Appendix G

Flooding Assessment

Hume Coal

Flooding Assessment

Hume Coal Project

PARSONS BRINCKERHOFF

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Glossary

Annual exceedence probability (AEP)	Chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, there is a 5% chance (that is, a one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see 'average recurrence interval').
Australian Height Datum (AHD)	Reference point (very close to mean sea level) for all elevation measurements, and used for correlating depths of channels and water levels.
Average recurrence interval (ARI)	Long-term average number of years between the occurrences of a flood as big as or larger than the selected event. For example, floods with a discharge as great as or greater than the 20-year ARI flood event will occur, on average, once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Catchment	Land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
Digital terrain model (DTM)	Digital representation of ground surface topography or terrain. It is also widely known as a digital elevation model (DEM).
Discharge	Rate of flow of water measured in terms of volume per unit time — for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving — for example, metres per second (m/s).
Flood	Relatively high streamflow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam; and/or local overland flooding associated with major drainage before it enters a watercourse; and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences, excluding tsunami.
Floodplain	Area of land that is subject to inundation by floods up to and including the probable maximum flood event — that is, flood-prone land.
Hydrologic Engineering Centre River Analysis System (HEC-RAS) model	Software package that allows modellers to perform one-dimensional steady and unsteady flow river hydraulics calculations, sediment transport – mobile bed modelling and water temperature analysis.
Hydraulics	Study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
Hydrograph	Graph that shows how the discharge or flood level at a particular location varies with time during a flood.
Hydrology	Study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
Hyetograph	A graphical representation of the distribution of rainfall over time.
Light detection and ranging (LiDAR)	Optical remote-sensing technology that can measure the distance to, or other properties of, a target by illuminating the target with light (often pulses from a laser).

Local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
m/s	Metres per second. Unit used to describe the velocity of floodwaters.
m^3/s	Cubic metres per second. A unit of measurement for flows or discharges. It is the rate of flow of water measured in terms of volume per unit time.
Model	Mathematical representation of the physical processes involved in runoff generation and streamflow. Models are often run on computers, due to the complexity of the mathematical relationships between runoff, streamflow and the distribution of flows across the floodplain.
Peak discharge	Maximum discharge occurring during a flood event.
Probable maximum flood (PMF)	Largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood-producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land — that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event, should be addressed in a floodplain risk management study.
Probable maximum precipitation (PMP)	Greatest depth of precipitation for a given duration that is meteorologically possible over a given size of storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends. It is the primary input to PMF estimation.
Runoff	Amount of rainfall that actually ends up as streamflow; also known as rainfall excess.
Velocity	Speed of floodwaters, usually in m/s (metres per second).
XP-RAFTS	Software package used for runoff routing for hydrologic and hydraulic analysis of drainage and conveyance systems.

Abbreviations

AEP	Annual exceedence probability
AHD	Australian Height Datum
ARI	Average recurrence interval
AR&R	Australian Rainfall and Runoff
BOM	Bureau of Meteorology
CPP	Coal preparation plant
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCP	Development control plan
DEM	Digital elevation model
DTM	Digital terrain model
EAF	Elevation adjustment factor
EIS	Environmental impact statement
EPW	Extreme perceptible water
GSAM	Generalised Southeast Australia Method
GSDM	Generalised Short-Duration Method
ha	Hectares
HEC-RAS model	Hydrologic Engineering Centre River Analysis System model
IFD	Intensity frequency duration
LiDAR	Light detection and ranging
MAF	Moisture adjustment factor
m/s	Metres per second
m^3/s	Cubic metres per second
MHL	Manly Hydraulics Laboratory
mm/hr	Millimetres per hour
Mt	Million tonnes
Mtpa	Million tonnes per annum
Q	Discharge
PMF	Probable maximum flood
PMP	Probable maximum precipitation
PRM	Probabilistic rational method
PWD	Primary water dam
RCBC	Reinforced concrete box culvert
ROM	Run of mine
SEARs	Secretary’s Environmental Assessment Requirements

TAF	Topographic adjustment factor
WLEP	Wingecarribee Local Environmental Plan
WSC	Wingecarribee Shire Council
WTP	Water treatment plant

Executive summary

Parsons Brinckerhoff has been commissioned by Hume Coal to prepare a flooding assessment as part of the Environmental Impact Statement (EIS) for the Hume Coal Project (the project). This report provides an assessment of the existing flood behaviour and the impacts of the Project on flooding in the local catchments, and mitigation measures required to minimise potential impacts and to protect the mine infrastructure during flood events.

Mine infrastructure is located within two stream catchments: Medway Rivulet and Oldbury Creek. Medway Rivulet is located to the south of the proposed administration and workshop area (AWA) precinct. Oldbury Creek is located to the north of the proposed coal preparation plant (CPP) precinct.

Hydrologic and hydraulic models using XP-RAFTS and HEC-RAS respectively were used to define the flood levels and extents for existing conditions and mining scenarios for the 5, 20 and 100 year average recurrence interval (ARI) events and the probable maximum flood.

The assessment considered the existing conditions and operation and rehabilitation scenarios of the Project. A cumulative assessment including the Berrima Rail Project was also undertaken.

The assessment found that the impacts on flooding for the operation and rehabilitation scenario are within proposed acceptability criteria, with the exception of a localised area of land owned by Hume Coal on Oldbury Creek adjacent to the surface infrastructure area.

Comparison of the cumulative 100 year ARI flood extents shows that changes in flood extent during operation of the mine and rail will occur in the vicinity of the rail loop and upstream of the rail crossings on Oldbury Creek. Any significant changes in flood extent occur on land owned by Hume Coal or Boral. The impacts of both projects were found to be hydraulically independent.

Peak velocities are expected to increase immediately downstream of the conveyor piers and culverts. Erosion and scour protection measures will be required around piers and culvert inlets and outlets so that locally increased velocities do not cause erosion of the adjacent channel sections.

A drainage easement with buried pipe exists that appears to drain a small catchment from east to west across the Hume Motorway into a farm dam on land owned by Hume Coal. The downstream section of this pipe will be intercepted by the proposed Primary Water Dam (PWD). It is proposed to modify the existing drainage arrangement within land owned by Hume Coal to allow the pipe to discharge around the PWD and allow this drainage line to continue to function unimpeded and ultimately discharge to Oldbury Creek as it does currently.

1. Introduction

Parsons Brinckerhoff has been commissioned by Hume Coal to prepare a flooding assessment as part of the Environmental Impact Statement (EIS) for the Hume Coal Project (the project).

This report provides an assessment of the impacts of the project on flooding in the local catchments and mitigation measures required to minimise potential impacts and protect the mine infrastructure during flood events. The assessment of potential impacts of the project on the dominant flow regime in the catchments (i.e. on normal to low flows) is addressed in the Flow and Geomorphology Assessment Report (Parsons Brinckerhoff 2016).

1.1 Project description

The project involves developing and operating an underground coal mine and associated infrastructure over a total estimated project life of 23 years. Indicative mine and surface infrastructure plans are provided in Figure 1.1 and Figure 1.2. A full description of the project, as assessed in this report, is provided in Chapter 2 of the main EIS (EMM 2016a).

In summary it involves:

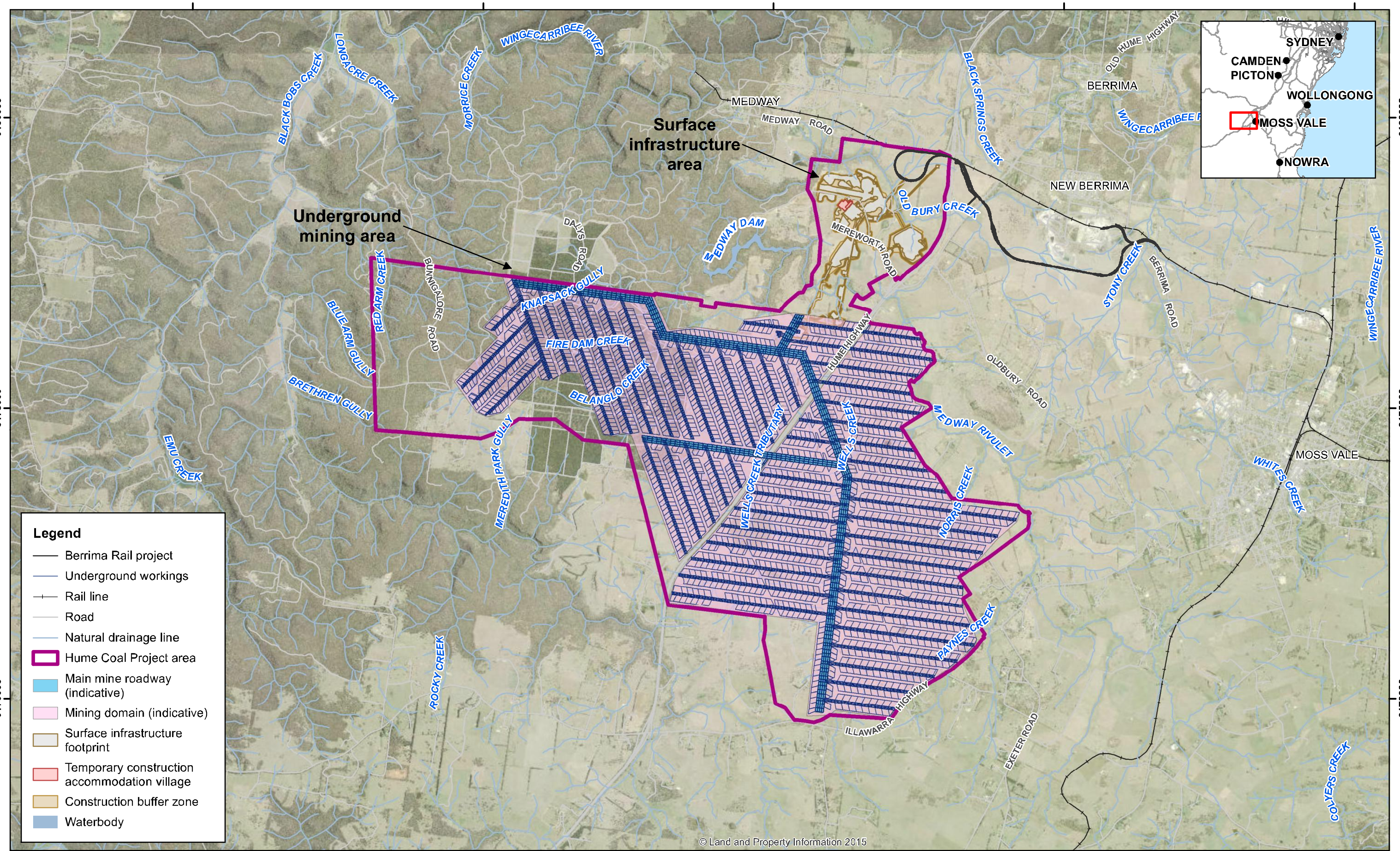
- Ongoing resource definition activities, along with geotechnical and engineering testing, and other low impact fieldwork to facilitate detailed design.
- Establishment of a temporary construction accommodation village.
- Development and operation of an underground coal mine, comprising of approximately two years of construction and 19 years of mining, followed by a closure and rehabilitation phase of up to two years, leading to a total project life of 23 years. Some coal extraction will commence during the second year of construction during installation of the drifts, and hence there will be some overlap between the construction and operational phases.
- Extraction of approximately 50 million tonnes (Mt) of run-of-mine (ROM) coal from the Wongawilli Seam, at a rate of up to 3.5 million tonnes per annum (Mtpa). Low impact mining methods will be used, which will have negligible subsidence impacts.
- Following processing of ROM coal in the coal preparation plant (CPP), production of up to 3 Mtpa of metallurgical and thermal coal for sale to international and domestic markets.
- Construction and operation of associated mine infrastructure, mostly on cleared land, including:
  - one personnel and materials drift access and one conveyor drift access from the surface to the coal seam;
  - ventilation shafts, comprising one upcast ventilation shaft and fans, and up to two downcast shafts installed over the life of the mine, depending on ventilation requirements as the mine progresses;
  - a surface infrastructure area, including administration, bathhouse, washdown and workshop facilities, fuel and lubrication storage, warehouses, laydown areas, and other facilities. The surface infrastructure area will also comprise the CPP and ROM coal, product coal and emergency reject stockpiles;
  - surface and groundwater management and treatment facilities, including storages, pipelines, pumps and associated infrastructure;
  - overland conveyors;
  - rail load-out facilities;

  - explosives magazine;
  - ancillary facilities, including fences, access roads, car parking areas, helipad and communications infrastructure; and
  - environmental management and monitoring equipment.
- Establishment of site access from Mereworth Road, and minor internal road modifications and relocation of some existing utilities.
- Coal reject emplacement underground, in the mined-out voids.
- Peak workforces of approximately 414 full-time equivalent employees during construction and approximately 300 full-time equivalent employees during operations.
- Decommissioning of mine infrastructure and rehabilitating the area once mining is complete, so that it can support land uses similar to current land uses.

The project area, shown in Figure 1.1, is approximately 5,051 hectares (ha). Surface disturbance will mainly be restricted to the surface infrastructure areas shown indicatively on Figure 1.2, though will include some other areas above the underground mine, such as drill pads and access tracks. The project area generally comprises direct surface disturbance areas of up to approximately 117 ha, and an underground mining area of approximately 3,472 ha, where negligible subsidence impacts are anticipated.

A construction buffer zone will be provided around the direct disturbance areas. The buffer zone will provide an area for construction vehicle and equipment movements, minor stockpiling and equipment laydown, as well as allowing for minor realignments of surface infrastructure. Ground disturbance will generally be minor and associated with temporary vehicle tracks and sediment controls as well as minor works such as backfilled trenches associated with realignment of existing services. Notwithstanding, environmental features identified in the relevant technical assessments will be marked as avoidance zones so that activities in this area do not have an environmental impact.

