Proposed cemetery site, Old Cooma Road

Hydrological assessment

Prepared for
Queanbeyan-Palerang Regional Council

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Abbreviations, acronyms and initialisms

Abbreviation	Description
AEP	Annual Exceedance Probability
AIP	Aquifer Interference Policy
ARI	Annual Recurrence Interval
BoM	Bureau of Meteorology
ELA	Eco Logical Australia Pty Ltd
GDE	Groundwater Dependent Ecosystems
HEC-RAS	Hydrologic Engineering Centre's River Analysis System
IFD	Intensity-Frequency-Duration
MDB	Murray Darling Basin
NOW	NSW Office of Water (now DPI Water)
QPRC	Queanbeyan-Palerang Regional Council
RFFE	Regional Flood Frequency Estimation
WSP	Water Sharing Plan

Executive summary

Eco Logical Australia (ELA) has been engaged by the Queanbeyan-Palerang Regional Council (QPRC) to undertake a hydrogeological and hydrological review and constraints assessment for the proposed development and use of a cemetery site located within Lot 2 (DP112382) and Lot 126 (DP754881) of Old Cooma Road, Queanbeyan.

The assessment was undertaken to identify any potential hydrological and hydrogeological impacts and impacted areas to assess the suitability of the site for the proposed activity. In addition to a desktop review and data search, drainage and flood modelling was undertaken to assess potential flood constraints for the project.

The project area is located within the Murrumbidgee River catchment. The proposed development Site contains a section of Church Creek, a creek line that drains local farmland and a new housing development currently under development. There are no other major creek lines within the study area. Overland flow paths, however, exist from culverts that drain the roads surrounding the site.

Sheet flow from surface water run-off during large rainfall events may potentially cause impacts in isolated areas. These are unlikely to pose a risk to the site with appropriate stormwater management. Aside from the potential for overland flow downstream of the road culverts, the Site is not expected to be significantly affected by flooding; hydrological and hydraulic modelling indicates that with the exception of the area immediately adjacent to Old Cooma Road, flows in the creek are likely to be retained within the existing banks up to at least the 1% Annual Exceedance Probability design event.

Whilst no groundwater level or quality data is reported from a high-level assessment of available national databases, numerous (38) registered local stock and domestic bores do exist, though all tap deep (>20m) groundwaters in the underlying fractured rock systems. Ten shallow auger holes, drilled to a depth of 3.5 m below ground surface within the study area during a recent geotechnical investigation, did not encounter groundwater (ACT Geotechnical Engineers, 2017) and risk to and from local groundwater resources is not predicted to occur, based on a qualitative assessment.

No potentially significant aquatic or terrestrial groundwater dependent ecosystems were identified within a 2 km buffer of the study area and the project is determined to pose minimal risk as defined by the NSW Aquifer Interference Policy.

1 Introduction

Eco Logical Australia (ELA) has been engaged by the Queanbeyan-Palerang Regional Council (QPRC) to undertake a hydrogeological and hydrological review and constraints assessment for the proposed development and use of a cemetery site located within Lot 2 (DP112382) and Lot 126 (DP754881) of Old Cooma Road, Queanbeyan (**Figure 1-1**).

The assessment was undertaken to identify any potential hydrological and hydrogeological impacts and impacted areas to assess the suitability of the site for the proposed activity.

1.1 Project Background

The Queanbeyan Lanyon Drive Cemetery currently services the Queanbeyan region and is expected to reach capacity during the next five years, based on a forecasted population growth of approximately 36% by 2031 (QPRC, 2017). The Queanbeyan region includes the main growth centres of Googong, Tralee/South Jerrabomberra and infill units in Queanbeyan (QPRC, 2017).

To meet the future cemeterial needs of the region, the Queanbeyan-Palerang Regional Council (QPRC) has been engaged in a process of strategic planning to identify a new cemetery site, as well as undertaking works to prolong the serviceability of the existing Lanyon Drive Cemetery. As part of the planning proposal for the new cemetery site, QPRC is required by the New South Wales Department of Planning and Environment (DPE) to undertake background studies to characterise the existing environment at the site and identify potential areas that may impact upon the proposed development.

1.2 Study Area

The study area is approximately 36.4 hectares and is located approximately 11 kilometres south-west of Queanbeyan, and approximately 5 km west of the Queanbeyan River (**Figure 1-1**). The site is triangular in shape and bounded by Old Cooma Road to the west and Burra Road to the east. The Burra Road – Old Cooma Road intersection is located at the northern point of the site.

The site is currently used for grazing and agricultural purposes and has been farmed since the 1800's (QPRC, 2017). An existing dwelling is located near the centre of the site. Outside the site, the surrounding area comprises land that is zoned for environmental living purposes with the Mount Campbell community title development located to the west of the site, containing dwellings on smaller rural lots (QPRC, 2017).

1.3 Objectives of the assessment

The objectives of this assessment are to identify any potential hydrological and hydrogeological constraints with the proposed site use and provide advice on the assessment and management of such issues. Issues identified through this assessment are documented with:

- A clear description of the potential issue or impact.
- Presentation of the potential issue or impact (as needed).
- Assessment of the potential issue or impact
- Identification of options to address / mitigate the potential issue or impact.
- Suggestion of aspects that need to be considered in the final design to avoid the potential issue or impact.
- At the completion of the study, a final recommendation on the suitability of the site for the proposed use.

Figure 1-1: Study Area (the line across the top shows two lots associated with this site)

2 Statutory requirements

The following sections detail the relative State legislative requirements for the Project, applied to hydrological and hydrogeological aspects.

2.1 *Environmental Planning and Assessment Act 1979* (EP&A Act)

The EP&A Act is the principal planning legislation for NSW, providing a framework for the overall environmental planning and assessment of development proposals. A variety of other legislation and environmental planning instruments, such as the *Water Management Act 2000* are integrated with the EP&A Act.

Section 9.1 (formerly S117) Direction 4.3 Flood Prone Land provides that a draft Local Environmental Plan (LEP) shall not rezone land within flood planning areas from Special Area, Recreation, Rural or Environmental Protection Zones to a Residential, Business, Industrial or Special Area Zone, unless the relevant planning authority can satisfy the Director General that the planning proposal is in accordance with a floodplain risk management plan, or the provisions of the planning proposal that are inconsistent are of minor significance.

2.2 *Water Management Act 2000* (WM Act)

The main objective of the WM Act is to manage NSW water in a sustainable and integrated manner that will benefit current generations without compromising future generations' ability to meet their needs. The WM Act is administered by DPI Water and establishes an approval regime for development on waterfront land, defined as the land 40 m from the highest bank of a river, lake or estuary.

Section 91E of the Act creates an offence for carrying out a controlled activity within waterfront land without approval. According to Section 38 of the *Water Management (General) Regulations 2011*, a public authority is exempt from Section 91E of the Act. Therefore, if works are undertaken under Part 5 of the EP&A Act then a Controlled Activity Approval (CAA) will not be required. If works are undertaken under Part 4 of the EP&A Act however, then development within 40 m will require a CAA and DPI Water may also require a Vegetation Management Plan (VMP) to be prepared.

The Act also recognises the need to allocate and provide water for the environmental health of the State's rivers and groundwater systems, whilst also providing licence holders with more secure access to water and greater opportunities to trade water through the separation of water licences from land. The main tools within the Act for managing the State's water resources are Water Sharing Plans (WSPs), which establish rules for sharing water between different water uses such as town supply, rural domestic supply, stock watering, industry and irrigation and ensures that water is provided for the health of the system.

The following WSPs (Murrumbidgee Water Management Area) have been identified as relevant to surface water and groundwater environments within the subject lots:

- Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources (2011) and
- Water Sharing Plan for the Murrumbidgee Unregulated and Alluvial Water Sources (2012, current version January 2017 to date)

The Queanbeyan Water Source in *Unregulated Murrumbidgee Above Burrinjuck Dam Extraction Management Unit* forms part of the NSW Murrumbidgee Unregulated and Alluvial Water Sources WSP.

The Queanbeyan River is a major river system in this area and one of the seven surface water sources within the WSP area identified as having high instream values, i.e. likelihood of presence of known and expected threatened species. Some of these threatened species are highly sensitive to low flow extraction, whilst other threatened species, such as plants that occur in the riparian zone, are less sensitive. The shallow alluvial aquifer associated with surface water drainage lines within the site area can also be identified as potentially being impacted in relation to impacts on groundwater level and quality due to the possibility of excavations intercepting the water table (construction dewatering if required, contaminants from construction equipment etc.) during construction works.

The Murrumbidgee Unregulated River WSP also includes rules on the location of new works and extraction from existing works to protect high priority groundwater dependent ecosystems (GDE), high priority karst systems and other environmentally sensitive areas and provides conditions on works undertaken in the vicinity of GDEs.

The Aquifer Interference Policy (AIP) was established to define the assessment process for development applications in terms of their potential impacts on aquifers, to clarify the requirements for obtaining water licenses for aquifer interference activities, and to define the considerations for assessing potential impacts on key water-dependent assets. The policy focuses on activities that remove water from aquifers for non-water supply purposes.

The WM Act defines an aquifer interference activity as that which involves any of the following:

- The penetration of an aquifer.
- The interference with water in an aquifer.
- The obstruction of the flow of water in an aquifer.
- The taking of water from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations.
- The disposal of water taken from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations.

The AIP clarifies water licensing requirements and details how these potential interference activities will be assessed under relevant planning and approvals processes. The policy provides ‘minimal impact considerations’ to evaluate potential impacts on groundwater levels, pressures, and quality for different categories of groundwater sources. The policy also includes provisions for water take from a source following the cessation of the aquifer interference activity.

According to the AIP, a water licence is required under the WM Act (unless an exemption applies, or water is being taken under a basic landholder right) where any act by a person carrying out an aquifer interference activity causes:

- the removal of water from a water source; or
- the movement of water from one part of an aquifer to another part of an aquifer; or
- the movement of water from one water source to another water source, such as:
    - from an aquifer to an adjacent aquifer; or
    - from an aquifer to a river/lake; or
    - from a river/lake to an aquifer.

According to the AIP, the assessment of impacts on surface water sources, groundwater and GDEs is based on the project proponents’ ability to demonstrate:

1. The capacity to obtain the necessary licences to account for the take of water from a given source, or if licences are unavailable, that the Project has been designed to prevent the take of water;
2. That adequate arrangements will be in place to meet the ‘minimal impact considerations’ defined in the policy; and
3. Proposed remedial actions for impacts greater than those that were predicted as part of the relevant approval.

The ‘minimal impact considerations’ provided in the AIP have been developed for impacts on groundwater sources, connected water sources, and their dependent ecosystems, culturally significant sites and water users. These considerations are defined for ‘highly productive’ and ‘less productive’ groundwater sources, both of which are further grouped into categories according to aquifer type (e.g. alluvial, coastal sands, fractured rock, etc.). Two levels of ‘minimal impact considerations’ are provided, and if the predicted impacts are less than the Level 1 impact considerations, the impacts from the project would then be considered acceptable. If the predicted impacts are greater than the Level 1 considerations, studies would be required to fully assess these impacts.

For the purposes of this study, a desk-top assessment of the potential impact of the proposed works on the Lachlan Fold Belt MDB Groundwater Source (which forms part of the Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources, 2011) and Alluvial Water Sources (Water Sharing Plan for the Murrumbidgee Unregulated and Alluvial Water Sources, 2012) has been undertaken based on the criteria described in the AIP and re-produced in **Table 2-1**.

Table 2-1: Minimal Impact Considerations for Aquifer Interference Activities (Level 1)

<table>
<tr><th>Aquifer</th><th>Water table</th><th>Water pressure</th><th>Water quality</th></tr>
<tr><td>Alluvial Water Sources</td><td rowspan="2">Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic “post-water sharing plan” [1] variations, 40m from any high priority groundwater dependent ecosystem or high priority culturally significant site listed in the schedule of the relevant water sharing plan;

or

A maximum of a 2 m decline cumulatively at any water supply work.</td><td>A cumulative pressure head decline of not more than 40% of the post-water sharing plan” pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.</td><td rowspan="2">(a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity; and

(b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity.

Redesign of a highly connected[2] surface water source that is defined as a “reliable water supply” [3] is not an appropriate mitigation measure to meet considerations (a) and (b) above.</td></tr>
<tr><td>Lachlan Fold Belt MDB Groundwater Source</td><td>A cumulative pressure head decline of not more than 40% of the “post-water sharing plan” pressure head above the top of the relevant aquifer[4] to a maximum of a 3 m decline, at any water supply work.</td></tr>
</table>

1 “post-water sharing plan” – refers to the period after the commencement of the first water sharing plan in the water source, including the highest pressure head (allowing for typical climatic variations) within the first year after commencement of the first water sharing plan;

2 “Highly connected” surface water sources are identified in the Regulations and will be based those determined during the water sharing planning process;

3 “Reliable water supply” is as defined in the SRLUP

4 “relevant aquifer” in relation to alluvial water sources is defined in the relevant WSP and relates to that part of the aquifer that can be utilised for productive purposes.

2.3 *Fisheries Management Act 1995* (FM Act)

The FM Act provides for the protection, conservation, and recovery of threatened species defined under the Act. It also makes provision for the management of threats to threatened species, populations, and ecological communities defined under the Act, as well as the protection of fish and fish habitat in general. In particular, the FM Act has mechanisms for the protection of mangroves, seagrasses and seaweeds on public water, land and foreshores. It is an offence to harm marine vegetation without a permit from NSW Department of Industry and Investment (Fisheries).

None of these protected matters are present onsite are therefore do not represent constraints to development, however, DPI Water have mapped Church Creek within the site as Key Fish Habitat. Where possible, future works should avoid disturbances to the creek bed and bank including riparian vegetation to protect Key Fish Habitat. Any future works under Part 4 of the EP&A Act involving the dredging of the creek bed, land reclamation, excavations to the bed or bank or obstruction of fish passage may require a Part 7 Permit under the FM Act and consultation with DPI Water. For works under Part 5 of the EP&A Act clauses 199 and 200 of the Act apply depending on whether dredging or reclamation works are being undertaken by or on behalf of a council or a pubic authority other than a council. Clauses 199 and 200 specify where a permit is required and where notification to the Minister is required.

2.4 NSW Government Flood Prone Land Policy

The primary objective of the NSW Government Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible.

The Policy devolves the management of flood prone land, primarily, to local government. The Floodplain Development Manual 2005 has been prepared by the government to guide councils in the implementation of the Policy. In addition, the NSW Department of Planning and Environment has a lead role in the development of regional strategies and plans under the EP&A Act and therefore Councils need to be cognisant of regional strategies and plans, when determining standards and implementation arrangements for flood prone land in their service areas.

The flood modelling described in this report confirms flood extents and allow the placement of proposed development features that need to be clear of surface water flows.

2.5 Queanbeyan Local Environmental Plan 2012

The Queanbeyan LEP (2012) makes local environmental planning provisions for land in the Queanbeyan-Palerang Regional Local Government Area (LGA) in accordance with the relevant standard environmental planning instrument under section 3.20 of the EP&A Act.

The subject lots are located on land which is currently zoned as E4 Environmental Living. Council has prepared a planning proposal to allow for a cemetery on the subject land. This requires the definition of ‘cemetery’ to be added to Schedule 1 Additional Permitted Uses as this land use is otherwise prohibited in the E4 Environmental Living zone. This will be done as an amendment to the Queanbeyan Local Environmental Plan 2012.

