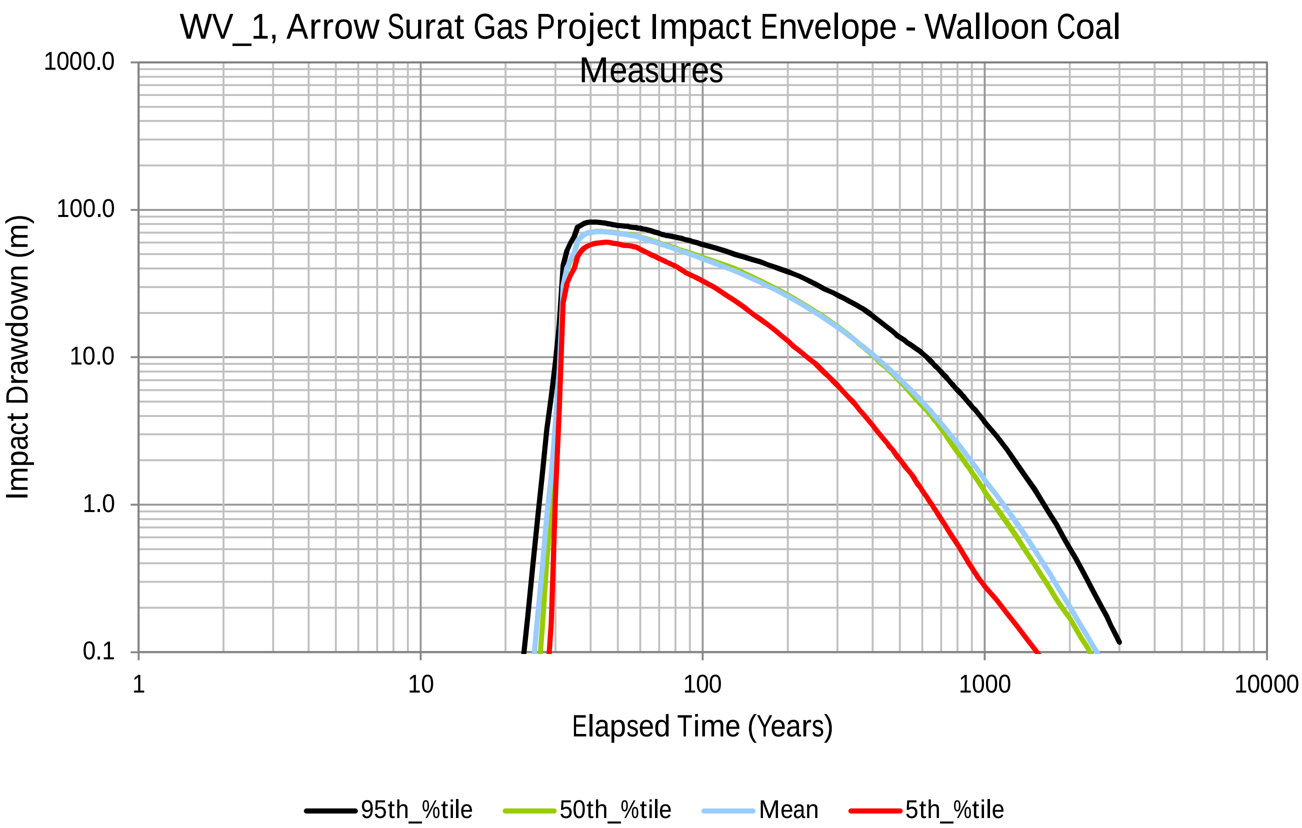




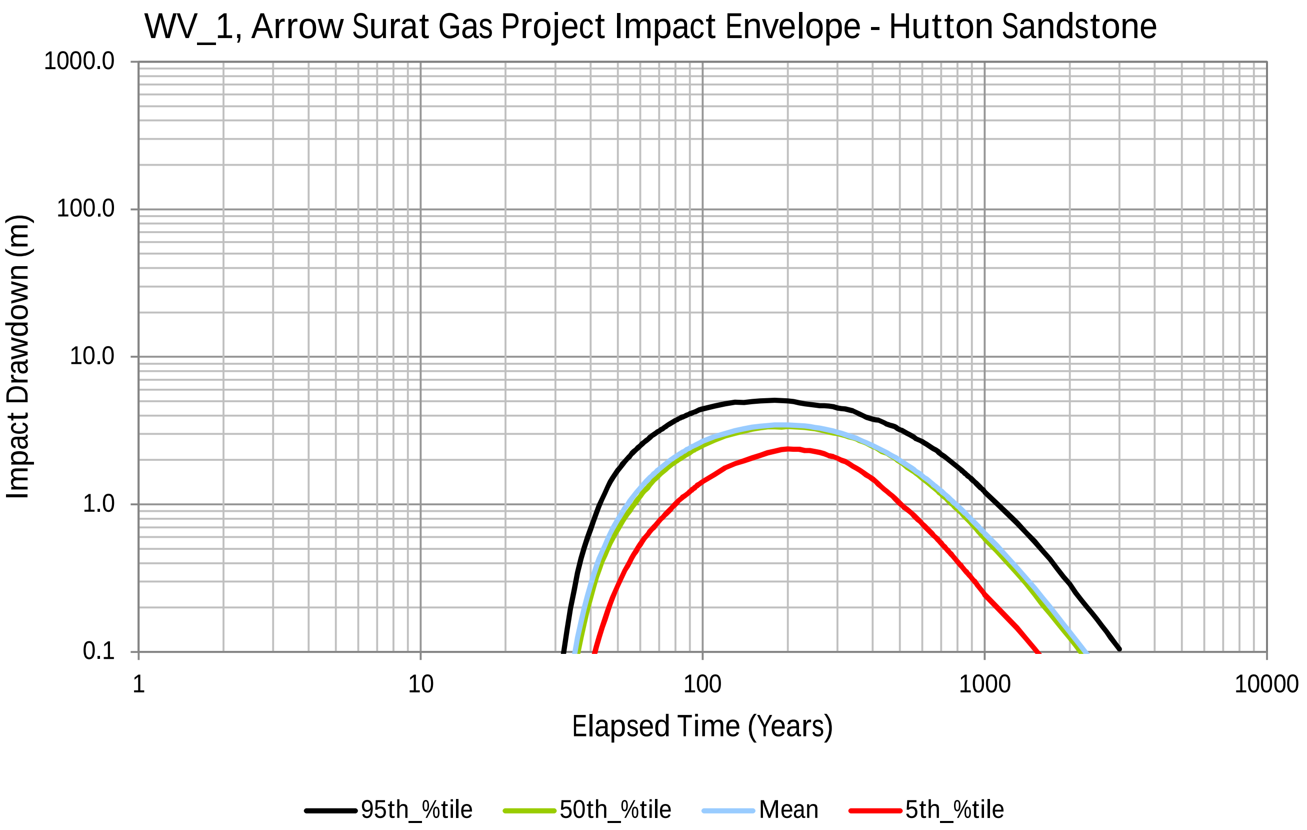
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_9)

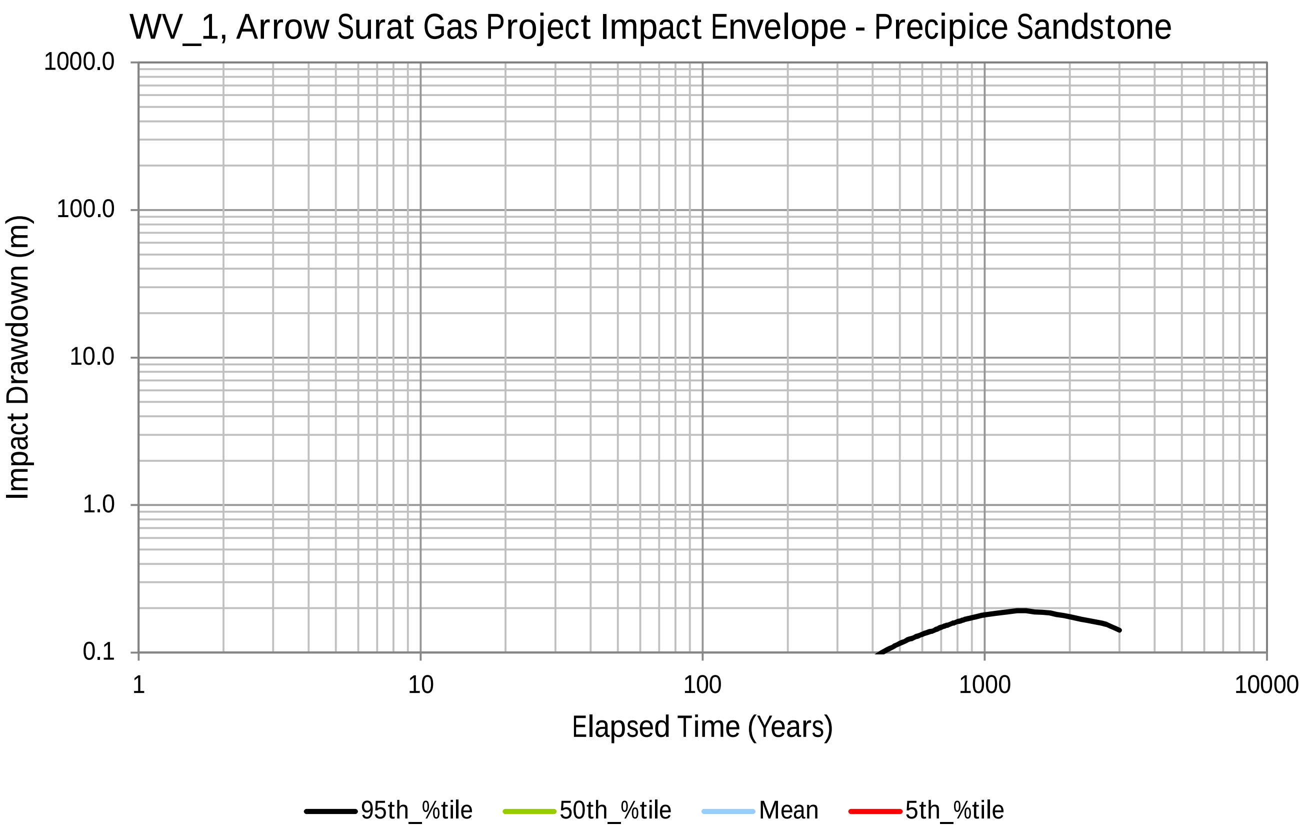
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9



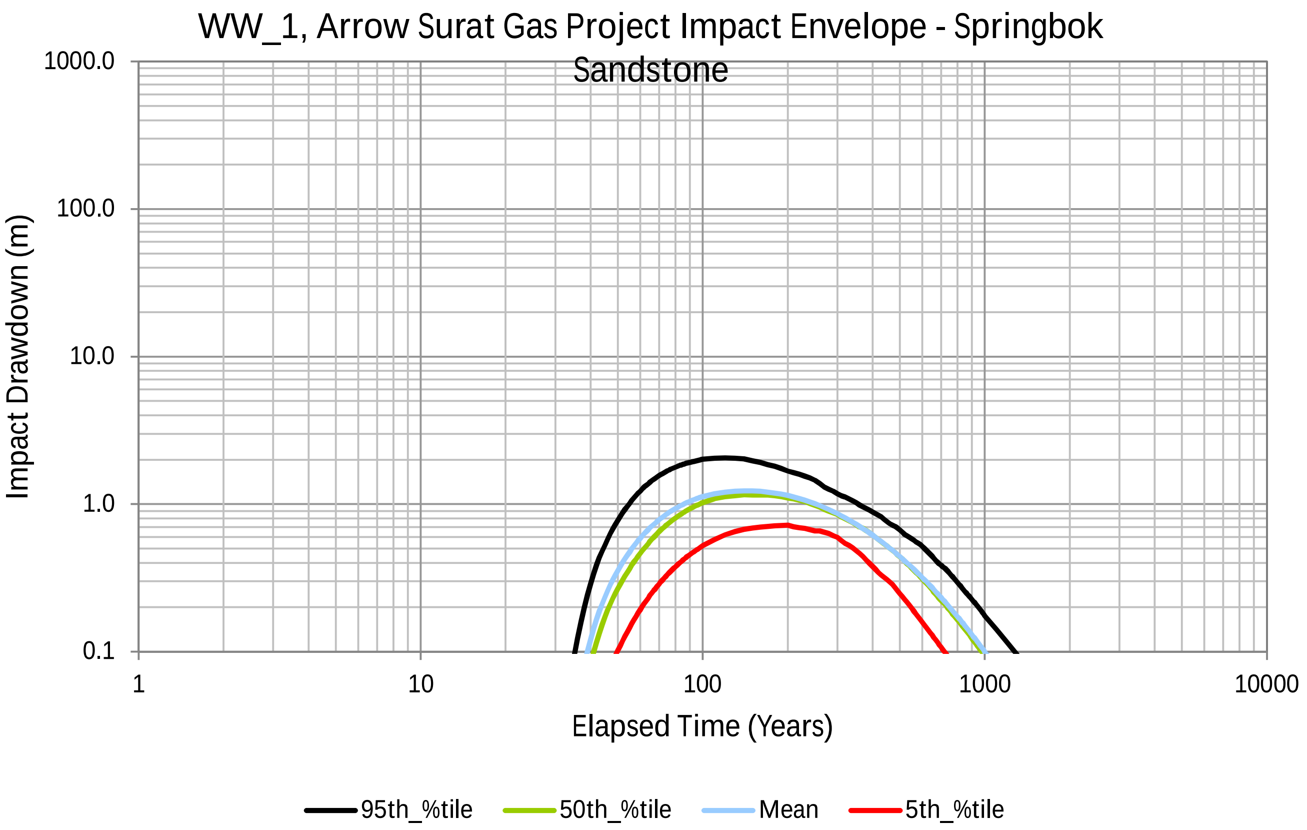


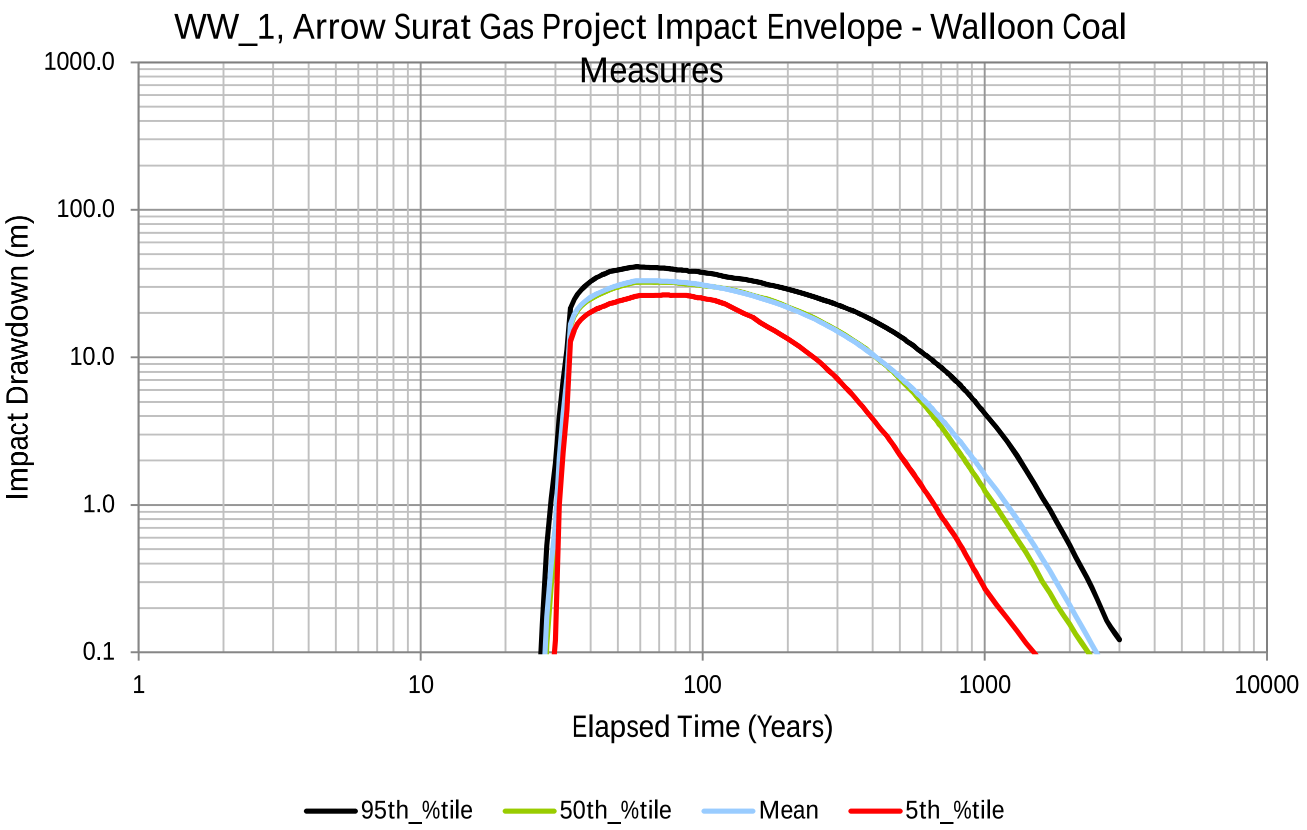
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9

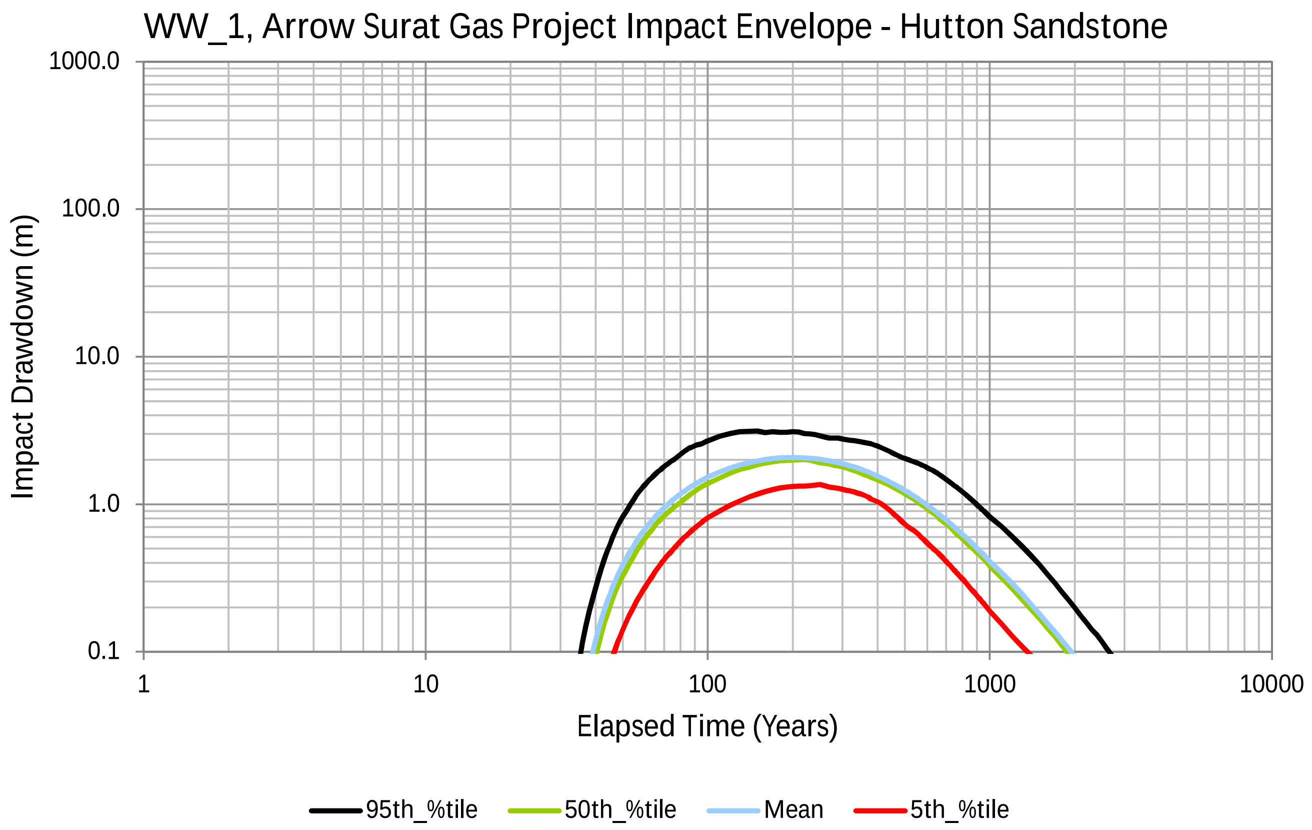


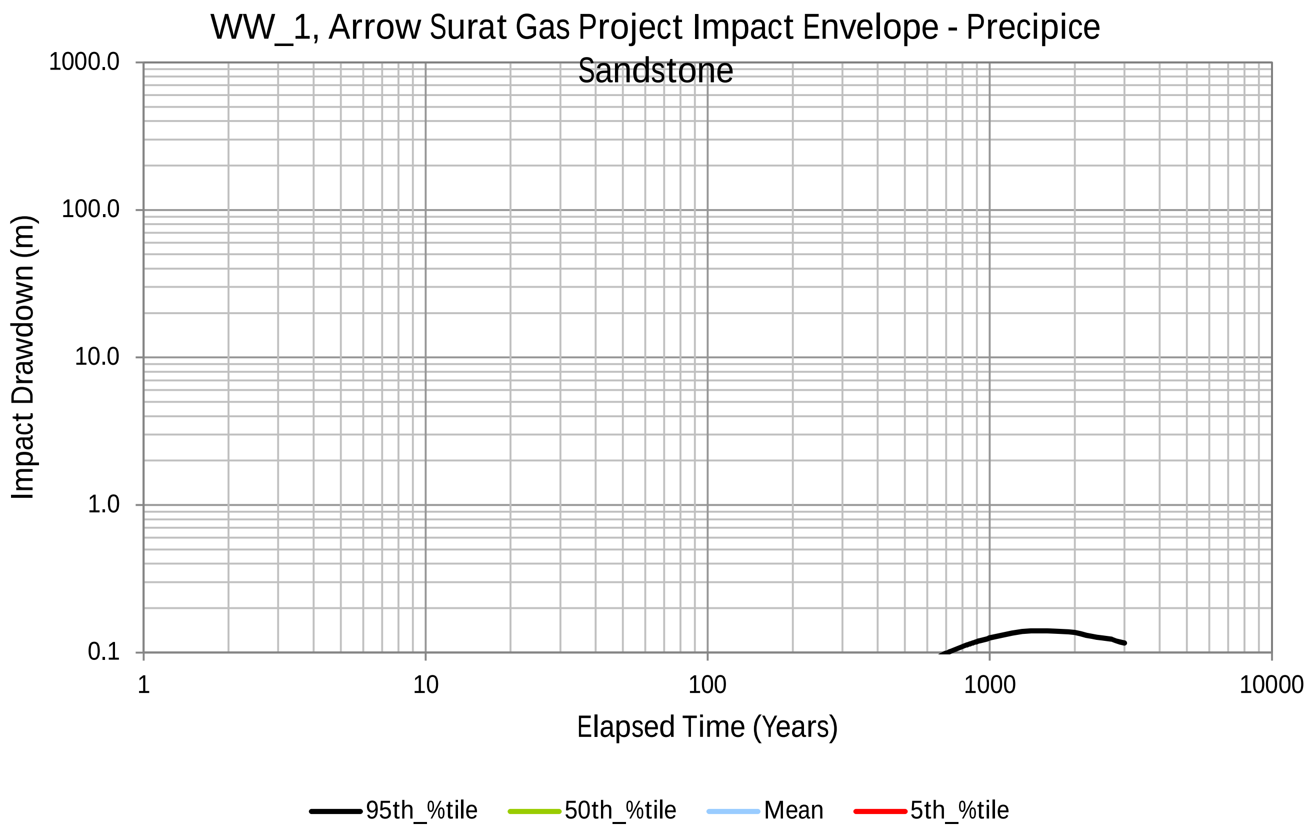


Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9

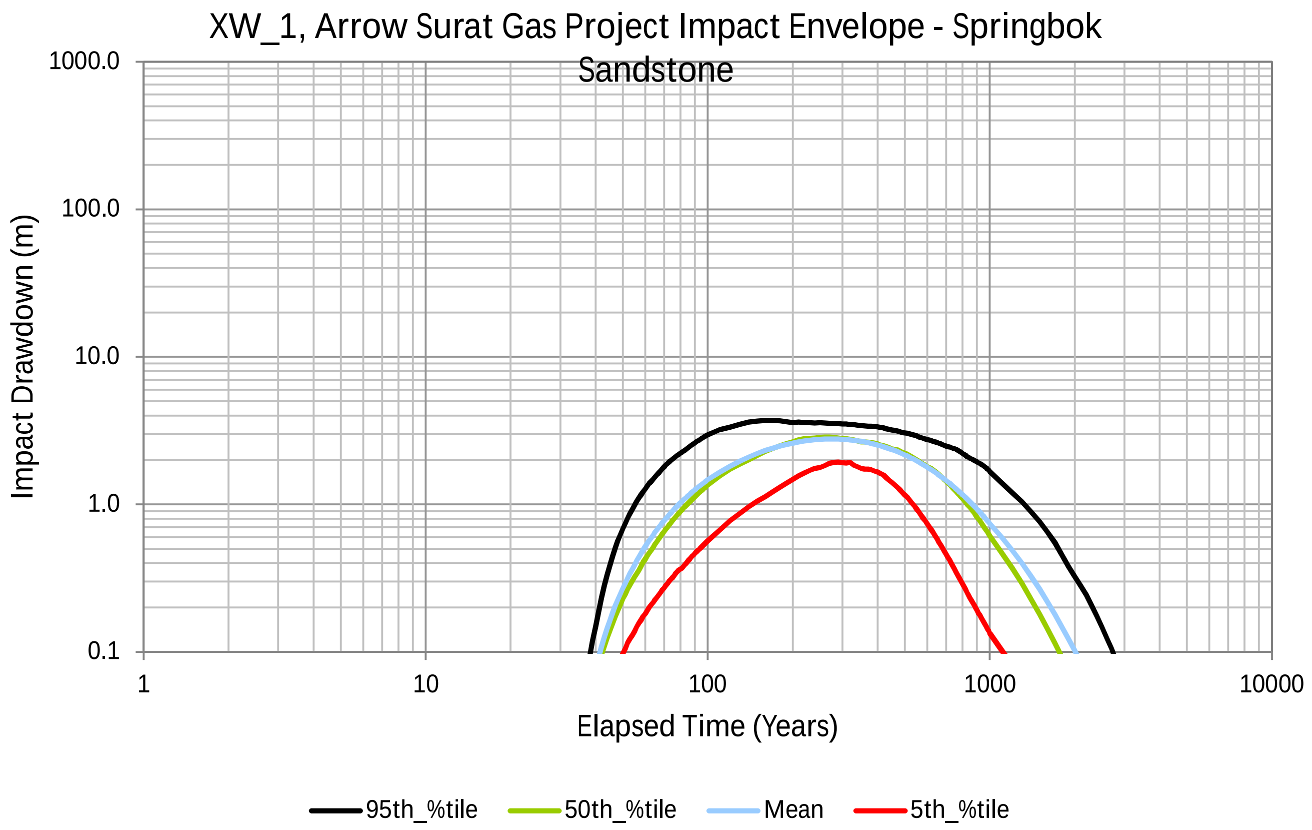


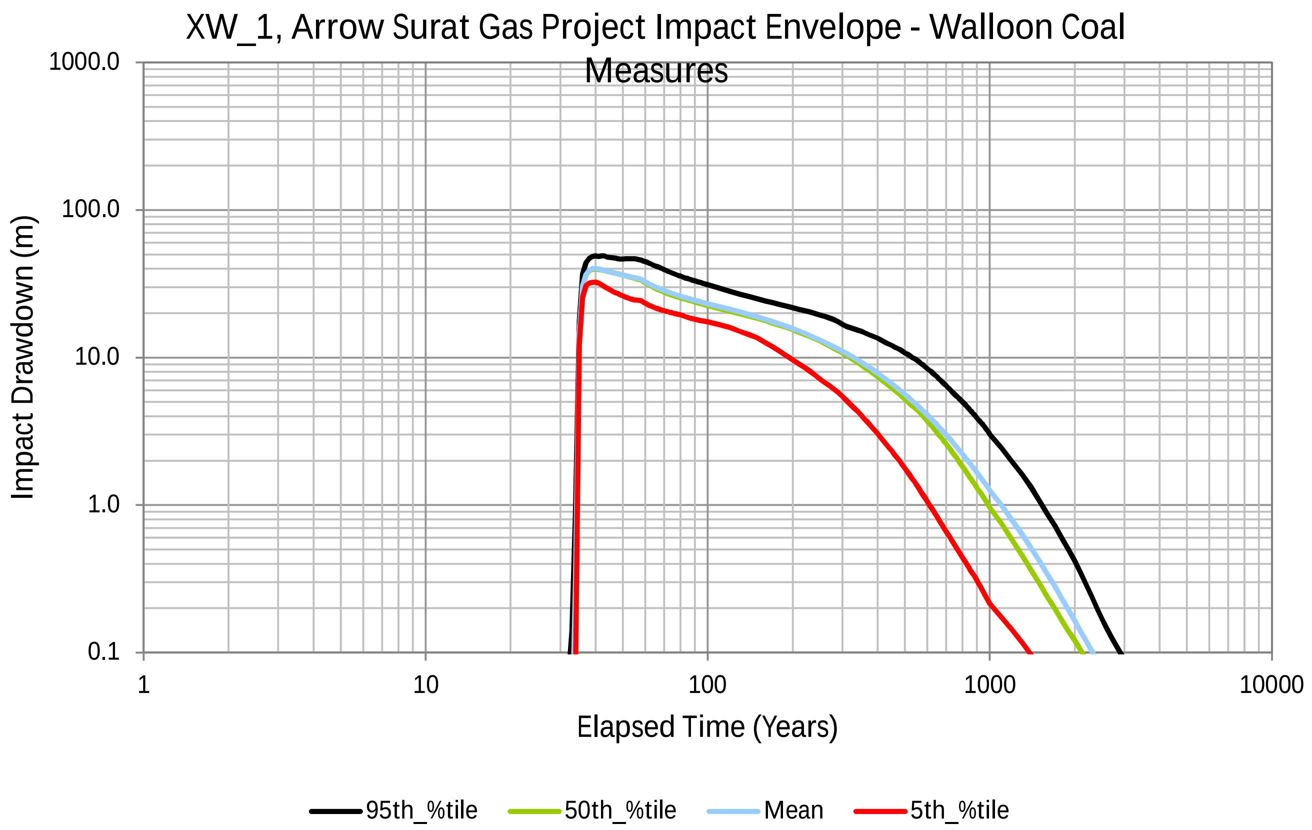



WW_1, Arrow Surat Gas Project Impact Envelope - Hutton Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile


WW_1, Arrow Surat Gas Project Impact Envelope - Precipice Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

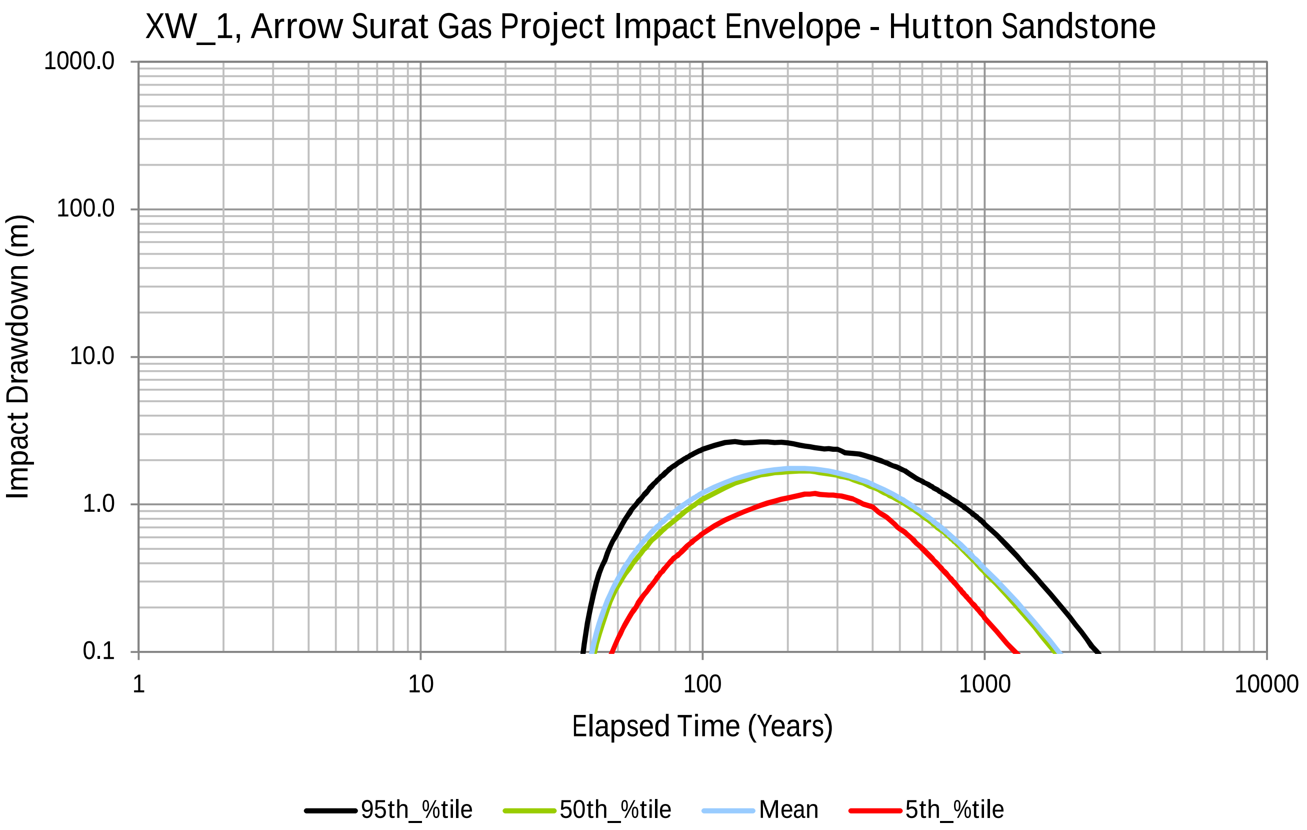
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9

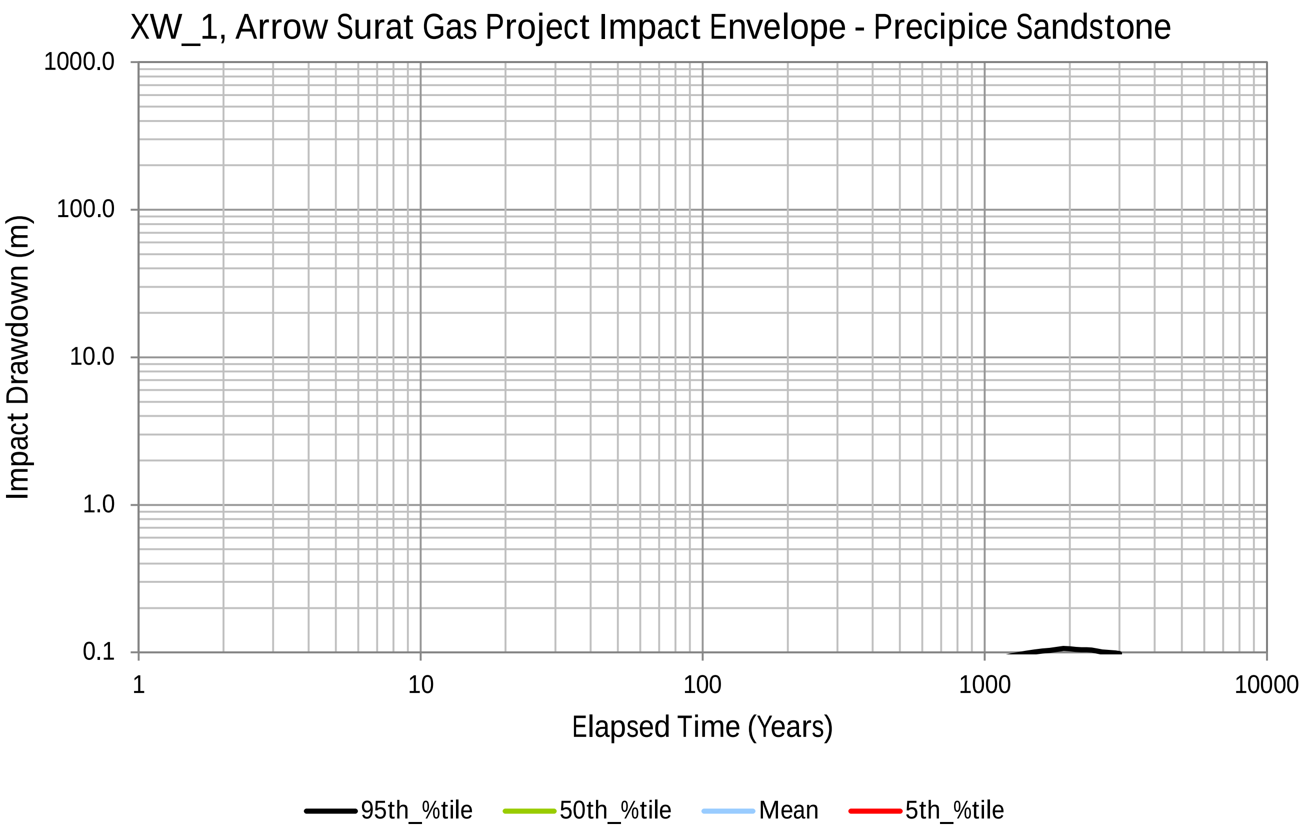




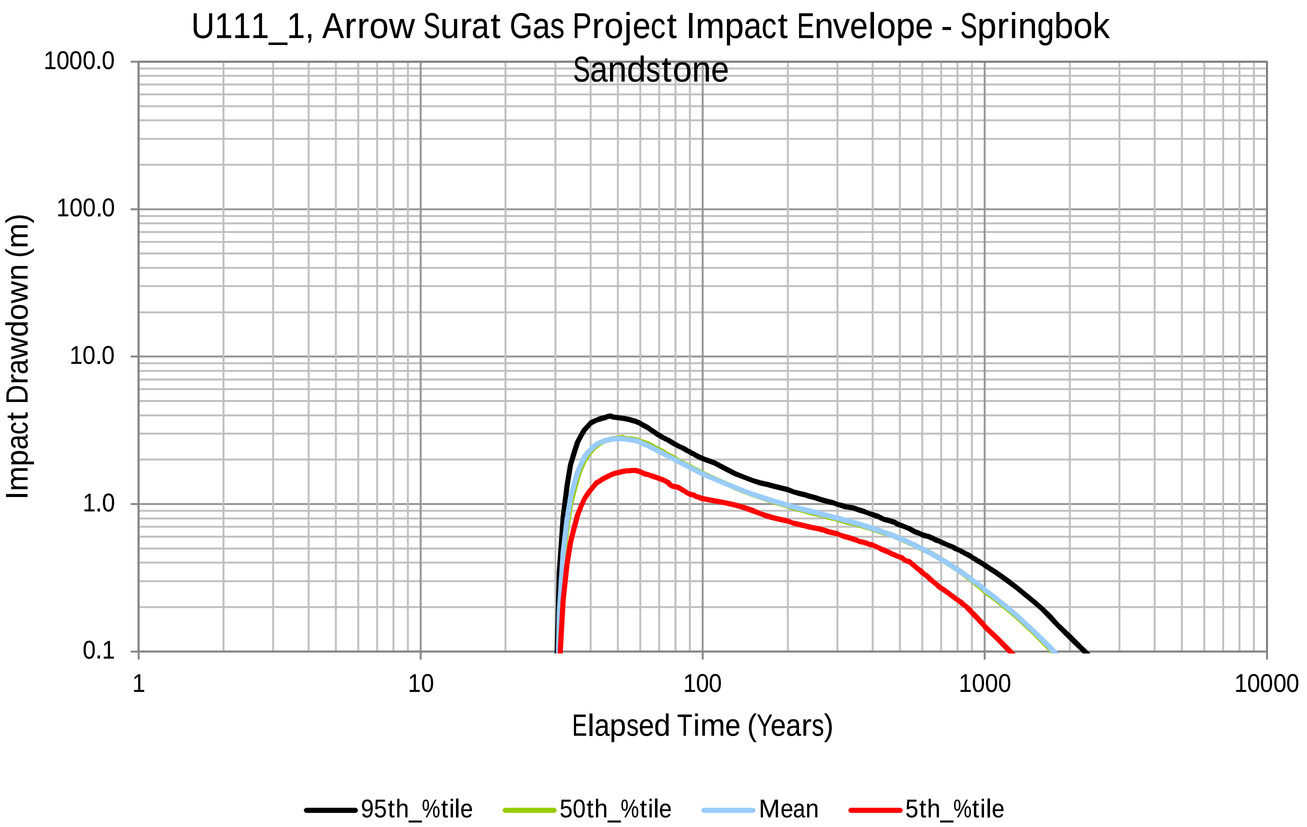
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_9)

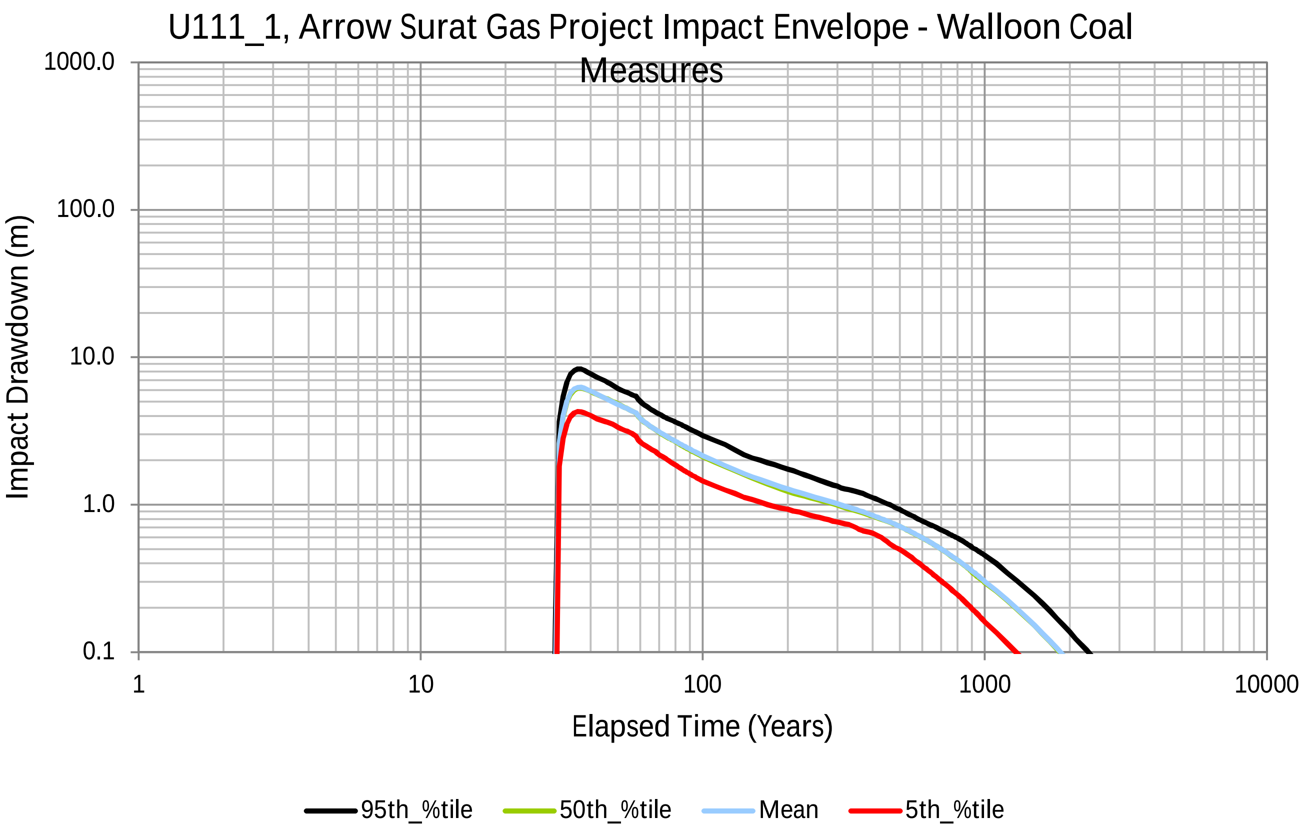
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 9

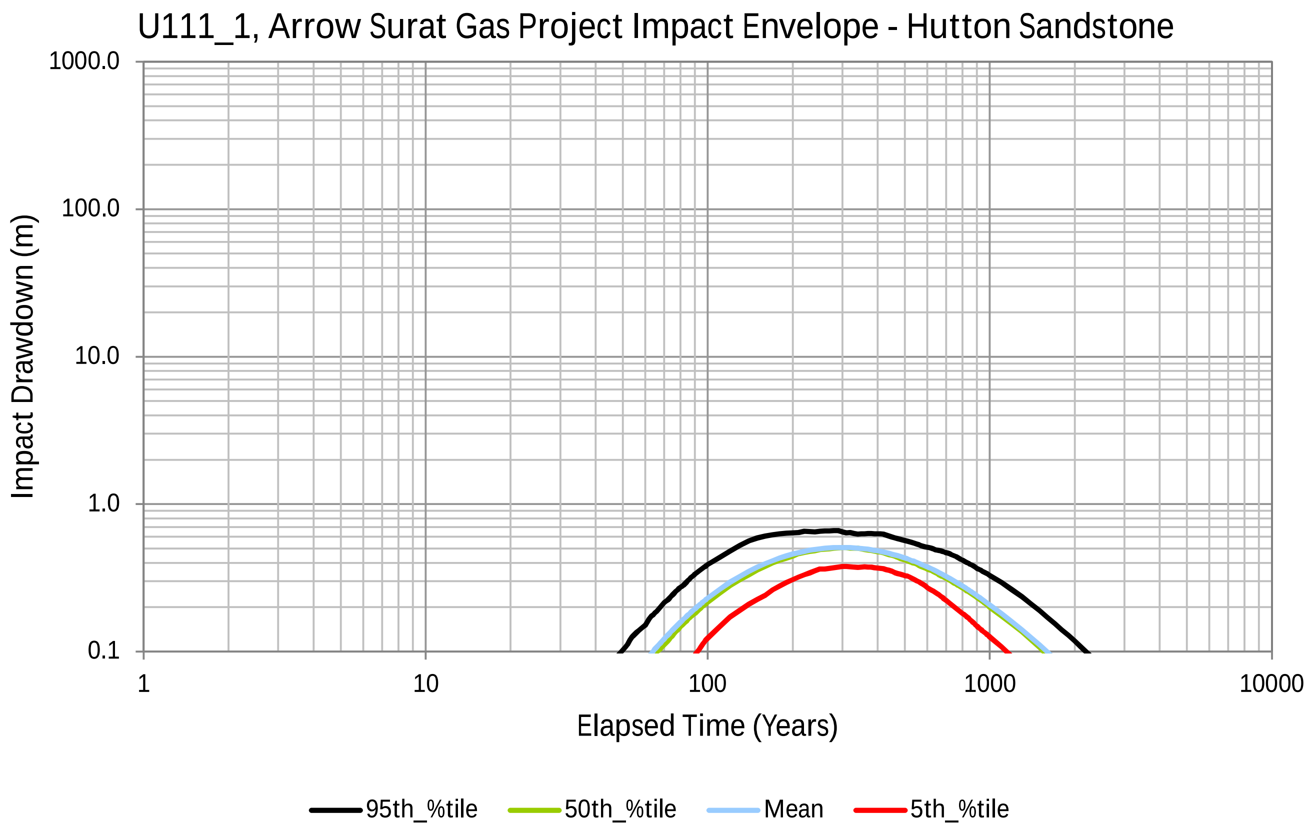


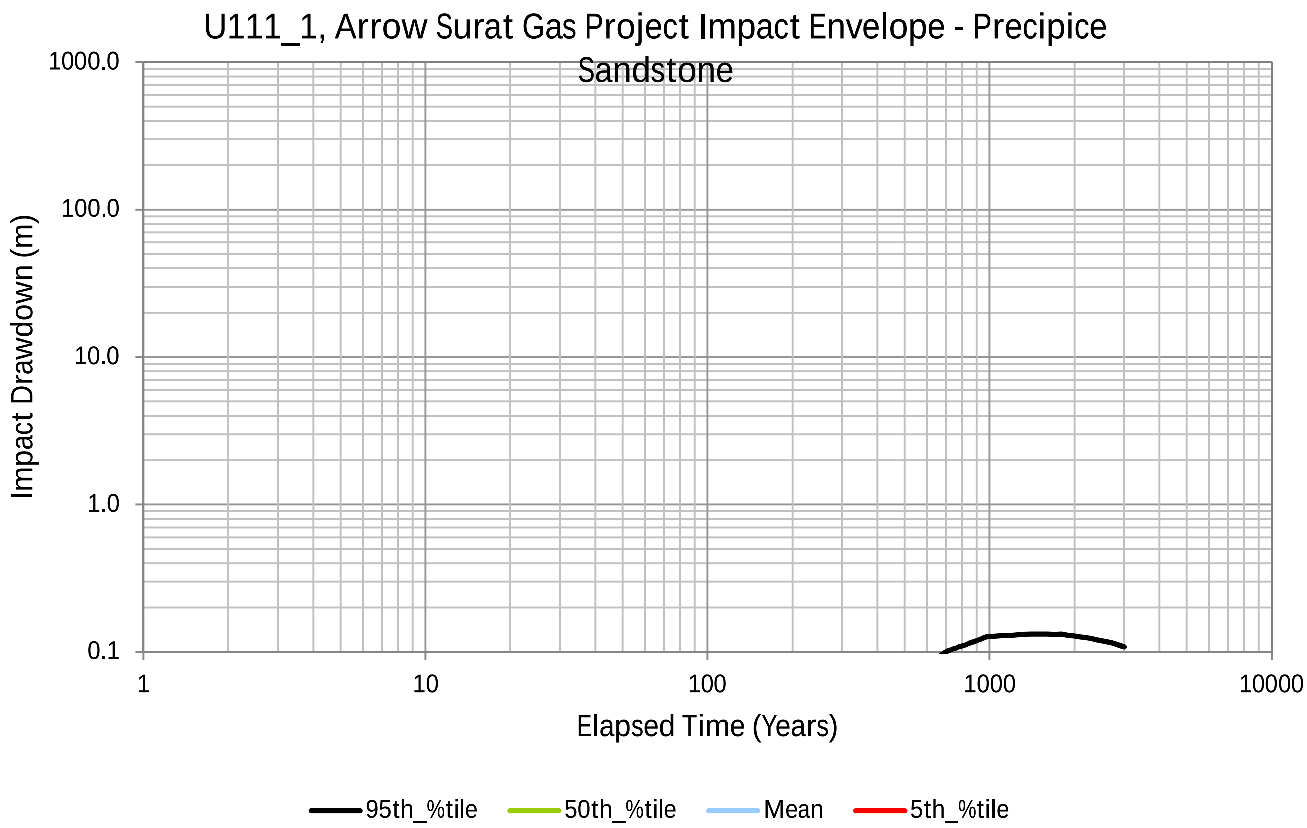


Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10

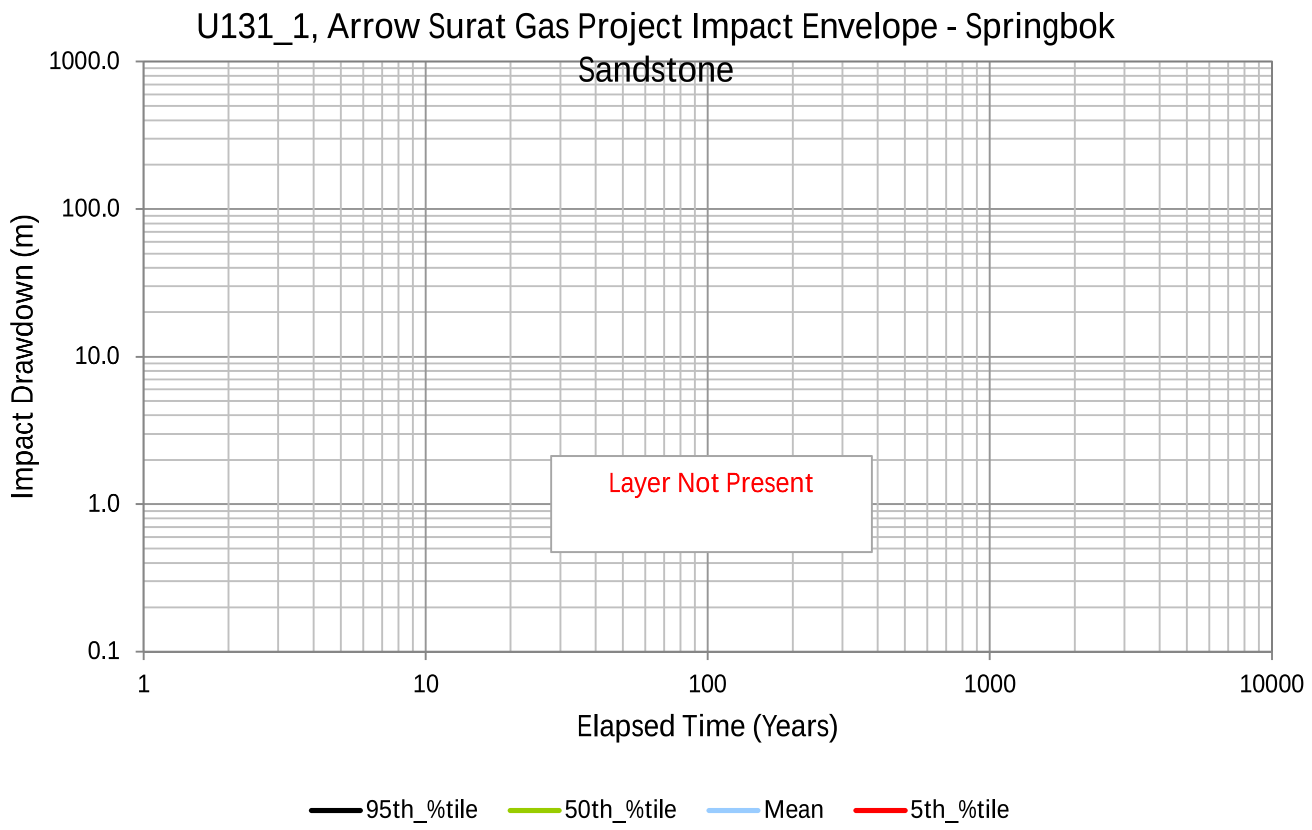


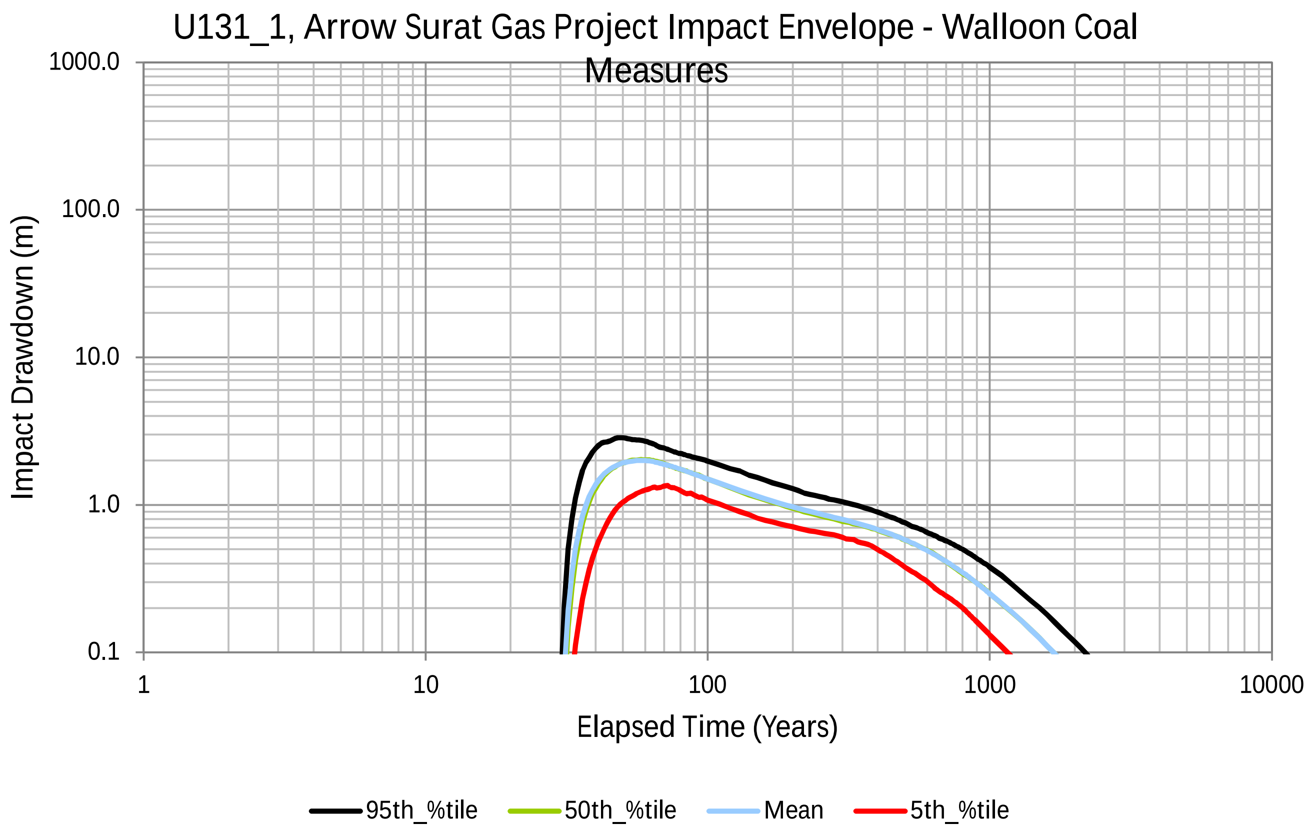



U111_1, Arrow Surat Gas Project Impact Envelope - Hutton Sandstone
1000.0
100.0
10.0
1.0
0.1
Impact Drawdown (m)
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

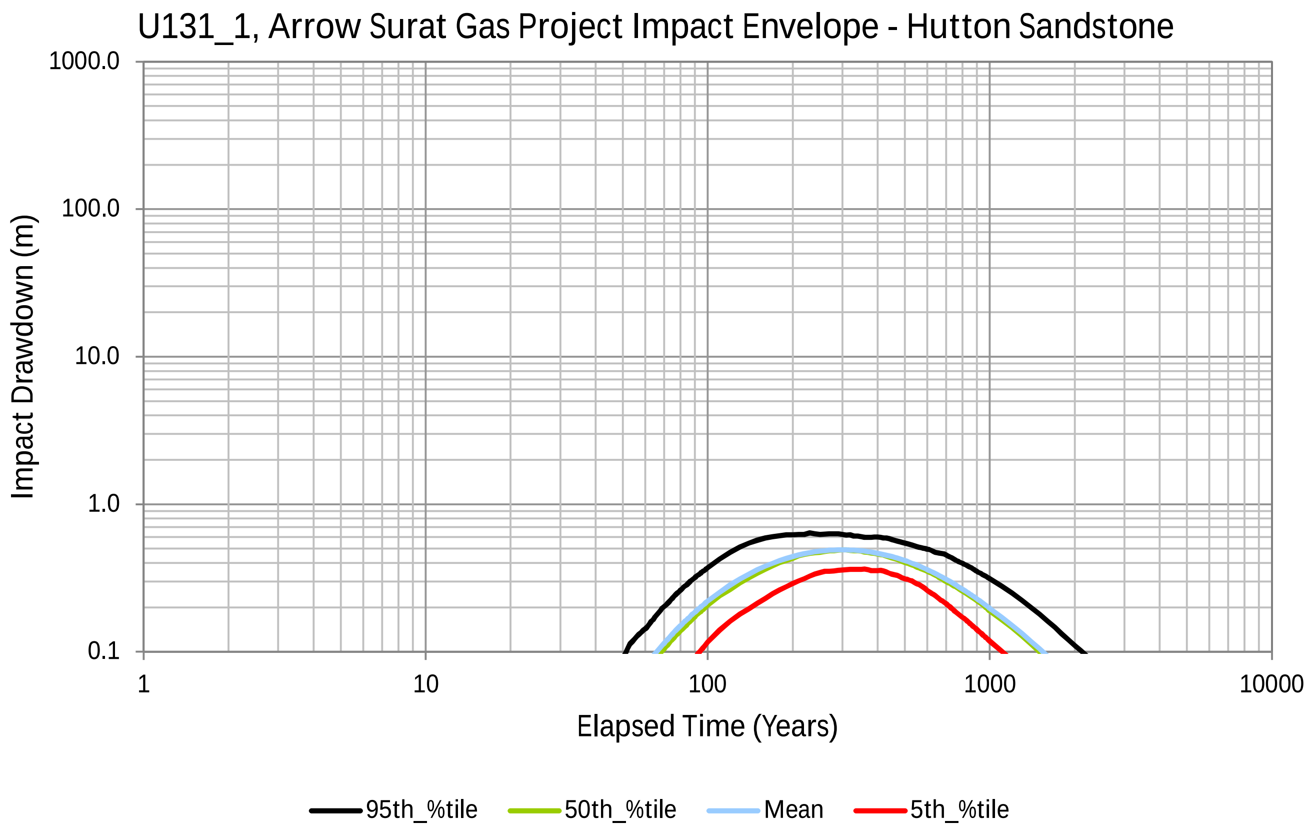

U111_1, Arrow Surat Gas Project Impact Envelope - Precipice Sandstone
1000.0
100.0
10.0
1.0
0.1
Impact Drawdown (m)
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

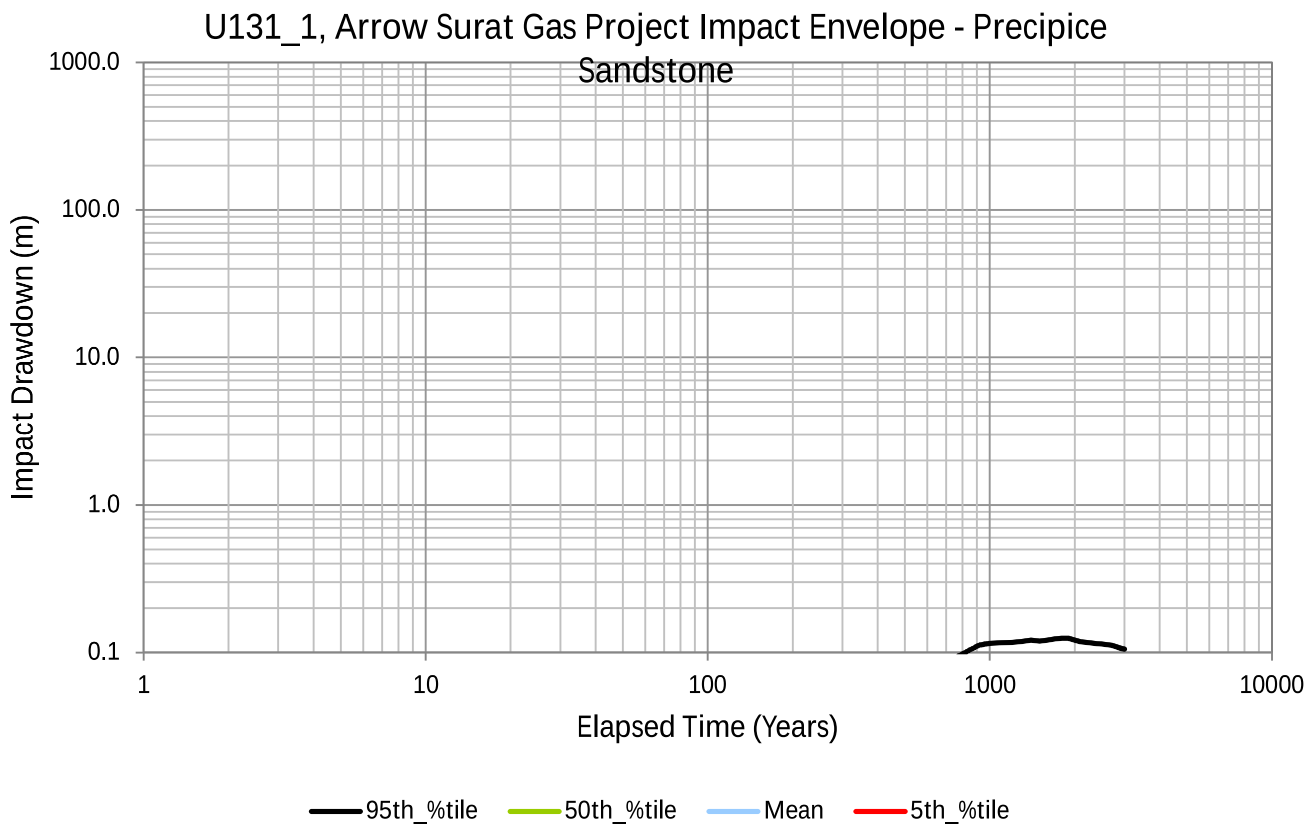
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10



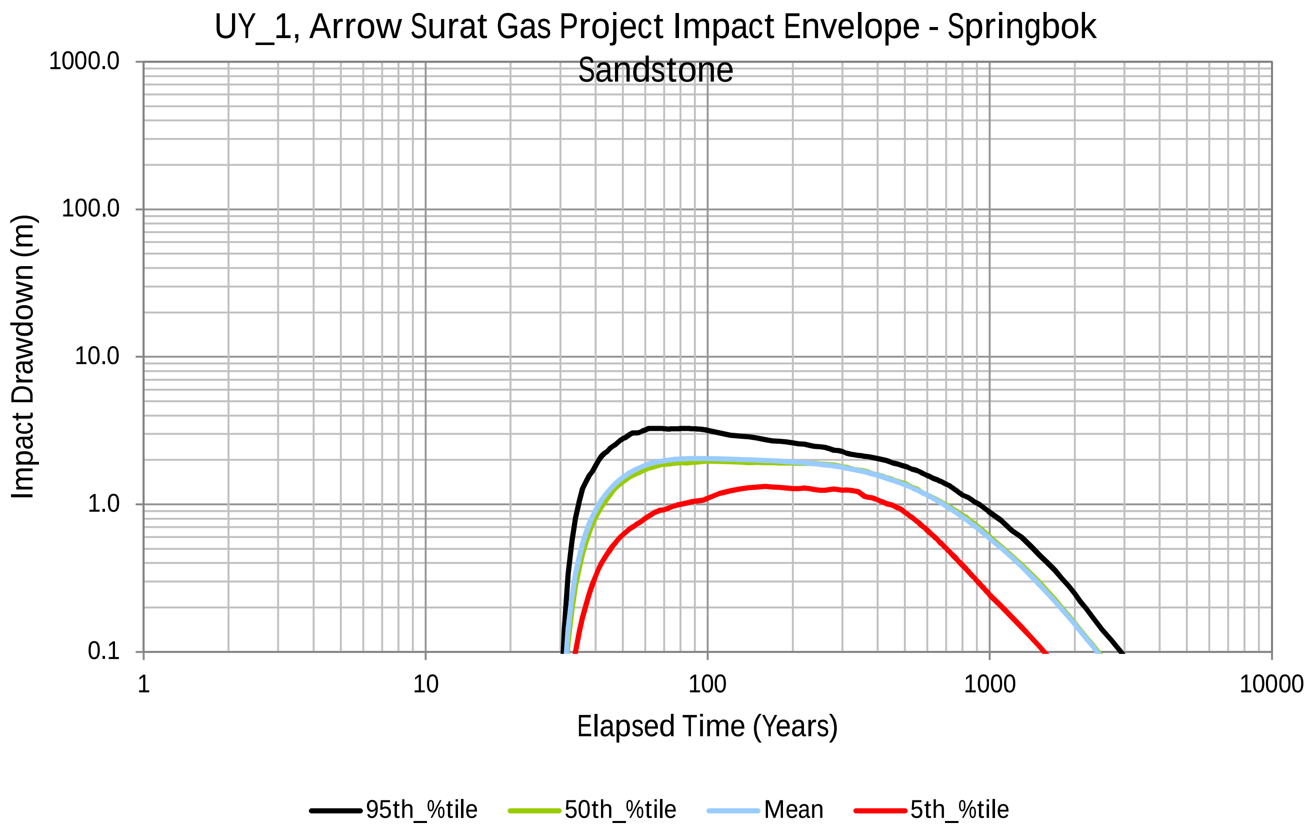


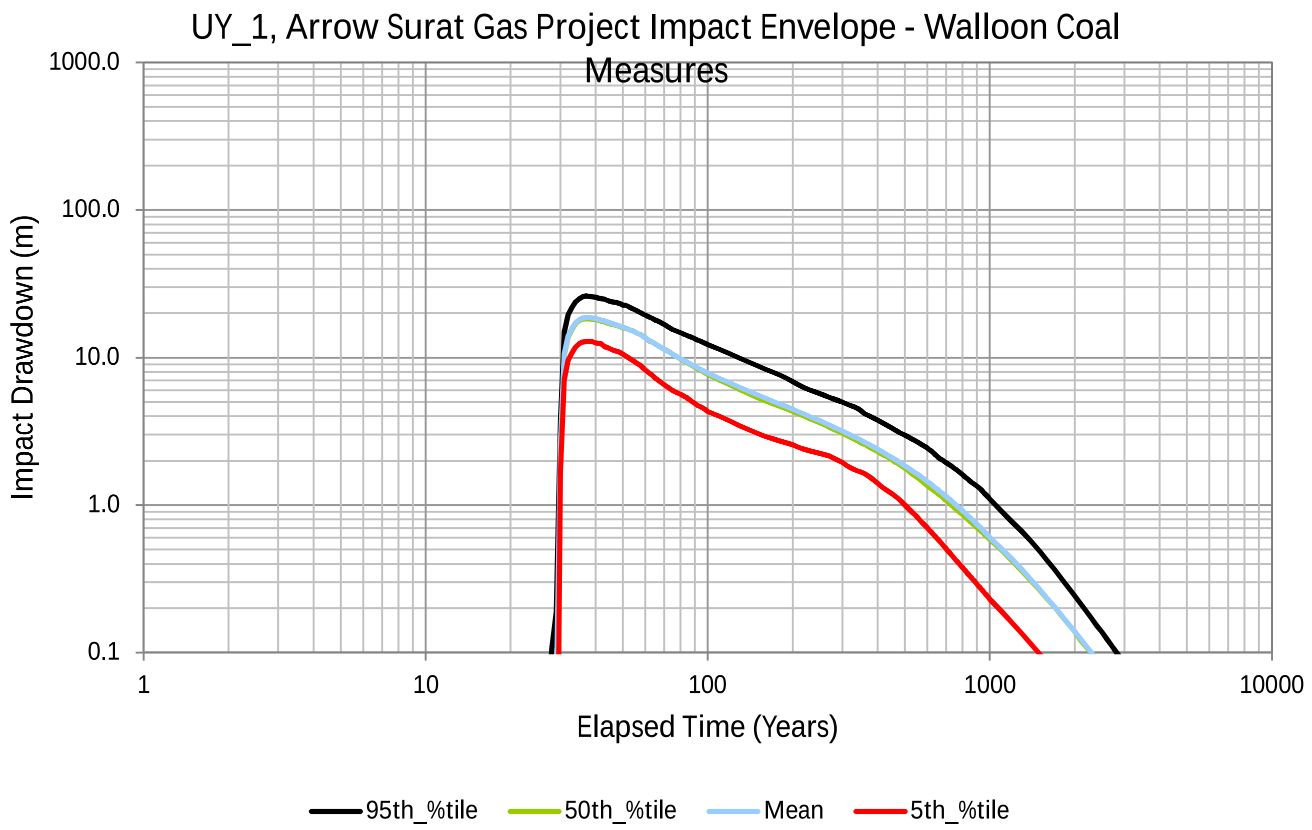
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10



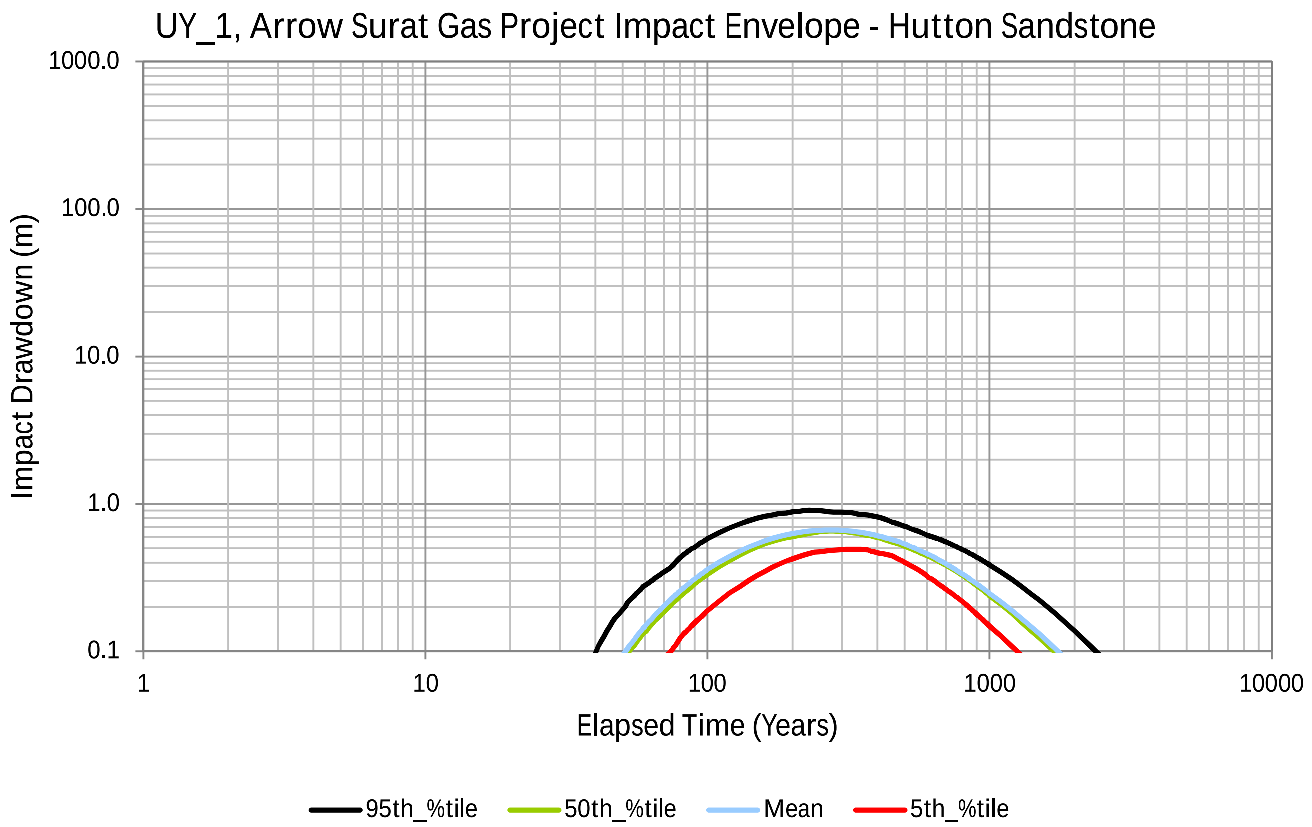


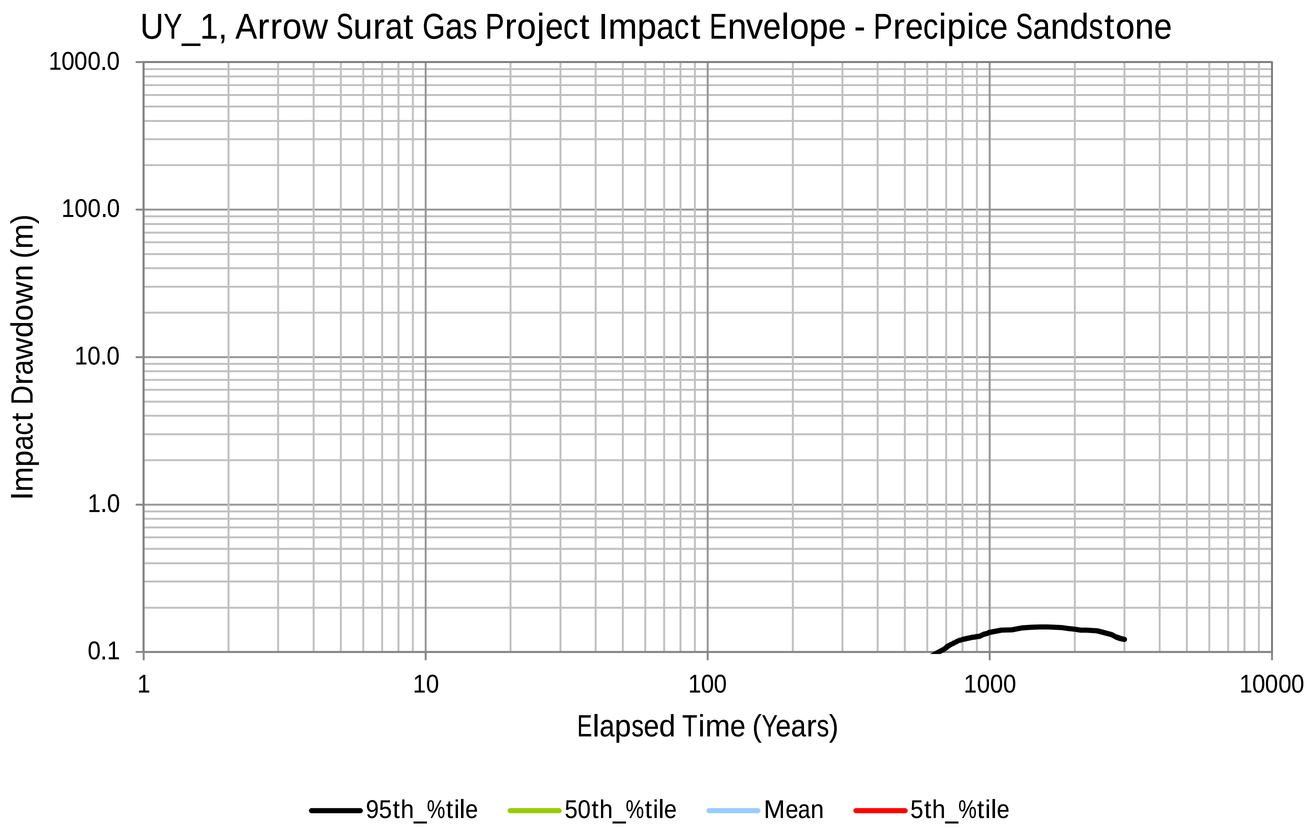
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10





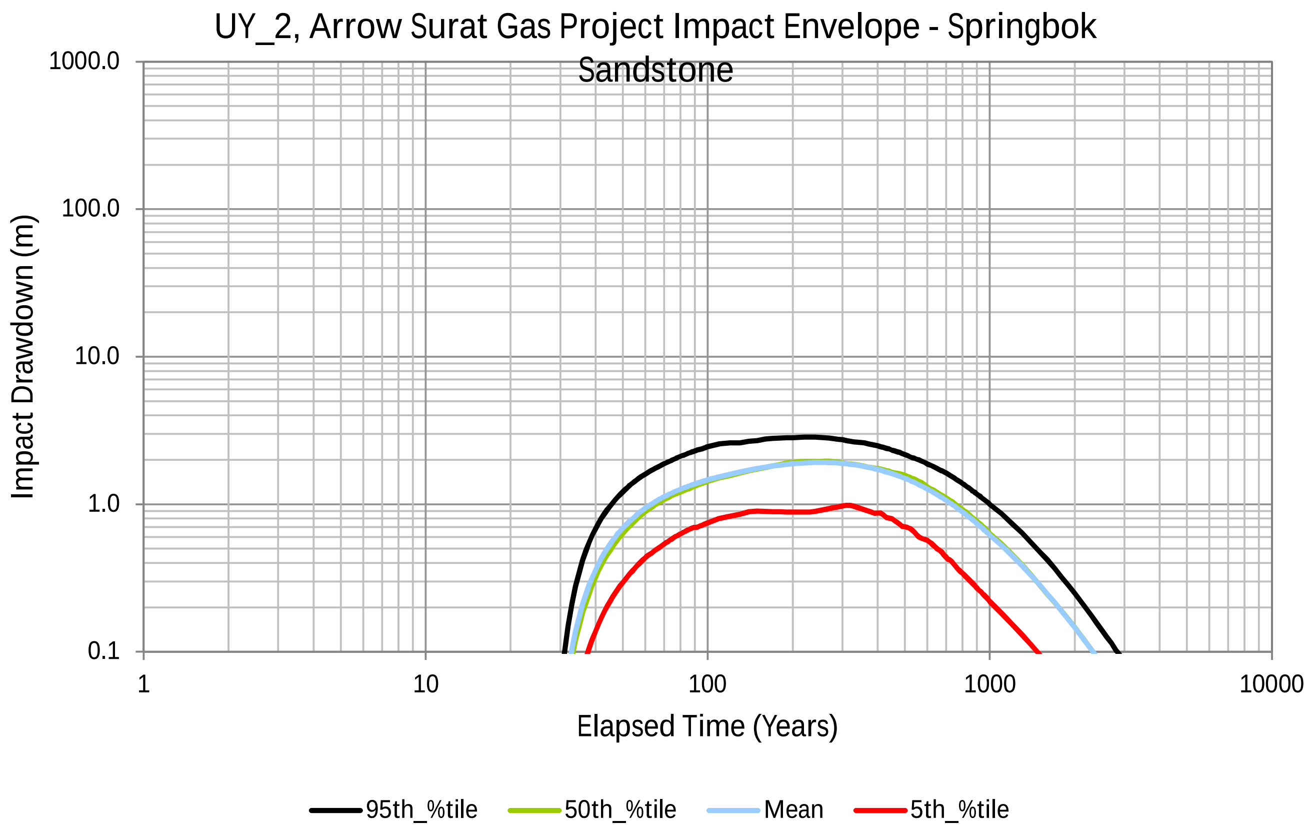
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10

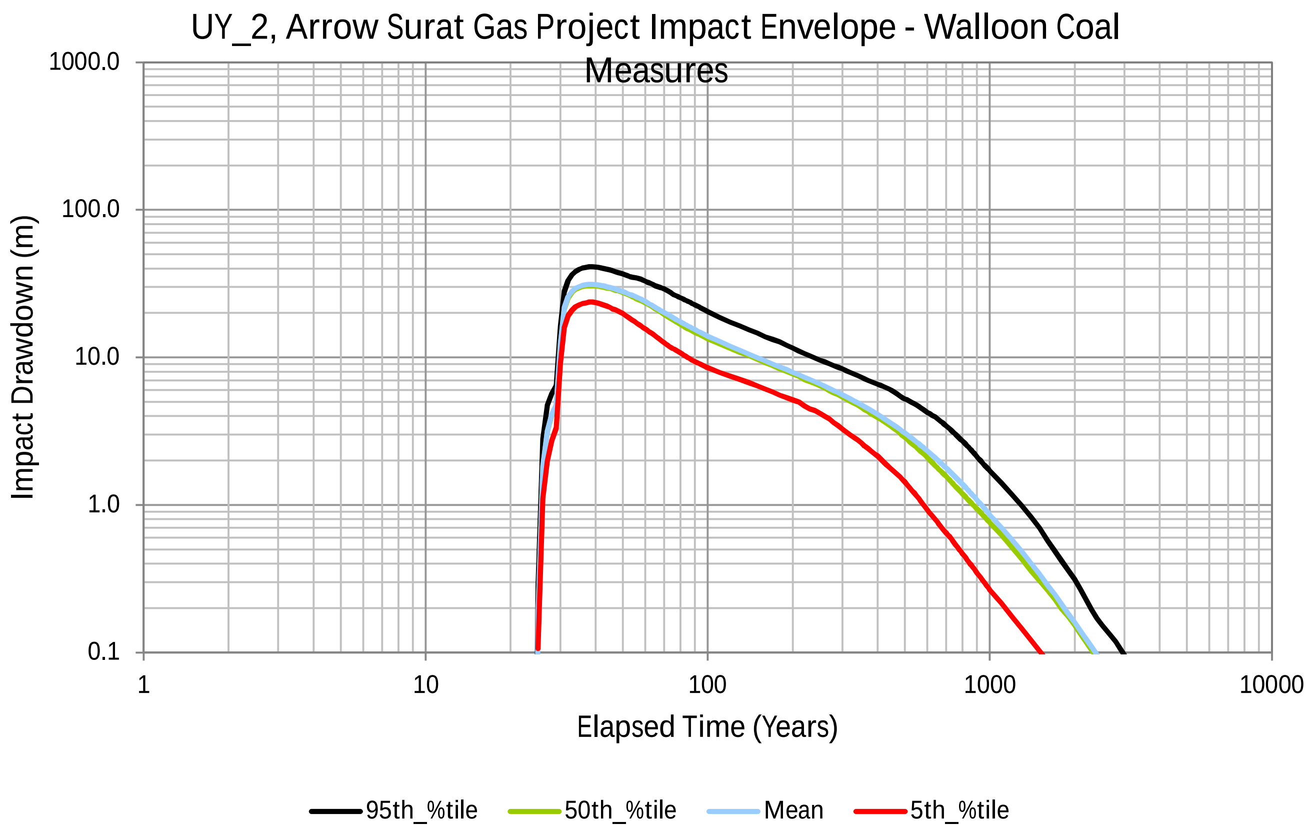




G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_10)

Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10





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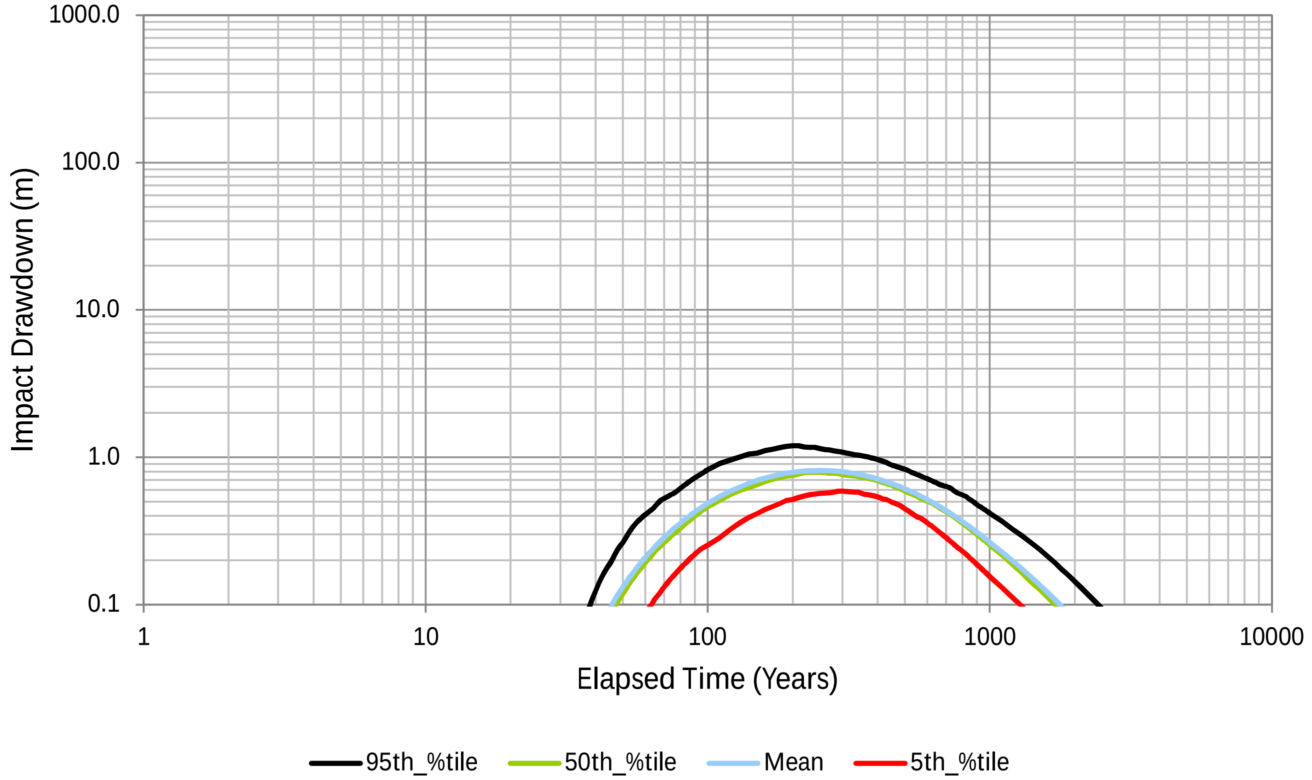
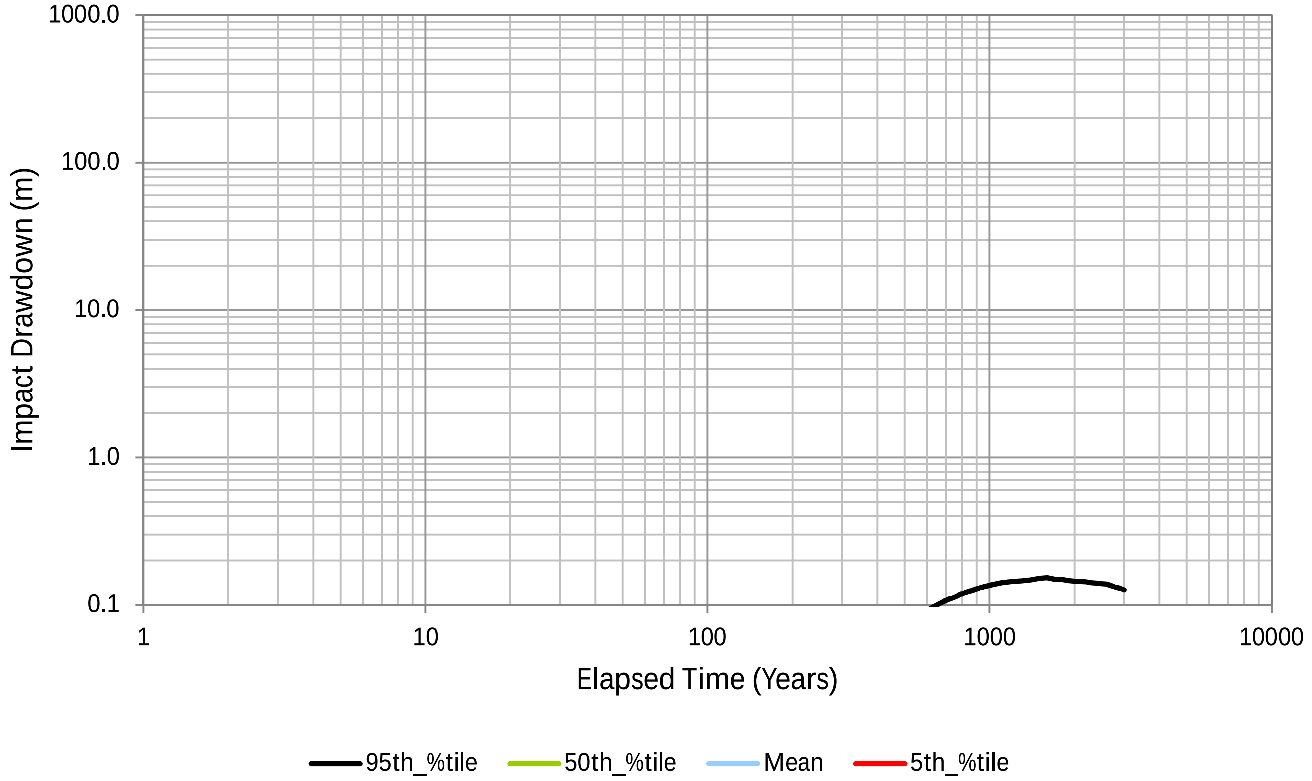
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10

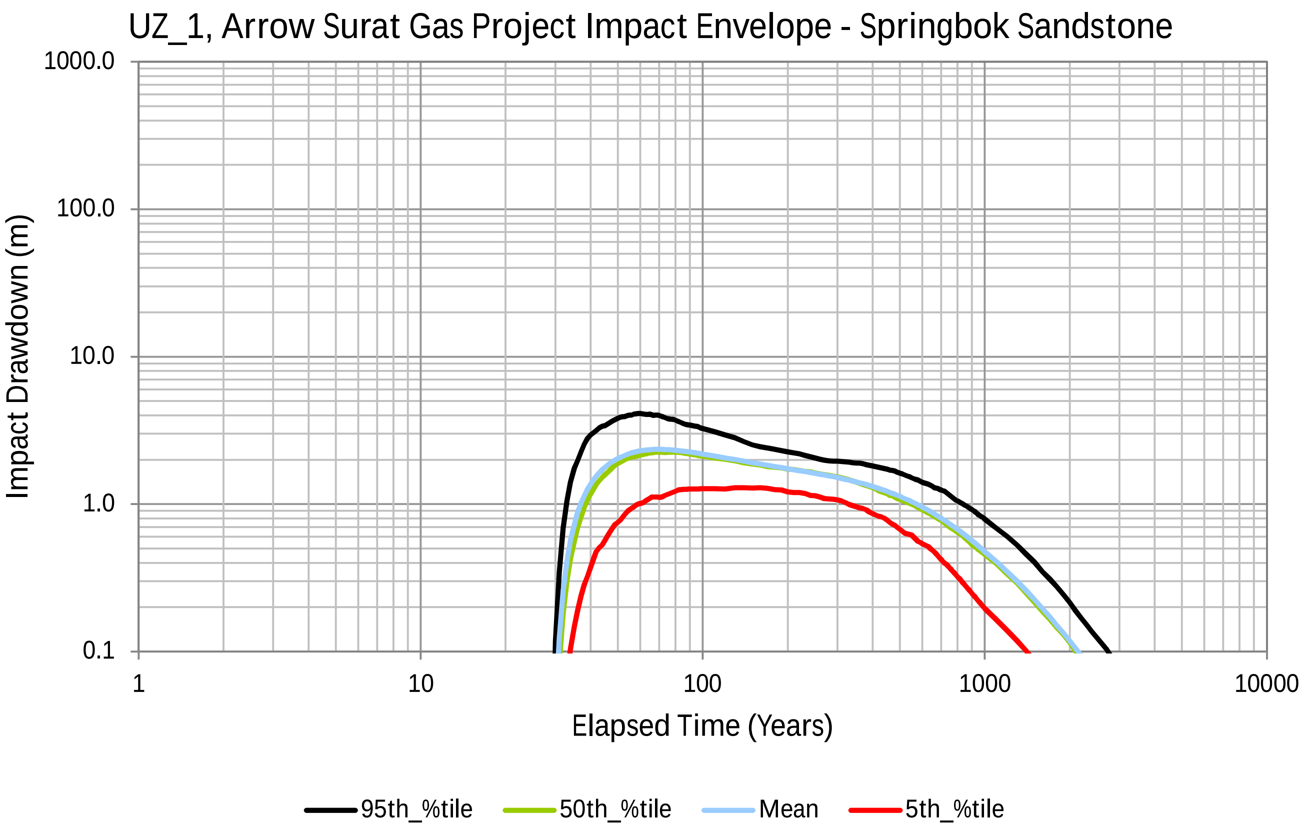
UY_2, Arrow Surat Gas Project Impact Envelope - Hutton Sandstone

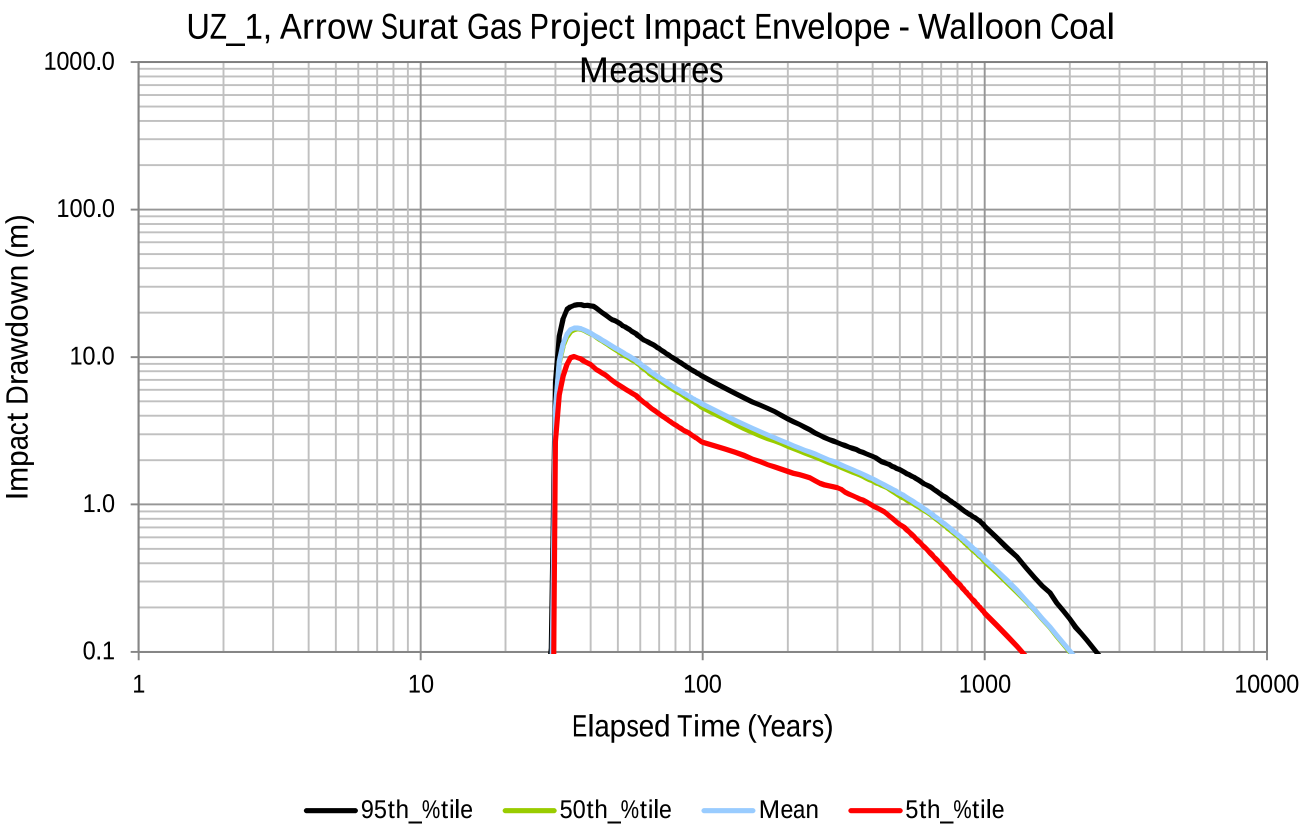


UY_2, Arrow Surat Gas Project Impact Envelope - Precipice Sandstone



Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10





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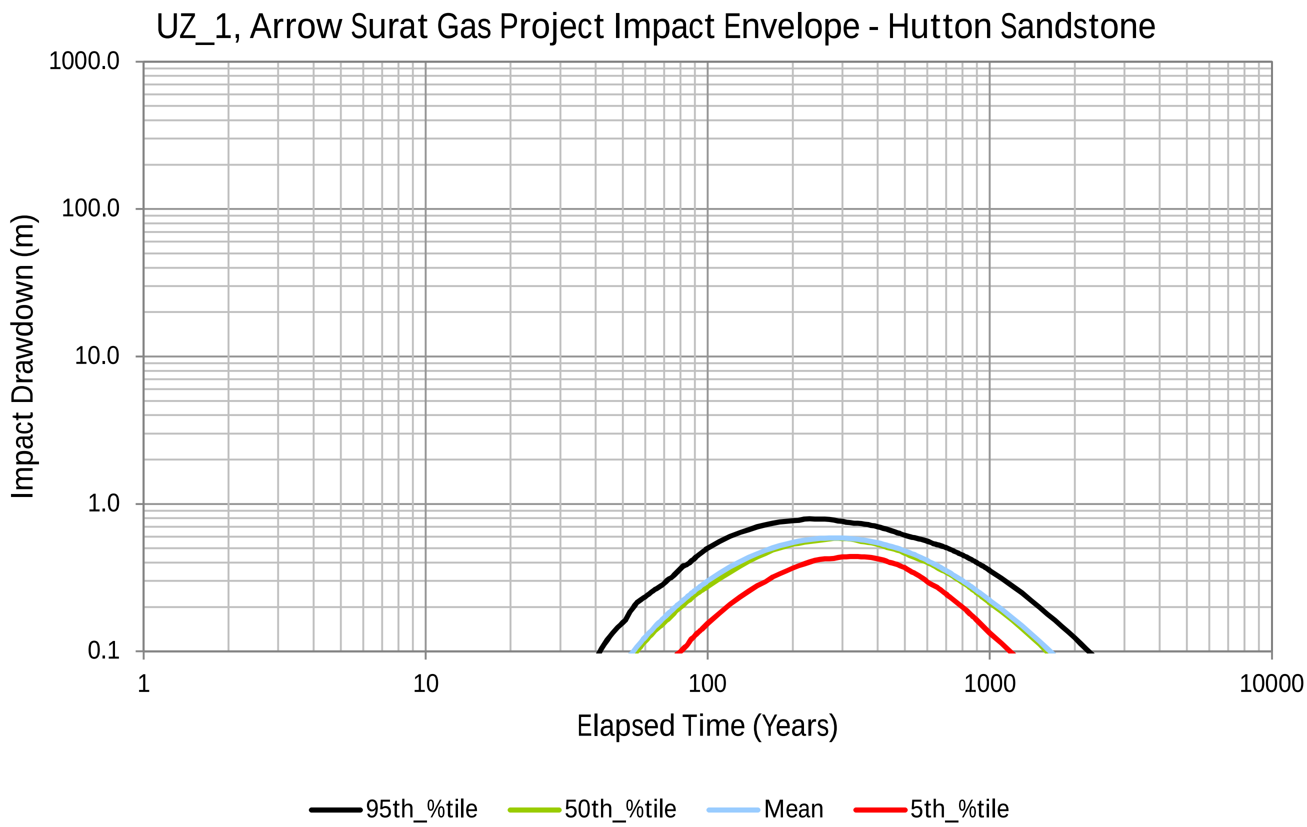
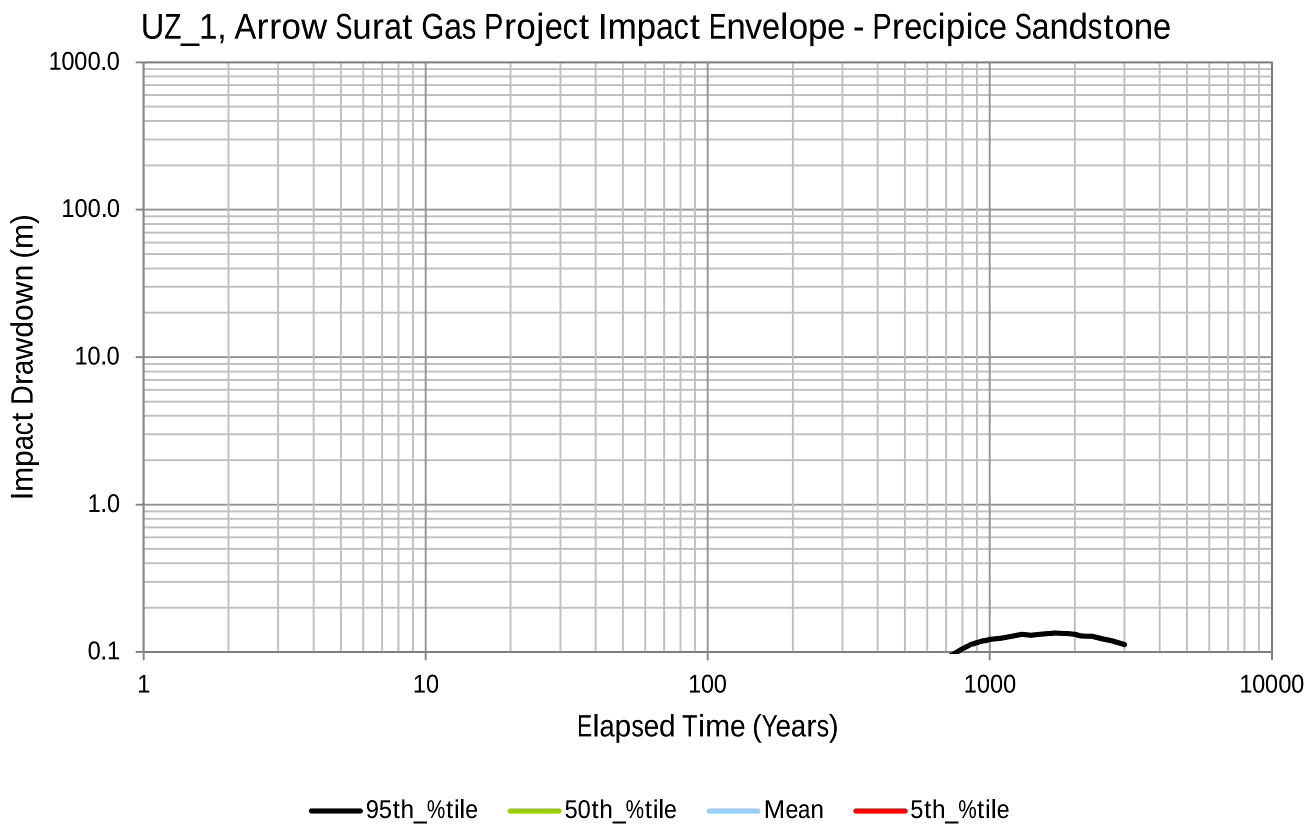
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10





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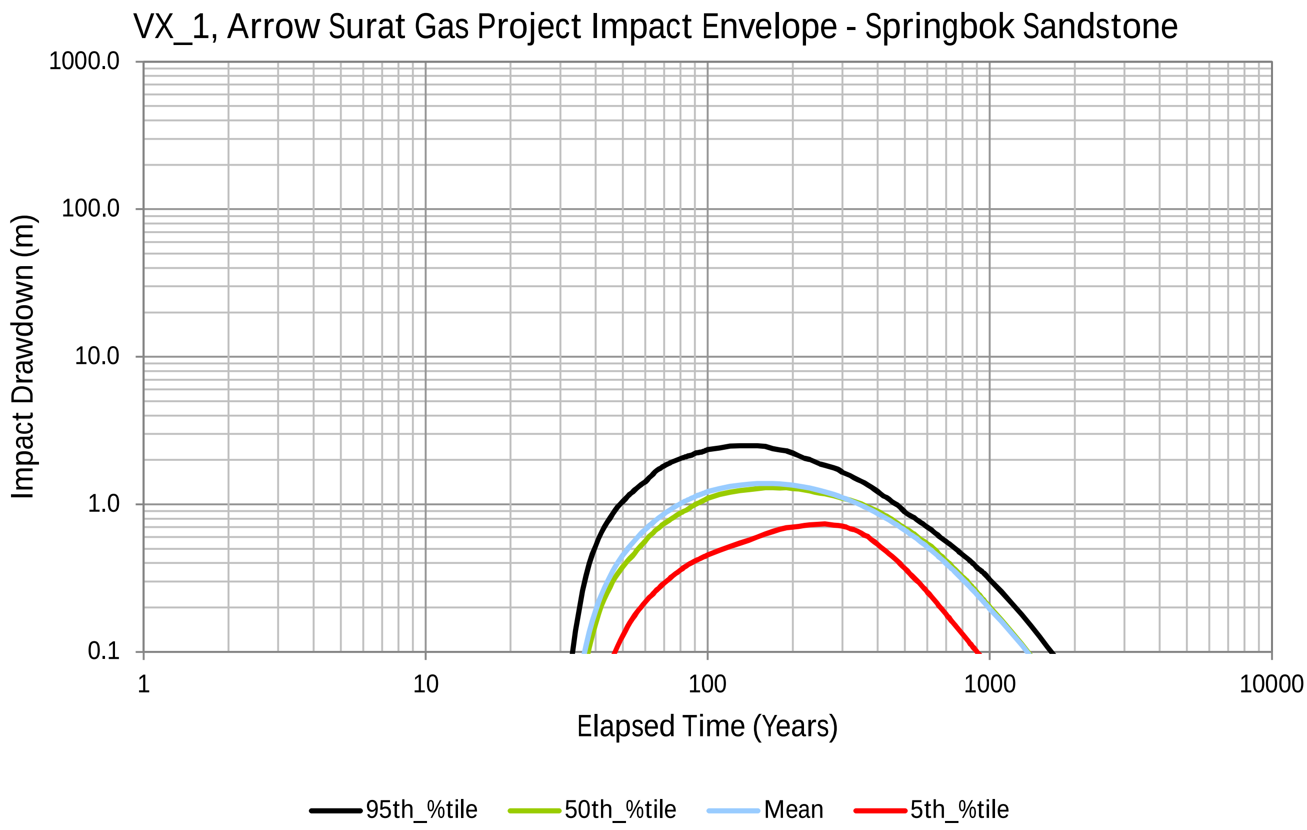
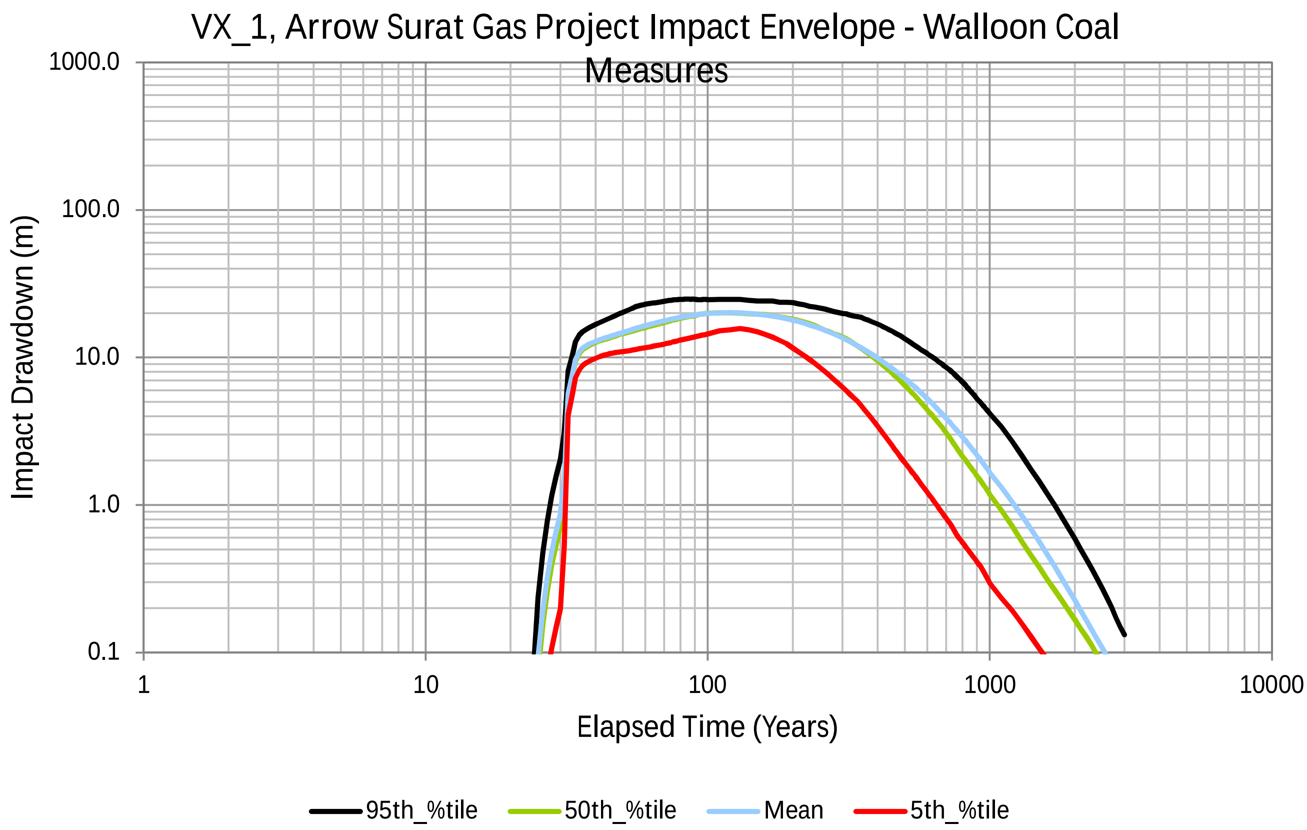
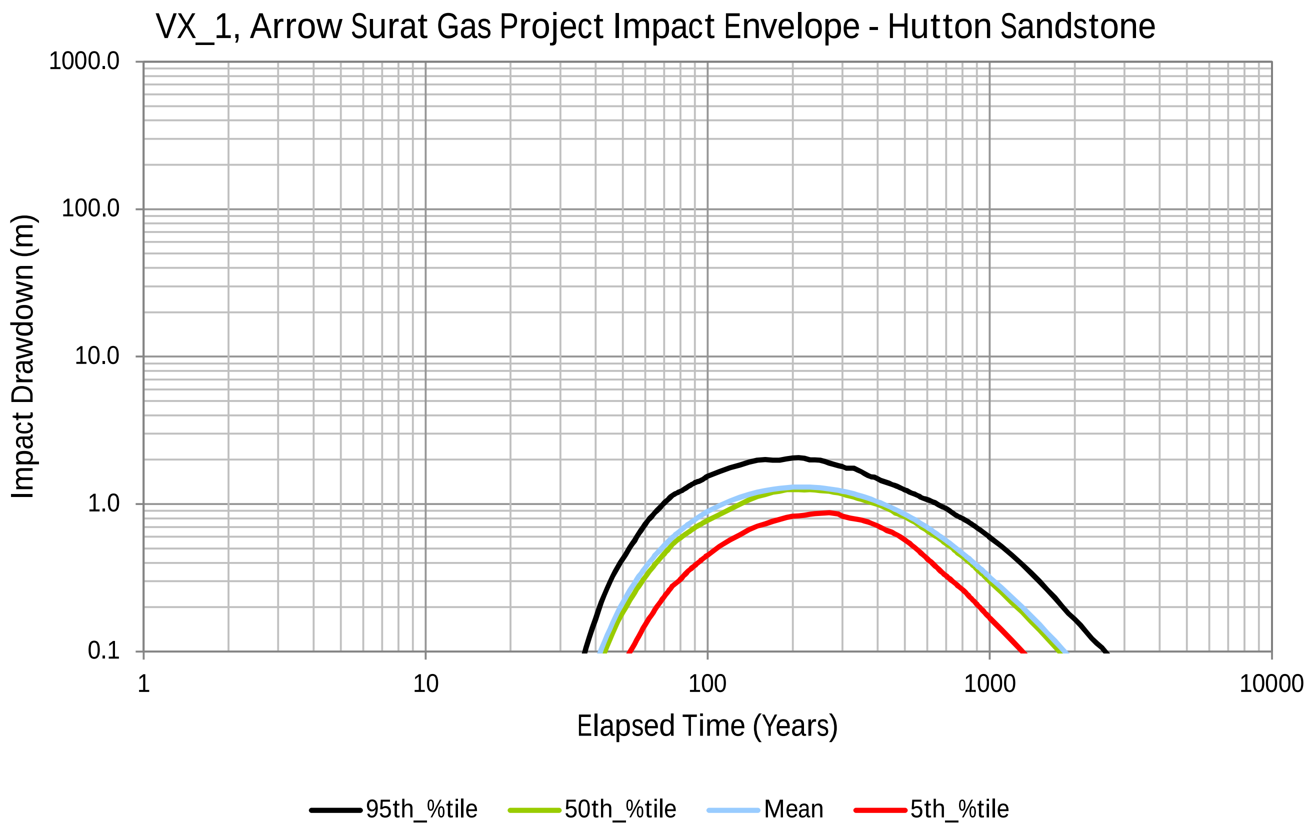
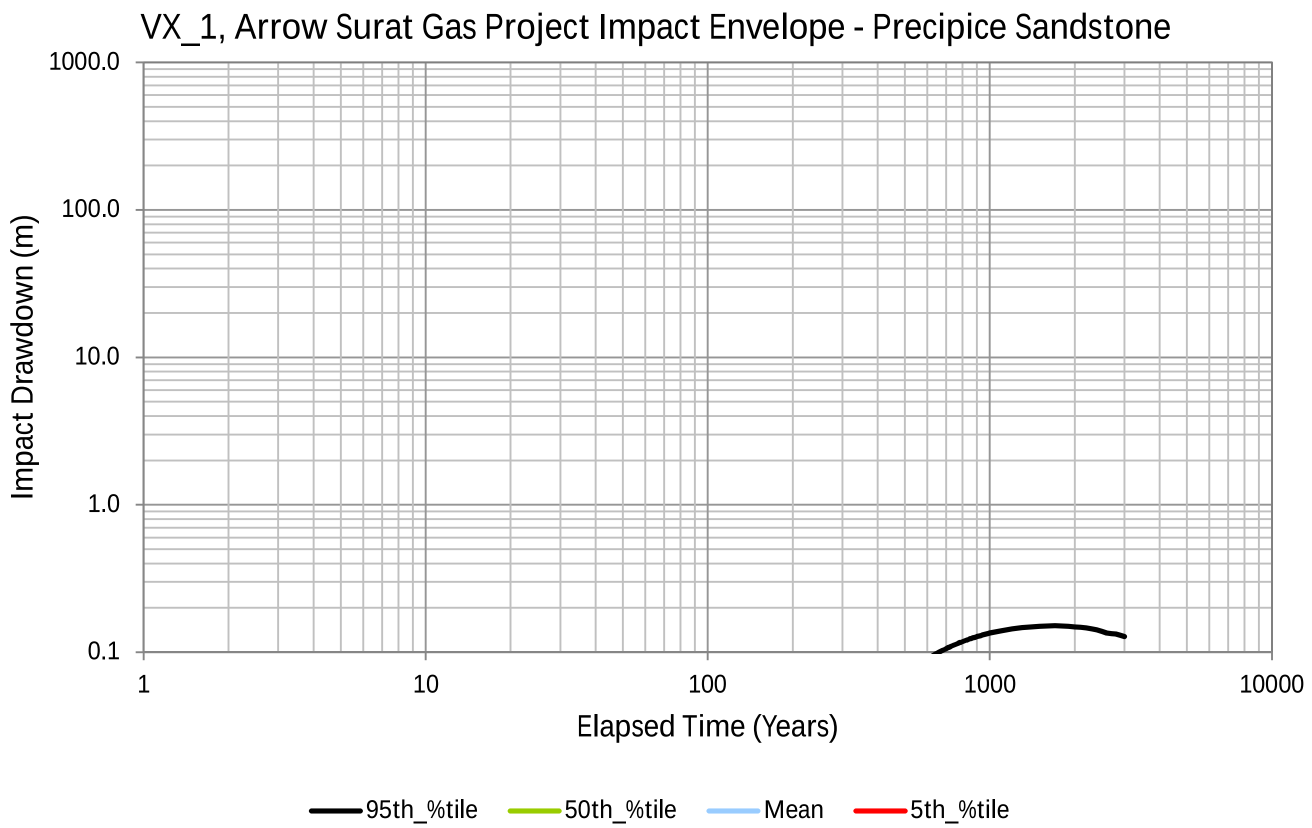
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10





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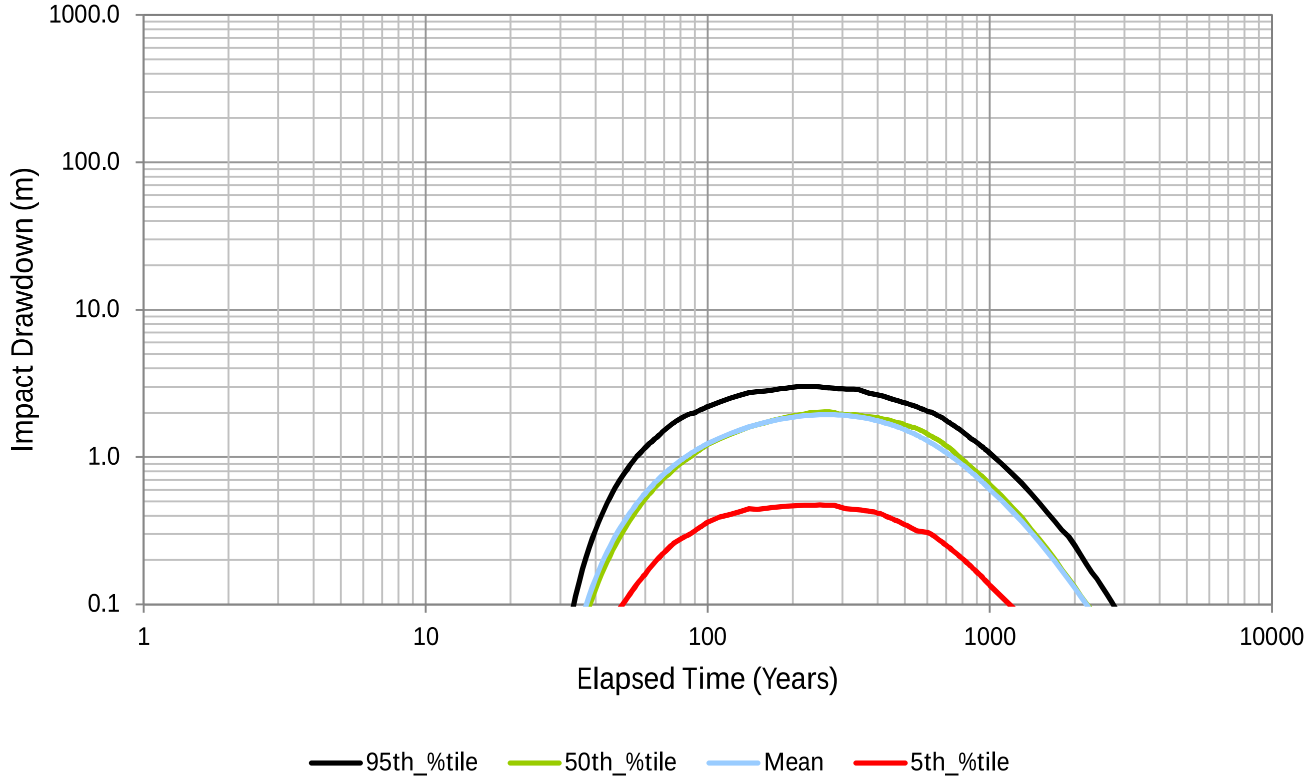
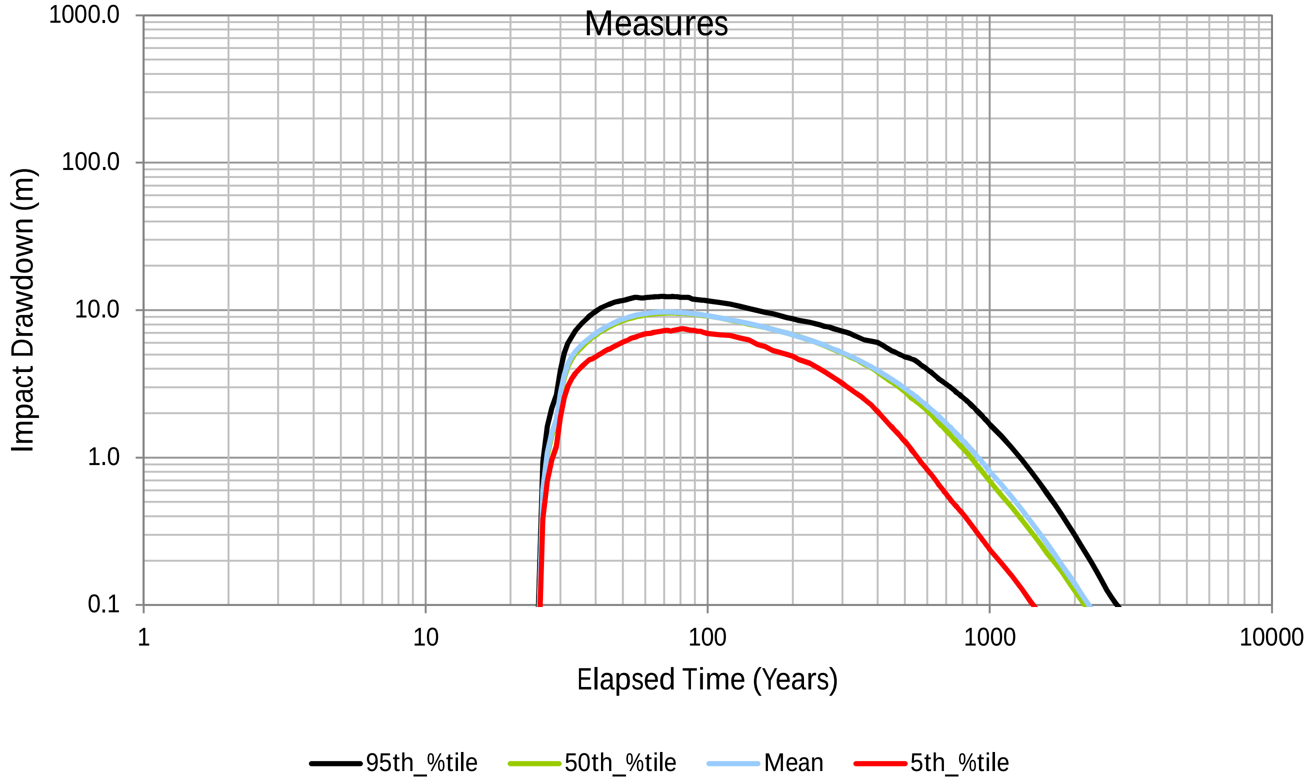
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10

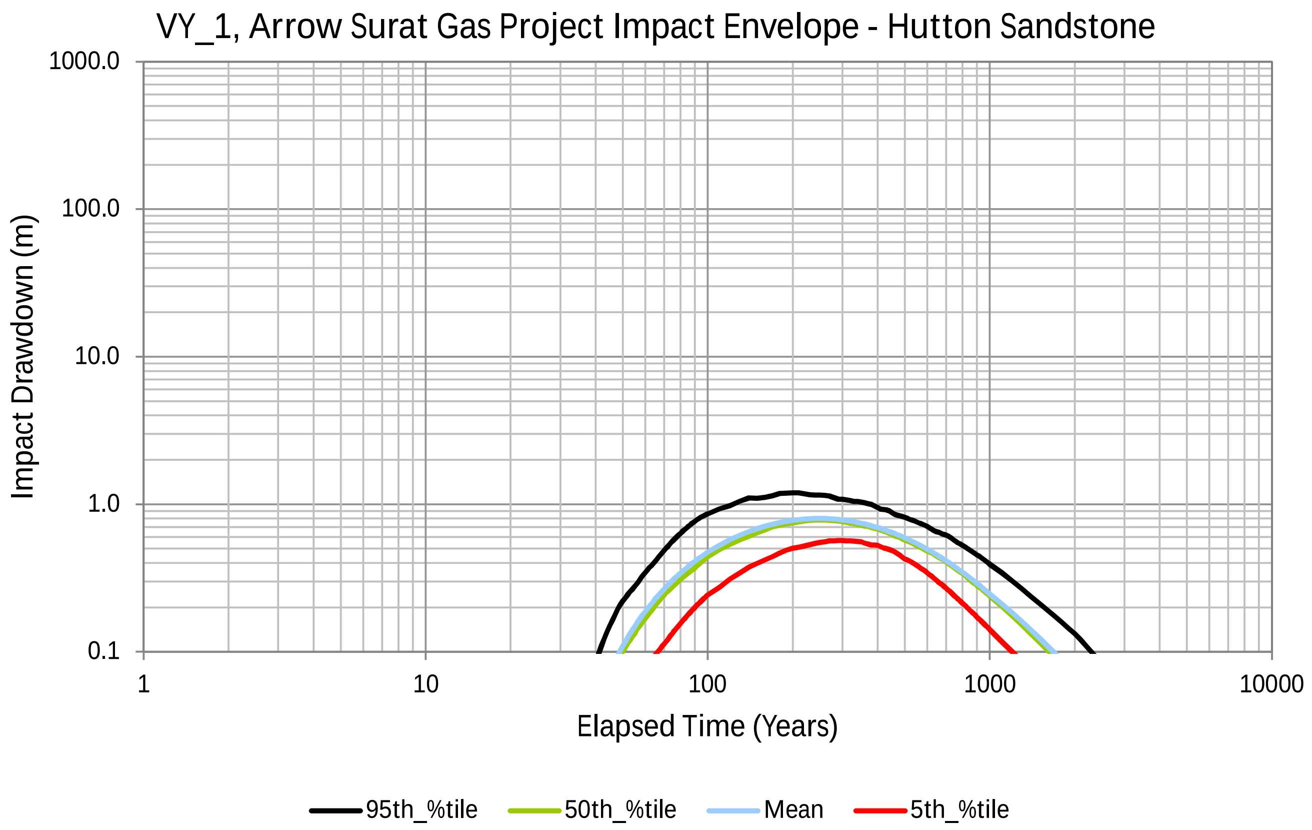
VY_1, Arrow Surat Gas Project Impact Envelope - Springbok Sandstone

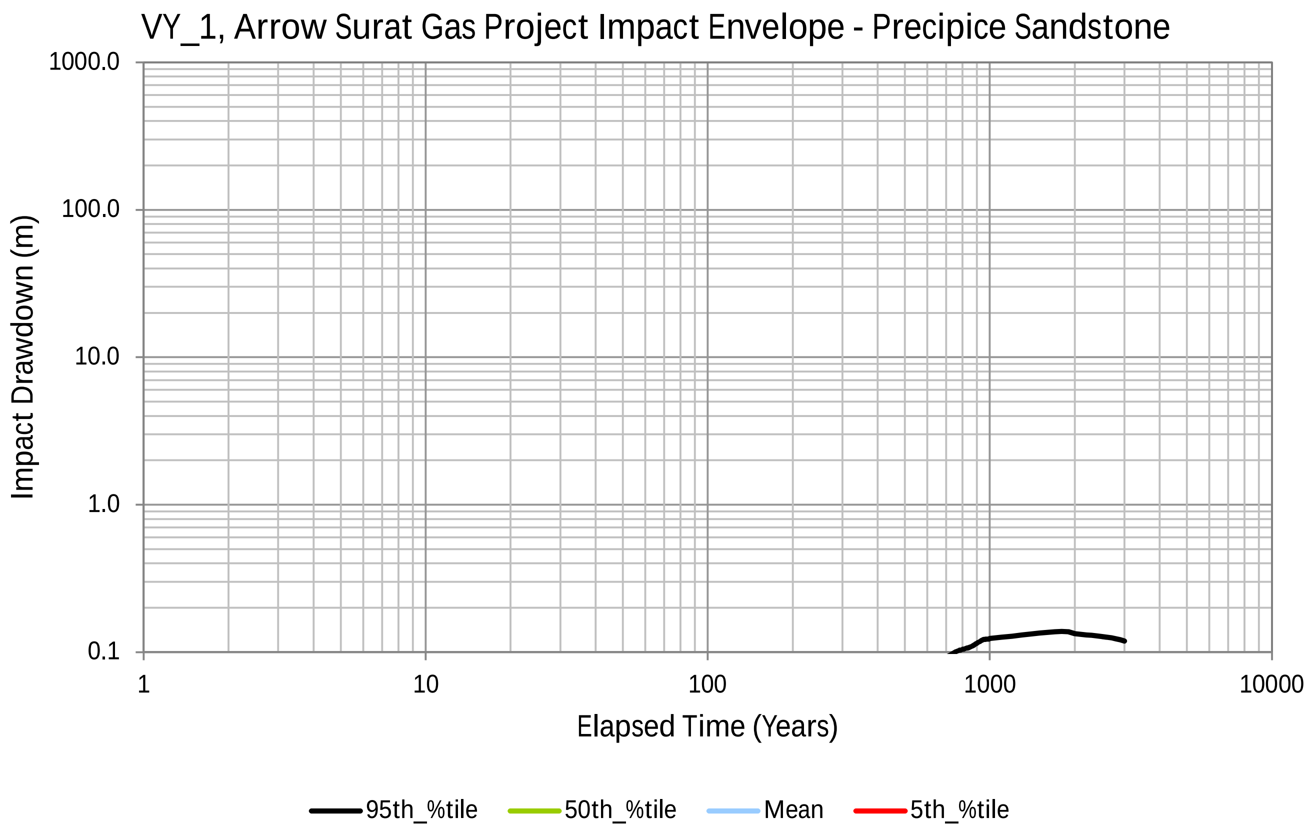


VY_1, Arrow Surat Gas Project Impact Envelope - Walloon Coal Measures



Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10





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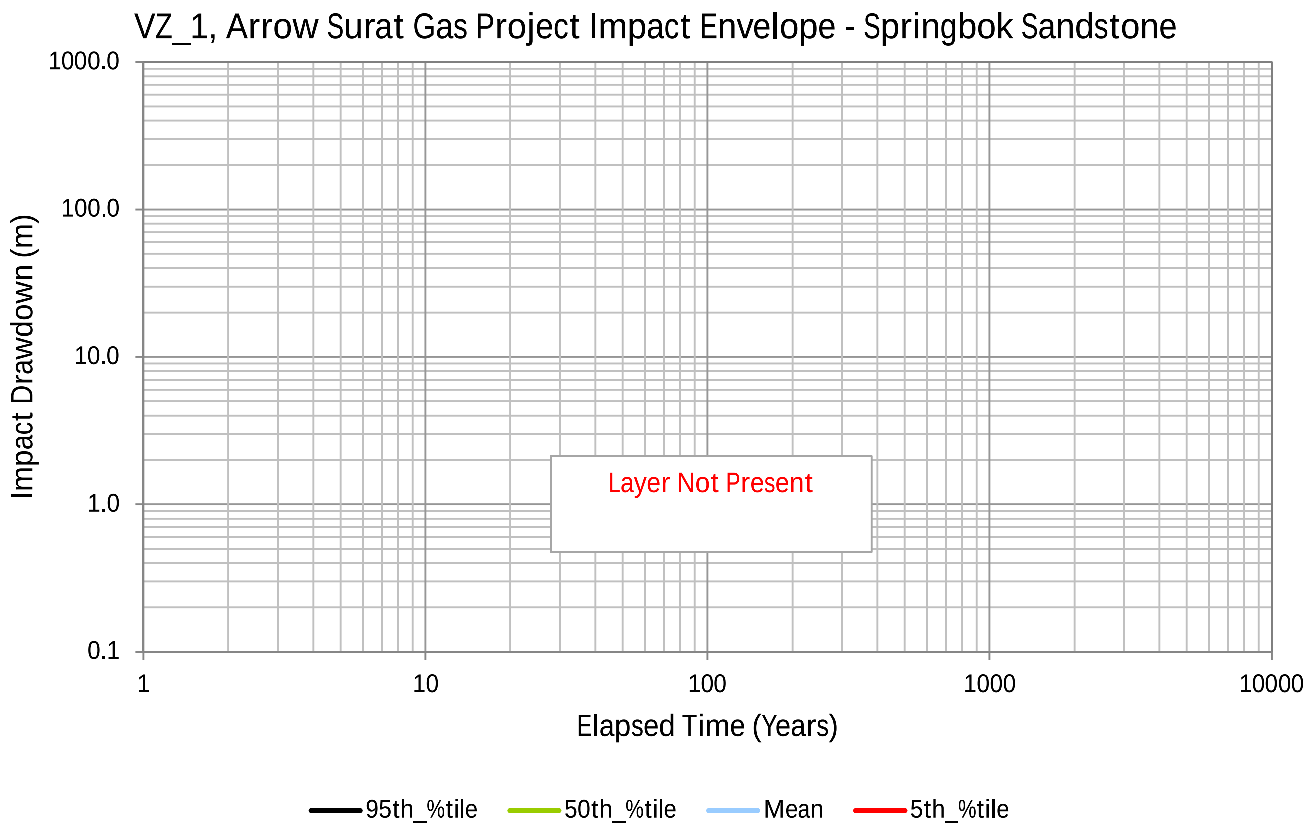
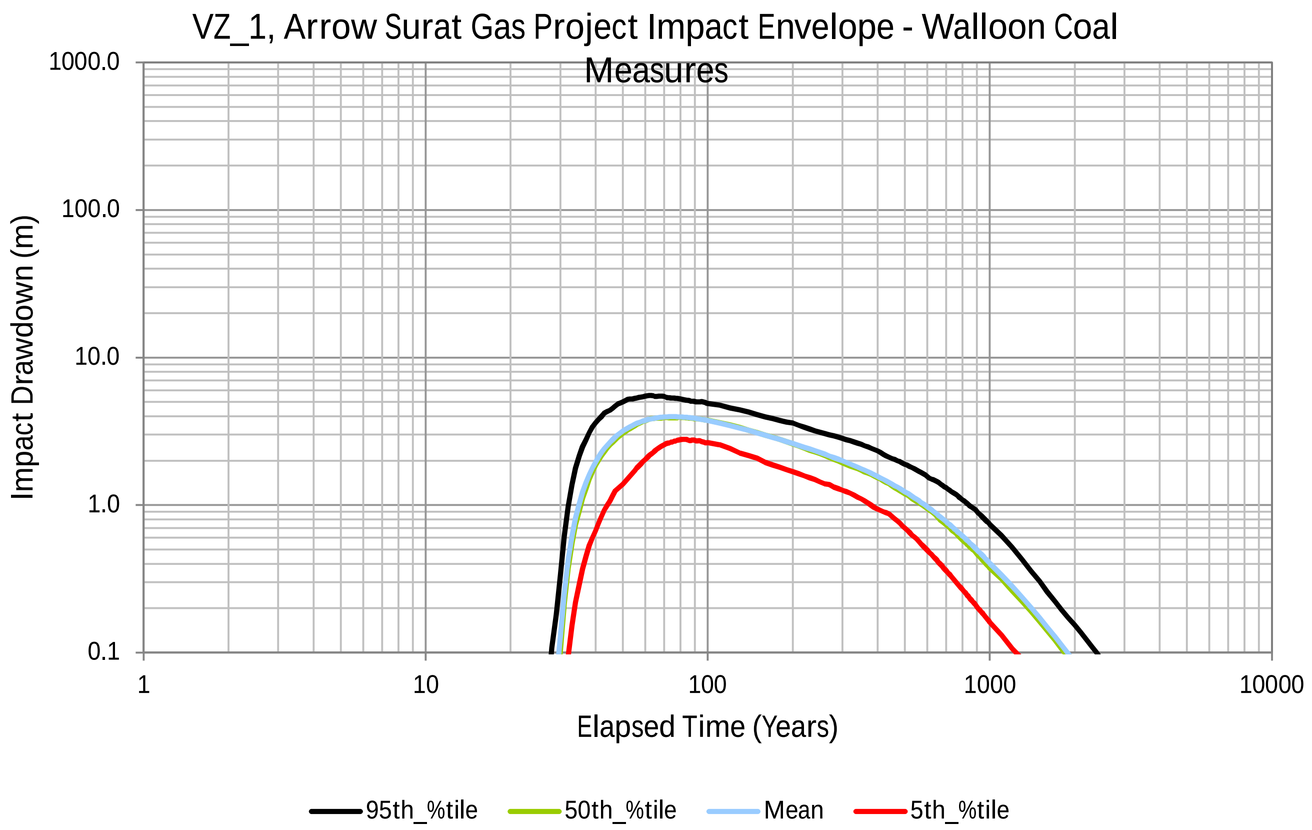
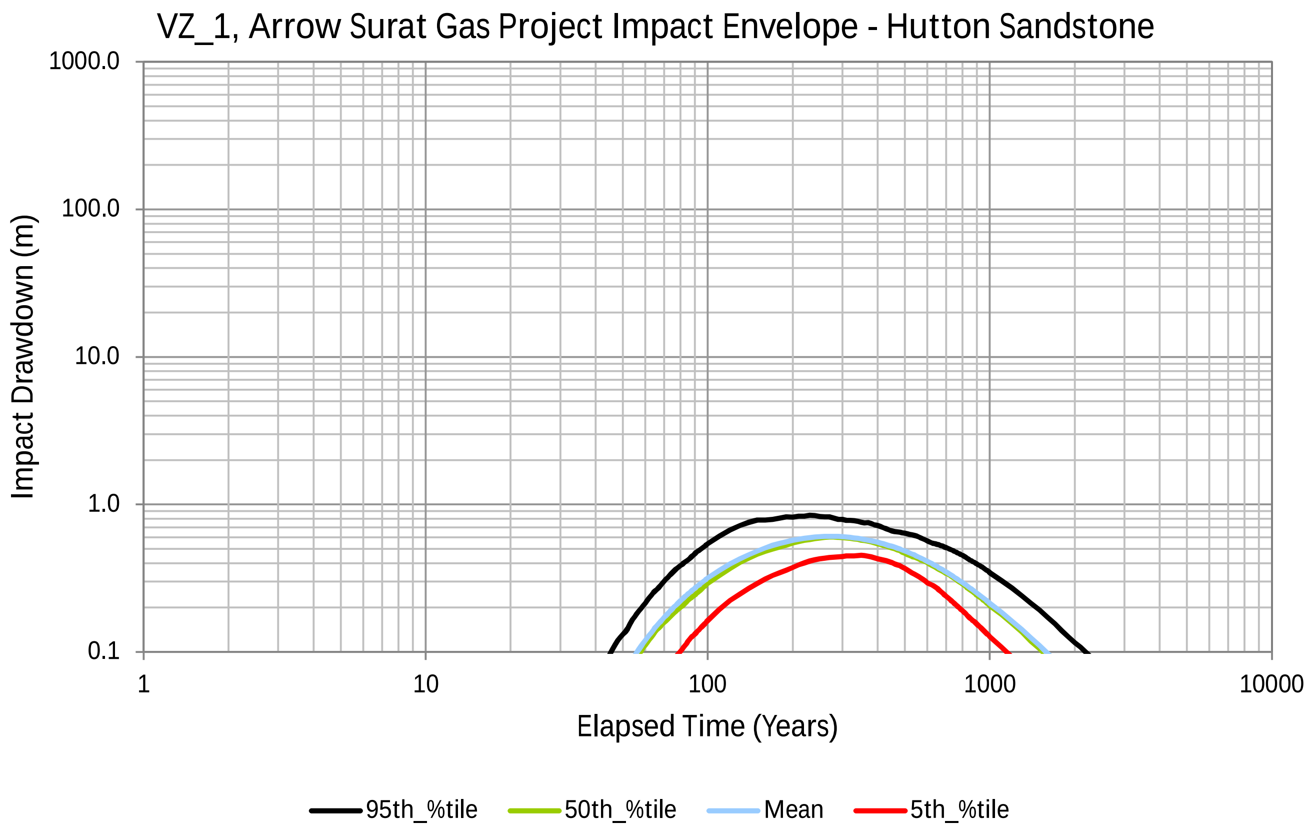
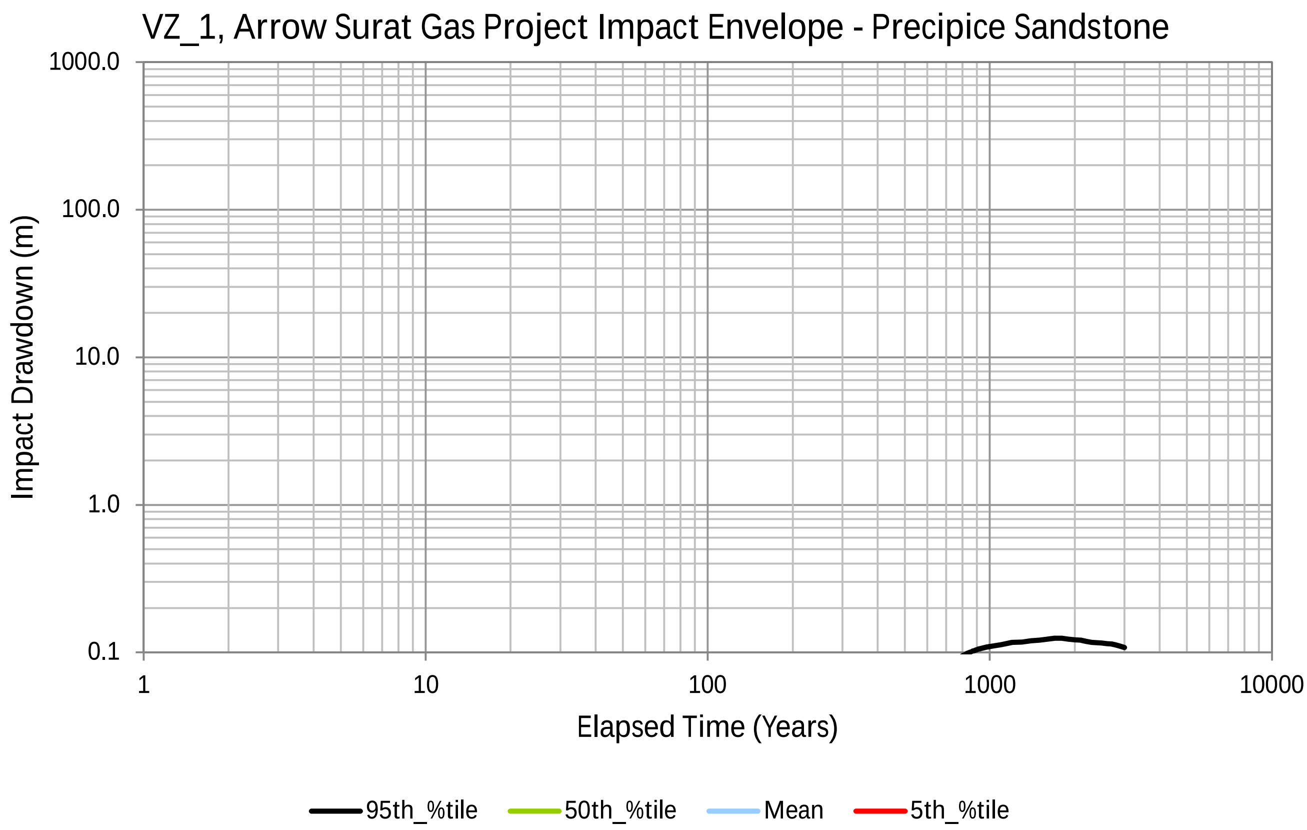
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10

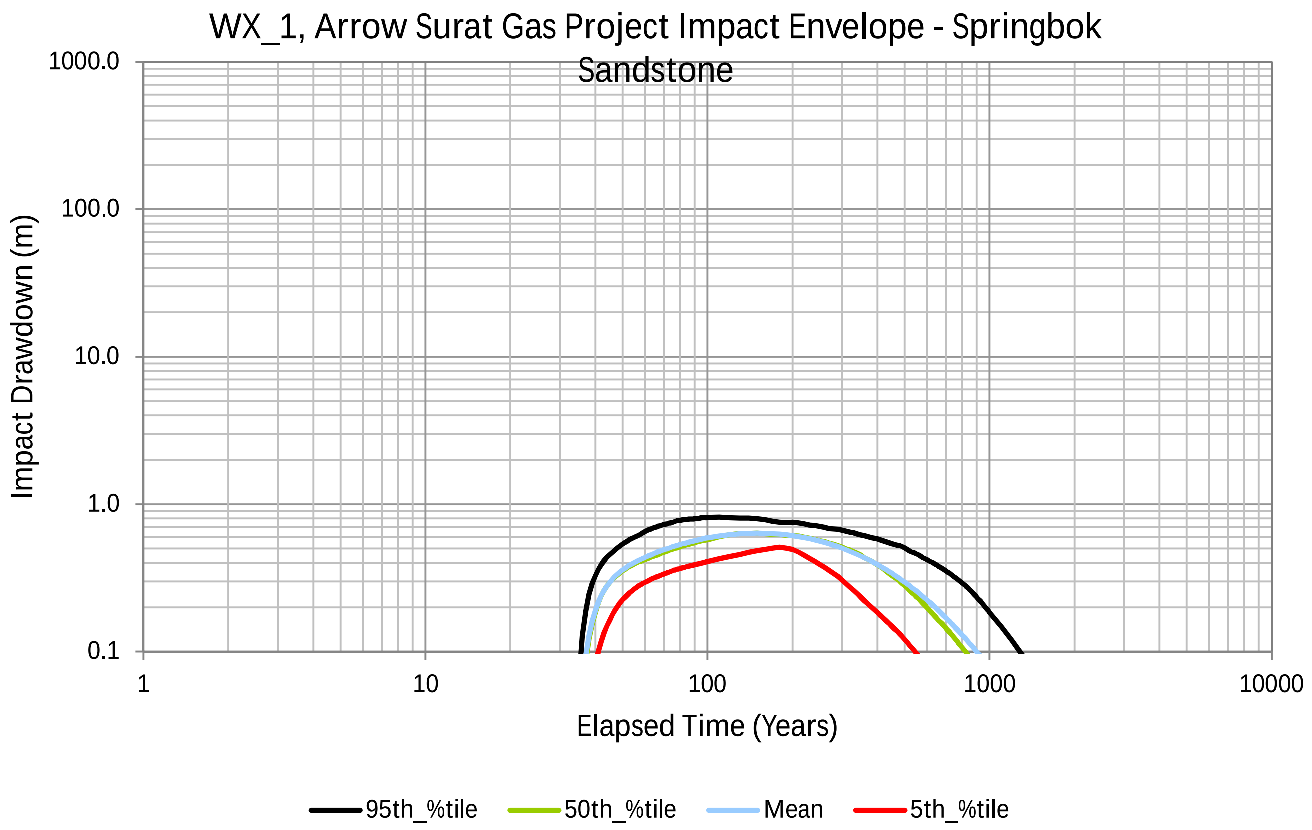


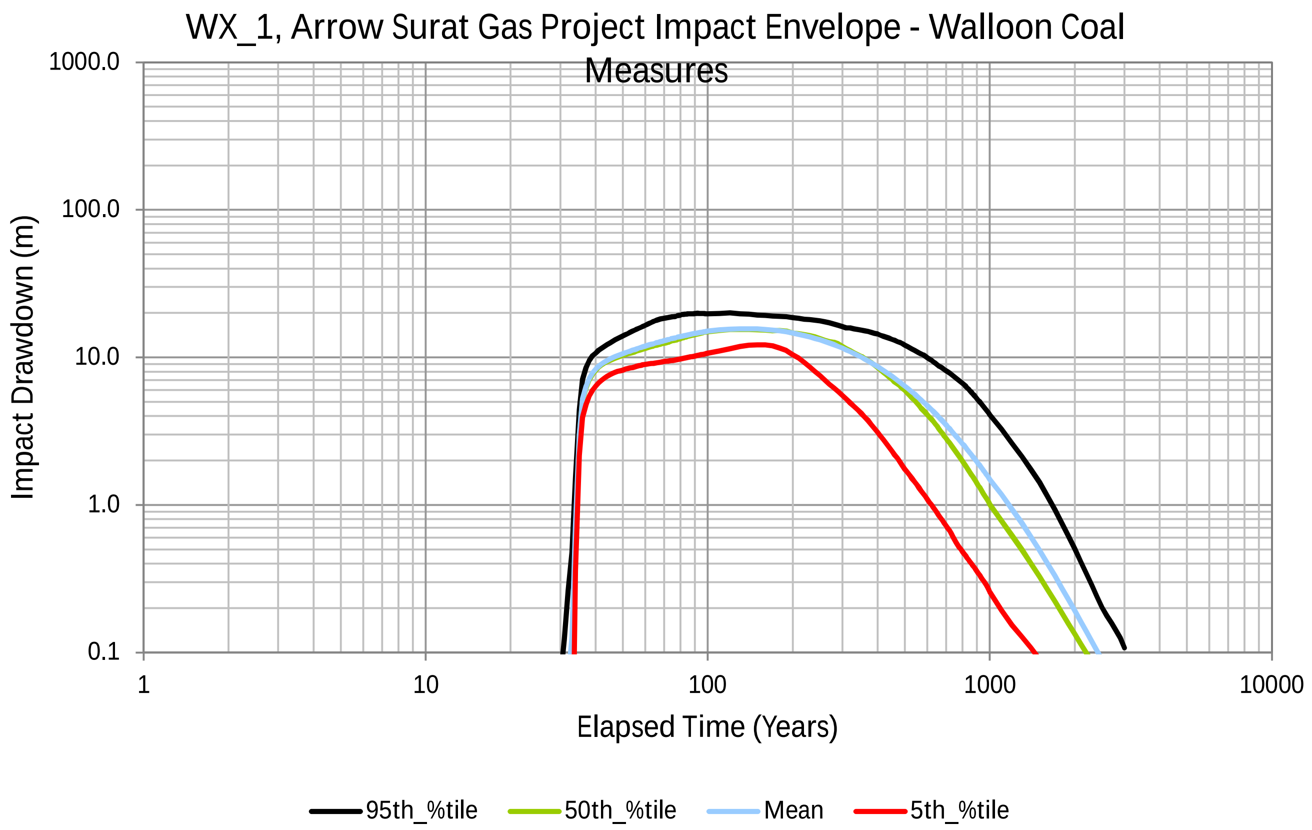



VZ_1, Arrow Surat Gas Project Impact Envelope - Hutton Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile


VZ_1, Arrow Surat Gas Project Impact Envelope - Precipice Sandstone
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10





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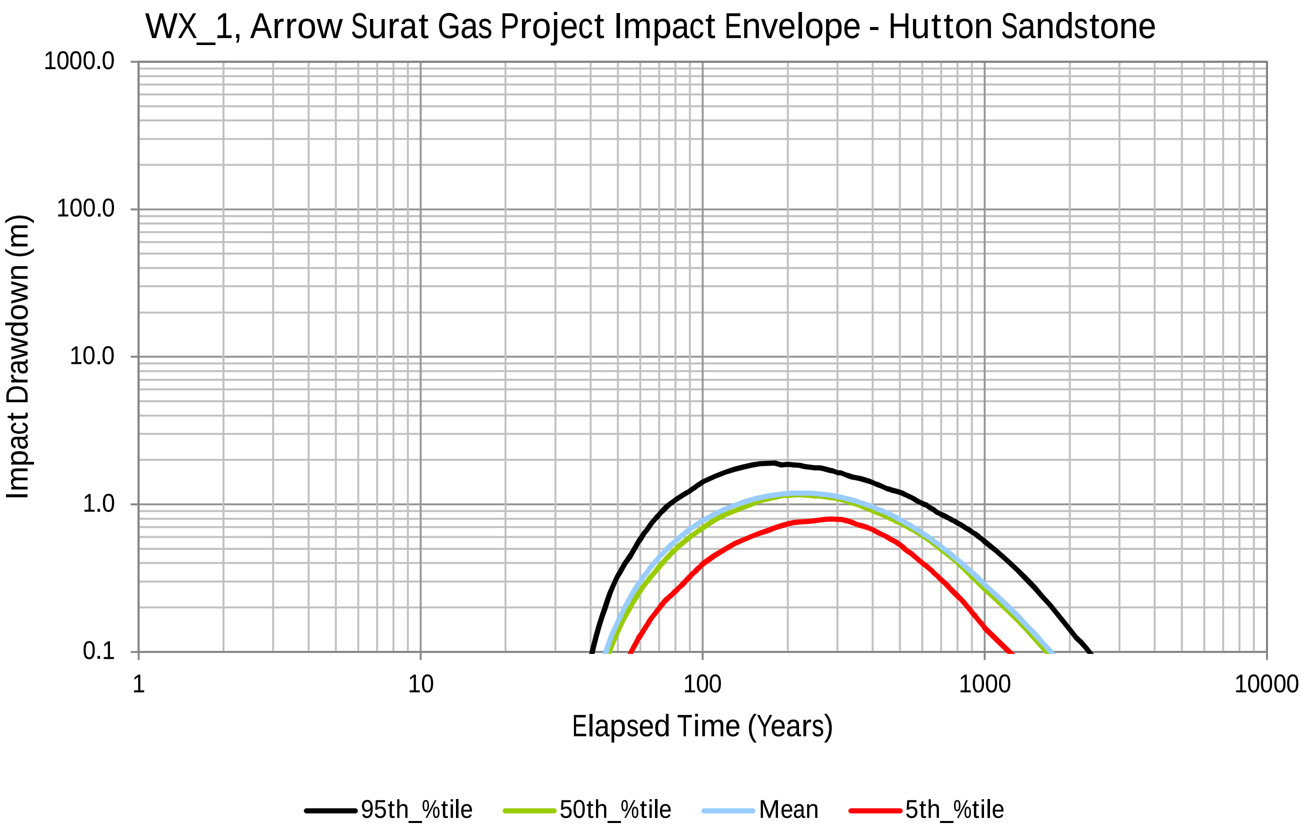
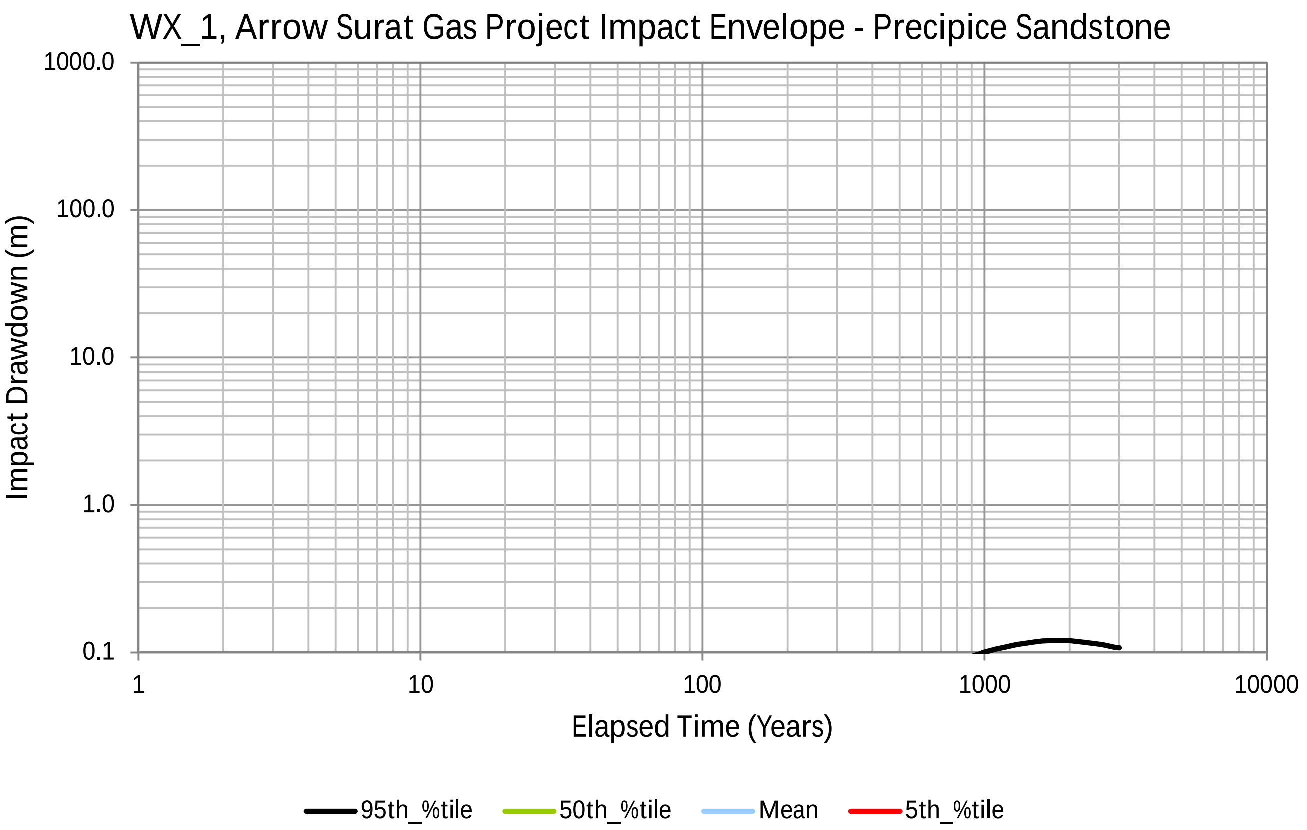
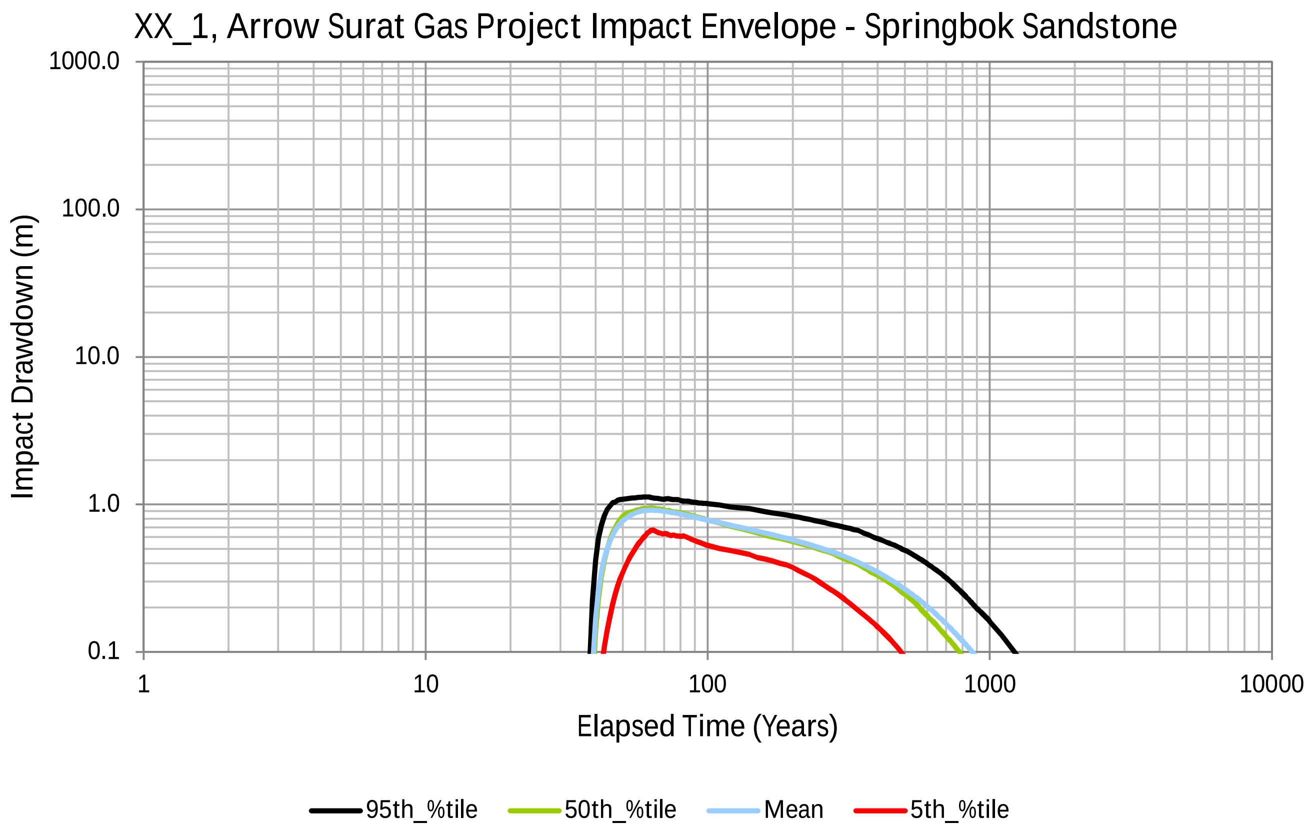
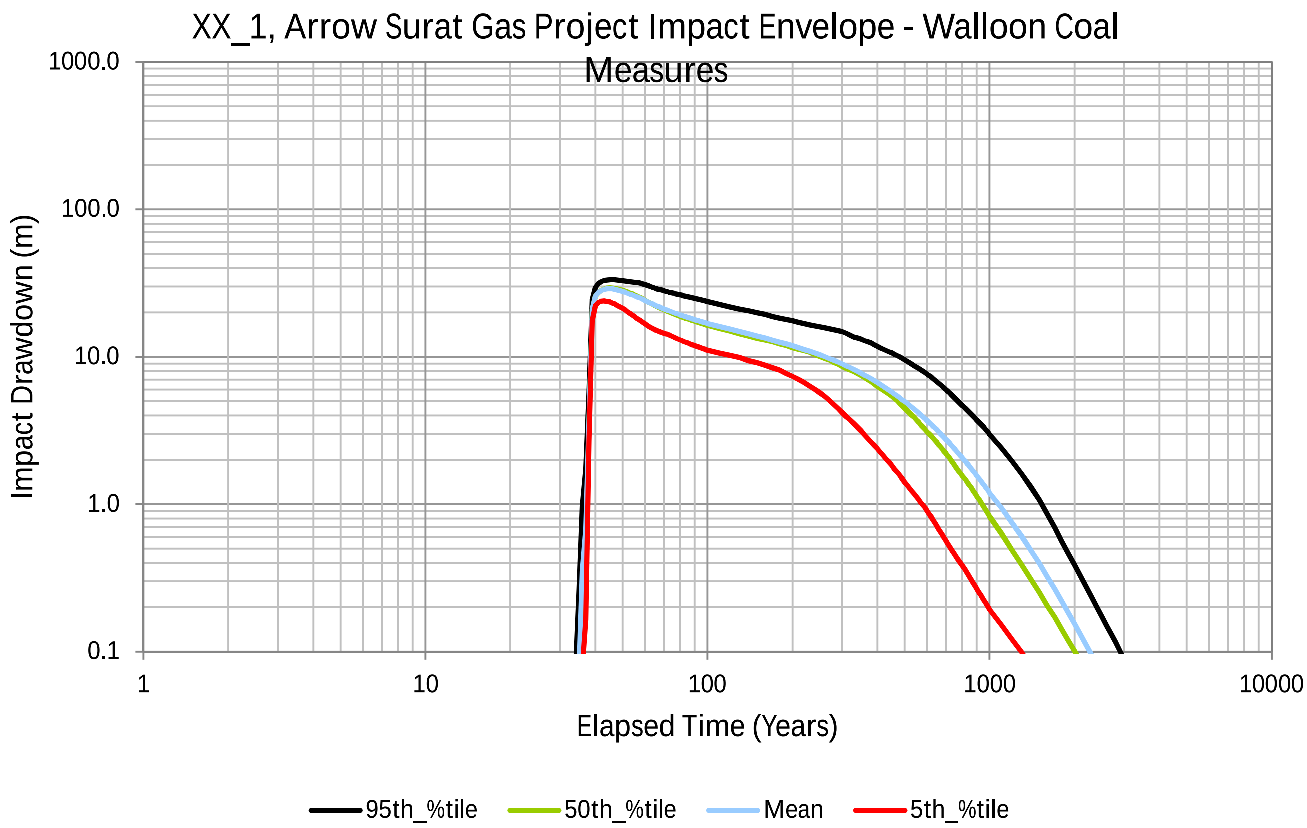
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10





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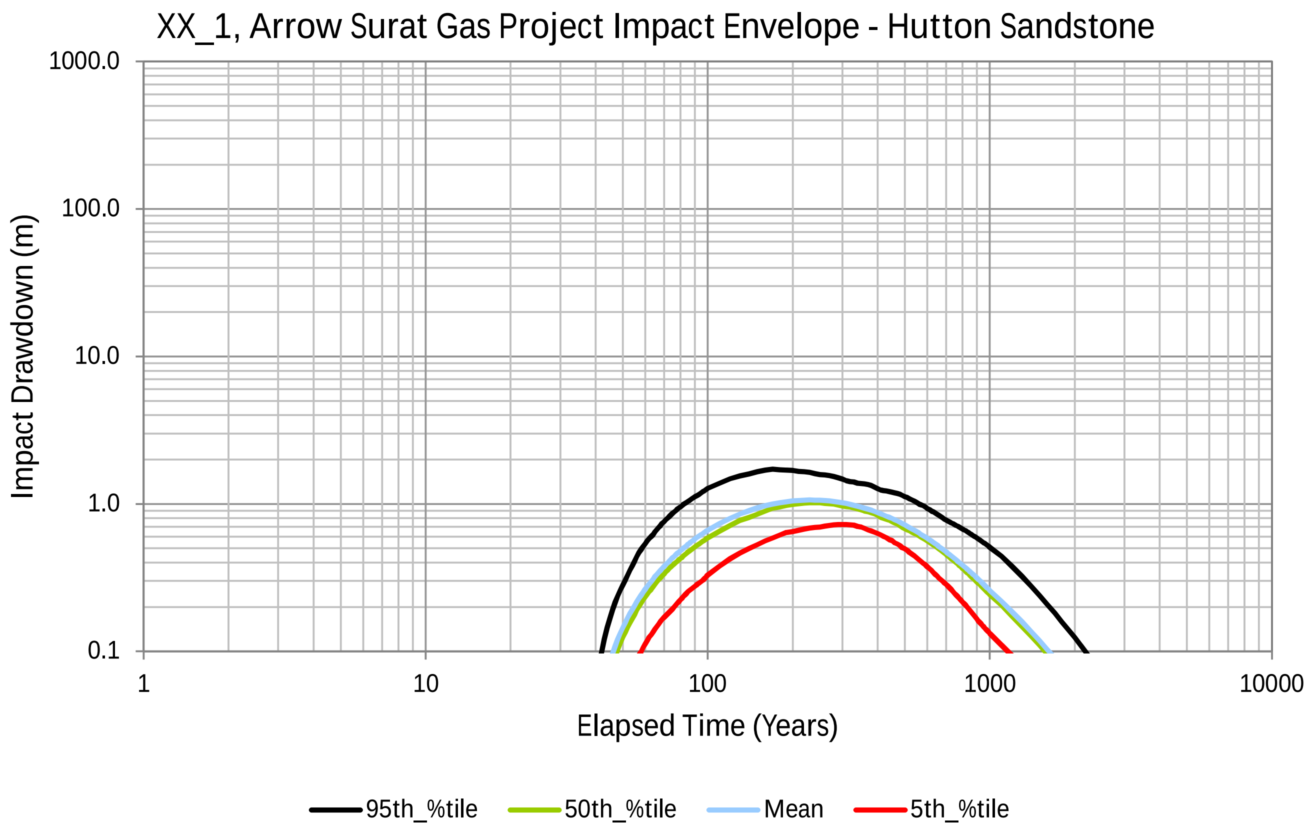
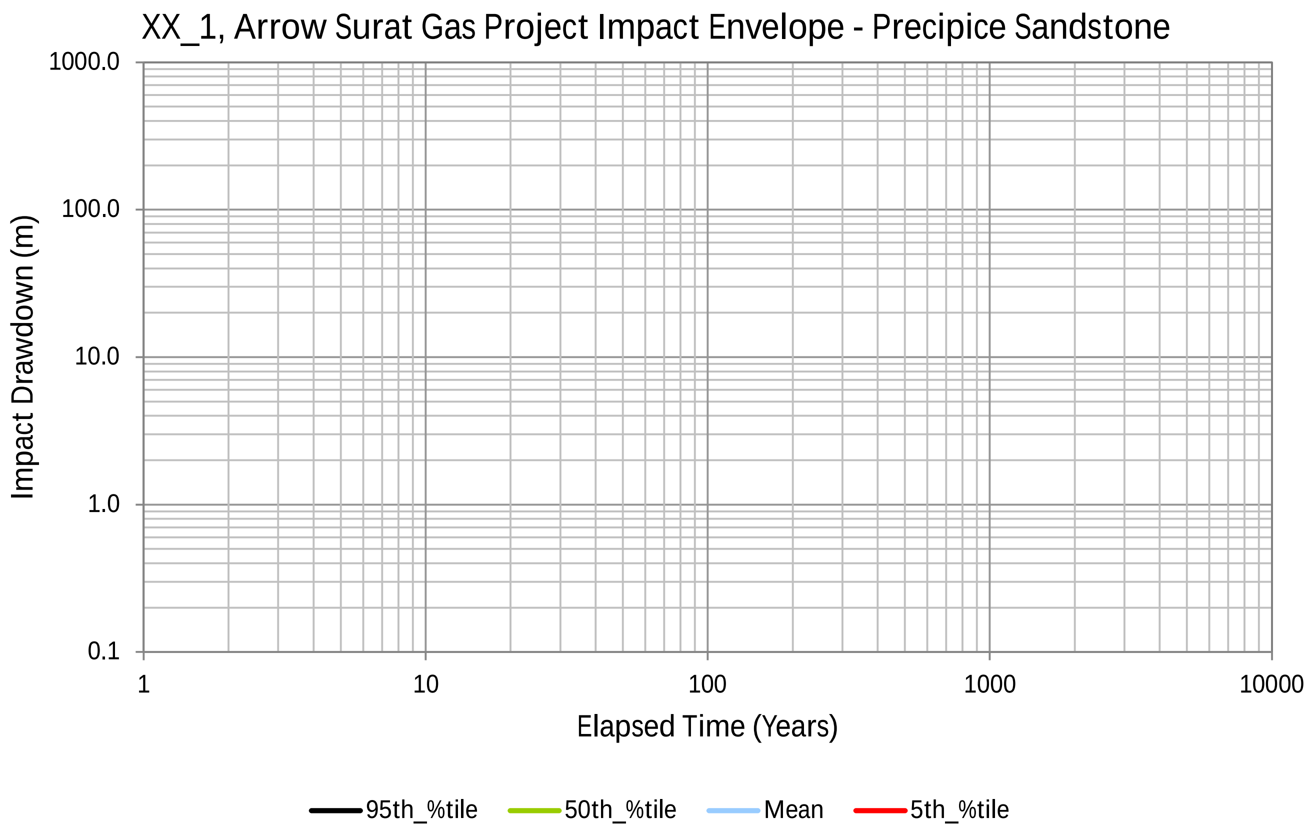
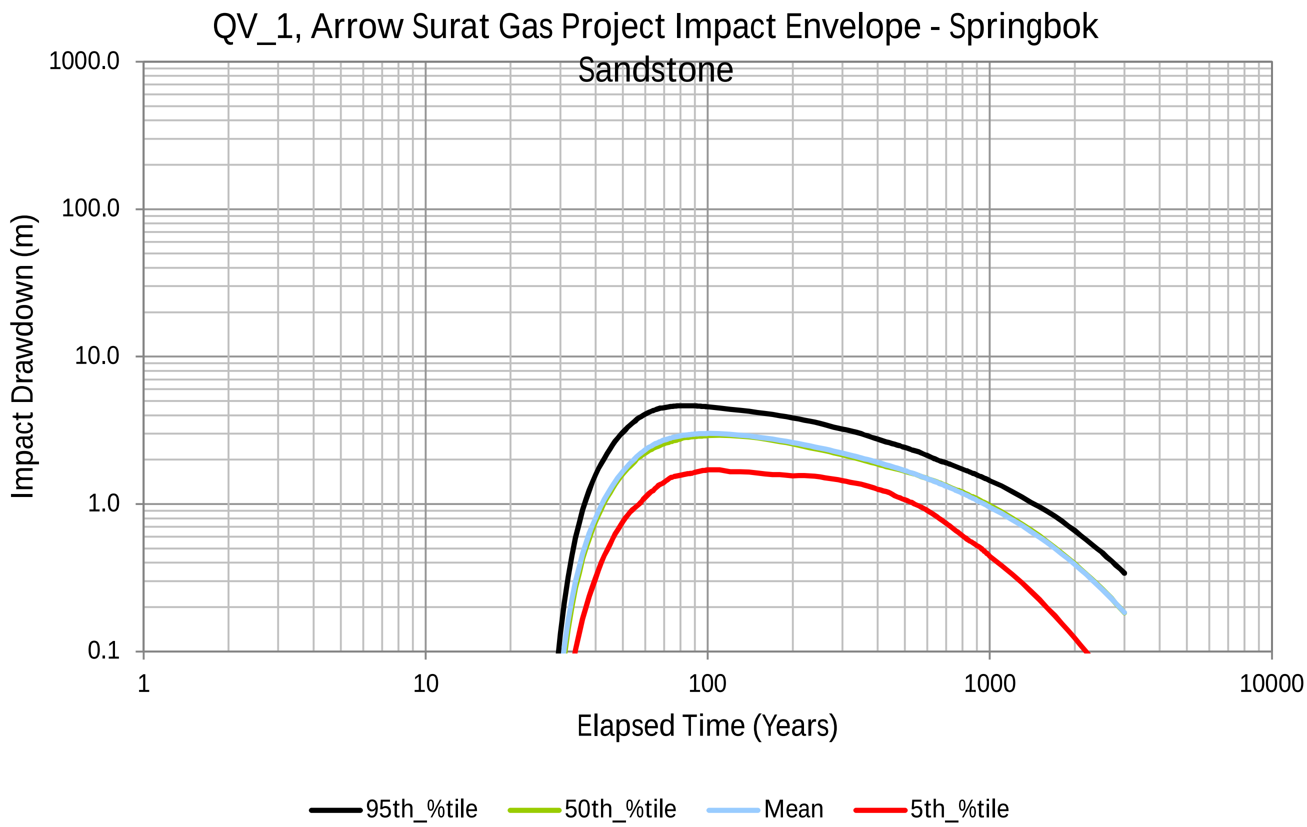
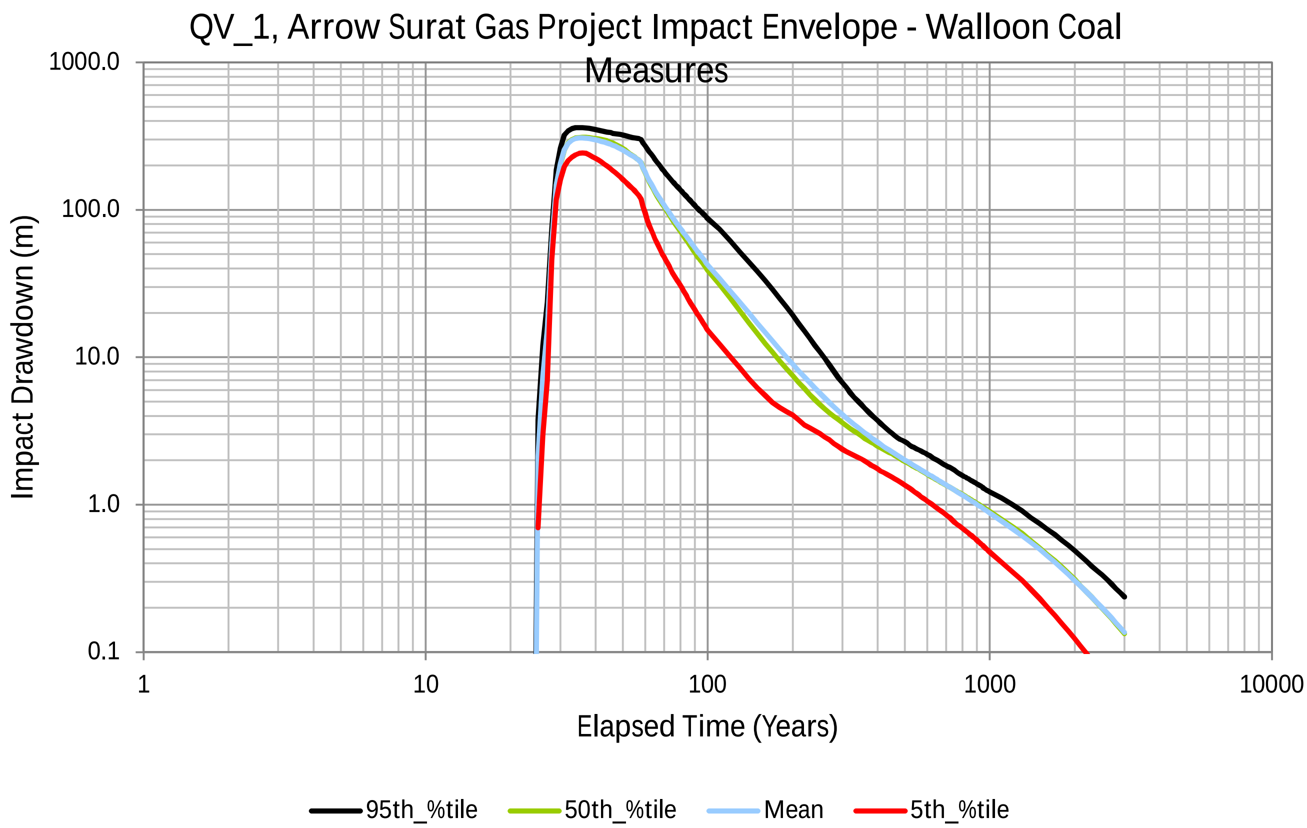
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 10



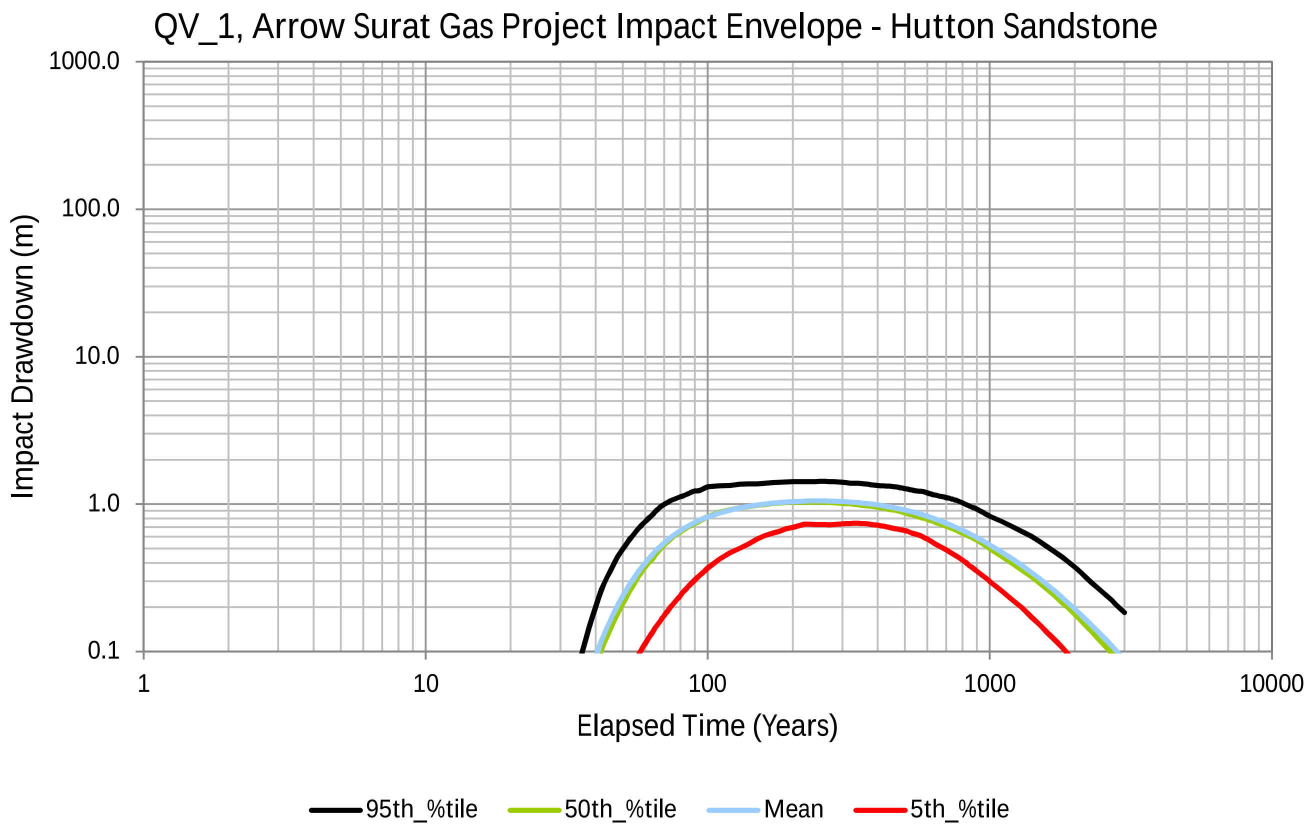


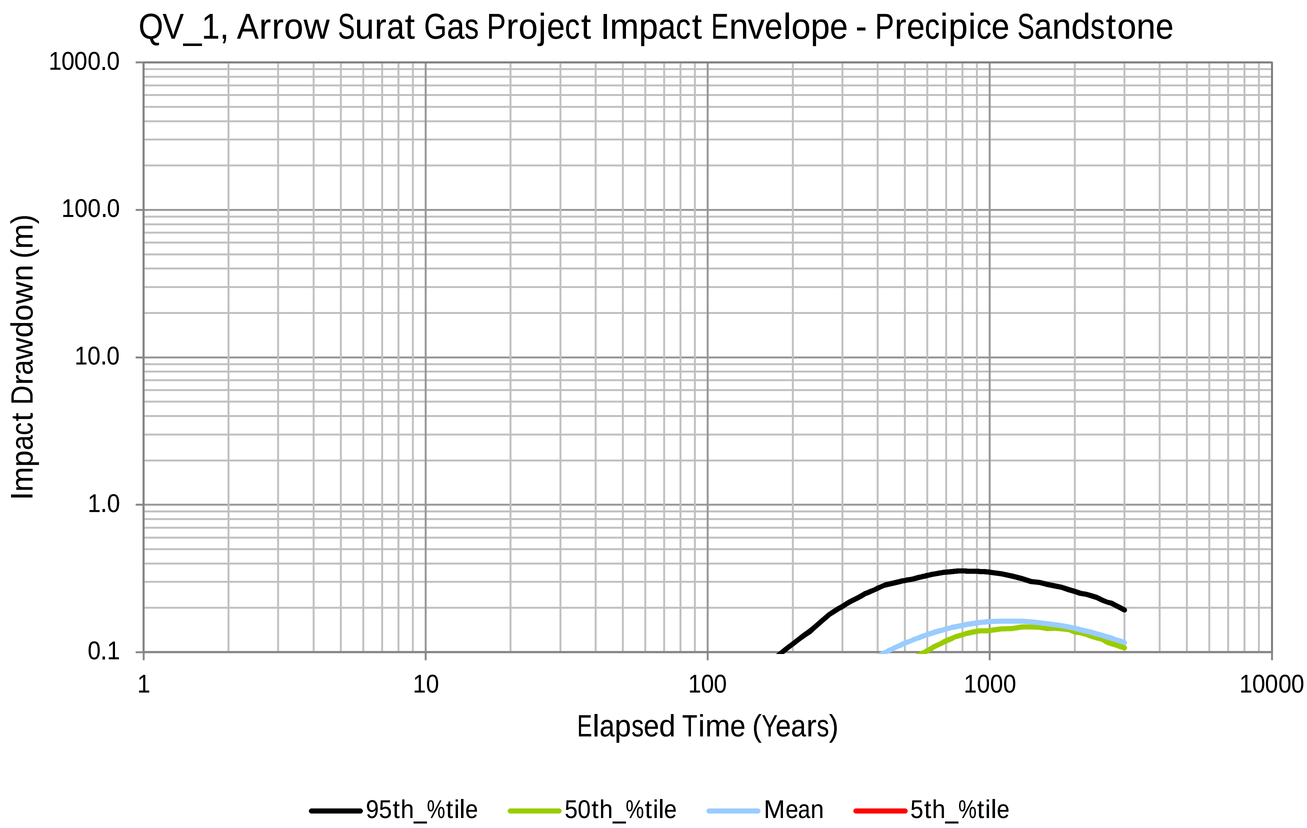
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 11





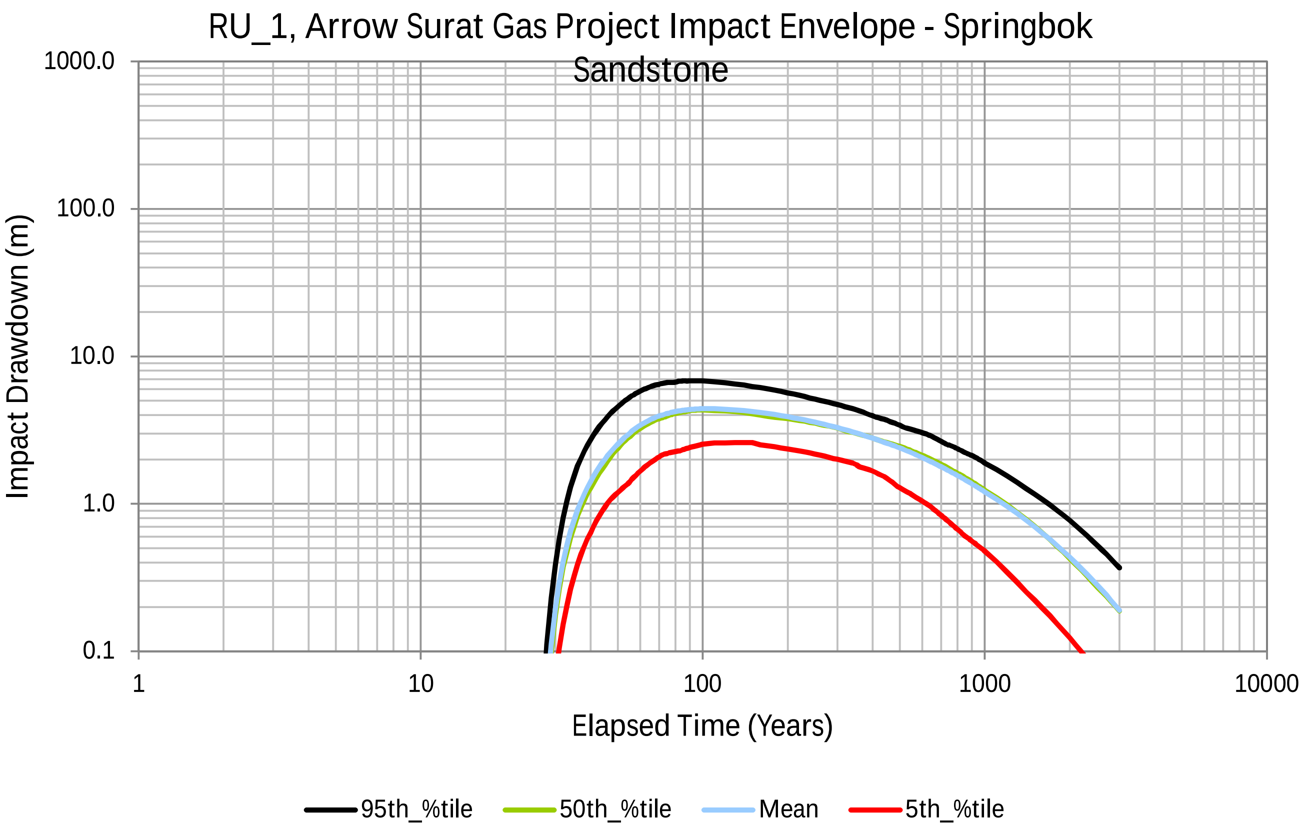
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 11