Product coal will be transported by rail, primarily to Port Kembla terminal for the international market, and possibly to the domestic market depending on market demand. Rail works and use are the subject of a separate EIS and State significant development application for the Berrima Rail Project.



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Coordinate system: GDA 1994 MGA Zone 56

Scale ratio correct when printed at A3

Data source: © Land and Property Information 2015, Hume Coal

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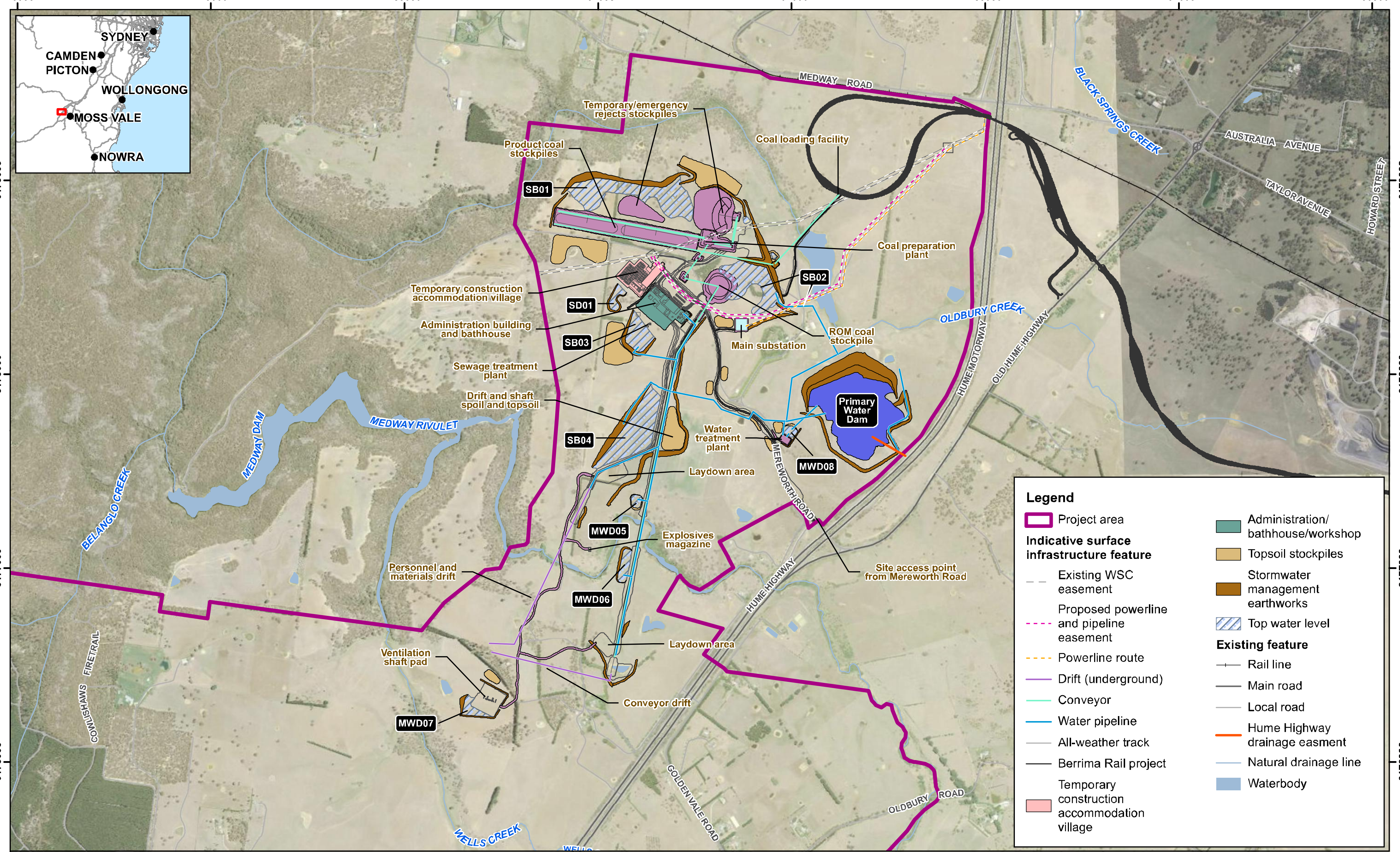
Hume Coal Flooding Assessment
Figure 1.1
Project area



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Data source: © Land and Property Information 2015, Hume Coal, Google Earth			

Hume Coal Flooding Assessment
Figure 1.2
Surface infrastructure layout

1.2 Project area

The project area is approximately 100 kilometres (km) south-west of Sydney and 3 km west of Moss Vale in the Wingecarribee LGA (refer to Figure 1.1 and Figure 1.2). It is in the Southern Highlands region of NSW and the Sydney Basin Biogeographic Region.

The project area is in a semi-rural setting, with the wider region characterised by grazing properties, small-scale farm businesses, hobby farms, natural areas, forestry, scattered rural residences, villages and towns, industrial activities such as the Berrima Cement Works and Berrima Feed Mill, and some extractive industry and major transport infrastructure such as the Hume Highway.

Surface infrastructure is proposed to be developed on predominately cleared land owned by Hume Coal or affiliated entities, or for which there are appropriate access agreements in place with the landowner. Over half of the remainder of the project area (principally land above the underground mining area) comprises cleared land that is, and will continue to be, used for livestock grazing, small-scale farm businesses and hobby farms. Belanglo State Forest covers the north-western portion of the study area and contains introduced pine forest plantations, areas of native vegetation and several creeks that flow through deep sandstone gorges. Native vegetation within the project area is largely restricted to parts of Belanglo State Forest and riparian corridors along some watercourses.

The project area is traversed by several drainage lines including Oldbury Creek, Medway Rivulet, Wells Creek, Wells Creek Tributary, Belanglo Creek and Longacre Creek, all of which ultimately discharge to the Wingecarribee River, located around 1.5 km north of the project area (Figure 1.1). The Wingecarribee River's catchment forms part of the broader Warragamba Dam and Hawkesbury-Nepean catchments. Medway Dam is also adjacent to the northern portion of the project area (Figure 1.1).

Most of the central and eastern parts of the project area have very low rolling hills with occasional elevated ridge lines. However, there are steeper slopes and deep gorges in the west in Belanglo State Forest.

Existing built features across the project area include scattered rural residences and farm improvements such as outbuildings, dams, access tracks, fences, yards and gardens, as well as infrastructure and utilities including roads, electricity lines, communications cables and water and gas pipelines. Key roads that traverse the project area are the Hume Highway and Golden Vale Road. The Illawarra Highway borders the south-east section of the project area.

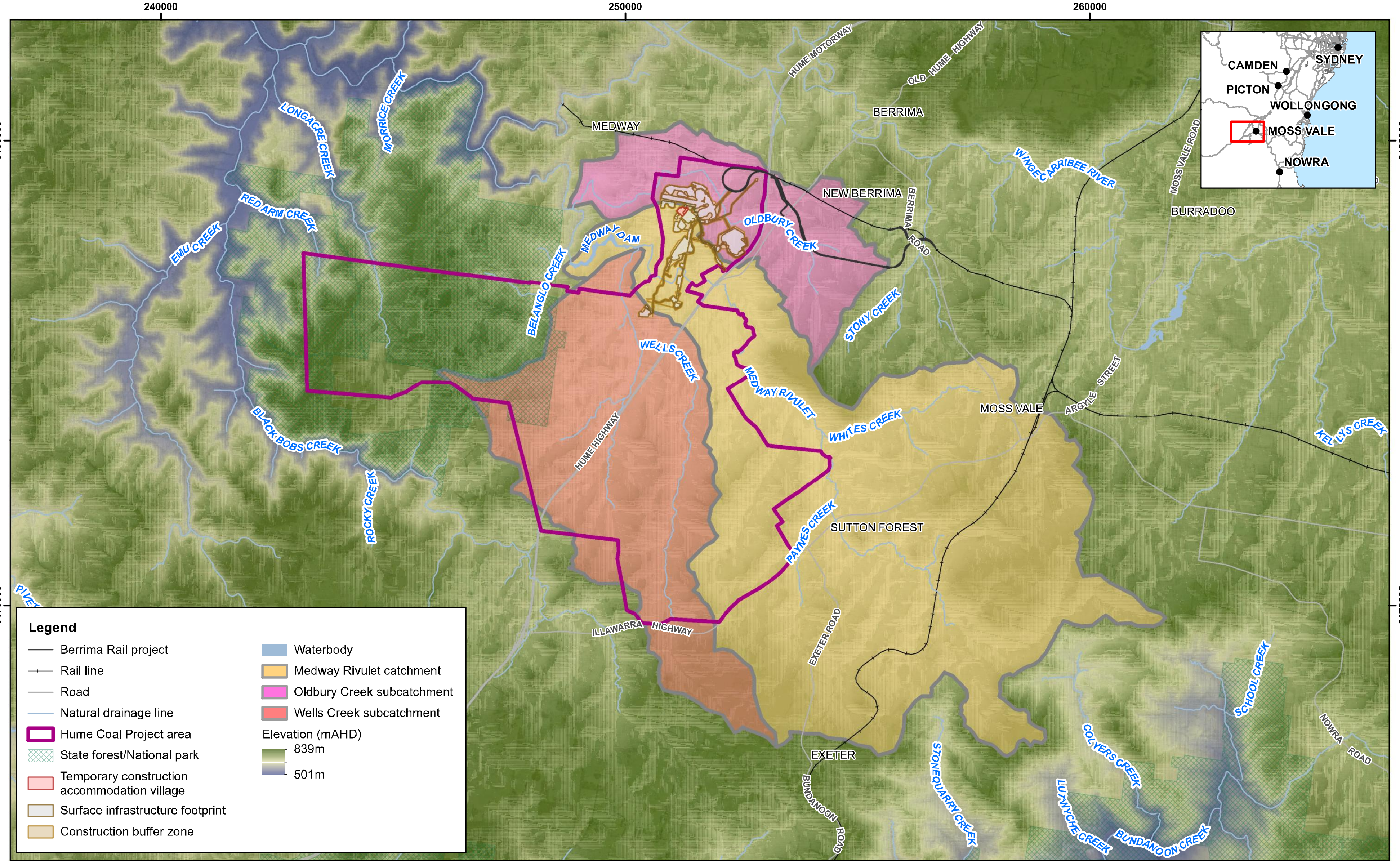
Industrial and manufacturing facilities adjacent to the project area include the Berrima Cement Works and Berrima Feed Mill on the fringe of New Berrima. Berrima Colliery's mining lease (CCL 748) also adjoins the project area's northern boundary. Berrima Colliery is currently undergoing closure having ceased production in 2013 after almost one hundred years of operation.

1.3 Study area definition

The flooding assessment study area is shown on Figure 1.3 and includes the surface infrastructure area and surrounding Medway Rivulet and Oldbury Creek catchments. The surface infrastructure area includes the AWA precinct, the CPP precinct and supporting infrastructure.

The area located above the proposed underground mining area is not part of the study area for the flooding assessment as the underground mine workings will result in negligible subsidence and therefore negligible impacts on flooding in overlying catchments. Worst case estimates of subsidence associated with the proposed first workings mining method predict 'imperceptible' surface disturbance due to mining, with predicted settlement less than 20 mm (Mine Advice 2016). Such low magnitude subsidence will not impact on flooding regimes.

The Berrima Rail Project is located in the Oldbury Creek catchment to the north of the project (refer Figure 1.2) and has been considered for assessment of potential cumulative impacts (refer Section 6.2).



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Data source: © Land and Property Information 2015, Hume Coal

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Coordinate system: GDA 1994 MGA Zone 56

Scale ratio correct when printed at A3

Hume Coal Flooding Assessment
Figure 1.3
Study area

1.4 Catchment description

1.4.1 Medway Rivulet

Medway Rivulet is located to the south of the proposed AWA precinct. The Medway Rivulet catchment used in this assessment covers an area of approximately 103 km^2 (excluding the Oldbury Creek catchment). The downstream limit of the catchment is just downstream of Medway Dam (Figure 1.3).

Medway Rivulet flows in a north-westerly direction from its headwaters in Moss Vale to its discharge to the Wingecarribee River approximately 5.5 km downstream of the study area. Medway Rivulet's major tributaries are Wells Creek, Whites Creek, Paynes Creek, Oldbury Creek and Belanglo Creek (Figure 1.3).

East of the Hume Highway, Medway Rivulet is characterised by run/riffle sequences and its natural flow is impeded by several instream farm dams. West of the Hume Highway, Medway Rivulet is confined by Hawkesbury Sandstone banks which form a steep gully to the west of the study area.

Downstream of the surface infrastructure area, Medway Rivulet has been dammed to create a 1,350 ML reservoir. The reservoir is commonly referred to as 'Medway Dam' and is part of Wingecarribee Shire Council's (WSC's) water supply system.

Land use within the catchment is predominantly cleared farm land for grazing with some irrigation. The Belanglo State Forest, an exotic pine plantation, occurs in the north-western part of the catchment. Urban areas are associated with Sutton Forest, Exeter and Moss Vale (Figure 1.3).

1.4.2 Oldbury Creek

Oldbury Creek is located to the north of the proposed CPP precinct. The Oldbury Creek catchment used in this assessment covers an area of approximately 13.3 km^2. The downstream limit of the catchment is just upstream of the confluence with Medway Rivulet (Figure 1.3).

Oldbury Creek flows in a westerly direction from its headwaters in New Berrima to its discharge to Medway Rivulet (Figure 1.3). Its natural flow is impeded by several instream farm dams used for agricultural water supply, including a large storage to the east of the CPP precinct. West of the Hume Highway, Oldbury Creek is confined by Hawkesbury Sandstone banks which form a steep gully to the west of the study area.

Land use within the catchment is predominantly cleared farm land for grazing with some irrigation. Urban areas are associated with Medway and New Berrima (Figure 1.3).