Pursuant to clause 7.2 the objectives of the LEP with regards to flood planning include minimising the flood risk to life and property associated with the use of land, allowing development on land that is compatible with the land’s flood hazard and taking into account climate change and avoiding significant adverse impacts on flood behaviour and the environment. The clause applies to land at or below the flood planning level. For the purposes of the LEP, “land at or below the flood planning level” means the level of a 1:100 ARI (Average Recurrence Interval) flood event plus 0.5 metres freeboard as described in the modelling results, including flood planning levels, described in this report.

Pursuant to clause 7.4 the objective of the LEP with regards to riparian land and watercourses includes protecting and maintaining water quality within water courses, stability of bed and banks, aquatic and riparian habitats and ecological processes. This clause applies to land identified as “Watercourse” on the Riparian Lands and Water Courses Map and all land within 40 m of the top of the bank of each watercourse on that land. Before determining a development application, council must consider all potential adverse impacts to riparian and watercourses, whether the development is likely to increase water extraction and any appropriate measures to avoid minimise and mitigate impacts of the development. Church Creek which flows through the Site is also marked on the LEP Riparian and Watercourses Map.

3 Methodology

This hydrology and hydrogeology assessment was undertaken using the steps outlined in the sections below covering:

- Data collation and review;
- Site conceptualisation;
- Hydrological and hydraulic modelling; and,
- Environmental constraints assessment.

3.1 Data collation and review

Data was collated from several online sources, including spatial databases, the Bureau of Meteorology (BoM) and government legislative sites. Data was categorised as:

- General information;
- Groundwater information; or,
- Surface water information.

The general information included spatial datasets, climate data and any relevant reports or associated project data.

Groundwater information consisted of the current NSW legislation data sets and any previous hydrogeological studies in the area. Online databases were also accessed to identify existing groundwater use in the area and the locations of any significant/registered groundwater dependent ecosystems (GDEs). Surface water information included any relevant previous studies and collated hydrological data, such as contour information and watercourses.

The following data sources were interrogated during this assessment:

- Previous studies, including but not limited to:
    - Groundwater Report on Beatty Hill, Old Cooma Road Development Application, 2001, Hyrdroilex Geological Consultants
    - Geotechnical Investigation Report, 1241 Old Cooma Road, Googong, NSW, ACT Geotechnical Engineers, 2017, Geotechnical Engineers Pty Ltd,
    - Flood analysis and concept culvert design, Rural Residential Subdivision, Burra Road, Mount Pleasant, 2015, CIC Australia P/L.
- Intensity-Frequency-Duration (IFD) information, Bureau of Meteorology
- NSW Office of Water (NOW) PINNEENA Groundwater database;
- Bureau of Meteorology (BoM) Groundwater Explorer database; and
- BoM GDE Atlas.
- Local contour maps

The above information was synthesised to aid in the development of the site conceptualisation and environmental constraints assessment. The outcomes are discussed in **Section 4**.

3.2 Site conceptualisation

A conceptual understanding of the site was developed as part of the desktop study. The conceptualisation incorporated hydrological systems, hydrogeological systems and any existing human or environmental receptors (determined through the data collation and review stage). The outcome of this conceptualisation is discussed in **Section 4.1**

3.3 Hydrological and hydraulic modelling

To categorise the existing design flood conditions from Church Creek at the site, the use of regionalised flood models was required as no appropriate water level or flow information exists in or near the catchment of interest. The flood volumes and levels were determined using a combination of models that build on each other. Thus, the Regional Flood Frequency Estimation (RFFE) model (University of Western Sydney) provides representative runoff rates to calibrate the RORB model in the absence of local gauged data. The RORB model generates likely flow conditions for designated drainage lines which are fed in to the HEC-RAS model together with local site information (e.g. land cover) to calculate water level conditions and hence potential for flooding as defined by over-banking under specific rainfall conditions.

3.4 Environmental constraints assessment

The environmental constraints assessment utilised the site conceptual model as well as various other data sources to identify potential areas of concern or limitations to be considered. Constraints that were examined included water quality, water quantity, groundwater flows and flood behaviour. Constraints were categorised according to risk and gaps in the available data requiring further investigation were identified.

4 Existing environment

4.1 Site conceptualisation

Church Creek is a third order watercourse within the Project Site marked on the LEP Riparian and Watercourses Map, that crosses the site from the south to the west (**Figure 4-2**). The creek receives discharge from several smaller tributaries, and the flow direction is to the north-west. There are a number of other smaller non-defined overland flow paths that cross the site from culverts under the roads that border the site.

Two other unnamed first and second order water courses have also been mapped from the local contour maps as feeding into Church Creek (shown in **Figure C-1** in Appendix C) however it is unclear if these watercourses actually exist or if they meet the definition of a river under the WM Act. Further site survey and Top of Bank mapping would be required to confirm which watercourses within the subject lots meet the definition of a river under the Act.

The Guidelines for Riparian Corridors on Waterfront Land (DPI Water) recommends Vegetated Riparian Zones (VRZs) have a width based on watercourse order as classified under the Strahler System. The width of the VRZ should be measured from the top of highest bank on both sides of the water course. **Table 4-1** below lists DPI Water recommended riparian corridor (RC) widths based on Strahler Stream Order.

Table 4-1: Recommended riparian corridor (RC) widths

Watercourse type	VRZ width	Total RC width
1st order	10 metres	20 m + channel width
2nd order	20 metres	40 m + channel width
3rd order	30 metres	60 m + channel width
4th order and greater	40 metres	80 m + channel width

A review of the NSW Office of Water (NOW) surface water database identified no registered stream flow monitoring gauges near the site, with the closest stream gauge (# 410770) located on the Queanbeyan River at the ACT border (approximately 12.5 km north of the Project site).

Groundwater flow dynamics in the study area are also not fully delineated as no active monitoring bores could be identified in or around the study area to allow for monitoring of groundwater levels. However, there is an old well located on the site that may have been used as a water source in the past.

Aspects of this conceptualisation are discussed in greater detail in the sections below.

4.1.1 Climate

Rainfall and temperature data was obtained from the Bureau of Meteorology (BoM) online climate database for the Tuggeranong (Isabella Plains) AWS (BoM site 070339) located approximately 10.2 km west of the study area. The regional climate is categorised as cool temperate, with year-round rainfall (average annual rainfall 631.3 mm) with a seasonal distribution showing greater rainfall in the summer months (**Figure 4-1**). Mean maximum temperatures range from 11.8 °C in July to 29 °C in January (**Figure 4-1**).

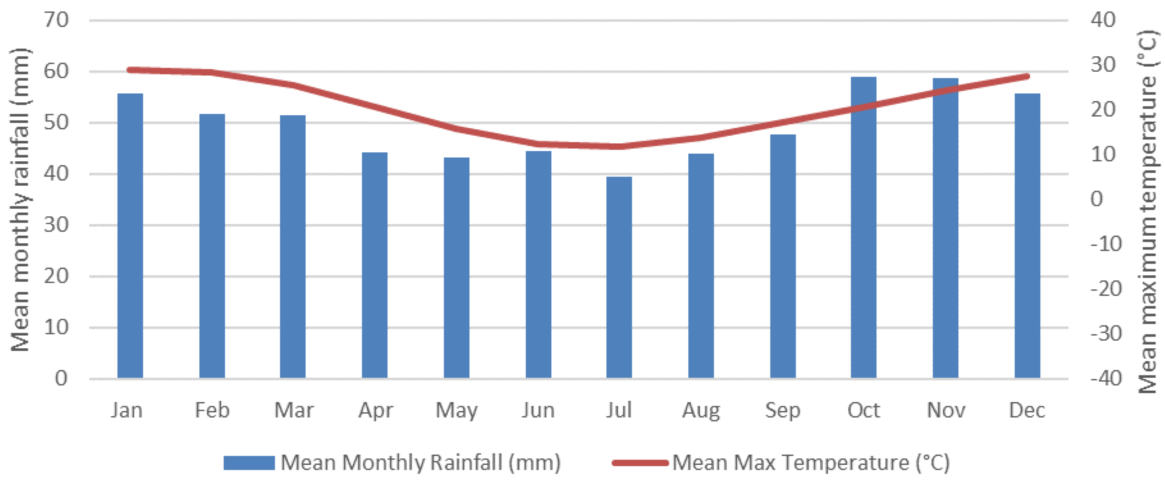


Figure 4-1: Monthly rainfall and temperature near the study area

4.1.2 Hydrology

The study area falls within the Murrumbidgee catchment (**Figure 4-2**). The Church Creek passes through the southern portion of the site in a south-east to north-west direction that drains local farmland (and a soon to be constructed housing development (**Figure 4-2**).

Sheet flow from surface water run off during rainfall events may potentially cause impacts in isolated areas and may enhance local recharge to any perched water tables.

4.1.1 Regional geology

The regional geological setting of the property is shown in **Figure 4-3**. The study area is located within a complex structural corridor within rock sequences of Silurian age, regionally described as the Canberra Graben. This structural feature is bounded to the west by the Murrumbidgee Batholith, comprised of granodioritic intrusives, and to the east by the Cullarin Horst, a complex geological province represented by deformed Ordovician-aged sediments intruded by granites (HGC, 2001).

The 1:100,000 Canberra Geology map indicates that the site is located mostly on the Colinton Volcanics bedrock, with a small part south of the study area located on the Williamsdale Volcanics. Two faults separate the Colinton Volcanics from the Deakins Volcanics approximately 3.5 km west and from Cappanana formation approximately 4 km east of the study area.

Figure 4-2:Catchment and watercourses in the study area

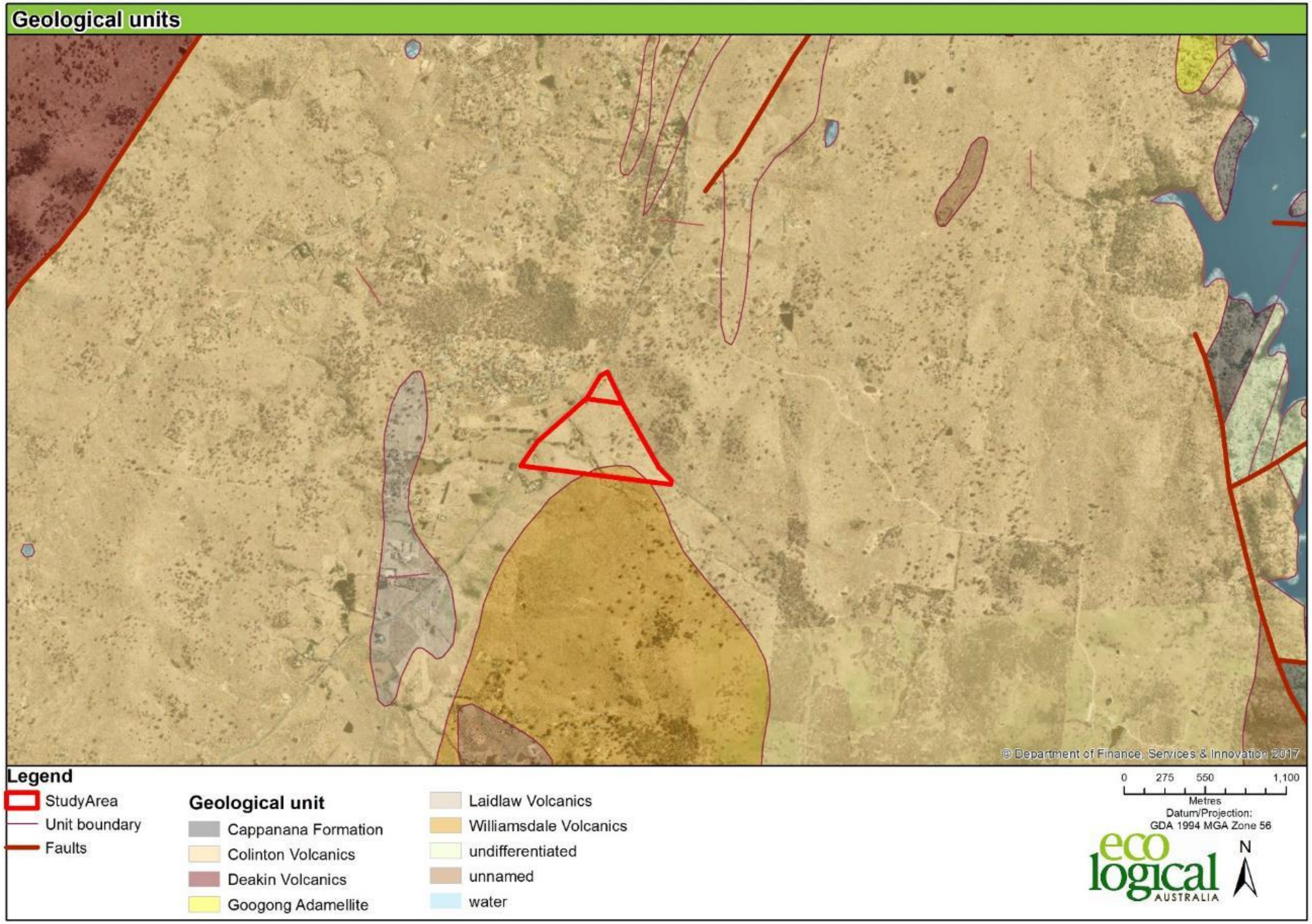


Figure 4-3: Geological units

4.1.2 Subsurface soil profile

The subsurface conditions near the study site was investigated via ten auger holes (ACT Geotechnical Engineers, 2017) and is summarized in **Table 4-2**, below.

Table 4-2: Generalised soil and sub-soil conditions at the site (ACT Geotechnical Engineers, 2017)

Geological profile	Typical Depth Interval	Description
Topsoil	0 m to between 0.1m and 0.2m	SILTY SAND; fine to coarse sand, low plasticity silt, brown, some grass roots, dry to moist, loose.
Slopewash	Between 0.1m and 0.2m to between 0.4m and 0.6m	SILTY SAND; fine to medium sand, low plasticity silt, pale grey-brown, dry to moist, medium dense.
Alluvial/ Residual Soil	Between 0.1mto 0.6 m to between 0.3m and >3.5m	SILTY SANDY CLAY, SILTY CLAYEY SAND, & SANDY CLAY; fine to coarse sand, low to medium and some medium to high plasticity clay, red-brown, orange-brown, brown, grey, dry to moist and moist, stiff to very stiff and dense.
Bedrock	Typically, from 0.2 to 1 m and below	DACITE; fine to coarse grained, orange brown, grey, highly weathered (HW) and weak rock grading to moderately weathered (MW) and medium strong rock.

4.1.3 Hydrogeology

Interrogation of the NOW online groundwater database and the BoM Groundwater Explorer database identified 38 registered groundwater bores within approximately 2 km of the project area, with only two of the 38 bores located within the project area as shown in **Figure 4-4**. No water level/quality data for these bores were available in the NOW PINNEENA database. The five registered bores within (or within 200m of) the project boundary were all drilled in the 1950s and are unlikely to be functioning today. All other bores were drilled since 1986 for stock and domestic use (29 for household use; two for stock use and two of unknown use). As such, there is no requirement for these bores to monitor or report level or quality information, though property owners may have this information.