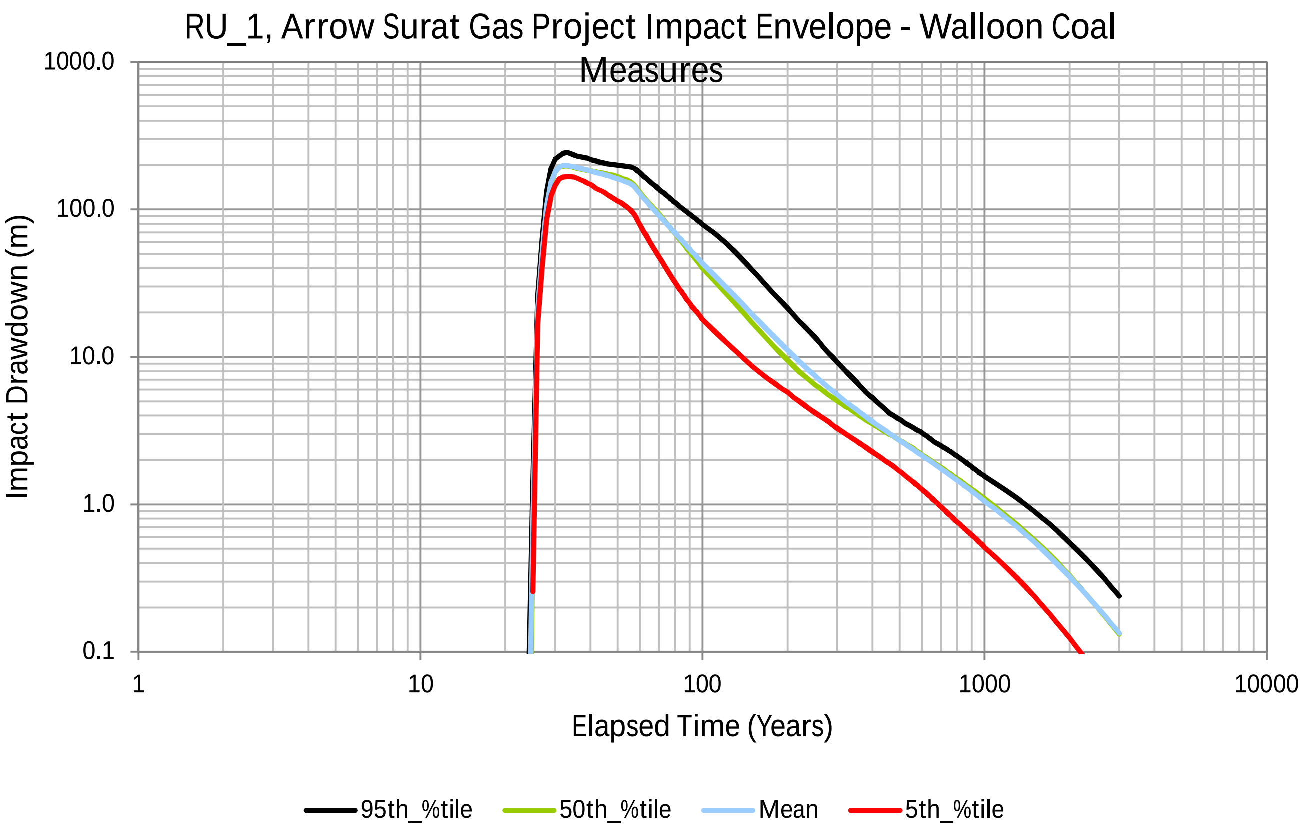




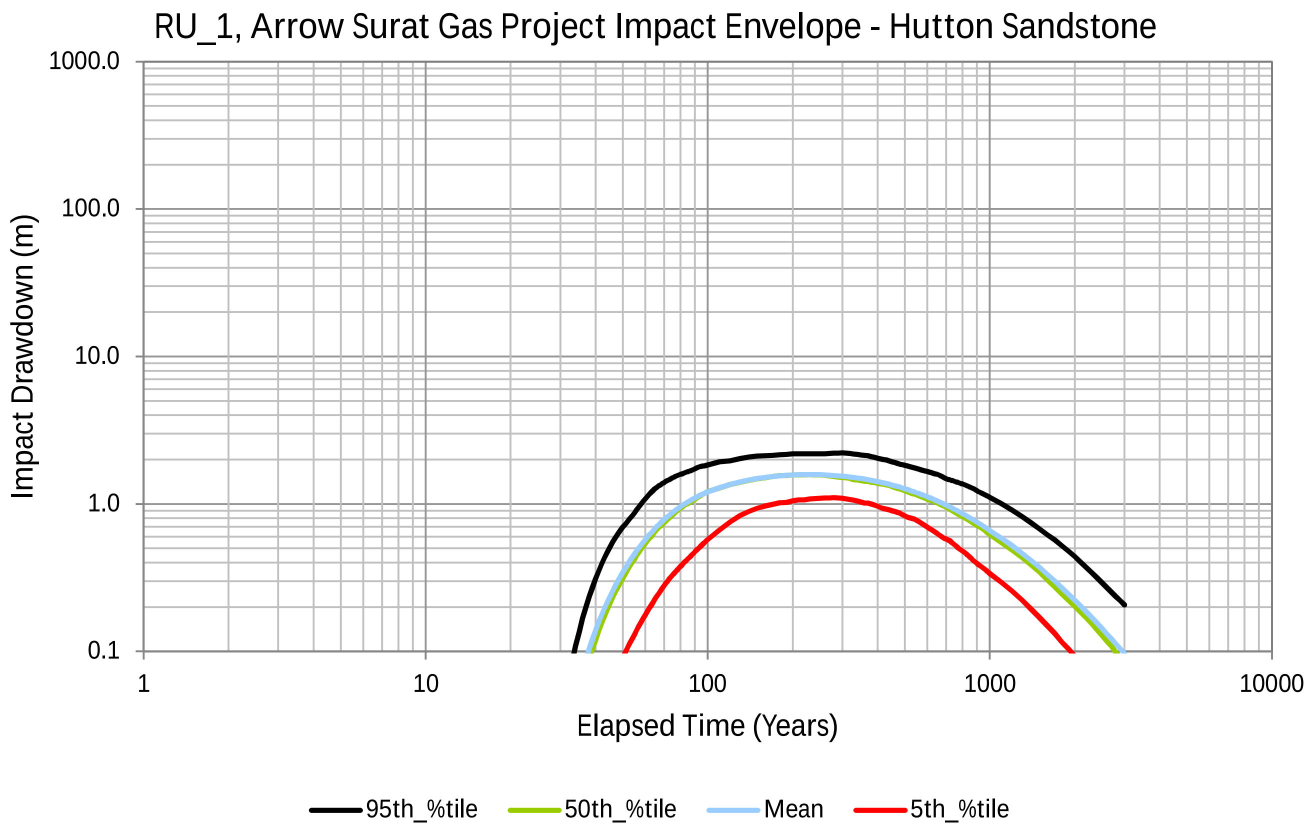
G:\41\26392\Tech\Design\GWModel\NSMC_results\percentile_calc_hydr\Hydrograph_stats_arrcase (Drainage_Area_11)

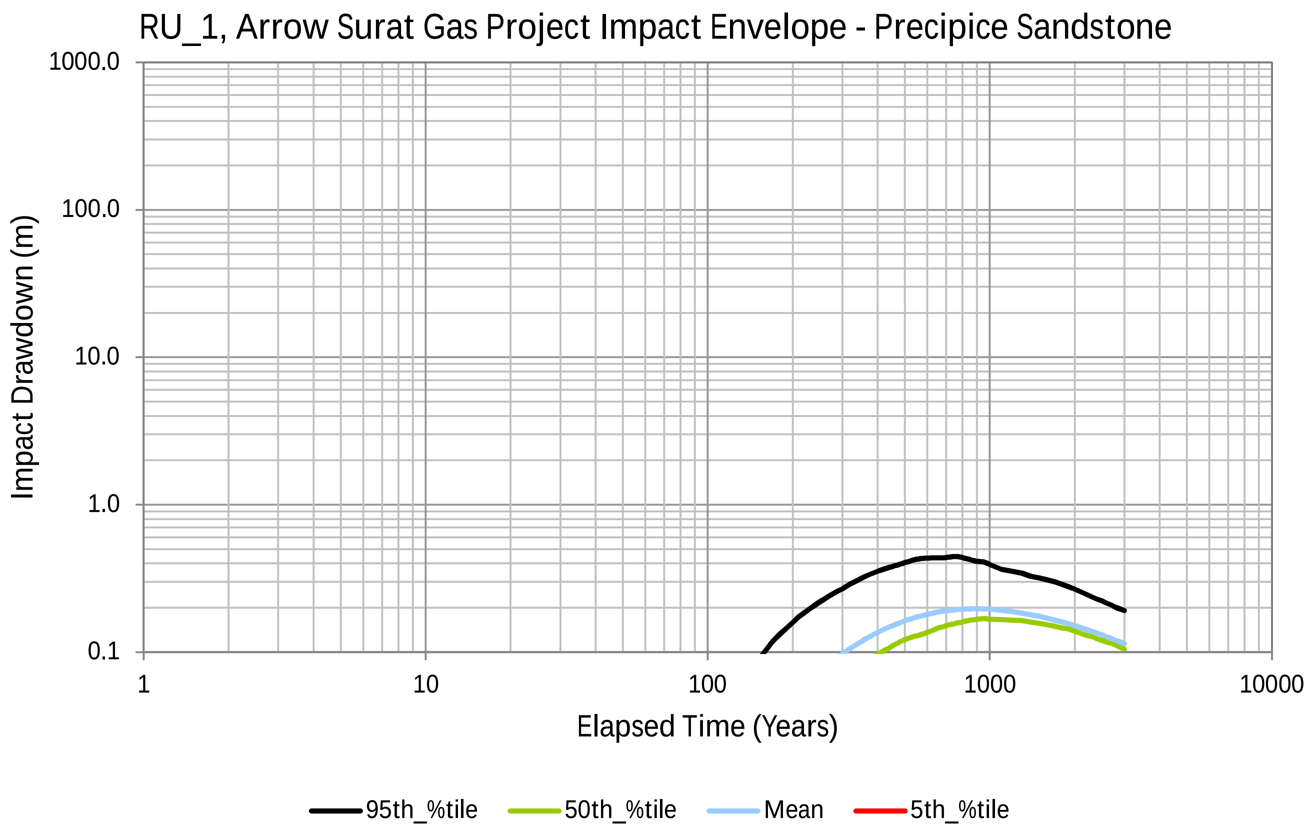
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 11



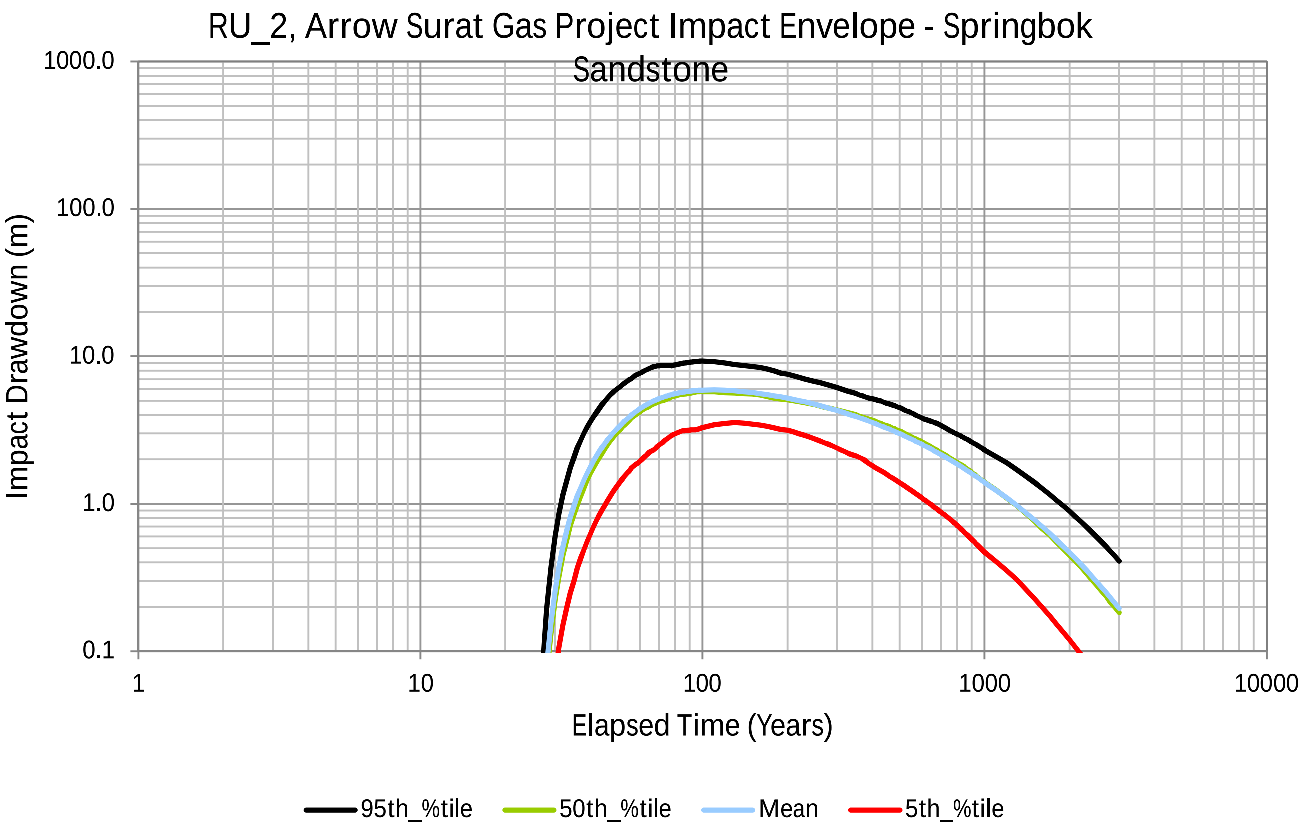


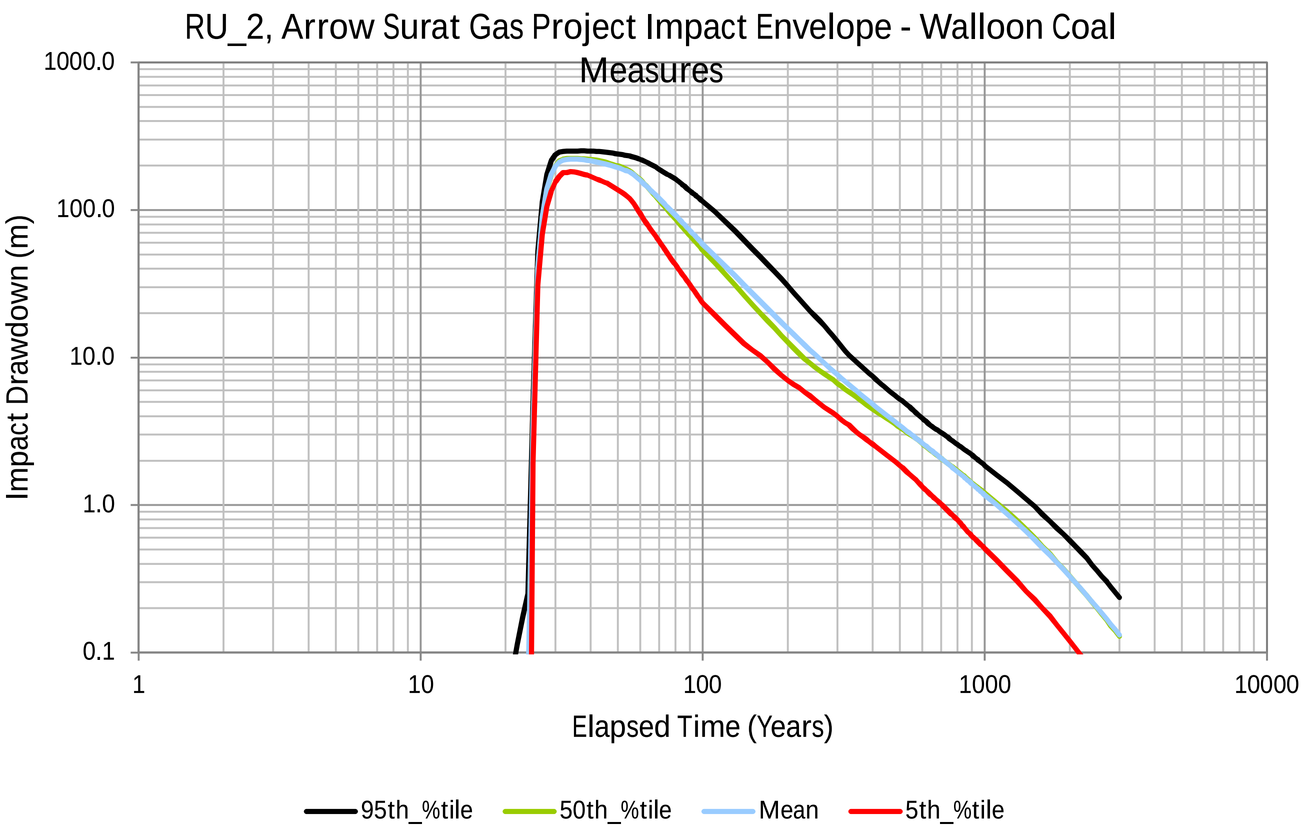
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 11





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 11





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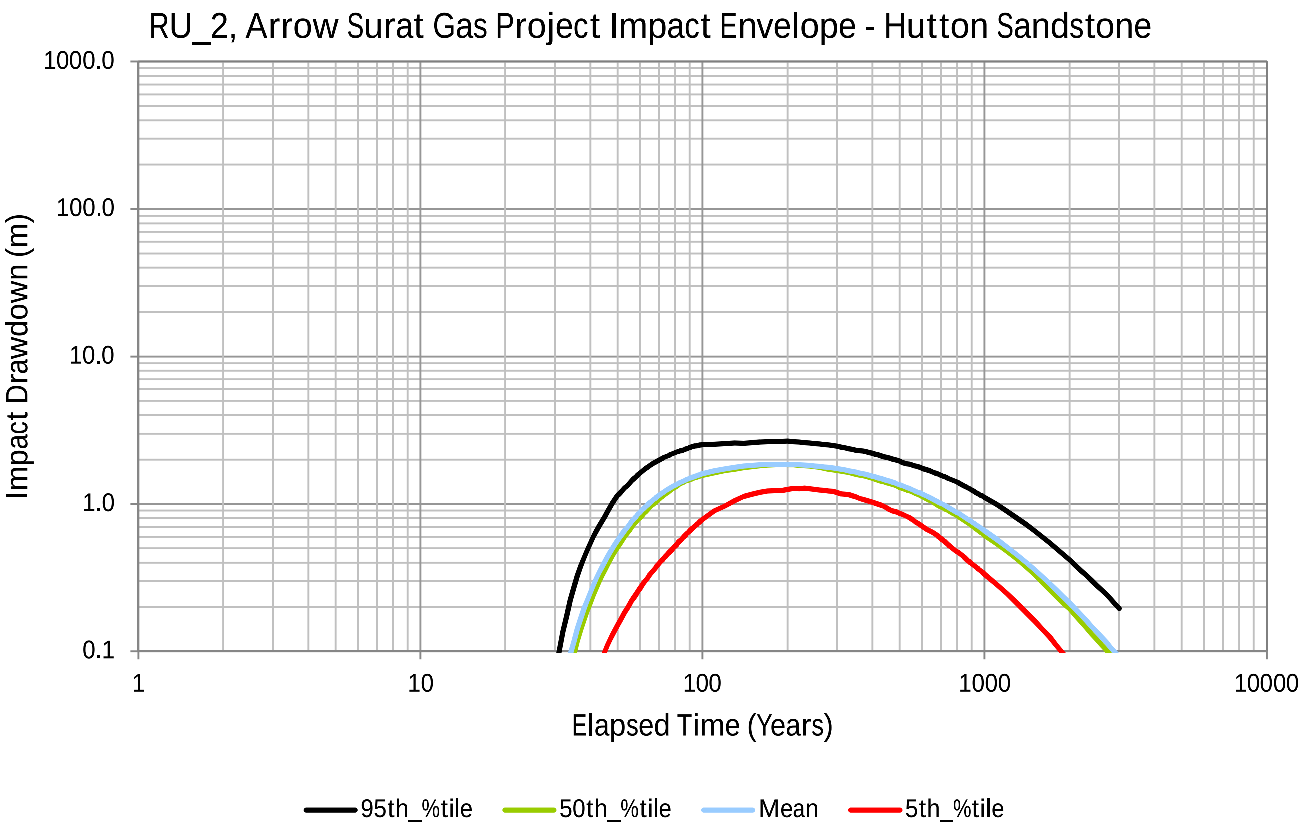
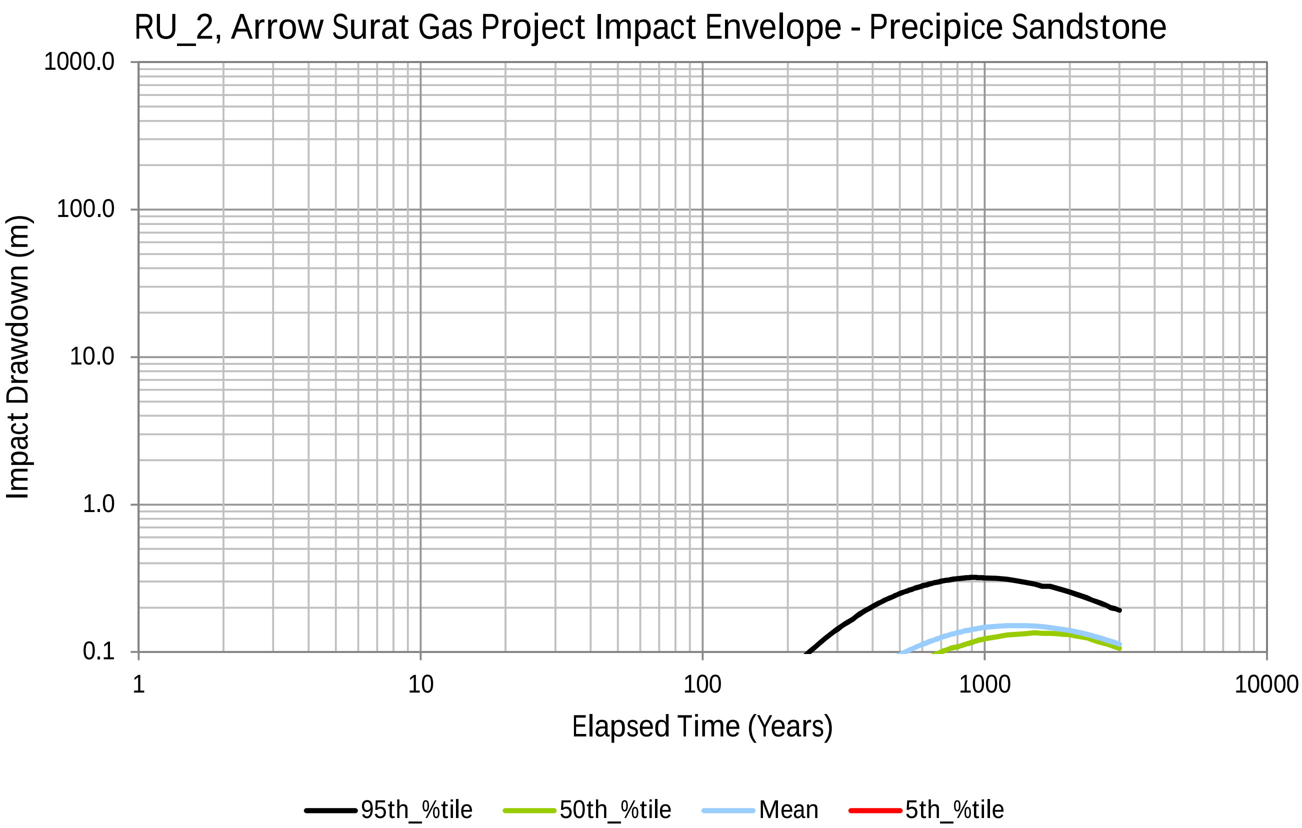
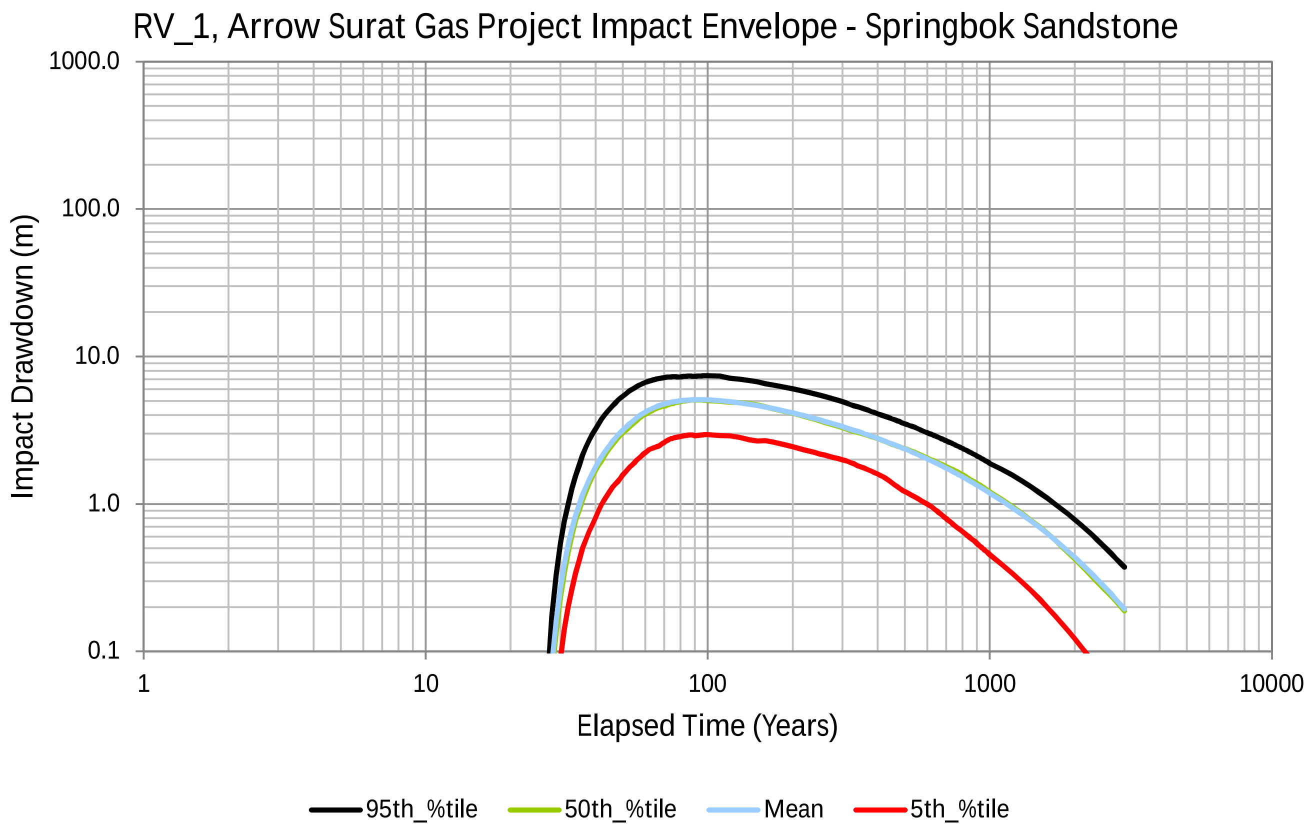
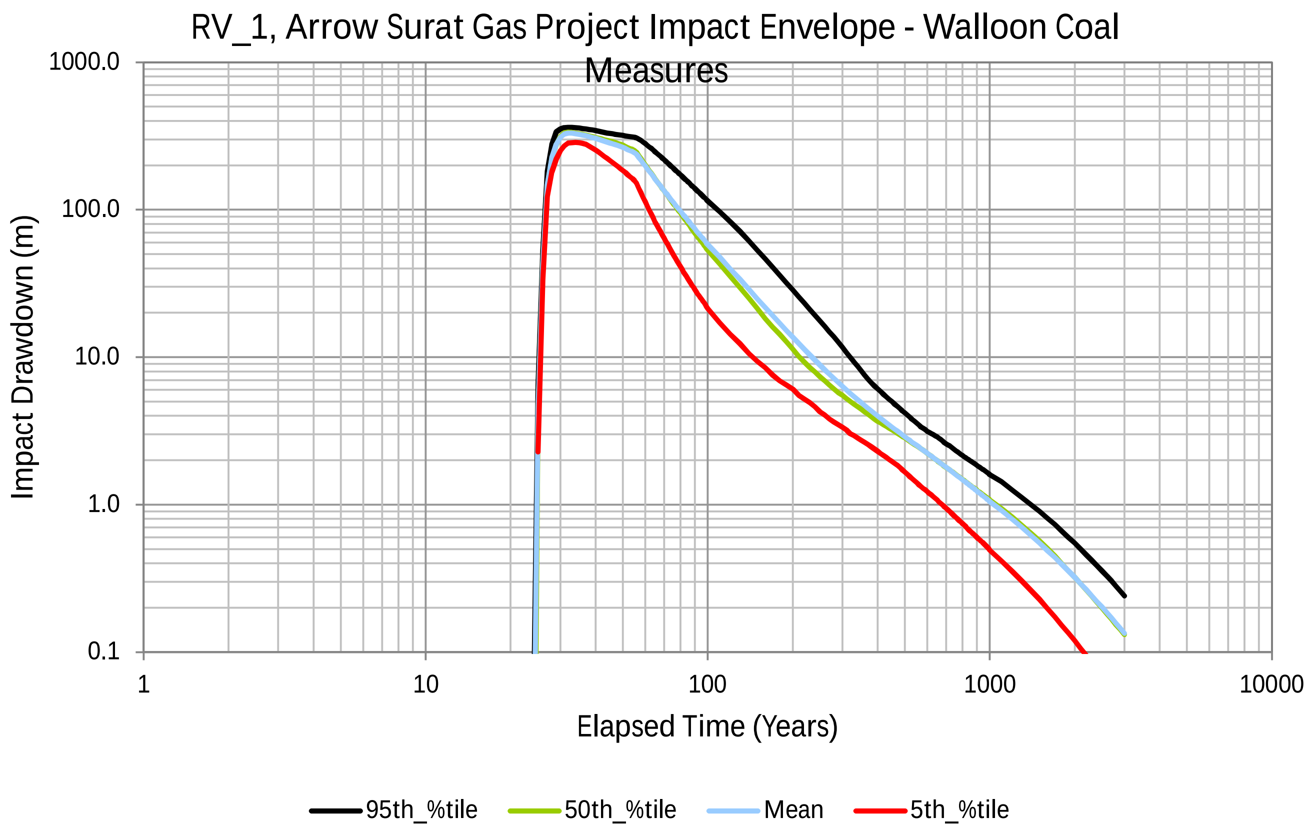
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 11





Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 11





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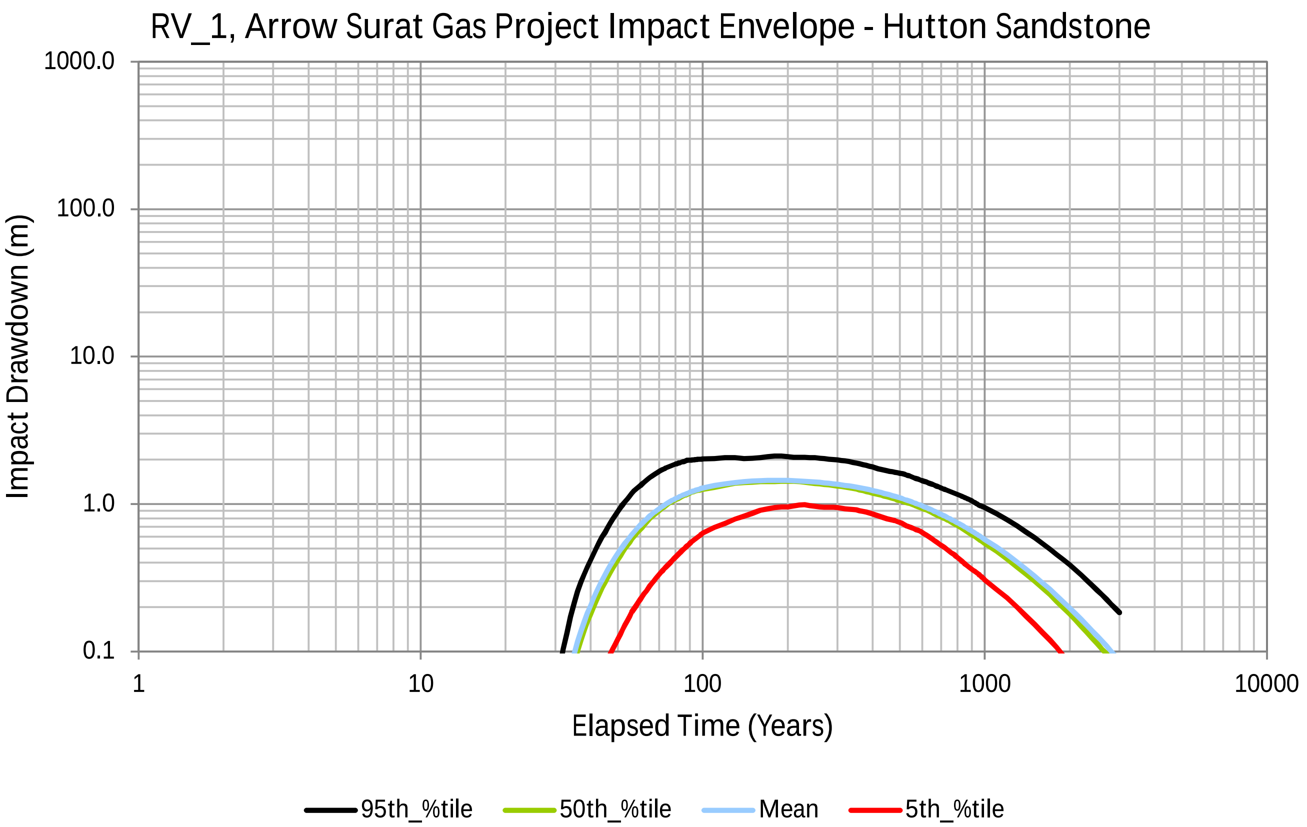
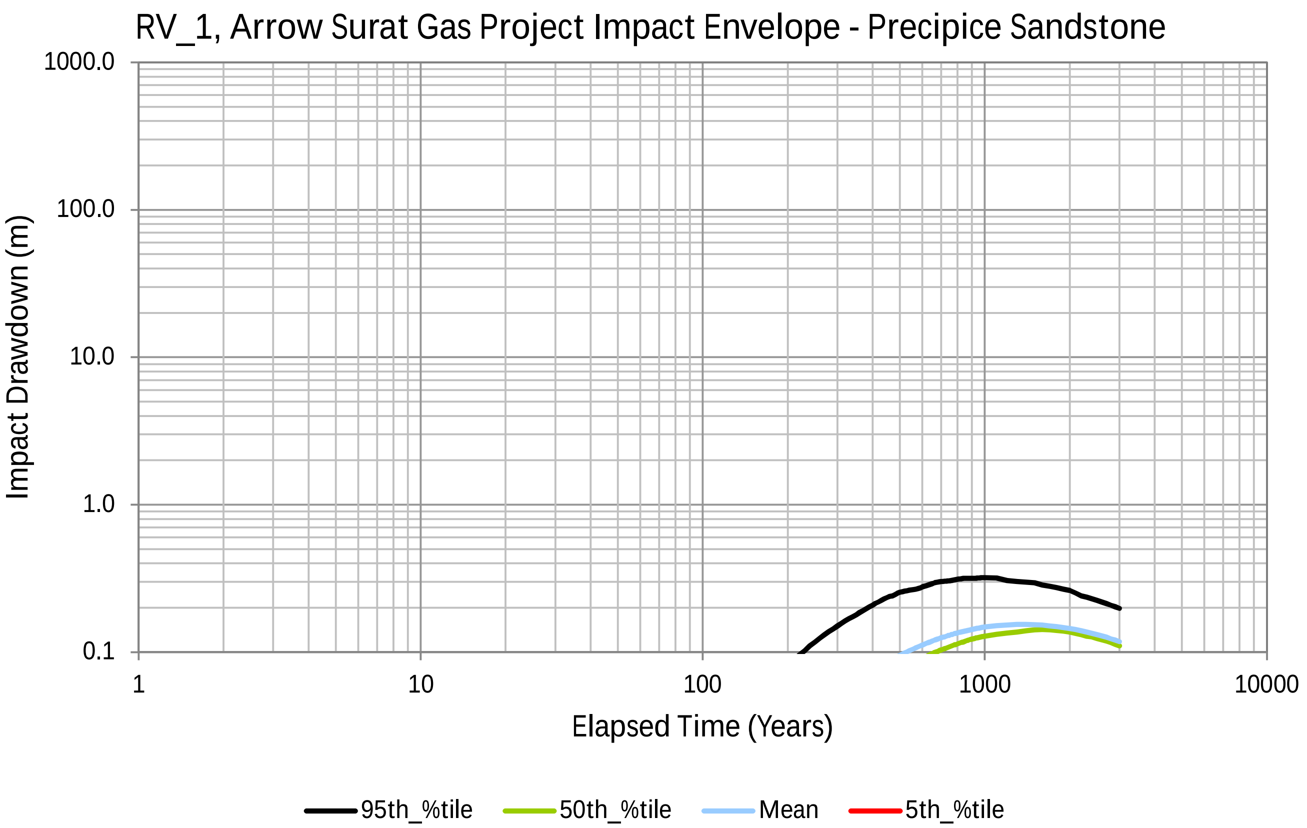
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 11





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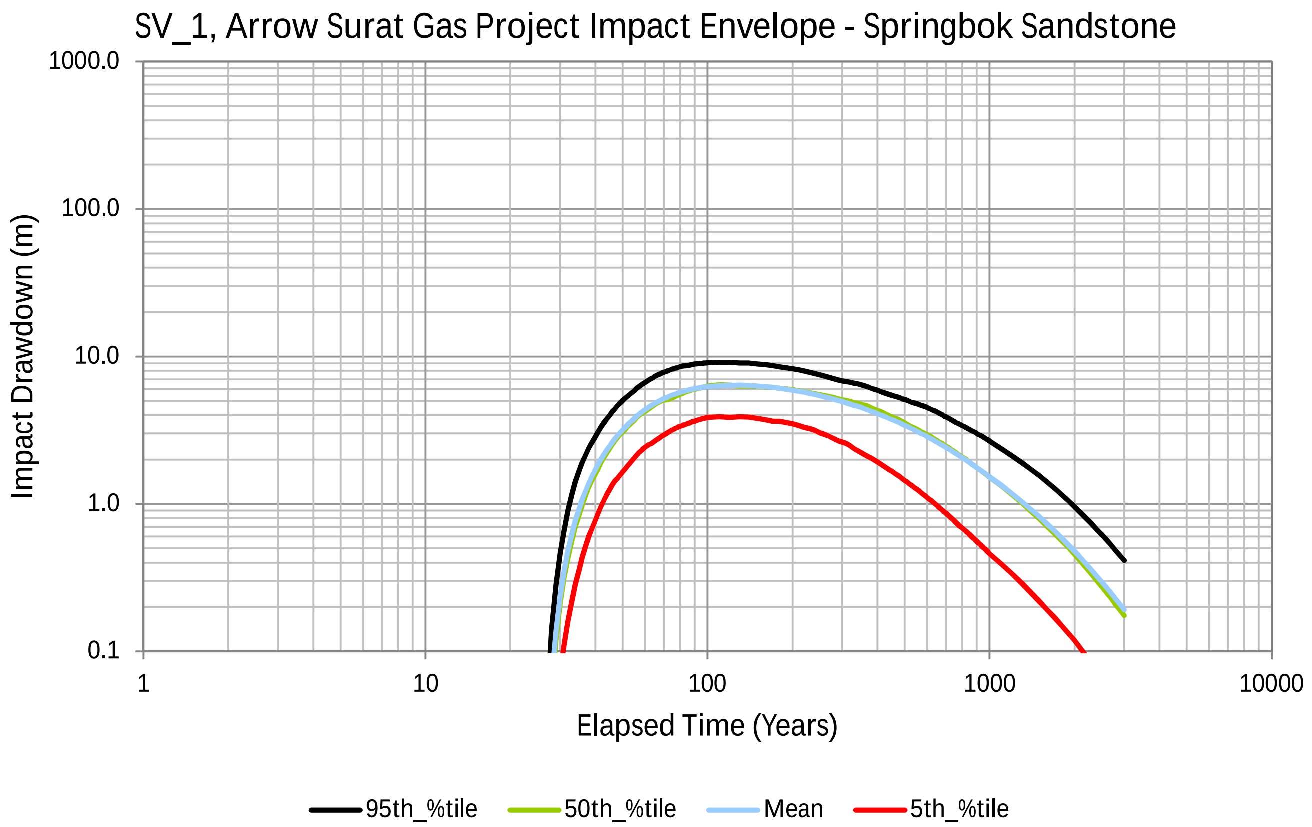
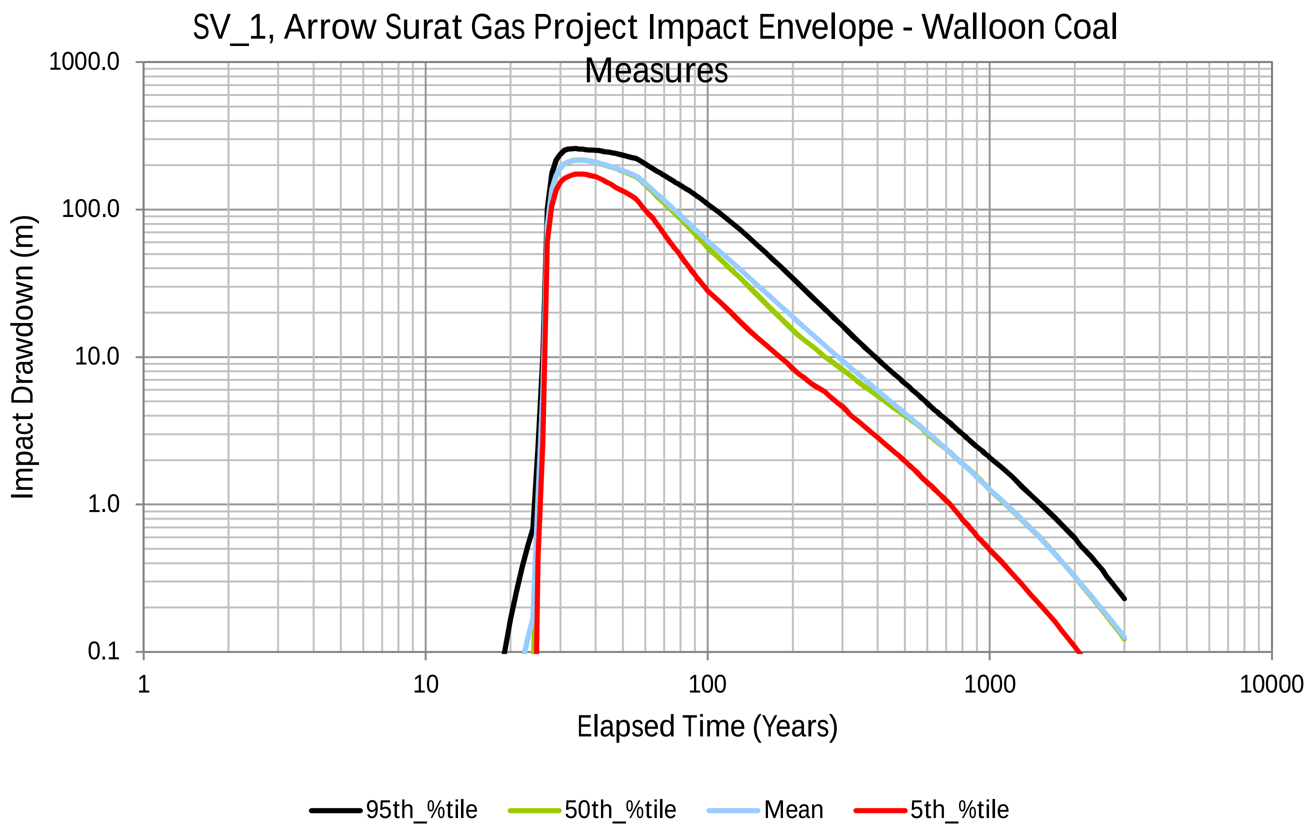
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 11





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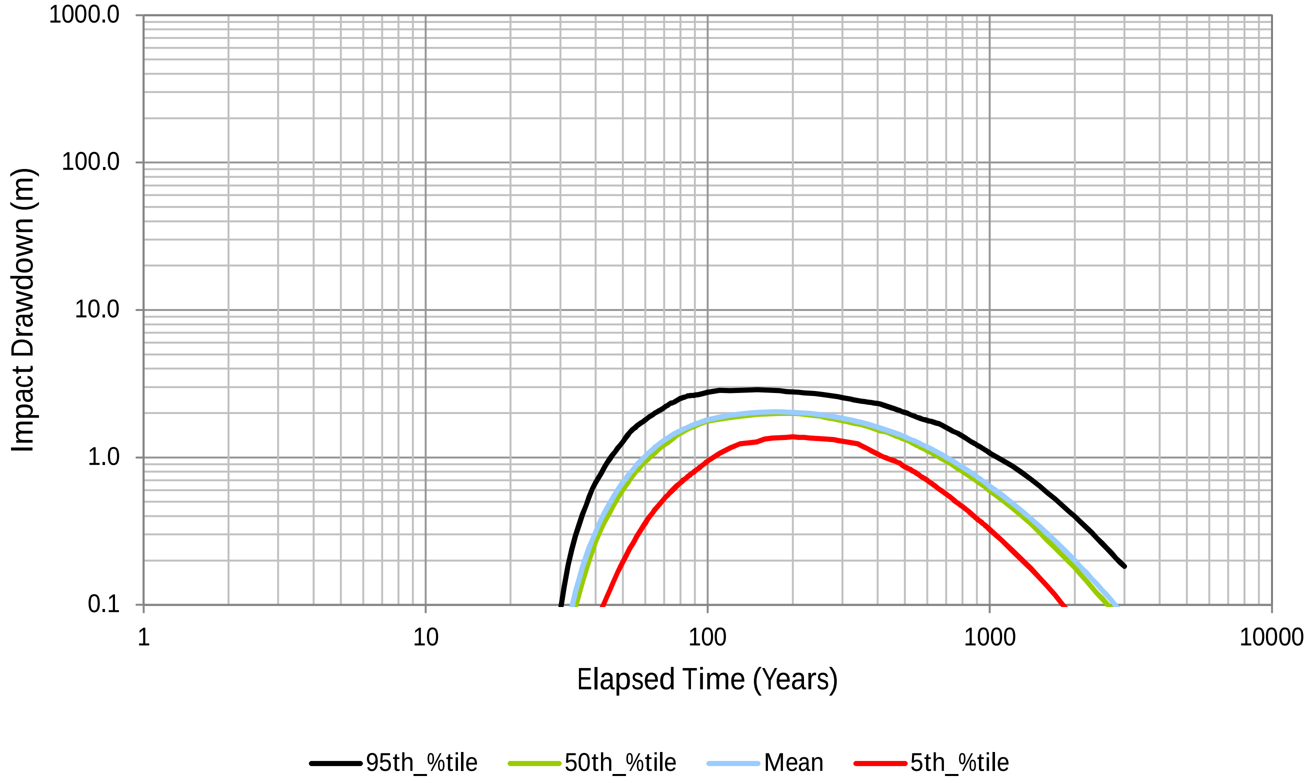
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 11

SV_1, Arrow Surat Gas Project Impact Envelope - Hutton Sandstone



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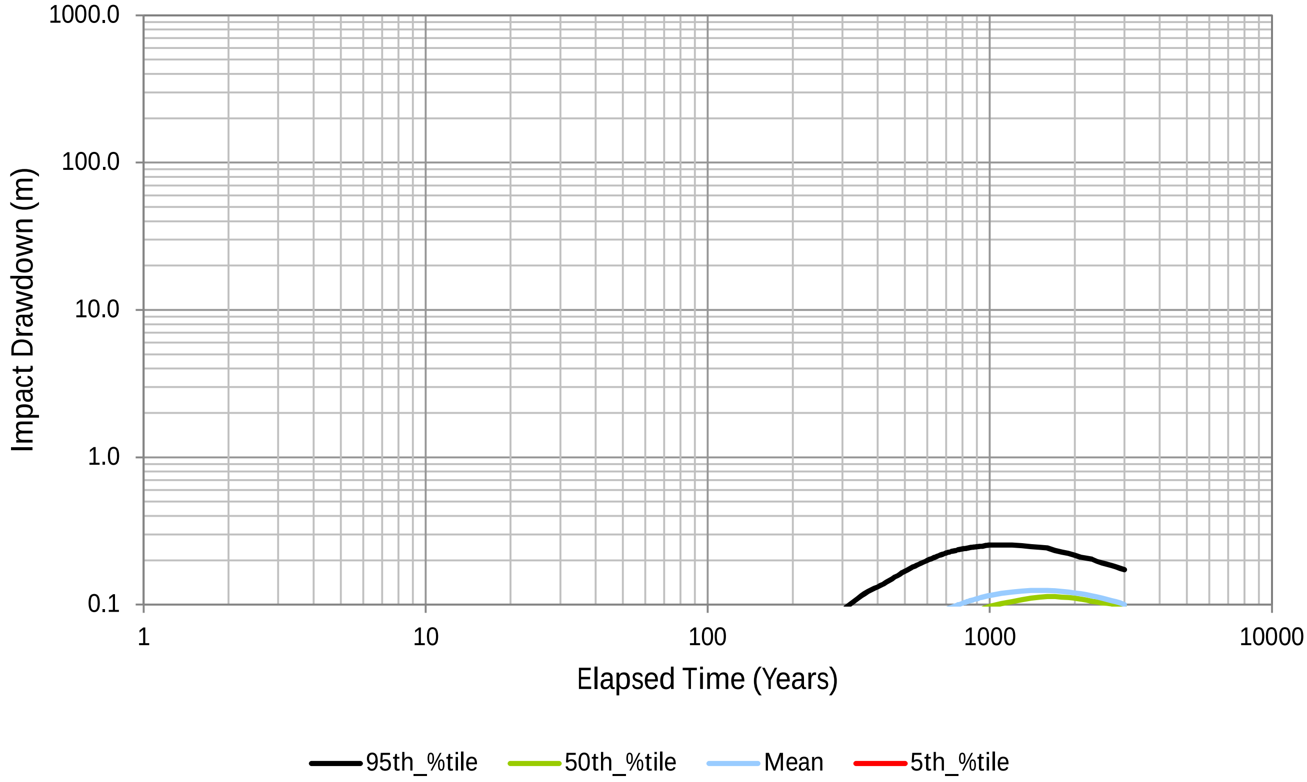

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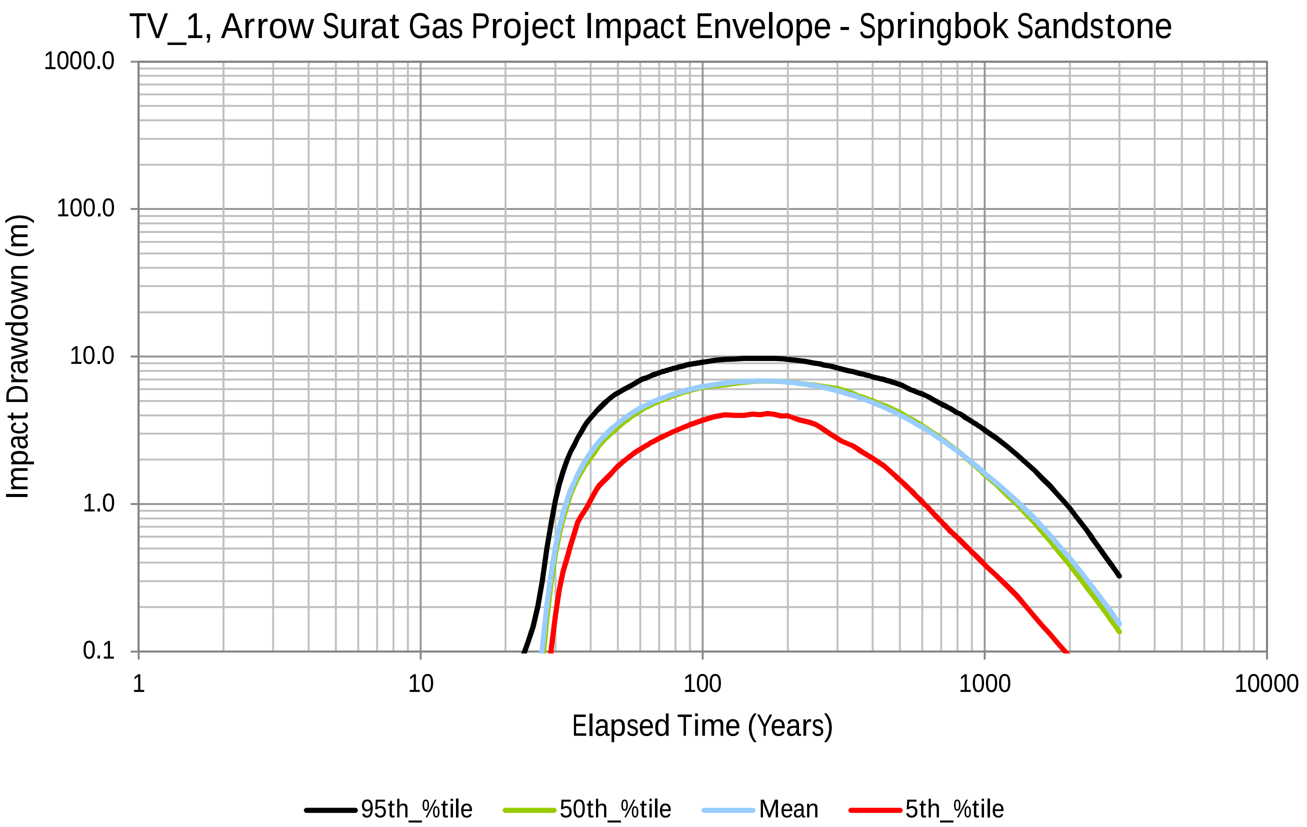
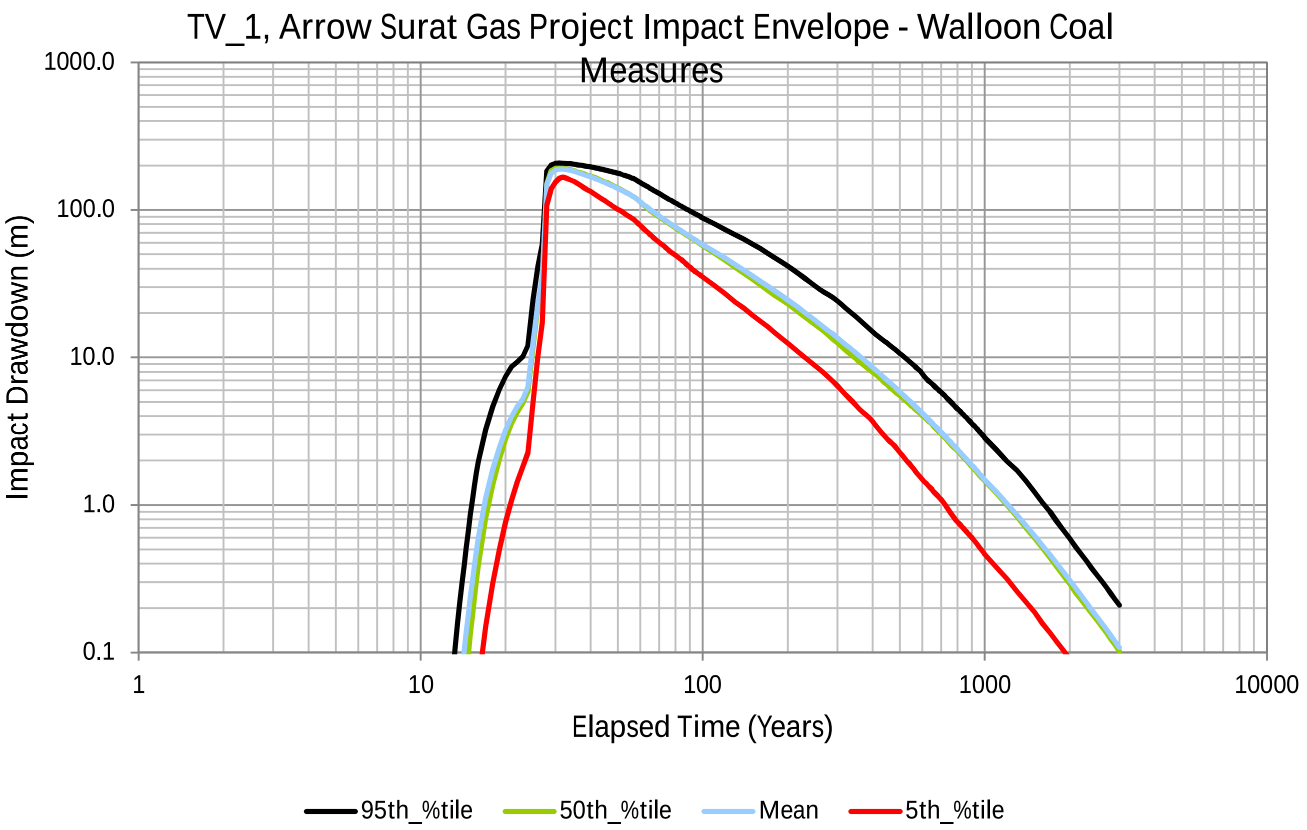
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 11





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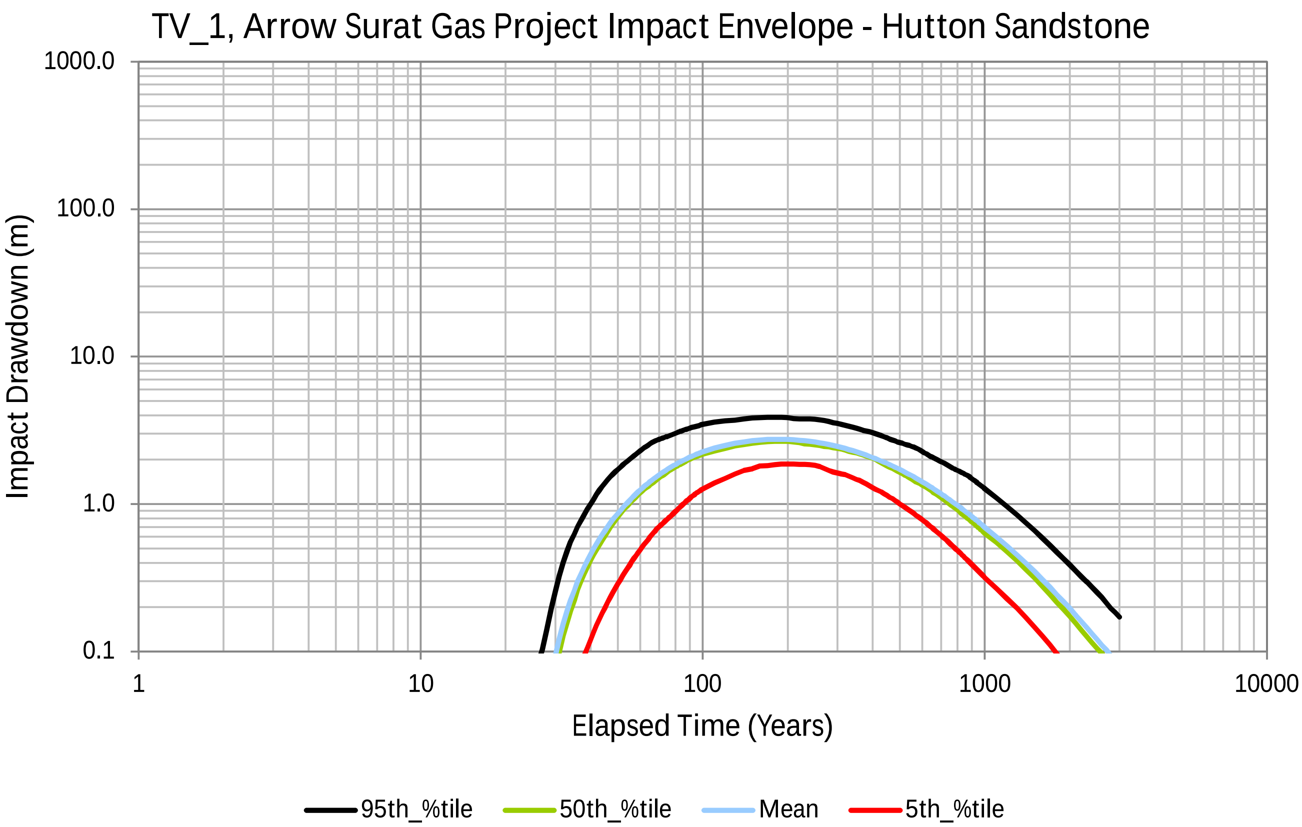
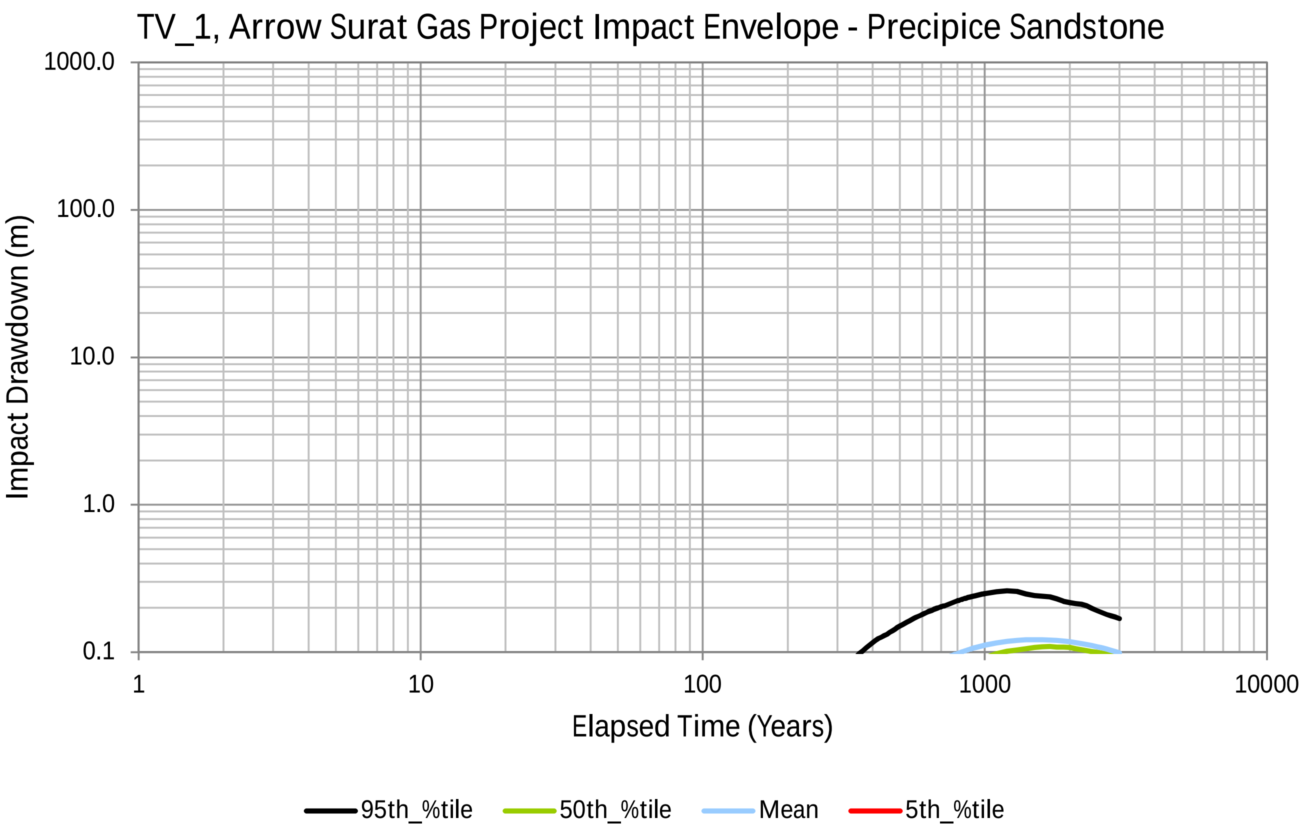
Appendix F - Arrow Surat Gas Project Impact Envelope at Extraction Block Centres - Drainage Area 11





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Appendix G – Cumulative Time Series Impact Plots

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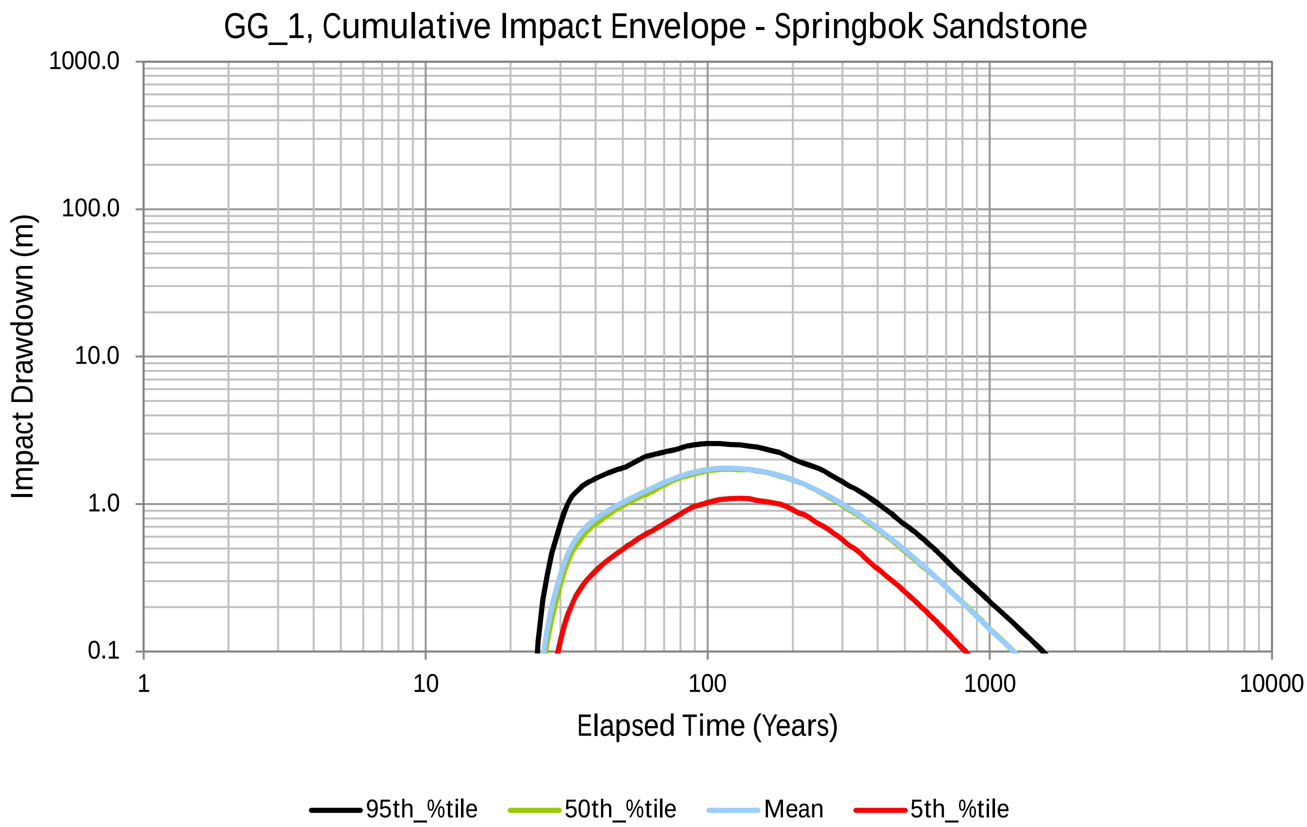
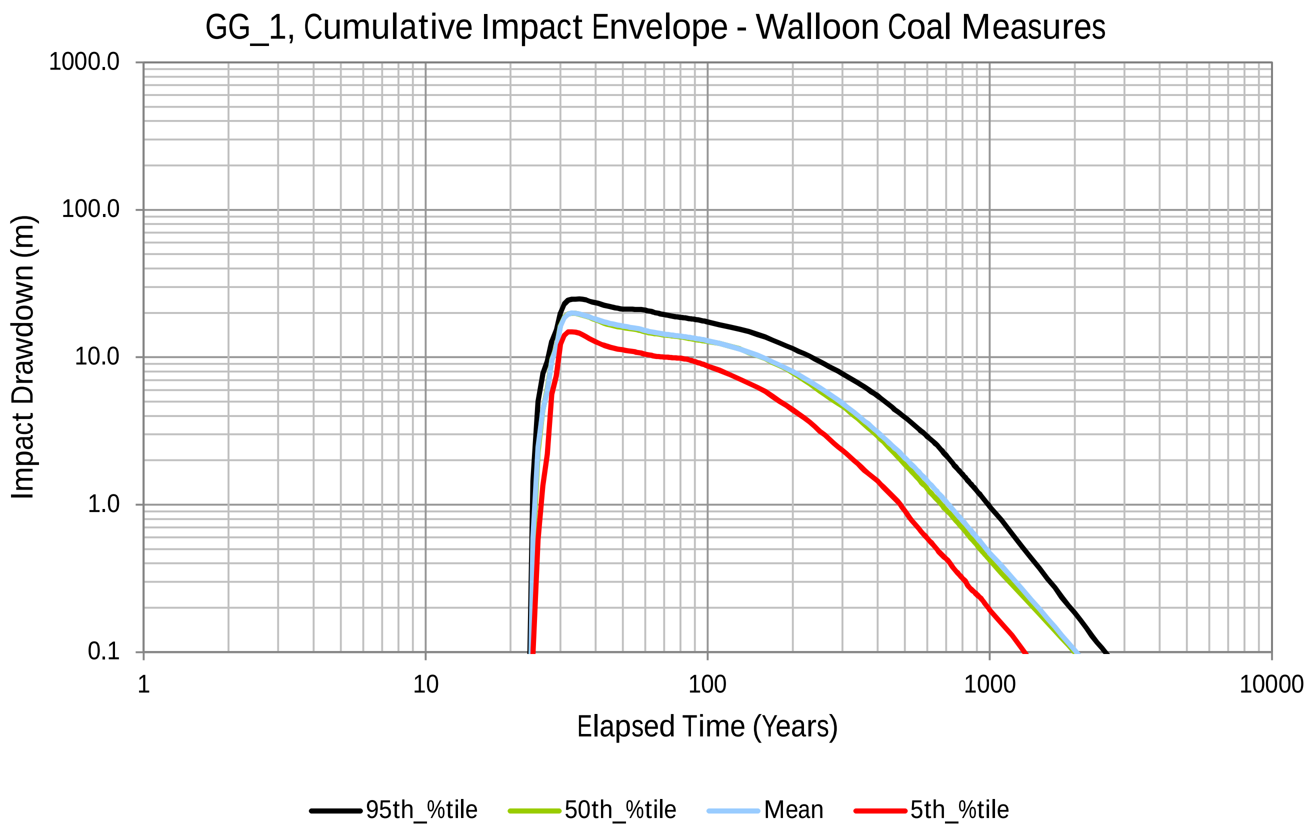
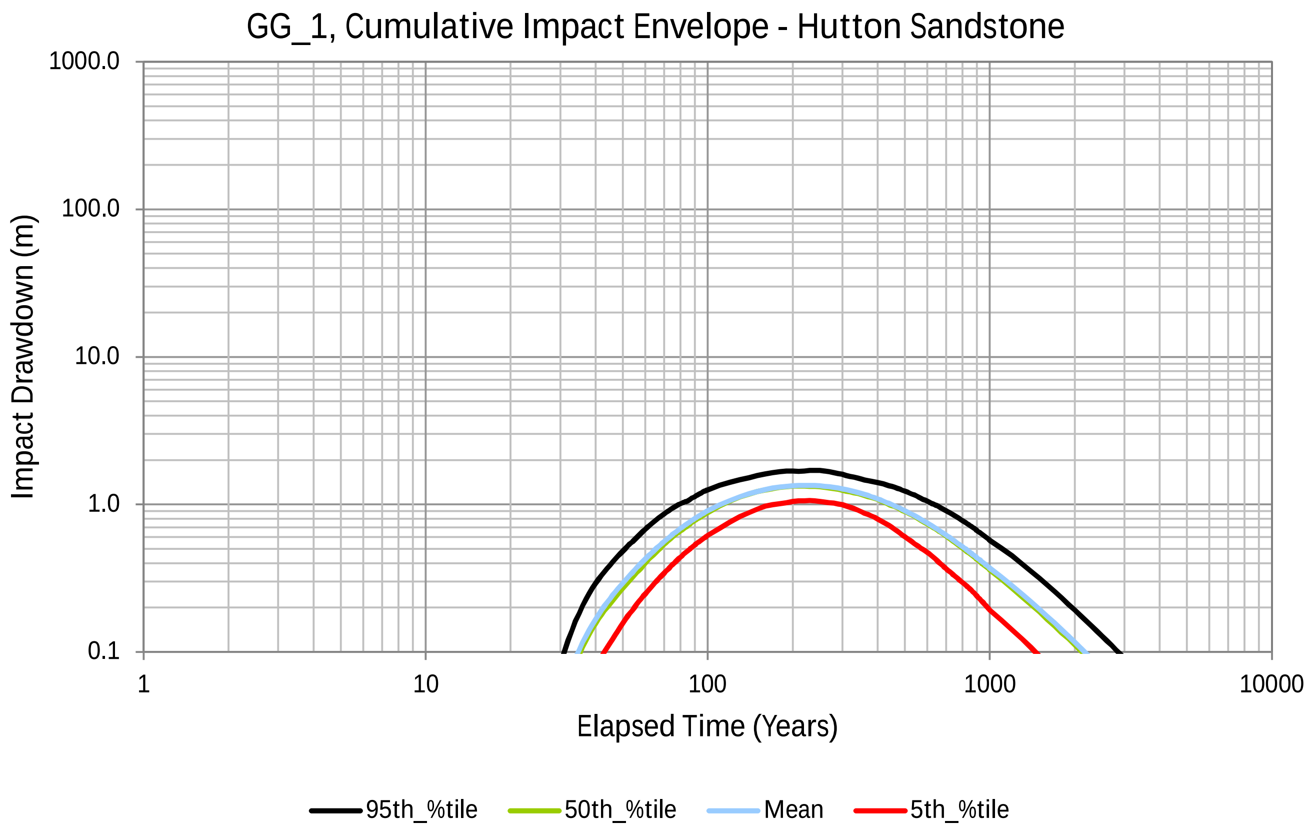
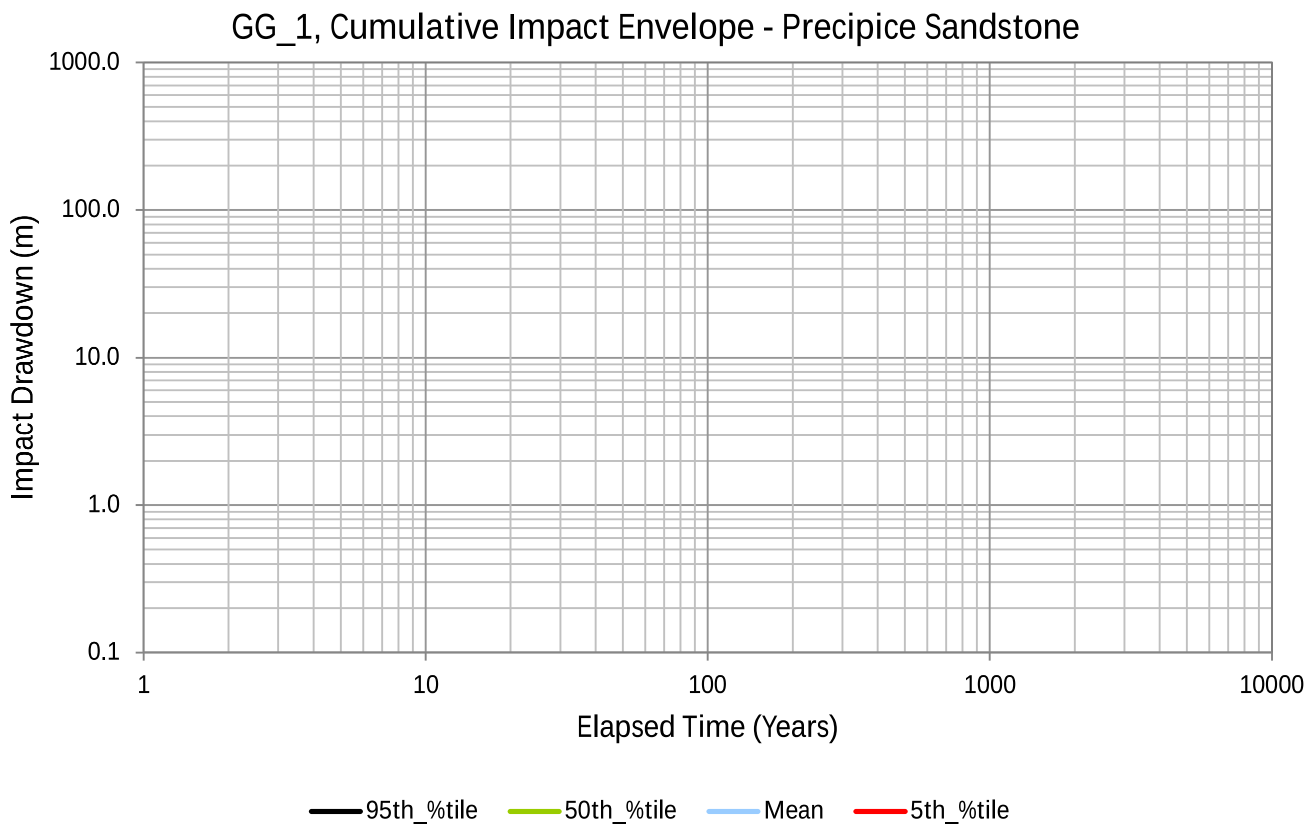
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



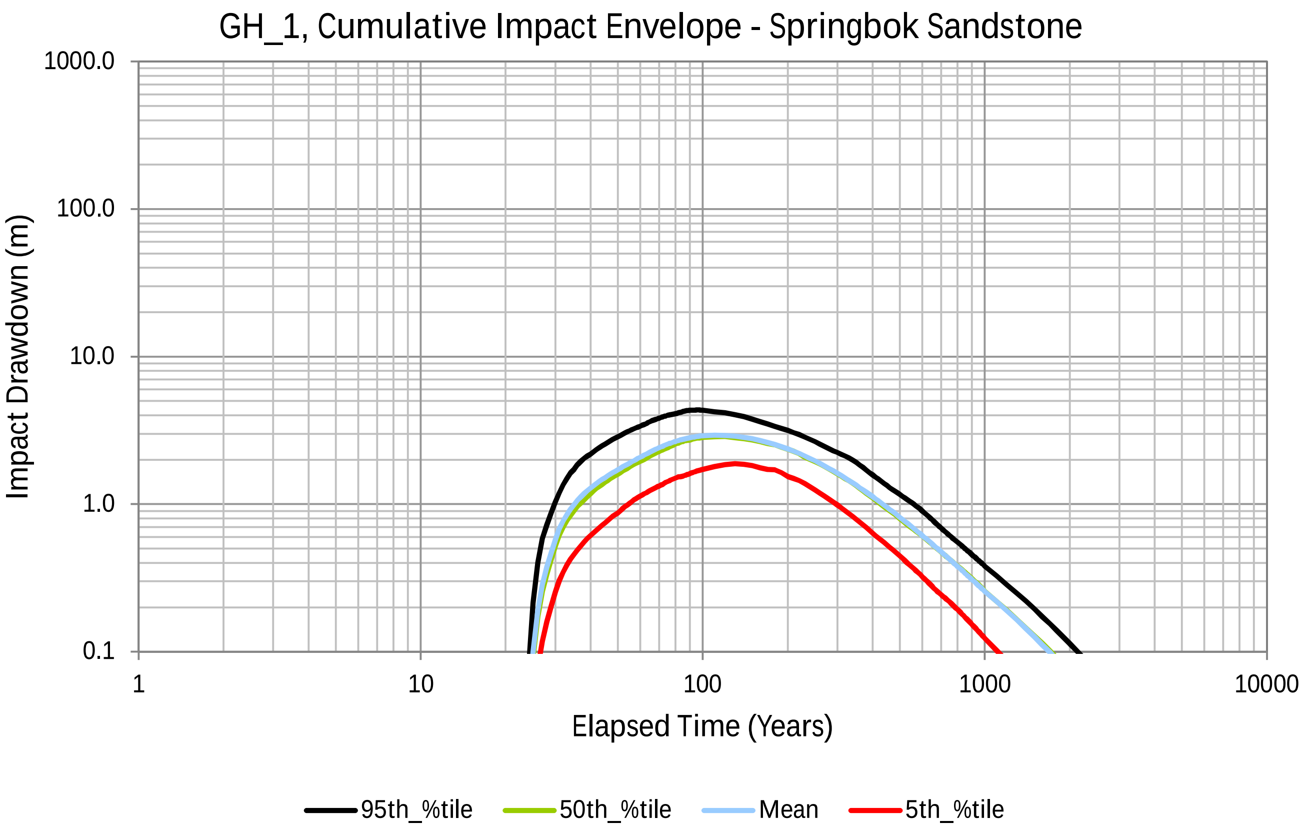


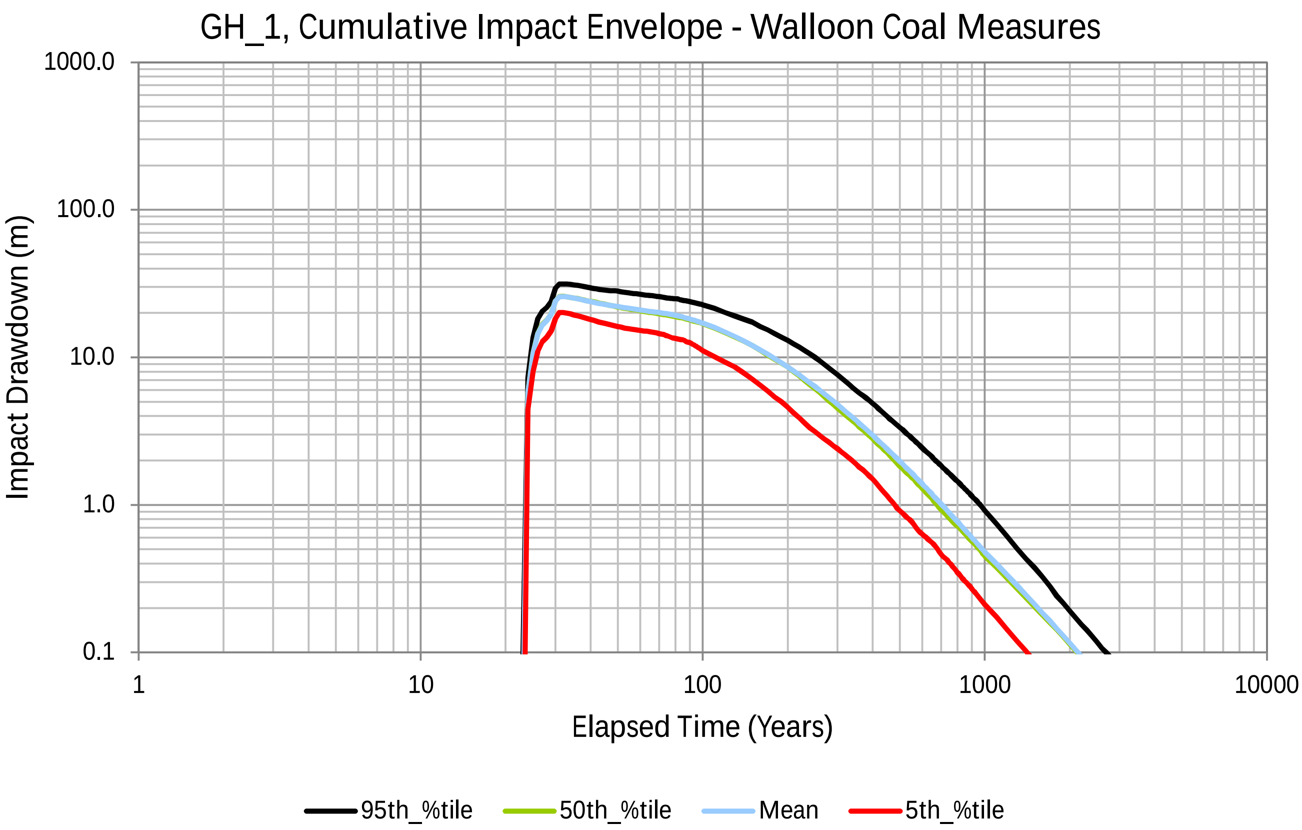
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



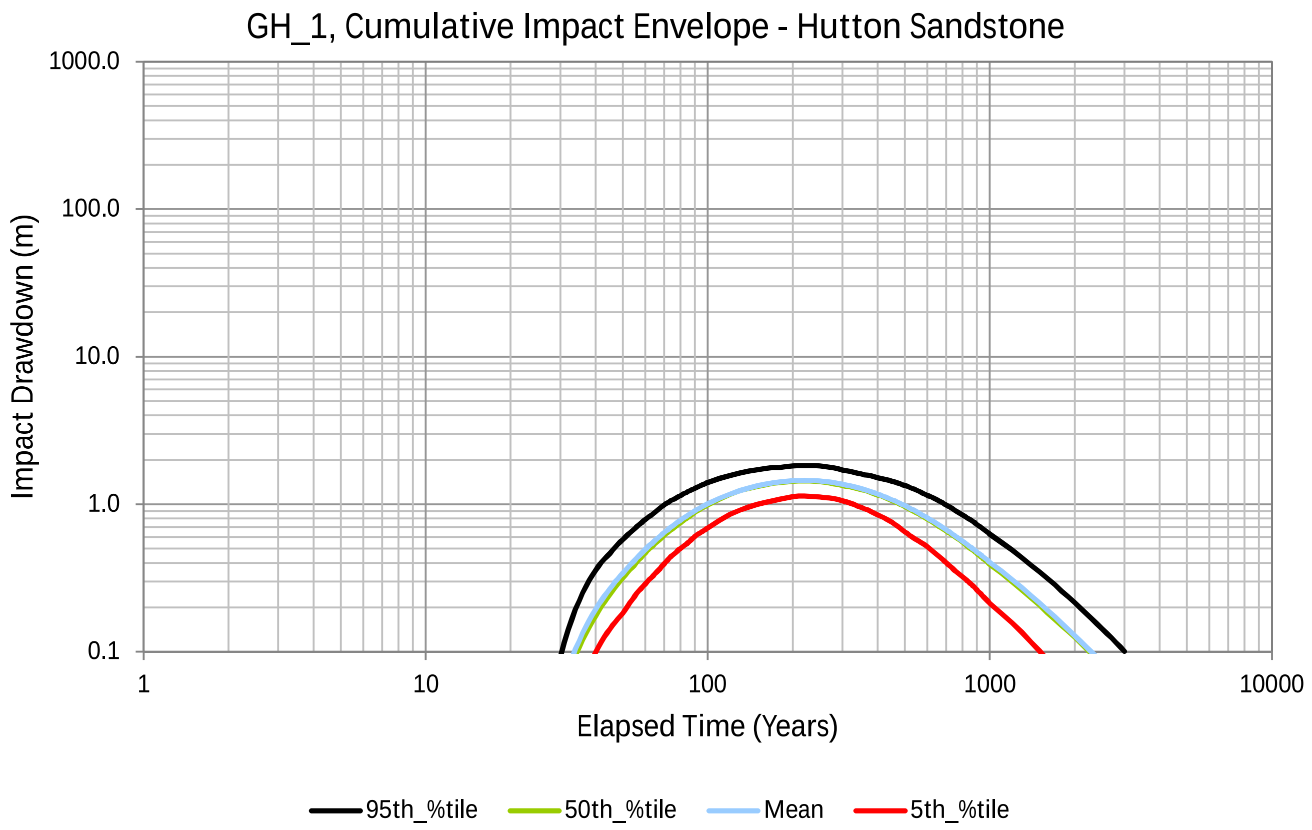


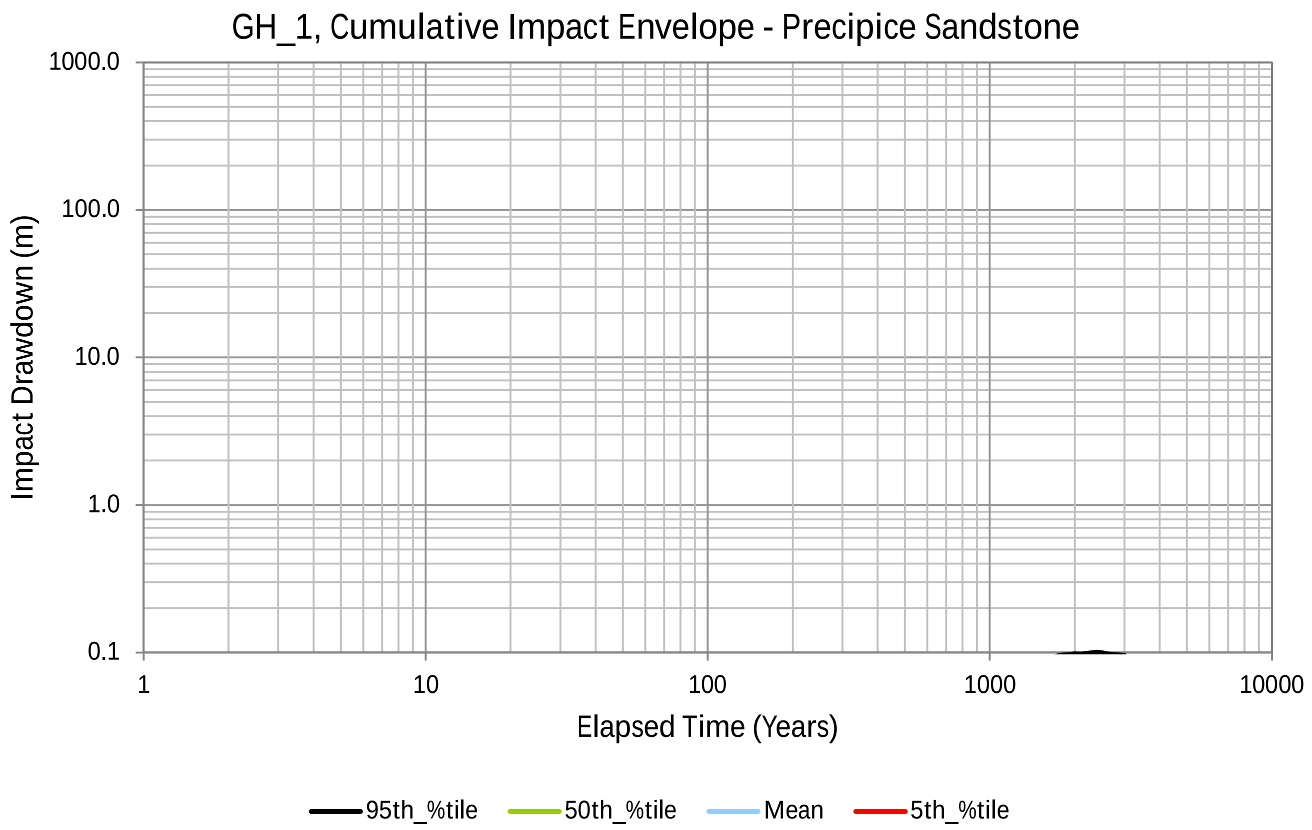
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



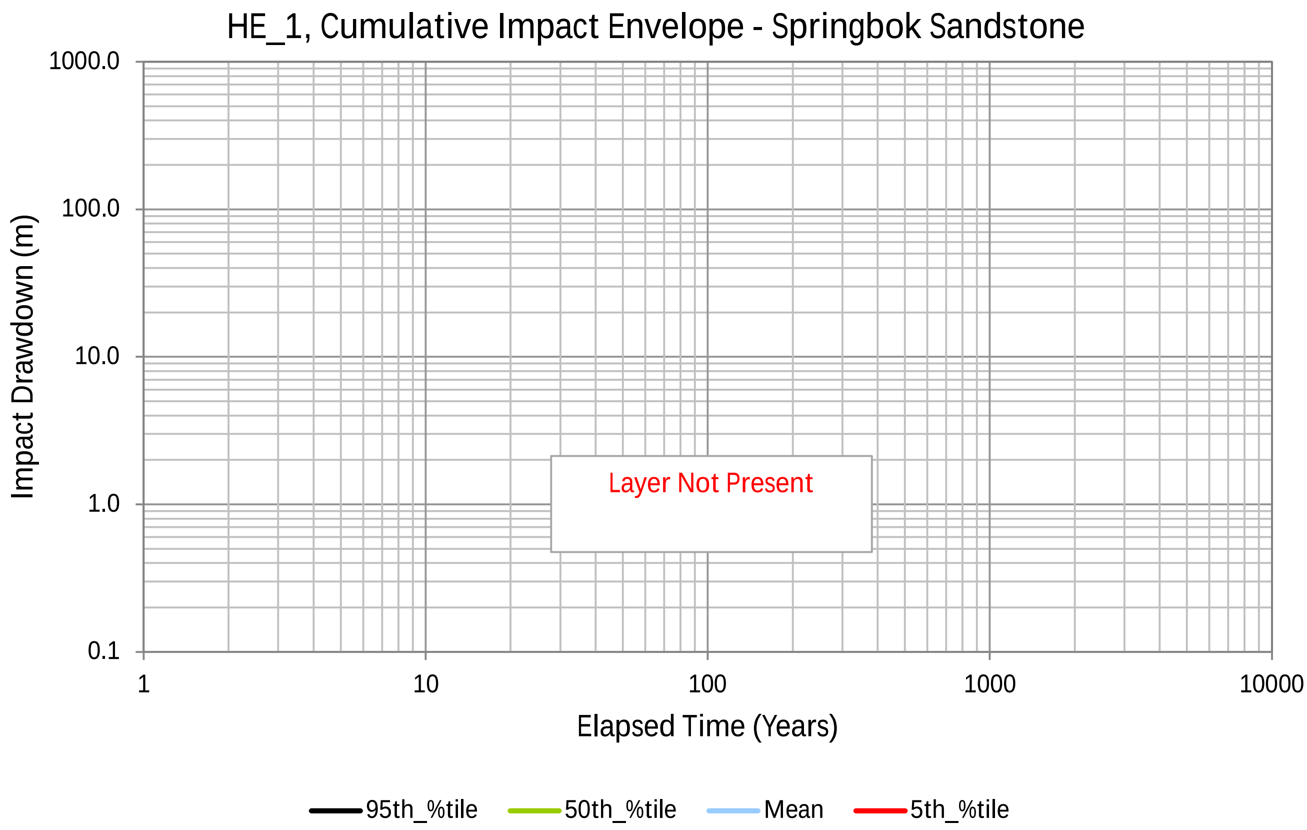


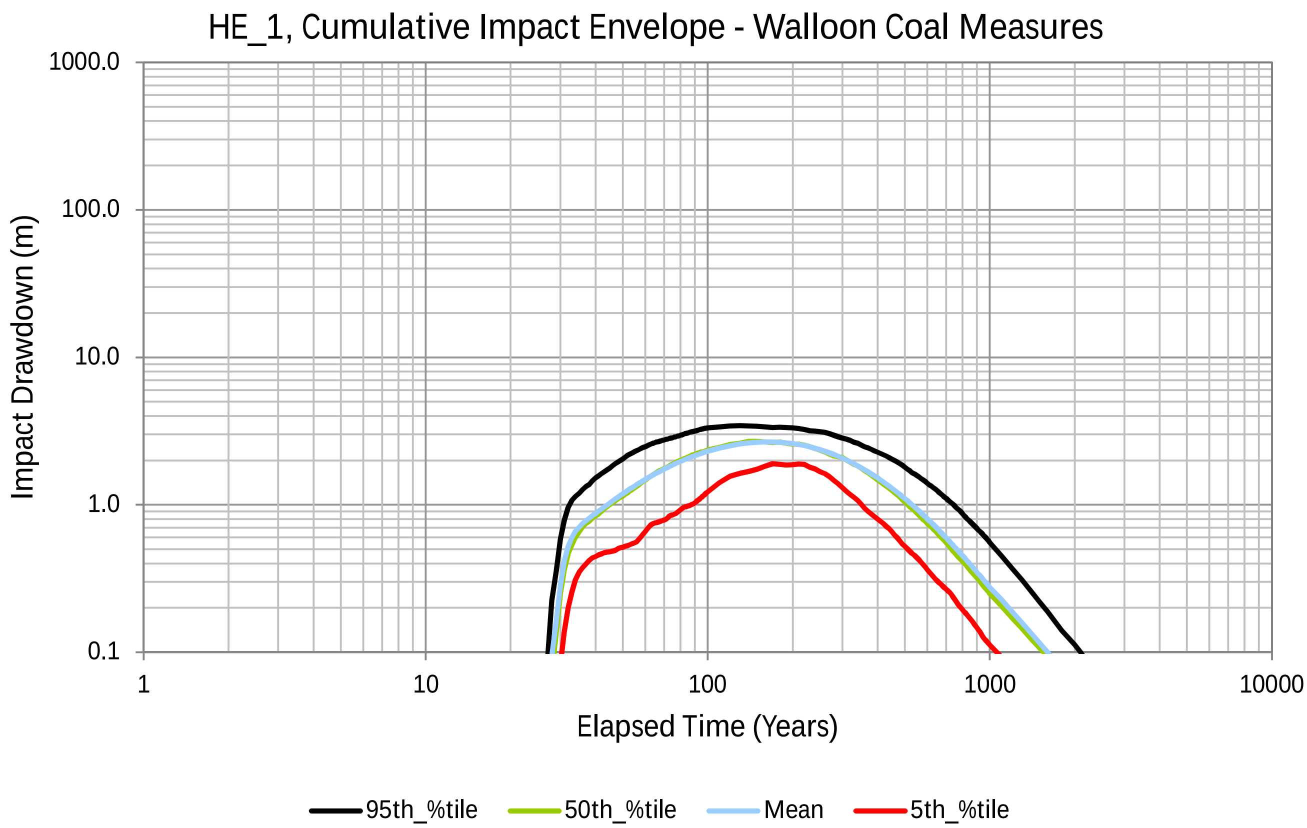
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



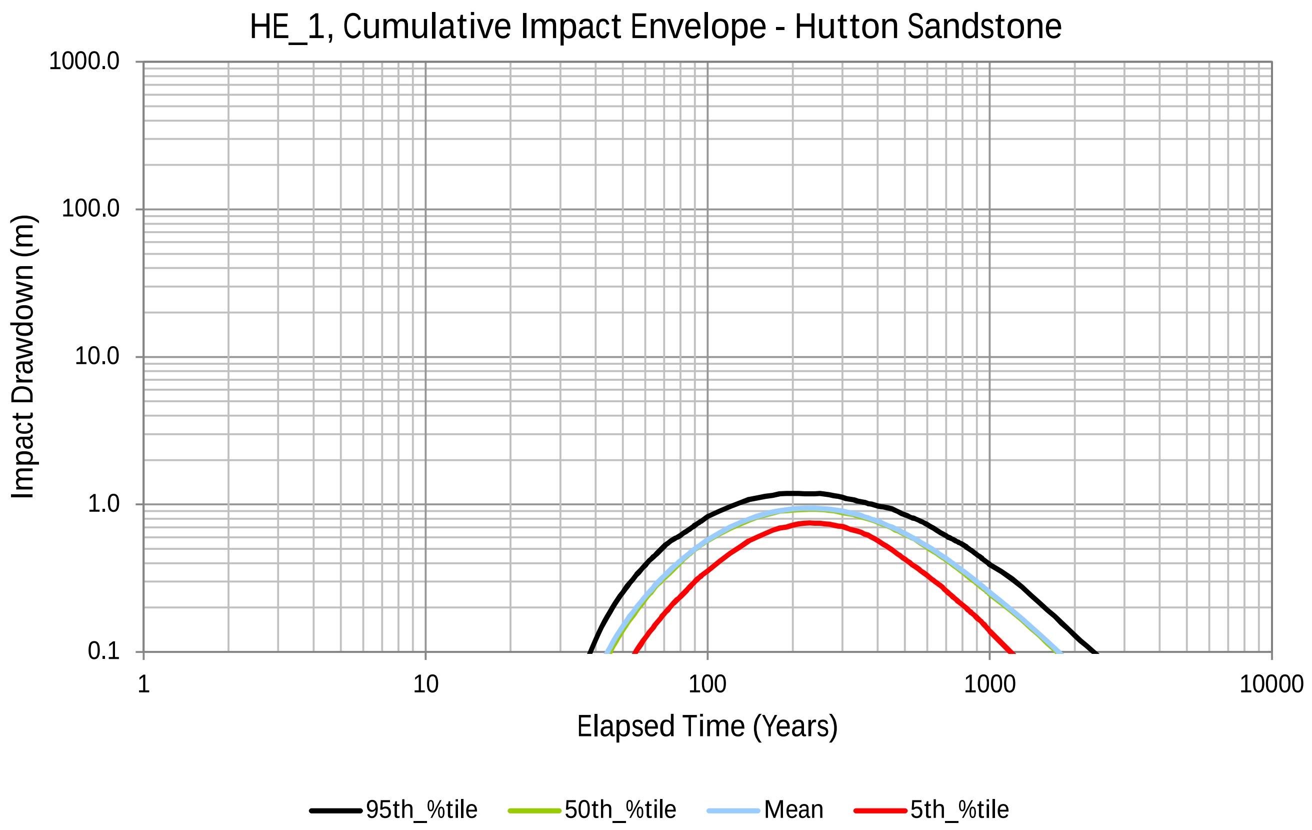


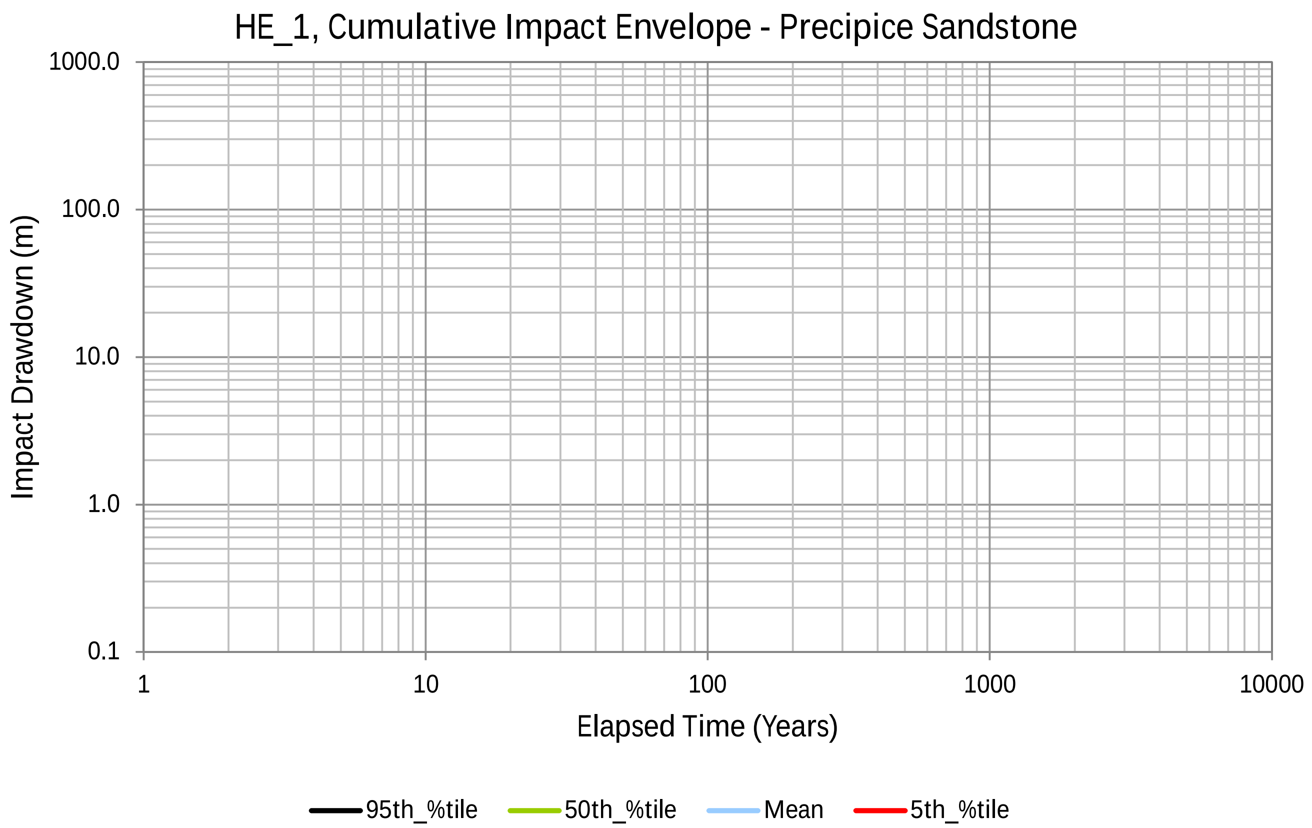
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



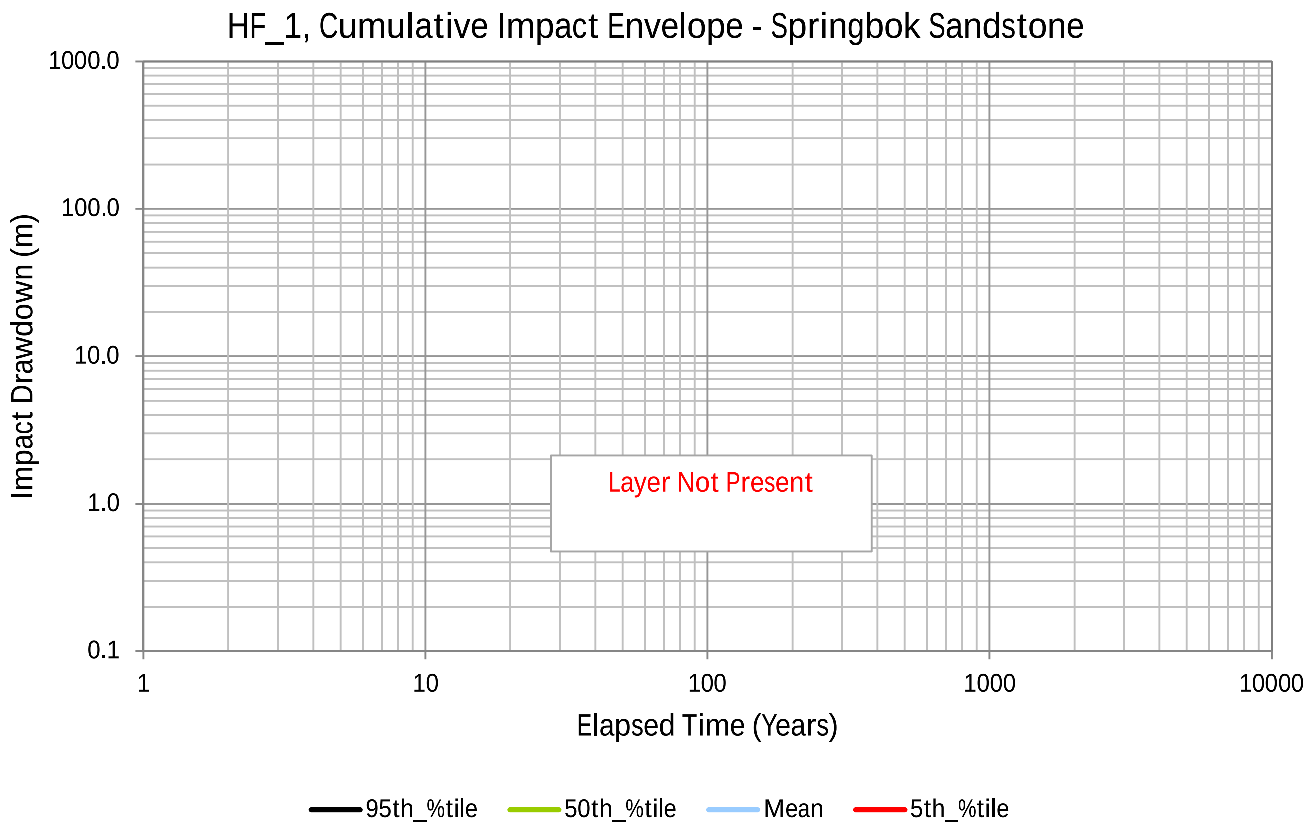


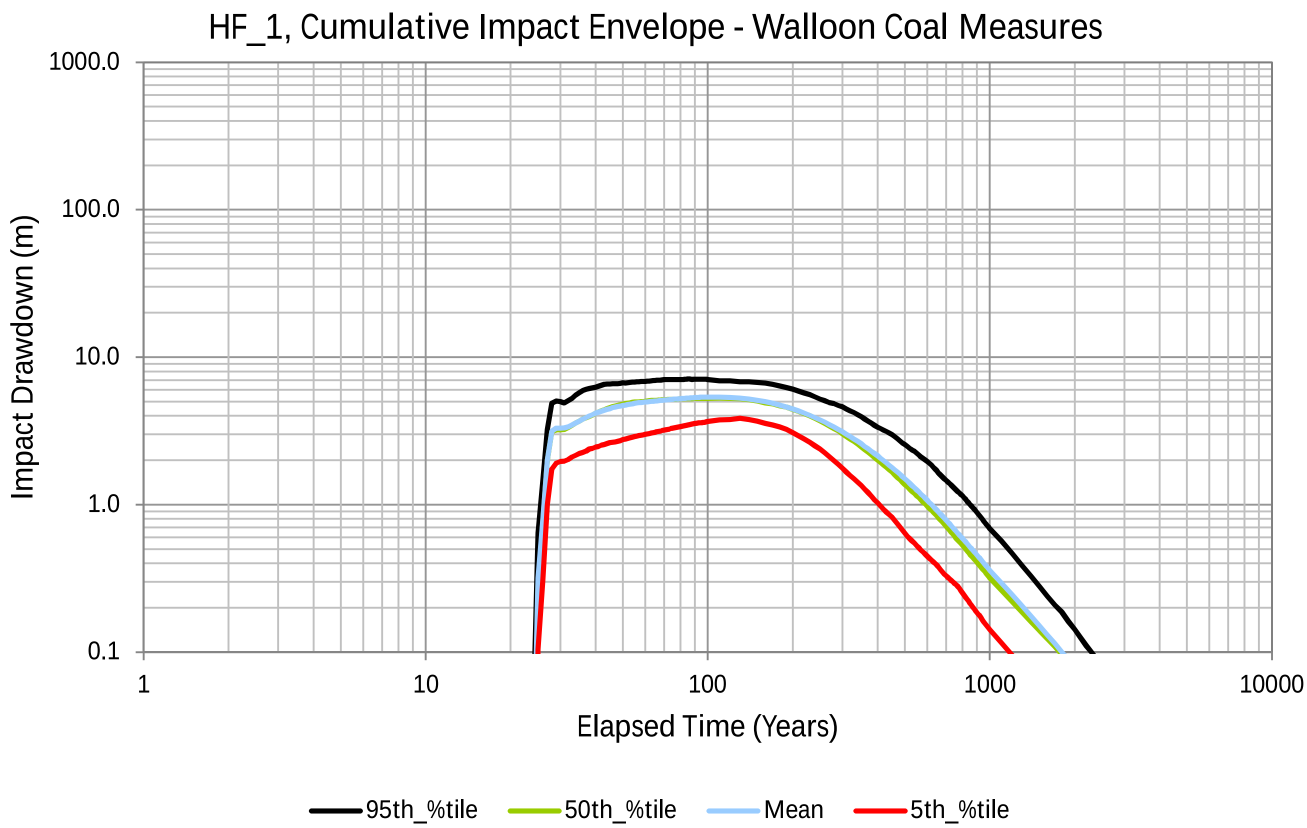
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



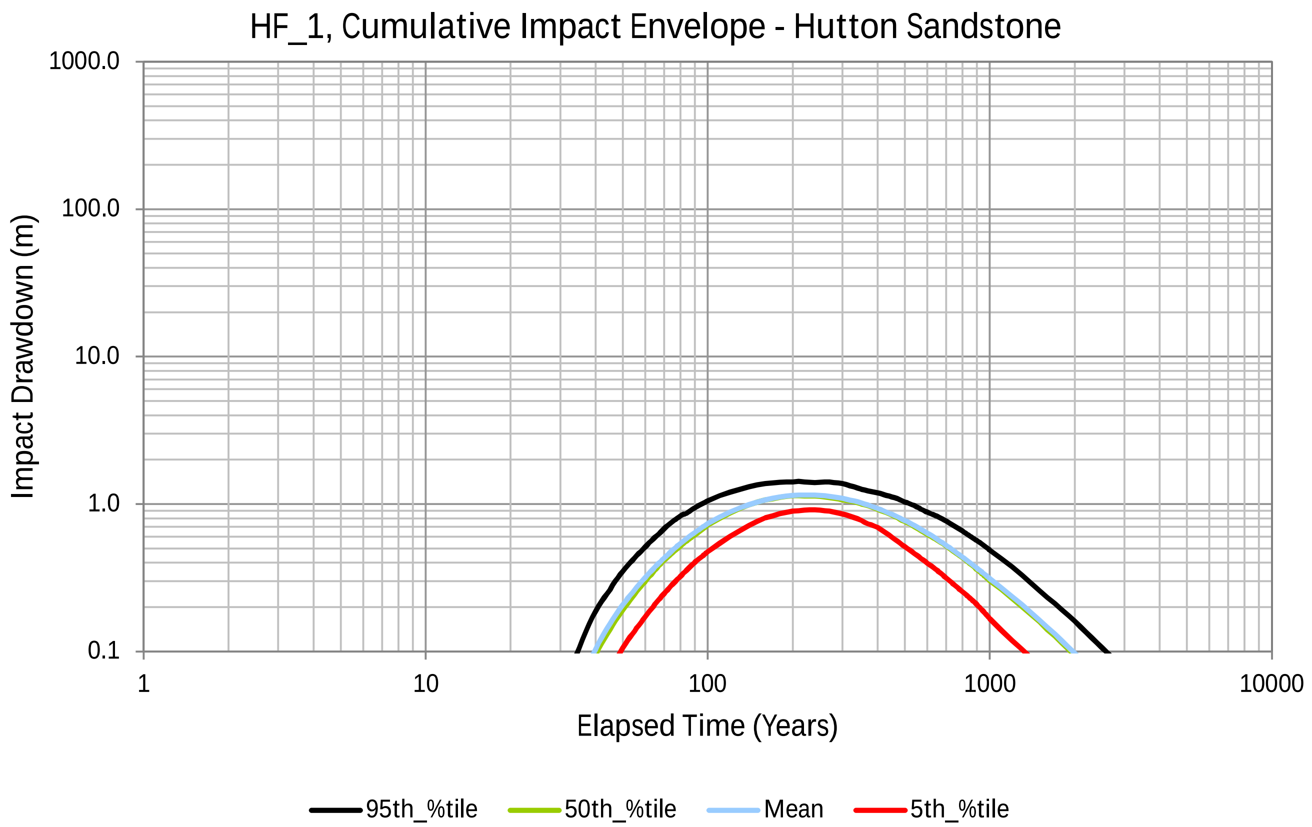


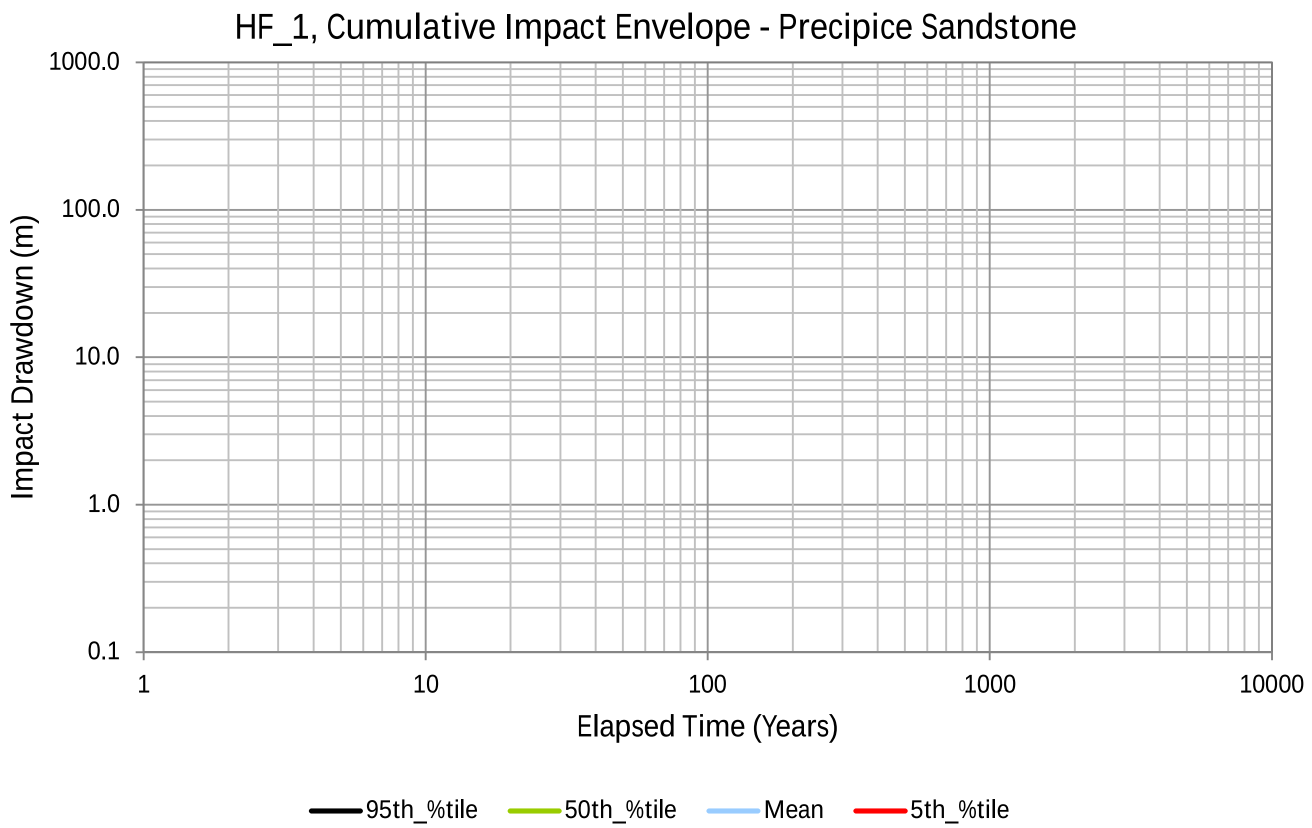
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



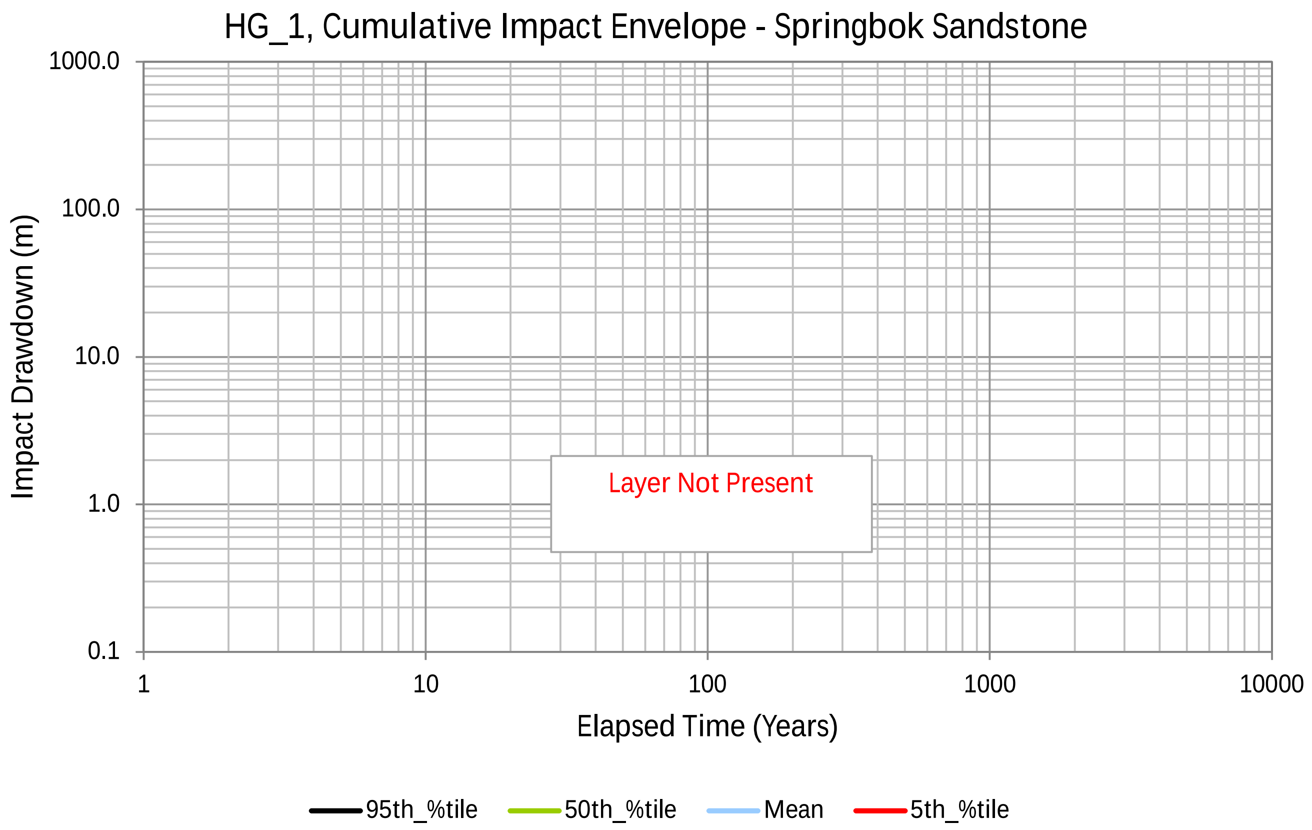


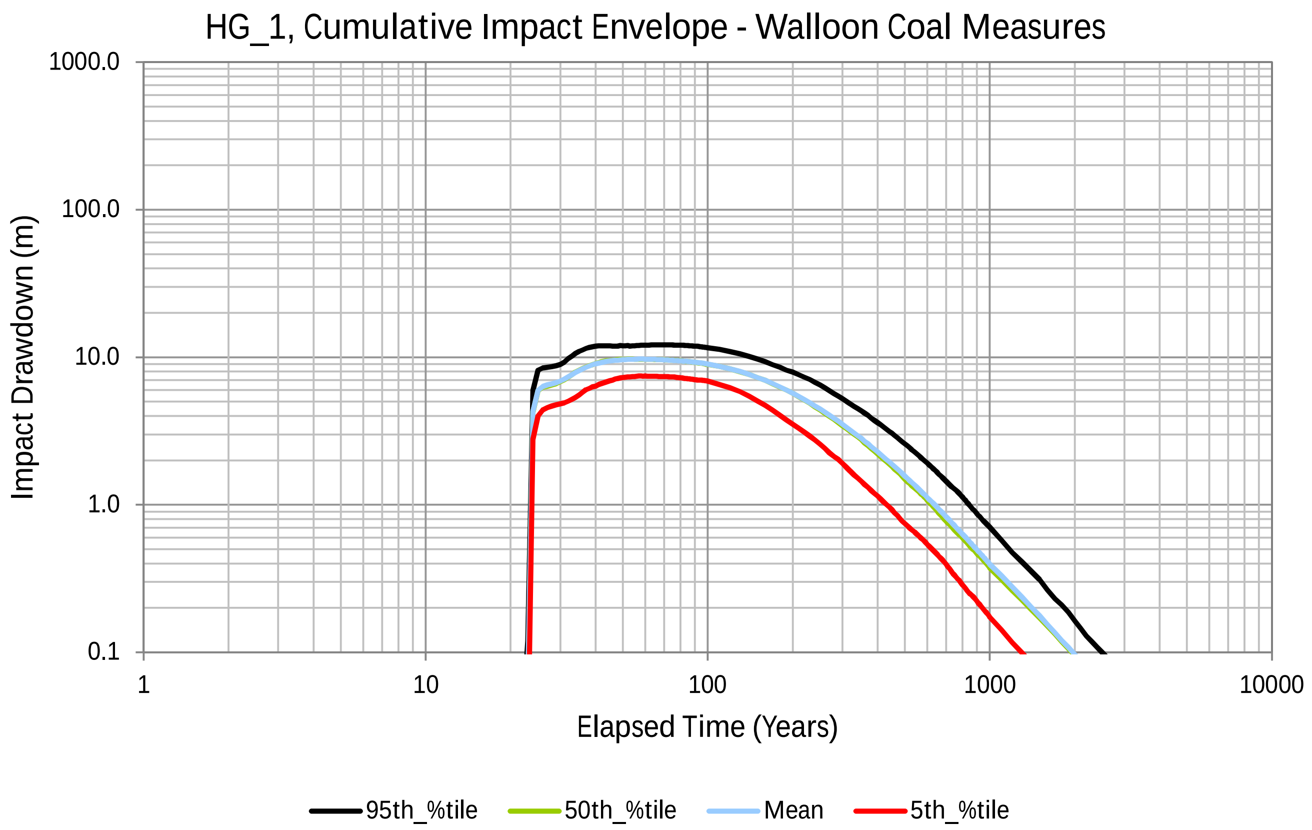
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



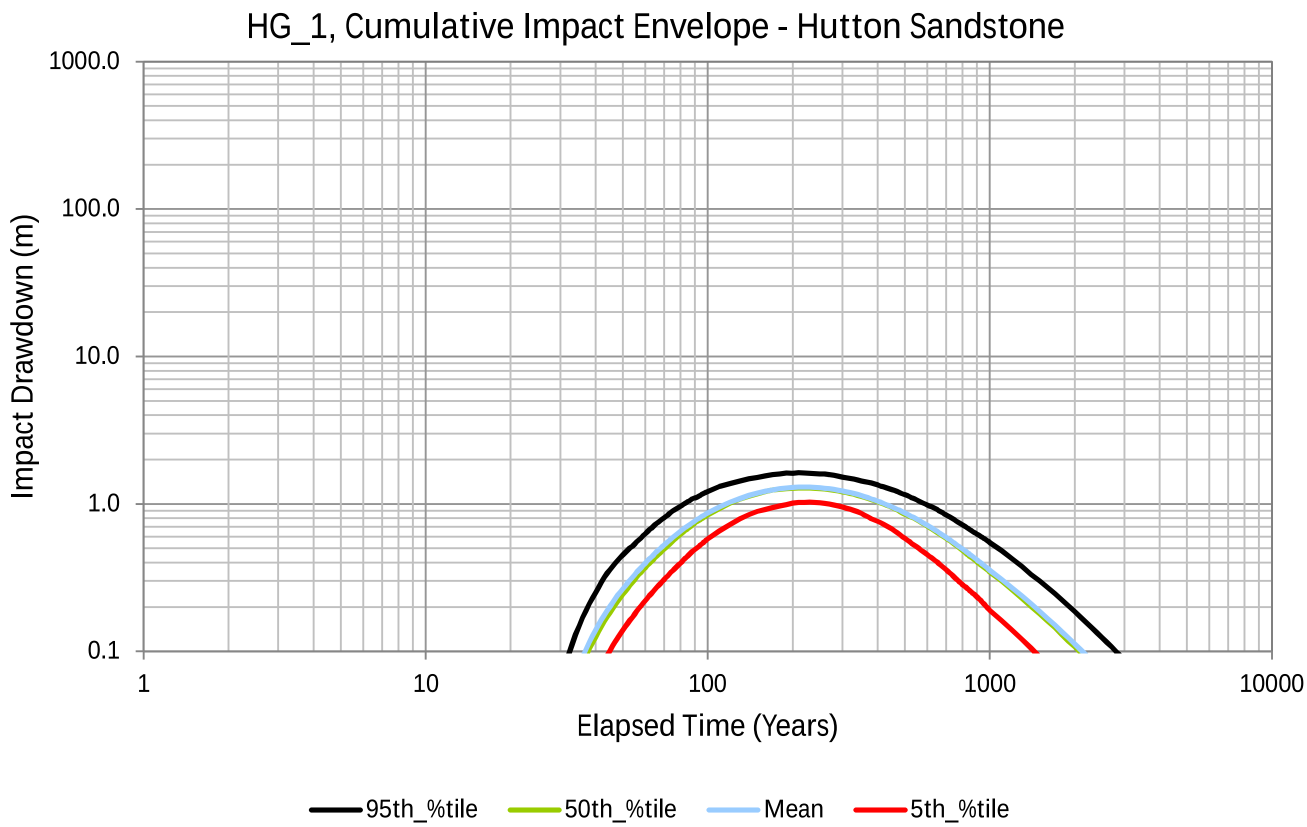


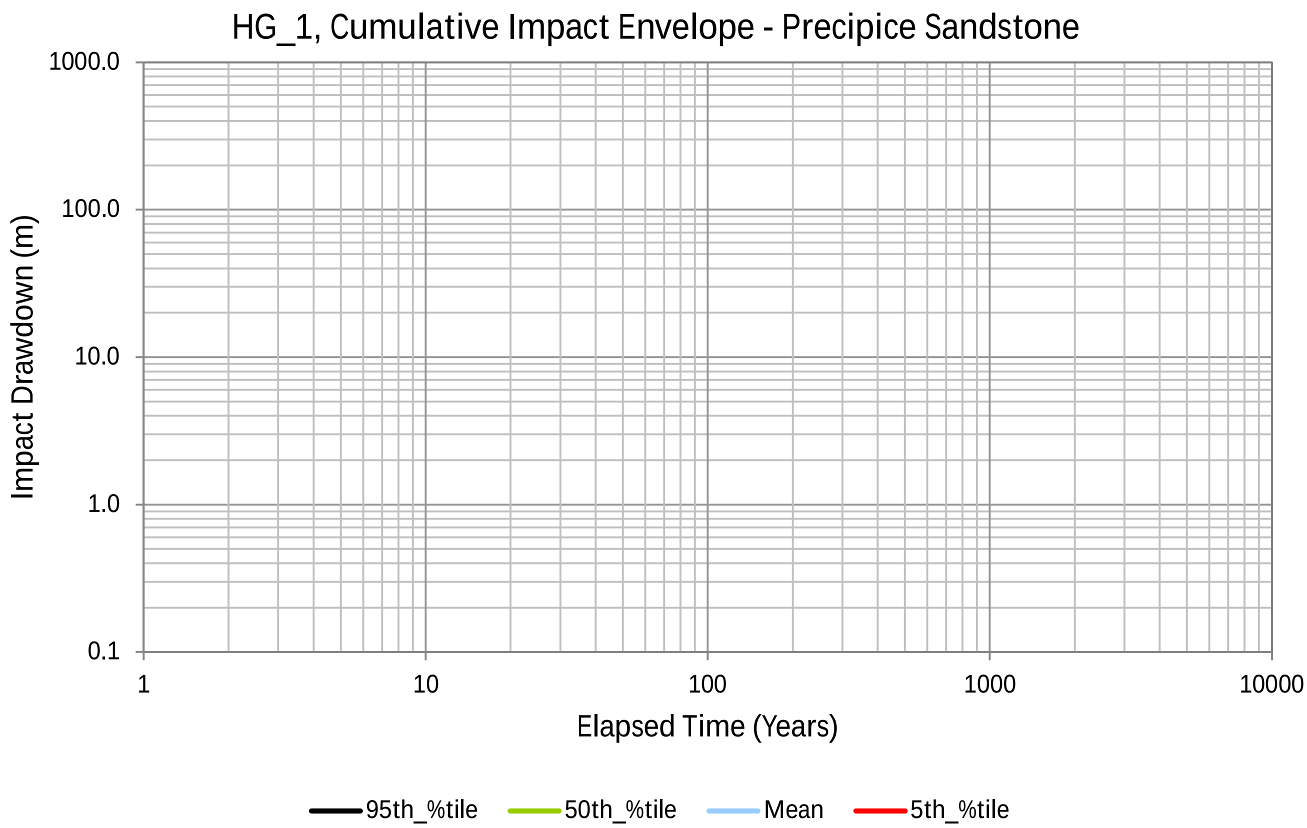
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



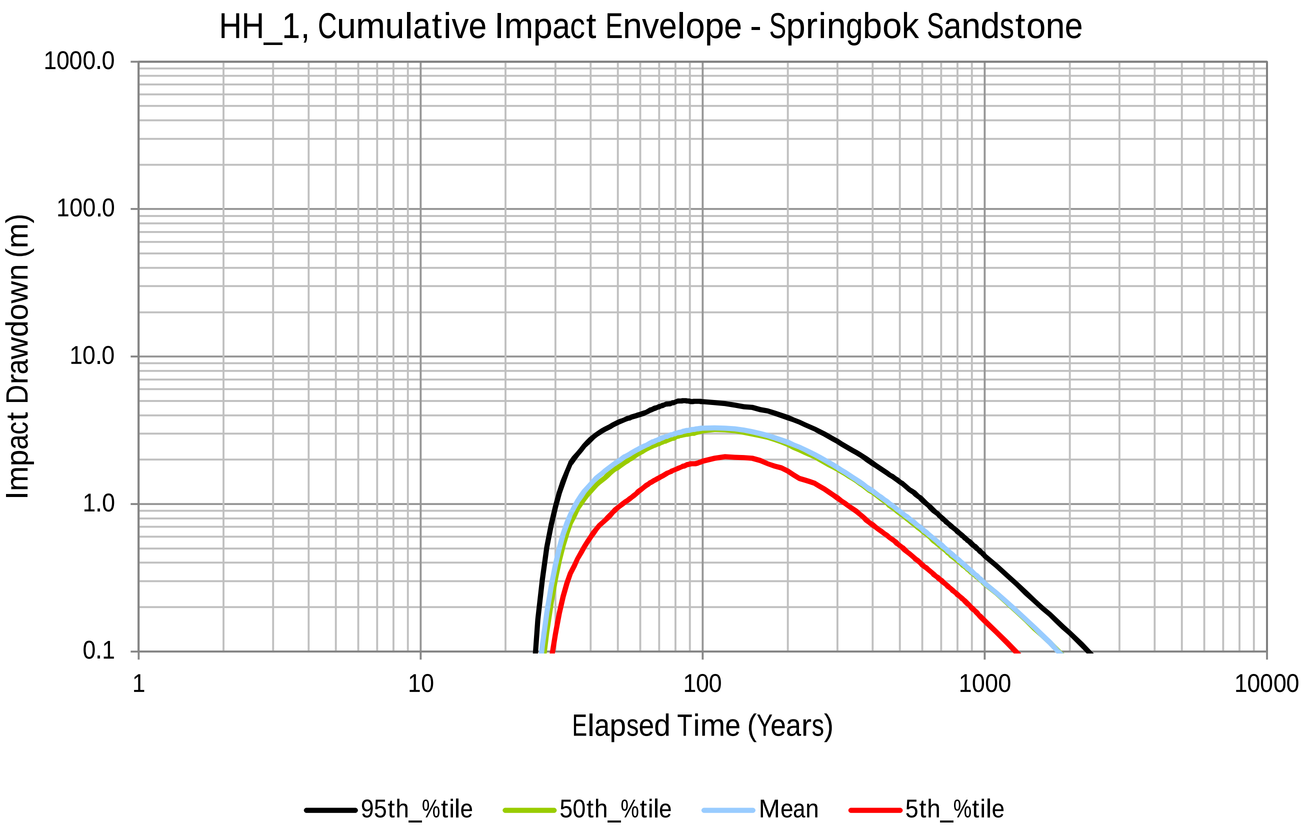


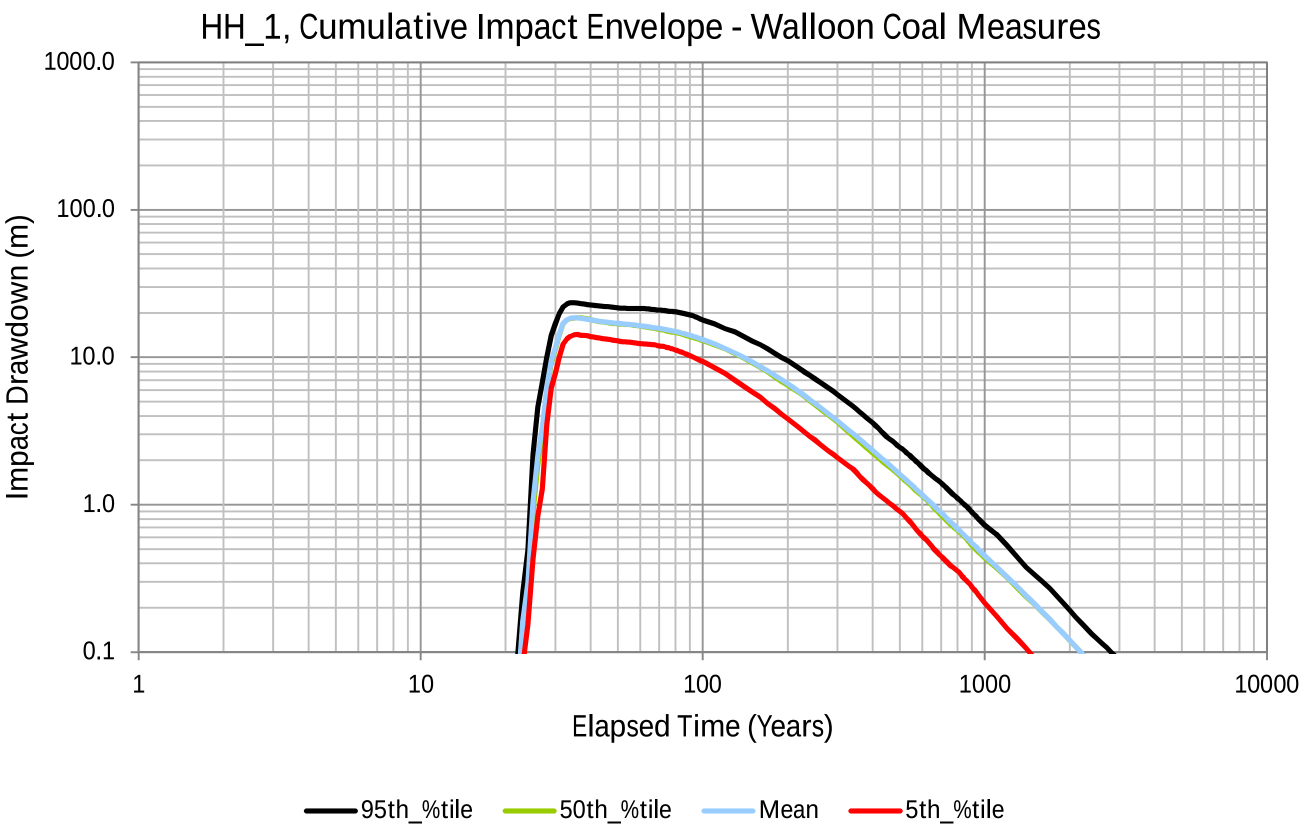
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



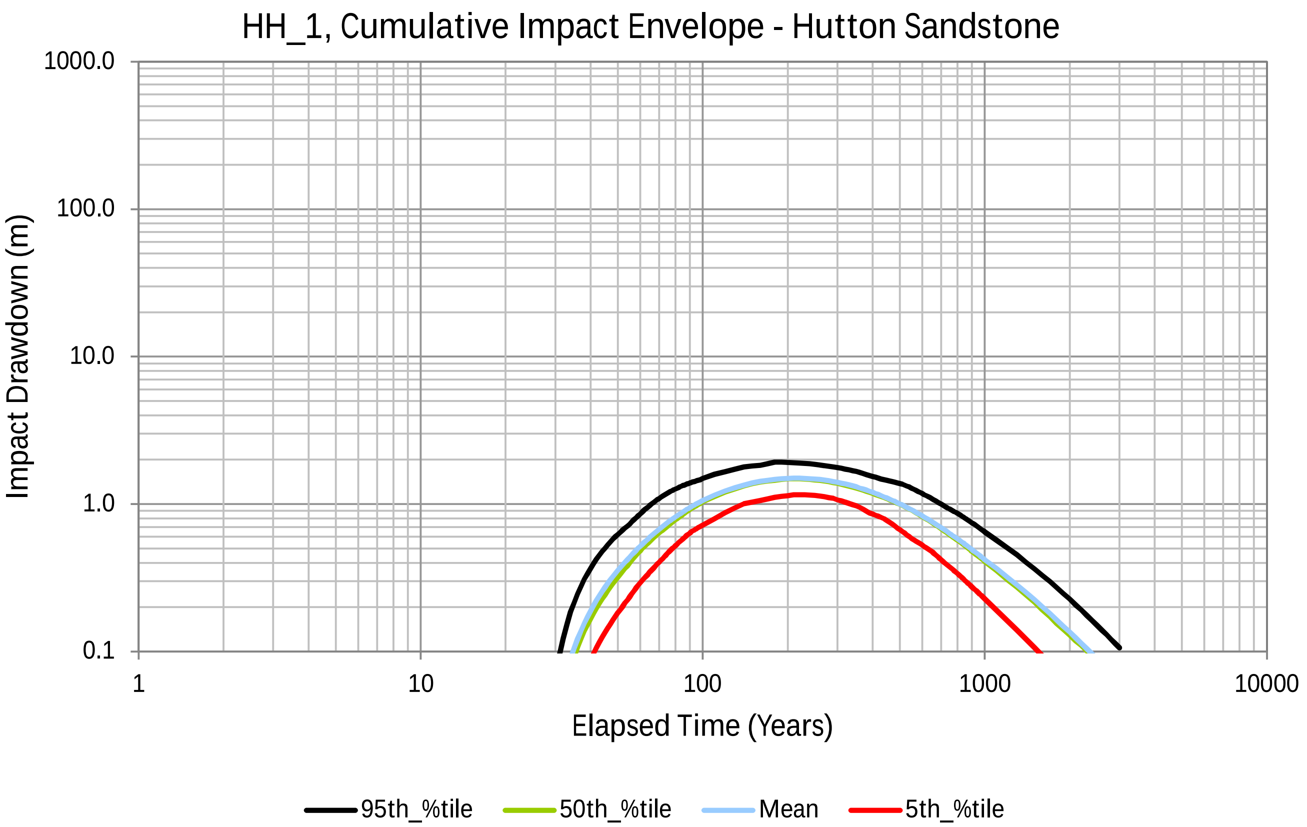


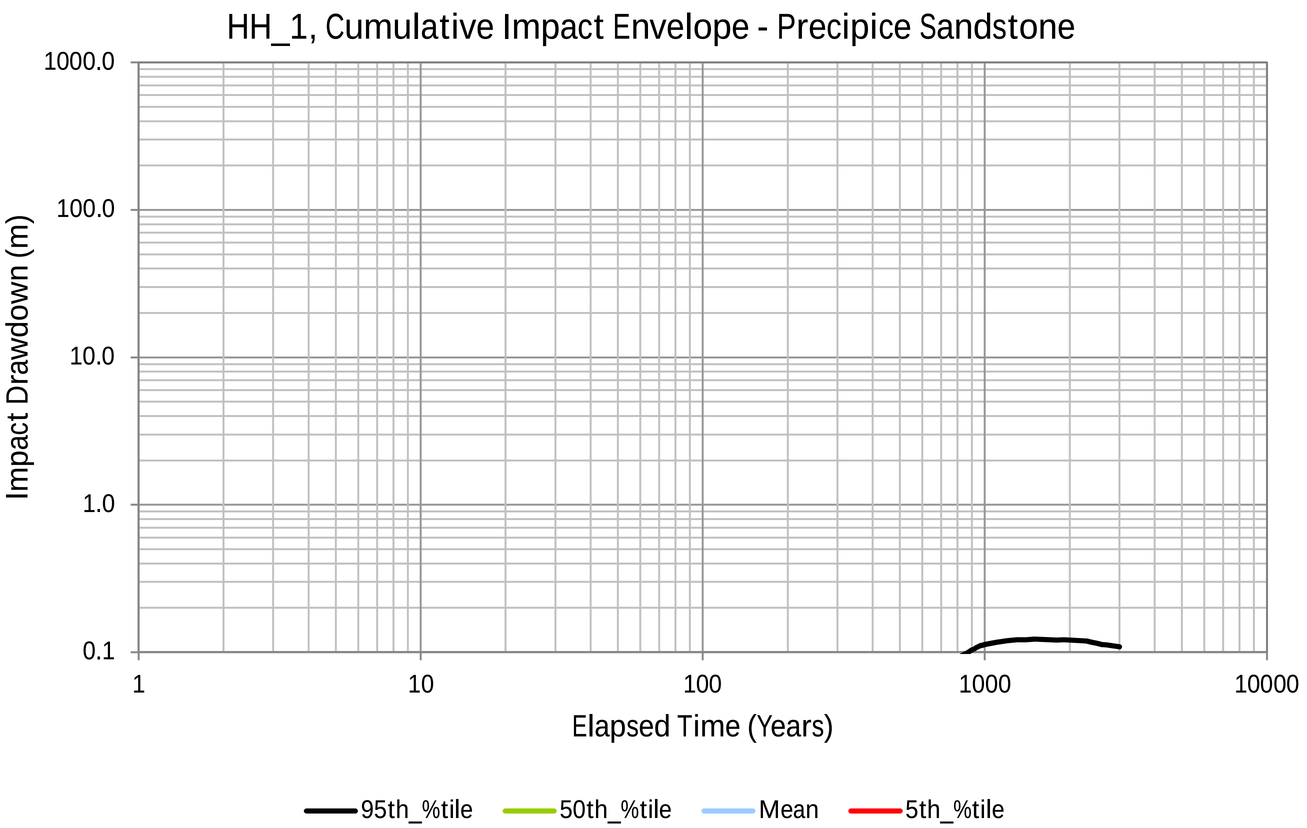
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



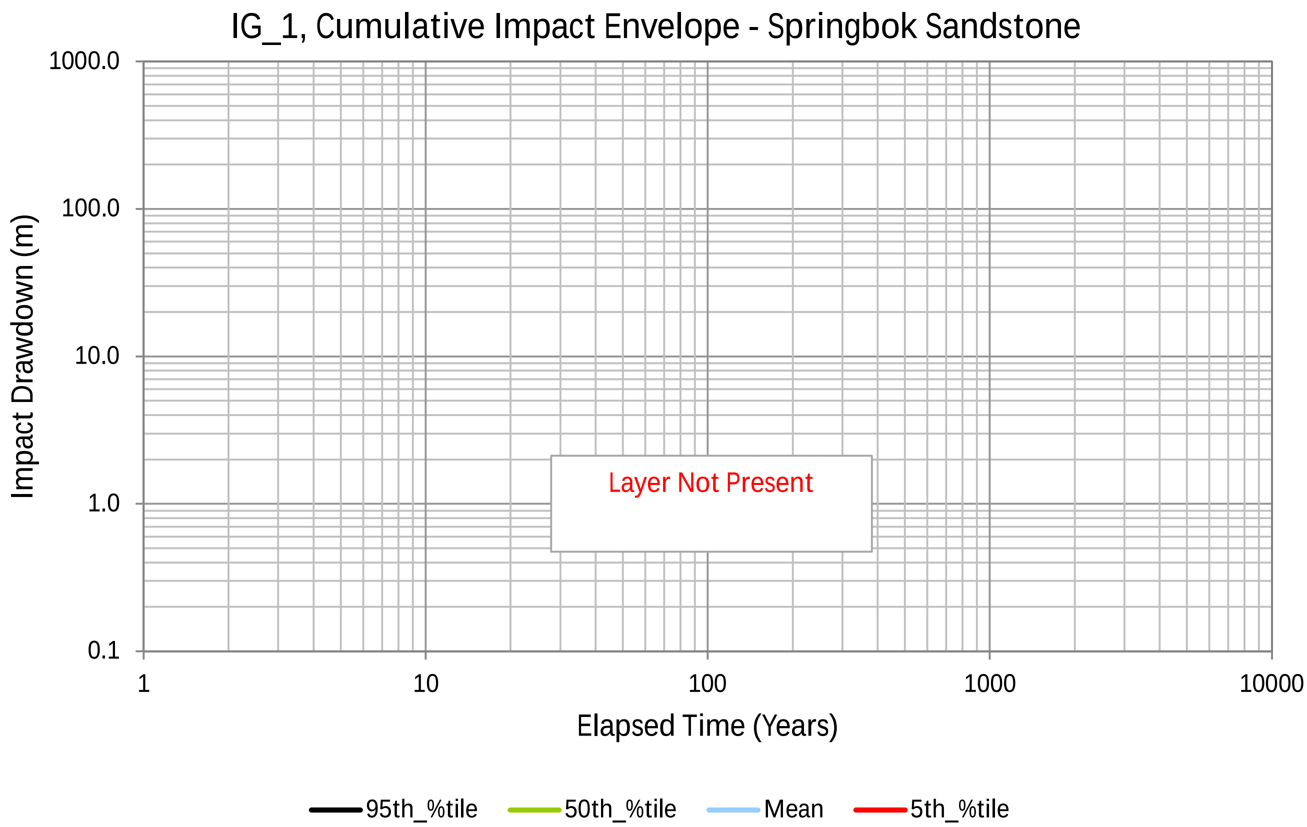


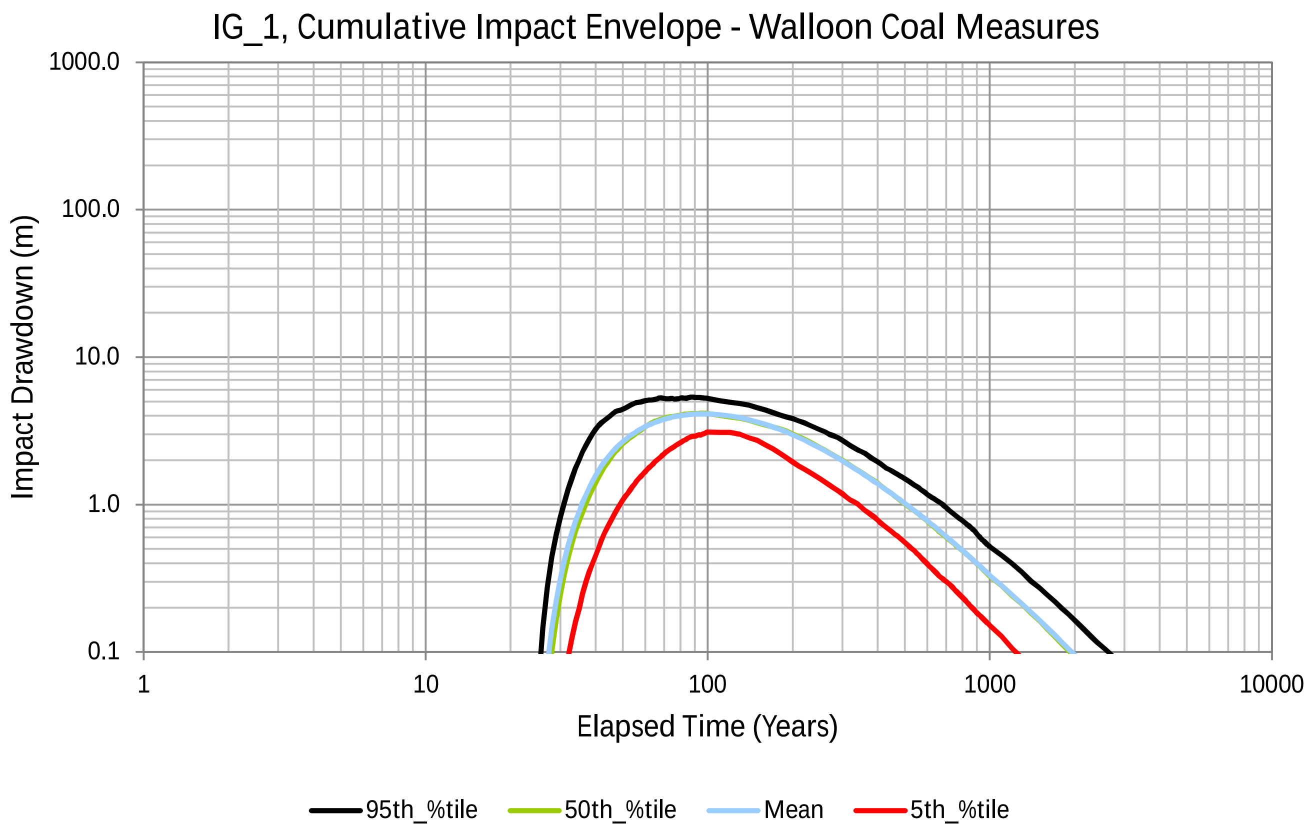
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



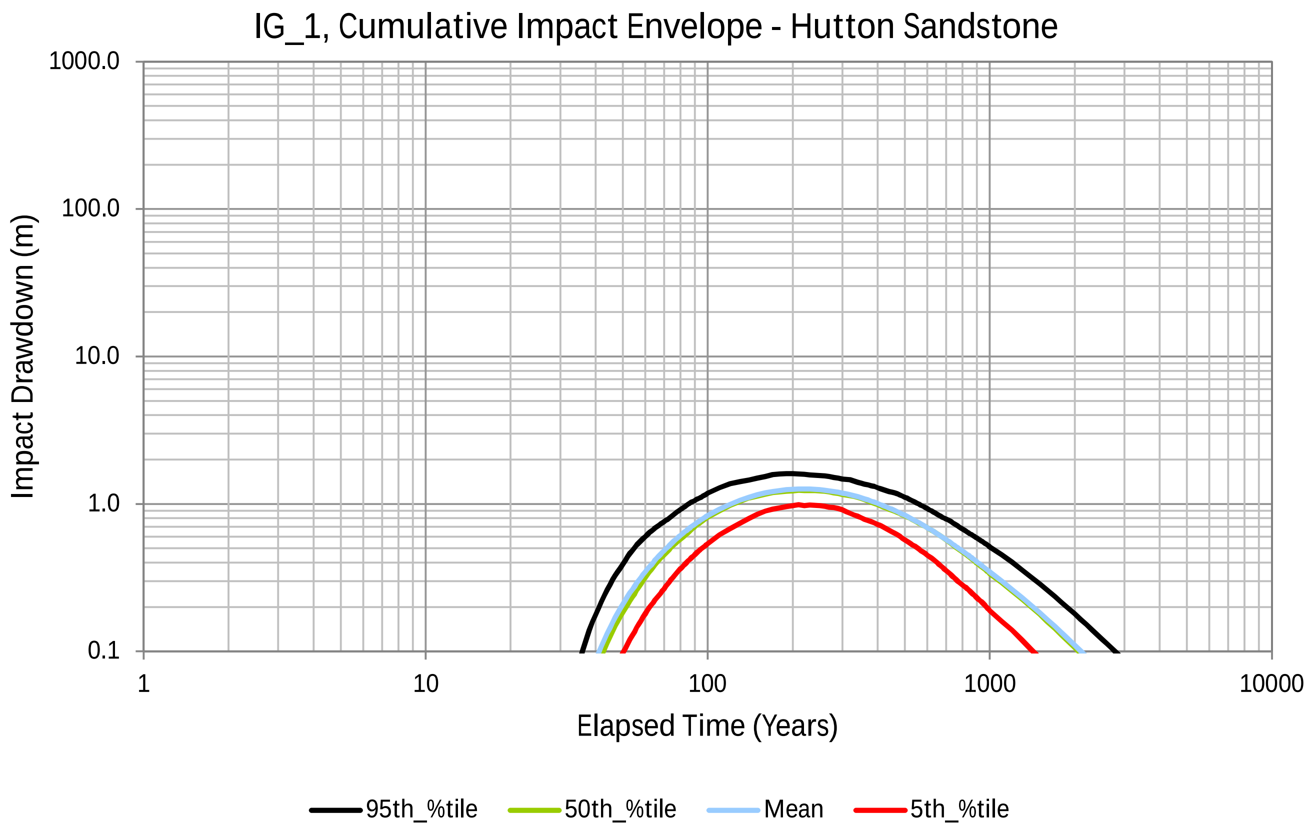


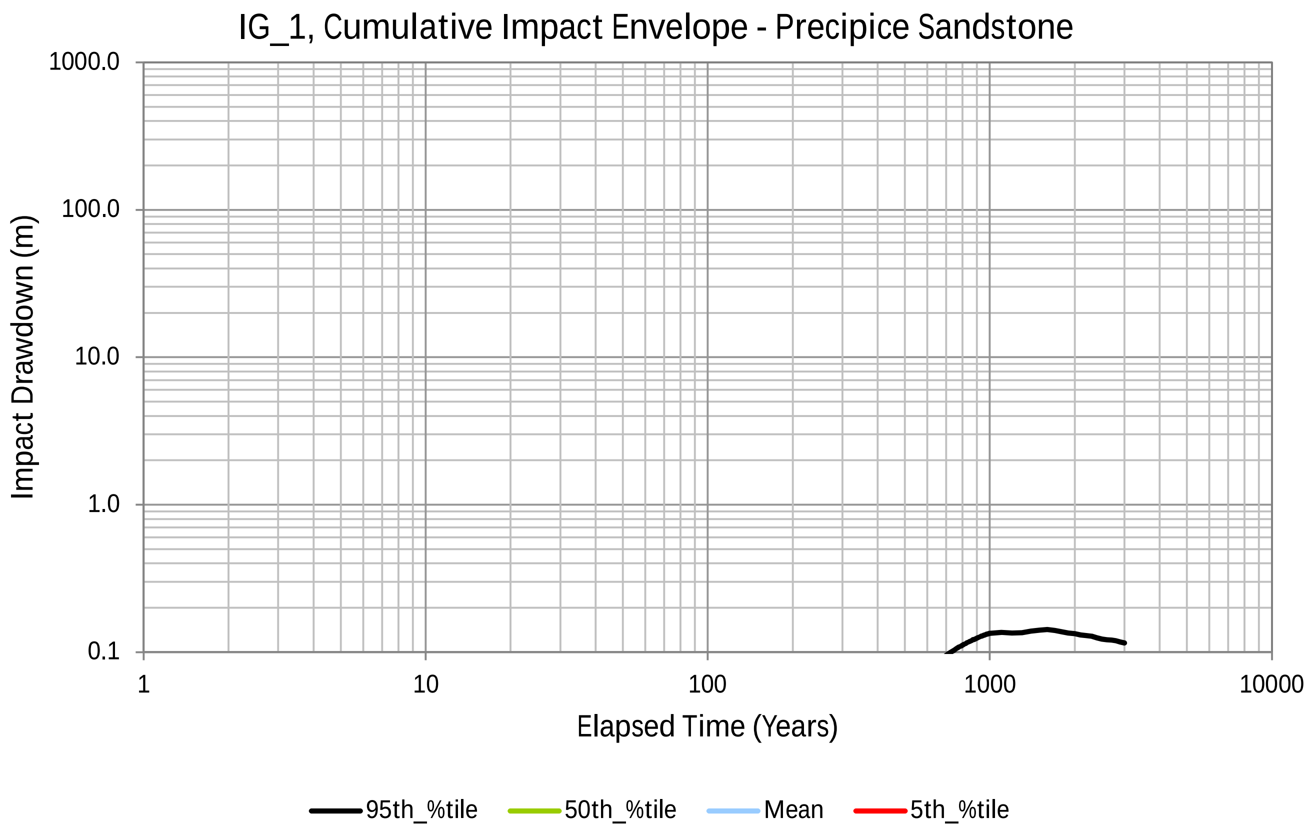
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



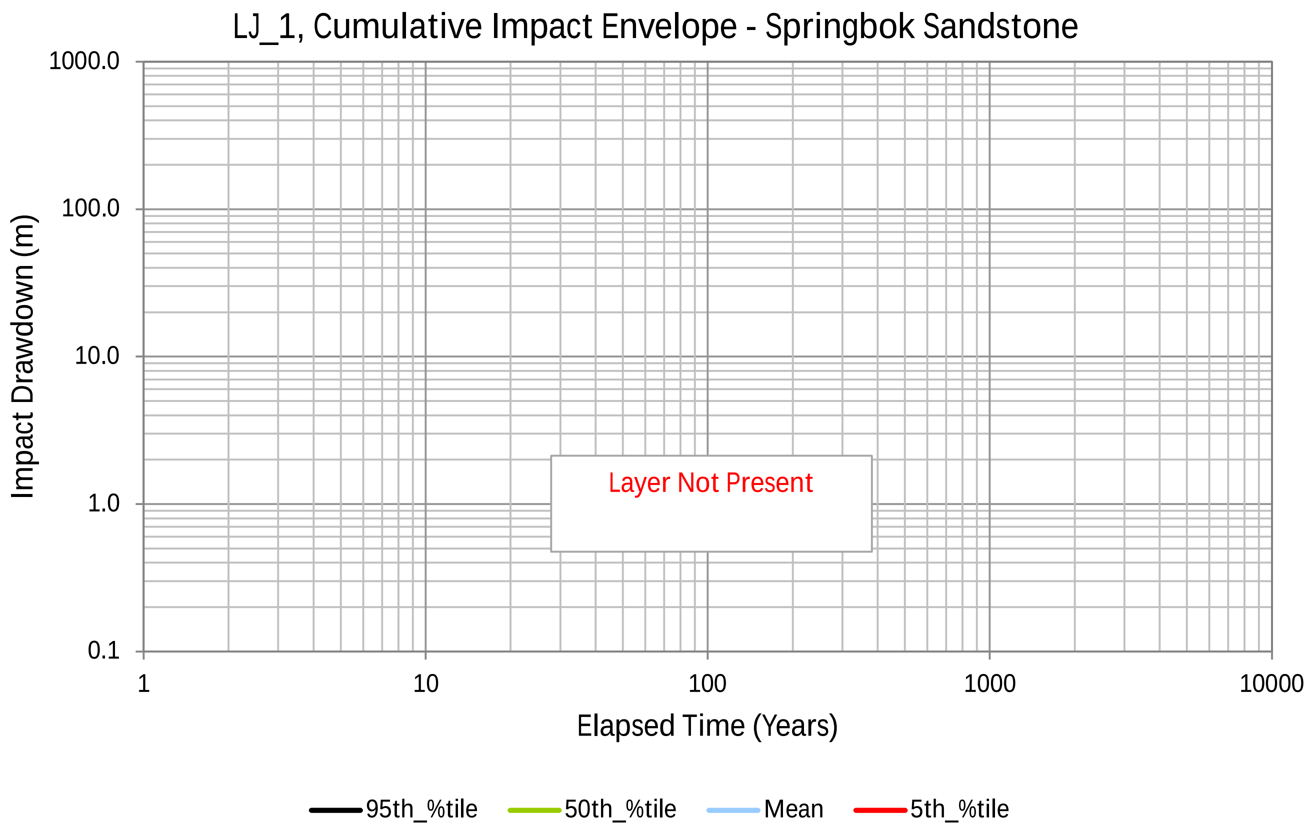


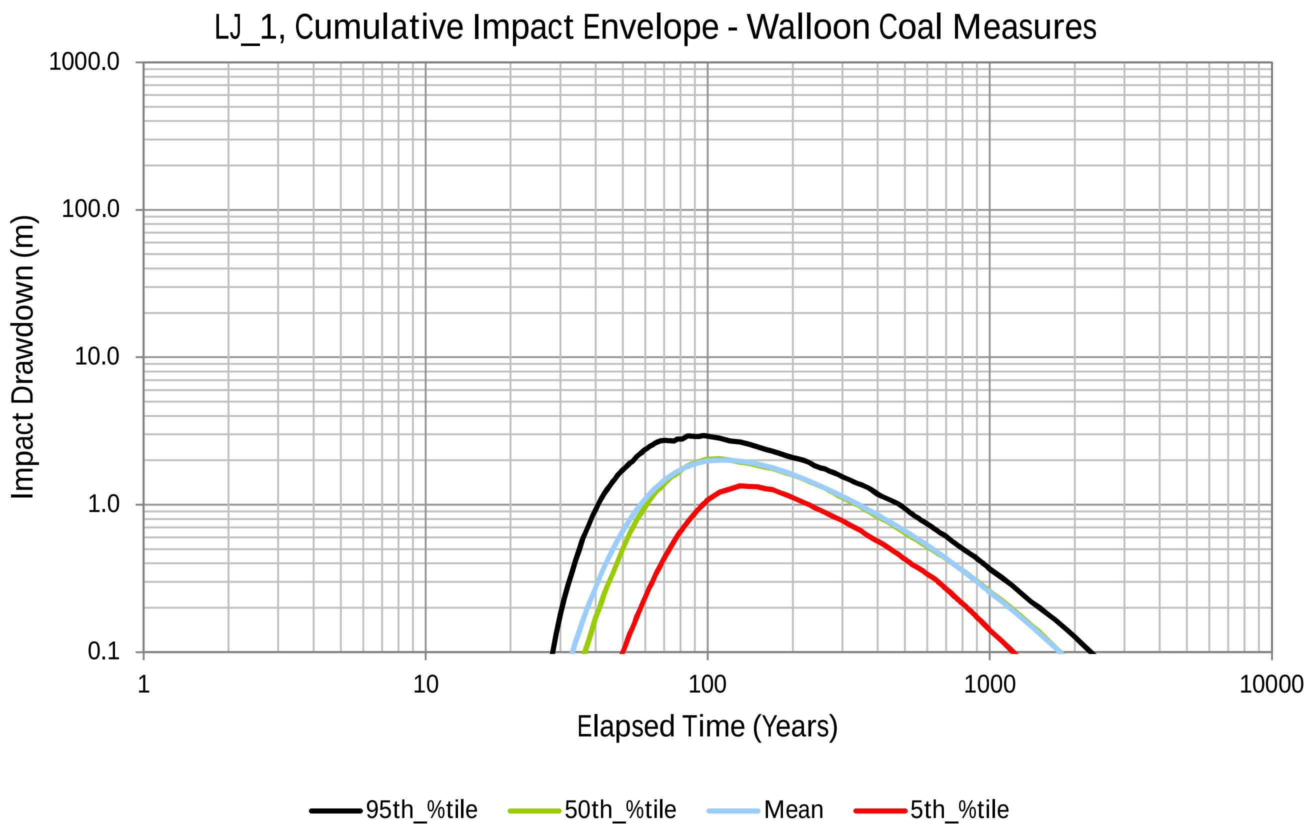
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 1



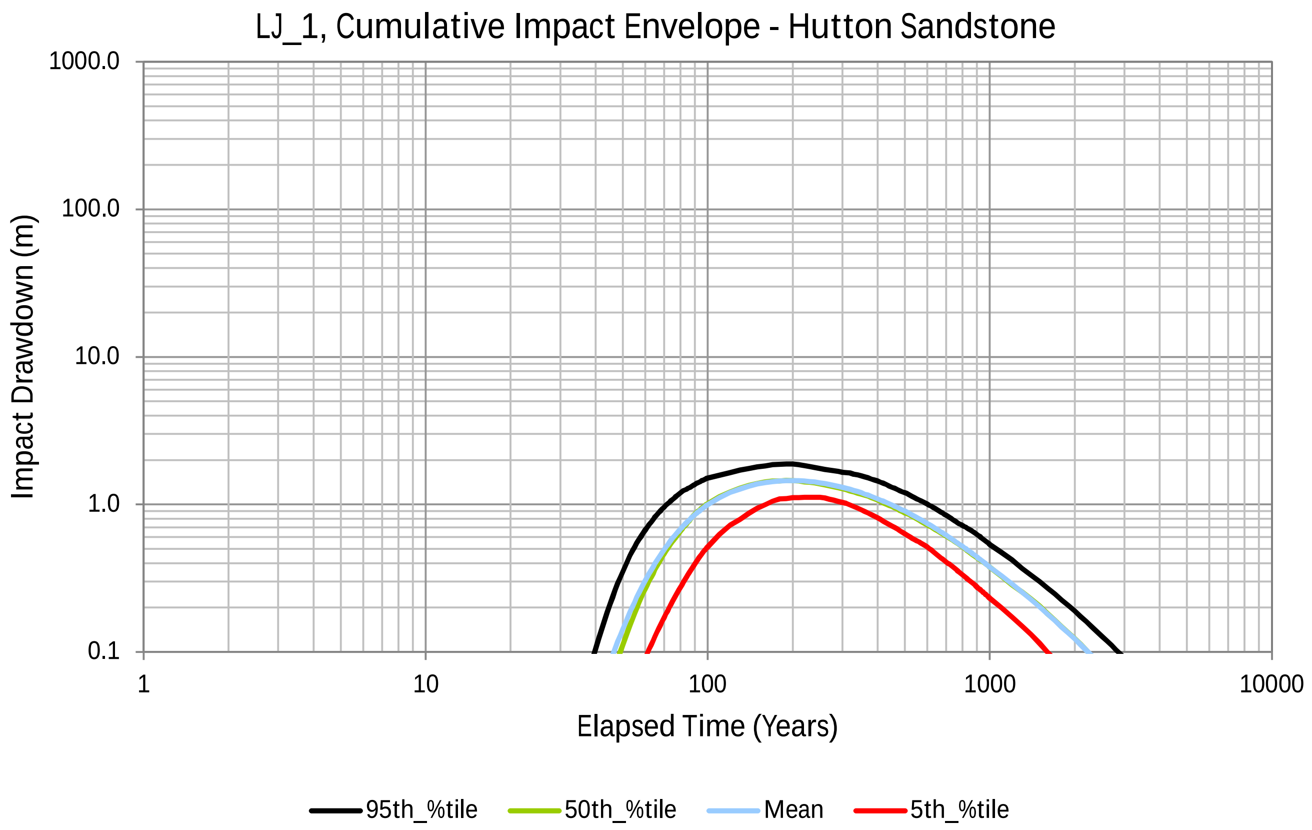


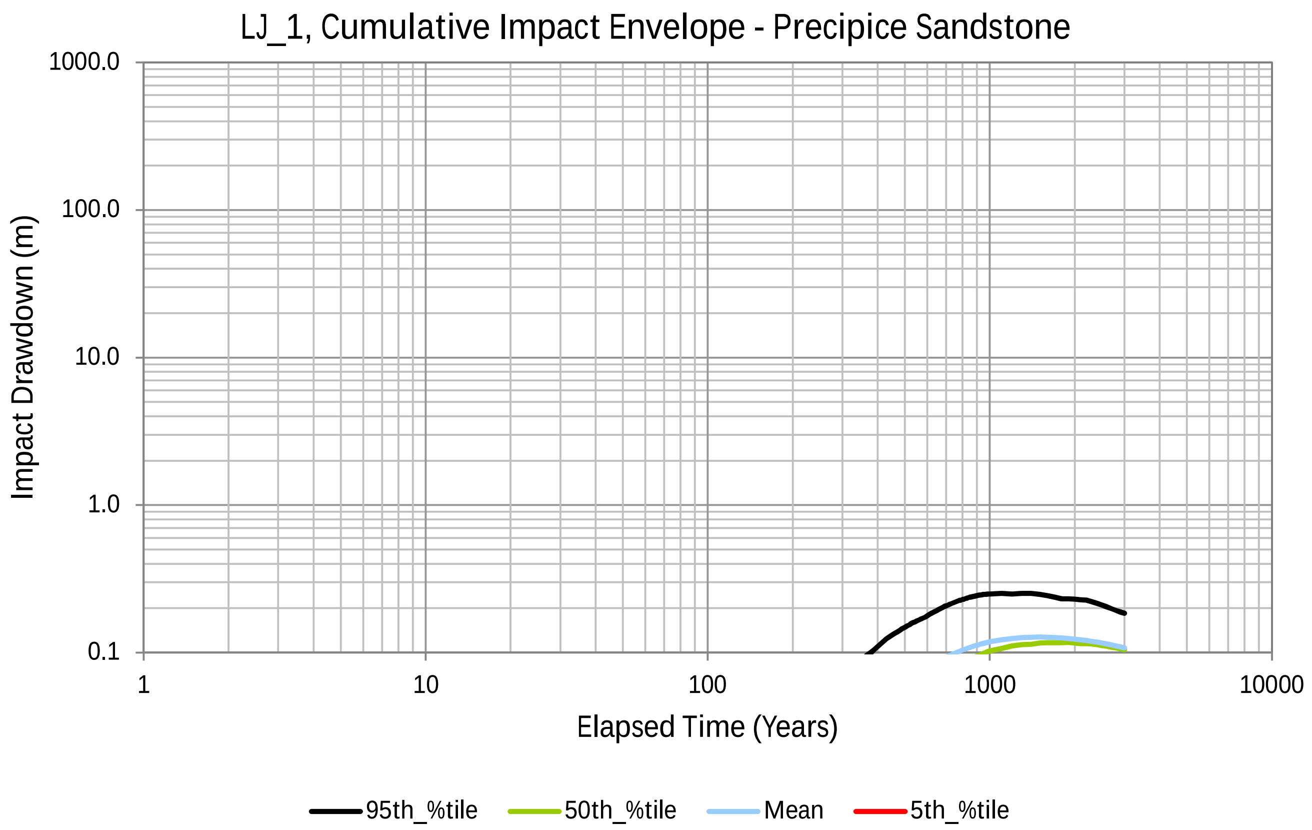
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



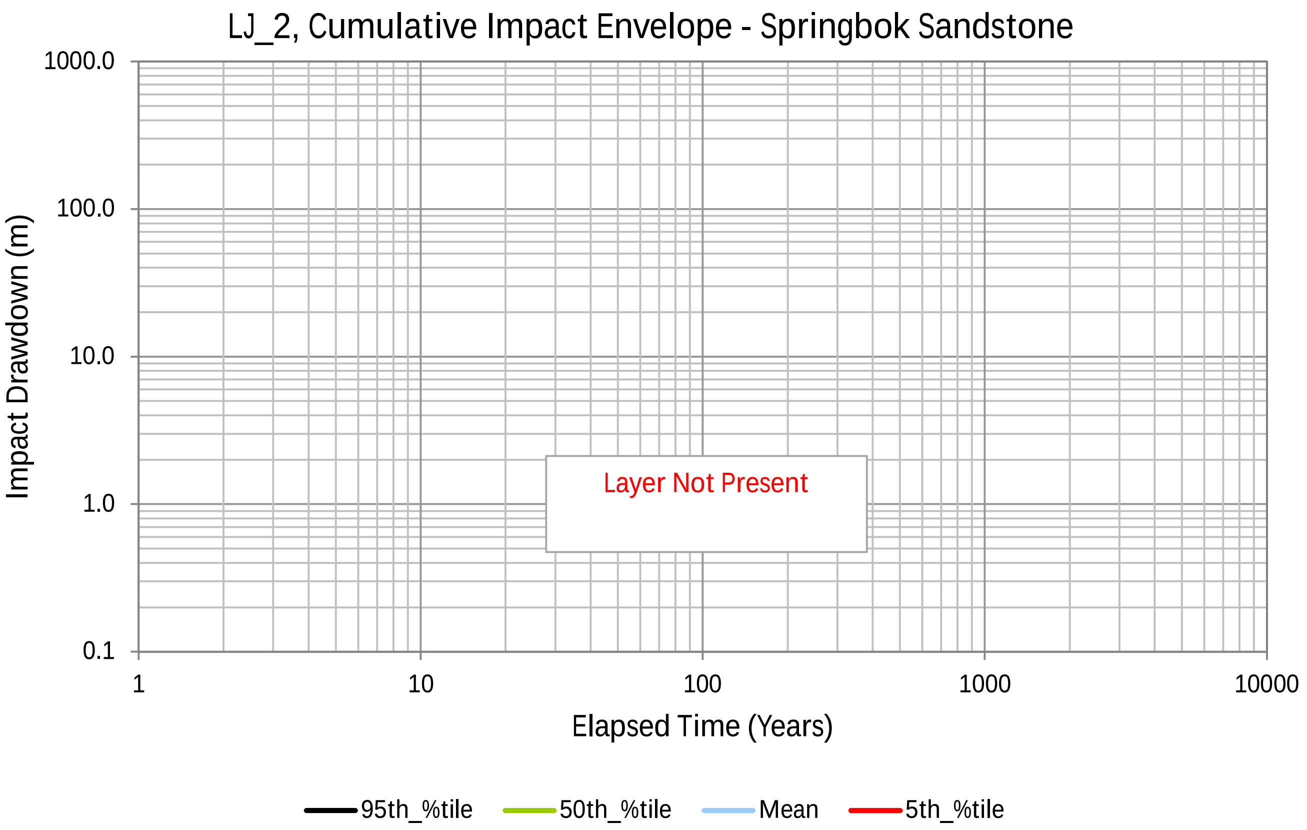


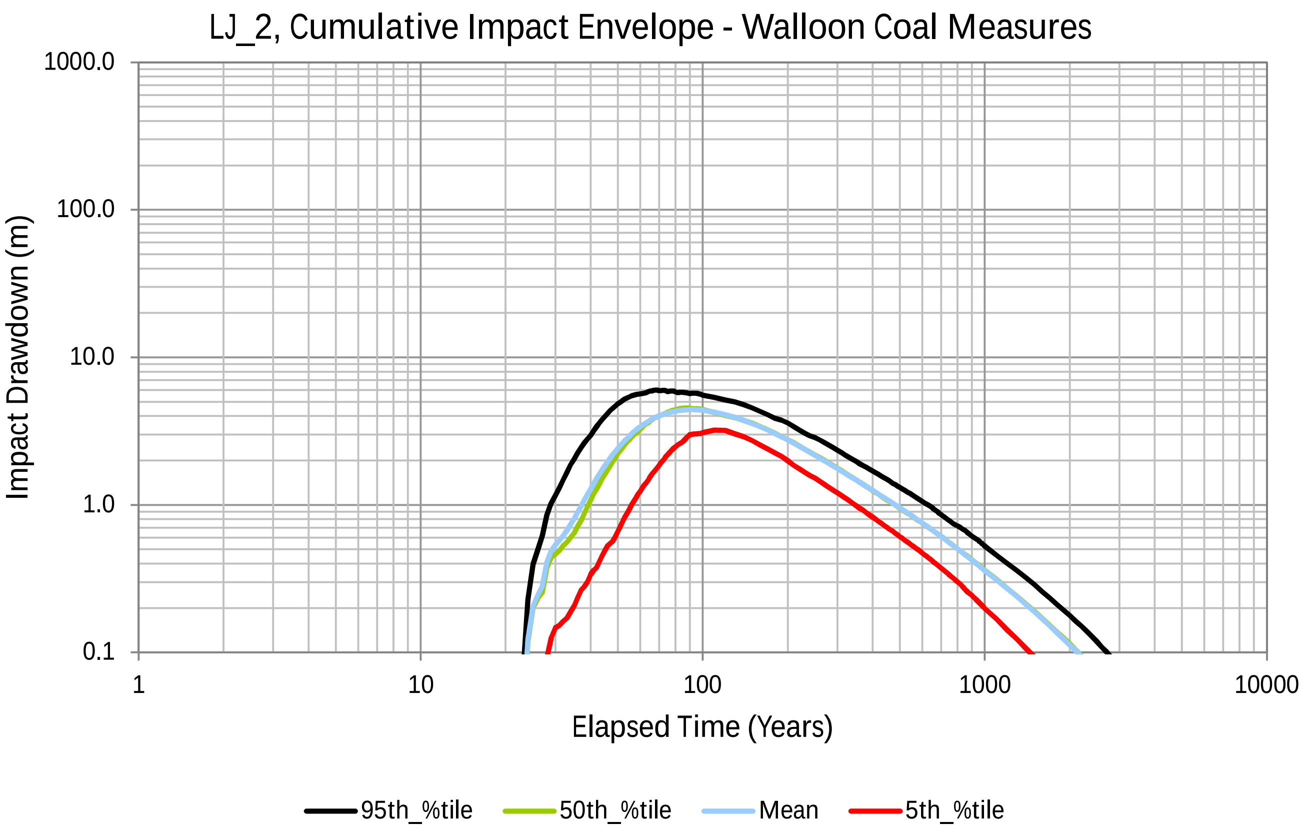
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



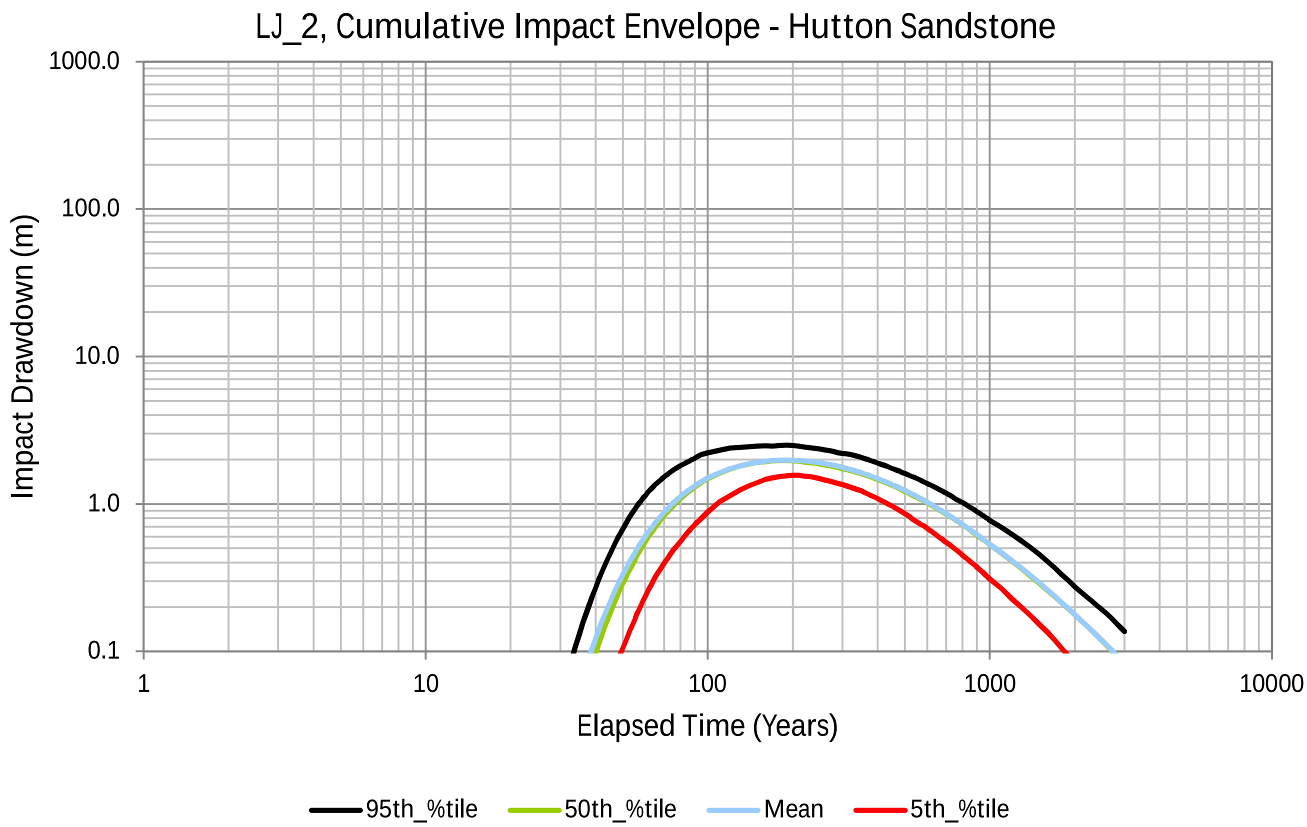


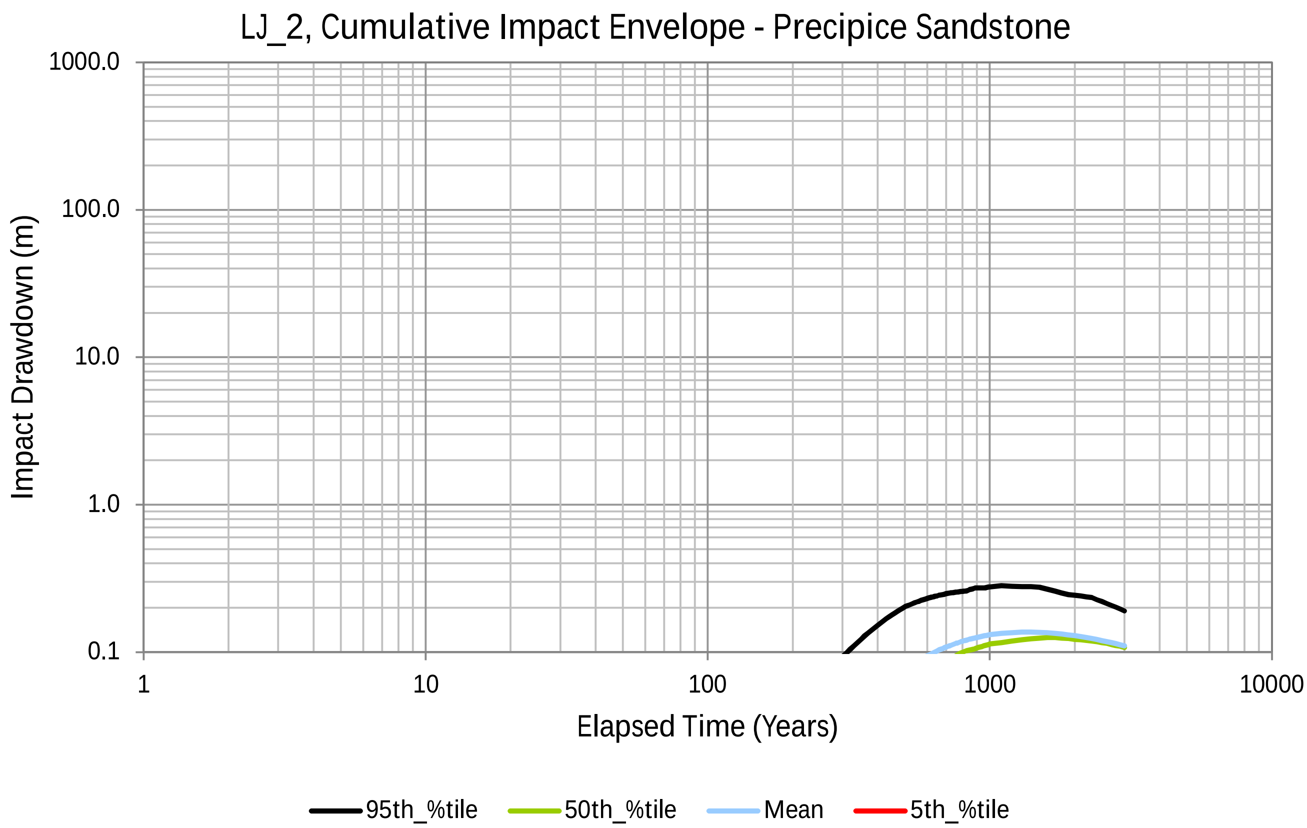
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



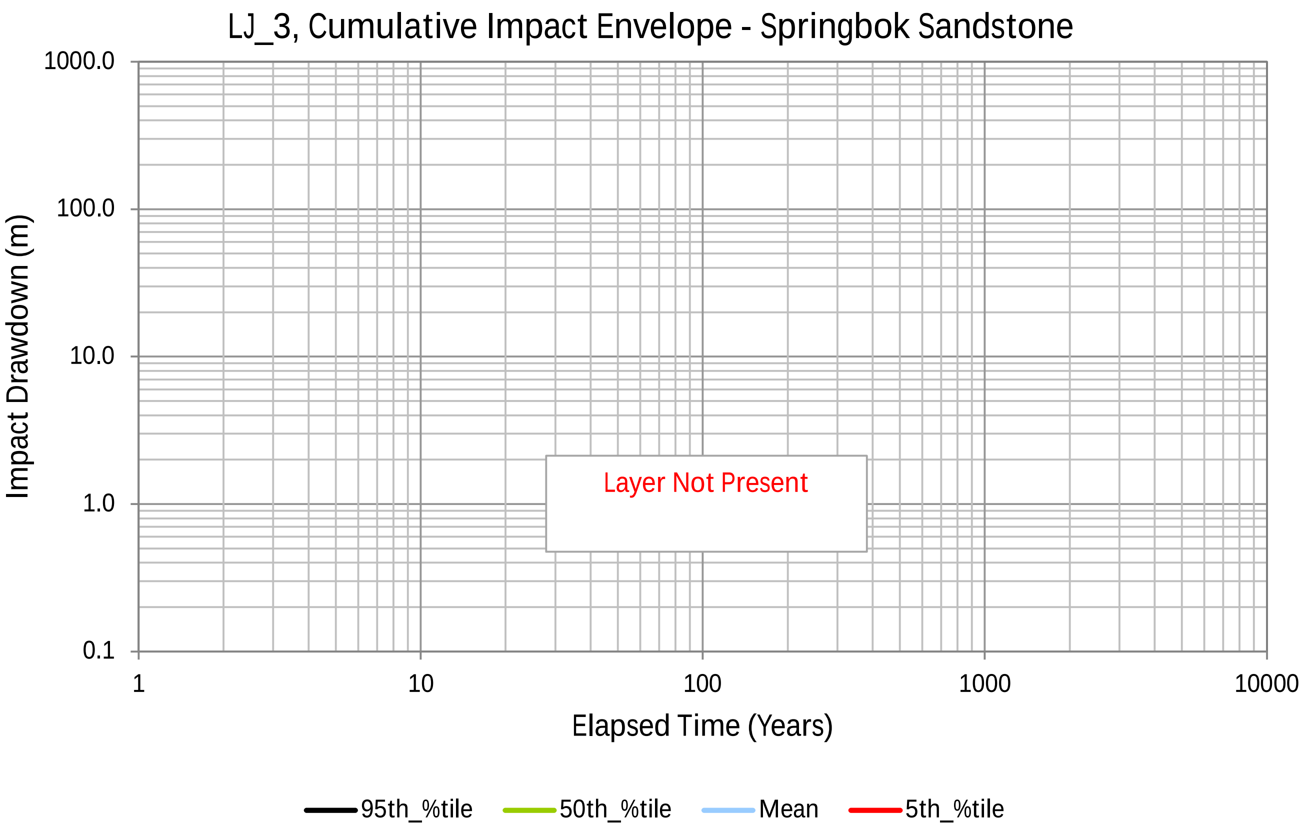


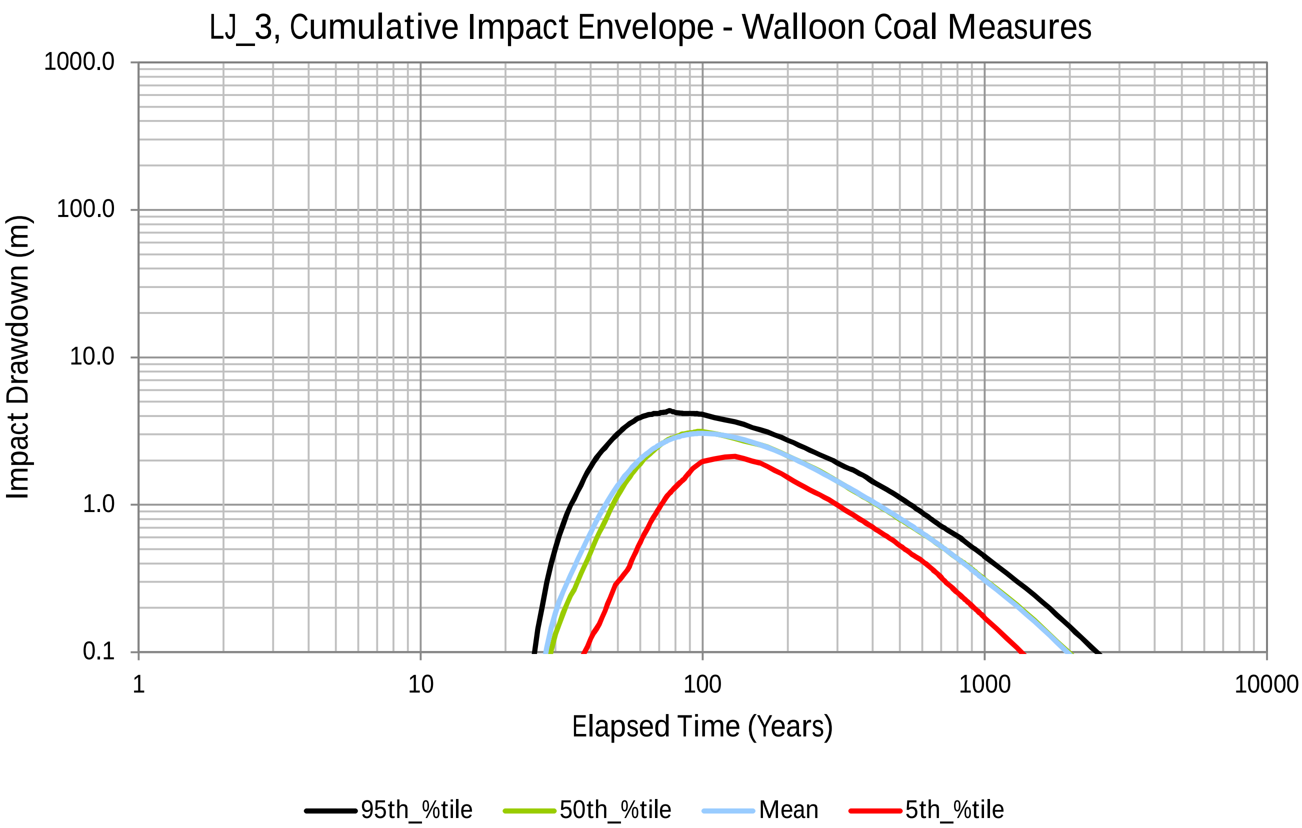
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2