1.5 Environmental assessment requirements

This assessment has been prepared in accordance with the relevant governmental assessment requirements, guidelines and policies, and in consultation with the relevant government agencies. Guidelines and policies considered are as follows:

- Floodplain Development Manual (NSW Government 2005)
- Practical Consideration of Climate Change (Department of Environment and Climate Change 2007)
- Australian Rainfall and Runoff – A Guide to Flood Estimation (Engineers Australia 1987)
- Wingecarribee Local Environmental Plan (Wingecarribee Shire Council 2010).

Further details of these legislation, policy and guideline documents, and how they apply to this assessment, are provided in Section 2 of this report.

The Secretary's Environmental Assessment Requirements (SEARs) related to flooding, and the section of this report where the requirement is addressed, are provided in Table 1.1.

Table 1.1 Flooding assessment related SEARs

Requirement	Section addressed
An assessment of the potential flooding impacts of the development	Section 6

To inform preparation of the SEARs, the Department of Planning and Environment (DP&E) invited other government agencies to recommend matters for address in the Environmental Impact Statement (EIS). These matters were then taken into account by the Secretary for DP&E when preparing the SEARs. Copies of the government agencies' advice to DP&E was attached to the SEARs.

One agency, the Department of Primary Industries (DPI), raised matters relevant to the flooding assessment. These were mainly their standard requirements for projects of this nature, though included some project-specific requirements. These matters are listed in Table 1.2 and have been taken into account in preparing this report, as indicated in the tables.

Table 1.2 Agency requirements

Requirement	Section addressed
DPI Water	
The predictive assessment of the impact of the proposed project on surface water sources should include assessment of predicted impacts on: ▪ Flow of surface water (including floodwater) ▪ Flood regime.	Section 6

The Hume Coal Project was declared as a controlled action on 1 December 2015 by the then Commonwealth Department of the Environment (now Department of Environment and Energy). The project will be assessed under the Bilateral Agreement between the NSW Government and the Commonwealth Government. Accordingly, the Commonwealth Department of the Environment and Energy has issued supplementary SEARs to address matters of national environmental significance relevant to the project. There were no supplementary SEARs specifically relating to the flooding assessment.

2. Design objectives and criteria

2.1 Terminology

AR&R has indicated that the annual exceedance probability (AEP) terminology is preferred to the average recurrence interval (ARI) terminology. The ARI and the AEP are both a measure of the probability of occurrence of a rainfall event. The ARI terminology has been used throughout this report.

ARI is defined as the average, or expected, value of the periods between exceedances of a given rainfall total accumulated over a given duration. It is implicit in this definition that the periods between exceedances are generally random. AEP is defined as the probability that a given rainfall total accumulated over a given duration will be exceeded in any one year.

With ARI expressed in years, the relationship is:

$$AEP = 1 - \exp\left(\frac{-1}{ARI}\right)$$

A summary of the conversion between ARI and AEP is shown in Table 2.1.

Table 2.1 Conversion from ARI to AEP

ARI (years)	AEP
1	0.632
2	0.393
5	0.181
10	0.095
20	0.049
50	0.020
100	0.010

ARIs greater than 10 years are very closely approximated by the reciprocal of the AEP.

2.2 Legislation, policy and guidelines

This section details the legislation, policy and guidelines that were used for the flooding assessment.

2.2.1 Floodplain Development Manual (NSW Government 2005)

The Floodplain Development Manual (NSW Government 2005) was prepared in accordance with the NSW Government's Flood Prone Land Policy. The objective of the Flood Prone Land Policy is to reduce flooding impacts and flood liability on individual owners and occupiers of flood prone property and to reduce private and public losses resulting from floods.

The purpose of the Floodplain Development Manual (NSW Government 2005) is to provide guidance to local councils during the development and implementation of detailed local floodplain risk management plans in order to produce effective floodplain risk management outcomes. The manual identifies the need to consider the full range of flood sizes up to and including the probable maximum flood (PMF) when developing floodplain risk management plans; to recognise flood risk on a strategic basis; to manage not only riverine flooding but local overland flooding and to promote the preparation and adoption of local flood plans that address flood response and recovery. The manual clearly sets out the floodplain risk management process undertaken by local councils.

2.2.2 Practical Consideration of Climate Change in Floodplain Risk Management (Department of Environment and Climate Change 2007)

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Bureau of Meteorology (BOM) are currently undertaking research on climate change impacts with the objective of estimating rainfall intensities for a range of events under current climatic conditions (1960 to 2000) and under increased greenhouse gas concentrations for future conditions (2030 and 2070). This document outlines current advice on how to incorporate climate change impacts into flooding assessments.

This document also provides guidance on the evaluation of climate change impacts and their significance. Management options and strategies that should be considered are also outlined in the document.

2.2.3 Australian Rainfall and Runoff – A Guide to Flood Estimation (Engineers Australia 1987)

Australian Rainfall and Runoff (AR&R) is a national guideline for the estimation of design flood characteristics in Australia developed by Engineers Australia. It provides robust estimates of flood risk to ensure development does not occur in high risk areas and that infrastructure is appropriately designed.

A number of research projects are currently underway to fill knowledge gaps that have arisen since the 1987 edition was published. The projects are being completed progressively and a number were launched at the Water Resources Symposium in Hobart in 2015. However, the sections released so far are insufficient to be used for flooding assessment, and AR&R (1987) has been used as the basis for this assessment.

2.2.4 Wingecarribee Local Environmental Plan (Wingecarribee Shire Council 2010)

The Wingecarribee Local Environmental Plan (WLEP) was approved in 2010. The plan was prepared in accordance with the *Environmental Planning and Assessment Act 1997* and *Environmental Planning and Assessment Regulation 2000*. The WLEP aims to minimise flood risk to life and property associated with the use of the land, allow development that is compatible with the land’s flood risk (taking into account projected climate change), and avoid significant adverse impacts on flood behaviour and the environment.

Clause 7.9 of the WLEP states that development consent must not be granted to development in a Flood Planning Area or other land at or below the flood planning level, unless the consent authority is satisfied that the development:

- is compatible with the flood hazard of the land;

- will not significantly adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties;
- incorporates appropriate measures to manage risk to life from flood;
- will not significantly adversely affect the environment or cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses; and
- will not be likely to result in unsustainable social and economic costs to the community as a consequence of flooding.

The WLEP includes Flood Planning Area Maps (refer Appendix A). The flood planning level is the level of the 100 year ARI flood event plus 0.5 m freeboard.

2.2.4.1 Development Control Plans

A Development Control Plan (DCP) provides detailed guidelines for the assessment of development applications at a local level. DCPs applicable under the WLEP and within the Medway Rivulet and Oldbury Creek catchments include:

- Rural Lands and Living DCP;
- New Berrima and Medway DCP;
- Moss Vale DCP (including the Moss Vale Flood Map);
- Sutton Forest DCP; and
- Industrial Lands DCP.

The DCPs identify types of development and outline controls that will guide the development to suitable areas. These specific elements follow an overarching control mechanism that is presented in a matrix containing degrees of flood risk (Flood Risk Precincts), land use categories and planning considerations. The matrix provides a consolidated list of preferred controls.

The development controls are graded relative to the severity and frequency of the potential floods based on the findings of the Floodplain Risk Management Plan.

Council does not have flood risk mapping available for rural areas, therefore it is the applicant's responsibility to provide evidence of the relevant flood risk category for their development in potentially flood liable areas.

2.2.5 Floodplain Risk Management Study and Plan, Wingecarribee Shire Council, in progress

WSC is currently developing floodplain risk management studies and plans in accordance with the Floodplain Development Manual (NSW Government 2005).

WSC has completed a flood study of the Whites Creek catchment, which is located to the south east of the study area (URS 2008). The flood study was completed in 2008 and assessed various potential floods in the study area, including the 5 year, 10 year, 20 year, 50 year, 100 year, 200 year ARI and PMF event flood extents. A draft Floodplain Risk Management Study and Plan for the Whites Creek Catchment was prepared in 2013.

WSC has also completed a flood study for the Wingecarribee River catchment, covering the area between Wingecarribee Dam and Wallaby Rocks in Berrima (SMEC 2014). The study was completed in 2014 and considered the 1100 year ARI flood depths and provisional hydraulic hazard. A Floodplain Risk Management Study and Plan was prepared for the Wingecarribee River at Berrima in 2002 based on the results of an earlier flood study undertaken in 2000.

2.3 Flood design criteria for mine infrastructure

Preliminary flood modelling was undertaken during the mine design phase to inform the siting and design of mine infrastructure. Surface infrastructure for the mine has been located and designed to minimise potential flooding impacts and ensure critical mine infrastructure is protected during extreme flood events.

The flood immunity criteria adopted for siting of surface infrastructure is provided in Table 2.2. The main drifts and ventilation shaft are located above the PMF level to prevent ingress of flood waters into the underground mine workings.

Table 2.2 Flood immunity criteria for mine infrastructure

Infrastructure	Design criteria
Main drifts and ventilation shafts	PMF
AWA precinct	100 year ARI
CPP precinct	100 year ARI
PWD and WTP	100 year ARI

2.4 Flood impact criteria

To ensure that the flooding impact is acceptable to land users adjacent to the Project, for flooding events up to the 100 year ARI the following acceptability criteria are proposed:

- Buildings – less than 50 mm increase in flood level (or afflux) if the building is already flooded and no new flooding of buildings not currently flooded due to proposed works is allowed unless owner's consent is obtained.
- Public roads/rail - less than 100 mm afflux if the road/rail is already flooded and no new flooding of public roads/rail that are not currently flooded.
- Private properties – less than 250 mm afflux.
- No increase in velocity above a threshold of 1.5 m/s, where existing conditions velocities are below the threshold. No more than a 10% increase in velocity where existing conditions velocities are above this threshold.

3. Data sources

3.1 Topography, aerial photography and survey

Catchment delineation for the hydrological modelling and development of a digital terrain model (DTM) for the hydraulic modelling used light detection and ranging (LiDAR) data obtained from aerial laser survey of the project area on 25 October 2013 (Hume Coal 2013). The data were supplied as thinned ground points in ASCII format, and a triangulated irregular network was created to form the DTM.

Aerial photography was used for catchment delineation and to estimate channel and floodplain roughness in the hydraulic model.

Surveys of significant culvert crossings of roads and rail lines within the study area were surveyed and represented in the hydraulic model. Cross-section surveys undertaken by Xylem and Manly Hydraulics Laboratory (MHL) during installation of Hume Coal stream gauges SW04 on Medway Rivulet and SW08 on Oldbury Creek (Parsons Brinckerhoff 2016) were included in the hydraulic model. Two inline storages on Oldbury Creek were surveyed so that embankment height and water levels could be input to the hydrological model.

3.2 Design rainfall intensity data

Design rainfall intensity estimates were derived for the range of storm events up to the 100 year ARI using AR&R (Engineers Australia 2001) as discussed in Section 2.2.3.

Intensity frequency duration (IFD) input parameters adopted in the hydrologic models for the Medway Rivulet and Oldbury Creek catchments are provided in Table 3.1. The IFD data for Medway Rivulet and Oldbury Creek are provided in Tables 3.2 and 3.3 respectively.

Table 3.1 IFD parameters

Variable	Symbol	Medway Rivulet	Oldbury Creek
Rainfall intensity (mm/hr) (2-year ARI; 1-hour storm duration)	${}^{2}I_{1}$	30.8	28.8
Rainfall intensity (mm/hr) (2-year ARI; 12-hour storm duration)	${}^{2}I_{12}$	7.11	6.28
Rainfall intensity (mm/hr) (2-year ARI; 72-hour storm duration)	${}^{2}I_{72}$	2.27	1.87
Rainfall intensity (mm/hr) (50-year ARI; 1-hour storm duration)	${}^{50}I_{1}$	62.9	58.46
Rainfall intensity (mm/hr) (50-year ARI; 12-hour storm duration)	${}^{50}I_{12}$	14.4	12.78
Rainfall intensity (mm/hr) (50-year ARI; 72-hour storm duration)	${}^{50}I_{72}$	4.84	3.84
Average coefficient of skewness	G	0.04	0.04
Geographical factor (2-year ARI)	F2	4.28	4.29
Geographical factor (50-year ARI)	F50	15.73	15.73

Table 3.2 IFD data for Medway Rivulet

Duration	Rainfall intensity (mm/hr)						
	1 year ARI	2 year ARI	5 year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI
5 mins	77.1	99.7	130	147	171	202	225
6 mins	72.3	93.6	122	138	160	189	212
10 mins	59.1	76.5	99.6	113	131	155	173
20 mins	43	55.6	72.4	82.4	95.6	113	126
30 mins	34.9	45.2	58.9	67.1	77.8	92	103
1 hr	23.8	30.8	40.2	45.8	53.2	62.9	70.4
2 hrs	15.9	20.6	26.9	30.6	35.5	42	47
3 hrs	12.5	16.2	21.1	24	27.8	32.9	36.8
6 hrs	8.28	10.7	14	15.9	18.4	21.7	24.3
12 hrs	5.49	7.11	9.26	10.5	12.2	14.4	16.1
24 hrs	3.61	4.69	6.14	7.01	8.15	9.66	10.8
48 hrs	2.32	3.02	3.99	4.58	5.34	6.36	7.15
72 hrs	1.74	2.27	3.02	3.47	4.06	4.84	5.45

Table 3.3 IFD data for Oldbury Creek

Duration	Rainfall intensity (mm/hr)						
	1 year ARI	2 year ARI	5 year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI
5 mins	72.3	93.9	123	141	164	195	218
6 mins	67.6	87.9	115	132	153	182	204
10 mins	55.2	71.8	94.2	108	125	149	167
20 mins	40.2	52.2	68.4	78.1	90.8	108	121
30 mins	32.6	42.3	55.5	63.3	73.5	87.1	97.7
1 hr	22.1	28.7	37.5	42.8	49.7	58.9	66
2 hrs	14.6	18.9	24.8	28.2	32.8	38.9	43.5
3 hrs	11.4	14.7	19.3	22	25.6	30.3	33.9
6 hrs	7.41	9.6	12.6	14.3	16.7	19.7	22.1
12 hrs	4.82	6.25	8.19	9.35	10.9	12.9	14.4
24 hrs	3.1	4.03	5.28	6.03	7.02	8.32	9.33
48 hrs	1.94	2.52	3.31	3.78	4.4	5.23	5.86
72 hrs	1.44	1.86	2.45	2.8	3.26	3.87	4.35

3.3 Probable maximum precipitation

The probable maximum precipitation (PMP) design rainfall intensity was determined using the method outlined by the BOM (2003, 2006) publications detailing the Generalised Short-Duration Method (GSDM) for durations from 15 minutes up to 6 hours and the Generalised Southeast Australia Method (GSAM) for longer durations from 24 hours up to 96 hours. The 12 hour event was estimated through interpolation. Table 3.4 shows the parameters used in the PMP calculation for Medway Rivulet (excluding the Oldbury Creek catchment) and Oldbury Creek and Table 3.5 provides a summary of the resulting PMP rainfall depths.