A summary of registration details for these bores is provided in **Appendix A.** Thirty-four of the 38 bores were drilled to about 20 m or deeper, giving good evidence that local groundwaters are deep and in the fractured rock aquifers. The lithology of two of the shallow bores is not provided and these likely represent perched lenses in the weathered regolith as the other two shallow bores are reportedly completed in clay.

Groundwater in the area is expected to be associated with fractures within bedrock and contained within joints, fractures, faults and fissures in the rock mass (HGC, 2001). The closest fault observed was approximately 1.5 km north of the study area (**Figure 4-3**). A recent geotechnical investigation at this site (ACT Geotechnical Engineers, 2017) augered ten holes to a maximum depth of 3.5 m within the project area (**Figure 4-5**). No groundwater was encountered in any of the augered holes, with the soils mostly dry to moist. Temporary, perched seepages might be expected following rainfall within the more pervious soils in the southern area, with shallow hard rock encountered in the north (**Figure 4-5**).

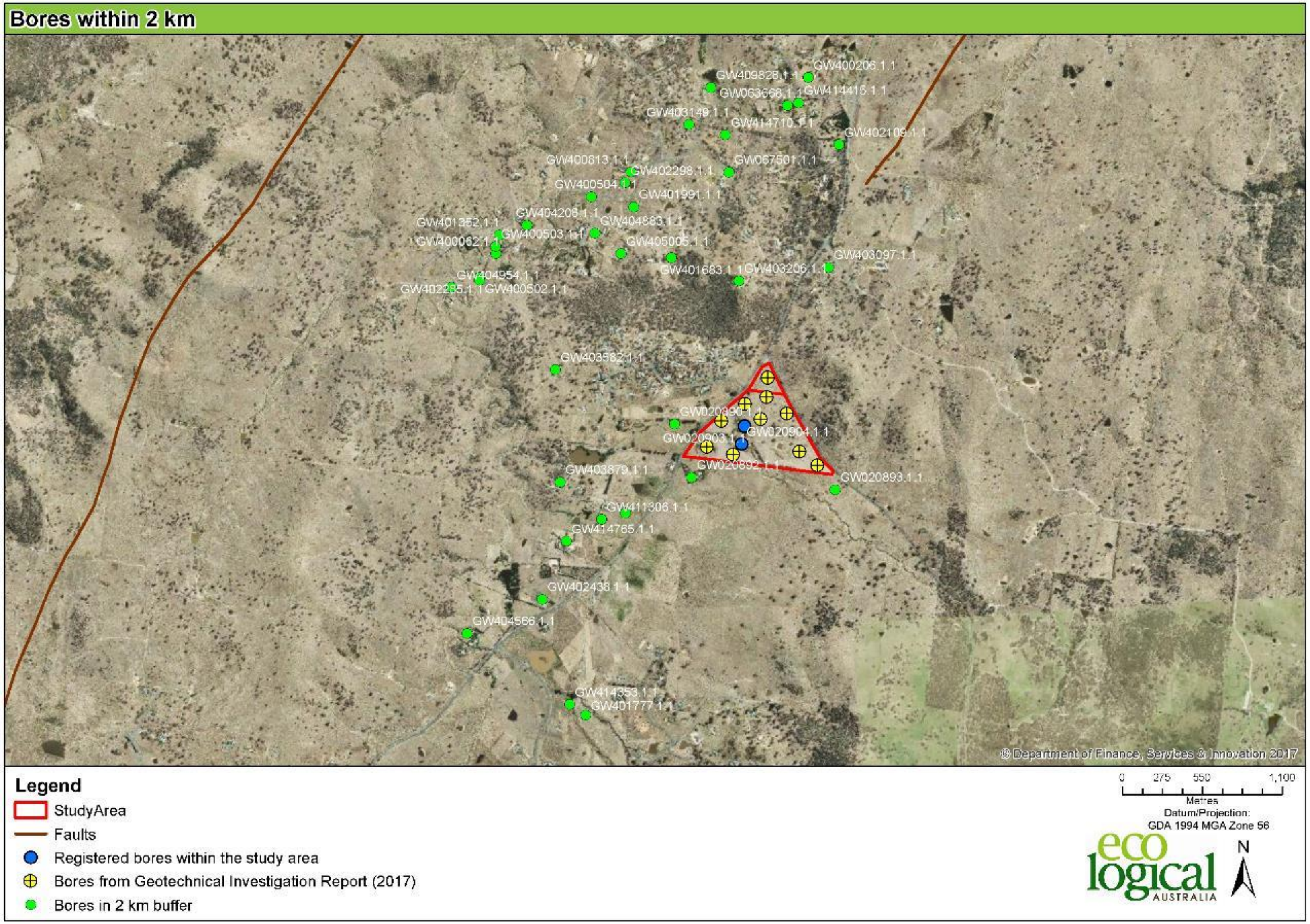


Figure 4-4: Groundwater bores around the study area

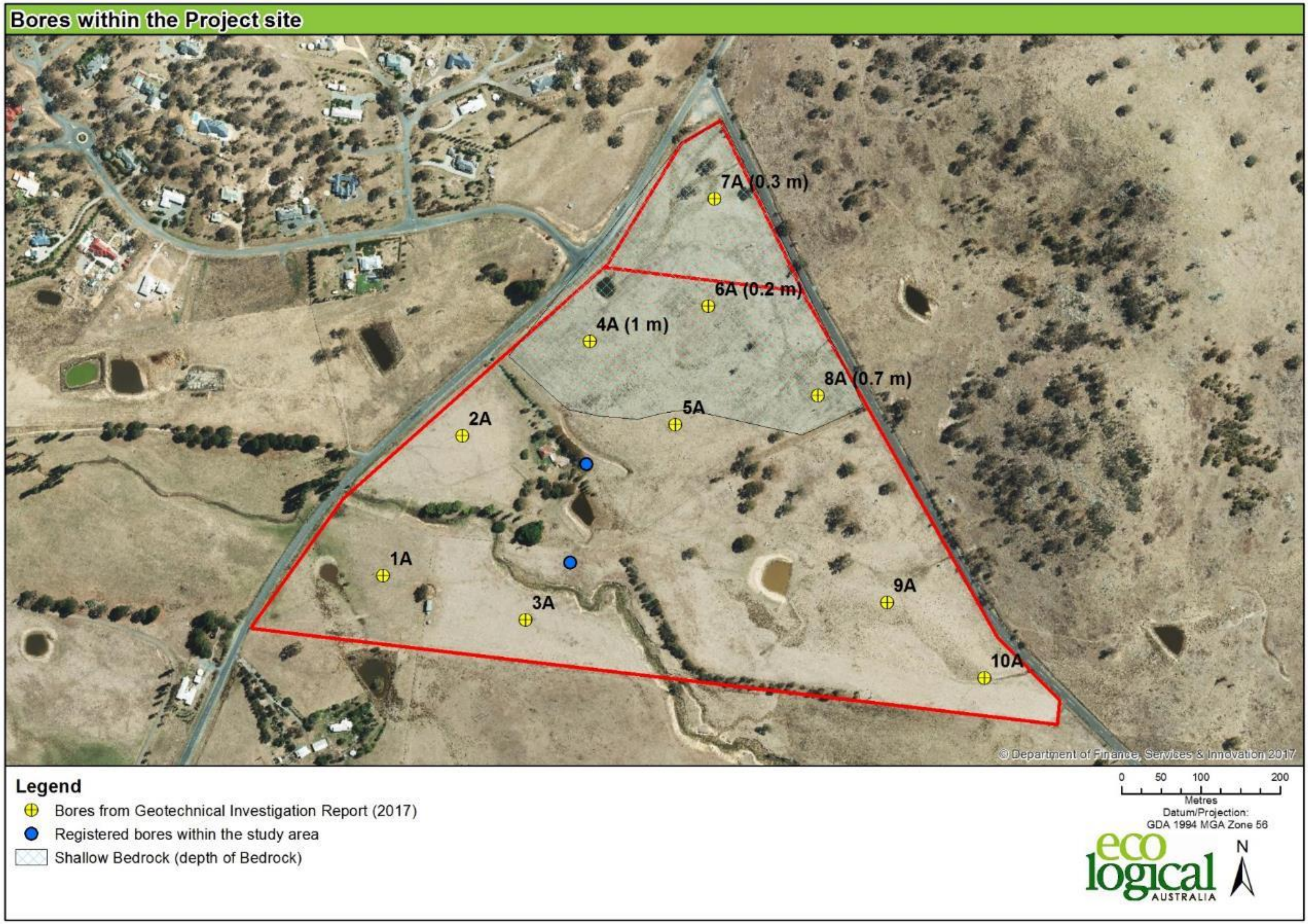


Figure 4-5: Groundwater bores within the project area.

Table 4-3: Summary information for geotechnical holes within the project area (*after* ACT Geotechnical Engineers, 2017)

Bore ID	Logging Date	Soil Type	Moisture status	Excavation depth (m)	Water encountered	Geological profile (at 3.5 m)
1A	6/04/2017	Silty sand/silty sandy clay/ clayey sand	dry to moist at 2 m depth below ground, moist at 3 m below ground	3.5	No	Alluvium
2A	6/04/2017	Silty sand/silty sandy clay/ silty clayey sand	dry to moist at 1 m depth below ground, moist at 1.4 m below ground	3.5	No	Alluvium
3A	6/04/2017	Silty sand/ sandy clay	dry to moist at 1 m depth below ground, moist at 2.5 m below ground	3.5	No	Alluvium
4A	6/04/2017	Silty sand/ sandy clay	dry	Excavation terminated at 1.5 m (medium strong rock)	No	Bedrock
5A	6/04/2017	Silty sand/ sandy clay/ silty sandy clay	dry at 0.4 m depth below ground, dry to moist at 3-3.5 m	3.5	No	Alluvium
6A	6/04/2017	Silty sand	dry	Excavation terminated at 0.3 m (medium strong rock)	No	Bedrock
7A	6/04/2017	Silty sand/ silty sandy clay	dry	Excavation terminated at 0.6 m (medium strong rock)	No	Bedrock
8A	6/04/2017	Silty sand/ sandy clay	dry	Excavation terminated at 1.3 m (medium strong rock)	No	Bedrock
9A	6/04/2017	Silty sand/silty sandy clay/ sandy clay/ clayey sand	dry to moist at 1-2 m below ground, moist to wet at 2-3.5 m below ground	3.5	No	Alluvium
10A	6/04/2017	Silty sand/clayey sand/silty sandy clay/ sandy clay	dry to moist at 1.5-22 m below ground, moist at 2-3.5 m below ground	3.5	No	Alluvium

4.1.4 Water chemistry

No salinity data was recorded from the 38 registered bores located within 2 km distance of the study area. A previous study at Old Cooma Road (HGC, 2001), located approximately 3 km south-west of the project area, reported that the likely total salinity is expected to be in the range of 500-800 mg/L, with elevated bicarbonate and total hardness in the range of 300-500 mg/L. The significant number of local stock and domestic bores suggests that deeper, fractured rock, aquifers provide water of reasonable quality.

4.1.5 Groundwater Dependent Ecosystems (GDEs)

No potentially significant GDEs could be identified within a 2 km buffer around the site based on a high level, desk-top assessment of available data (**Figure 4-6**).

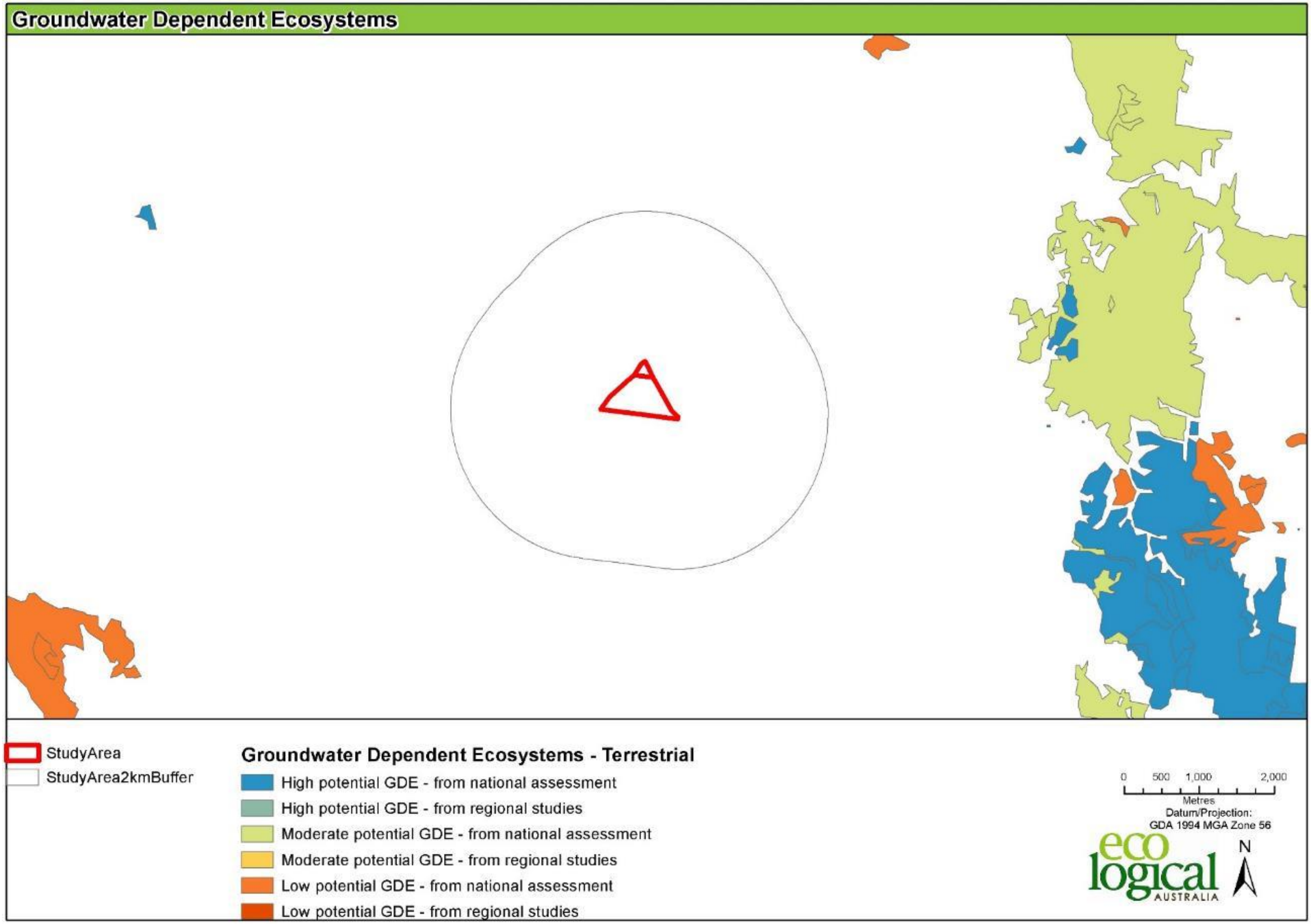


Figure 4-6: Groundwater Dependent Ecosystem map

5 Hydrological and Hydraulic modelling

5.1 Flooding assessment

For the purposes of identifying the flood conditions for the site, only catchments that drained to the defined Church Creek waterway were modelled. Catchments were delineated using available terrain mapping with resolutions ranging from 1-metre to 5-metres.