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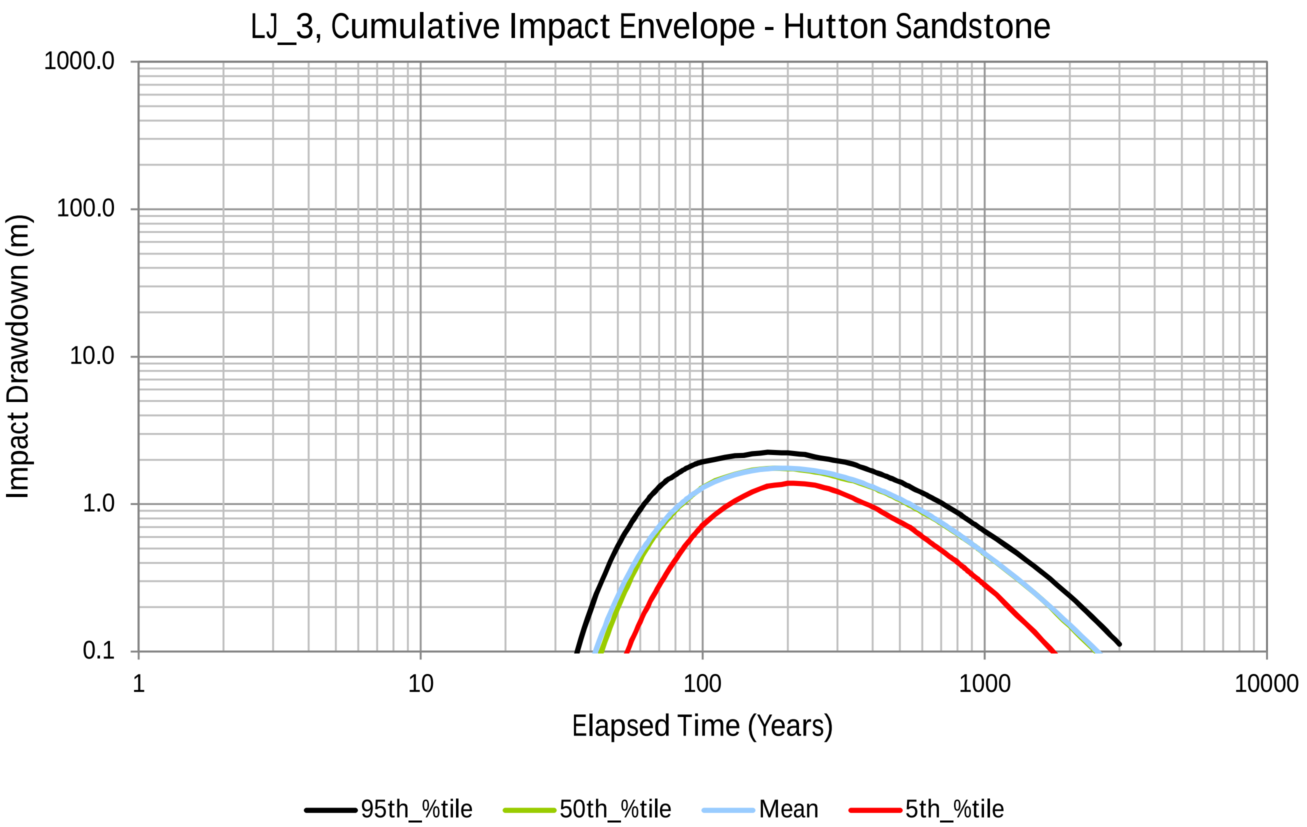
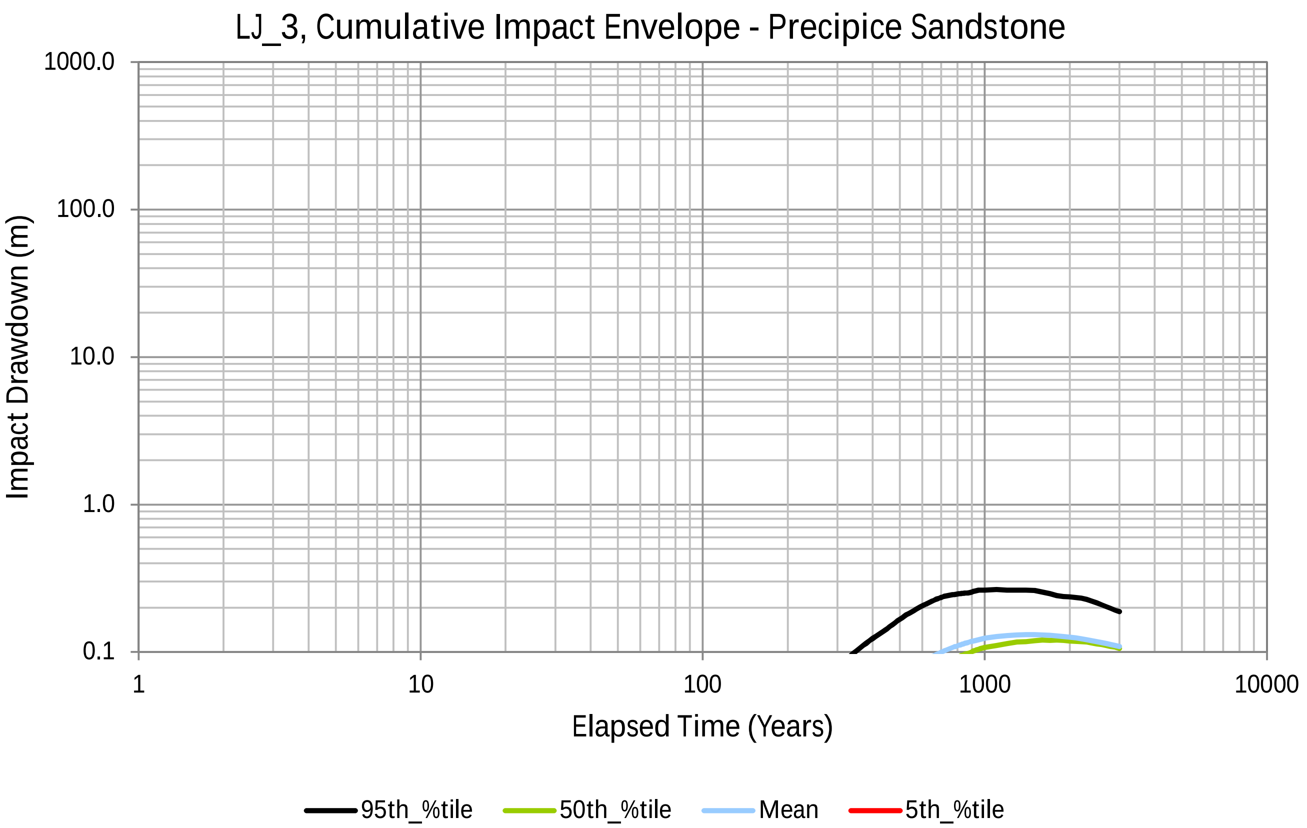
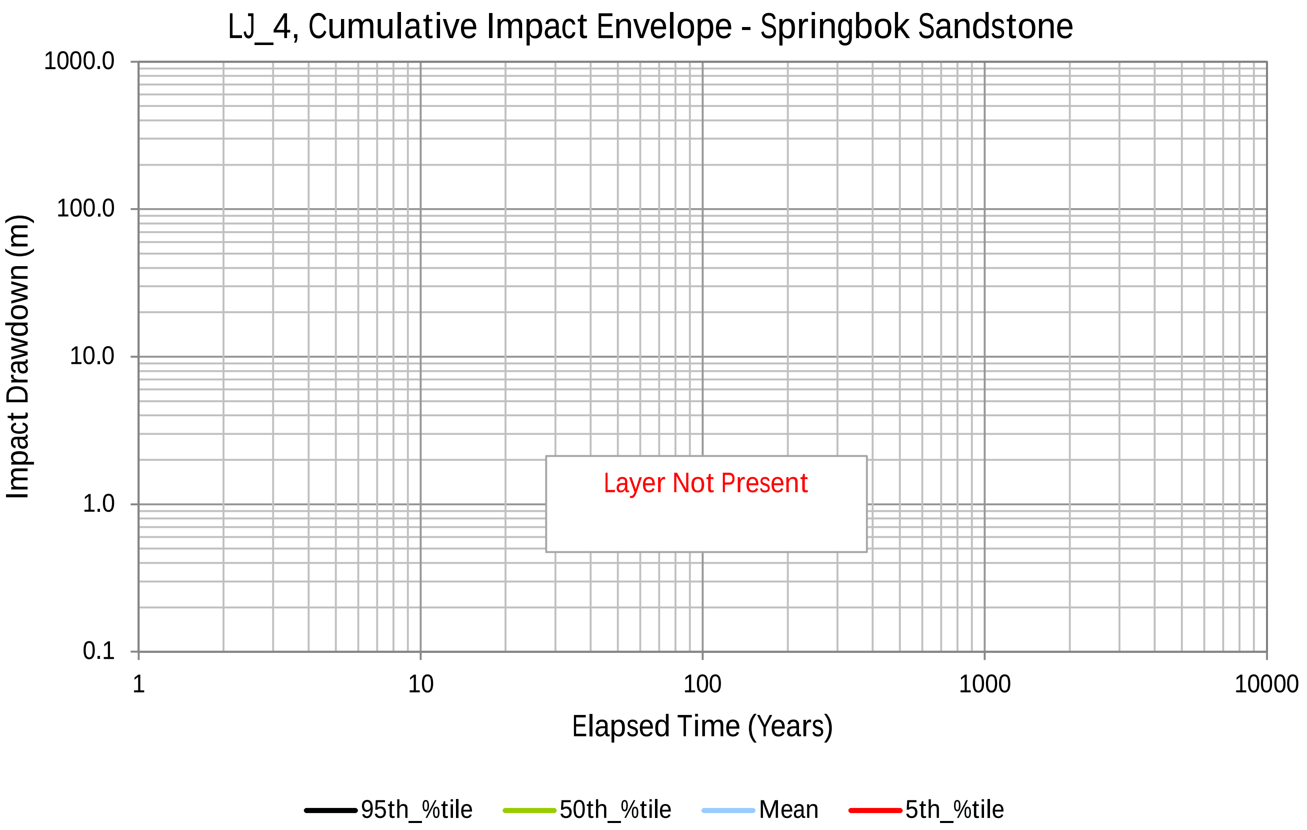
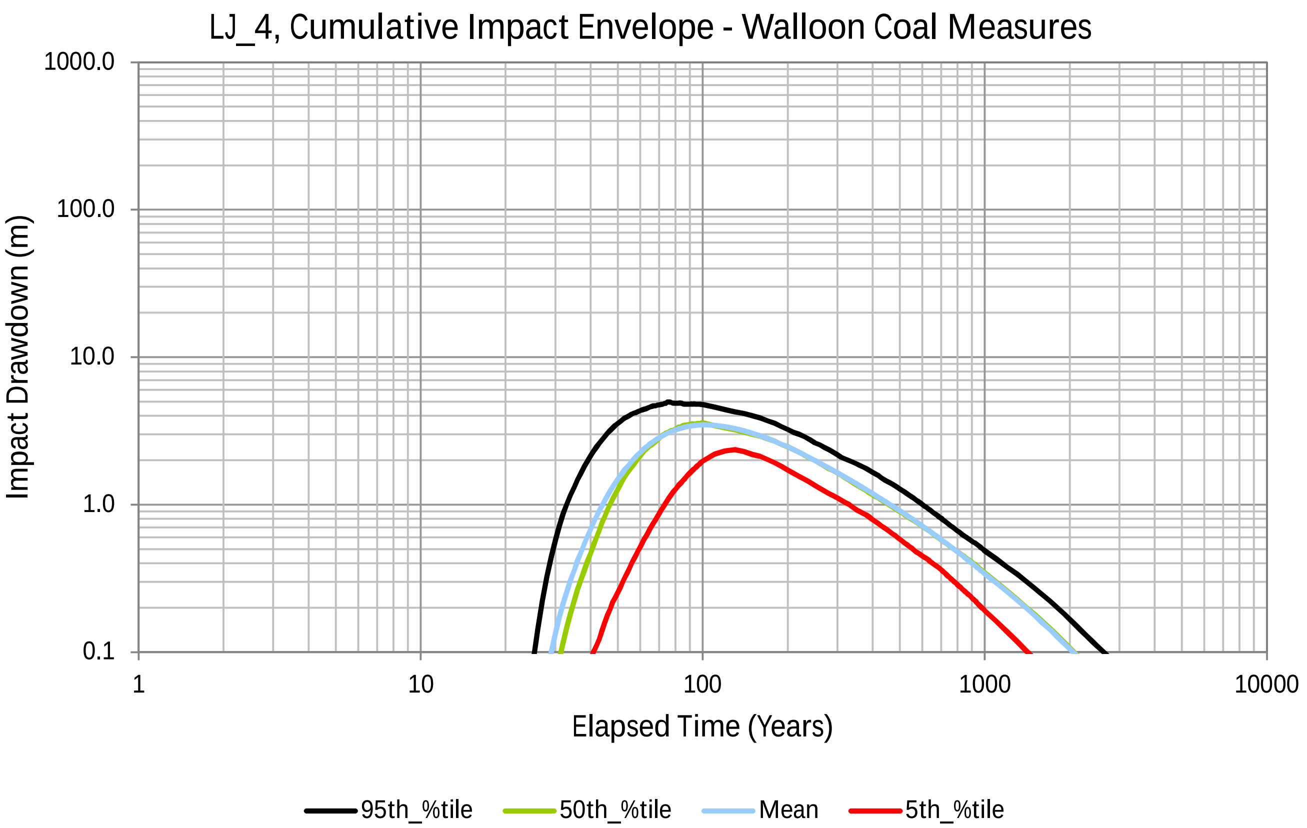
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



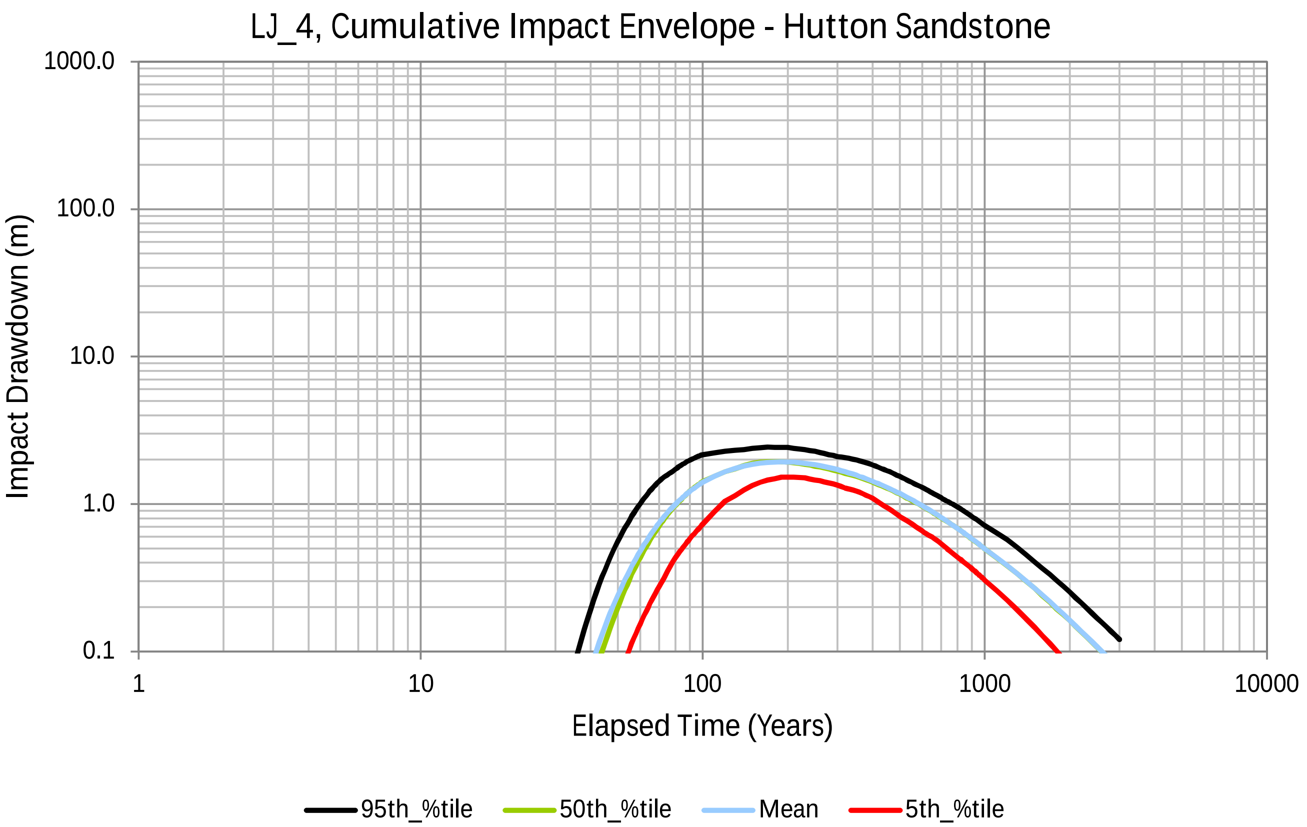


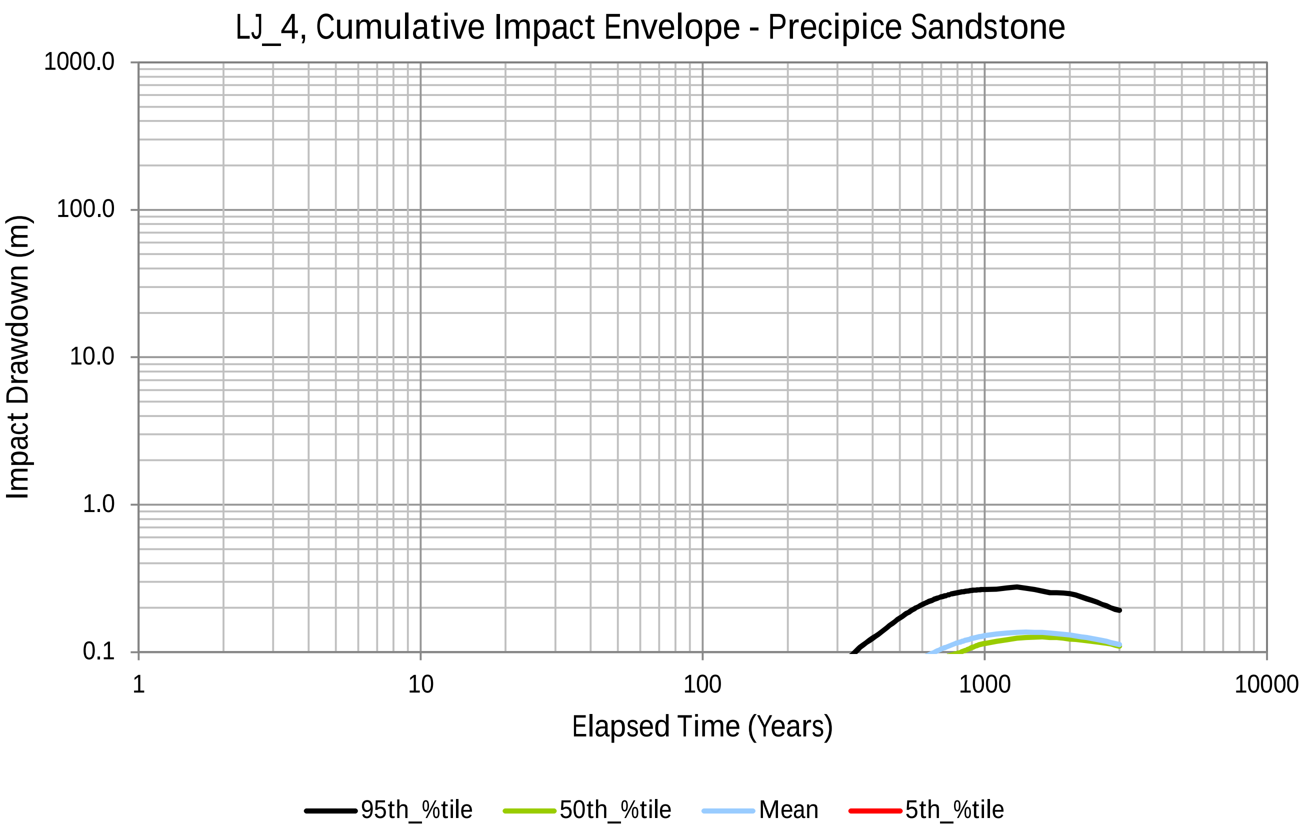
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



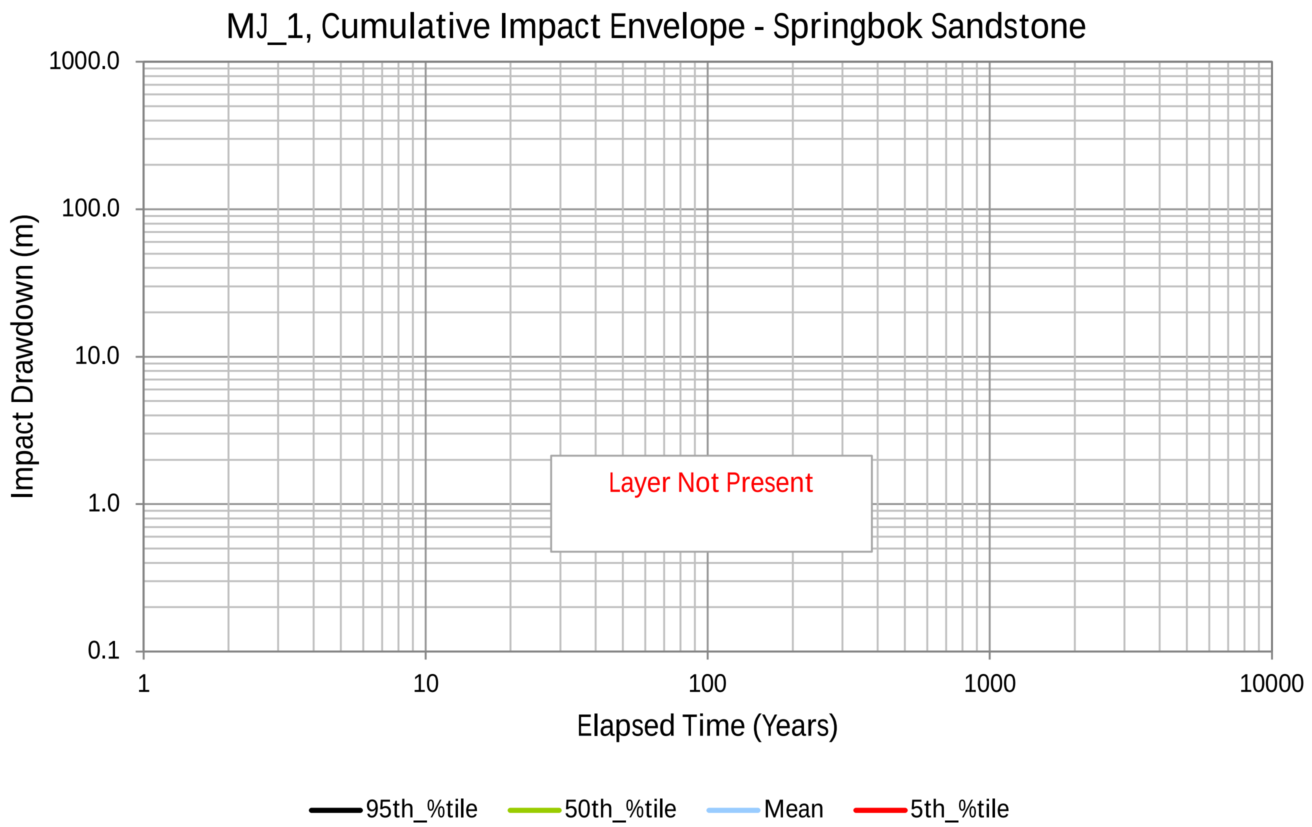


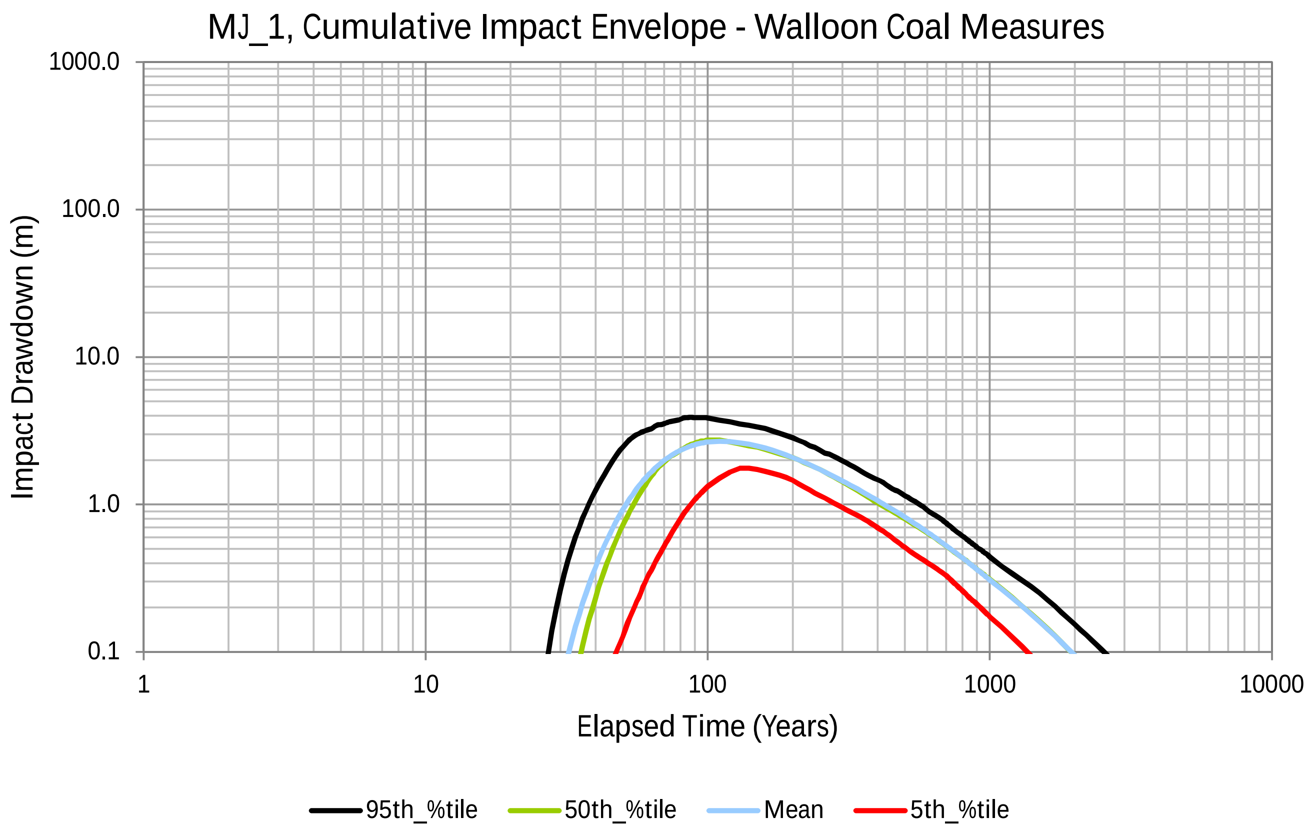
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



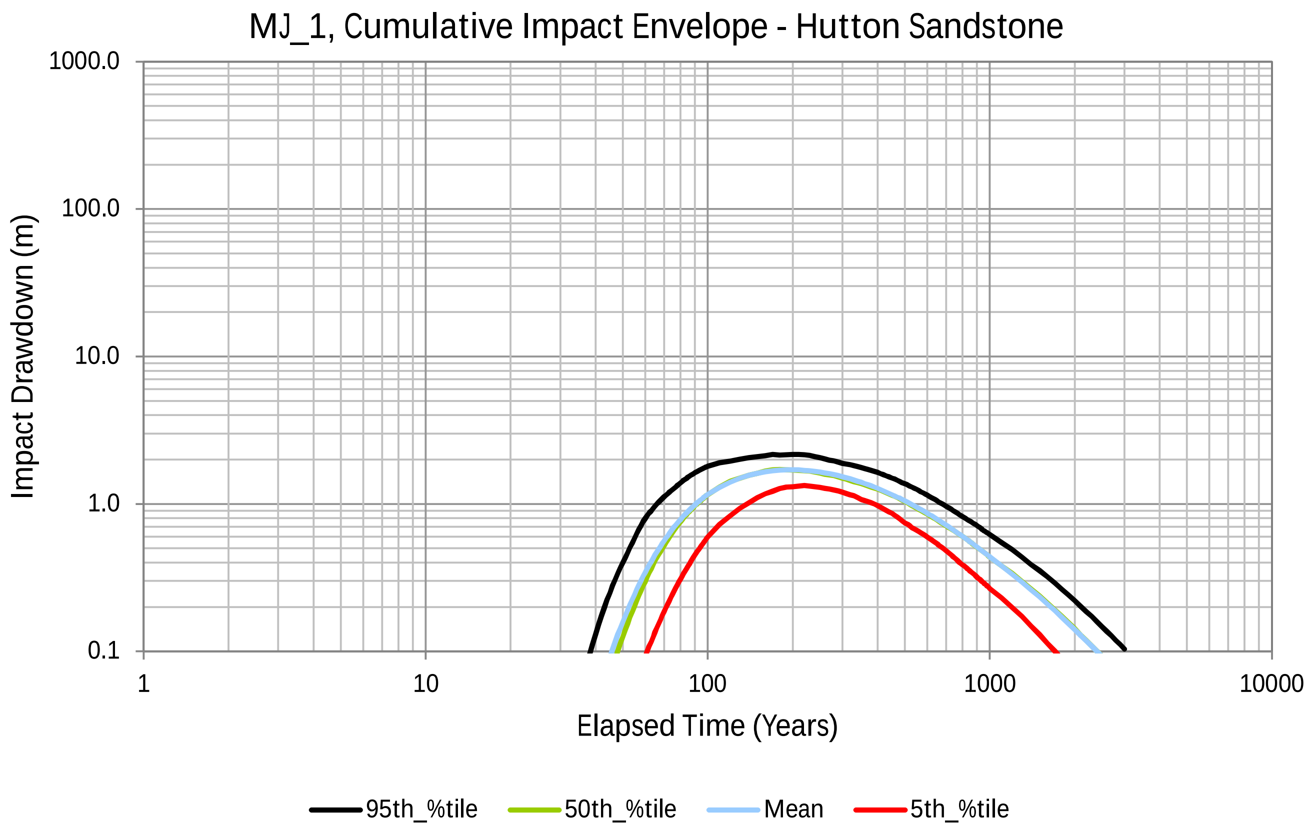


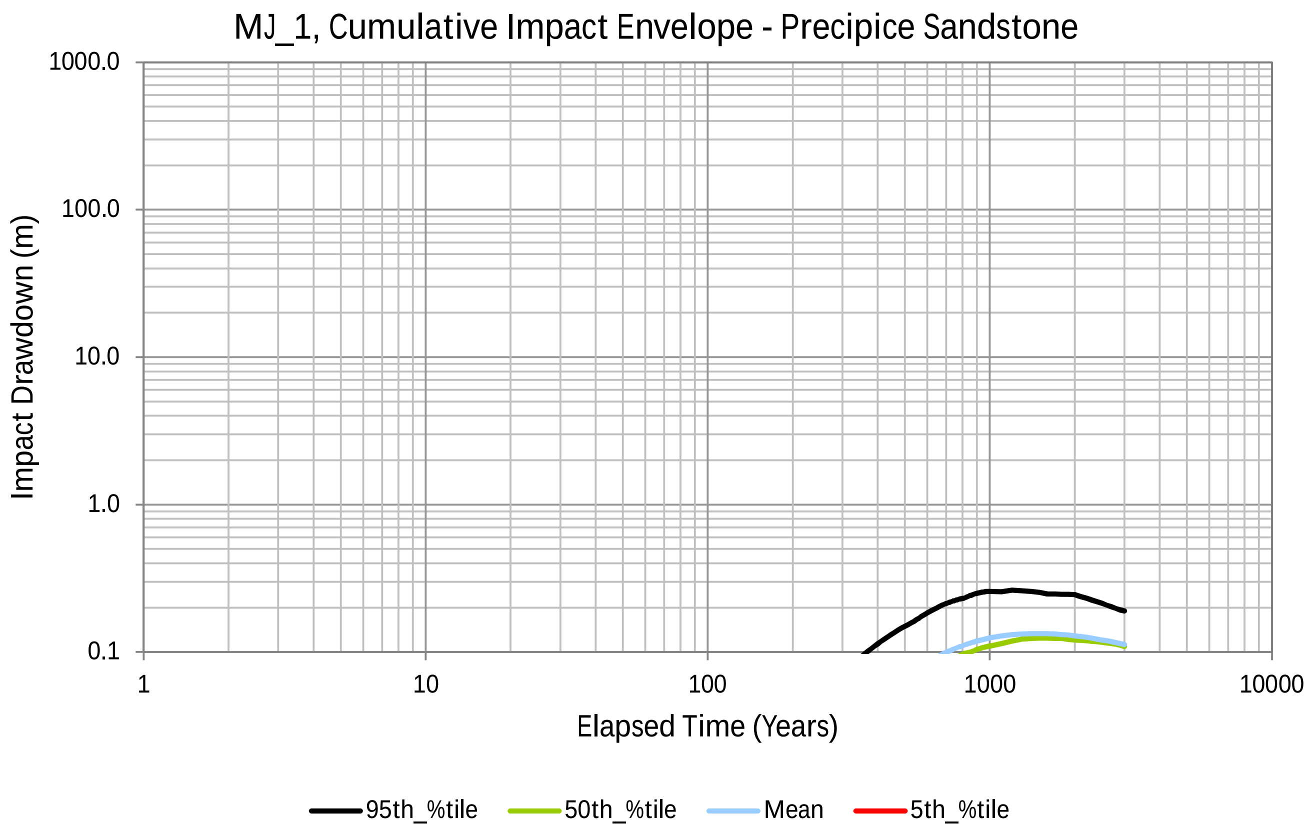
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



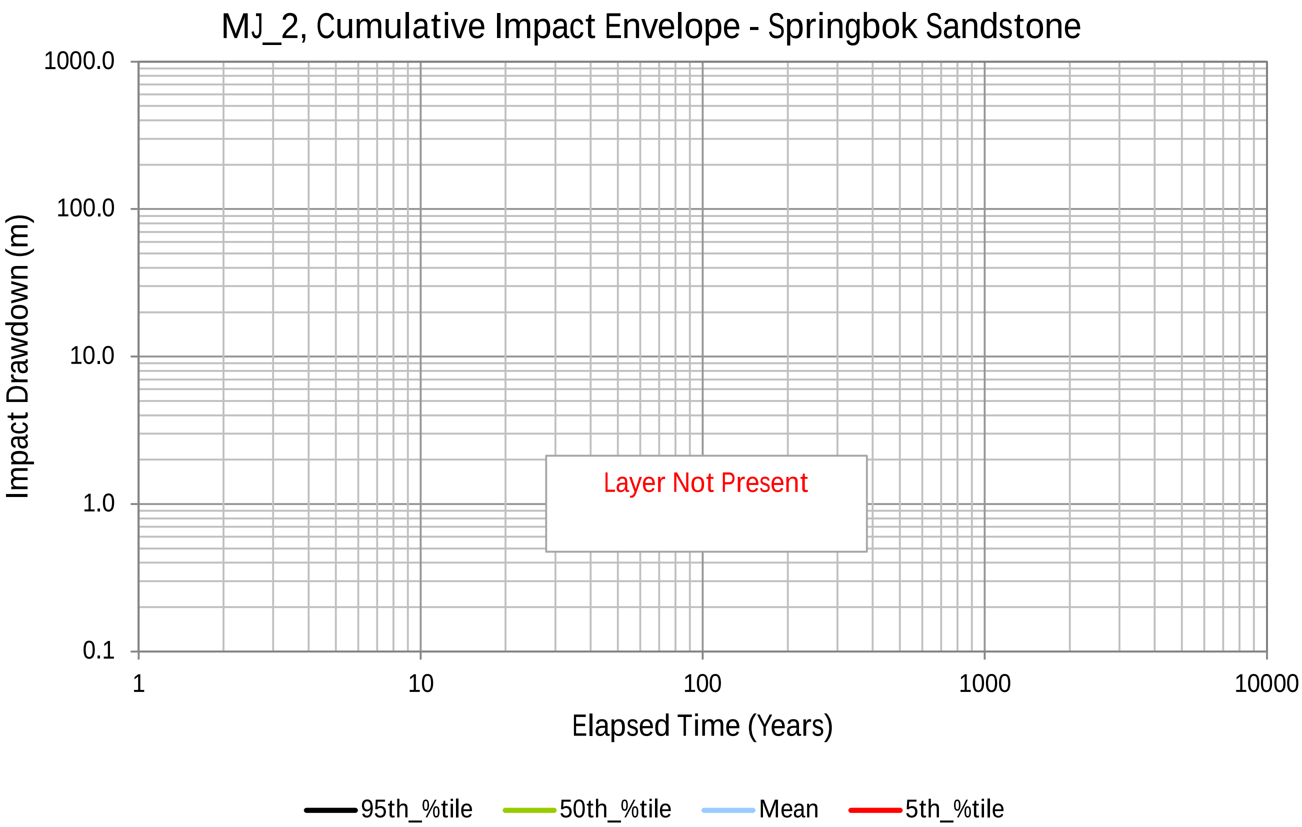


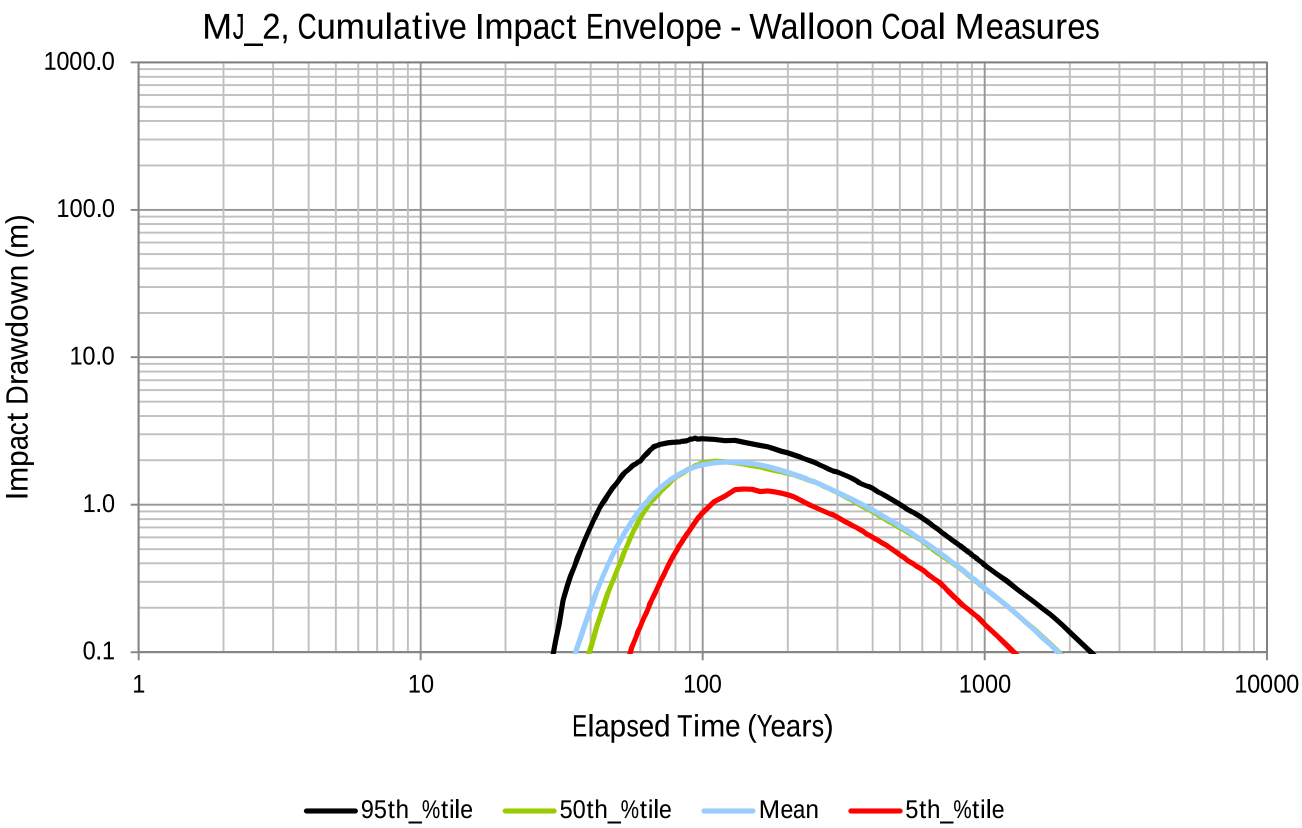
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



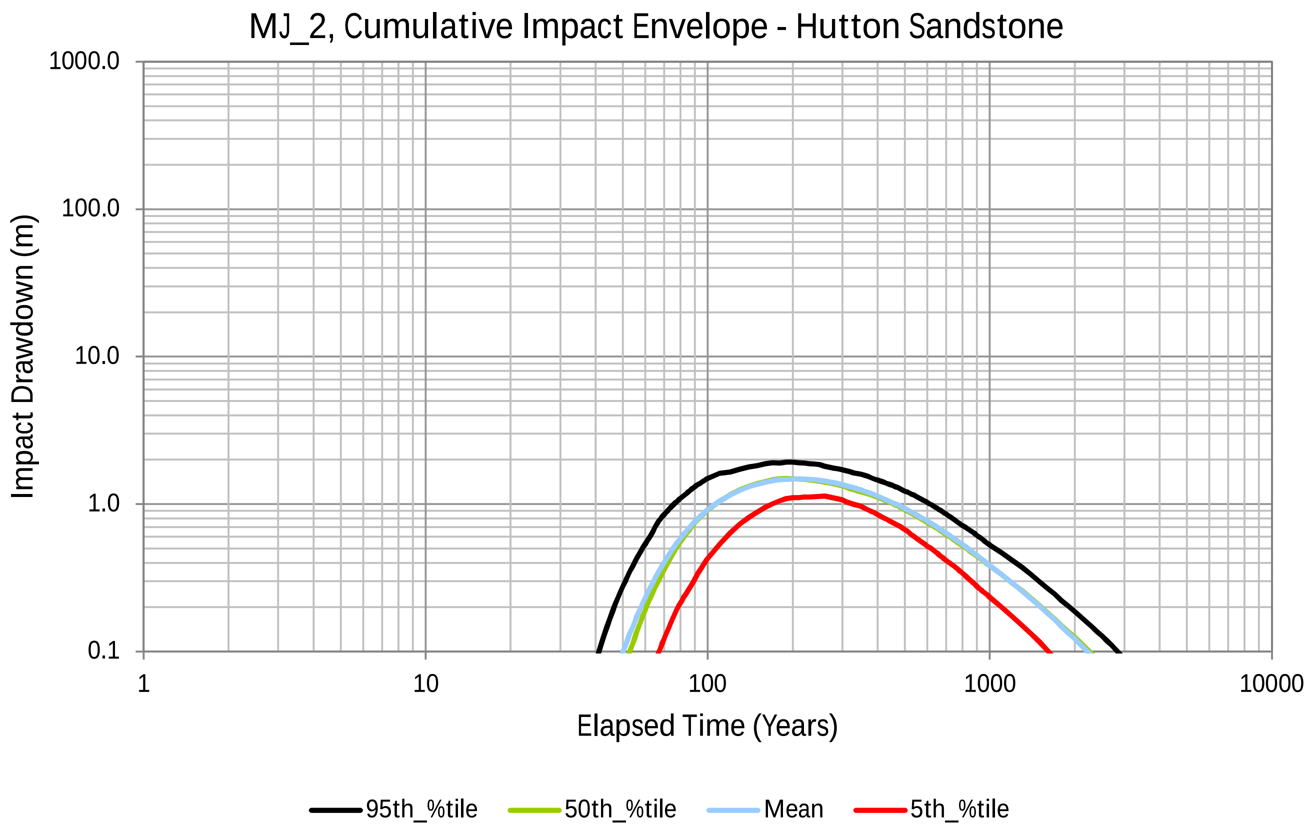


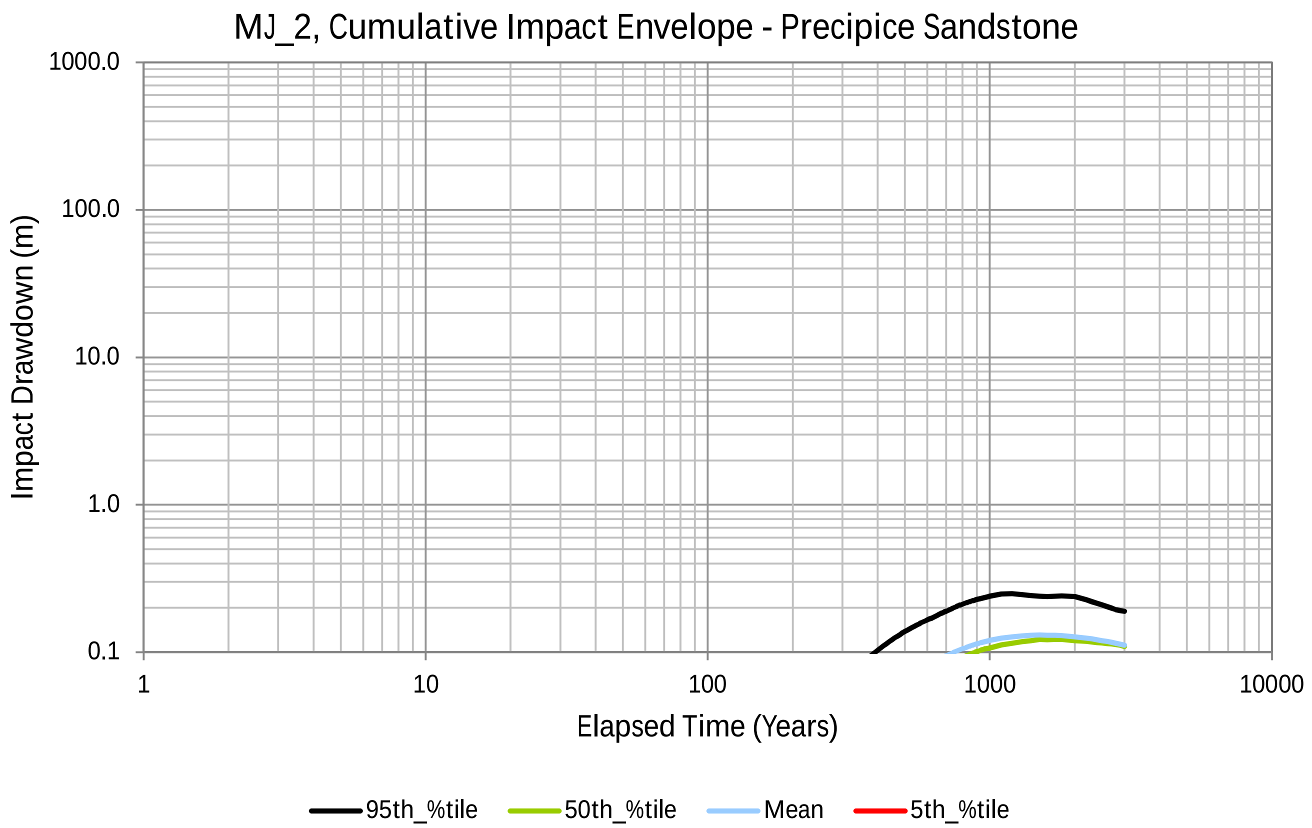
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



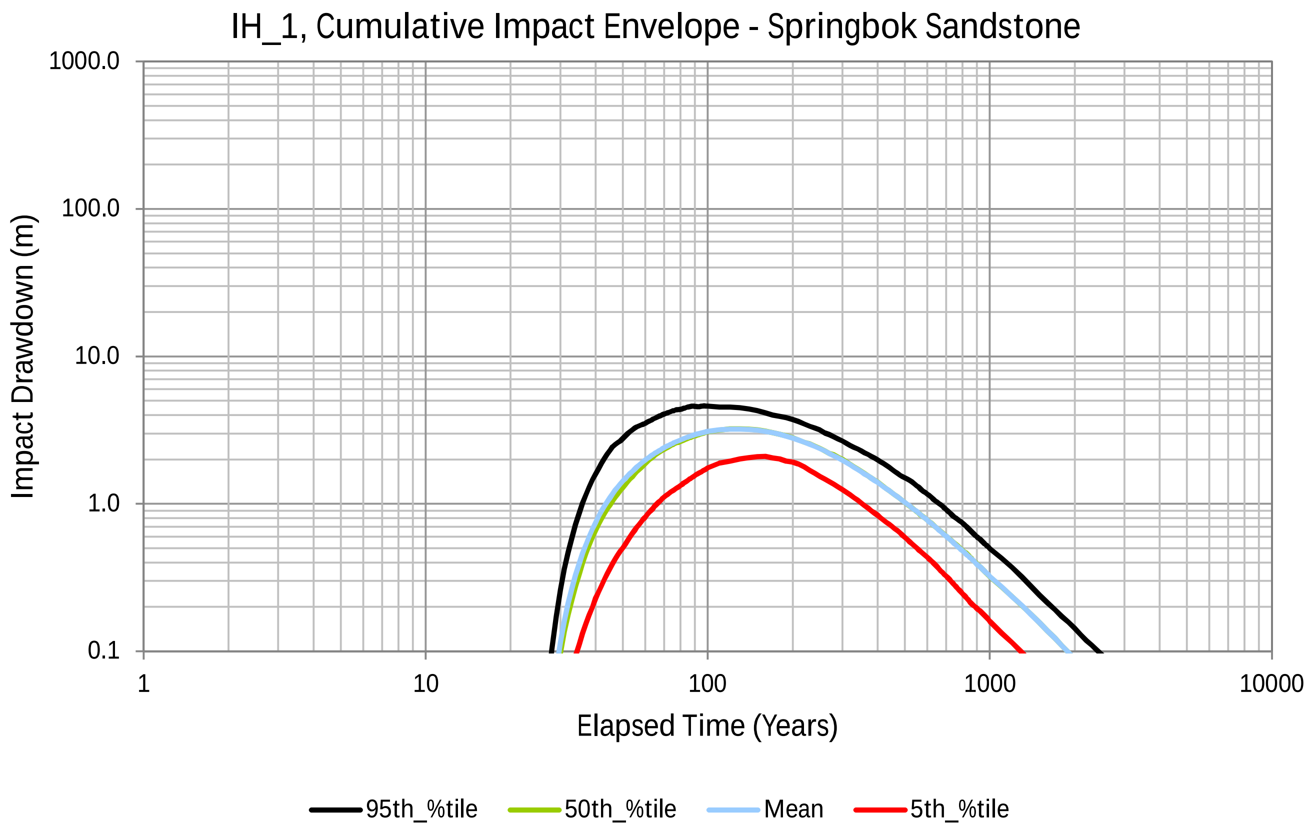


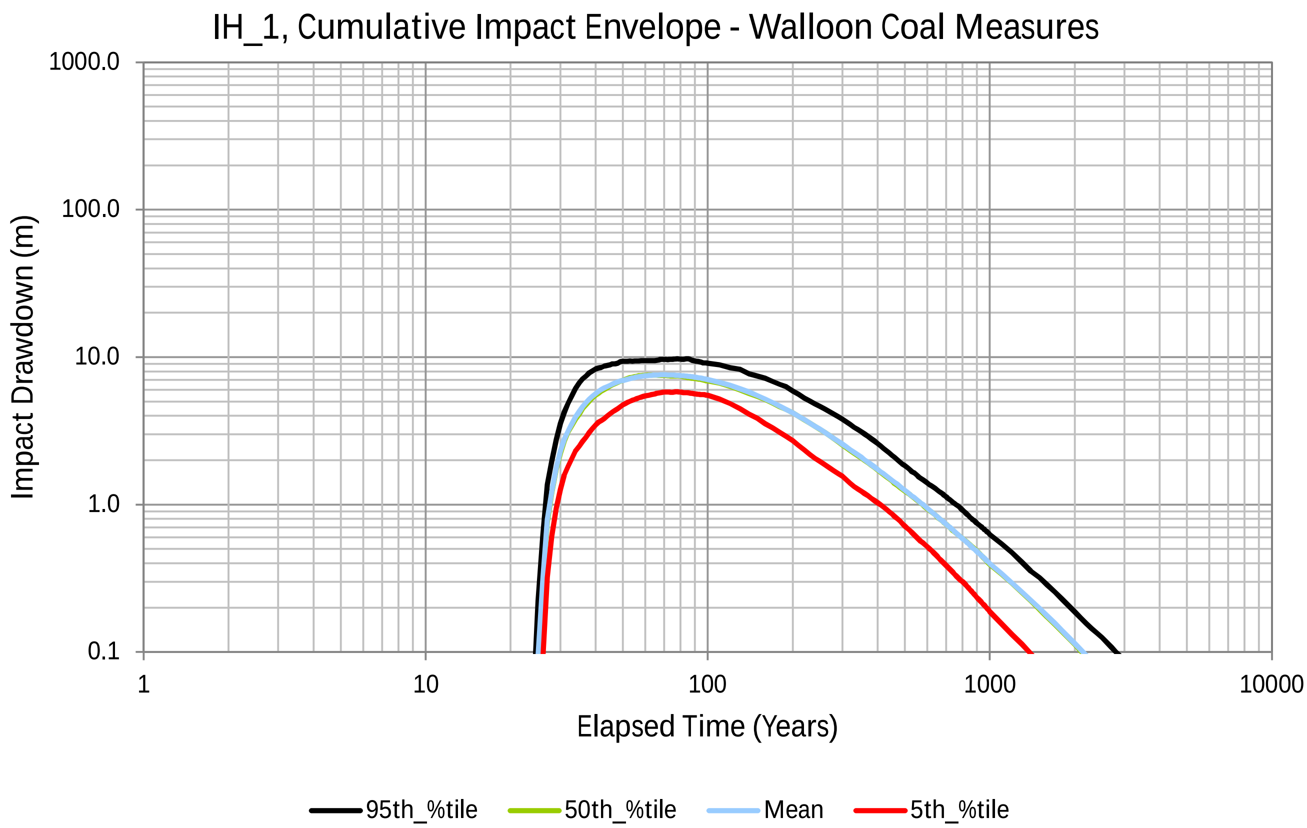
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



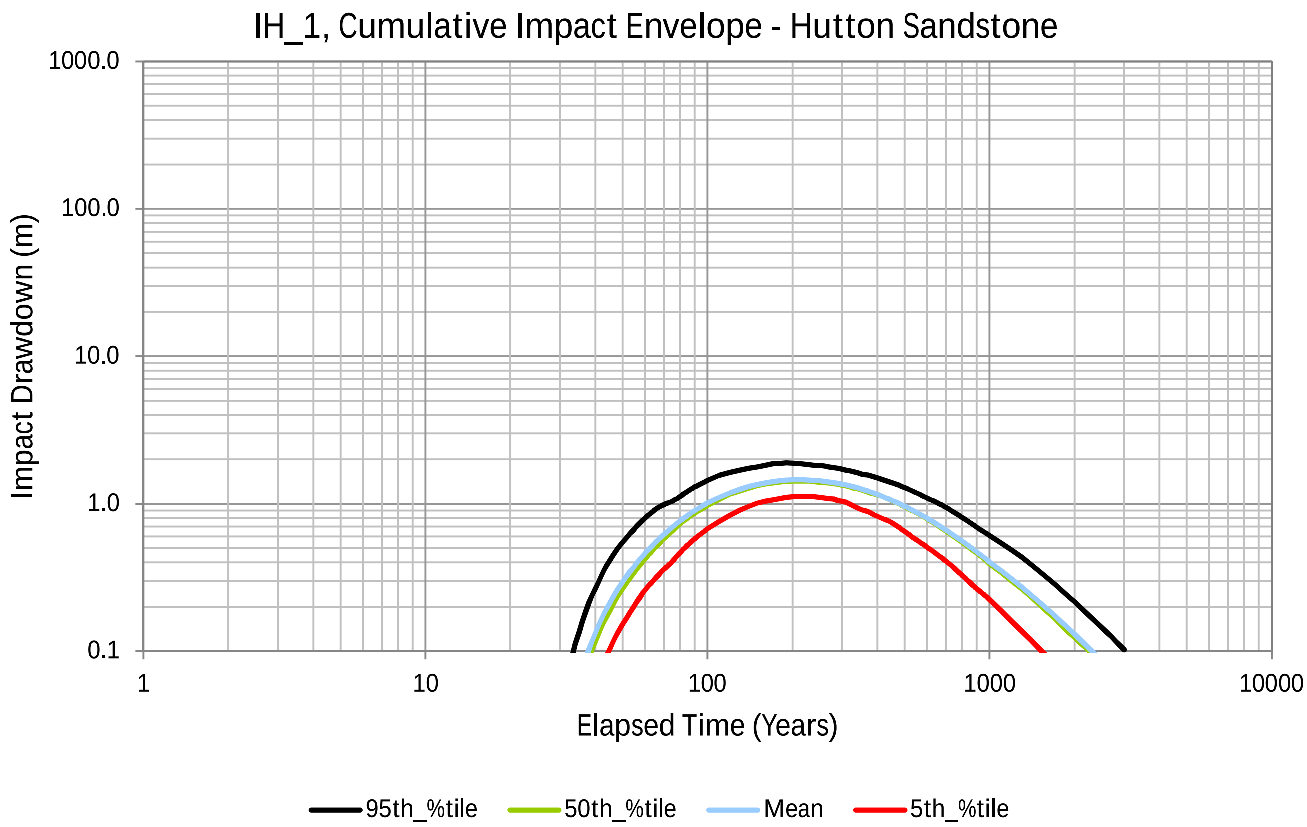


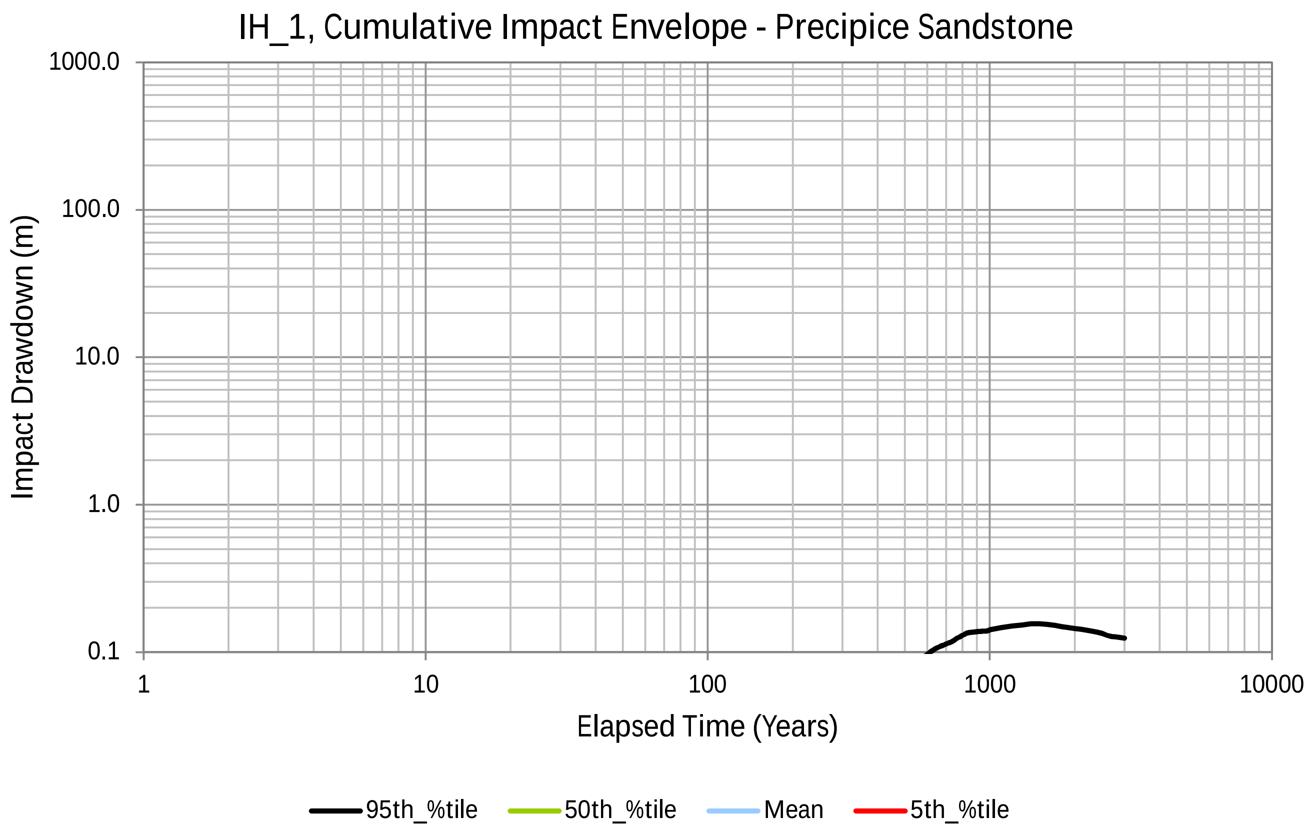
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2





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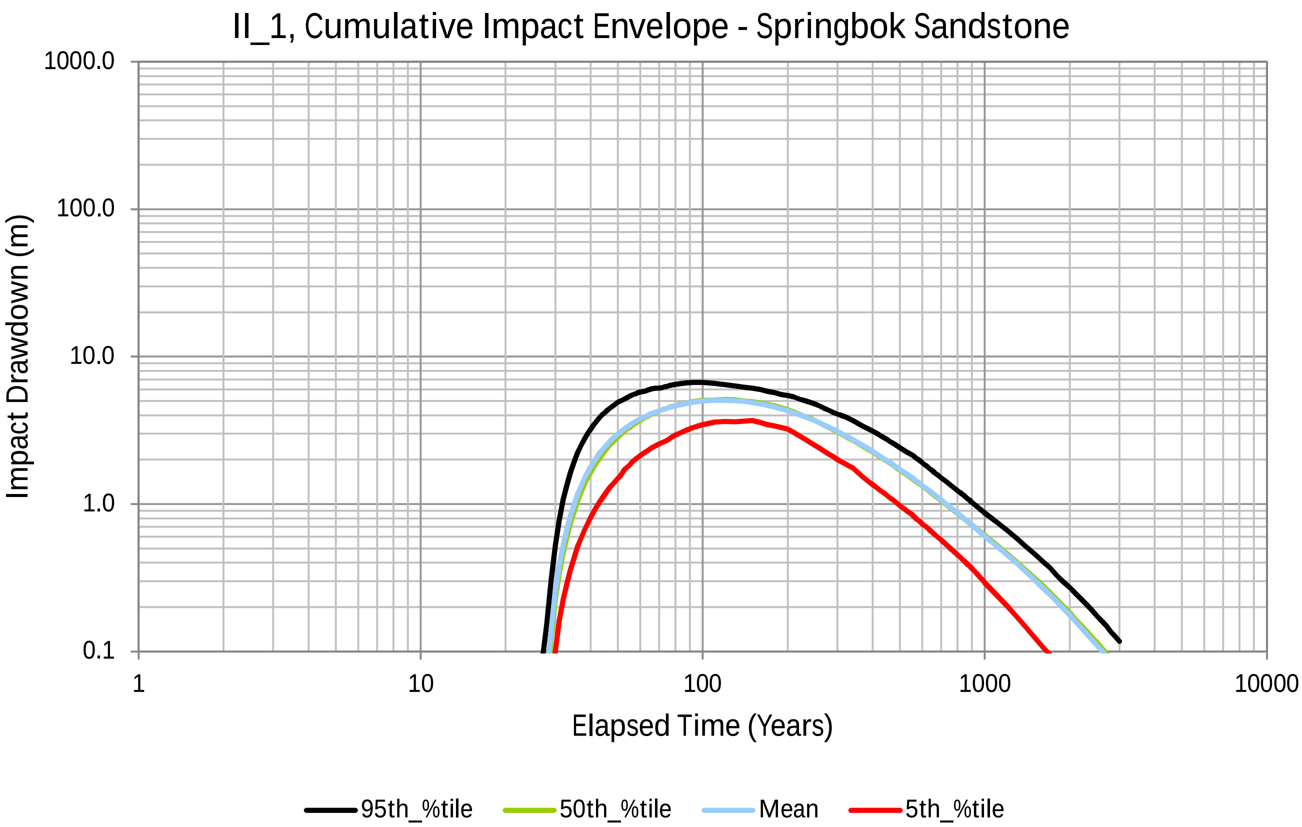
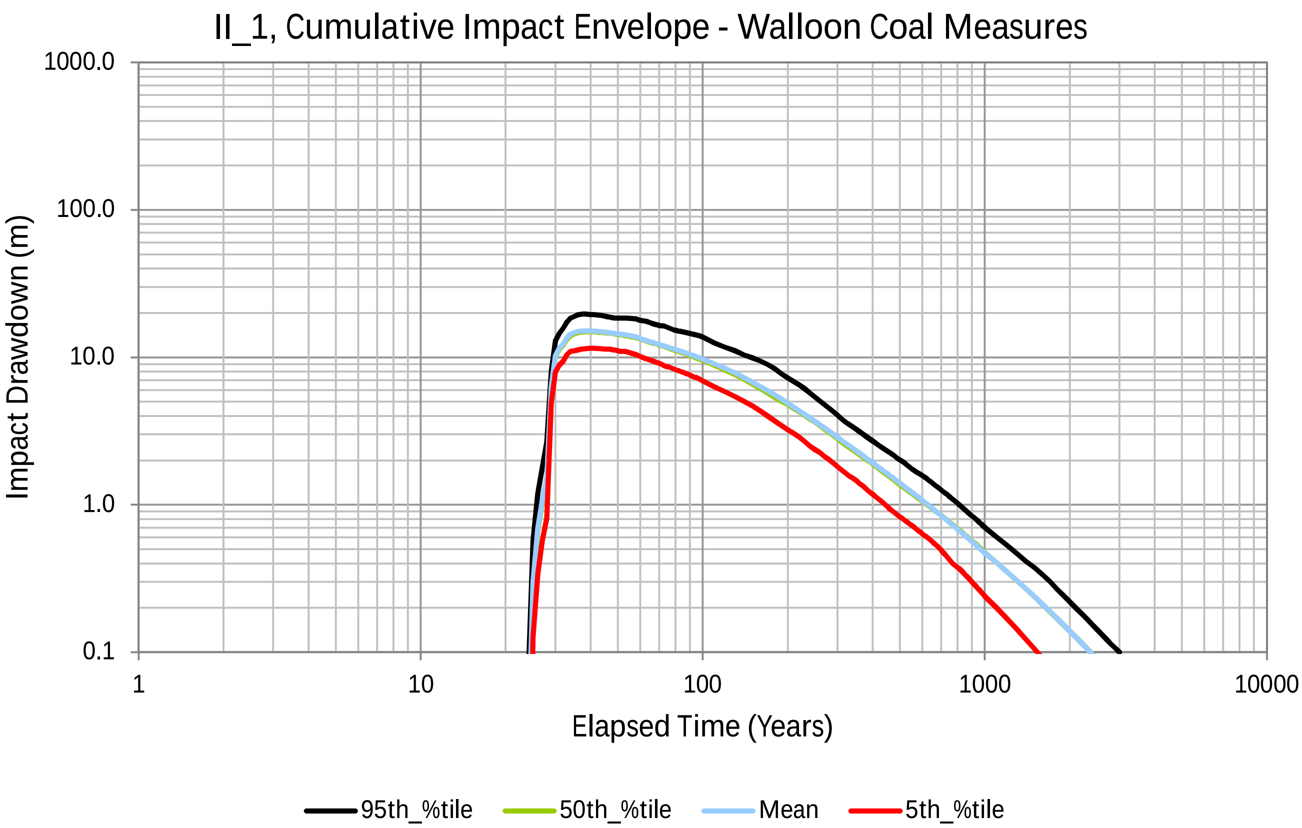
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2





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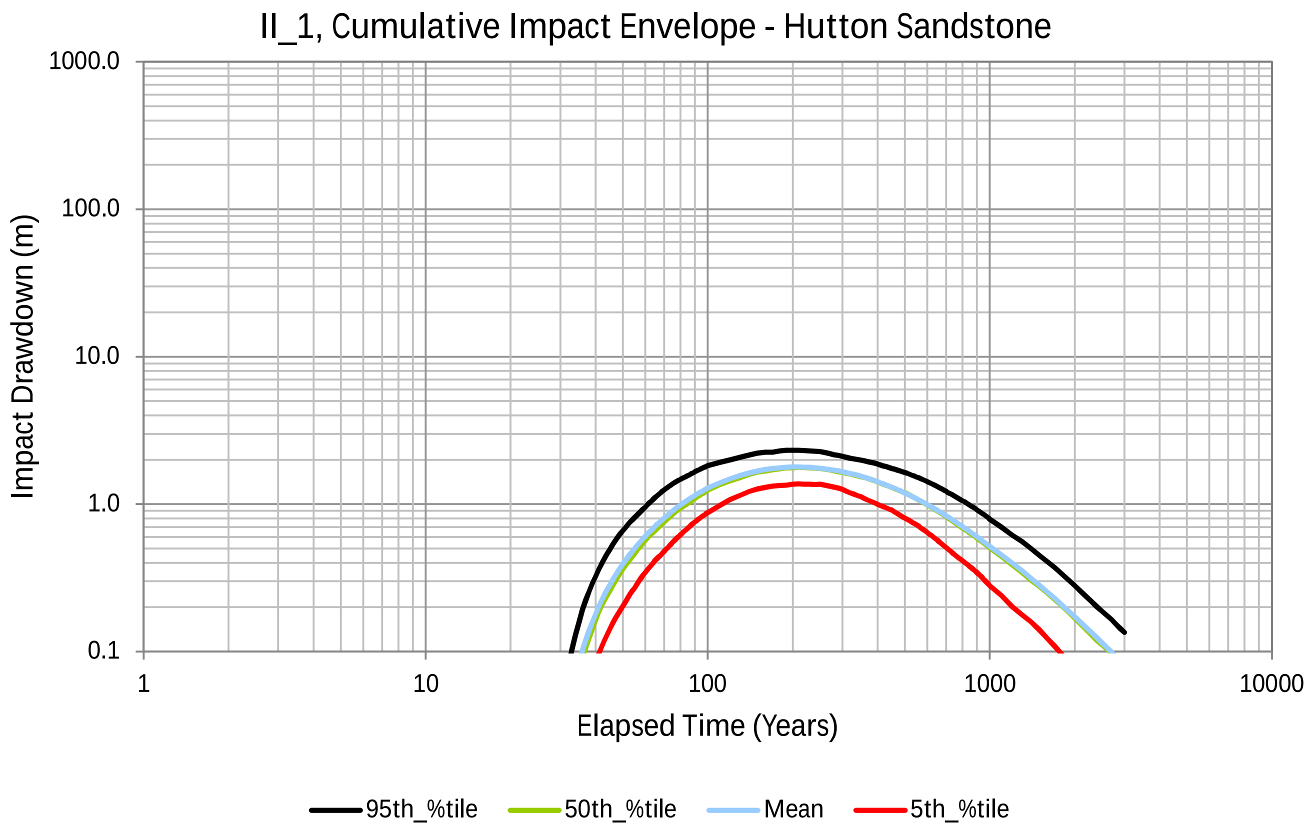
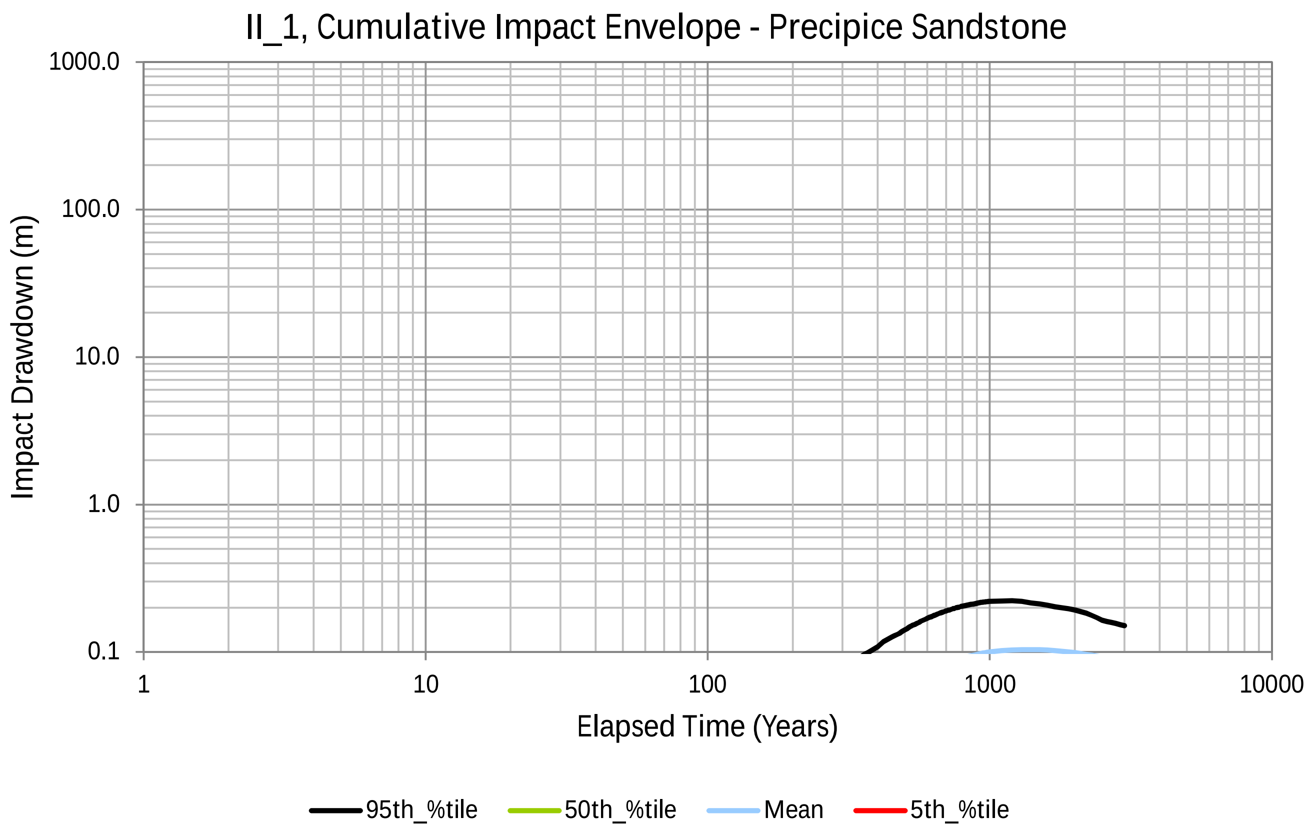
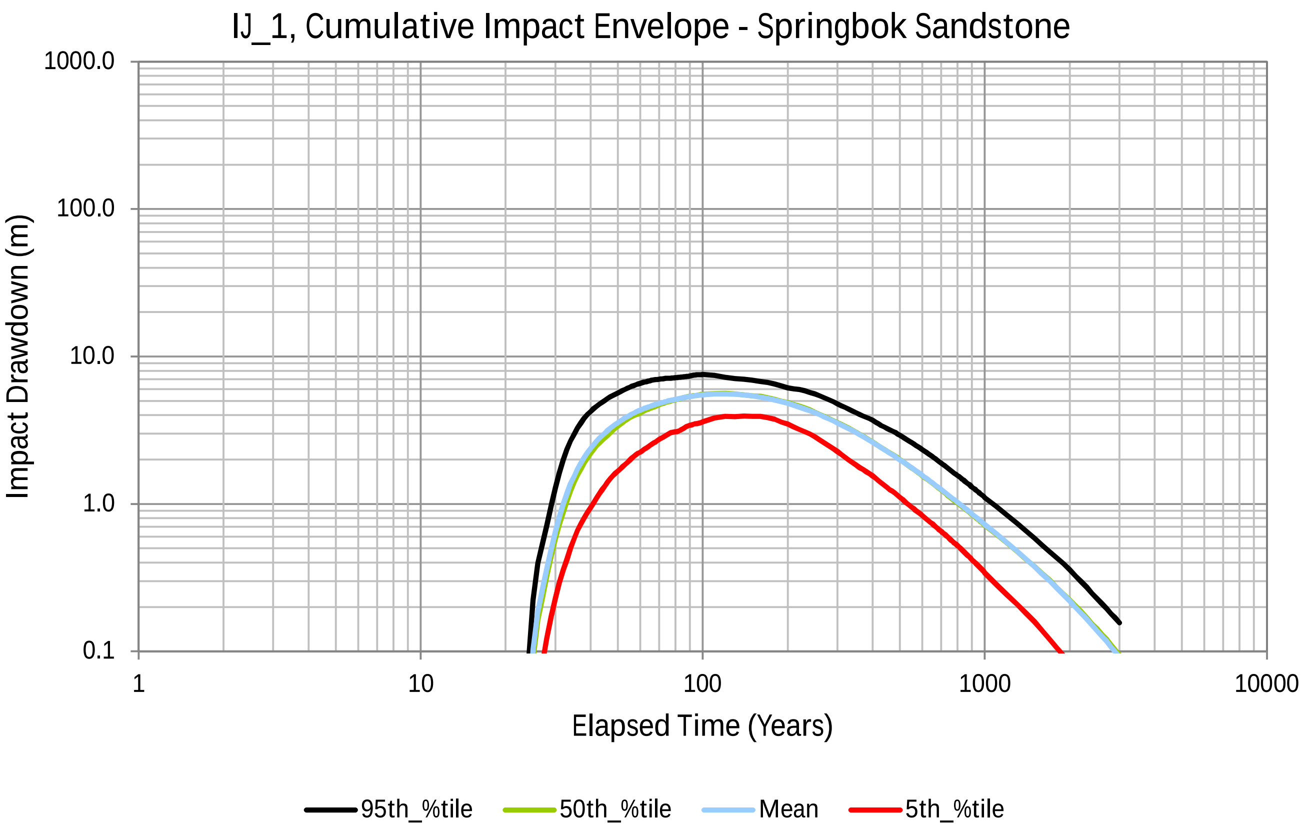
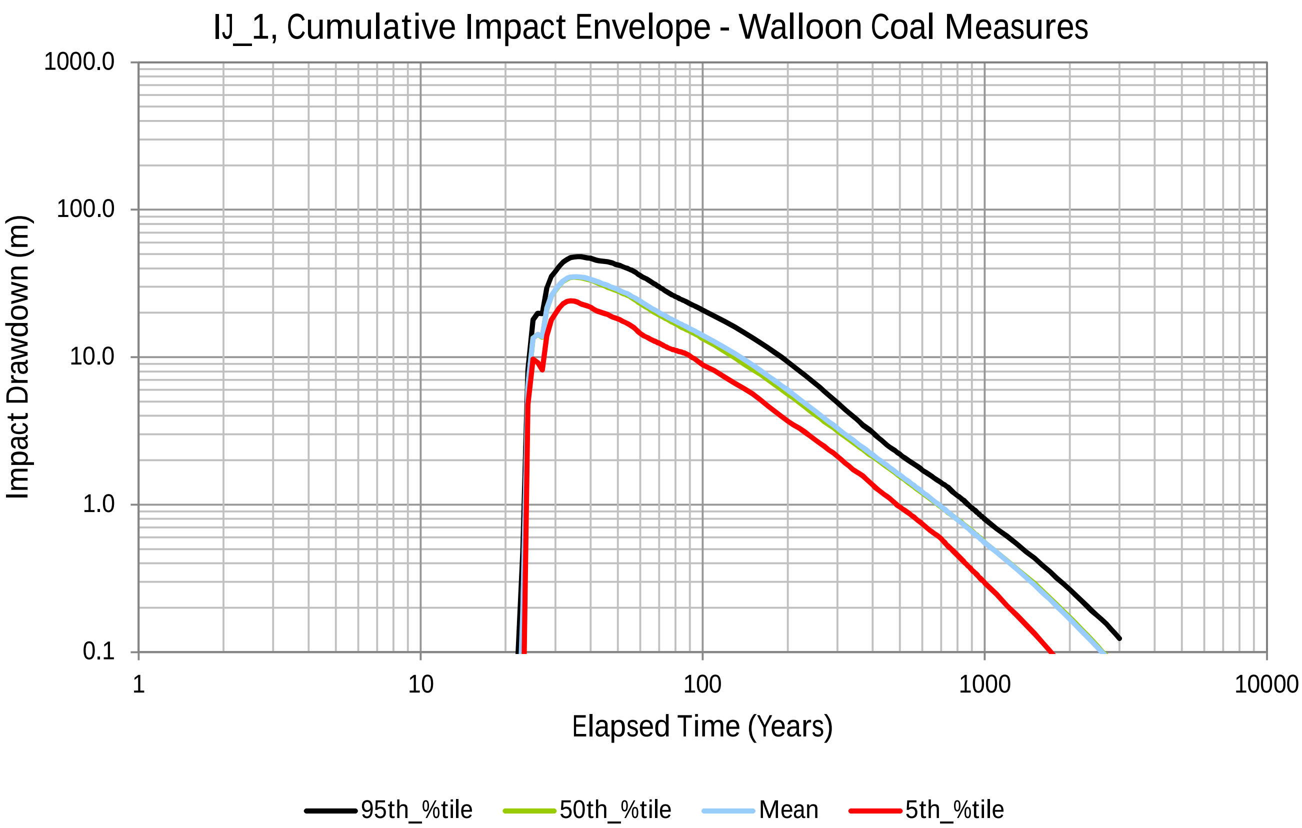
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



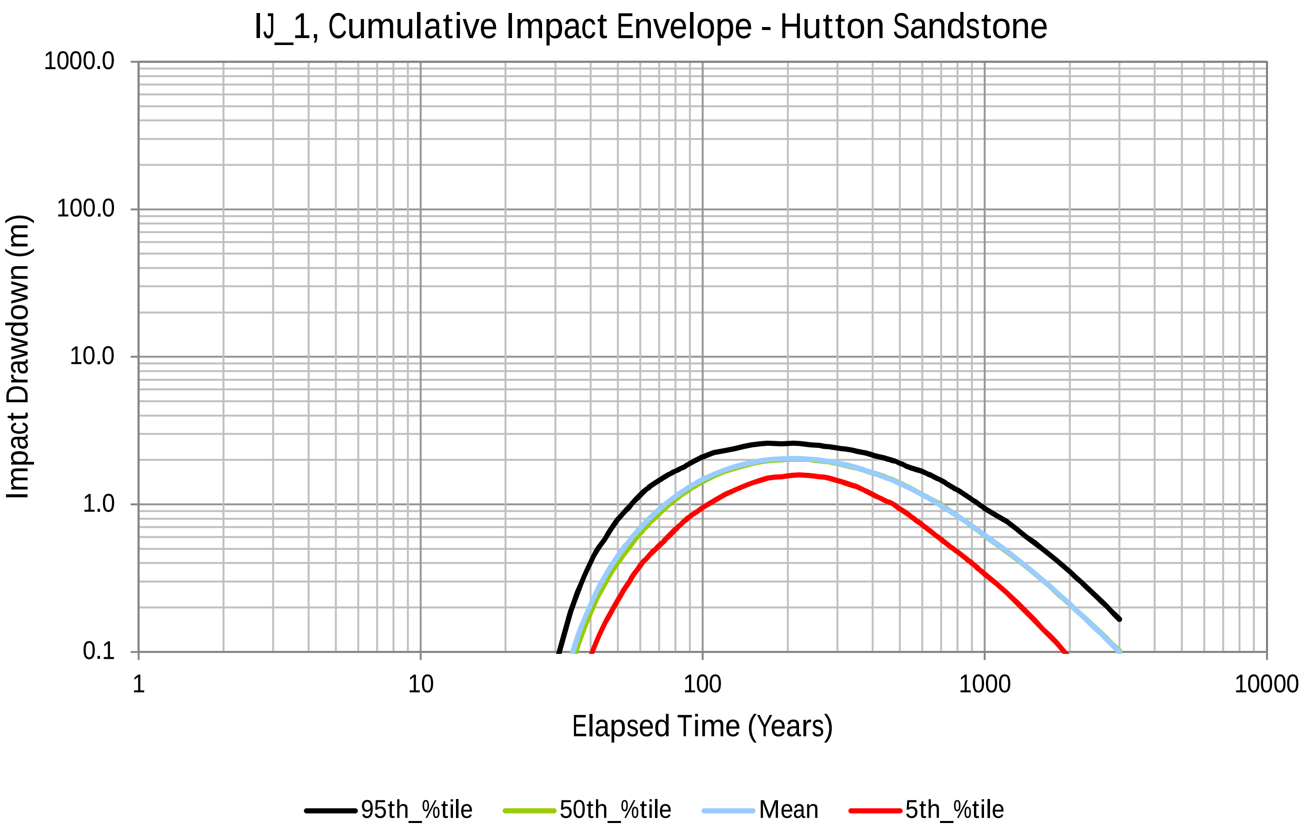


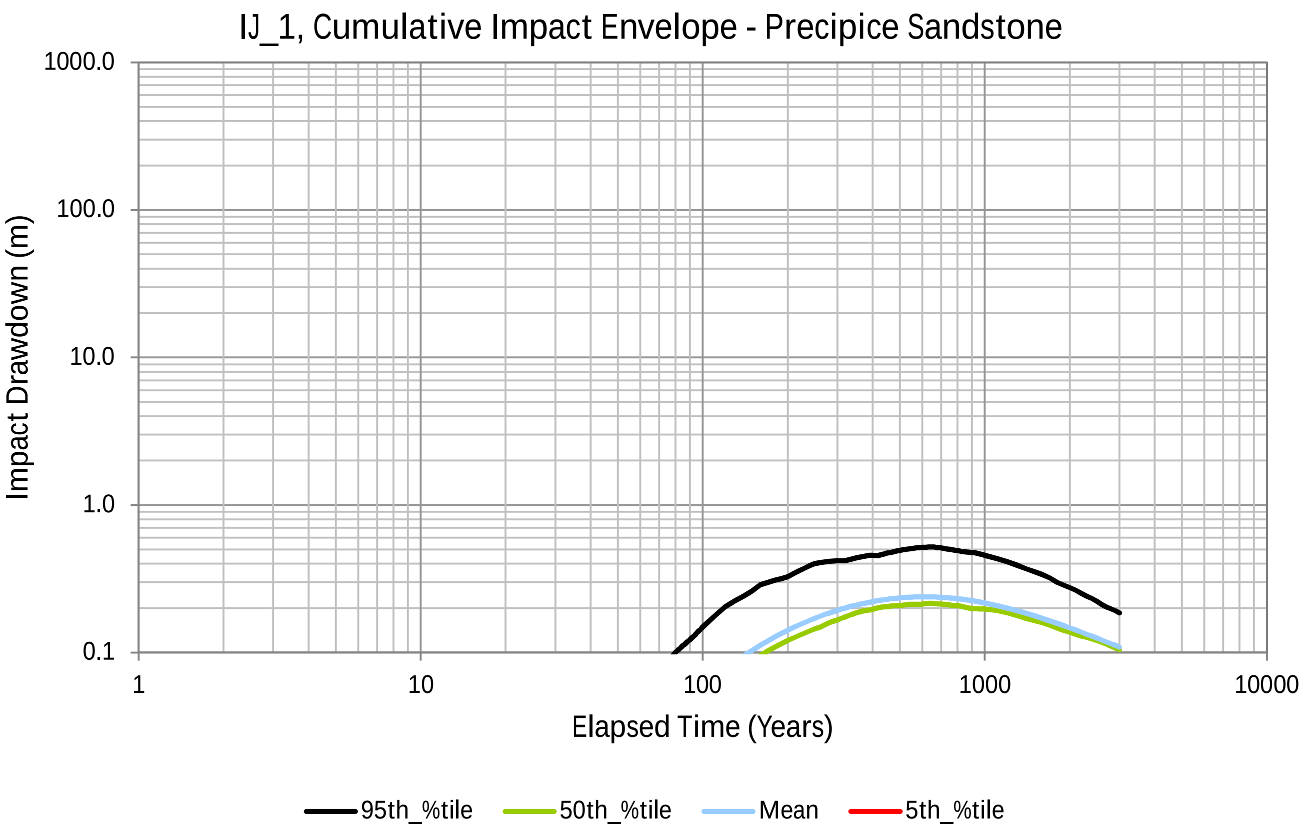
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2

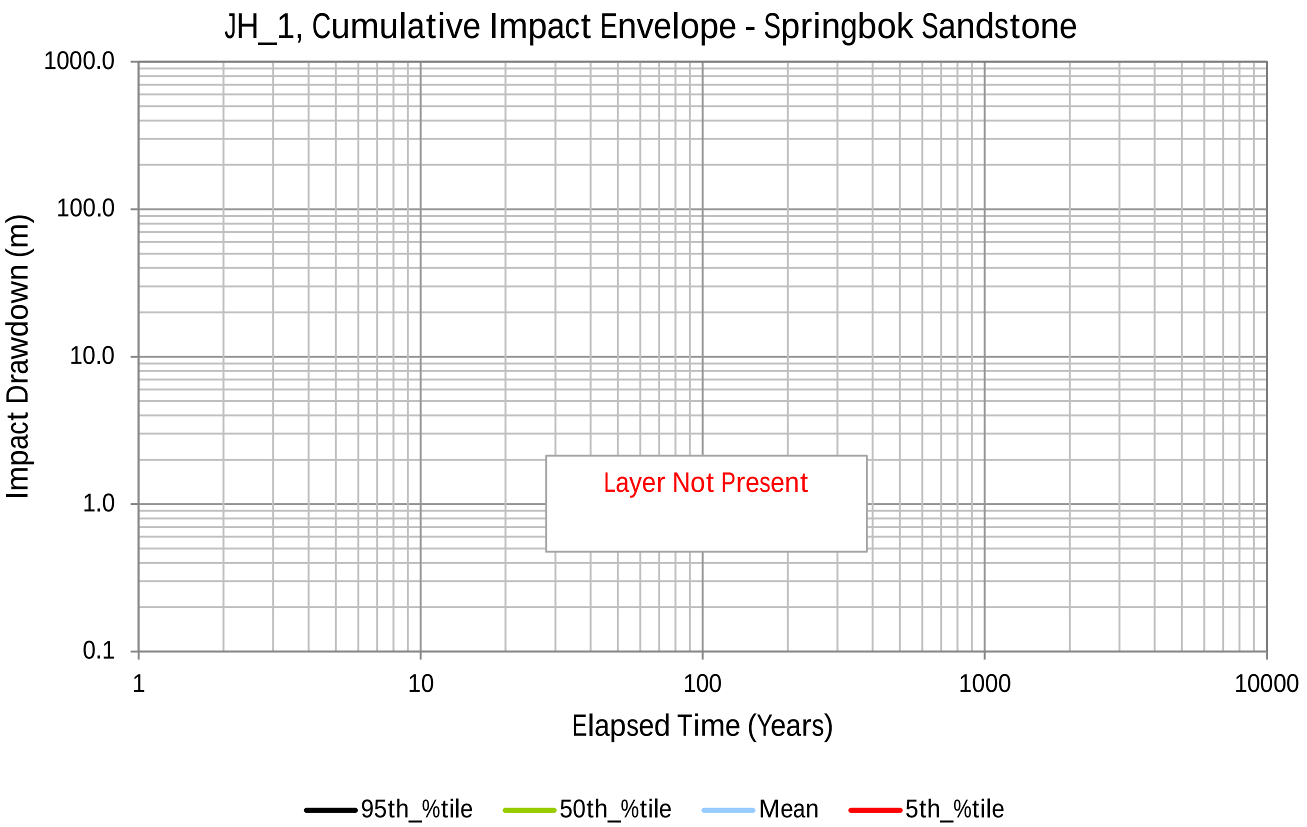




Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



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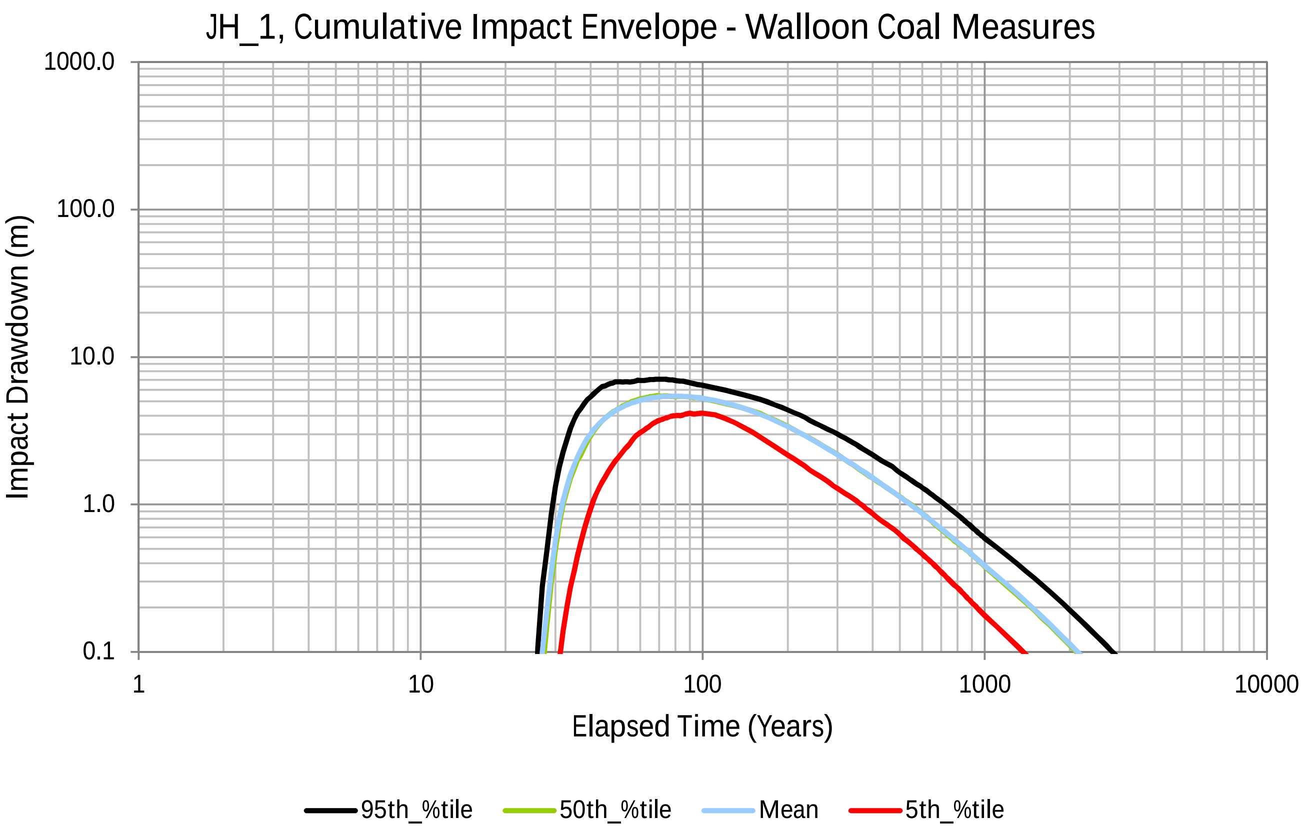
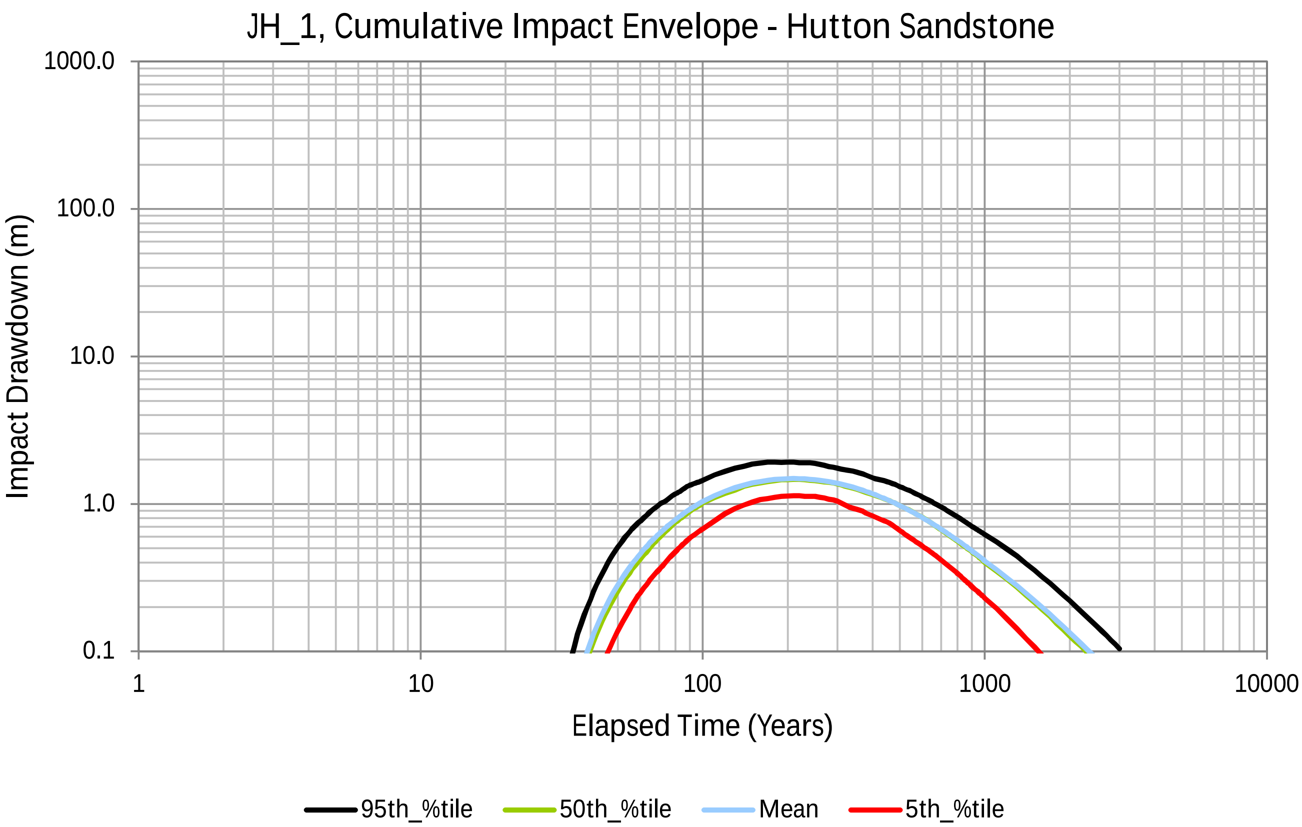
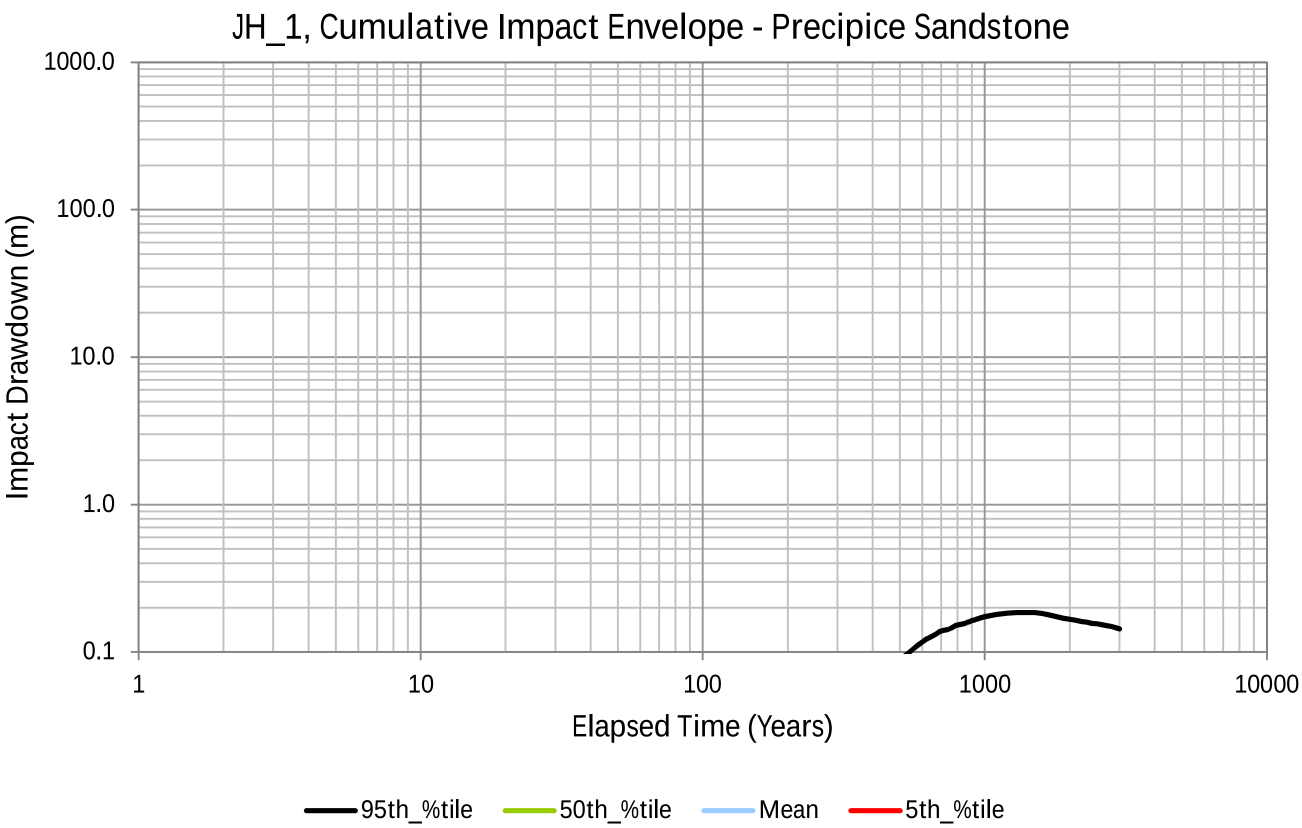
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
Layer Not Present
95th_%tile
50th_%tile
Mean
5th_%tile

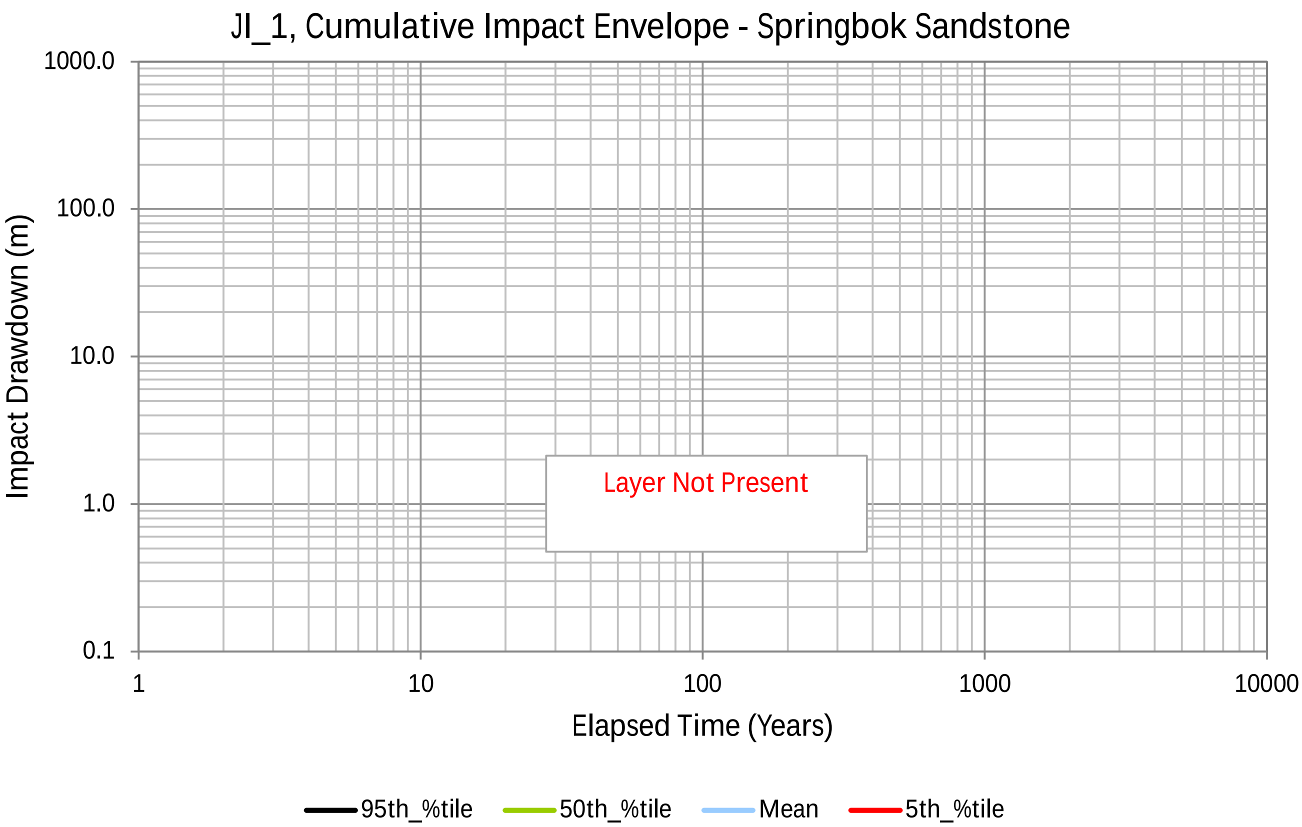

JH_1, Cumulative Impact Envelope - Walloon Coal Measures
Impact Drawdown (m)
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
10000
Elapsed Time (Years)
95th_%tile
50th_%tile
Mean
5th_%tile

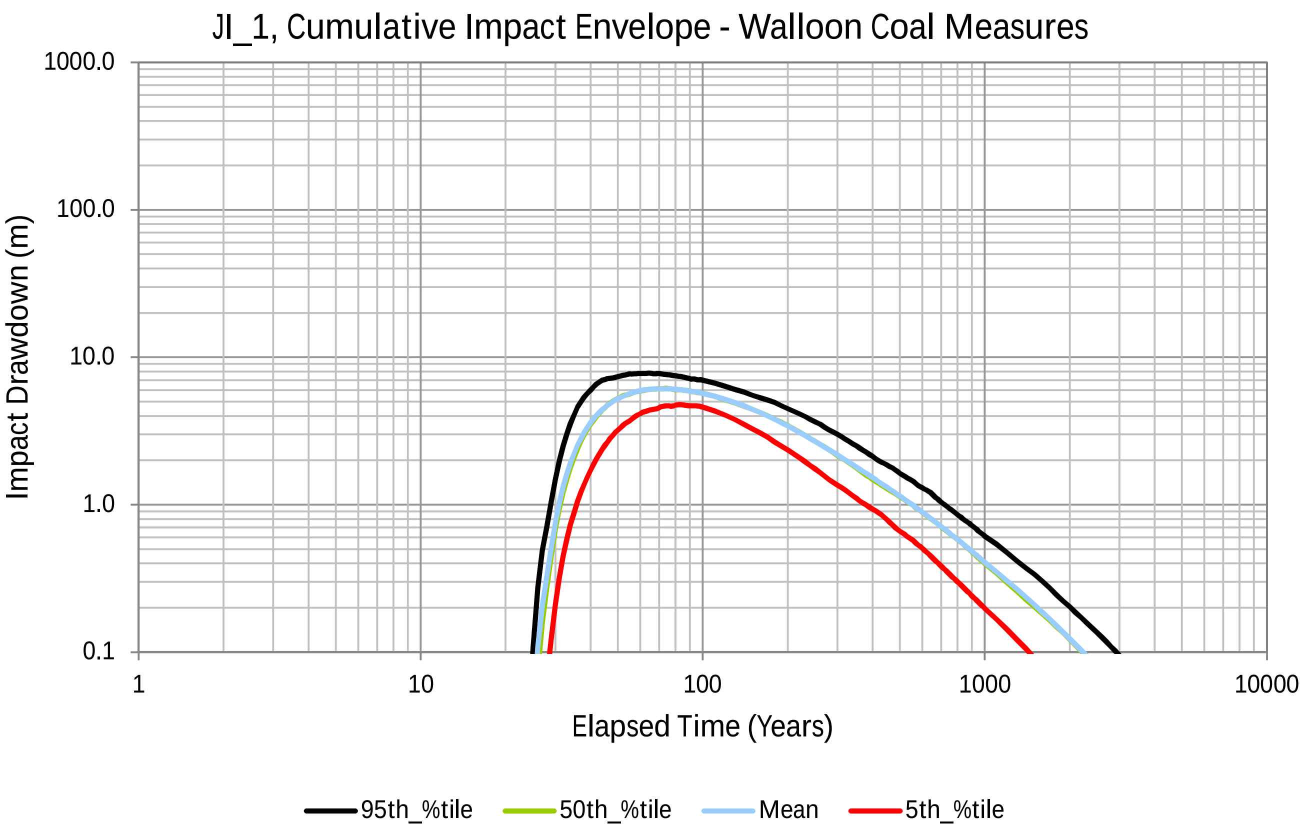
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



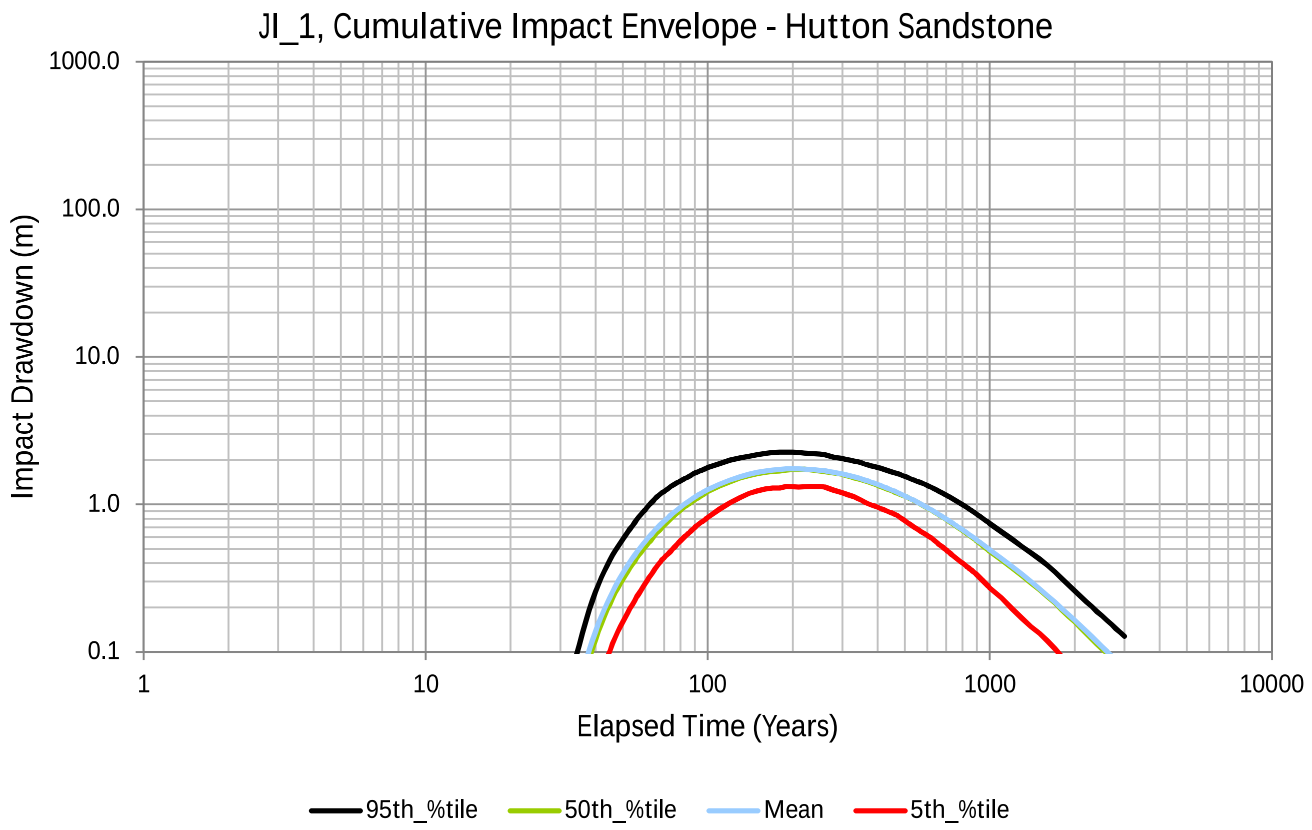


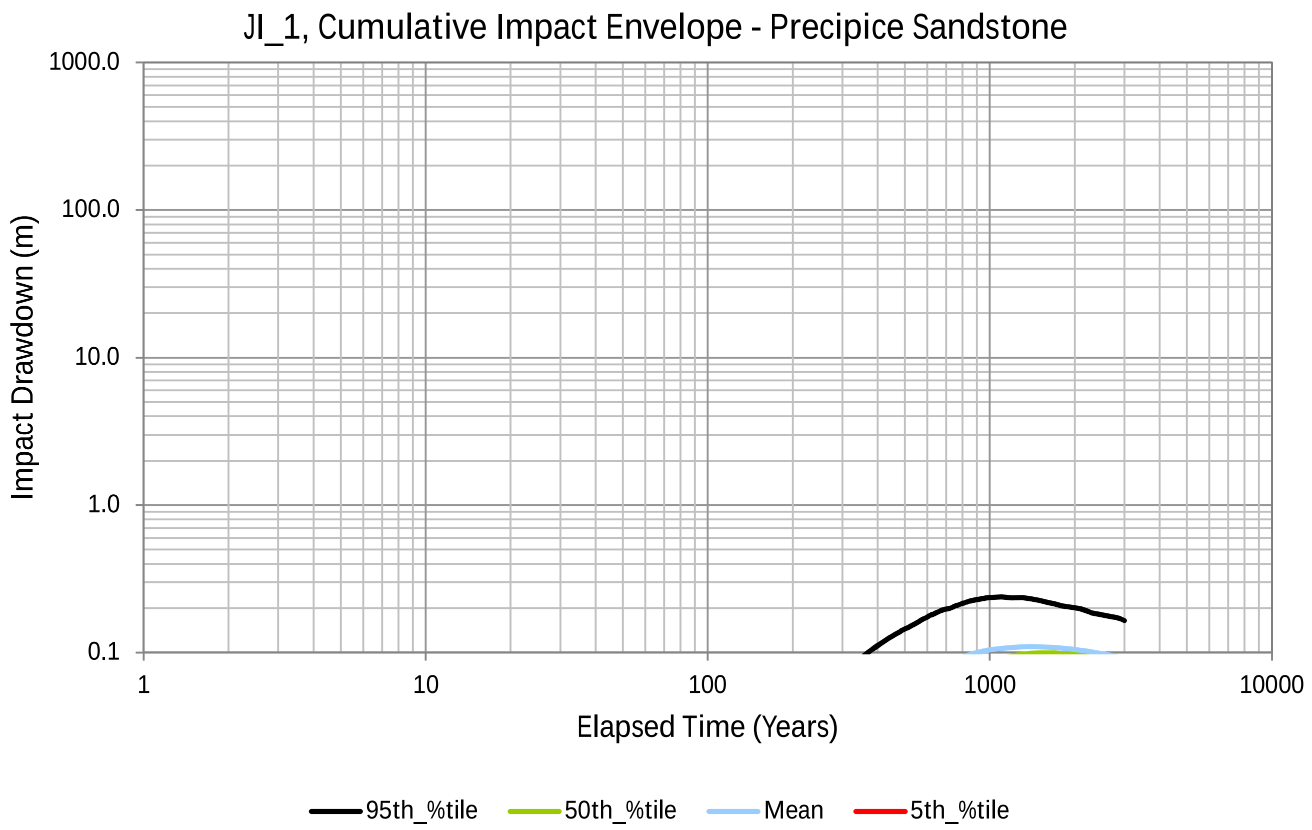
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



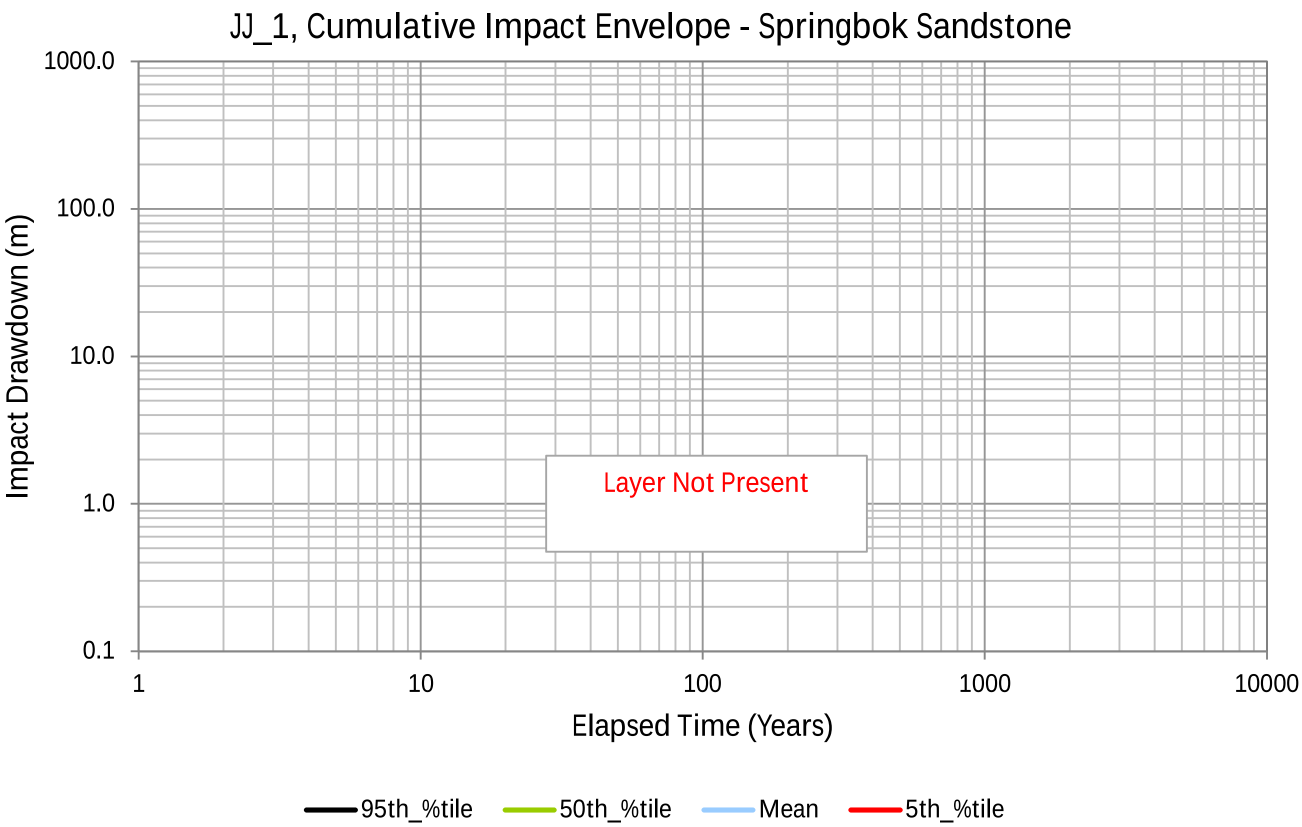


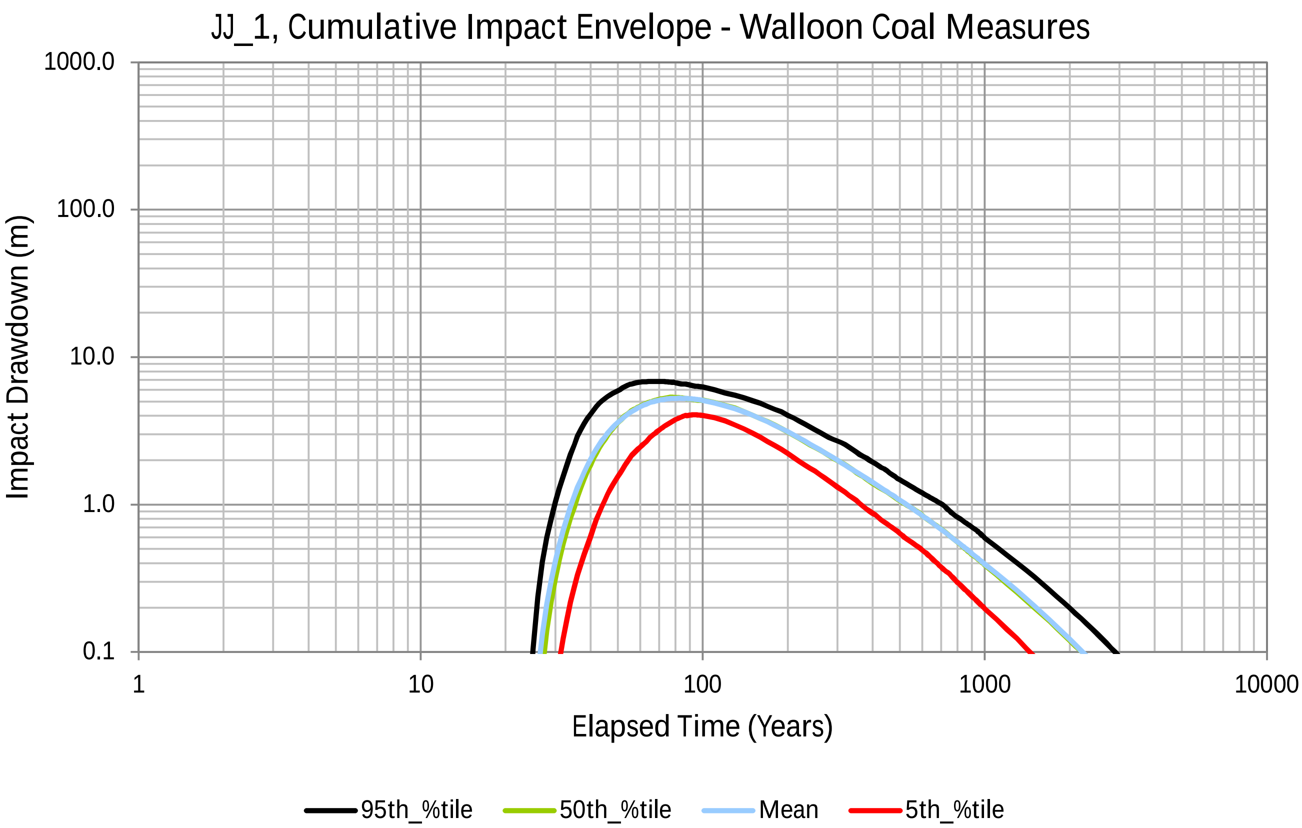
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



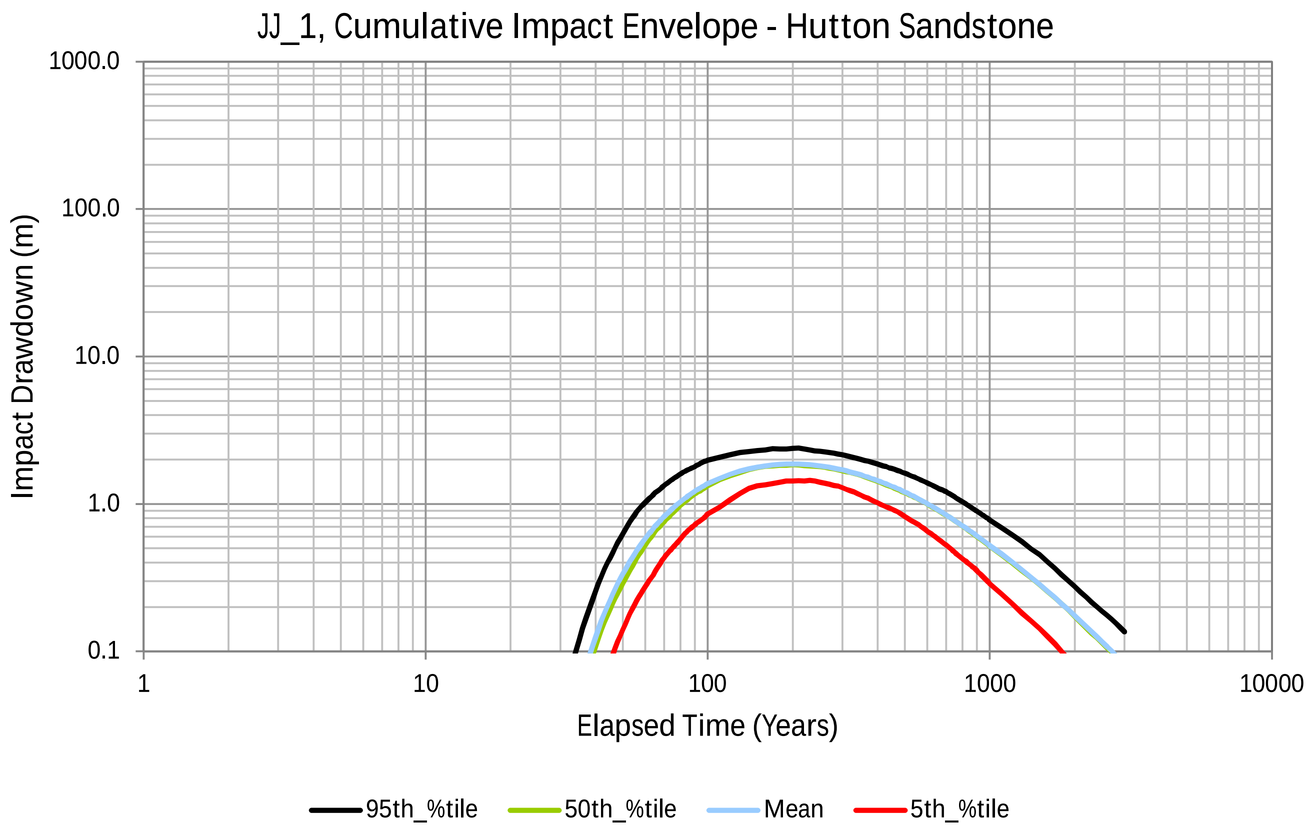


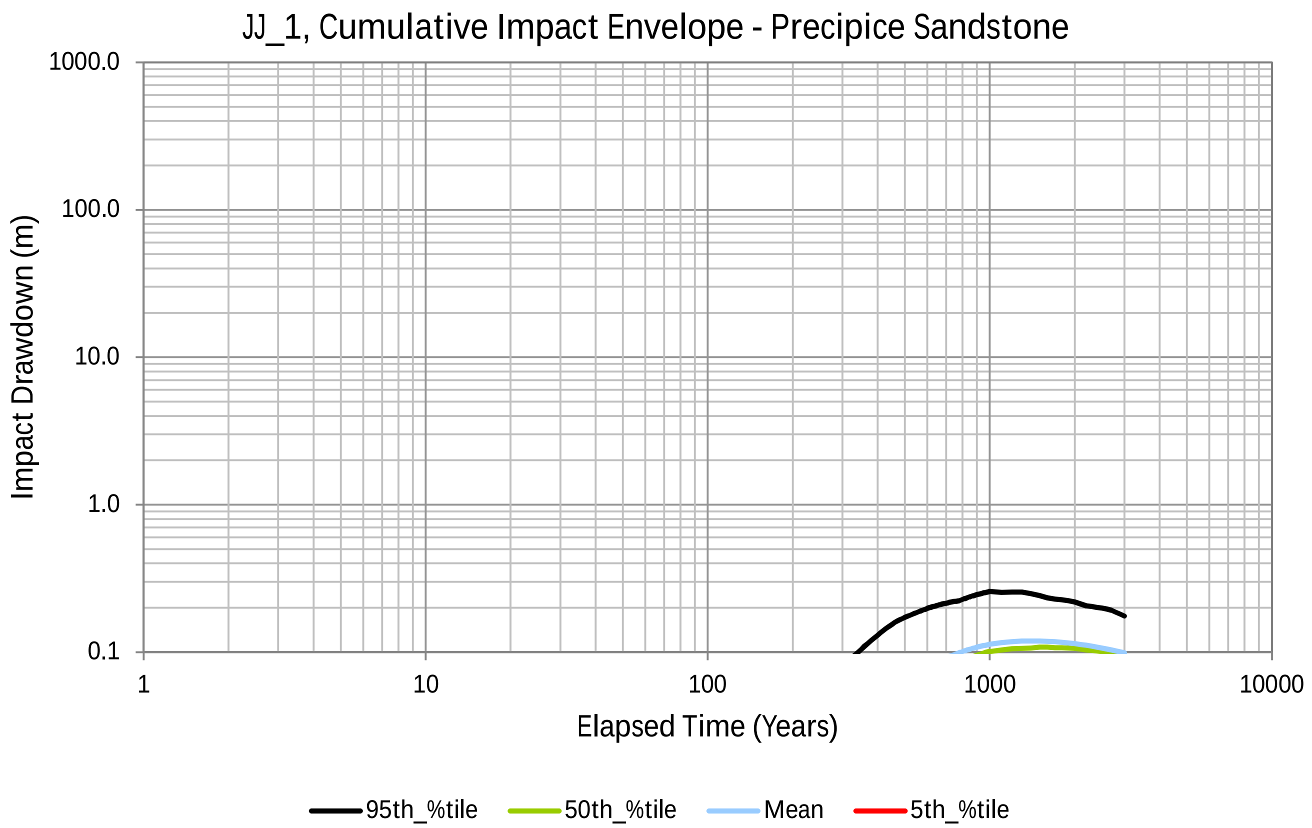
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



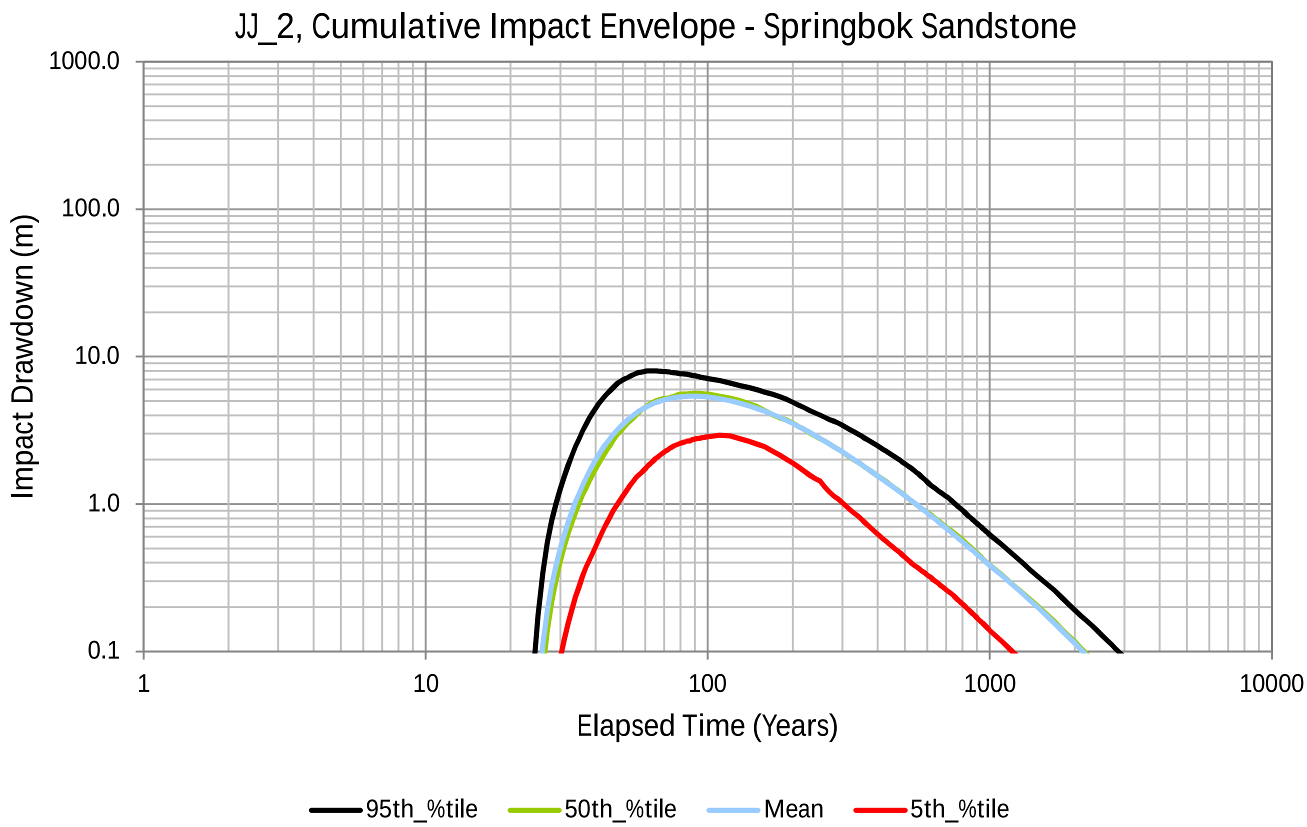


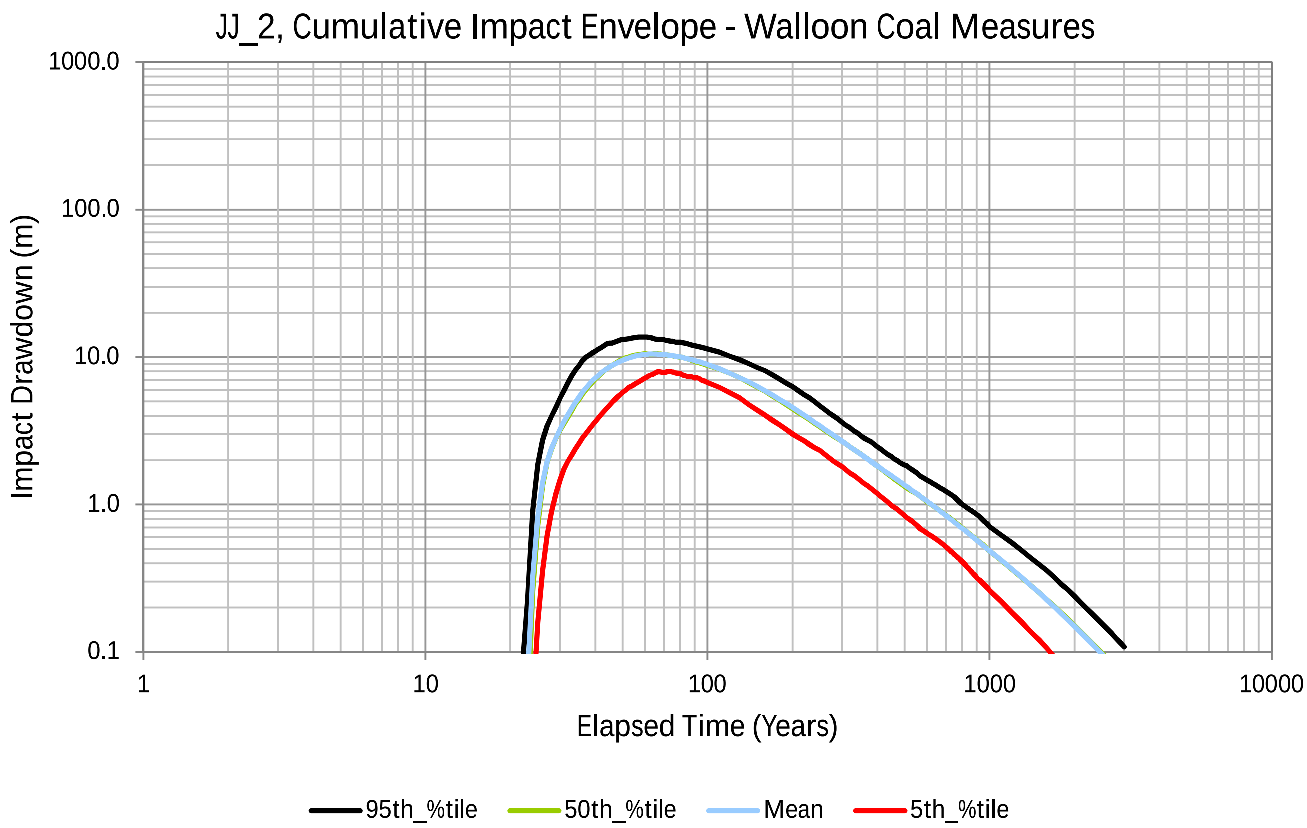
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



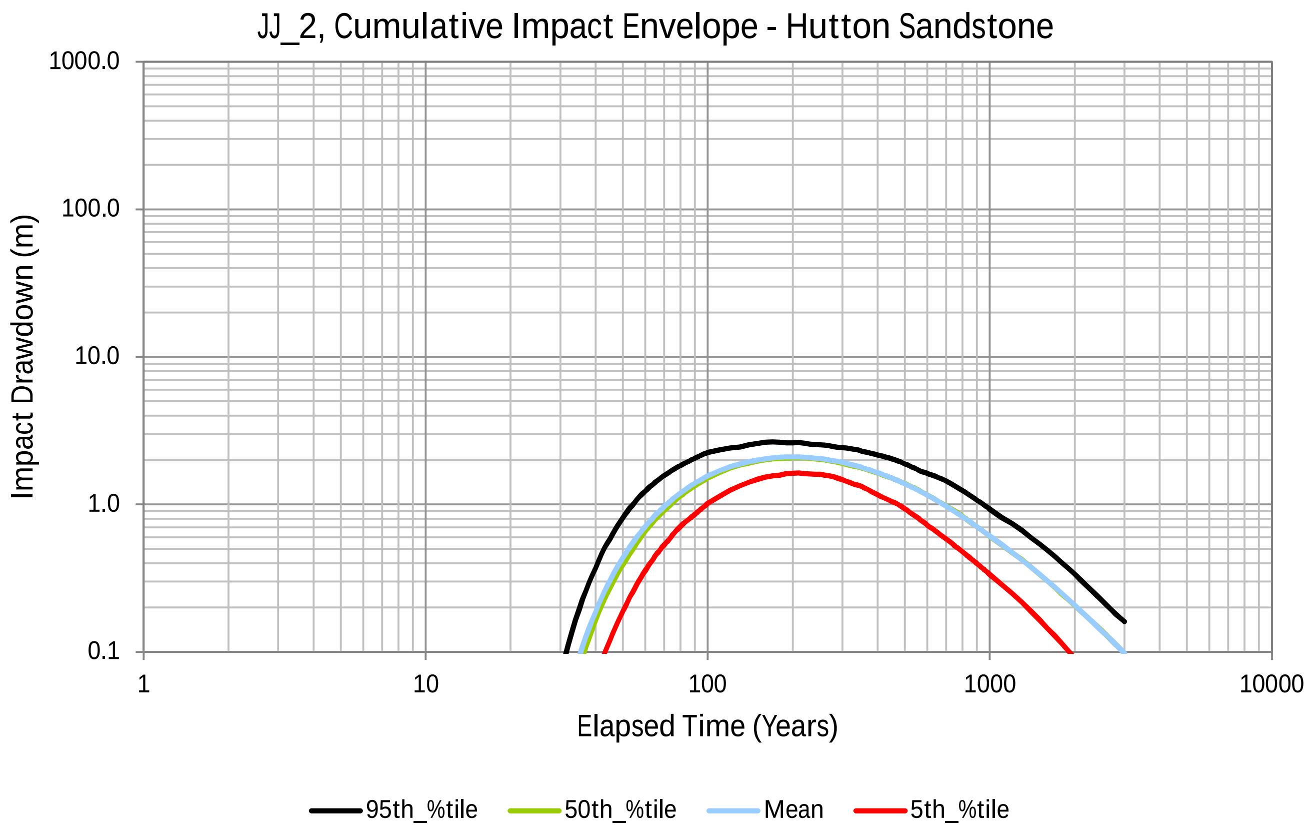


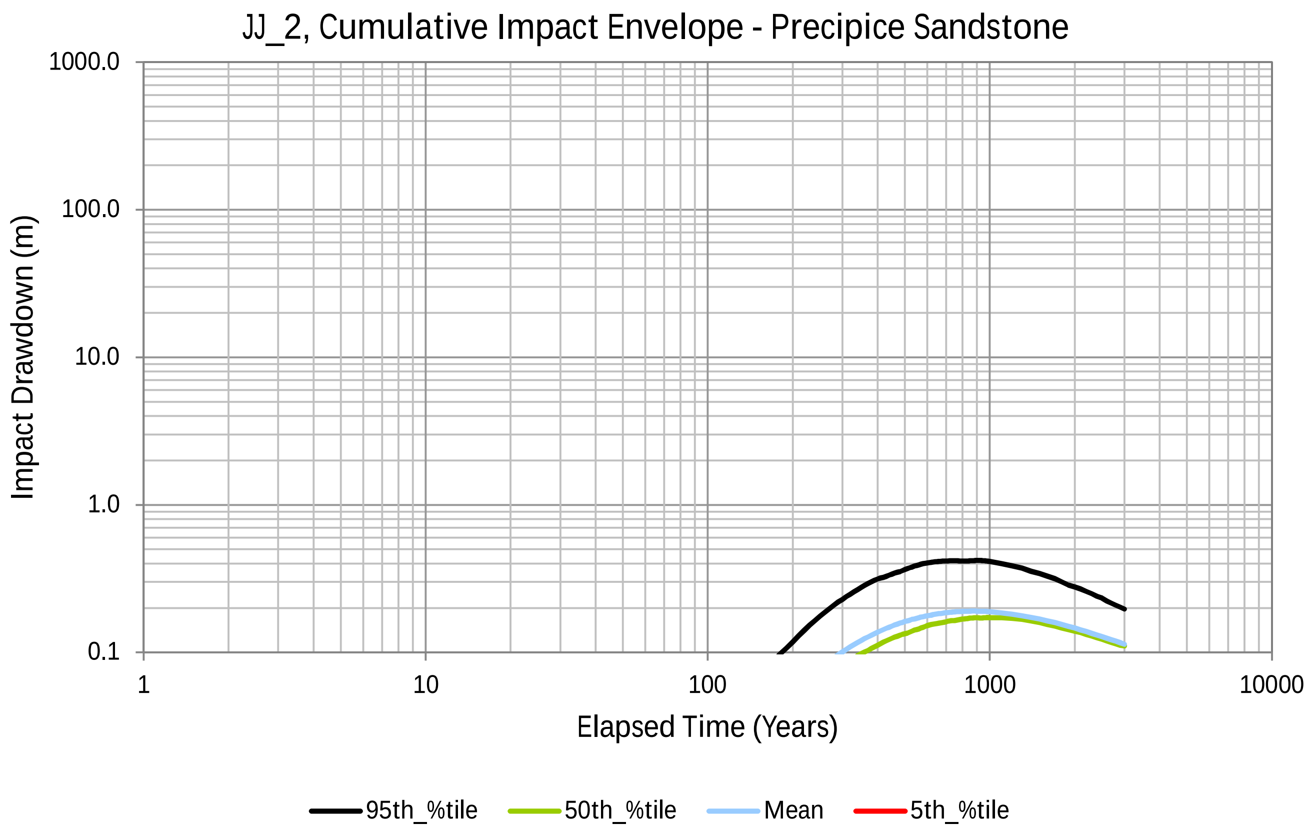
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2





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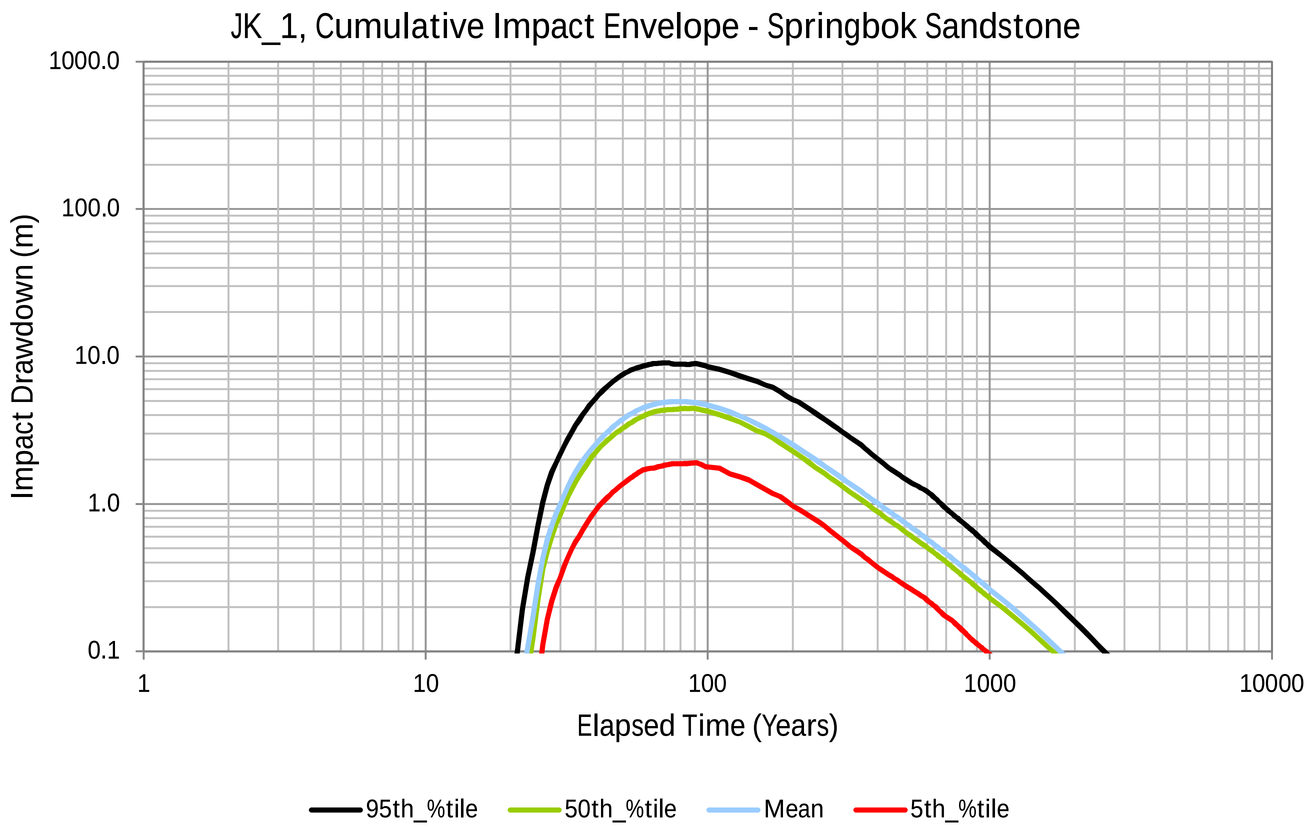
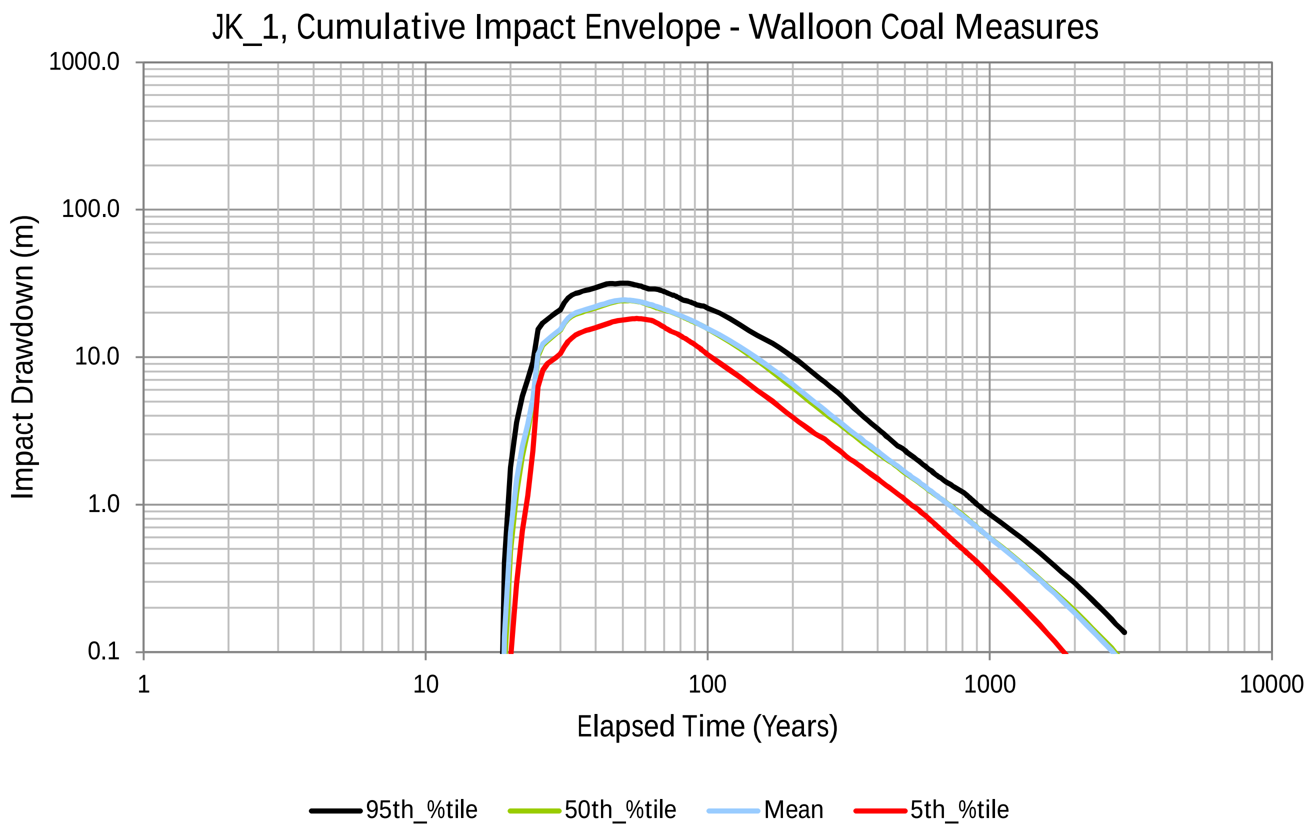
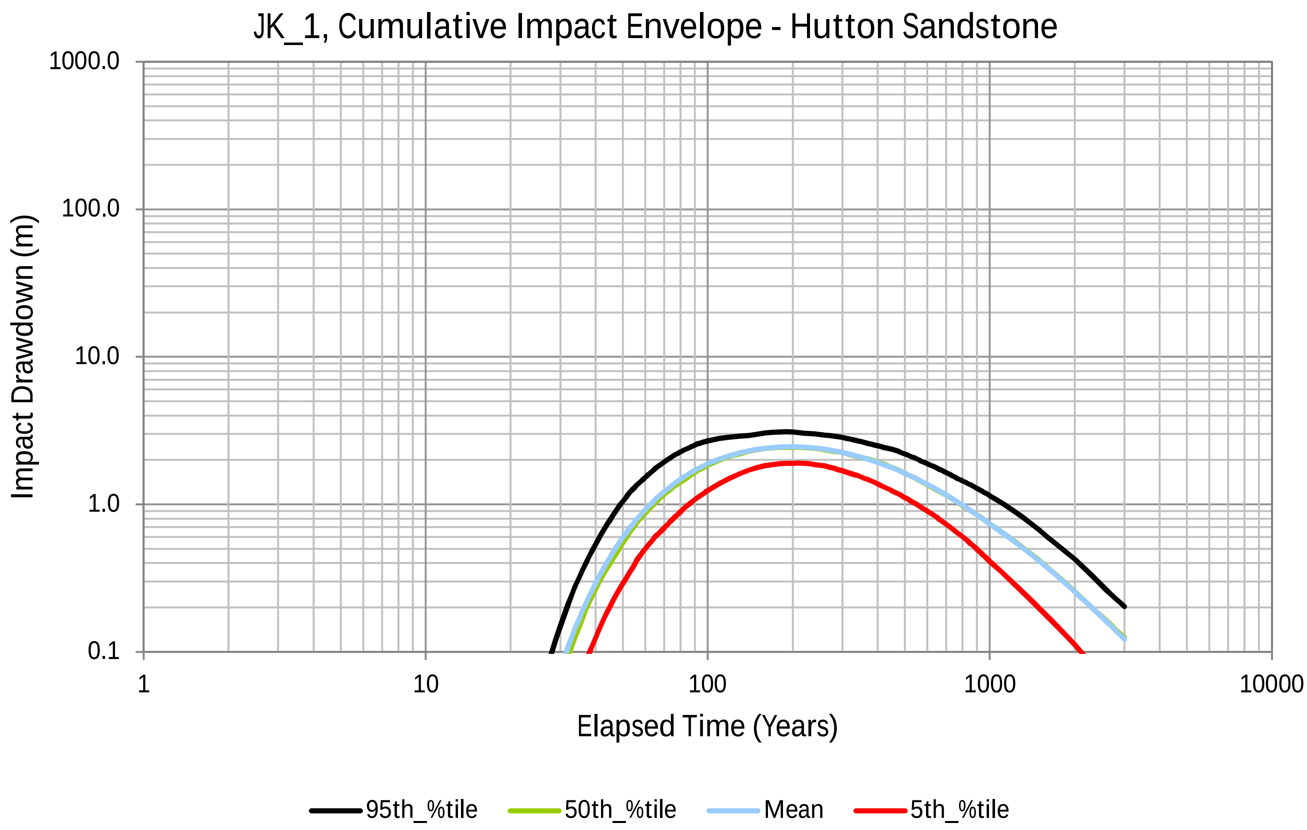
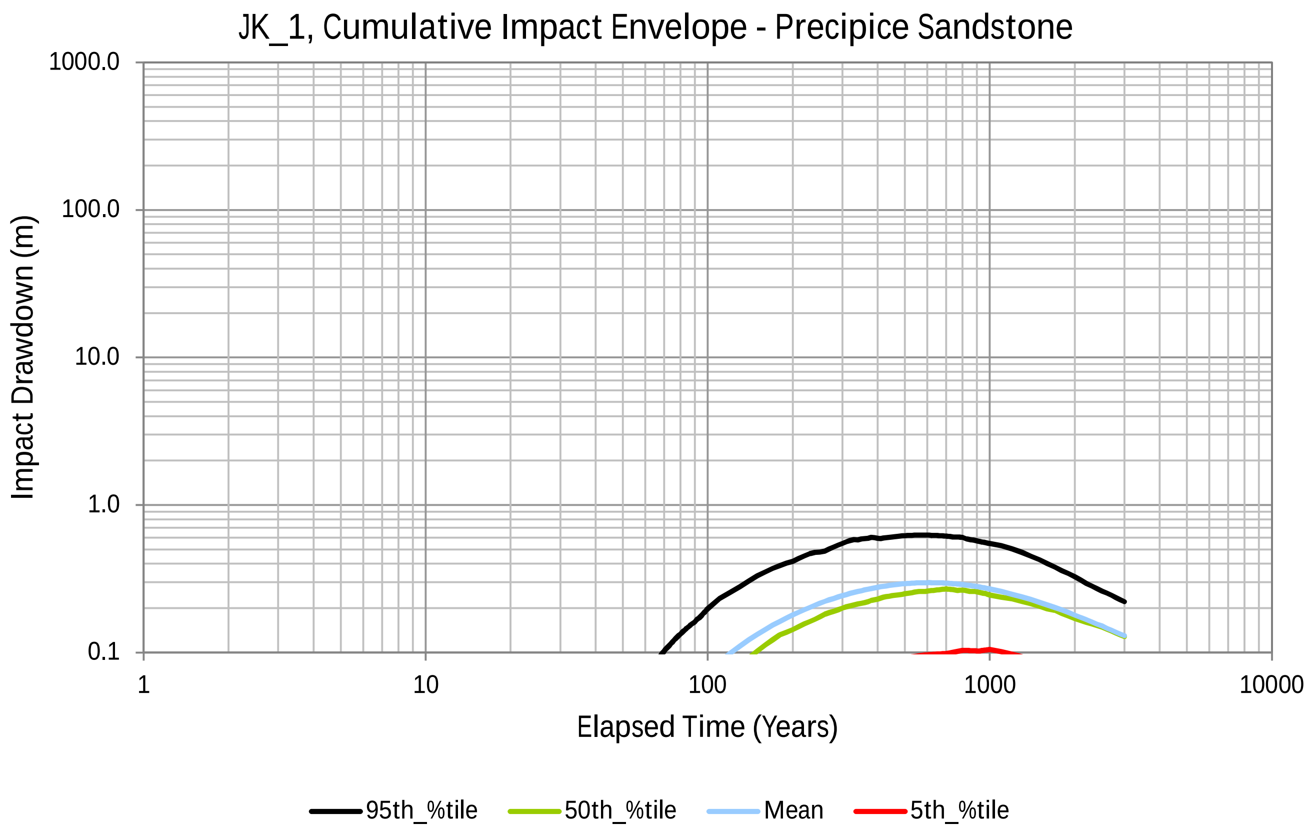
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



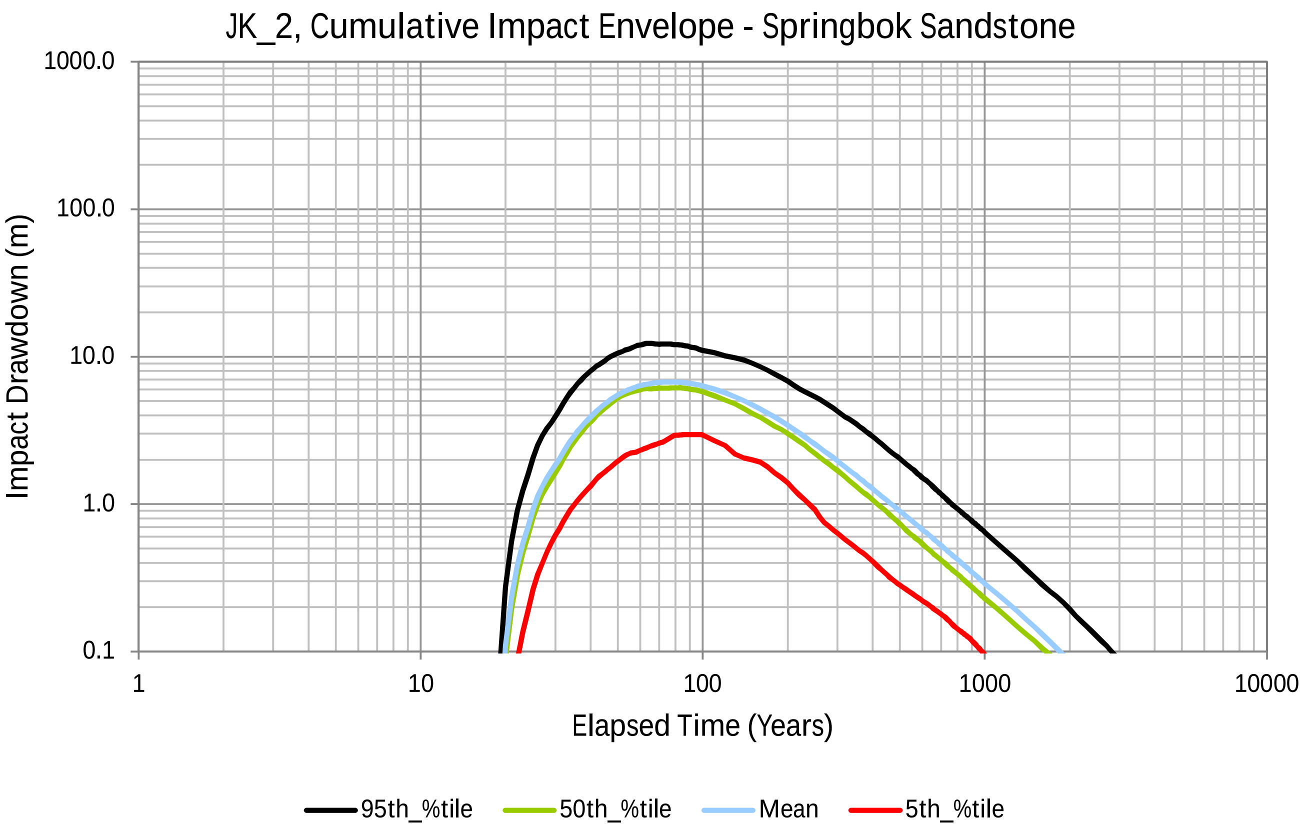


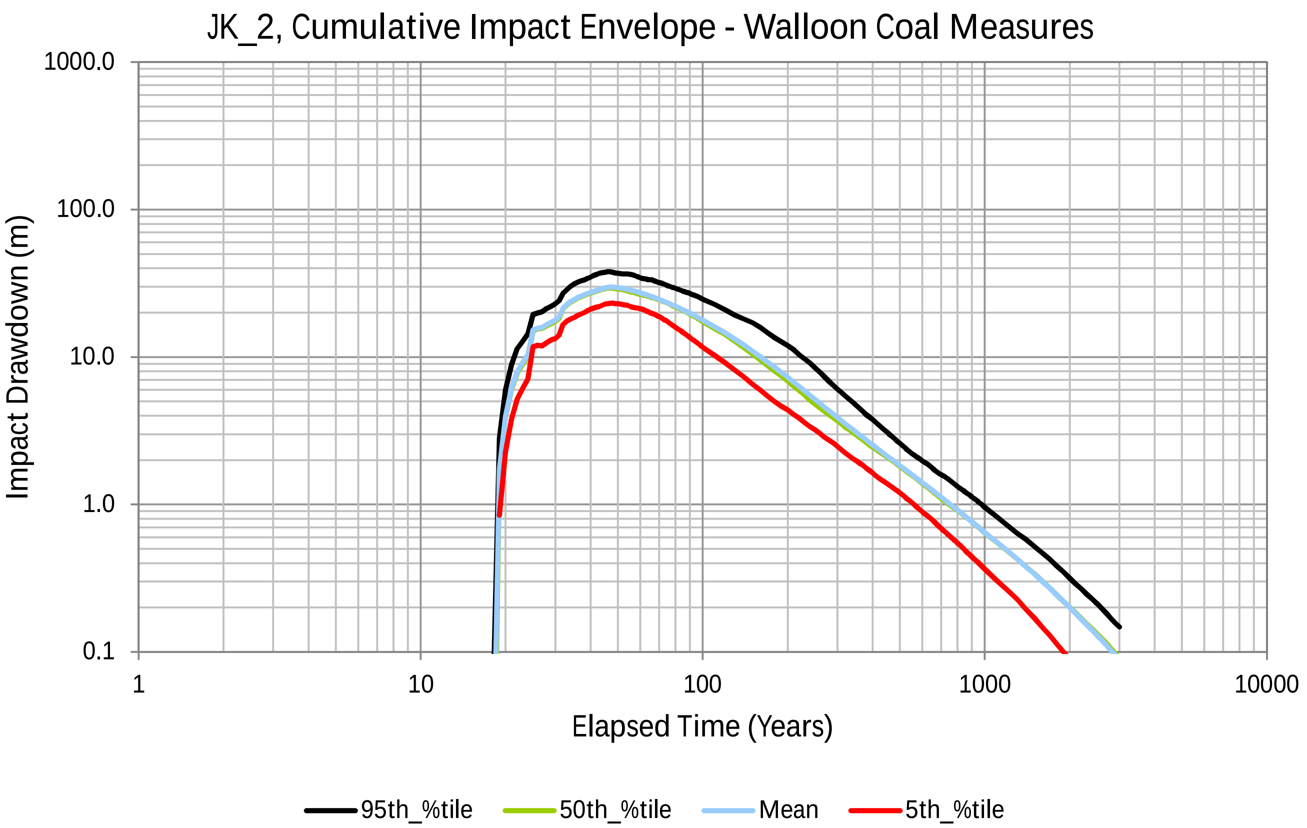
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



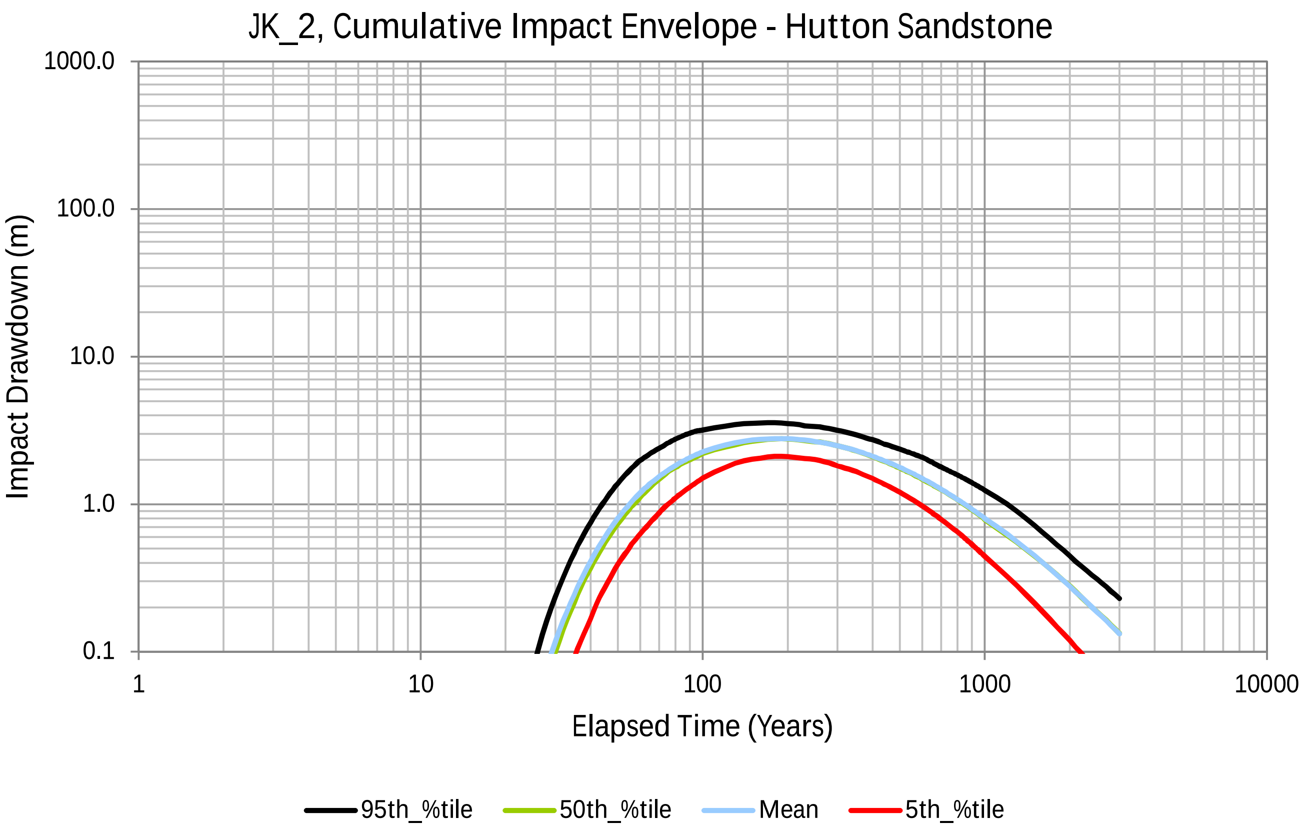


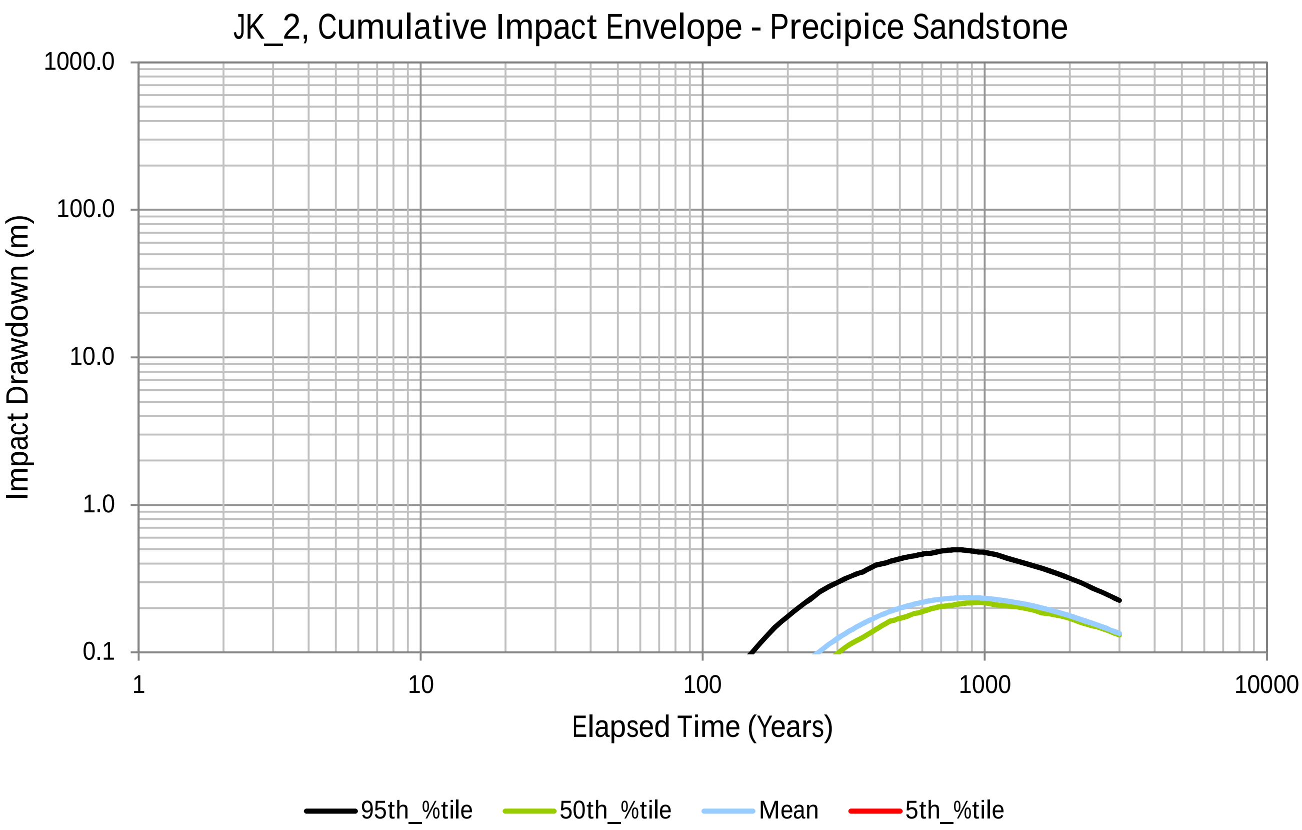
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



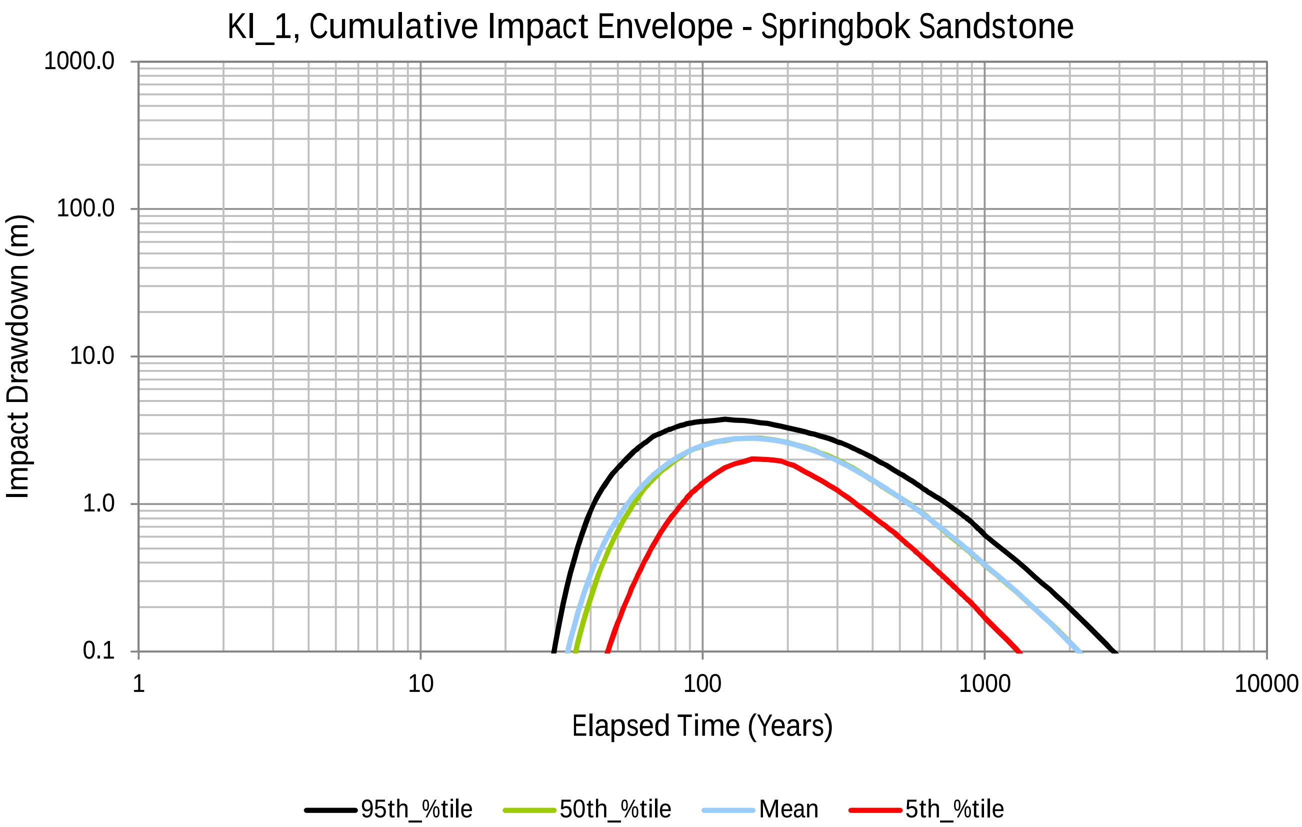


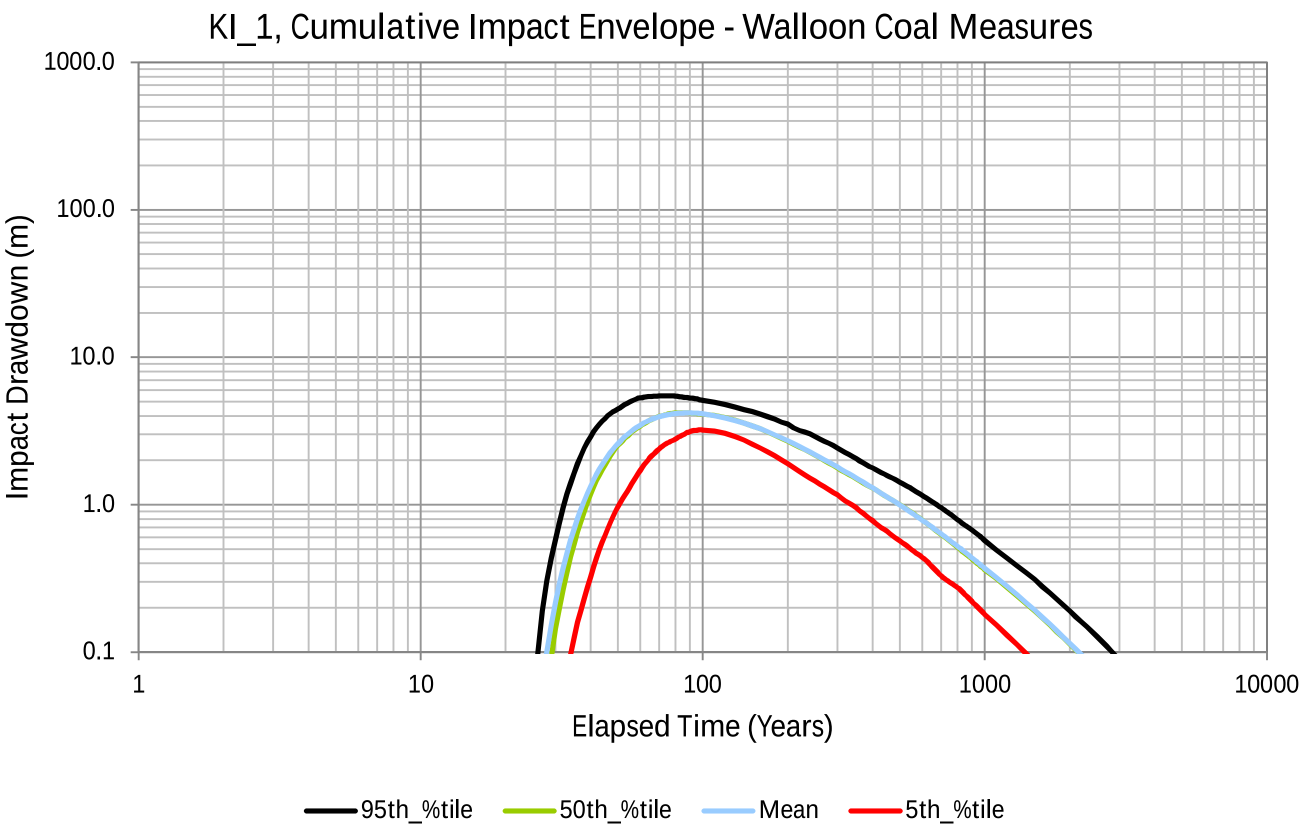
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



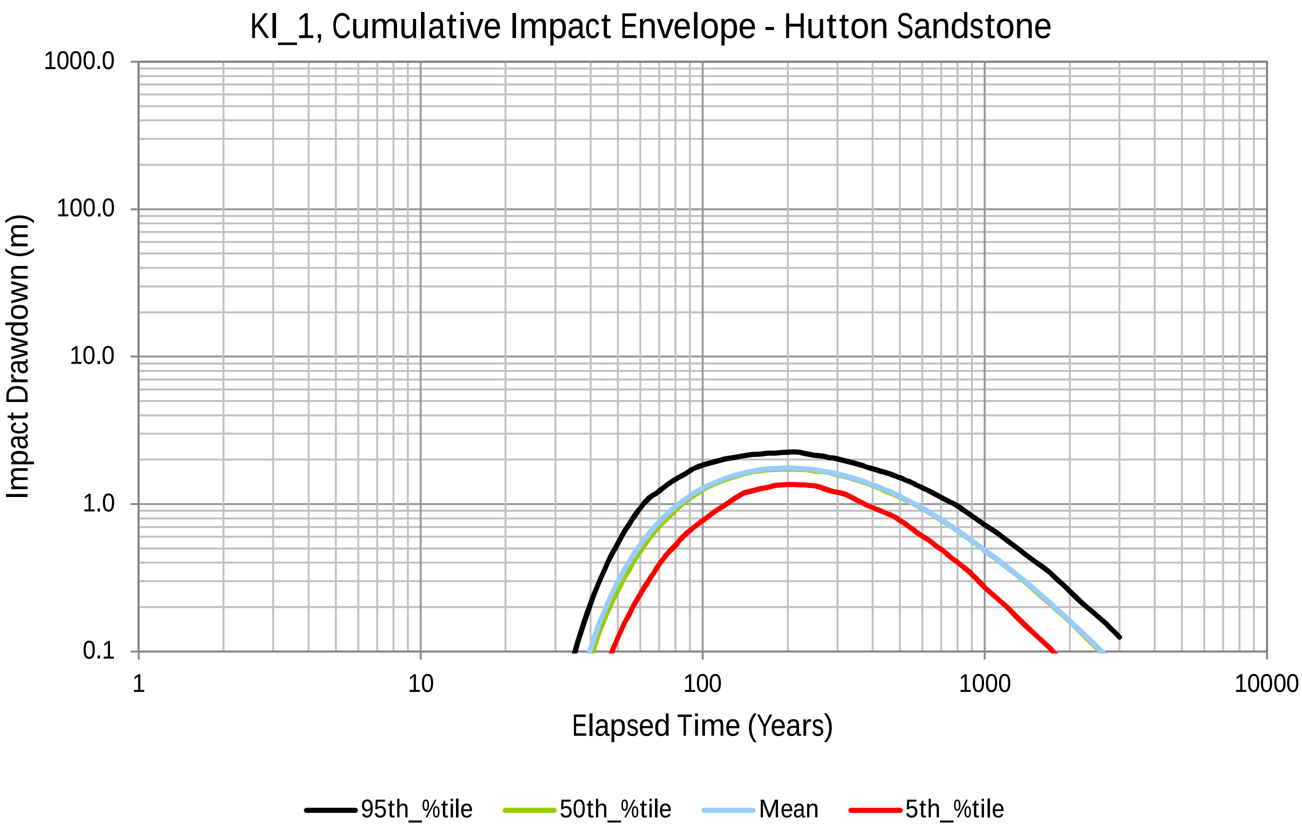


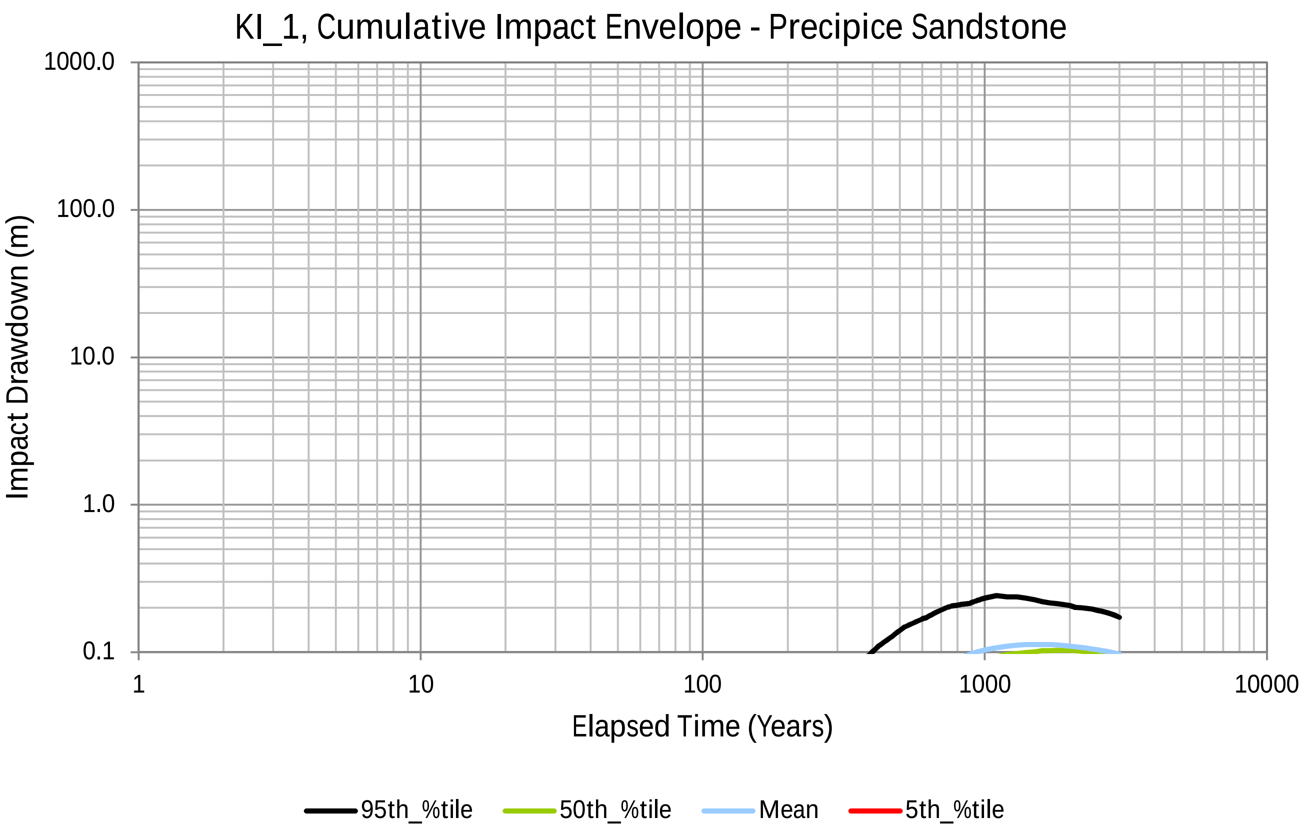
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



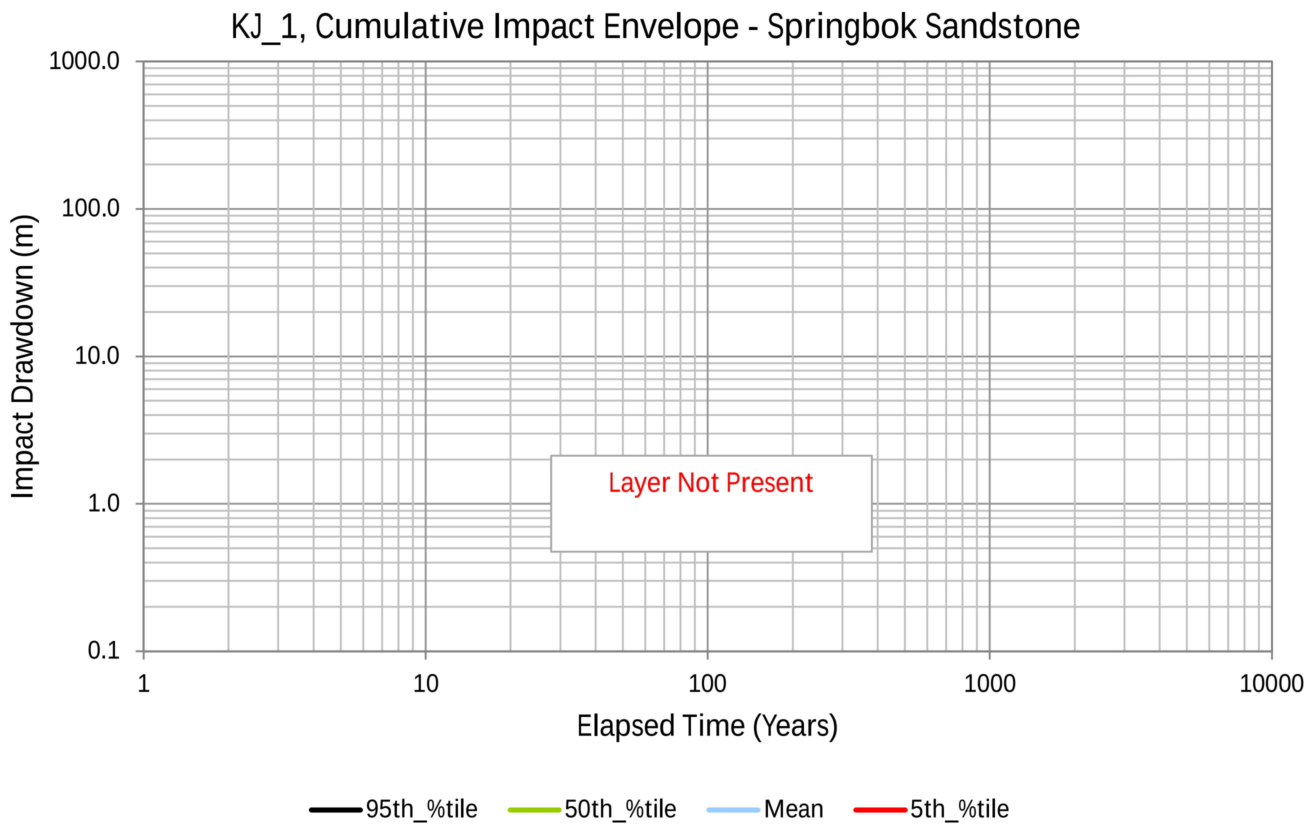


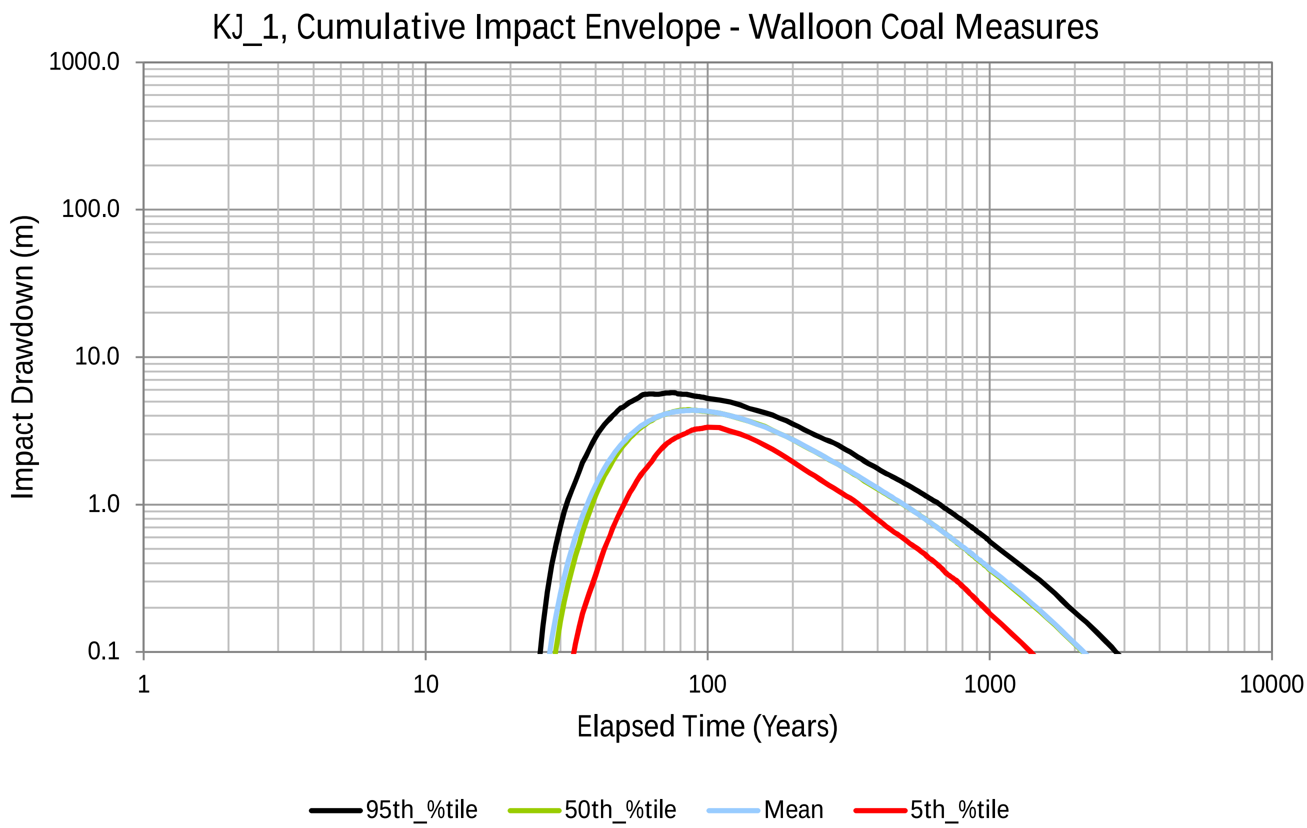
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