Table 3.4 Parameters used for PMP calculation

Parameter	Medway Rivulet (excluding the Oldbury Creek catchment)	Oldbury Creek
Catchment area	103 km^2	13.3 km^2
GSDM parameters		
Elevation adjustment factor (EAF)	1 (below 1500 m elevation)	1 (below 1500 m elevation)
Moisture adjustment factor (MAF)	0.67	0.68
Portion of catchment area considered smooth	0 (entire catchment considered rough because there are elevation changes of 50 m or more within horizontal distances of 400 m within the catchment.)	0 (entire catchment considered rough because there are no elevation changes of 50 m or more within horizontal distances of 400 m within the catchment.)
GSAM parameters		
Topographic adjustment factor (TAF)	1.51	1.51
Extreme perceptible water (EPW) - summer (annual)	70.87	70.87
EPW – autumn	57.05	57.05
Annual MAF - summer	0.88	0.88
Annual MAF - autumn	0.80	0.80

Table 3.5 PMP rainfall depths

Storm duration	PMP rainfall depth (mm)	
	Medway Rivulet	Oldbury Creek
15 minutes	110	150
30 minutes	160	210
45 minutes	210	270
1 hour	250	320
1.5 hours	320	410
2 hours	370	470
2.5 hours	420	520
3 hours	450	570

Storm duration	PMP rainfall depth (mm)	
	Medway Rivulet	Oldbury Creek
4 hours	510	650
5 hours	560	710
6 hours	590	820
12 hours	820	930
24 hours	1,060	1,150
36 hours	1,180	1,290
48 hours	1,250	1,360
72 hours	1,310	1,420
96 hours	1,360	1,470

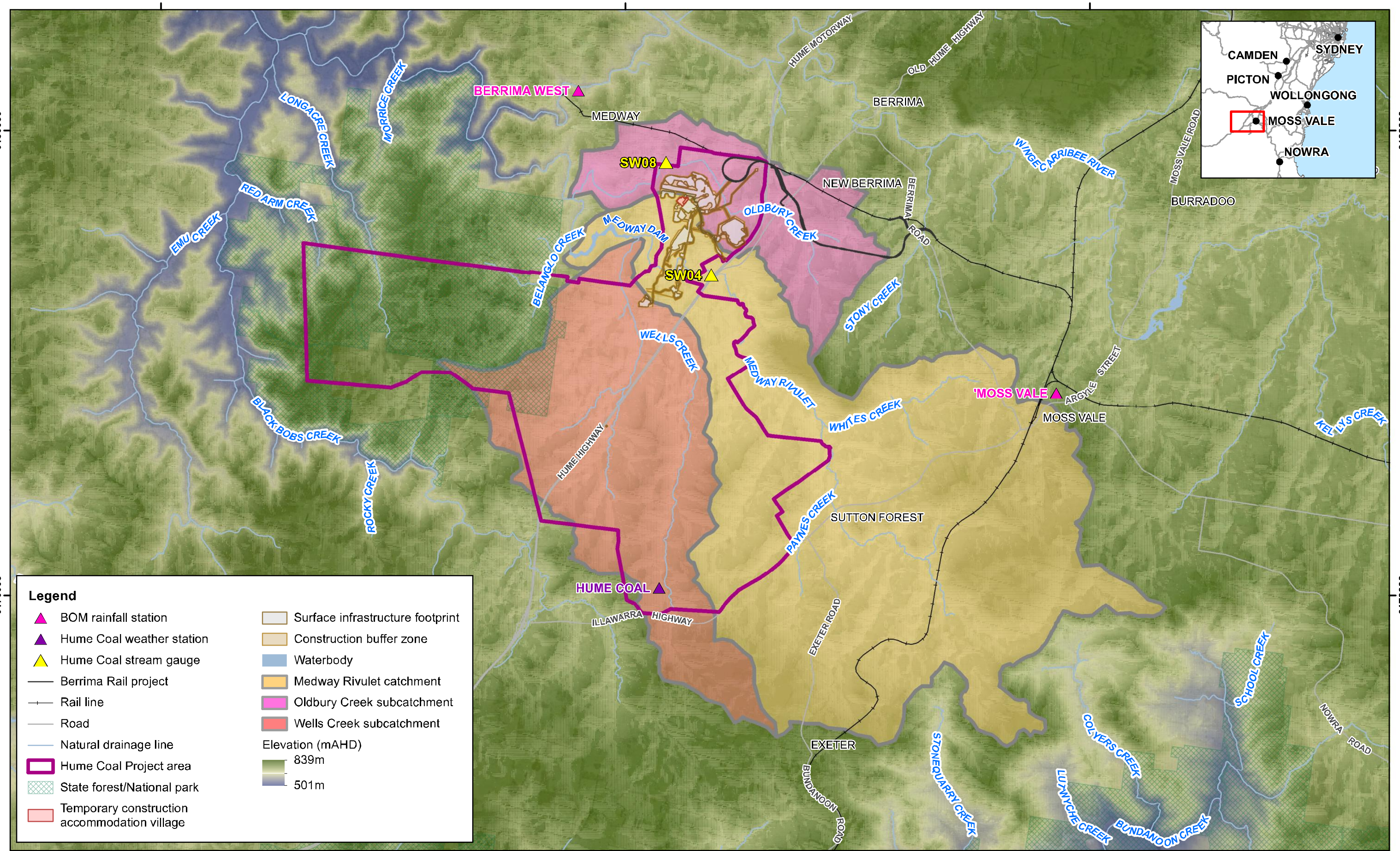
3.4 Rainfall data

The rainfall data used in the flooding assessment was collected from BOM rainfall stations in the vicinity of the study and the Hume Coal weather station installed in the project area in February 2012. The locations of the stations are shown on Figure 3.1 while details of each are provided in Table 3.6.

Table 3.6 Summary of rainfall stations

Station	Station number	Easting	Northing	Elevation (mAHD)	Period of record#	Data frequency
Moss Vale (BOM)	68045	259560.3	6174849	675	1870 – 2015	Daily
Berrima West (BOM)	68186	251120.2	6181286.9	655	1970 - 2015	Daily
Hume Coal	n/a	250727	6170163	675	2012 – 2015	10 minute

All weather stations have some data gaps, however data is available each month in each year



Map: 2200540A_GIS_017_B4	Author: RP
Date: 25/10/2016	Approved by: LR

Data source: © Land and Property Information 2015, Hume Coal

0 1,000 2,000 m

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Coordinate system: GDA 1994 MGA Zone 56

Scale ratio correct when printed at A3

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Figure 3.1

Rainfall stations and stream gauge locations

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The nearest BOM weather station to the surface infrastructure area is the station at Berrima West (68186). Daily rainfall data collected at this station for the baseline monitoring period from 2013 to 2015 is presented in Figure 3.2. Peak rainfall events during the baseline monitoring period occurred on:

- 26 June 2013
- 8 August 2014
- 7 December 2014
- 5 January 2015
- 25 August 2015.

The largest event occurred on 25 August 2015. Data from the Hume Coal MET01 station for this event was used for calibration of the hydrologic models for Medway Rivulet and Oldbury Creek. IFD rainfall data (refer Section 3.2) was used to identify the duration and ARI of the August 2015 rainfall event. Given the Berrima West rainfall station only records daily totals, analysis of 10 minute rainfall data from the Hume Coal weather station MET01 was carried out instead and concluded the August 2015 event was approximately a 1 year ARI 2 hour storm event.

Ideally for calibration, a larger event is preferred given the hydrologic models are simulating storm events up to the 100 year ARI. Data from local rainfall stations and flow gauges on the Wingecarribee River with a longer period of record were reviewed to assess whether a relationship could be established between the flow gauge on the Wingecarribee River, flow gauge SW04 on Medway Rivulet and local rainfall stations with sub-daily rainfall data. There were no rainfall stations with sub-daily data within 20 km of SW04 recording rainfall data before the year 2000. The rainfall depth recorded in the August 2015 event was similar to the depth of other major storm events in the early 2000's, and therefore the August 2015 event was considered to be a representative major storm event in the recent flood history for calibration.

The Hume Coal MET01 weather station was selected for calibration as it recorded sub-daily rainfall data during the August 2015 event. The station is located within the Wells Creek catchment (a tributary of Medway Rivulet) approximately 4km south west of the centroid of the Medway Rivulet catchment and approximately 9km south west of the centroid of the Oldbury Creek catchment (refer to Figure 3.1). Given its proximity to the Medway Rivulet catchment the temporal pattern of the rainfall at MET01 was assumed to be an accurate representation of the rainfall that would fall on the Medway Rivulet catchment and at SW04.

The Berrima West station (68186) is the closest weather station to the Oldbury Creek catchment. Comparison of rainfall at the Berrima West station to rainfall at the Hume Coal MET01 weather station indicated that rainfall at the Hume Coal station is higher than at Berrima West. The total rainfall for each day during the August 2015 storm event at the Hume Coal MET01 station was therefore factored down accordingly for the purpose of developing a calibration rainfall dataset for Oldbury Creek. The adjustment factor was determined by comparing total daily rainfall at the Berrima West station with total daily rainfall at the Hume Coal station during the August 2015 event (Table 3.5).

Table 3.7 Total daily rainfall at the Berrima West and Hume Coal rainfall stations

Date	Berrima West 68186	Hume Coal MET01 station
24/08/2015 9:00am	1.2	0.1
25/08/2015 9:00am	52.2	78.8
26/08/2015 9:00am	96.2	200.6
27/08/2015 9:00am	9.6	0.0
Total	159.2	279.5
Factor	**0.57**	

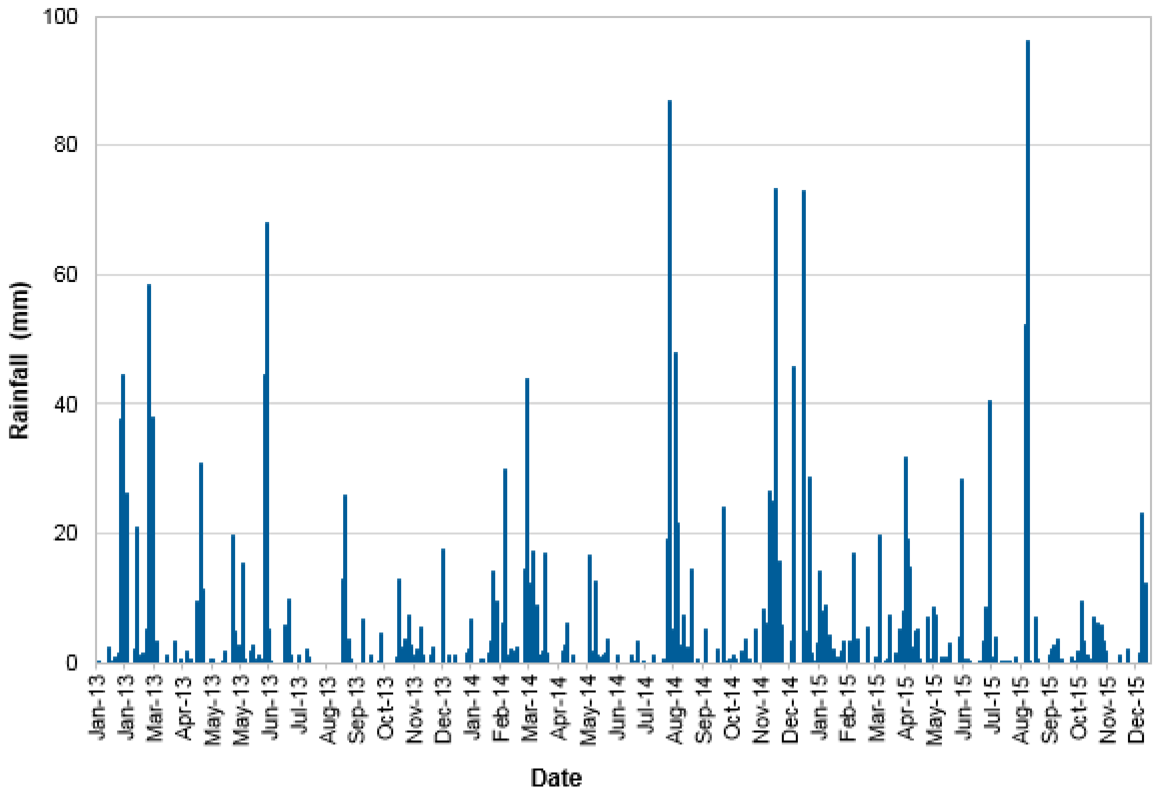


Figure 3.2 Daily rainfall at the Berrima West weather station (2013 - 2015)

The highest daily rainfall data in each month for the baseline monitoring period (2013 – 2015) at the BOM station at Berrima West (68186) was compared against the data for the period of record (1970 – 2015) as well as data for the period of record (1870 – 2015) at the BOM rainfall station at Moss Vale (68045) (Figure 3.3). The comparison indicates that the highest daily rainfall in each month has been lower during the baseline monitoring period.