To categorise the existing design flood conditions from Church Creek at the site, the use of regionalised flood models was required as no appropriate water level or flow information exists in or near the catchment of interest. The flood volumes and levels were determined by the Regional Flood Frequency Estimation (RFFE) model (University of Western Sydney), RORB (Monash University and Hydrology and Risk Consulting) and Hydrologic Engineering Centre's River Analysis System (HEC-RAS) (U.S. Army Corps of Engineers) programs, which calculate flow and water level conditions.

The RFFE model was parameterised using GIS datasets. The model was used to determine representative runoff rates to calibrate the RORB model in the absence of local gauged data. The RORB model was parameterised using GIS datasets, Bureau of Meteorology's Intensity-Frequency-Duration (IFD) information, the Australian Rainfall and Runoff (2016) data hub and the RFFE outputs. The HEC-RAS model was parameterised using GIS datasets, RORB model outputs and local site information (e.g. land cover).

Event durations from 10 minutes to 7 days were run through the RORB model to determine the critical flood duration and volume for the 10% Annual Exceedance Probability (AEP), 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and 0.1% AEP events. AEP is defined as the likelihood (e.g. 1%) each year that a flood of a particular magnitude will be exceeded. The AEP may be directly compared to the Average Recurrence Interval (ARI) which reports the probability (e.g. 1 in 100 year) that a flood of a particular magnitude will be exceeded. The AEP and ARI are two ways of expressing the same information (i.e. the 1% AEP is essentially equivalent to the 1 in 100 ARI) and they are approximately the inverse of each other (1/100-year ARI ≈ 1% AEP). As it is statistically feasible to have multiple ARI events within the designated interval, the ARI has fallen out of favour in deference to reporting the AEP for a given location.

As the AEP numbers become smaller the magnitude of the flows increases to a maximum flow which designates the probable maximum flood (PMF). The PMF is generally only used as a design criterium for dam construction and structures that should not get flooded (e.g. electrical sub stations) with a risk level based on a specific AEP (generally 1% – or an ARI equivalent of 1 in 100 years) is commonly used for flood assessment purposes.

The critical event duration (the event with the highest peak flow) for the study catchment was 6 or 12 hours, depending on the AEP event examined. The peak flows from these events are outlined in at the downstream end of the RORB model (as shown in **Figure B-3** in Appendix B). Please note that unless a specific catchment (relating to the RORB model) or chainage (reported in the HEC-RAS model) location is specified, all table results in this document refer to the downstream end of these catchments.

Table 5-1: Peak flows for existing conditions

AEP (%)	Catchment Peak flow (m³/s)

10%	7.064
5%	10.722
2%	15.407
1%	18.879
0.5%	22.081
0.2%	27.069
0.1%	32.230

The flows for the relevant sub-catchments were used as inputs to the HEC-RAS model. The water levels within Church Creek adjacent to the existing dwelling for selected peak flow events are shown in **Table 5-2**. The depths are the depth of water from the surface to the lowest point in the cross section.

Table 5-2: Peak water levels for existing conditions

AEP (%)	Catchment Water Depths (m)
5%	1.34
2%	1.46
1%	1.53
0.1%	1.75

The results show that it is likely that with the exception of the area immediately upstream of Old Cooma Road, flow events up to the 1% AEP event would be contained within the banks; for some sections, larger events up to the 0.1% AEP would be contained.

It should also be noted that the RORB and HEC-RAS modelling relies on the accuracy of the existing DEM and any available stream bathymetry of the mapped creeks shown in **Figure B-3** in Appendix B).

Figure 5-1 to Error! Reference source not found. show the inundation extents for indicated AEP (labelled as corresponding ARIs in the model).

5.1.1 Implications of results for the Proposed Development

Modelling results indicate that flooding from Church Creek is unlikely to expand widely across the property and is therefore likely to have a limited to no impact on the use of the property as a cemetery.

It is recommended that monitoring of future flood levels is conducted to allow calibration of predicted rainfall-runoff relationships and flood levels.

Figure 5-1: Maximum flood extents for the 5% AEP event

Figure 5-2: Maximum flood extents for the 2% AEP event

Figure 5-3: Maximum flood extents for the 1% AEP event

Figure 5-4: Maximum flood extents for the 0.1% AEP event

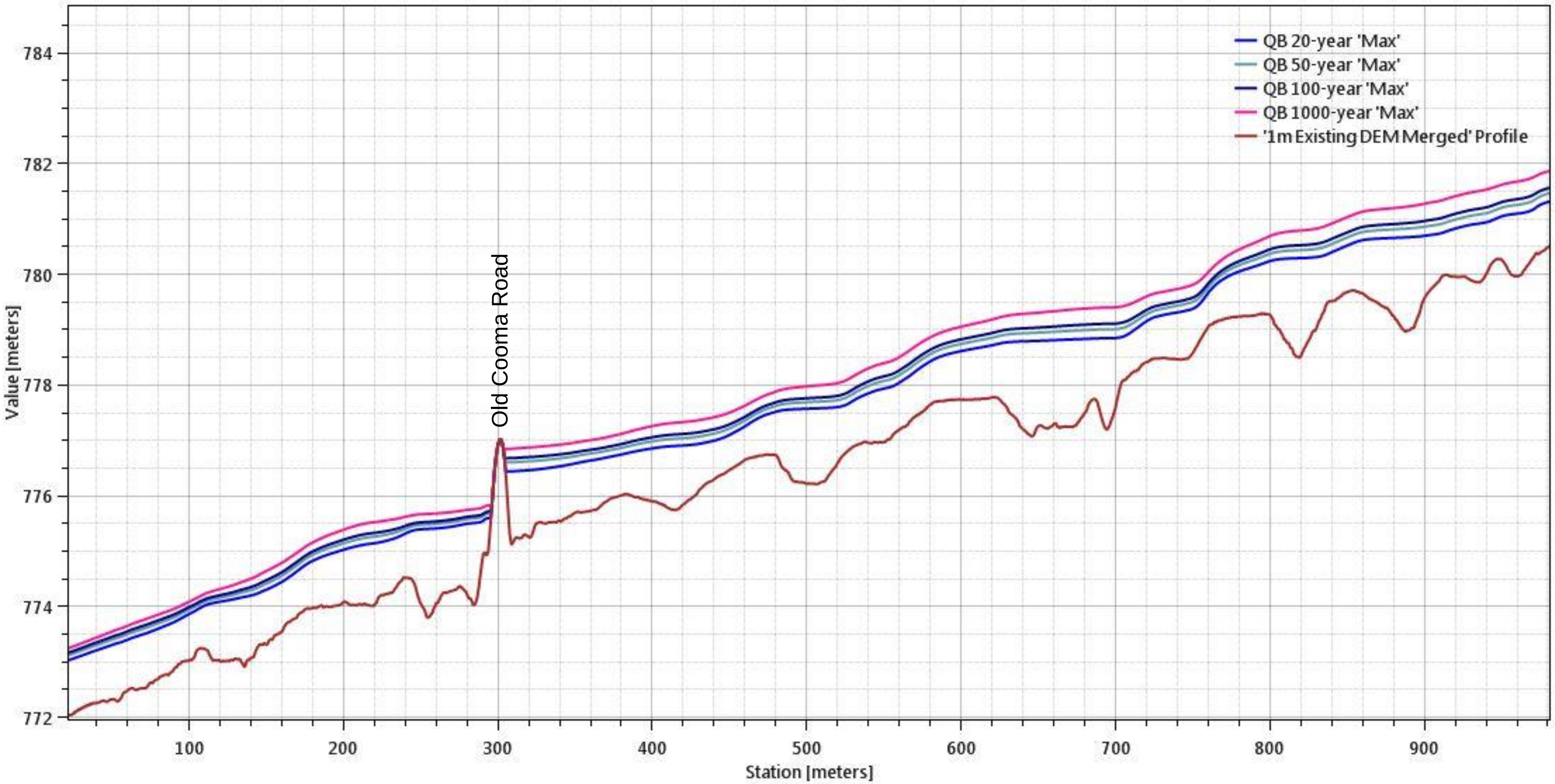


Figure 5-5: Water surface elevation profile for the 5%, 2%, 1% and 0.1% events

6 Constraints assessment

6.1 Hydrology

The hydrology constraints assessment assesses whether the proposed development has the potential to alter existing surface water flow patterns, affect drainage capacity and modify the existing flood regime. Any alteration of surface permeability has the potential to increase peak surface water flows, sheet flow and runoff volumes.

Table 6-1: Hydrology Constraint 1

Item	Description
Issue	<u>*Flooding from Church Creek*</u> Flood waters from the Church Creek have the potential to inundate the site. This would only occur during high flow events.
Map/Figure	**Figure 5-1** to Error! Reference source not found.
Assessment of Issue	**Figure 5-4** to Error! Reference source not found. show cross-sections f rom HEC-RAS models with potential water levels above the banks at the downstream end. Potential flooding under extreme (<1% AEP) events may occur downstream of cross section 7. Provided key infrastructure is set back from the creek this should not cause an issue.
Mitigation option(s)	Once modelling has occurred with detailed survey data, some mitigation options may need to be considered, though would be expected to be minor in nature (e.g. earthworks to form levees).
Final design consideration	To be confirmed based on revised modelling.

Table 6-2: Hydrology Constraint 2

Item	Description
Issue	<u>*Drainage through site*</u> The alteration of the land use of the site will require existing culvert drainage onto the property to be controlled and diverted through the site. This would be combined with the drainage within the site that would need to be managed and controlled through to Church Creek.
Map/Figure	Figure B-3 in Appendix B
Assessment of Issue	It is expected that adequate surface drainage features would be constructed to manage surface water.

Mitigation option(s)	Appropriately designed stormwater infrastructure
Final design consideration	As above.

Table 6-3: Hydrology Constraint 3

Item	Description
Issue	*Water quality / Erosion* The potential for surface water flows to interact with the proposed construction of the cemetery along with its operational activities poses a potential risk that water quality through increased erosion or pollution from chemicals including hydrocarbons. Church Creek is also an erosive stream that over time may change its course due to erosion from flows down the channel.
Map/Figure	Examples of erosion within Church Creek are presented in **Figure 6-1** and **Figure 6-2**.
Assessment of Issue	It is expected that drainage and diversion infrastructure within the site would capture, store and/or discharge surface water appropriately to minimise its impact on Church Creek. The banks within Church Creek may need to be armoured to protect the surrounding site from encroachment from the Creek. Any alterations within the creek would need to manage any impact to existing (or potential) Aboriginal artefacts within and on the banks of the creek.
Mitigation option(s)	Appropriately designed stormwater infrastructure and armouring of creek banks.
Final design consideration	As above.

Figure 6-1: Example 1 of erosion within Church Creek

Figure 6-2: Example 2 of erosion within Church Creek

6.2 Hydrogeology

The hydrogeology constraints assessment assesses whether the proposed development has the potential to impact groundwater in the area. Potential hydrogeological constraints are identified in the following tables and these are followed by an assessment against the minimal impact criteria of the NSW Aquifer Interference Policy.

Table 6-4: Hydrogeology Constraint 1

Item	Description
Issue	*Absence of groundwater quality data* An investigation on the NOW PINNEENA online groundwater database and the BoM Groundwater Explorer database showed no available groundwater level and quality data for the thirty-eight registered bores identified within 2 km distance of the study area.
Map/Figure	**Figure 4-4**
Assessment of Issue	A high level / qualified assessment of available online databases could not identify water quality/ water level data from the registered bores within the study area. Available information on bore construction, however, indicates that groundwater levels are deep (>20m) and unlikely to impact on the site. Shallow auger holes (to 3.5m) did not encounter groundwater, indicating dry conditions at least to this depth.
Mitigation option(s)	Conduct sampling rounds for water quality assessments/ water level measurements to validate information cited from previous studies in this area (e.g., HCG, 2001, ACT Geotechnical Engineers, 2017.)
Final design consideration	N/A

Table 6-5: Hydrogeology Constraint 2

Item	Description
Issue	*Potential groundwater contamination due to increased recharge* Potential groundwater contamination due to water entering the water table from the grave sites.
Map/Figure	N/A
Assessment of Issue	Surface water flow or sheet flow during a high rainfall event can increase recharge to shallow perched groundwater sources. Increased recharge is likely to result in localised water-level rise and has the potential to enter grave sites which can create potential groundwater contamination issues.

Item	Description
	Existing information suggests this not to be an issue, but it is recommended to undertake groundwater monitoring at the site to monitor local conditions.
Mitigation option(s)	Appropriately designed stormwater infrastructure and groundwater monitoring bores.
Final design consideration	N/A

Table 6-6: Hydrogeology Constraint 3

Item	Description
Issue	<u>*Reduction of groundwater quantity to impact Groundwater Dependent Ecosystems (GDEs).*</u> Lowering of the groundwater table, and/or disruption of groundwater flow to GDEs if groundwater dewatering is required at any excavated areas (including grave sites), could have the potential to impact on ecosystems. Areas of high groundwater risk may indicate areas of high environmental sensitivity.
Map/Figure	<u>N/A</u>
Assessment of Issue	A high level / qualified assessment of potential GDE occurrence has been made using data from the BoM GDE Atlas (2017). Data suggests that there are no likely aquatic/ terrestrial GDEs present within the study area. There are no water level data observed in the registered bores within the study area to assess the potential for any possible terrestrial vegetation species to be accessing groundwater. A recent study did not encounter groundwater to 3.5 m deep in bores dug in different locations within the study area and the soils were mostly dry to moist (ACT Geotechnical Engineers, 2017). It may be considered that the terrestrial vegetation in the Site is unlikely to be dependent on groundwater to maintain ecosystem health.
Mitigation option(s)	Establish regional baseline groundwater level dataset that includes seasonal variation to confirm depths to groundwater, and whether dewatering is likely to be necessary.
Final design consideration	N/A

Table 6-7: Hydrogeology Constraint 4

Item	Description
Issue	*<u>Salinisation/contamination of groundwater</u>* Impediment of shallow groundwater flow may result in elevation of groundwater tables and transport of salt to the soil zone, inducing salinisation and scalding at the surface. Construction activities (including grave excavations) and interaction of groundwater with the occupied grave sites may result in deterioration of groundwater quality and areas with high environmental sensitivity.
Map/Figure	N/A
Assessment of Issue	The proposed interments will be to a maximum depth of 3.5 m (quadruple occupation). Since groundwater was not encountered within 3.5 m of the local ground surface, the impacts on groundwater of these activities are likely to be minimal.
Mitigation option(s)	Install two monitoring bores to establish baseline groundwater level or quality dataset that includes seasonal variation to confirm depths to groundwater, flow directions and water quality. Minimise interaction with groundwater during construction activities.
Final design consideration	N/A

6.2.1 Aquifer Interference Policy

A preliminary assessment of the proposed activities against the ‘minimal impact considerations’ outlined in the AIP suggests the local groundwater level (>3.5 metres below ground level) is unlikely to be significantly impacted during construction and operational activities and hence no impacts to groundwater level or quality are anticipated. No impacts are therefore expected under the Water Management Act 2000 to existing groundwater users, including groundwater dependent ecosystems.

Our assessment therefore conservatively considers potential impacts to the Lachlan Fold Belt MDB Groundwater Source falls within the Level 1 impact considerations as defined in **Table 2-1**.