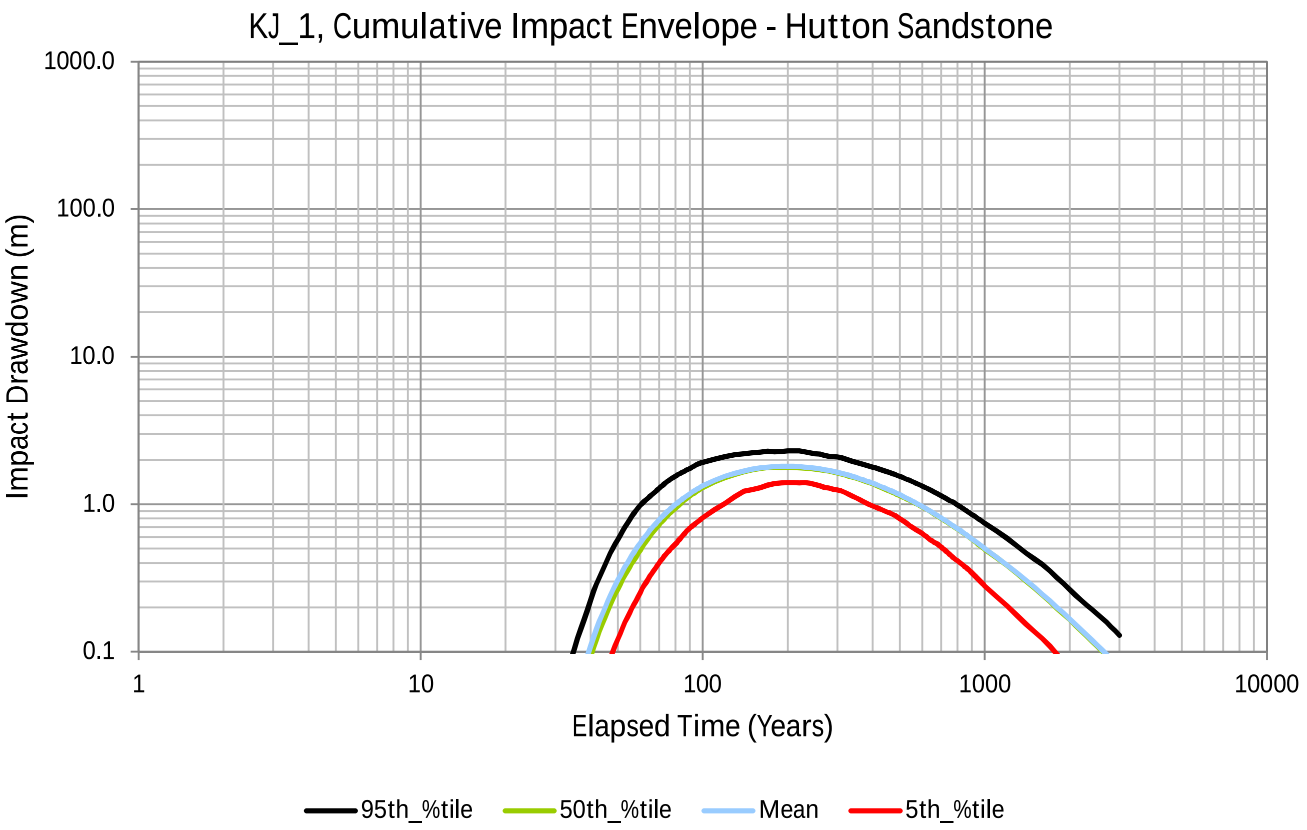


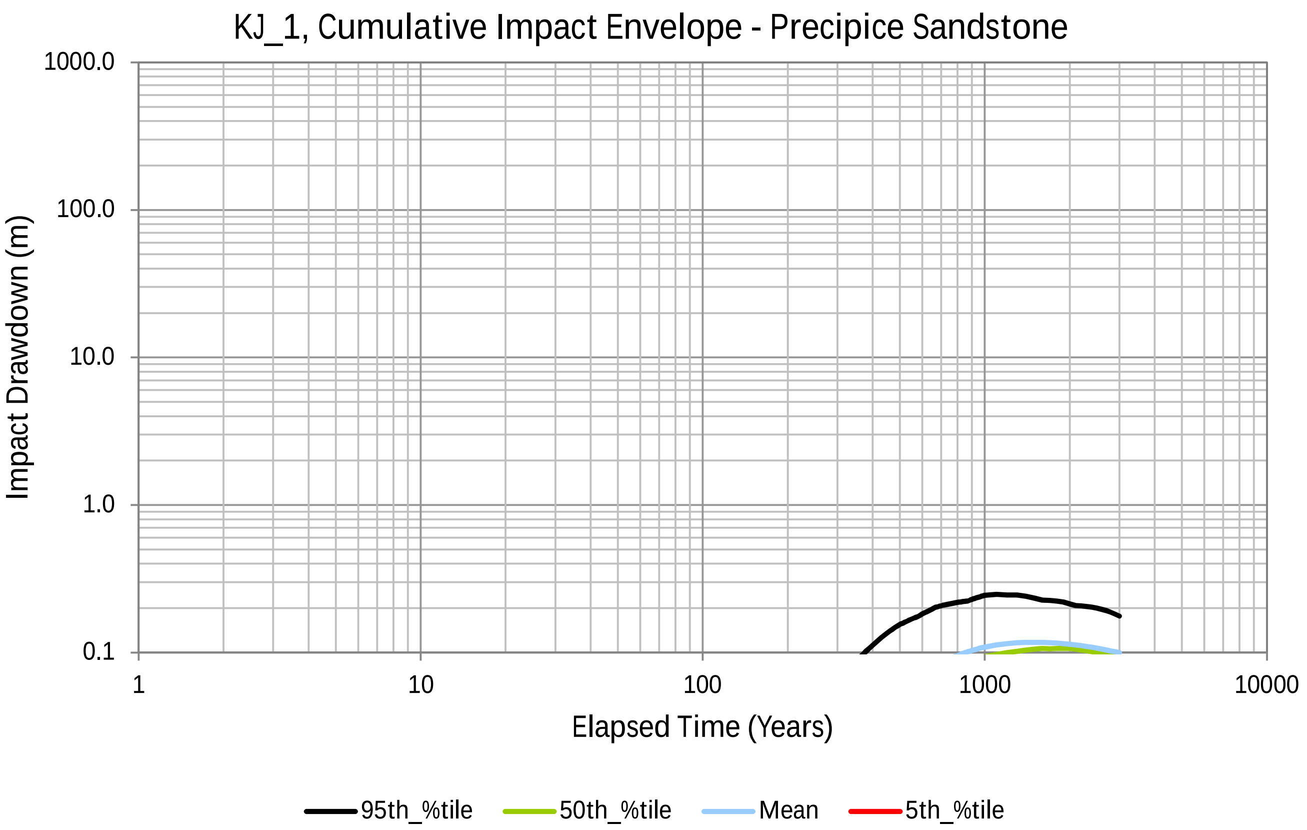
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



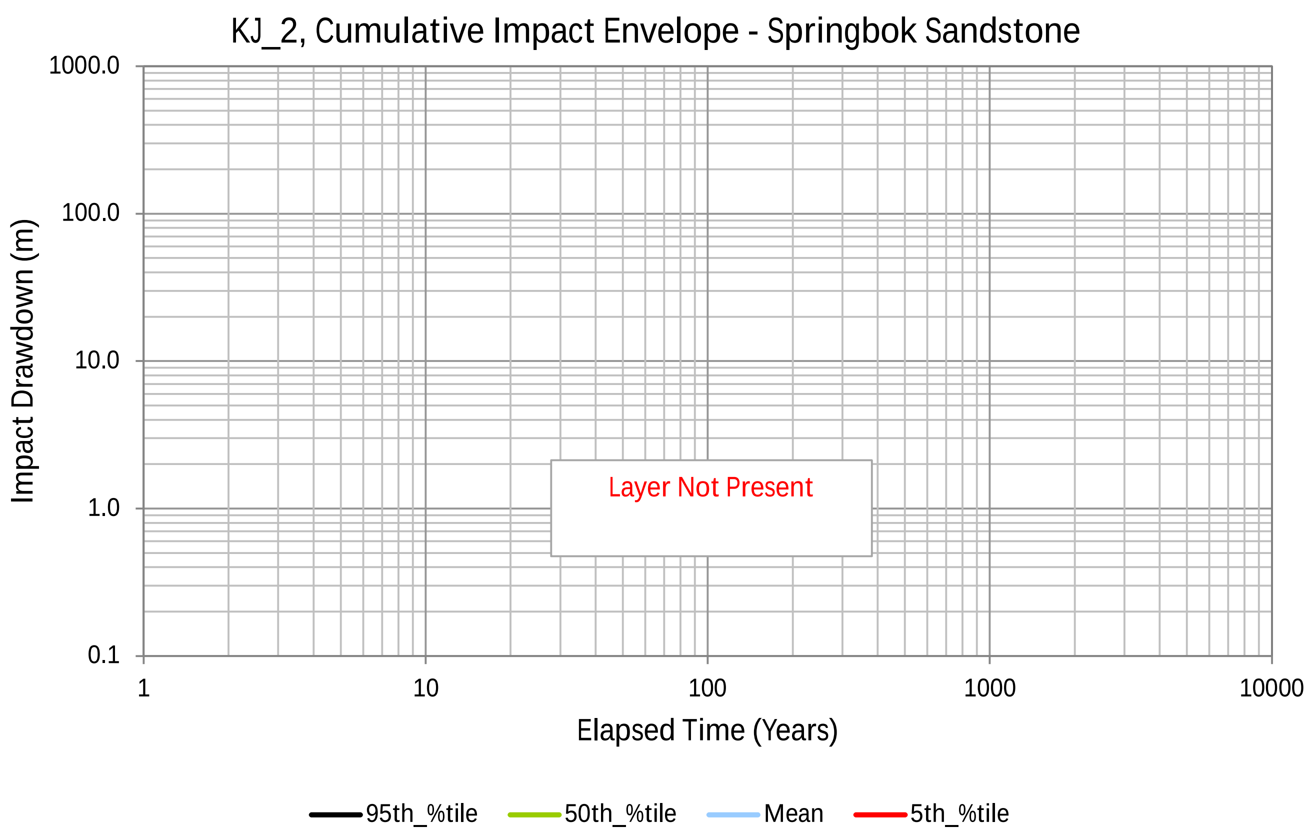


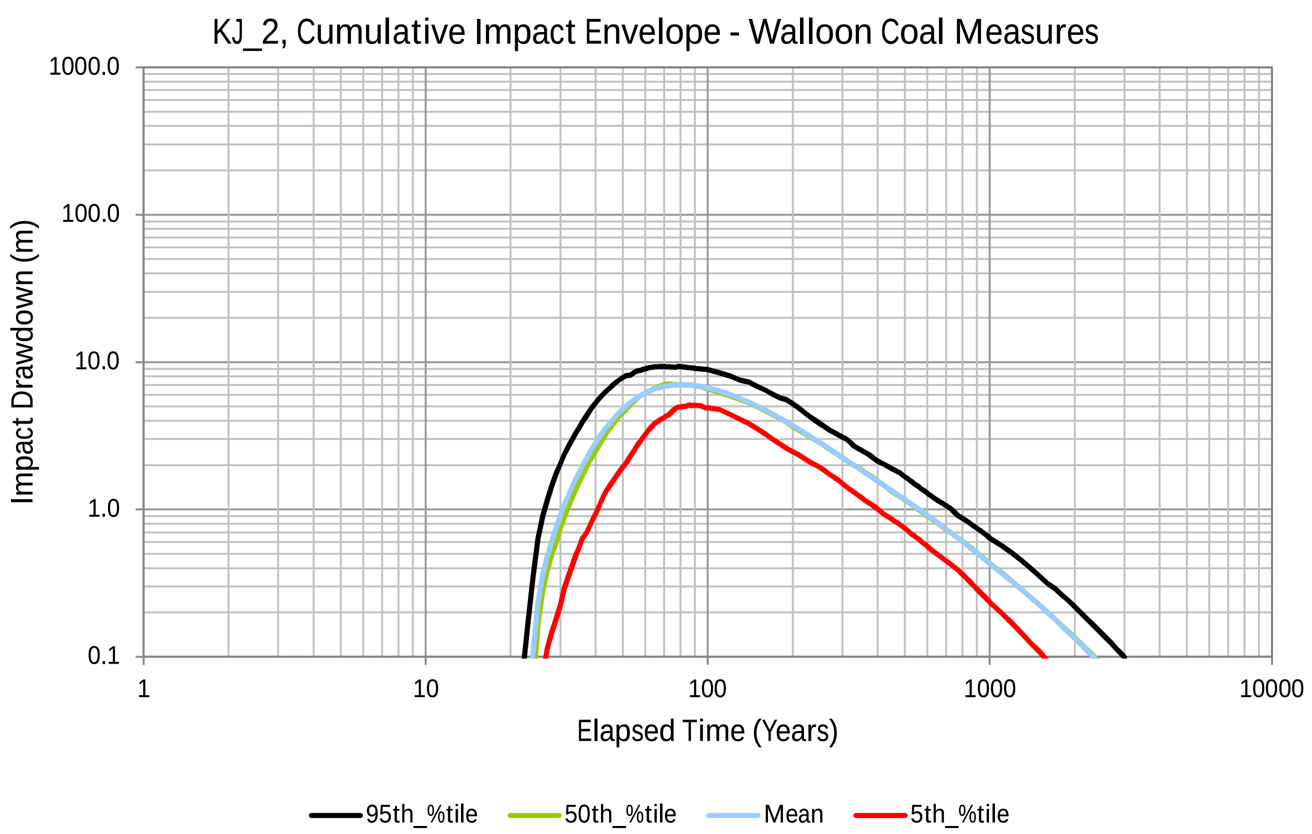
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



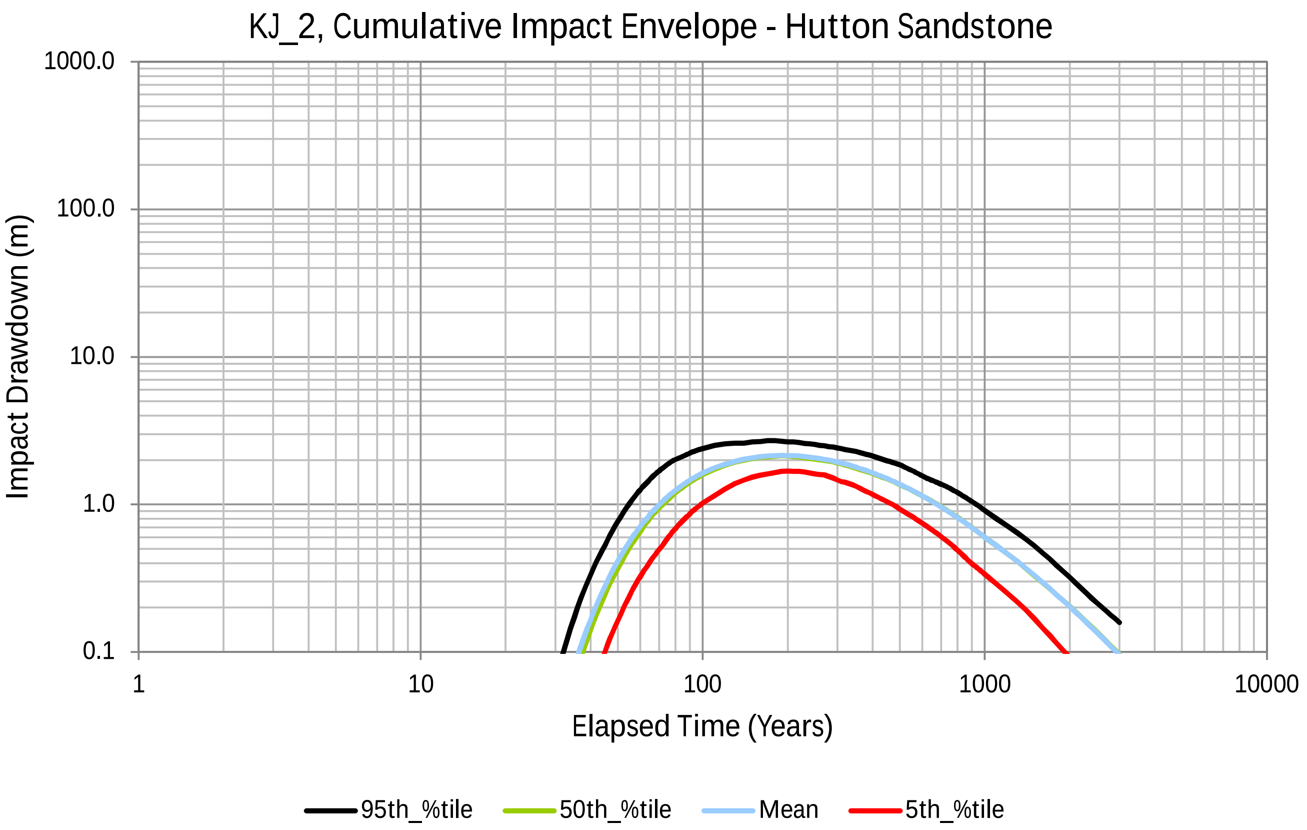


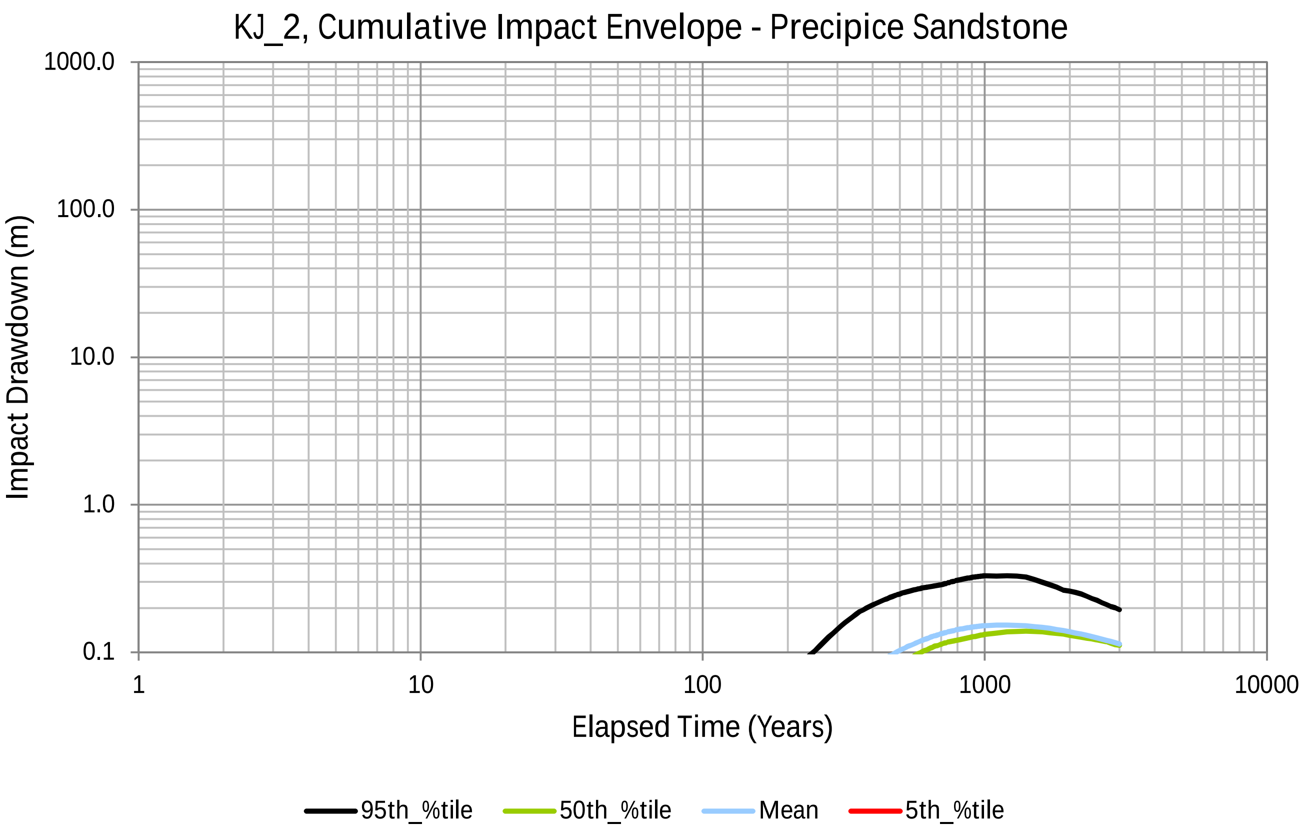
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



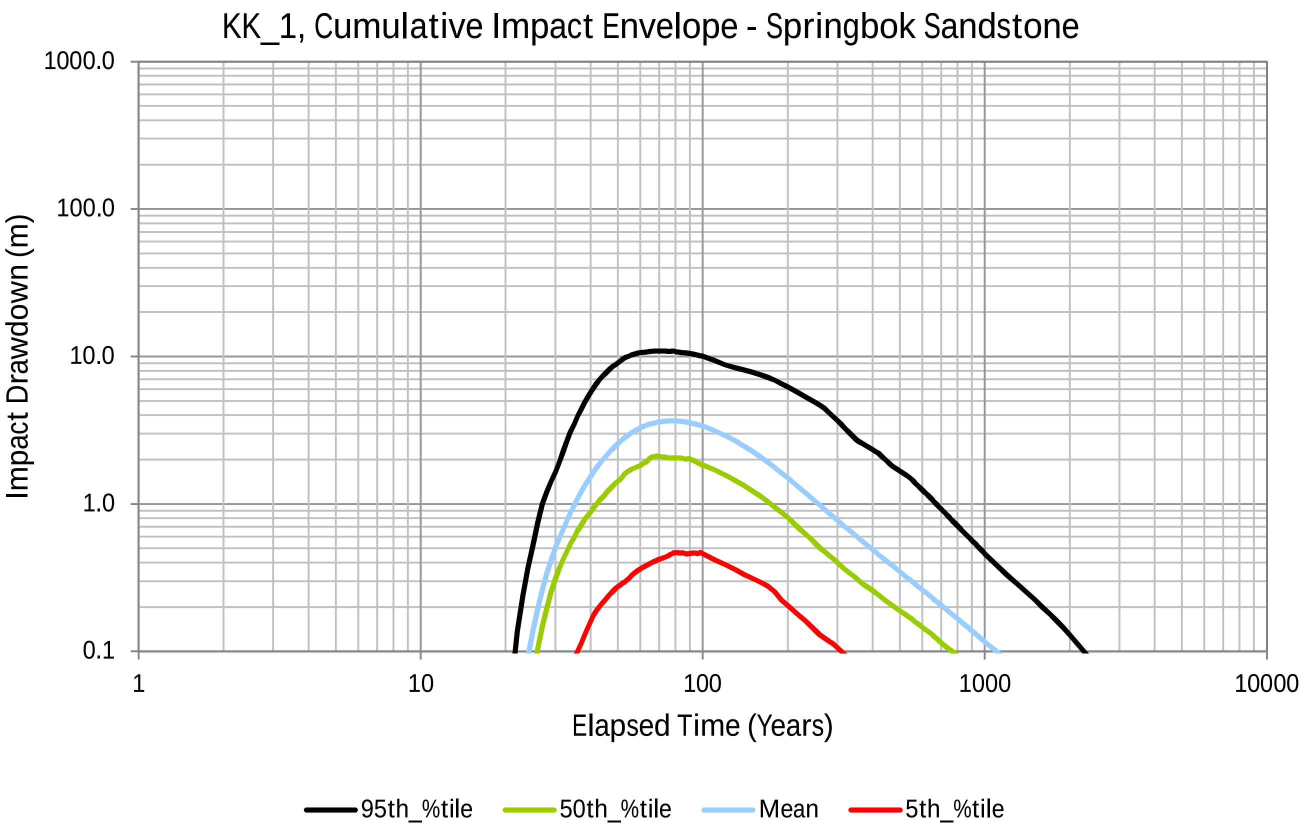


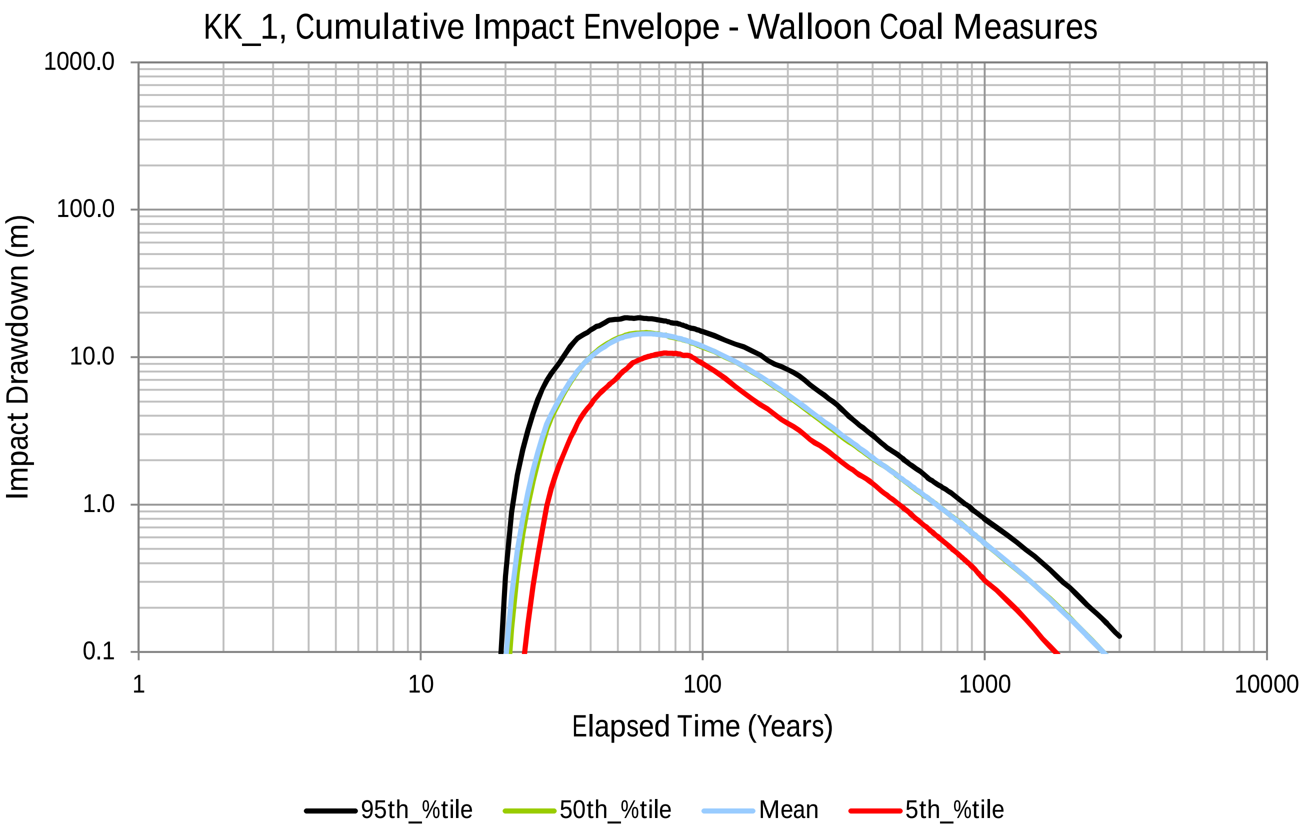
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



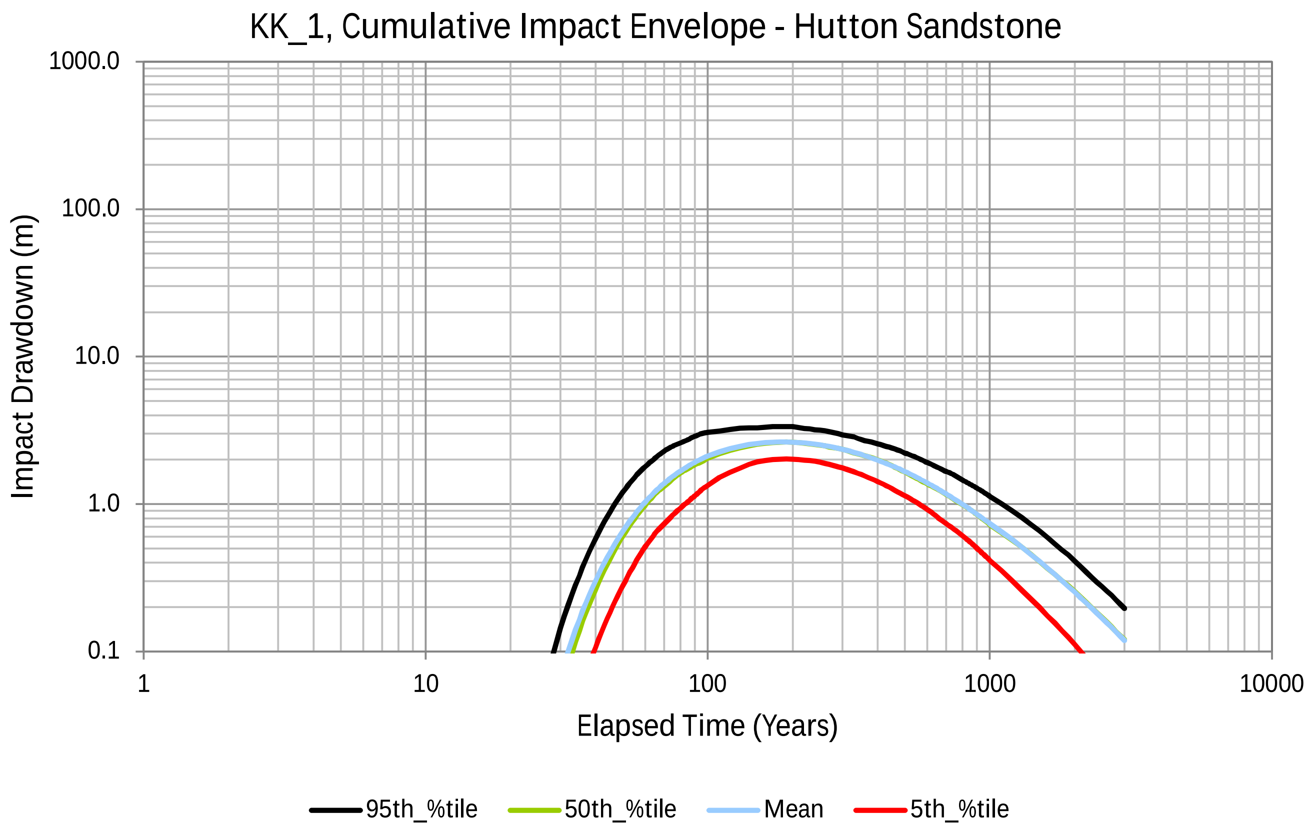


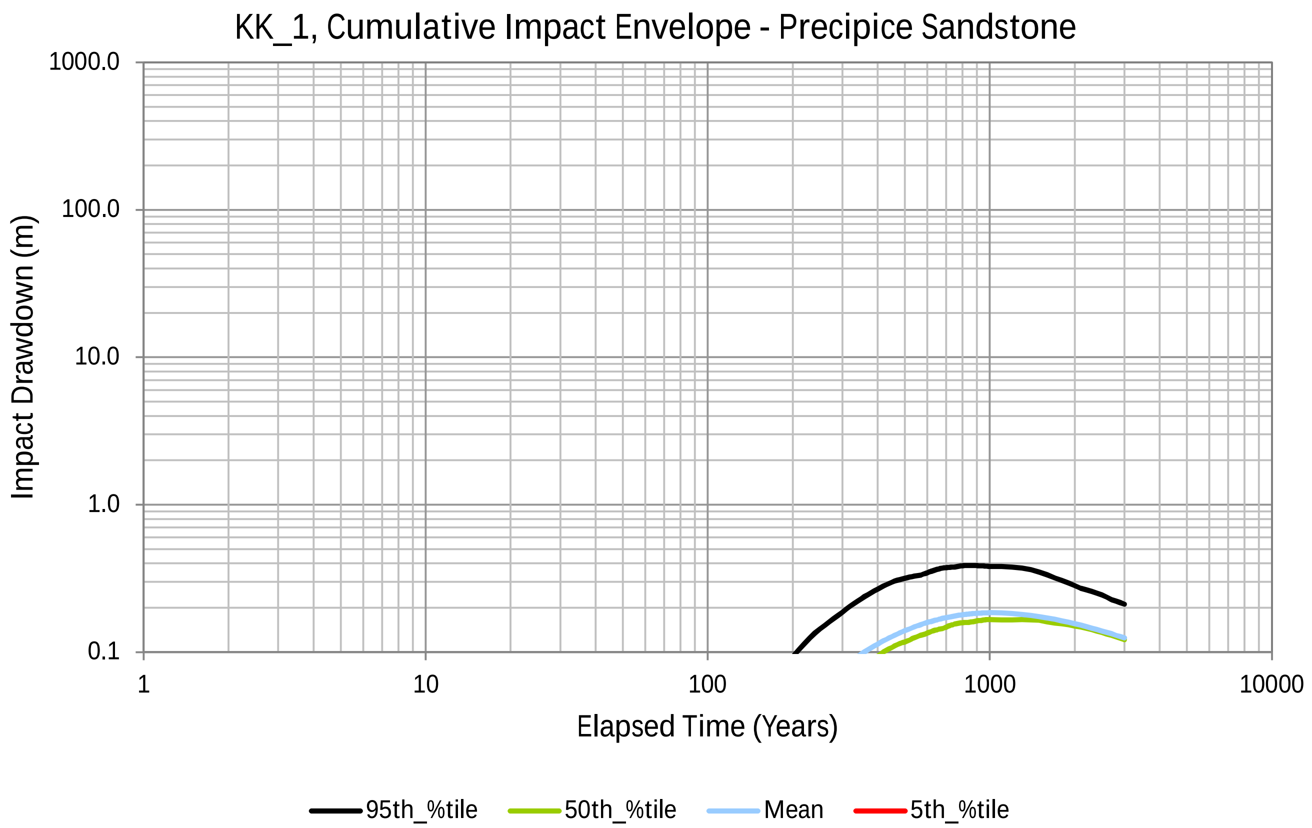
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



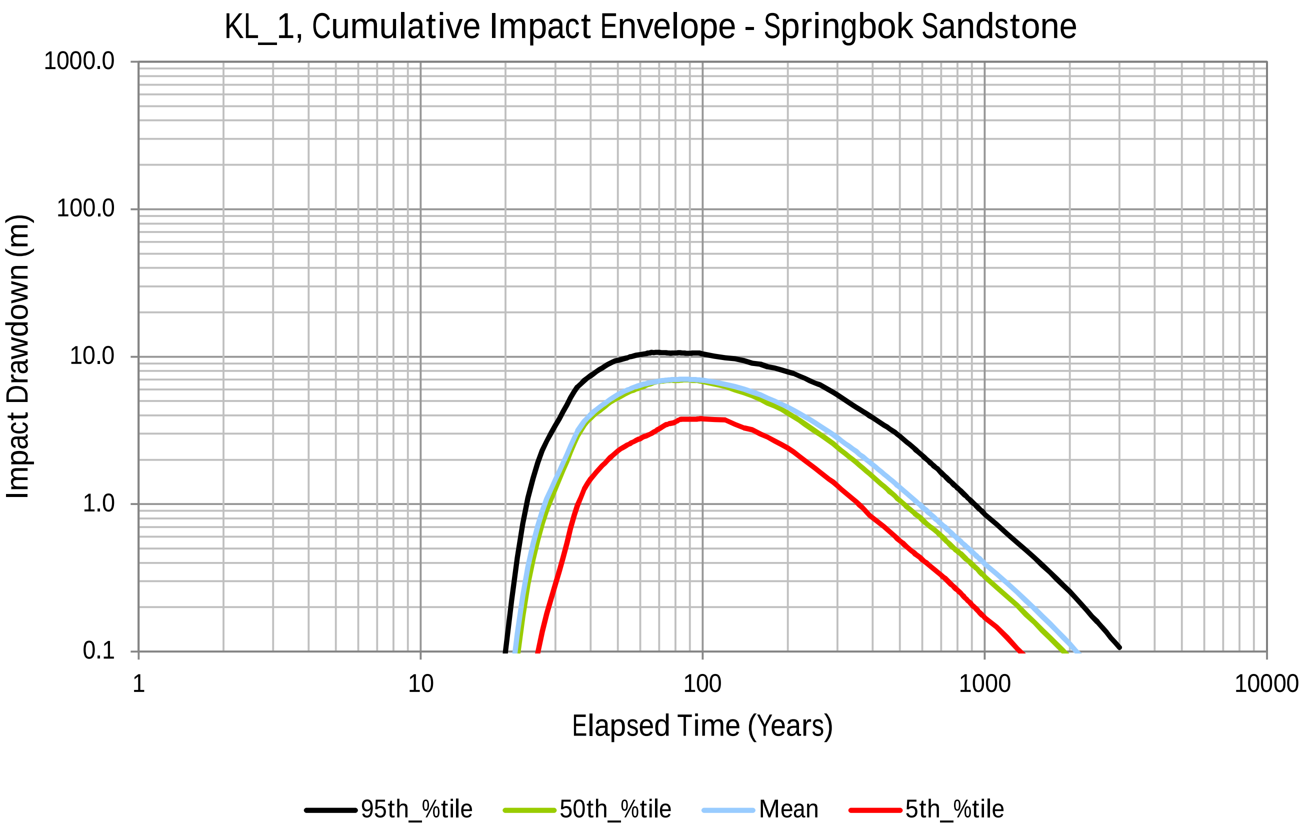


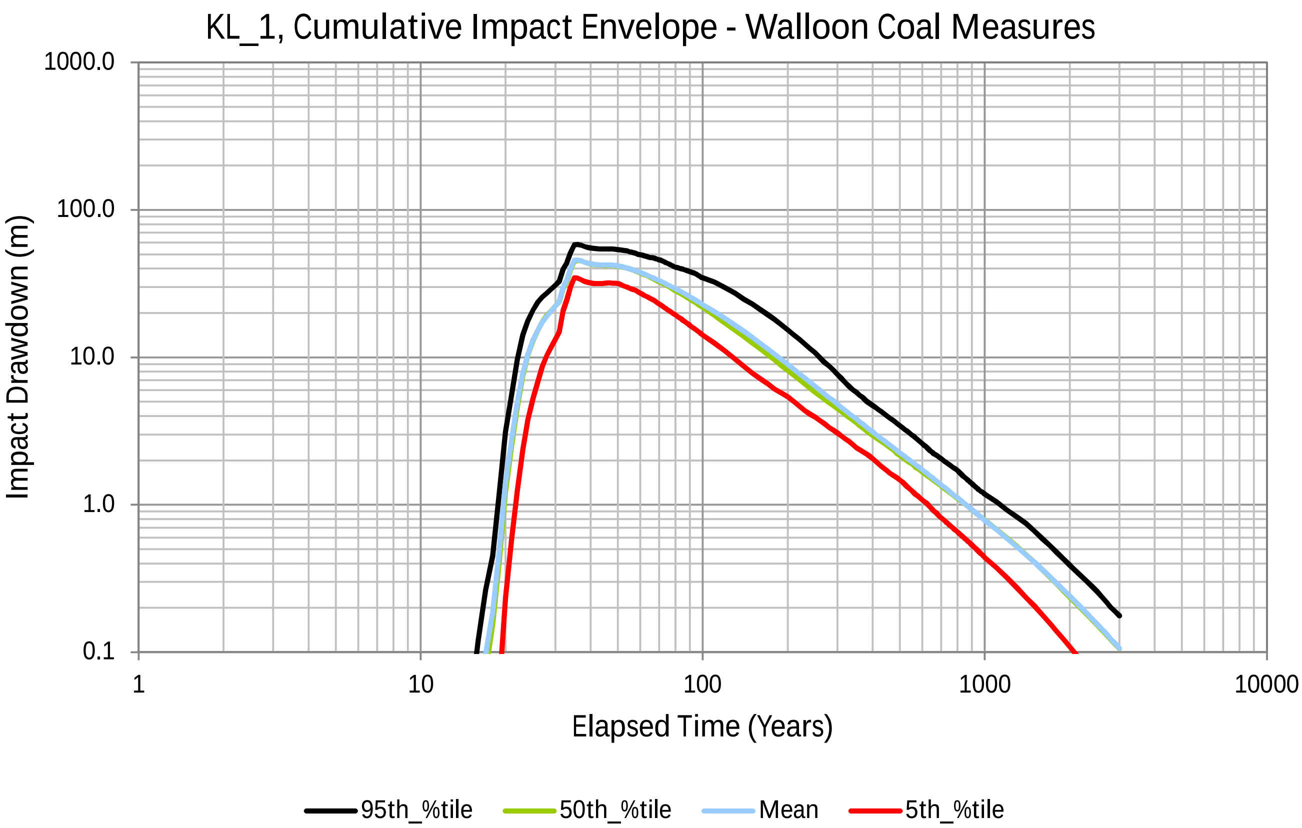
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2





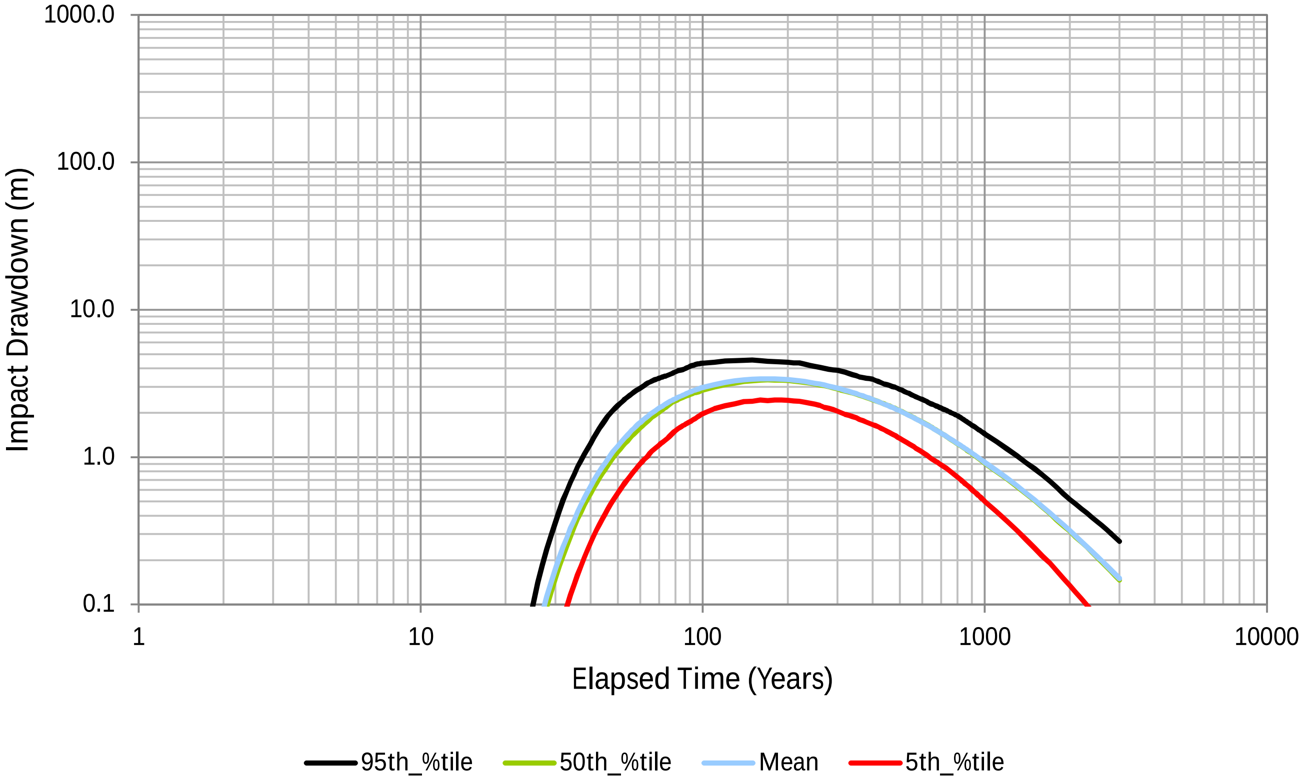
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2

KL_1, Cumulative Impact Envelope - Hutton Sandstone



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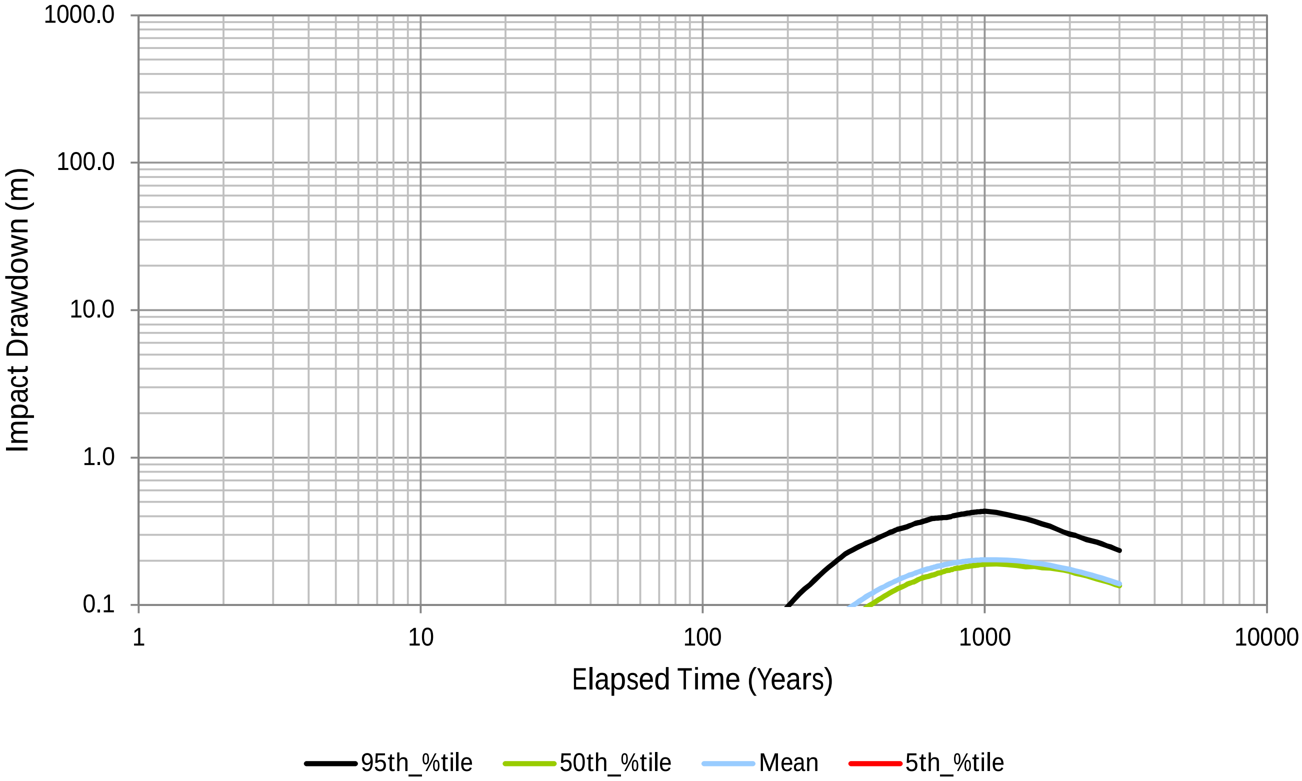
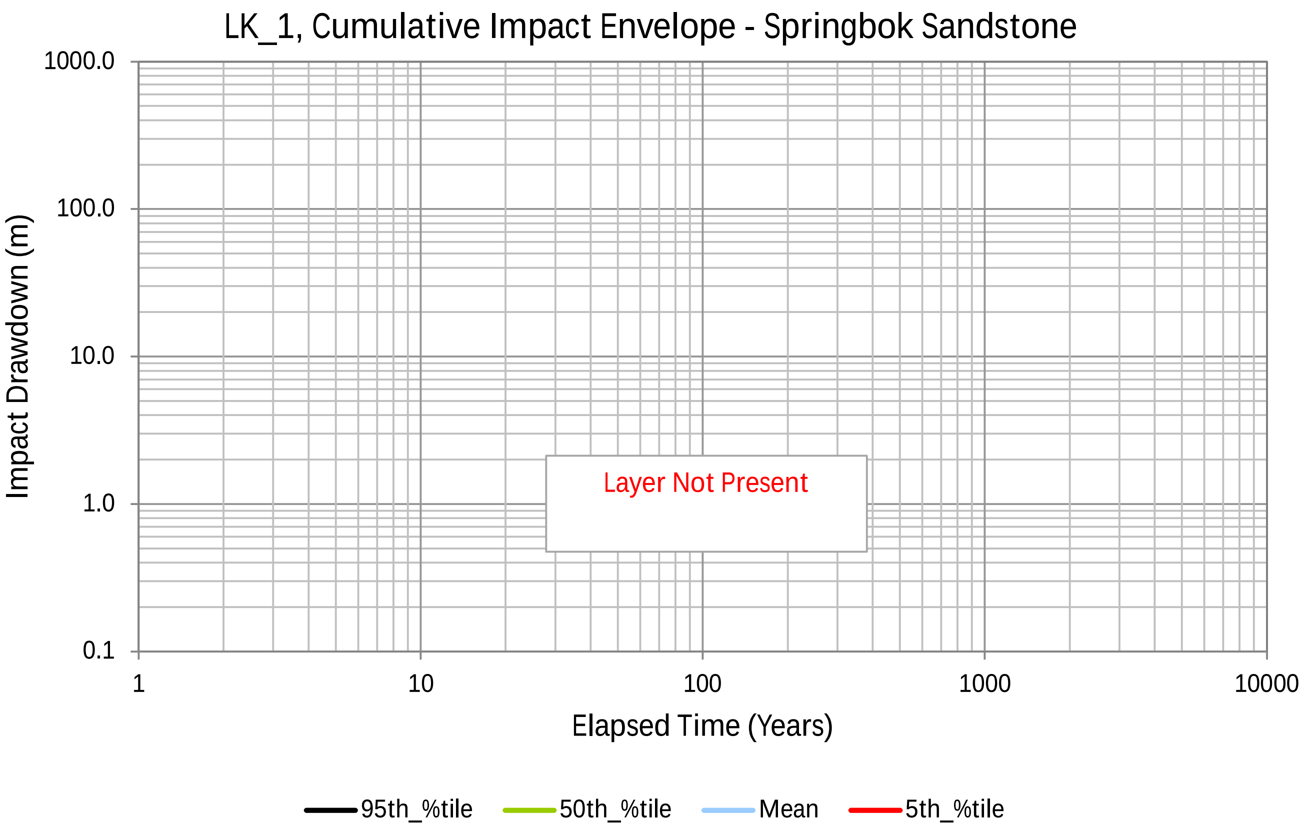
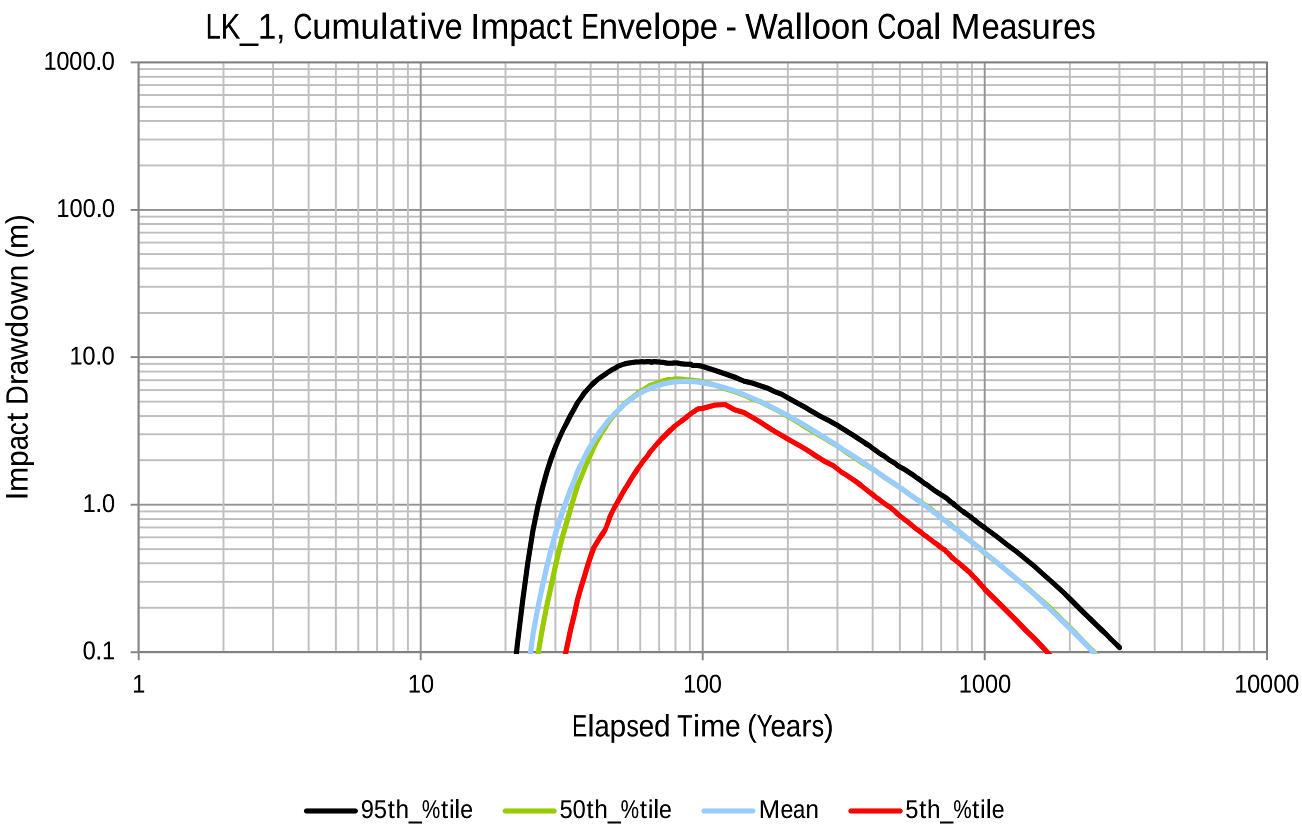
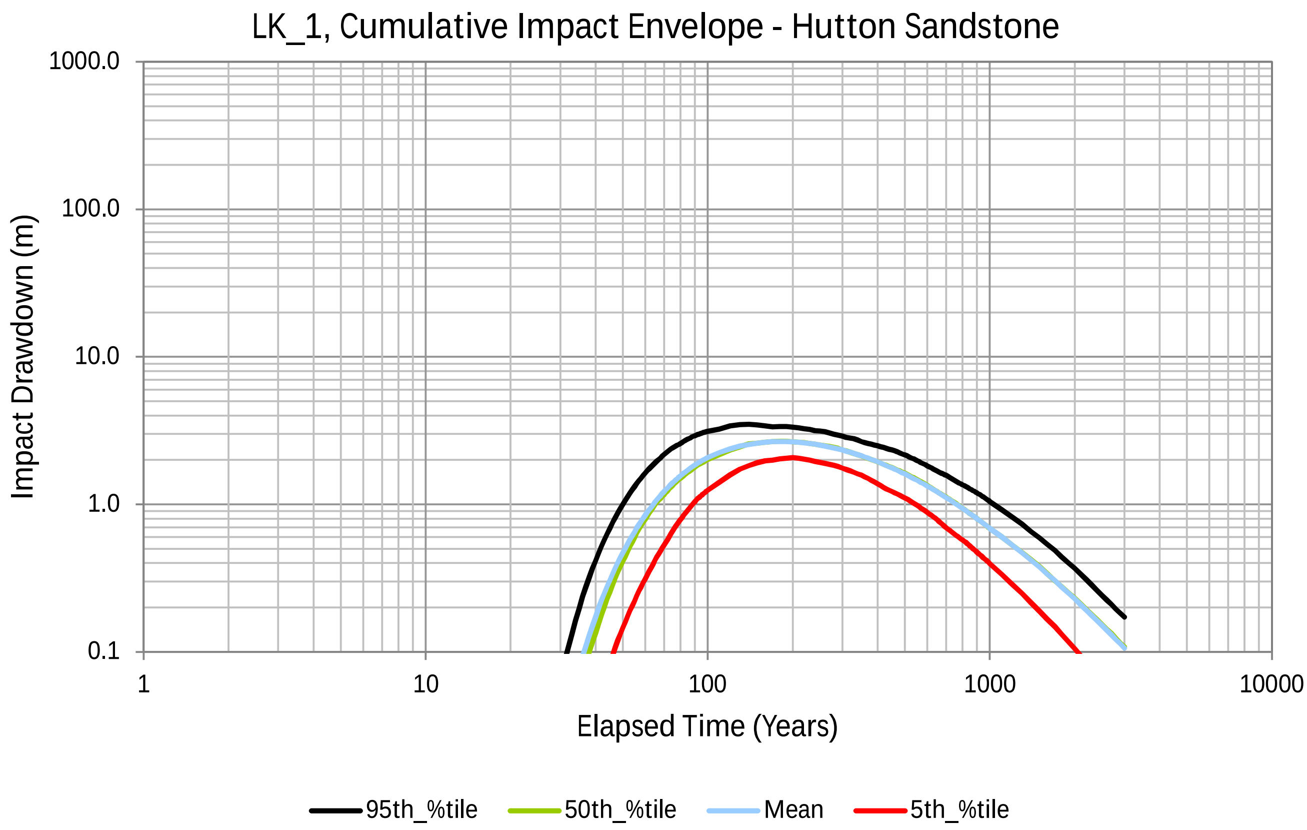


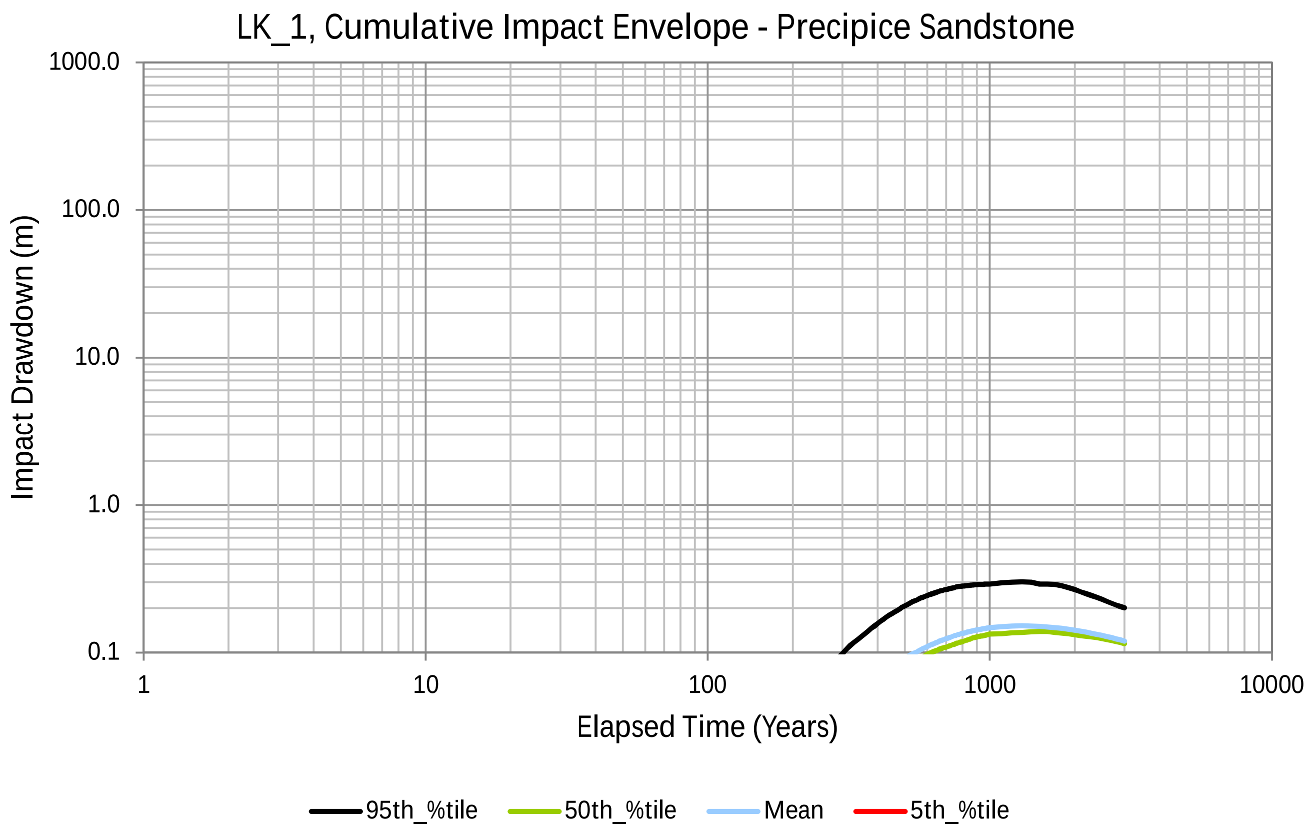
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



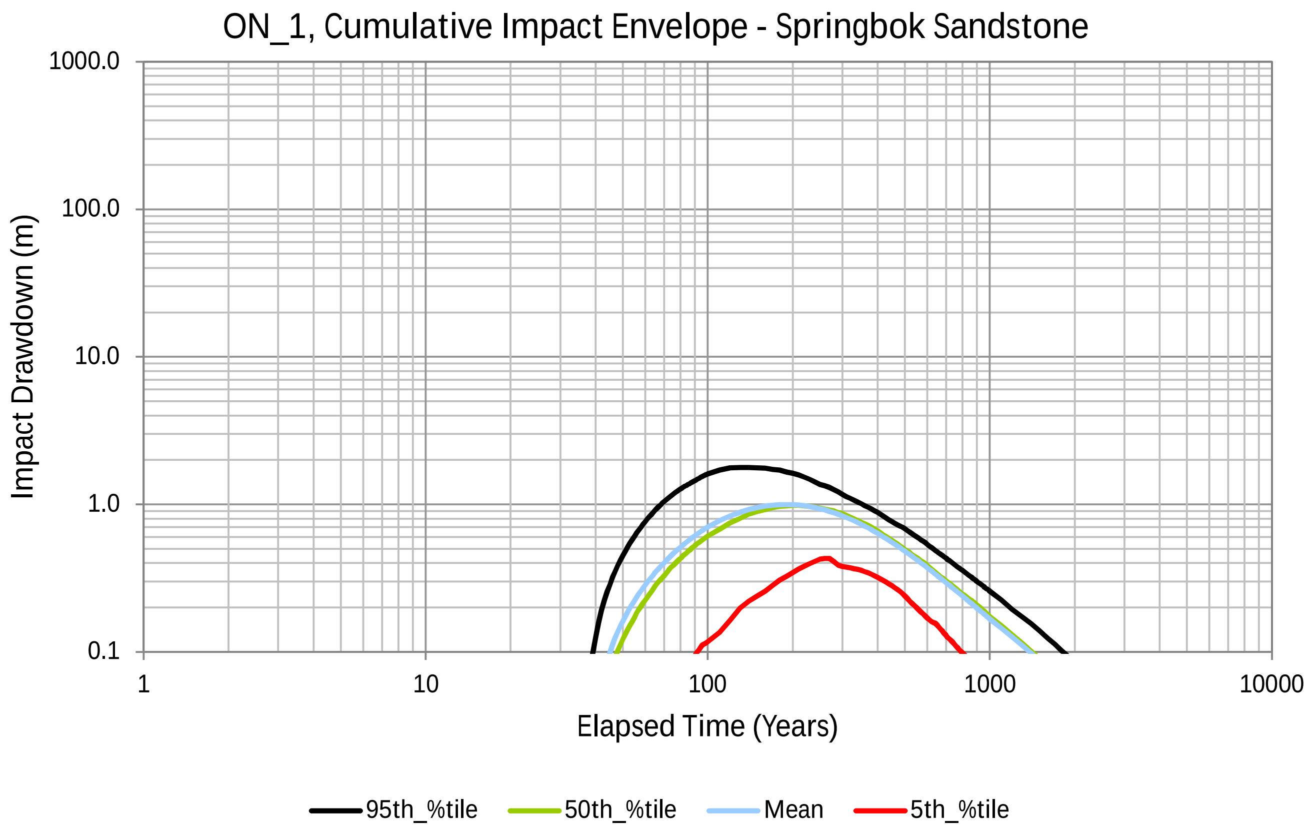


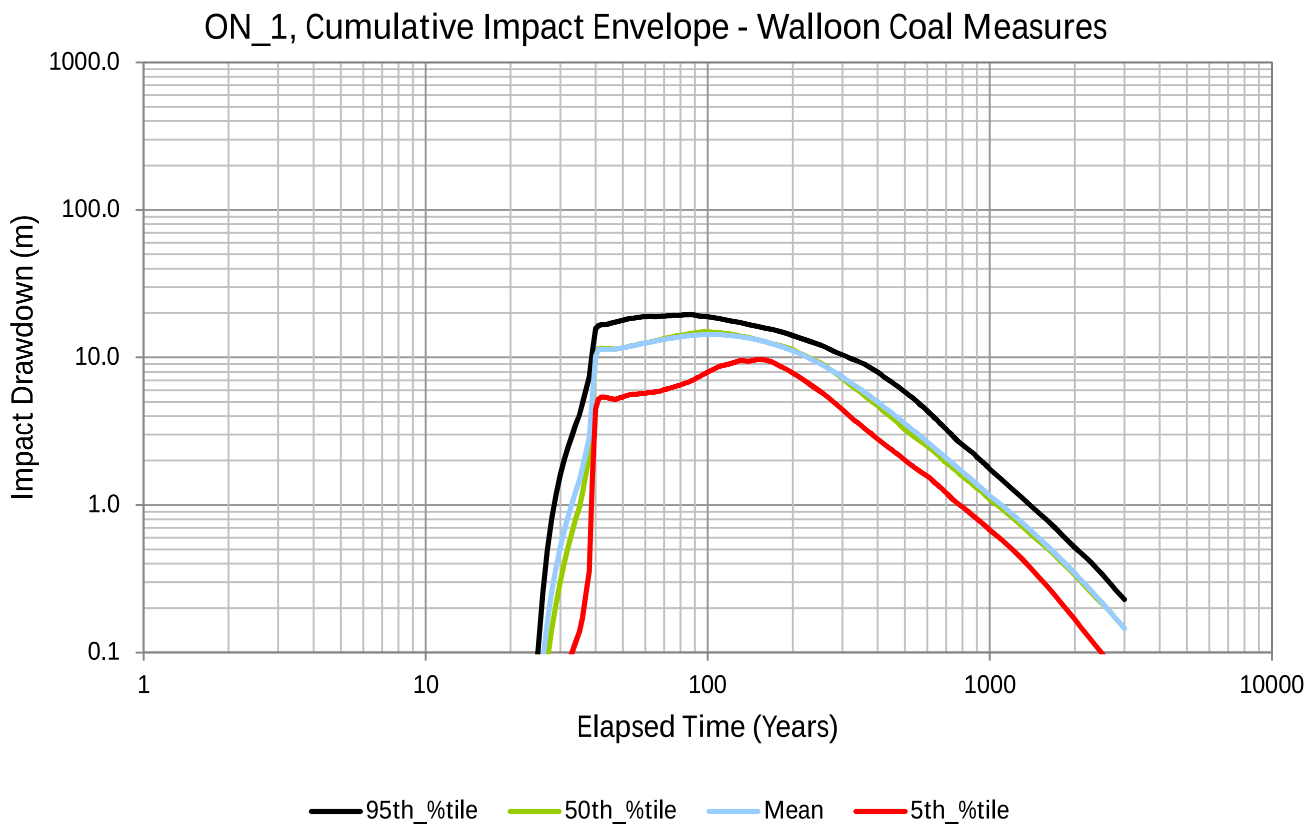
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 2



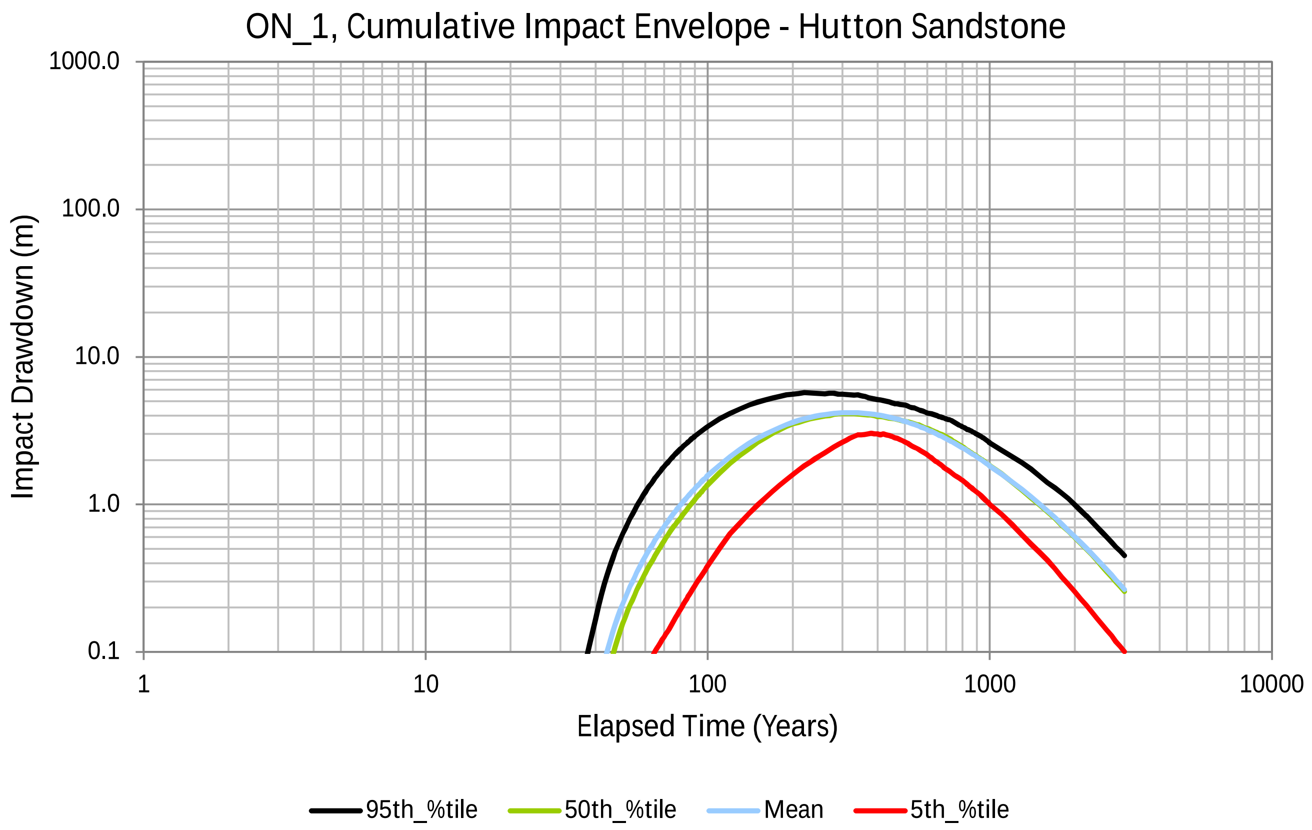


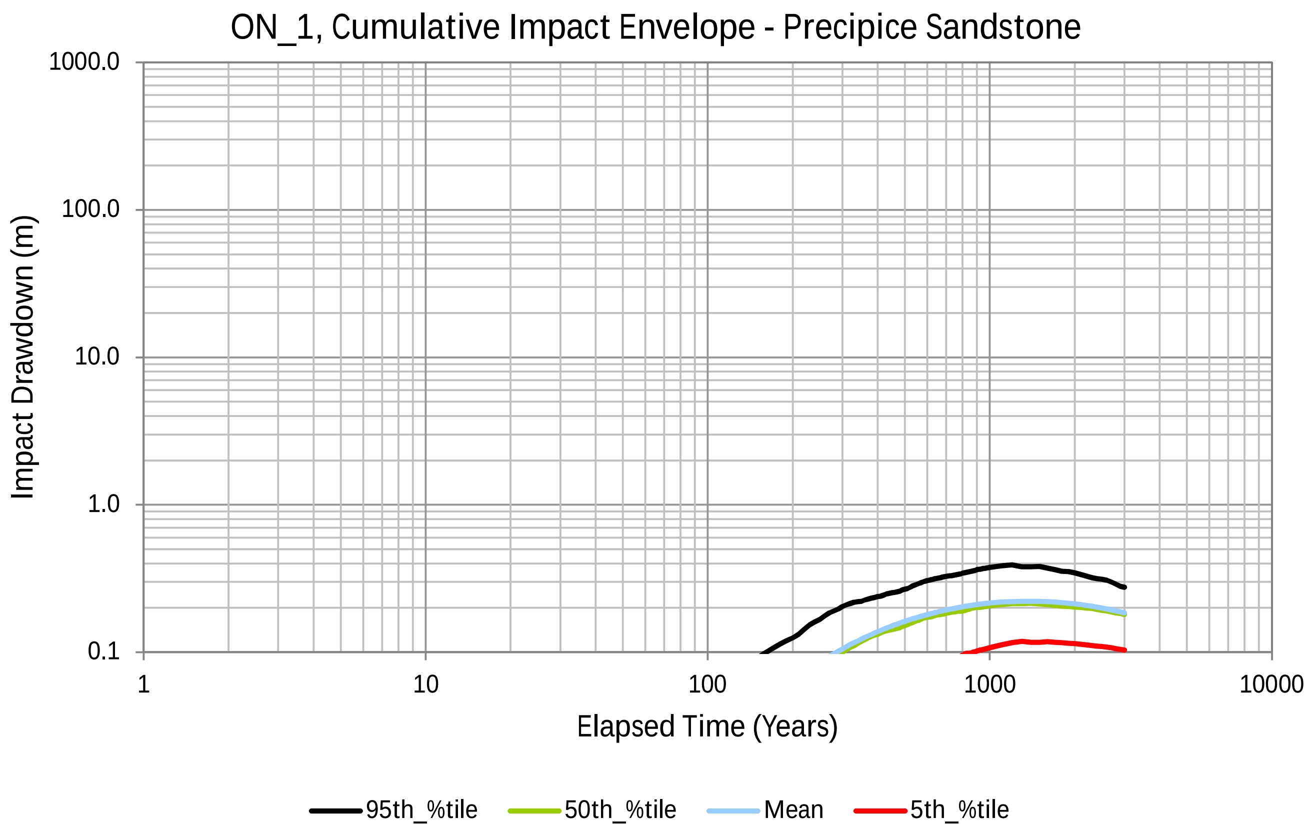
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



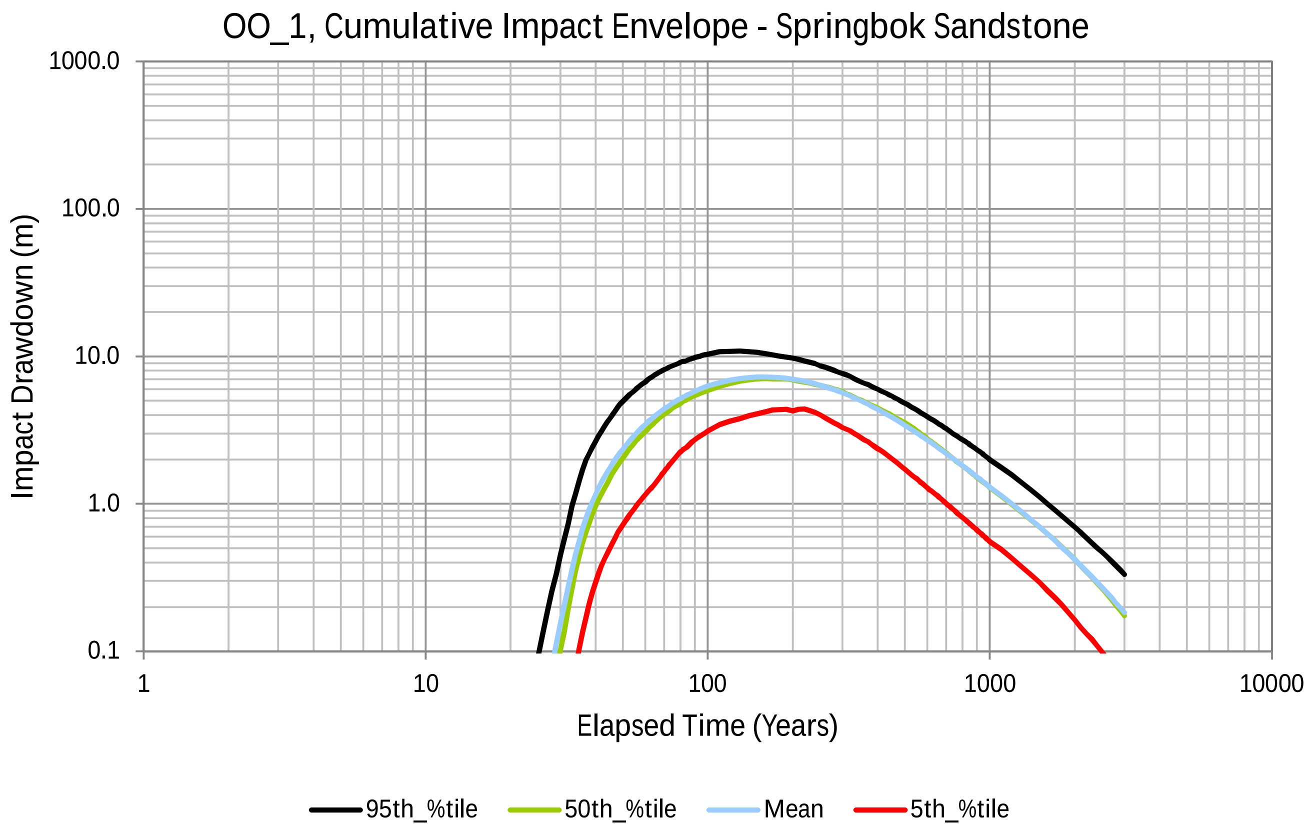


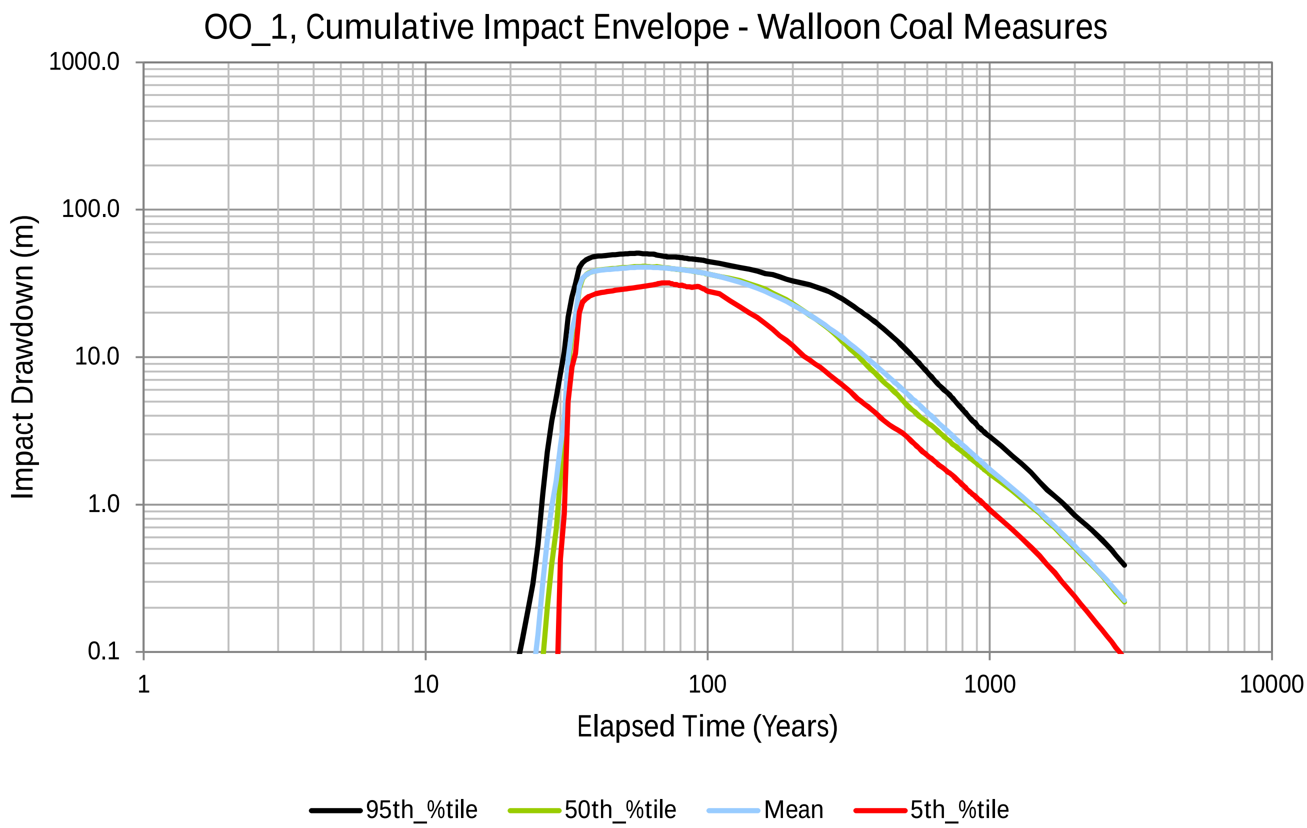
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



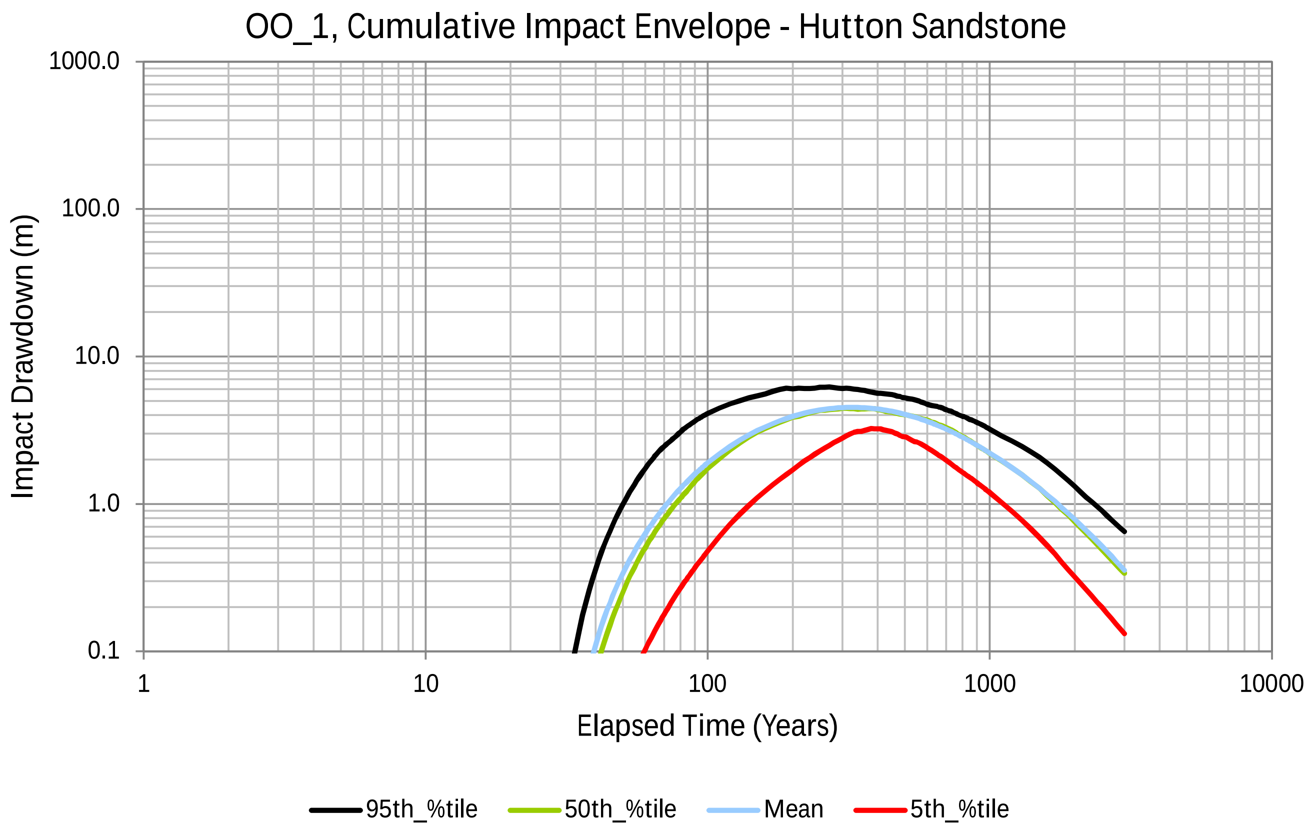


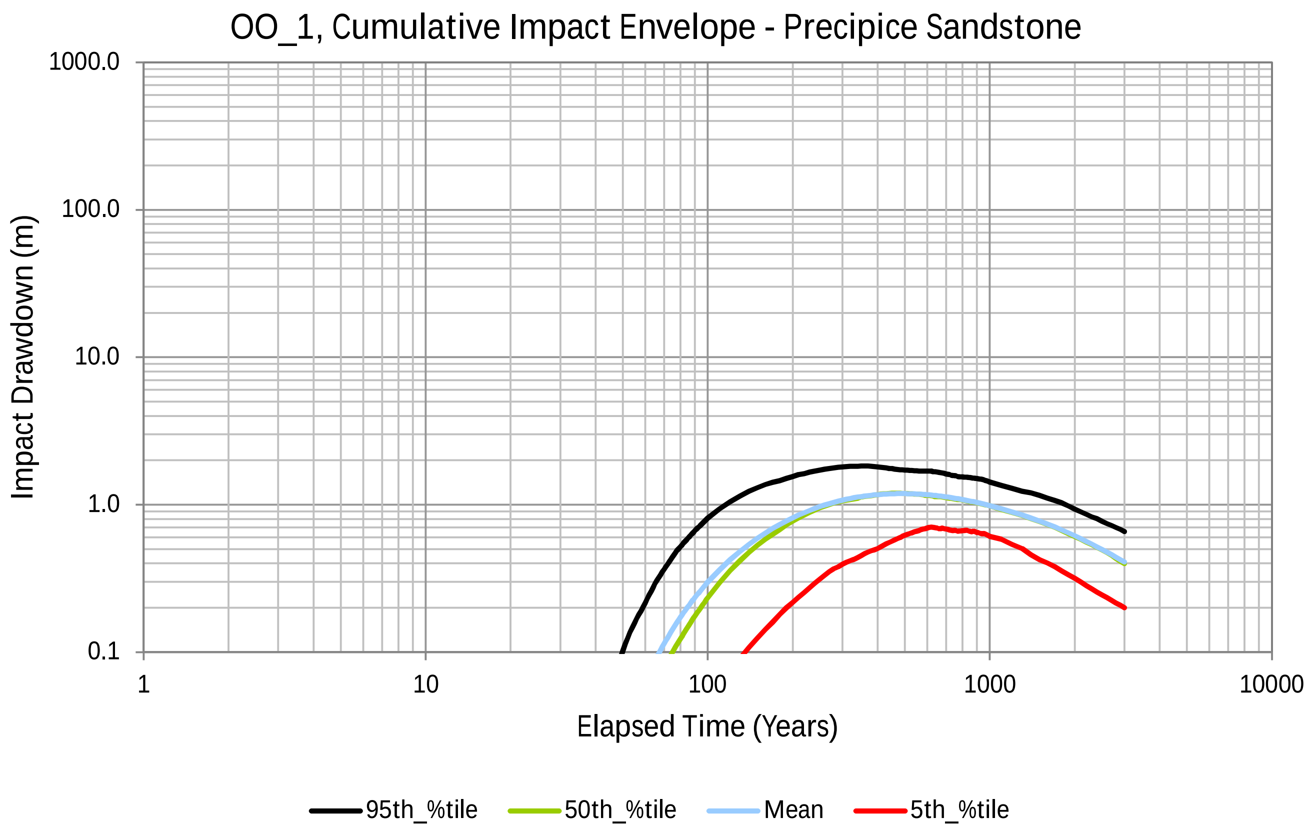
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



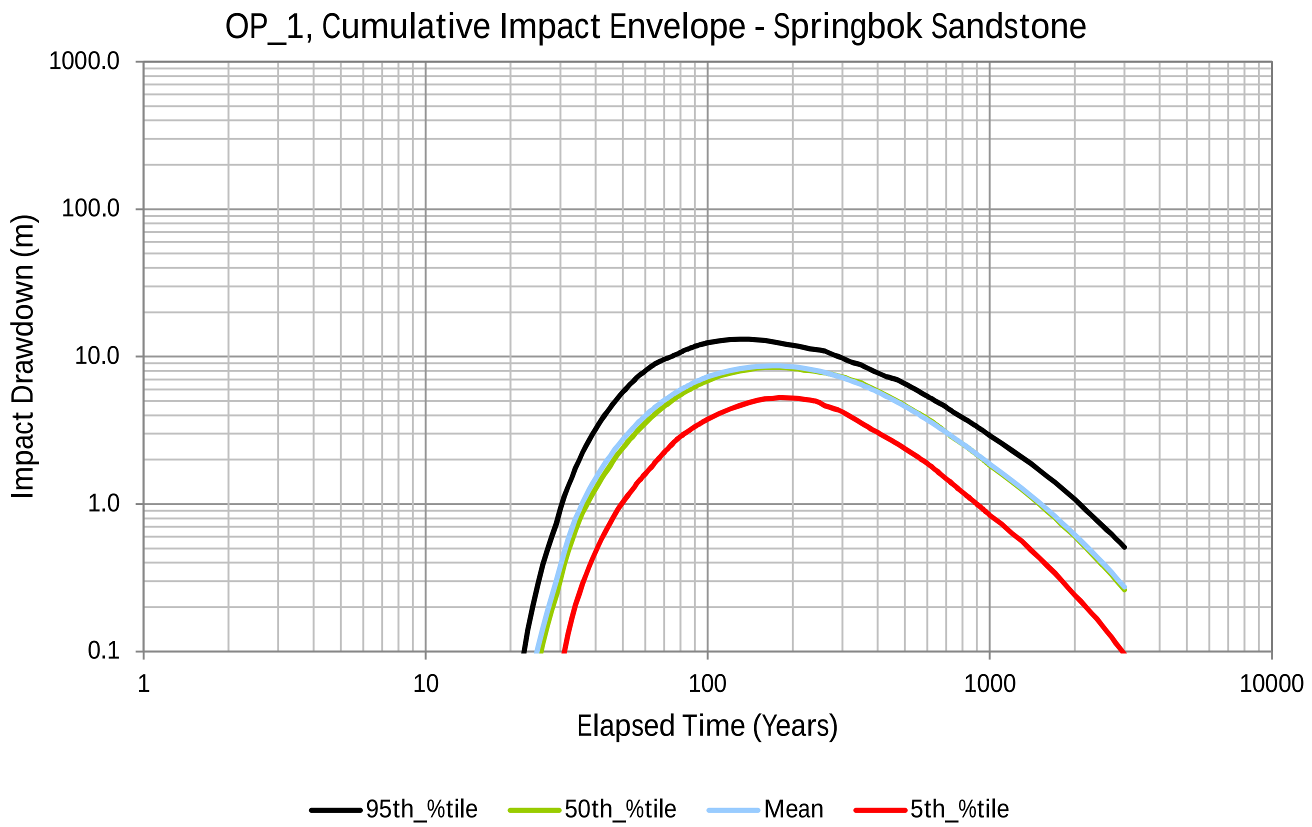


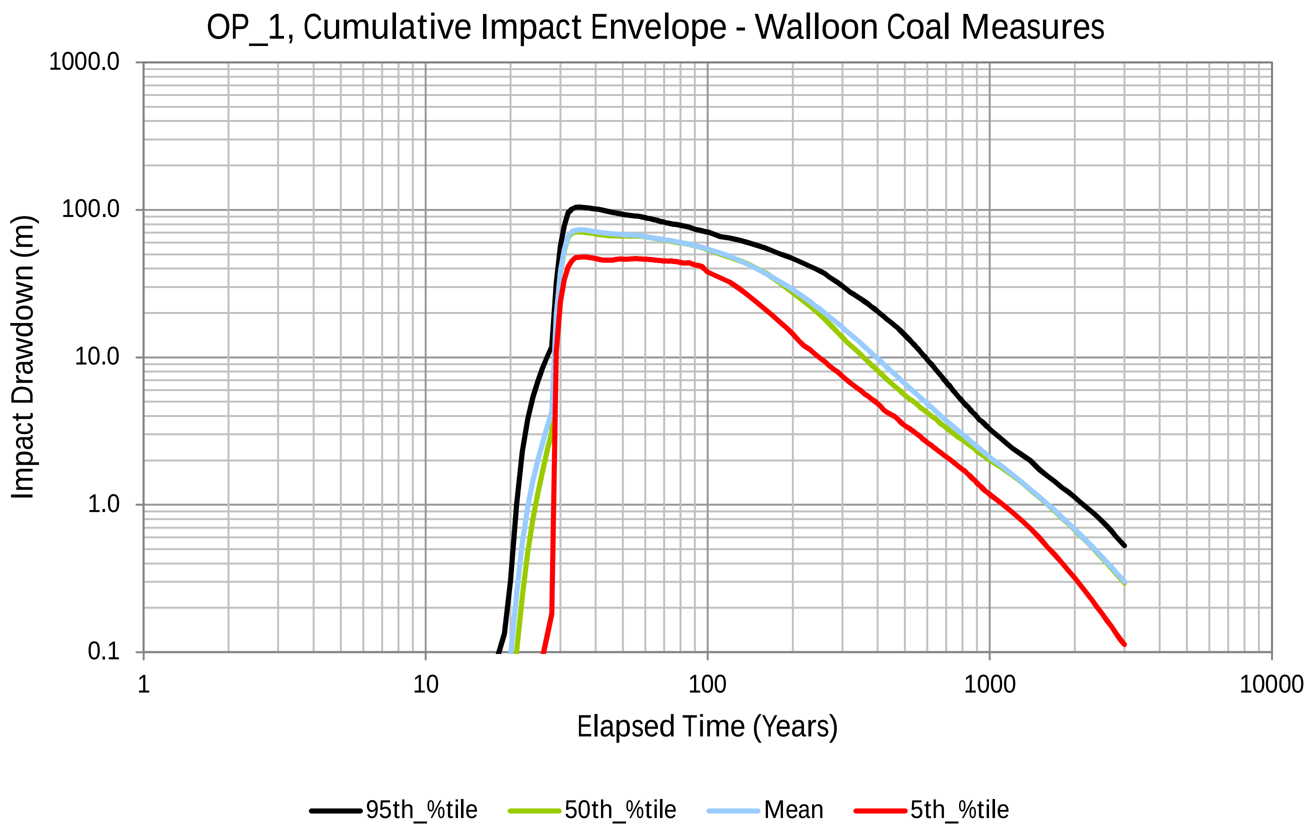
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



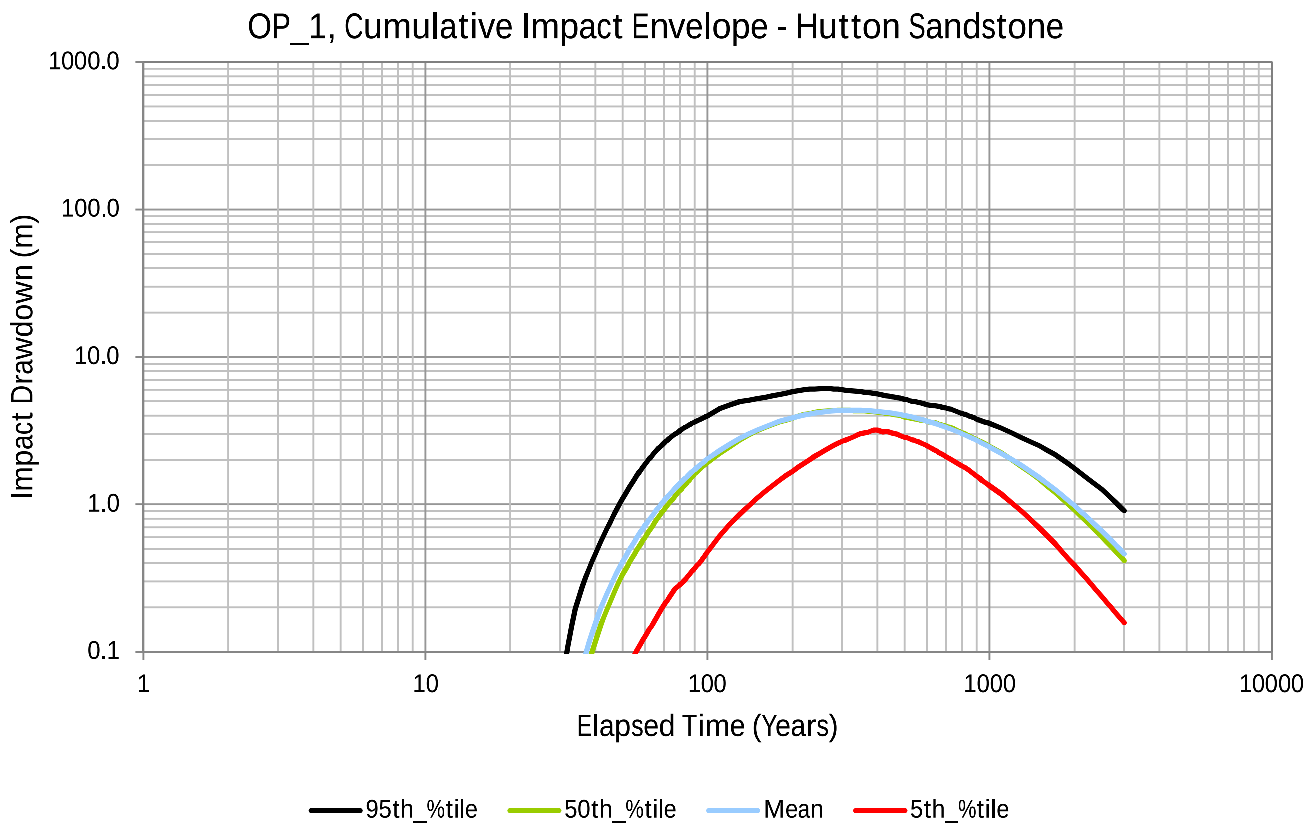


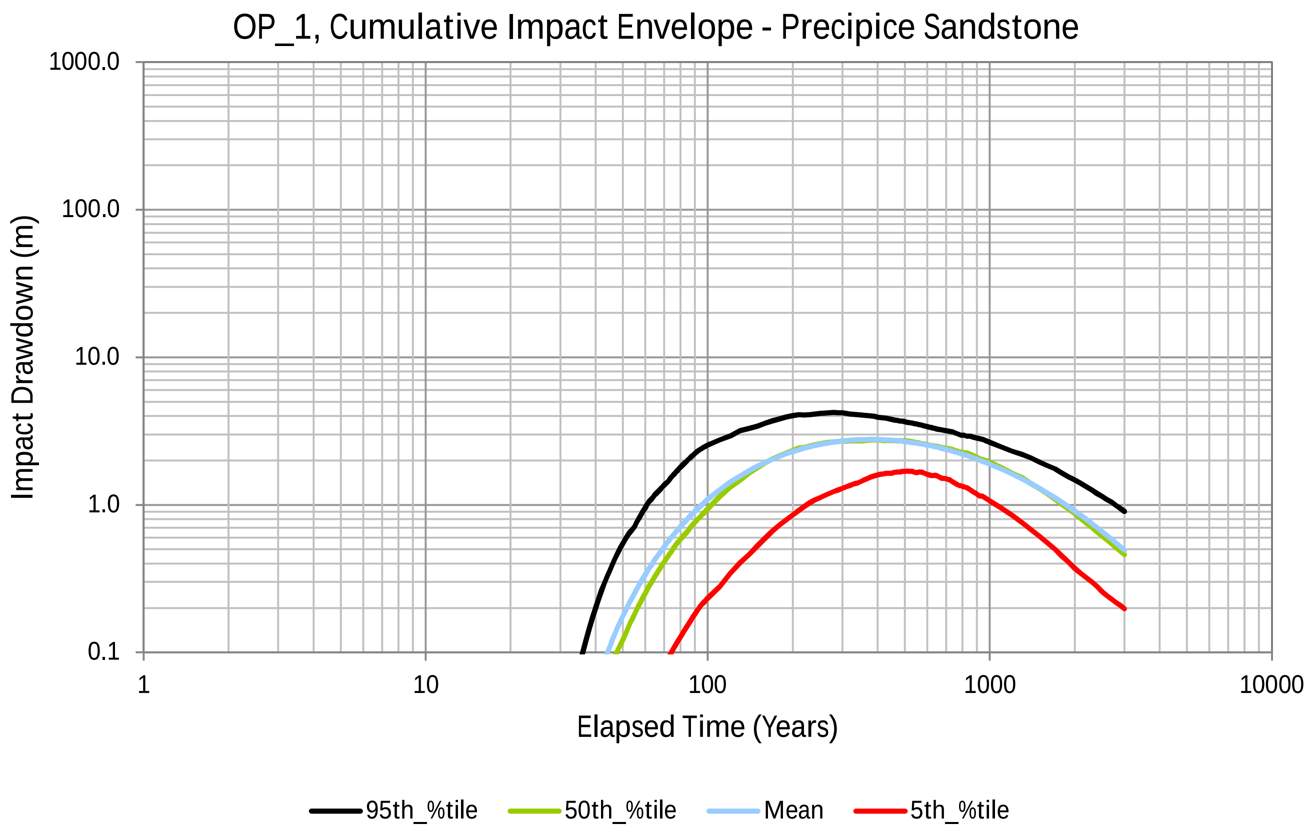
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



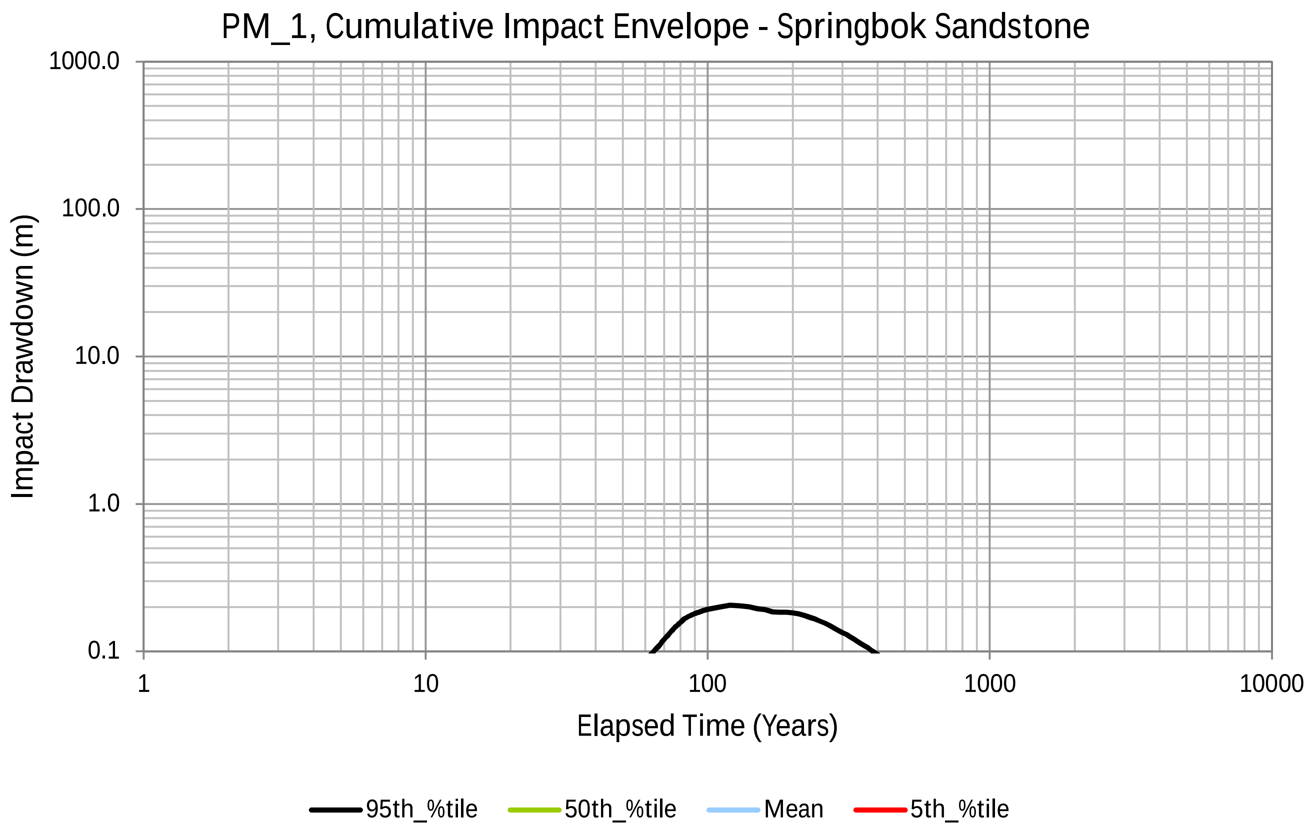


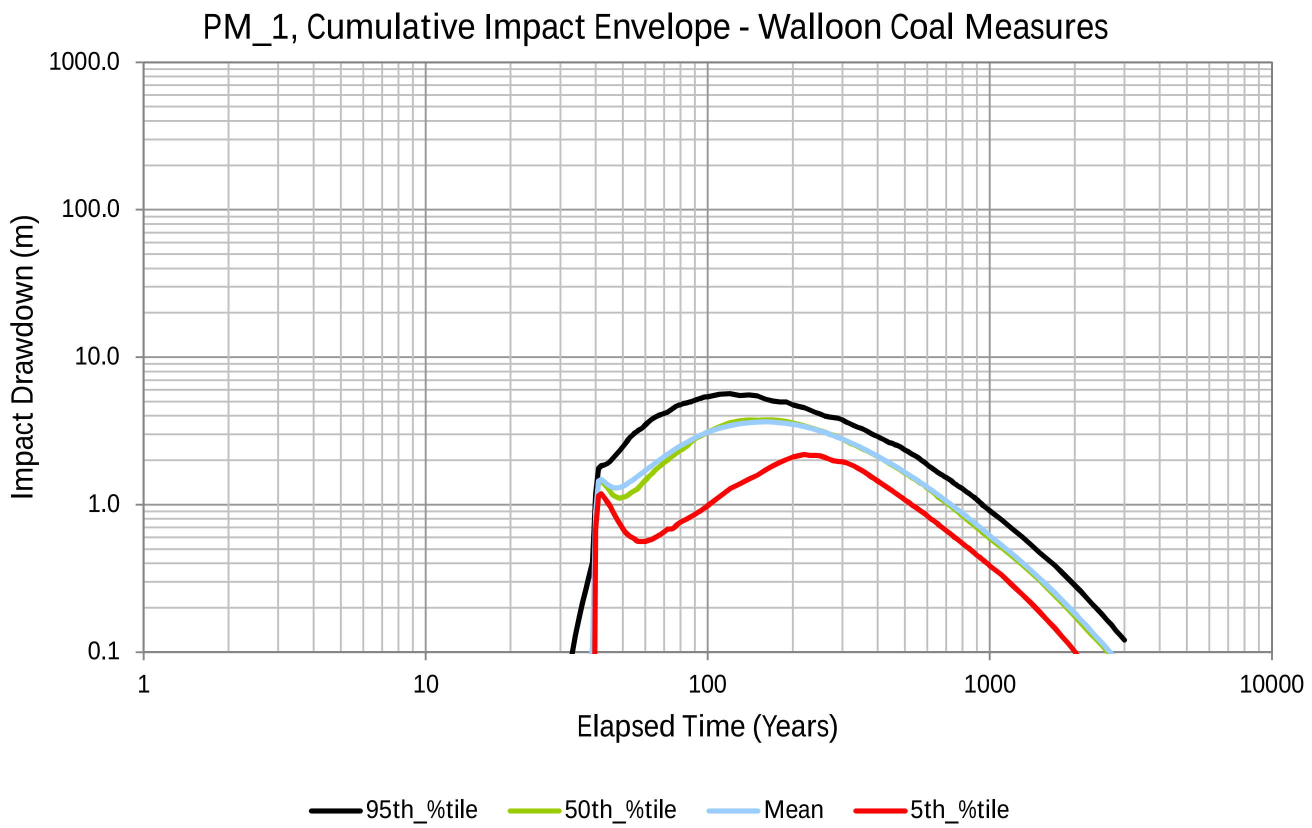
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



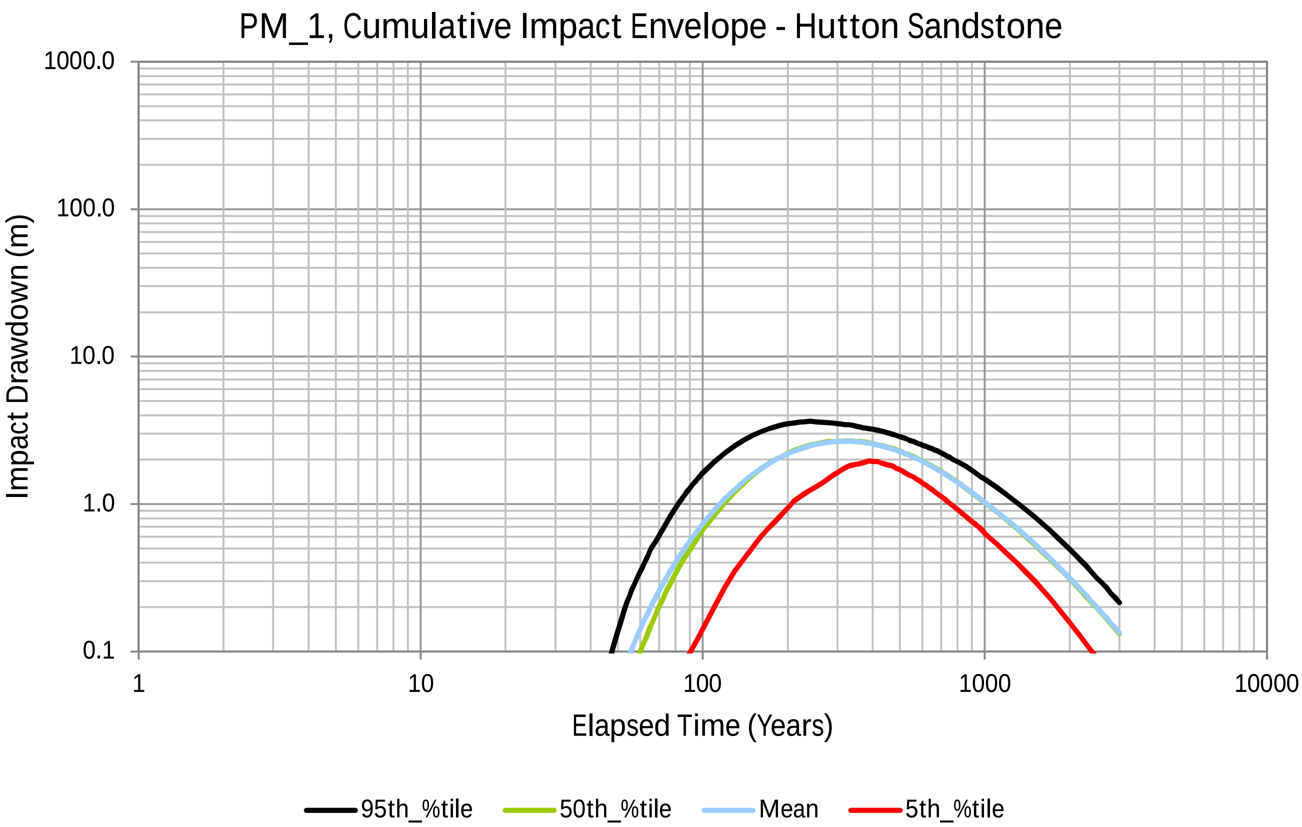


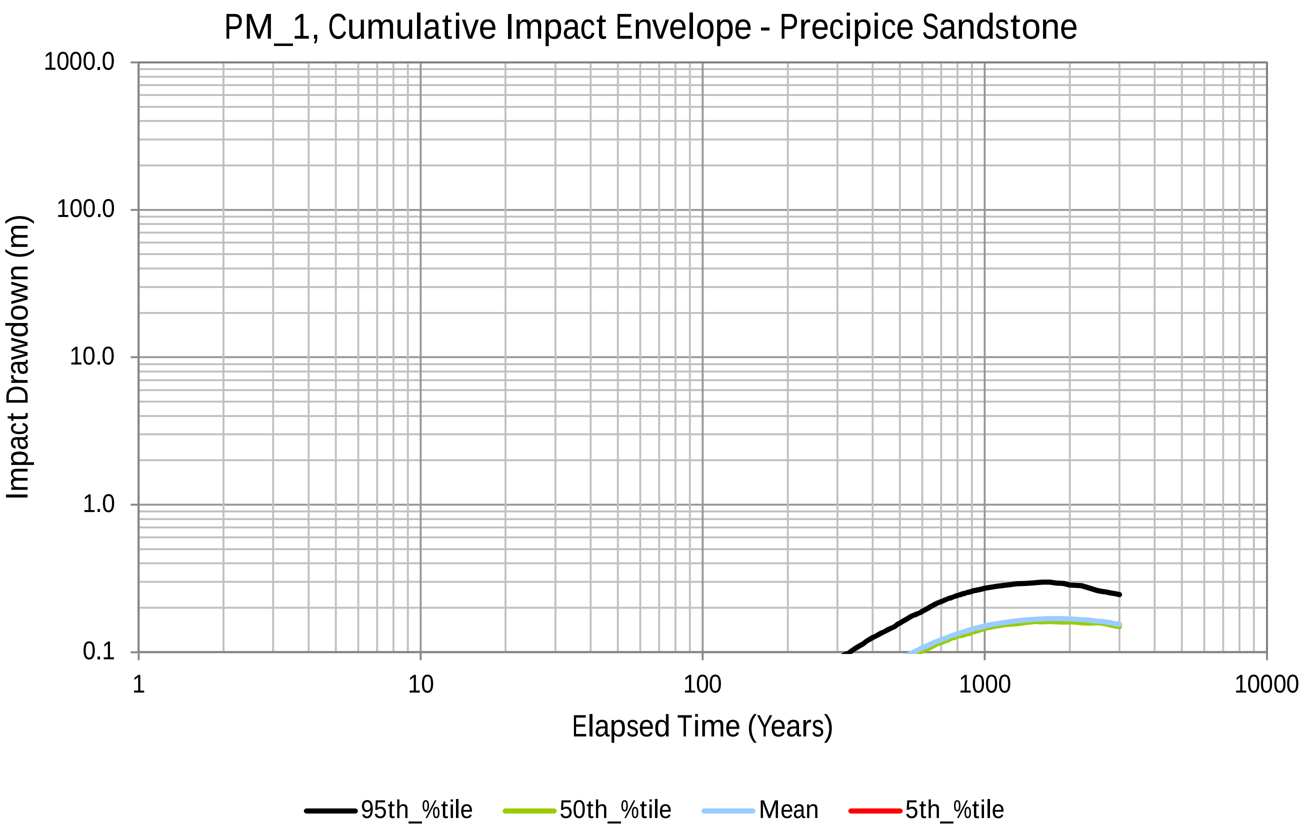
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



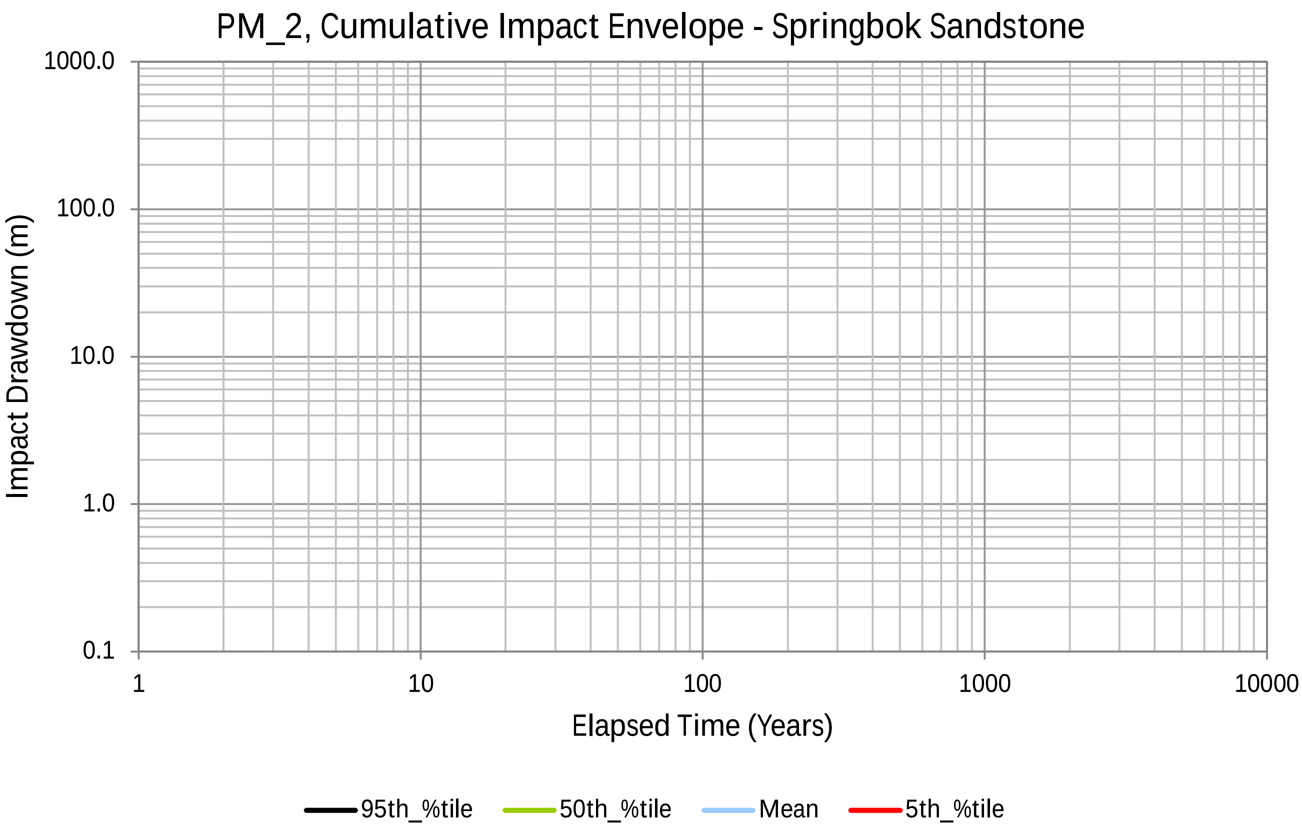


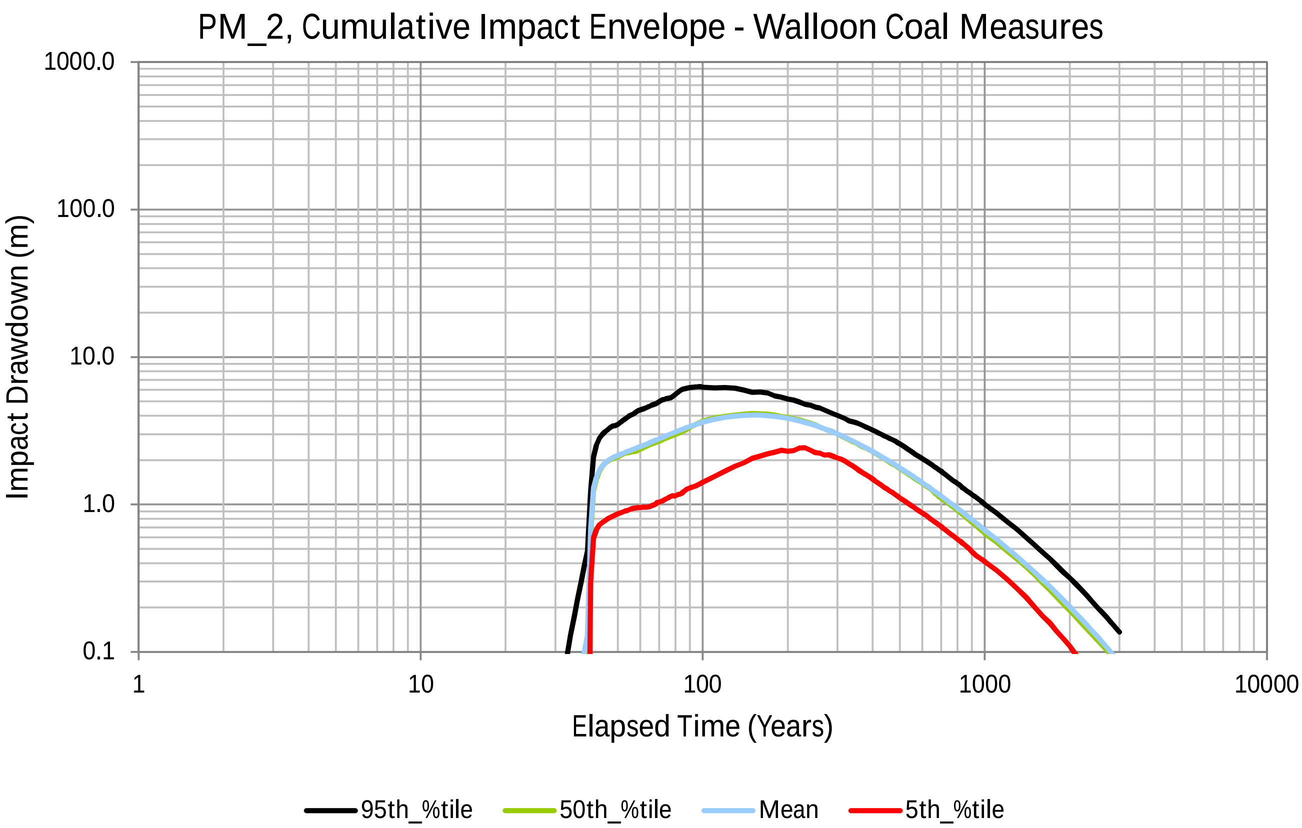
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



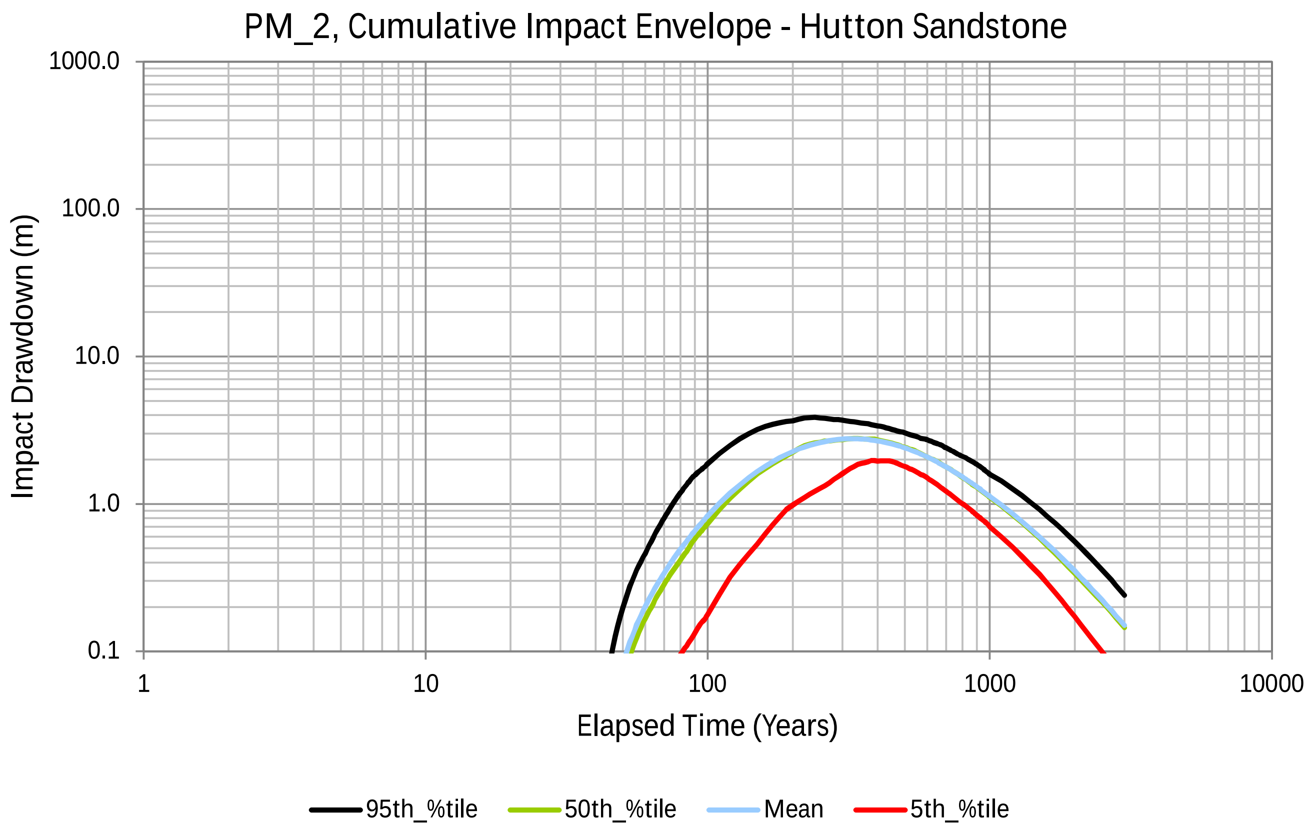


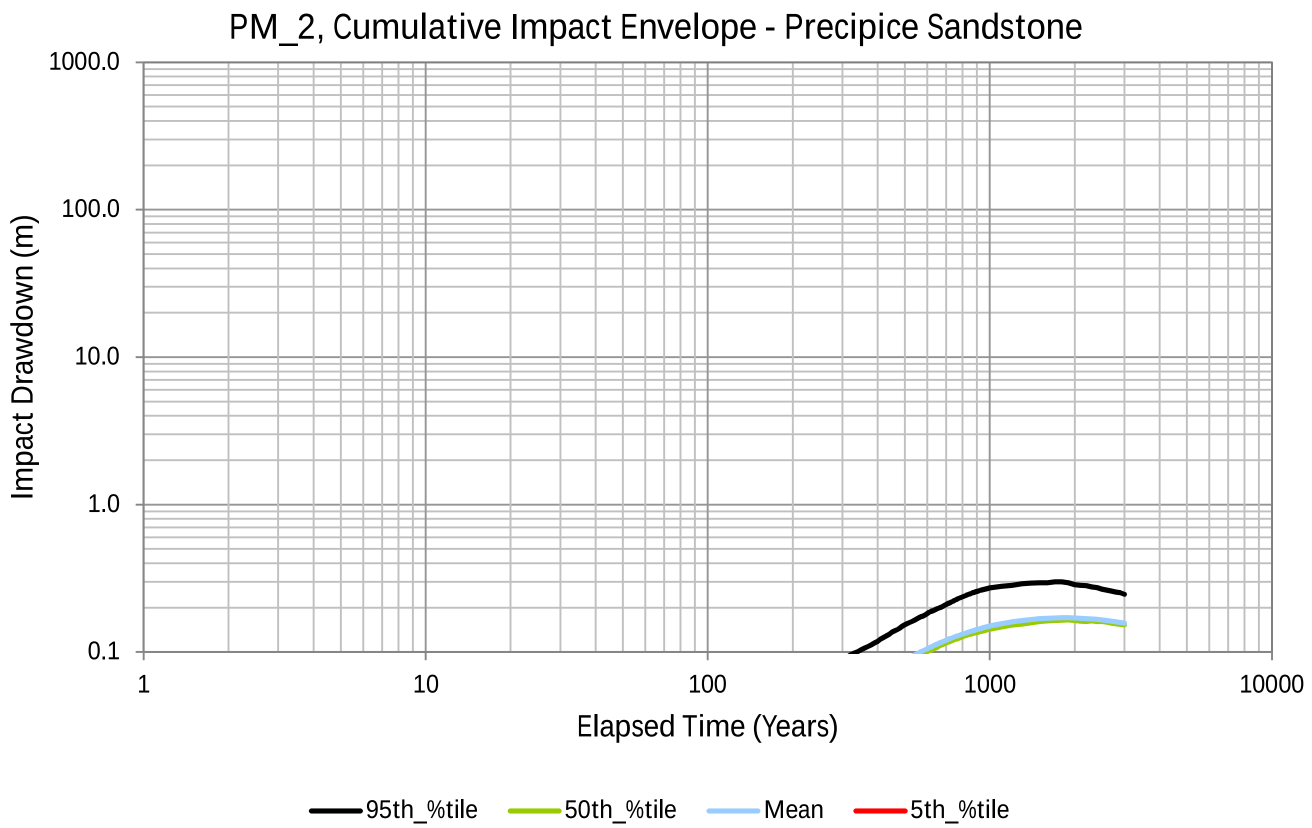
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



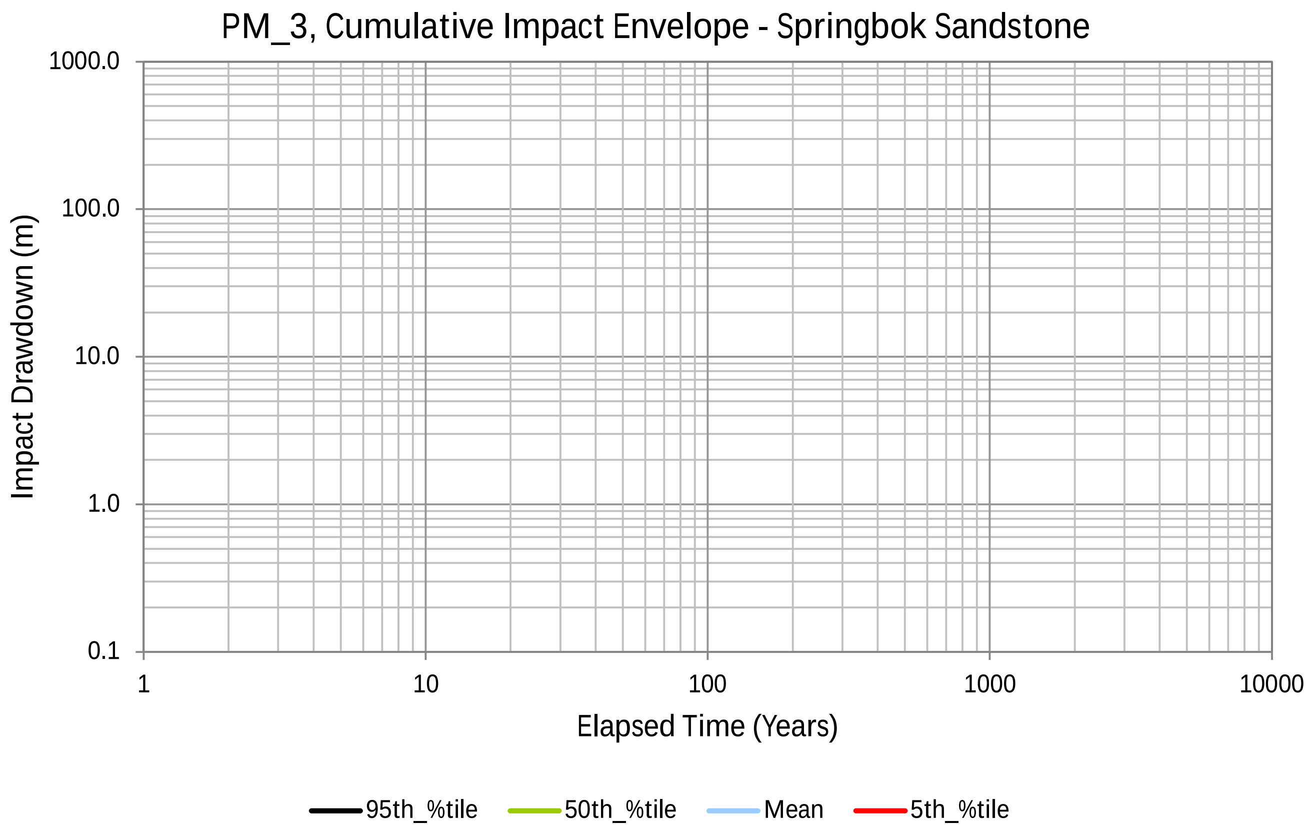


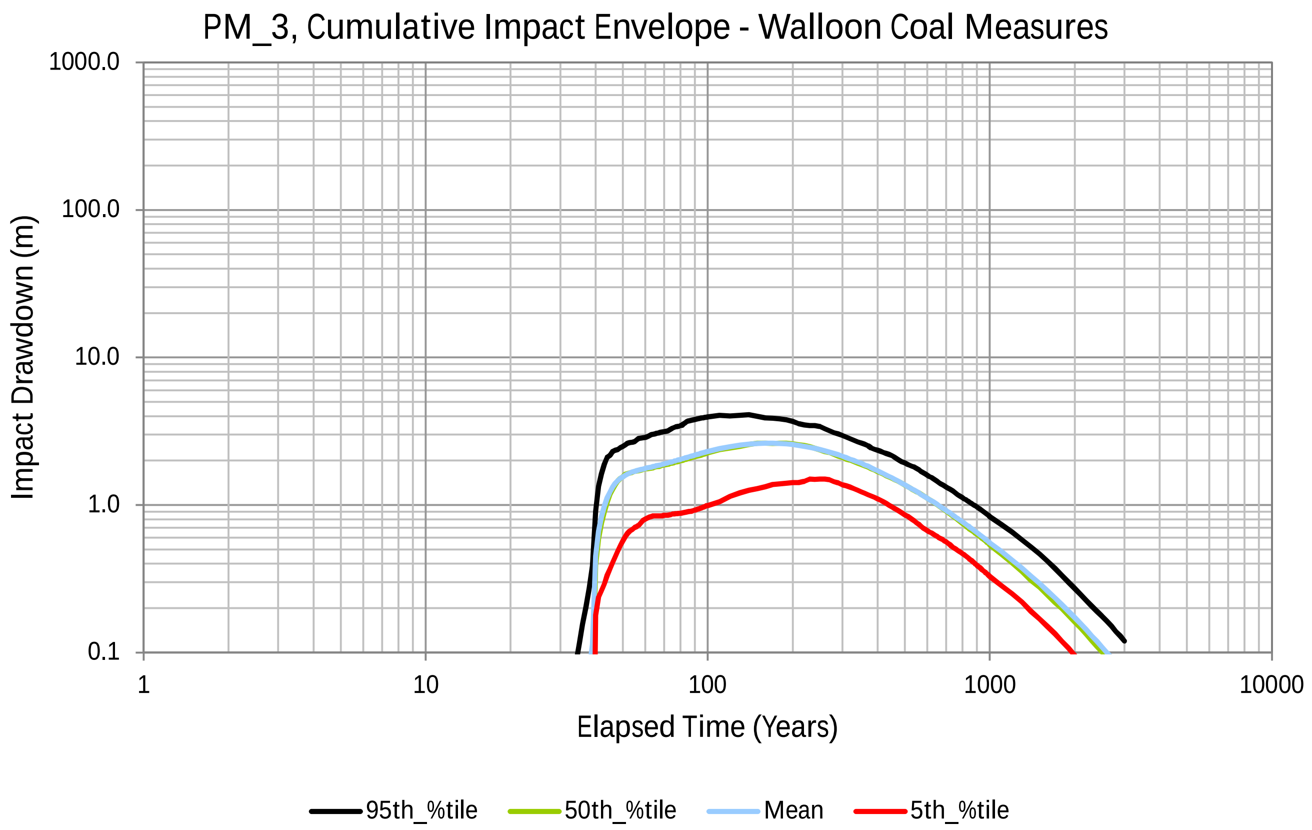
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



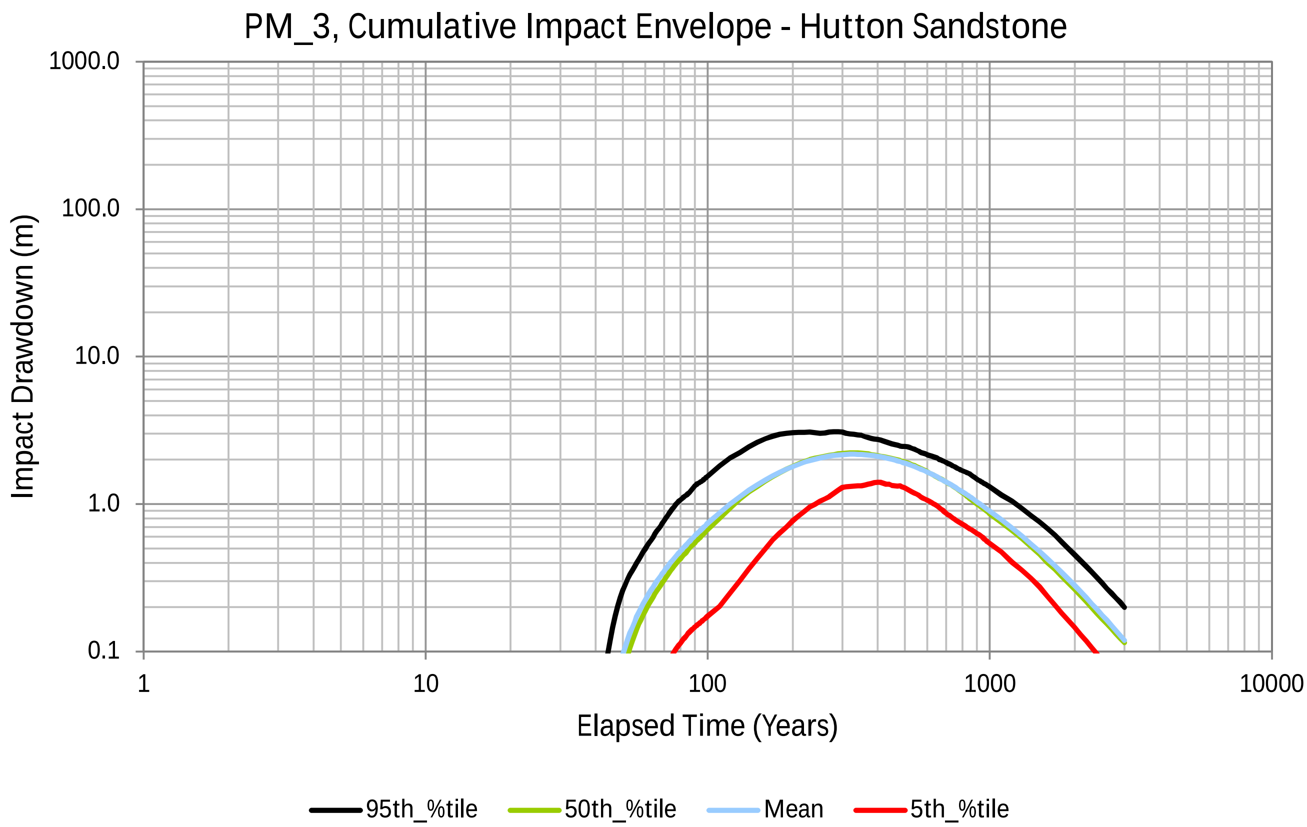


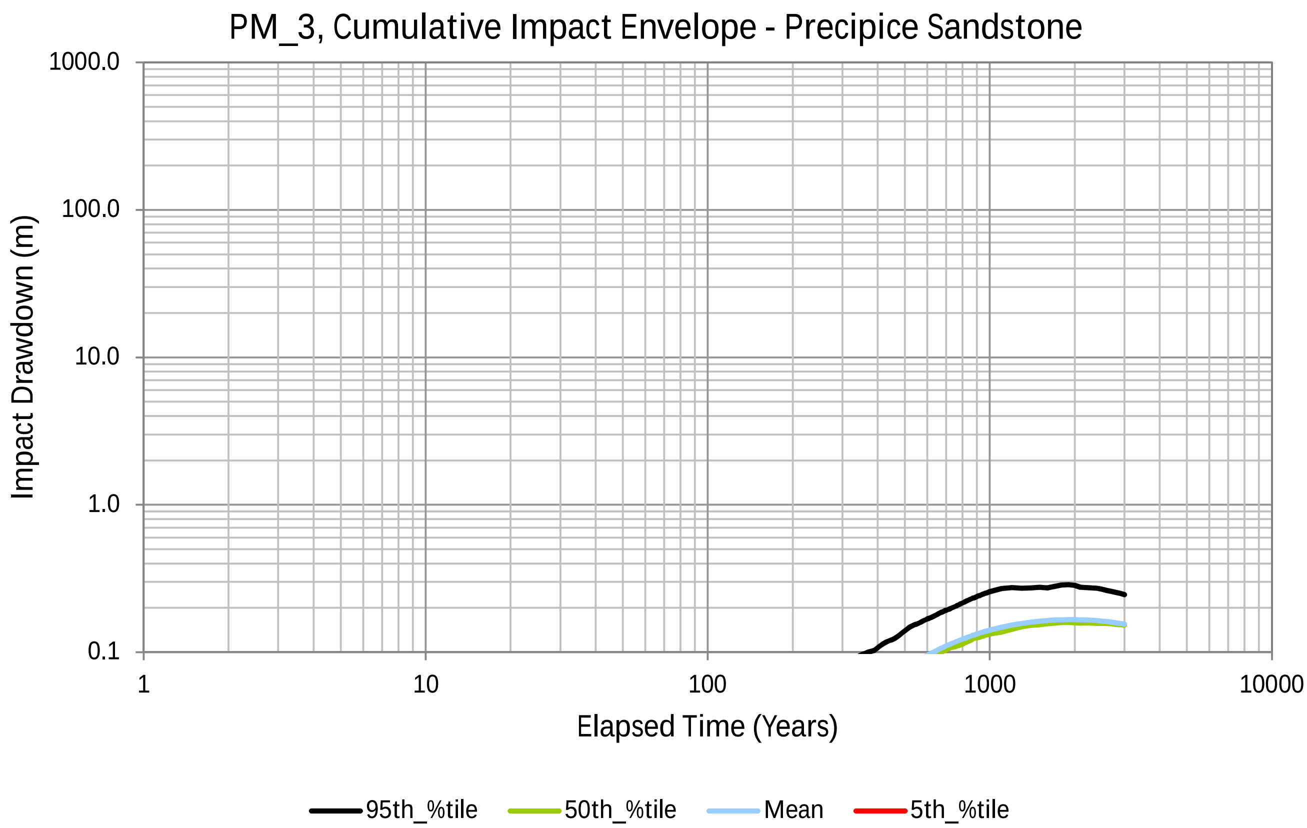
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



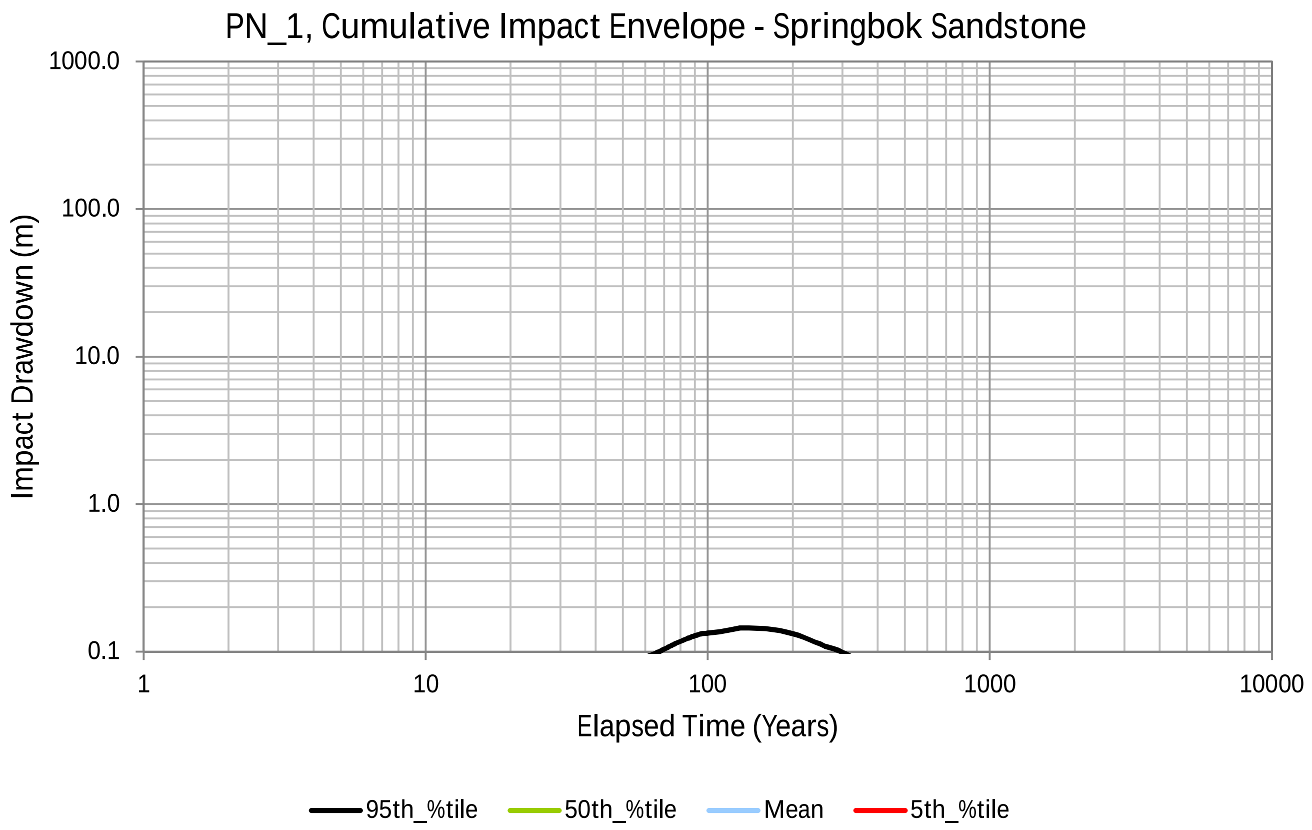


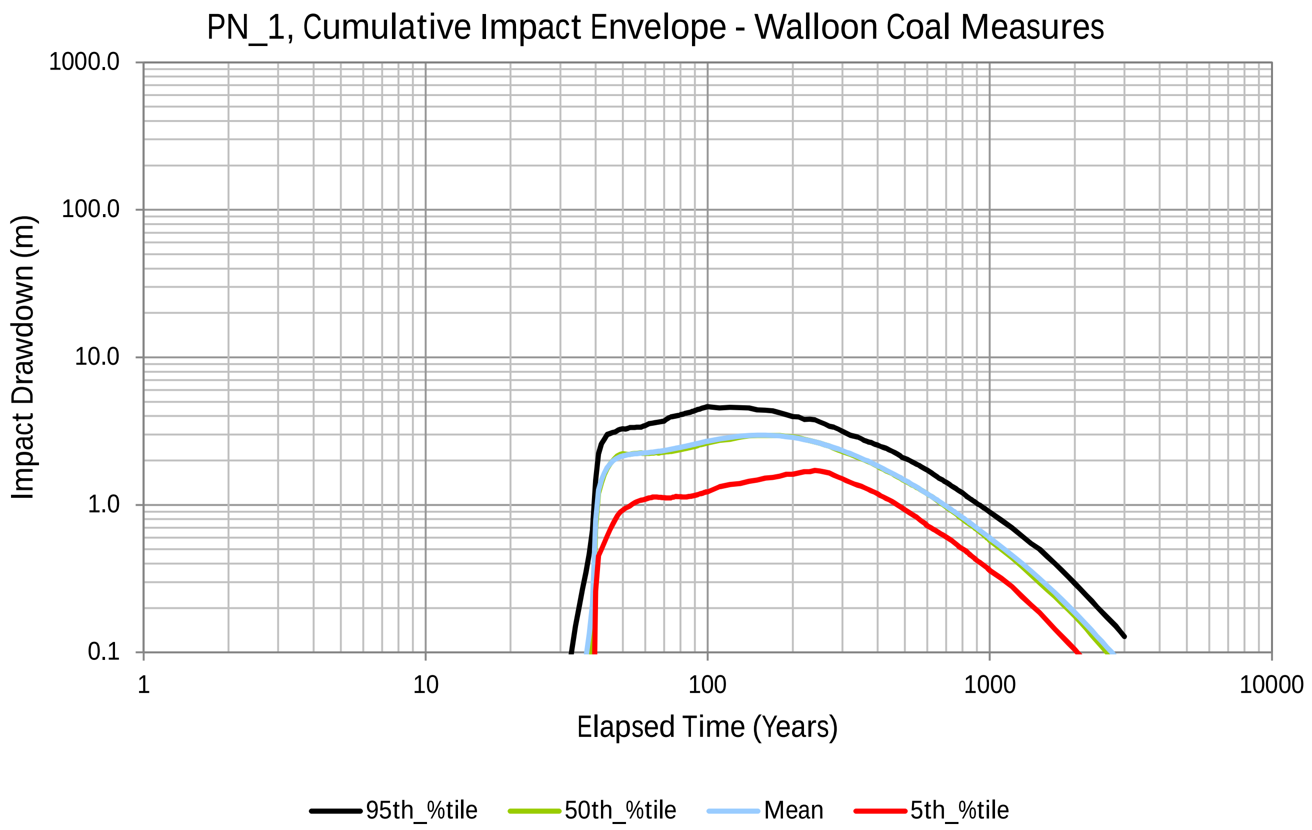
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



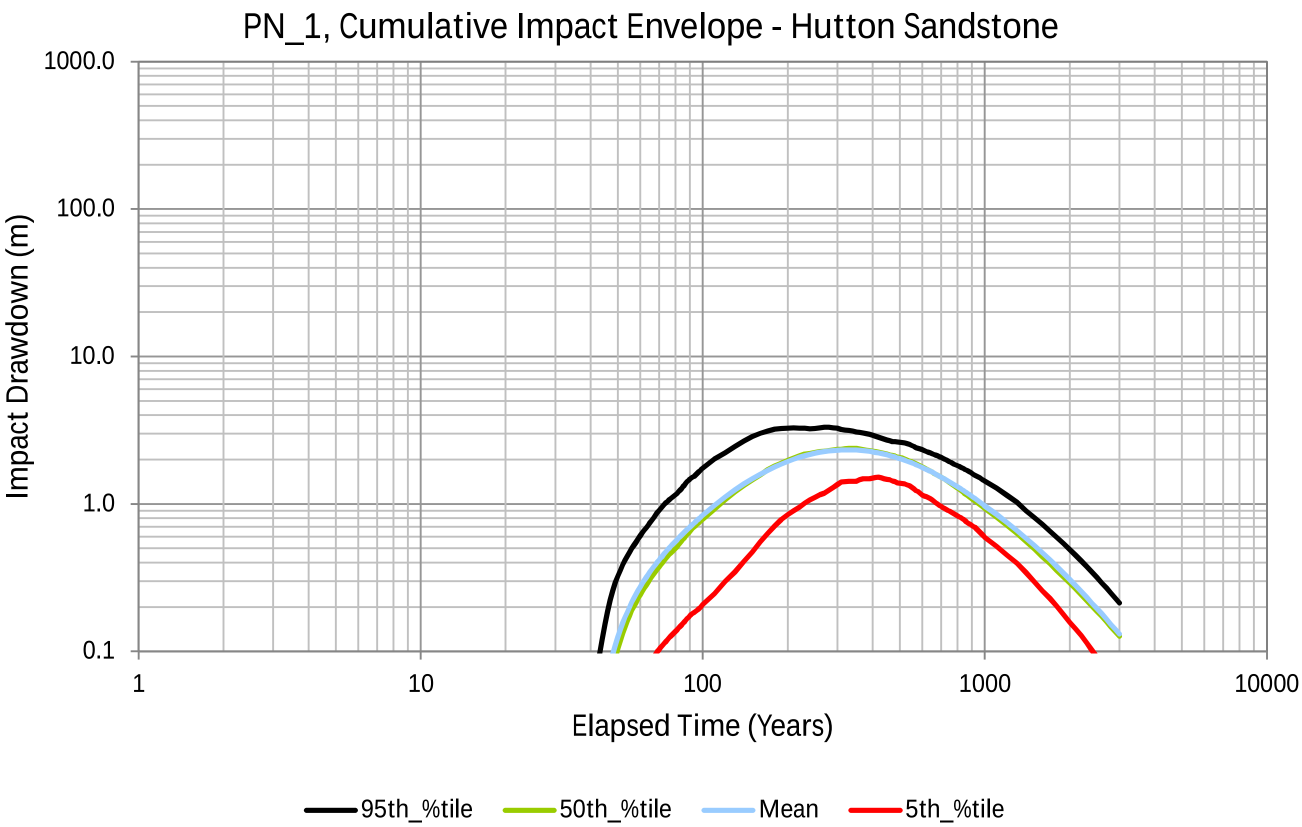


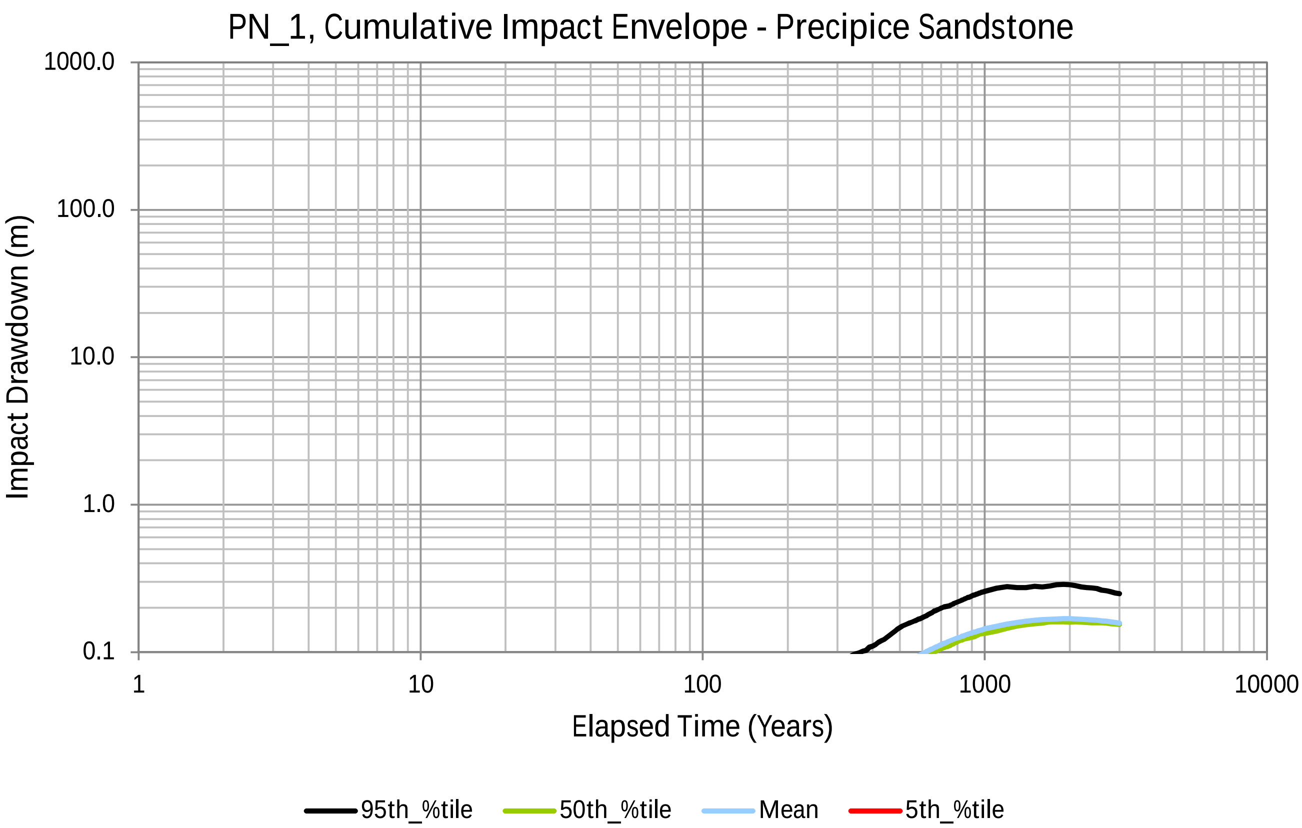
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



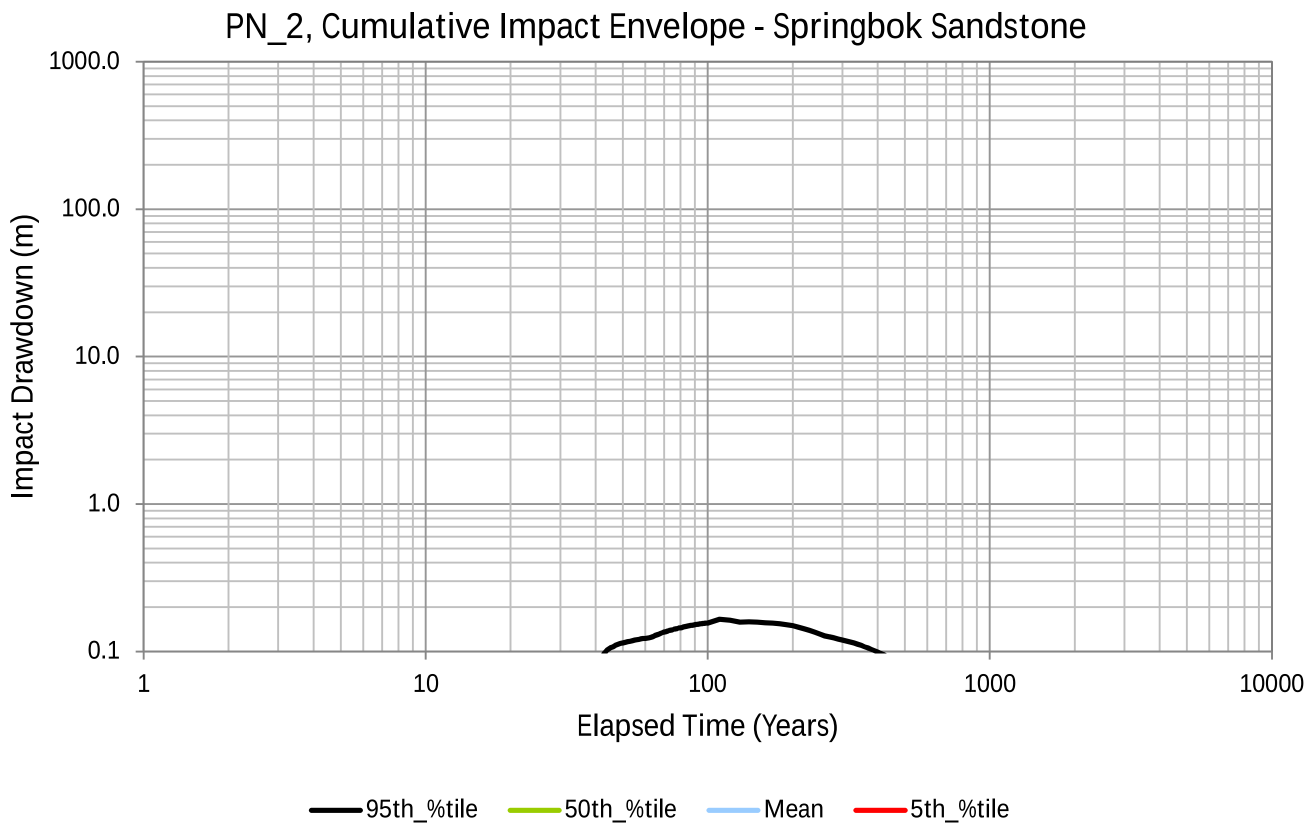


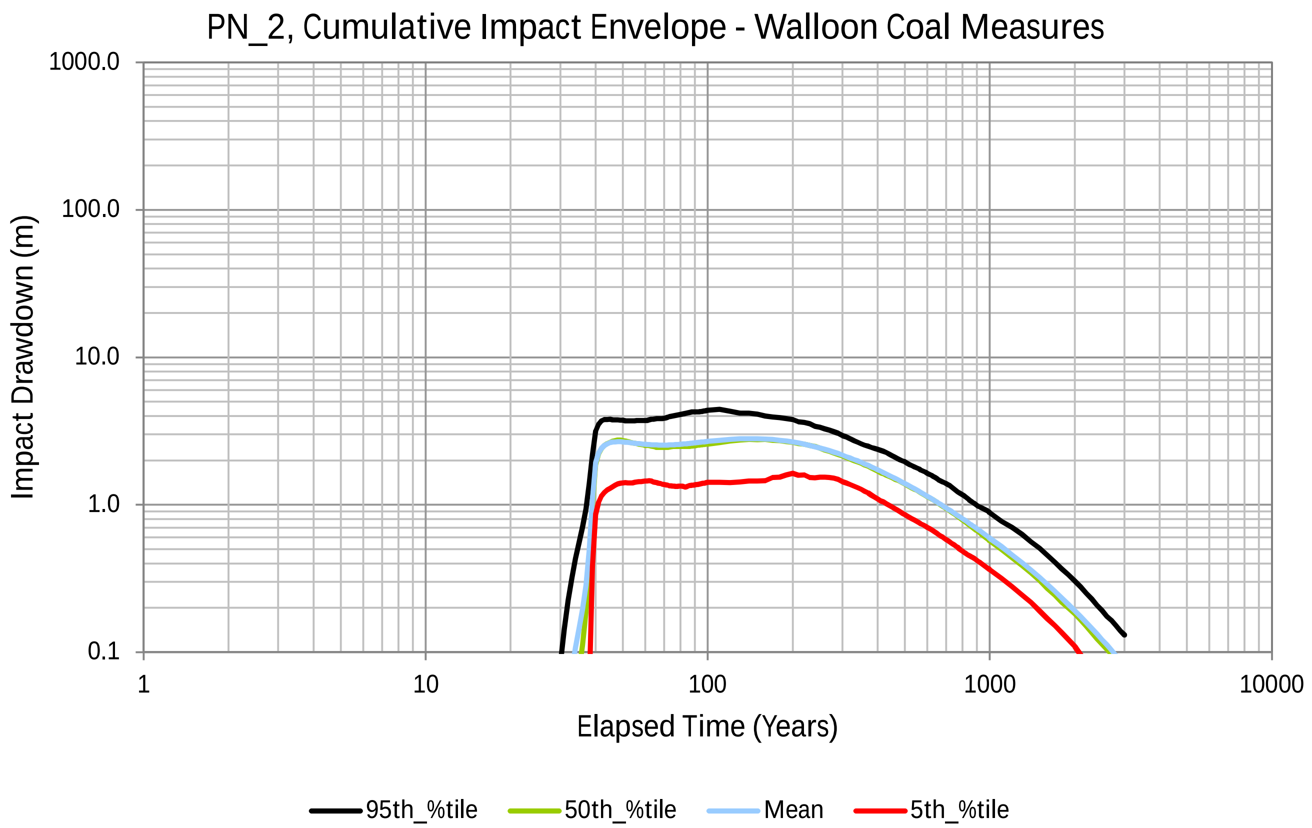
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



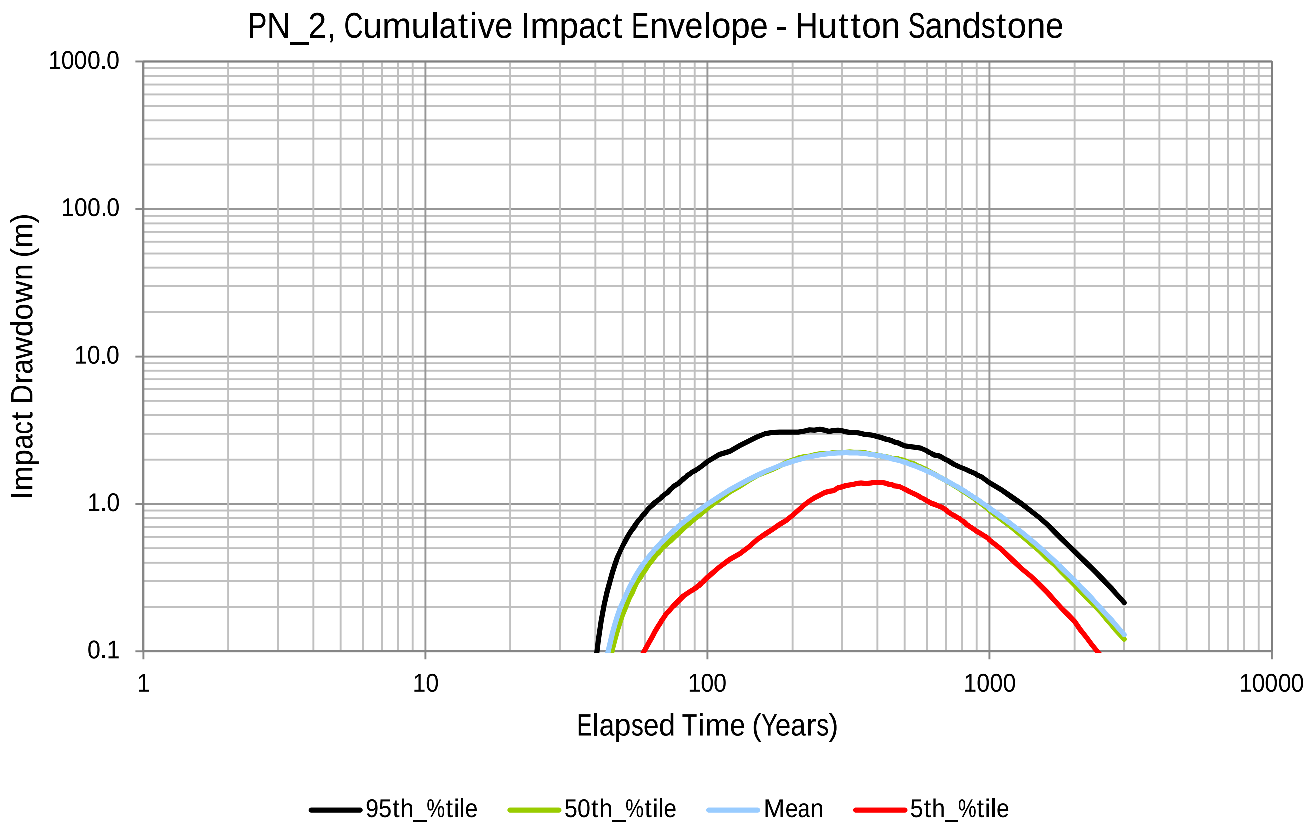


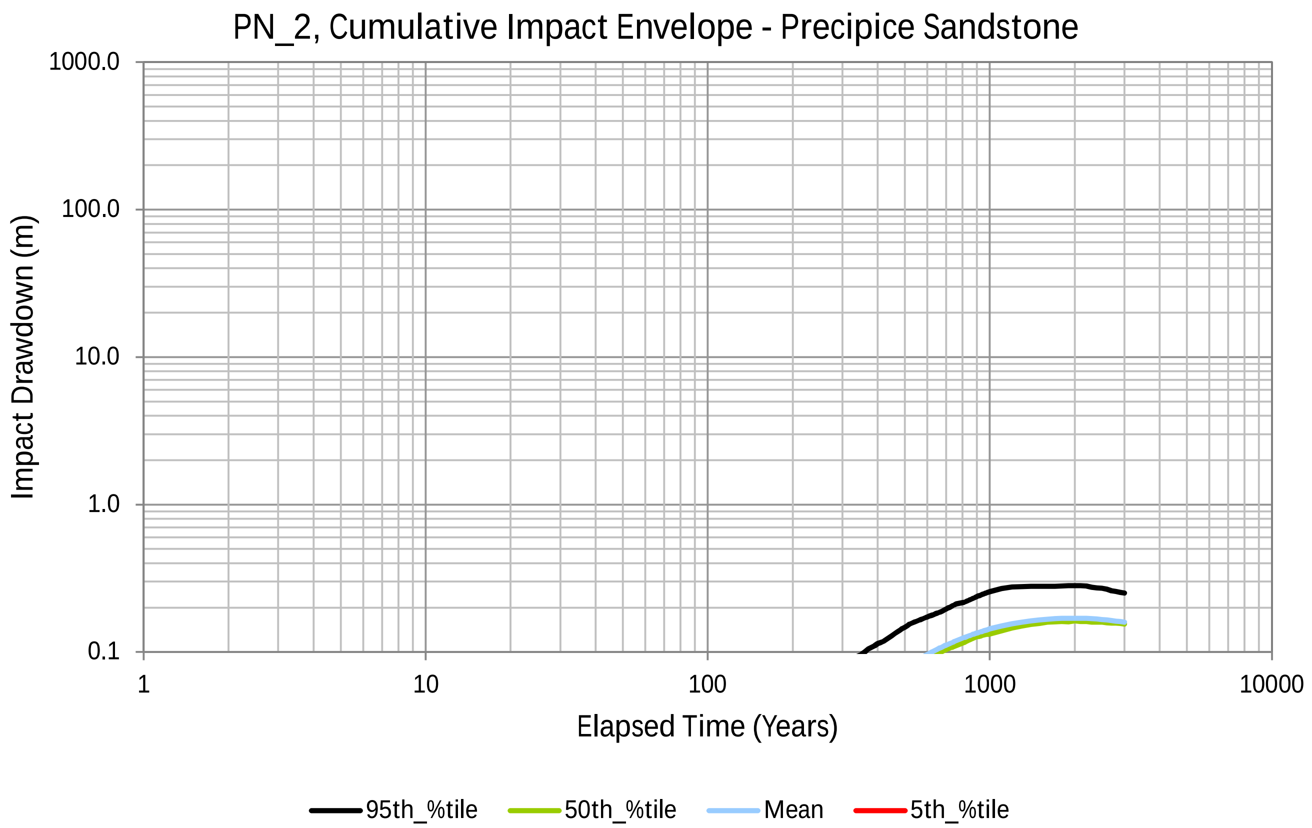
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



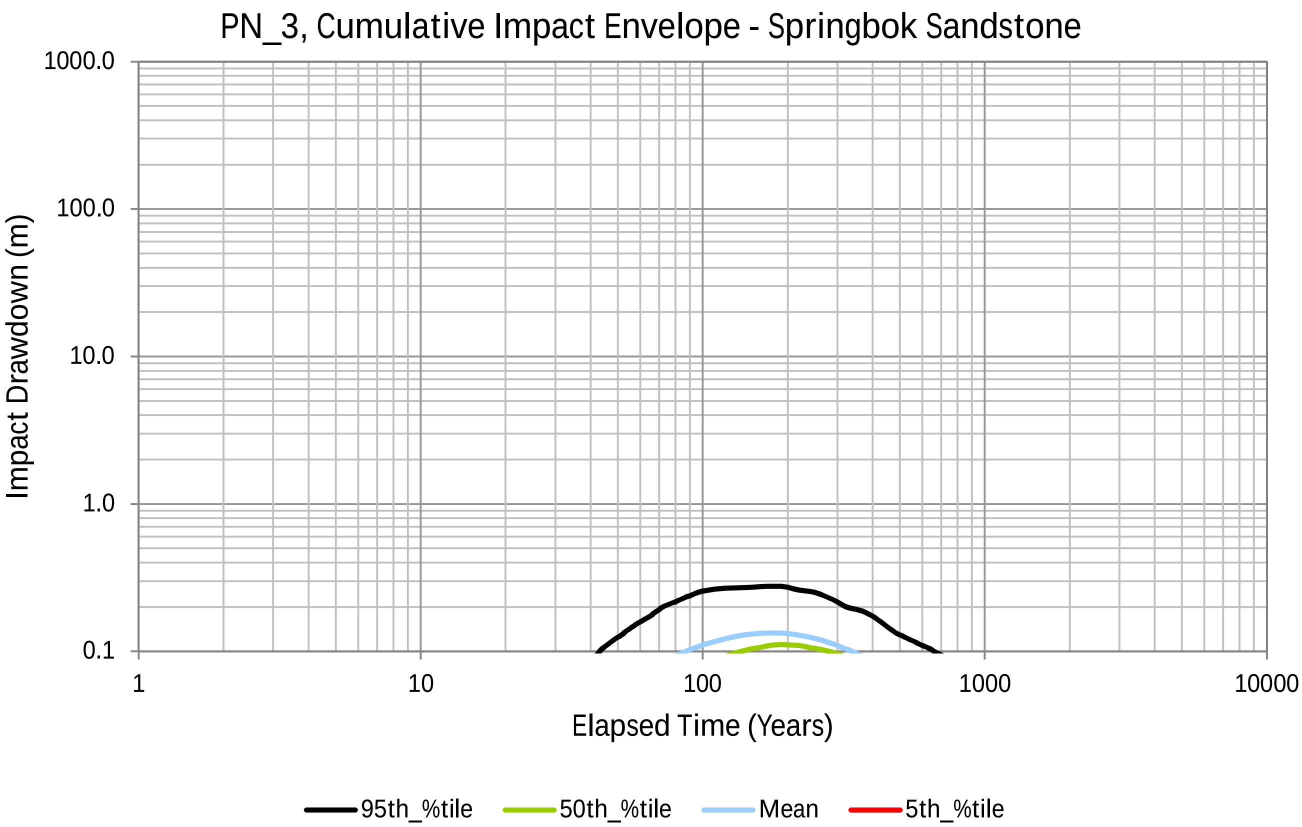


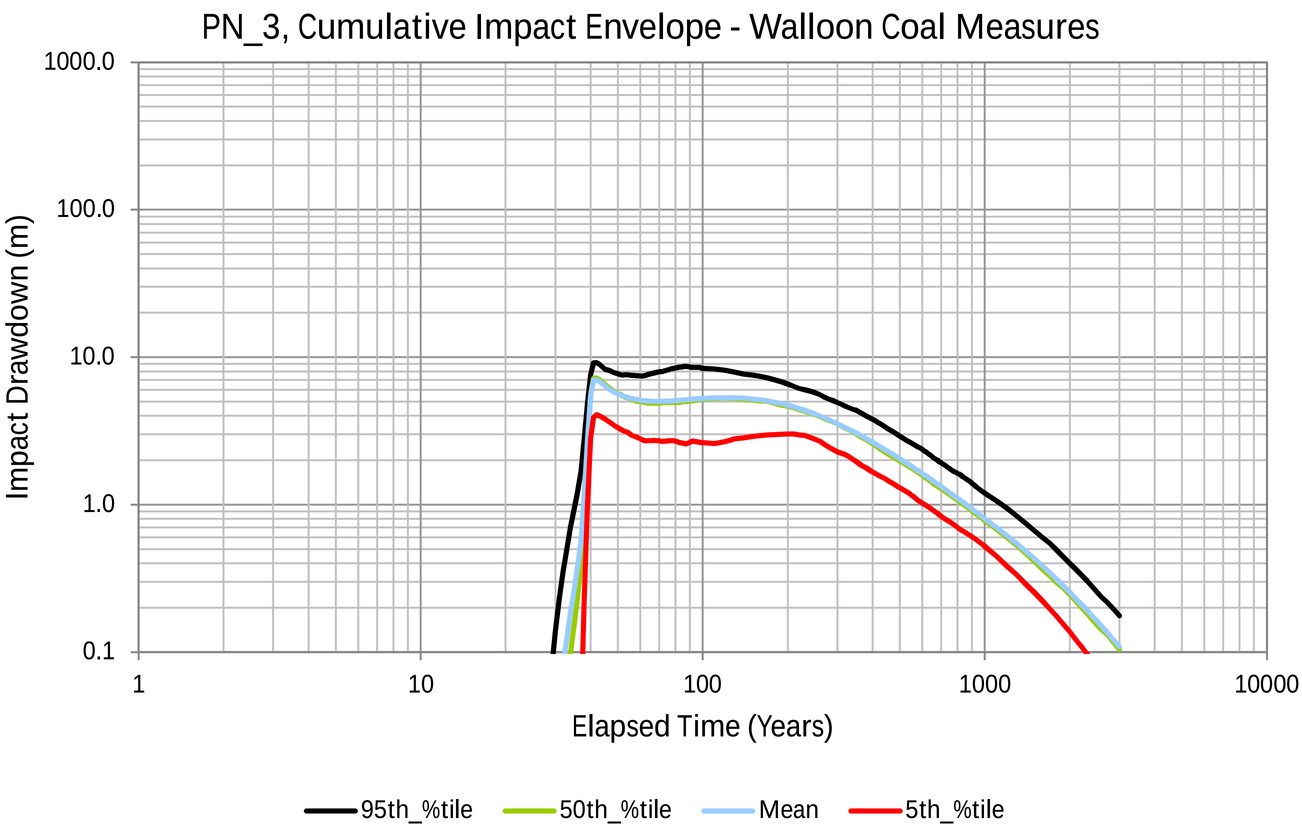
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



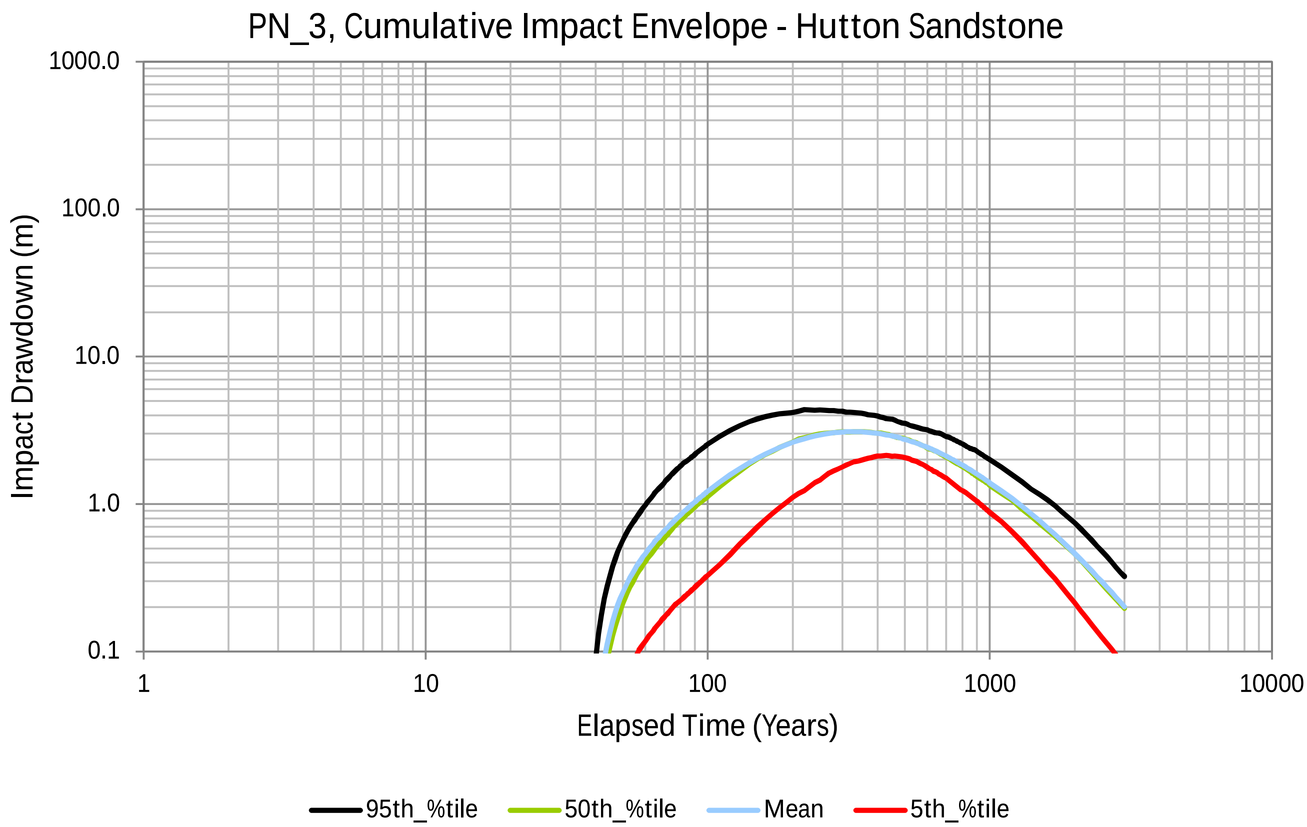


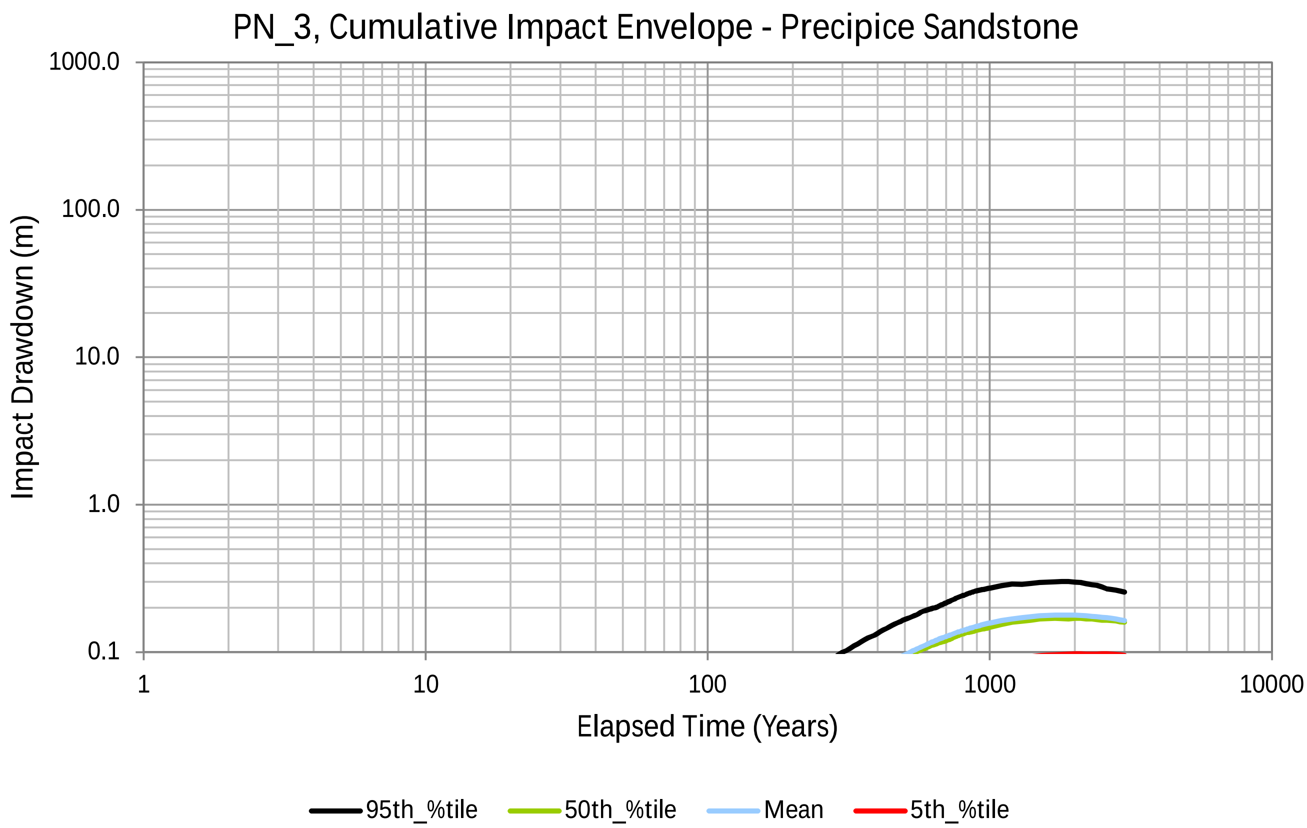
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



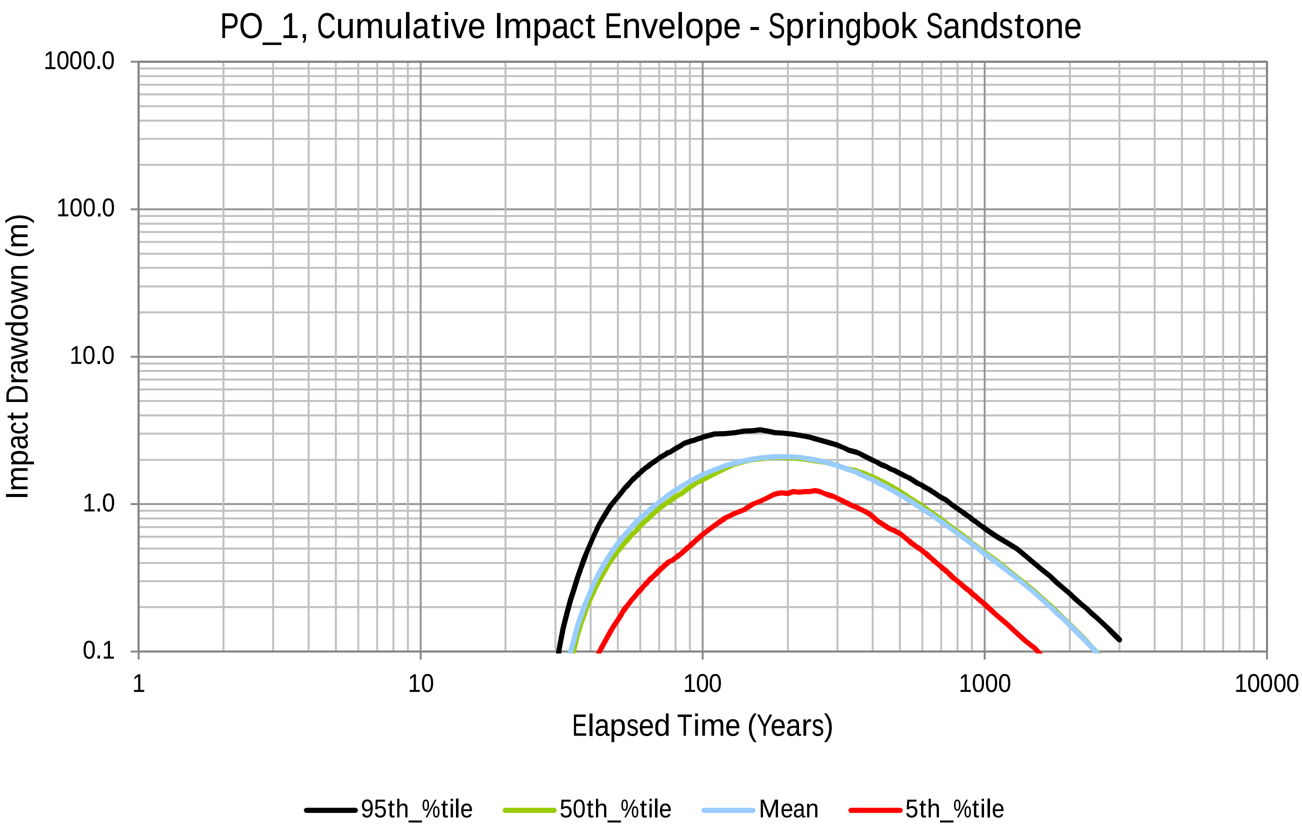


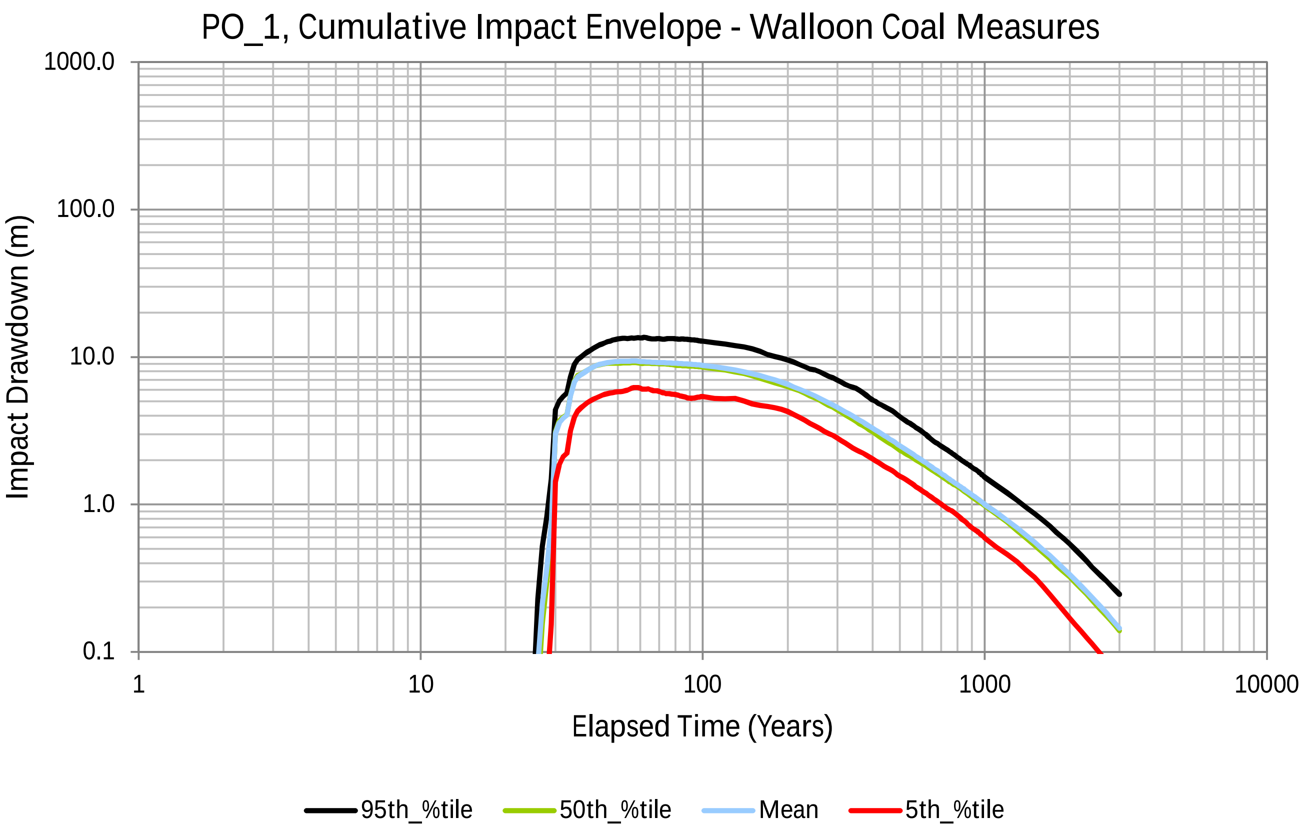
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



