Byford

District Water Management Strategy

Prepared for:

Shire of Serpentine-Jarrahdale

By Urbaqua

June 2018

urbaqua
land and water solutions

Disclaimer and Limitation

This document is published in accordance with and subject to an agreement between Urbaqua and the Client, Shire of Serpentine-Jarrahdale, for who it has been prepared for their exclusive use. It has been prepared using the standard of skill and care ordinarily exercised by environmental professionals in the preparation of such Documents.

This report is a qualitative assessment only, based on the scope of services defined by the Client, budgetary and time constraints imposed by the Client, the information supplied by the Client (and its agents), and the method consistent with the preceding. Urbaqua has not attempted to verify the accuracy or completeness of the information supplied.

Any person or organisation that relies upon or uses the document for purposes or reasons other than those agreed by Urbaqua and the Client without first obtaining the prior written consent of Urbaqua, does so entirely at their own risk and Urbaqua, denies all liability in tort, contract or otherwise for any loss, damage or injury of any kind whatsoever (whether in negligence or otherwise) that may be suffered as a consequence of relying on this Document for any purpose other than that agreed with the Client.

Copying of this report or parts of this report is not permitted without the authorisation of the Client or Urbaqua.

CONTENTS

1 Introduction........1
1.1 Planning background........2
1.2 Previous studies........2
1.3 Requirements for future stages of planning and development........4

2 Pre-development environment........7
2.1 Study area........7
2.2 Topography........7
2.3 Soils........7
2.4 Acid sulfate soils........10
2.5 Wetlands and Environmental Assets........10
2.6 Social considerations........13
2.7 Surface water........13
2.8 Groundwater........16

3 Proposed development........18
3.1 Key elements of the structure plan........18

4 Protection of environmental assets........19
4.1 Minimise changes to hydrology to prevent impacts on watercourses and wetlands........19
4.2 Manage and restore watercourses and wetlands........20
4.3 Assess and manage impacts on native flora and fauna........20
4.4 Assess and manage impacts on Aboriginal Heritage Sites........20
4.5 Investigate opportunities to mitigate for the potential impacts of climate change........20

5 Urban water use........21
5.1 Potable water use........21
5.2 Fit for purpose water........21

6 Stormwater management strategy........23
6.1 Floodplain management........23
6.2 Surface water quality management........25
6.3 Surface water quantity management........26

7 Groundwater management strategy........37
7.1 Glossary of groundwater terms........37
7.2 Groundwater quantity management........38
7.3 Groundwater quality management........40

8 Commitment to water sensitive urban design........41
8.1 Hierarchy of preferred approaches to water sensitive urban design........41

9 Implementation........43
9.1 Requirements for following stages........43
9.2 Review of District Water Management Strategy........44
9.3 Monitoring strategy........44
9.4 Action plan........48

10 References and resources........49
10.1 Local structure plans........50
10.2 Local water management strategies and urban water management plans........51

Appendix A – Stormwater modelling in InfoWorks ICM 52
A.1 Initial modelling assumptions 55
A.2 Base model hydraulics 55
A.3 Base model hydrology 57
A.4 Base model validation 60
A.5 Revised parameterisation....62
A.6 Australian Rainfall & Runoff 2016 methodology 65
A.7 Current system model development 68
A.8 Current system detailed modelling results....93

Appendix B – Site inspection photographs and notes 94

Appendix C – Detailed flood mapping and longitudinal sections 95

Tables

Table 1: Criteria for emptying time of a stormwater storage system for different AEP 25
Table 2: Top water levels, peak flows and timing of peaks at critical locations....29
Table 3: Subcatchment details for undeveloped areas 32
Table 4:Actions and responsibilities for implementation of the strategy....48
Table A1: Modelled hydraulic structures – base model 55
Table A2: Culvert roughness coefficients (Manning's N) 57
Table A3: InfoWorks model runoff area properties....57
Table A4: InfoWorks model land use surface breakdown 57
Table A5: InfoWorks model catchment properties for base model scenario 58
Table A6: Base model peak flow comparison to Byford Townsite DWMP (DWER, 2008) post-development model....60
Table A7: Base model top water level comparison to Byford Townsite DWMP (DWER, 2008) post-development model....61
Table A8: Birrega Oaklands model peak flow comparison to base model 62
Table A9: InfoWorks model runoff area properties – revised....62
Table A10: Base model peak flow comparison to base model with revised parameters 63
Table A11: Base model top water level comparison to base model with revised parameters....64
Table A12: Birrega Oaklands model peak flow comparison to base model with revised parameters 65
Table A13: Base model peak flow comparison to base model with AR&R 2016 methods....66
Table A14: Base model top water level comparison to base model with AR&R 2016 methods ..67
Table A15: Birrega Oaklands model peak flow comparison to base model with AR&R 2016 methods 68
Table A16: InfoWorks model catchment properties for current system model scenario 72
Table A17: Modelled hydraulic structures – current system model....83
Table A18: Current system model peak flow comparison to base model 91
Table A19: Current system model top water level comparison to base model 92
Table A20: Birrega Oaklands model top water level comparison to current system model....93