As minimal hydrogeological data (specifically groundwater level and quality) is available for the site and the surrounding area, these findings are indicative only and require on-ground assessment and validation through hydrogeological and geotechnical studies at the site and within the regional area to better assess the potential threats to groundwater. As a minimum, the assessments should consist of an updated survey of groundwater levels and sampling at the existing bores identified within the study area (**Figure 4-4**) to establish a baseline dataset. Collection of the monitoring data should be undertaken to capture changes due to seasonal variation.

7 Recommendations

The following recommendations are made in relation to hydrology, hydrogeology, water quality, and flooding, to better inform the project:

- Hydraulic modelling should be updated based on future observations of flood levels
- A climate change assessment of the hydrological aspects in the project area might be undertaken based on Australian Rainfall and Runoff guidelines
- Further data and information on groundwater and potential GDEs in the study area should be collected through a census of the groundwater bores, installation of shallow piezometers (if data from the census suggests groundwater levels may be an issue) and a site-specific survey to verify the presence of any terrestrial GDEs.

8 References

ACT Geotechnical Engineers. 2017. *Geotechnical Investigation Report,* ACT Geotechnical Engineers Pty Ltd.

HGC 2001. *Groundwater investigation, Proposed Beatty Hill subdivision, Old Cooma Road, Williamsdale area.* Hydroilex Geotechnical Consultants.

QPRC 2012. *Planning Proposal for Cemetery and Crematorium, Lot 2 DP 112382 and Lot 126 DP 754881*. Queanbeyan-Palerang Regional Council.

SRLE, 2015*. Rural Residential Subdivision, Burra Road, Mount Pleasant: Flood Analysis and Concept Culvert Design*, Southern Region Land Engineering.

WSP 2012. *Water Sharing Plan for the Murrumbidgee Unregulated and Alluvial Water Sources.*

Appendix A Registered groundwater bore details

Hydro Code	Latitude	Longitude	Easting	Northing	Ref Elevation (mAHD)	Bore Depth (m)	Drilled Depth (m)	Drilled Date	Major Lithology	Lithological description	Function Type
GW400062.1.1	-35.442476	149.189309	698713	6075684	756	90	90	4/02/1992	DCIT	Dacite	Household Use
GW020893.1.1	-35.457886	149.214262	700940	6073924	793.14	0	13.7	1/10/1952	CLAY	Clay yellow	Unknown
GW020903.1.1	-35.453719	149.207595	700345	6074400	782.08	0	7.9	1/01/1953	CLAY	Clay yellow some sand	Stock water
GW020890.1.1	-35.453442	149.202317	699866	6074441	776.15	19.8	19.8	1/10/1952	PRPR	Porphyry water supply	Unknown
GW067501.1.1	-35.437996	149.207135	700342	6076145	789.09	42	42	12/10/1989	GRNT	Black granite	Household Use
GW400206.1.1	-35.43233	149.213428	700927	6076761	778.12	39.6	39.6	28/04/1997	None	Soft shale.	Household Use
GW401352.1.1	-35.441325	149.189609	698743	6075811	756.63	78	78	31/12/1991	SLTE	Slate, soft	Household Use
GW401068.1.1	-35.458808	149.198345	699493	6073854	775.49	36	36	21/10/1999	BRKN	Broken brown shale	Household Use
GW400503.1.1	-35.442026	149.189296	698713	6075734	758.72	60.8	60.8	28/11/1994	None	Topsoil	Unknown
GW400504.1.1	-35.439188	149.196655	699388	6076034	735.8	60.8	60.8	5/12/1994	DCIT	Dacite	Household Use
GW400813.1.1	-35.437753	149.199745	699672	6076187	759.01	54	54	22/04/1998	HDBD	Hard grey black granite	Household Use
GW401683.1.1	-35.443137	149.202545	699913	6075584	788.92	121	121	23/05/2001	GRNT	Granite, broken	Household Use
GW401777.1.1	-35.471224	149.194716	699133	6072484	784.25	84	84	20/08/2001	SHLE	Shale, highly weathered yellow	Household Use
GW402438.1.1	-35.463971	149.19178	698884	6073295	776.22	75	75	26/05/2003	TPSL	Topsoil, and clay	Household Use
GW402285.1.1	-35.443879	149.188005	698591	6075531	738.38	66	66	18/12/2002	DCIT	Dacite	Household Use
GW020904.1.1	-35.45483	149.207317	700317	6074277	780.21	19.8	19.8	1/02/1953	PRPR	Porphyry decomposed	Stock water
GW402298.1.1	-35.438405	149.199269	699627	6076116	752.54	85	85	24/03/2003	SHLE	Shale, soft yellow	Household Use
GW401991.1.1	-35.439906	149.199848	699676	6075948	753.75	48	48	5/02/1992	DCIT	Dacite	Stock water
GW063668.1.1	-35.433997	149.211761	700772	6076579	773.01	22.9	22.9	1/09/1986	GRNT	Granite soft bands water supply	Household Use
GW020892.1.1	-35.456775	149.203428	699959	6074069	780.38	20.4	20.4	1/11/1952	CLAY	Clay yellow	Unknown
GW402109.1.1	-35.436553	149.215528	701108	6076288	789.63	23	23	2/12/2002	SHLE	Shale, weathered soft yellow	Household Use
GW400502.1.1	-35.444078	149.187975	698588	6075509	736.75	38	38	23/11/1994	None	Volcanics	Household Use

Hydro Code	Latitude	Longitude	Easting	Northing	Ref Elevation (mAHD)	Bore Depth (m)	Drilled Depth (m)	Drilled Date	Major Lithology	Lithological description	Function Type
GW403097.1.1	-35.444116	149.214394	700986	6075451	808.53	100	100	22/04/2001	TPSL	Topsoil	Household Use
GW403206.1.1	-35.44473	149.207586	700366	6075397	850.52	156	156	13/01/2004	CLAY	Clay	Household Use
GW403582.1.1	-35.449801	149.193442	699070	6074863	756.62	42	42	30/10/2002	SFBD	Soft volcanics	Unknown
GW403149.1.1	-35.43495	149.204271	700090	6076489	773.08	42	42	1/07/2005	SHLE	Shale, brown	Household Use
GW403879.1.1	-35.45677	149.193501	699058	6074090	781.55	71	71	30/10/2006	CLAY	Clay/shale - fine	Household Use
GW404208.1.1	-35.440783	149.191723	698936	6075867	743.04	82	0	7/02/2003	n/a	n/a	Household Use
GW405005.1.1	-35.442774	149.198739	699568	6075632	757.28	66	66	22/09/2008	TPSL	Topsoil	Household Use
GW404566.1.1	-35.465893	149.186025	698357	6073093	775.42	42	0	28/06/1999	n/a	n/a	Household Use
GW404883.1.1	-35.441447	149.196842	699399	6075783	743.22	10	0	1/11/1991	n/a	n/a	Household Use
GW404954.1.1	-35.444451	149.185841	698393	6075472	755.25	102	102	11/12/2008	BSLT	Basalt	Household Use
GW411306.1.1	-35.459158	149.196508	699325	6073819	775.11	36	36	22/04/2010	CLAY	Clay - brown	Stock water
GW409828.1.1	-35.432707	149.206032	700255	6076734	751.92	45	45	20/12/2009	TPSL	Topsoil	Household Use
GW414710.1.1	-35.435691	149.206984	700334	6076401	765.88	60	0	26/11/2002	n/a	n/a	Household Use
GW414353.1.1	-35.470525	149.193577	699031	6072564	783	114	114	11/05/2010	GRNT	Granite, blue	Household Use
GW414415.1.1	-35.433867	149.212607	700849	6076592	778.35	23.5	0	10/09/2010	n/a	n/a	Household Use
GW414765.1.1	-35.460443	149.193788	699075	6073682	775.22	5	0	15/09/2011	n/a	n/a	Household Use

Green shaded bores occur within the project area; orange shaded bores occur within 200 m of the project boundary

Appendix B Technical Hydrological Modelling Details

Water Volume Modelling

This section outlines the flow volume modelling that was undertaken to determine flows into Church Creek that formed the basis for determining water levels from flooding of Church Creek.

Regional Analysis

To provide an estimate of the likely design flow volumes from the catchment the Regional Flood Frequency Estimation (RFFE) model (http://rffe.arr-software.org/) was used. It uses information from nearby similar catchments to provide an estimation of their 6-hour peak durations. The details required for this are:

- Catchment outlet location (latitude and longitude);
- Catchment centroid location (latitude and longitude); and,
- Catchment area.

The results of RFFE model the catchment is shown in **Figure B-1**.

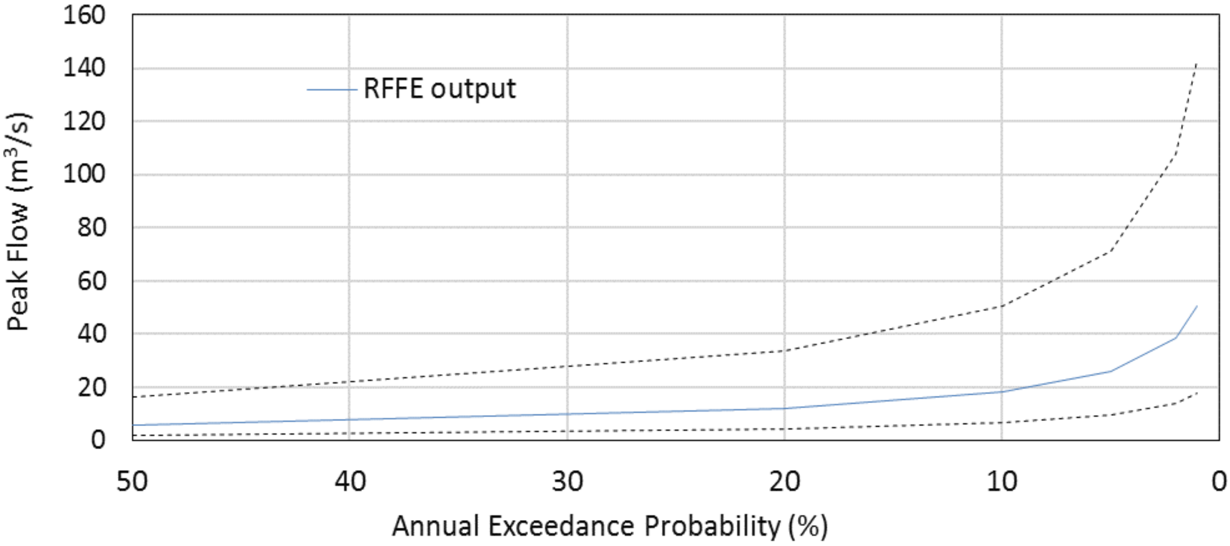


Figure B-1: RFFE 6-hour estimates for the study Catchment (dashed lines representing 5% and 95% confidence intervals).

Sub-catchment delineation

Figure B-2 shows the proposed site and the catchment determined based on the available DEM. The analysis of the proposed site and the DEM determined that the project boundary fell within one watershed region.

For the purposes of RORB modelling the modelled catchment was divided up into 12 sub-catchments. The catchment and link details for the existing that are applied to the RORB catchment file, shown in **Figure B-3**. The catchment characteristics and link parameters for the modelled catchment are shown in **Appendix C**.