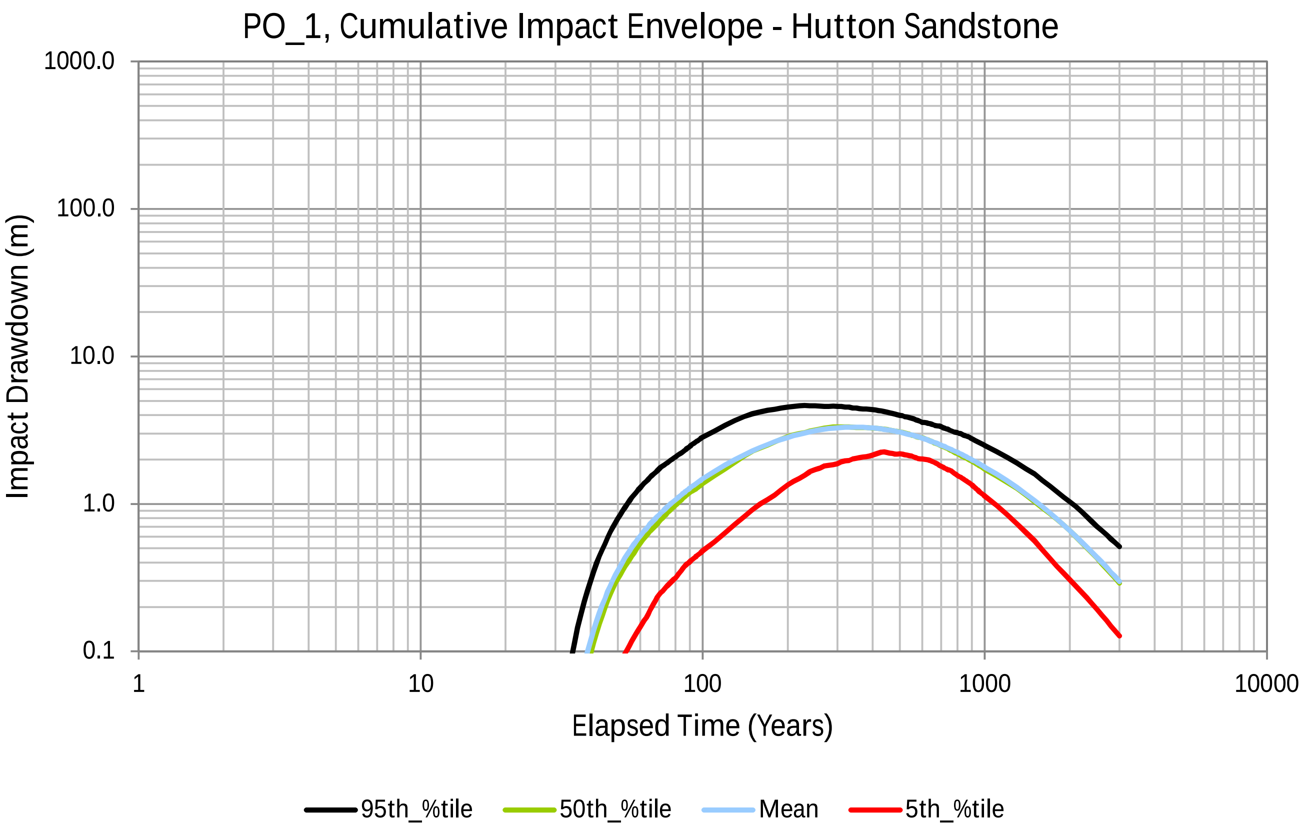


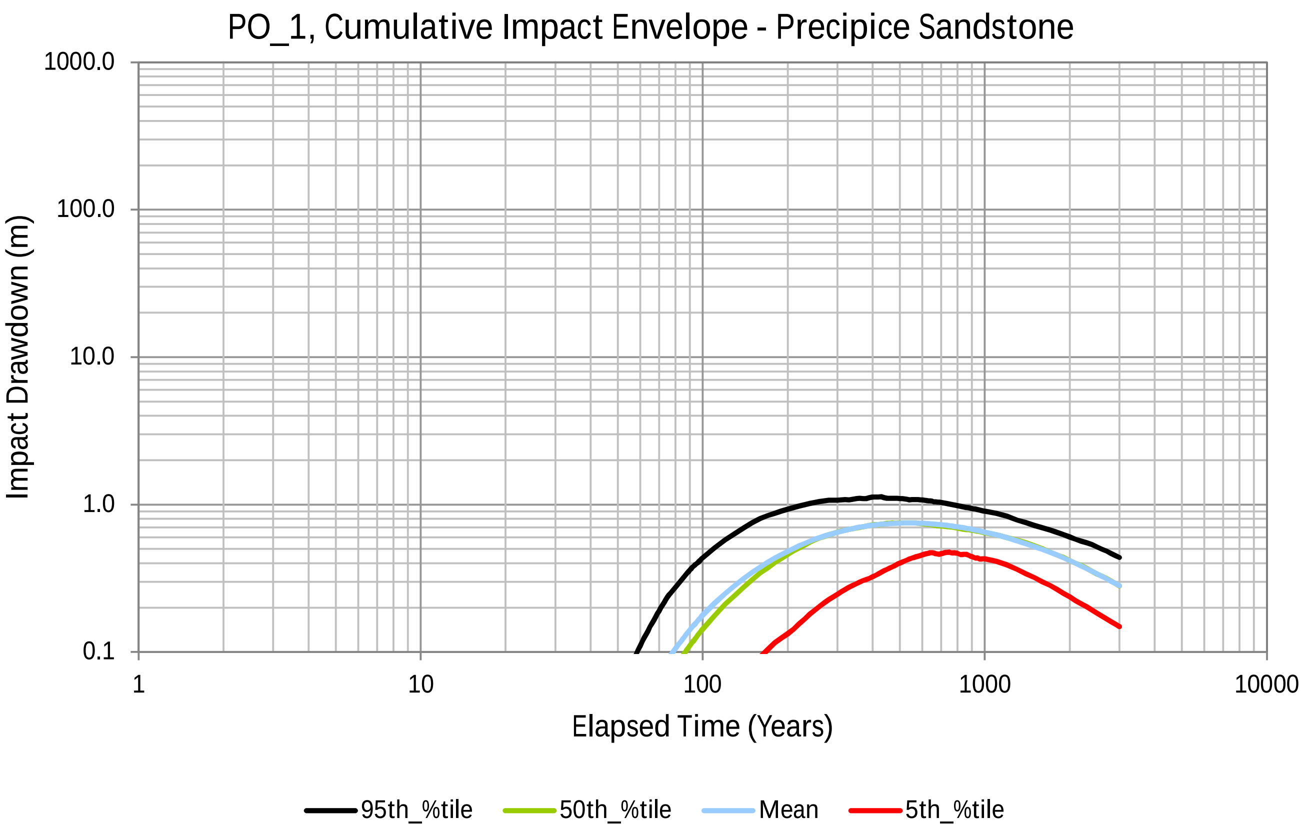
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5





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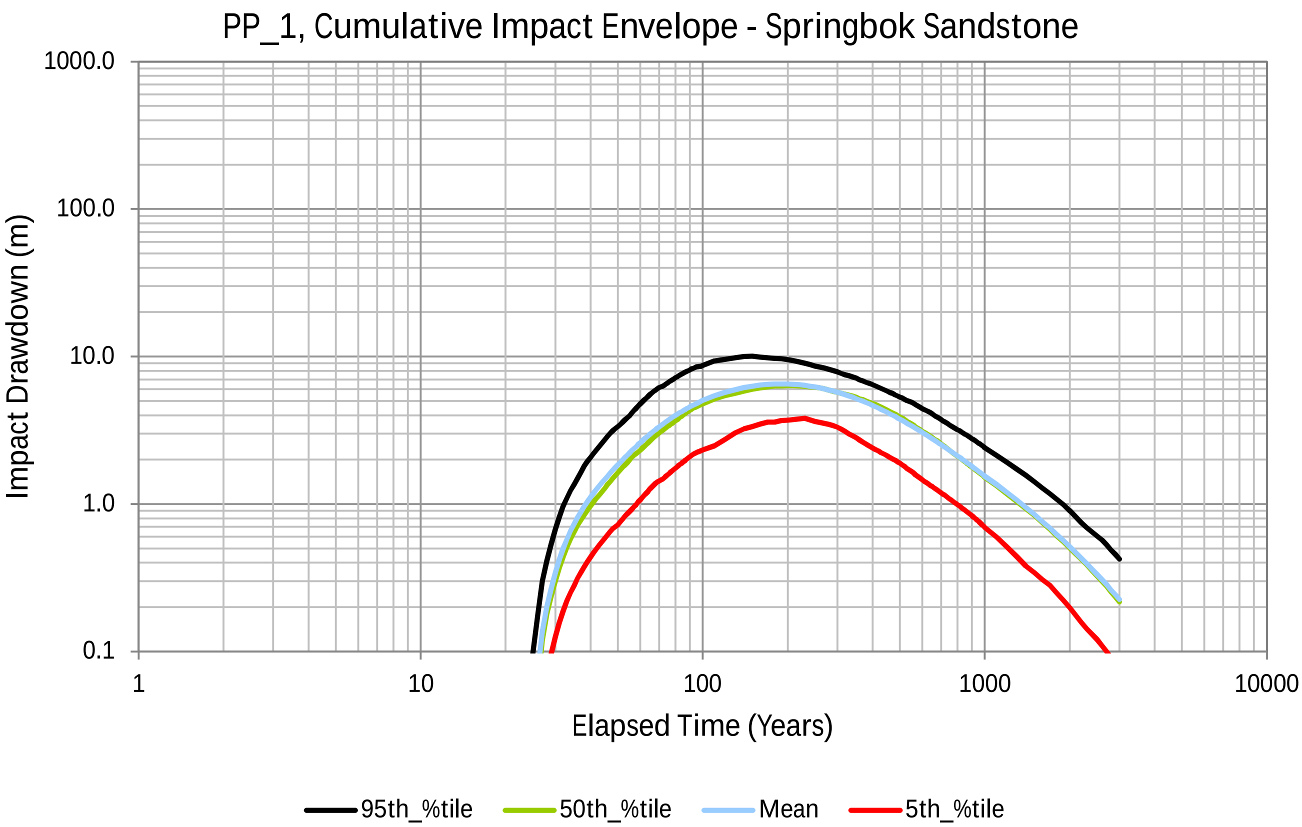
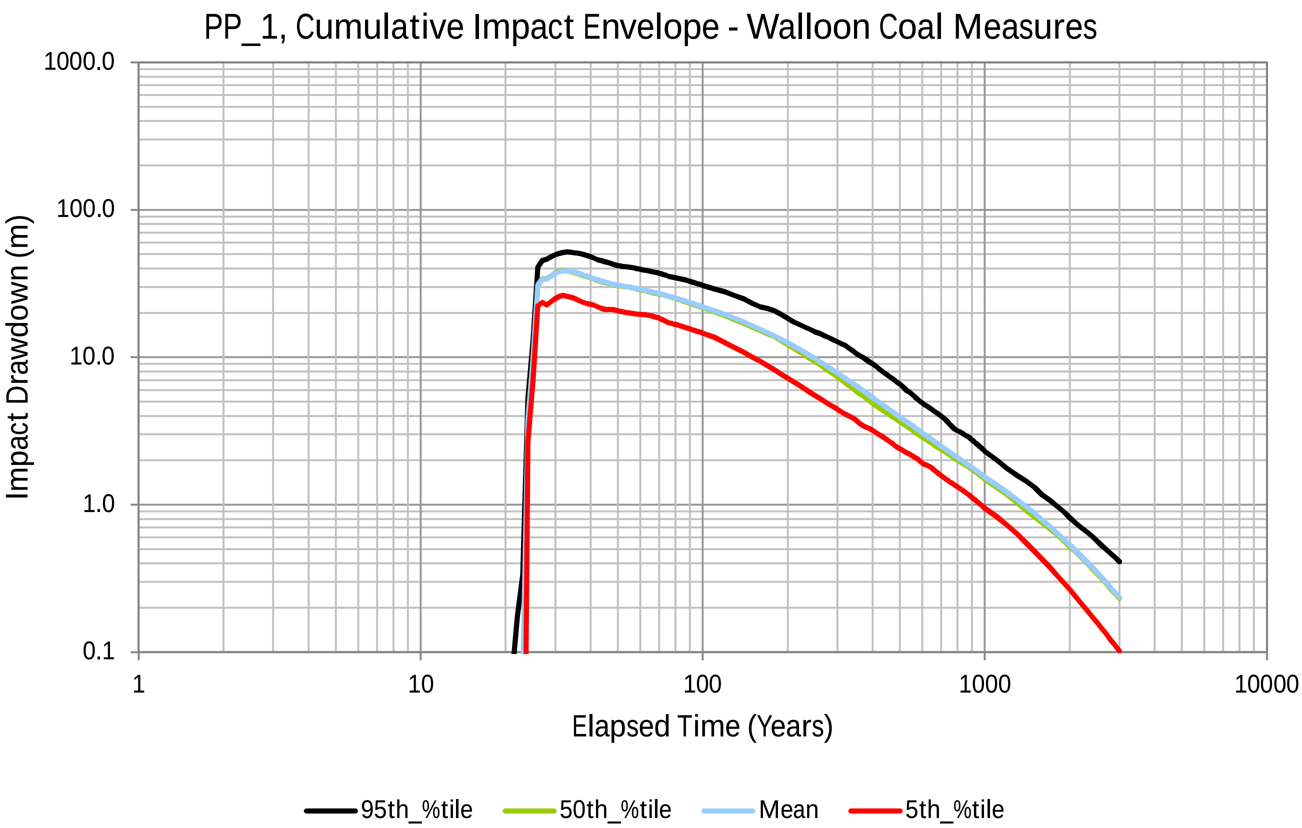
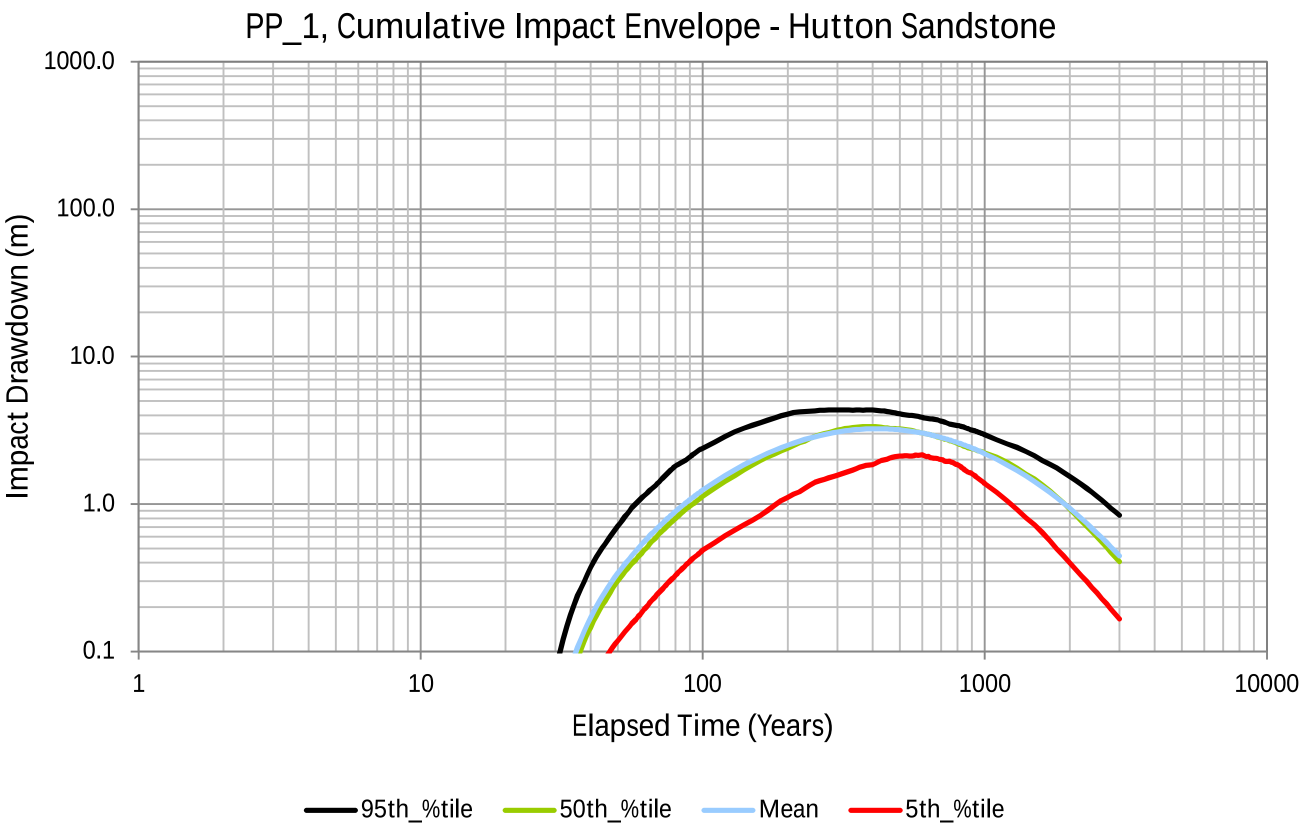
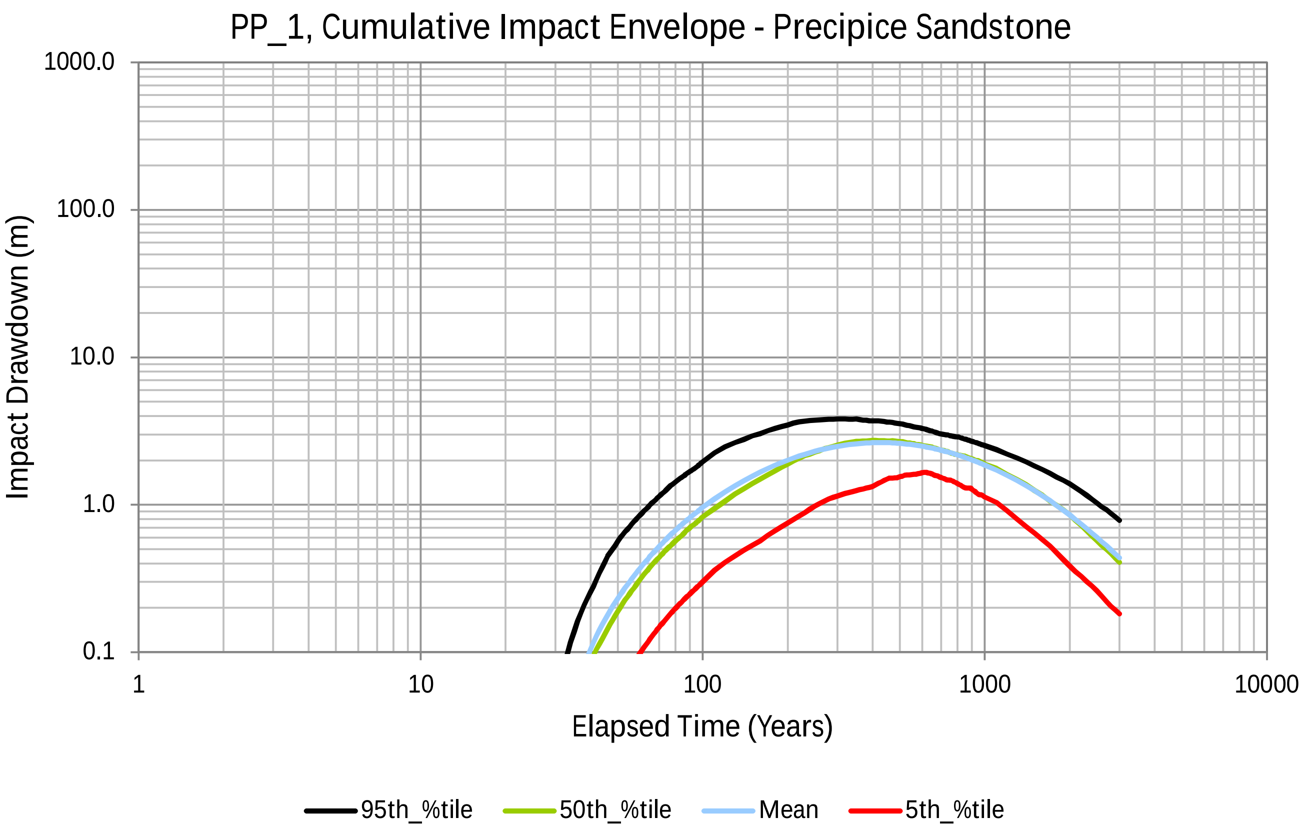
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



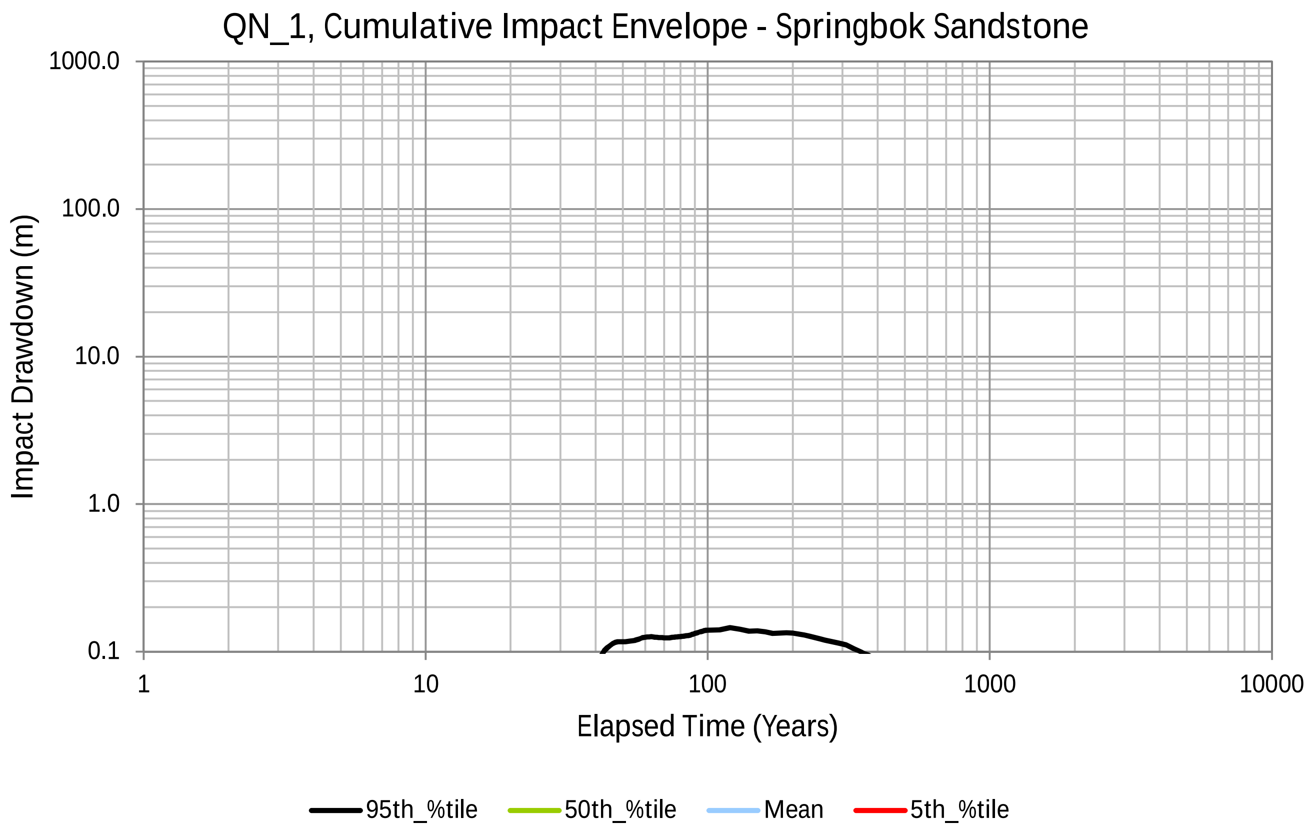


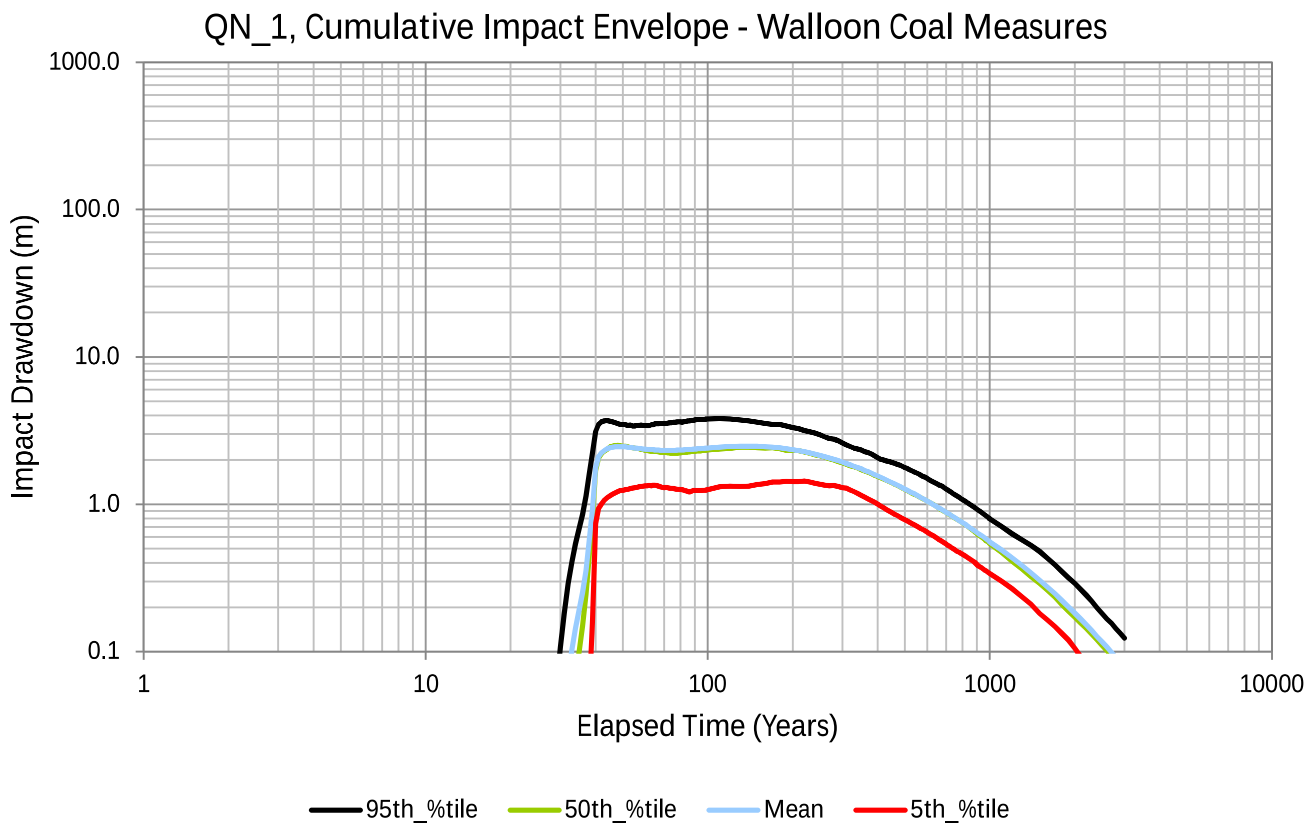
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



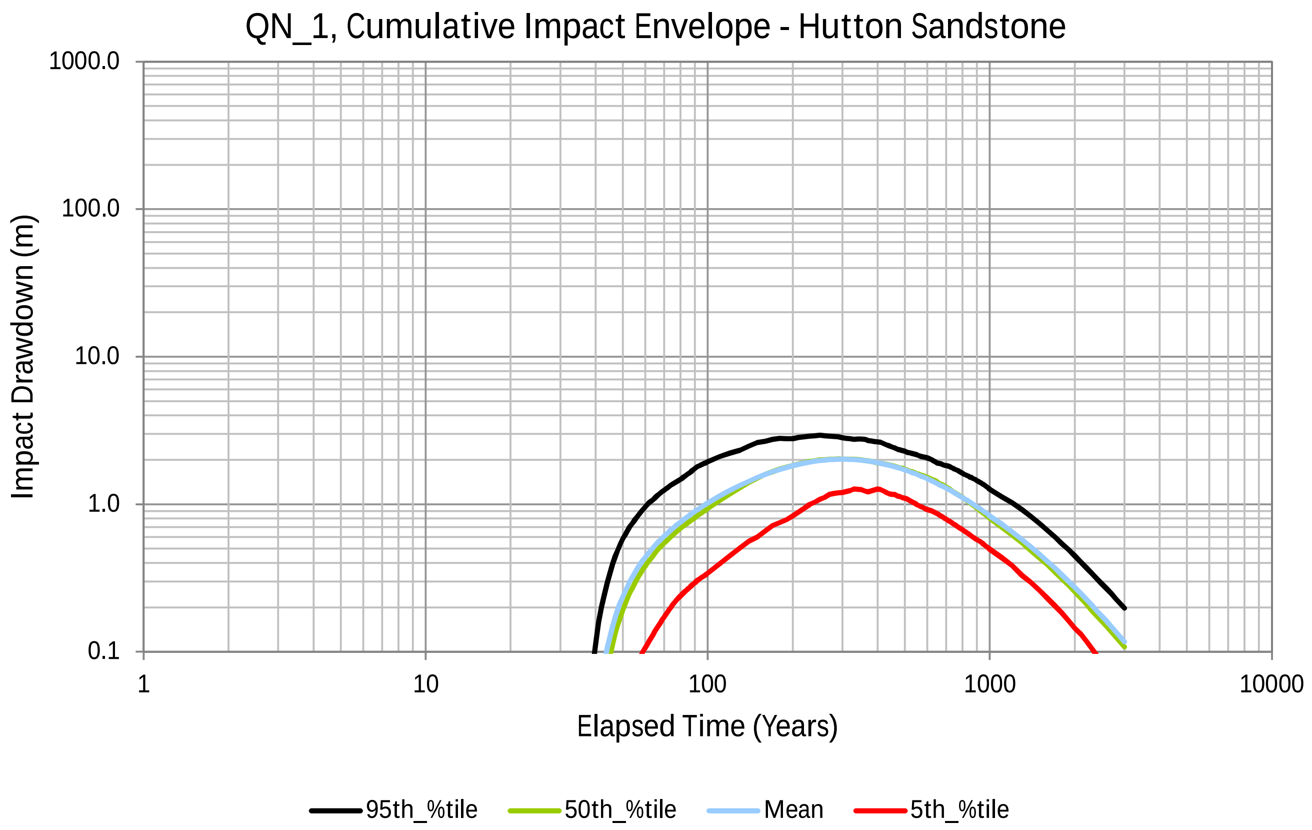


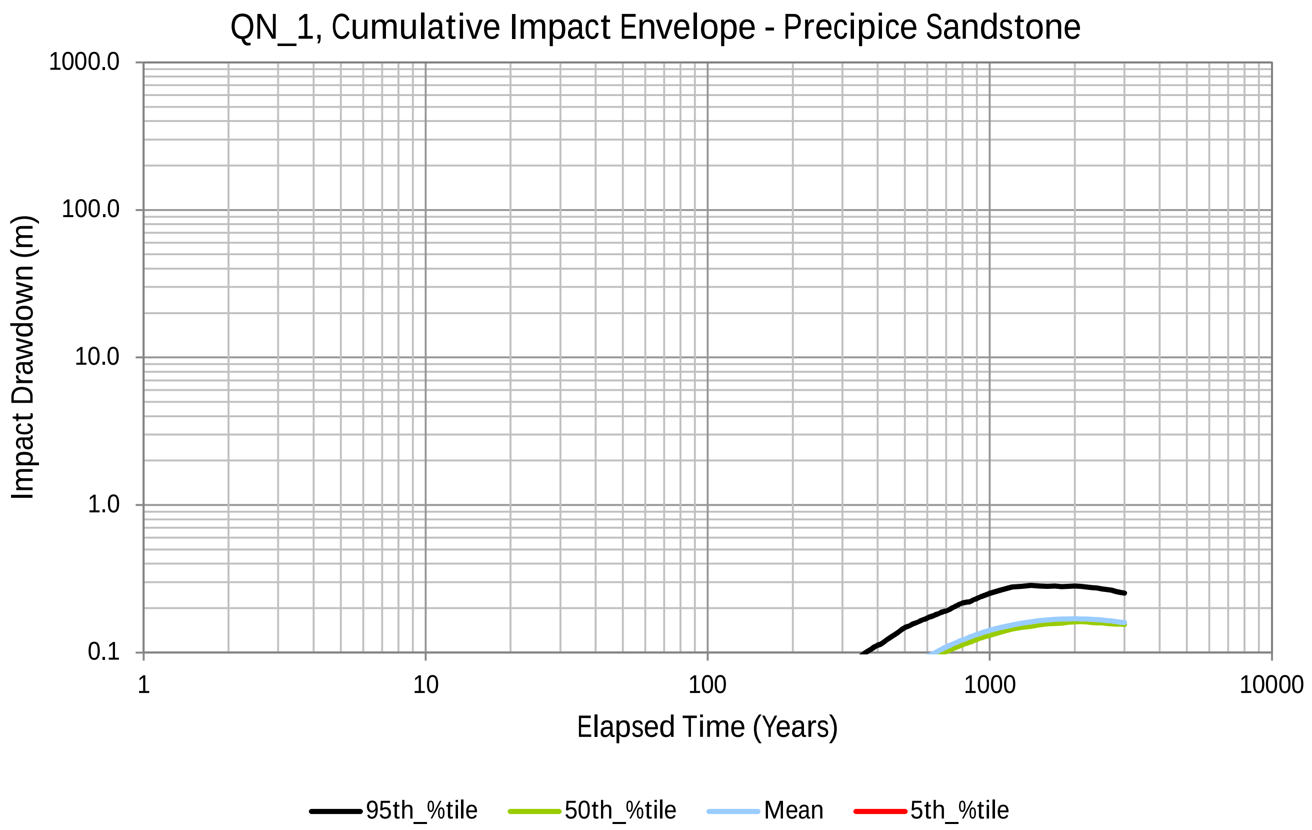
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



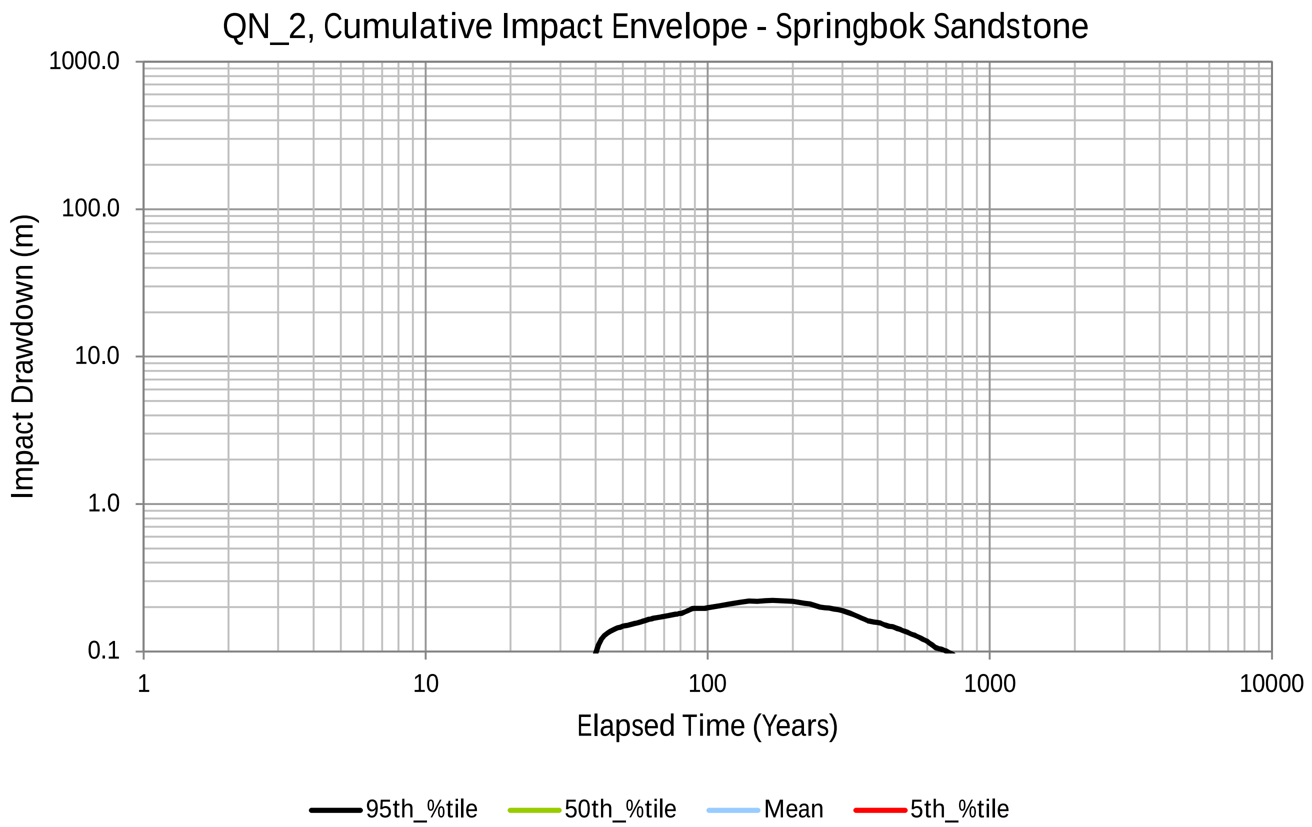


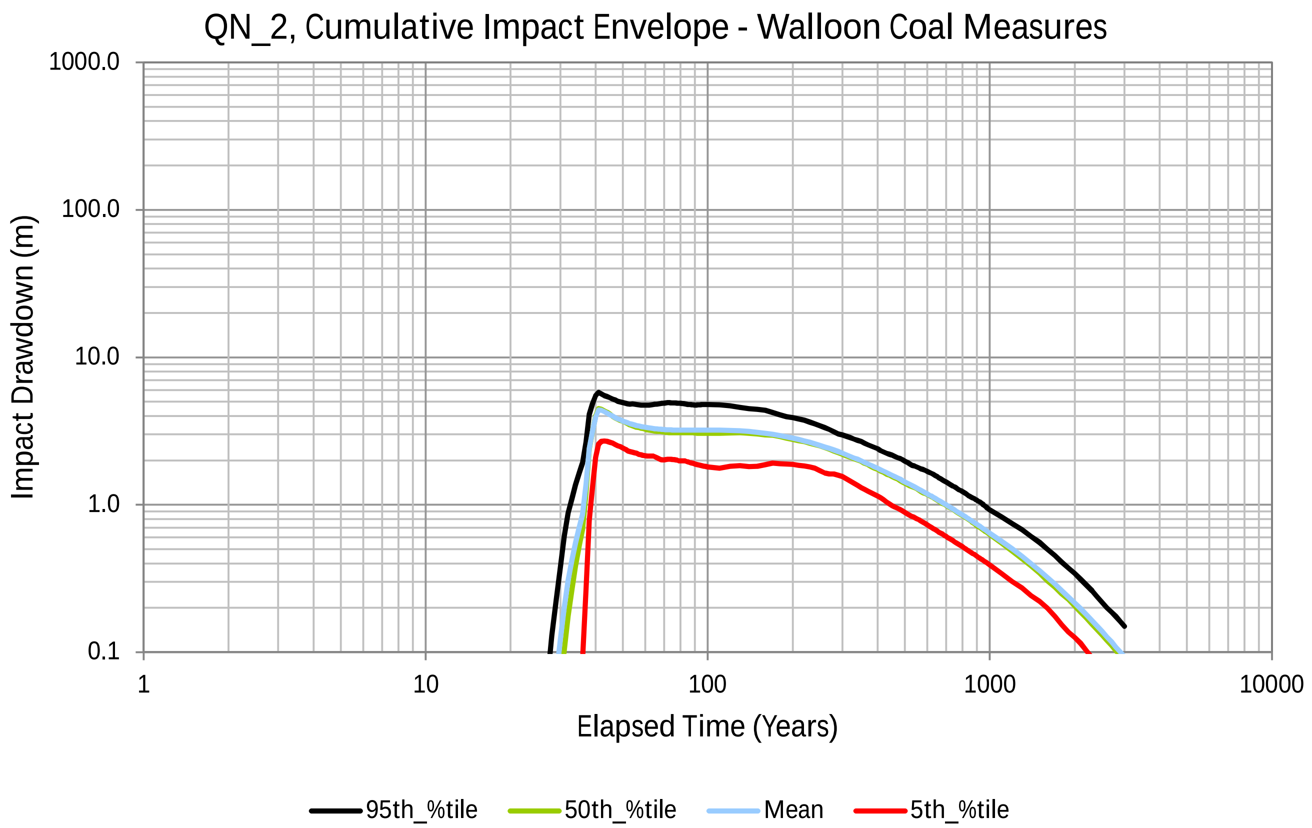
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



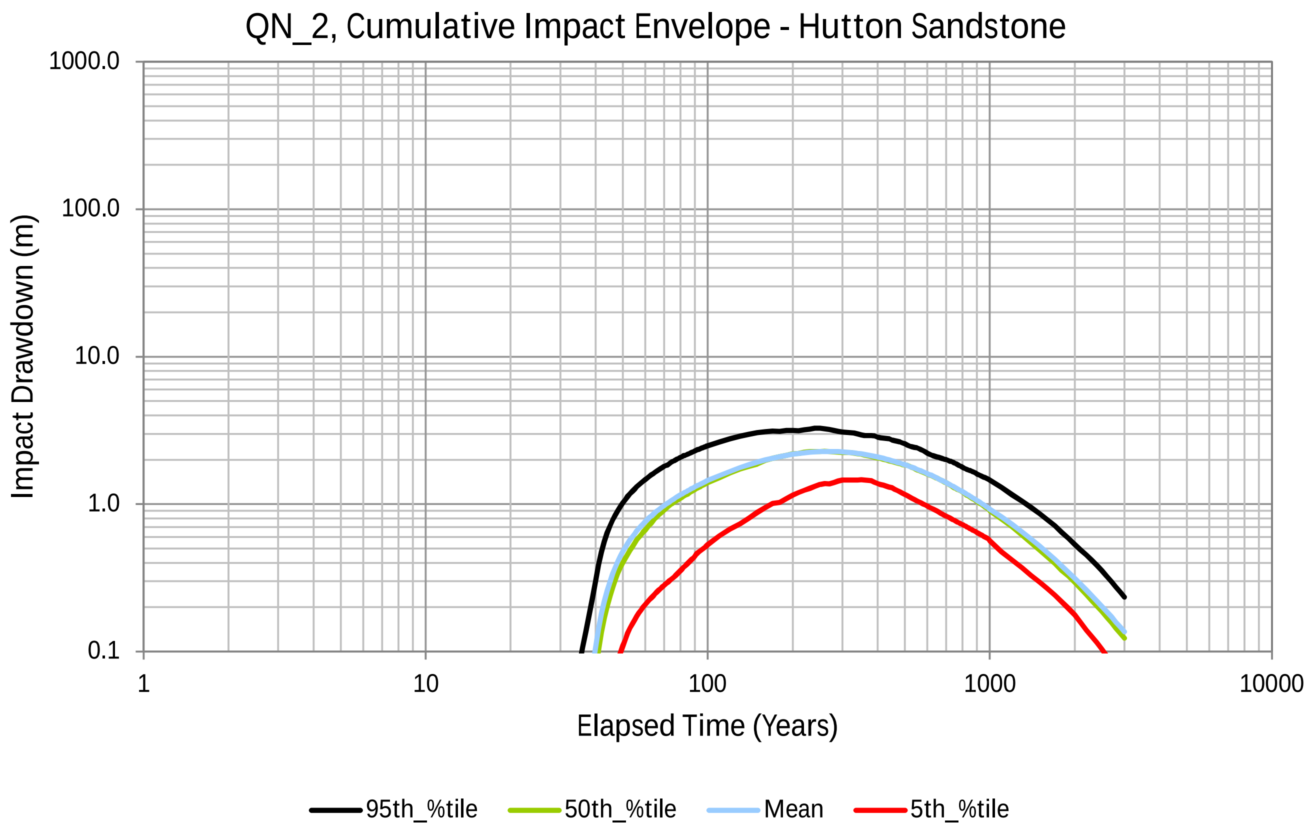


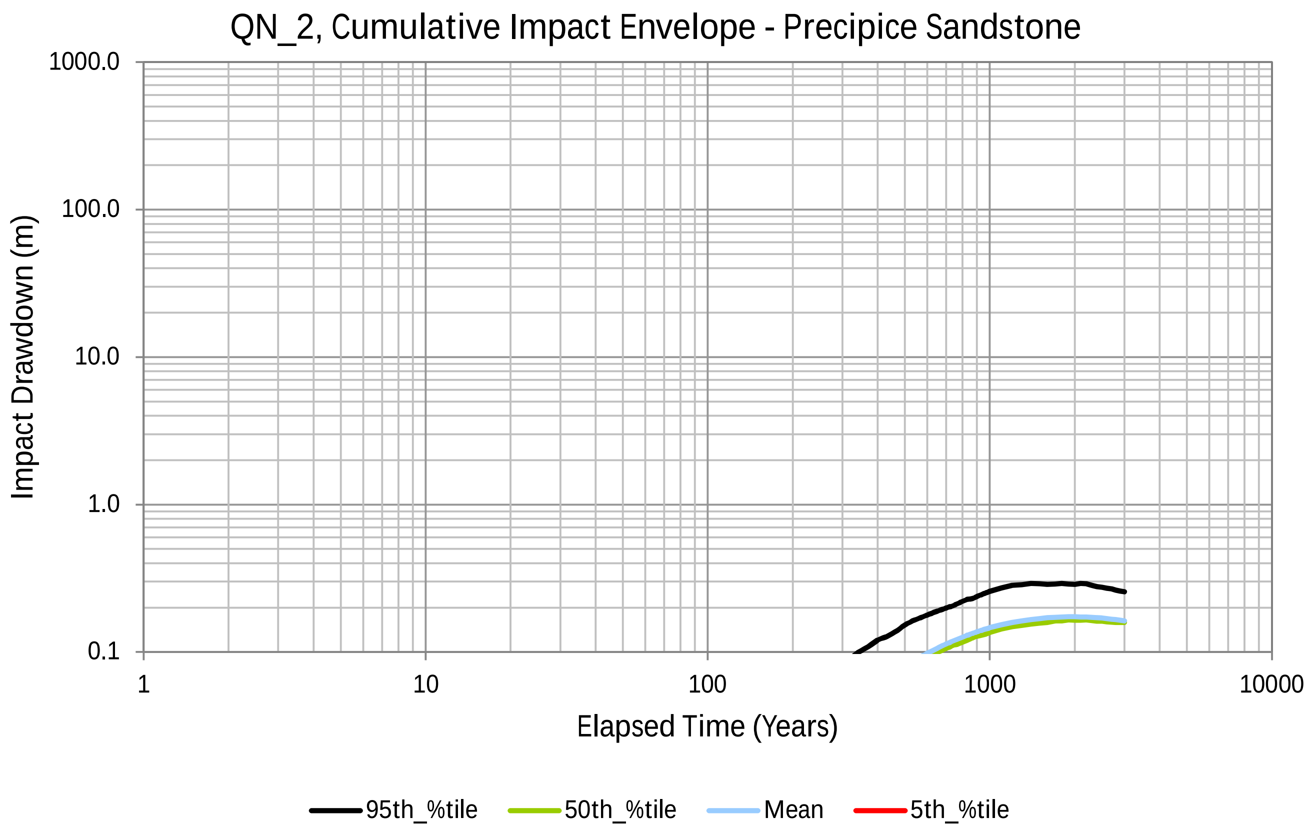
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



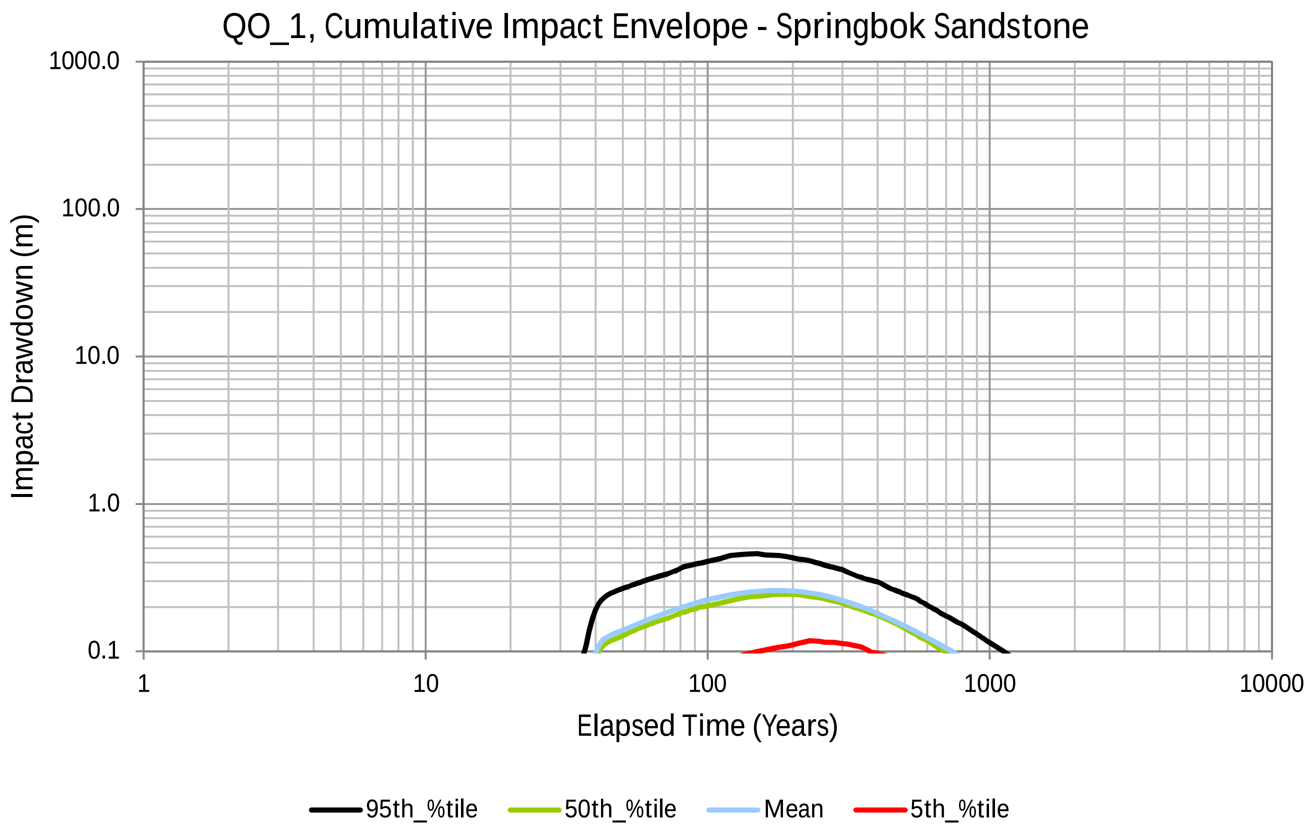


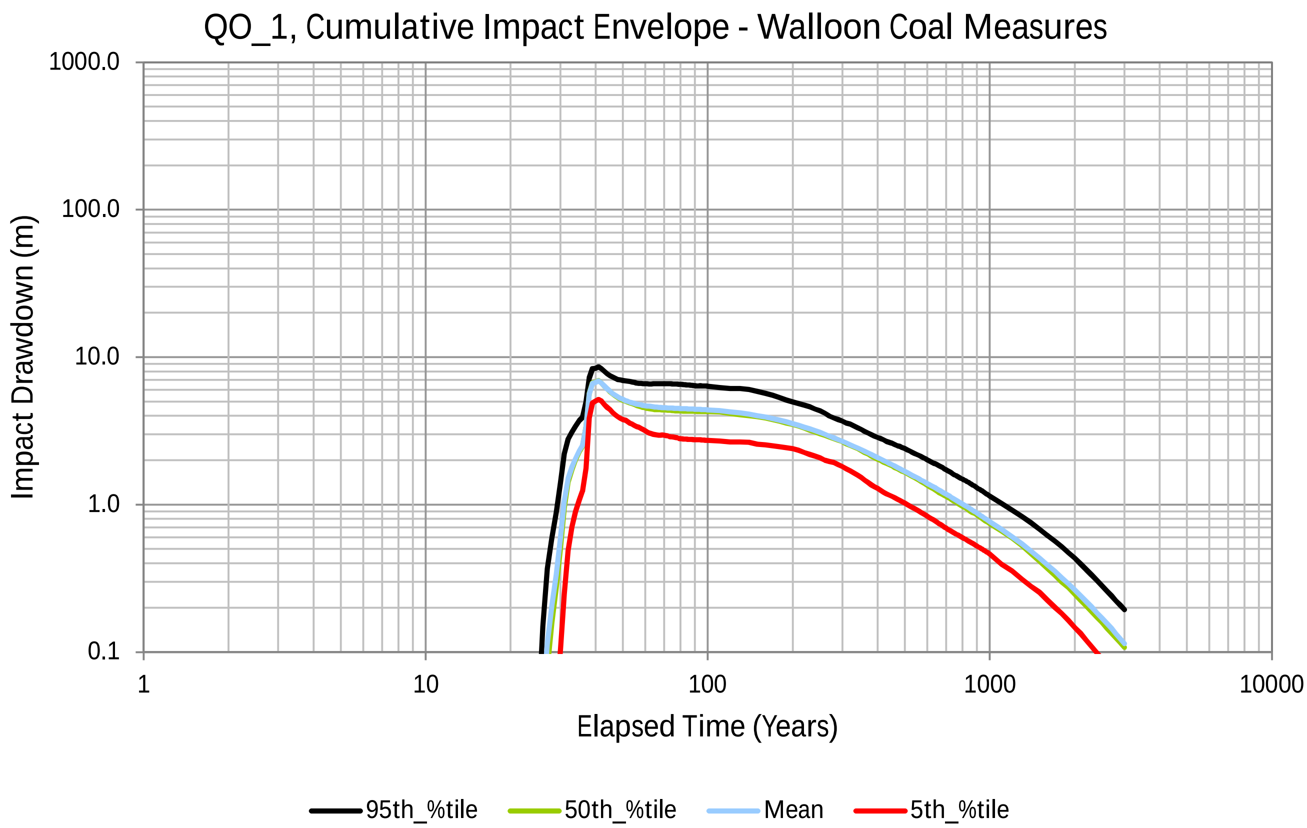
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



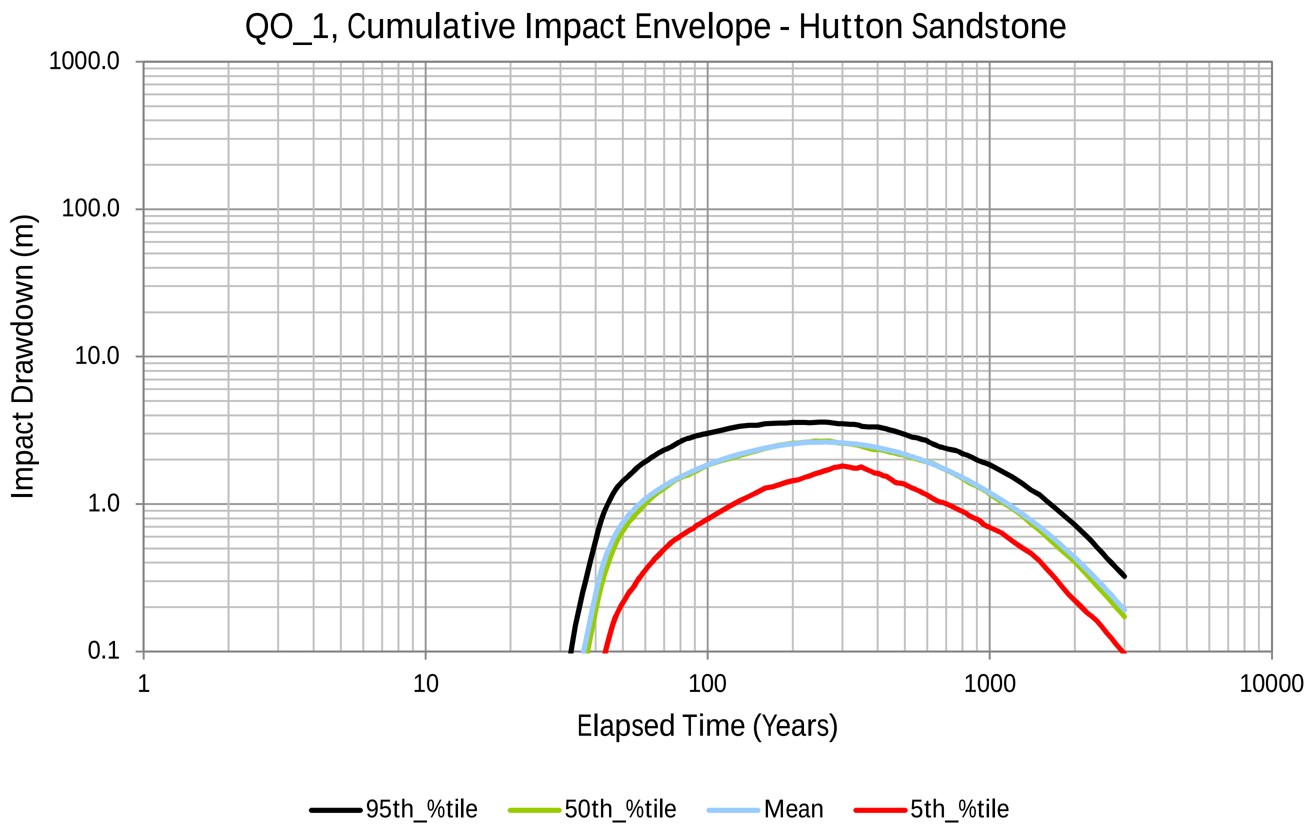


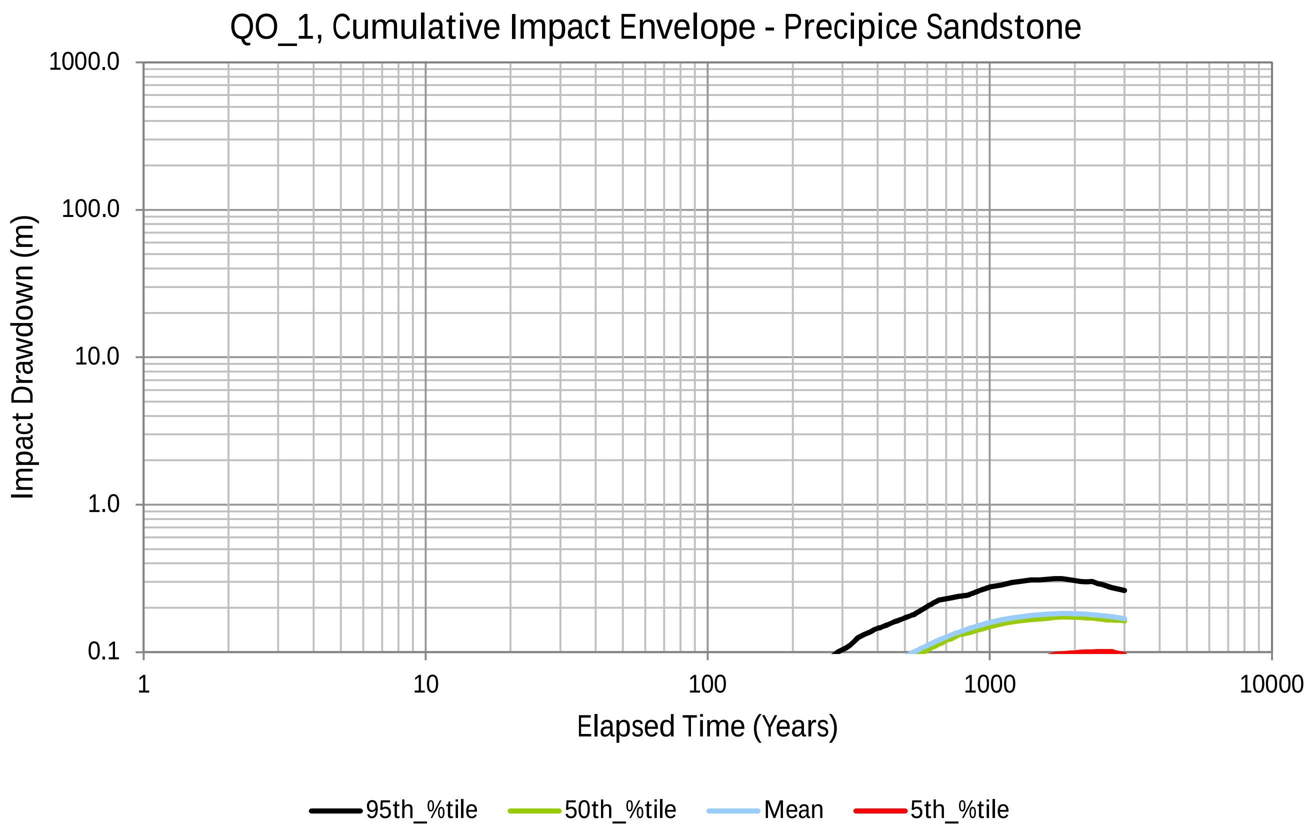
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



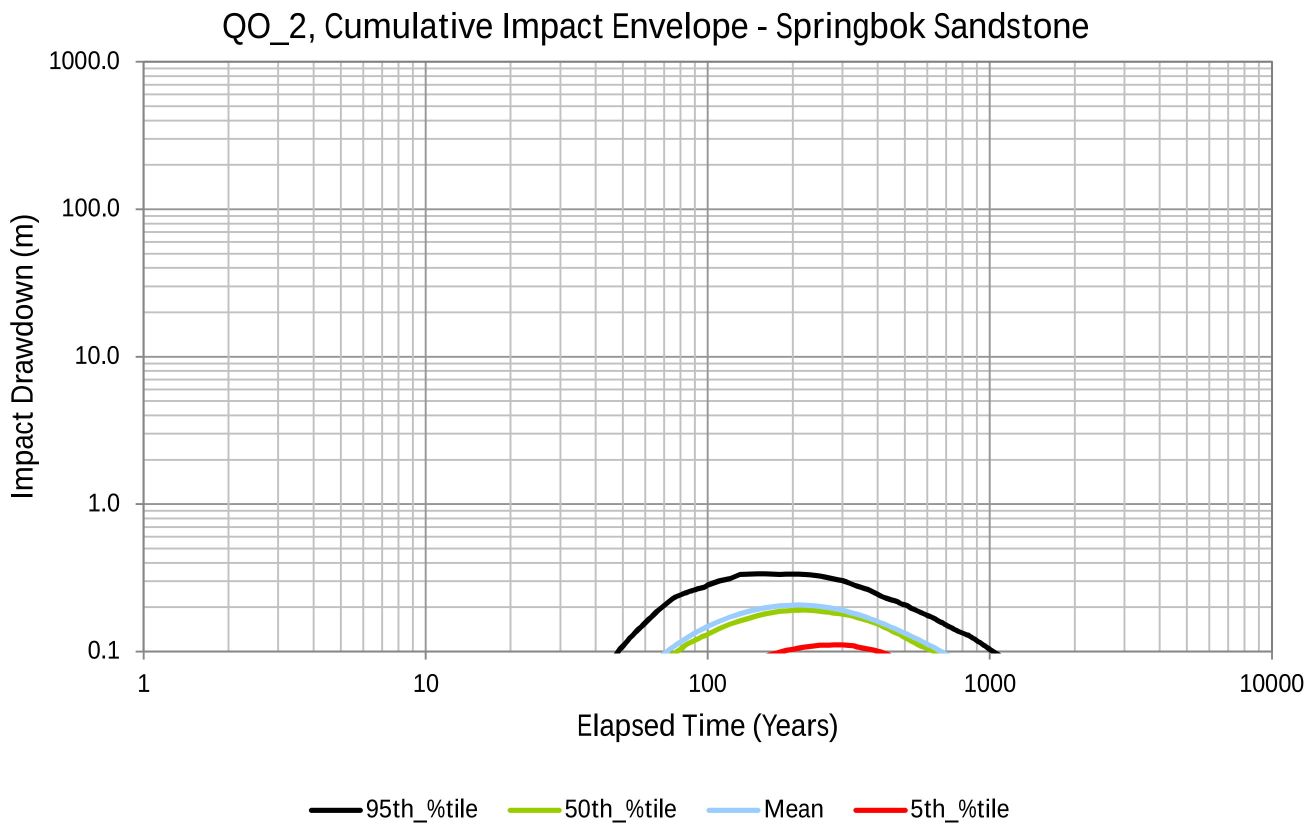


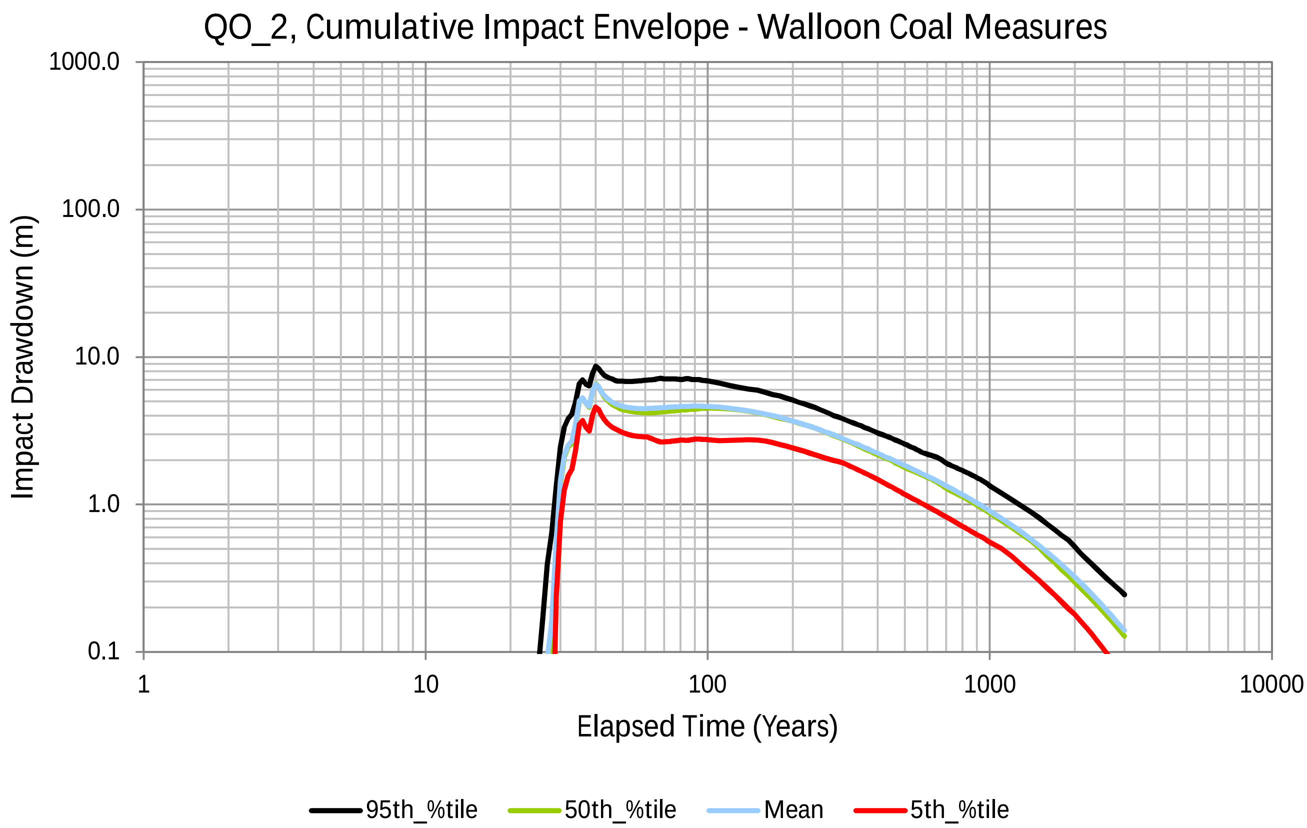
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



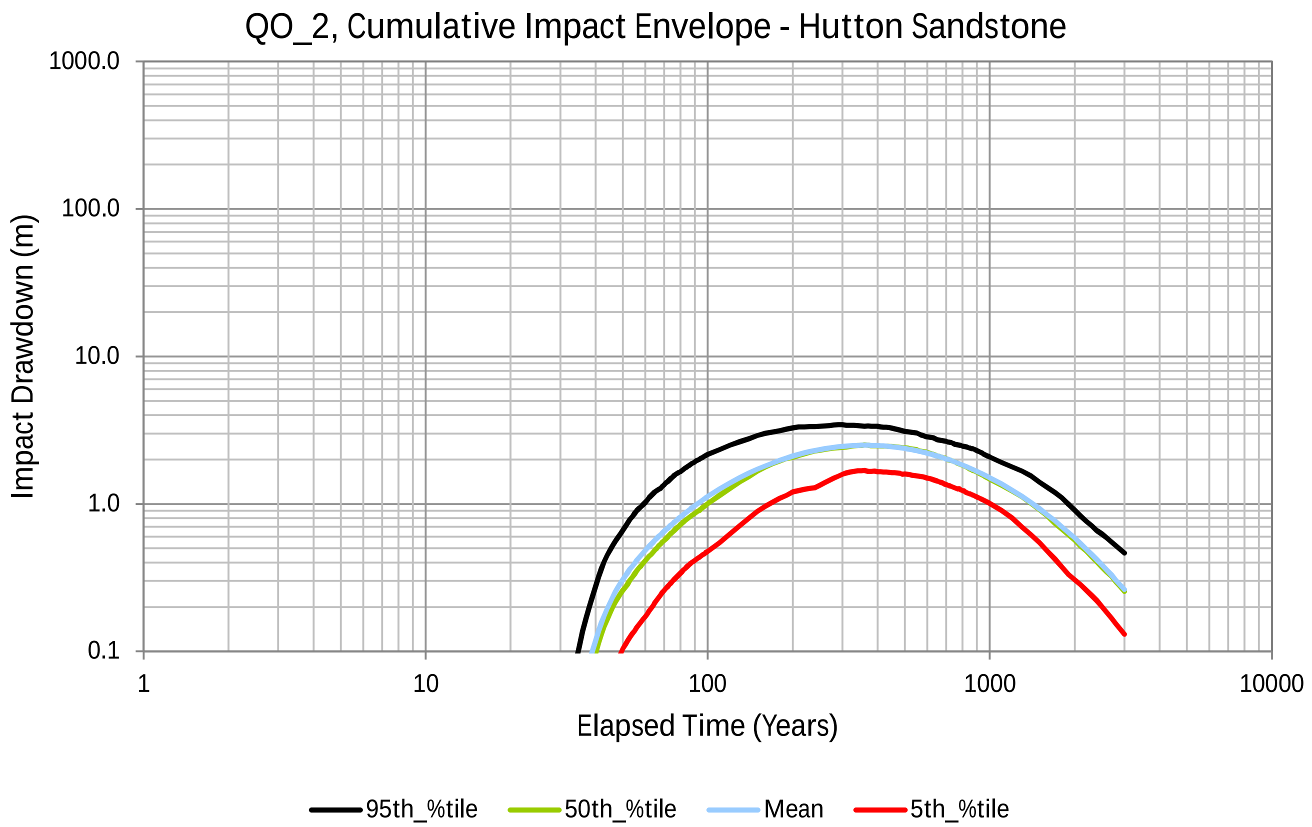


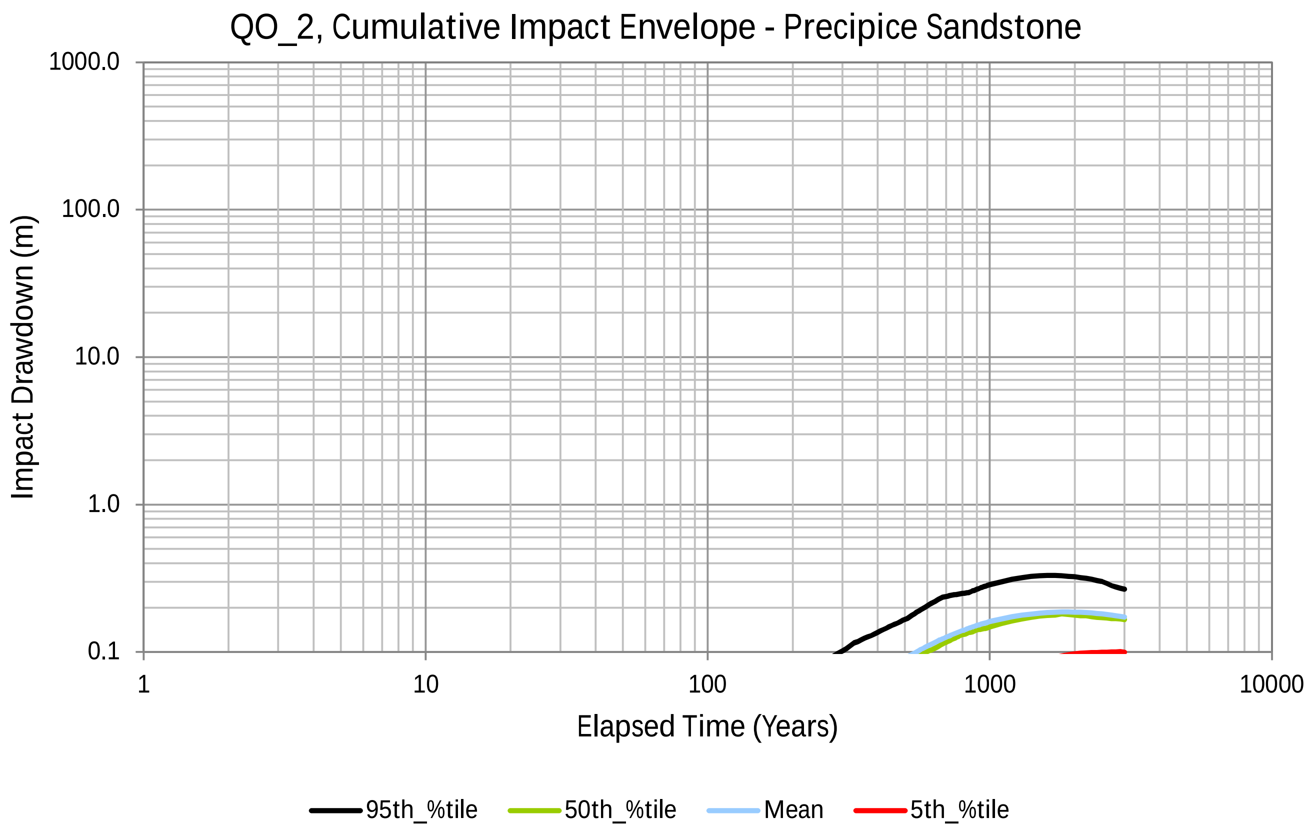
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5





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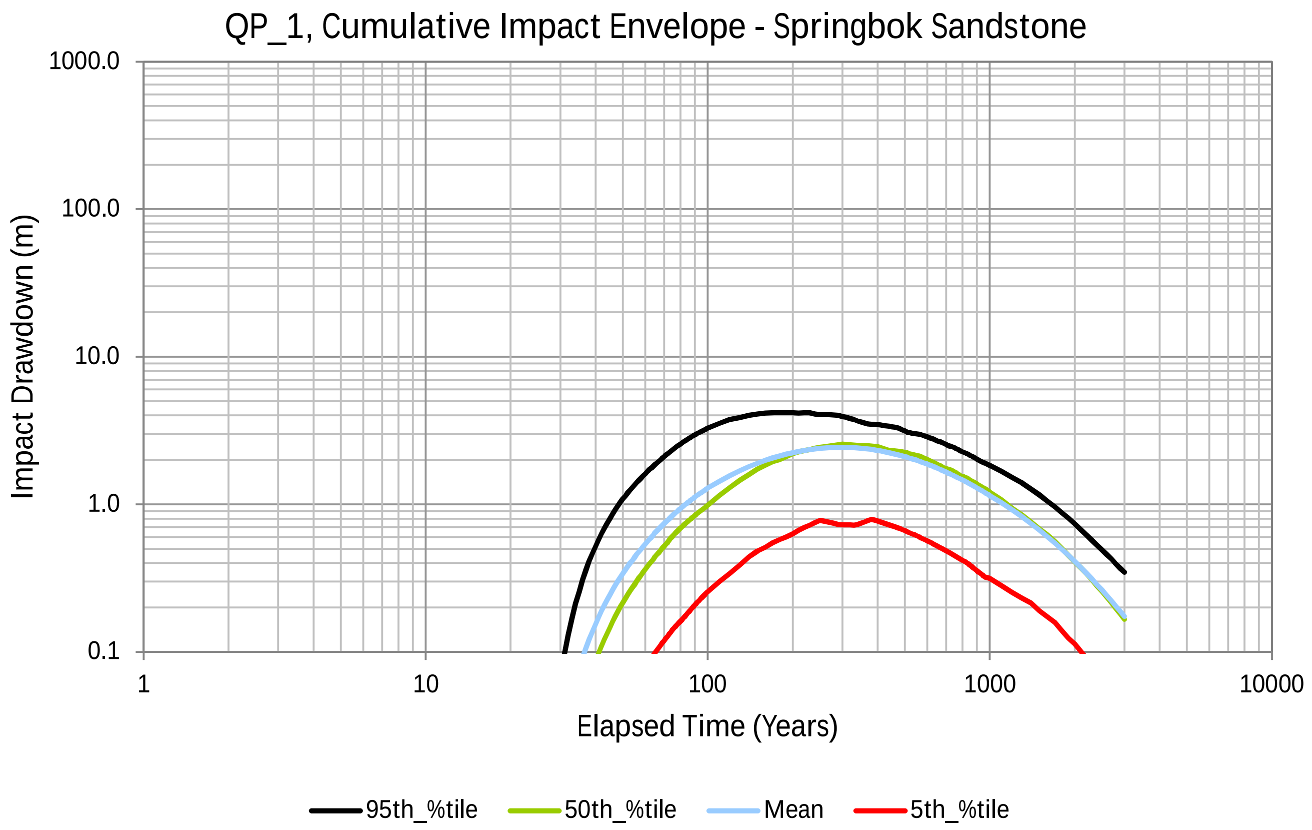
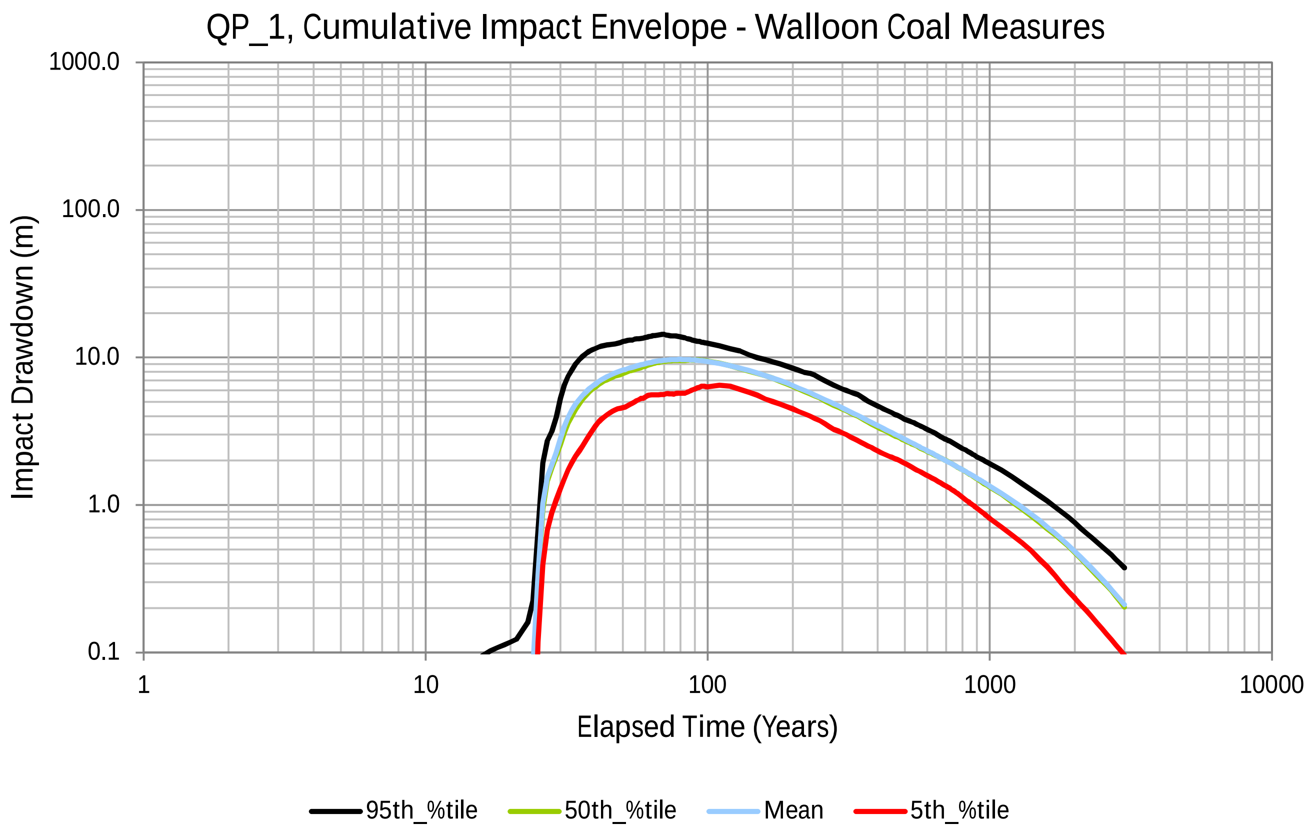
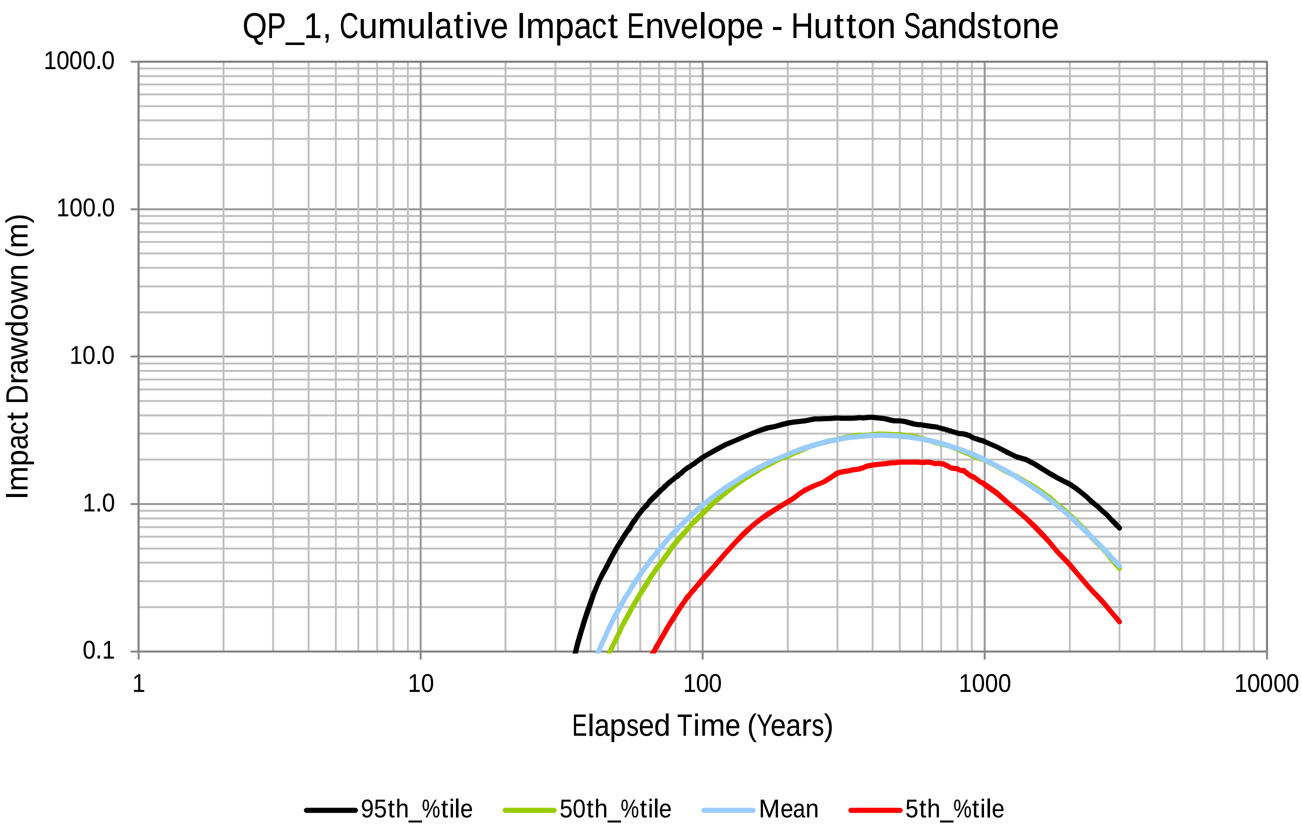
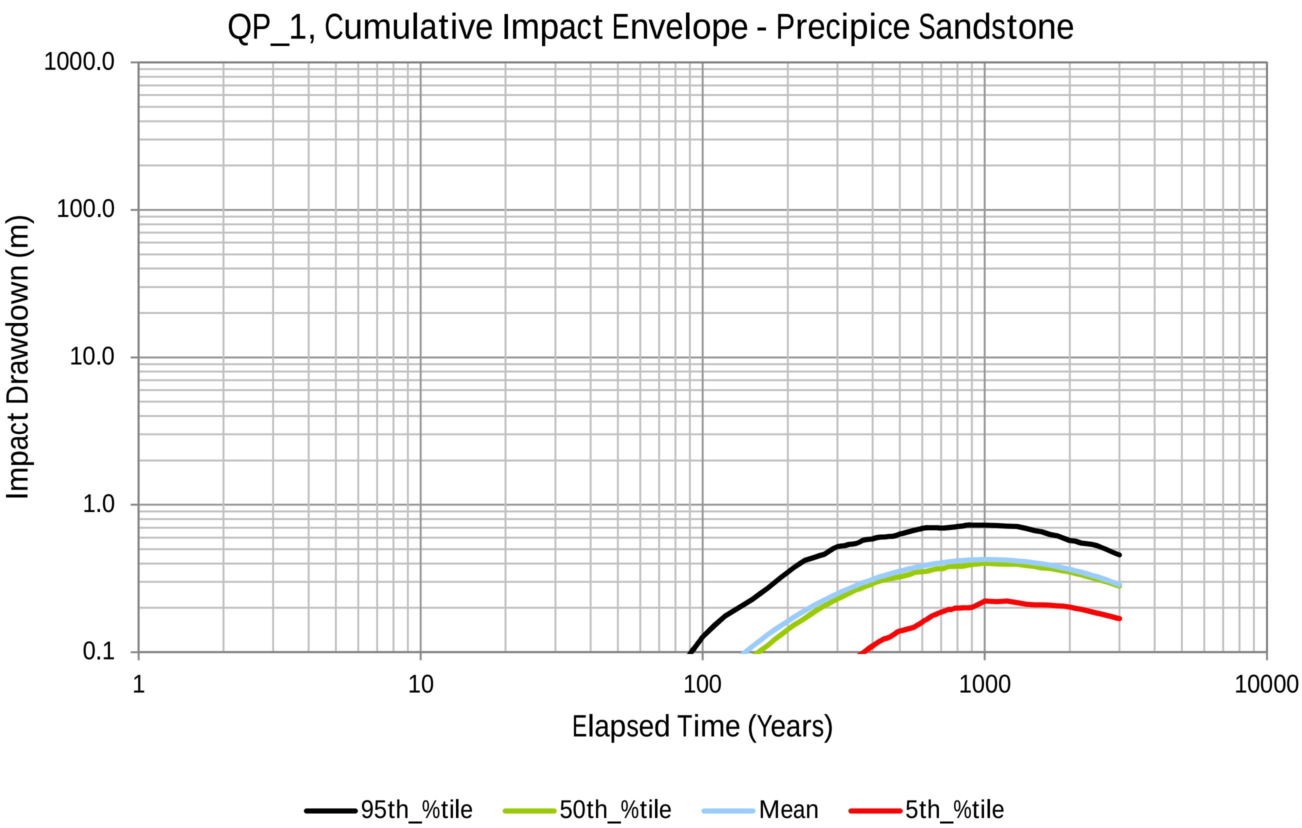
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



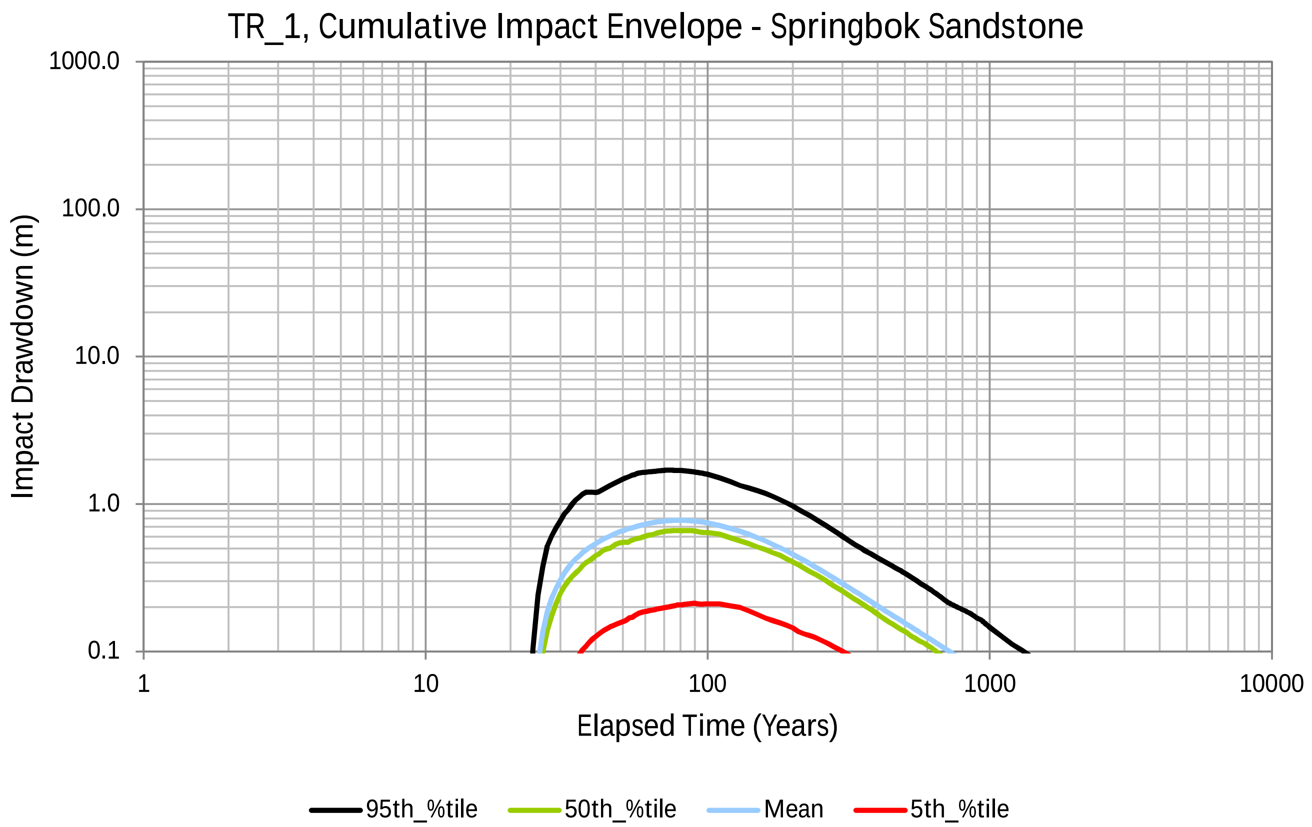


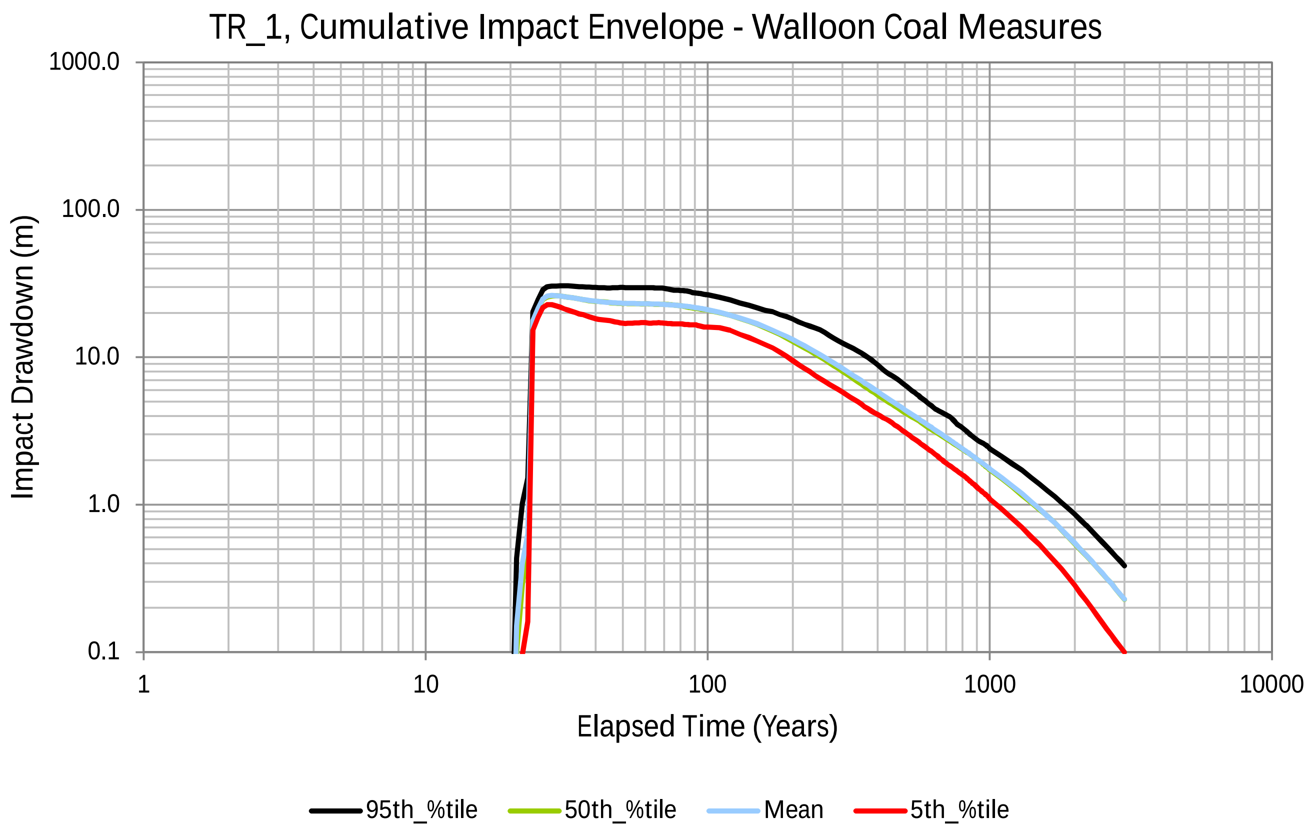
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 5



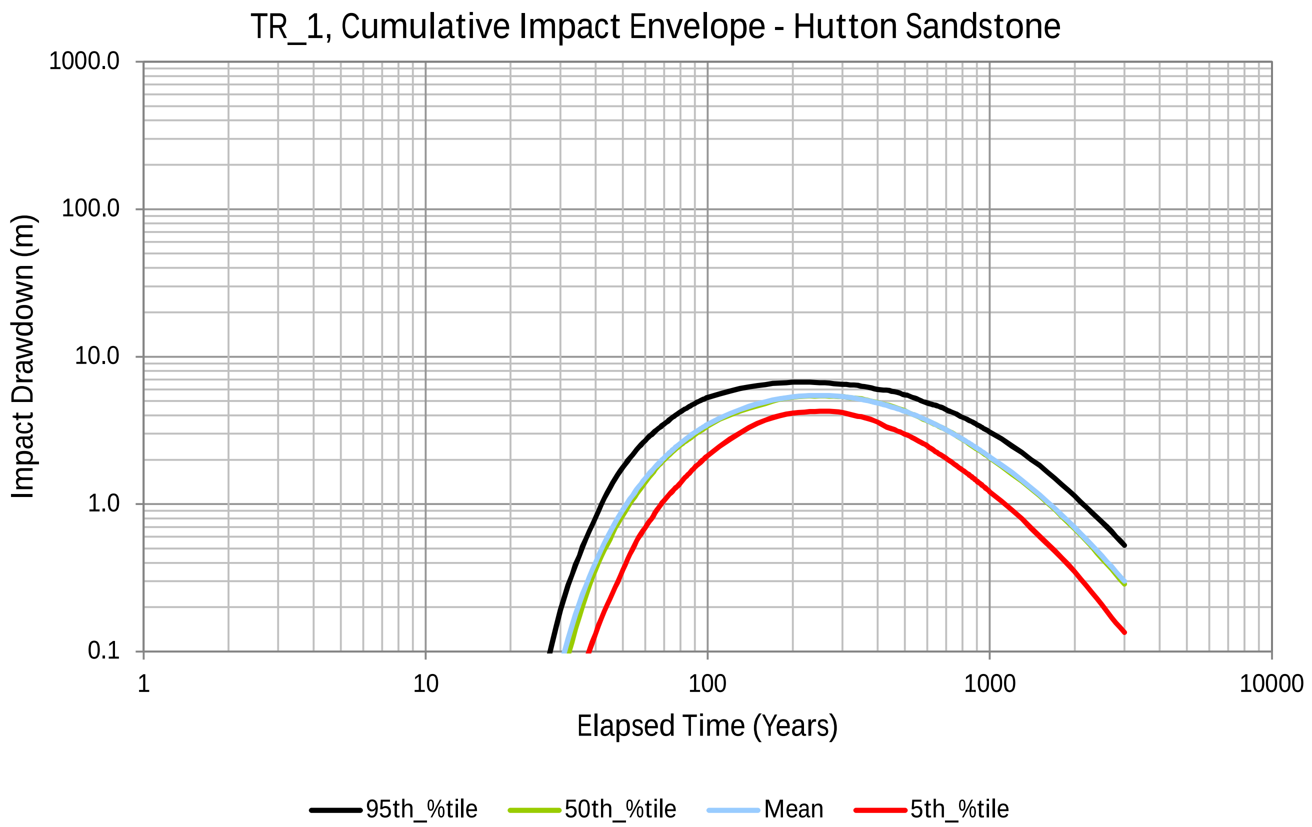


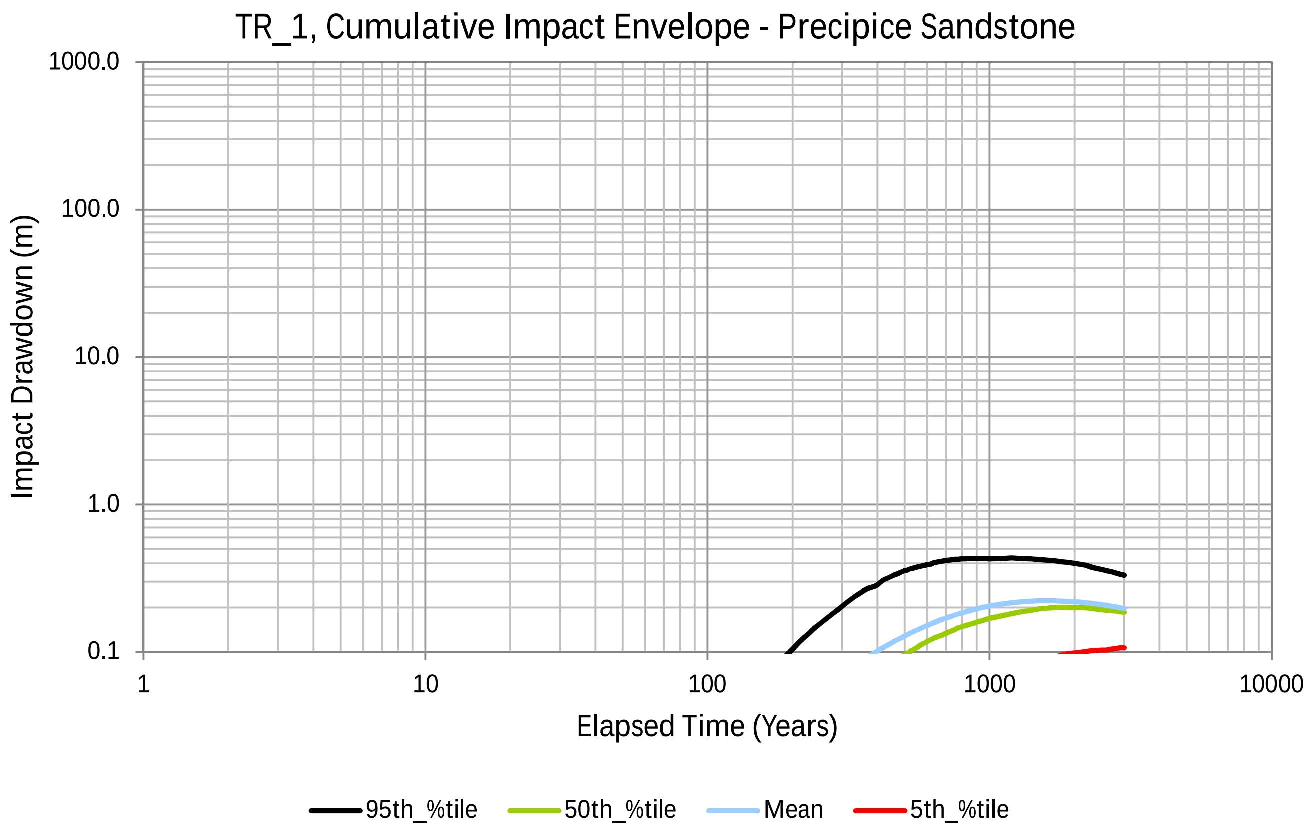
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 7



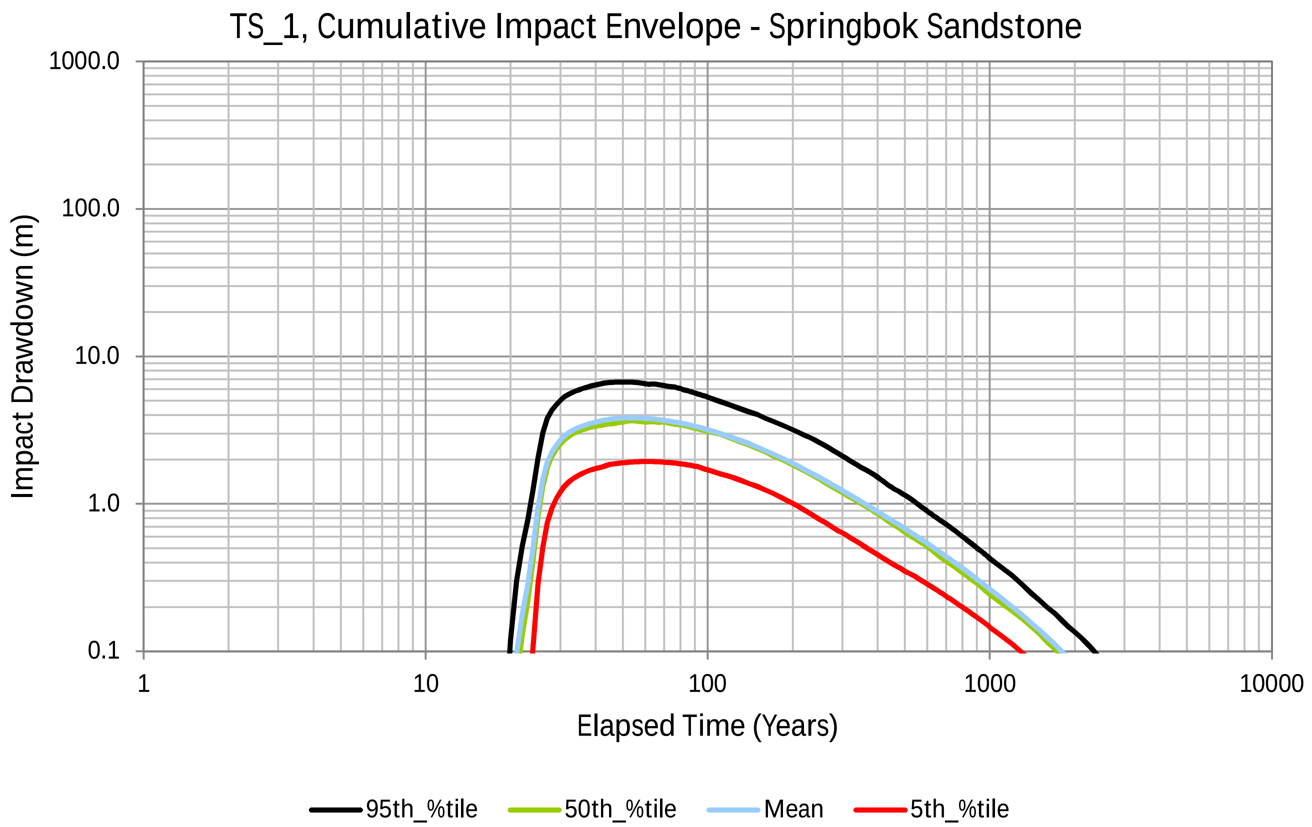


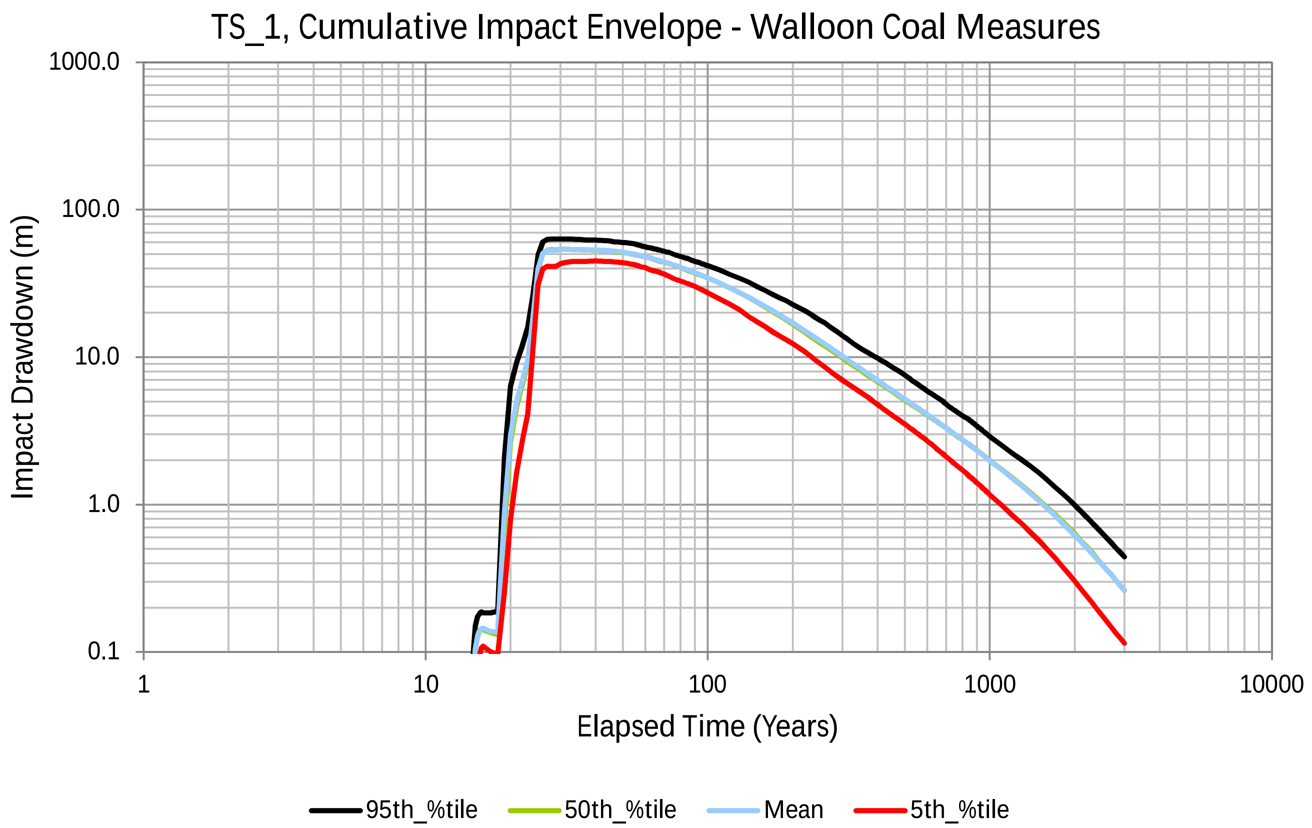
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 7



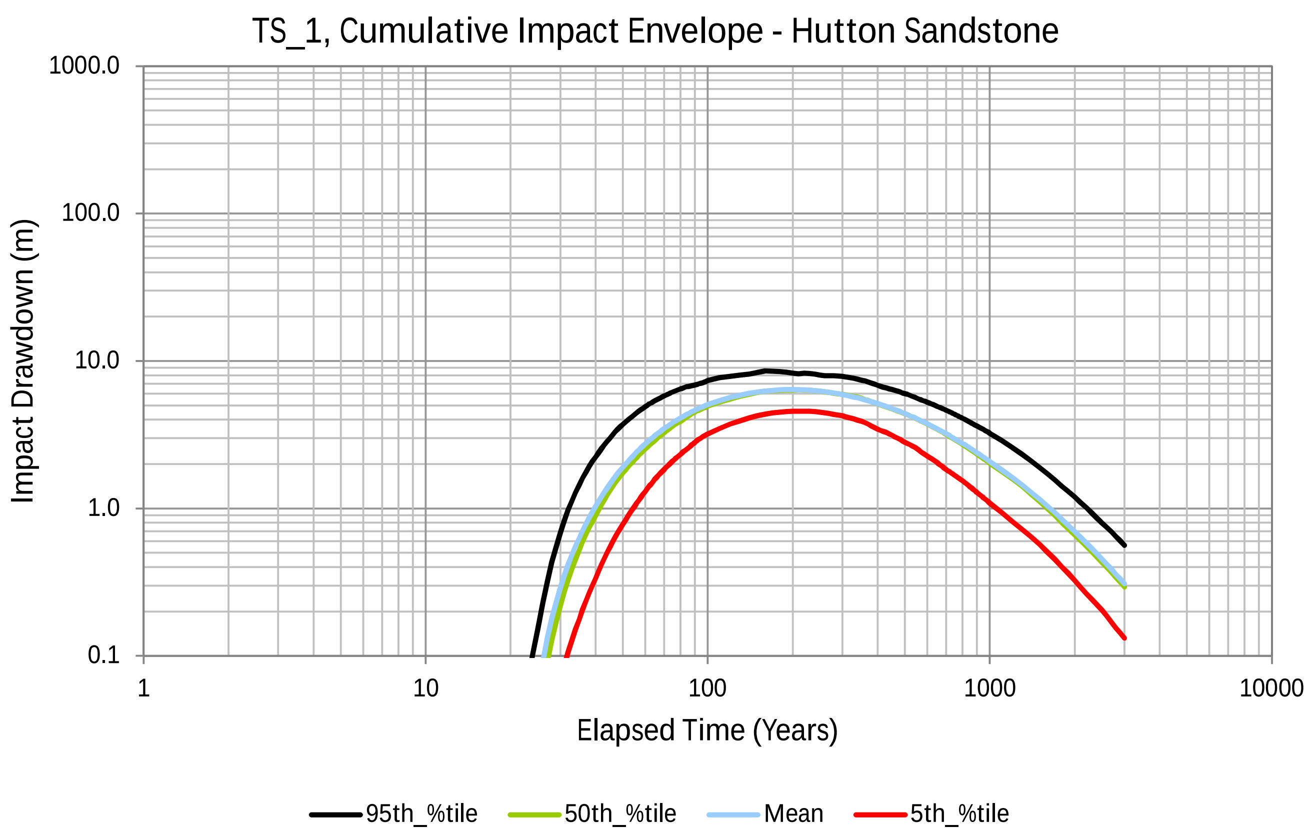


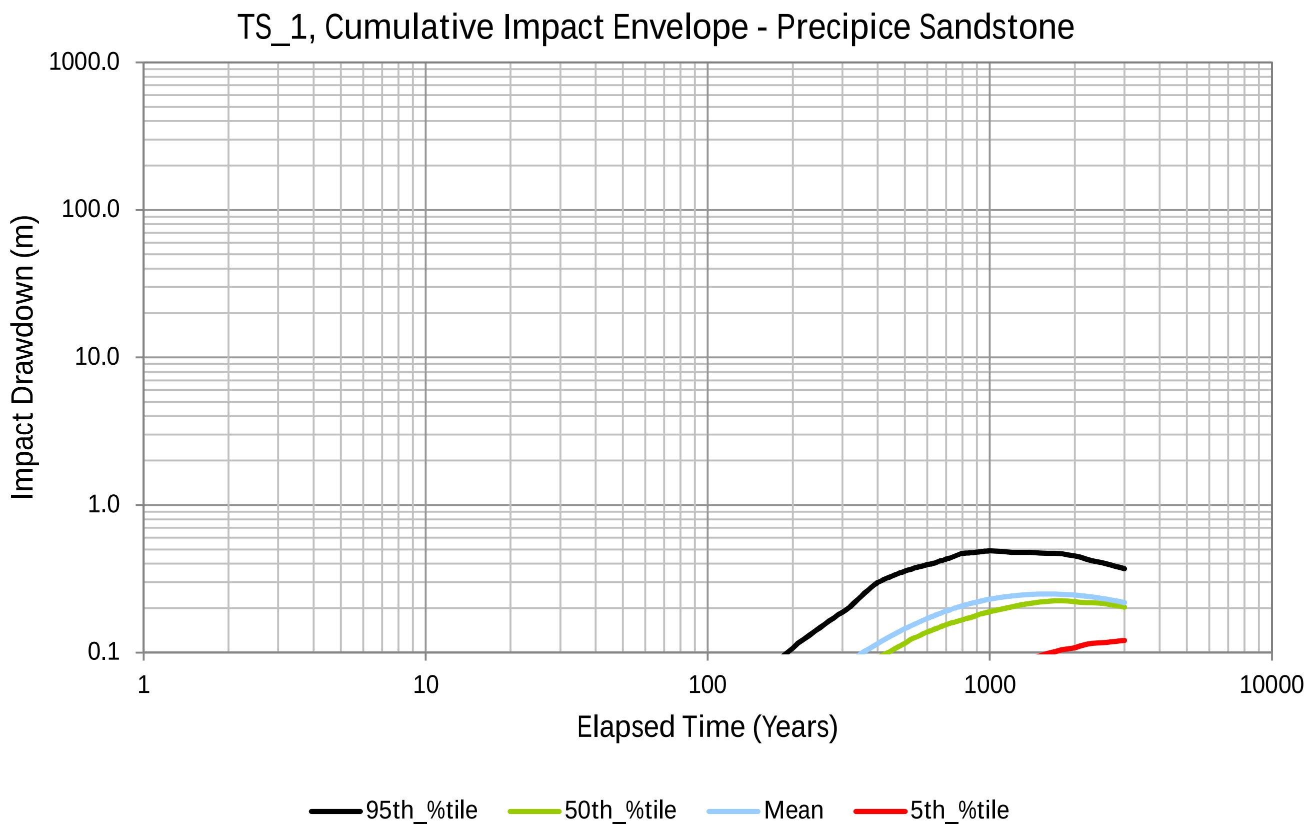
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 7





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 7





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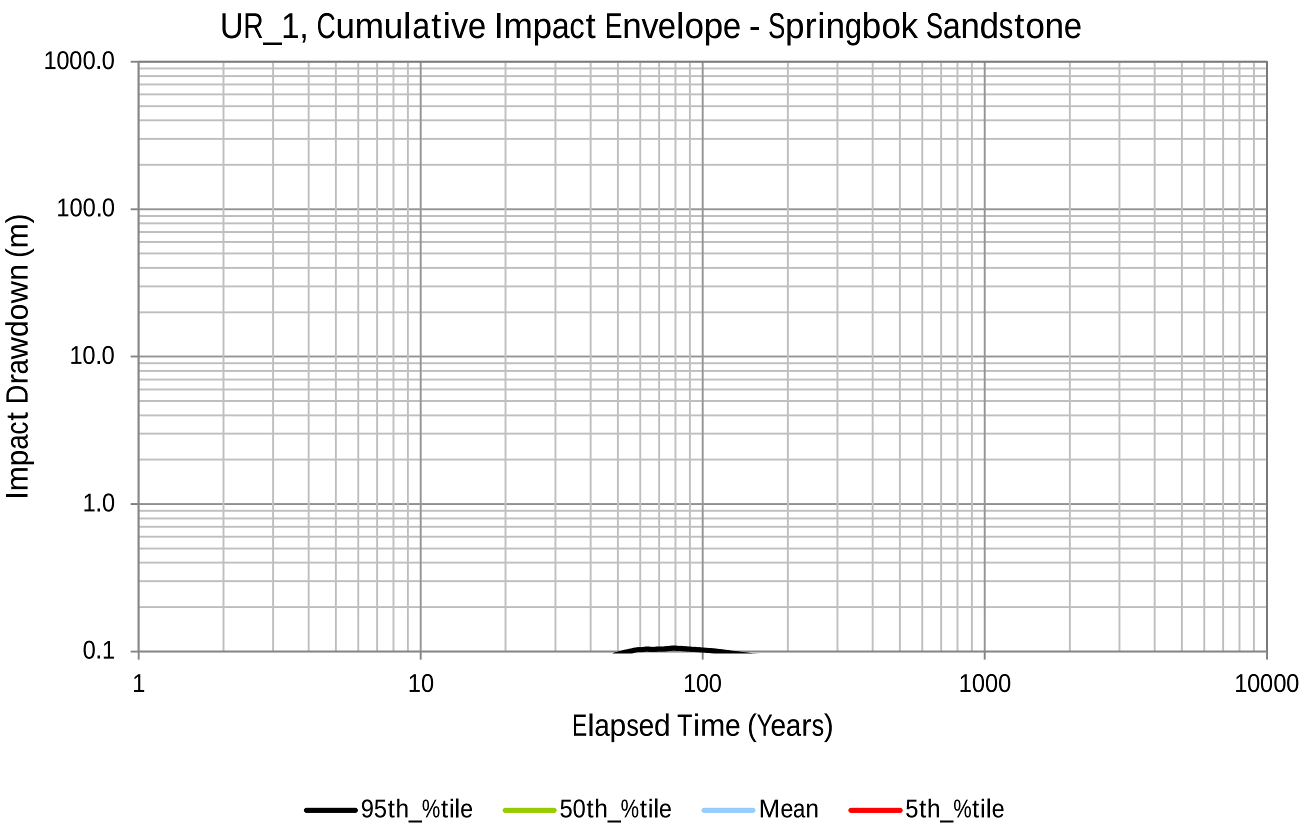
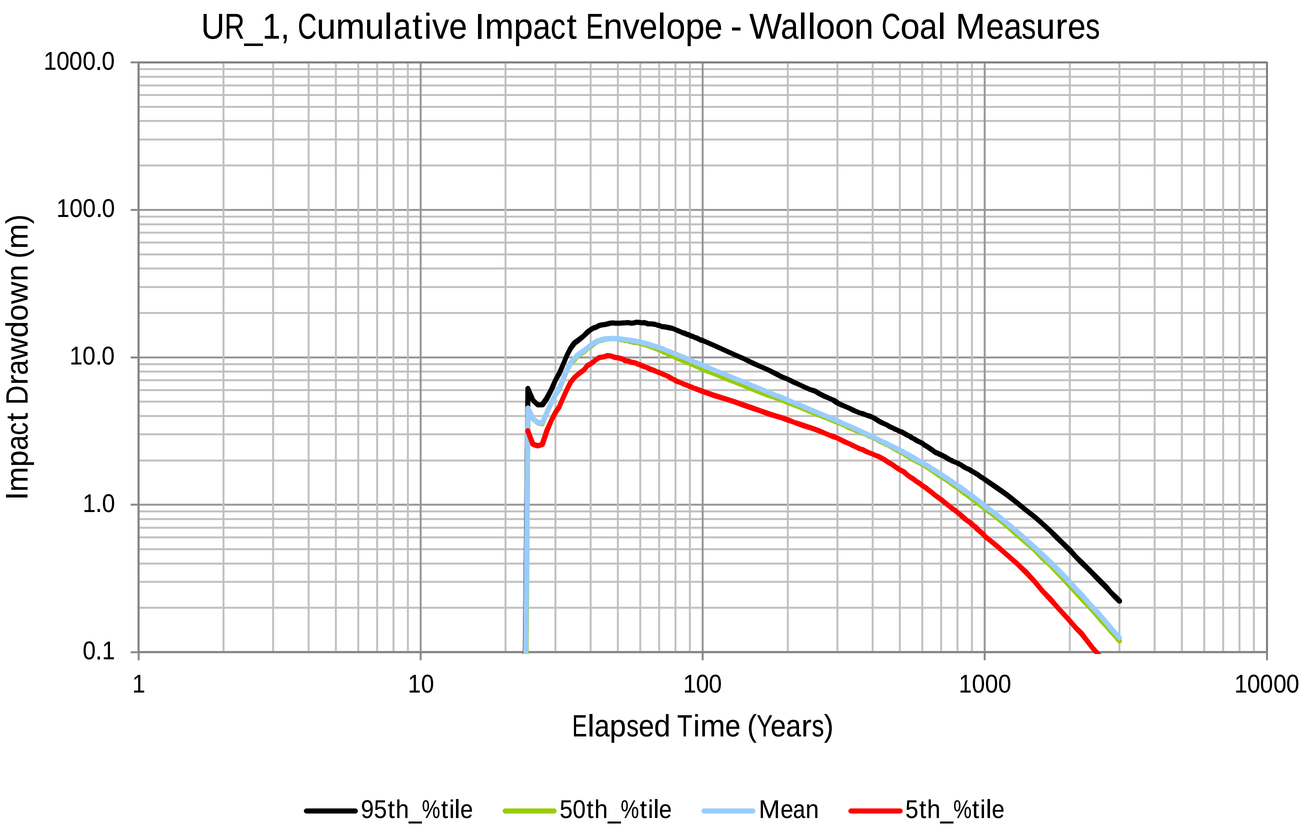
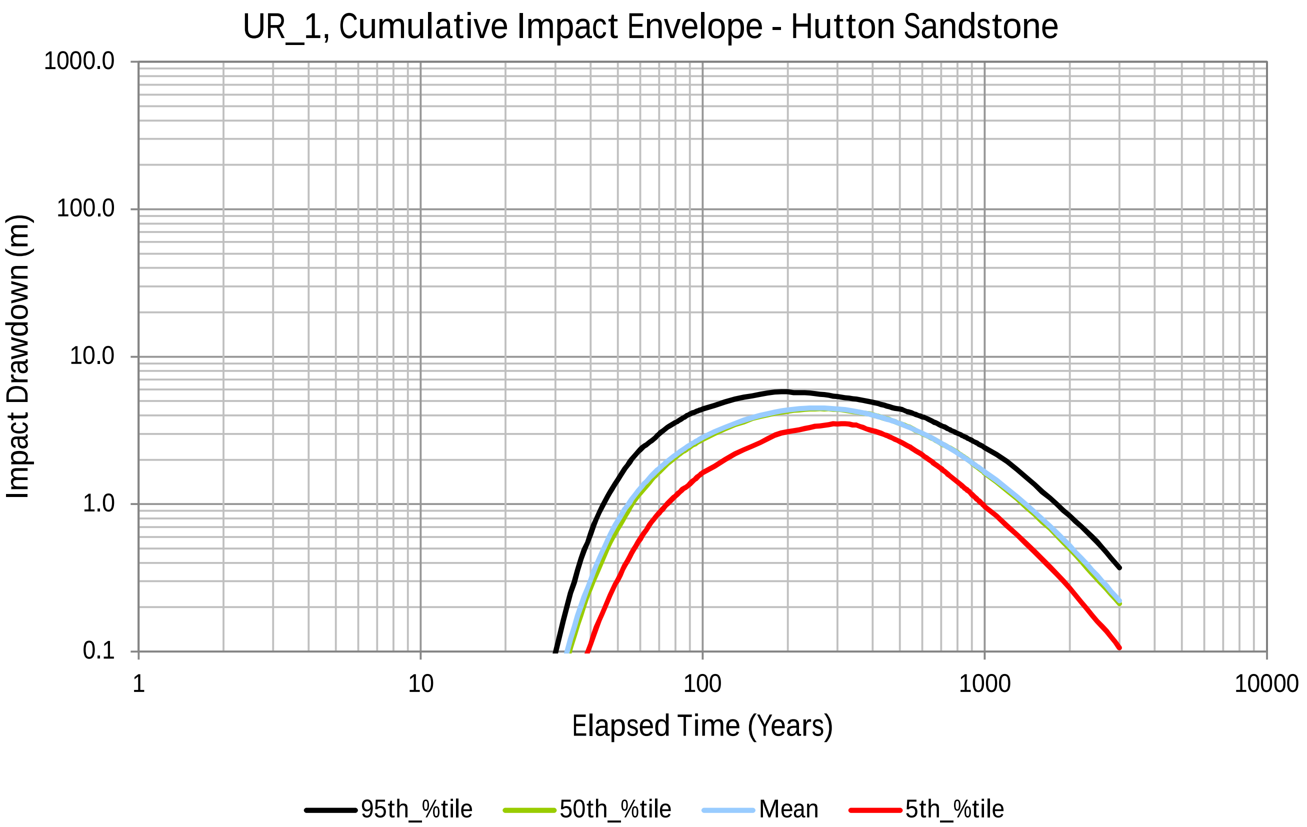
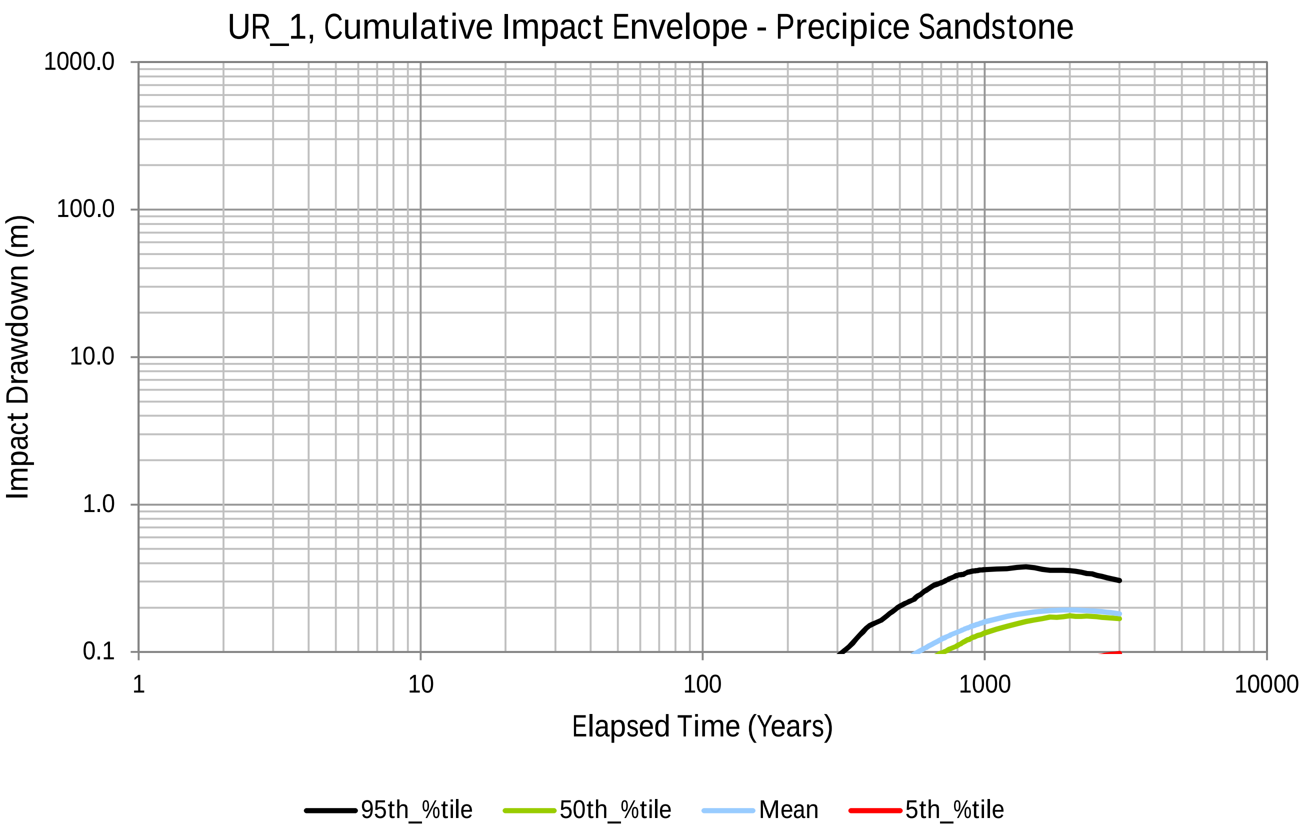
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 7



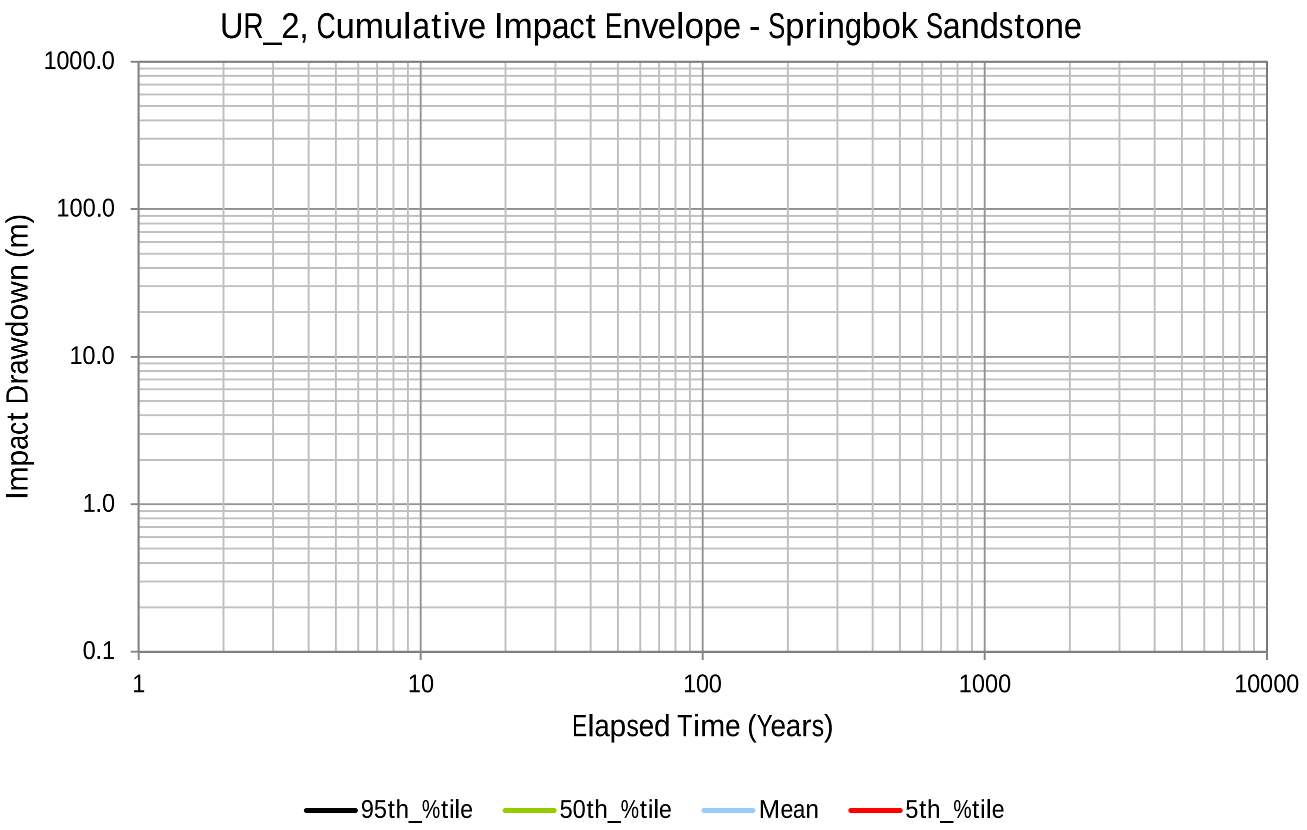


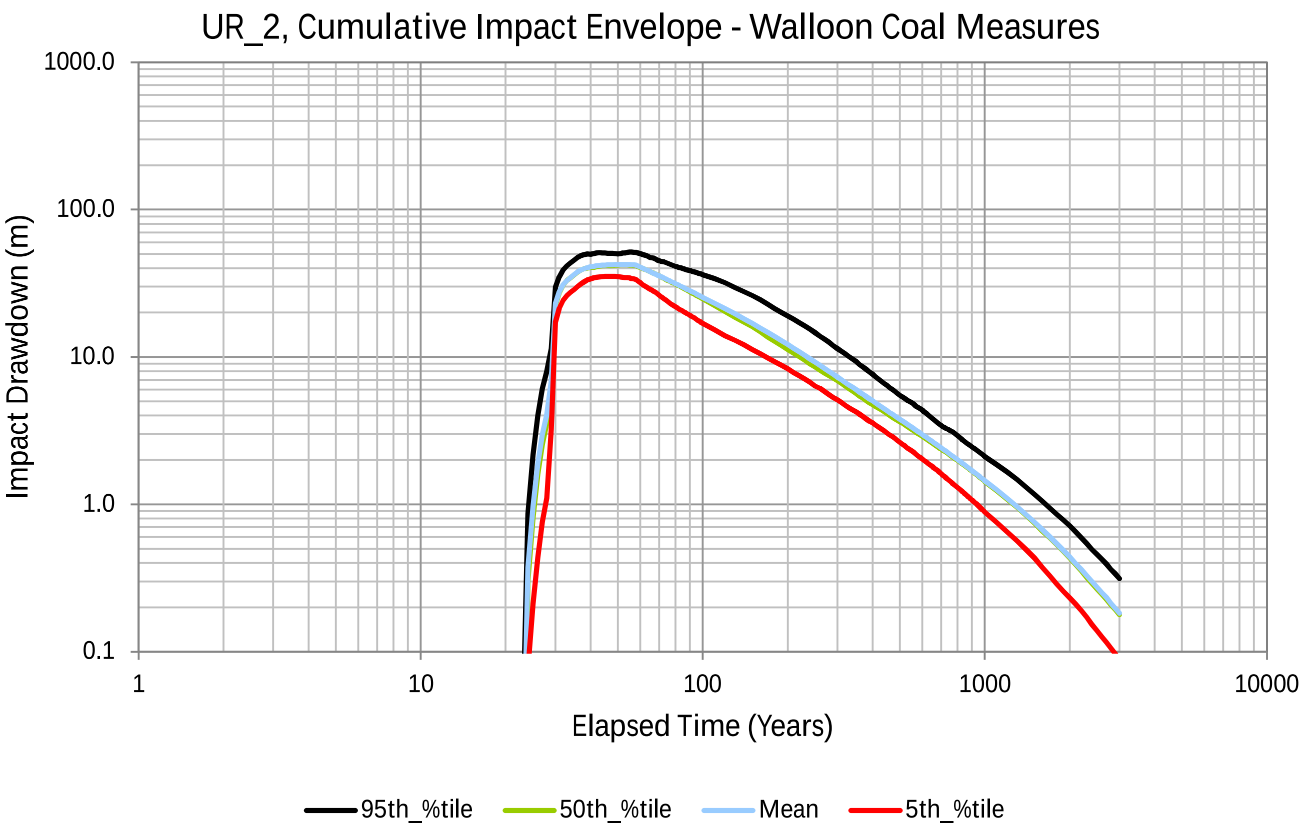
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 7



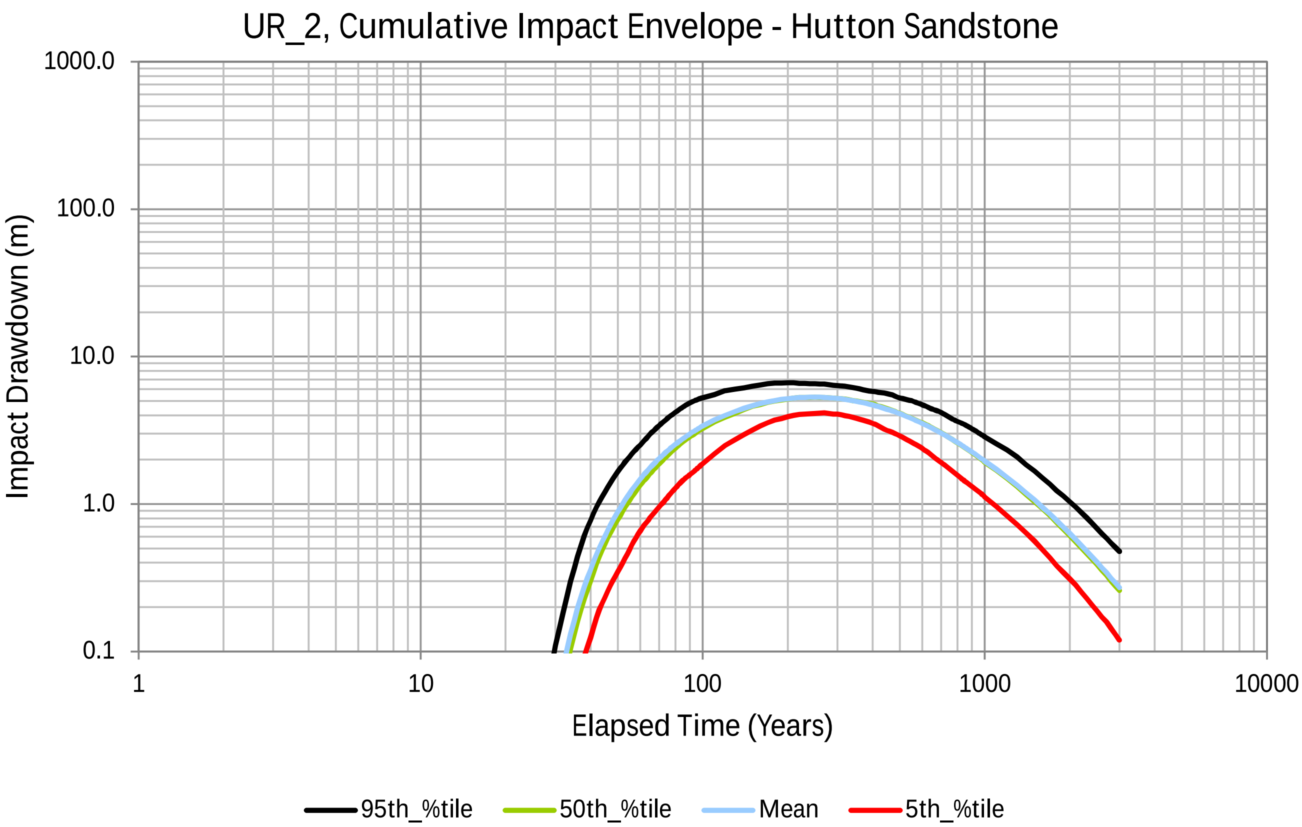


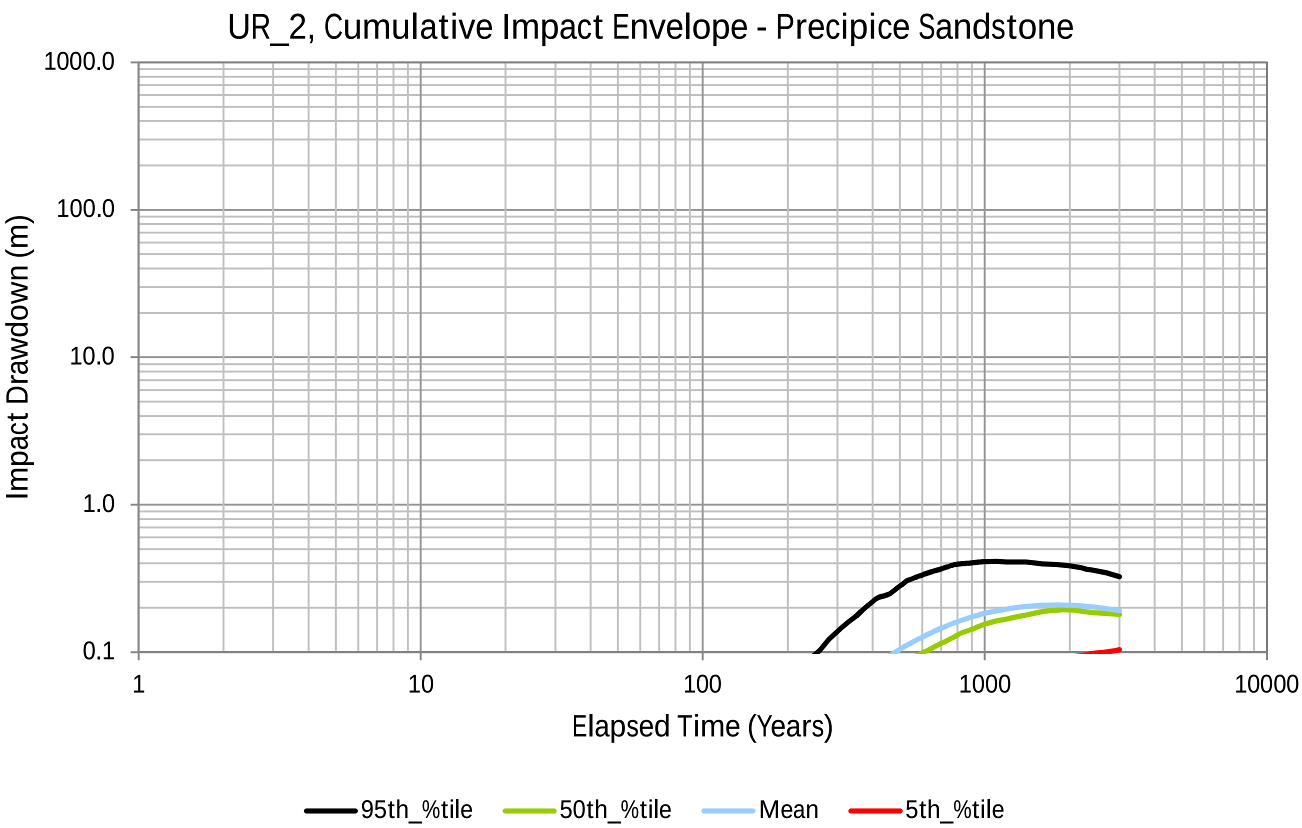
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 7





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 7





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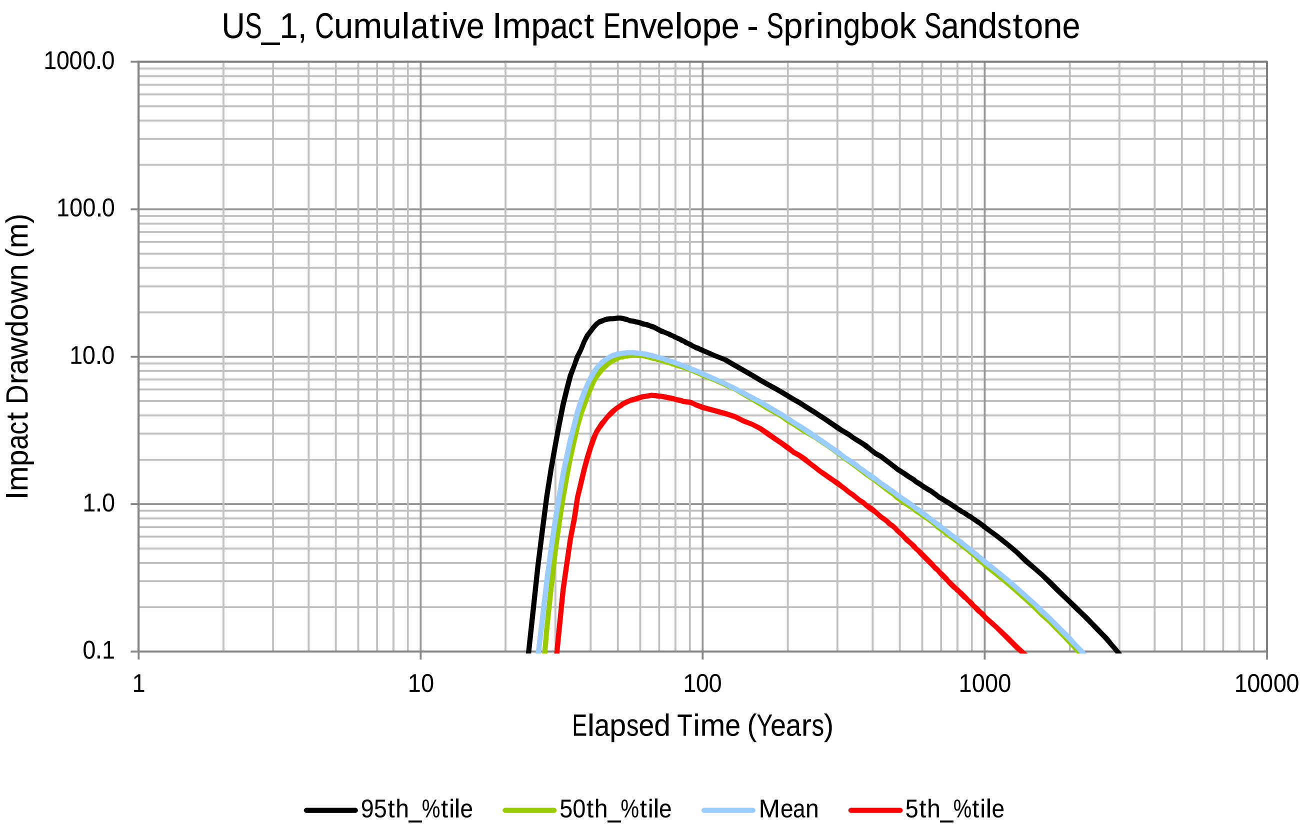
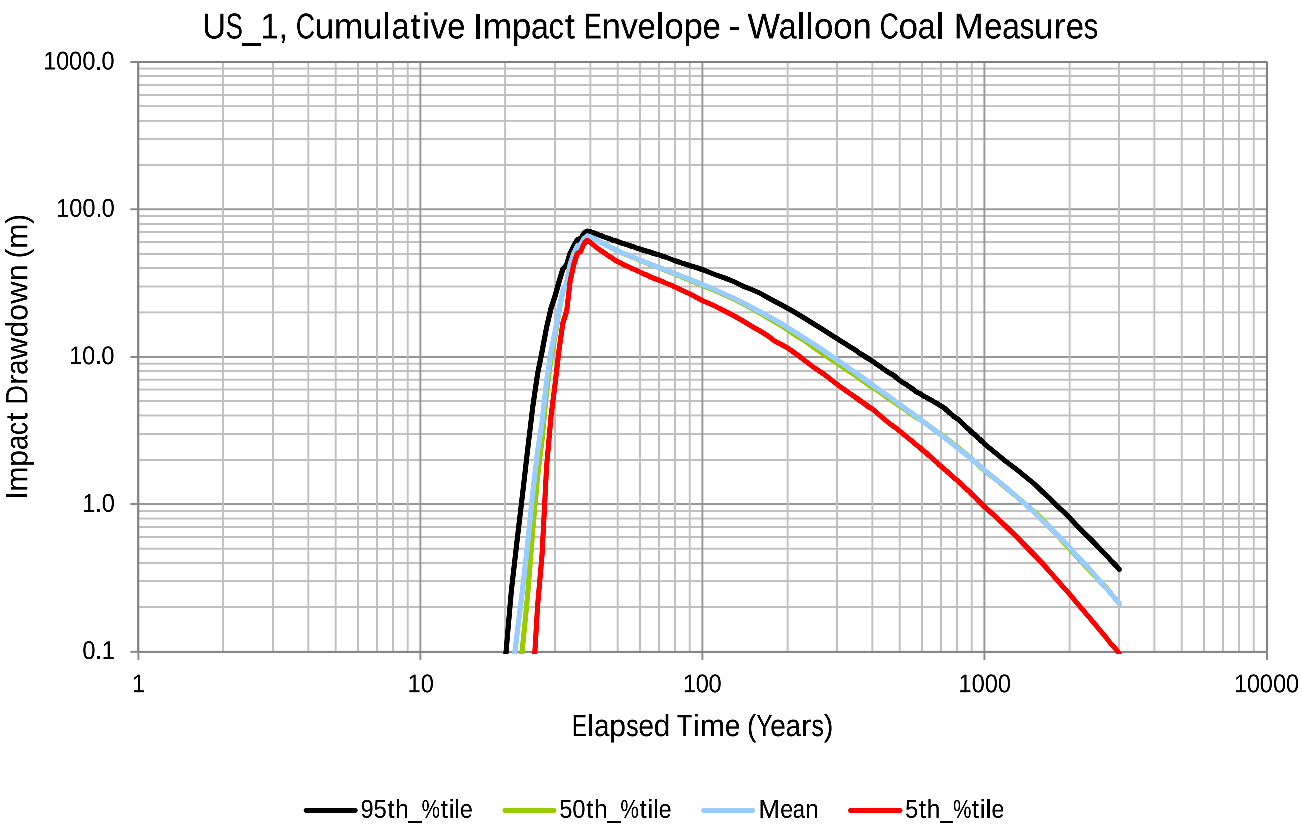
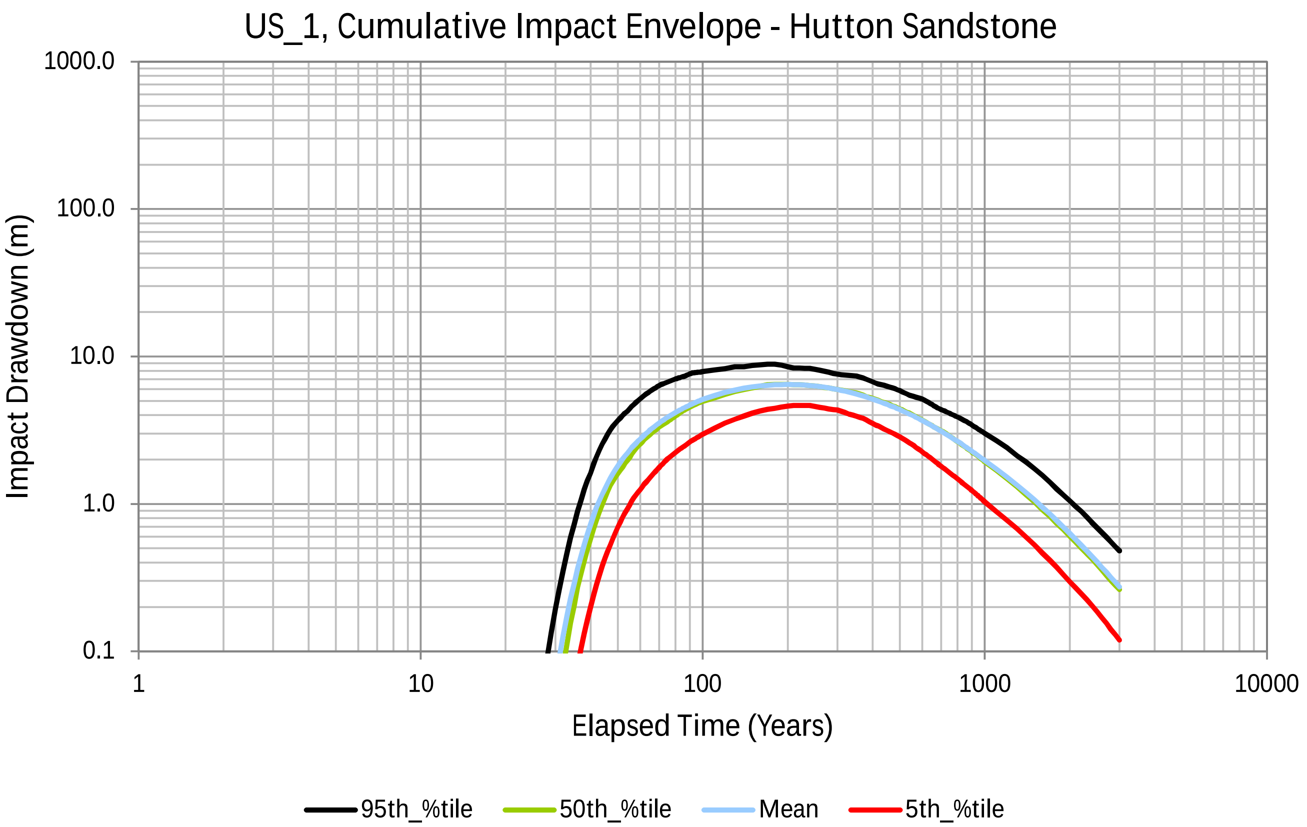
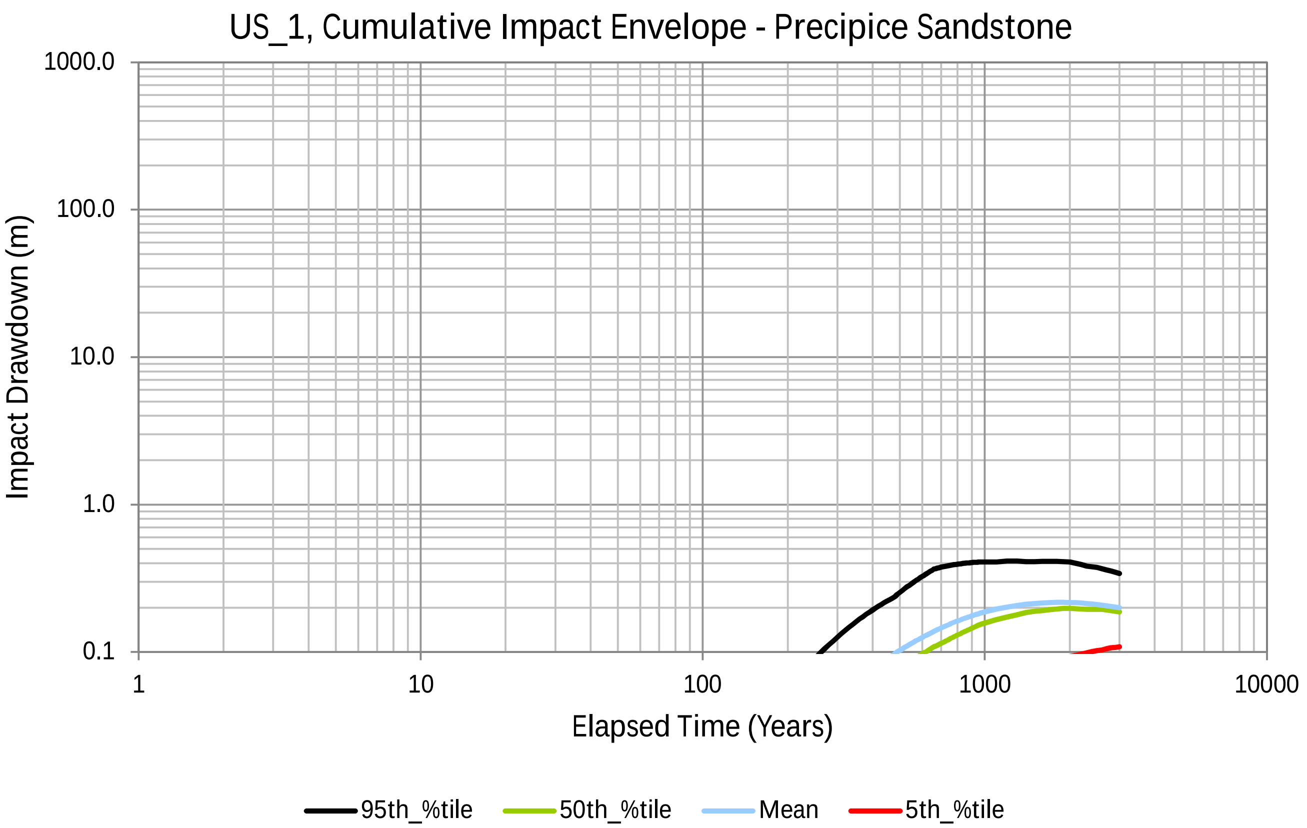
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 7



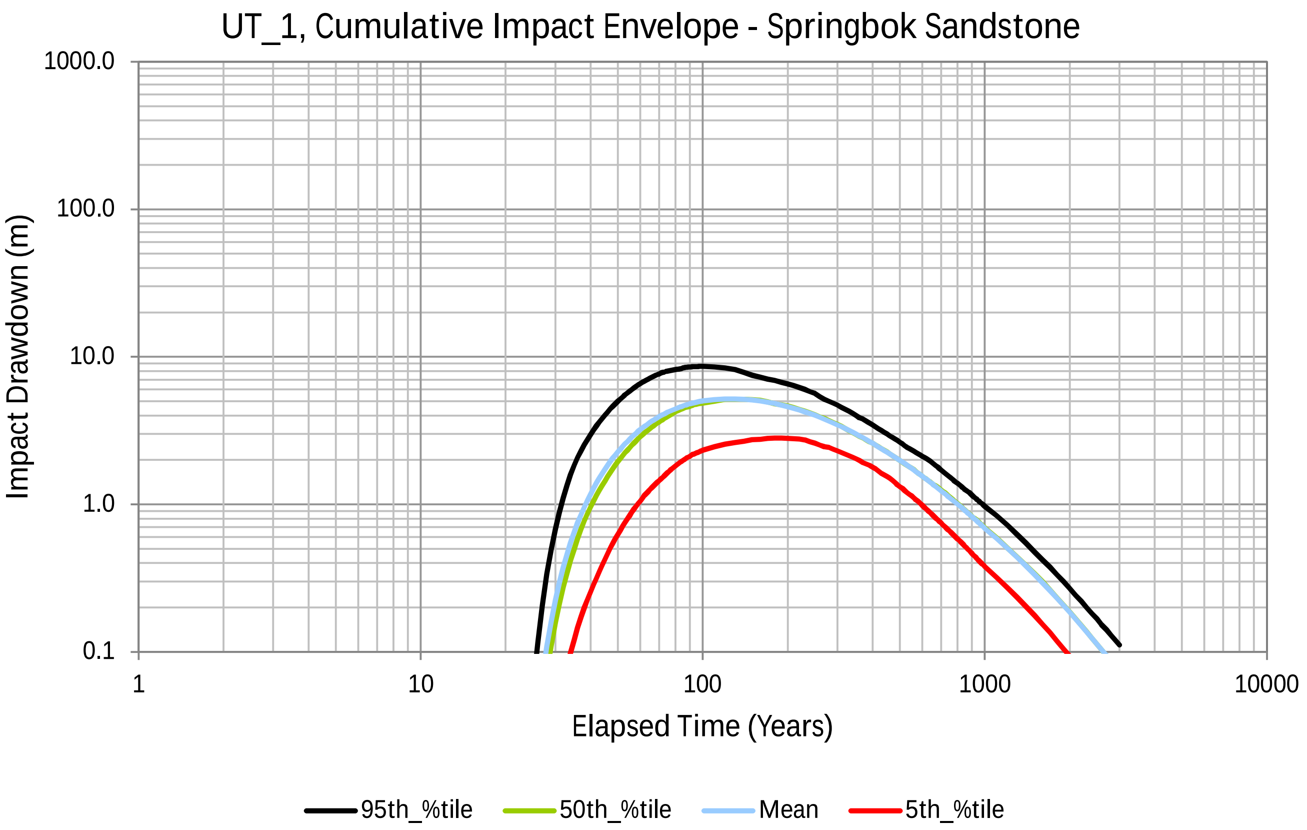


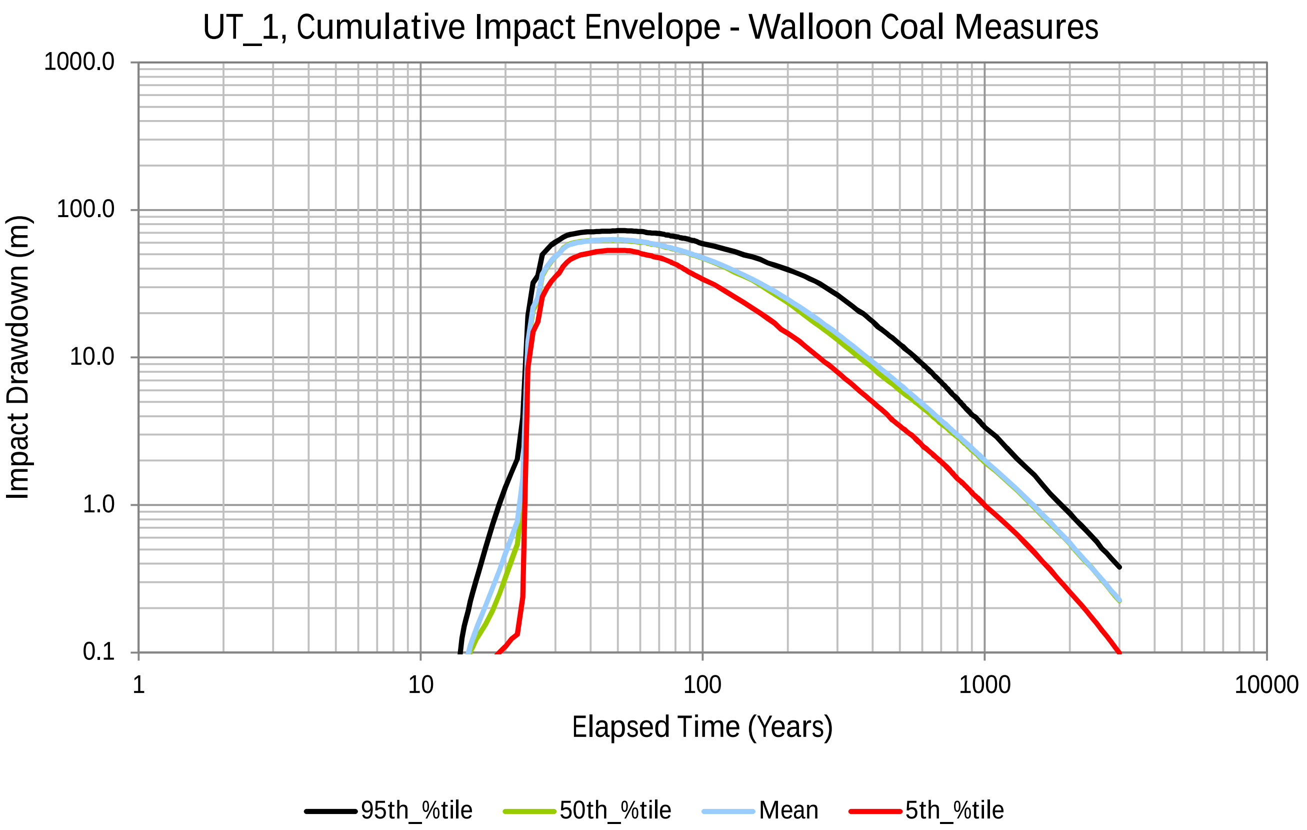
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 7



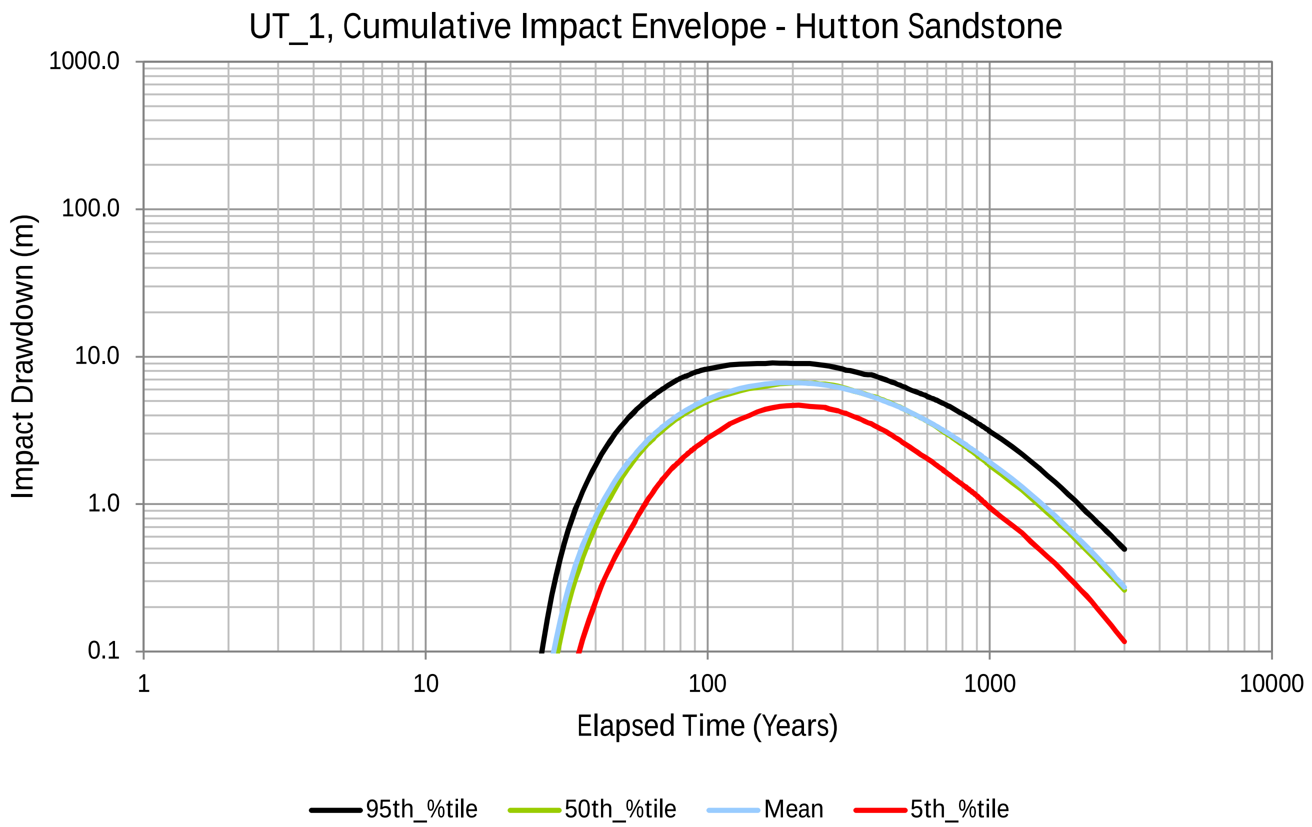


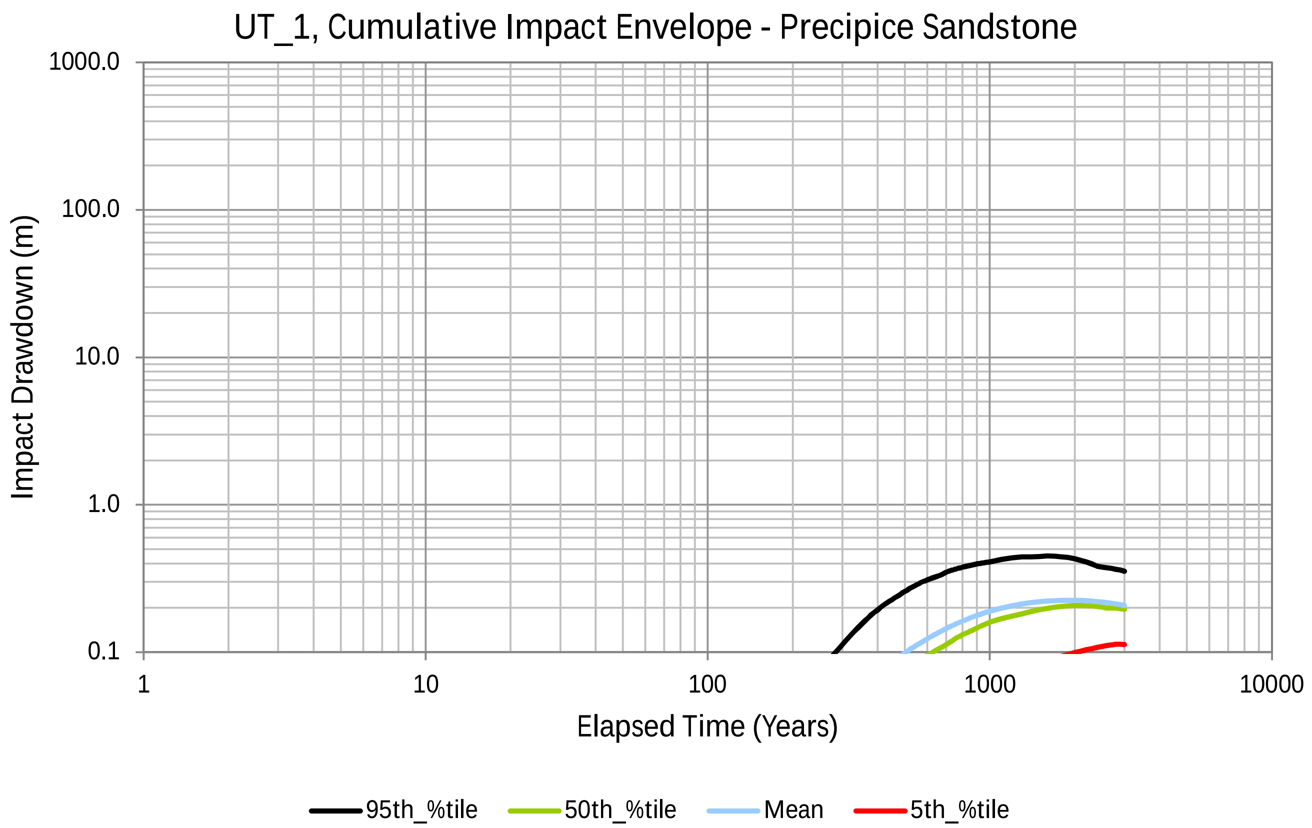
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8





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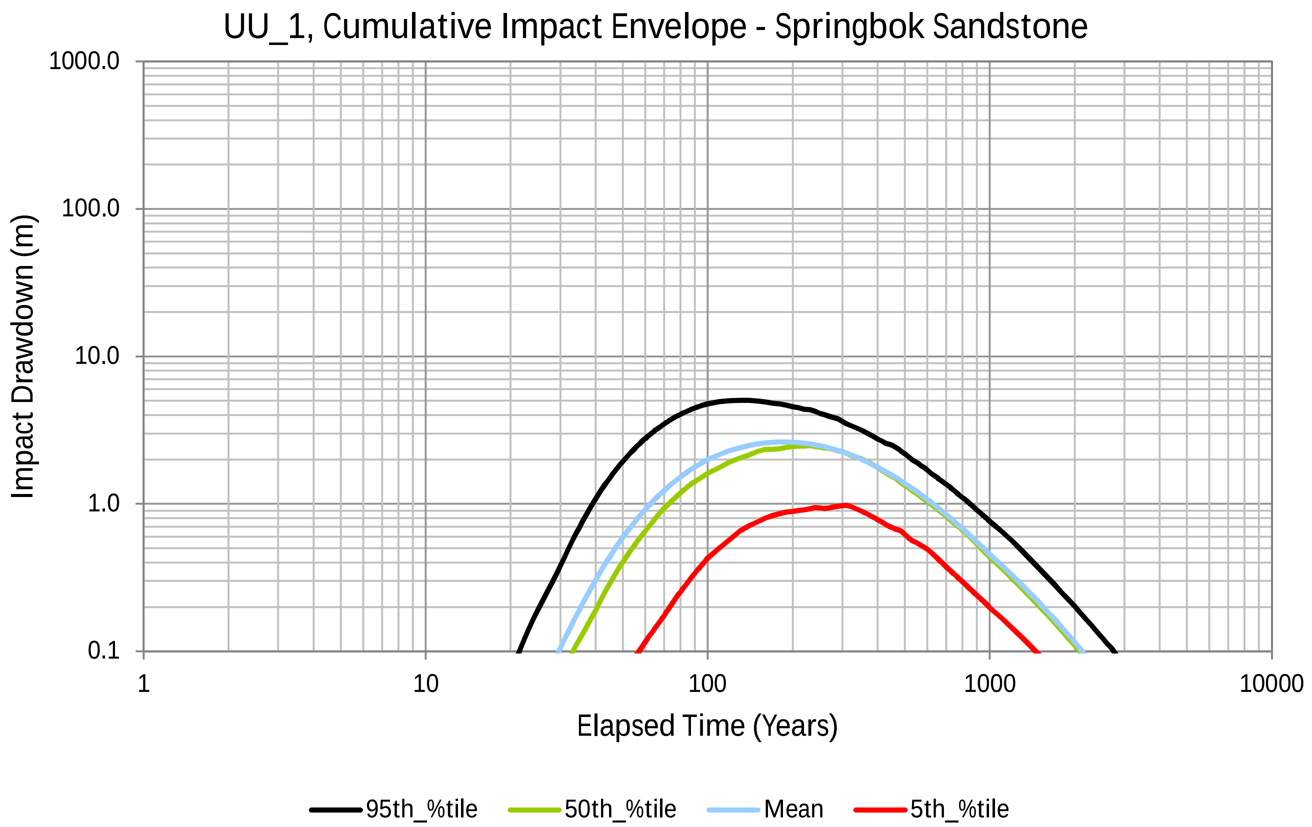
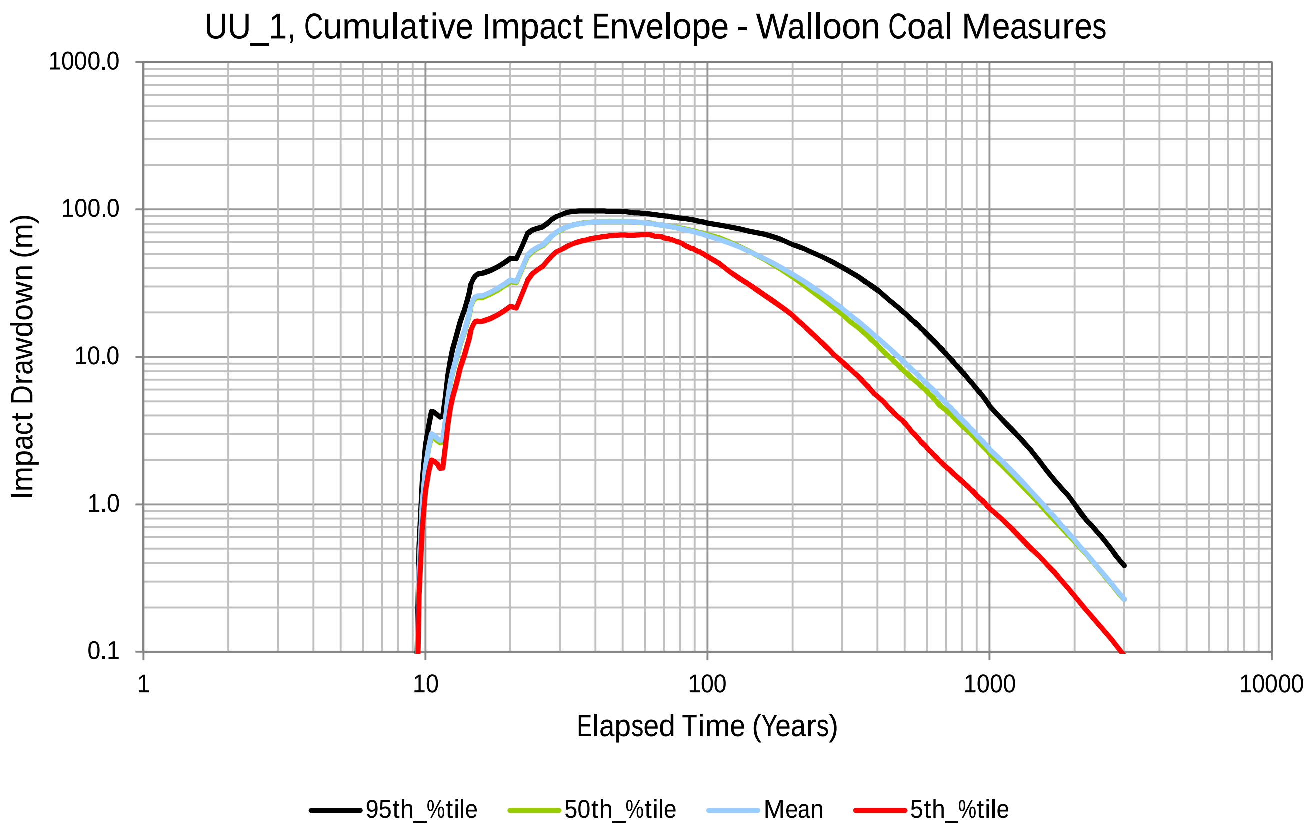
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8





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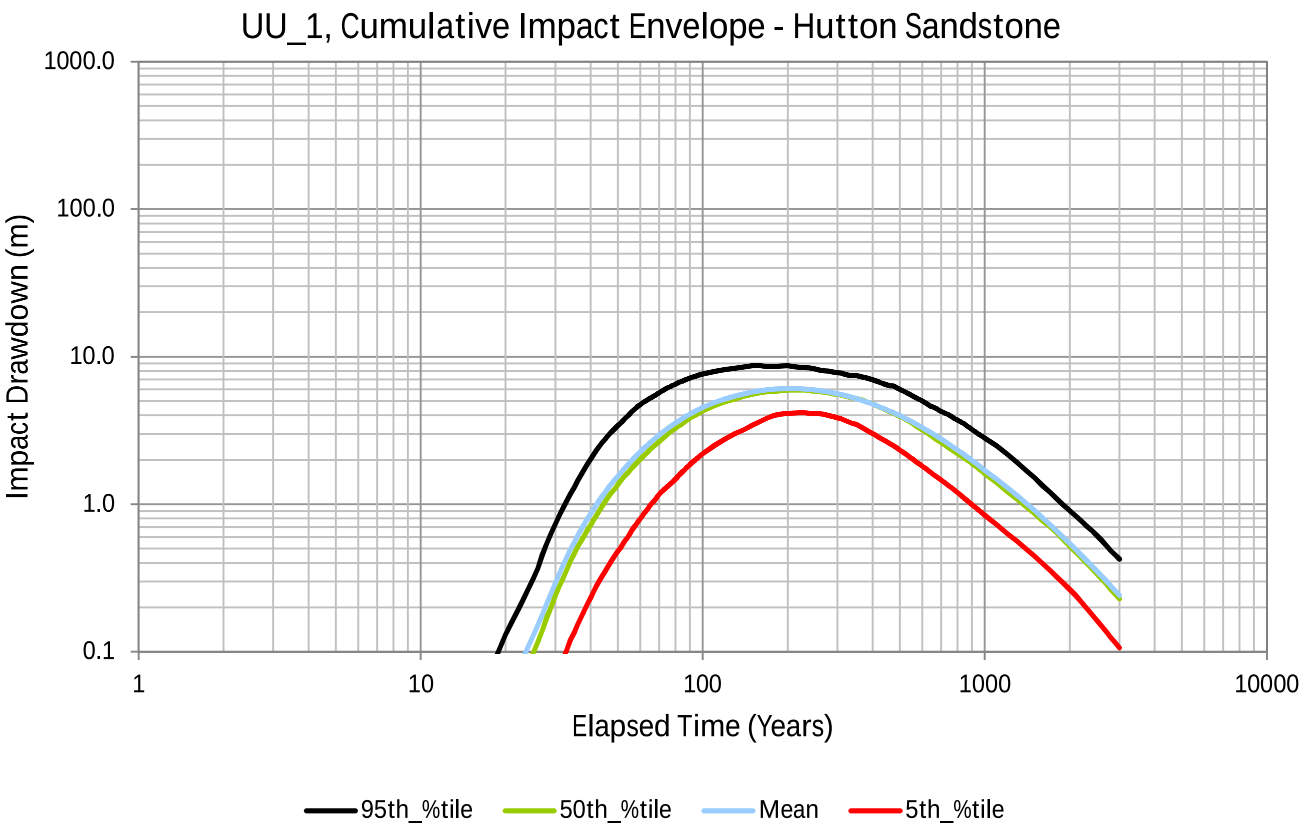
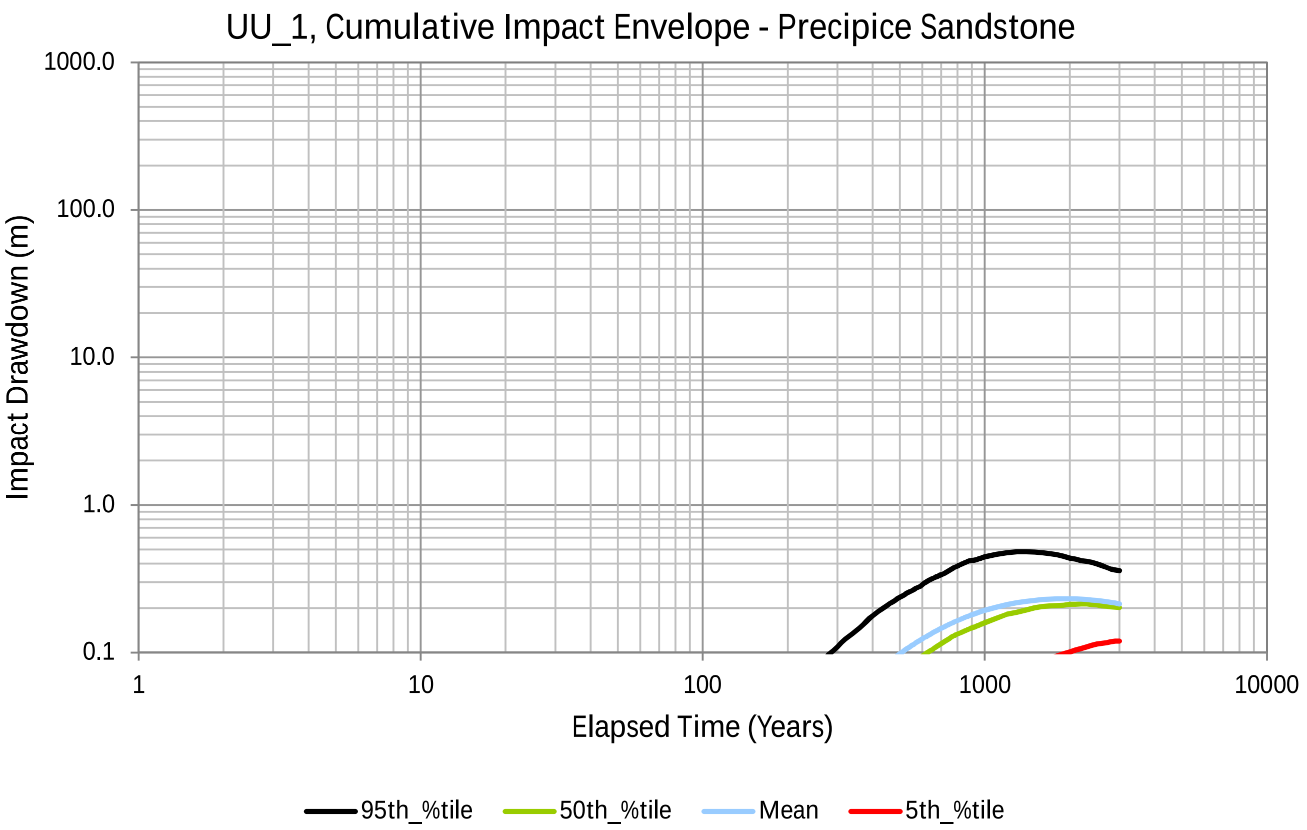
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8





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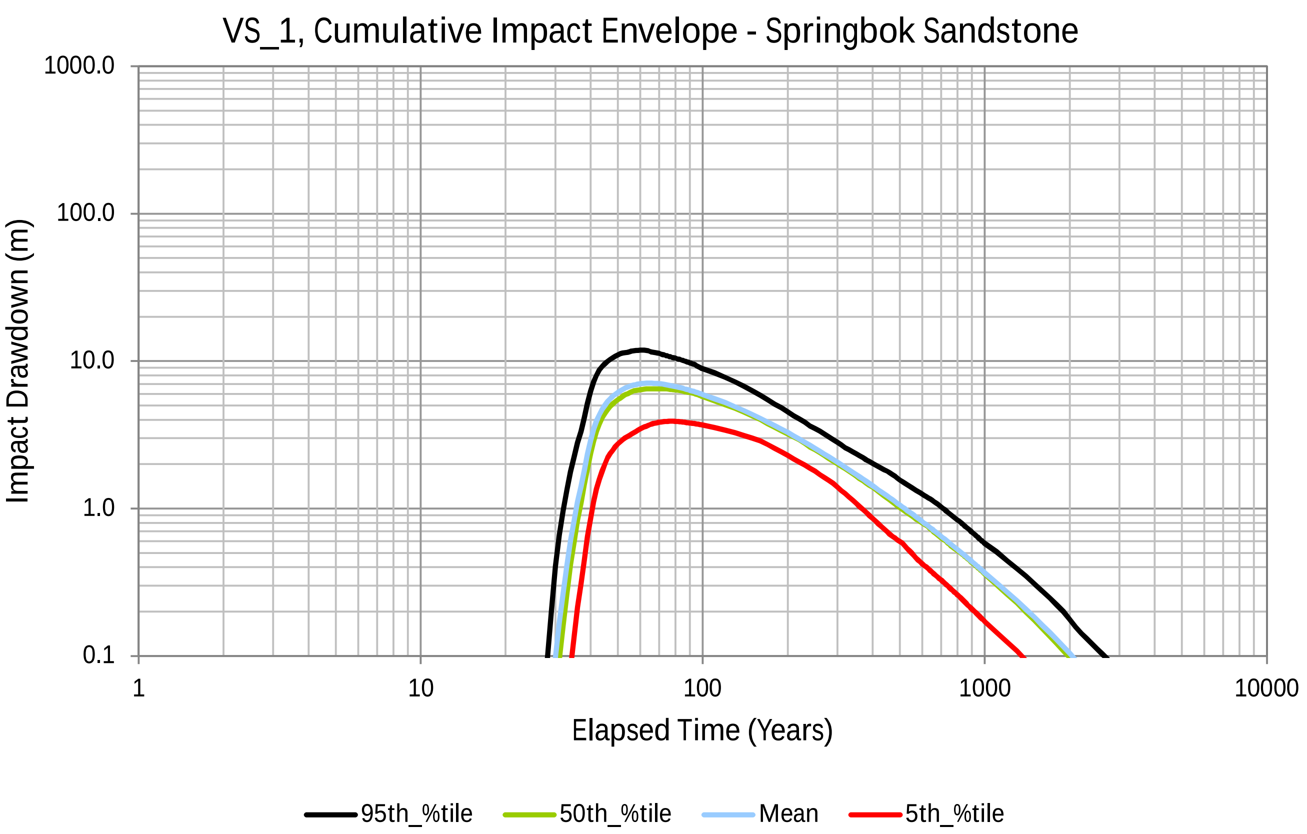
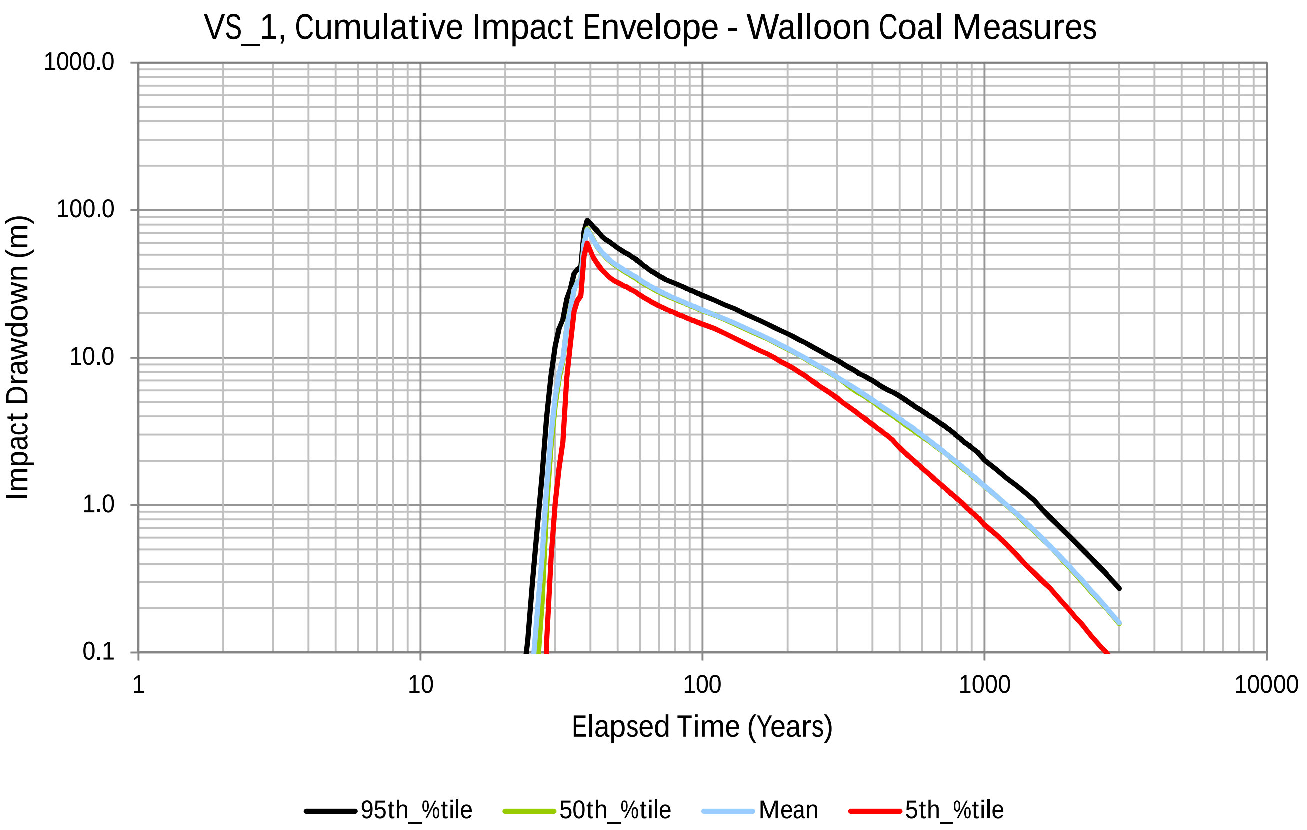
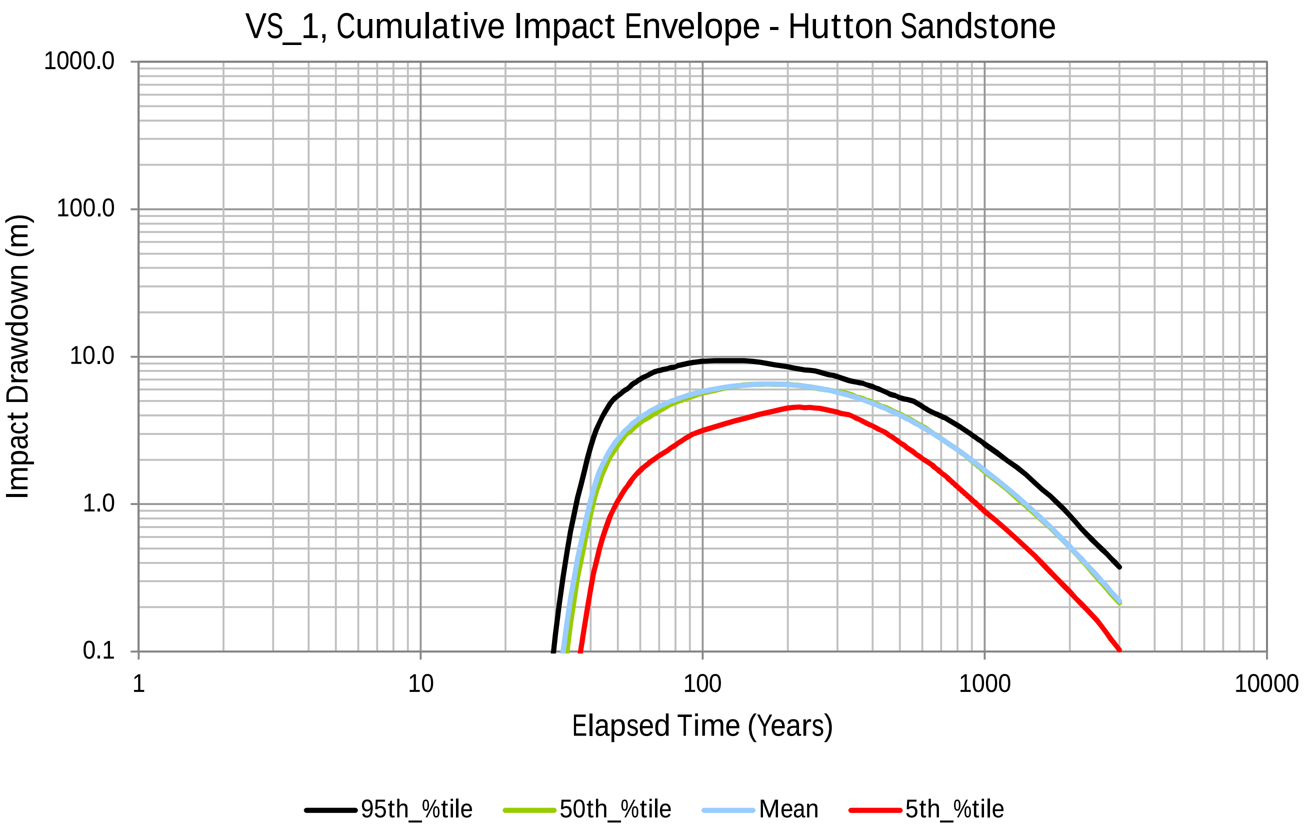
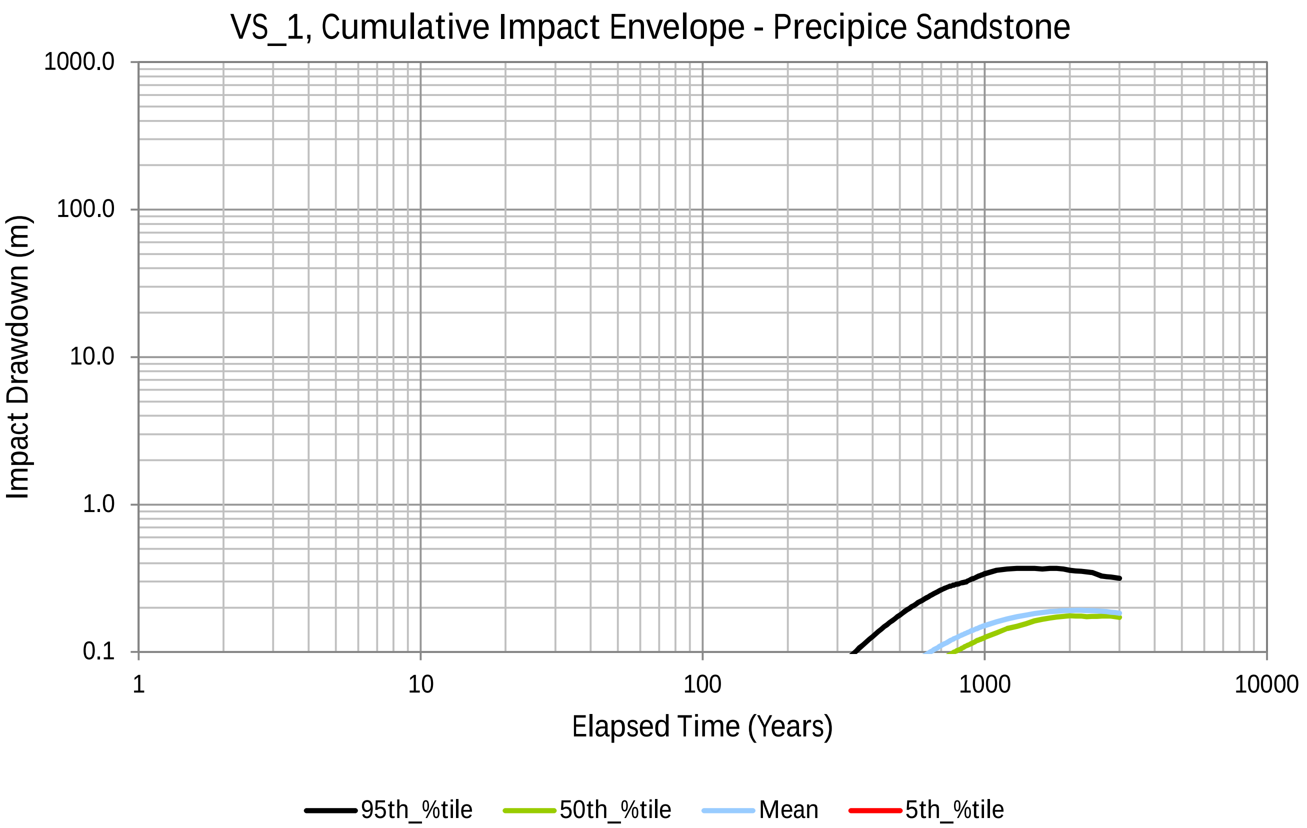
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8