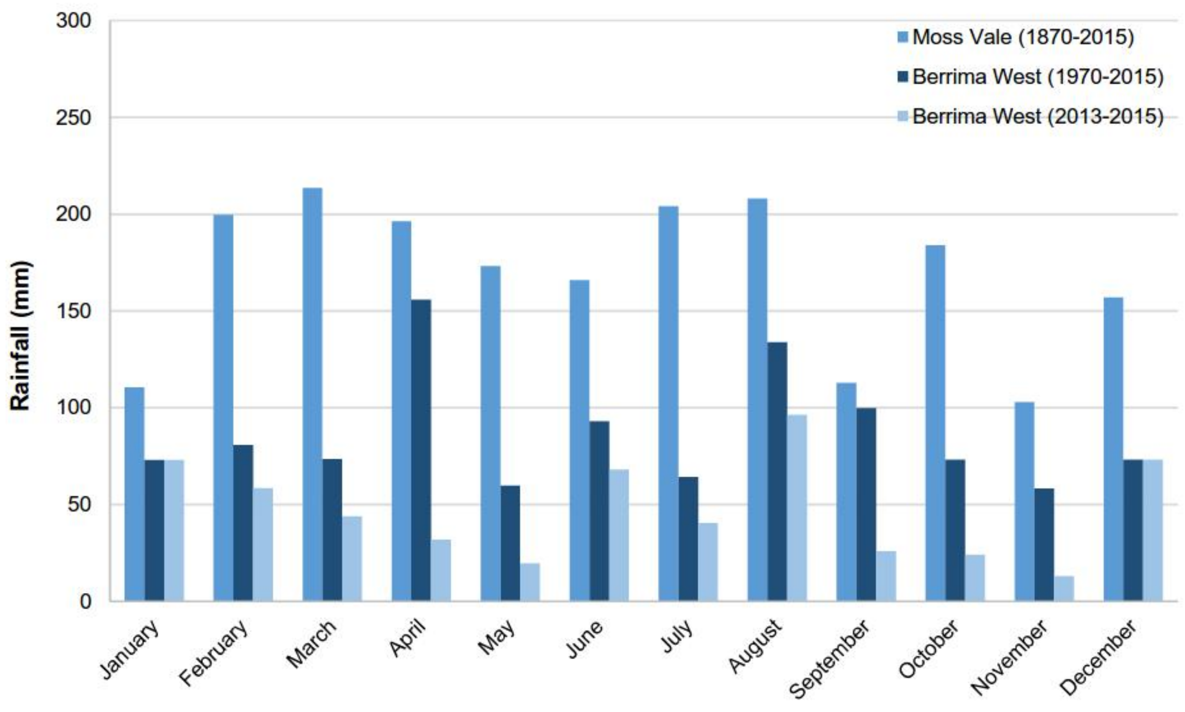


Figure 3.3 Highest daily rainfall in each month

3.5 Streamflow

A dedicated surface water monitoring network was installed by Hume Coal to provide baseline data for the project. The network includes 11 operational stream gauges installed by Xylem and MHL. Details of the stream gauge network are provided in the project's Water Fieldwork and Monitoring Report (Parsons Brinckerhoff 2016).

The streamflow data used in the flooding assessment for hydrologic model calibration was collected from the stream gauges located closest to the proposed surface infrastructure as shown on Figure 3.1 and in Table 3.8.

Table 3.8 Stream gauges

Location	Stream gauge ID	Easting	Northing	Elevation of cease to flow (mAHD)	Data available for this assessment	Data frequency
Medway Rivulet at Hume Highway	SW04	251847	6176898	627.451	21/01/2012* – 30/09/2016	15 minute
Oldbury Creek	SW08	250876	6179319	627.074	14/05/2015* – 30/09/2016	15 minute

* Date monitoring at this stream gauge commenced

Water level data collected at SW04 and SW08 during the August 2015 event was converted to flow data using rating curves (Figure 3.4 and Figure 3.5) generated using the HEC-RAS models for the Medway Rivulet and Oldbury Creek catchments (refer Section 5).

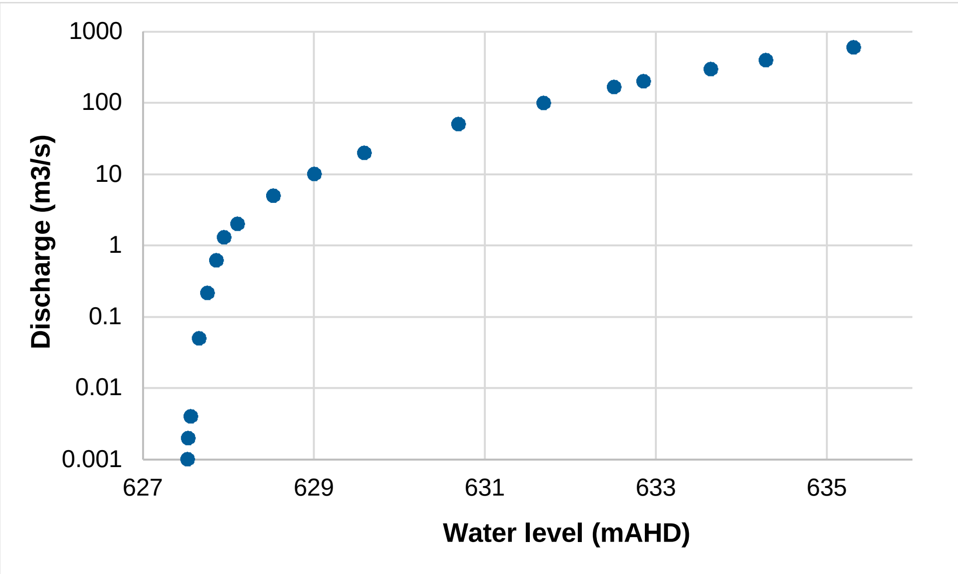


Figure 3.4 SW04 rating curve

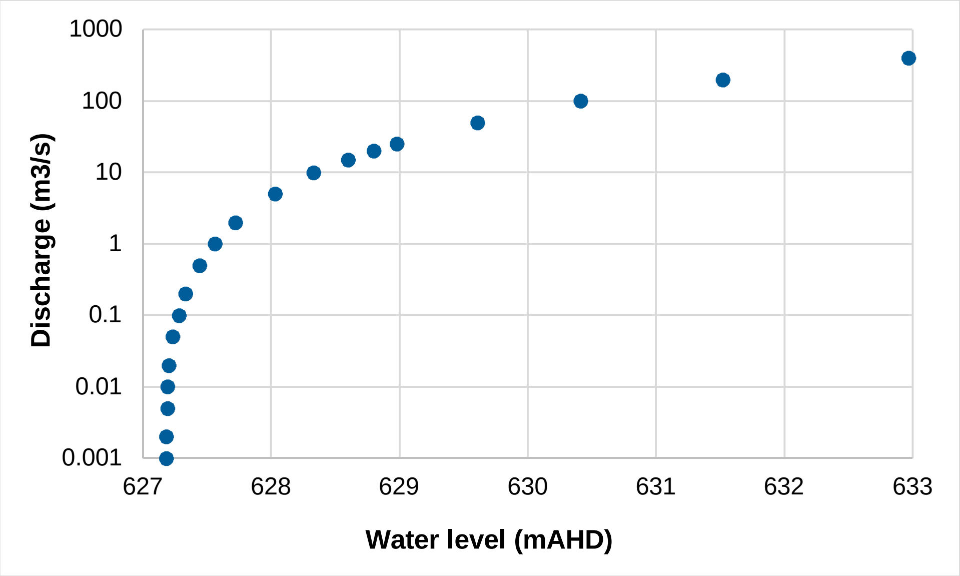


Figure 3.5 SW08 rating curve

Figure 3.6 and Figure 3.7 present streamflow data for SW04 and SW08 respectively. The hydrographs show that both streams are ephemeral waterways.

Flow events exceeding 50 m^3/s at SW04 on Medway Rivulet have been recorded during the baseline monitoring period on the following days:

- 24 February 2013
- 26 June 2013
- 26 August 2014
- 22 April 2015
- 28 August 2015.

The largest event occurred on 25 August 2015 and data from this event (along with rainfall data – refer Section 3.4) was used to calibrate the hydrologic models for Medway Rivulet and Oldbury Creek.

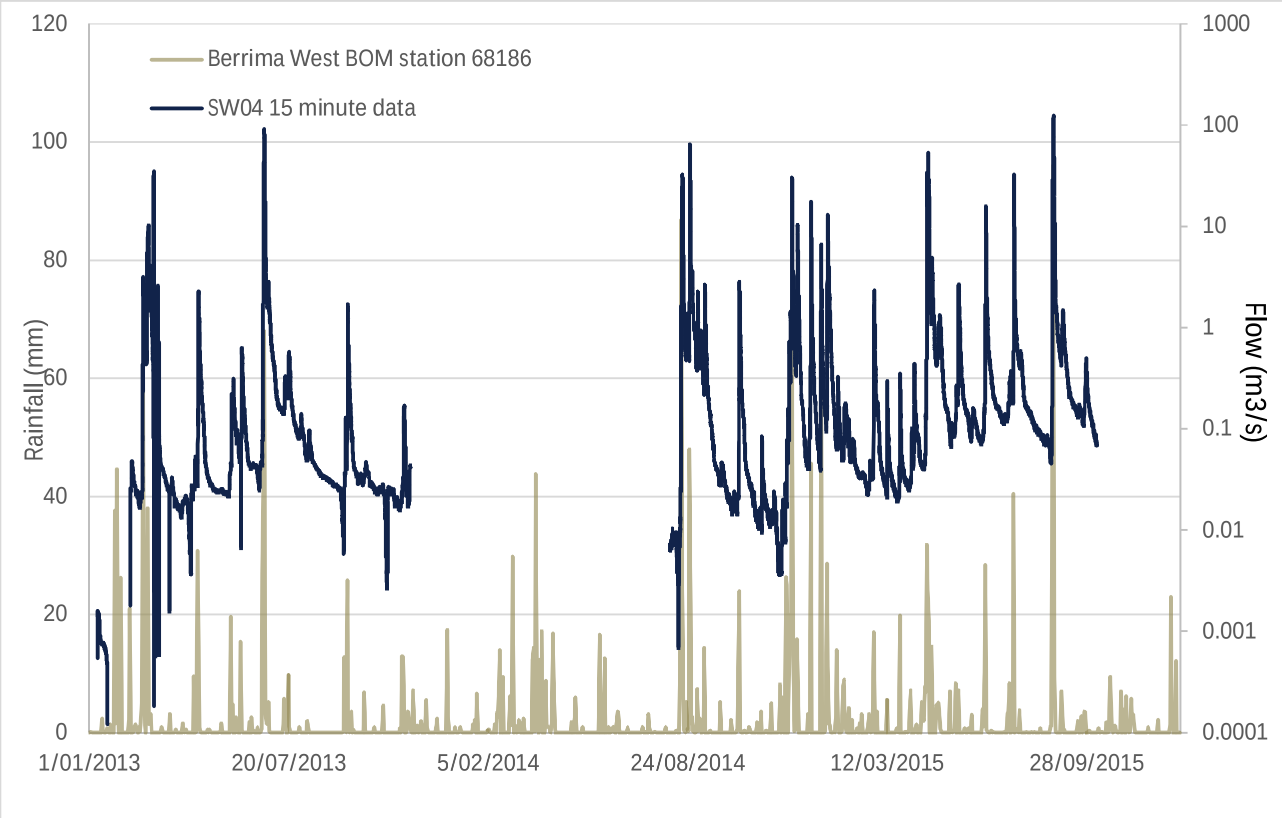


Figure 3.6 Streamflow at SW04

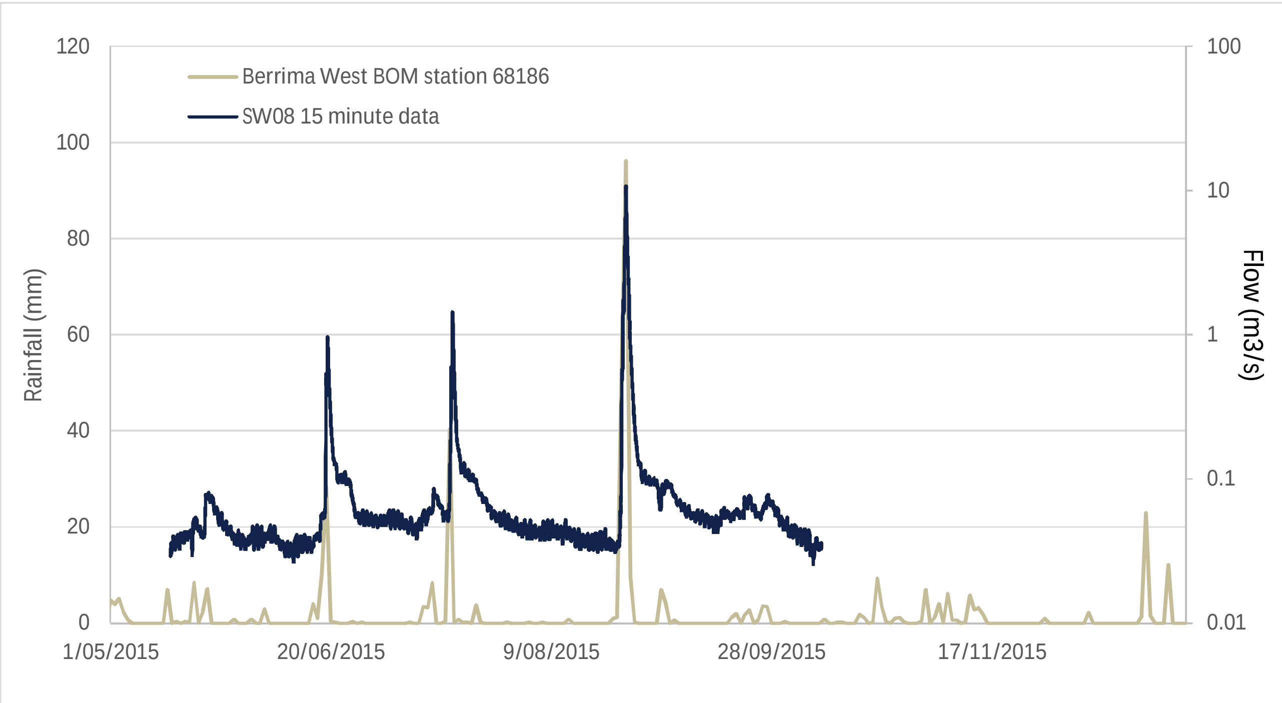


Figure 3.7 Streamflow at SW08

4. Hydrologic analysis

Hydrologic modelling is the process of determining runoff generated from rainfall on a catchment. The runoff estimates are then used by the hydraulic analysis, as described in Section 5. Factors affecting the volume and peak of runoff generated include:

- size and slope of the catchment and adjoining channels;
- level of development (fraction impervious) and type of catchment land use;
- condition of the catchment (dry or saturated) when the rainfall starts;
- intensity and temporal pattern of rainfall; and
- ability of the catchment and other features to store runoff.