Figures

Figure 1: Planning framework integrating drainage planning with land planning processes.........1
Figure 2: Byford District Water Management Strategy Study Area and Existing Land Use 8
Figure 3: Topography and Soils 9
Figure 4: Acid Sulfate Soil Risk...11
Figure 5: Wetlands and Environmental & Social Assets 12
Figure 6: Surface Water 15
Figure 7: Groundwater 17
Figure 8: Byford District Structure Plan (SSJ, 2018) 18
Figure 9a and b: Typical pre- and post-development runoff hydrograph comparison showing a: uncompensated and b: compensated post-development flows (Source: DWER, 2008) 19
Figure 10: Detailed 1%AEP floodplain mapping and ponded areas (Source: Hall et al, 2015) 24
Figure 11: Schematic presentation of information for subcatchments and main waterways......27
Figure 12: Byford district stormwater management strategy 35
Figure 13: Byford Town Centre precinct flood management strategy 36
Figure 14: Options for a 'limited fill' development 38
Figure A.1: Base model layout 53
Figure A.2: Current system model layout 54
Figure A.3: Principal data sources for model updates 70
Figure A.4: Current system modelled land use 71
Figure A.5: 2-dimensional model domain and gridded elevation data 89
Figure C1: Flood mapping overview..95
Figure C2.1-10: Detailed flood mapping...95
Figure C2.11-20: Longitudinal sections – 20% AEP 95
Figure C2.21-30: Longitudinal sections – 1% AEP..95

1 INTRODUCTION

This District Water Management Strategy (DWMS) has been prepared for Serpentine-Jarrahdale Shire (SJ Shire) to supersede and update *Byford Townsite Drainage and Water Management Plan* (DWMP) (DWER, 2008) and to support a review of the *Byford Townsite District Structure Plan* currently underway.

This DWMS considers a larger study area than both the preceding DWMP and the DSP, presents an updated summary of the existing environment and builds upon each of the strategies first presented in the DWMP with reference to updated state and local government policies where relevant. The document also provides a detailed review and update to the Arterial Drainage Scheme (ADS) for the Byford townsite that was proposed in the DWMP in accordance with the responsibilities for drainage planning assigned to the Department of Water by the state government.

The scope of the DWMS is to cover all aspects of total water cycle management, including:

- protection of significant environmental assets within the structure plan area, including meeting water requirements and managing potential impacts from development
- water demands, supply options, opportunities for conservation and demand management measures and wastewater management
- surface runoff, including peak event (flood) management and the application of water-sensitive urban design principles to frequent events
- groundwater, including the impact of urbanisation, variation in climate, installation of drainage to reduce groundwater levels, potential impacts on the environment and the potential to use groundwater as a resource
- water quality management, which includes source control of pollution inputs by catchment management, acid sulfate soil management, control of contaminated discharges from industrial areas and management of nutrient exports from surface runoff and groundwater through structural measures

The position of the DWMS within the state government planning framework is defined in *Better Urban Water Management* (WAPC, 2008) and outlined in Figure 1 below.