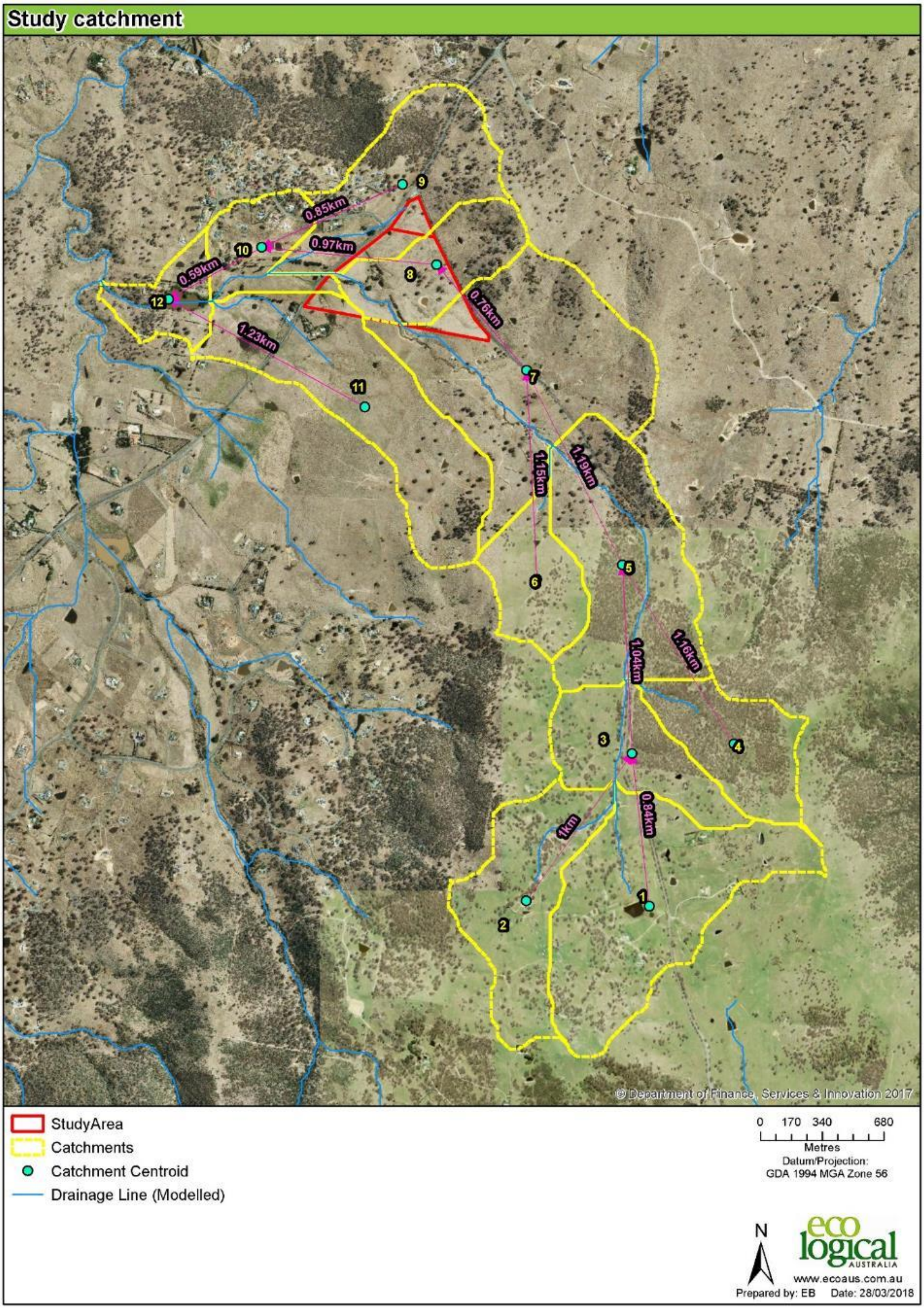


Figure B-2: Study catchments

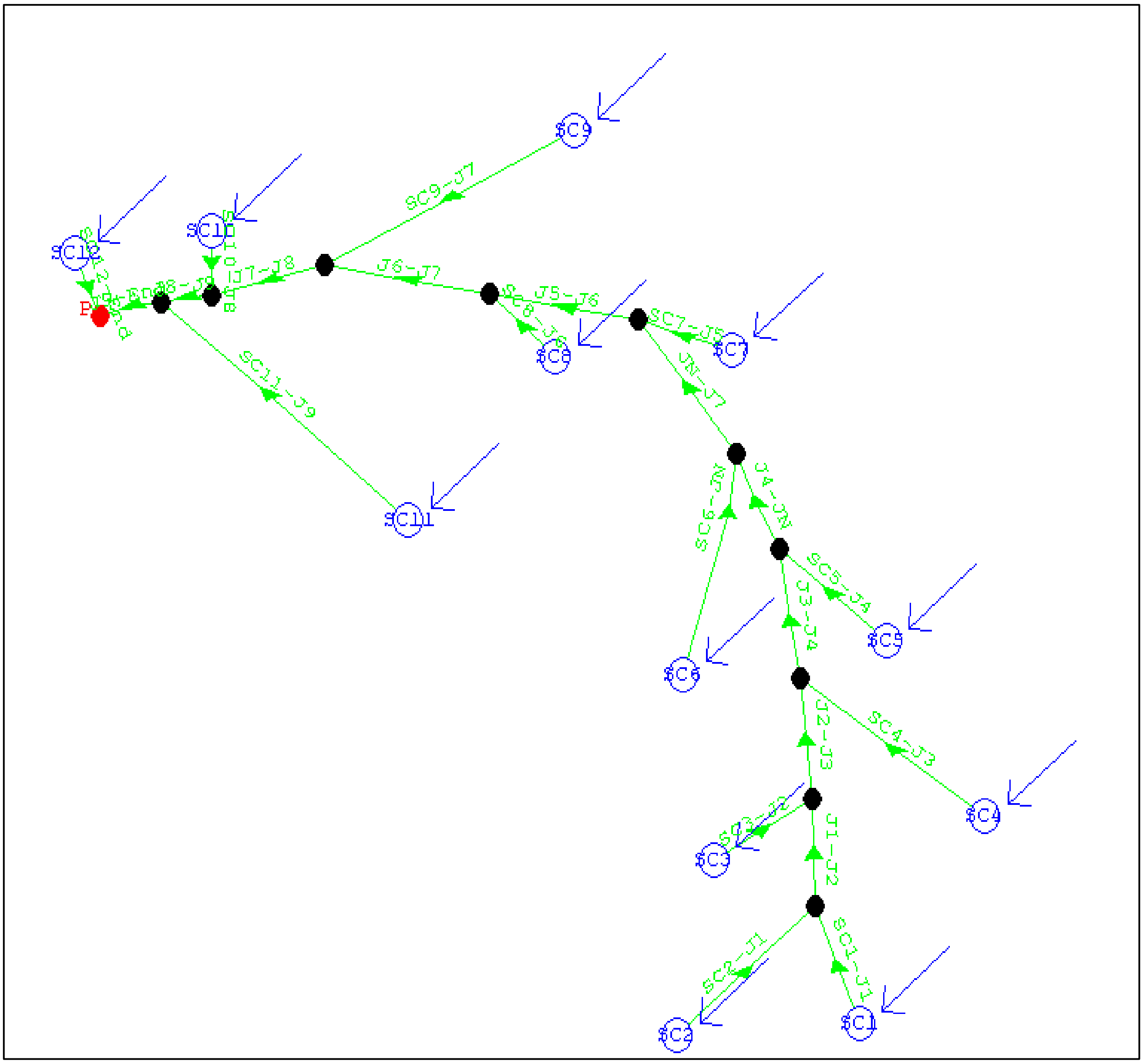


Figure B-3: RORB sub-catchment relationships for the study catchment

Intensity-Frequency-Duration (IFD) Information

The IFD information was sourced for the Site from the 2016 Bureau of Meteorology IFD curves on March 12, 2018 for coordinate 35.453985°S and 149.202299°E and is outlined in Table B-1. Exceedances rarer than the 1% AEP less than 24 hours in duration were not available on the BoM website and were infilled based on a logarithmic regression.

The temporal pattern used for this was sourced from Australian Rainfall and Runoff 2016 and is discussed in the following section, *Australian Rainfall and Runoff Information*.

Table B-1: IFD information for the Project site

Duration	Annual Exceedance Probability Rainfall Depths (mm)										
	63.2%	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.2%**	**0.1%**	**0.05%**
1 min	1.61	1.82	2.51	3.02	3.54	4.28	4.88	5.37	6.09	6.63	7.16
2 min	2.74	3.09	4.19	4.94	5.69	6.66	7.4	8.22	9.24	10.01	10.79
3 min	3.75	4.22	5.75	6.81	7.88	9.31	10.4	11.53	12.99	14.09	15.19
4 min	4.63	5.22	7.13	8.5	9.88	11.8	13.3	14.69	16.59	18.02	19.45
5 min	5.4	6.09	8.36	9.99	11.7	14	15.9	17.53	19.82	21.55	23.28
10 min	8.21	9.27	12.8	15.5	18.3	22.2	25.5	28.01	31.78	34.62	37.47
15 min	10.1	11.4	15.8	19.1	22.5	27.4	31.4	34.52	39.16	42.67	46.18
30 min	13.6	15.3	21.2	25.4	29.8	35.8	40.7	44.9	50.82	55.29	59.77
1 hour	17.6	19.8	27	32.1	37.2	44.2	49.7	54.95	61.96	67.27	72.58
2 hour	22.5	25.2	33.8	39.8	45.9	54.1	60.7	66.93	75.26	81.57	87.87
3 hour	26	29	38.6	45.4	52.2	61.8	69.4	76.31	85.77	92.93	100.09
6 hour	33.2	36.8	48.7	57.4	66.5	79.5	90.2	98.57	110.97	120.35	129.73
12 hour	42.1	46.5	61.8	73.5	86.1	104	120	130.3	147.2	159.97	172.75
24 hour	51.6	57.3	77.1	92.8	110	134	154	154	177	210	238
48 hour	60.6	67.8	92.9	113	134	162	185	185	207	240	267
72 hour	65.4	73.5	101	123	146	175	198	198	222	255	282
96 hour	68.8	77.5	107	129	153	183	206	206	232	267	295
120 hour	71.8	80.7	111	134	158	189	213	213	241	278	307
144 hour	74.6	83.7	115	138	162	194	220	220	248	289	321
168 hour	77.4	86.6	118	141	166	200	228	228	255	299	335

Australian Rainfall and Runoff Information

The other information required for setting up the RORB model was sourced from the Australian Rainfall and Runoff (2016) data hub (http://data.arr-software.org) for the same location as for the IFD information. The key information obtained were the temporal patterns and the losses. The division that these parameters are sourced from is the Murray-Darling Basin with the river region being Murrumbidgee River, SE Coast.

For this river region, the initial loss is 22.0 mm and the continuing loss is 5.2 mm/hr. For each temporal pattern duration, 30 patterns were available to be used by RORB. Patterns available for the durations are outlined in **Table B-2**. The shaded durations are durations where IFD information is not available (and therefore were not used in the modelling).

The temporal pattern information was used to provide inputs to the Monte Carlo model run in RORB.

Table B-2: Temporal Pattern Durations from Australian Rainfall and Runoff

Durations			
10 minute	1 hour	9 hour	48 hour
15 minute	1.5 hour	12 hour	72 hour
20 minute	2 hour	18 hour	96 hour
25 minute	3 hour	24 hour	120 hour
30 minute	4.5 hour	30 hour	144 hour
45 minute	6 hour	36 hour	168 hour

Parameter Files

As there are no observed flow data for this catchment, the RORB parameter file was set-up using the "Separate catchment and generated design storm(s)" option. The model operates using a single set of routing parameters for the whole model and an initial loss / continuing loss model. The design rainfall specification used is:

- A user defined IFD (detailed above in **Table B-1**);
- Monte Carlo simulation from 10 minute to 168 hour durations;
- Default time increments of 70;
- Uniform areal pattern; and,
- Constant losses.

The parameter specification is:

- main routing parameter for the overall catchment, k_c of 6.64 to calibrate to RFFE analysis (results shown below);
- dimensionless exponent for non-linear routing, m of 0.8; and,
- Initial loss and continuing loss based on the Australian Rainfall and Runoff values discussed above.

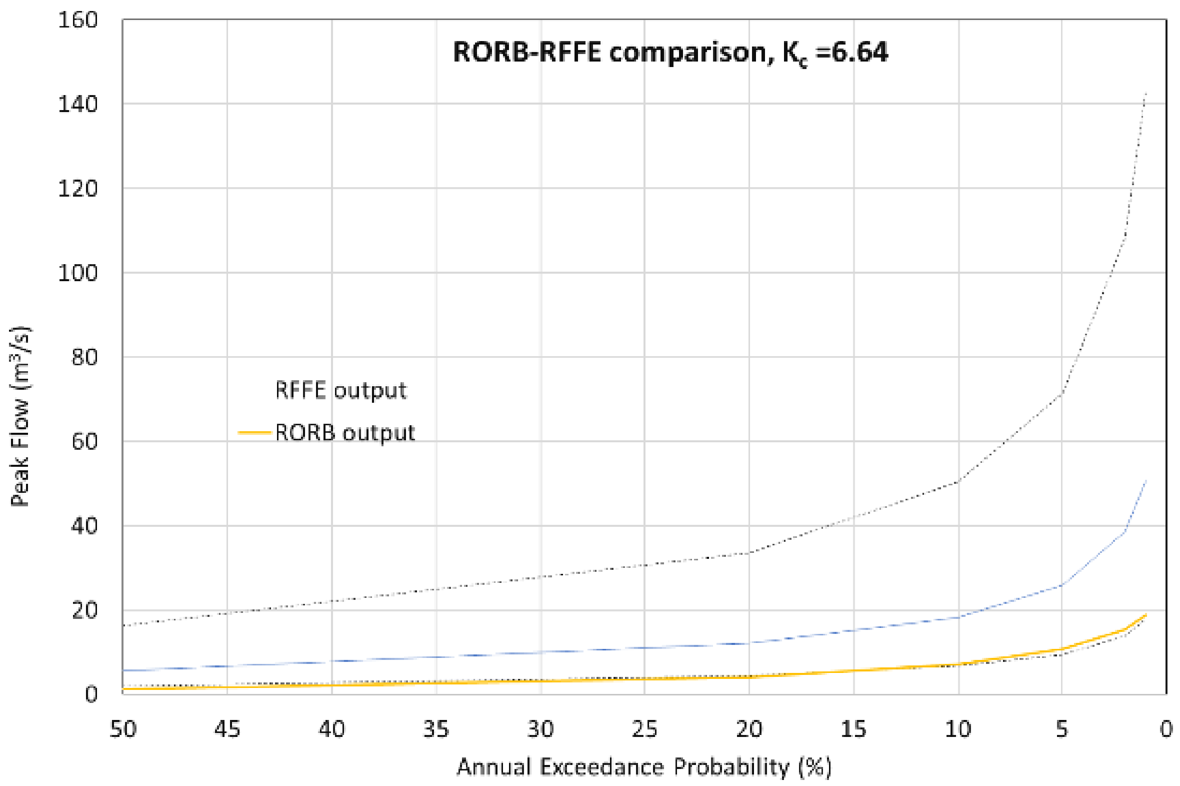
The Monte Carlo simulation details are:

- Number of rainfall divisions: 50 (default);
- Number of samples per division: 20 (default);
- Temporal patterns as described above;
- No pattern censoring; and
- Fixed initial loss.

Calibration Results

The RORB model was calibrated to the RFFE analysis to fit within the confidence limits of the results. This calibration targeted obtaining the best possible fit to the 1% AEP result (closet to best estimate) and be in line with a flood study undertaken for the upstream property (SRLE, 2015). The outcome of this is shown in **Figure B-4** which shows that the 1%, 2%, 5% and 20% AEP results fall within the confidence limits using the recommended k_c value (6.64). Adjusting the k_c value to fit the median RFFE output resulted in too much flow through the system.

The peak flow results from the RORB model for the existing conditions at the Site are shown in **Figure B-5**. **Figure B-6** shows the peak design flow (for existing conditions).



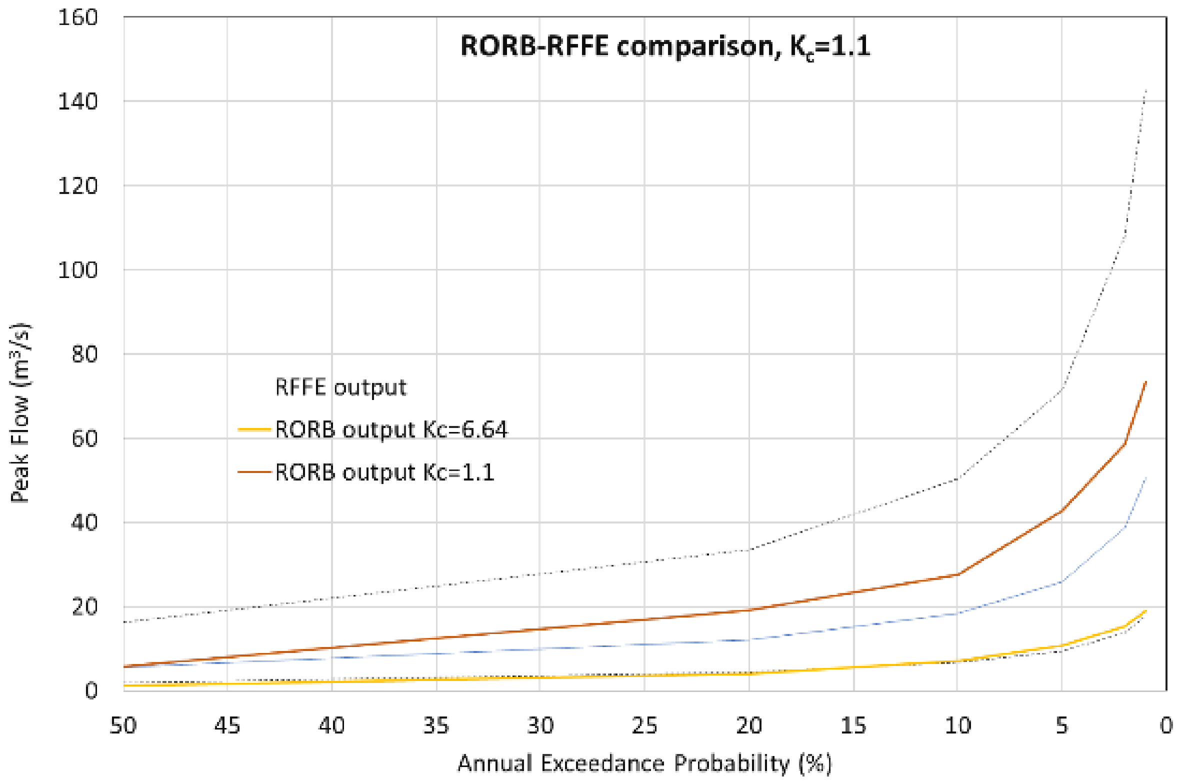


Figure B-4: RFFE – RORB calibration for the study catchment (Top panel, K_c = 6.64 and bottom panel, K_c = 1.1)