Simple analytical methods exist for estimating the amount of runoff from a catchment (i.e. peak flow methods like the Probabilistic Rational Method [PRM]). However, a rainfall-runoff model is necessary to allow more accurate prediction of the response of large and complex catchments to rainfall over time, and the interaction between sub-catchments. For this assessment, hydrologic models of the Medway Rivulet and Oldbury Creek catchments were developed using the XP-RAFTS software program.

XP-RAFTS has been used extensively across NSW for urban and rural flood investigations. XP-RAFTS is an event-based hydrologic model that calculates flood hydrographs from either recorded storm rainfall hyetographs or design storm rainfall parameters. The catchment is represented in the model as a series of sub-catchments for which factors affecting runoff, such as land use (proportion of pervious versus impervious land surfaces), rainfall losses, and runoff routing through the catchment and channels, are defined.

Details of how XP-RAFTS was used to represent the Medway Rivulet and Oldbury Creek catchments are provided below. The models of the Medway Rivulet and Oldbury Creek catchments developed for this study were used to estimate flow generated from the catchment for the 5 year ARI, 20 year ARI, 100 year ARI and PMF design storm events to represent a reasonable range of extreme event flood conditions. The models estimated flow for the following scenarios:

- The existing scenario, which represents the current state of the Medway Rivulet and Oldbury Creek catchments based on LiDAR data collected on 25 October 2013.
- The operational scenario, which incorporates the proposed surface infrastructure for the mine and associated mitigation measures. DWG files of the proposed surface infrastructure were merged with LiDAR data to create the landform to be modelled.
- The rehabilitation scenario, which is the final landform at completion of the project. DWG files of the final landform were merged with LiDAR data to create the landform to be modelled.

Calibration was undertaken using the rainfall and streamflow data discussed in Section 3, and the results are provided in Section 4.2.

4.1 Model set up

4.1.1 Catchment area

The Medway Rivulet catchment was divided into 19 sub-catchments (refer Figure 4.1) and the Oldbury Creek catchment was divided into 15 sub-catchments (refer Figure 4.2) for greater definition of catchment parameters within the XP-RAFTS models. For the Medway Rivulet model, a lumped inflow from the Wells Creek catchment was included in the model for the purposes of setting downstream boundary water levels.

Catchment parameters for the existing scenario, including sub-catchment area, percentage imperviousness, sub-catchment links and channel definition, were defined using the project LiDAR data and a review of aerial photography of the area. Operational 3D drawings and plans were used for the operational scenario and final landform 3D drawings and plans were used for the final landform scenario along with LiDAR and aerial photography.

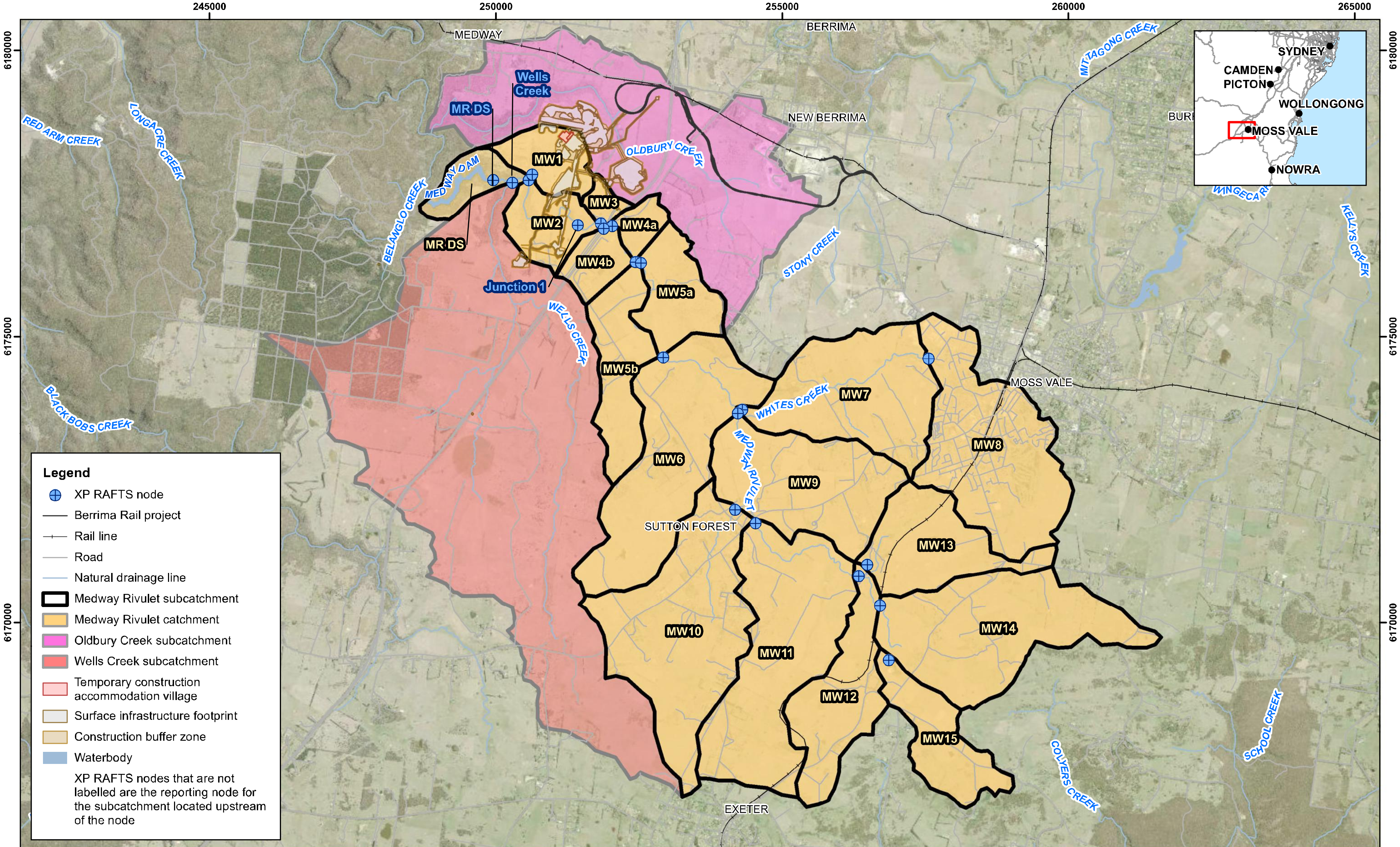
Catchment parameters adopted in the model are provided in Appendix C. The catchment parameters for the existing and final landform cases are the same. Catchment parameters, such as percent impervious and catchment area (excluding areas referring to stormwater basins and mine water dams), were varied for the operation case in sub-catchments MW1, MW2, OC6, OC7, OC8 and SW08 where the proposed infrastructure is to be located.

4.1.2 Model parameters

Initial loss and continuing loss refer to rainfall loss parameters which are input to the hydrologic model. Initially, rainfall losses adopted were in line with standard values; 2.5 mm/hr continuing loss rate and 20 mm initial loss.

The storage delay coefficient is another hydrologic model input parameter and was calculated for each sub-catchment using the average vectored slope of the catchment together with catchment area, percentage impervious, Manning's *n* value, loss rates and rainfall data. The average vectored slope of each sub-catchment was measured using the DTM.

Translation, or lagging of the hydrograph was applied to links within the models to represent the routing of flow through the stream network. The lag times were estimated by dividing the channel length (measured using the DTM) by an estimated channel velocity based on the slope of the channel (measured using the DTM) and corresponding approximate velocity in AR&R (Engineers Australia 2001).



Map: 2200540A_GIS_023_B4	Author: RP
Date: 25/10/2016	Approved by: LR

Data source: © Land and Property Information 2015, Hume Coal

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Coordinate system: GDA 1994 MGA Zone 56

Scale ratio correct when printed at A3

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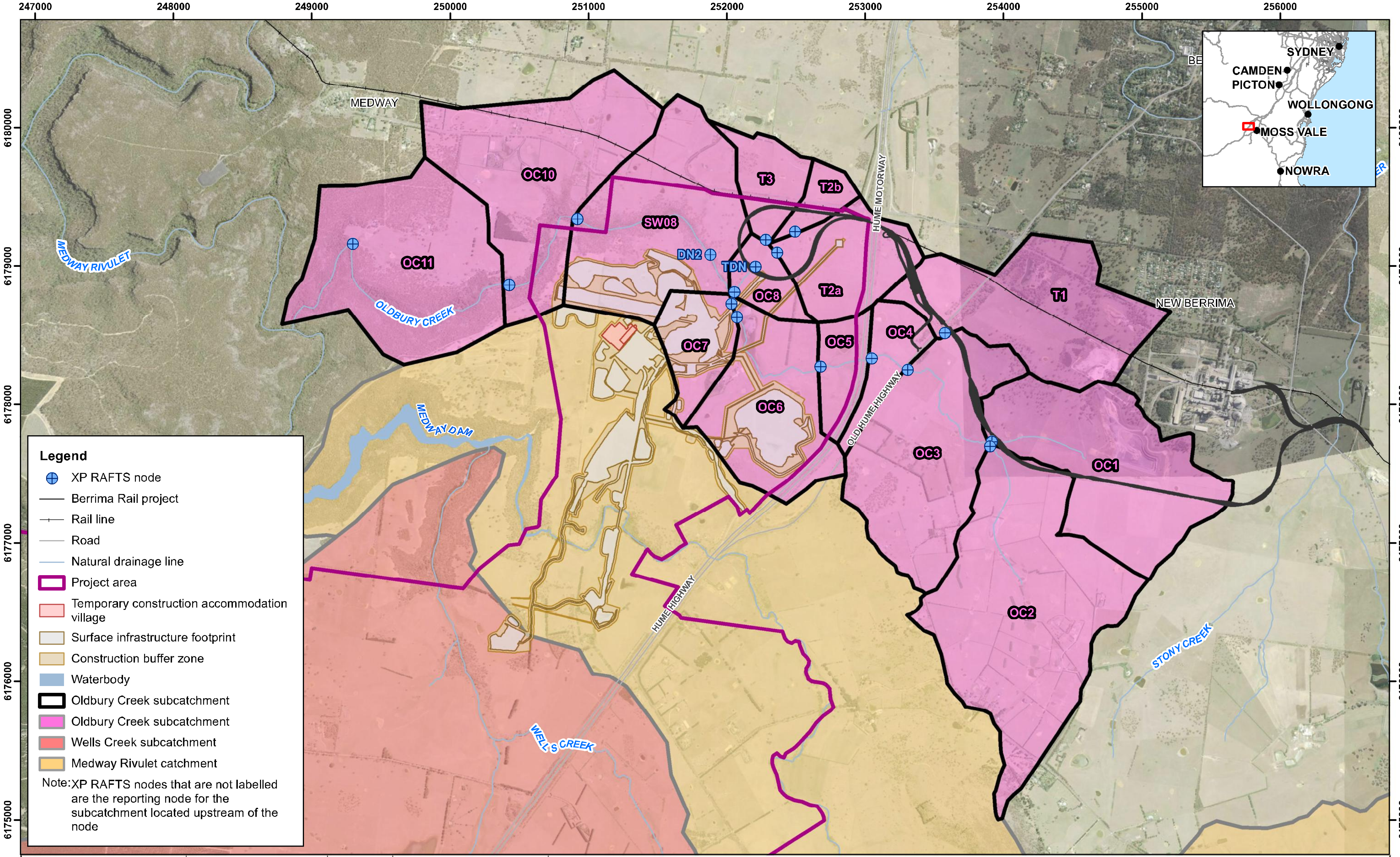
Figure 4.1

XP-RAFTS model layout - Medway Rivulet



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Date: 25/10/2016	Approved by: LR

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Coordinate system: GDA 1994 MGA Zone 56

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Figure 4.2

XP-RAFTS model layout - Oldbury Creek

4.1.3 Estimation of design rainfall

Design rainfall hyetographs for storm events up to the 100 year ARI were generated in XP-RAFTS using the IFDs (refer Section 3.2).

4.1.4 Probable maximum precipitation design rainfall

The parameters used in the PMP calculation for Medway Rivulet and Oldbury Creek are provided in Table 3.4 and the PMP rainfall depths are provided in Table 3.5. PMP rainfall depths were distributed into hyetographs using the GSDM temporal pattern for the 15 minute to 6 hour and the GSAM temporal pattern for the 24 hour to 96 hour events. The GSDM temporal pattern was used for the 12 hour event. These rainfall hyetographs were used as input to the XP-RAFTS models for the PMP rainfall event.

4.2 Model Calibration

Initial and continuing rainfall losses and B factor were adjusted within reasonable ranges based on values within AR&R (Engineers Australia 2001) until model calibration was achieved.