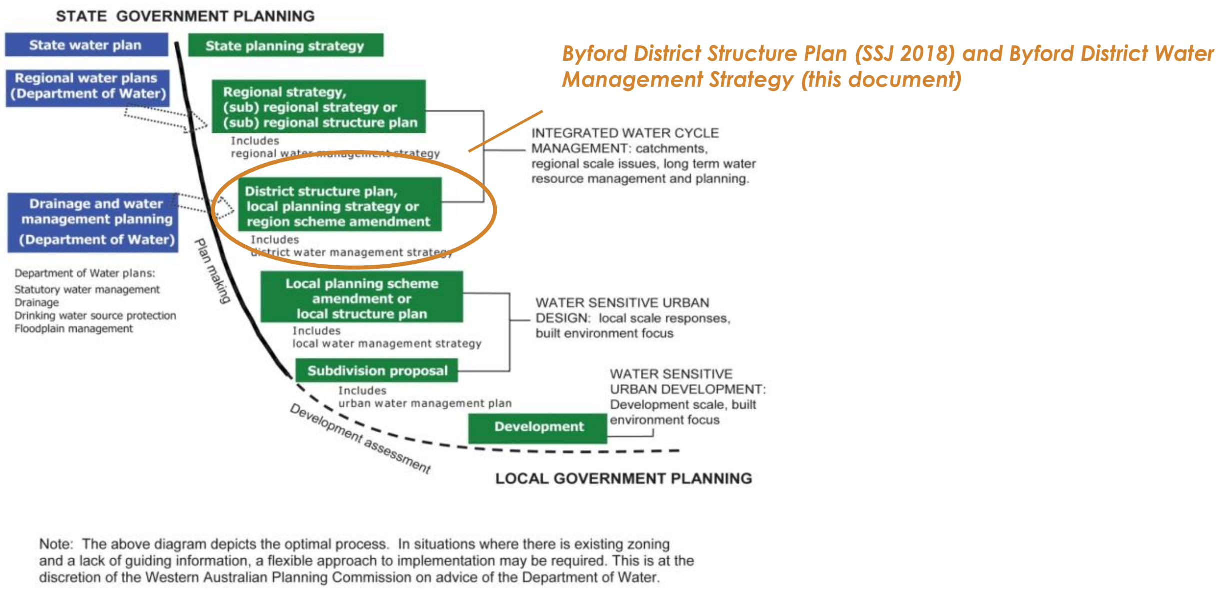


Figure 1: Planning framework integrating drainage planning with land planning processes

1.1 Planning background

1.1.1 District structure planning

The *Byford District Structure Plan* (TBB, 2005) provides high level guidance for land use change and development in the Byford Townsite, excluding the Byford Trotting Complex Precinct (see Figure 2).

The study area is the subject of a District Structure Plan review currently being undertaken by Hames Sharley. This review will ultimately deliver a revised District Structure Plan for the whole study area which will supersede the *Byford District Structure Plan* (TBB, 2005).

1.1.2 Local structure plans

There are numerous local structure plans in the study area which provide more detailed guidance for the development of specific areas. Current local structure plans within the study area include:

- Byford Town Centre Local Structure Plan
- Byford Central Local Structure Plan
- Byford West Local Structure Plan
- Byford Main Precinct - The Glades Local Structure Plan
- Kalimna Estate Local Structure Plan
- Redgum Brook Estate - North Local Structure Plan
- Redgum Brook Estate - South Local Structure Plan
- Marri Park Estate - Lot 3 Larsen Rd & Lot 3 Alexander Road, Byford Local Structure Plan
- Lot 6 and Lot 27 Abernethy Road, Byford - Grange Meadows Local Structure Plan
- L1, L3 & L128 South Western Highway, Byford - Map Local Structure Plan
- Lot 806 South Western Highway, Byford Local Structure Plan
- Lots 59-62 Briggs Road, Byford Local Structure Plan
- Lot 2 Nettleton Road, Byford Local Structure Plan
- Byford Meadows Estate Local Structure Plan
- Lot 9500 Thomas Road, Briggs Road, Byford Local Structure Plan
- Doley Road Precinct Local Structure Plan

1.2 Previous studies

A number of key investigations have been previously undertaken in the Byford locality. These include:

- Byford urban stormwater management strategy (Parsons Brinkerhoff, 2003)
- Byford urban stormwater management strategy – Developer guidelines (Parsons Brinkerhoff, 2005)
- Local scale groundwater modelling to assess effects of climatic variations and planned development (CyMod Systems, 2007)
- Serpentine River floodplain management study – flood modelling report (SKM, 2007)
- Serpentine River floodplain management study – floodplain management strategy (SKM, 2007)
- Byford drainage and water management plan (DWER, 2008)
- Lower Serpentine hydrological studies: conceptual model report (Hall et al, 2012)
- Lower Serpentine hydrological studies: model construction and calibration report (Hall et al, 2012)

- Lower Serpentine hydrological studies: Land development, drainage and climate scenario report (Hall et al, 2012)
- Birrega Oaklands flood modelling and drainage study (Hall et al, 2015)
- Birrega Oaklands drainage and water management plan (Unpub.)

1.2.1 Byford district structure plan supporting studies

The Byford urban stormwater management strategy was completed by Parsons Brinkerhoff in 2003. It presented stormwater management strategies for the study area and many of the proposed strategies have been incorporated into this study. The drainage hydraulic modelling carried out within this study has incorporated key hydraulic features of the strategy's XP-Storm model. The Byford urban stormwater management strategy was later simplified and issued as developer guidelines in 2005.