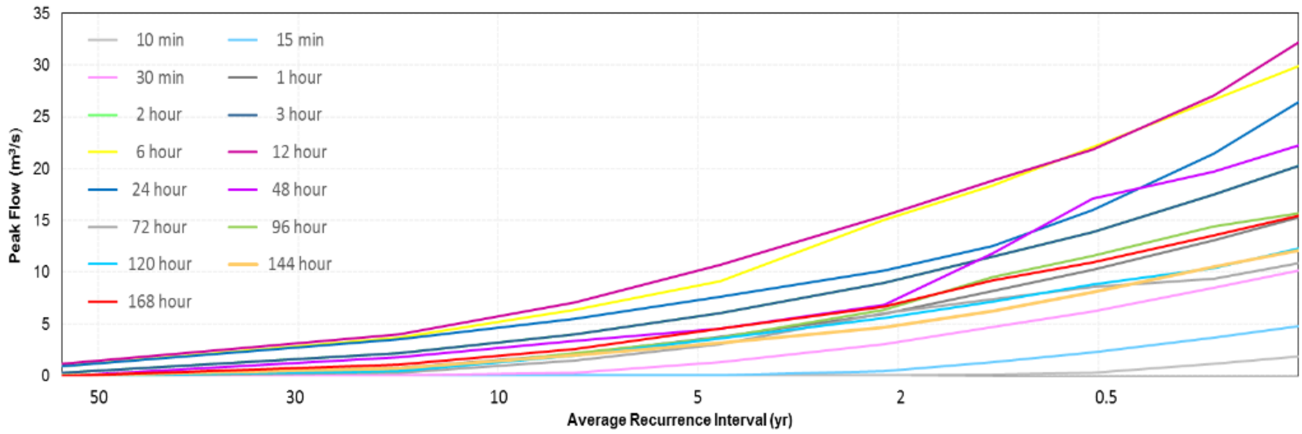


Figure B-5: RORB model results for existing conditions

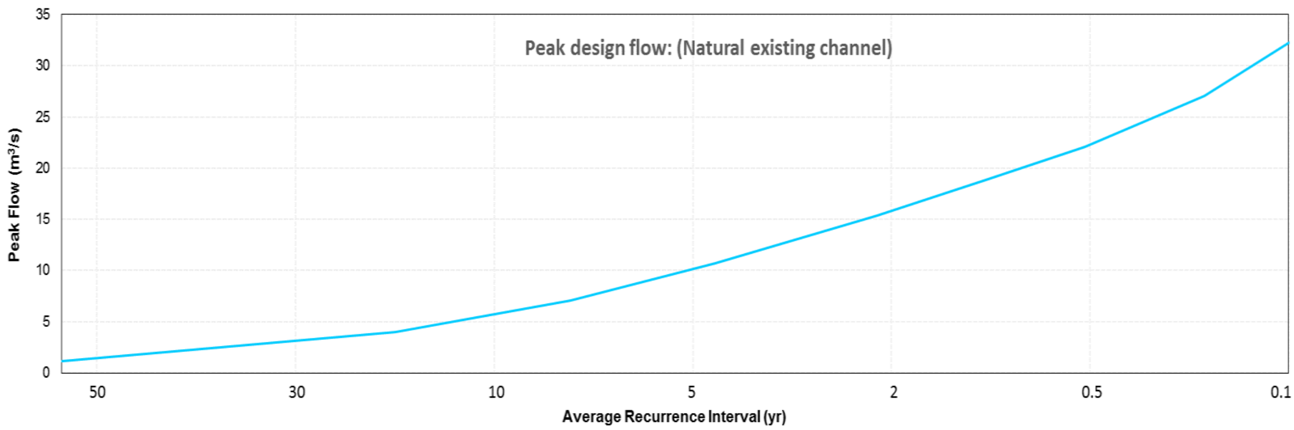


Figure B-6: Peak Design Flows

Technical Detail of Water Level Modelling

To model the water levels that correspond to the design flows produced by the RORB modelling a HEC-RAS model was developed to investigate the potential water levels from Church Creek.

Model Geometry

To set up the model required a number of GIS-based input sets and these were produced using the HEC-GeoRAS add-in to ArcMap. The key spatial datasets required were:

- The drainage centre line;
- Bank lines;
- Old Cooma Road centreline; and,
- The drainage cross sections.

A two-dimensional model grid was set up for the project using a 2-metre grid resolution. The features listed above were applied as breaklines with a 1-metre resolution. The culverts under Old Cooma Road were entered as a triple-barrel, 2-metre span by 1.5-metre rise concrete box culvert. A uniform Manning's roughness coefficient of 0.045 was applied to the modelled area, with sensitivities applied across a range from 0.03 to 0.06.

As a conservative measure, peak inflows from concentration points downstream of Old Cooma Road were introduced at the upstream boundary condition as pseudo-steady flows (filling all available storage areas). In addition to the Church Creek flood model, a localised rain-on-grid or direct rainfall model was applied to model overland flow. Intensity-Frequency-Duration (IFD) data were compiled across the catchment area from the Bureau of Meteorology (BoM) using the 2016 data set. The highest rainfall values were conservatively selected without areal reduction factors to compile a nested frequency storm for each site with an initial loss of 22 mm and a continuing loss of 5.2 mm/hour removed from the precipitation hyetograph based on values taken from the Australian Rainfall and Runoff (ARR) data hub (http://data.arr-software.org/, Ball et al., 2016). Rainfall excess was applied across the 2D flow area as an inflow boundary condition. Preliminary model runs were developed to determine the catchment response time, leading to the adoption of a 1-hour synthetic storm. A centrally loaded, nested frequency storm was applied across the entire catchment in HEC-RAS as unsteady flow boundary, with Church Creek receiving direct inflow as a time series hydrograph.

The downstream outlet was set to a normal depth boundary condition, using the uniform bed slope of 0.9% as the estimated energy gradient. A computational time step of 1 second was applied with a simulation window of 2 hours.

As shown in the velocity plots below, peak velocities in some sections of the channel exceed the typical 2 m/s threshold for requiring scour protection rock according to Austroads guidelines. Some erosion would be expected under the modelled scenarios.