To achieve a reasonable calibration a B factor of 2.8 and initial loss of 20mm and continuing loss rate of 3.7 mm/hr were adopted for Medway Rivulet. For Oldbury Creek a B factor of 1.0 and initial loss of 20mm and continuing loss rate of 3.7 mm/hr were adopted.

The results from the calibration are presented in Figures 4.3 and 4.4. The results show that the models achieved a good predictive estimate of the observed event.

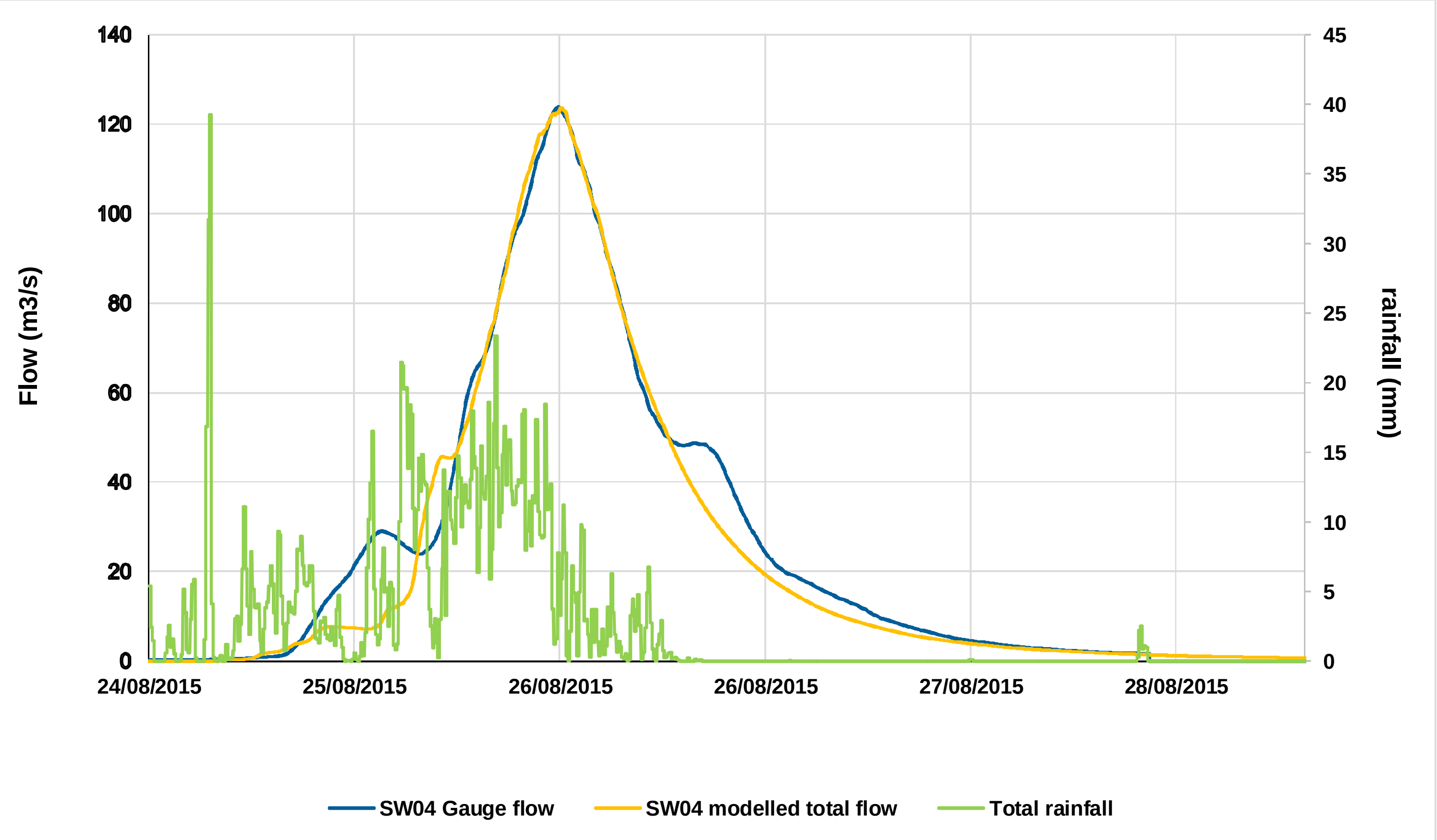


Figure 4.3 **Medway Rivulet XP-RAFTS calibration output**

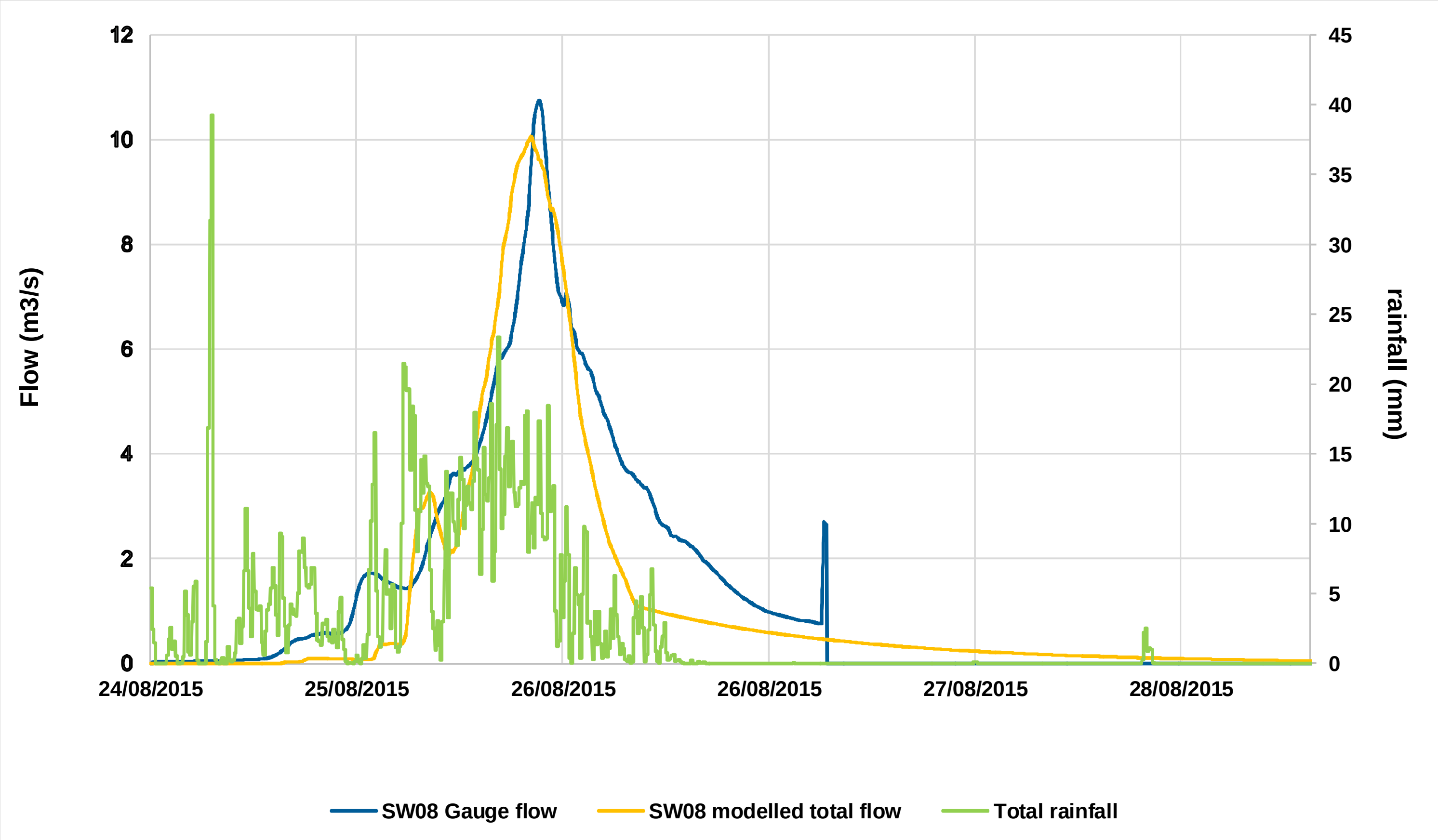


Figure 4.4 **Oldbury Creek XP-RAFTS calibration output**

4.3 Model check

A check of the hydrologic model was undertaken by comparing the model flow estimates against PRM calculations for the 5 year, 20 year and 100 year ARI events for Medway Rivulet. It was found that the model compared well to the PRM flow estimates for a B factor of 1.0 and did not compare well for the B factor of 2.8 that was used for calibration (Table 4.1).

Table 4.1 Validation of peak flows using PRM

Peak flow event	PRM flow estimates (m^3/s)	RAFTS B factor 2.8		RAFTS B factor 1.0	
		Flow estimates (m^3/s)	Difference to PRM (%)	Flow estimates (m^3/s)	Difference to PRM (%)
100 year ARI	691	287	-58	638	-8
20 year ARI	417	260	-38	443	+6
5 year ARI	259	150	-42	290	+12

4.4 Design event modelling

The rainfall losses used in calibration of the model were adopted for design event modelling. The high B factor used in calibration of the Medway Rivulet model was not adopted for design event modelling as it did not correlate well with the PRM flow estimates. Given that the calibration event was a relatively low order event (estimated to be a 1 year ARI event) there was no justification to adopt the B factor of 2.8 for design events of up to the 100 year ARI event. A B factor of 1.0 was therefore adopted for design event modelling of Medway Rivulet.

The adopted hydrological model parameters for design event modelling are provided in Table 4.2.

Table 4.2 Adopted loss and B factor values

XP-RAFTS input	Medway Rivulet and Oldbury Creek model values
Initial loss* (mm)	20
Continuing loss (mm/hr)	3.7
B factor	1.0
* Initial loss was set to zero in the PMP	

The Medway Rivulet and Oldbury Creek hydrologic models were run for the 5 year, 20 year and 100 year ARIs and the PMP rainfall events for the existing, operation and rehabilitation scenarios. The 5 year, 20 year and 100 year events were run for durations of 15 minutes to 48 hours, and the PMF event was run for durations up to 96 hours, in order to determine the critical duration for each event. Peak flows generated within the Medway Rivulet and Oldbury Creek catchments that are input to the hydraulic model are presented in Tables 4.3 and 4.4 along with the critical duration identified for each return period. Results indicate that the PMP critical duration for the Medway Rivulet catchment was the 4 hour event and for Oldbury Creek was the 2.5 hour event.

Table 4.3 Design peak flow results – Medway Rivulet

Model node	Peak flow (m^3/s)							
	Existing and rehabilitation cases				Operational case			
	5 year ARI (36 hr)	20 year ARI (36 hr)	100 year ARI (9 hr)	PMF (4 hr)	5 year ARI (36 hr)	20 year ARI (36 hr)	100 year ARI (9 hr)	PMF (4 hr)
MW6	157.6	239.5	367.1	1,612.0	157.6	239.5	367.1	1,612.0
Junction 1	175.8	268.3	411.9	1,771.3	175.8	268.3	411.9	1,771.3
MW1 local + US flow (half MW2 local + Junction1 total)*	184.2	280.7	433.0	1,853.0	183.7	279.7	432.0	1,851.8
MW2 total	266.3	406.1	584.4	2,407.7	265.8	405.1	583.0	2,399.9
MW3	1.7	2.5	5.1	16.1	1.7	2.5	5.1	16.1
MW1	6.1	8.9	15.9	57.4	5.5	7.9	14.6	57.4
Wells Creek	97.6	146.1	243.6	1,002.6	97.6	146.1	243.6	1,002.6
MW2 local	4.7	7.1	10.4	48.5	4.7	7.1	10.9	46.0

Notes:
The table only shows model node flows (or combinations of flows) that are input to the hydraulic model.
**This combination of flows is calculated to provide flow input to the hydraulic model at this location.*
Local flow from a model node is the flow from the sub-catchment represented by that node; total flow at a model node is the cumulative flow from all upstream sub-catchments to that node.

Table 4.4 Design peak flow results – Oldbury Creek

Model node	Peak flow (m^3/s)							
	Existing and rehabilitation cases				Operation case			
	5 year ARI (9 hr)	20 year ARI (9 hr)	100 year ARI (9 hr)	PMF (2.5 hr)	5 year ARI (9 hr)	20 year ARI (9 hr)	100 year ARI (9 hr)	PMF (2.5 hr)
OC2	9.3	14.2	19.6	166.1	9.3	14.2	19.6	166.1
T3	2.0	2.7	3.6	26.8	2.0	2.7	3.6	26.8
OC1	6.9	10.2	13.9	113.9	6.9	10.2	13.9	113.9
OC4	28.6	42.3	57.2	484.6	28.6	42.3	57.2	484.6
DN2	29.3	50.5	73.9	671.4	27.4	47.9	70.1	641.8
SW08	32.9	56.8	83.2	753.9	30.2	52.8	77.2	707.1
T2a	3.2	4.6	6.1	49.4	3.2	4.6	6.1	49.4
TDN	6.1	8.6	11.3	88.8	6.1	8.6	11.3	88.8
OC8	7.3	10.5	13.7	107.1	7.4	10.5	13.7	107.0
T2b	1.0	1.4	1.9	13.7	1.0	1.4	1.9	13.7
T1	5.1	7.7	10.3	86.3	5.1	7.7	10.3	86.3
OC7	2.3	3.3	4.3	33.6	1.2	1.6	2.1	16.1

Notes:
The table only shows model node flows that are input to the hydraulic model.

5. Hydraulic analysis

HEC-RAS hydraulic models were developed for Medway Rivulet, Oldbury Creek and their tributaries to assess extreme flood levels in the project area. This section describes the set-up of the hydraulic model and the key parameters specified in the model. The results from the hydraulic analysis are presented in Section 6.