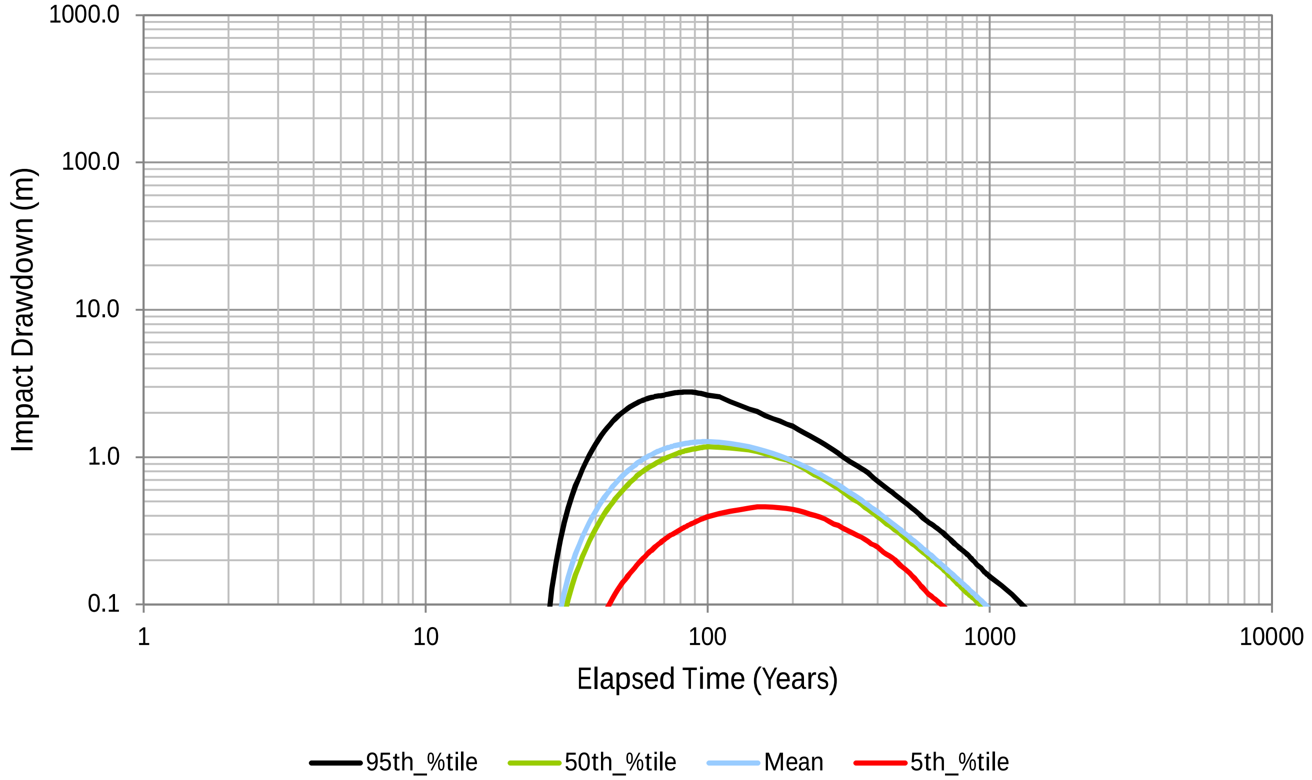
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8



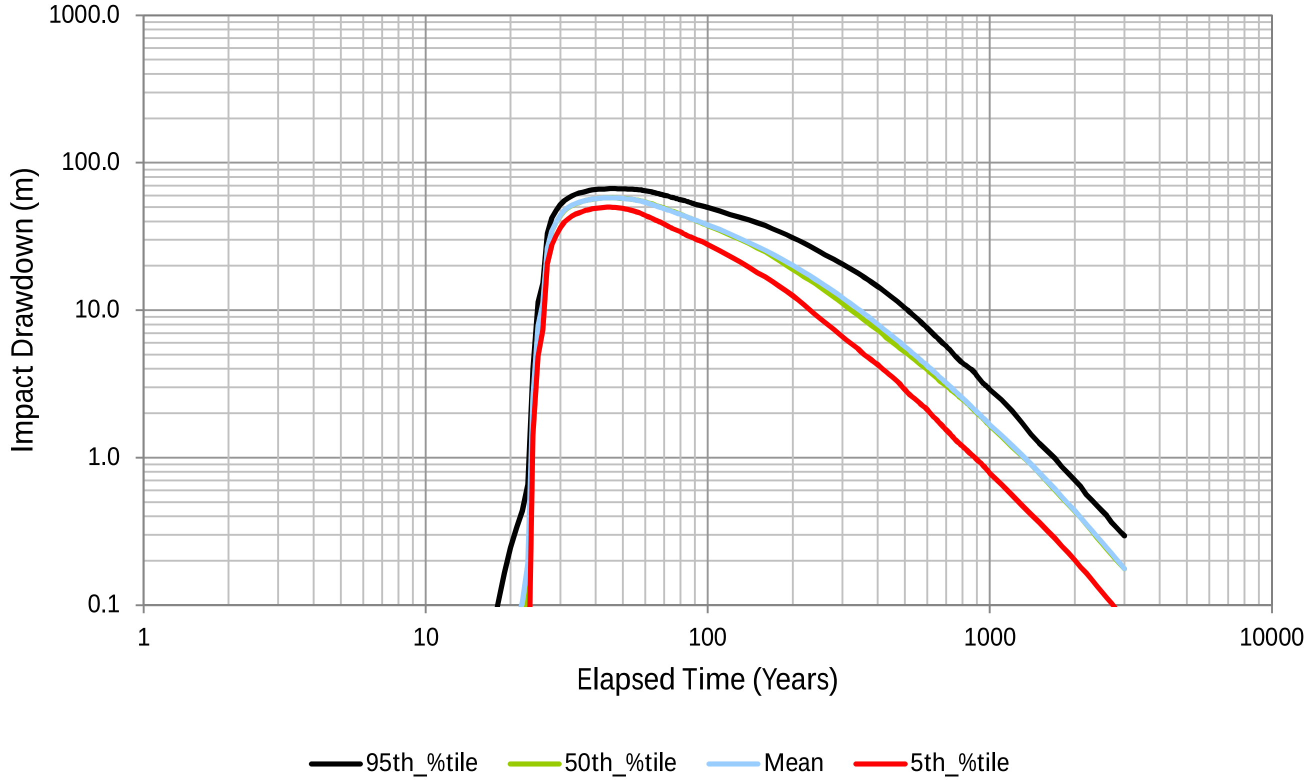


Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8

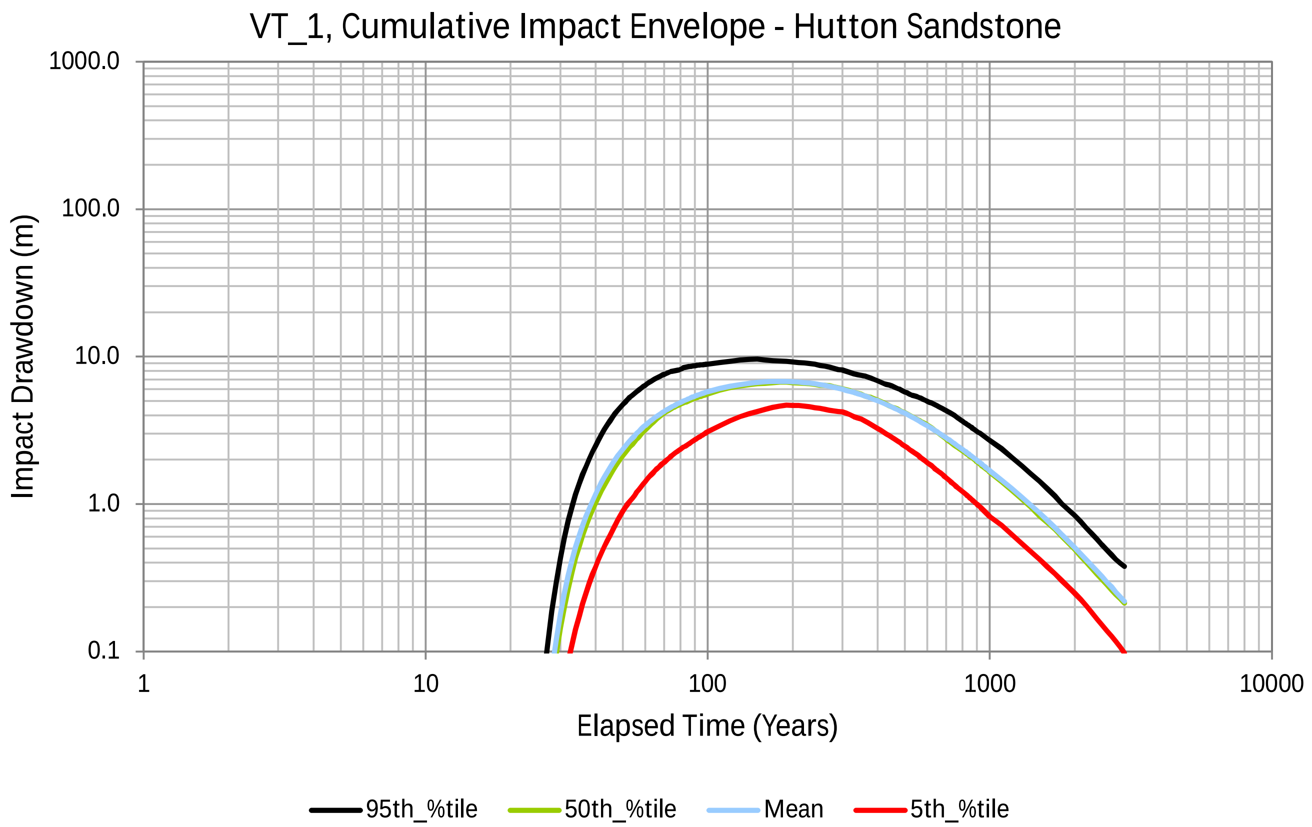
VT_1, Cumulative Impact Envelope - Springbok Sandstone

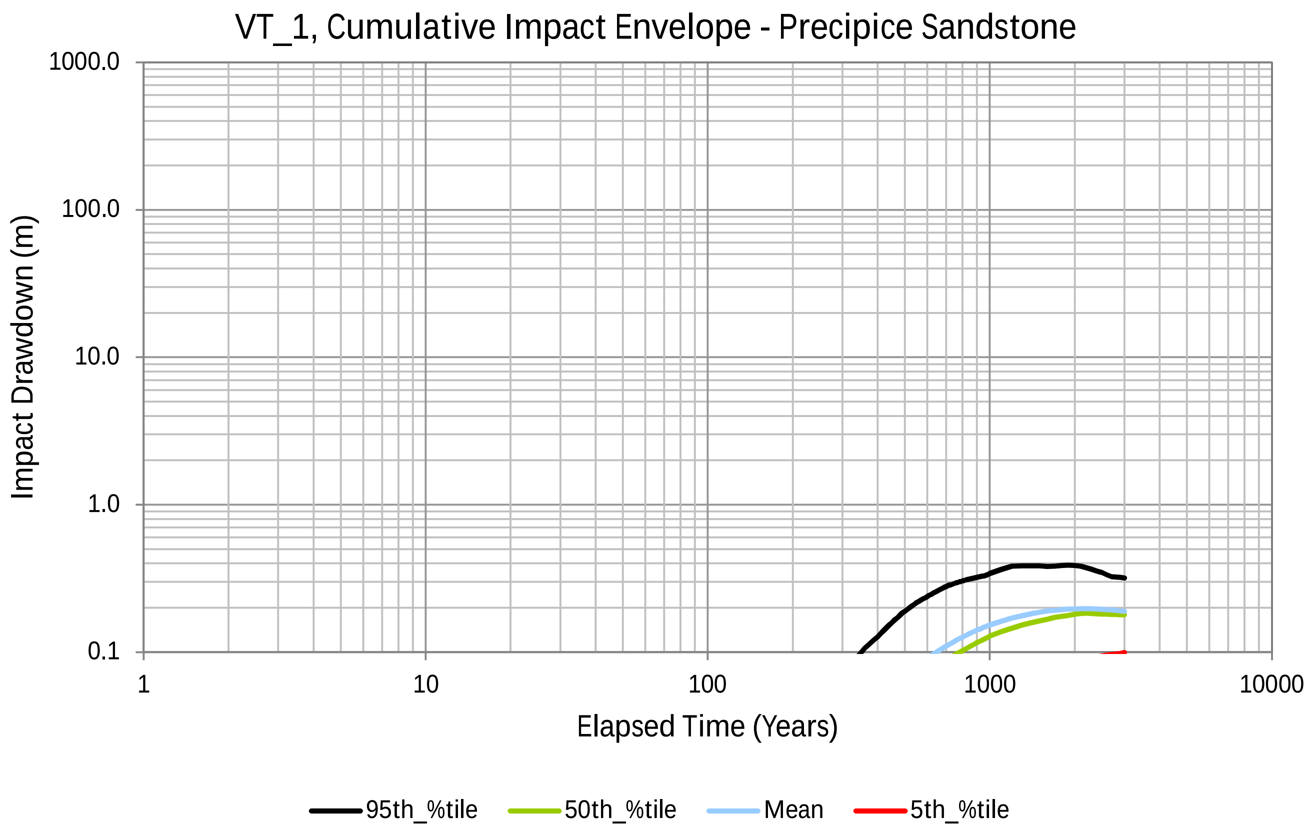


VT_1, Cumulative Impact Envelope - Walloon Coal Measures



Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8





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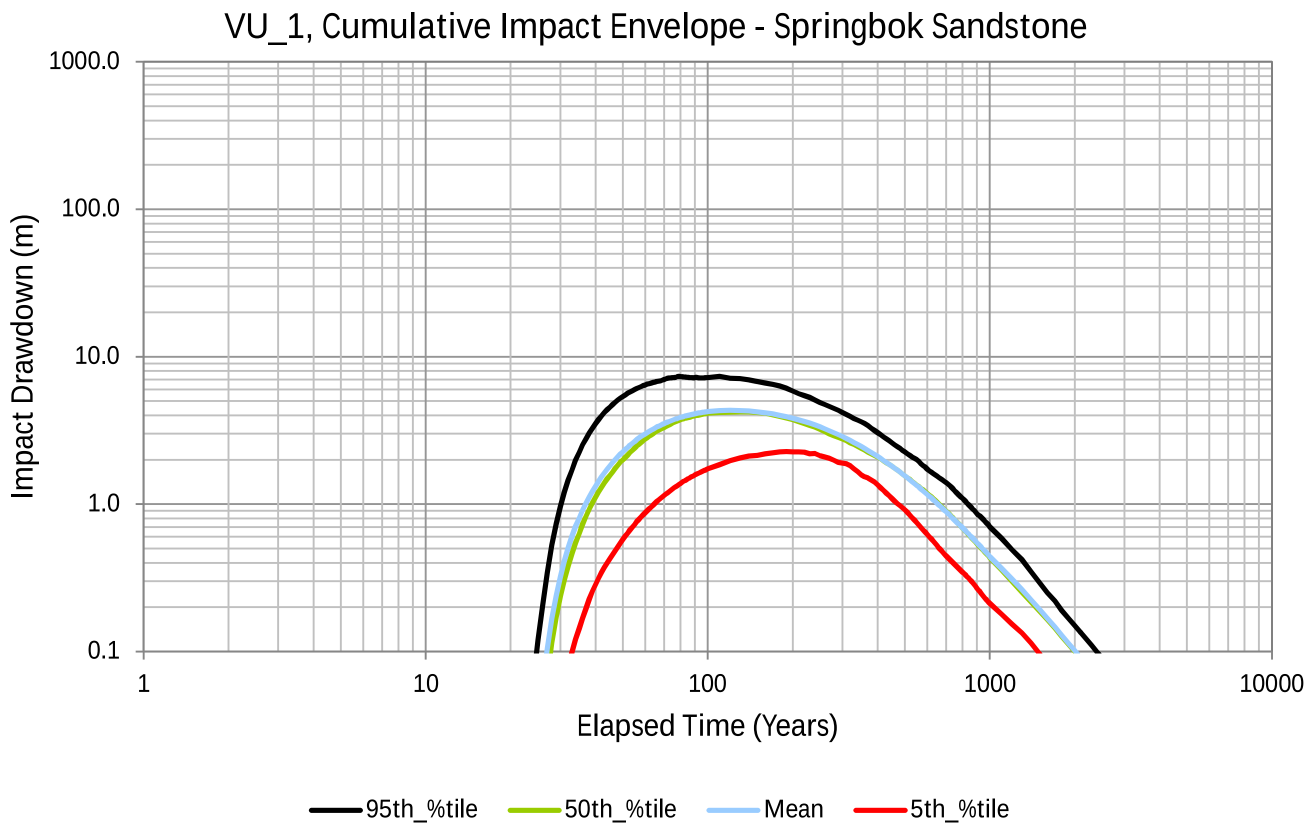
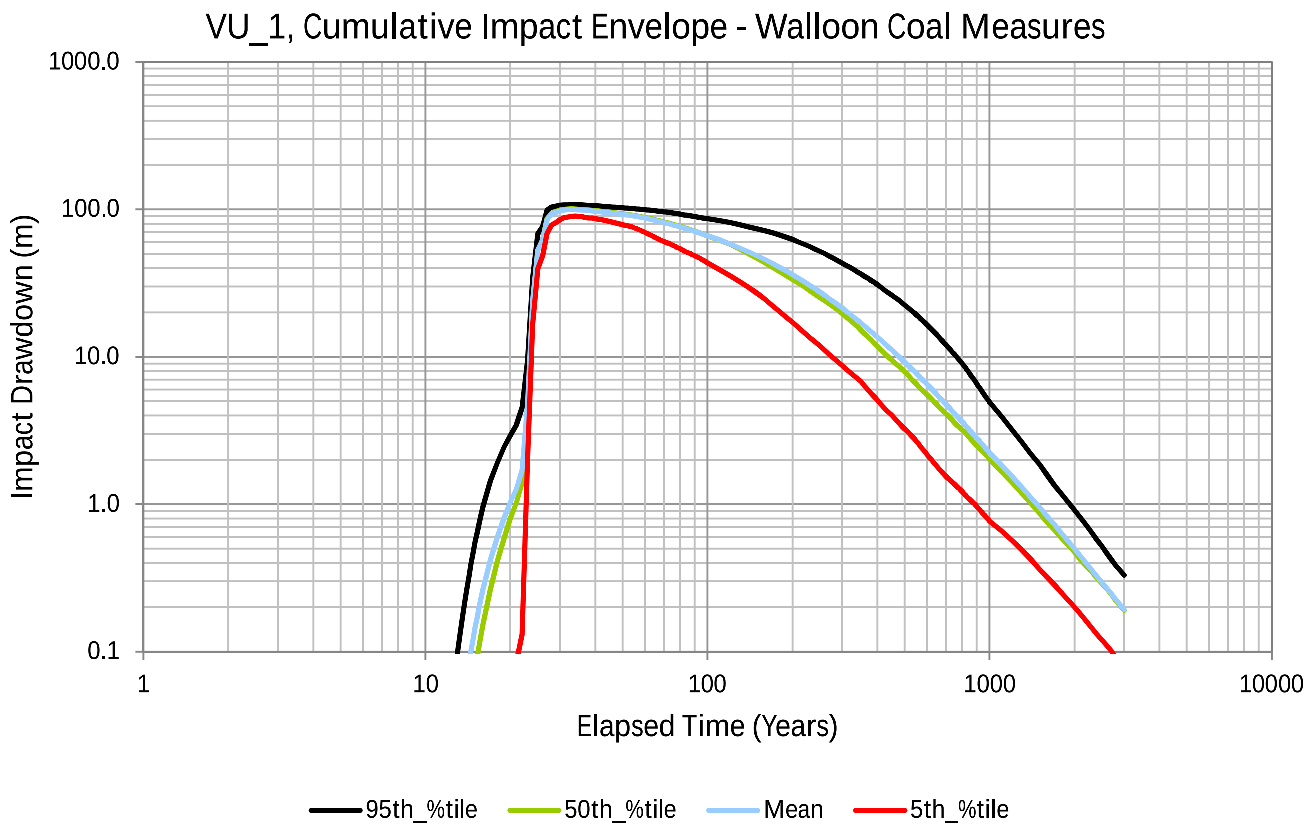
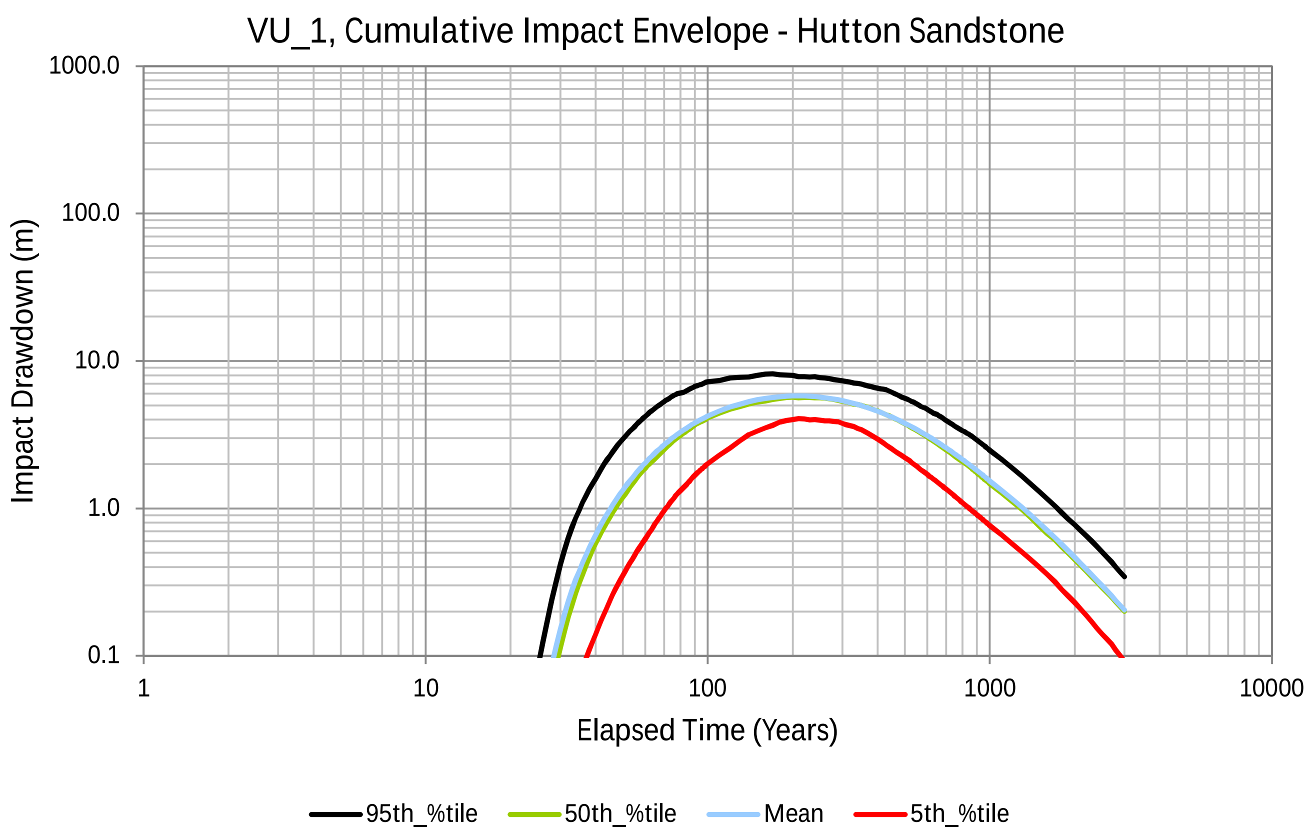
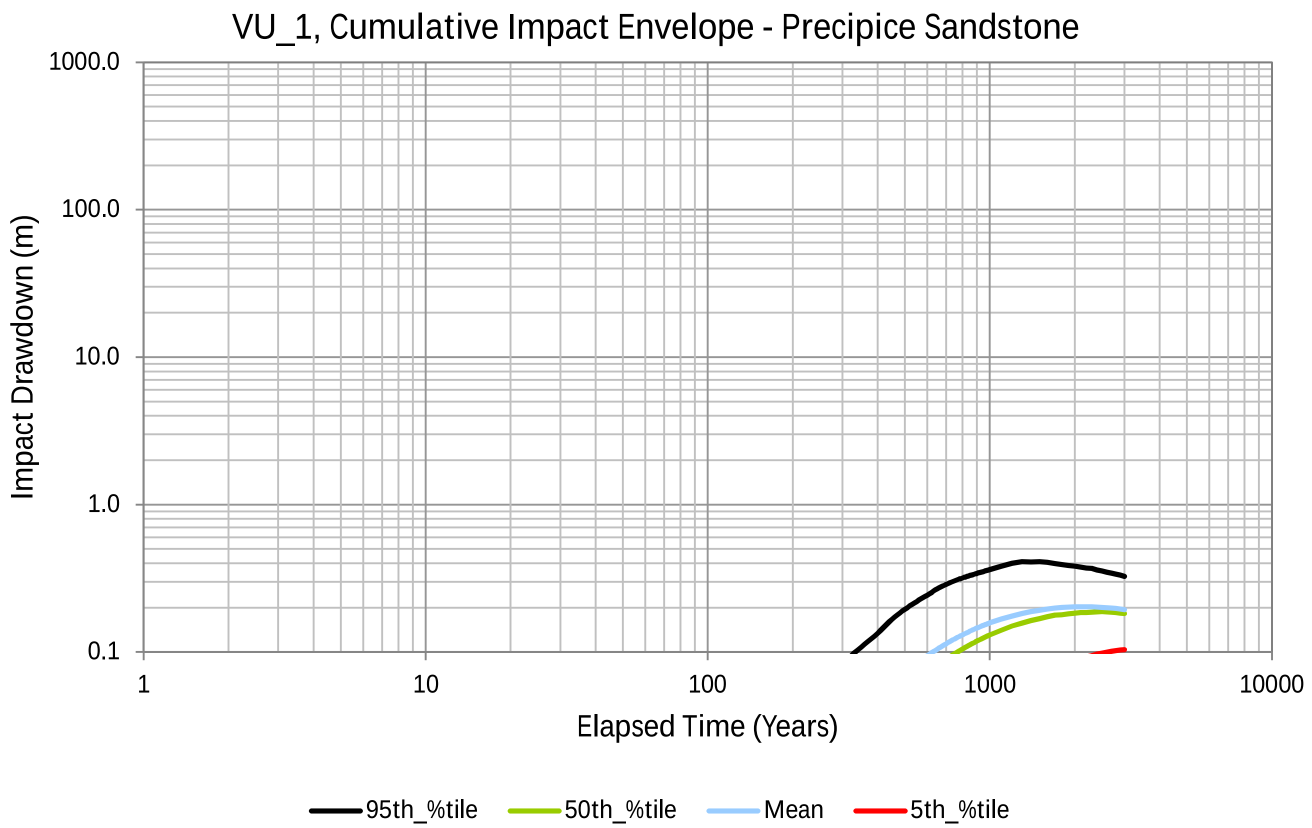
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8





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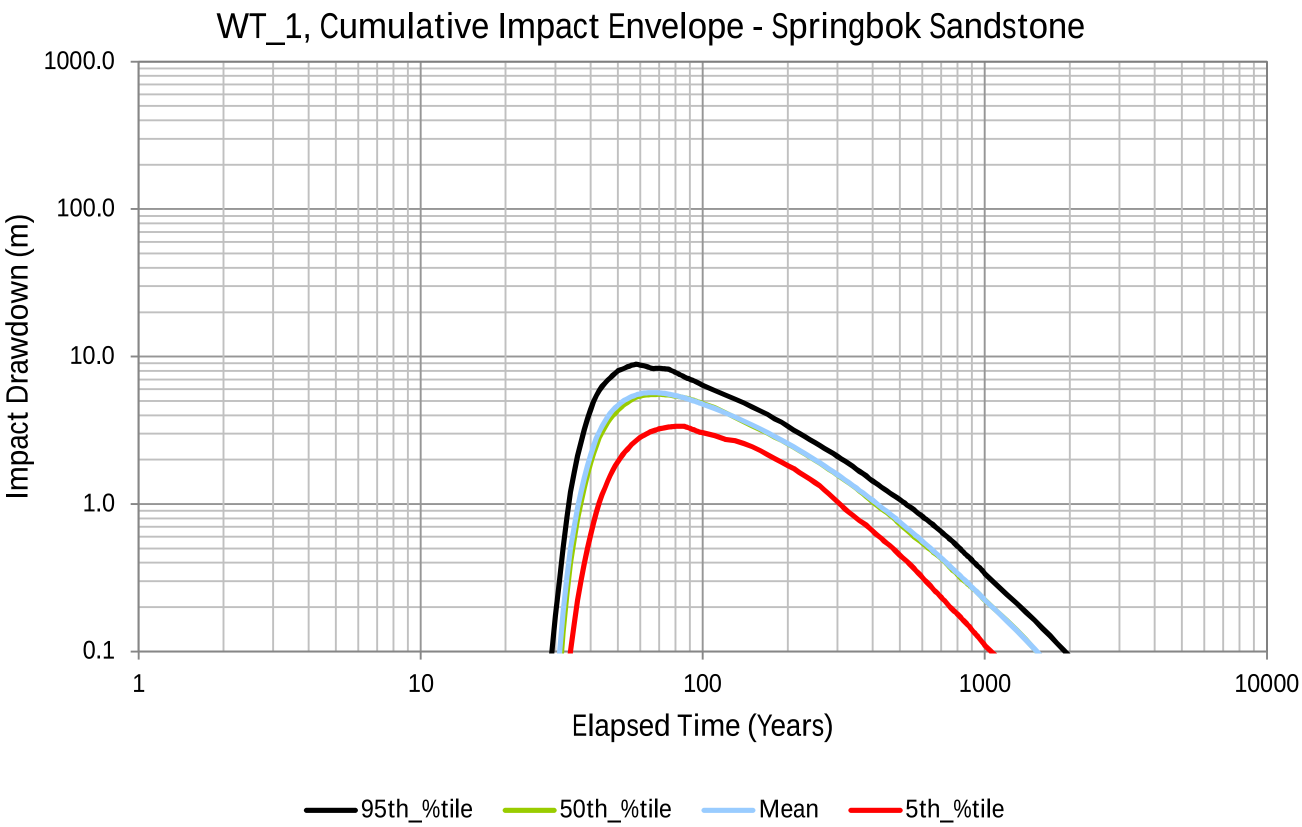
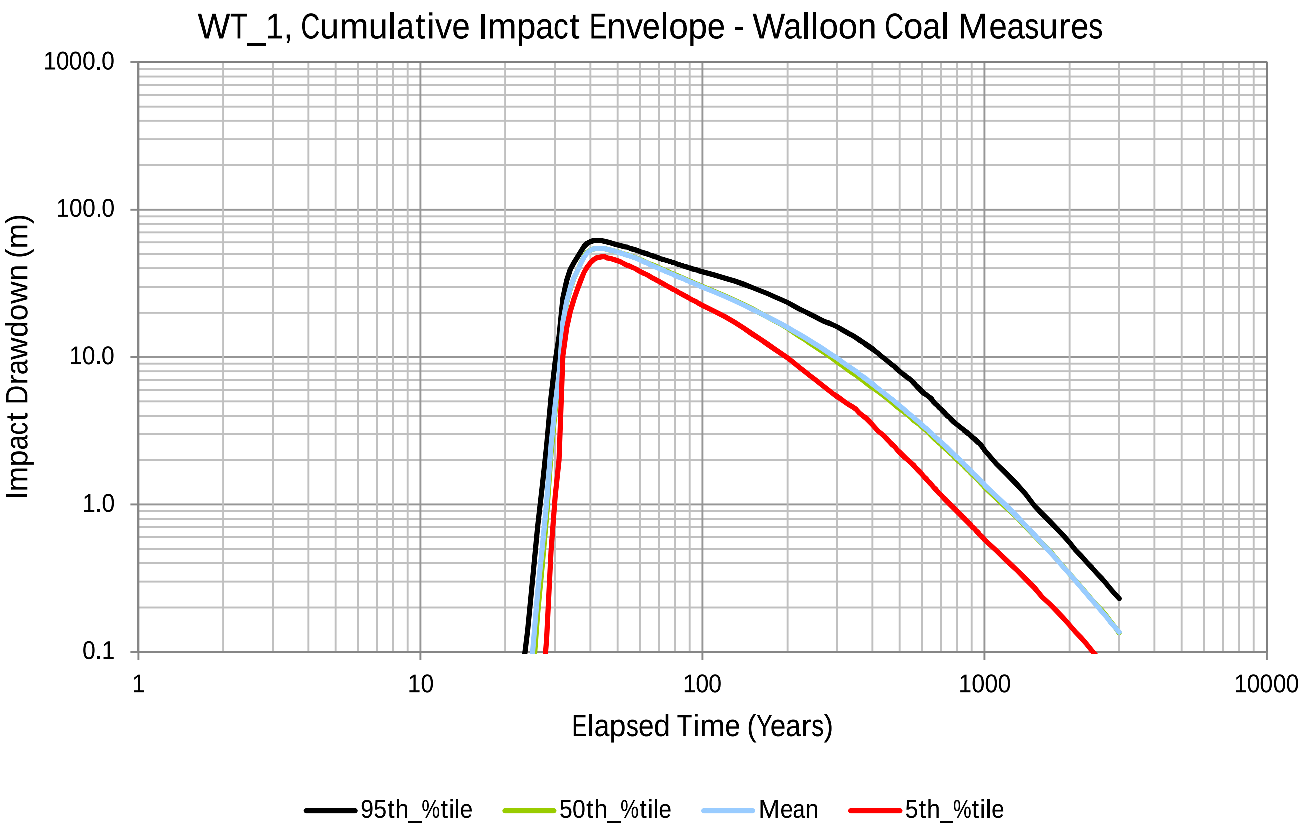
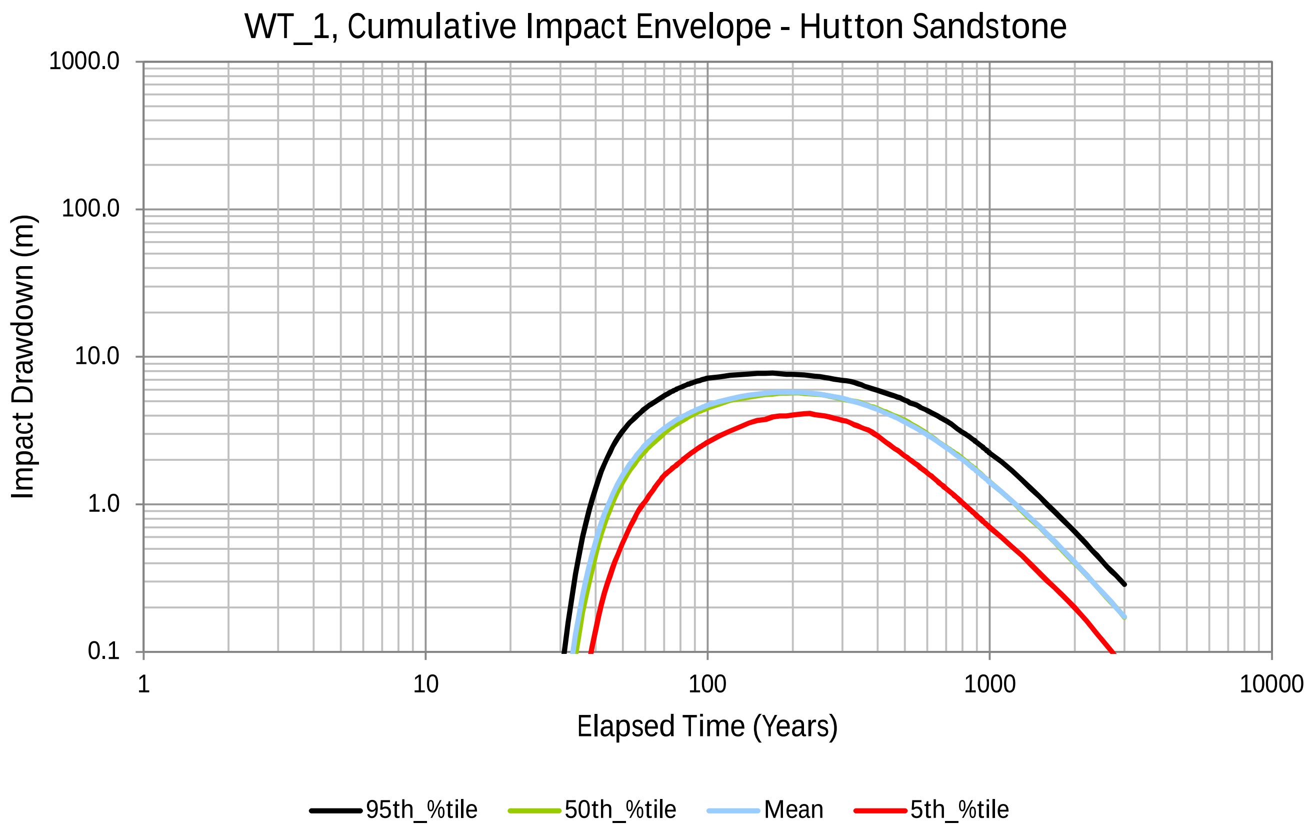
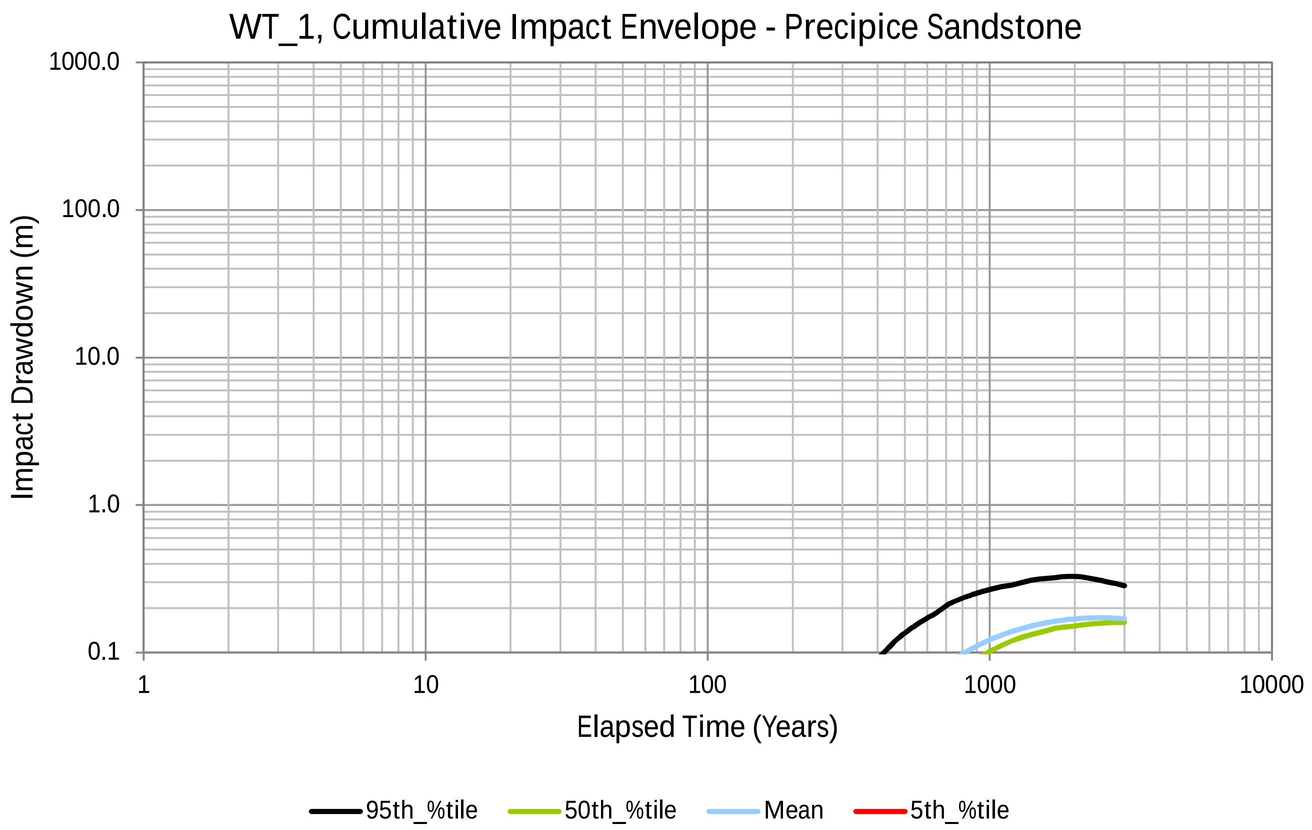
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8



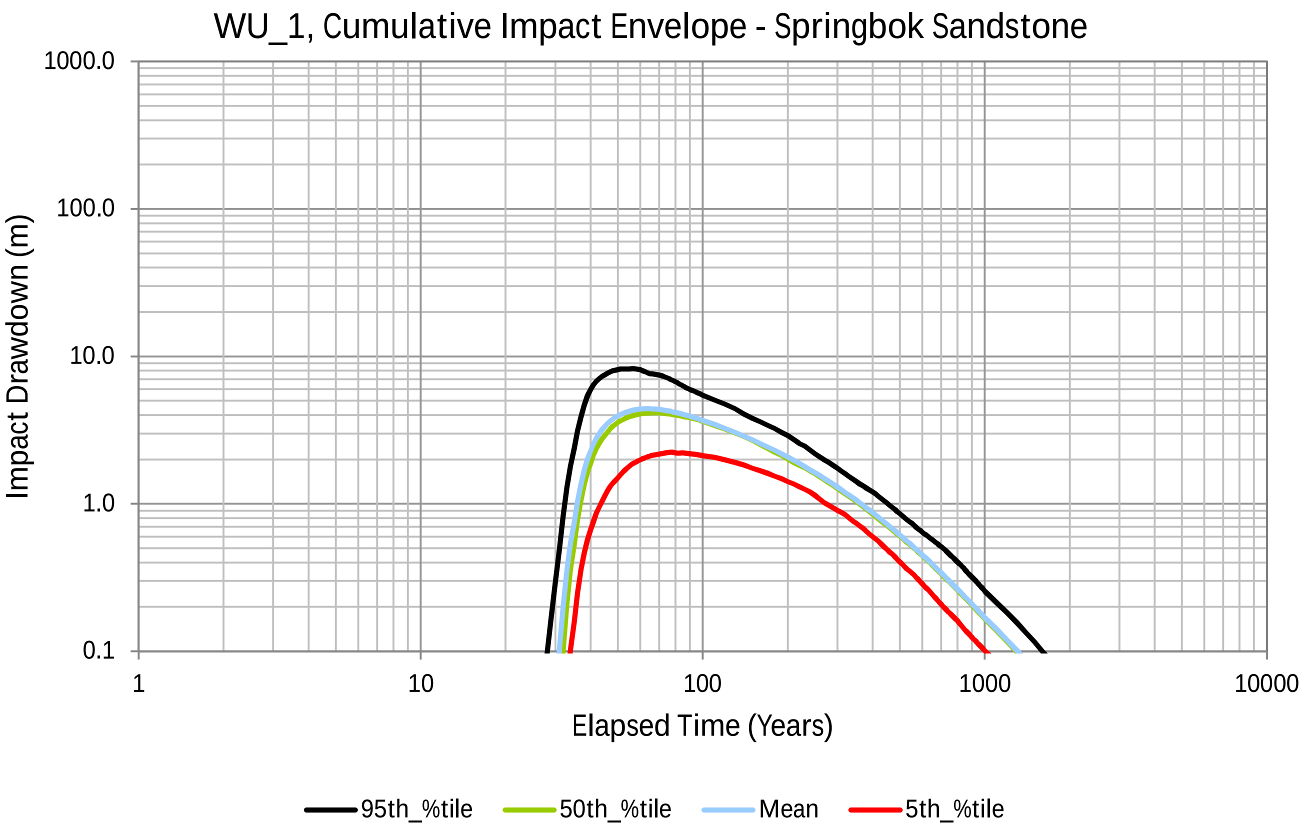


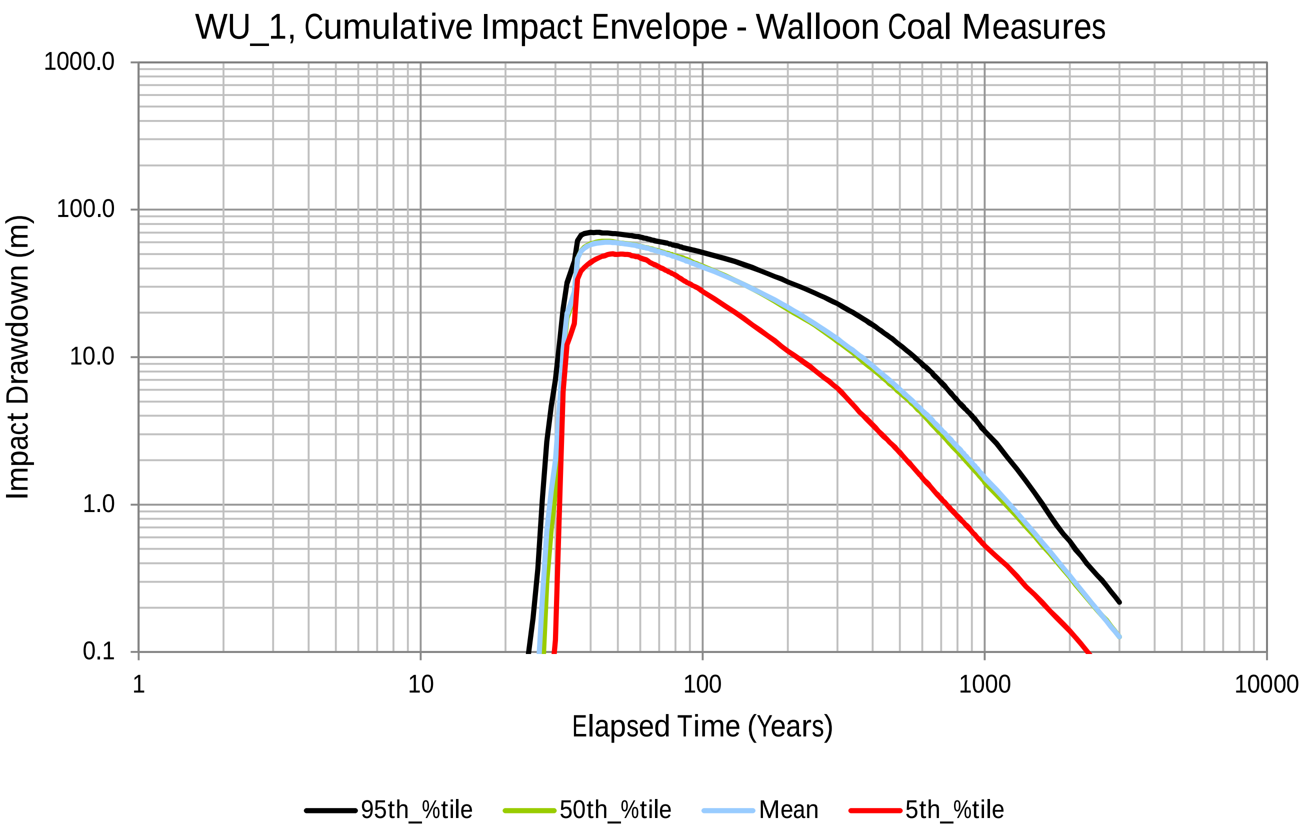
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8



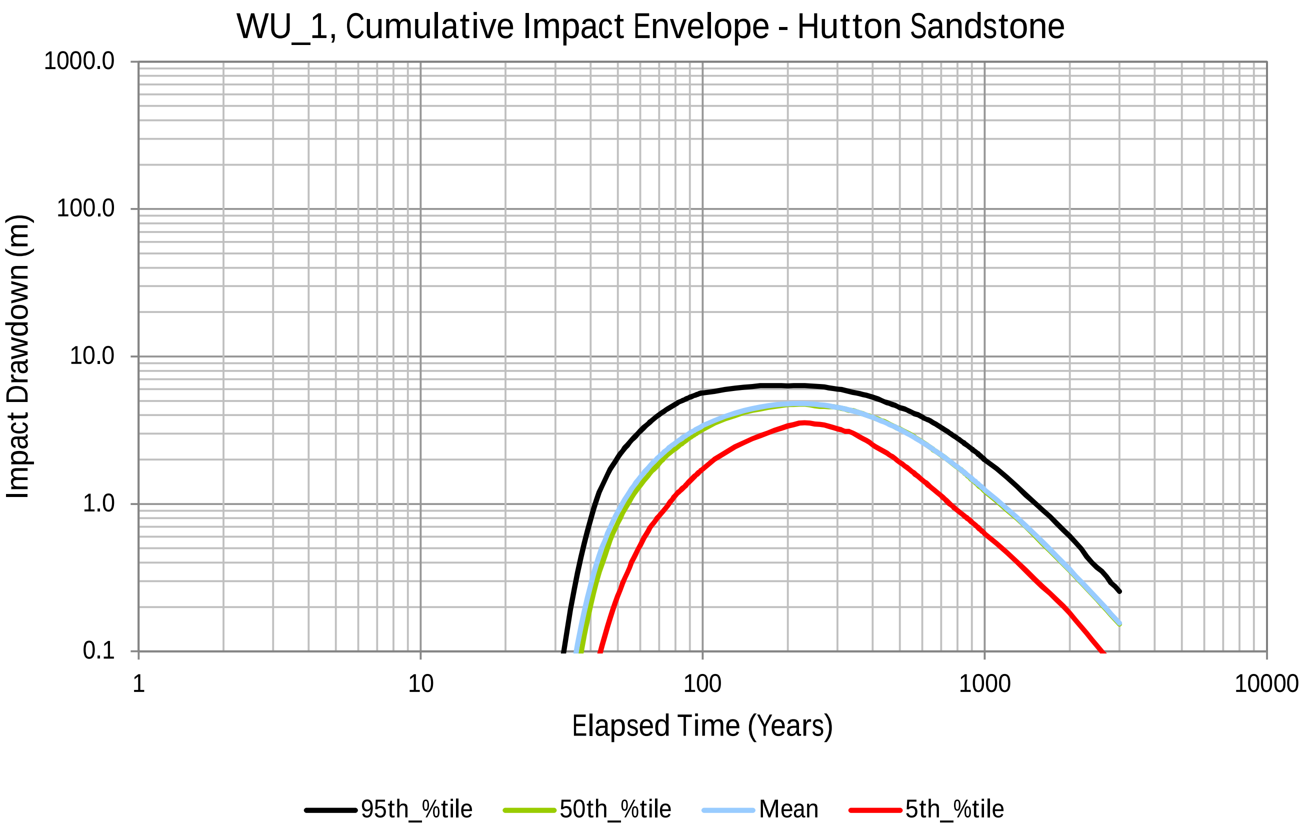


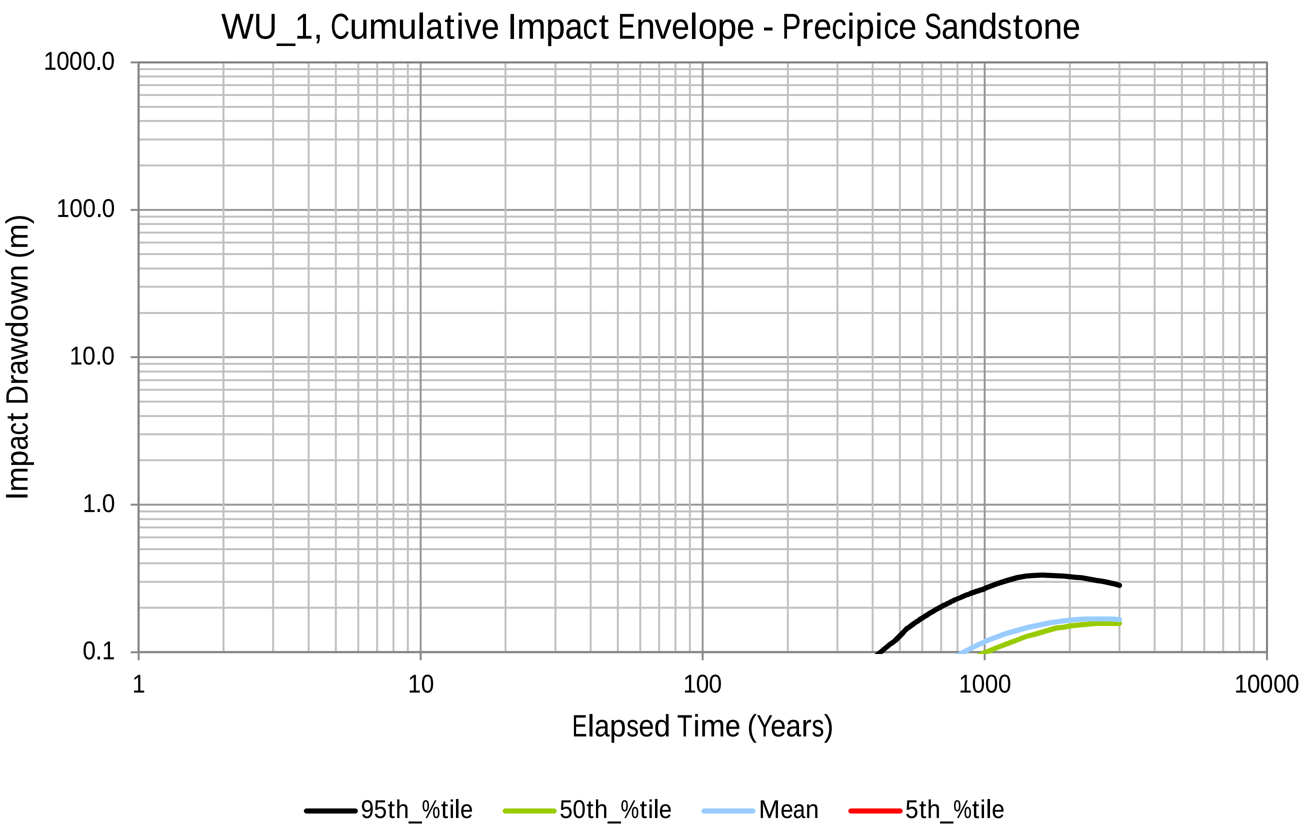
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8



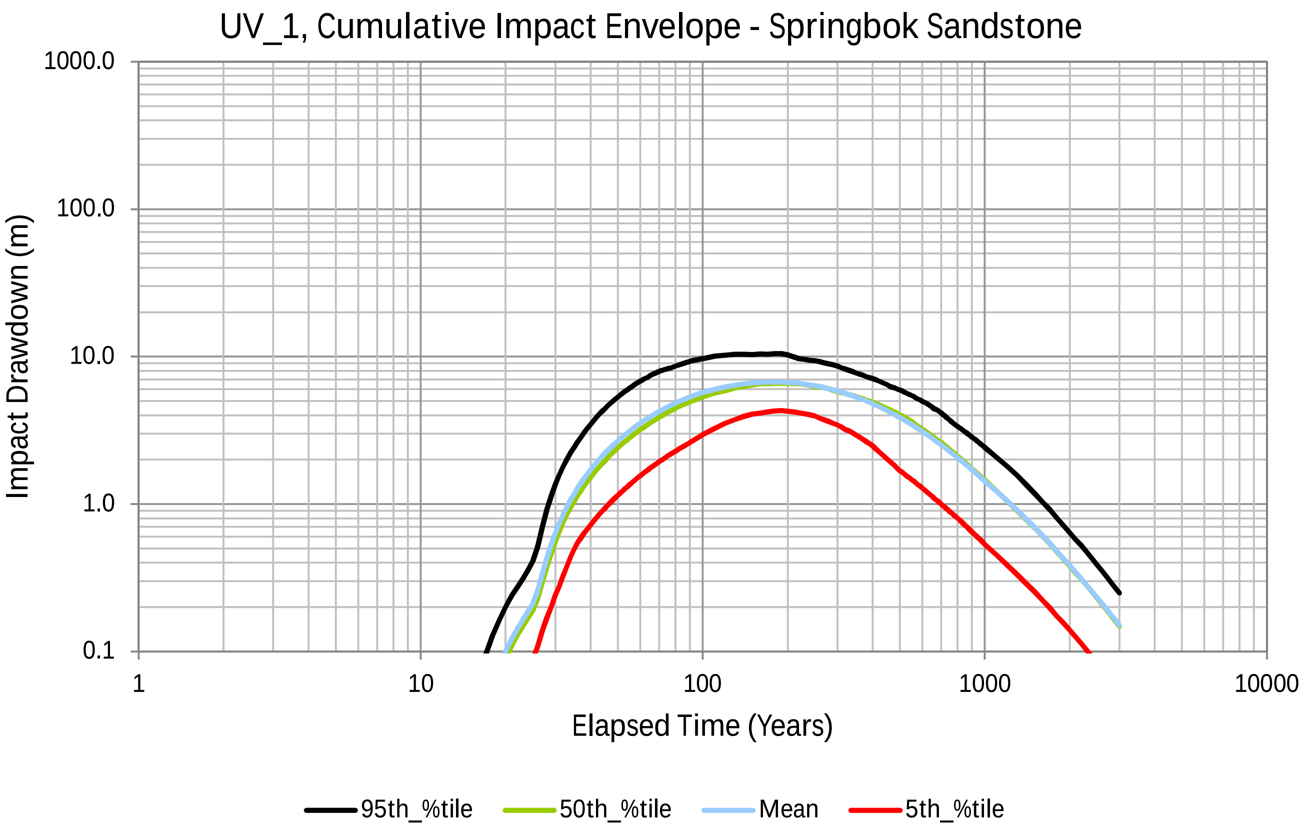


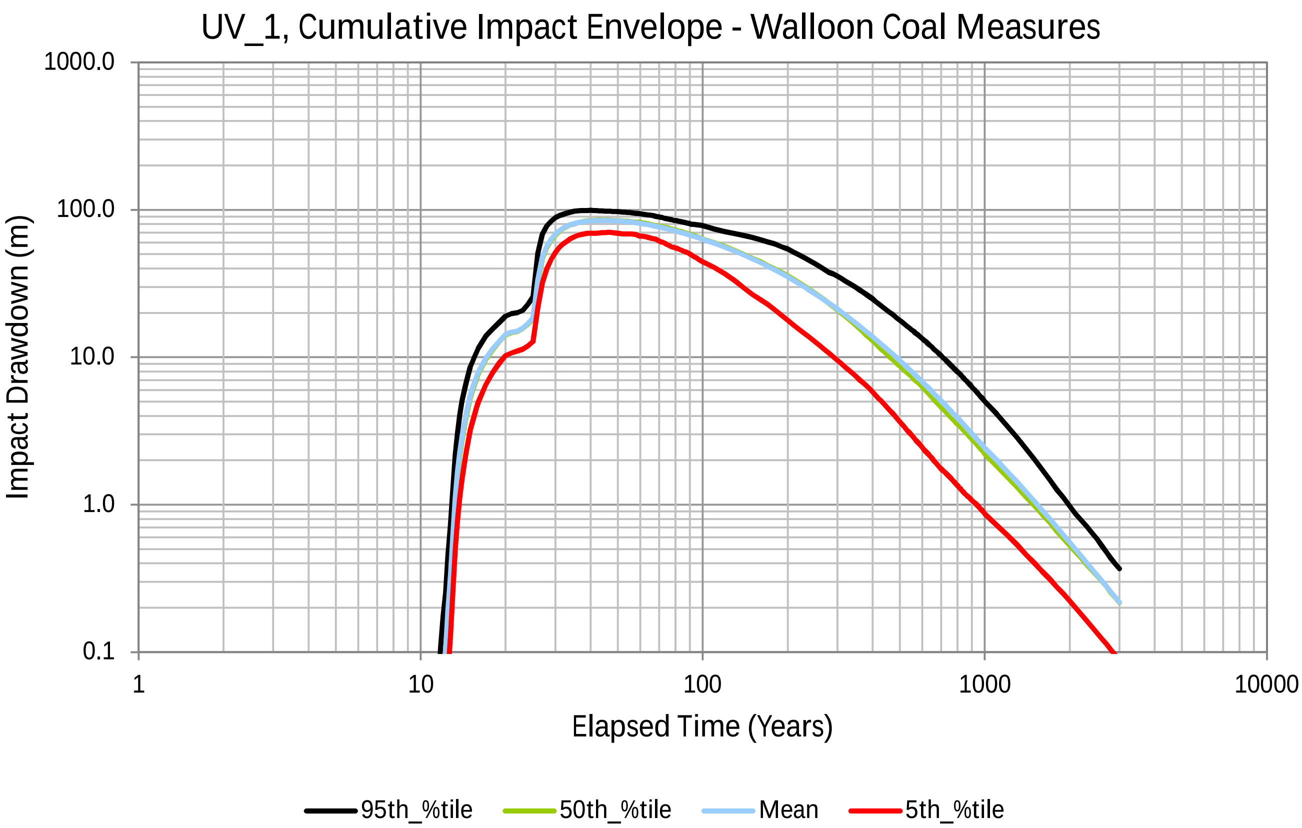
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 8



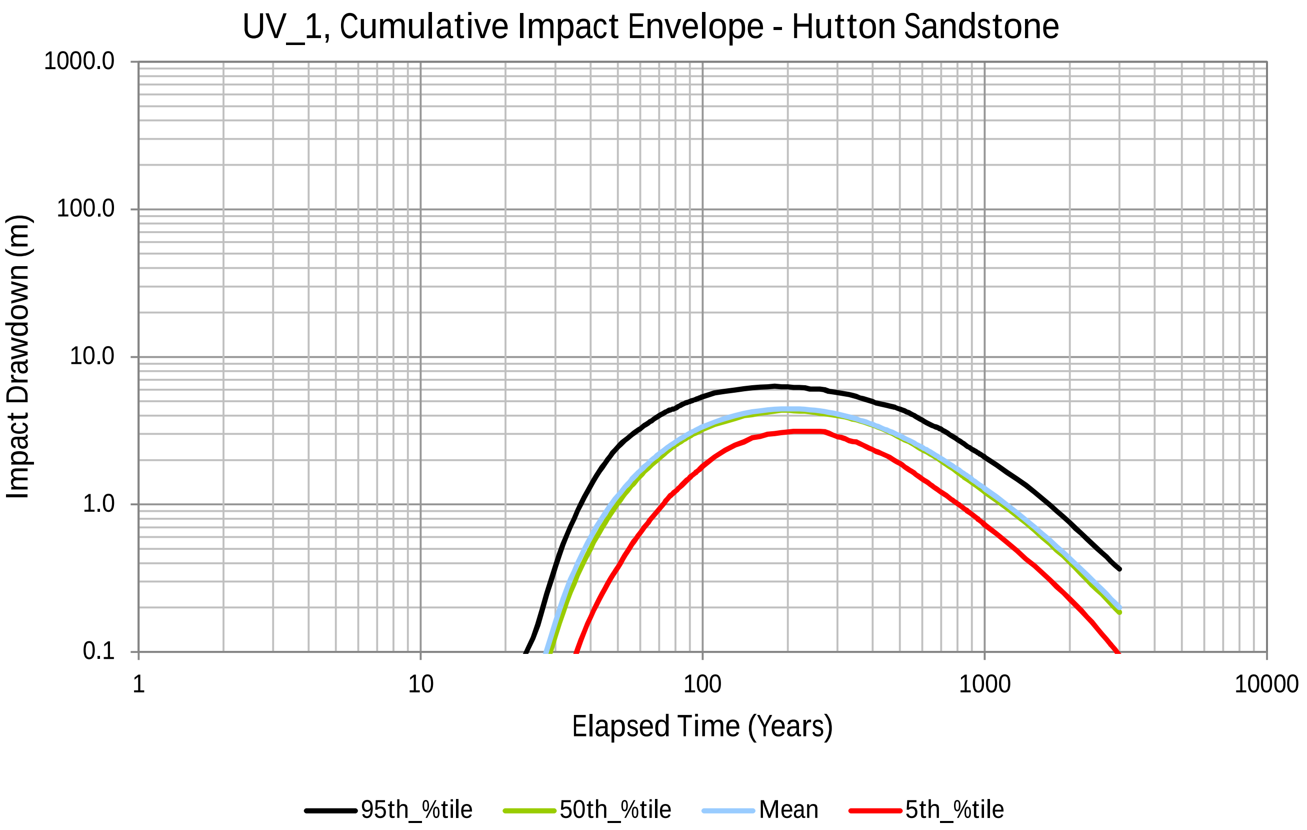


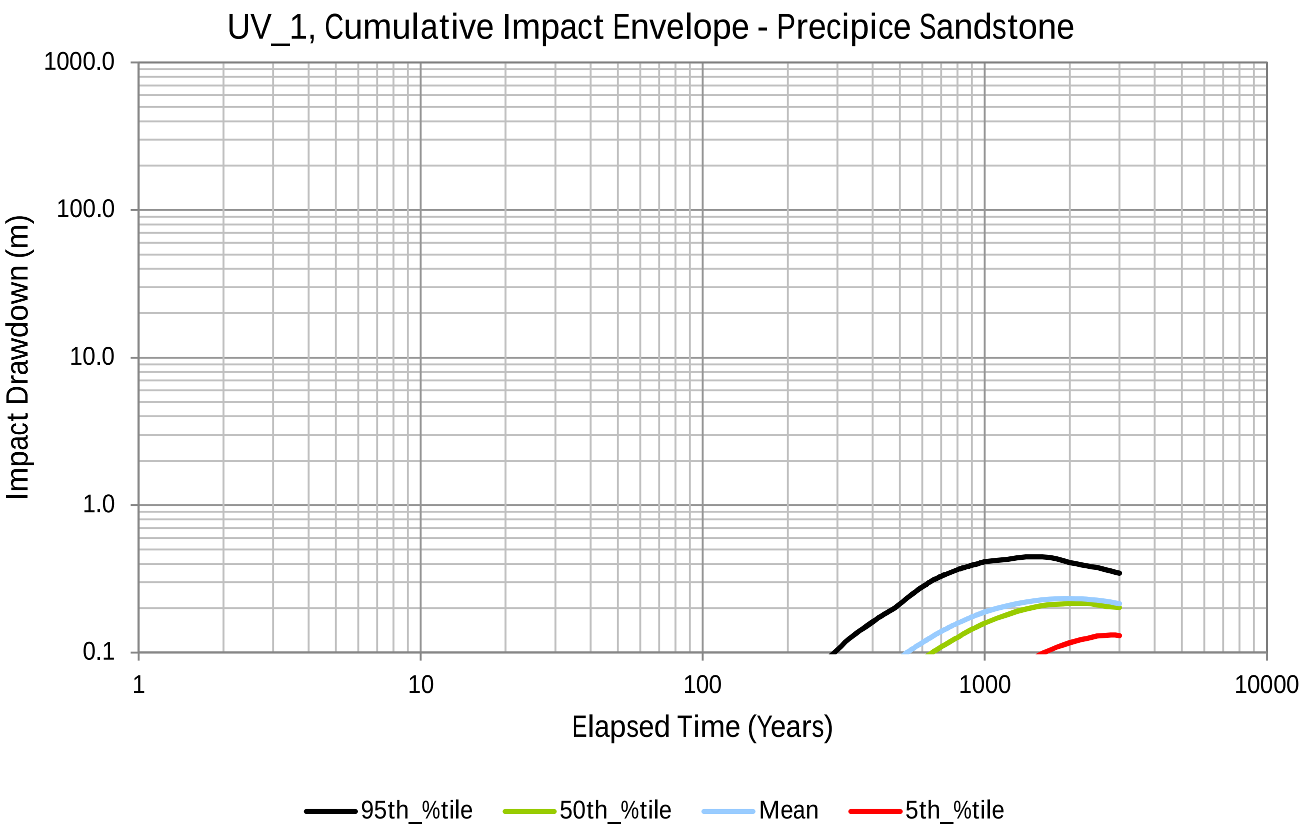
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9



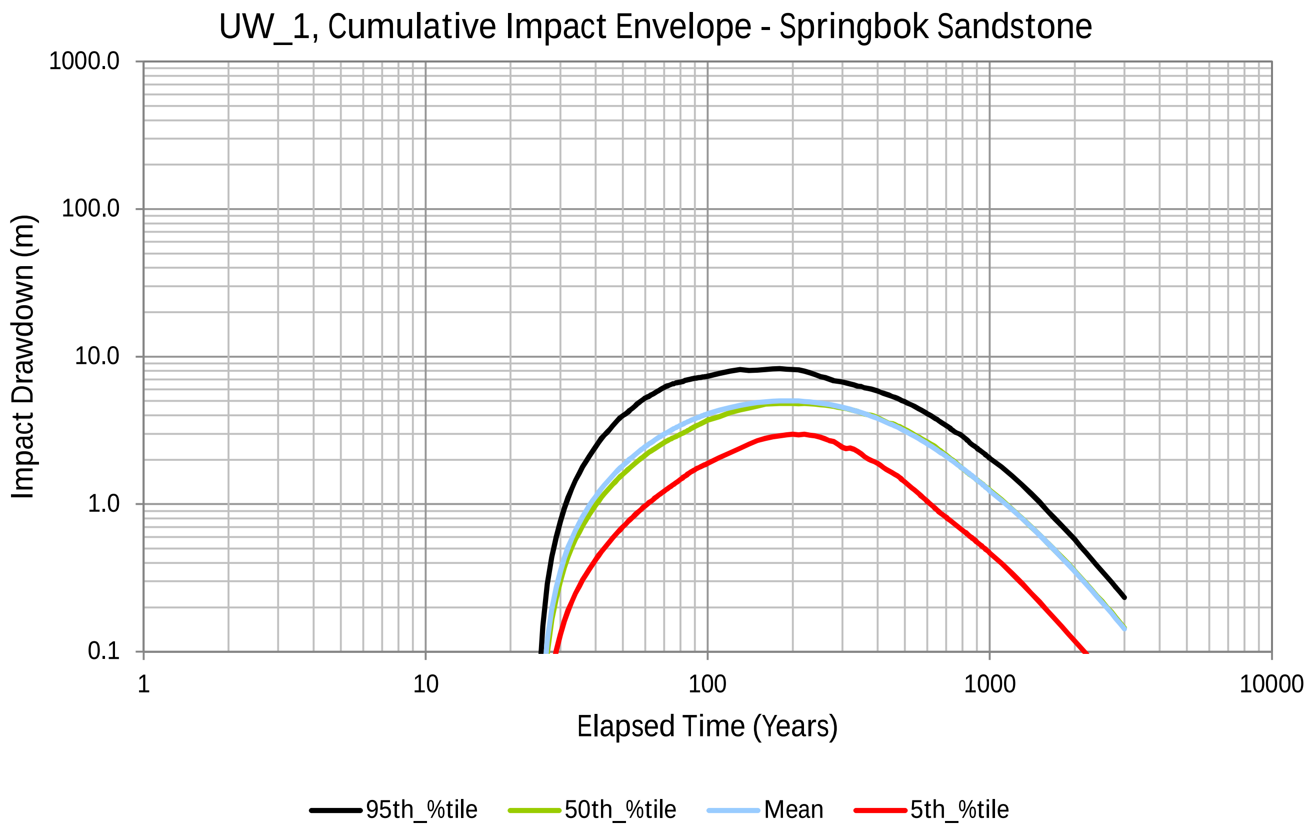


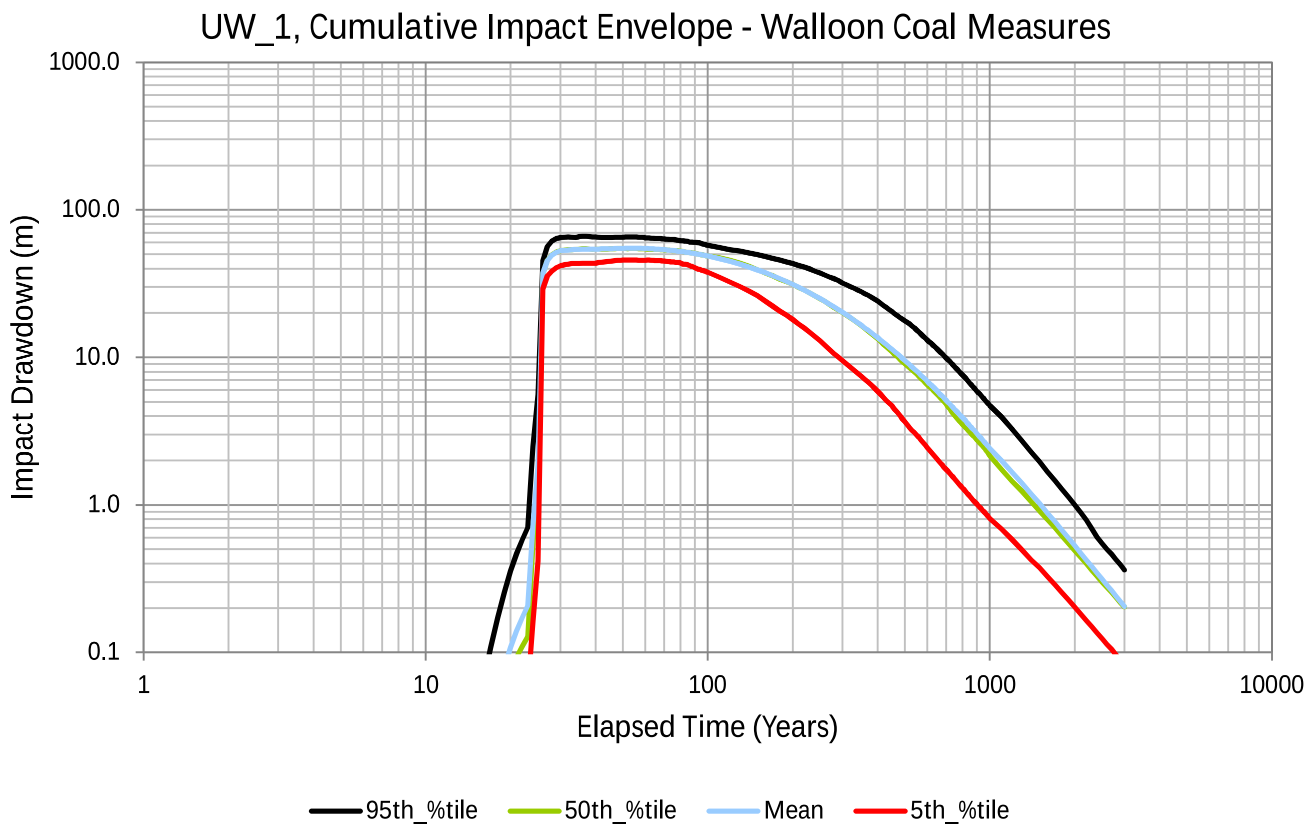
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9





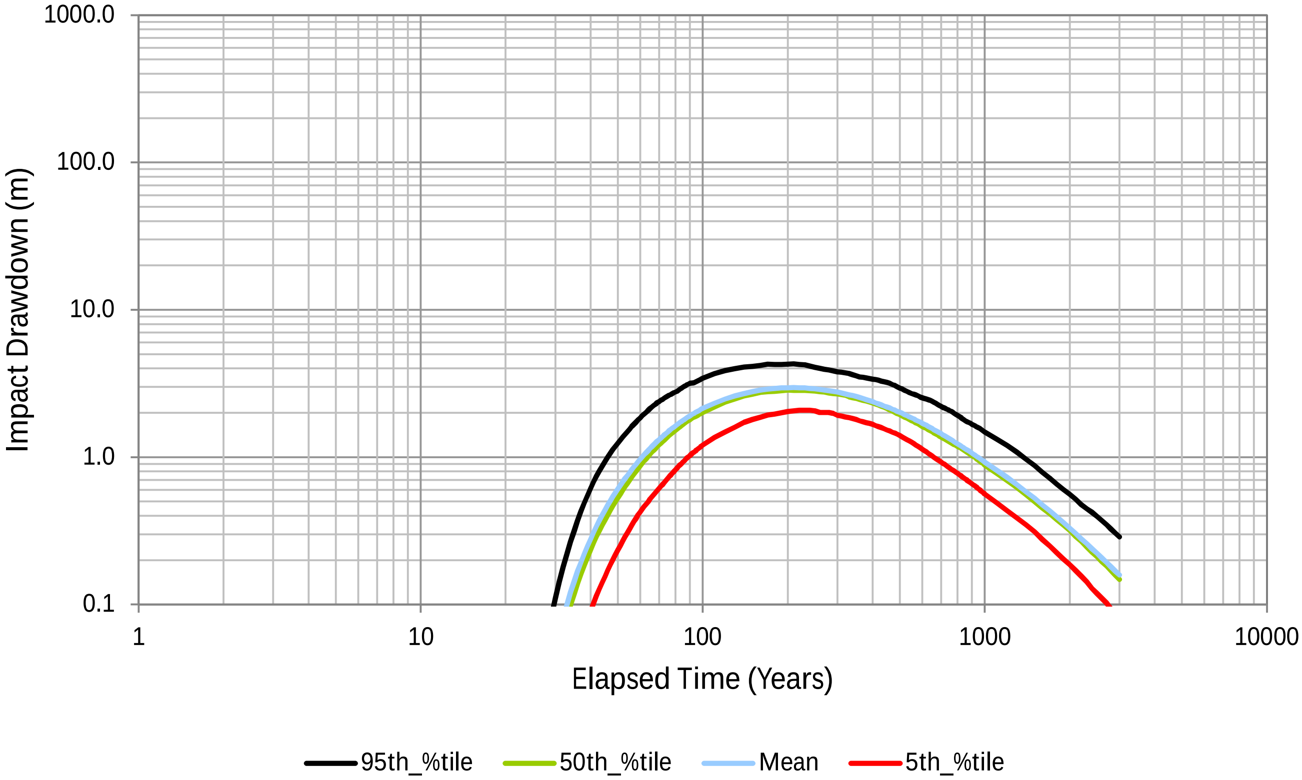
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9



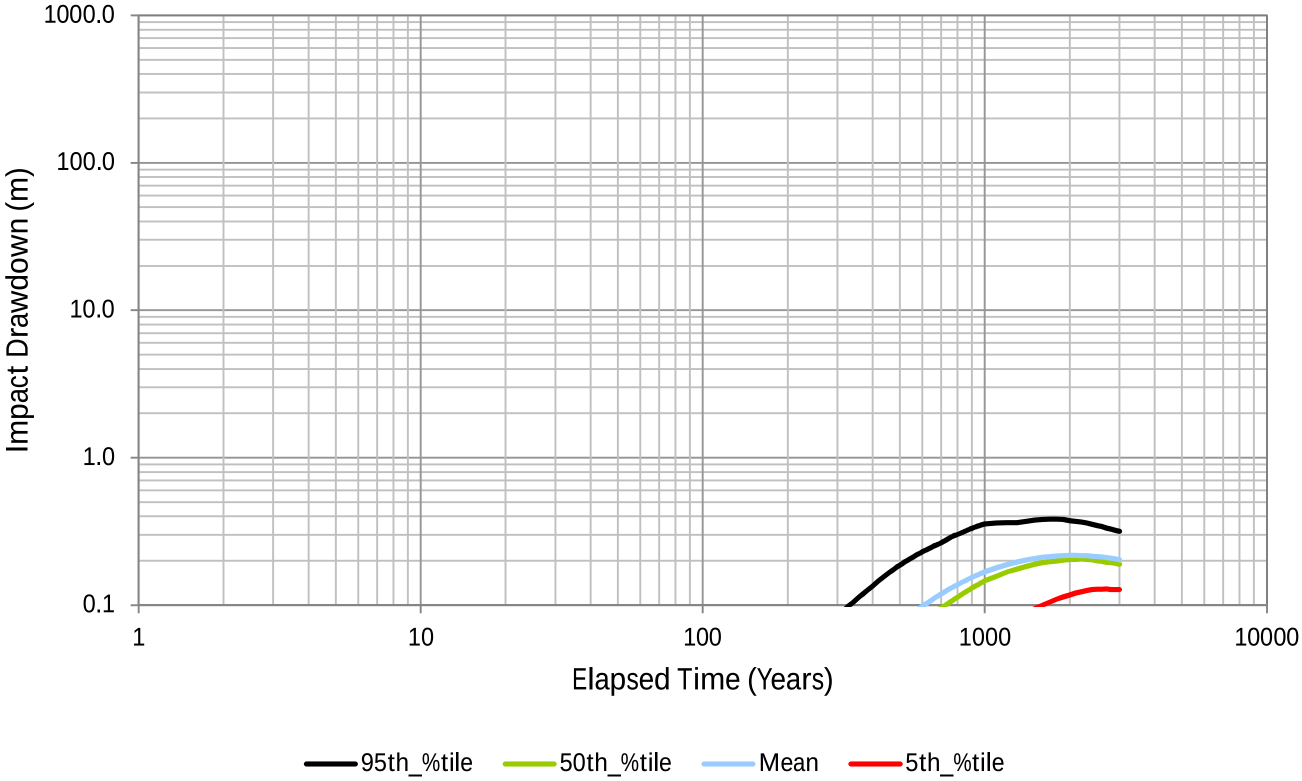


Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9

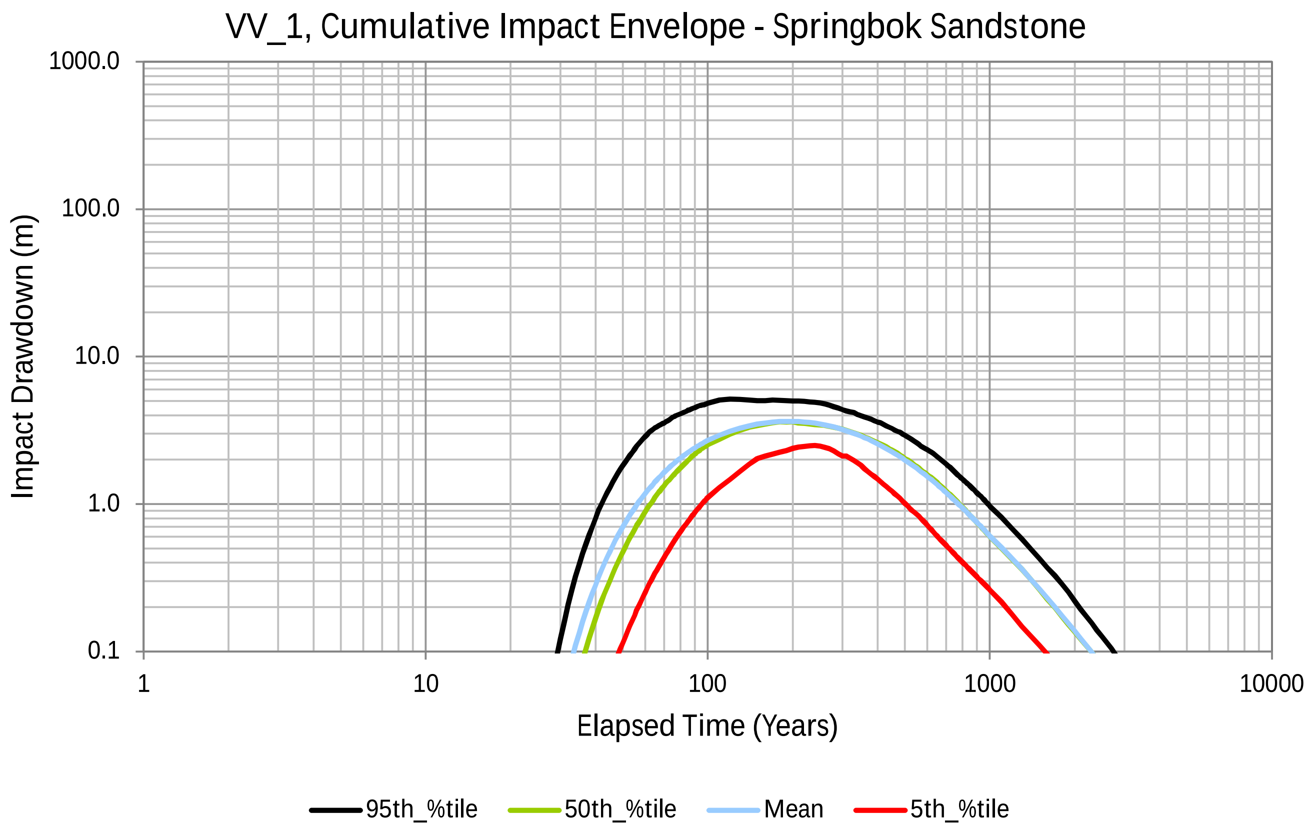
UW_1, Cumulative Impact Envelope - Hutton Sandstone

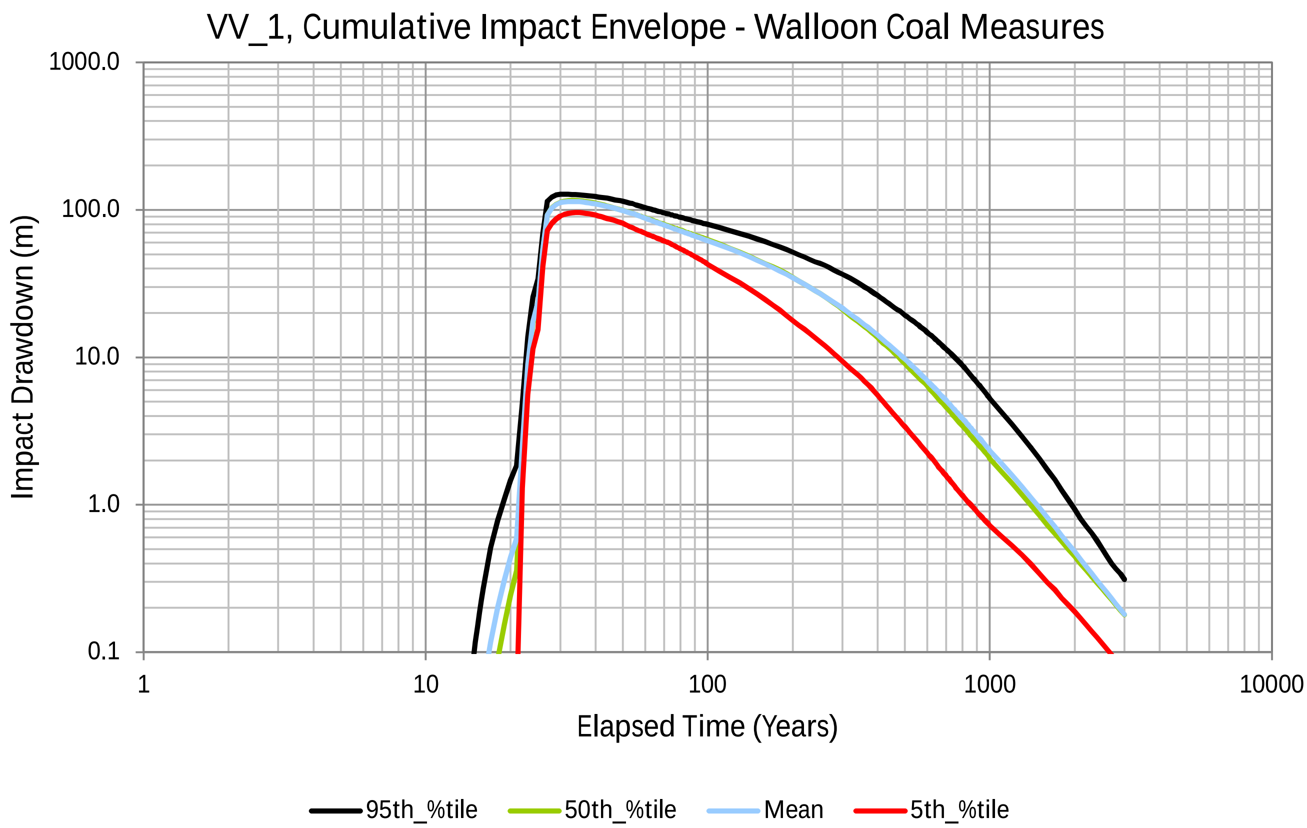


UW_1, Cumulative Impact Envelope - Precipice Sandstone

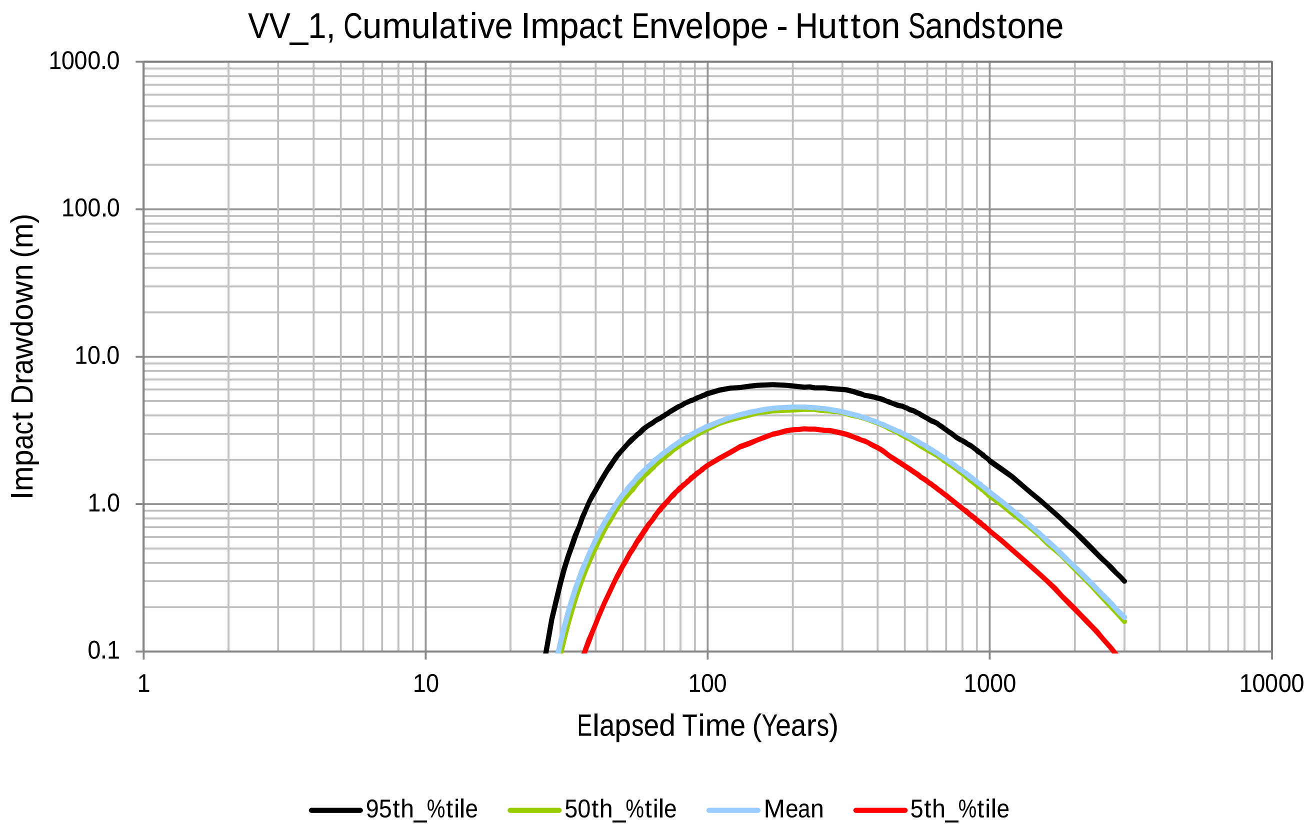


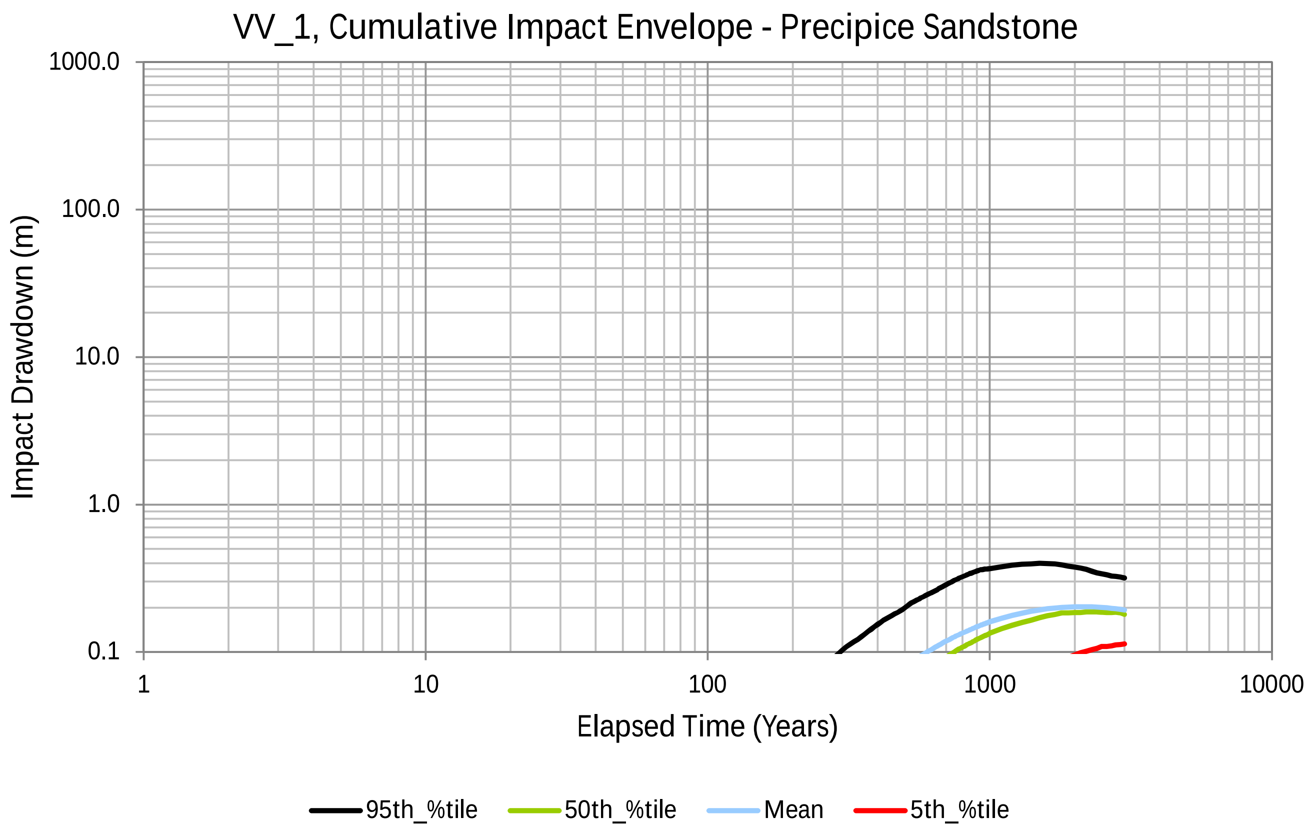
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9





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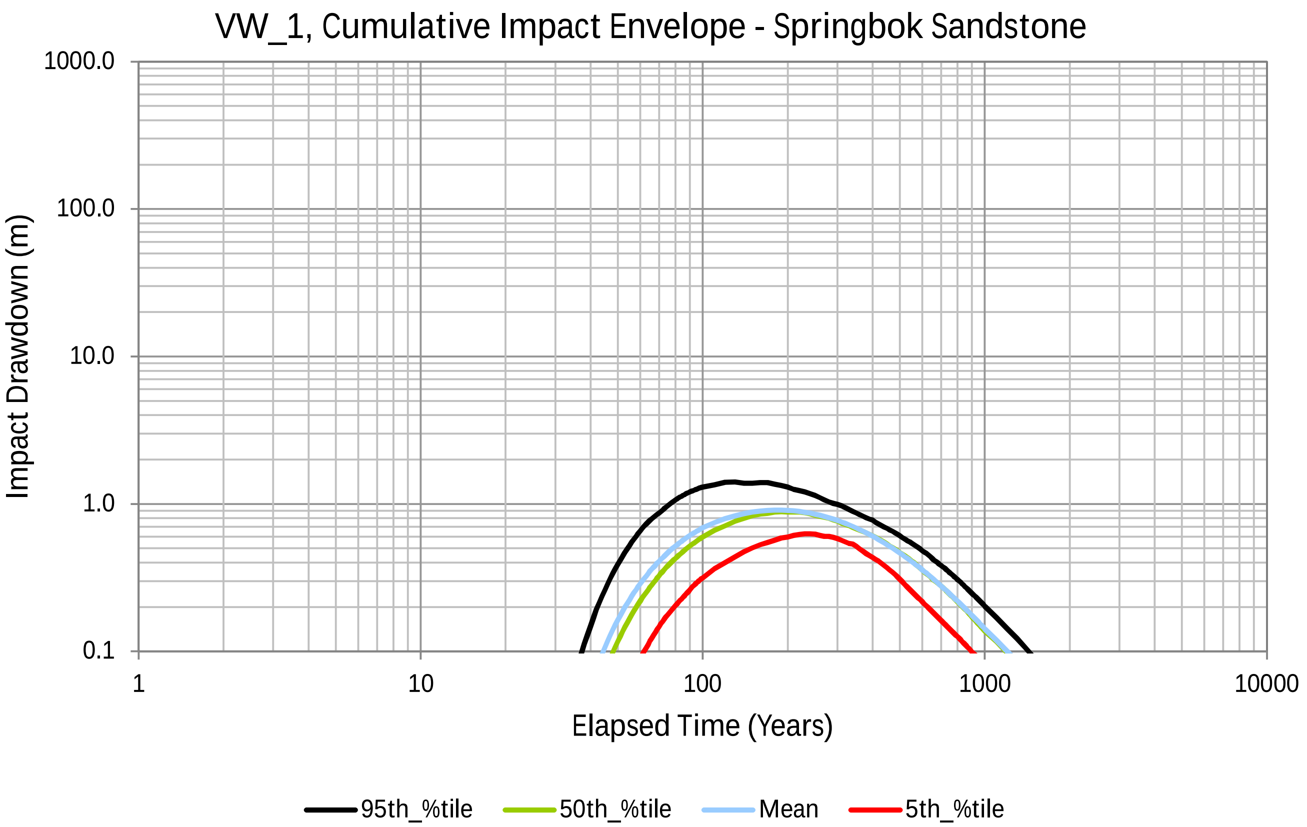
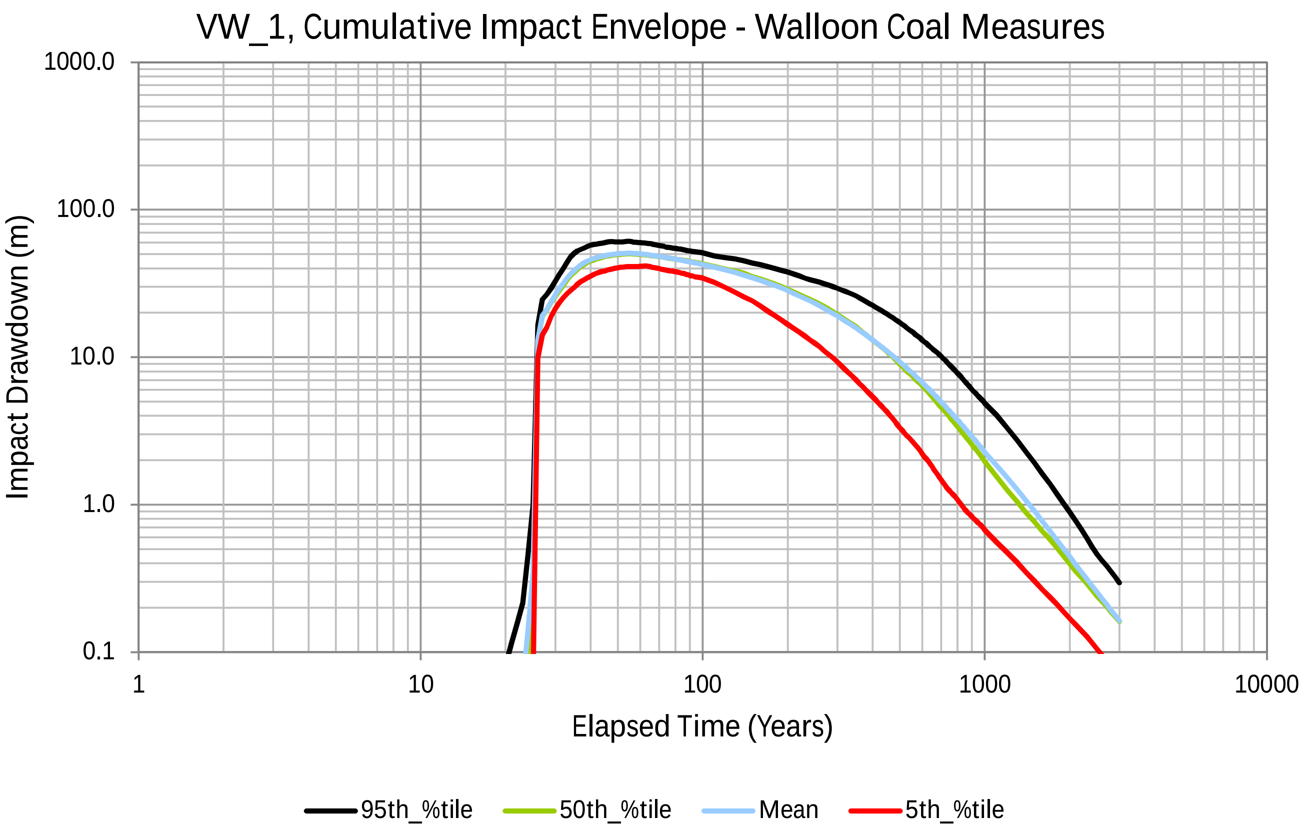
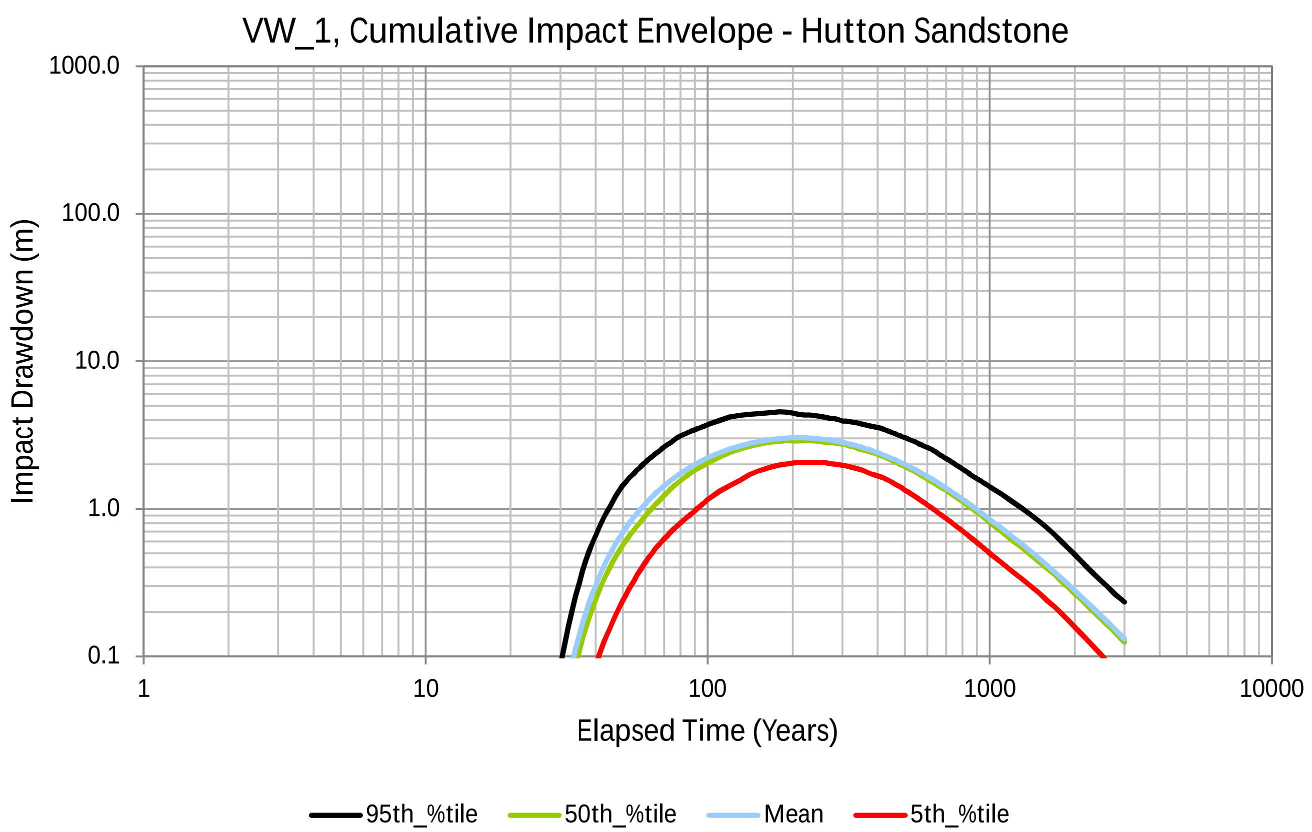
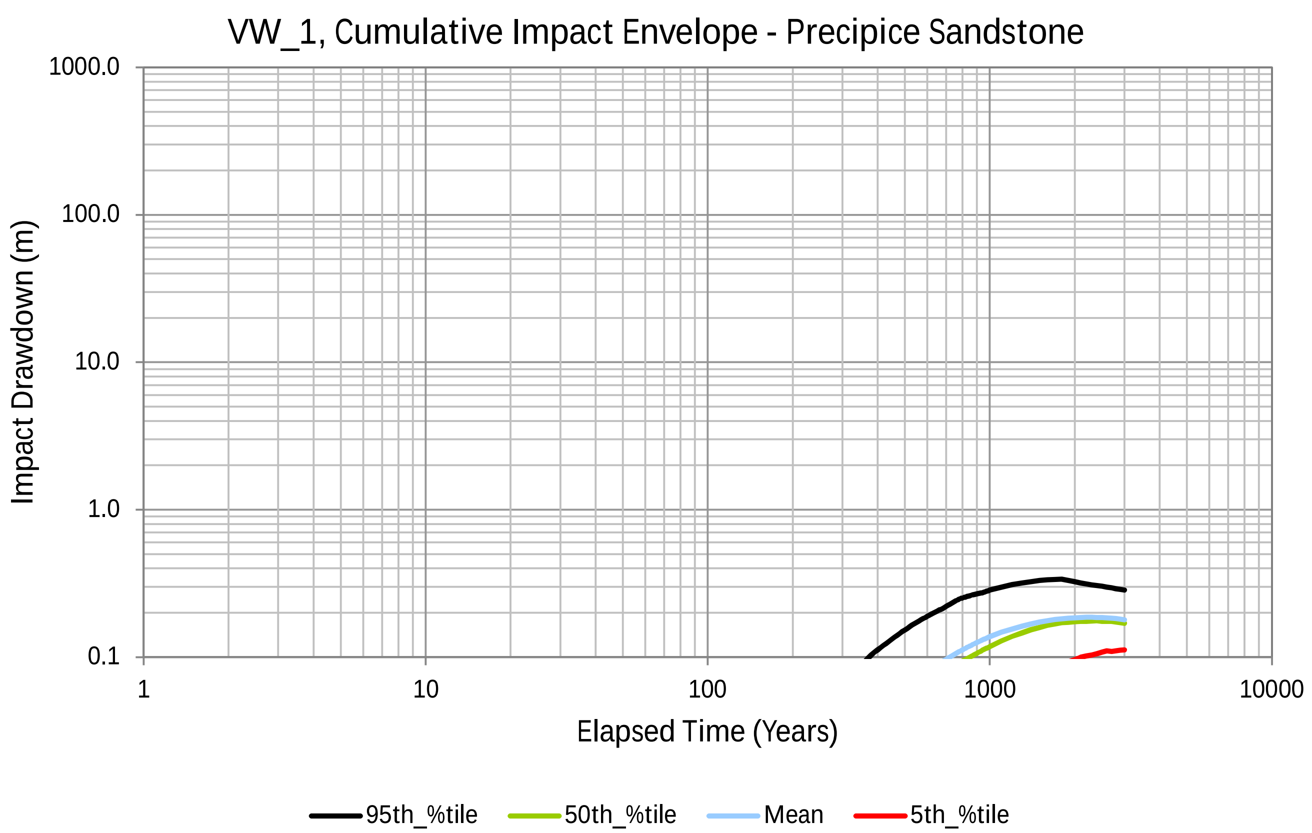
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9





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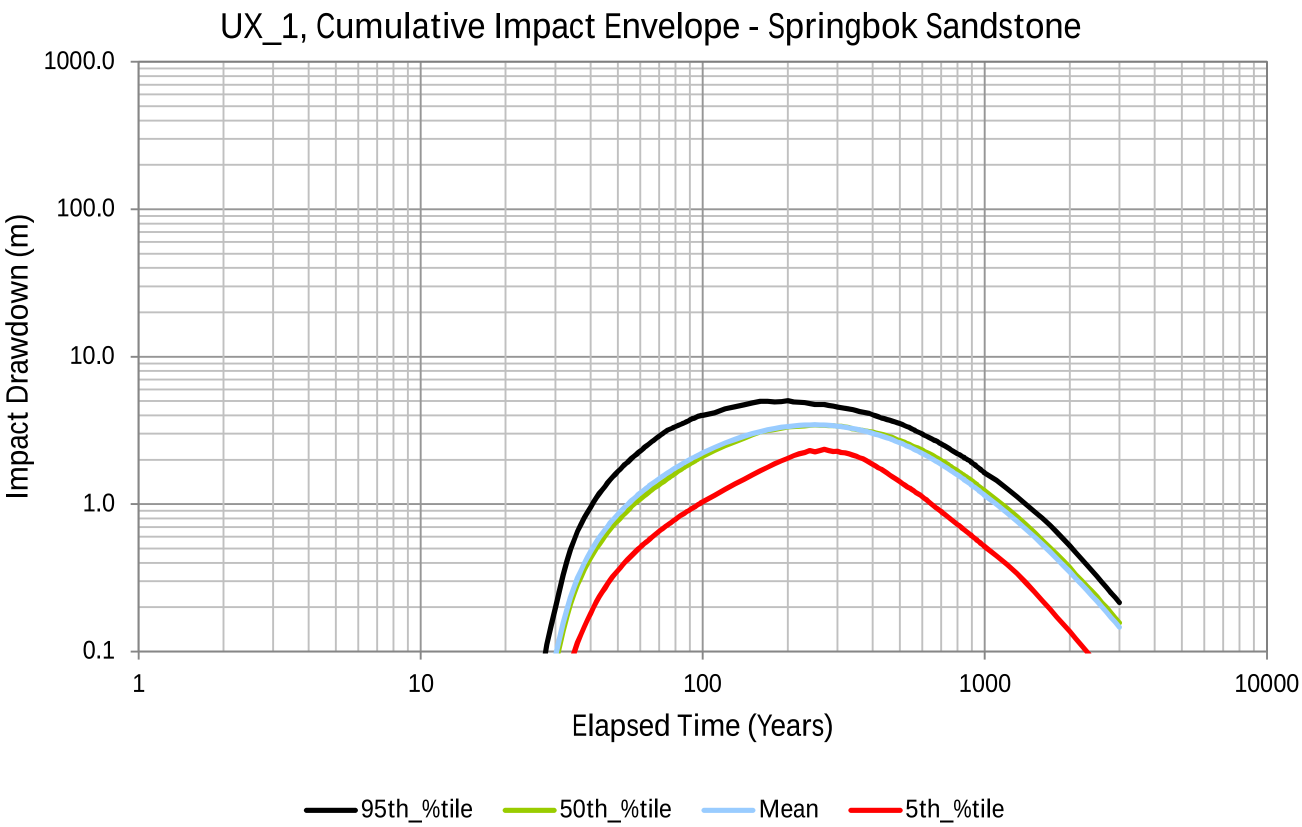
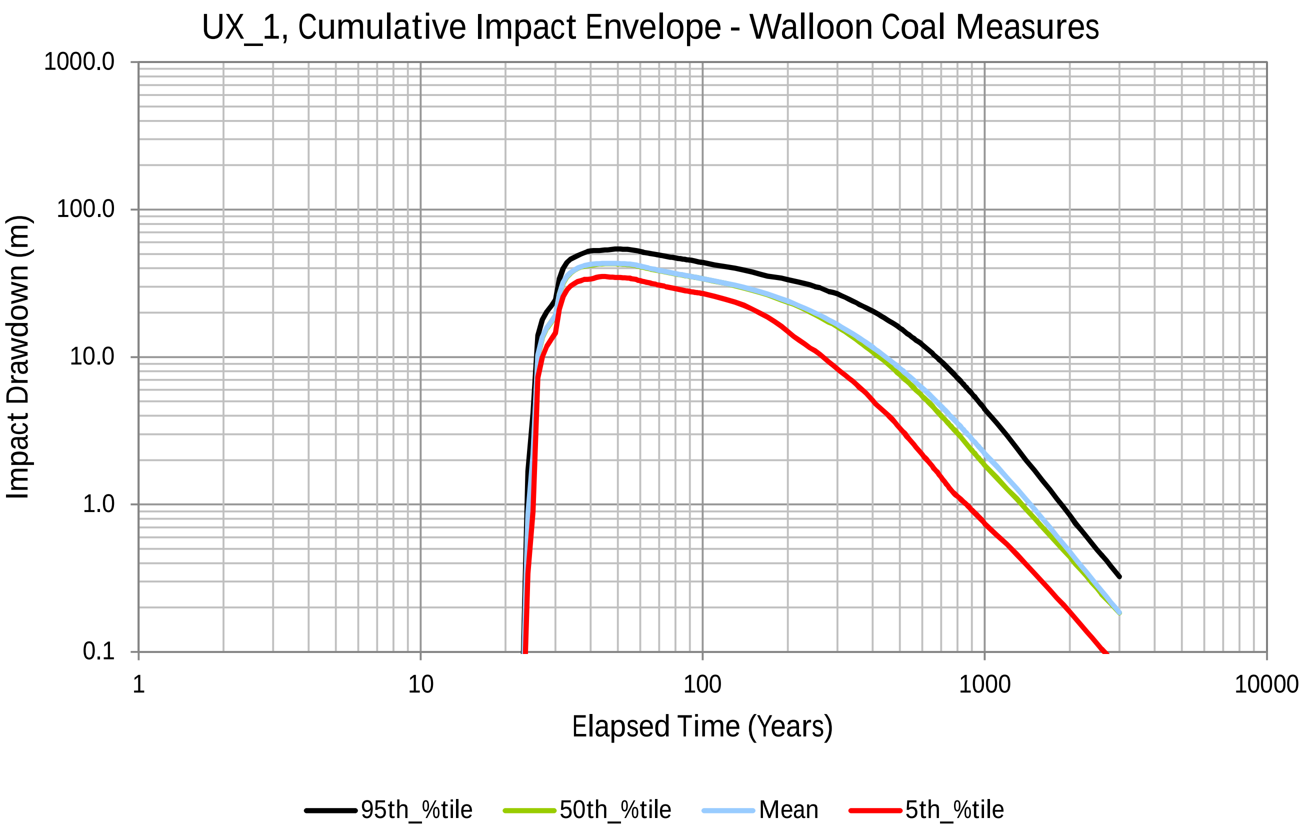
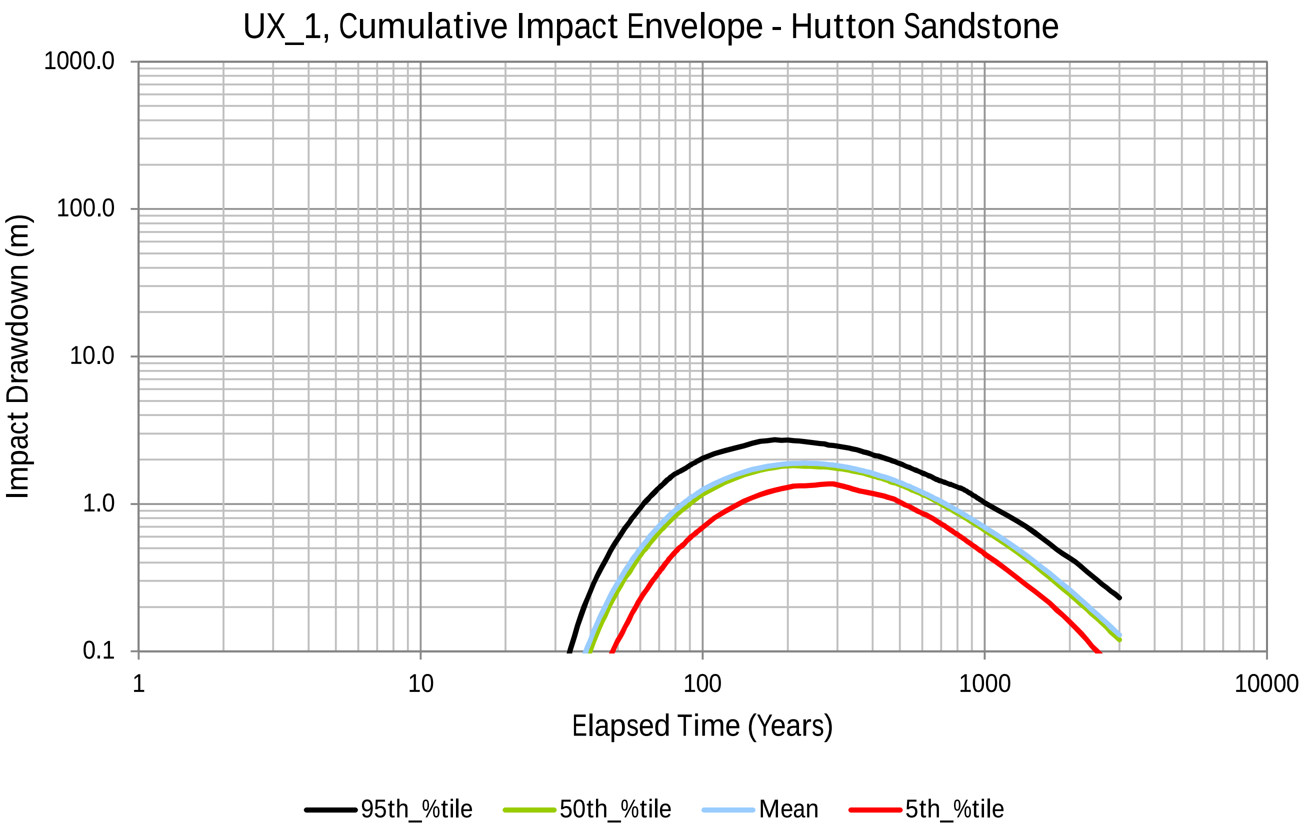
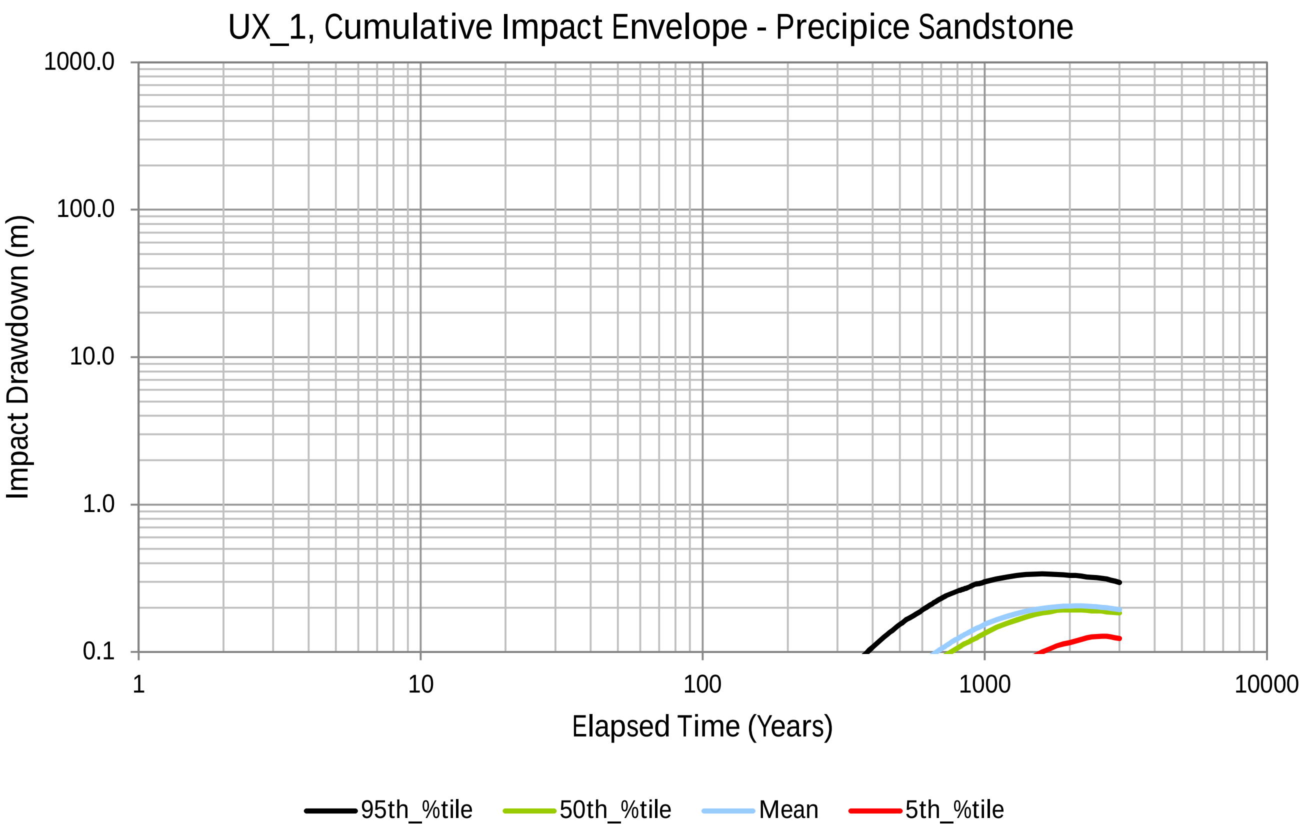
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9



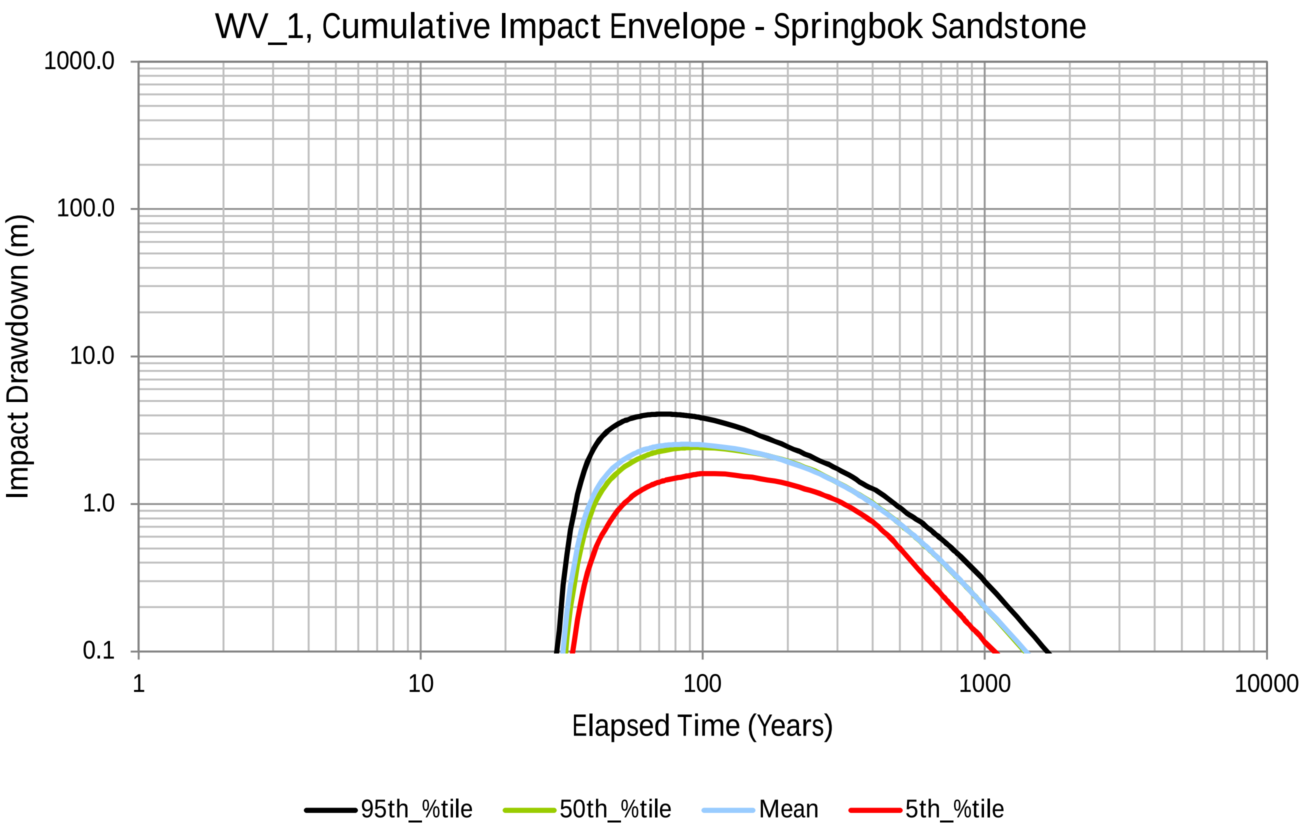


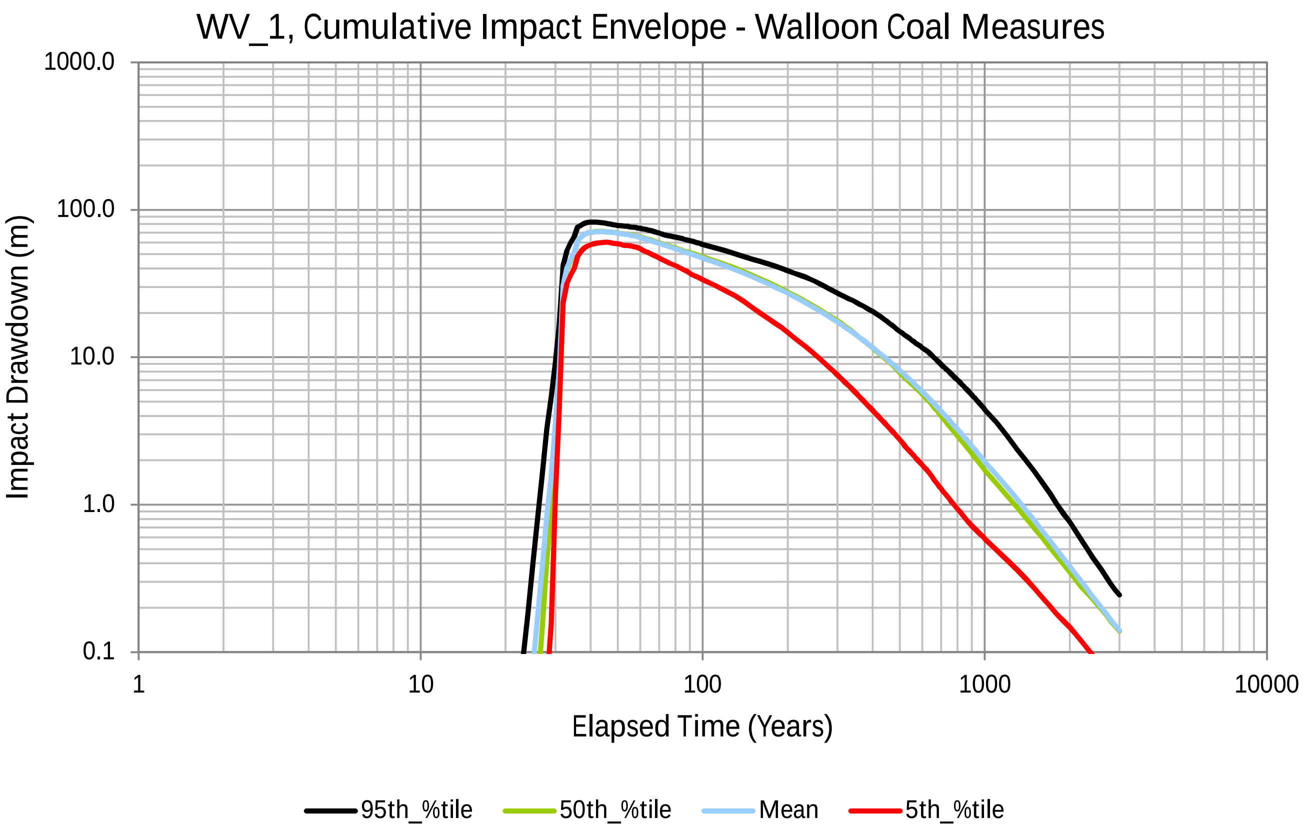
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9



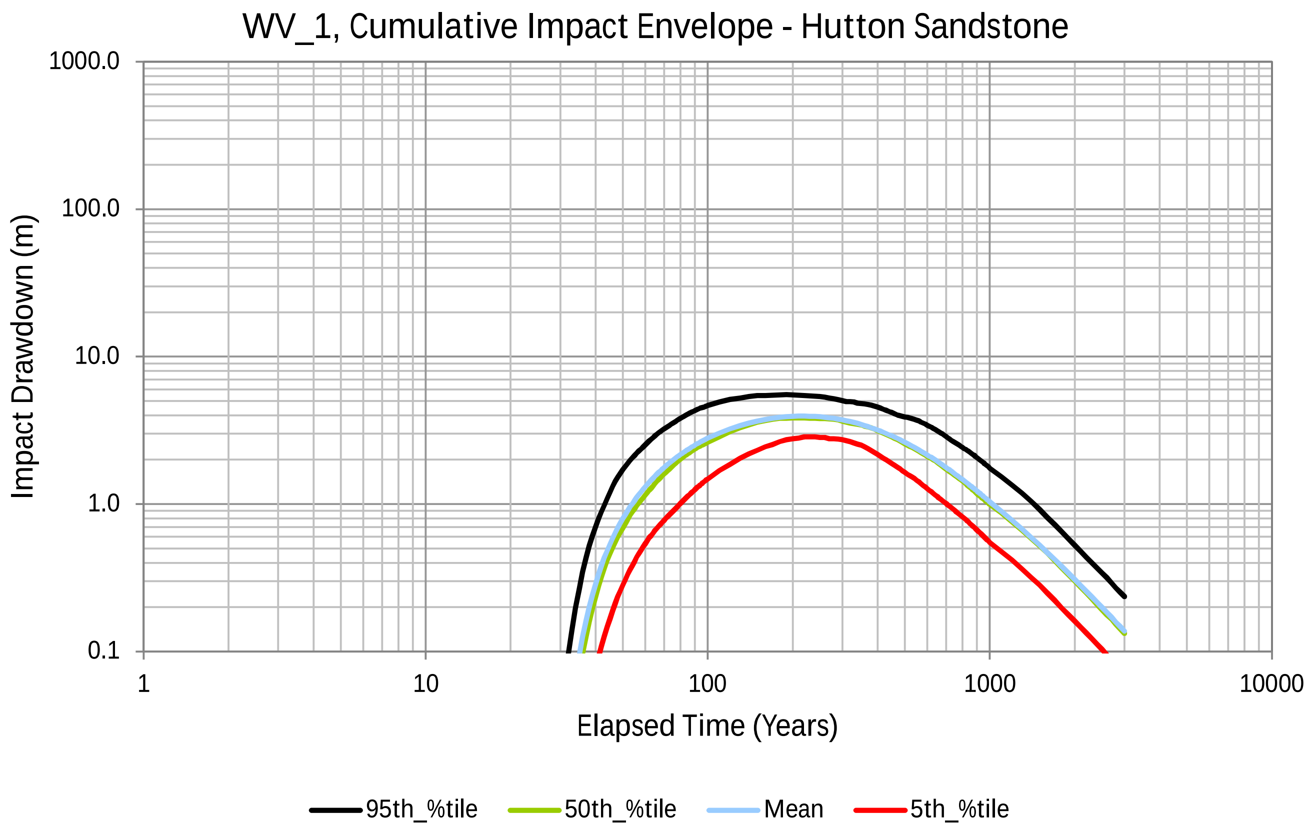


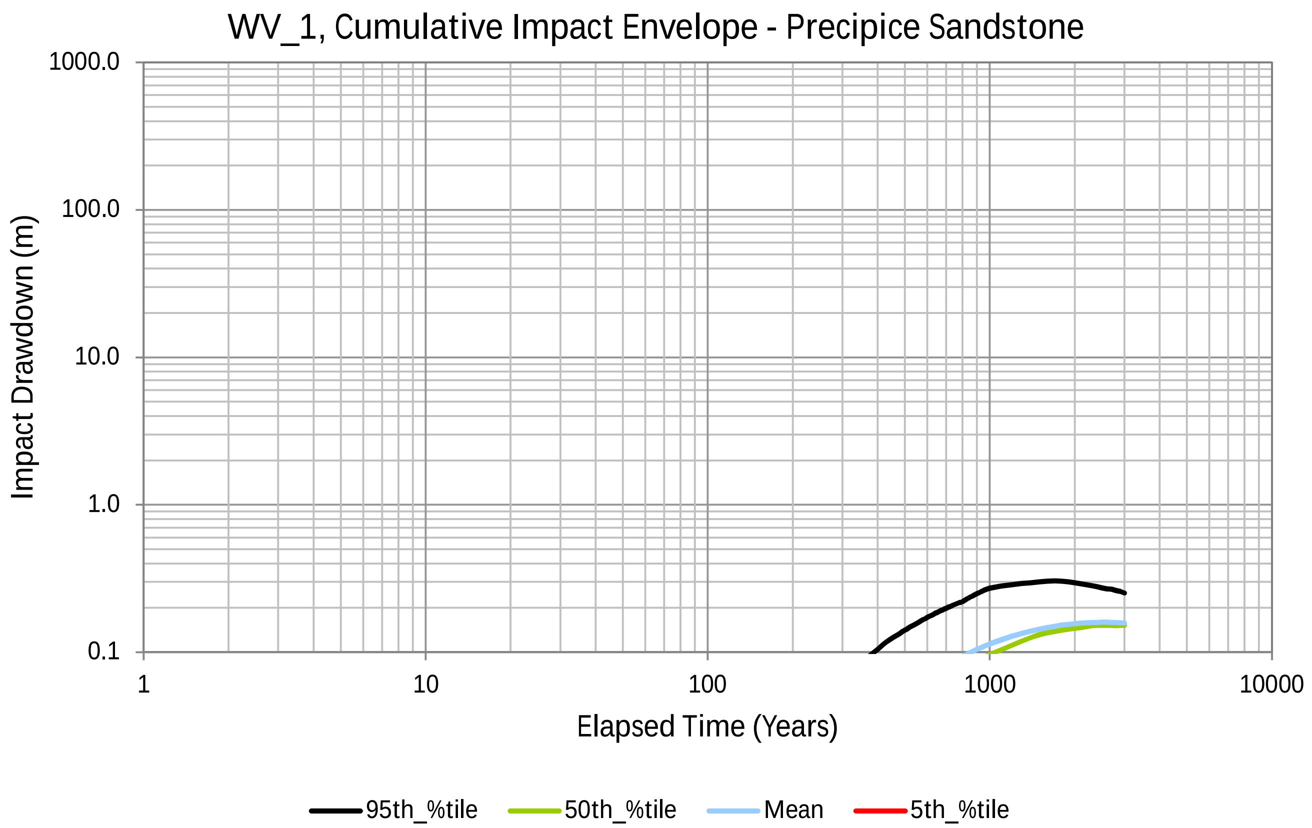
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9



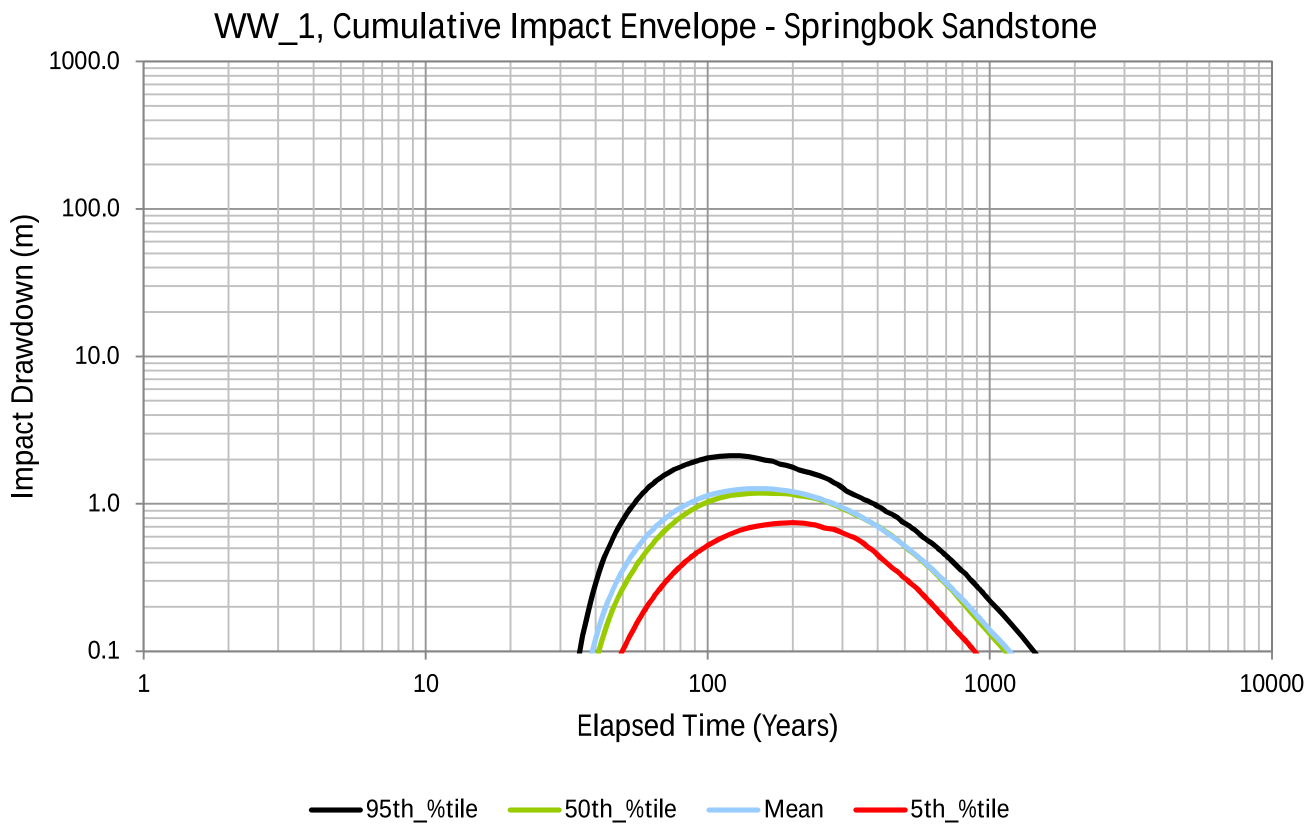


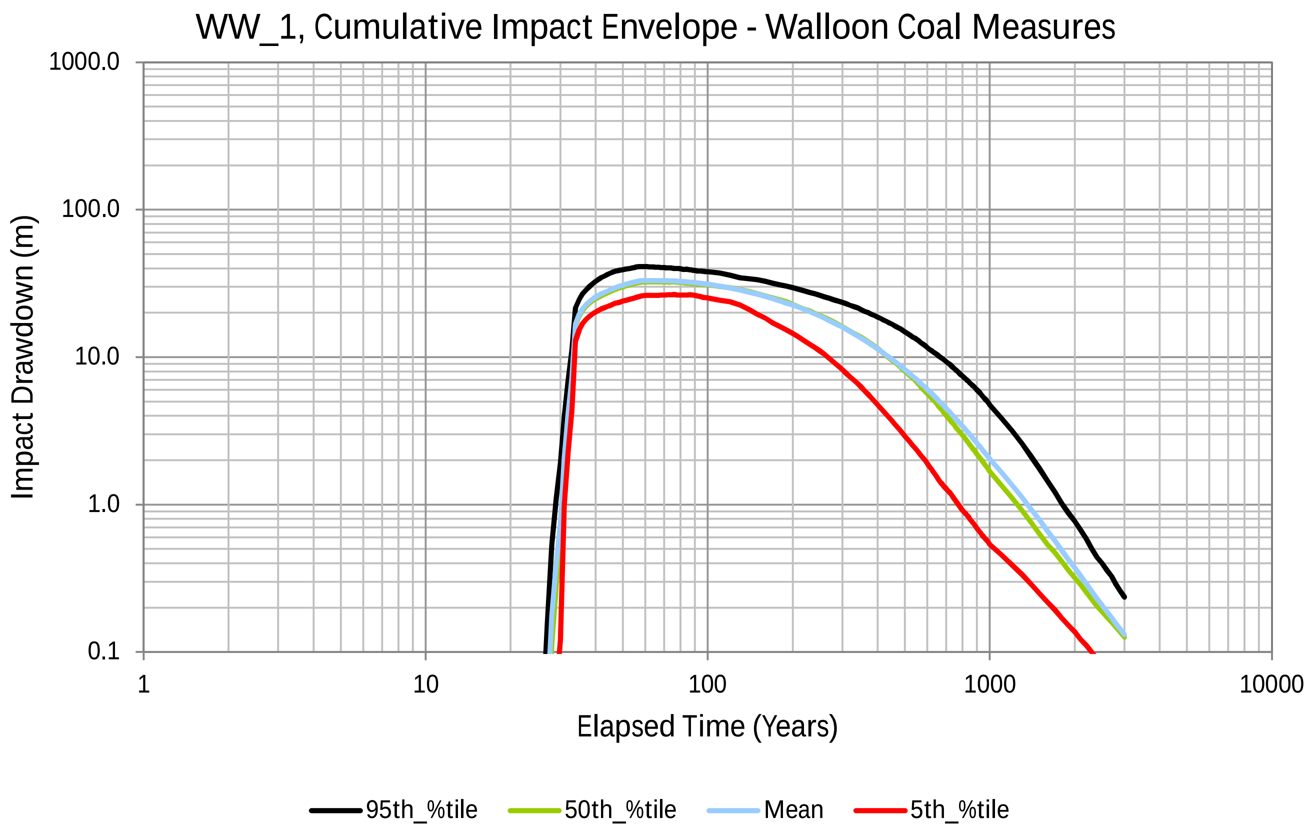
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9



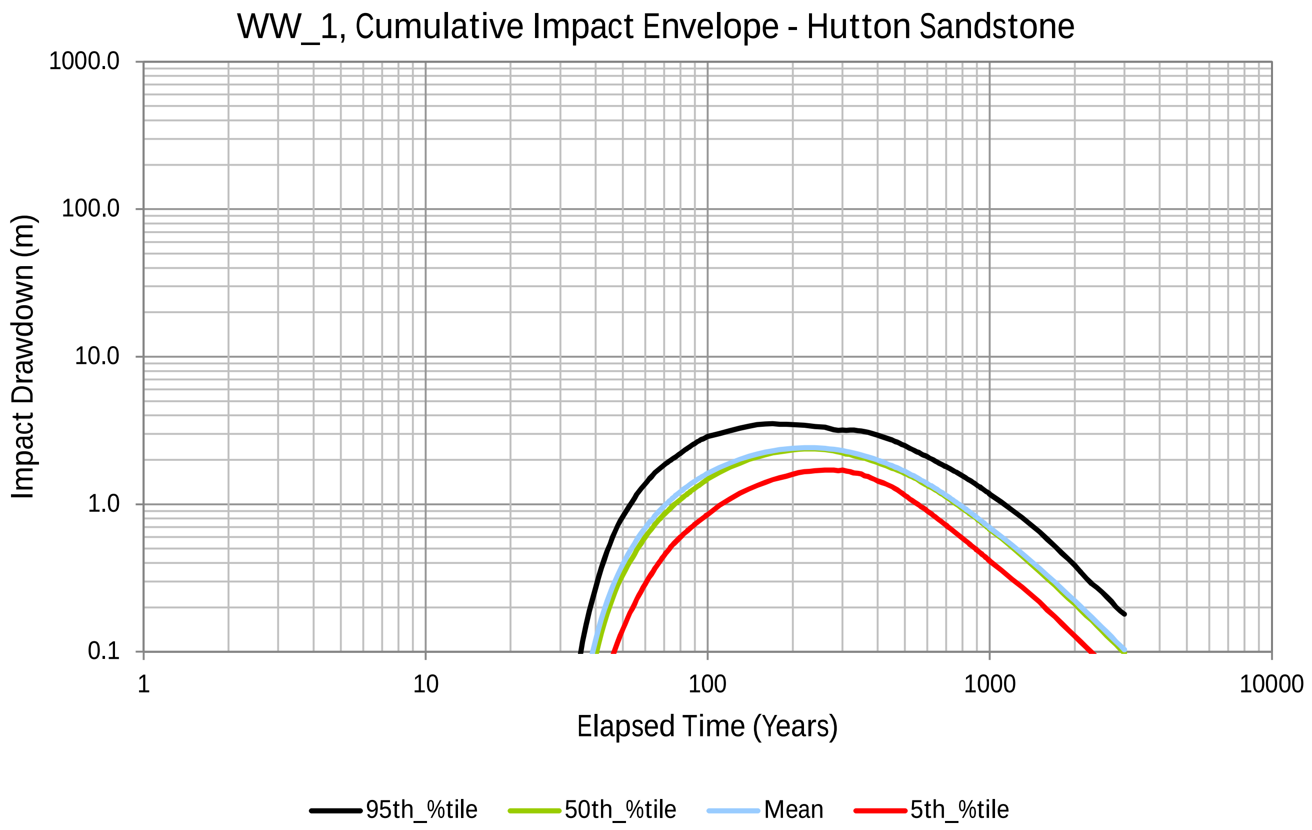


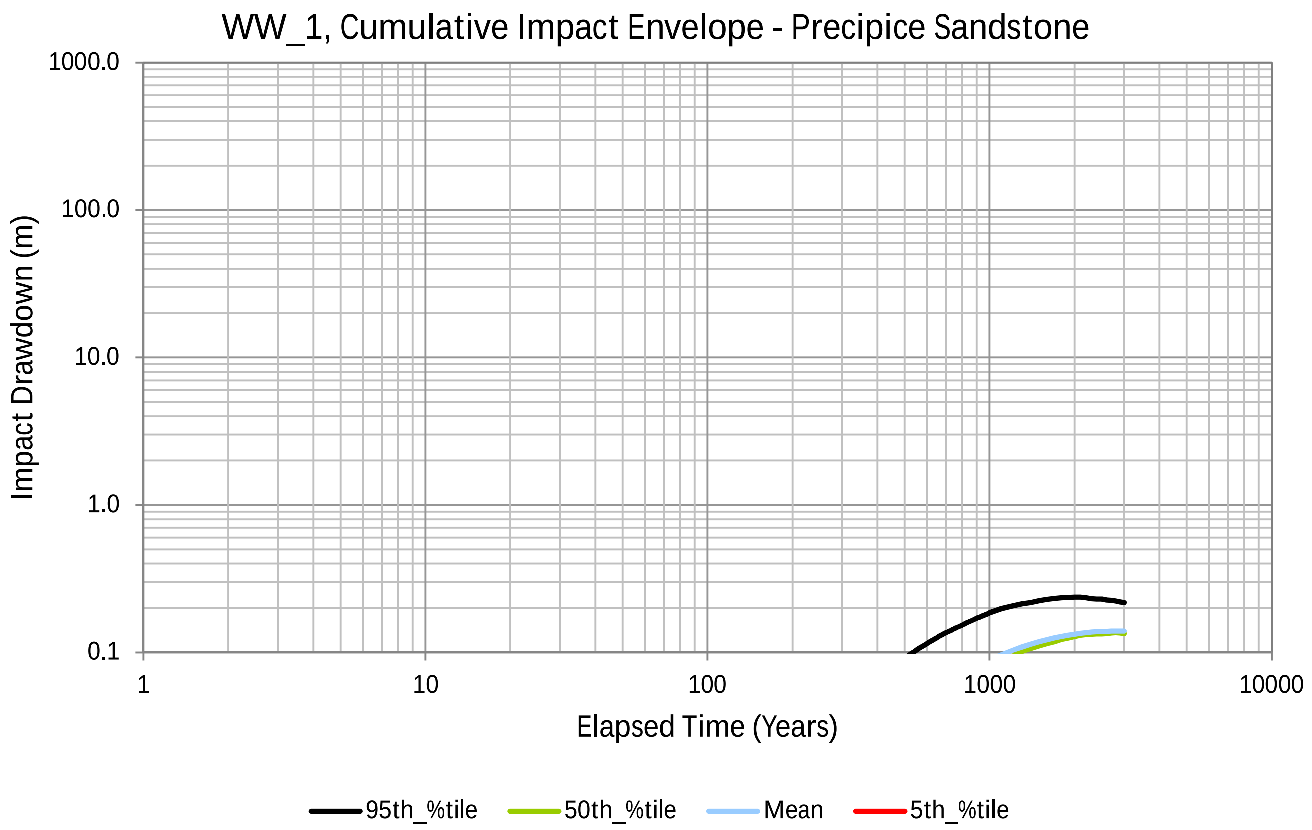
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9



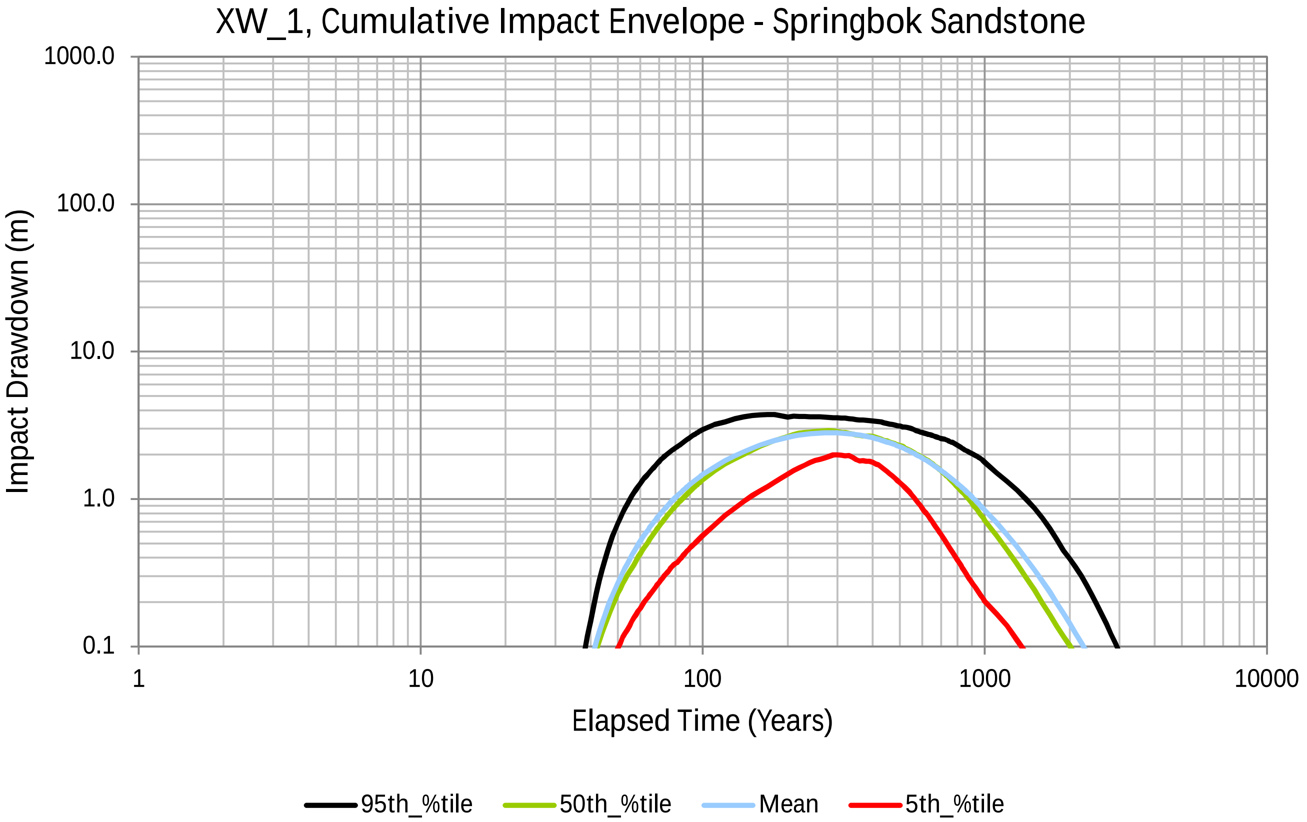


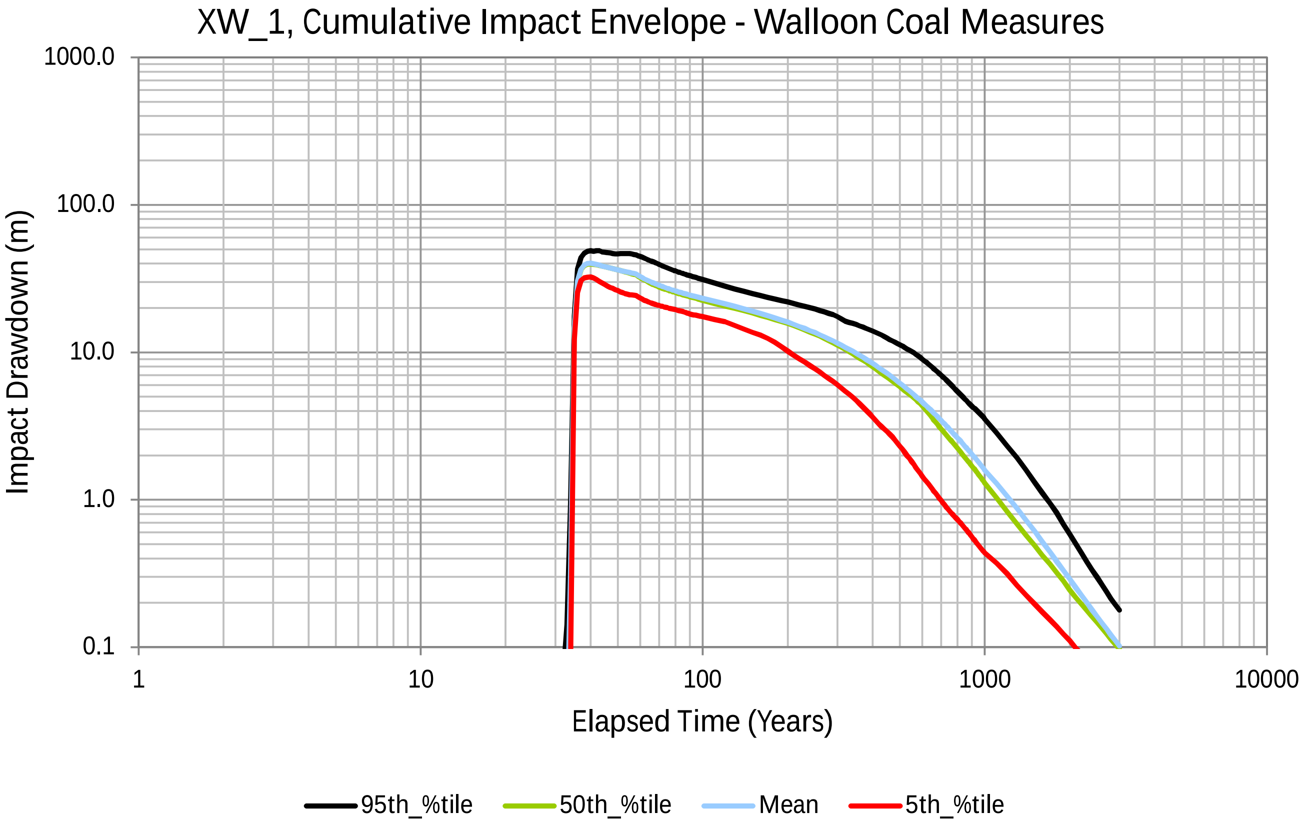
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9





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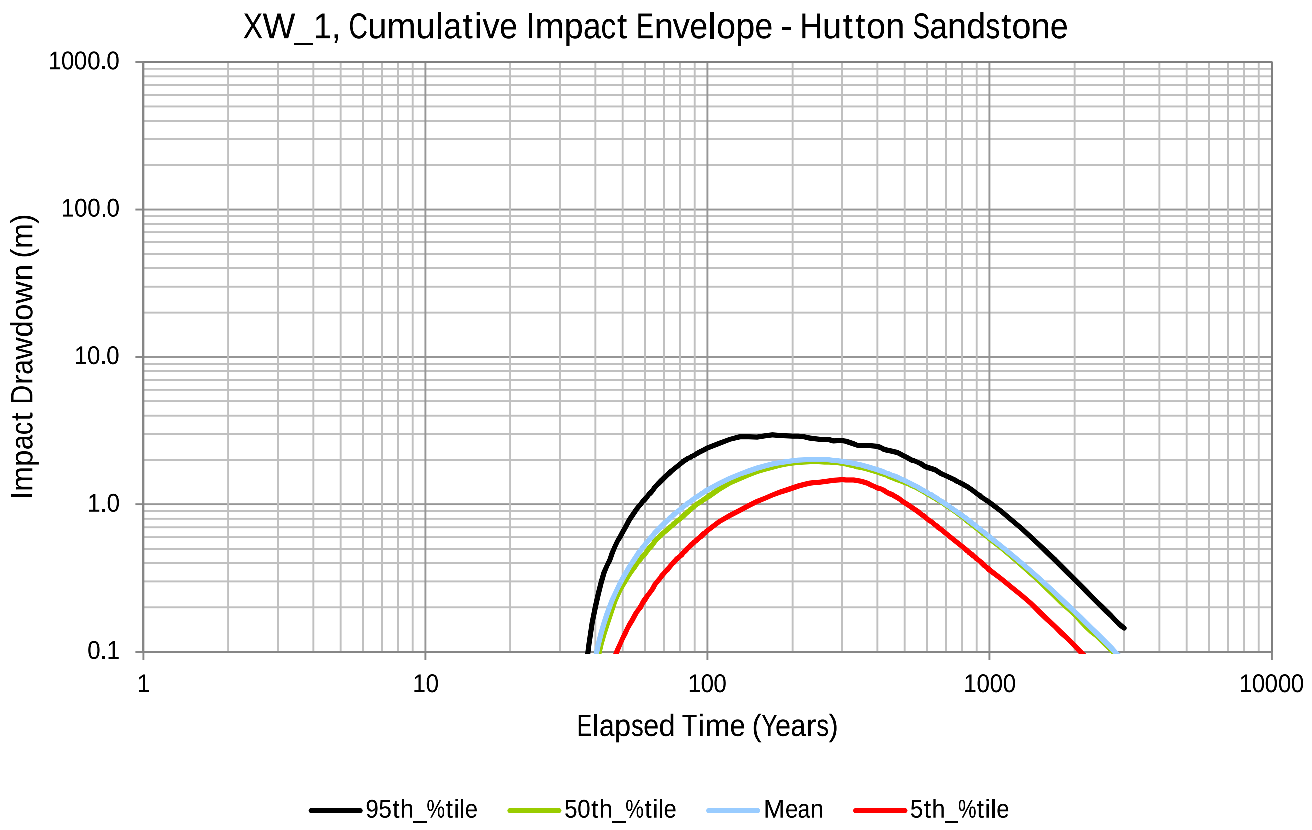
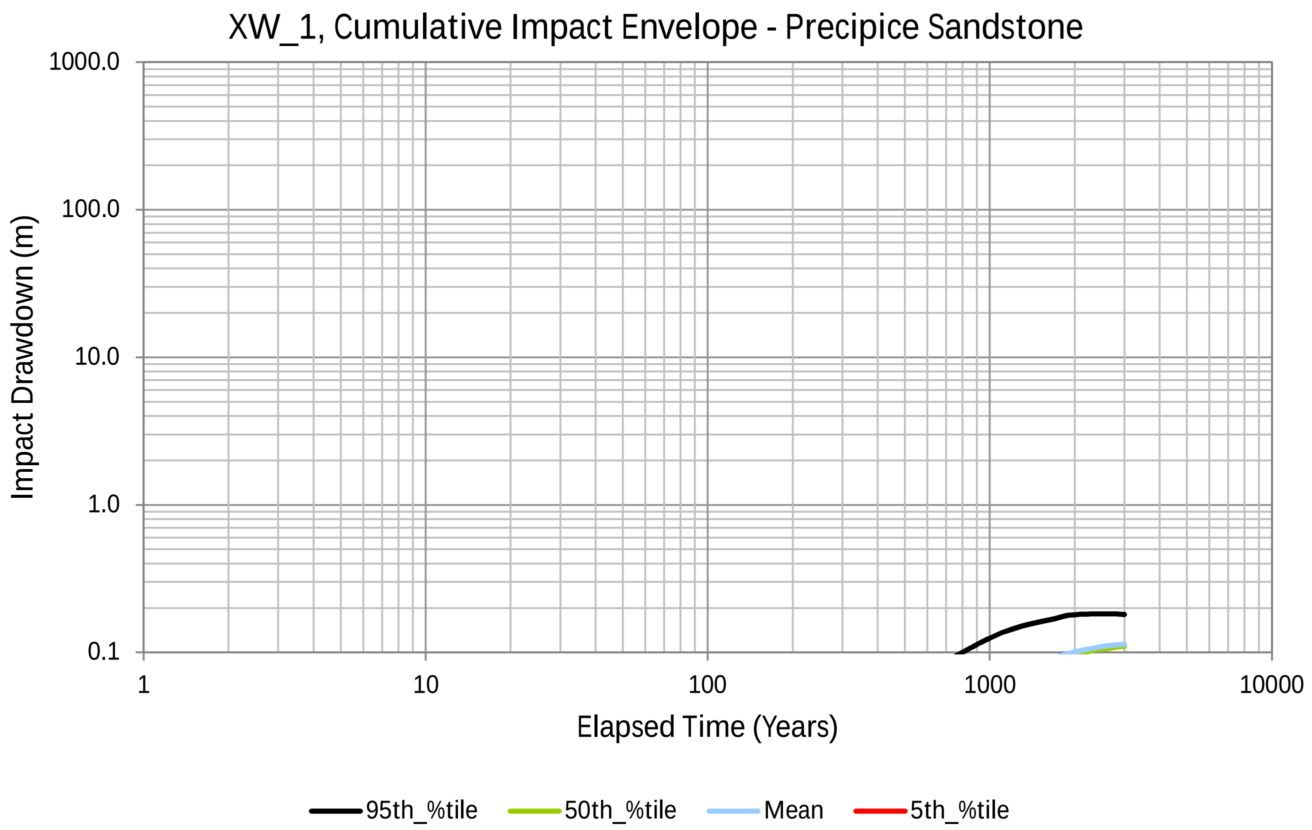
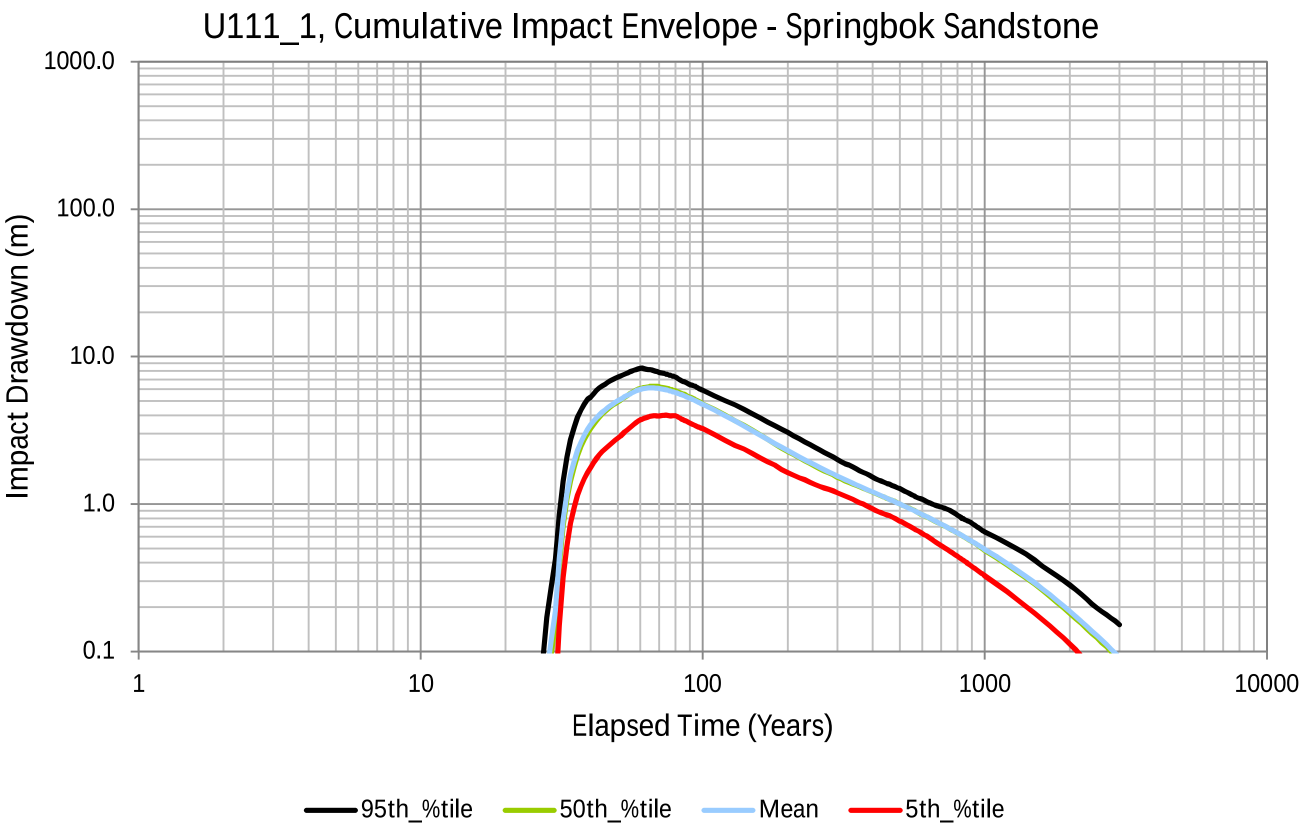
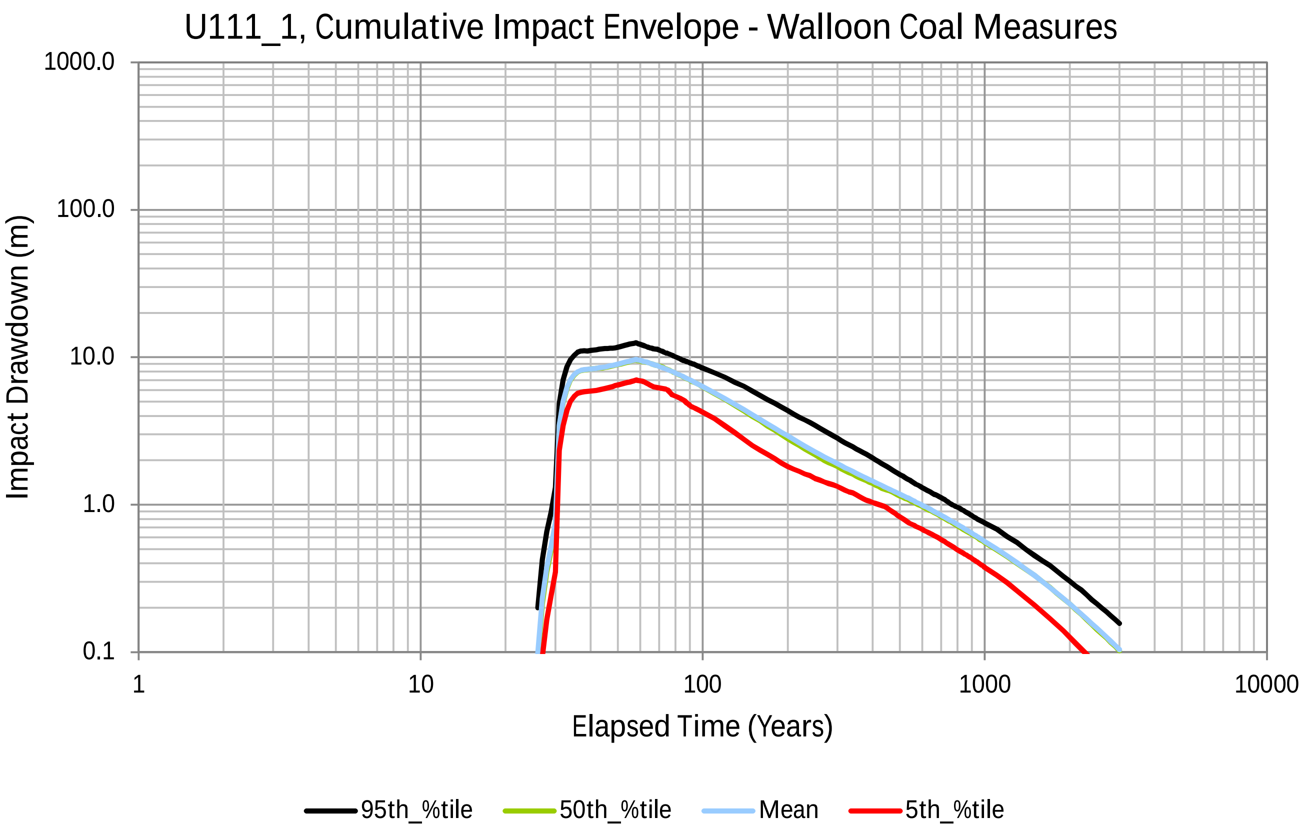
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 9





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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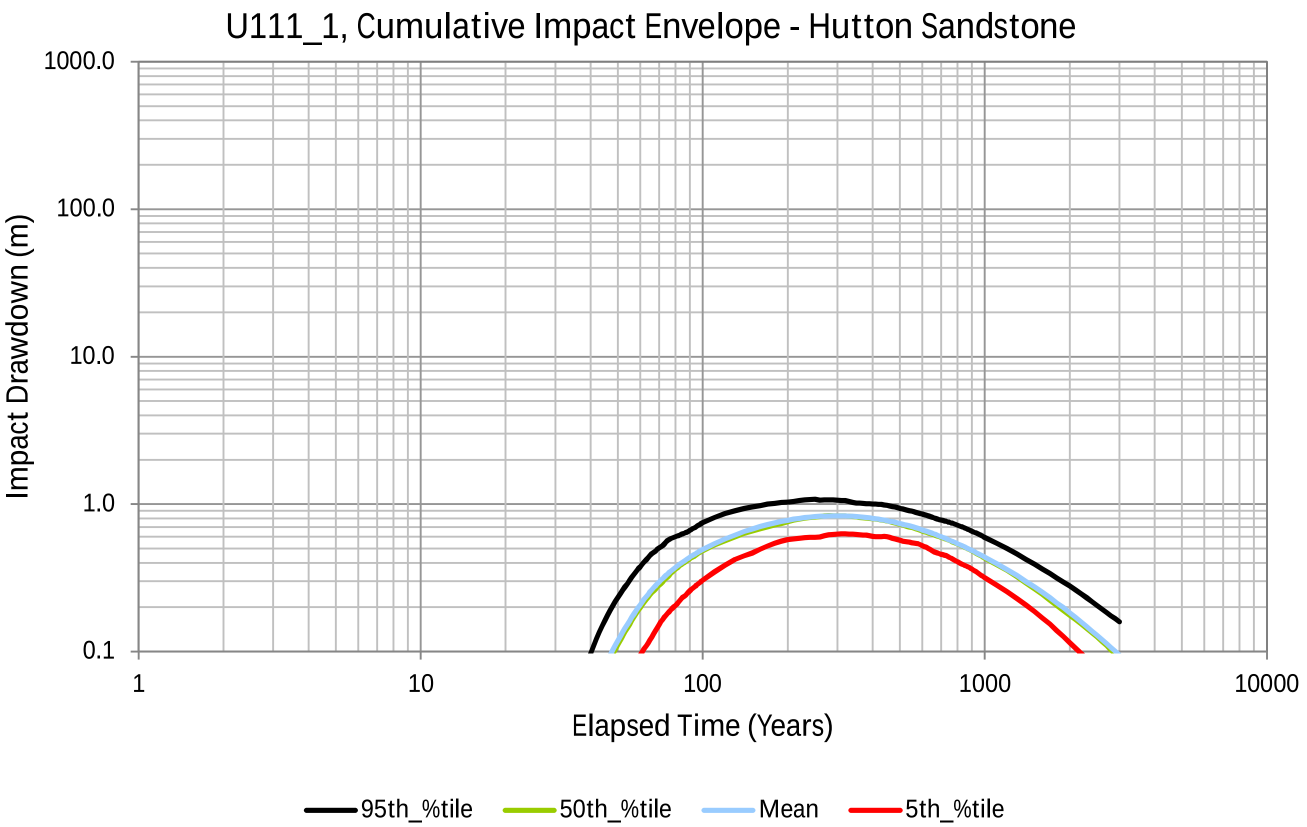
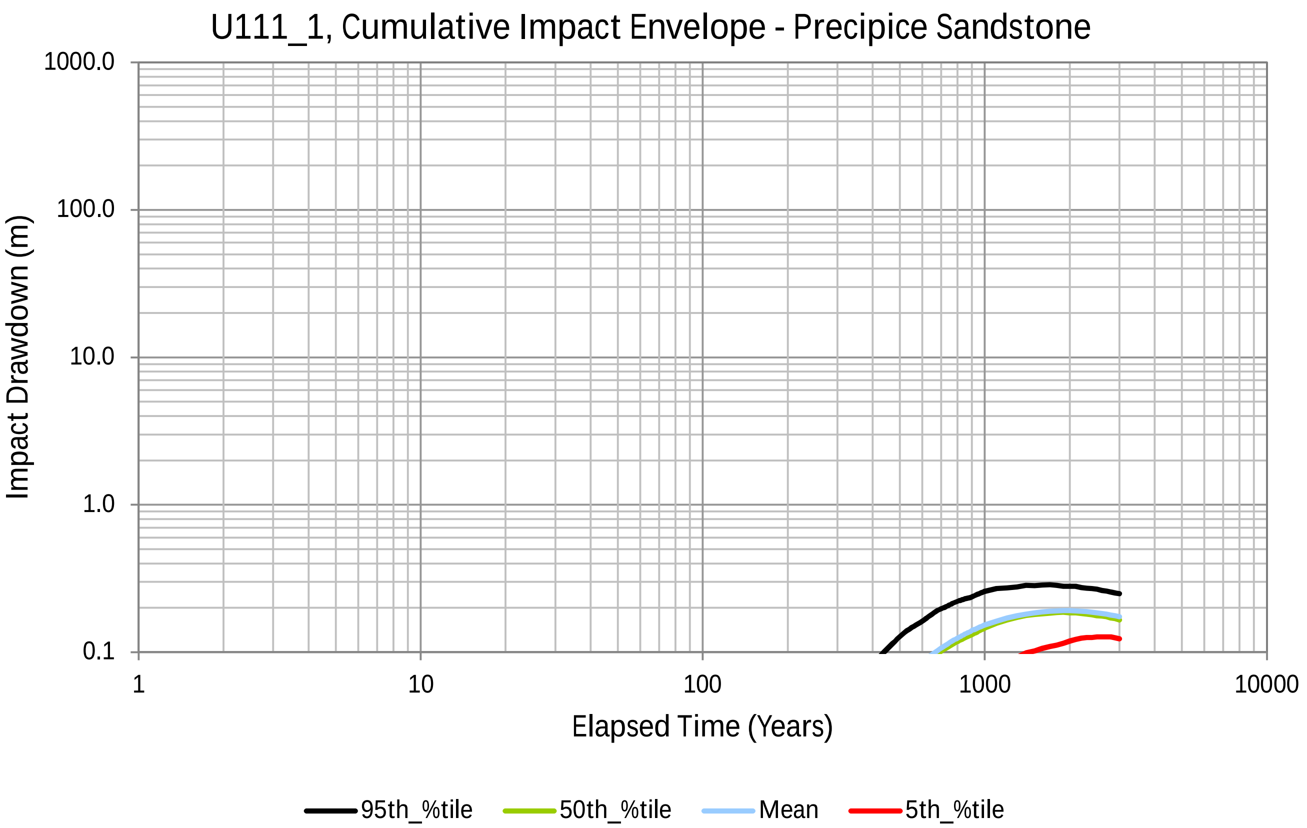
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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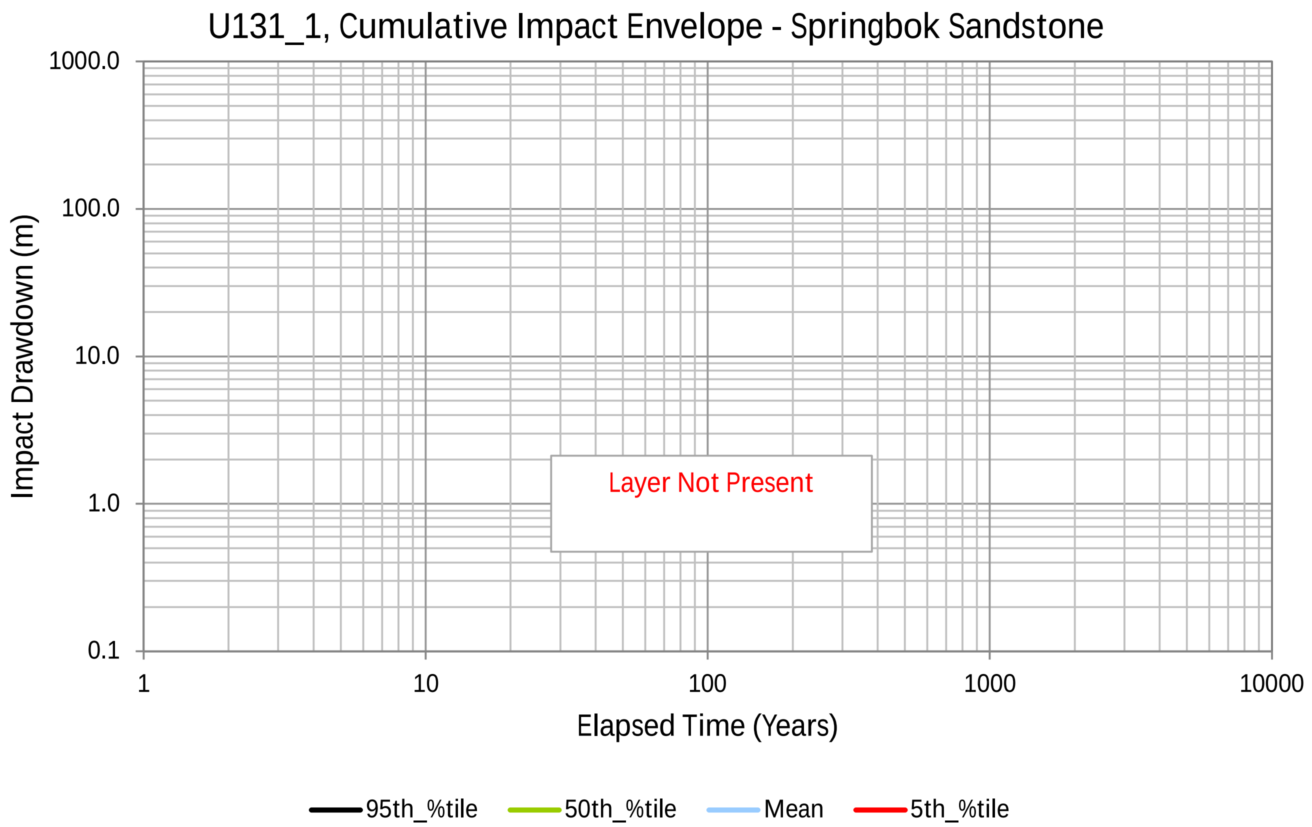
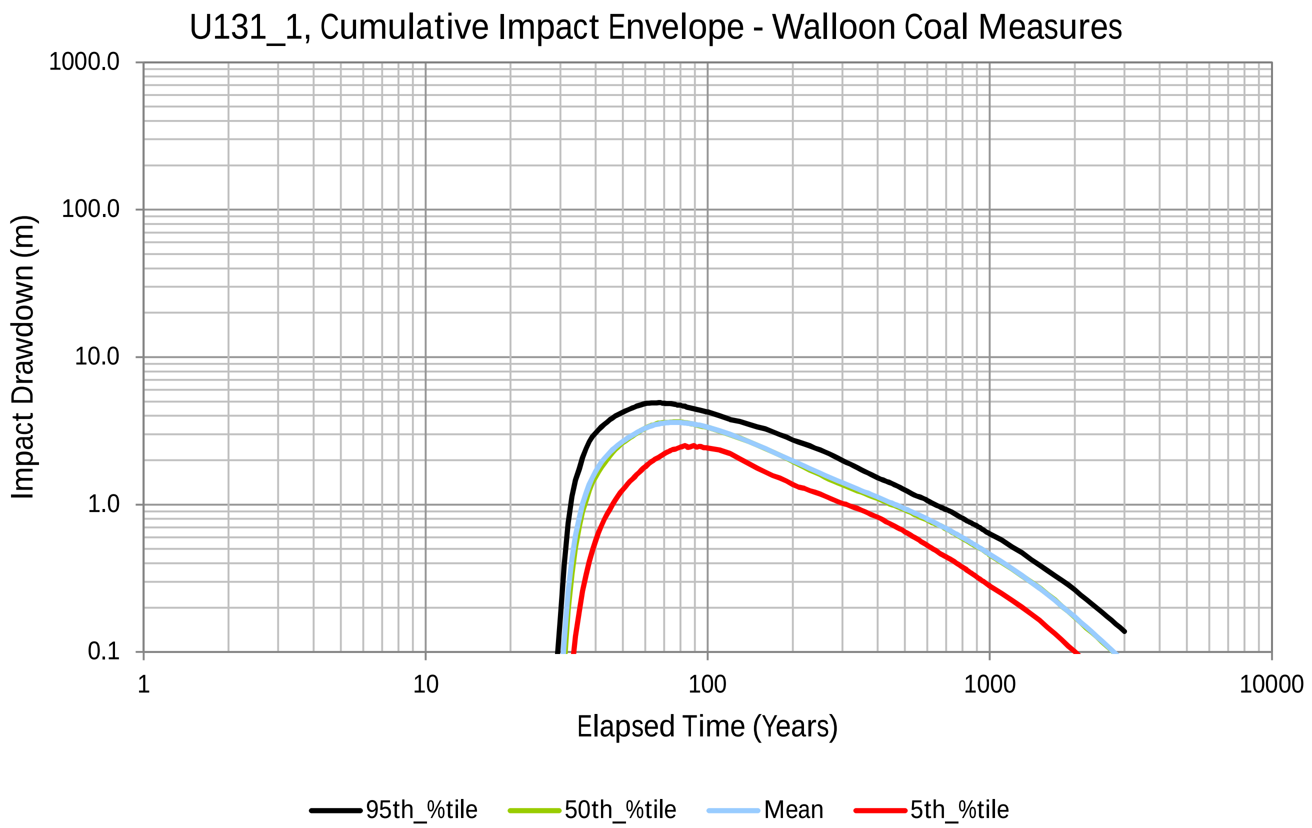
(Drainage_Area_10)

Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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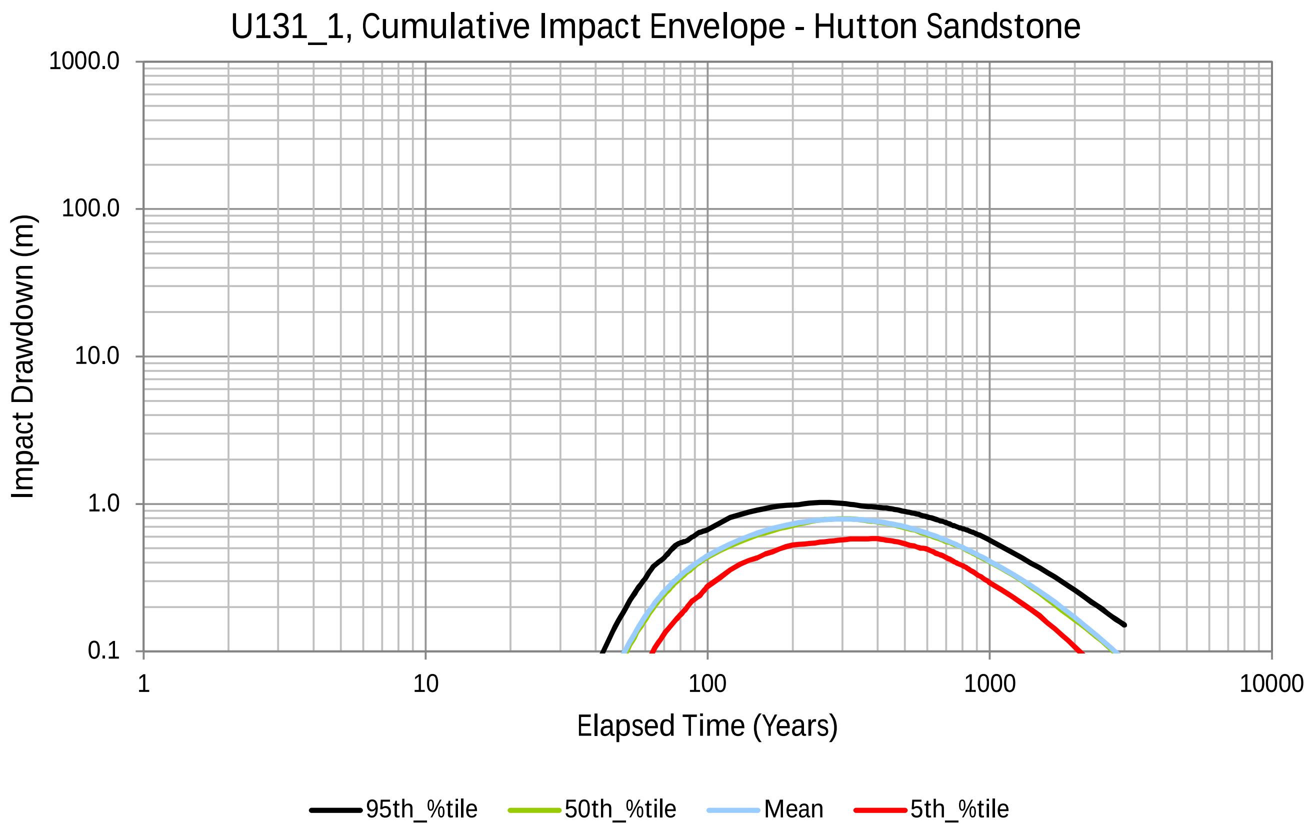
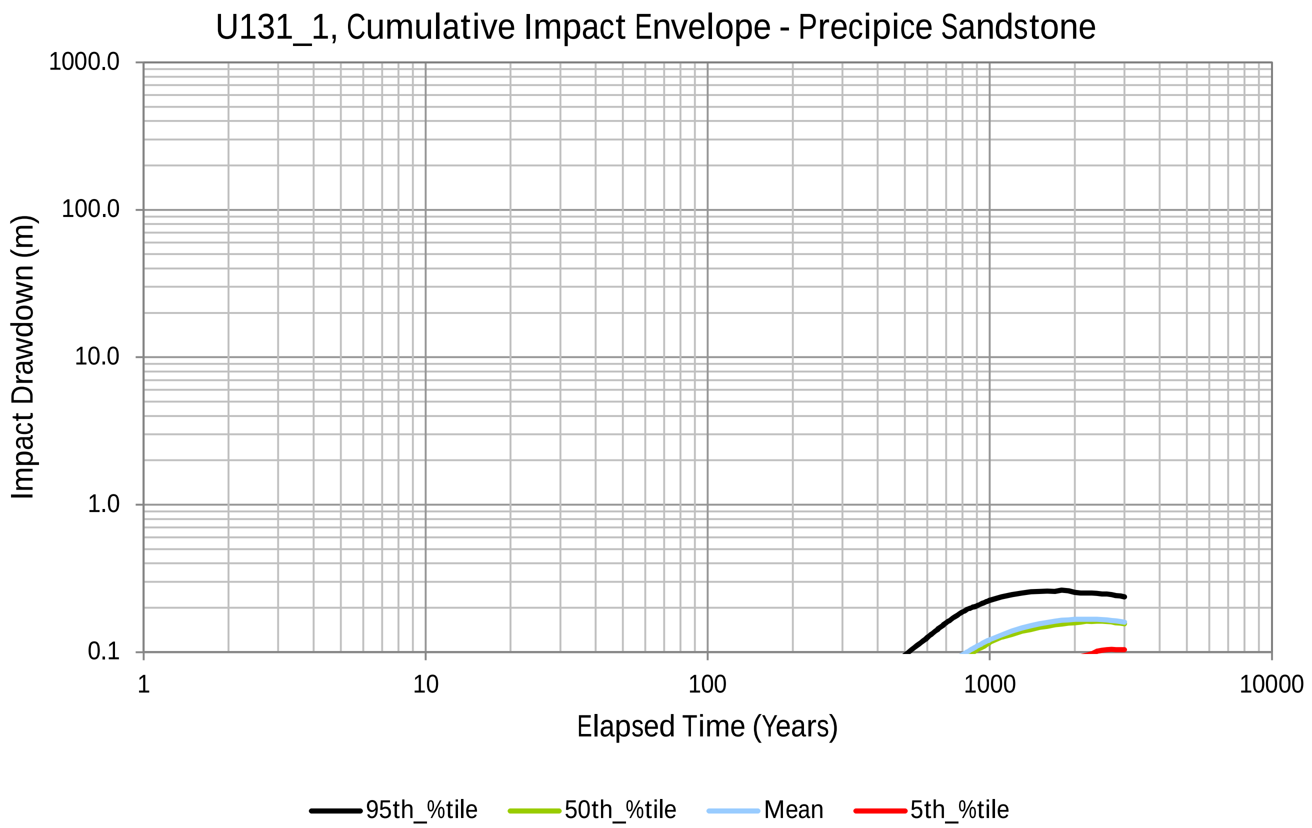
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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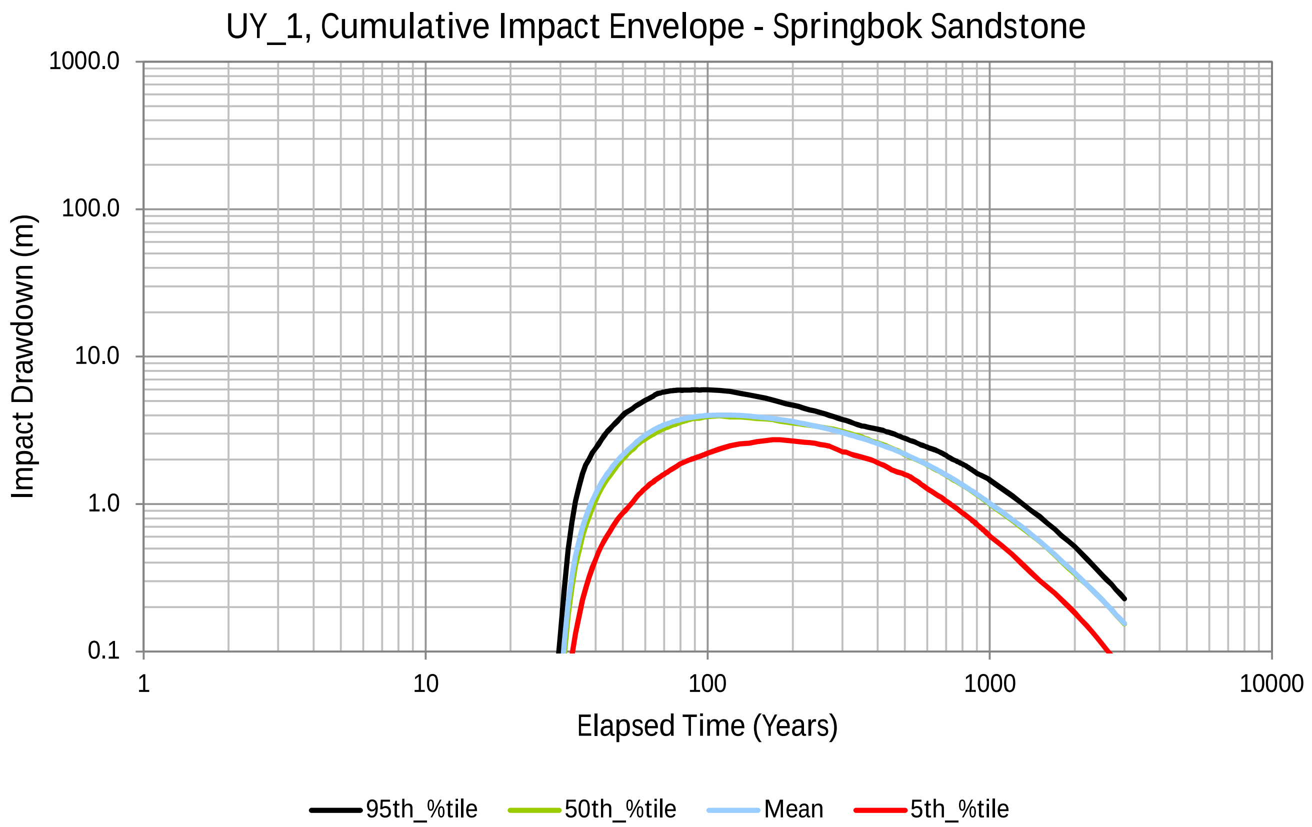
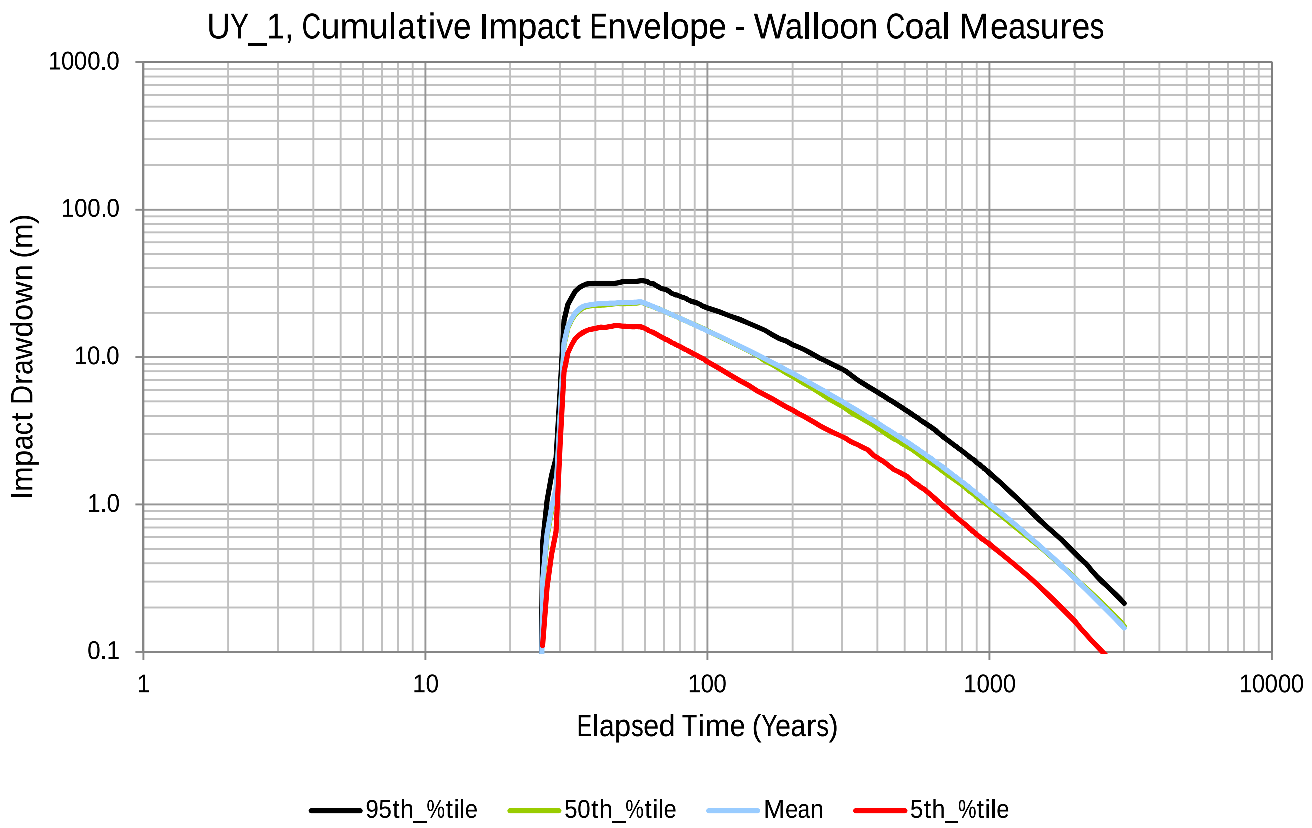
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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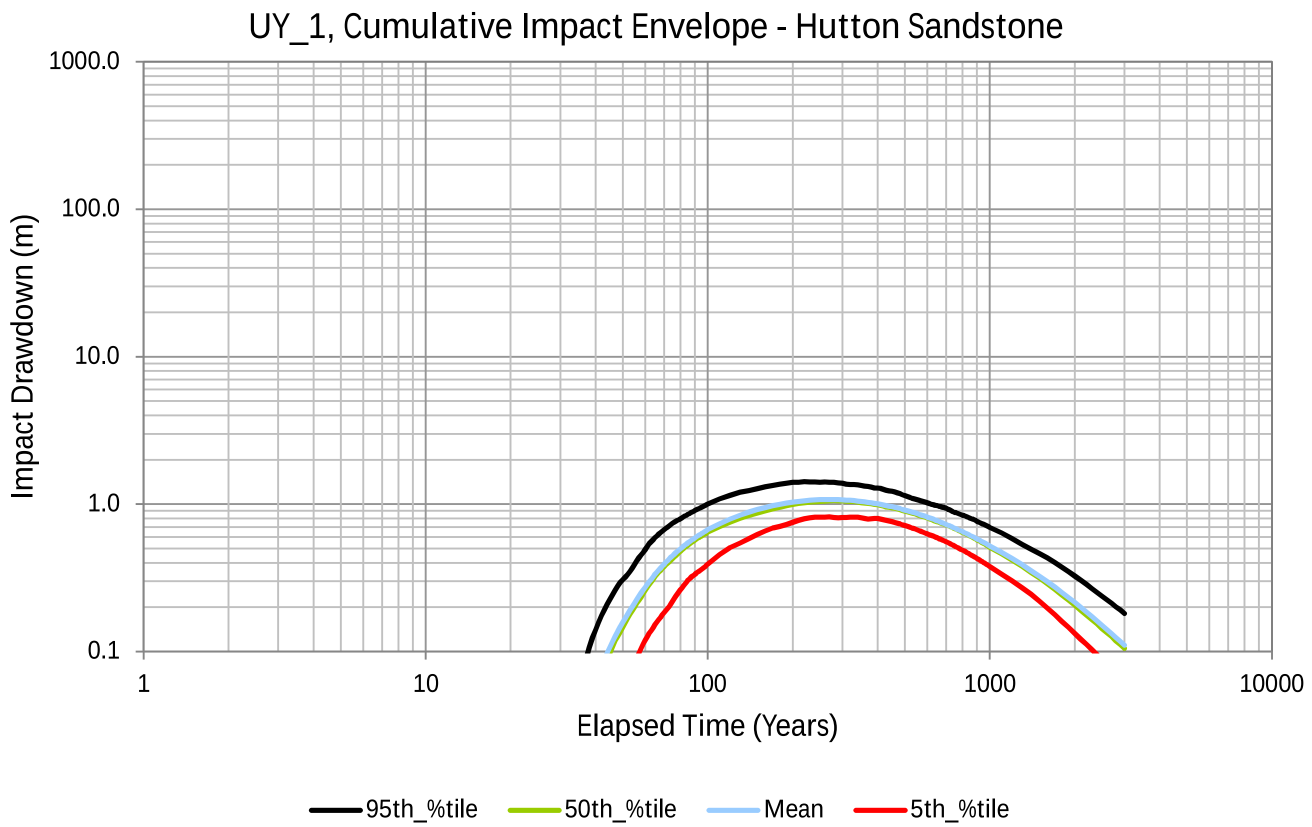
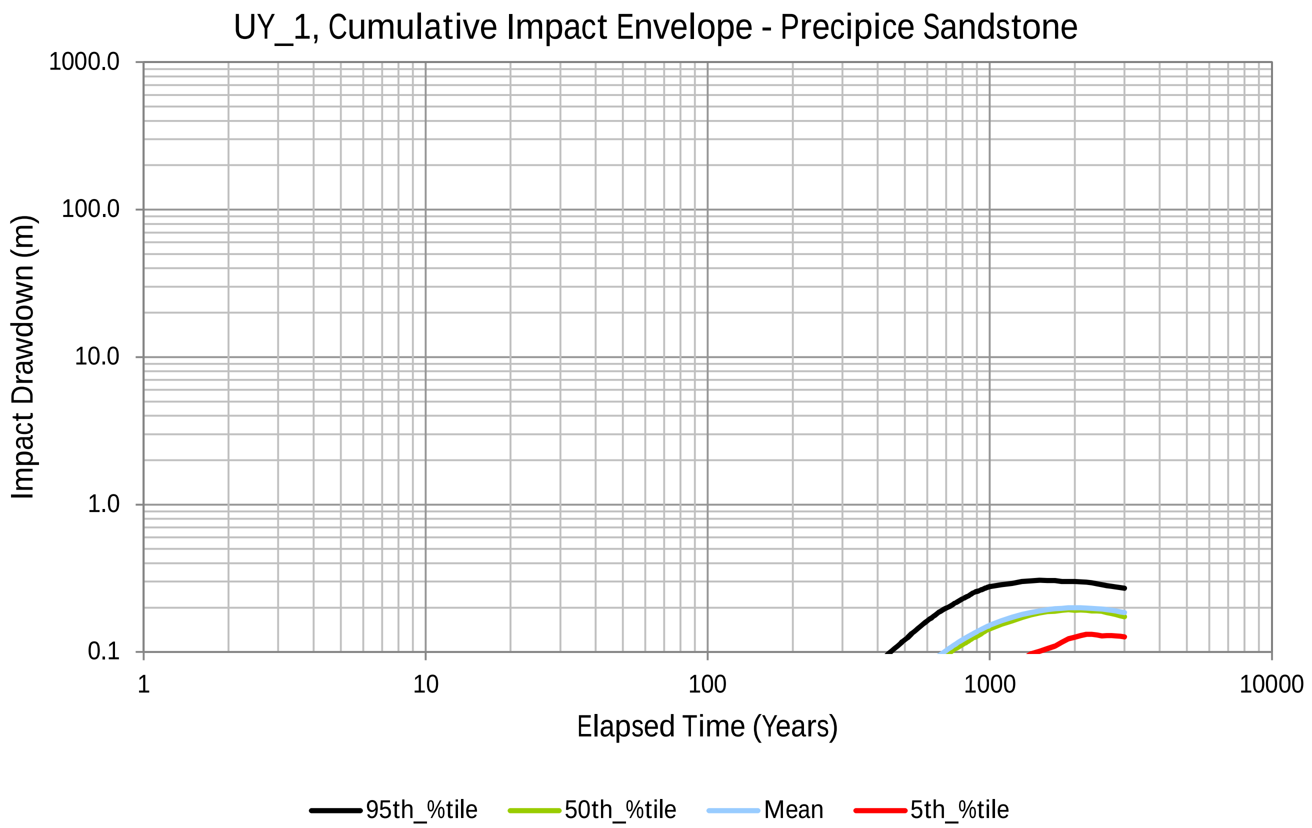
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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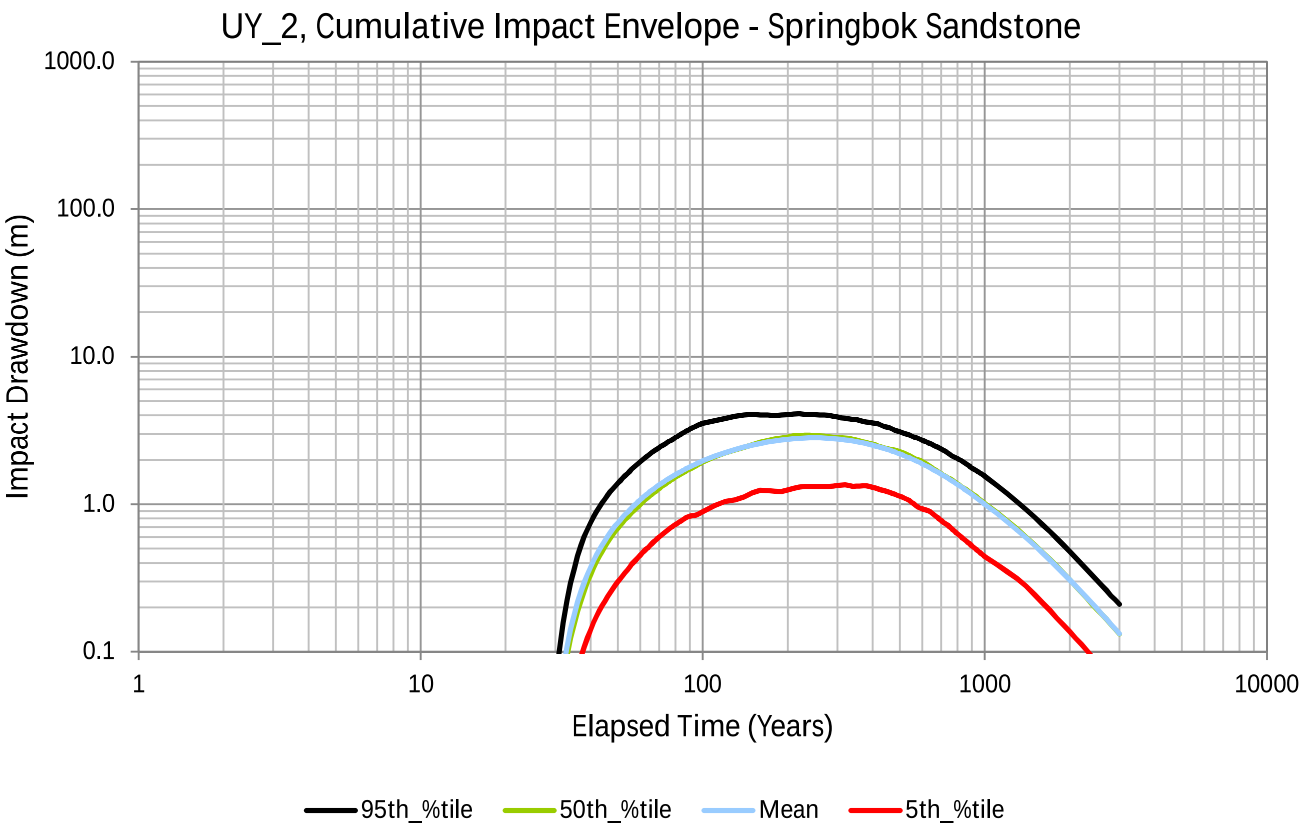
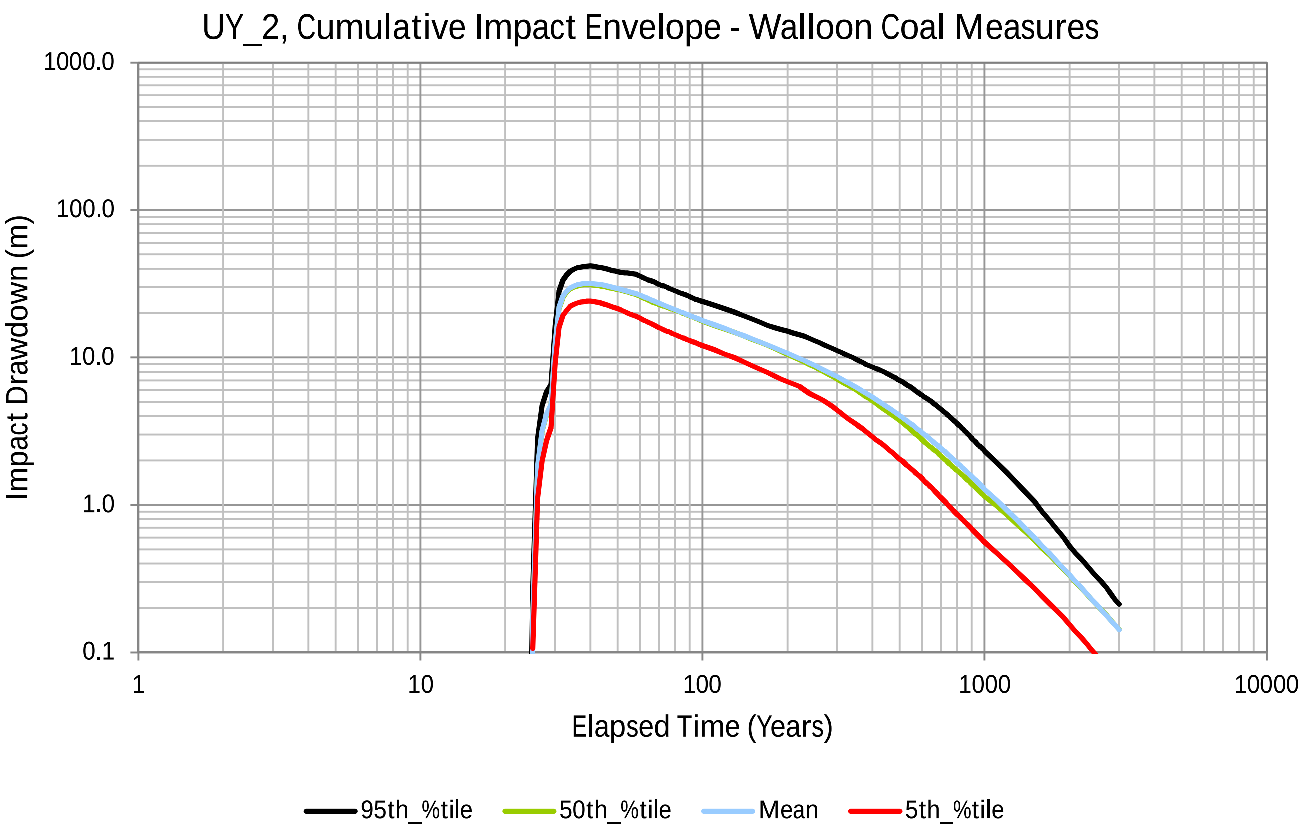
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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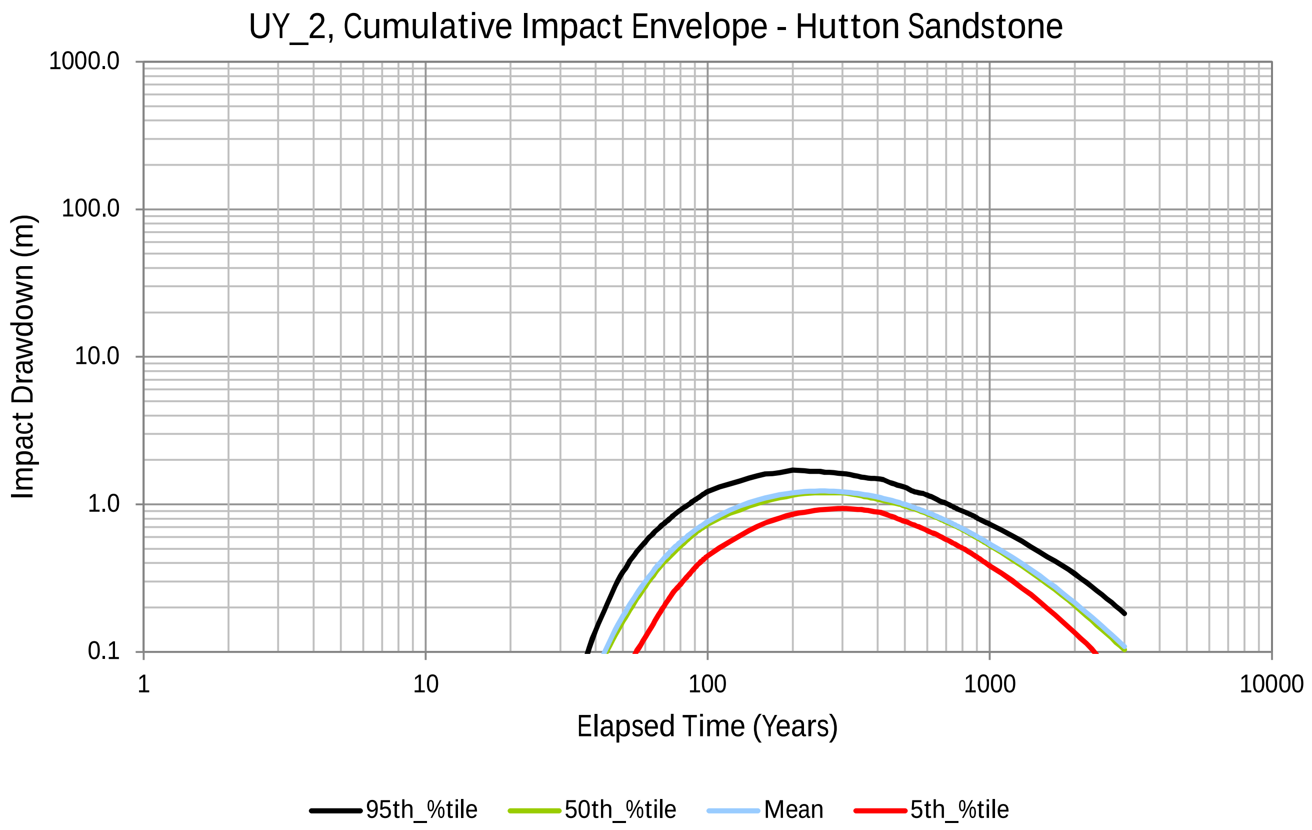
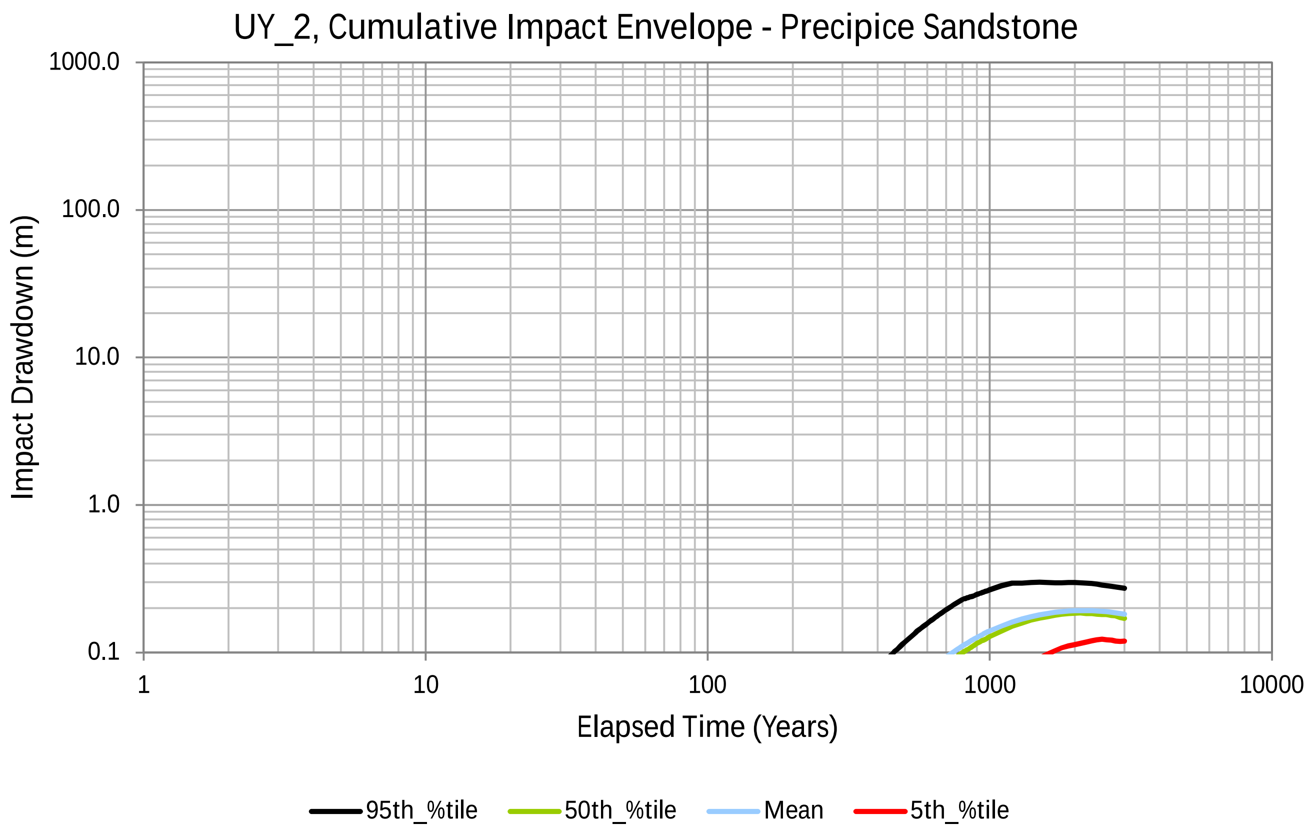
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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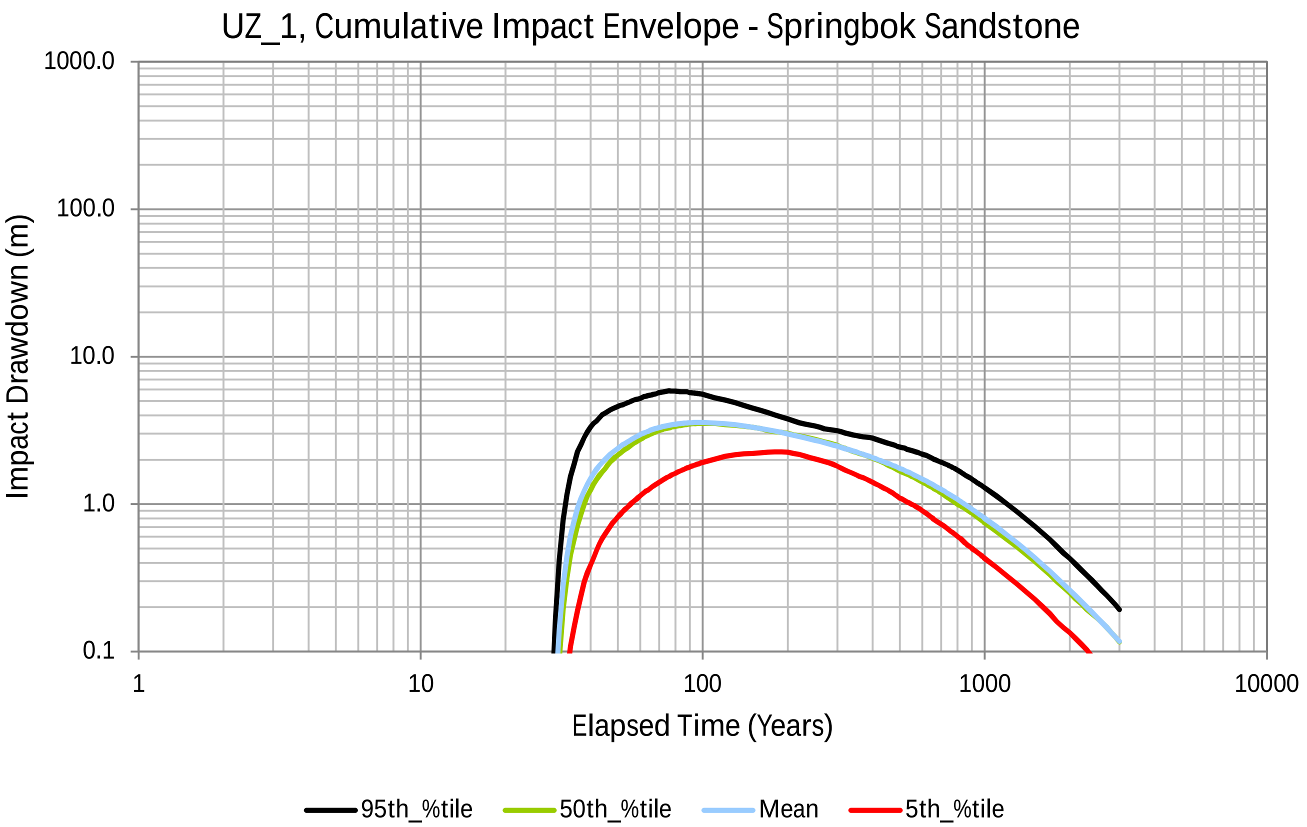
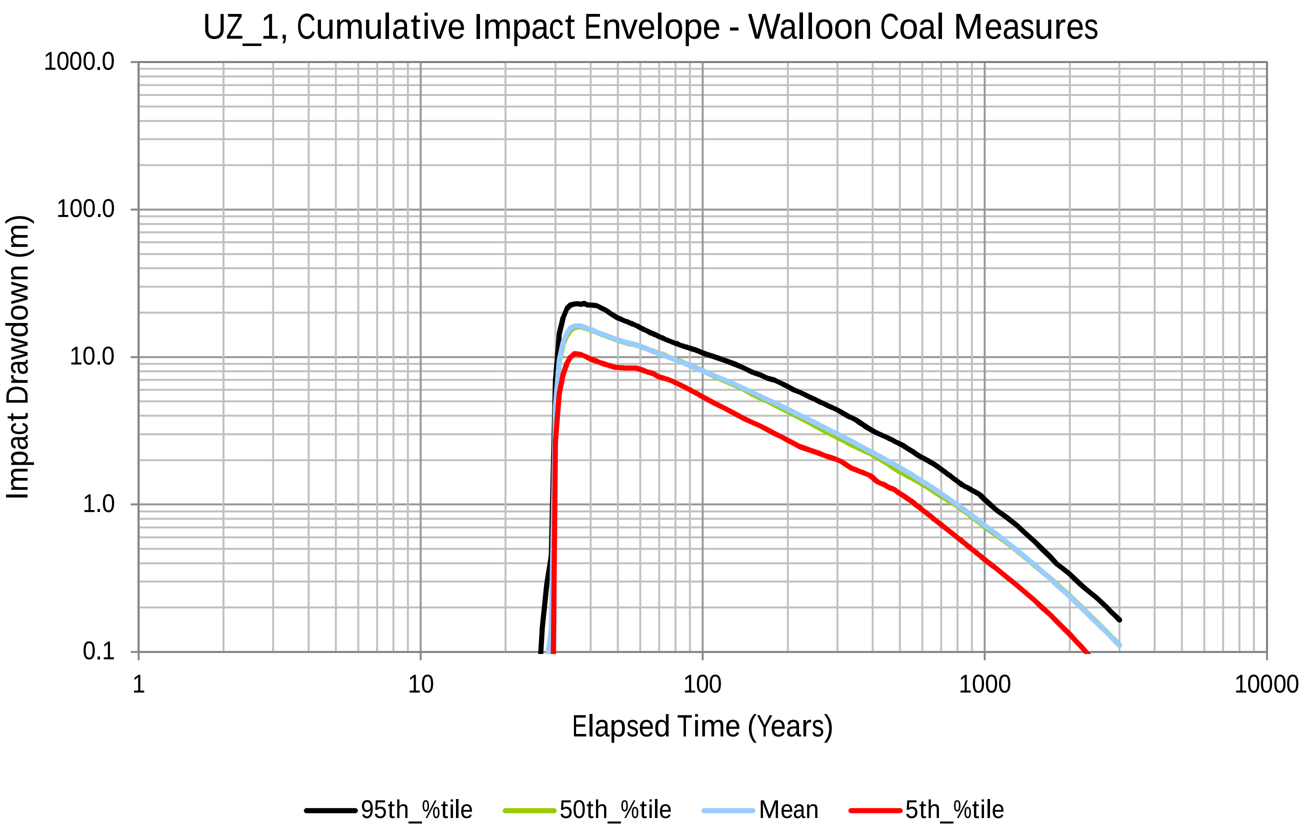
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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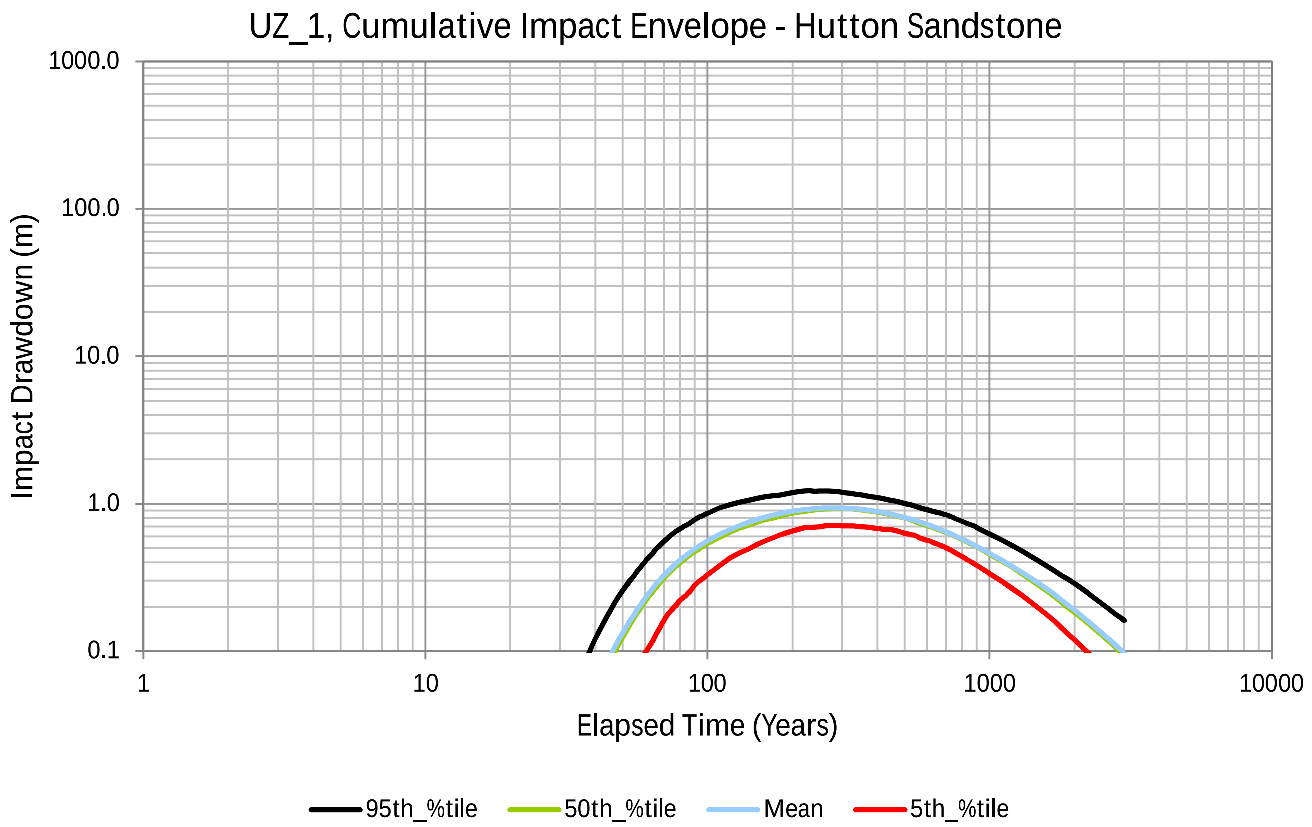
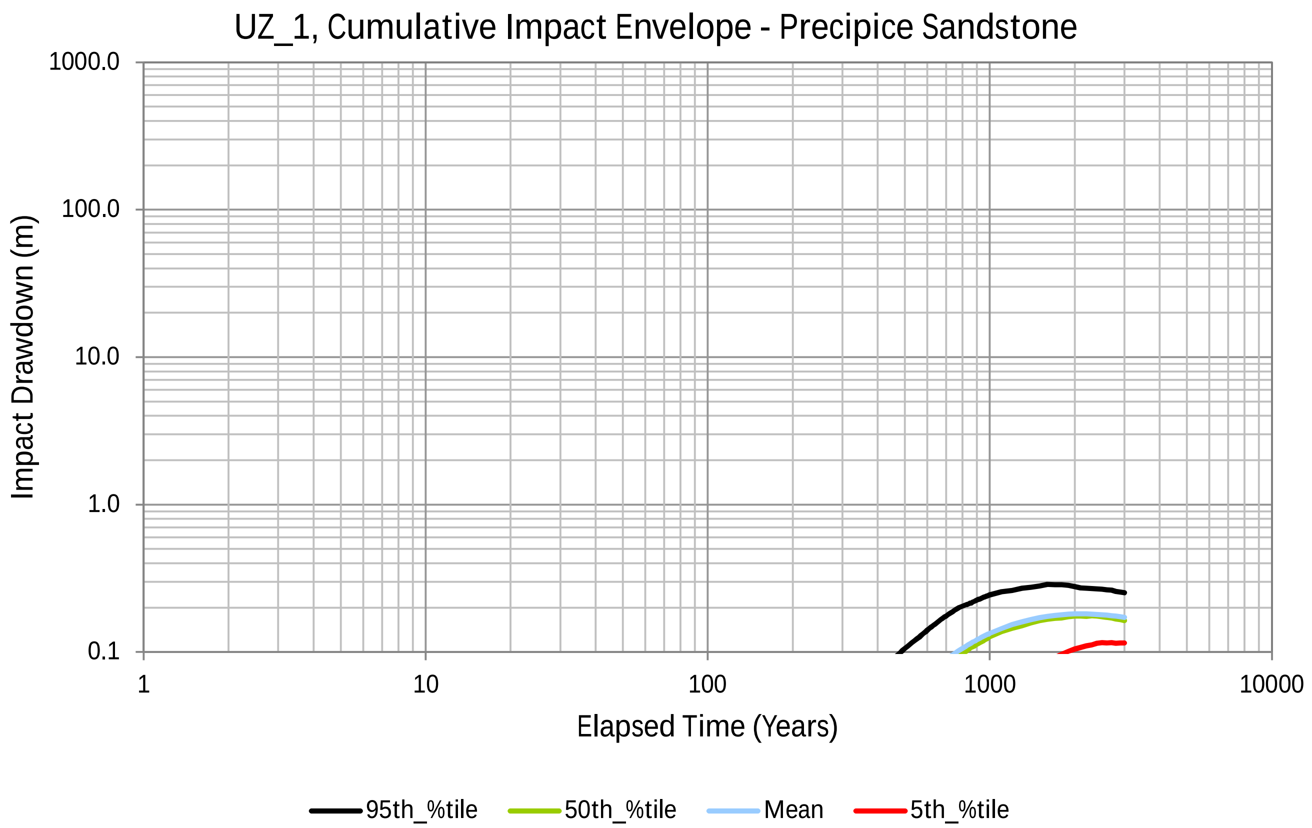
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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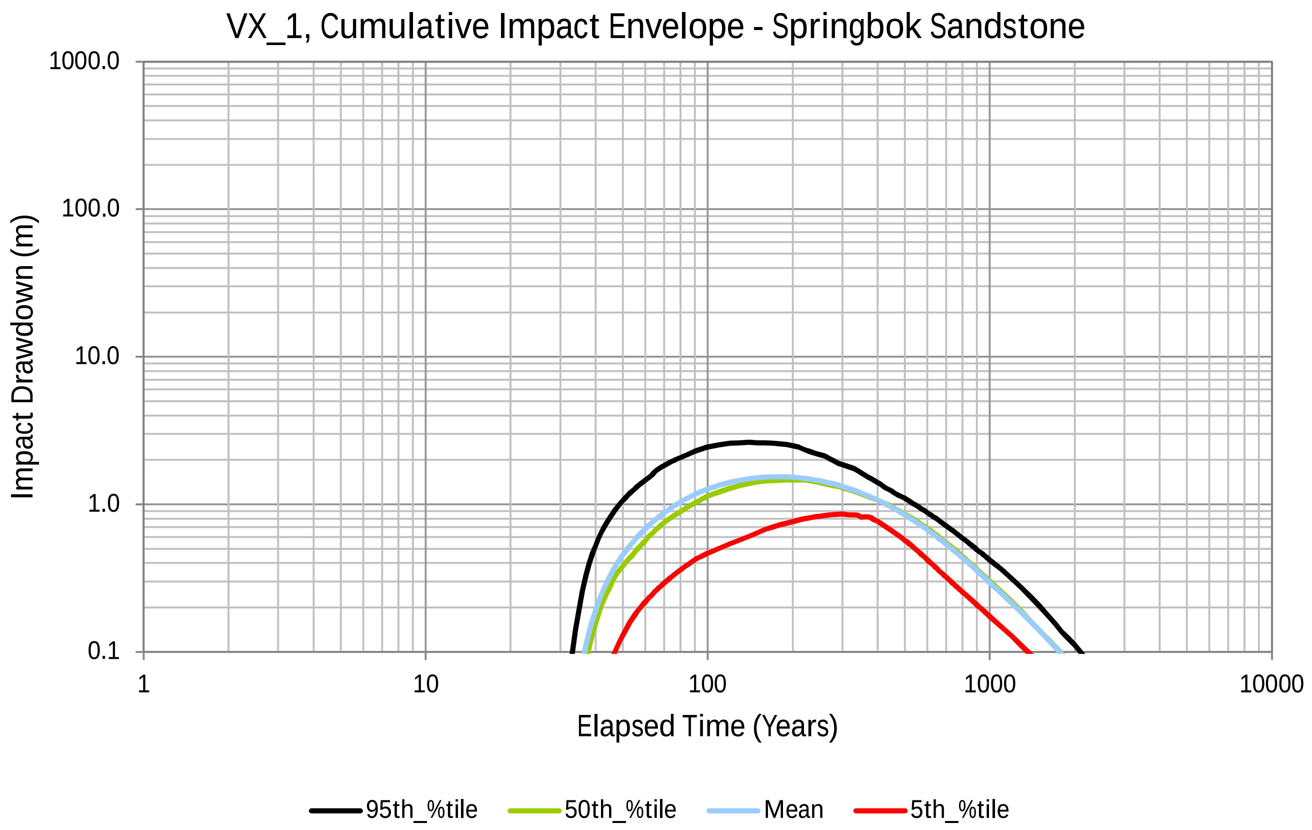
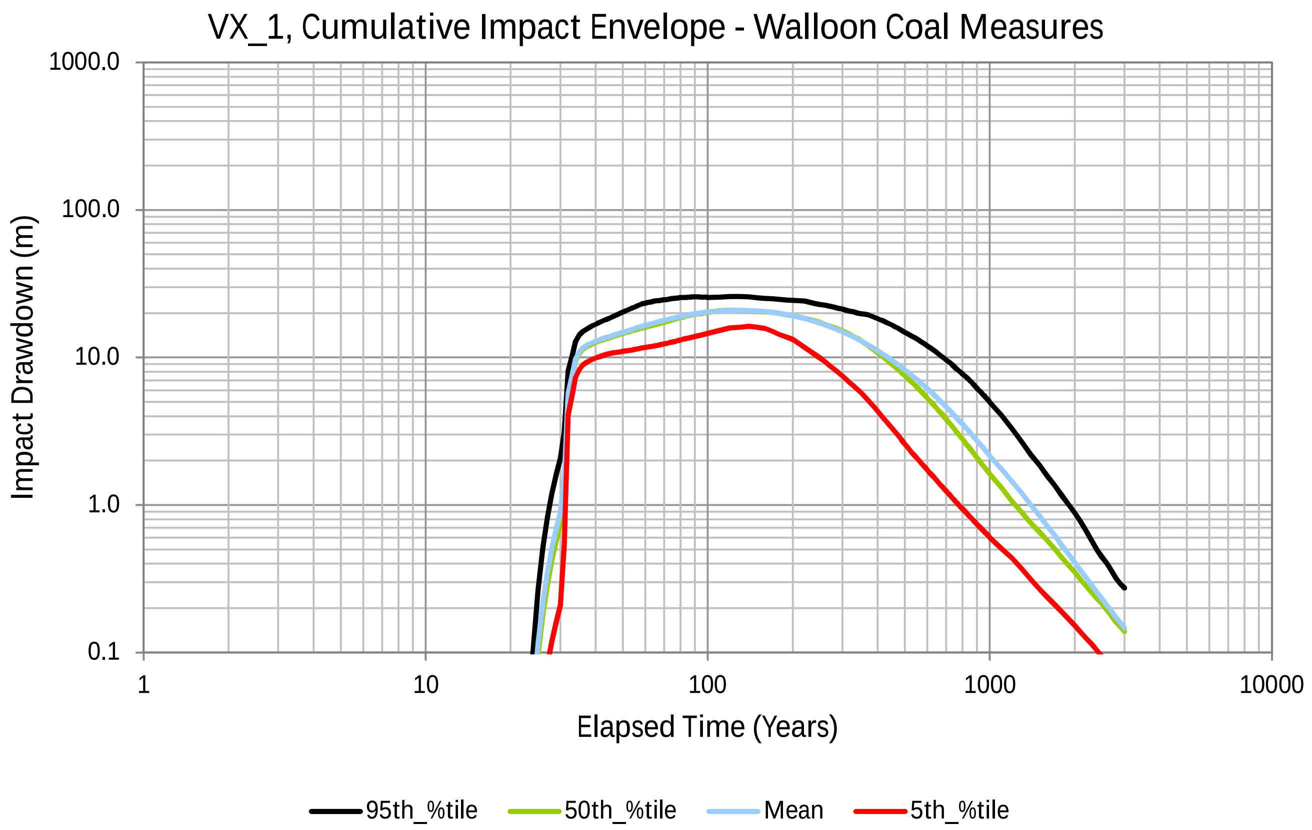
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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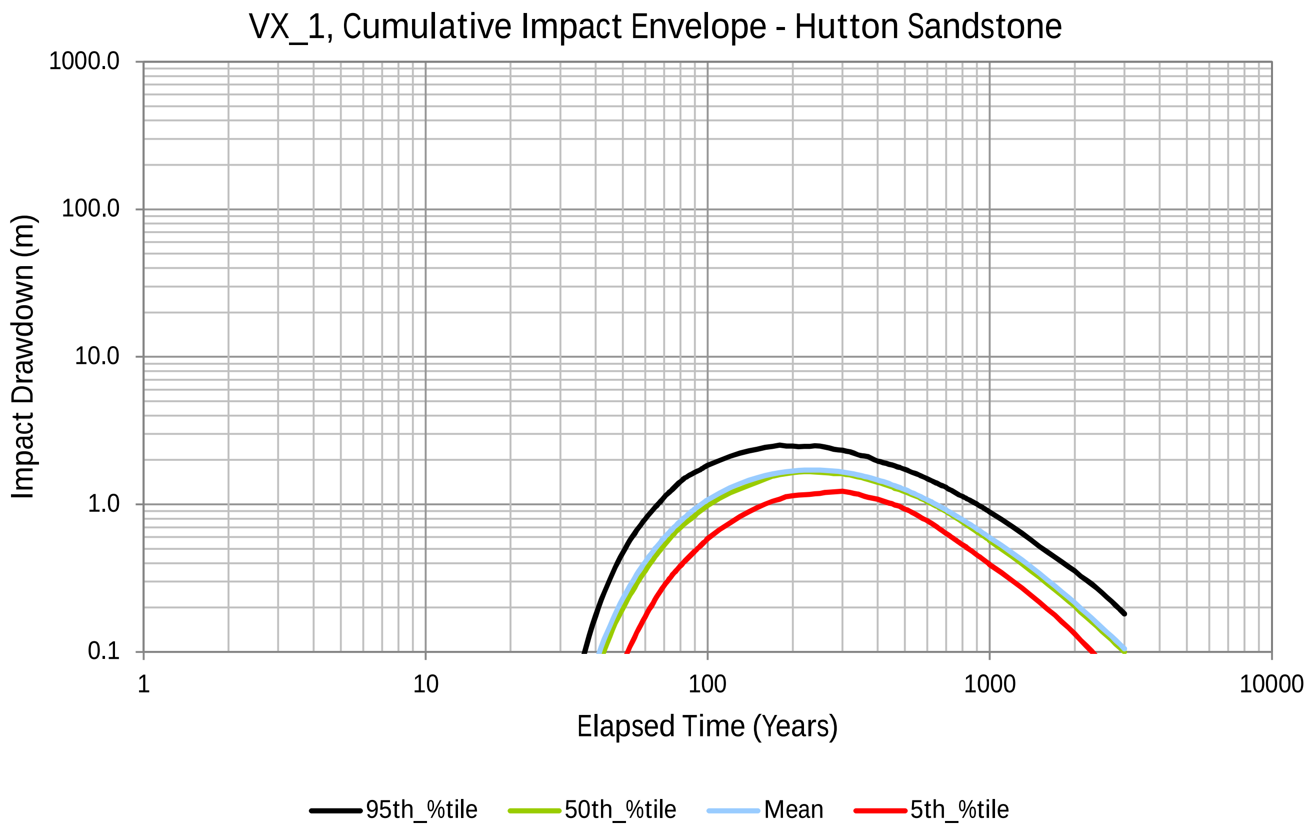
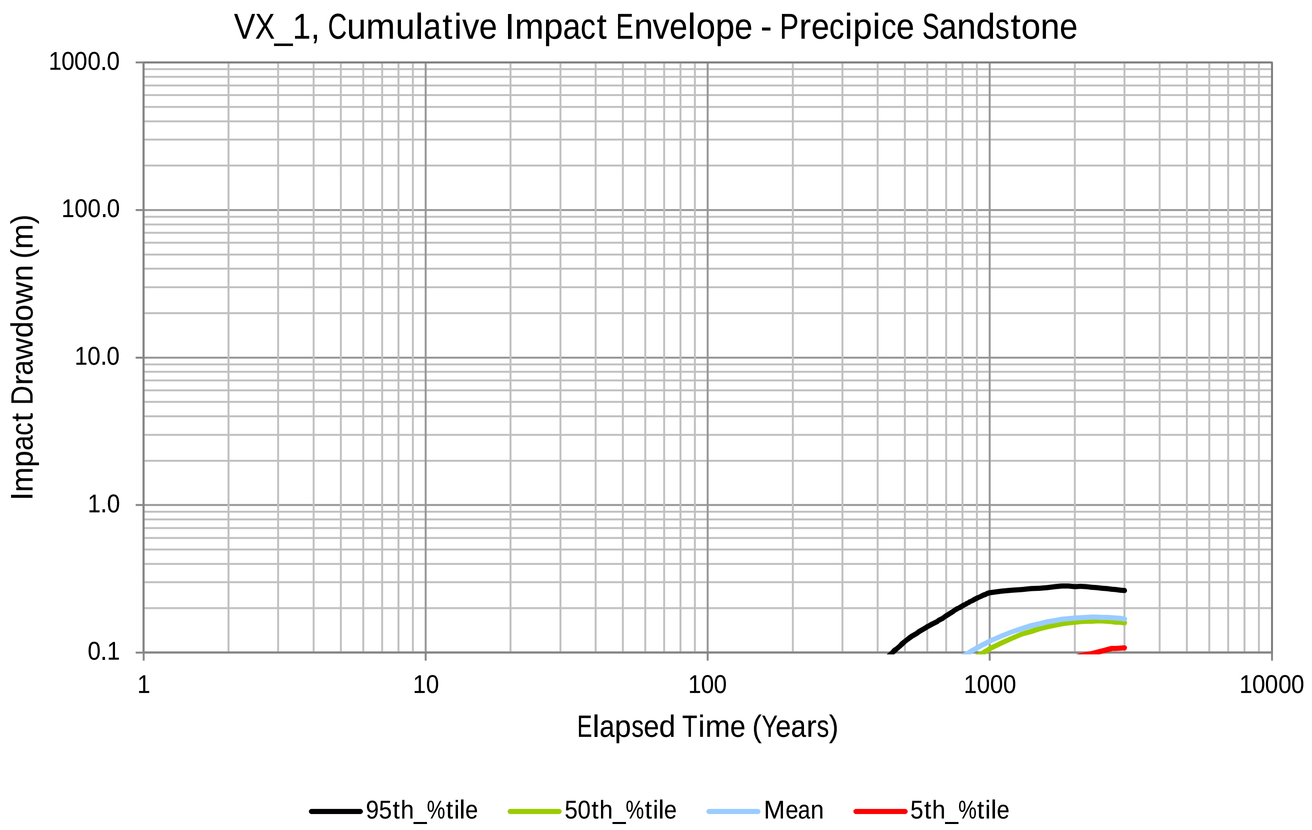
(Drainage_Area_10)

Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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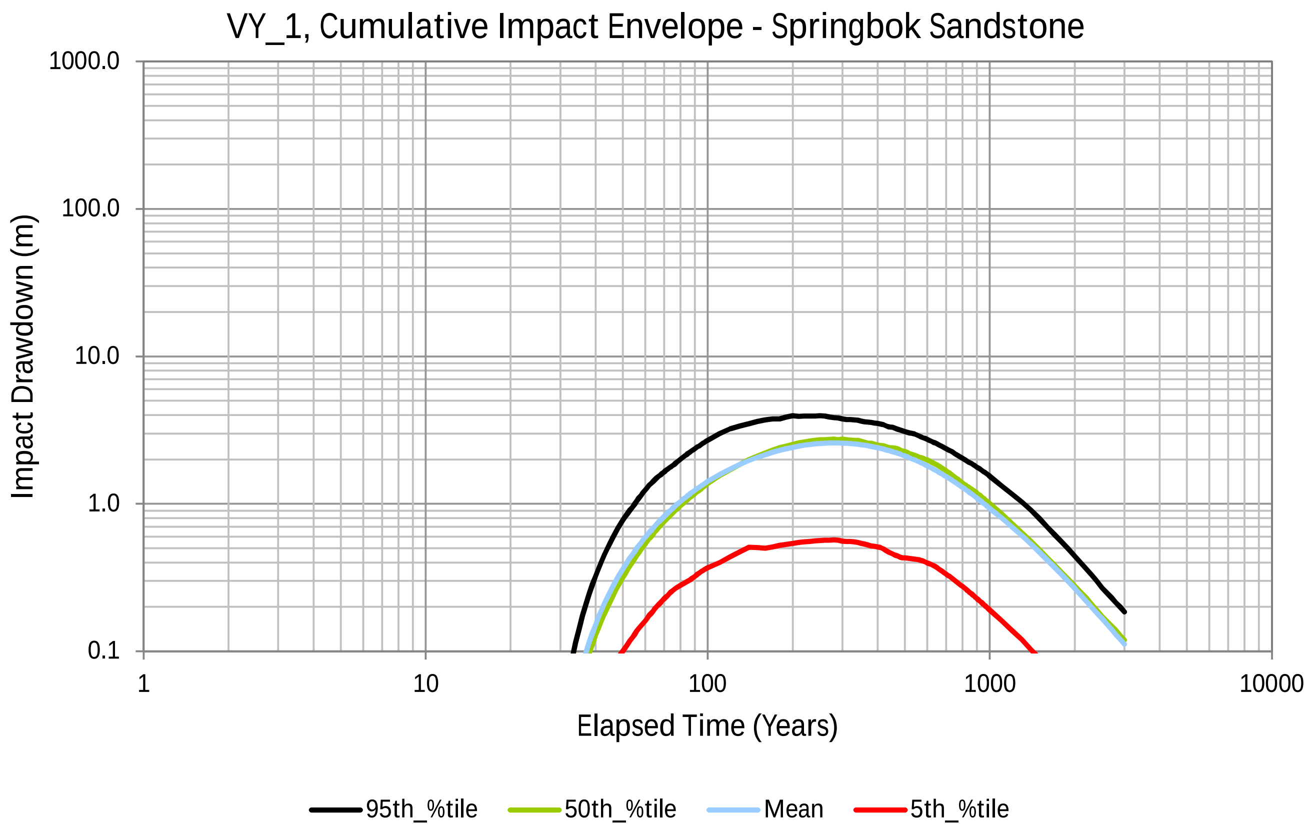
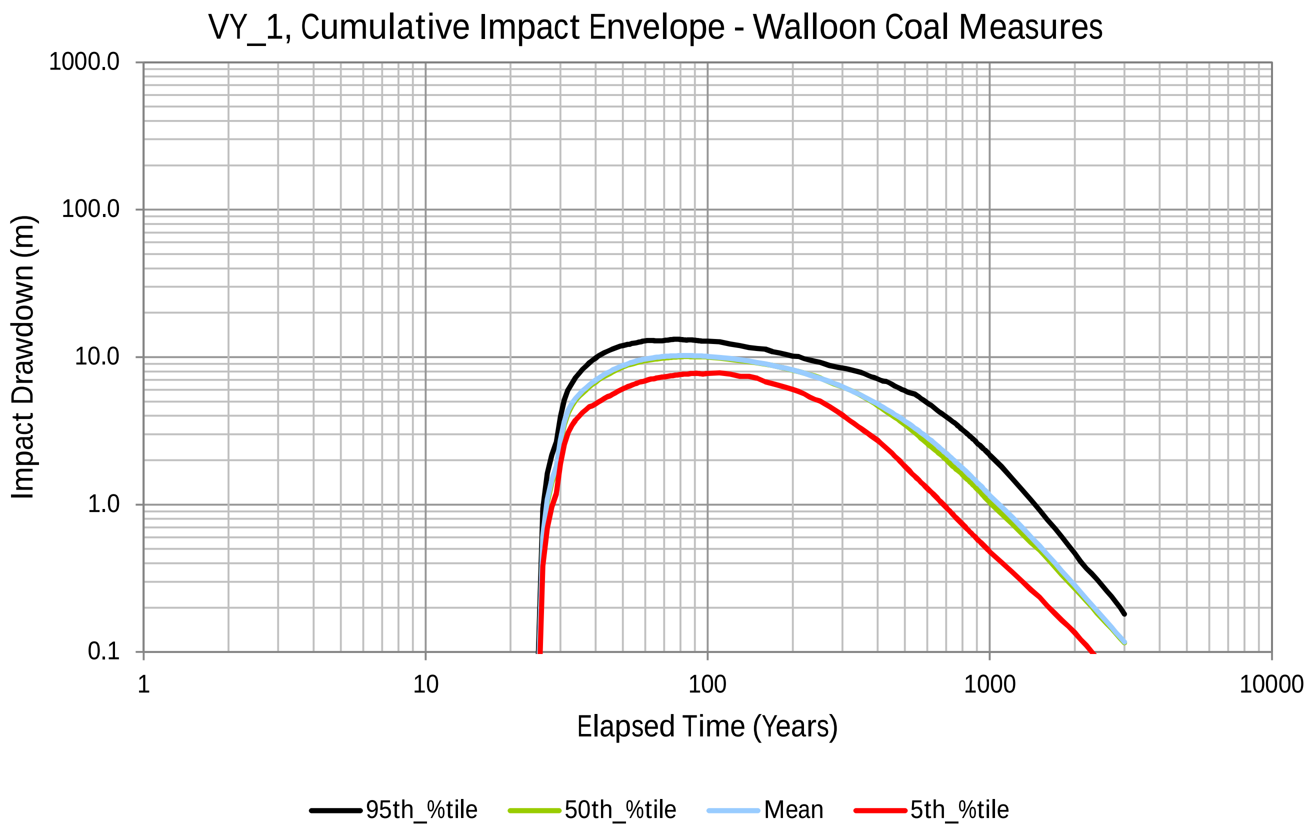
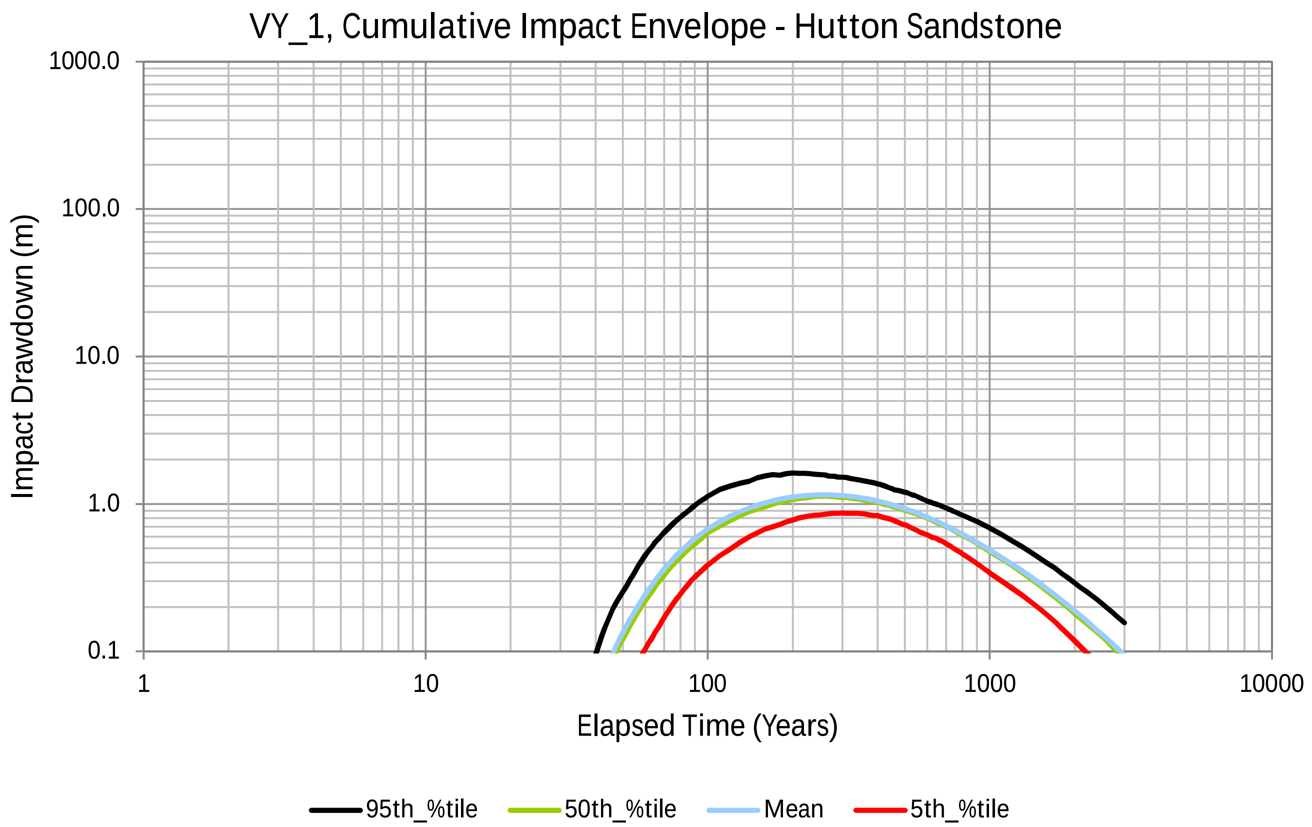
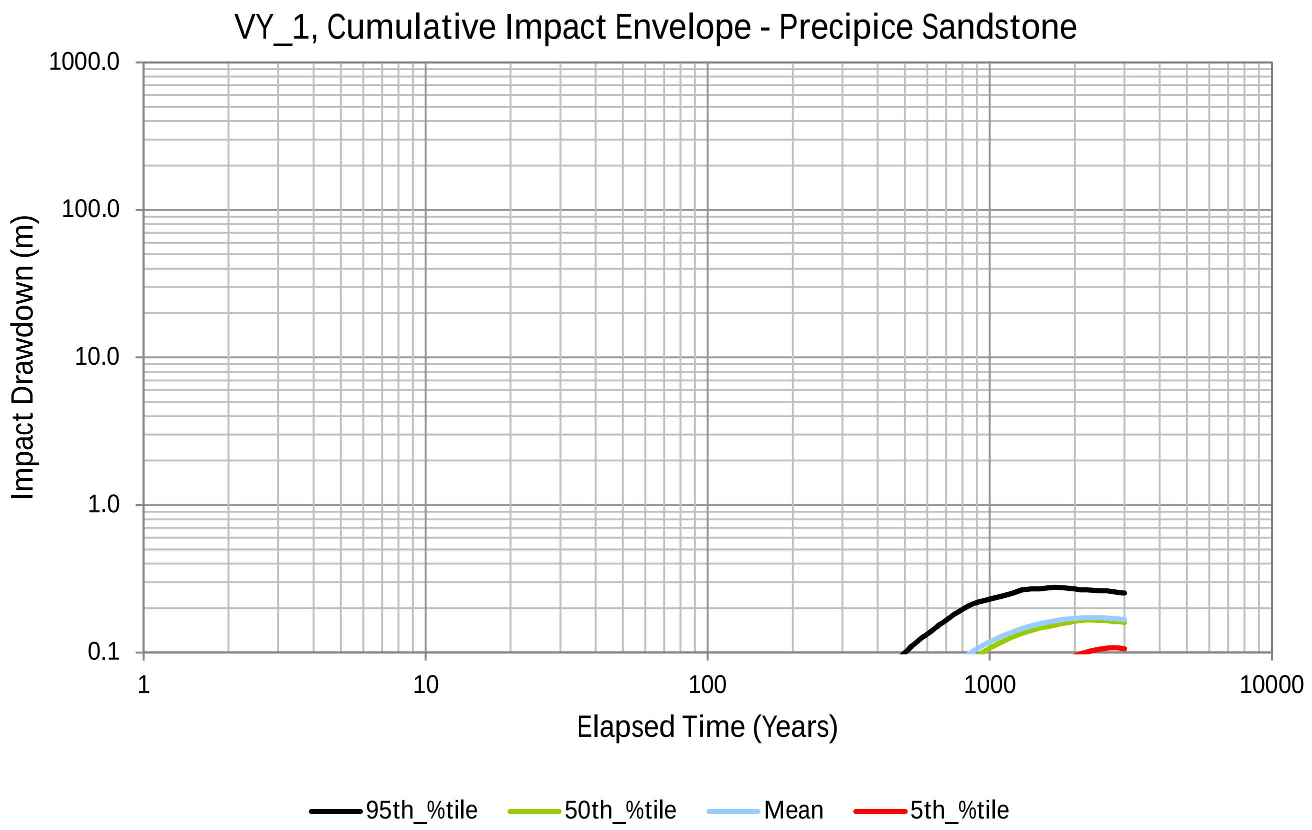
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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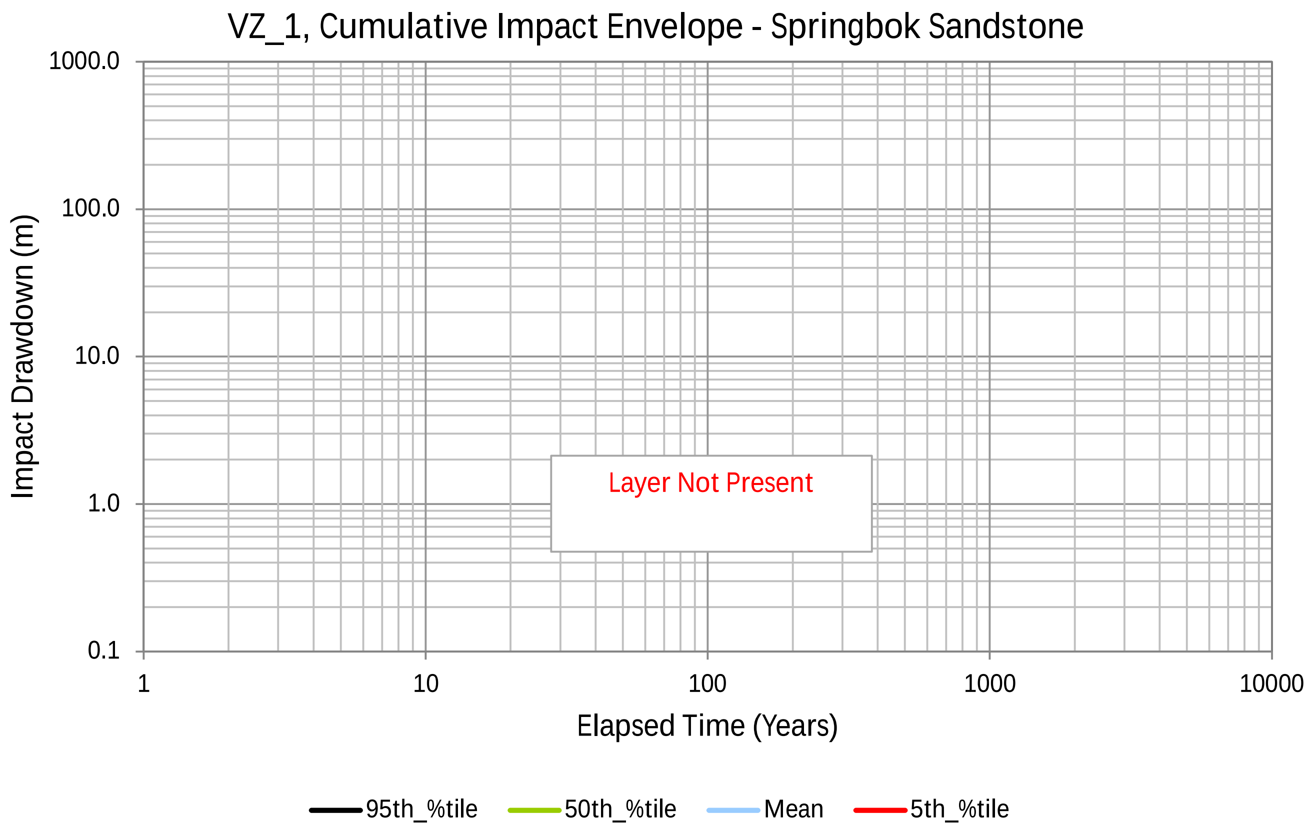
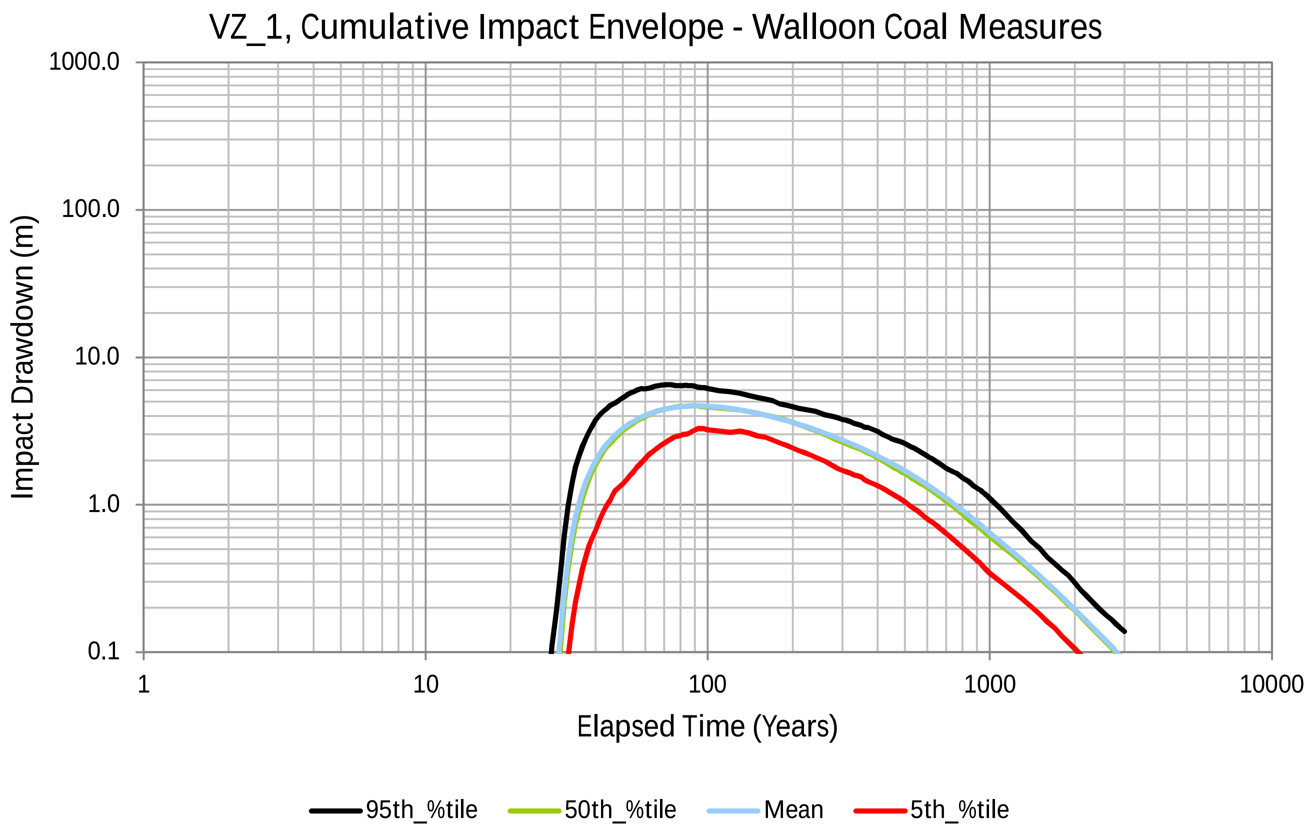
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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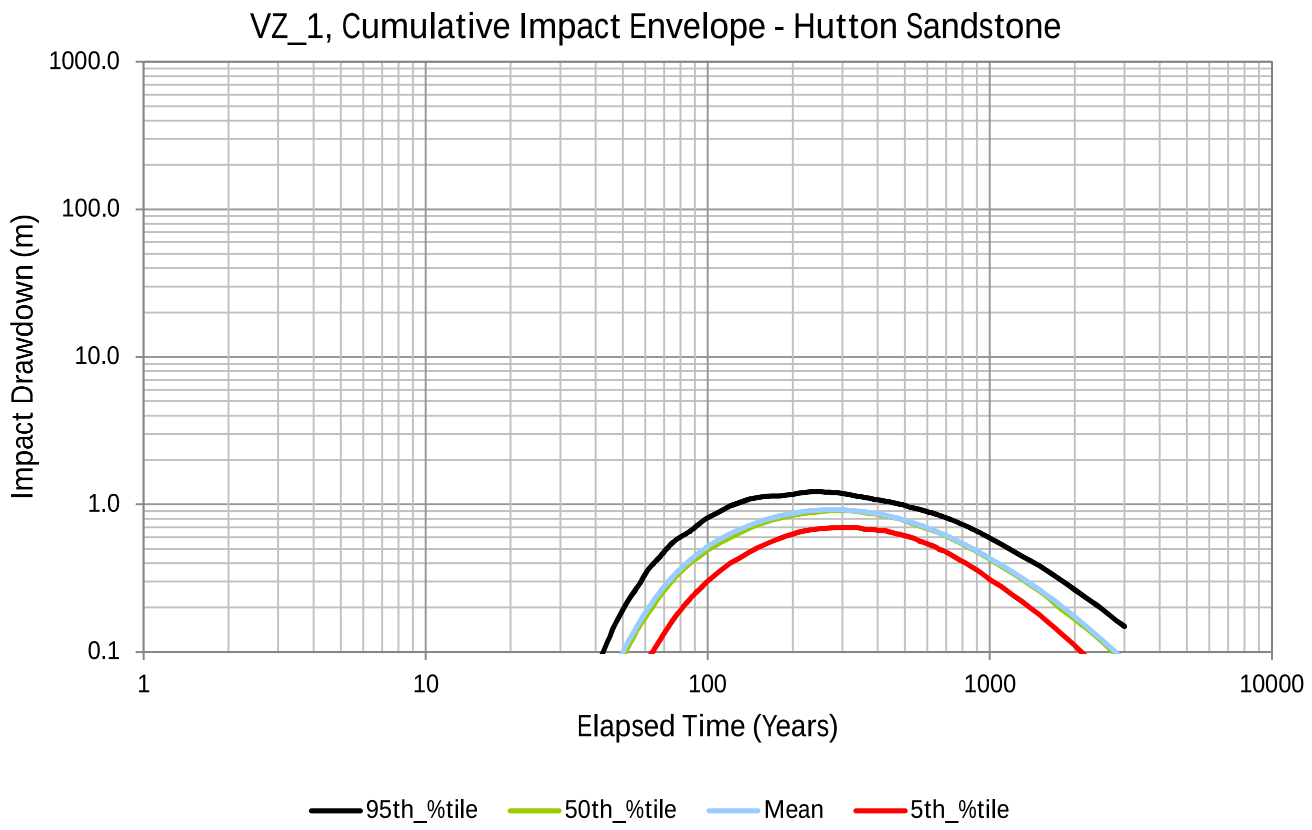
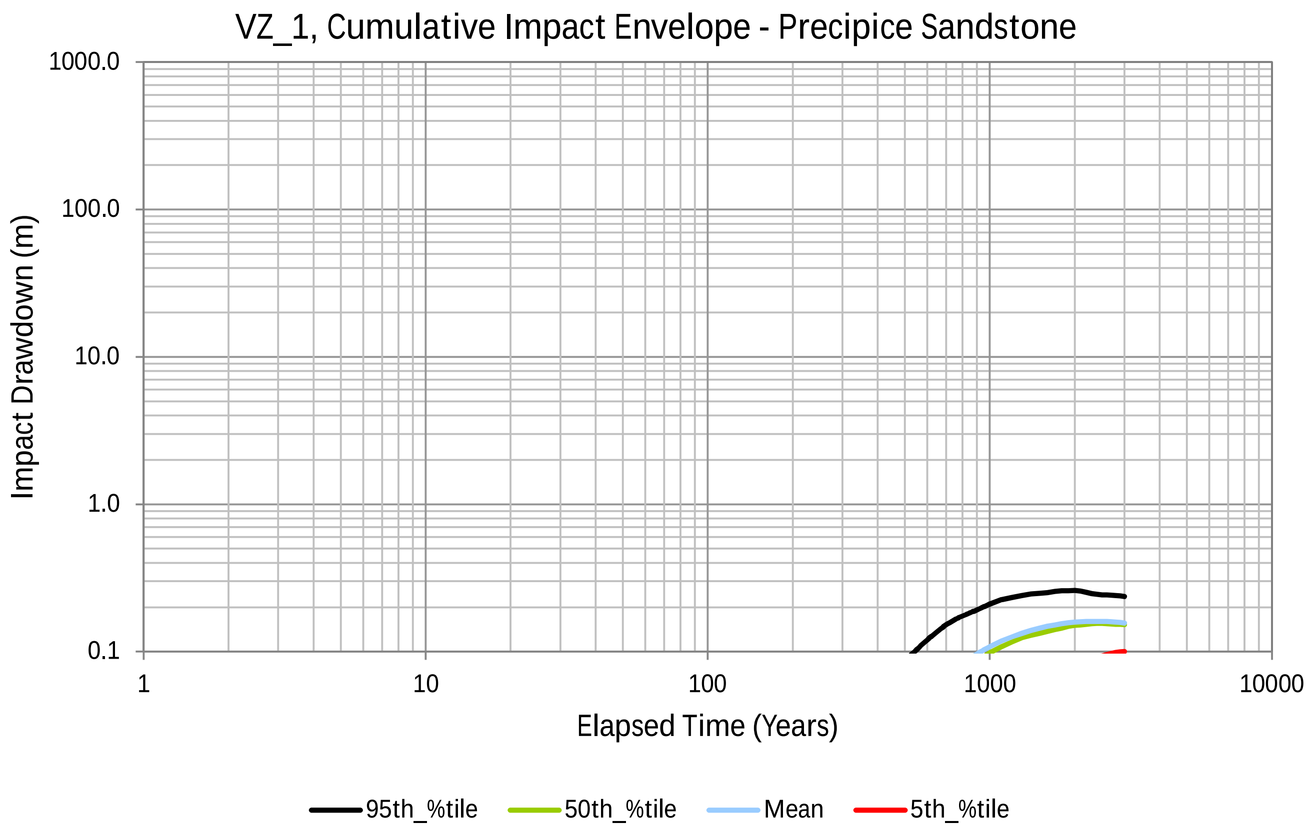
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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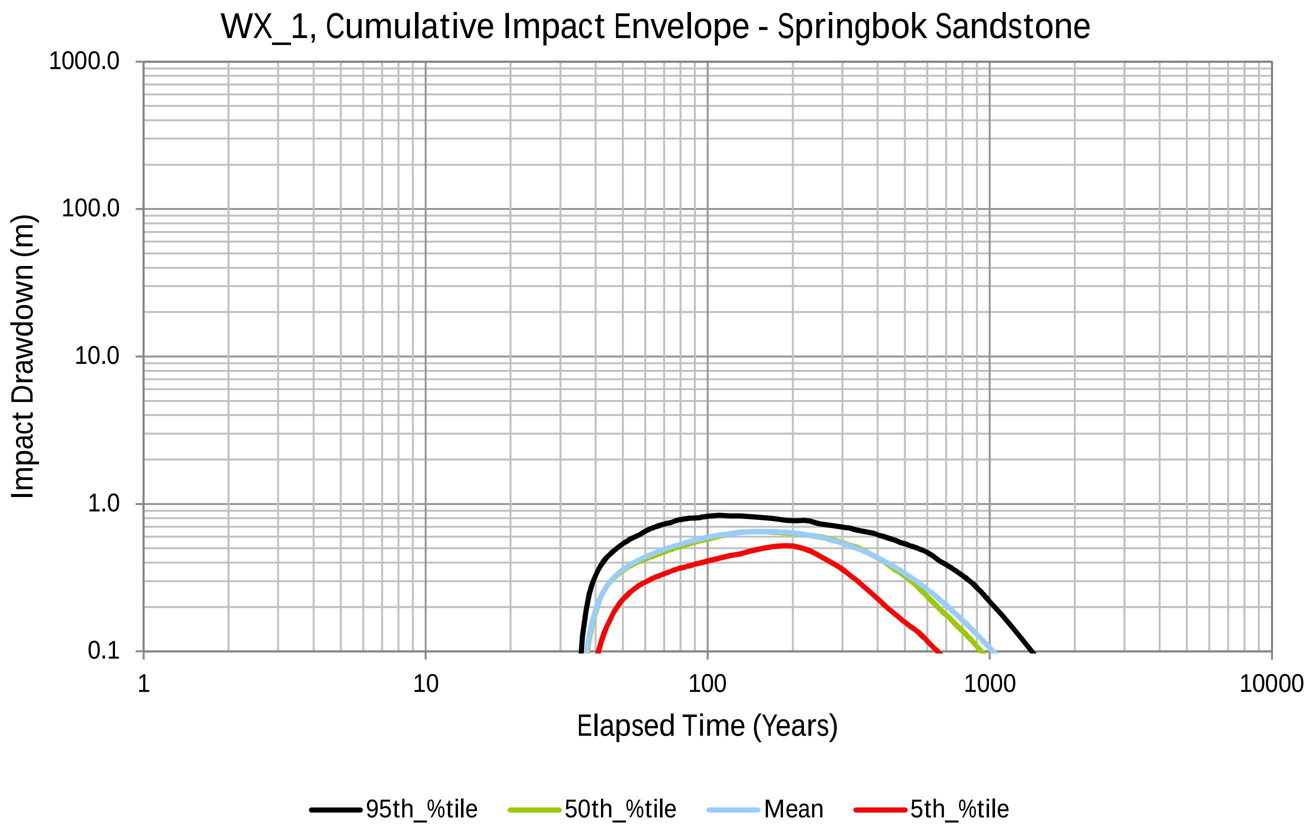
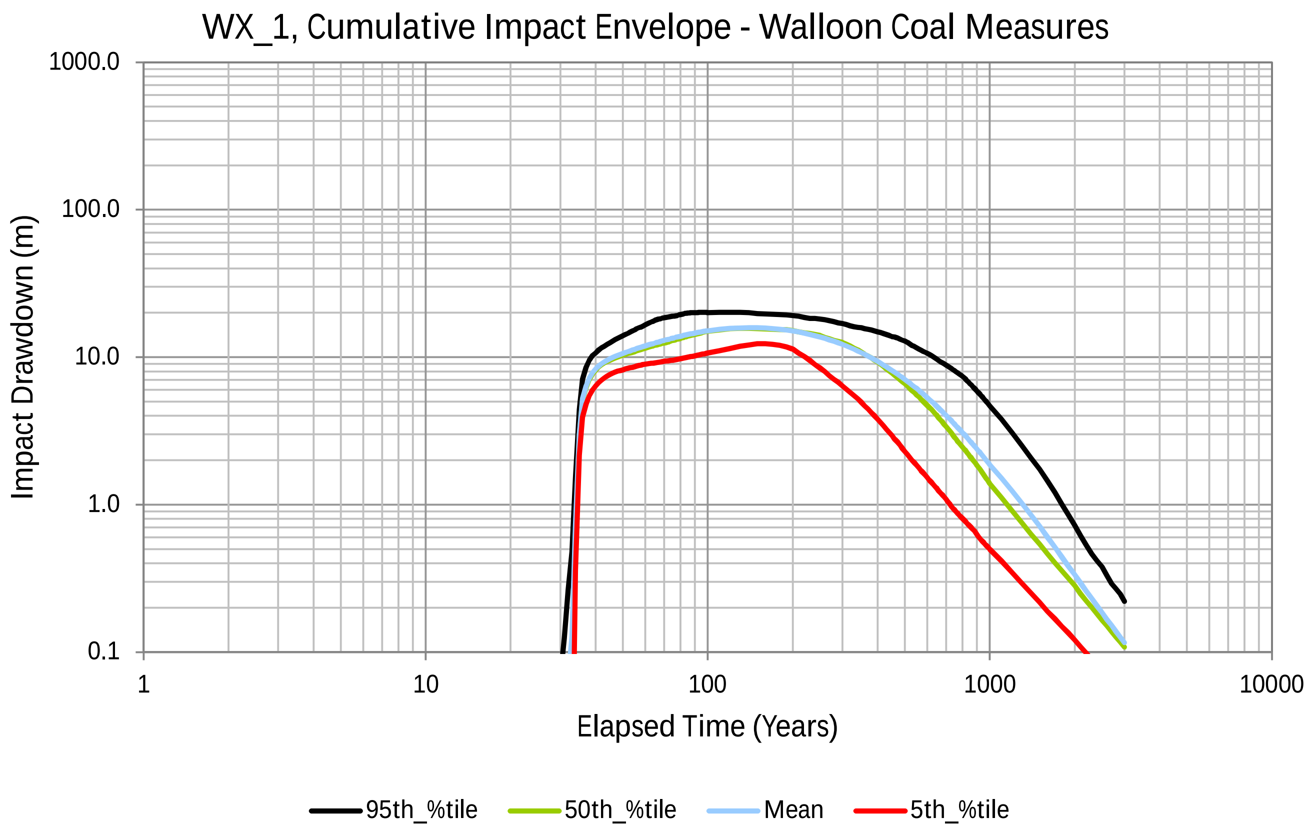
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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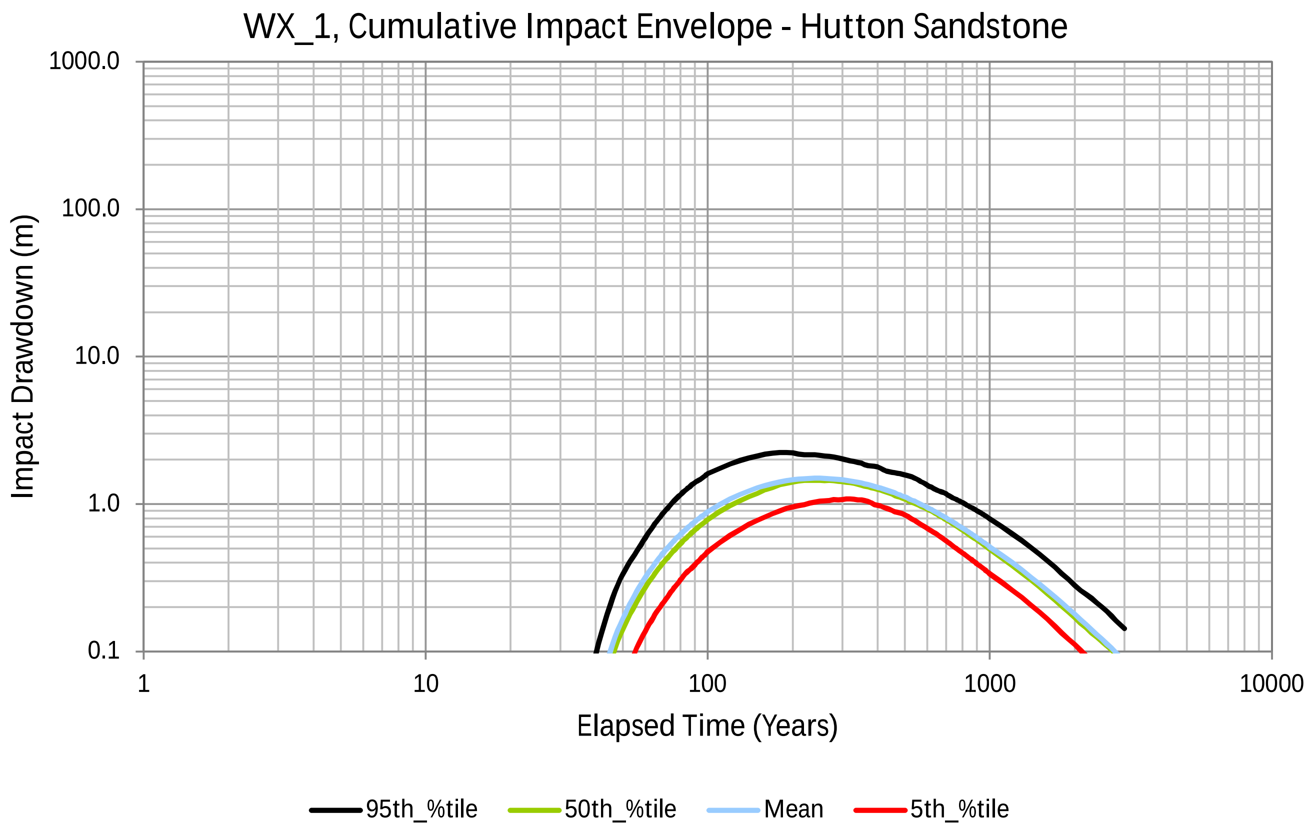
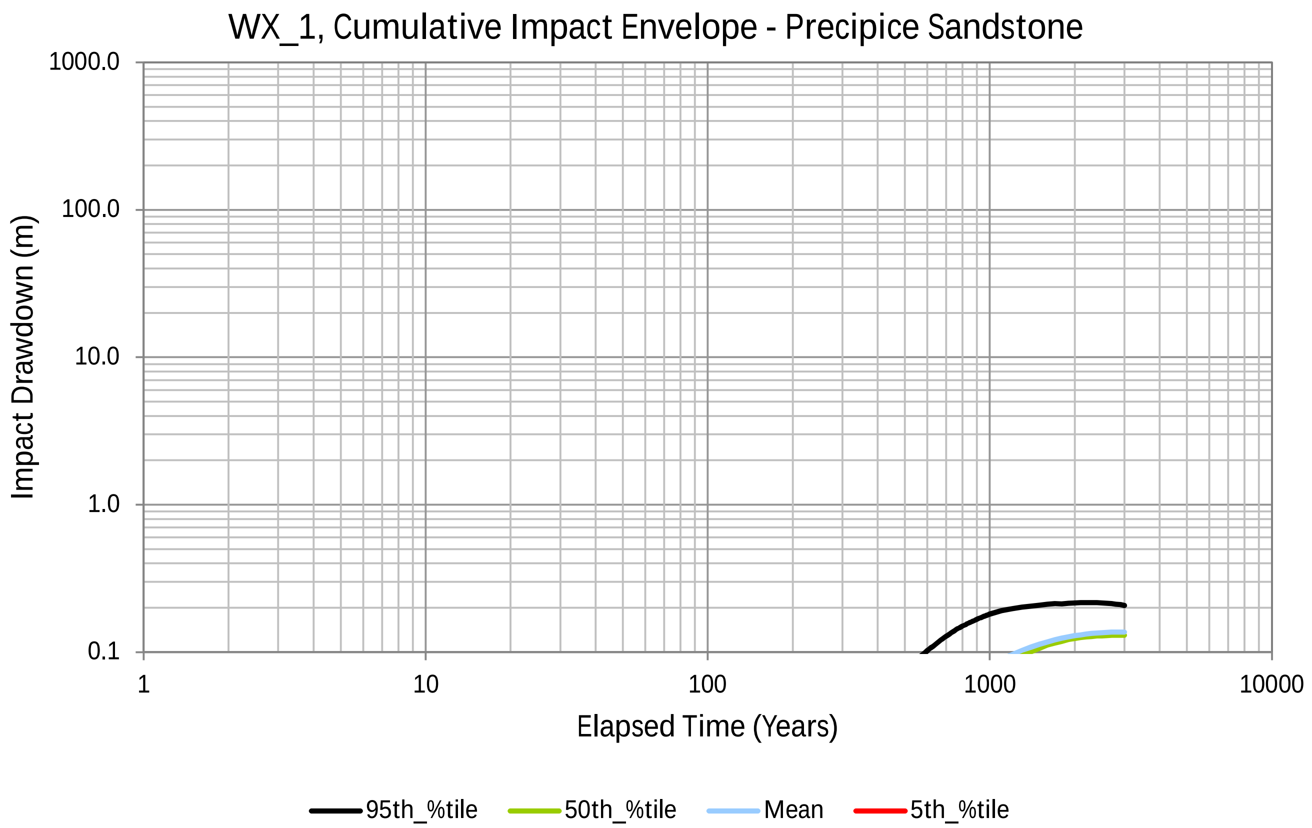
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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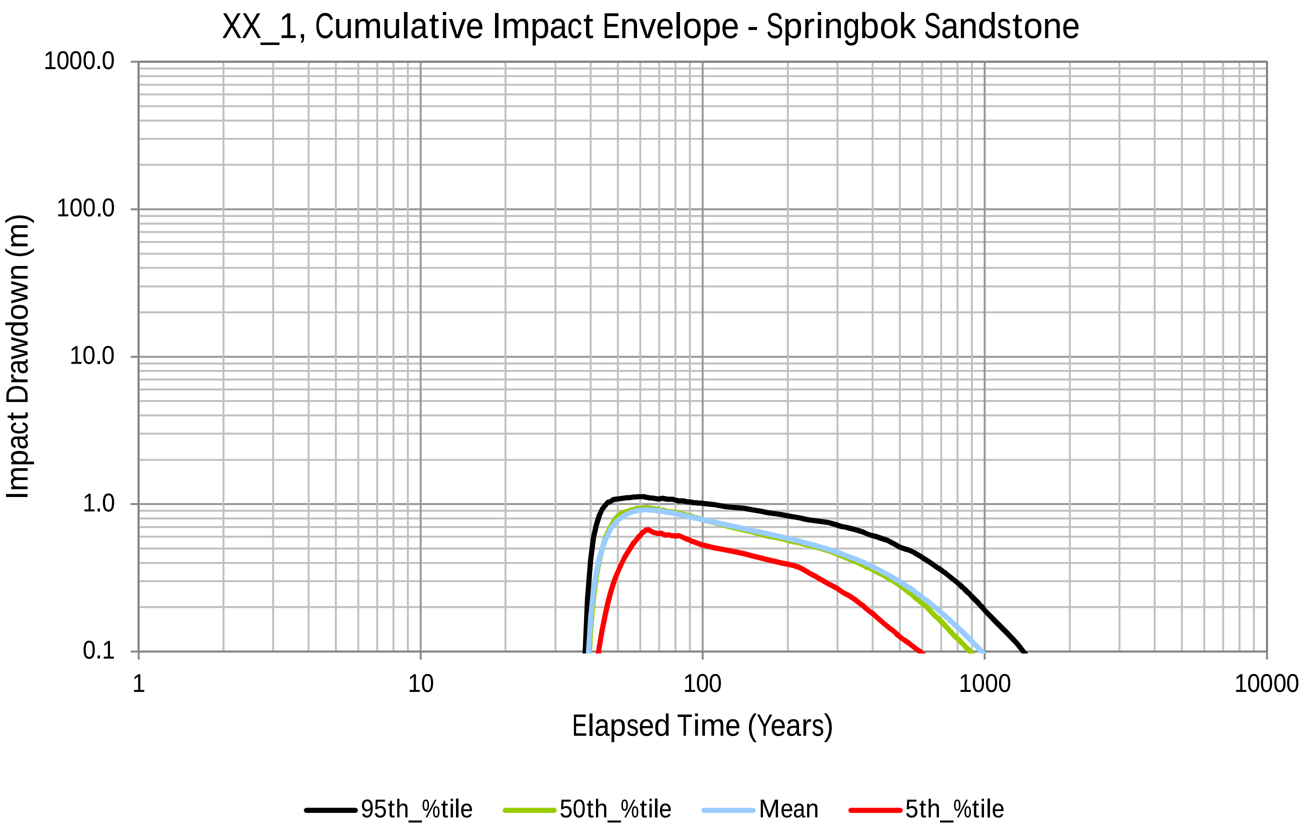
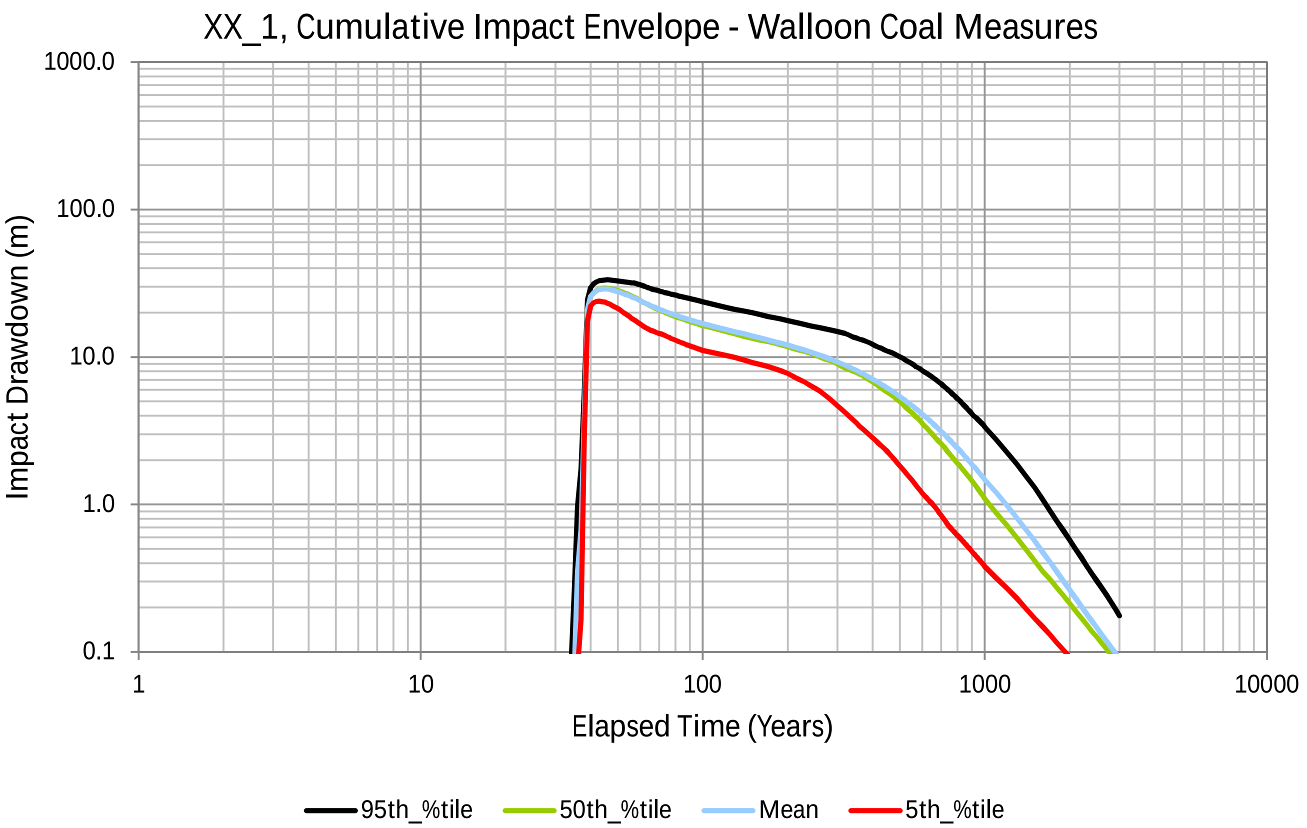
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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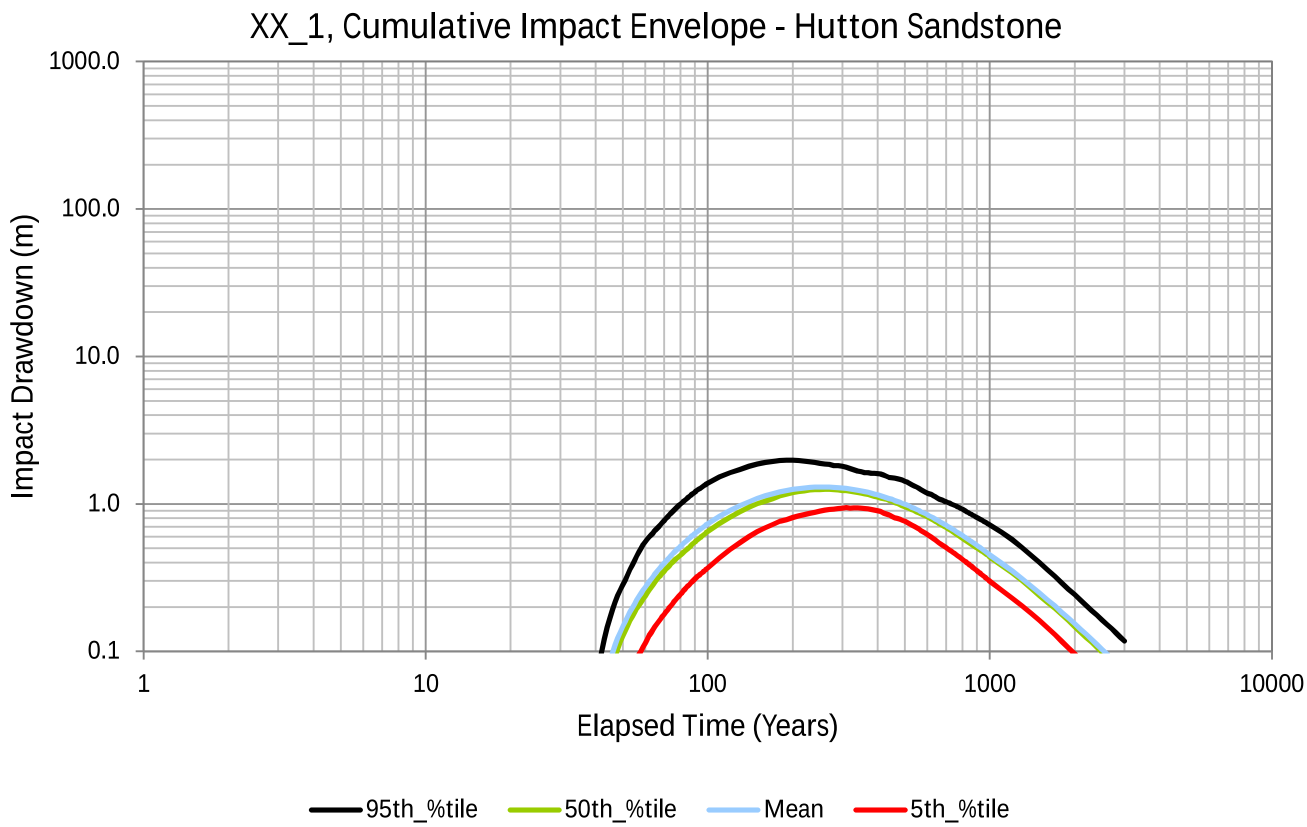
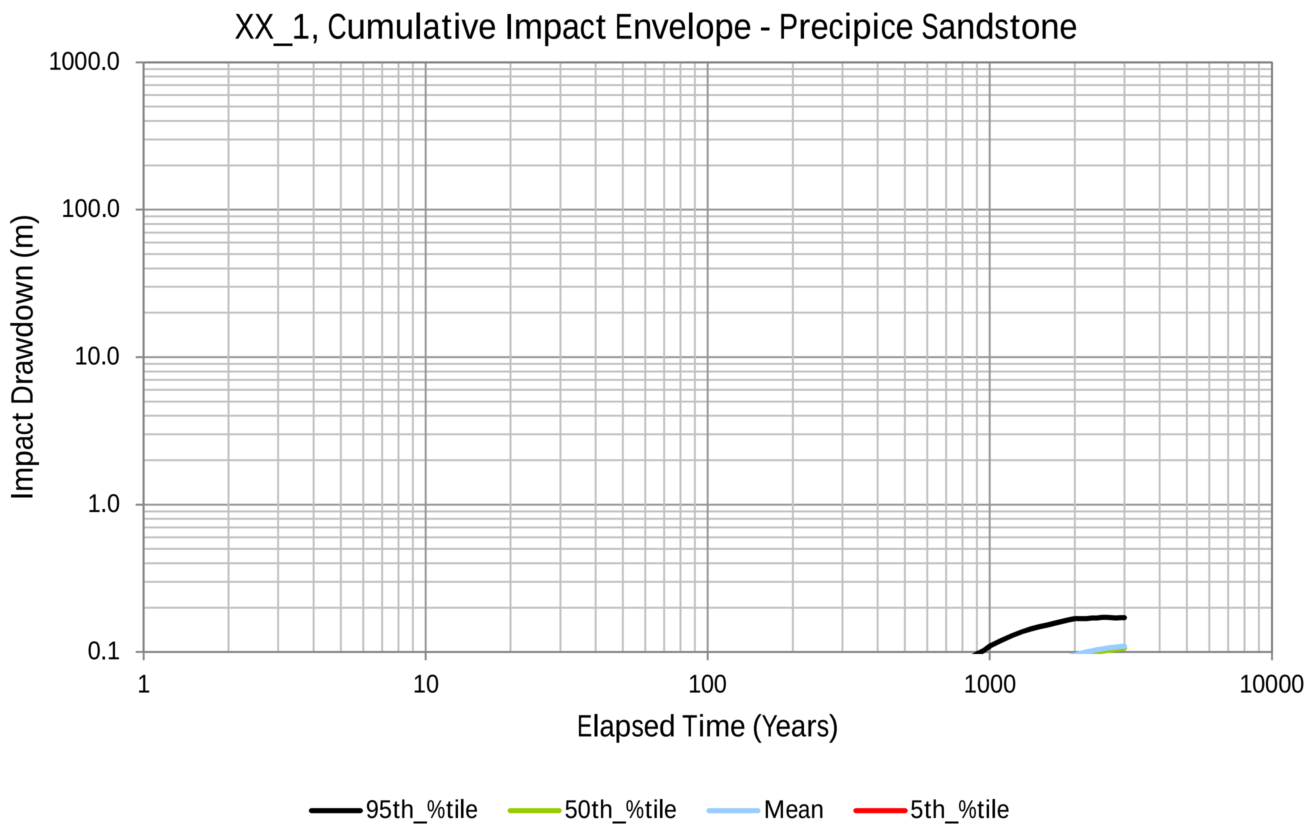
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 10





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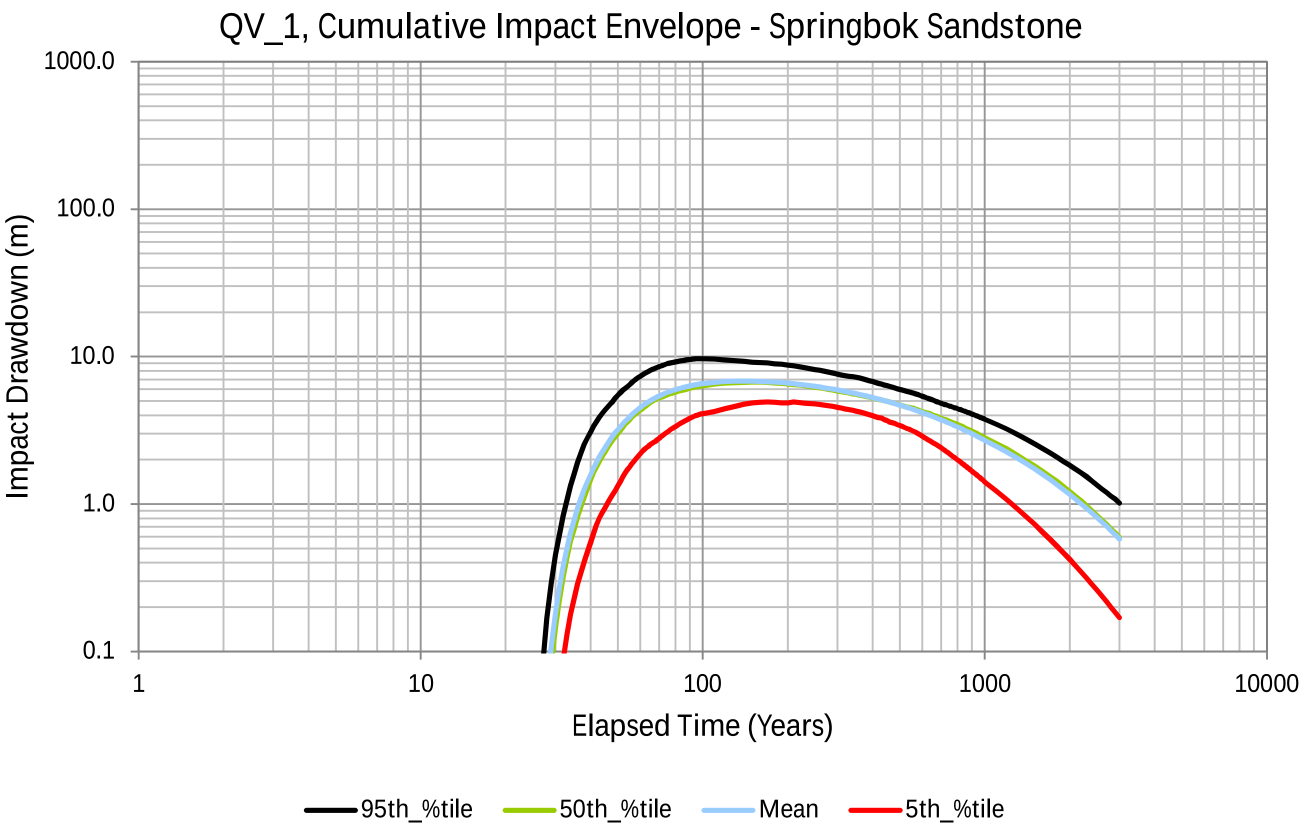
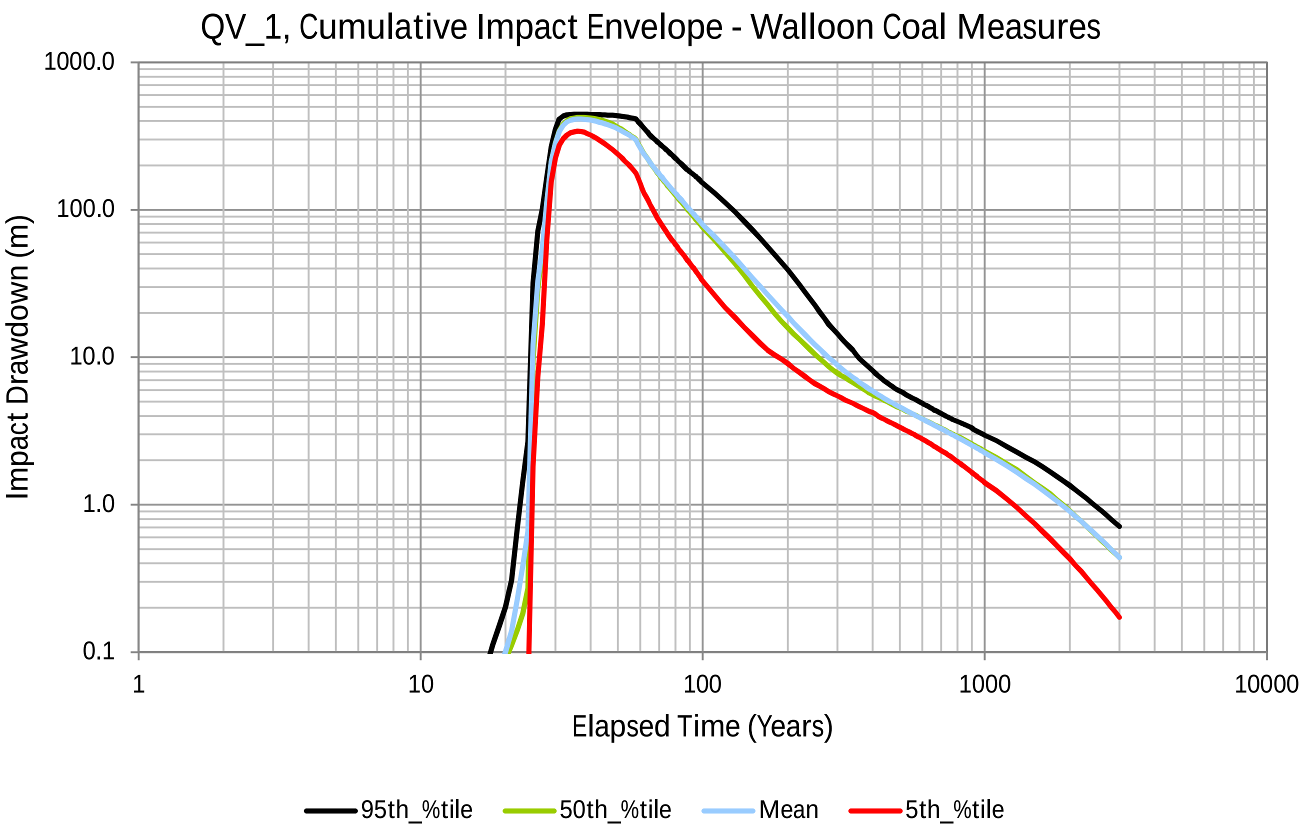
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 11





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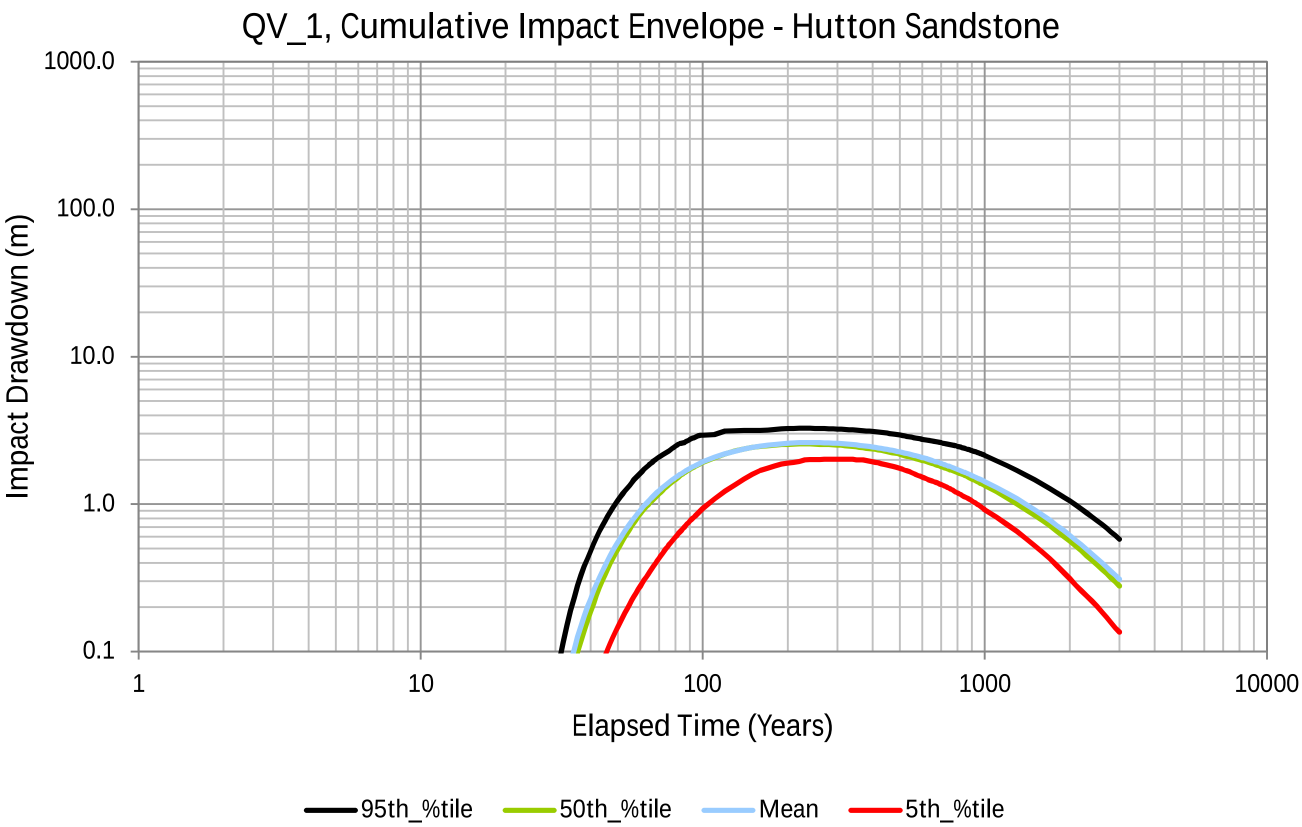
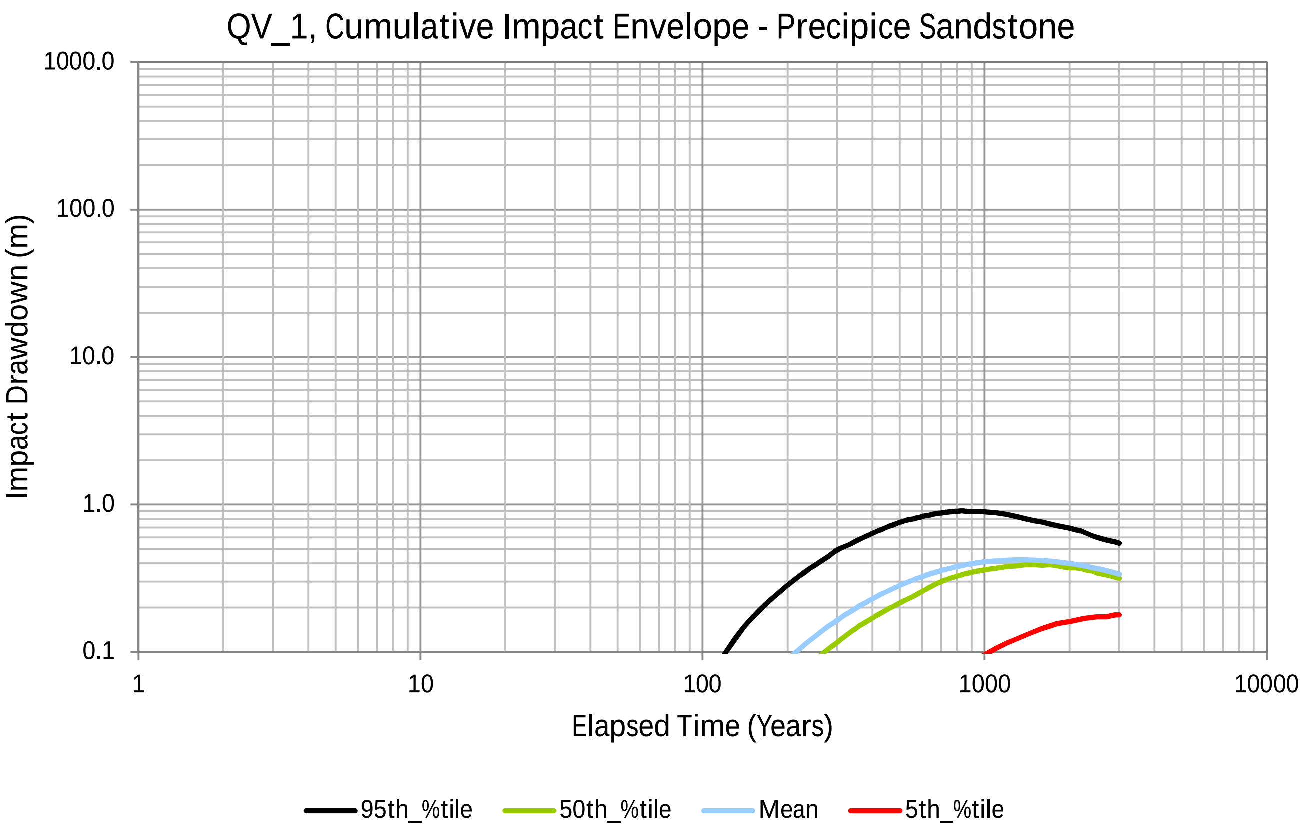
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 11





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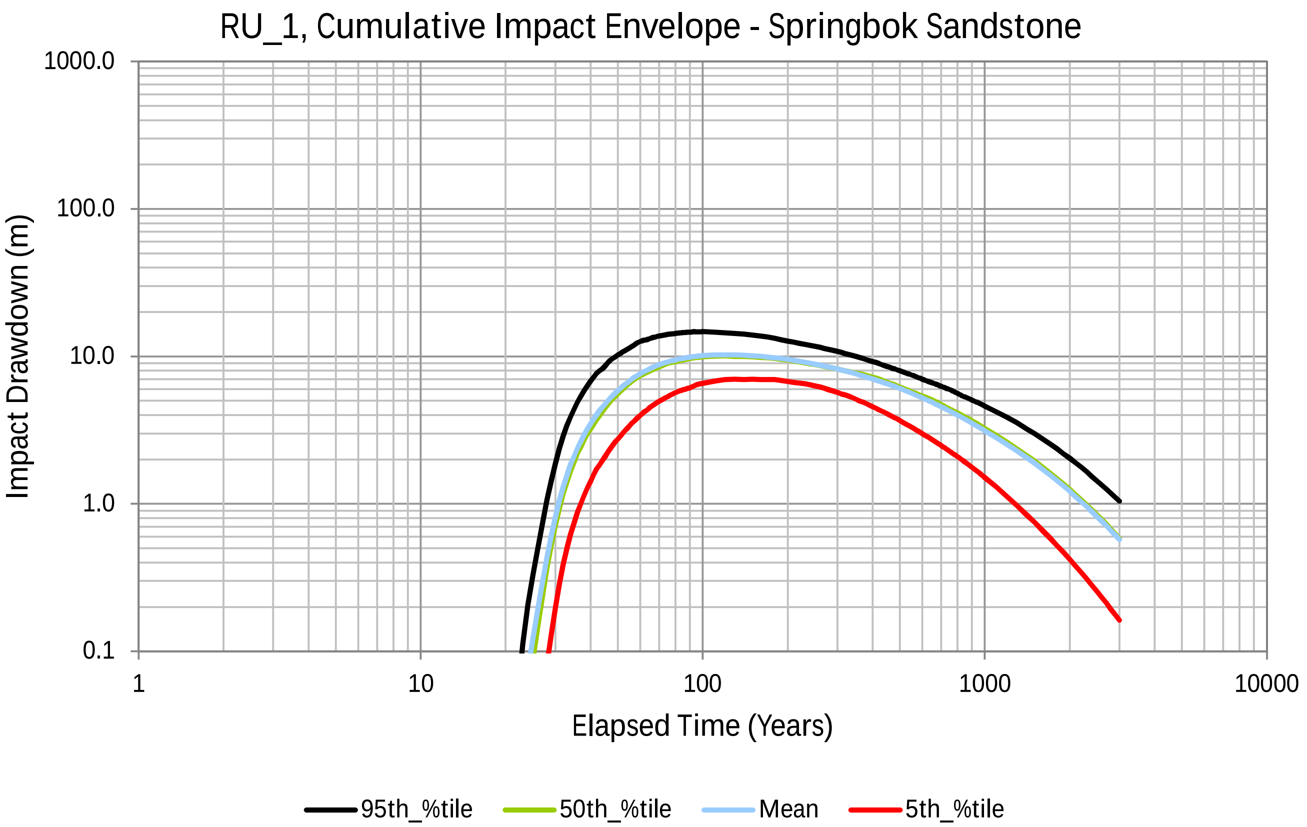
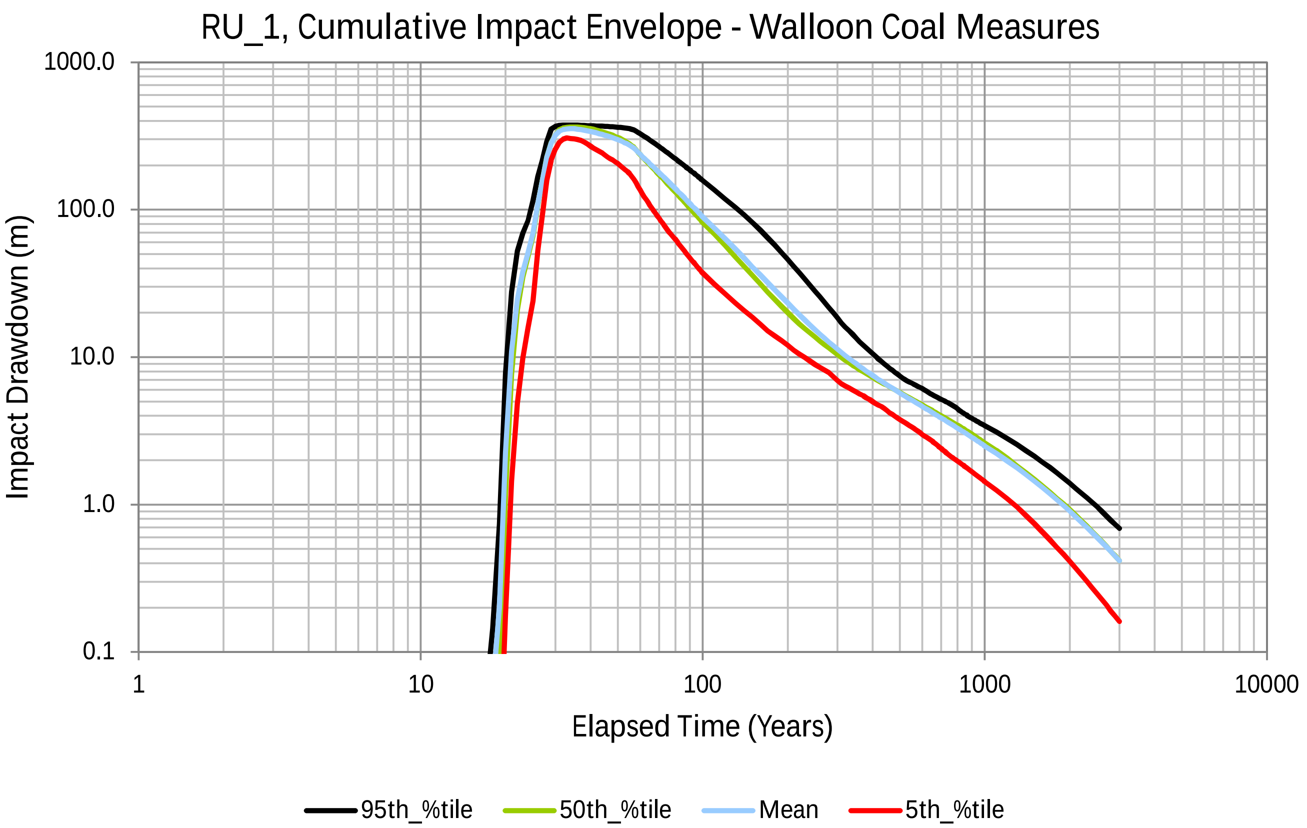
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 11





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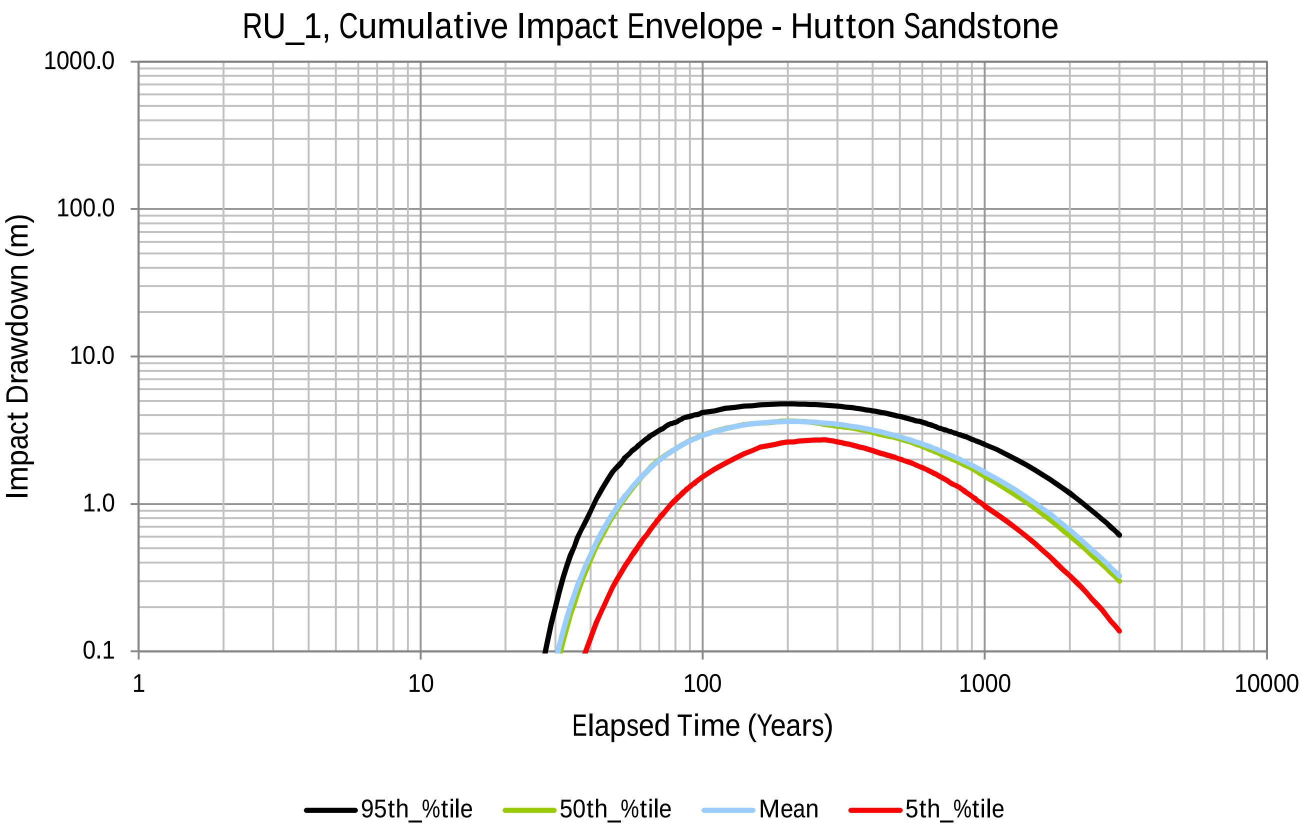
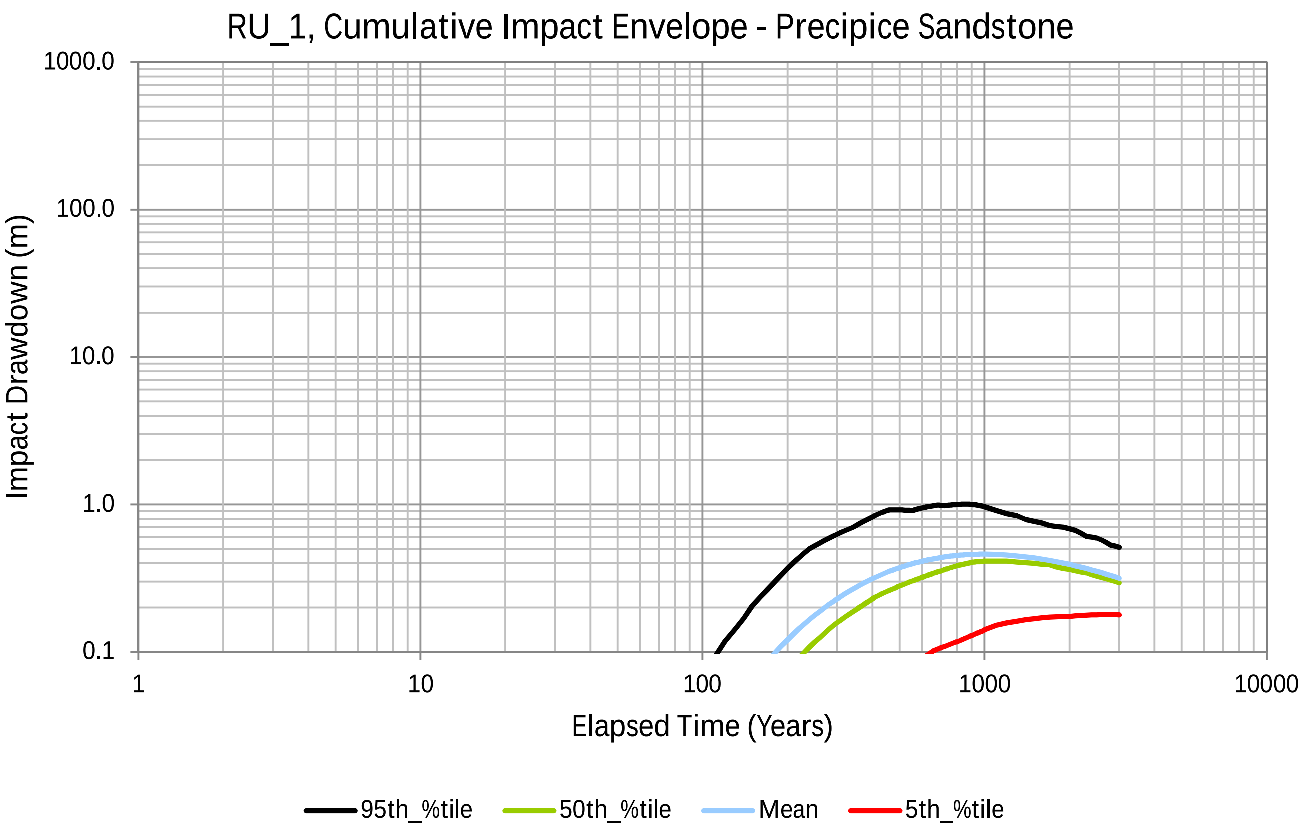
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 11





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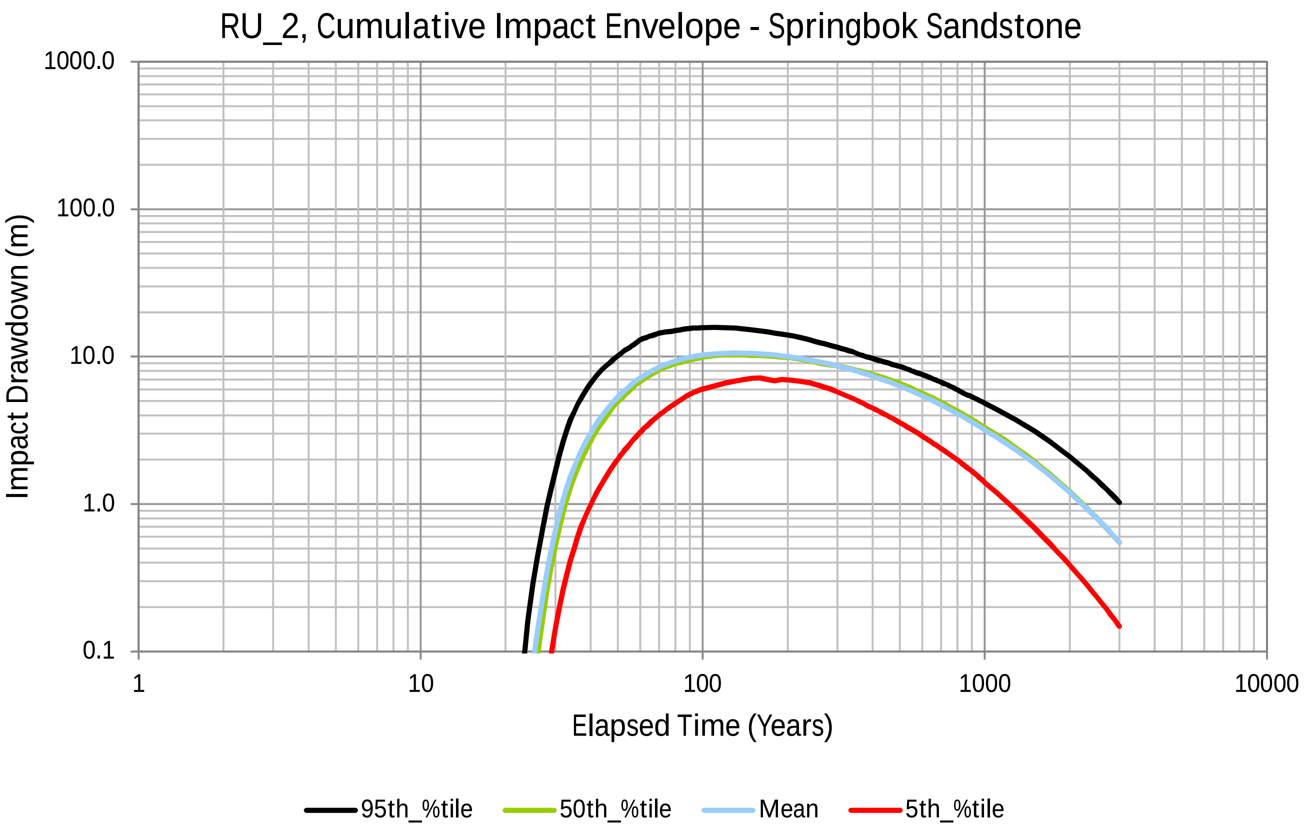
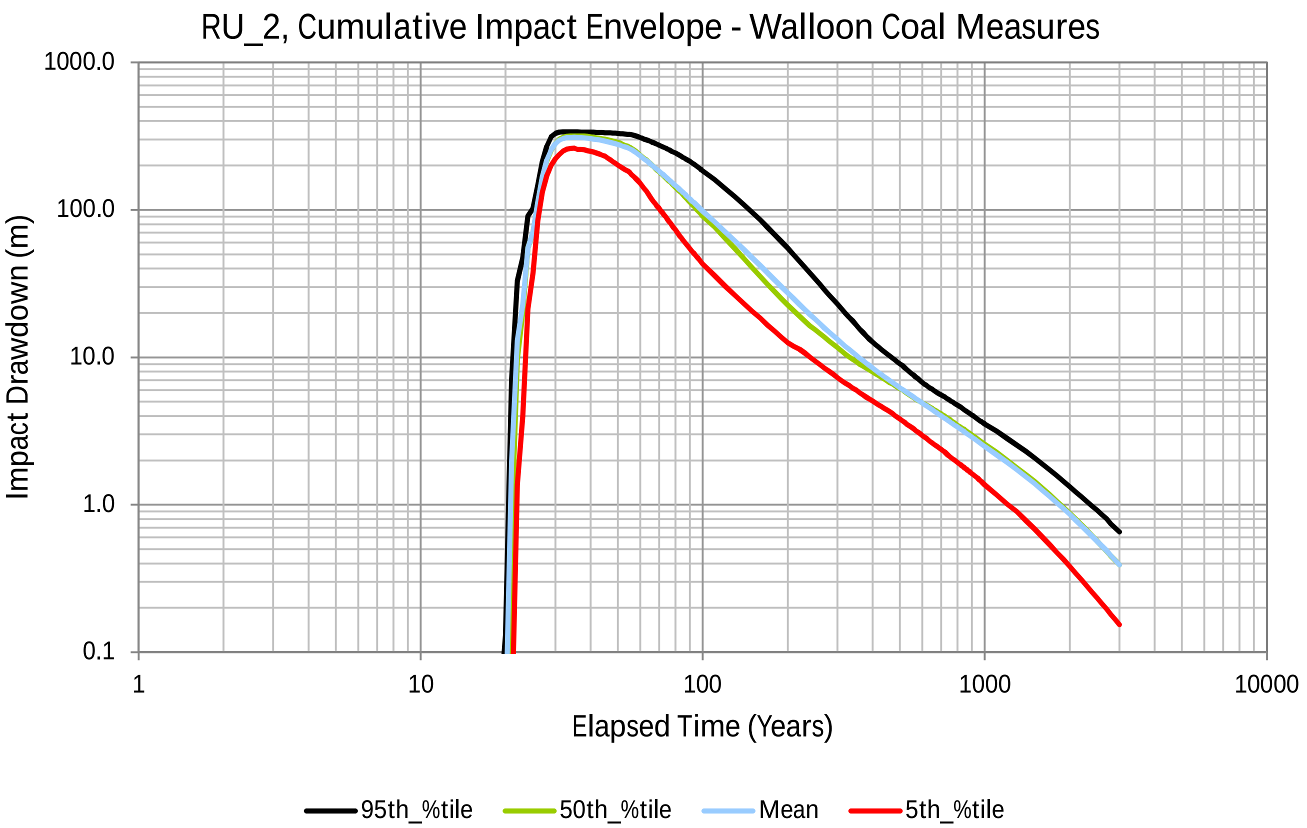
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 11





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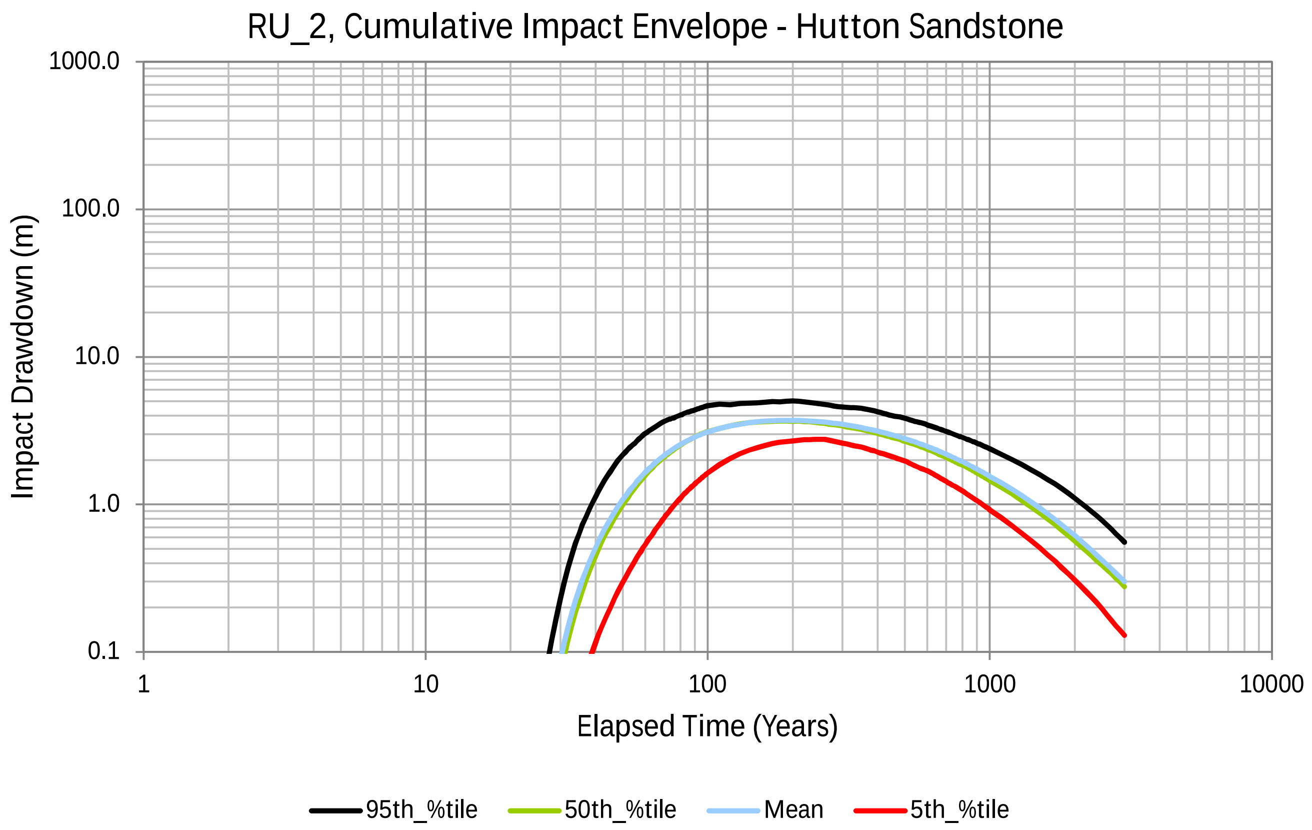
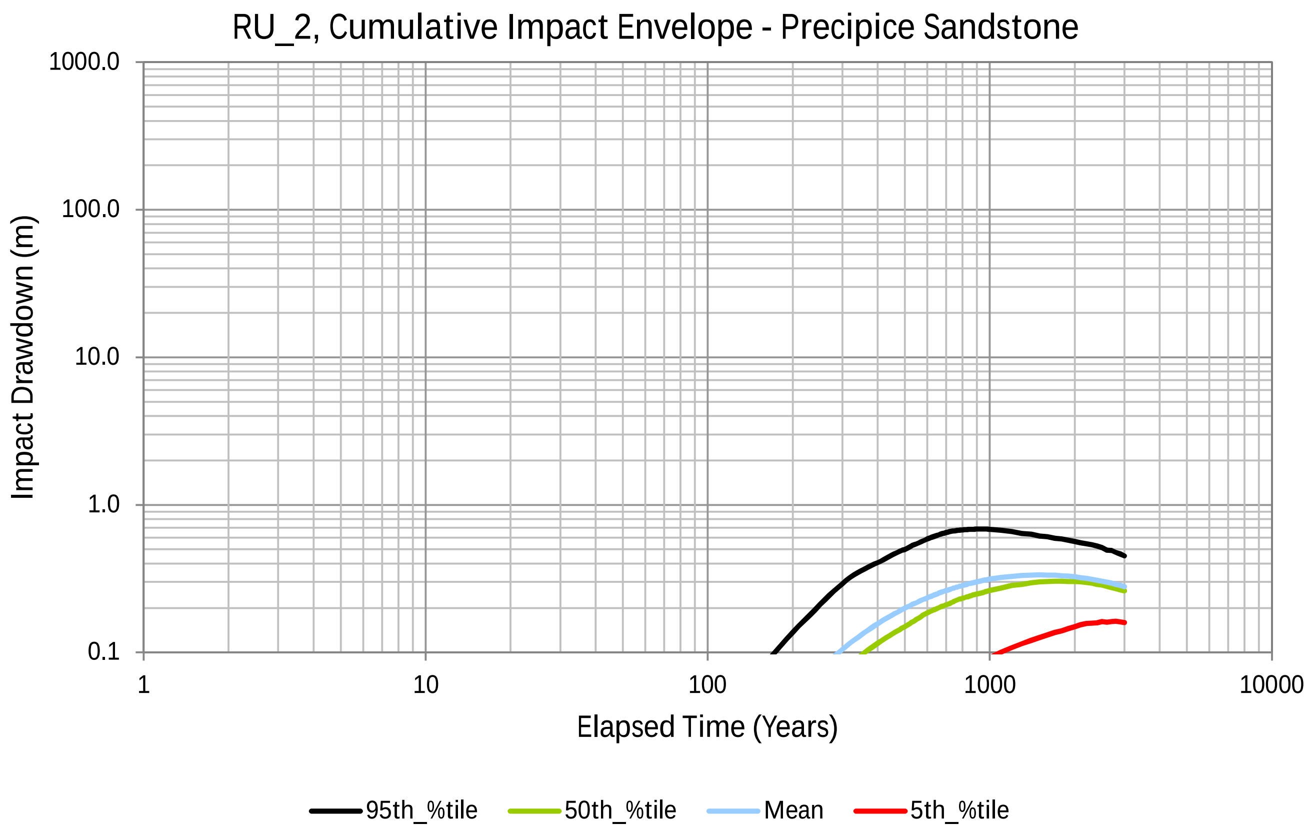
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 11





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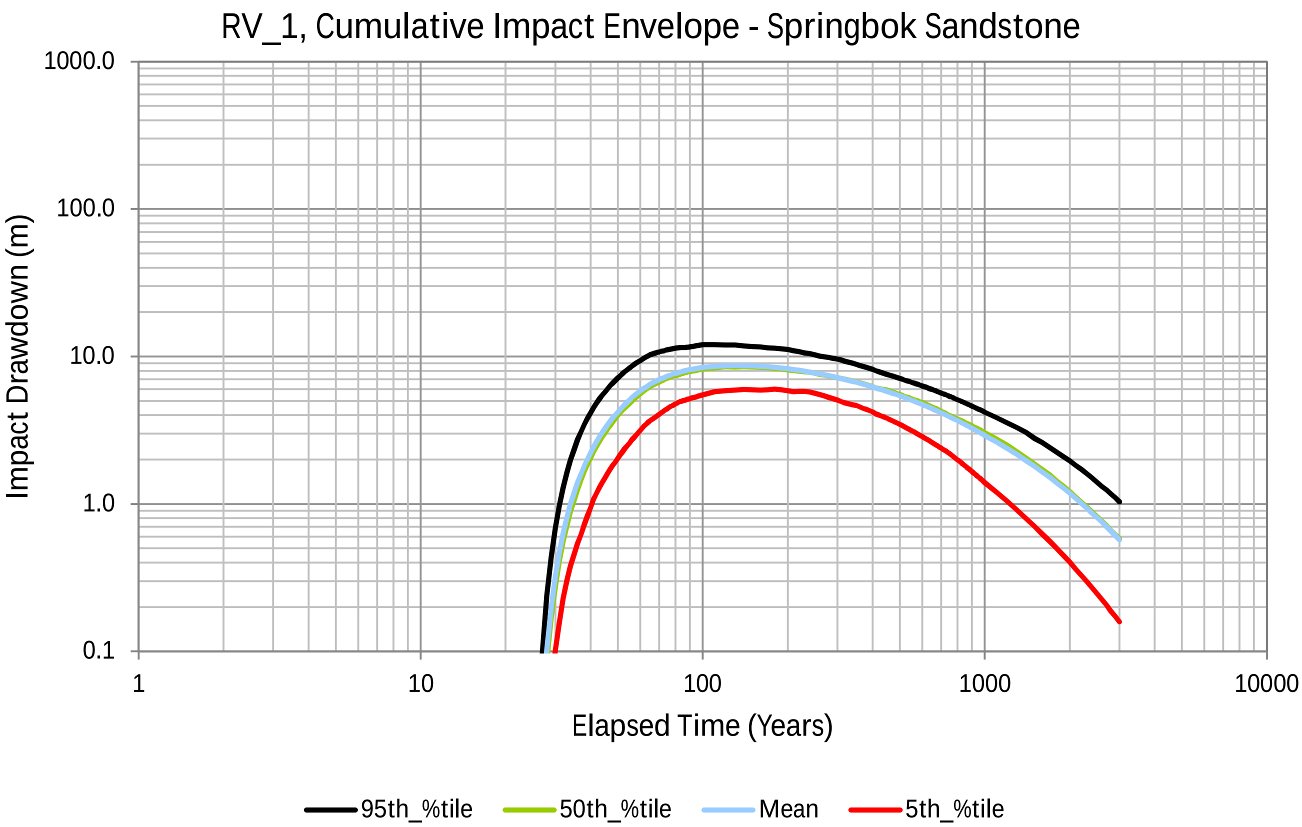
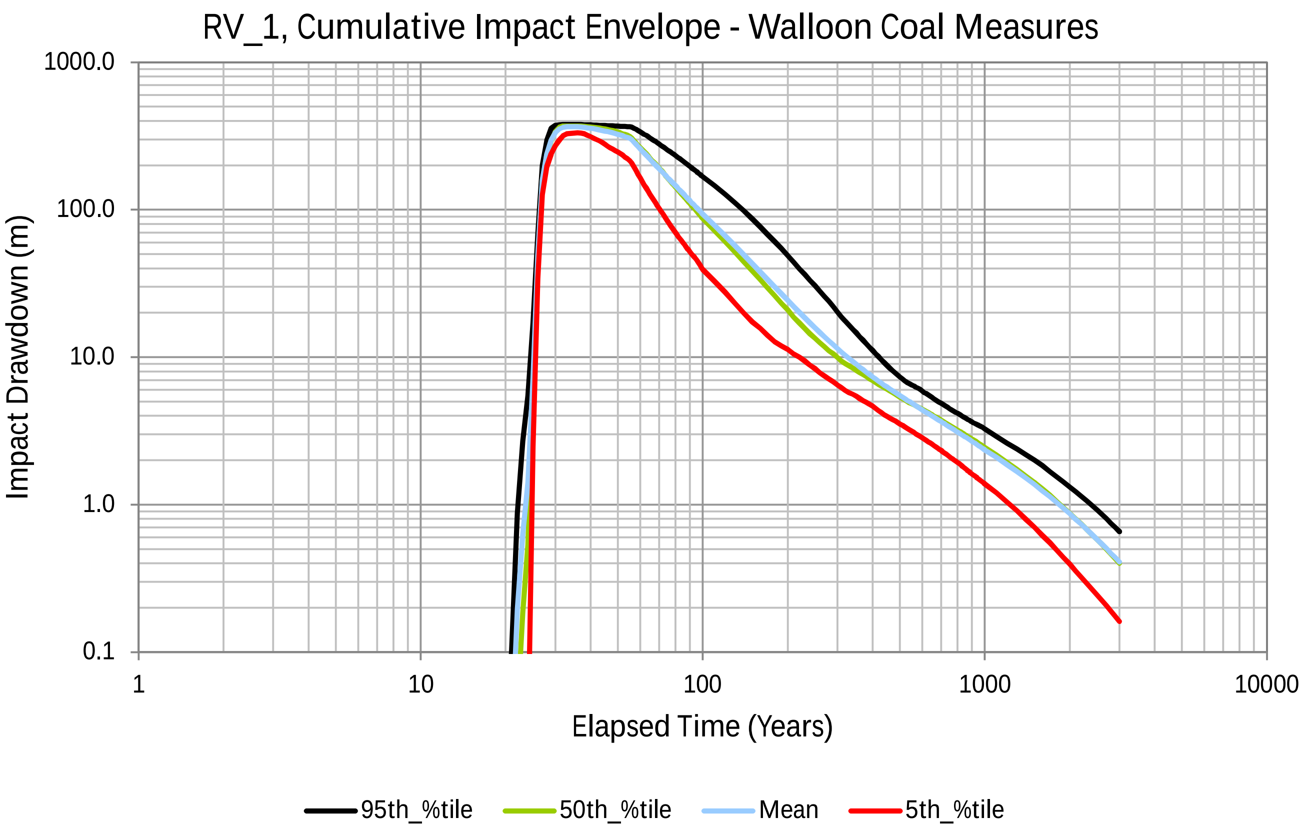
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 11





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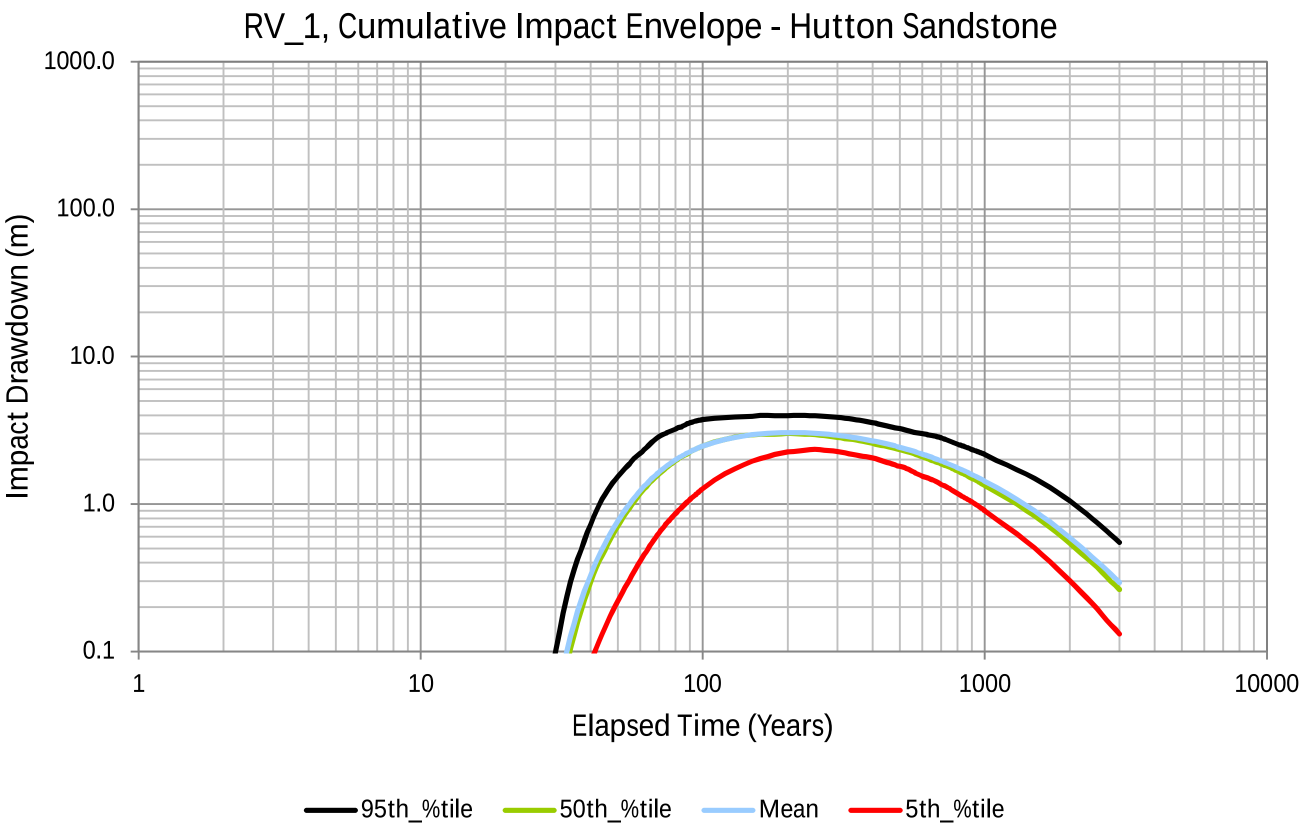
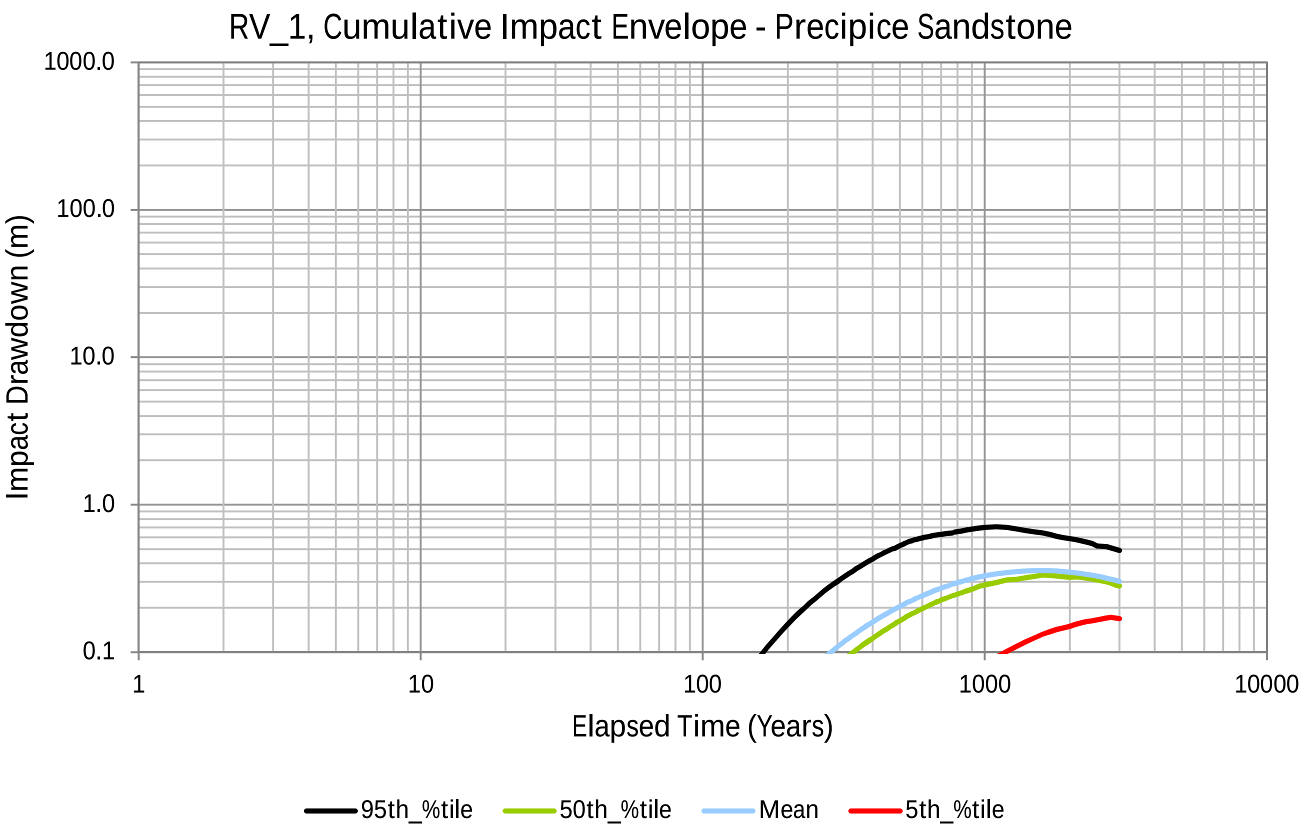
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 11





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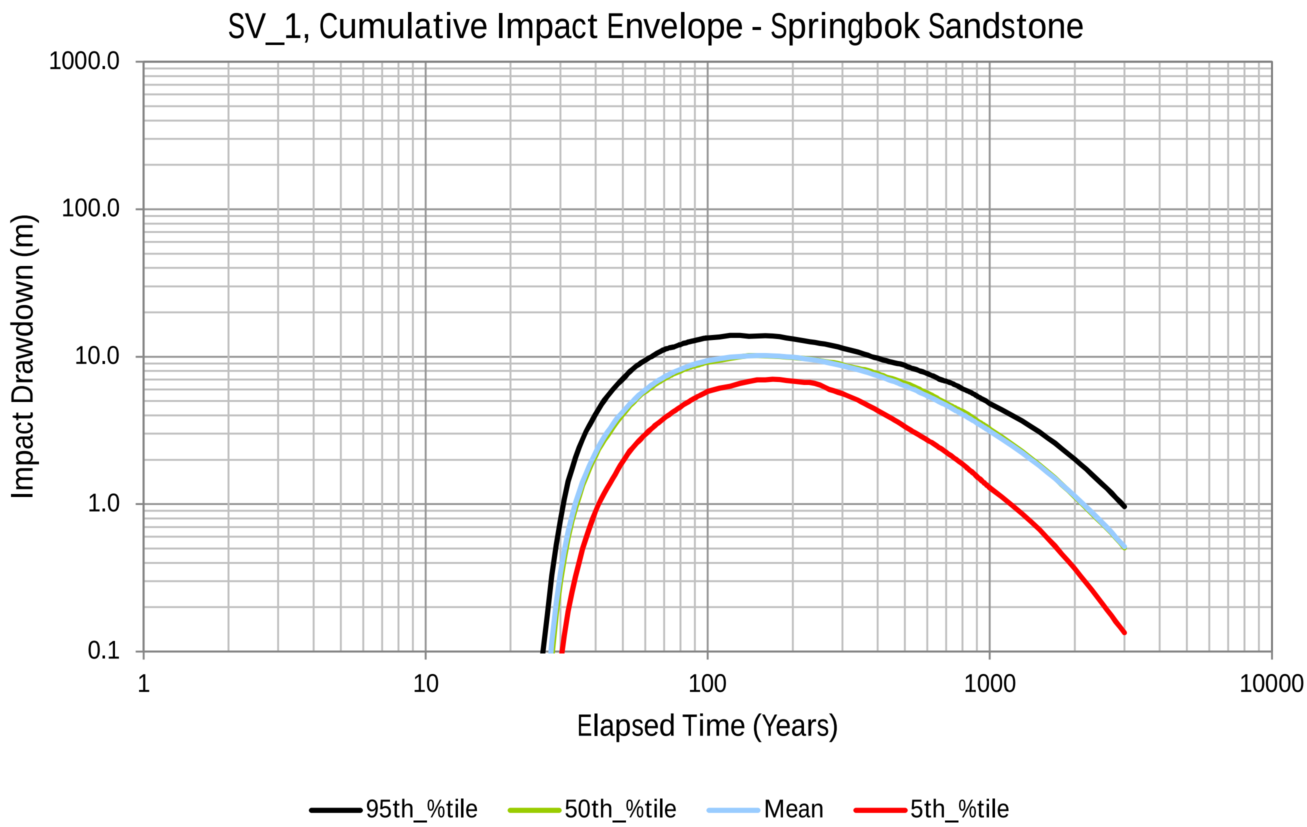
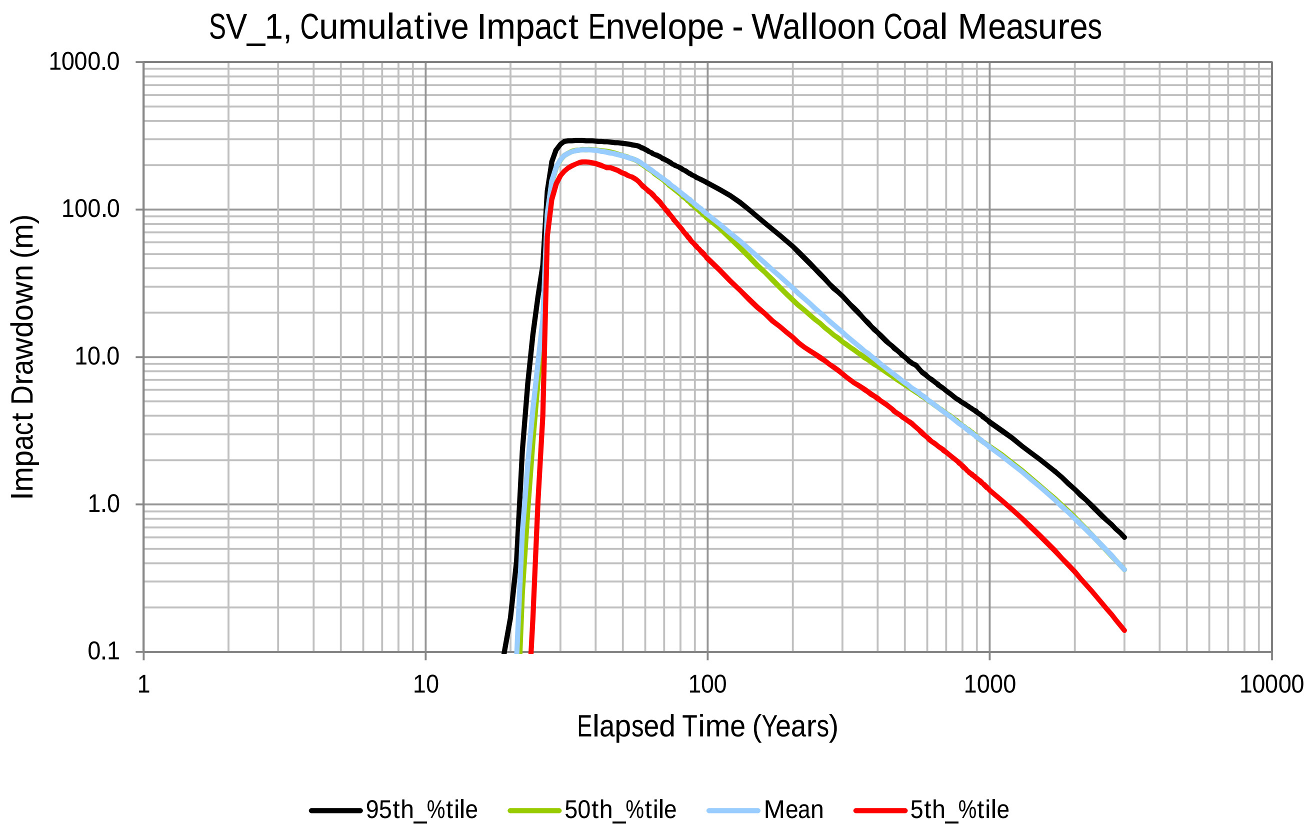
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 11





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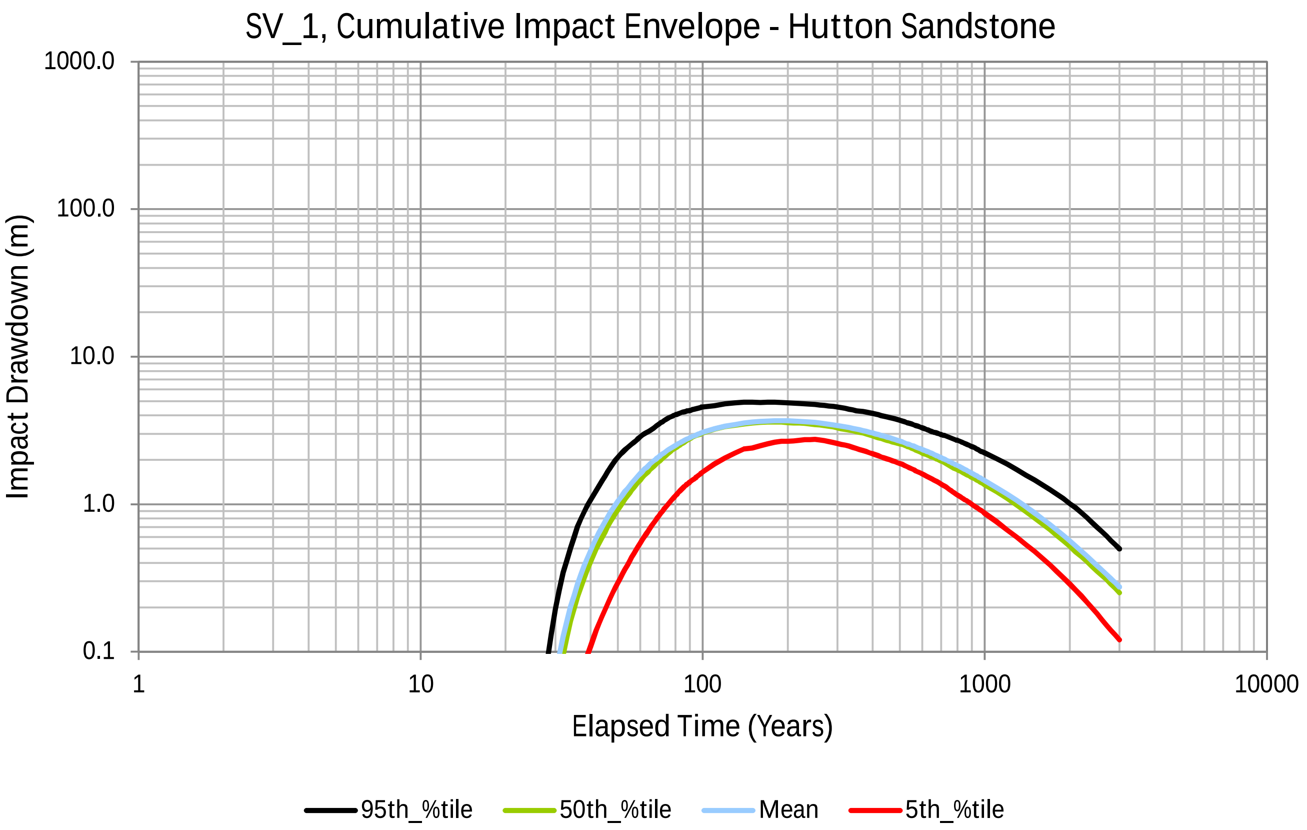
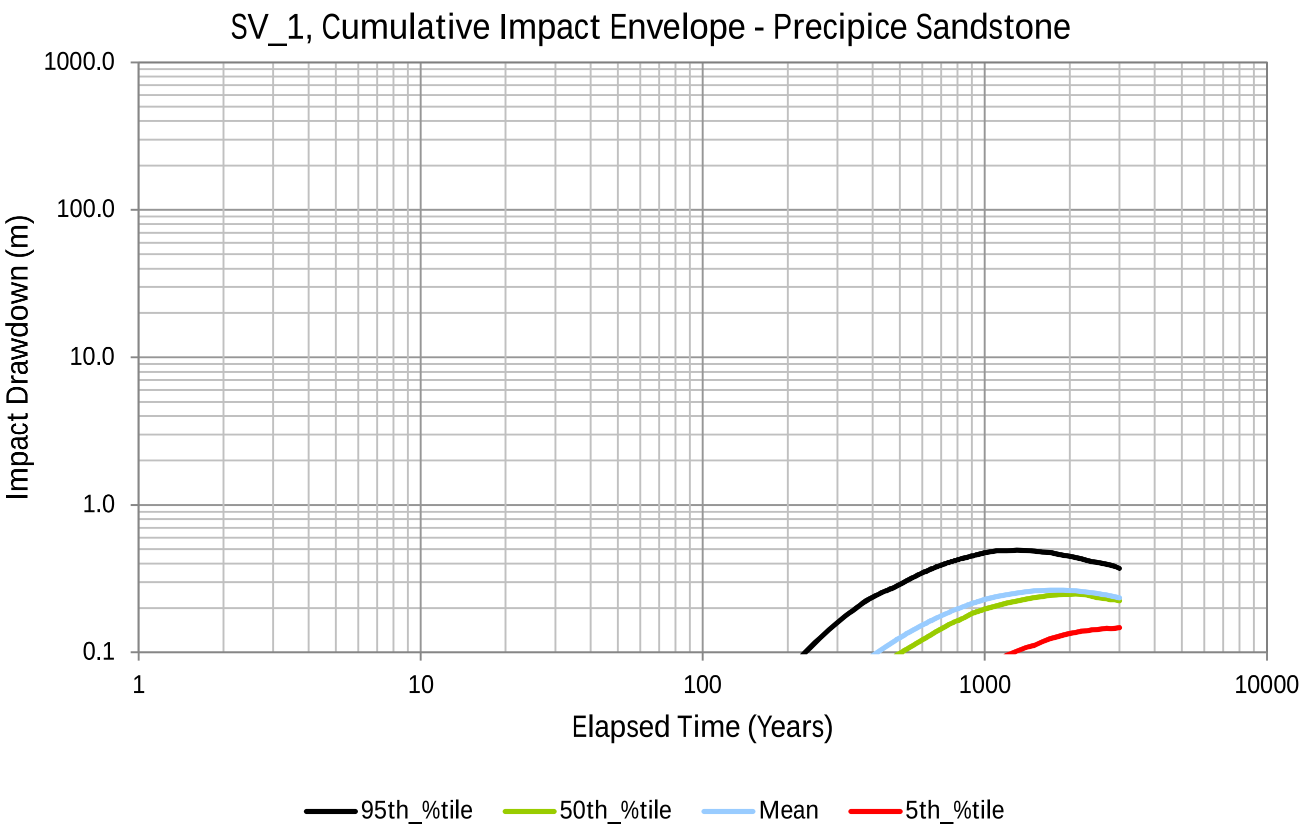
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 11





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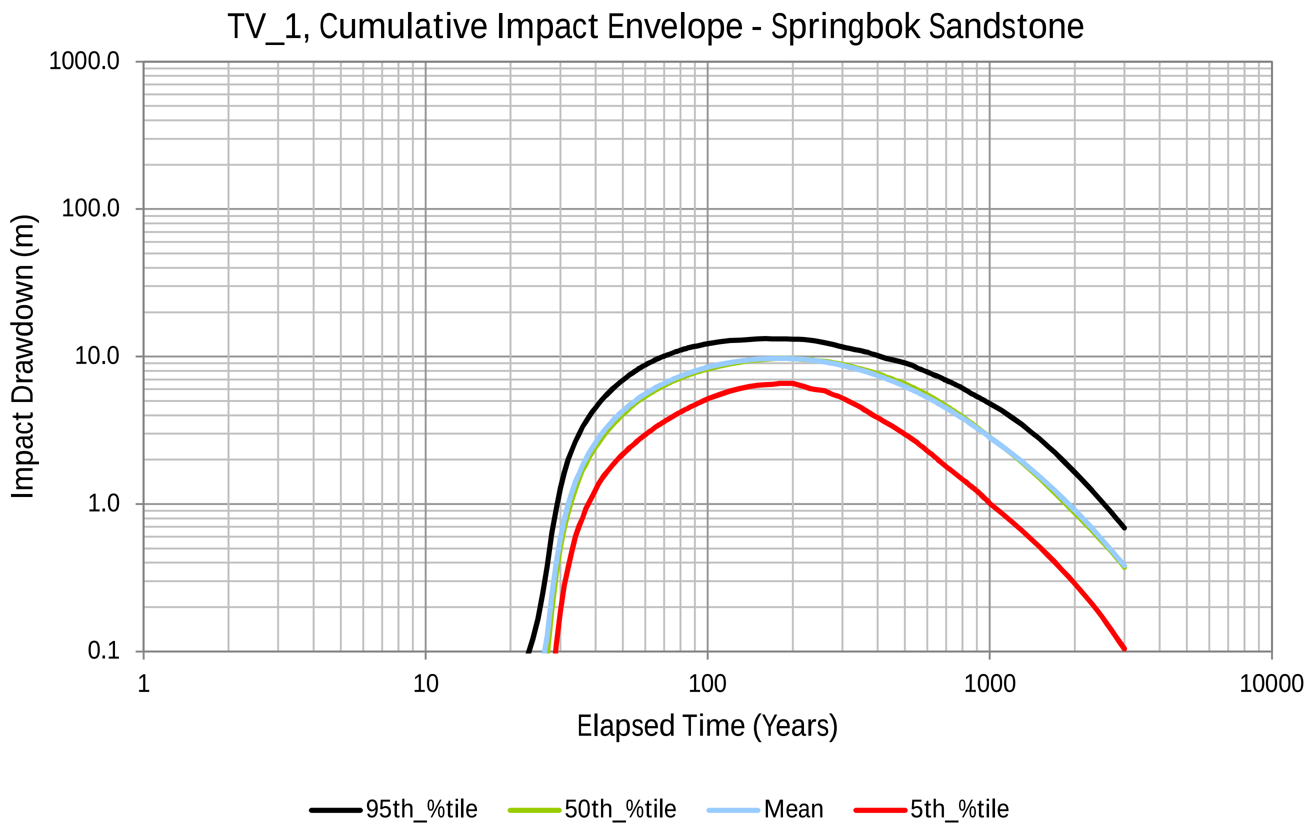
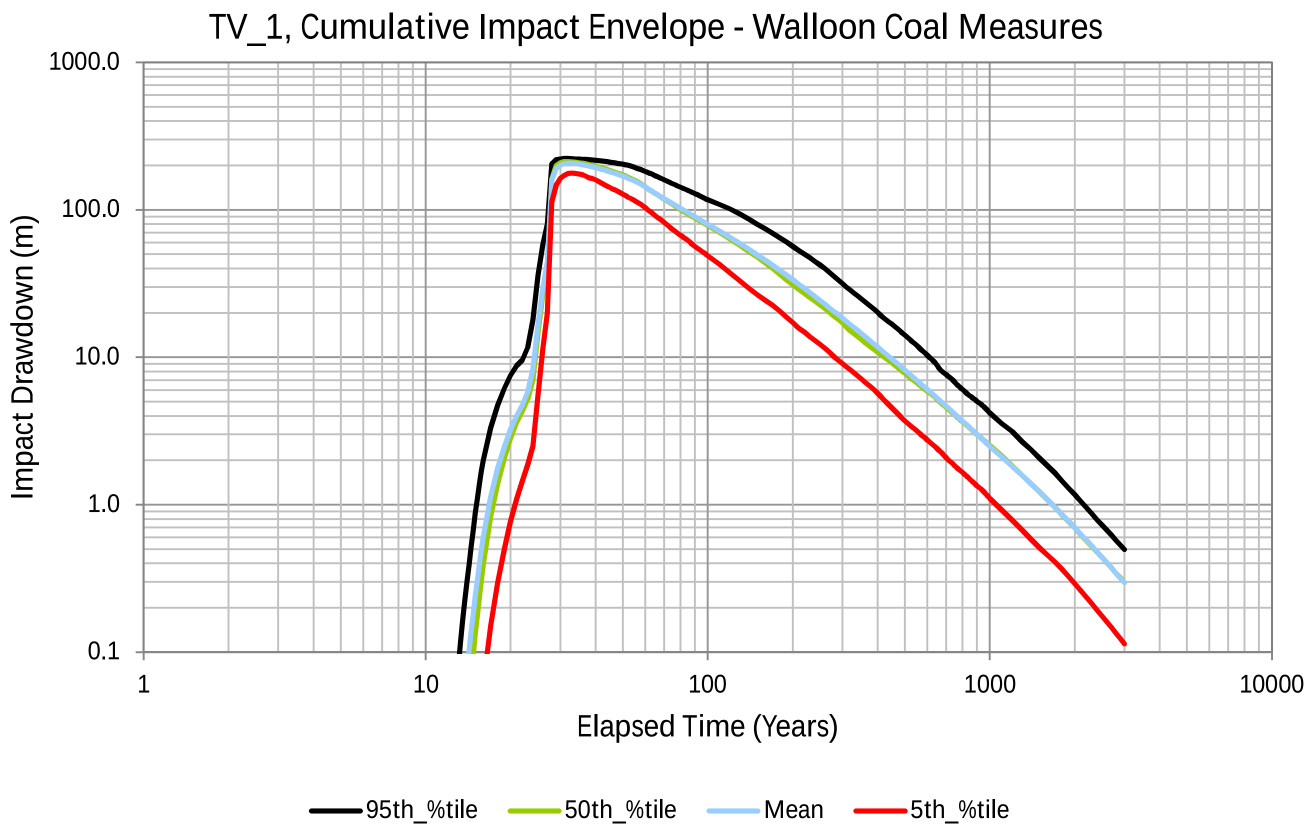
(Drainage_Area_11)

Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 11





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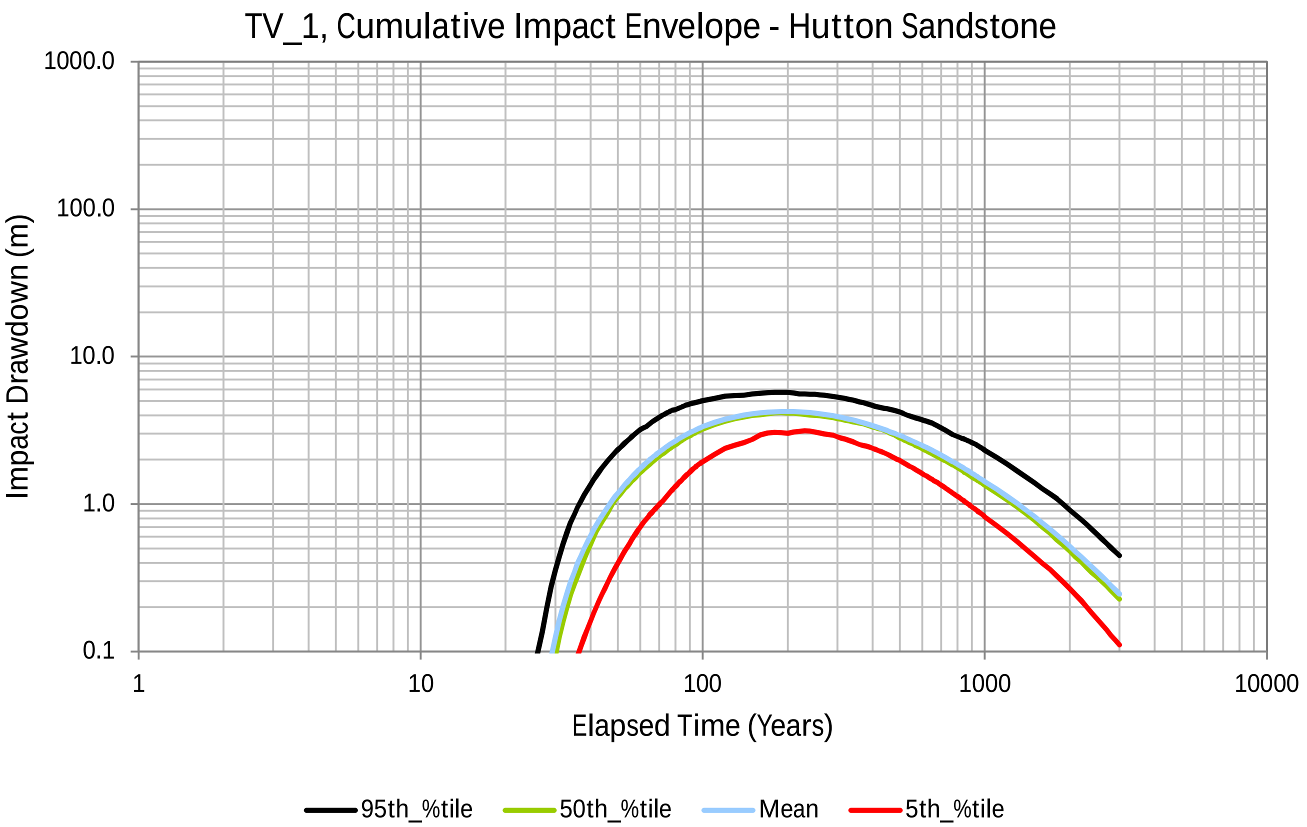
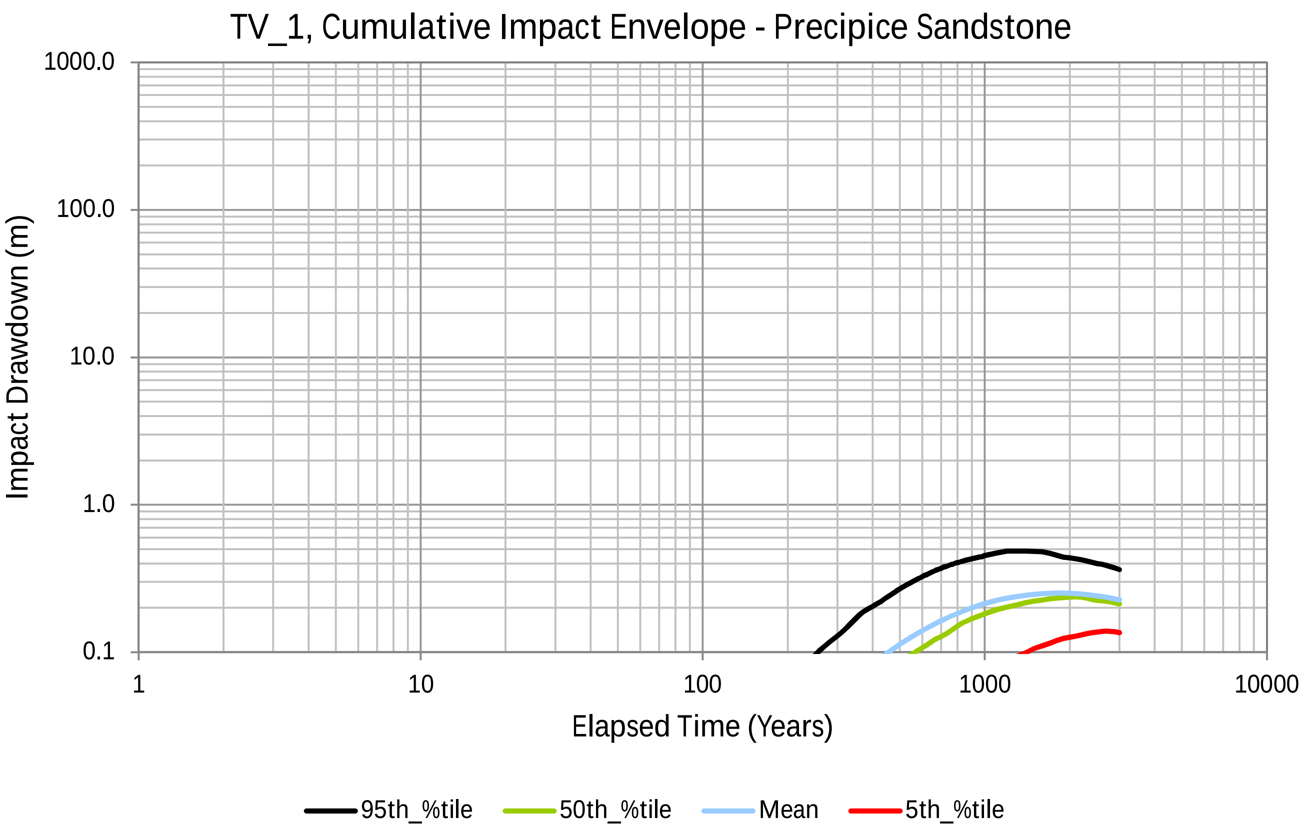
Appendix G - Cumulative Impact Envelope at Extraction Block Centres - Drainage Area 11





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Appendix H – Condamine Time Series Impact Plots