1.2.2 Byford DWMP and supporting studies

Byford Townsite Drainage and Water Management Plan was published by the Department of Water and Environmental Regulation in 2008. The document aimed to incorporate information from all previous studies and present design criteria and management strategies to guide development in the Byford Townsite District Structure Plan area.

Local-scale groundwater modelling was completed by CyMod Systems (2007) in support of the Byford DWMP to assess any impacts from variations in climate or planned development in the study area.

A floodplain management study including two-dimensional flood modelling has been completed by SKM (2007). A high resolution digital elevation model, created to assist flood modelling, has been made available as part of the surface water modelling outputs to supplement Landgate information.

1.2.3 Recent studies

The Department of Water and Environmental Regulation has recently undertaken a number of hydrological studies for the Lower Serpentine River catchments including the Birrega Oaklands drainage catchments with the intent to develop *Birrega Oaklands Drainage and Water Management Plan* (DWMP). The DWMP has not yet been published.

Groundwater modelling has been completed in the study area by the Department of Water and Environmental Regulation (DWER) and presented in a series of three *Lower Serpentine Hydrological Studies* reports (Hall et al 2015).

Flood modelling has also been completed in the study area by the Department of Water and Environmental Regulation (DWER) and presented in *Birrega Oaklands flood study* (DWER, 2015)

1.2.4 Local water management strategies and Urban water management plans

A large number of Local Water Management Strategies (LWMS) and Urban Water Management Plans (UWMP) have been prepared to support local structure planning and subdivisions within the study area. The following list is not exhaustive but provides a summary of most of the reports that have been previously approved in the study area:

- Byford Town Centre Local Water Management Strategy (GHD, 2014)
    - Lot 1 Abernethy Road, Byford UWMP (Wave International, 2016)

- Lot 2 Abernethy Rd, Byford UWMP (JDA, 2015)
  - Lot 4 Abernethy Road, Byford - UWMP (True Civil Consulting, 2018)
  - Lot 5 Abernethy Road, Byford UWMP (GHD, 2017)
  - Lot 15 Abernethy Road, Byford UWMP (RPS, 2016)
- Lots 1,2 & 63 Thomas Road, Larsen Road, Byford (Byford Central) DNMP (Cardno, 2006)
- Lots 4&5 Abernethy Road, Byford (Byford West) DNMP (Cardno, 2007)
- Byford Main Precinct Local Structure Plan (The Glades): LWMS (JDA, 2005)
  - The Glades at Byford: Stages 6, 7 & 8a UWMP (JDA 2011)
  - The Glades at Byford: Woodland Grove North UWMP (JDA 2013)
  - The Glades at Byford: Icaria Stages 1 to 4 UWMP (JDA, 2014)
  - The Glades at Byford: Icaria Stages 5 to 10 UWMP (JDA, 2014)
  - The Glades at Byford: Woodland Grove South UWMP (JDA 2013)
  - The Glades at Byford: Stage 2 UWMP (JDA, 2009)
  - The Glades at Byford: Stage 9 & High School Precinct UWMP (JDA, 2011)
  - The Glades at Byford: Stage 8 UWMP (JDA, 2012)
  - The Glades Cardup Brook, East and West Precinct, UWMP (JDA, 2016)
- Lot 9 Abernethy Road (Kalimna Estate) LWMS (DEC, 2009)
  - Lot 9 Abernethy Rd, Byford, UWMP (DEC, 2010)
- Redgum Brook Estate DNMP (GHD, 2008)
  - Redgum Brook Estate (Northern Section) LWMS (GHD, 2014)
  - Redgum Brook Estate Stages 9-12, UWMP (GHD, 2015)
  - Redgum Brook – East of Kardan Boulevard, UWMP (GHD, ???)
  - Redgum Brook Stage 10A, 10B and Stage 13 UWMP (GHD, 2014)
- Larsen Road Estate (Marri Park), Byford UWMP (Cardno 2008)
- Grange Meadows, Byford UWMP (BPA Engineering, 2013)
- Lot 9500 Thomas Road, Byford (Byford Meadows) LWMS (HyD2o, 2014)
  - Lot 9500 Thomas Road, (Byford Meadows), Stage 1 UWMP (Hyd2o, 2014)
  - Lot 9500 Thomas Road, (Byford Meadows), Stage 2(a&b) UWMP (Hyd2o, 2015)
  - Lot 9500 Thomas Road, (Byford Meadows), Stage 2c UWMP (Hyd2o, 2016)
  - Byford Meadows (Remaining Stages), UWMP (Hyd2o, 2017)
- Byford, Doley Road Precinct Local Water Management Strategy (EE, 2016)
  - Parcel Property Landholding, Byford (Doley Precinct) UWMP (Urbaqua, 2017)
  - Lot 8, 9 & 23 Warrington Road, Byford (Doley Precinct) UWMP (Cardno 2017)
- Lot 2 Nettleton Road, Byford (Brook @ Byford) LWMS (JDA, 2009)
  - Lot 2 Nettleton Road, Byford (Brook @ Byford) LWMS Addendum (Hyd2o, 2012)
  - Lot 2 Nettleton Road, Byford (Brook @ Byford) Stage 1 UWMP (Hyd2o, 2013)
  - The Brook @ Byford Stages 1-3 UWMP (EE, 2016)
- L1, L3 & L128 South Western Highway, Byford - LWMS (GHD, 2012)
- Town Planning Scheme 2 Amendment 77 (Byford on the Scarp) DNMP (Gilbert Rose Consulting, 1999)
  - Byford on the Scarp – Stages 4, 5 & 6 UWMP (JDA, 2008)
  - Byford on the Scarp – Stage 7 UWMP (EE, 2014)
  - Byford on the Scarp – Stage 8a UWMP (EE, 2016)