HEC-RAS is a one-dimensional hydraulic model that can simulate steady or unsteady flow in rivers and open channels. The river channel and floodplain is represented in HEC-RAS as a series of topographic cross-sections. The model can assess the effects of obstructions, such as bridges, culverts, weirs, and structures in the channel and floodplain.

5.1 Cross-section geometry

A DTM covering the extent of the hydraulic models was constructed using LiDAR data from 25 October 2013 (see Section 3.1).

Cross-sections of the river channel and floodplain were extracted from the DTM approximately every 100 m along the length of Medway Rivulet and Oldbury Creek and minor tributaries. Cross-sections were added to locations where there is hydraulic constraint, such as road crossings, to ensure all topographical features critical to hydraulic conveyance characteristics of the waterways are captured in the model. Cross-sections varied in length from about 300 m to 1500 m depending on the depth and size of the channel and width of floodplain. Junctions were modelled where tributaries join main channels and equal water levels were assumed across the junctions. Figures 5.1 and 5.2 show the modelled reaches and cross-sections.

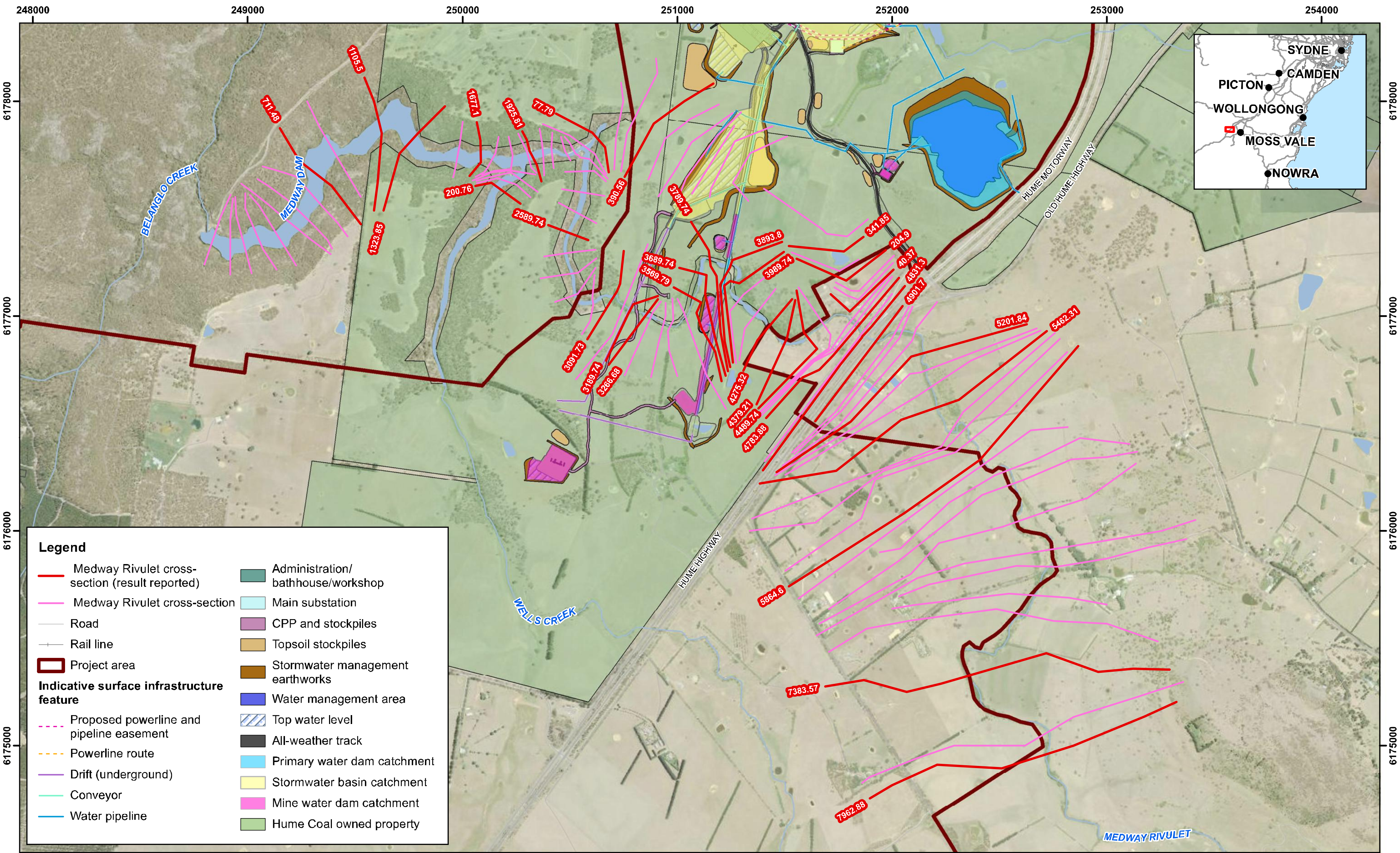
Detailed cross-sections at stream gauge SW04 were surveyed by Xylem in 2013 and MHL in 2015. Cross-sections at stream gauge SW08 were surveyed by MHL in 2015. Cross-section surveys were undertaken at the control and at the pool where the gauge is located. These cross-section surveys aim to measure low to medium flow, so their applicability to flood modelling is limited. However, the cross-sections at each of the surface water gauge locations were added into the HEC-RAS models to add more detail to the model for the development of rating curves and calibration of the hydrologic model (refer Section 3.5).

5.2 Boundary conditions

Inflows were assigned to reaches of the hydraulic model for each stream/tributary, based on the flow outputs of the hydrologic model (refer Tables 4.3 and 4.4).

The downstream limit of the hydraulic model for Medway Rivulet is located downstream of Medway Dam. The model was run using a normal depth boundary based on a downstream channel slope of 0.8%, determined using the DTM. Since the 25 m high spillway and dam wall of Medway Dam is the hydraulic control of the water level upstream of the dam, the hydraulic model is not sensitive to the downstream boundary conditions assumption.

A normal depth boundary condition was applied at the downstream end of the Oldbury Creek model at a location sufficiently far downstream of the study area so that the effect of hydraulic change is fully realised within the modelled extent. A channel slope of 0.07% was determined using the DTM.



Map: 2200540A_GIS_021_B4	Author: RP
Date: 24/10/2016	Approved by: LR

Data source: © Land and Property Information 2015, Hume Coal

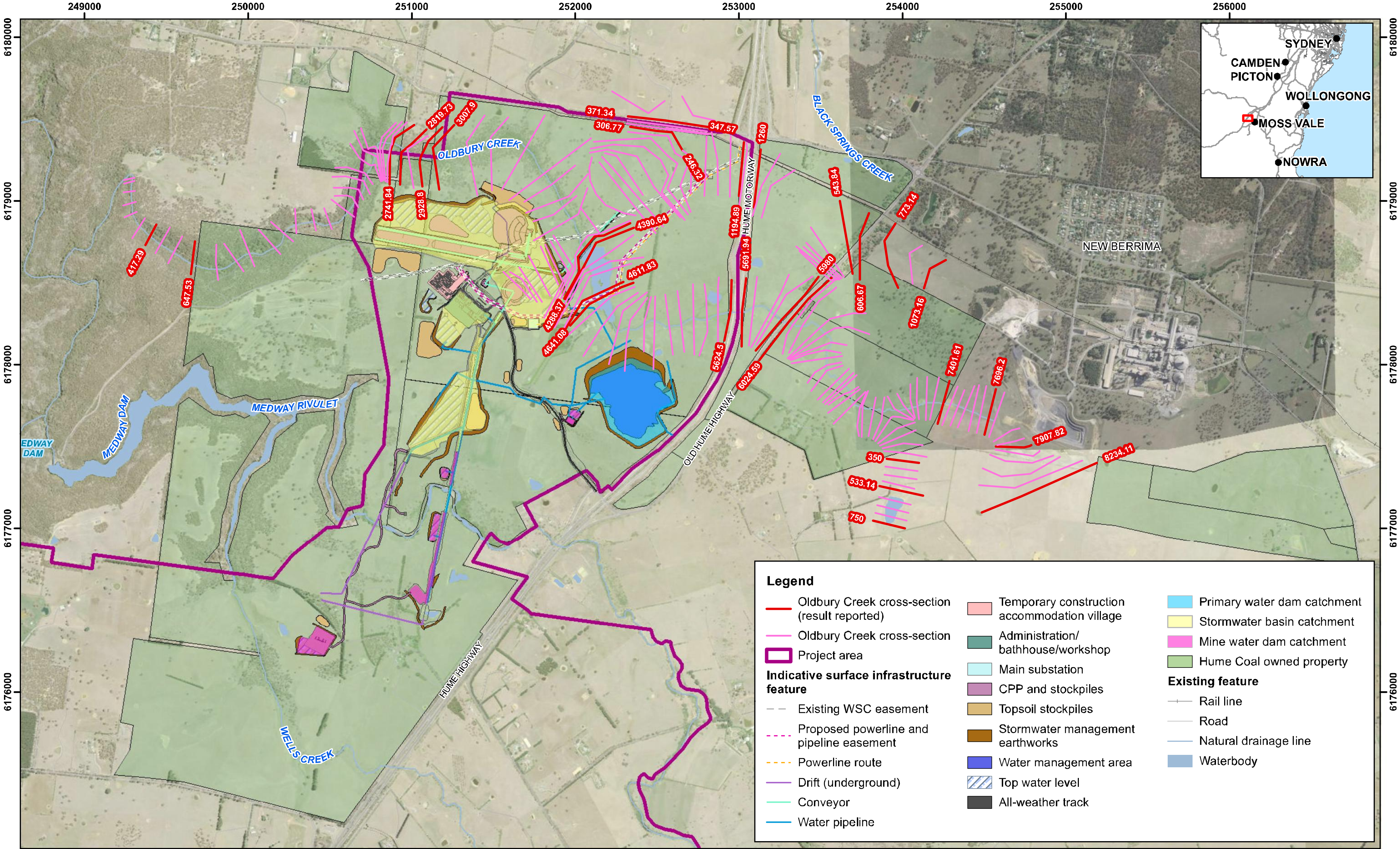
0 250 500 m

1:16,000

Coordinate system: GDA 1994 MGA Zone 56

Scale ratio correct when printed at A3

Hume Coal Flooding Assessment
Figure 5.1
Medway Rivulet cross-sections



Map: 2200540A_GIS_022_B4	Author: RP
Date: 14/11/2016	Approved by: LR

Data source: © Land and Property Information 2015, Hume Coal

0 250 500 m

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Coordinate system: GDA 1994 MGA Zone 56

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Figure 5.2

Oldbury Creek cross-sections

5.3 Hydraulic roughness

Manning's *n* roughness parameters are used to represent the type of channel and varying land cover across a floodplain to allow the model to simulate changes in flow behaviour as water crosses different surfaces. Each cross-section is assigned Manning's *n* roughness values based on the channel characteristics and land cover across the floodplain. The Manning's *n* values adopted for the modelled channels and overbank sections were based on knowledge of the site developed during site inspections, aerial photograph interpretation and engineering judgement and experience.

The predominant Manning's *n* values adopted in the Medway Rivulet and Oldbury Creek hydraulic models for the channel and overbank areas are given in Table 5.1. In some sections more vegetation / trees were evident in the channel when compared to the cleared agricultural land in the adjacent overbank areas and in these cases the Manning's *n* value was set higher in the creek channel than in the overbank.

Table 5.1 Manning's n values used in HEC-RAS models

Location	Description	Manning's *n*
In channel	Eroded gully	0.035
	Grassed channel, clean and straight	0.035-0.04
	Grassed channel with some pools and shoals	0.04
	Channel with some vegetation	0.05
	Densely vegetated with deep pools	0.08
Overbank areas	Short grass	0.035
	Mature crop field	0.04
	Light bush and trees	0.05
	Dense vegetation/ trees	0.10

5.4 Modelled scenarios

The Medway Rivulet and Oldbury Creek models were run for the 2 year, 5 year, 100 year ARI and PMF events for the existing, operation and rehabilitation scenarios detailed in Section 4.

The surface infrastructure will generally remain the same throughout mine operation. A layout with the maximum footprint and elevation has been considered for the purposes of assessing potential worst case flooding impacts.

Flood modelling has not been undertaken for the construction phase as the layout of temporary construction facilities will generally match the surface infrastructure layout used during operations. The temporary accommodation village is proposed only during the construction phase of the project and will not be used during the operation phase. The temporary village has not been assessed as it will be located on a ridge immediately to the south of the CPP precinct and will not impact on flooding regimes in Medway Rivulet.

5.5 Modelled structures

5.5.1 Existing structures

The HEC-RAS model for Medway Rivulet included the following existing structures:

- Medway Dam, located on Medway Rivulet downstream of the surface infrastructure area
- The ‘Three Legs O’Man Bridge’ located where the Hume Highway crosses Medway Rivulet upstream of the surface infrastructure area.

The HEC-RAS model for Oldbury Creek included the following existing structures:

- the two inline storages and associated embankments on Oldbury Creek downstream of the proposed rail infrastructure
- the box culverts located where the Hume Highway crosses Oldbury Creek downstream of the proposed rail infrastructure
- the plank bridge located where the Old Hume Highway crosses Oldbury Creek downstream of the proposed rail infrastructure
- the culverts located where Medway Road crosses the tributaries of Oldbury Creek north of the proposed rail loop
- the culverts located where the old rail embankment near Medway Road crosses the tributaries of Oldbury Creek north of the proposed rail loop
- the culvert located where the Hume Highway crosses a tributary of Oldbury Creek to the east of the proposed rail loop

Details of these structures are provided in Appendix B.

5.5.2 Proposed structures

The proposed structures associated with the operation scenario are described in Table 5.2. There are no proposed structures for the rehabilitation scenario.

Table 5.2 Proposed structures modelled

Waterway	Crossing type and location	Design option	Proposed structure
Medway Rivulet	Road between the conveyor drift and ventilation shaft	Hume Coal Project	17 x 1800 mm x 1200 mm Reinforced Concrete Box Culvert (RCBC)