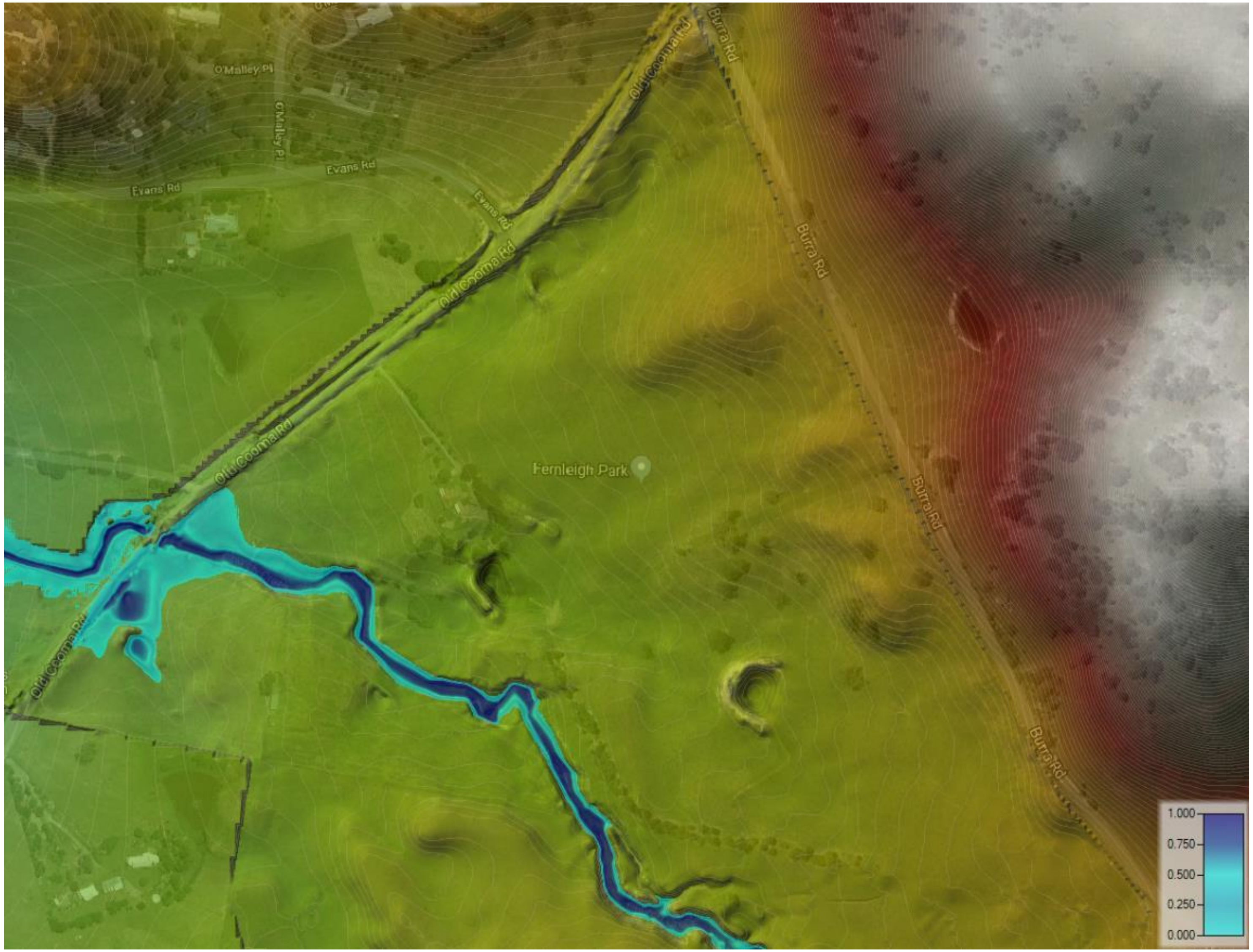


Figure B-7: Peak 100-year flow depths in Church Creek

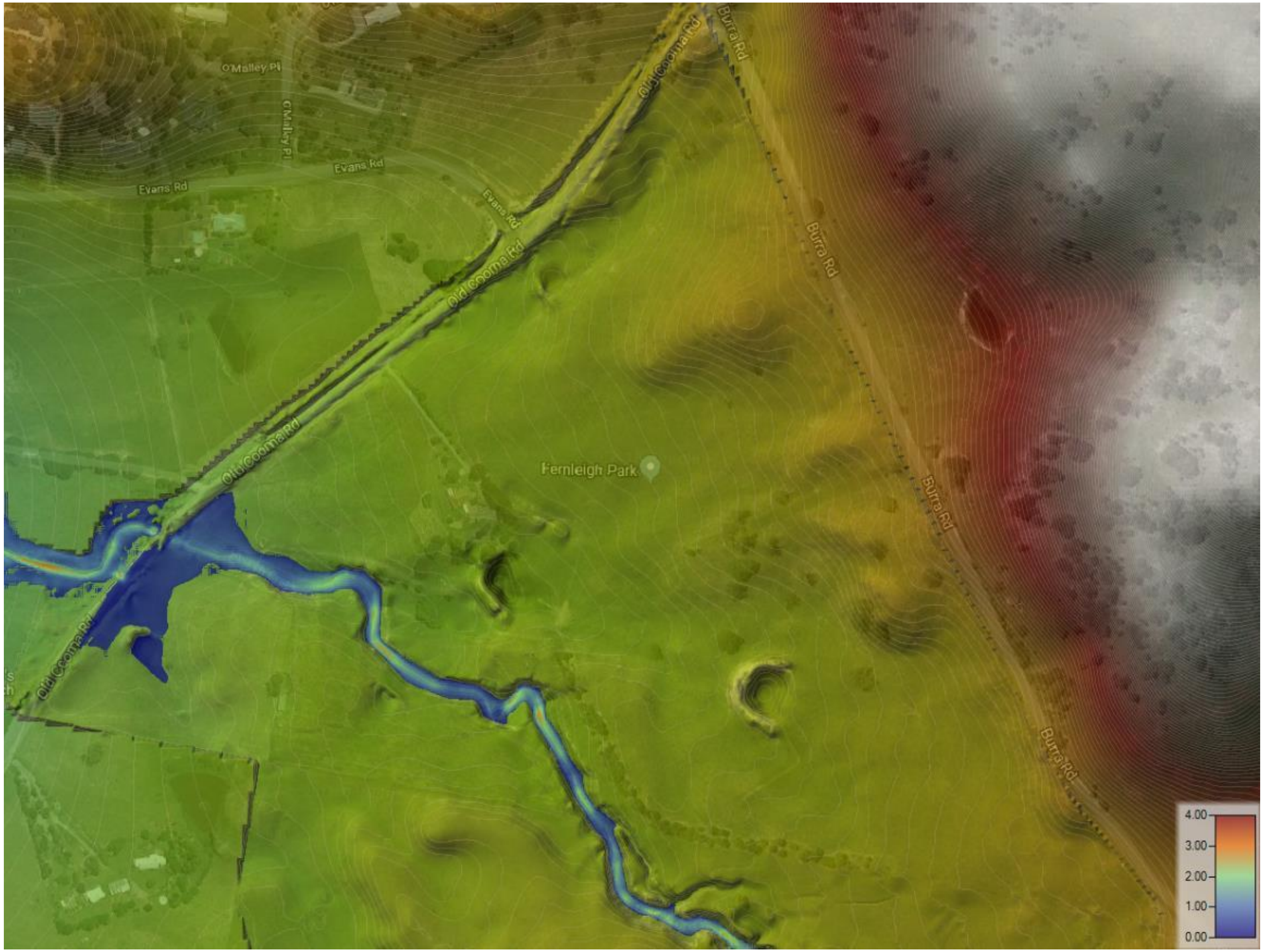


Figure B-7: Peak 100-year flow velocities in Church Creek

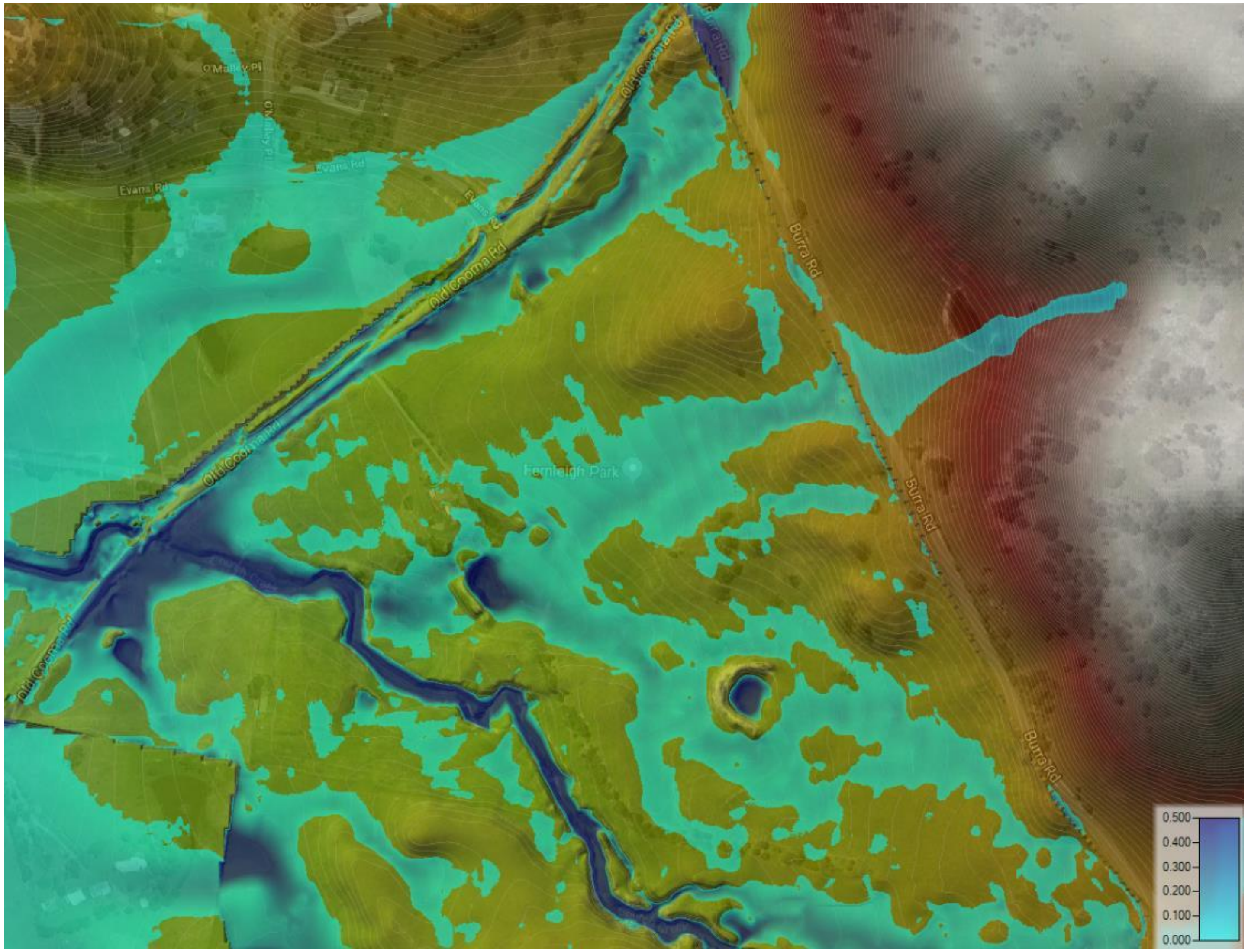


Figure B-7: Peak 100-year flow depths for overland flow

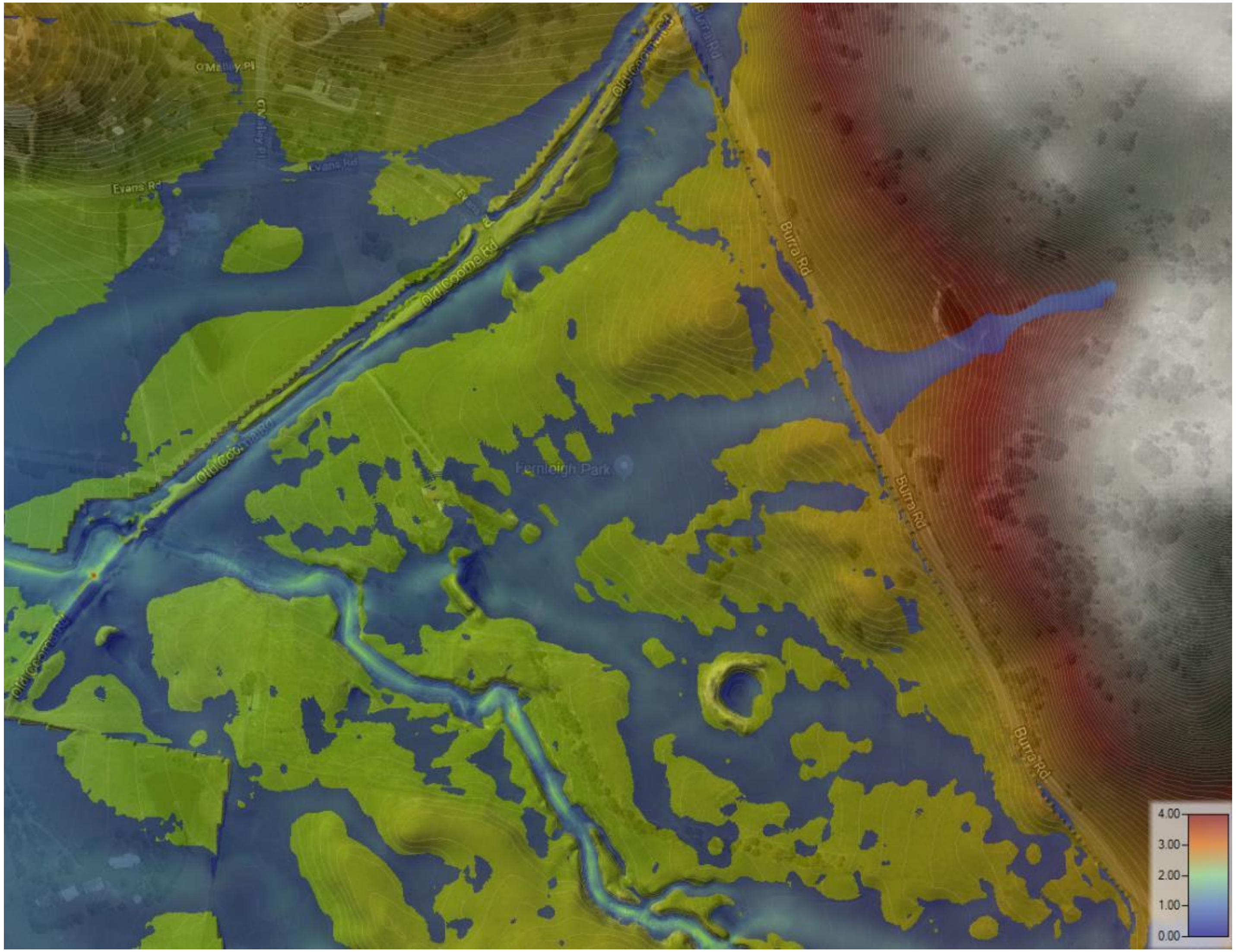


Figure B-7: Peak 100-year flow velocities for overland flow

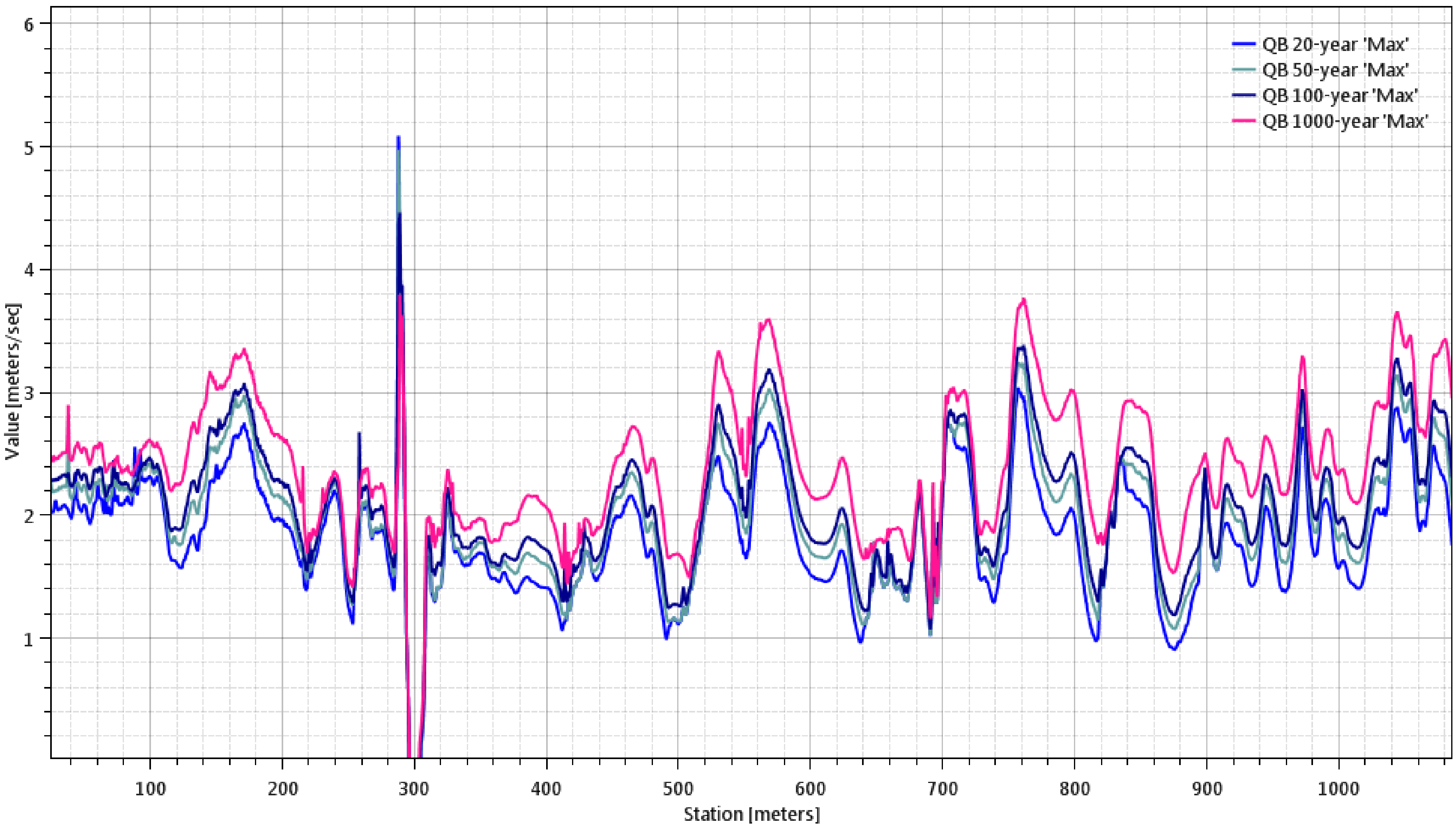


Figure B-7: Peak 100-year velocity profile

Appendix C Catchment Characteristics

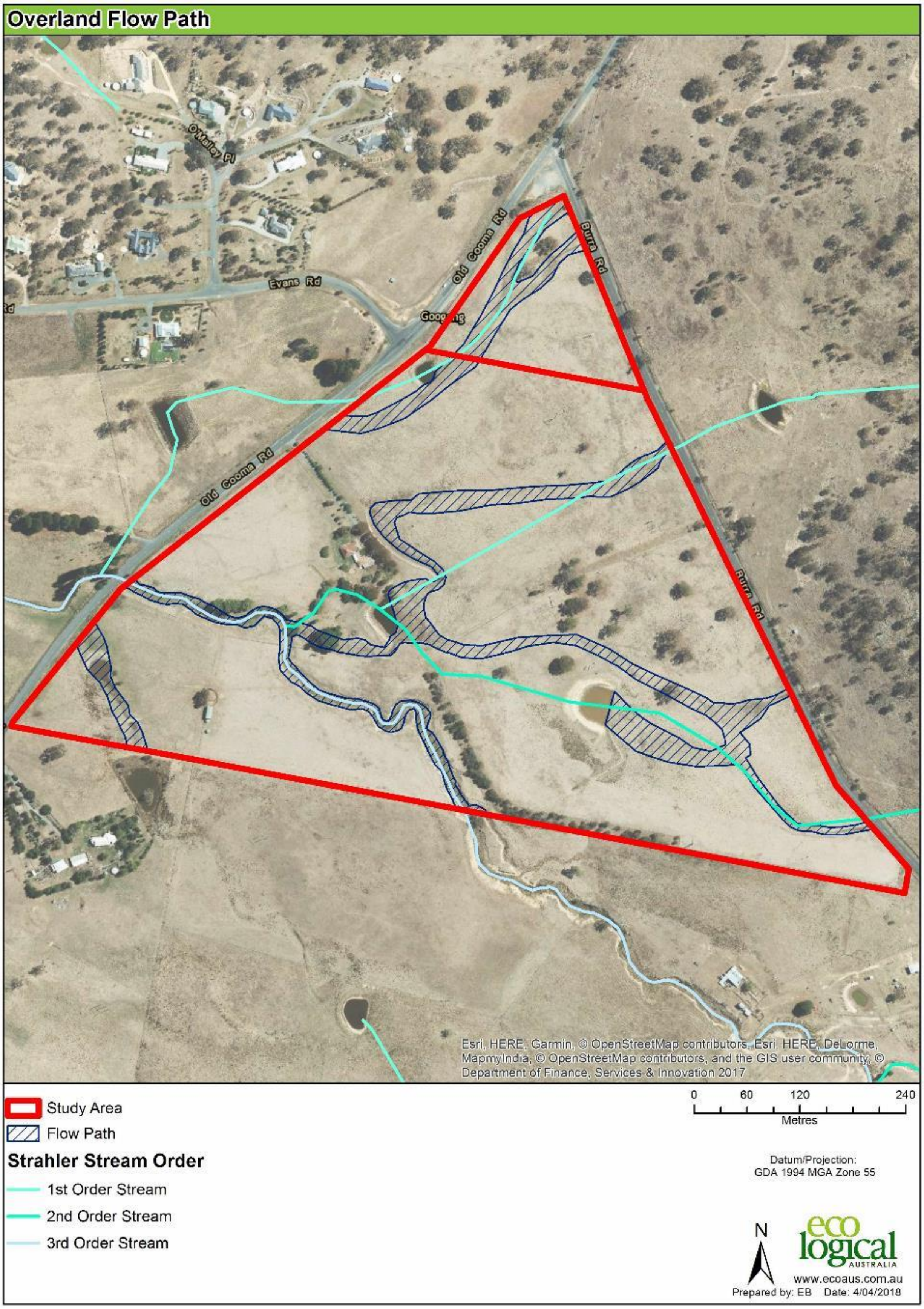


Figure C-1: Overland flow paths

Table C-1: Catchment characteristics

Node No	Sub Area	Area (km^2)
1	SC2	0.637
2	SC1	1.084
5	SC3	0.445
6	SC4	0.425
9	SC5	0.892
10	SC6	0.343
12	SC7	1.587
14	SC8	1.587
16	SC9	0.671
18	SC10	0.281
20	SC11	0.936
21	SC12	0.208

Table C-2: Link parameters

Reach No	Reach Name	Length (m)	Reach Type
1	SC1-J1	0.84	Natural
2	SC2-J1	1	
3	J1-J2	0.26	
4	SC4-J3	1.16	
5	SC3-J2	0.26	
6	J2-J3	0.26	
7	J3-J4	0.26	
8	SC5-J4	0.397	
9	SC6-JN	1.15	
10	J4-JN	0.397	
11	JN-J7	0.397	
12	SC7-J5	0.38	
13	J5-J6	0.38	
14	SC8-J6	0.485	
15	J6-J7	0.485	
16	SC9-J7	0.85	
17	J7-J8	0.197	
18	SC10-J8	0.197	
19	J8-J9	0.197	
20	SC11-J9	1.23	
21	SC12-End	0.5	
22	J9-End	0.5	

Table C-3: Flow calculation for HEC-RAS Model

RORB Location	HEC-RAS cross section river station (m)	10% AEP flow (m^3/s)	1% AEP flow (m^3/s)	0.5% AEP flow (m^3/s)	0.2% AEP flow (m^3/s)	0.1% AEP flow (m^3/s)
J5-J6	602.9097	4.5	12.2	14.4	17.4	20.6
0	293.1794	5.3	14	16.7	20	23.6
J6-J7	1.486383	6.1	15.8	19	22.7	26.6

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