1.3 Requirements for future stages of planning and development

In accordance with *Better Urban Water Management* (WAPC 2008) the implementation of this strategy will be through the land use planning process with proponents of development required to develop water management strategies and plans at each planning stage to support and inform their planning proposals, environmental investigations, engineering, landscaping and urban designs as follows.

1. A ***local water management strategy*** shall be prepared to support a local scheme amendment or the preparation of any local structure plan, whichever is the earlier consistent with *Better Urban Water Management* (WAPC, 2008), *Interim: Developing a Local Water Management Strategy* (DWER, 2008) and the *Byford District Water Management Strategy* (this document).

2. Where no approved local water management strategy exists, any application for subdivision in greenfield areas, or where more than 30 lots are proposed in infill or brownfield areas, shall be accompanied by a draft ***urban water management plan***, consistent with *Urban Water Management Plans: Guidelines for preparing plans and for complying with subdivision conditions* (DWER, 2008) and the *Byford District Water Management Strategy* (this document), and developed in consultation with the Shire of Serpentine-Jarrahdale, with advice as necessary from DWER.

3. Where an approved local water management strategy exists, the preparation and implementation of an ***urban water management plan*** will be required as conditions of urban or industrial subdivision. The urban water management plan shall be consistent with *Urban Water Management Plans: Guidelines for preparing plans and for complying with subdivision conditions* (DWER, 2008) and the *Byford District Water Management Strategy* (this document) and developed in consultation with the Shire of Serpentine-Jarrahdale, with advice as necessary from DWER.

4. In exceptional circumstances, subject to consultation with the Shire of Serpentine-Jarrahdale and DWER, where a development consists of a small area and/or has limited water management requirements, an urban water management plan may not be required. In this case, subsequent subdivision application(s) would only need to be accompanied by a simplified ***drainage design scoping summary*** developed in consultation with the Shire of Serpentine-Jarrahdale, with advice as necessary from DWER.

5. Where an urban water management plan has been prepared and approved at the time of subdivision, or to accompany the initial stage(s) of a multi-stage development it is recognised that the document may contain limited drainage design detail for all or part of the subdivision area. In this case it will be necessary for design submissions relating to future stages to be accompanied by a ***drainage design compliance summary***.

Proposals should address groundwater and surface water management, water conservation and efficiency; and water reuse and recycling in an integrated manner, focussing on key issues identified below.

1.3.1 Scale, complexity and timing – applying a risk-based approach

Different levels of detail in water management documents are expected dependent on the scale and complexity of the site as well as the timing of lodgement.

Urban water management plans lodged early in the design process are likely to contain less detail and may be informed by assumptions based on surrounding development and/or designers prior experience. However, the document must still contain critical elements of design that address key risks associated with public safety and the functionality of the water management system. These critical elements include but may not be limited to:

- Invert levels, bank slopes, top water levels and volumes of major flood storage areas.