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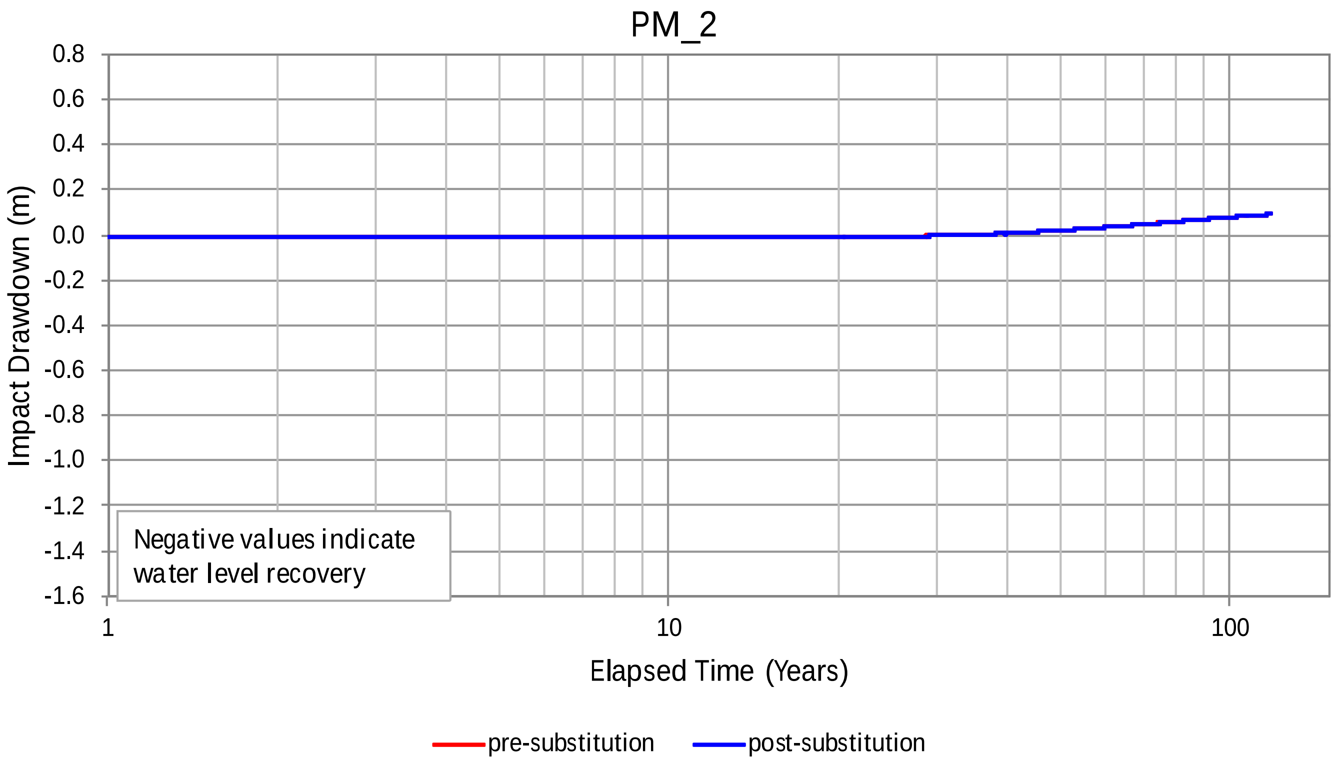
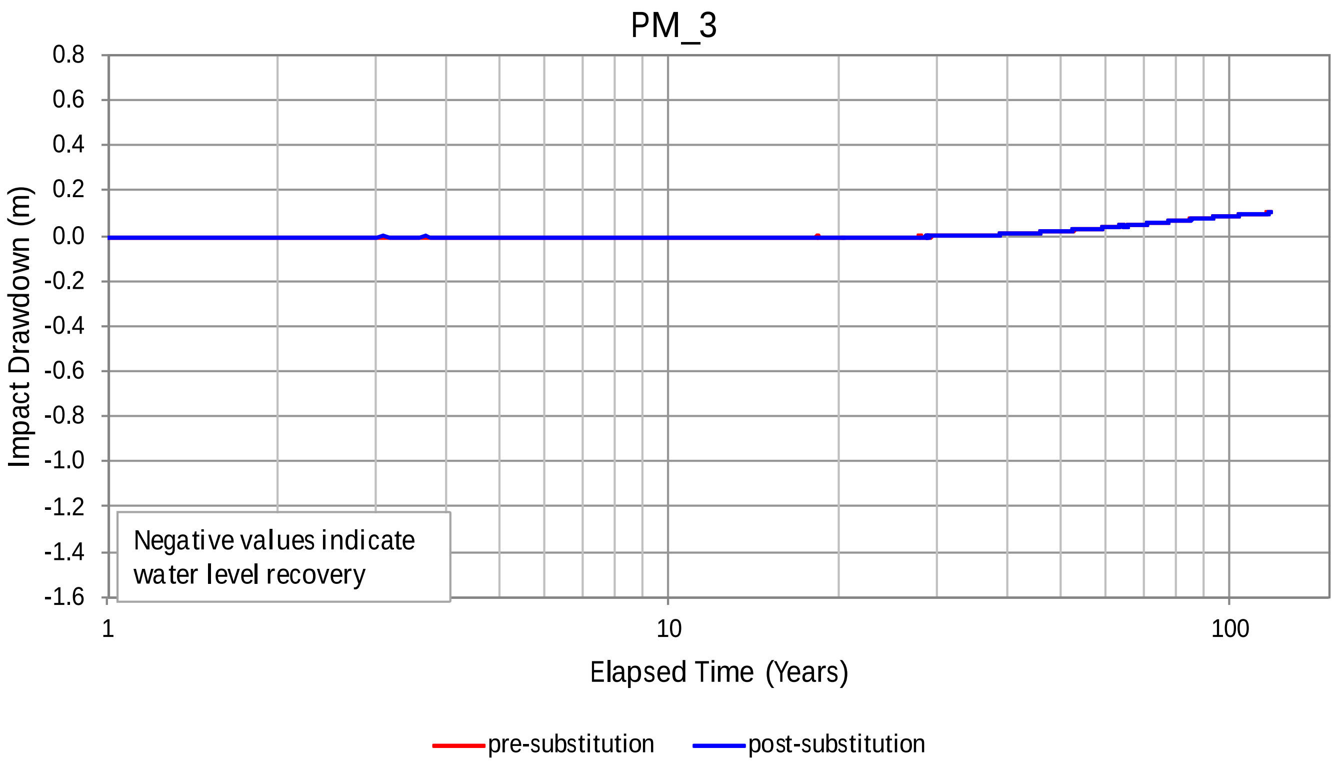
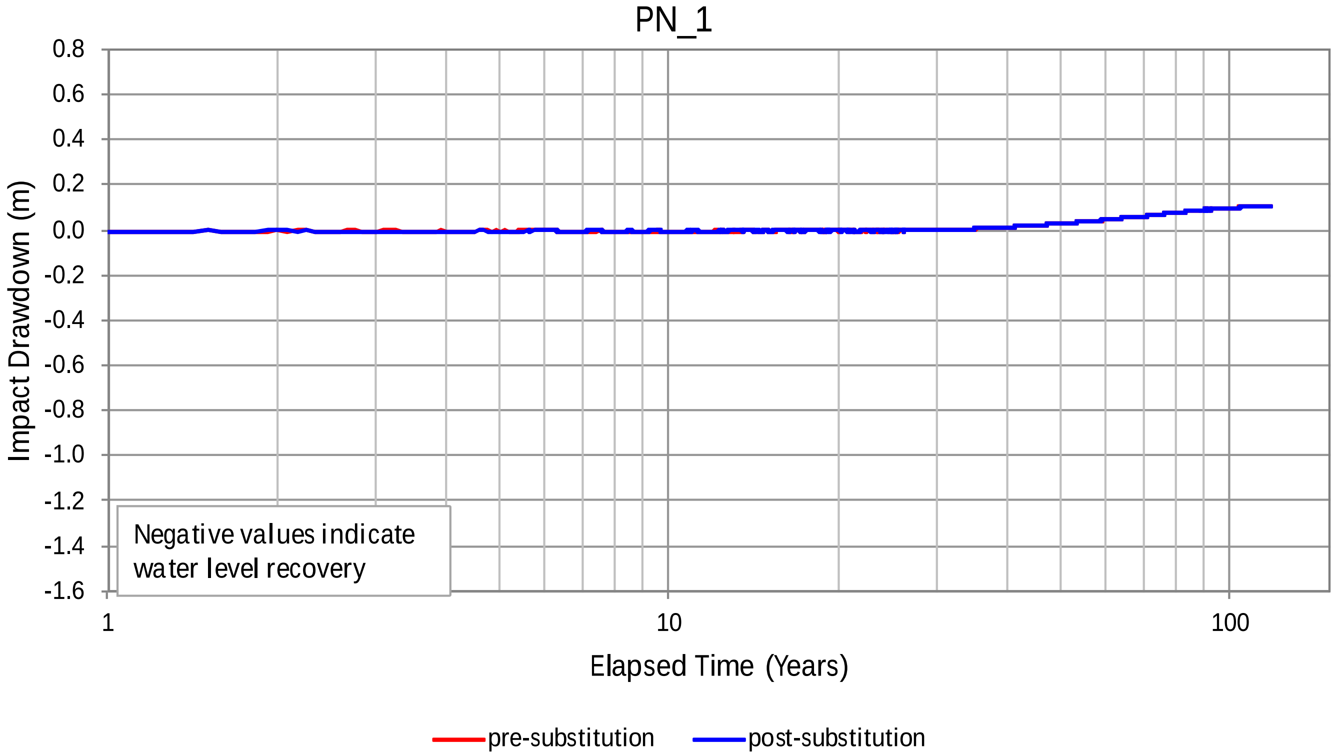
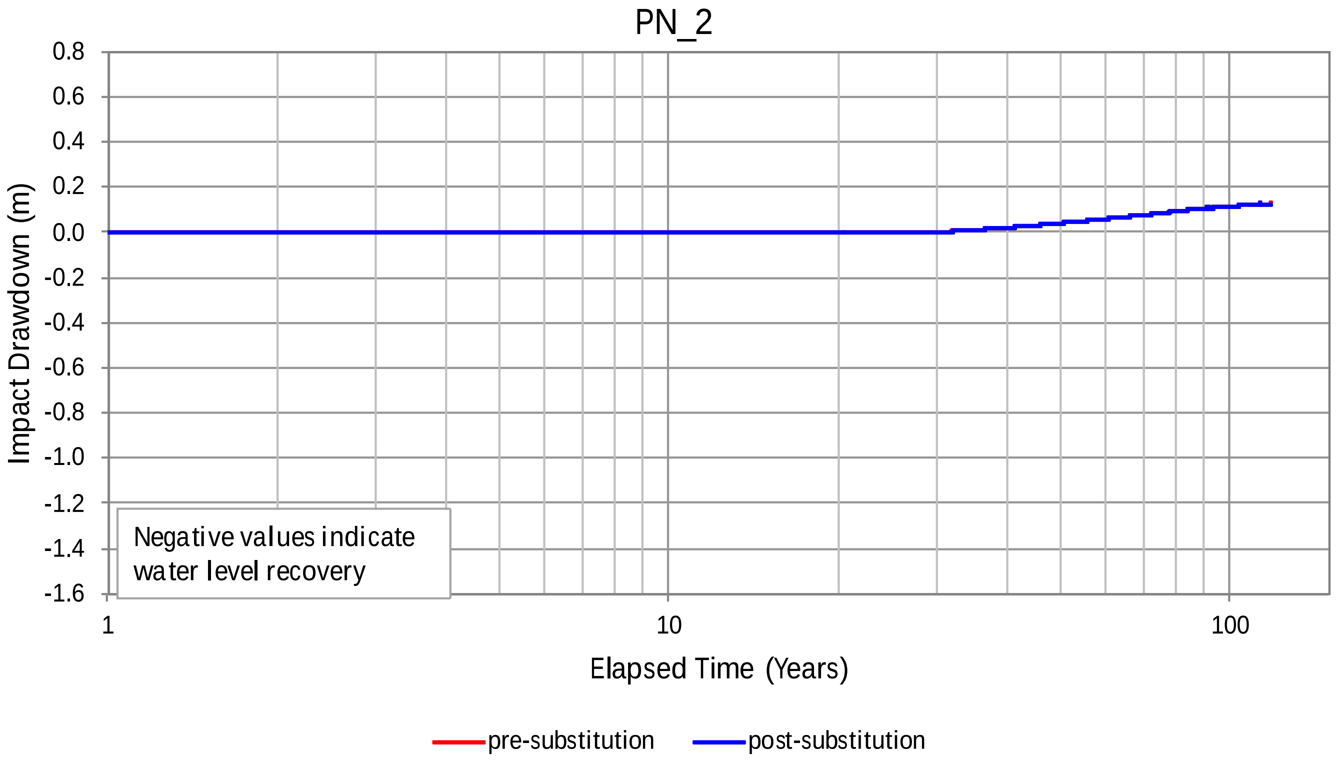
Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium



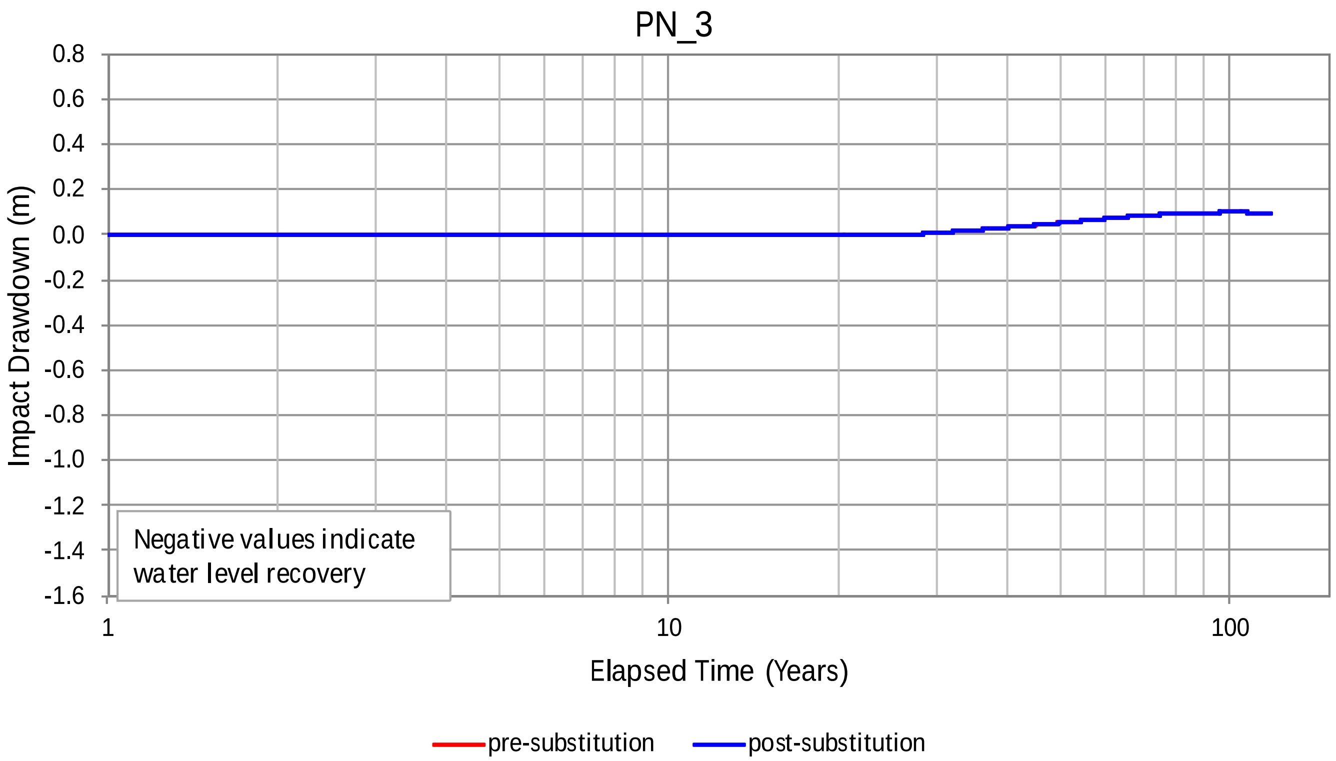


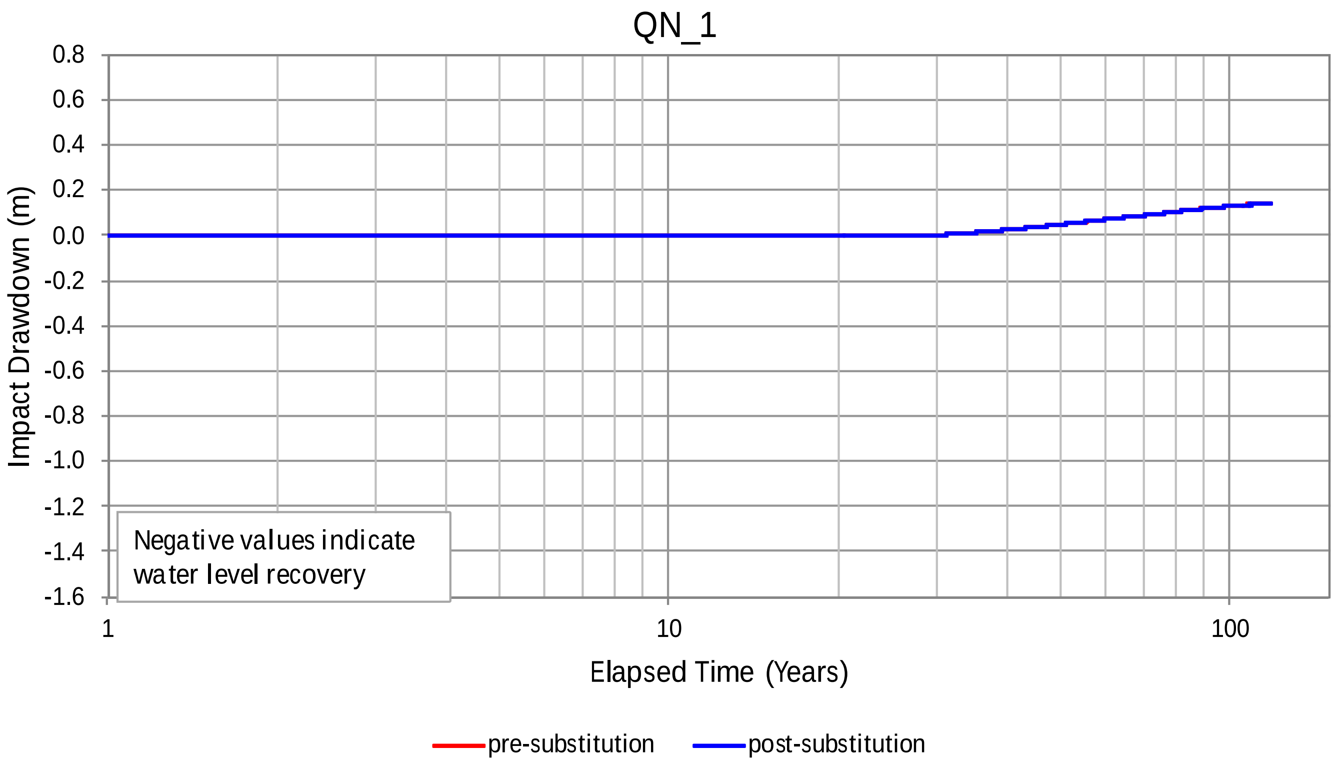
Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium



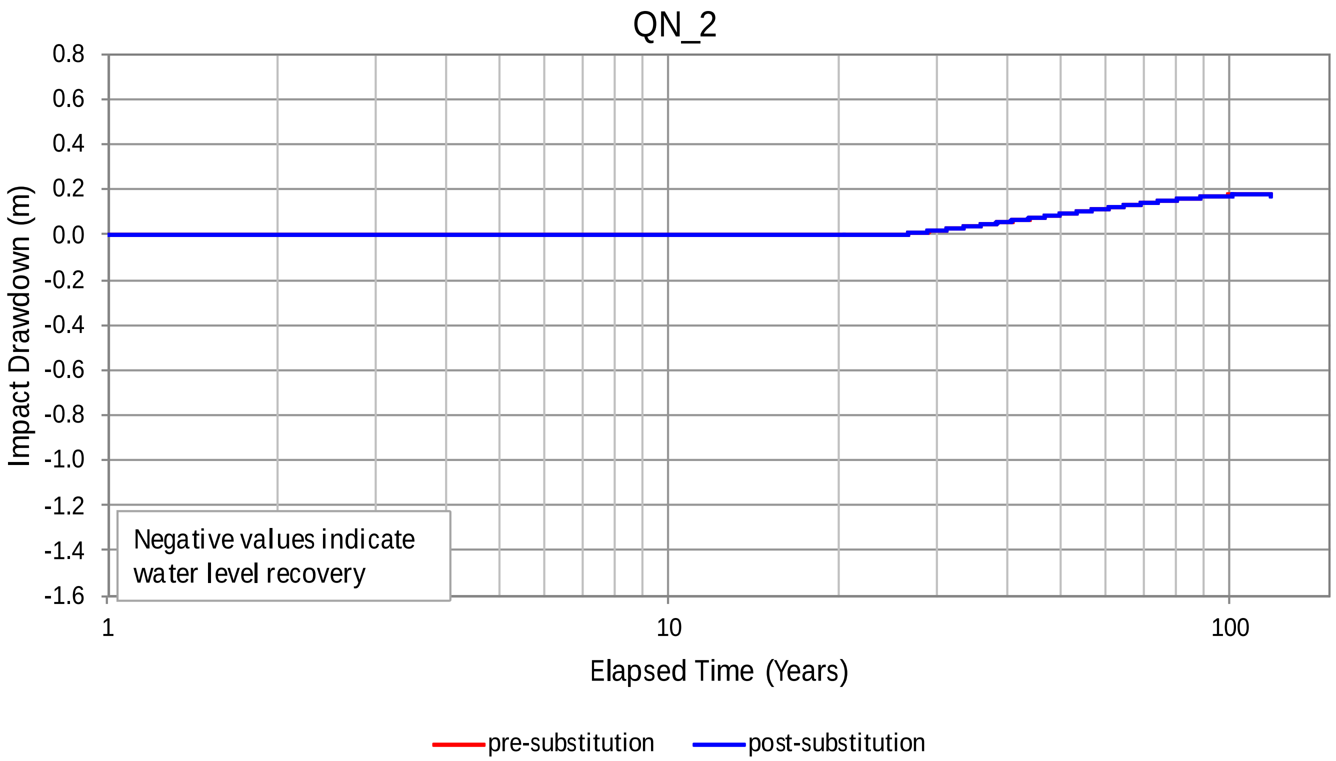


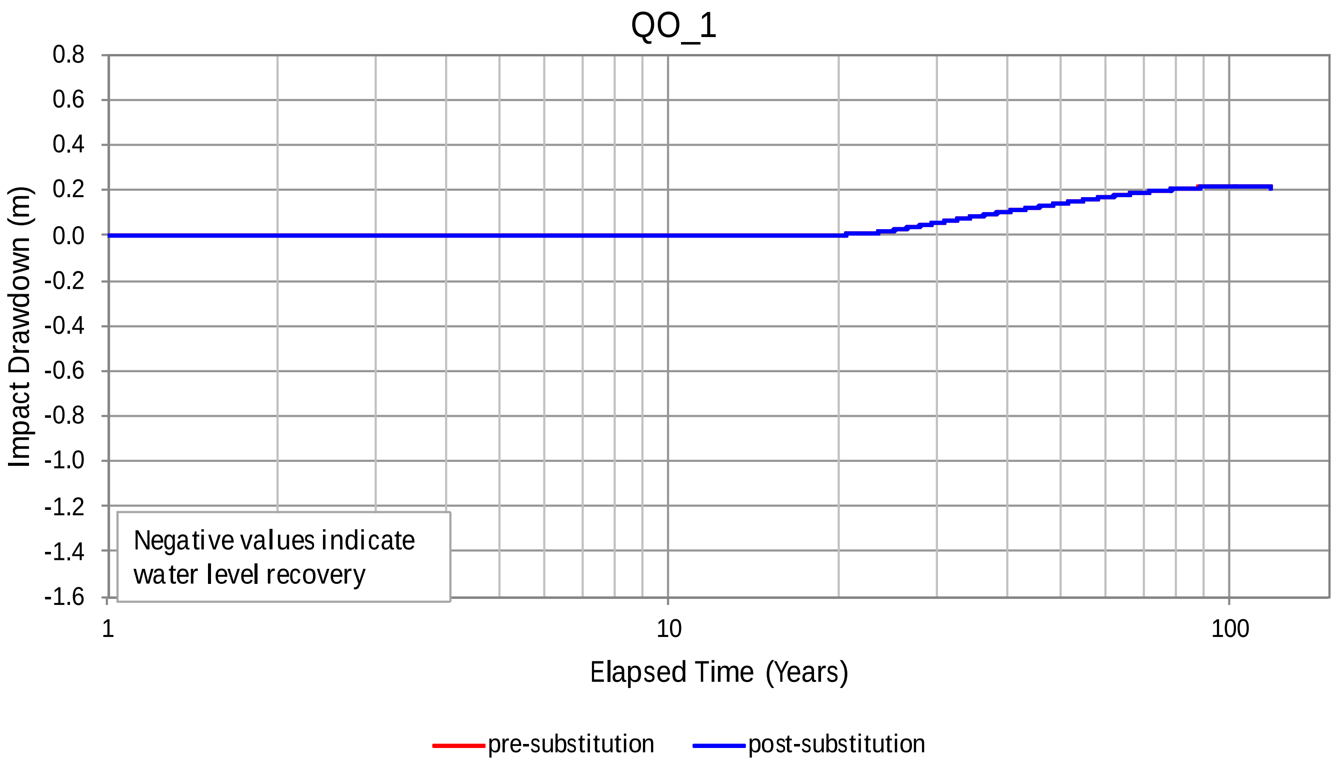
Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium



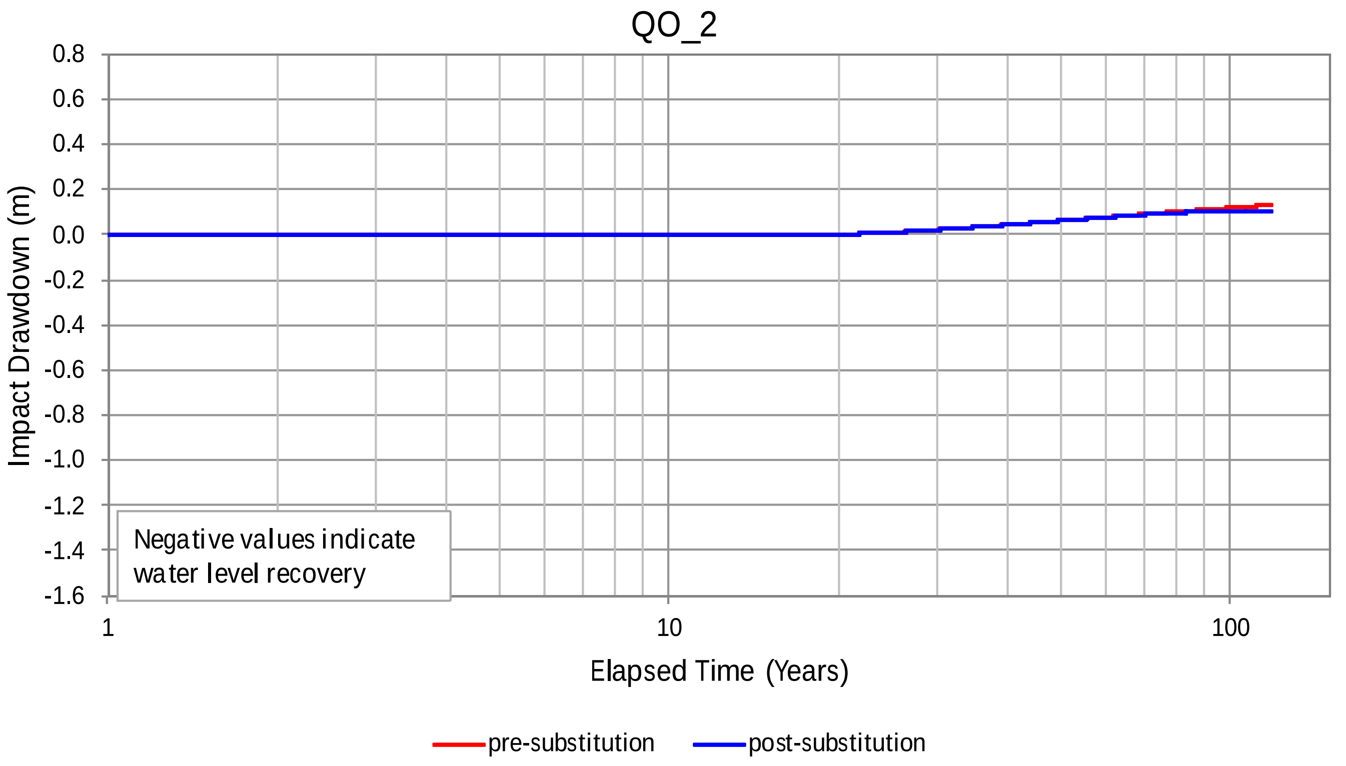


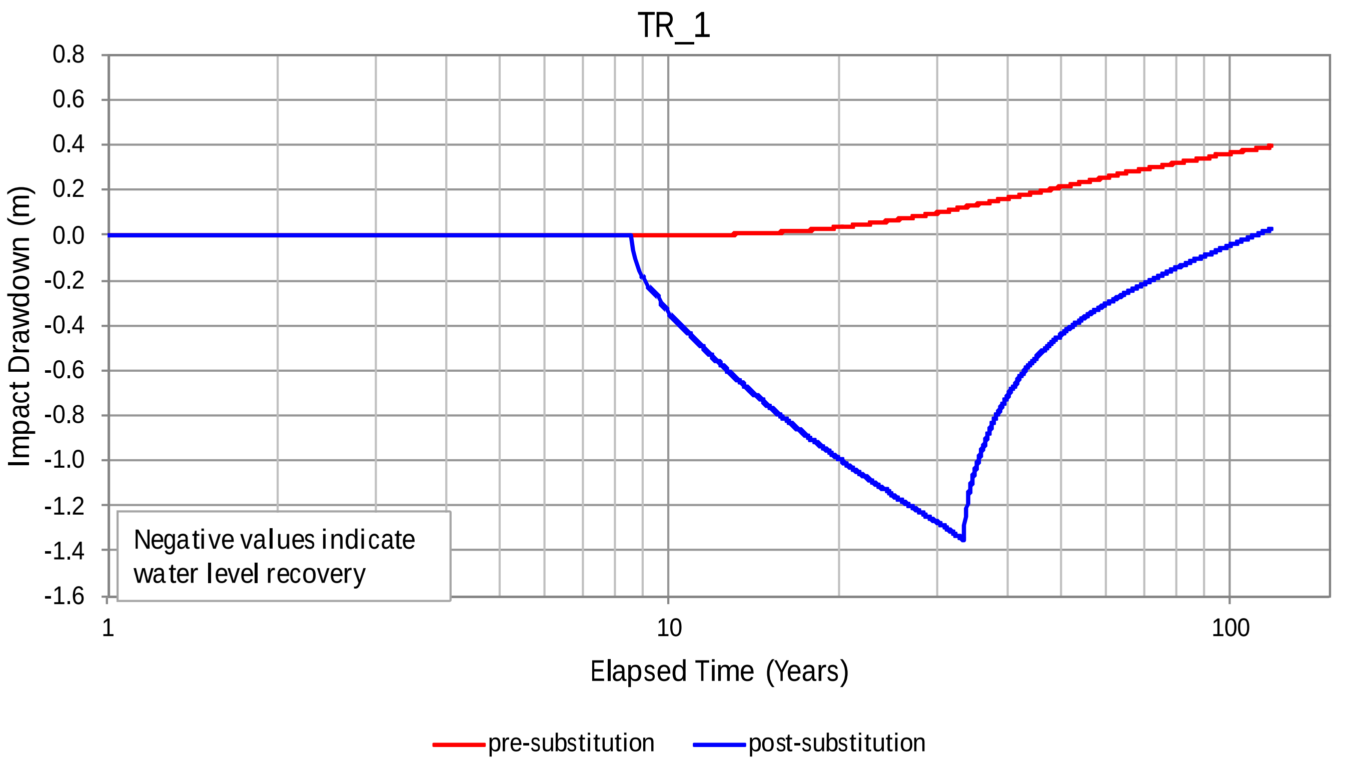
Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium



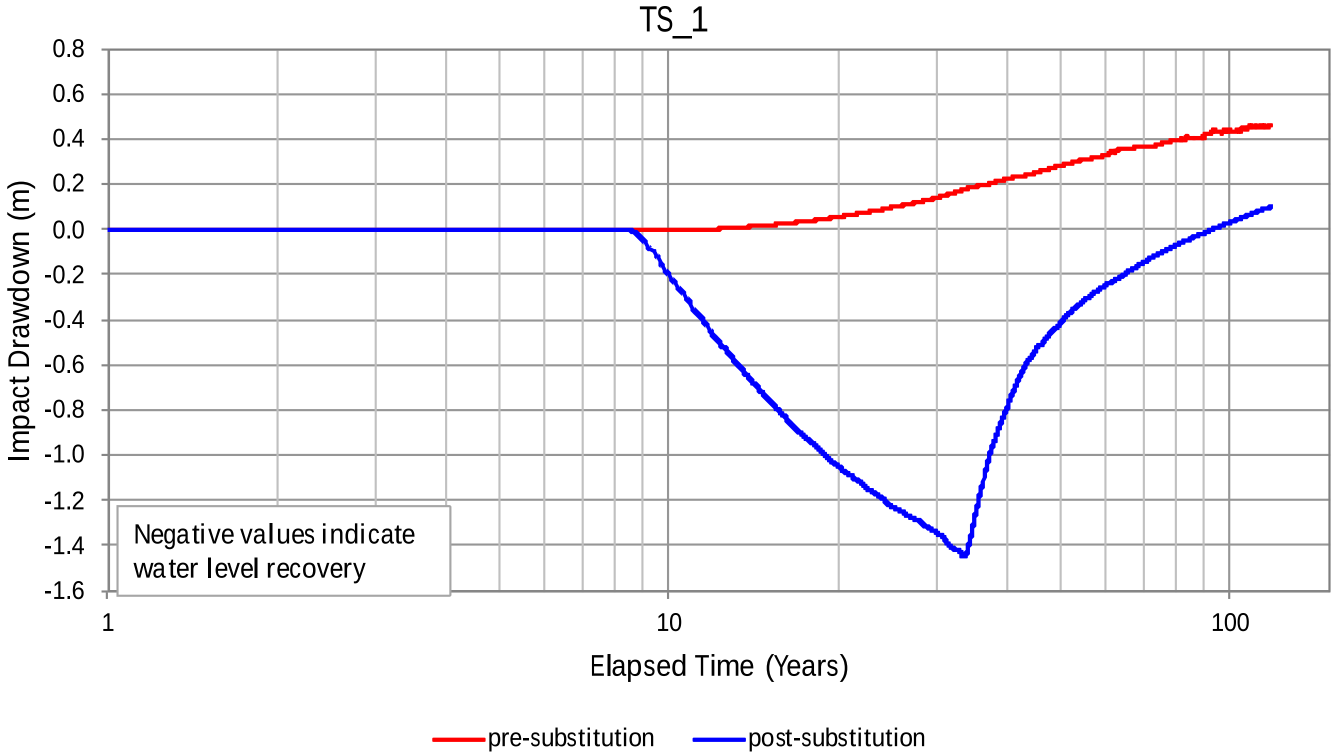


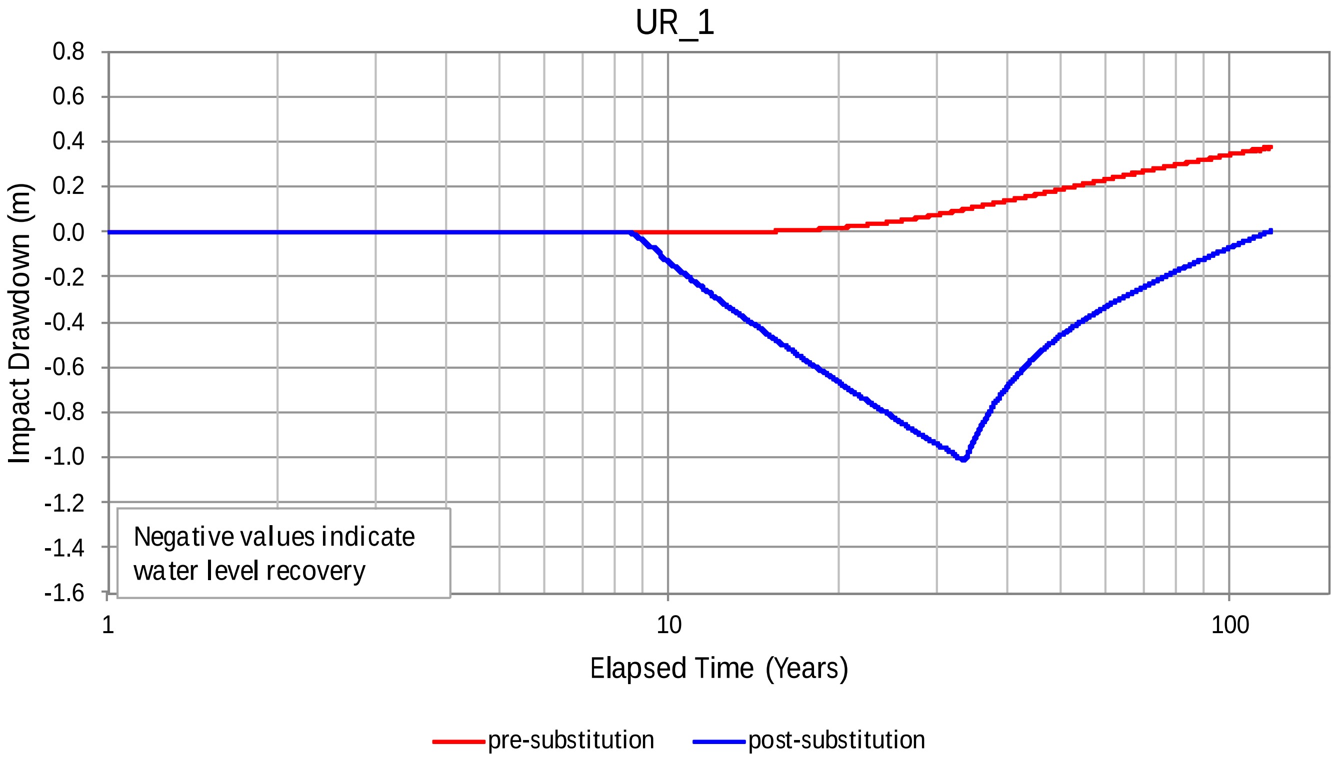
Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium



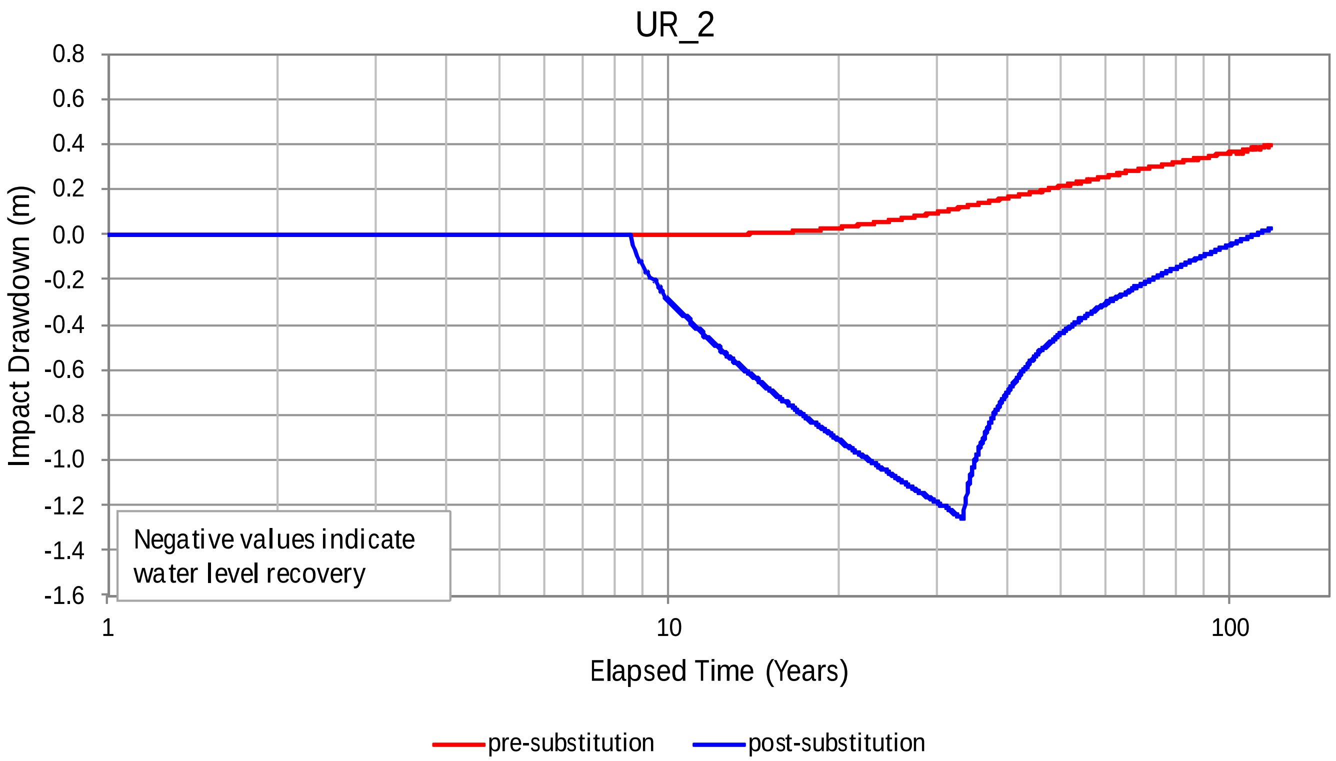


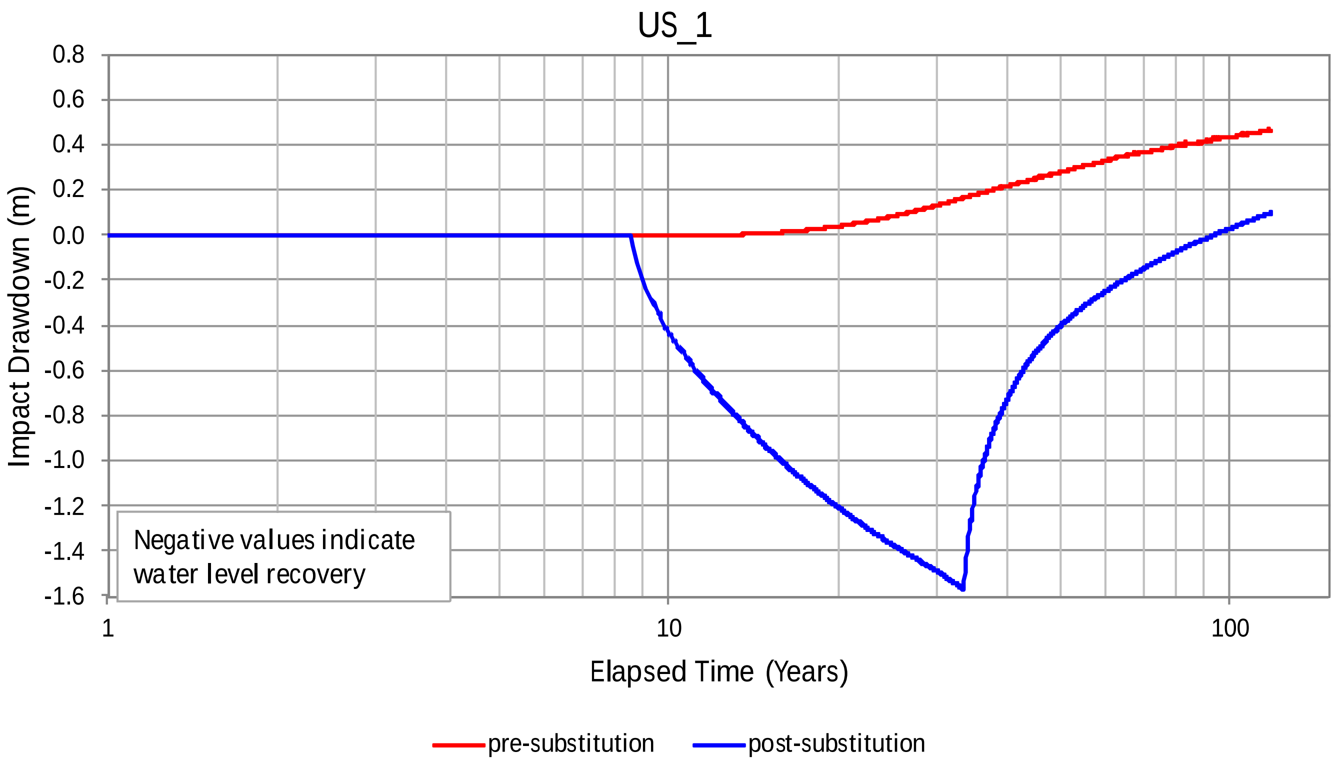
Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium





Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium





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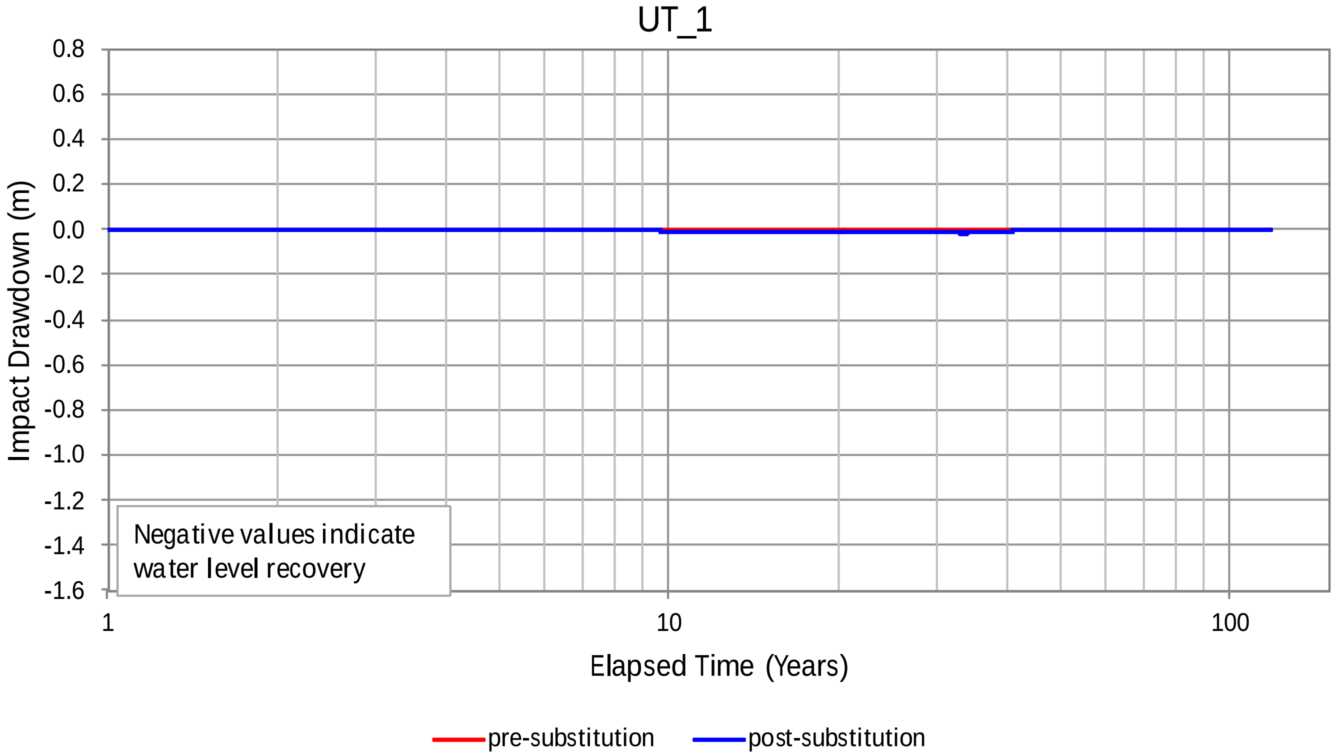
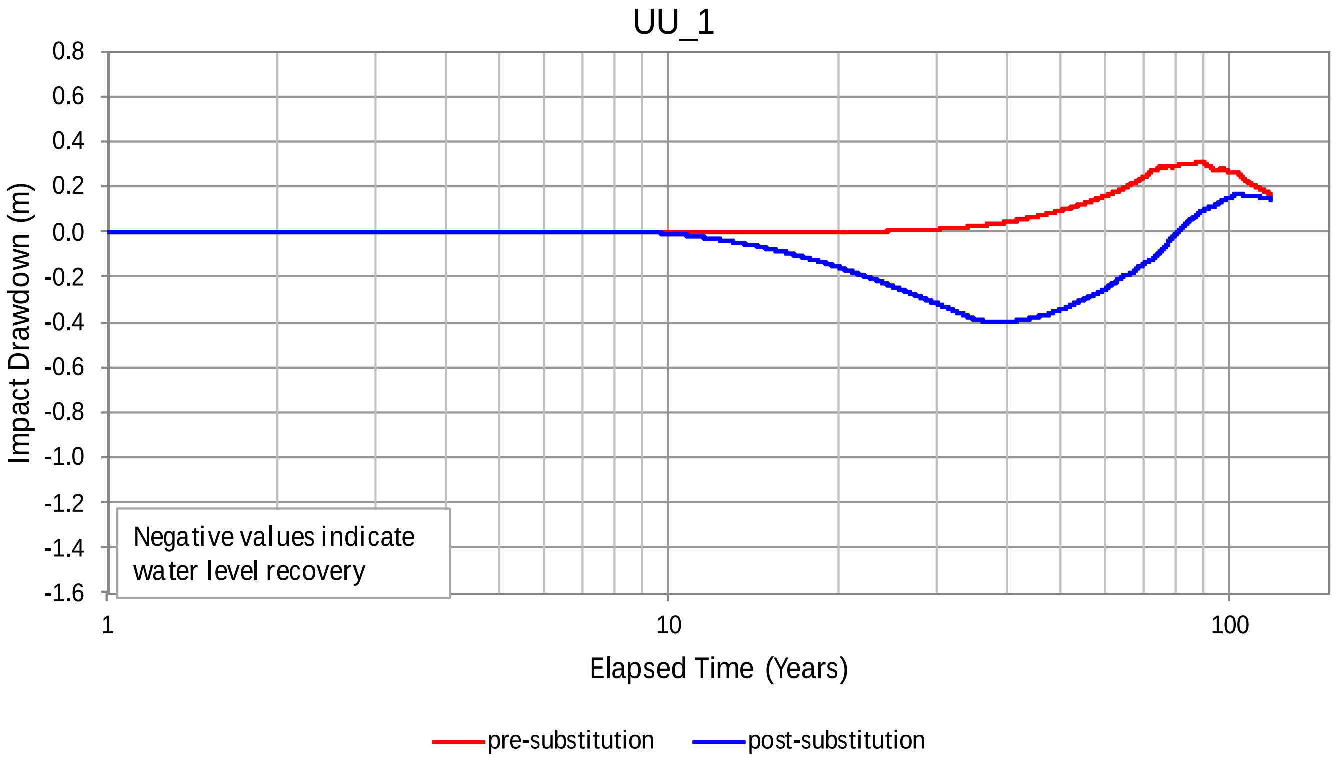
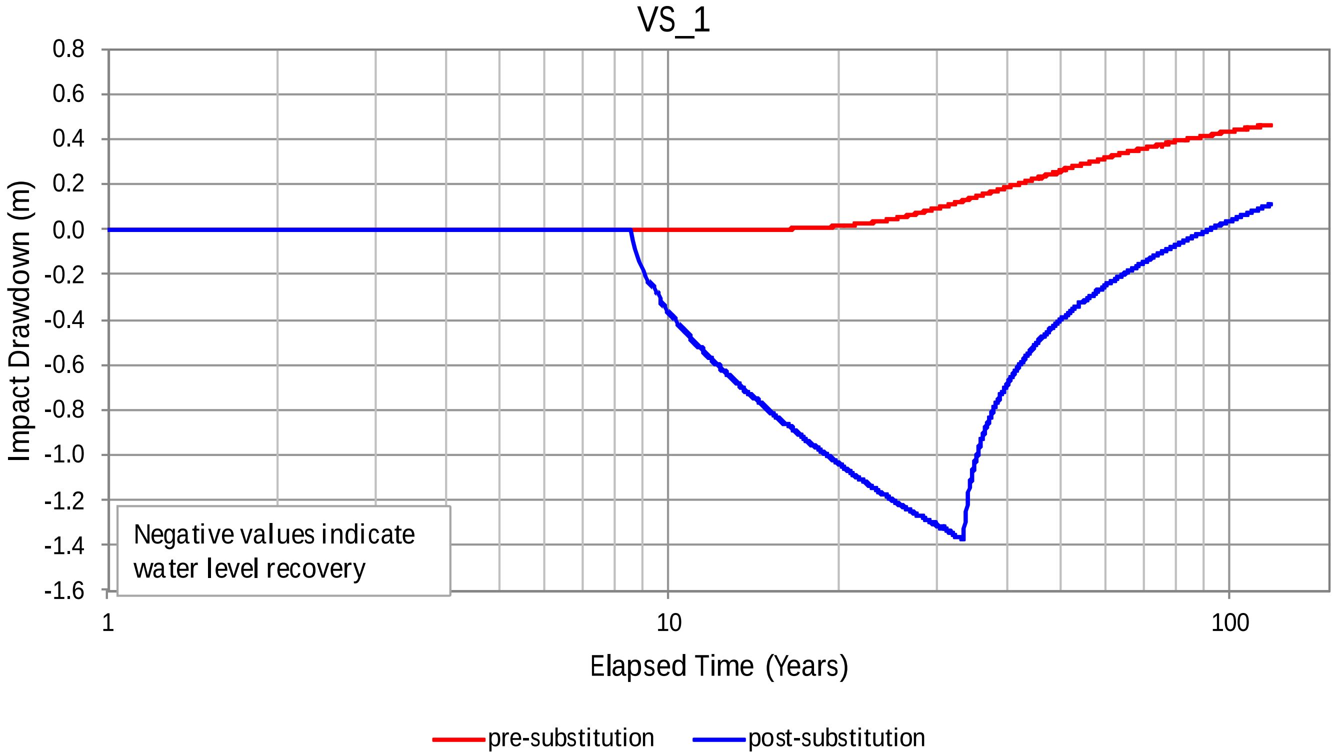
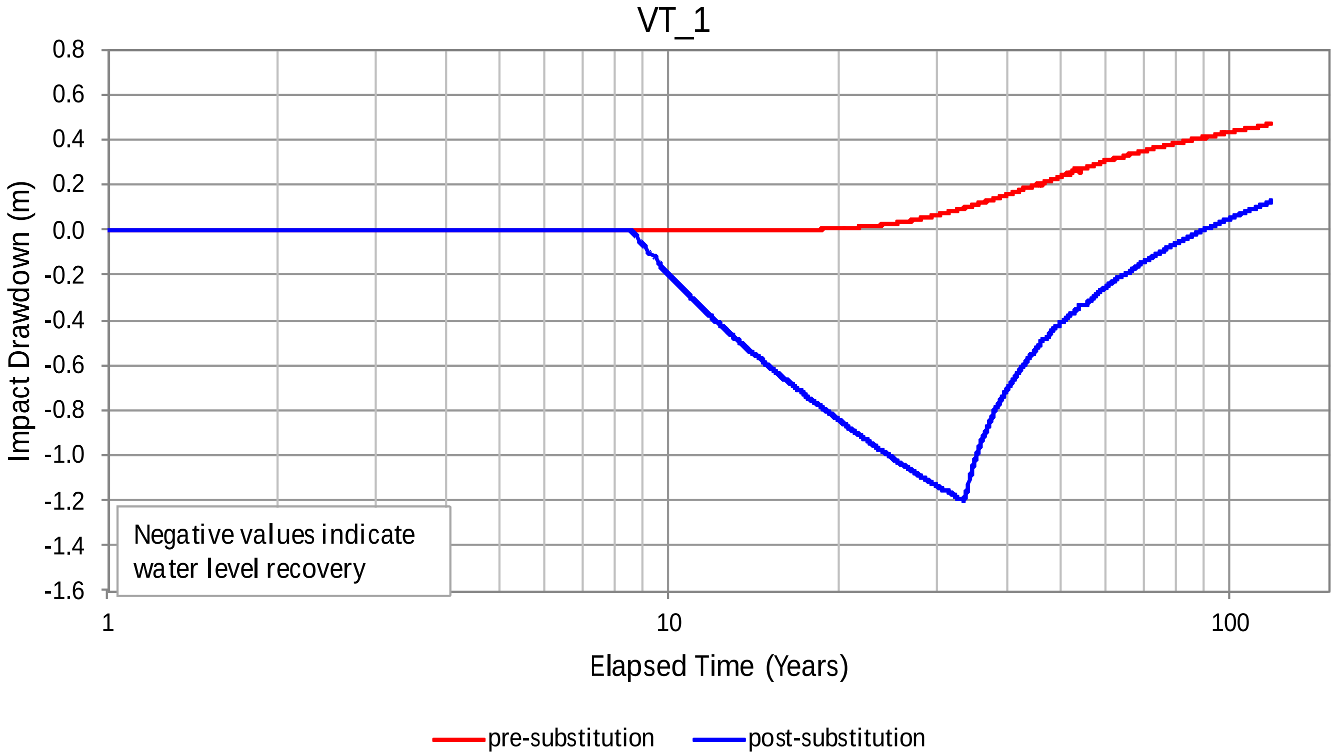
Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium





Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium





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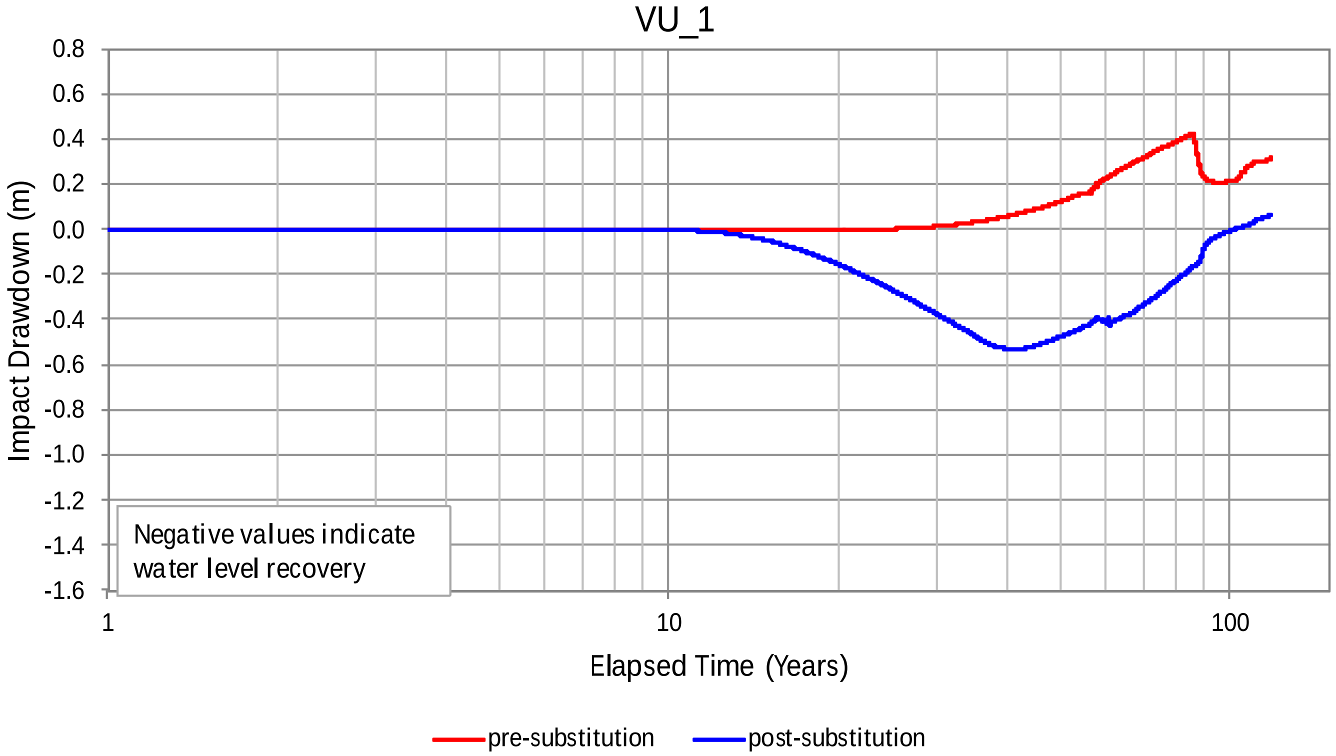
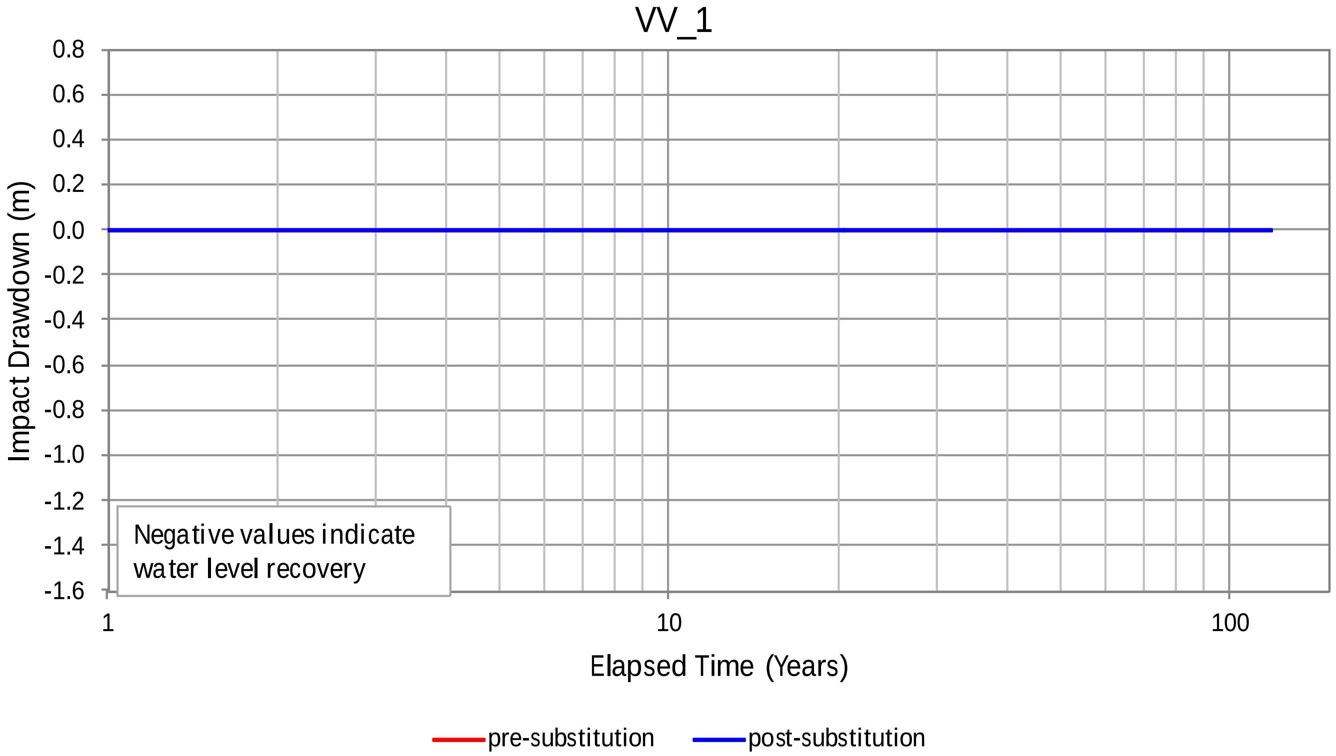
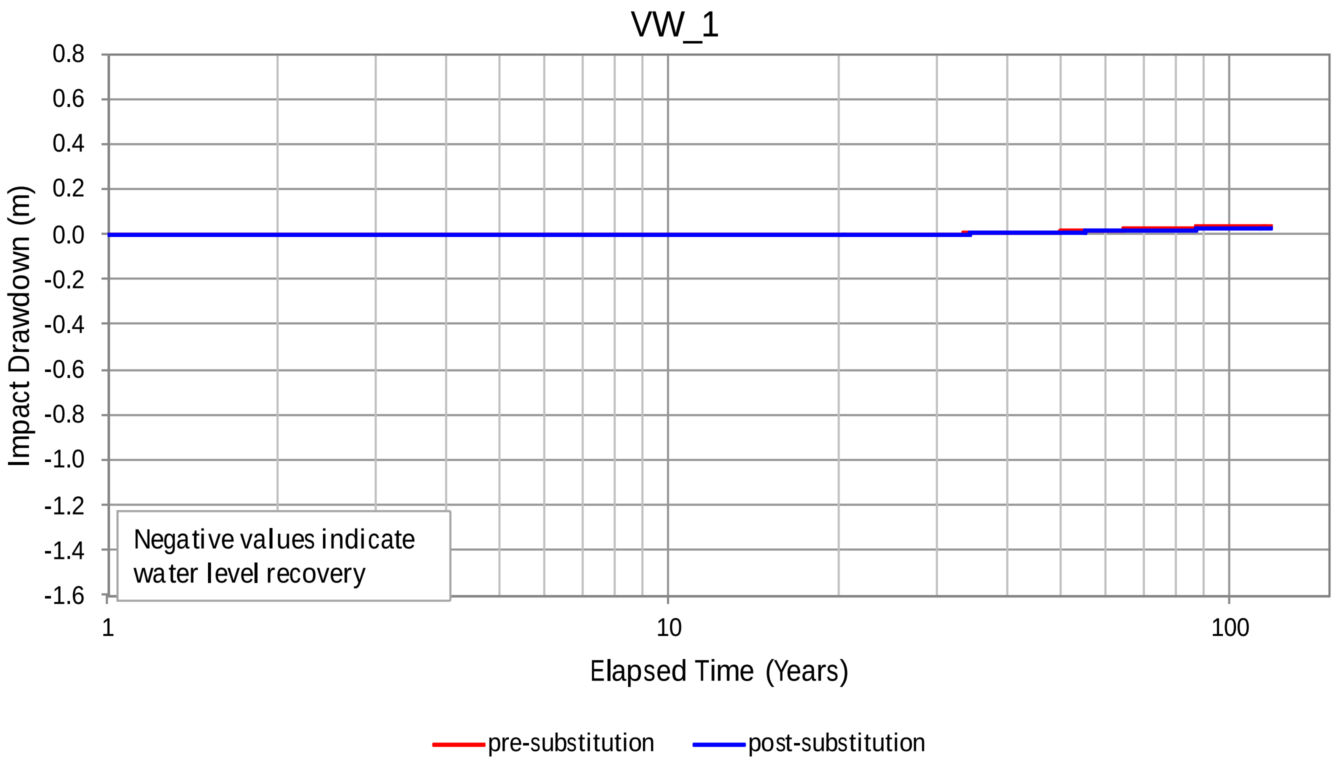
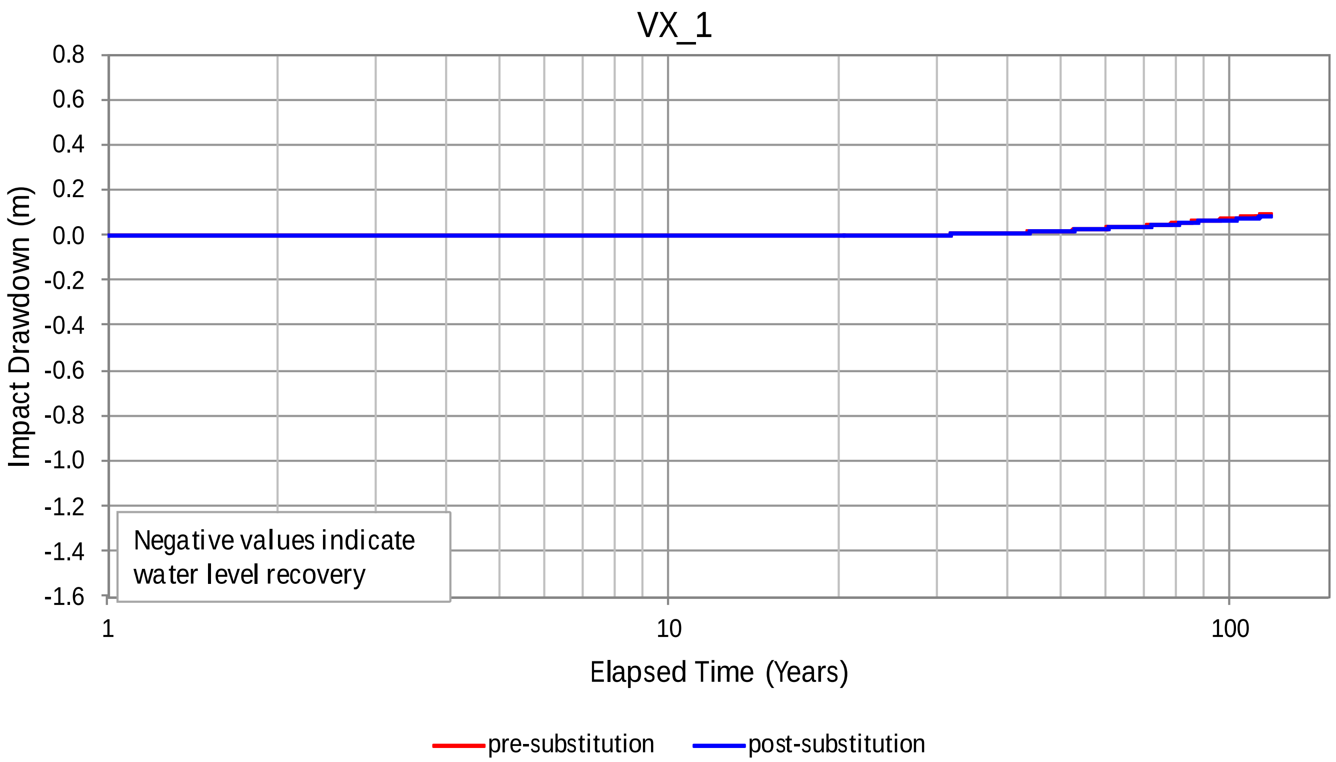
Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium



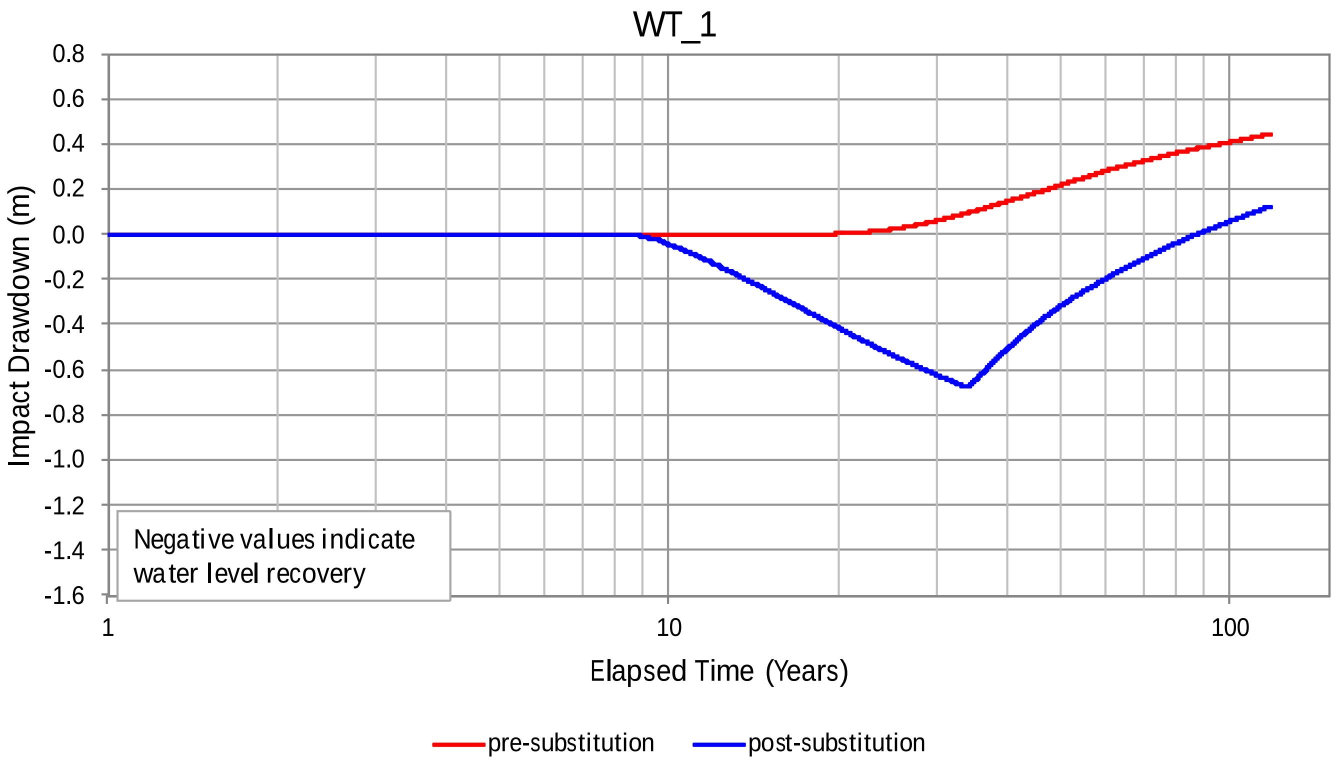


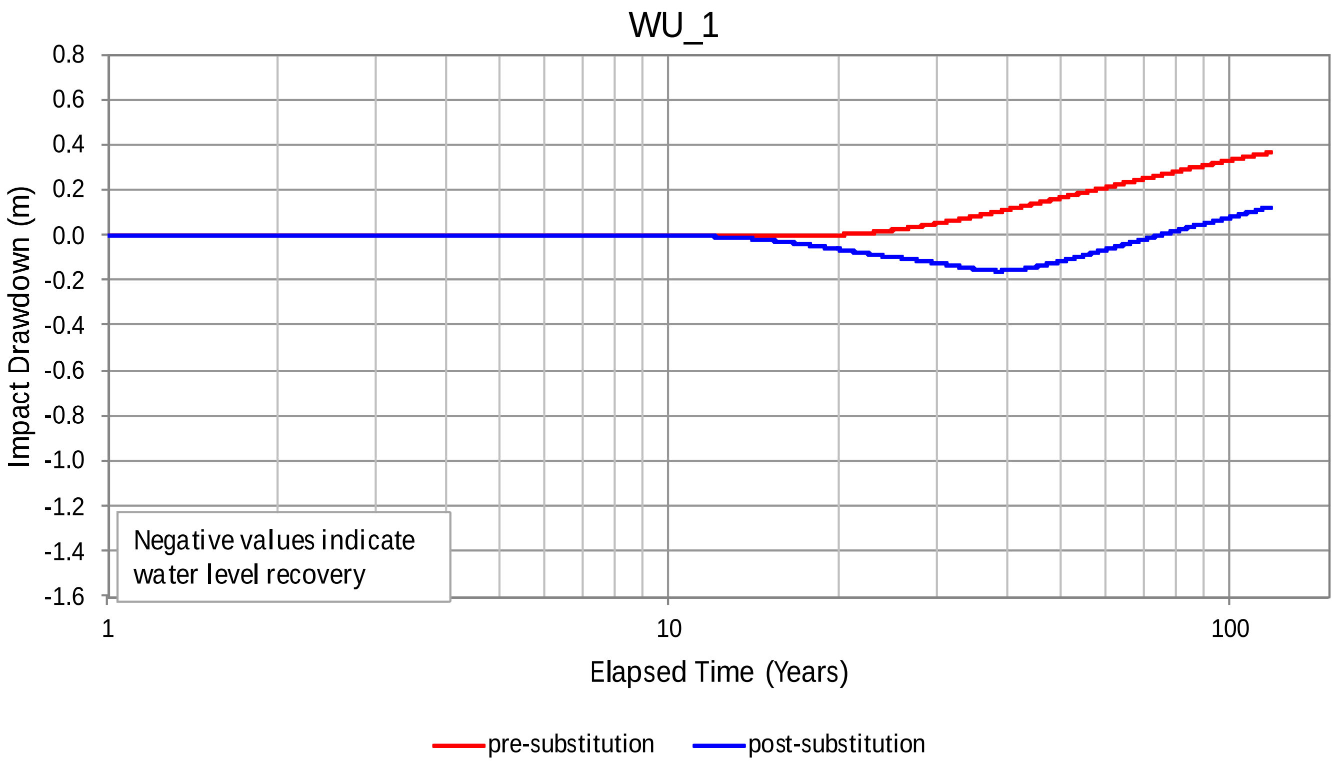
Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium



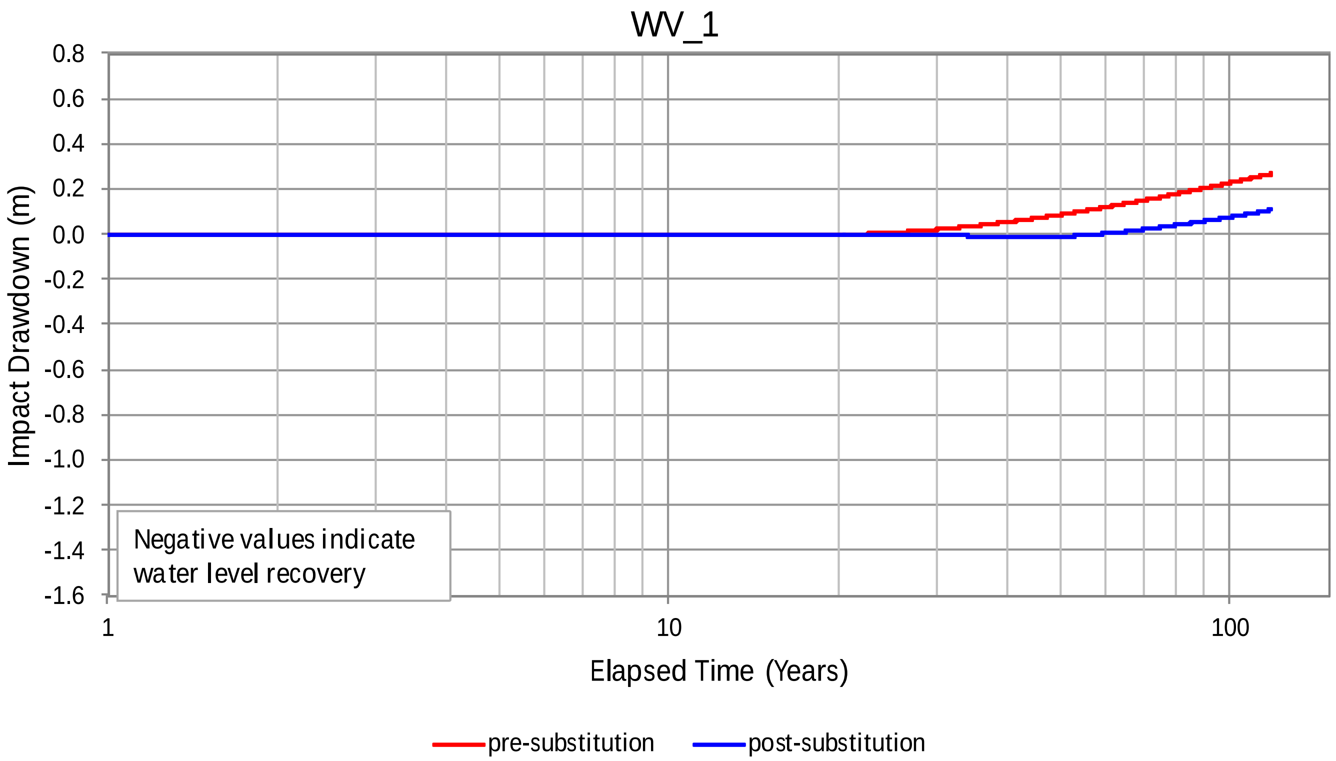


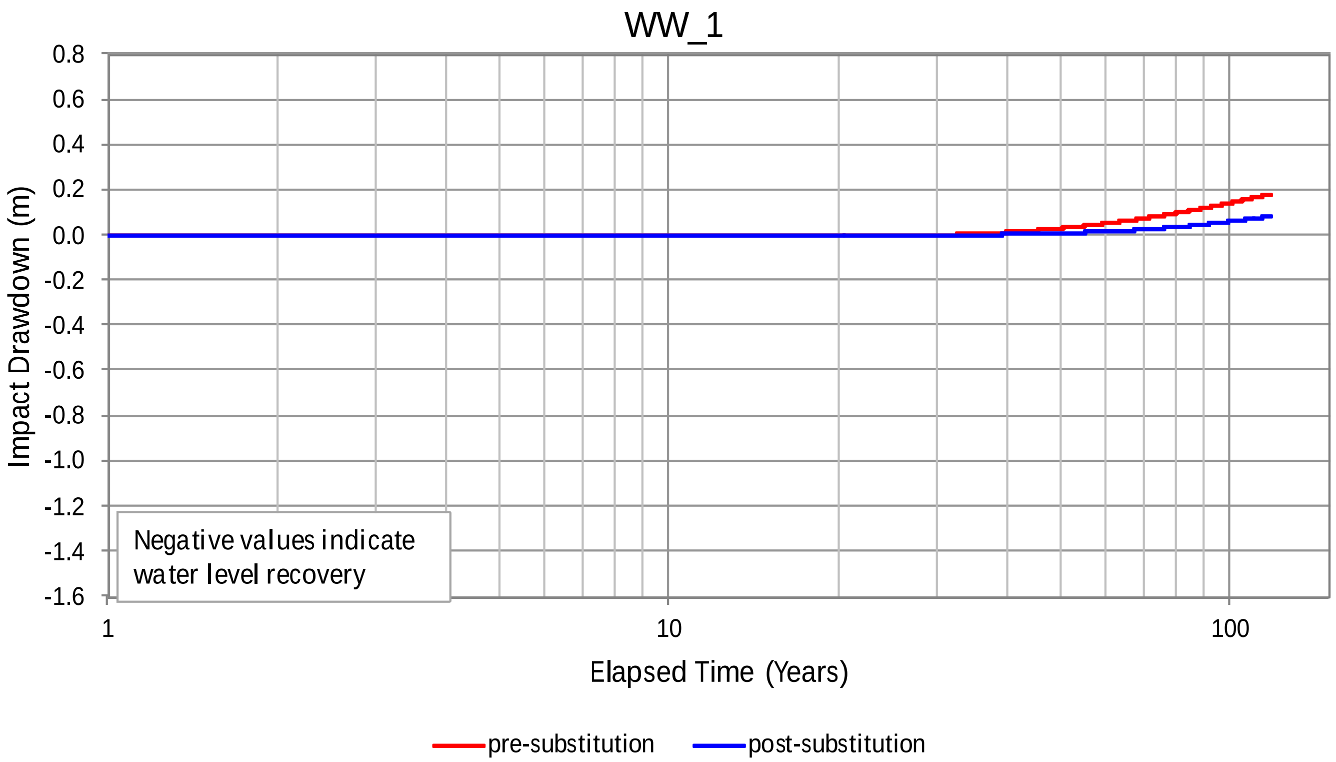
Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium



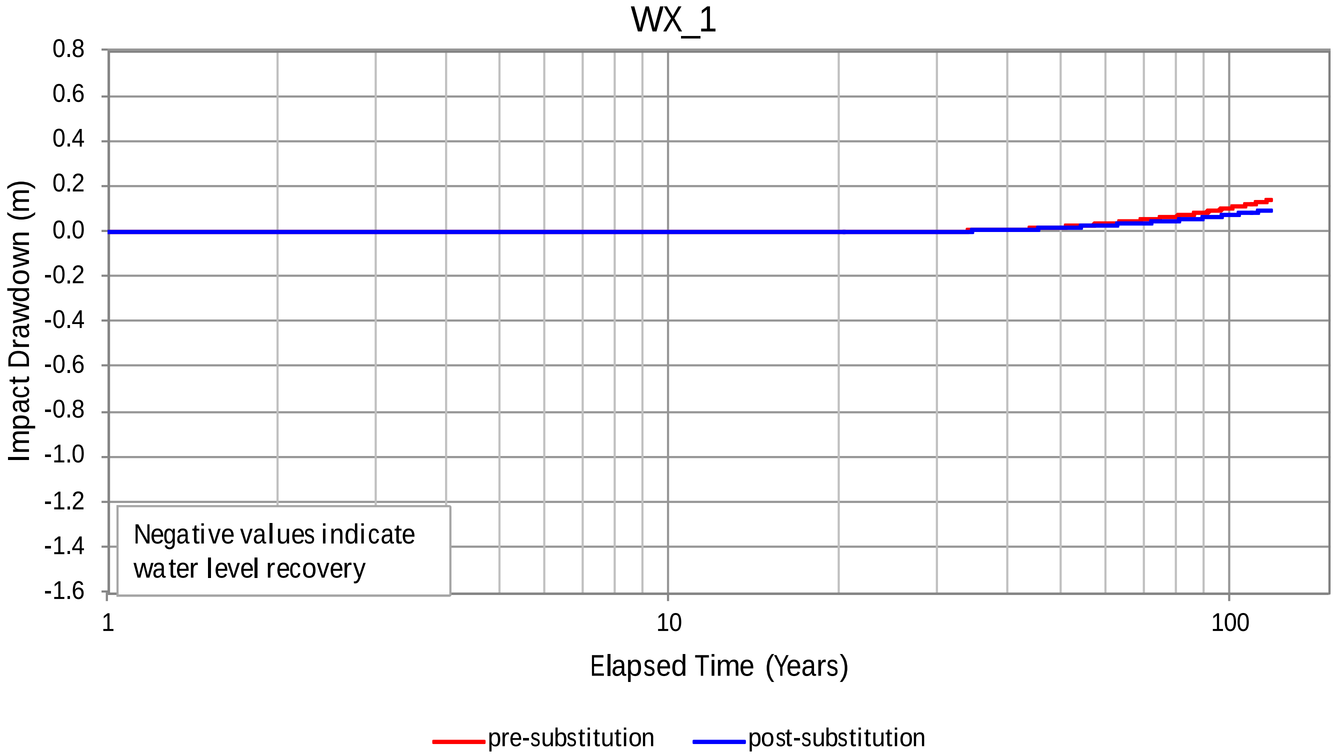


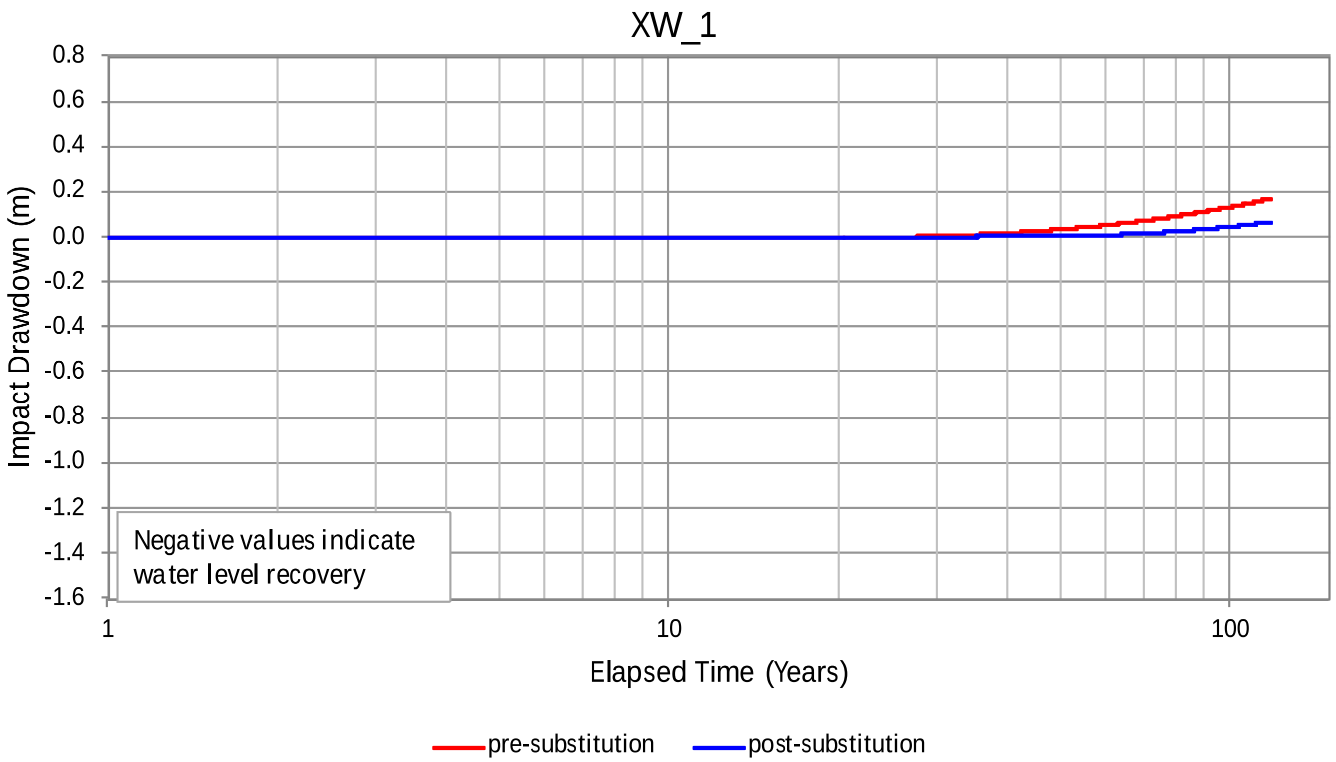
Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium

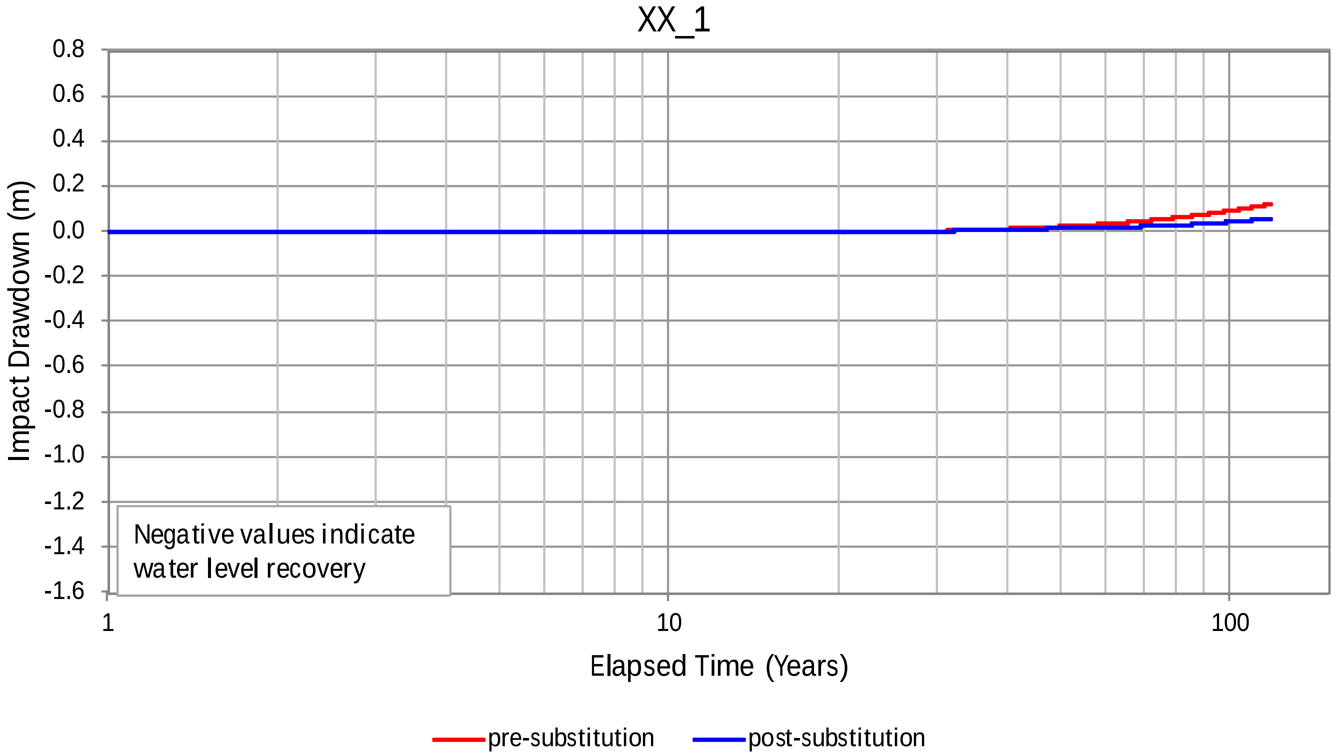




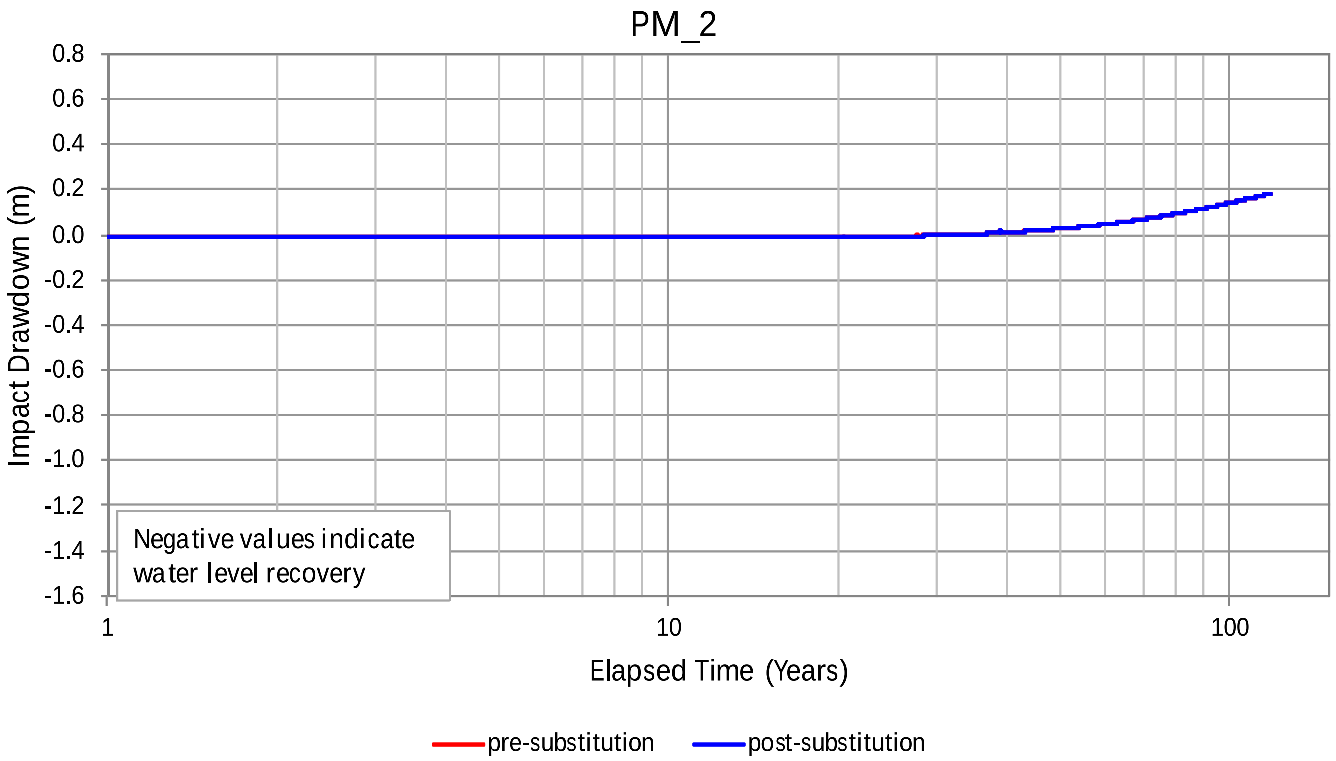
Appendix H - Predicted Arrow Gas Project Drawdown Impact Condamine Alluvium

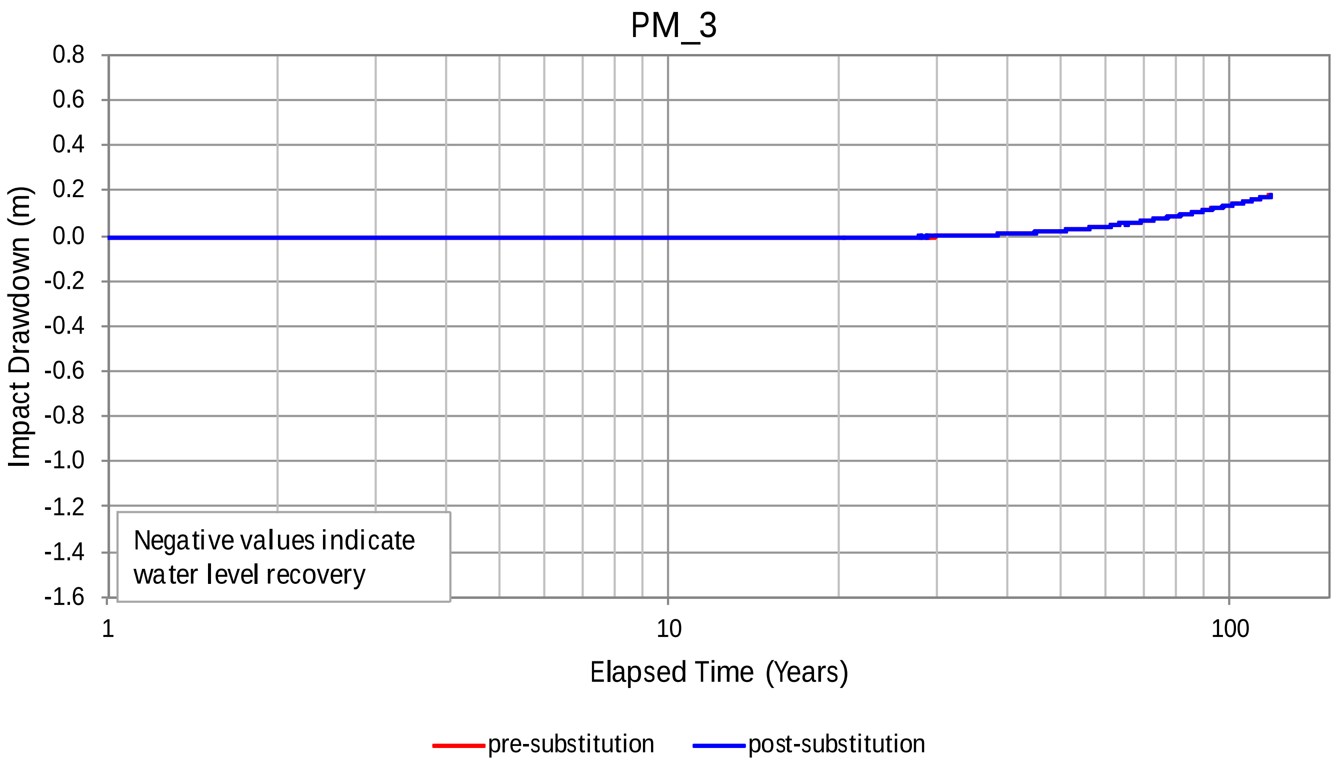




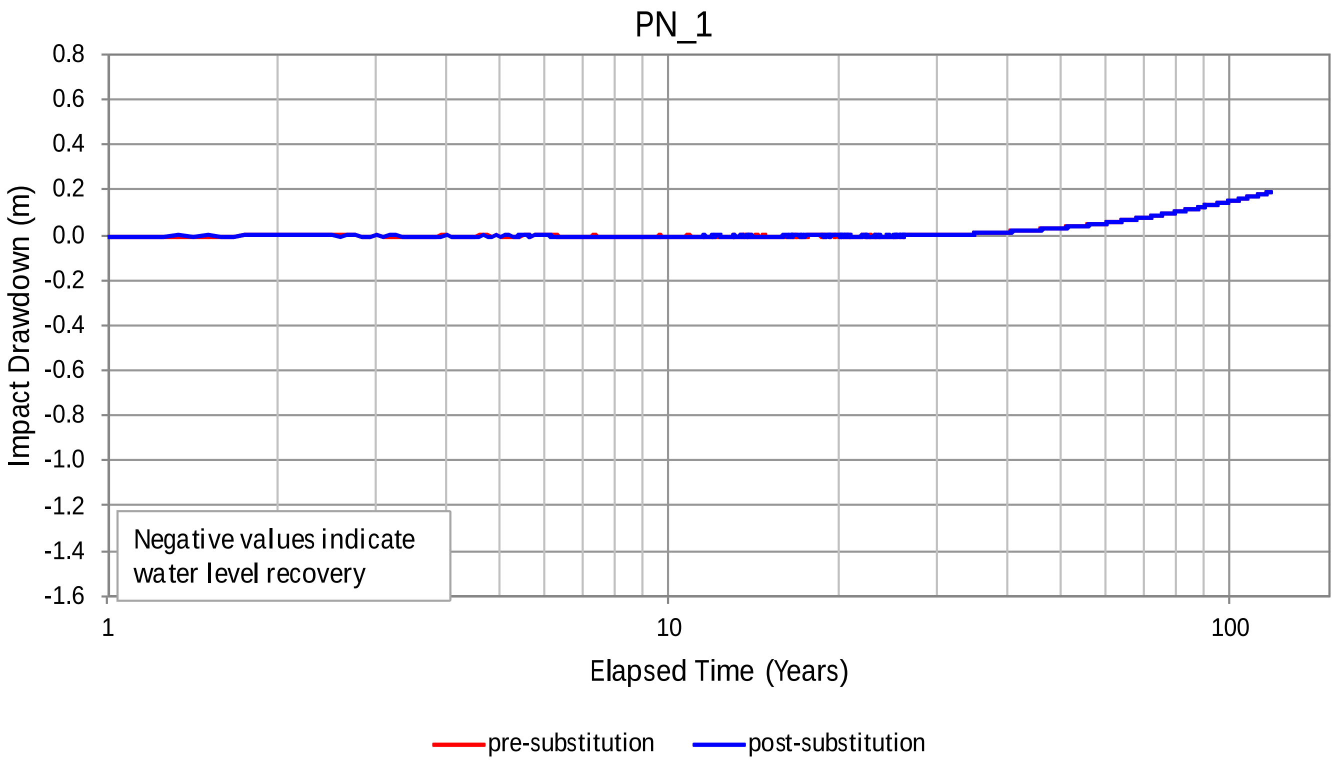

XX_1
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
Impact Drawdown (m)
Negative values indicate water level recovery
1
10
100
Elapsed Time (Years)
pre-substitution
post-substitution

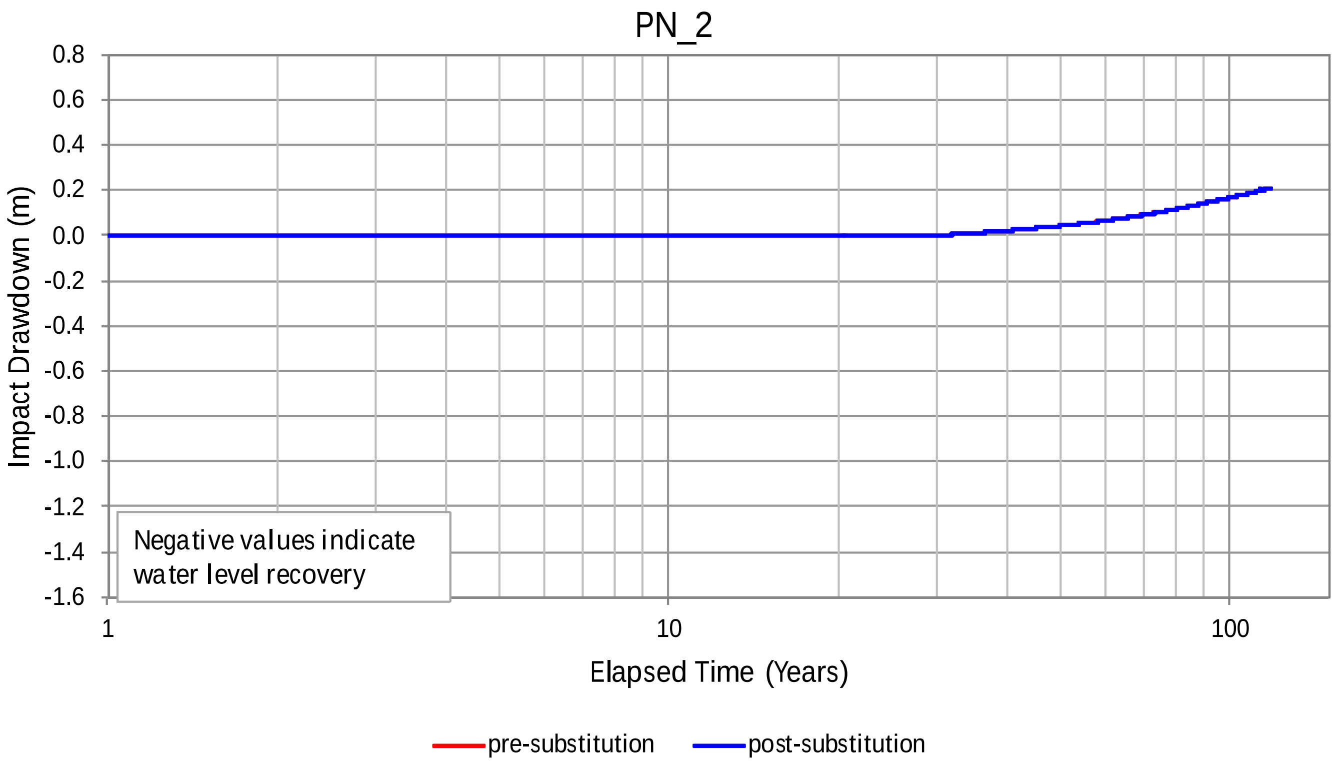
Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium



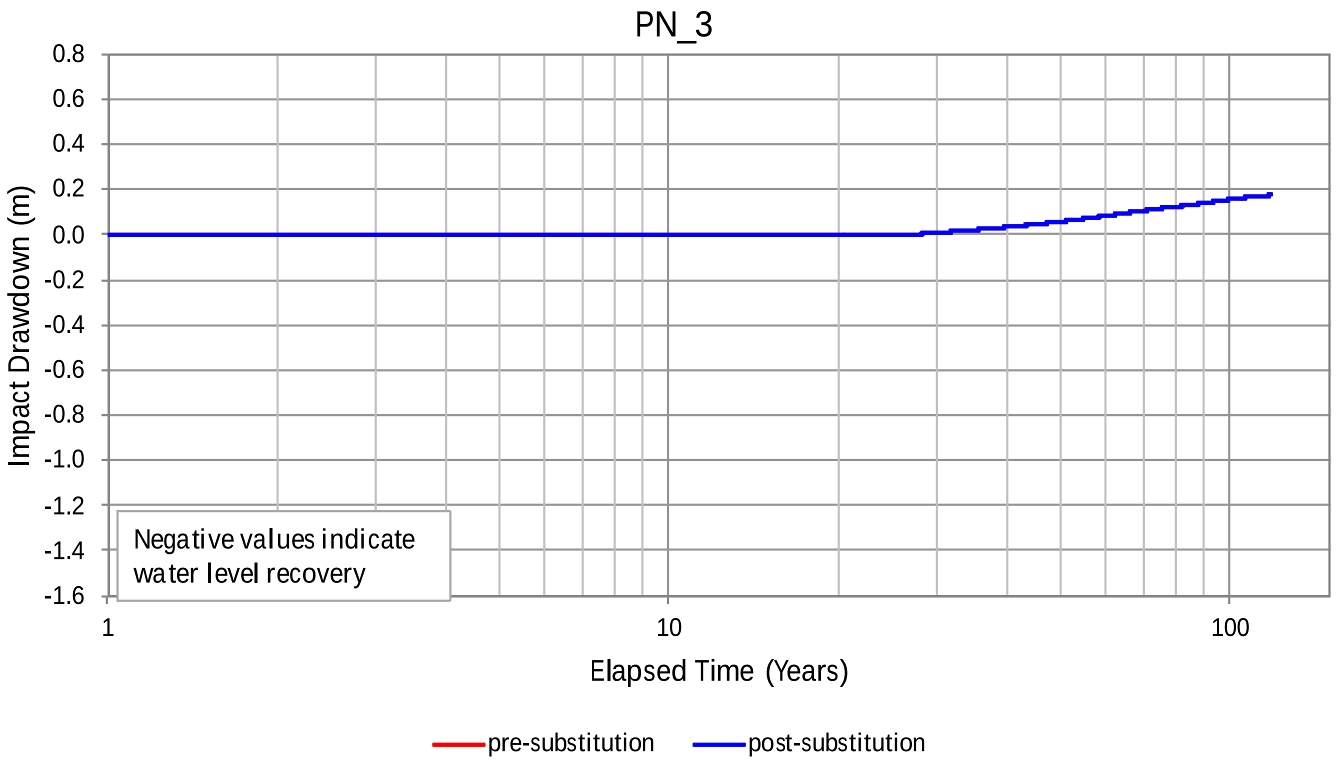


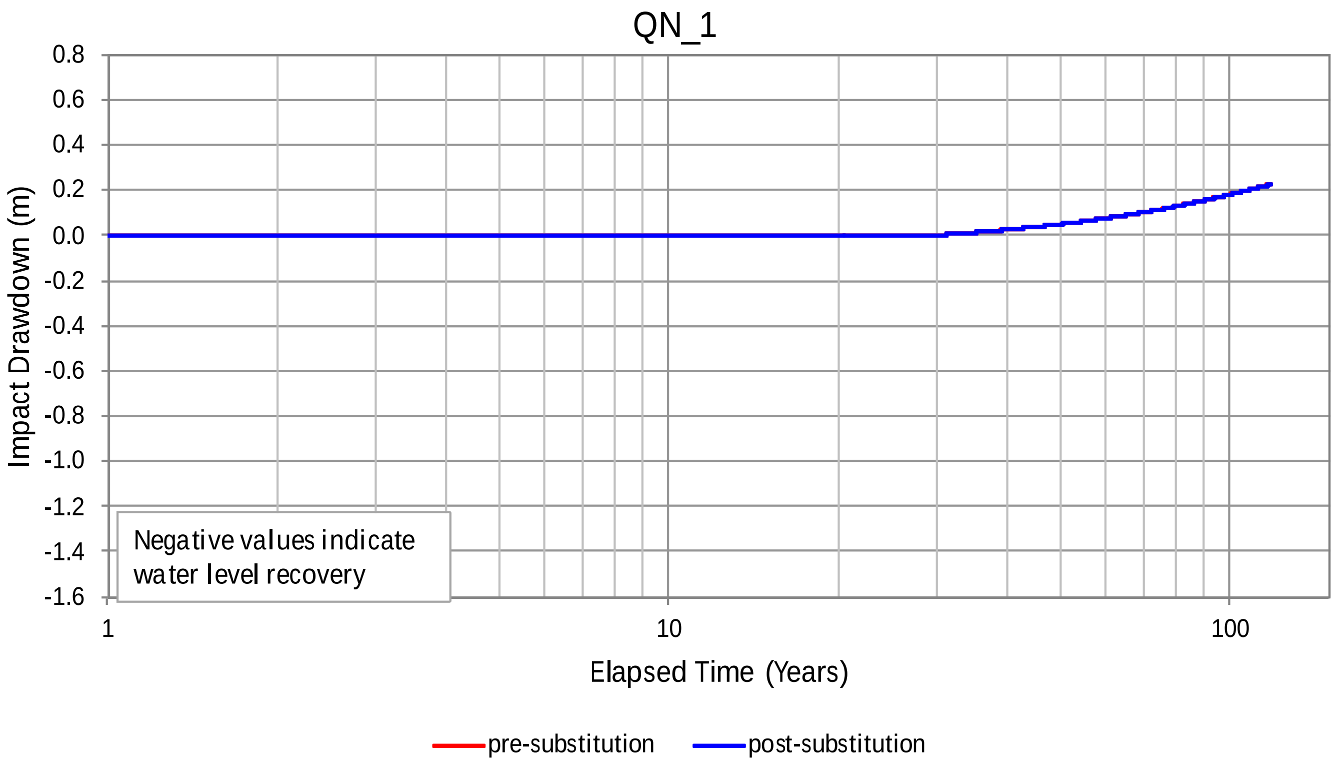
Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium



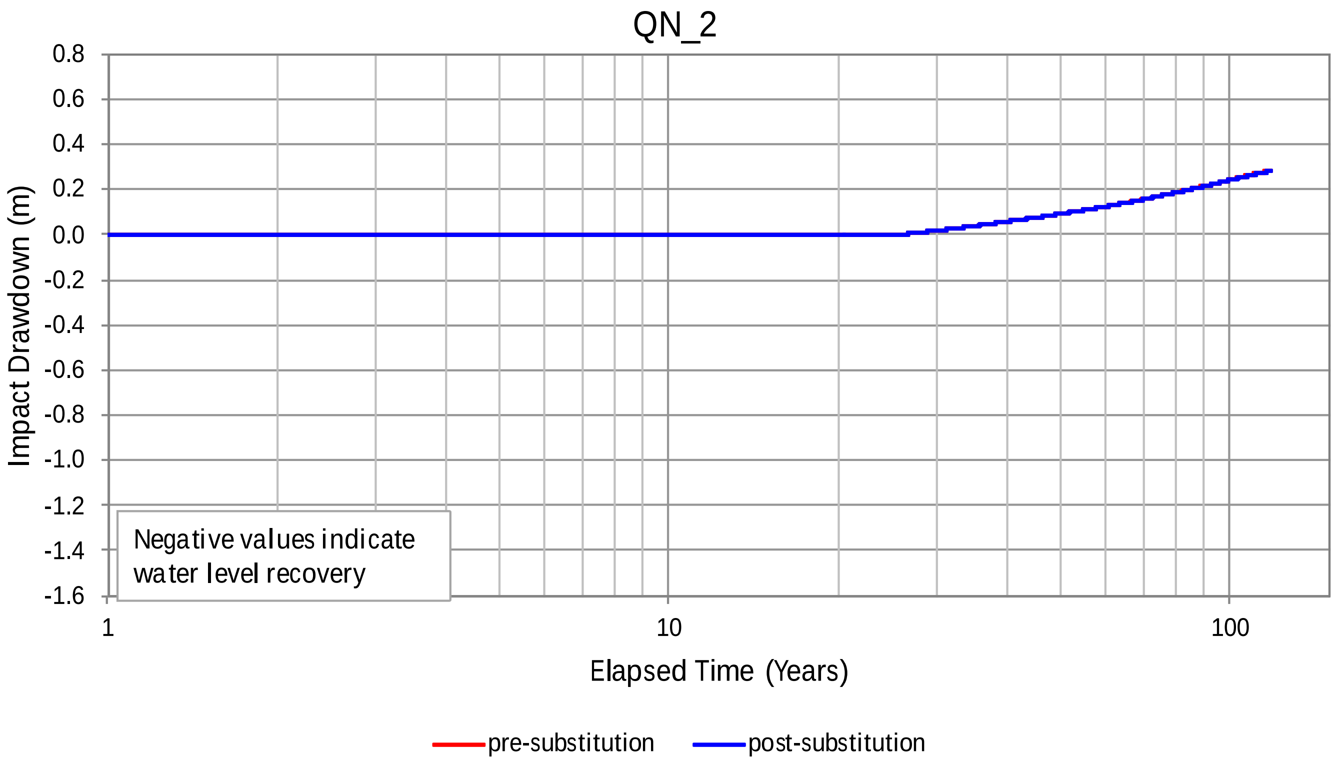


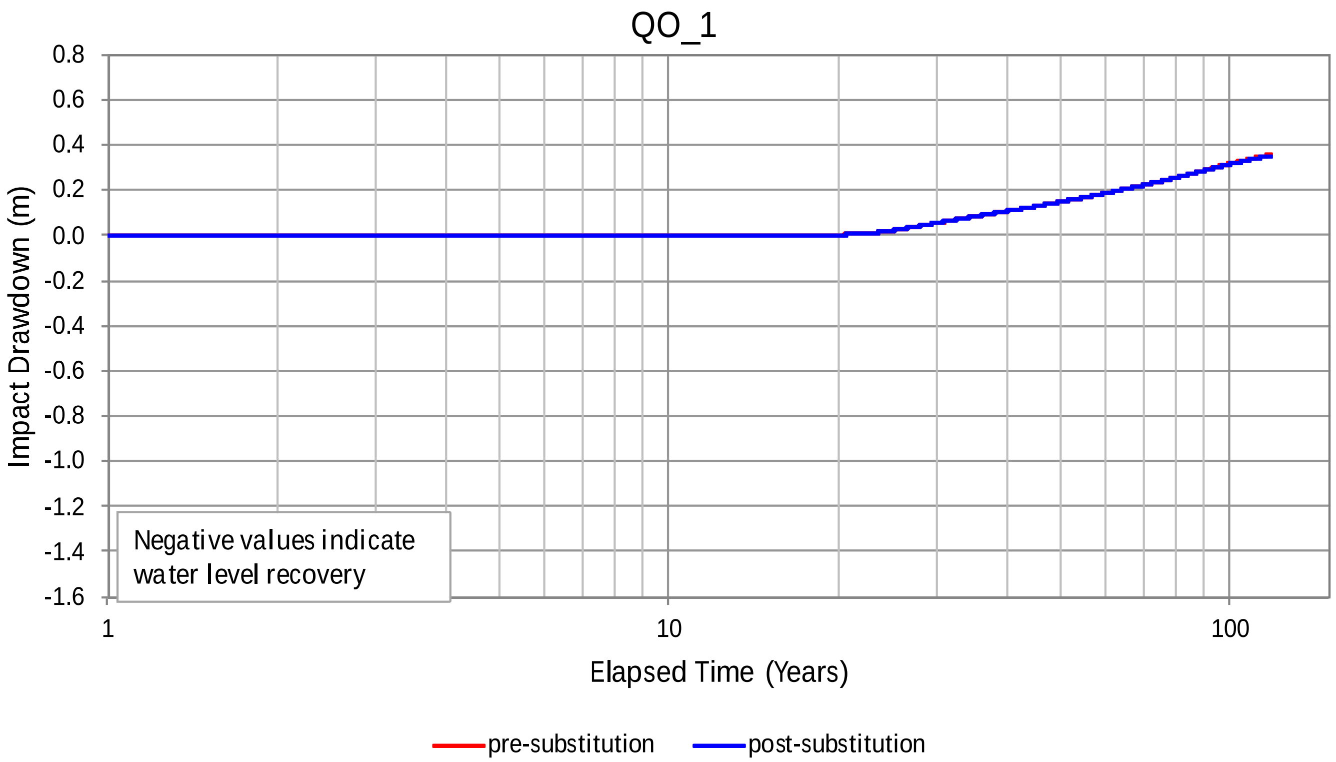
Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium



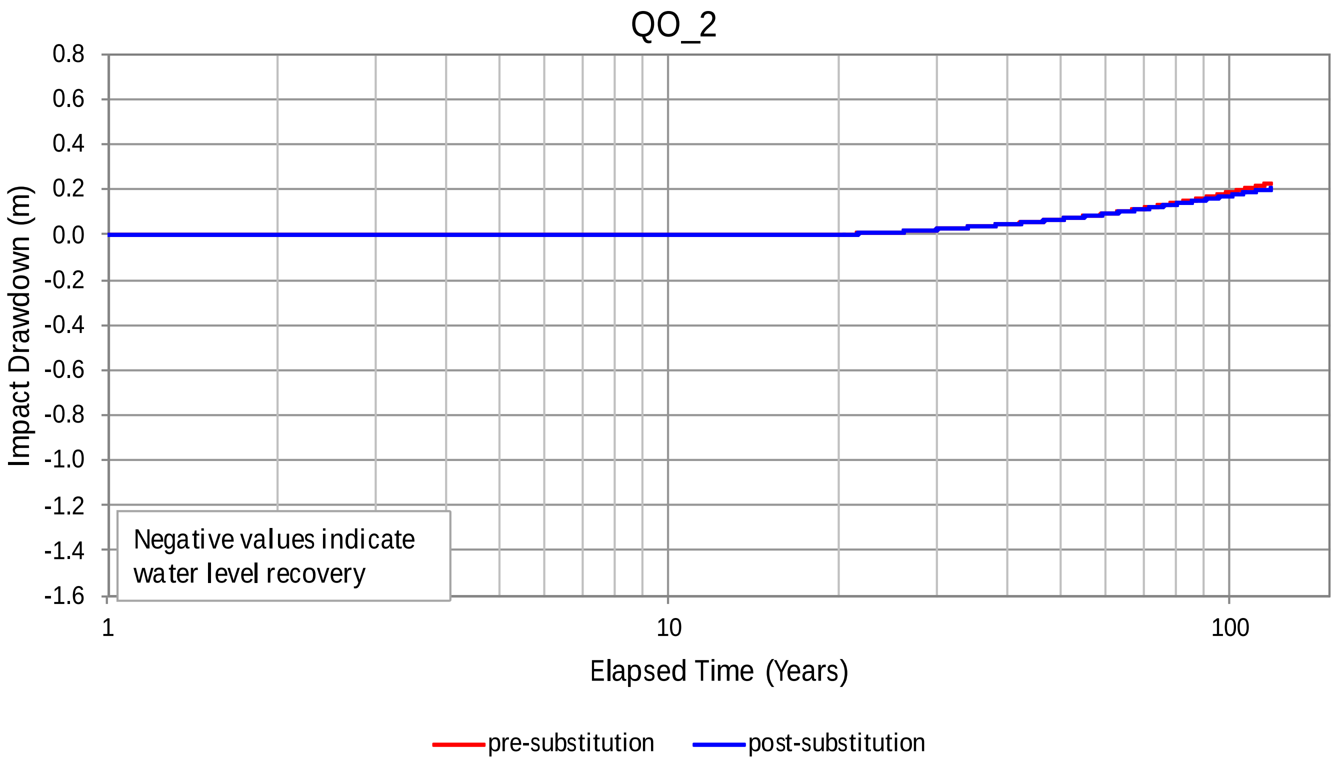


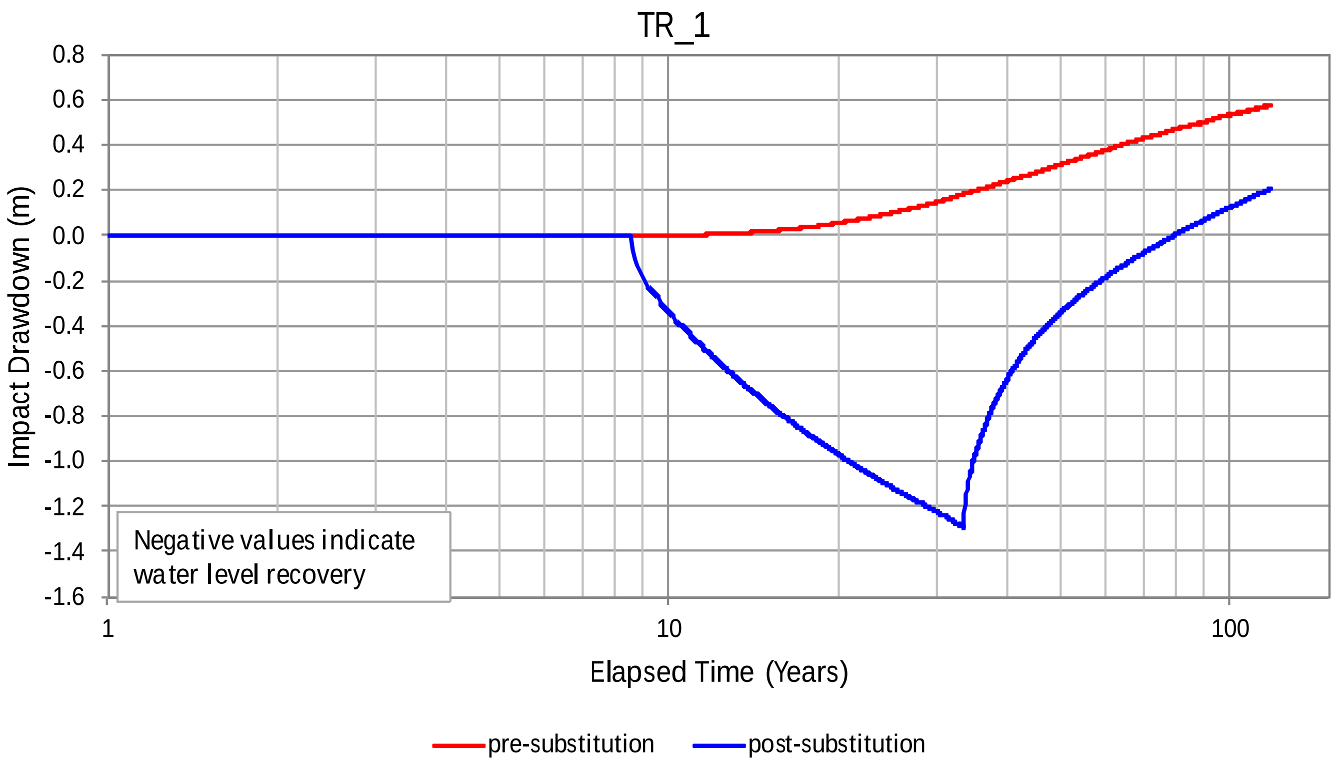
Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium



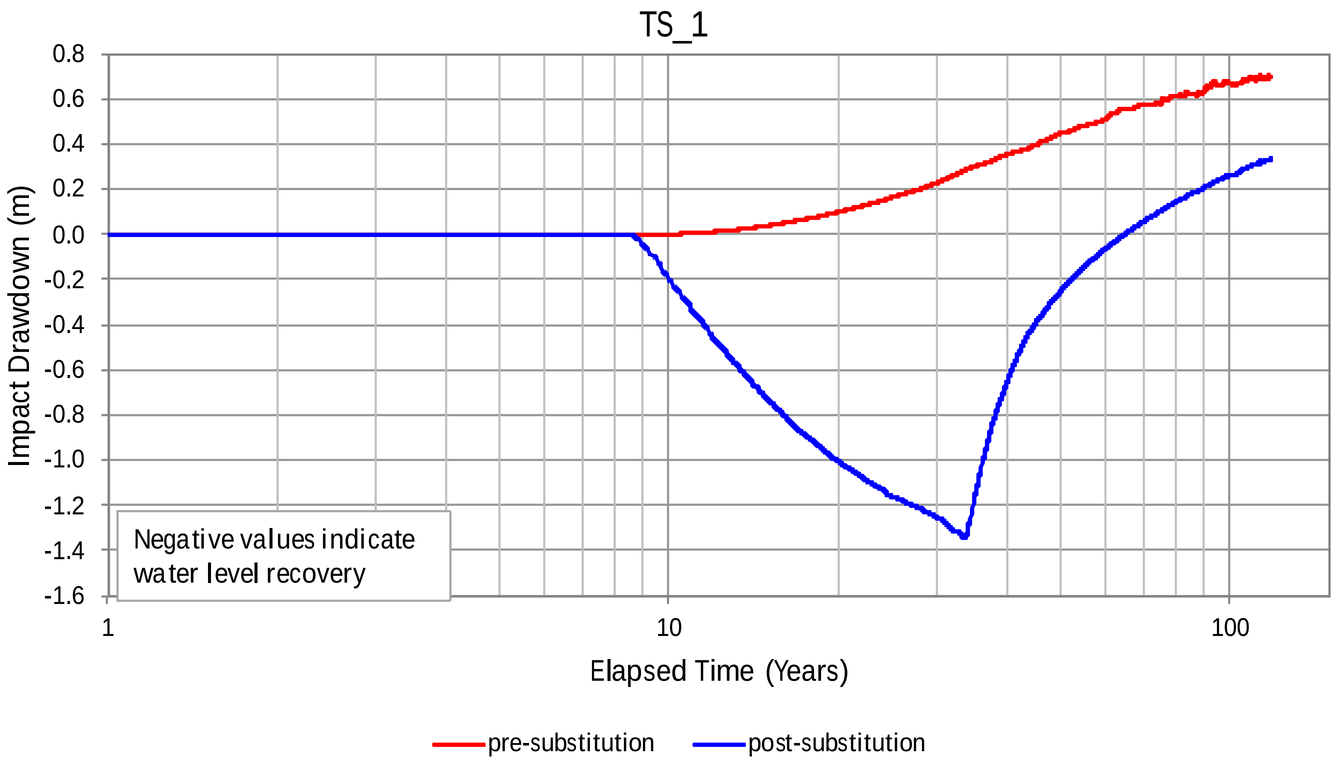


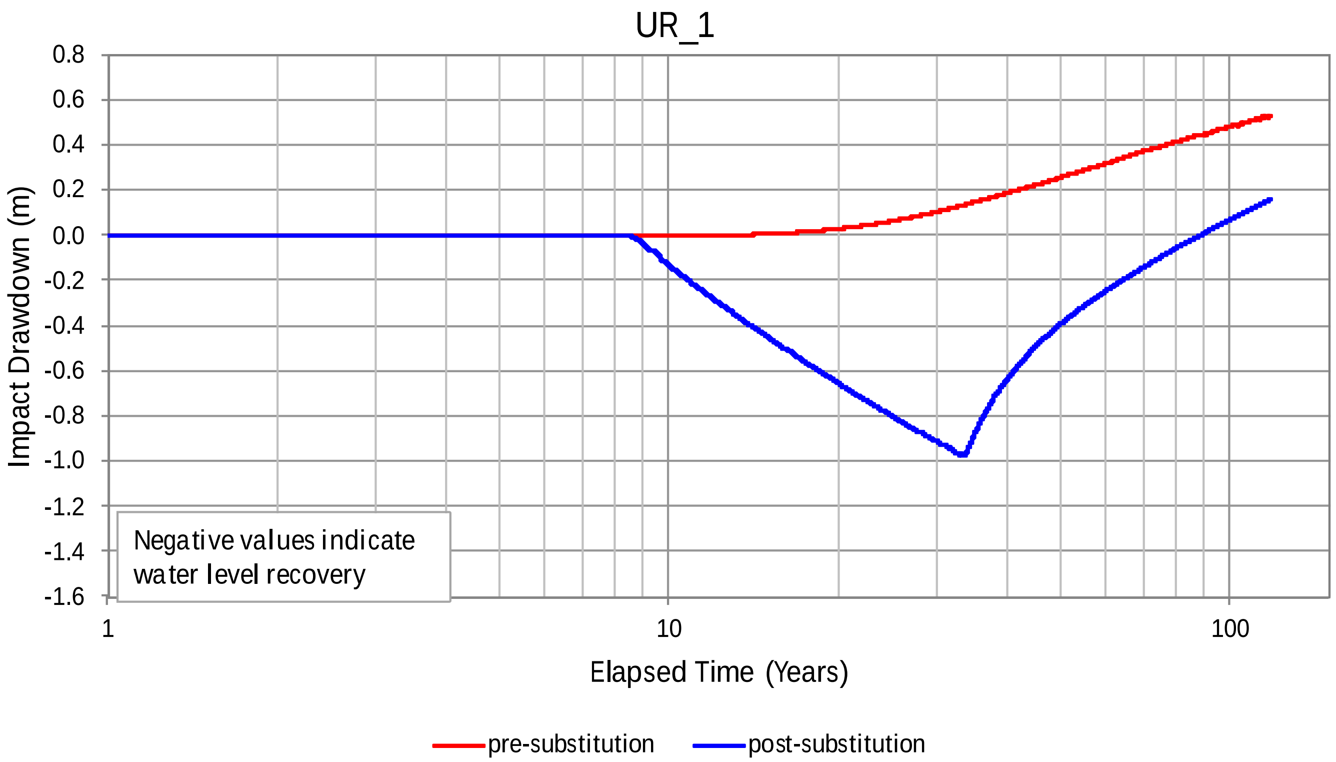
Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium





Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium





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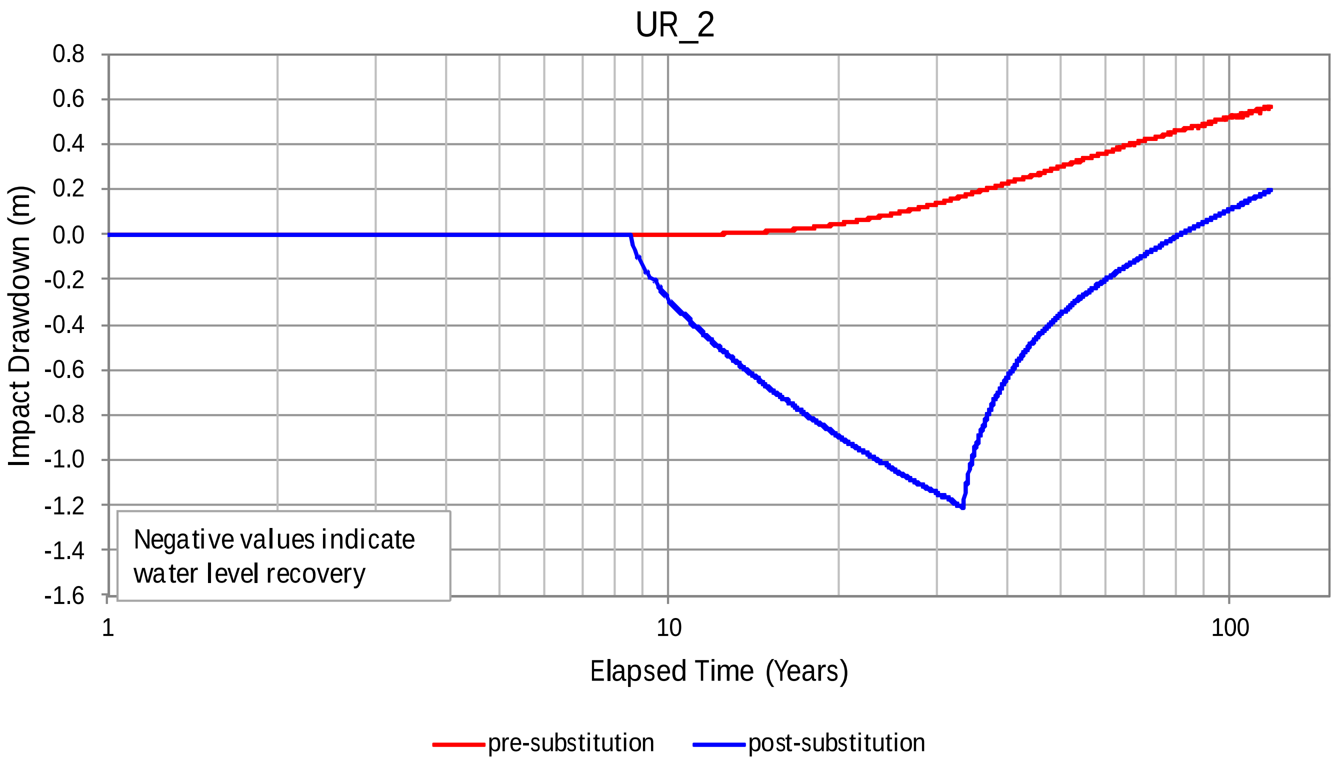
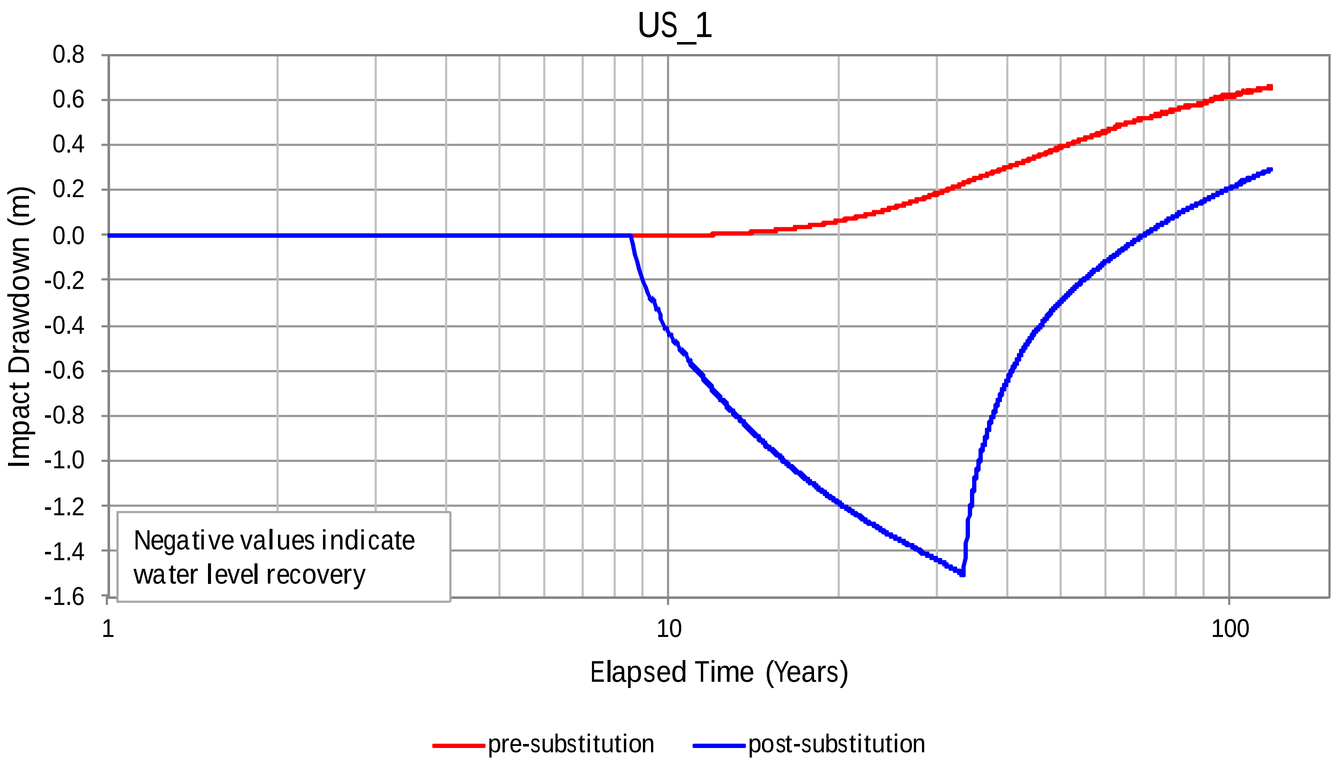
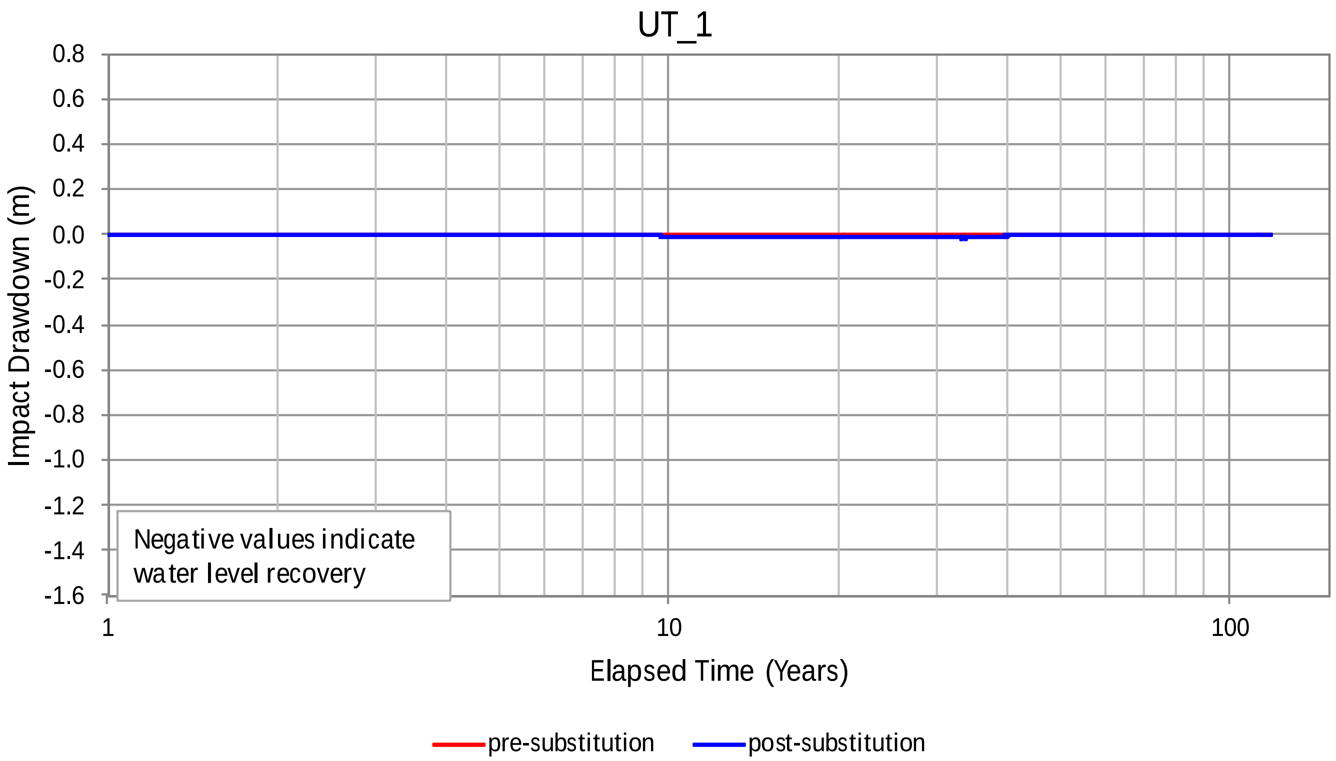
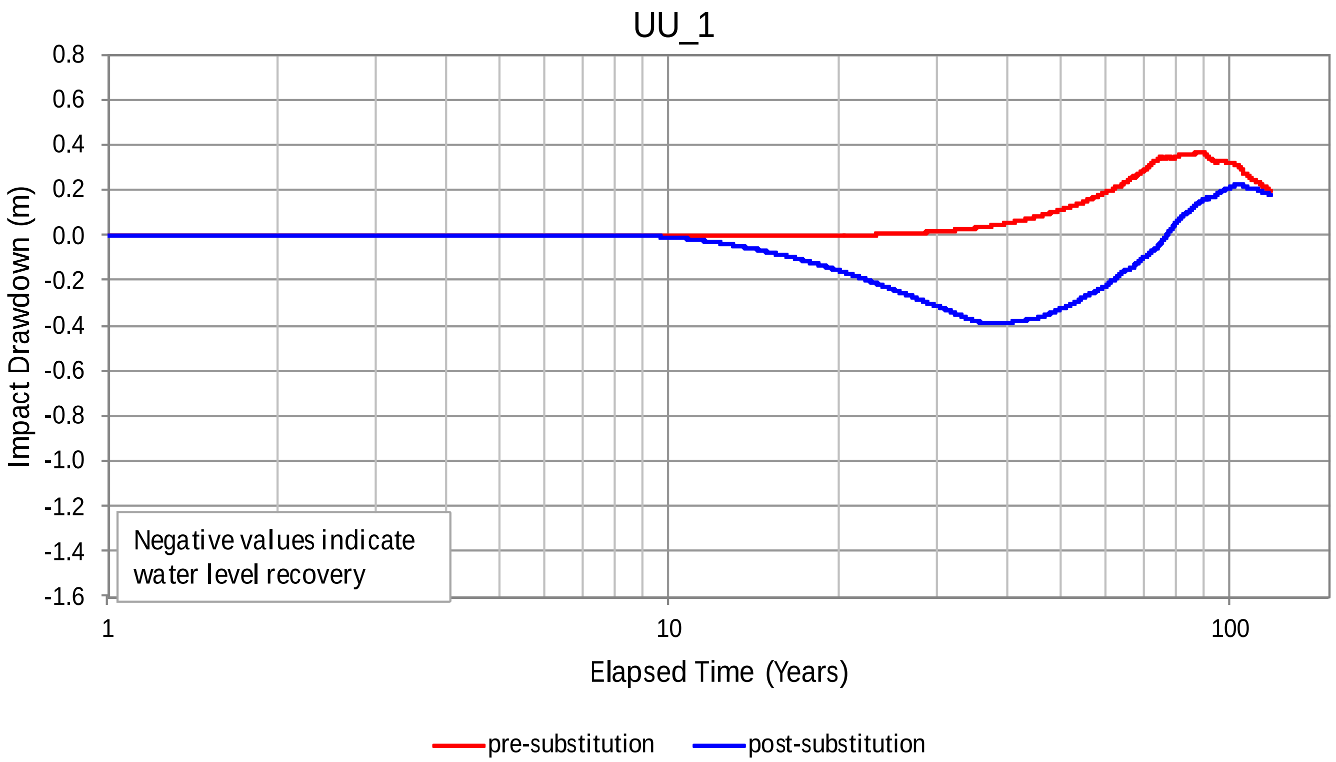
Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium



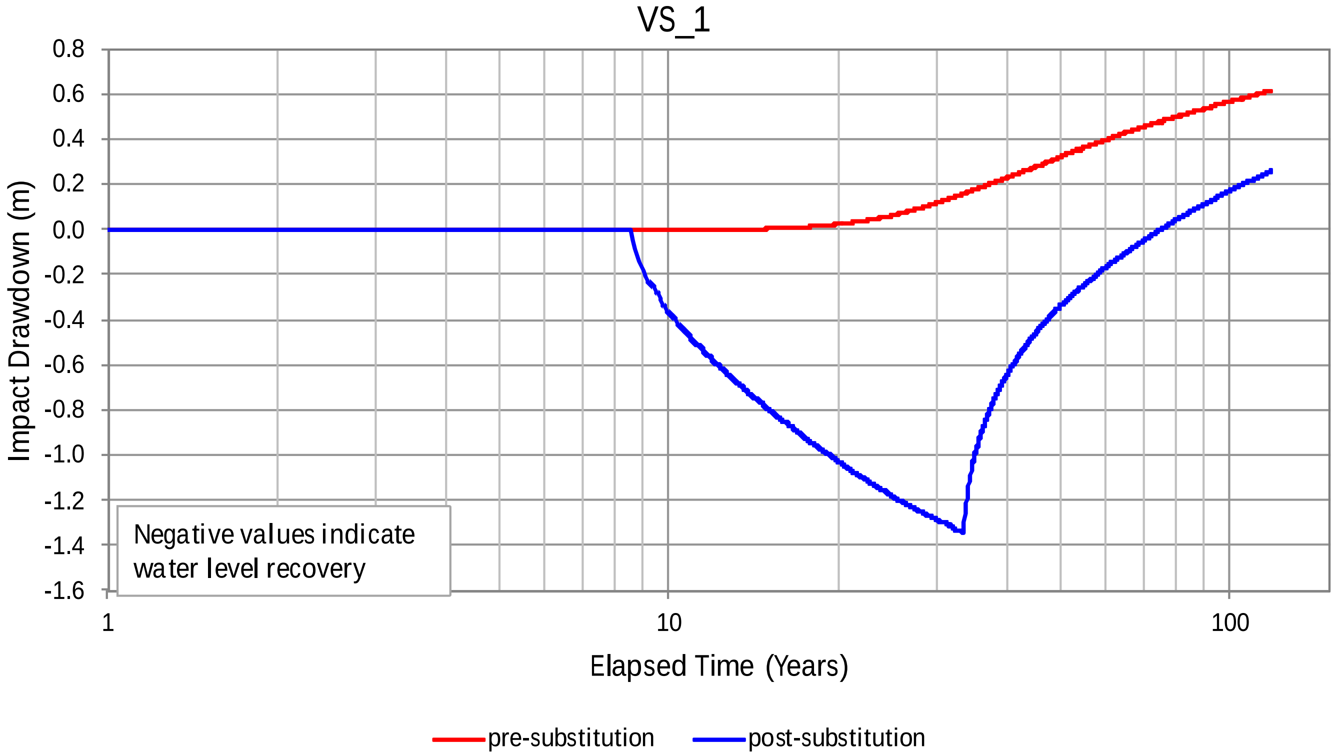


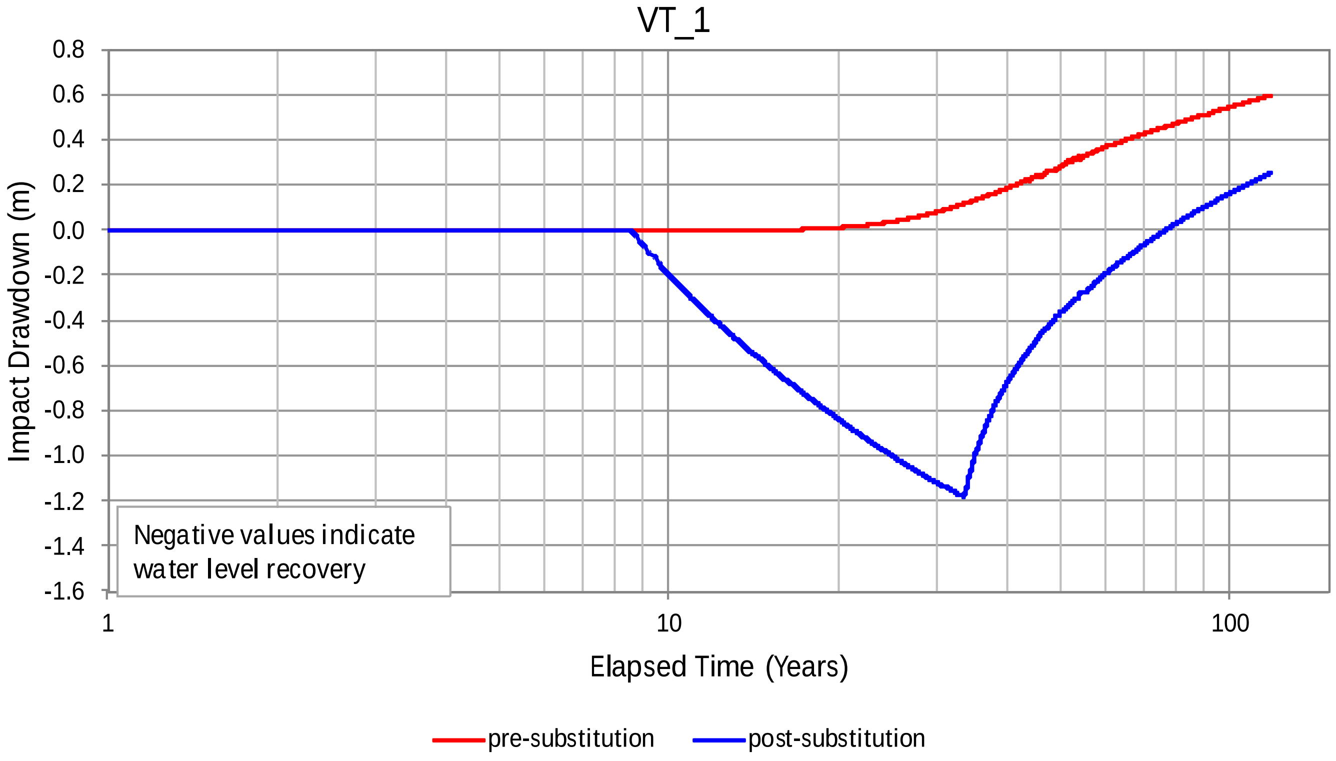
Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium



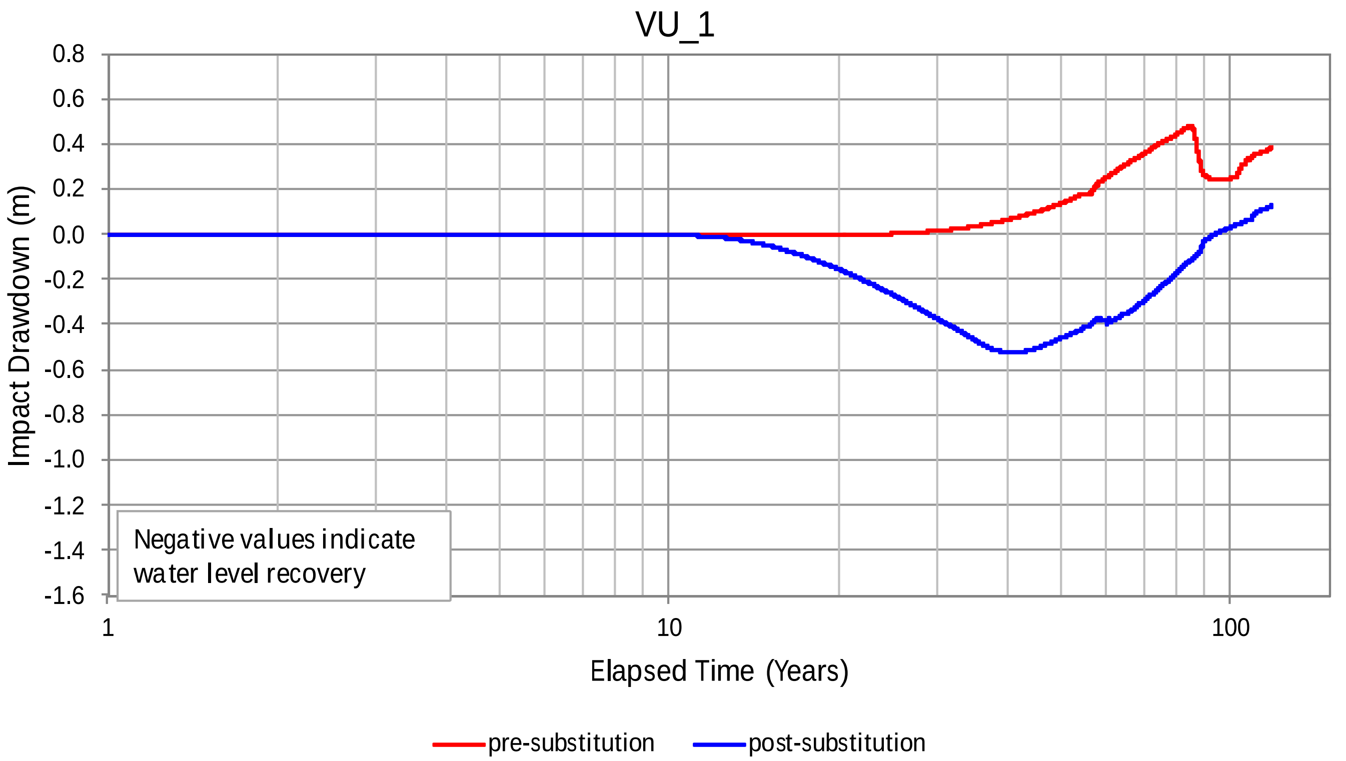


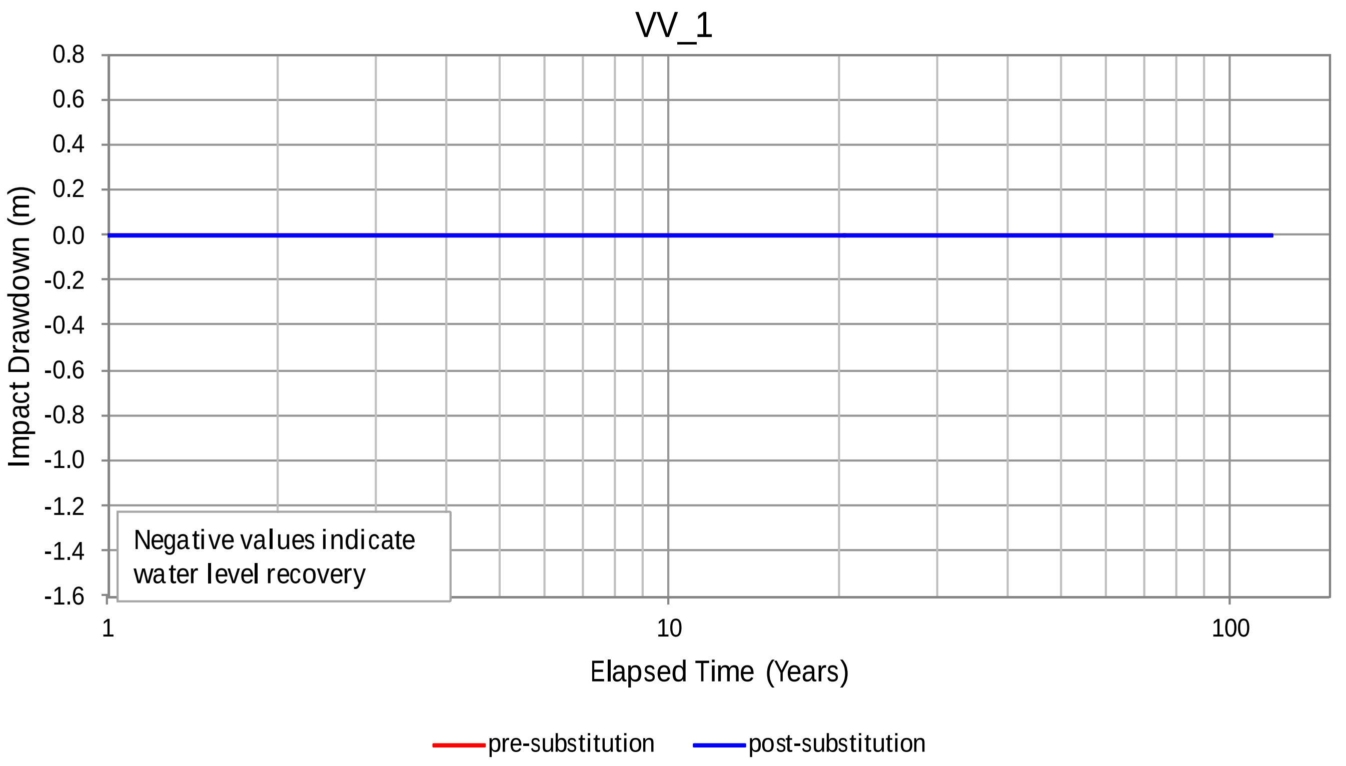
Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium



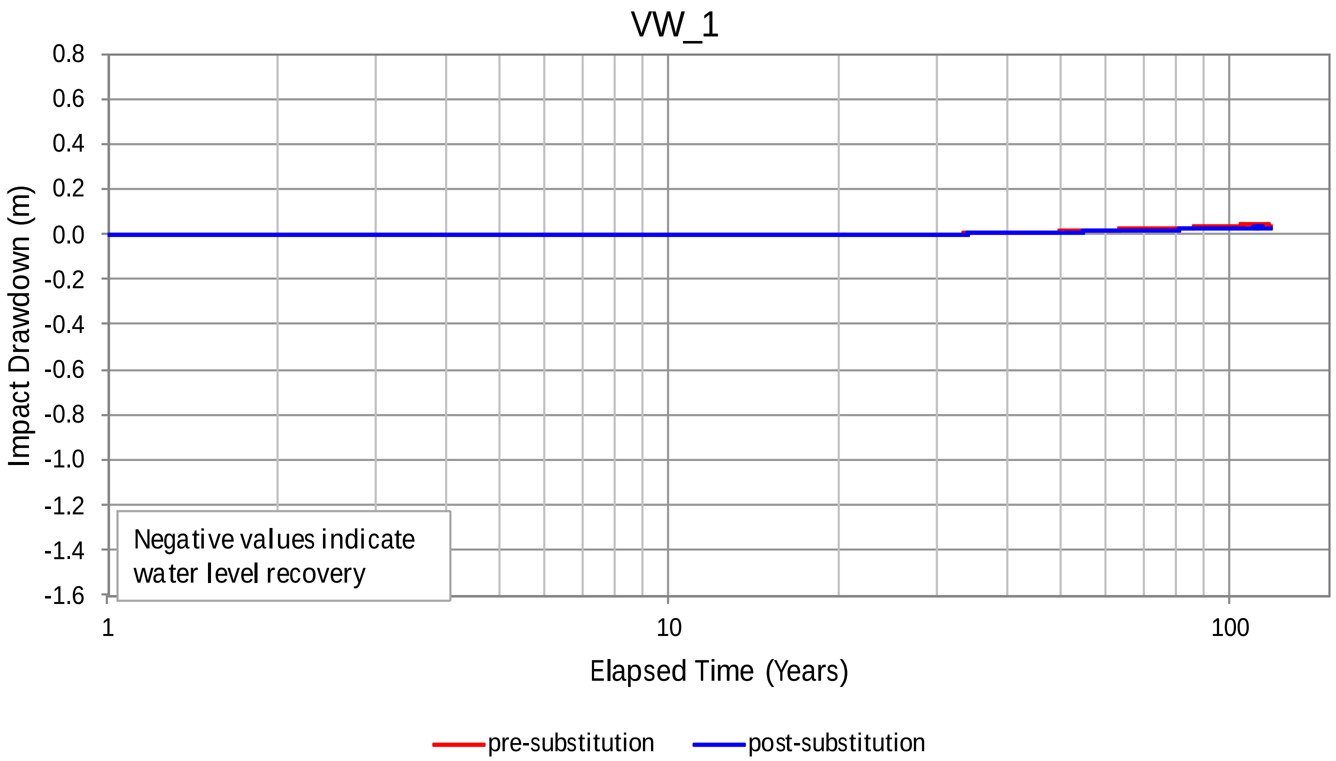


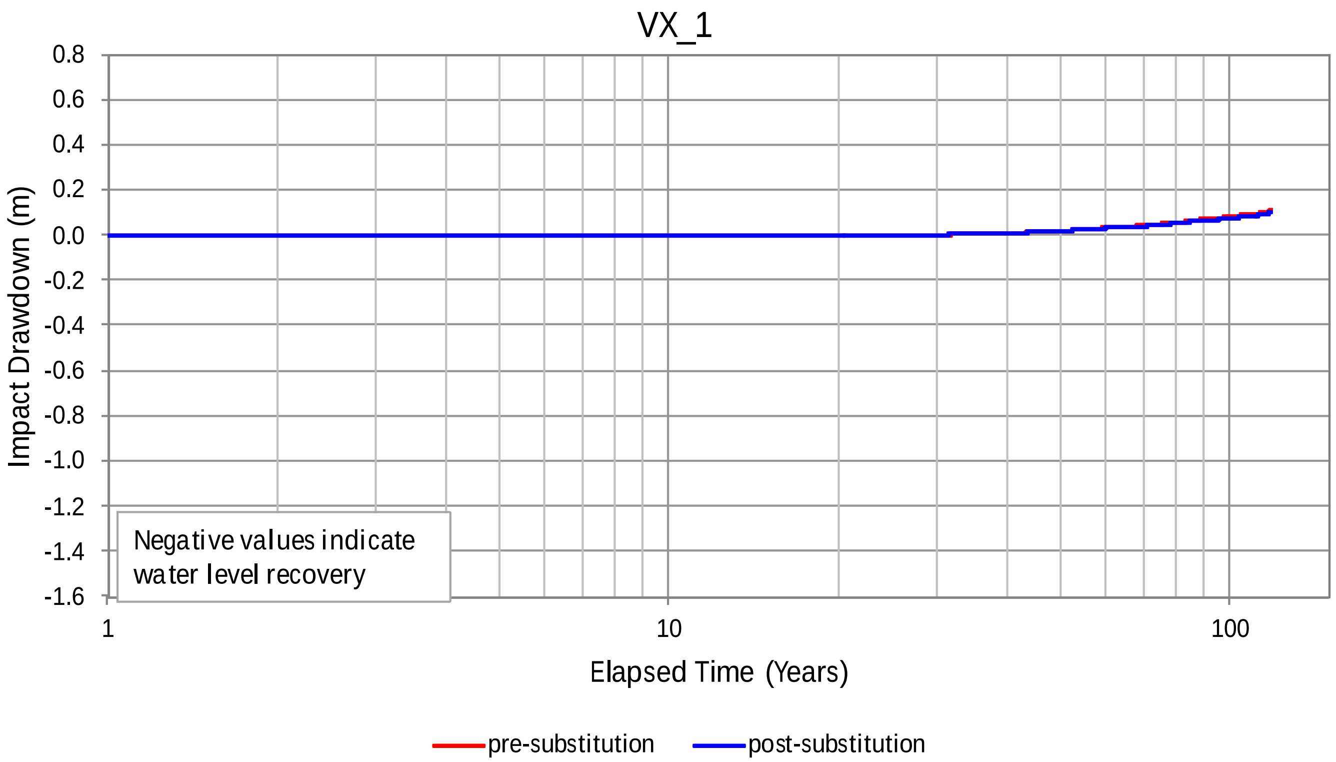
Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium



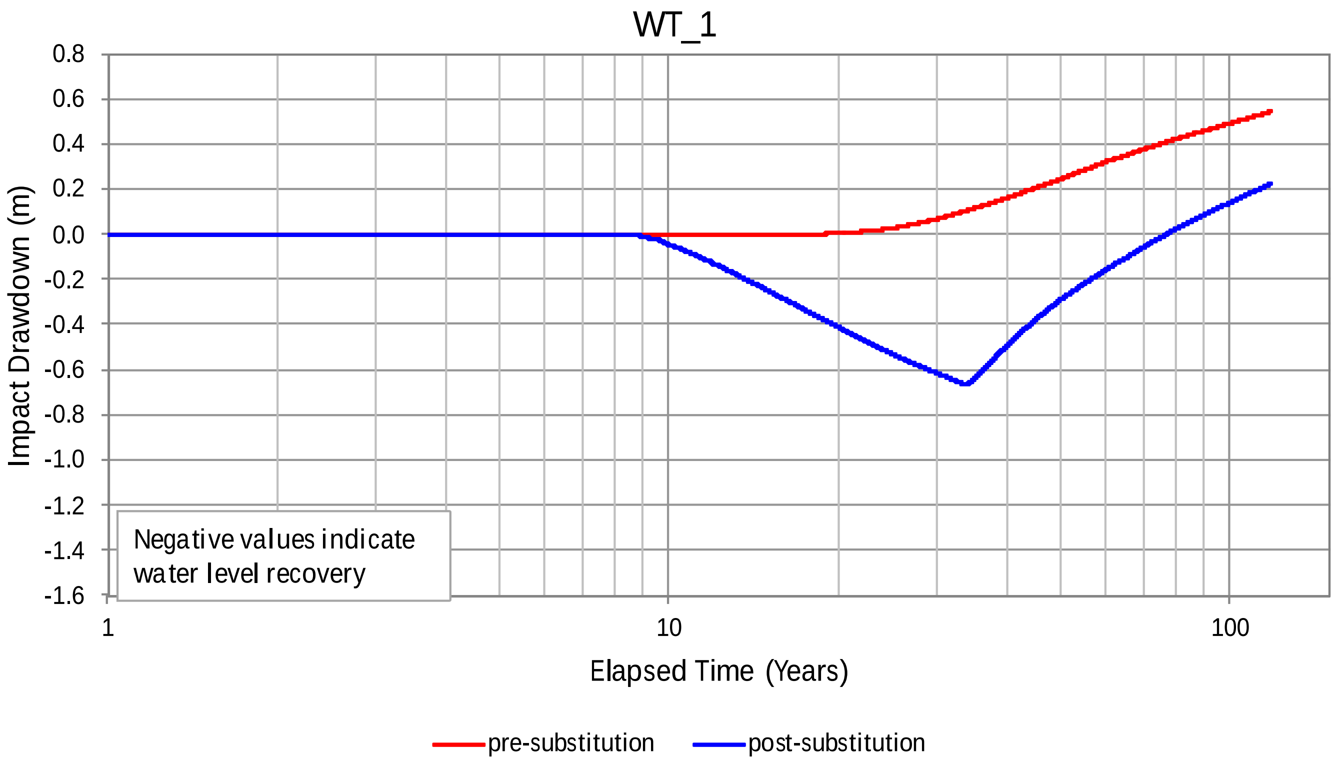


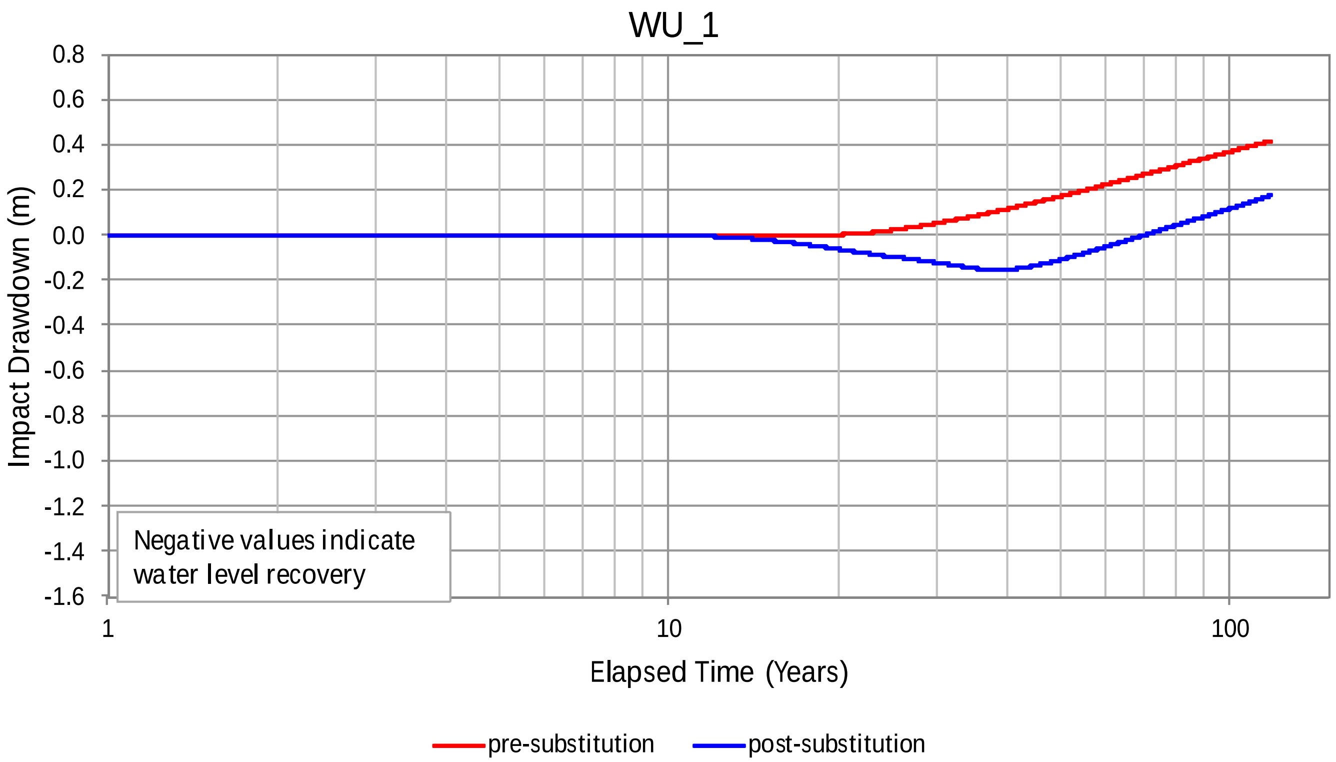
Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium



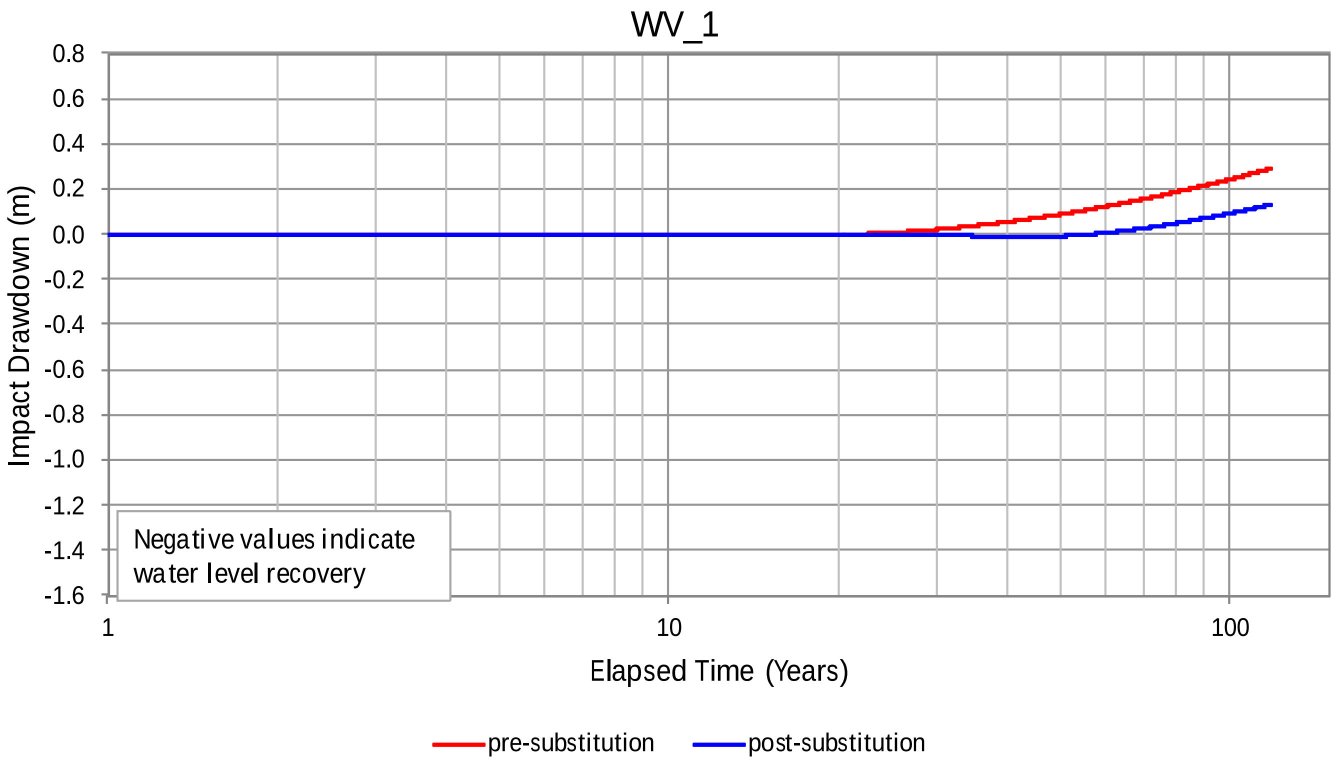


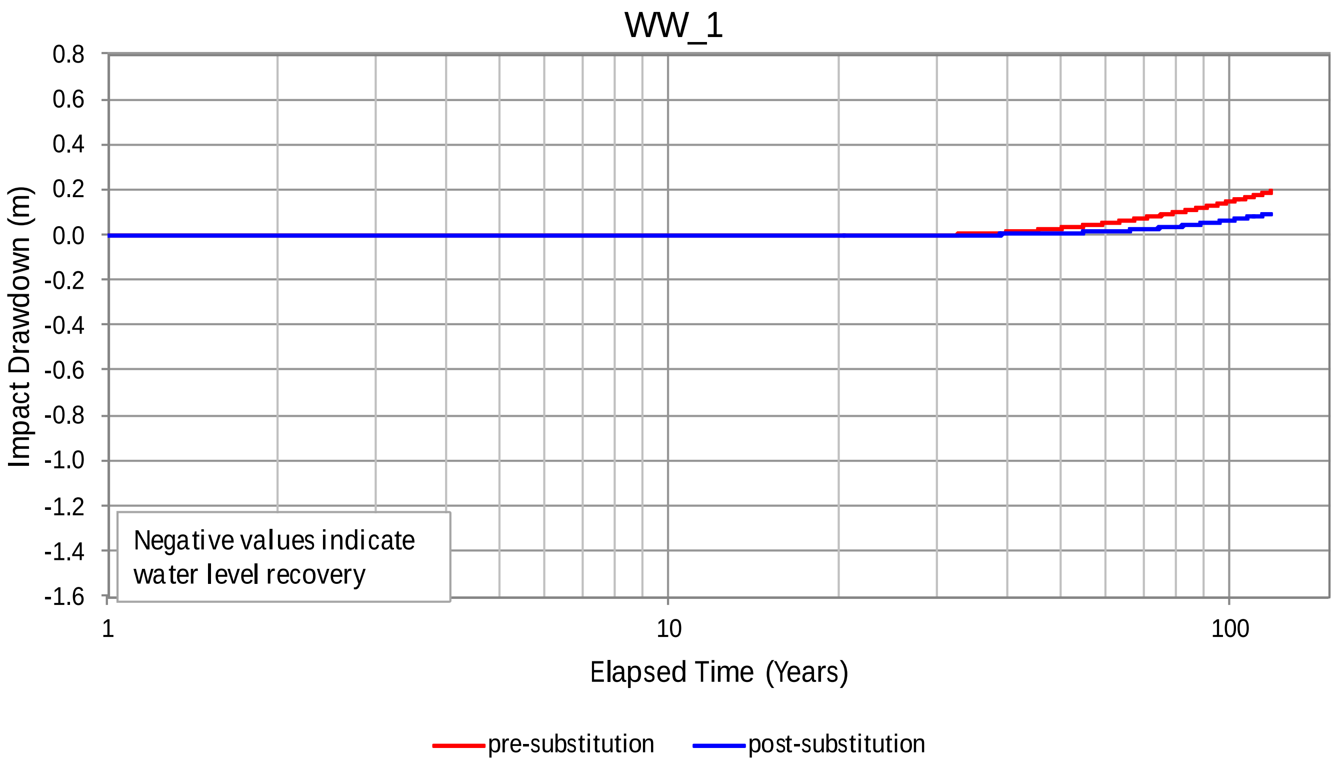
Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium



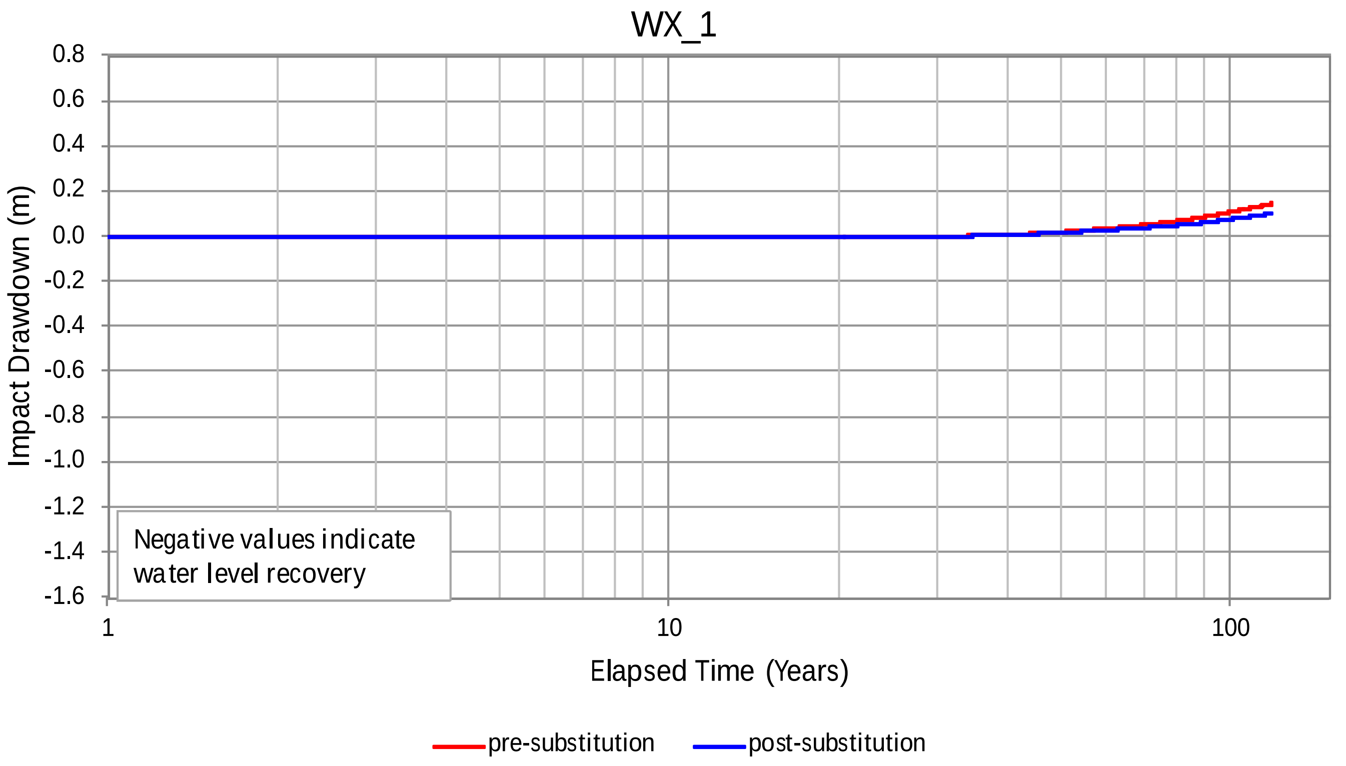


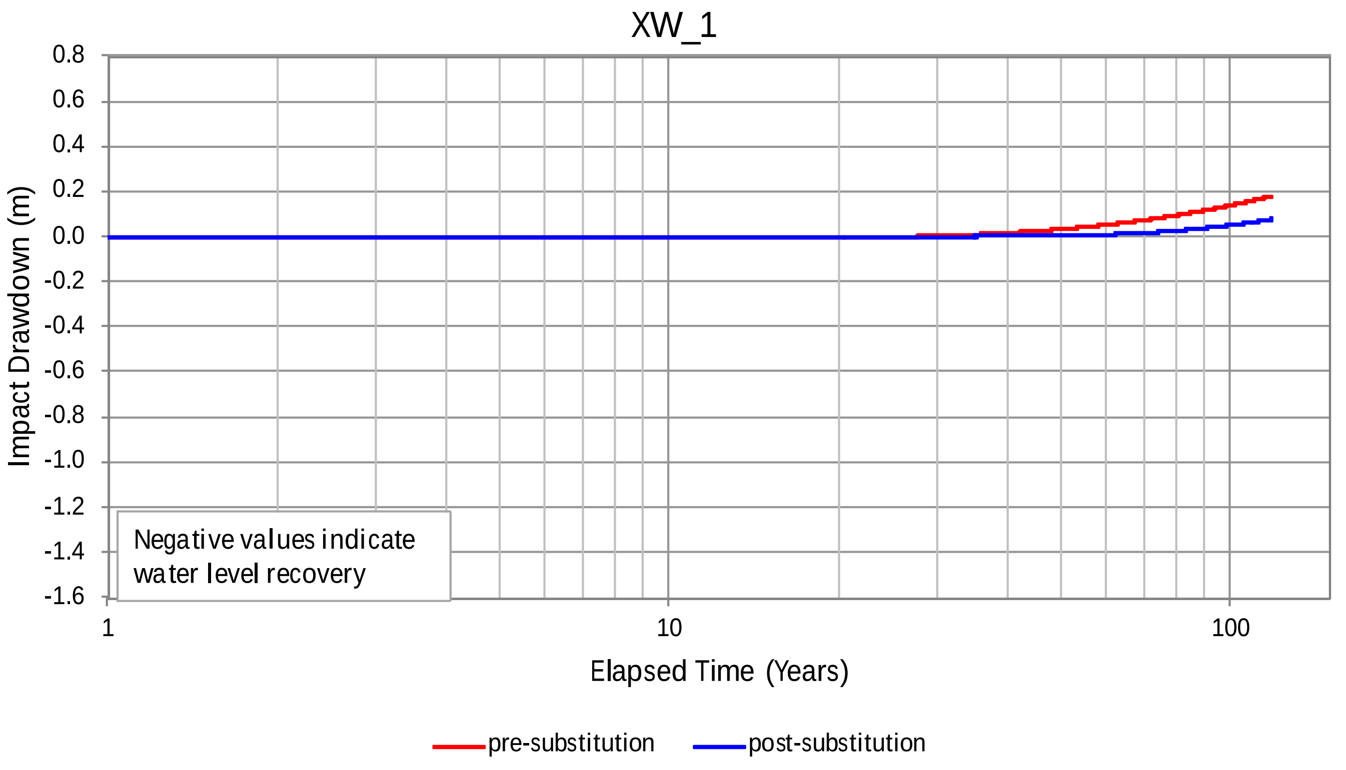
Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium



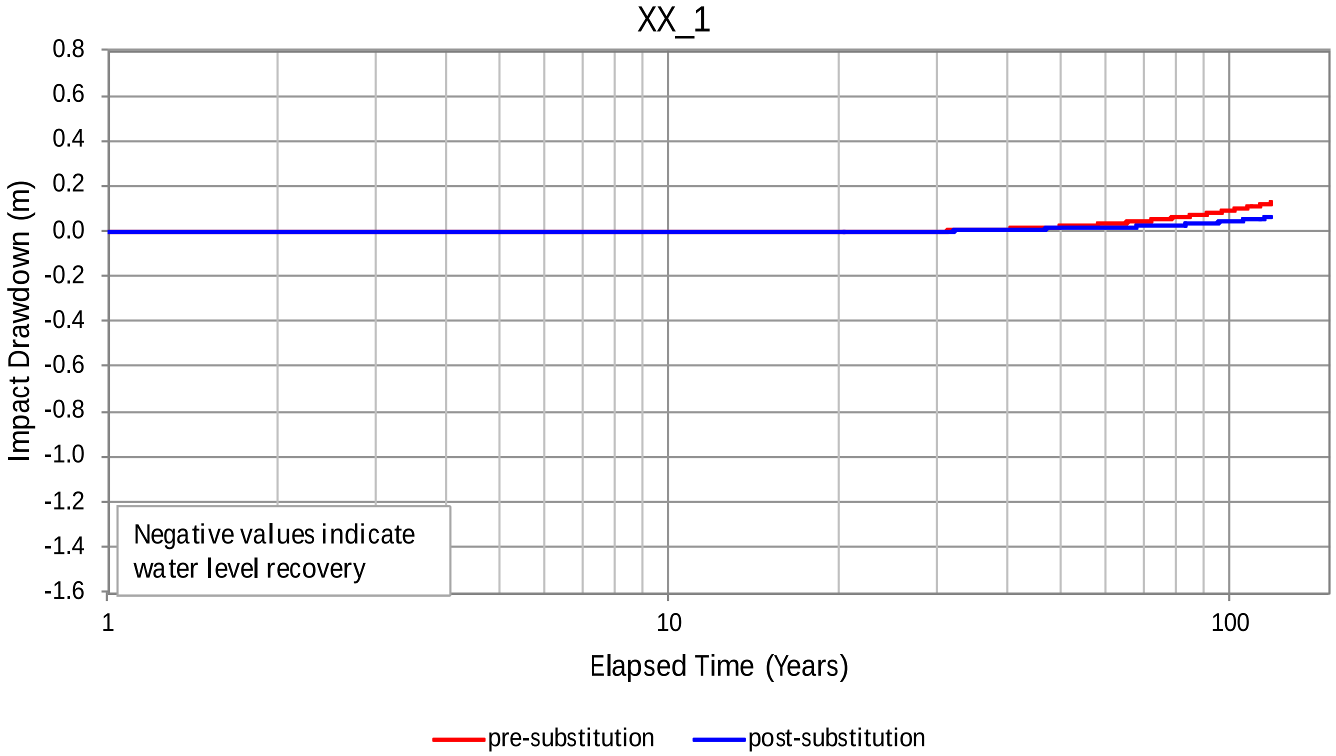


Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium





Appendix H - Predicted Cumulative Drawdown Impact Condamine Alluvium



Appendix I – Cumulative Impact Assessment Plot, Underground Water Impact Assessment Report – Surat Cumulative Management Area (QWC, 2012)

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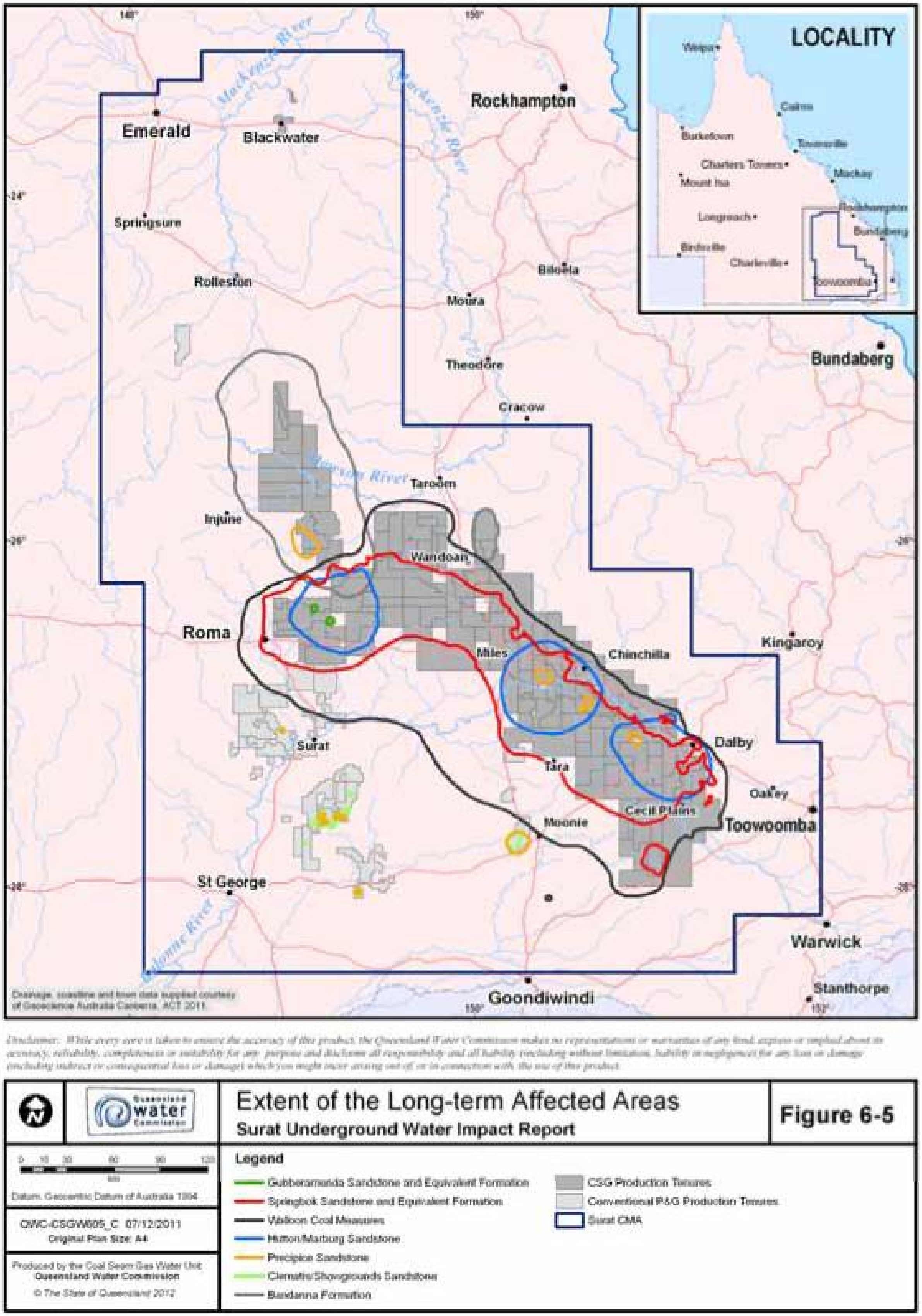

Figure 6-5 Extent of the Long-term Affected Areas

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Document Status

Rev No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
A	L Traverso	K Phillipson	Signed	A Kundu	Signed	20/5/2013
B	L Traverso	K Phillipson	Signed	A Kundu	Signed	5/6/2013
C	L Traverso	K Phillipson	Signed	A Kundu	Signed	14/06/2013
D	L Traverso	K Phillipson	Signed	A Kundu	Signed	18/06/2013
0	L Traverso	K Phillipson	Signed	A Kundu	Signed	18/06/2013
1	L Traverso	K Phillipson	Signed	A Kundu	Signed	19/06/2013
2	L Traverso	K Phillipson	[signature]	A Kundu	[signature]	24/06/2013

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