- Invert levels, staged cross-sections, top water levels and general landscape design characteristics of living streams.
- Critical invert levels, outlet arrangements, general layout and design characteristics for any proposed groundwater management system (including supporting modelling).
- Lot-scale stormwater management arrangements (location and general design characteristics of lot-based infrastructure including infiltration systems and/or raingardens where used).
- Street-scale stormwater management arrangements (location and general design characteristics of street-based infrastructure including infiltration systems, raingardens and/or tree-pits where used).

Each of the critical element listed above must also be addressed in any subsequent drainage design compliance summary which should either state that the element remains unchanged from the preceding UWMP or provide details of, and justification for, any changes.

Urban water management plans lodged to accompany detailed designs are expected to contain a greater level of detail and should be informed by accumulated knowledge of the site and any previous development stages with limited assumptions.

1.3.2 Staging and levels of detail – learning by doing

Staged developments can sometimes occur over long timeframes. Because building styles and methodologies evolve, it is important that urban water management plans and drainage designs recognise and adapt to these changes. Specifically, the following potential changes should be considered in preparation of each progressive document and/or design:

- Changes to built form/lot ratios – it is expected that runoff parameters used for design purposes are continually reviewed in relation to current practice.
- Innovations in best practice water management – it is expected that consideration is given to ways to progressively incorporate new or different approaches to water management into each stage of development.
- Changes to drainage configuration/storage provision – it acknowledged that there may be opportunities to rationalise previously approved storage volumes through optimised drainage system designs including using online storage within multiple use corridors. Any proposals to reduce previously approved storage volume provision must demonstrate, in an urban water management plan **lodged with or prior to subdivision**, that peak discharges can be managed within the arterial drainage system, to the satisfaction of the Shire of Serpentine Jarrahdale in consultation with Department of Water and Environmental Regulation.

1.3.3 Adoption of Australian Rainfall and Runoff 2016 procedures

It is expected that all future local water management strategies and urban water management plans include consideration of the revised rainfall patters and modelling procedures presented in the latest edition of Australian Rainfall and Runoff (AR&R 2016).

Where there is no previously approved local water management strategy or urban water management plan, full adoption of AR&R 2016 procedures is expected.

Where there is a previously approved local water management strategy or urban water management plan based on other modelling methodologies the consequences of adopting AR&R 2016 and the risks associated with retaining the previous methodology should be presented in subsequent documentation for consideration by the Shire of Serpentine-Jarrahdale in consultation with DWER as necessary.

2 PRE-DEVELOPMENT ENVIRONMENT

2.1 Study area

The *Byford District Water Management Strategy* (DWMS) study area is presented in Figure 2 and located approximately 35 km south-east of the Perth CBD, within the Serpentine Jarrahdale Shire. The area is approximately 4,500 hectares and includes the *Byford Townsite Drainage and Water Management Plan* study area (Byford Townsite) which is superseded by this document.

Byford Townsite is approximately 1,500 hectares and is bounded by Thomas Road to the north, Hopkinson Road and the future Tonkin Highway to the west, Cardup Siding Road to the south and the Byford townsite and Darling Range foothills to the east. Land within the townsite is predominantly urban or remnant rural residential which is zoned for future urban development. Key features of the townsite include:

- Byford Town Centre Precinct
- Byford Trotting Complex Precinct
- Briggs Park Sport and Education Precinct

Areas of the study area outside Byford Townsite are predominantly rural with some areas of urban and industrial land.

2.2 Topography

The topography of the DWMS study area, as shown in Figure 3, is characterised by steep slopes in the foothills of the Darling Range, with an elevation of 120 m AHD falling rapidly to 80 m AHD at Linton Street and then gradually to 55 to 60 m AHD at the South Western Highway. To the west of the South Western Highway, the terrain is relatively flat palusplain (seasonally waterlogged land).

2.3 Soils

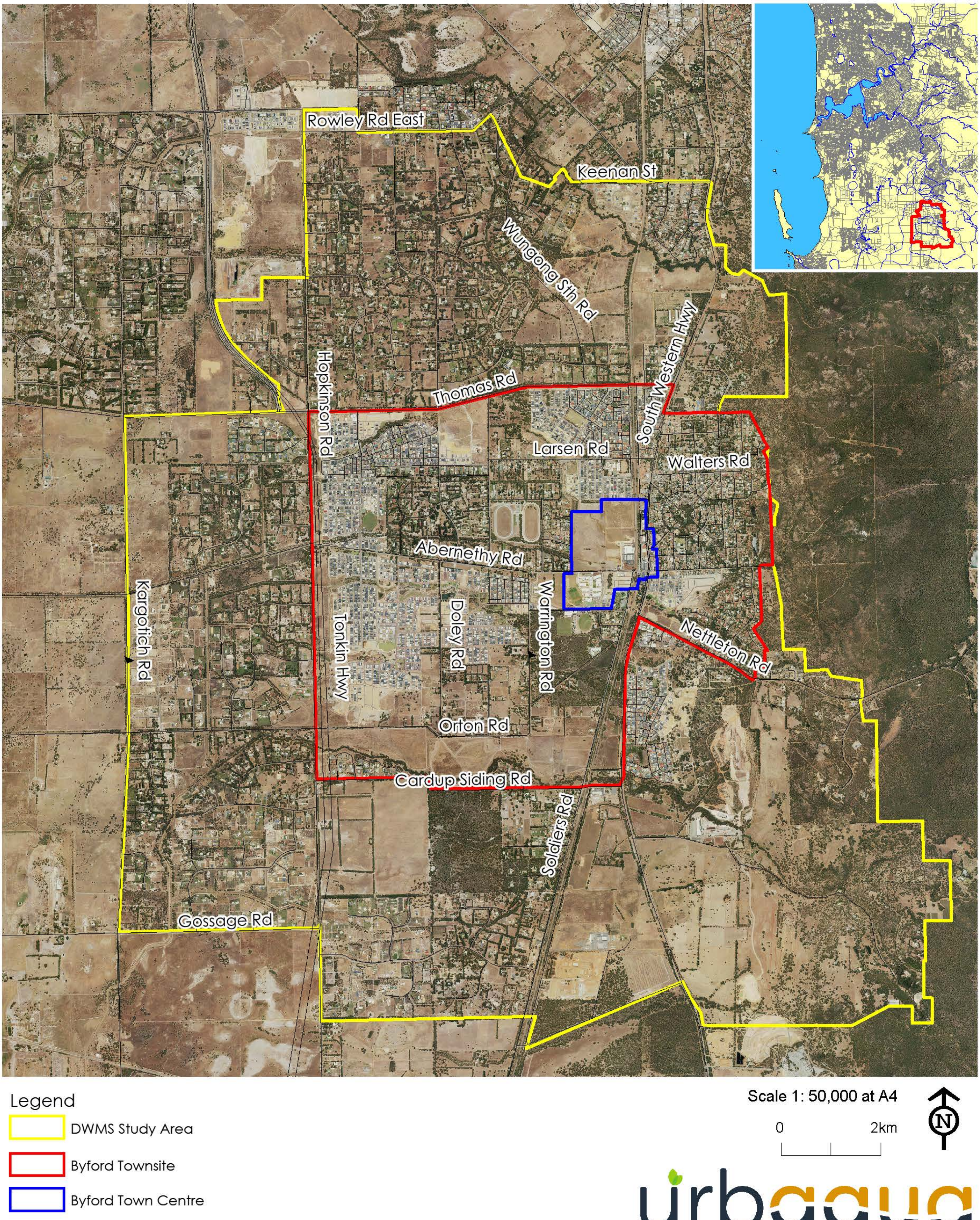
There are three primary soil types across the study area, as shown in Figure 3. The soil types are:

- Ridge Hill colluvium from the Yogannup formation (S12) – highly variable layers of gravelly to sandy clay with lenses of silt and gravel
- Guildford clay (Csg) – lenses of sandy clay, clayey sand, iron-rich cemented sand and sand. Low horizontal conductivity and very low vertical conductivity
- Bassendean sand (Cs) – bleached grey to pale yellow sand with little ability to retain moisture or nutrients

Ridge Hill colluvium is found to the east of the study area, in the region of the Darling Scarp. To the west of the study area Guildford clay can be found interlaced with Ridge Hill colluvium. Overlaying the Guildford clay is Bassendean sand, which occurs in thin layers across the majority of the site.

The on-site soils are highly variable in phosphorous retention capacity, with grey brown sands having a low capacity to retain phosphorous.

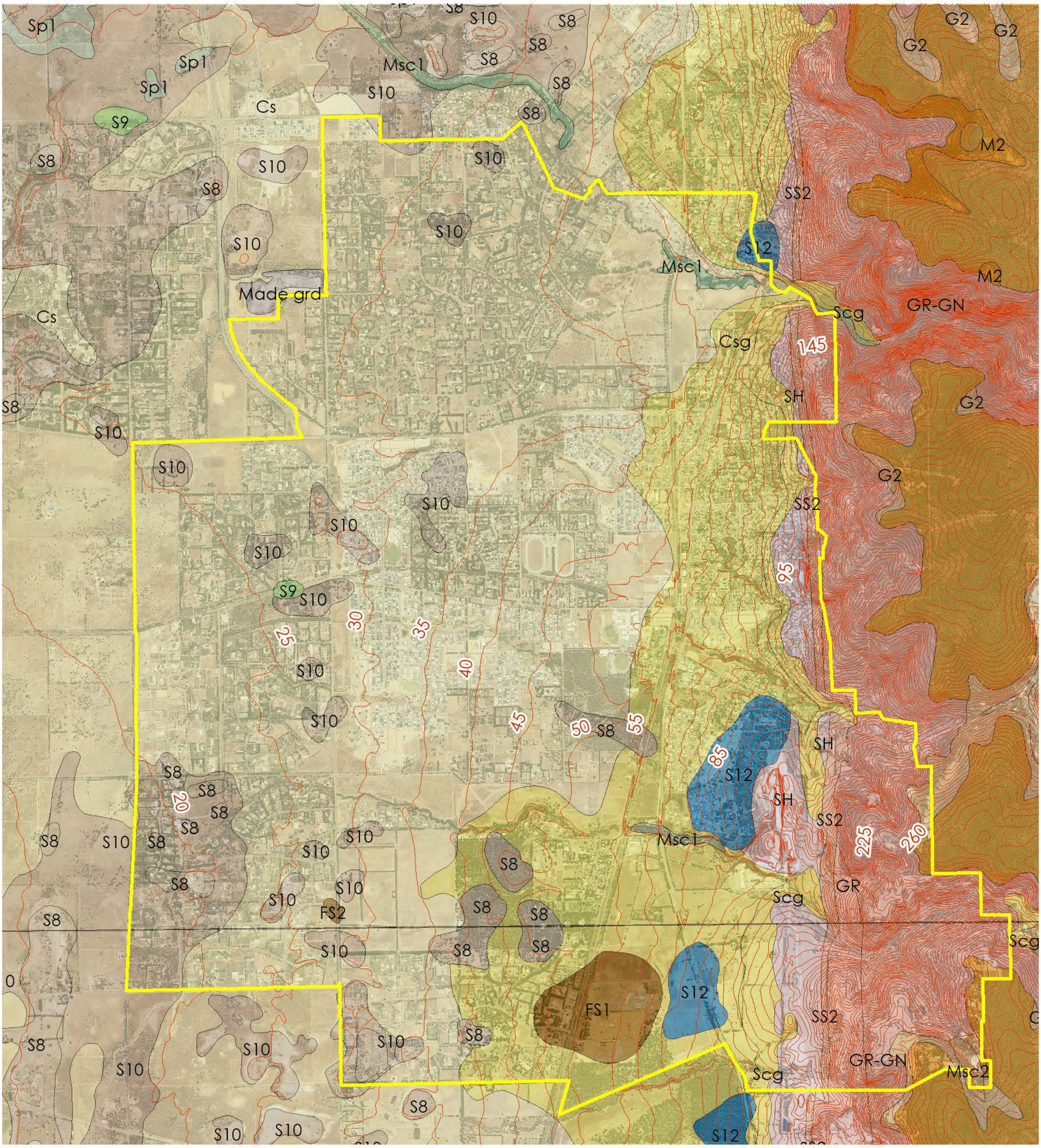
Shire of Serpentine Jarrahdale - Byford DWMS
Figure 2 - Study Area



urbaqua land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure 3 - Topography and Soils



Legend

DWMS Study Area

Elevation contours (mAHD)

Surface Geology:

S8/S10	SH	GR-GN	SS2
Cs	Csg	G2	LA1
FS1	S12	Msc1	S9

Scale 1: 50,000 at A4

0 2km

N

urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

2.4 Acid sulfate soils

The Department of Water and Environmental Regulation (DWER) maintains mapping of Acid Sulfate Soil Risk on the Swan Coastal Plan which was developed for the Western Australian Planning Commission's Planning Bulletin No. 64 (2003) and is presented for the DWMS study area in Figure 4. The mapping is based upon a review of geomorphological, geological and hydrological information, and indicates that the soils in the DWMS study area to the west of the South Western Highway consist of moderate to low risk of actual acid sulfate soils or potential acid sulfate soils occurring generally at greater than 3 m depth.

Low to no risk of actual acid sulfate soils or potential acid sulfate soils occurring generally at greater than 3 m depth can be found to the east of the South Western Highway in the DWMS study area.

The risk of acid sulfate soils being exposed to oxidation due to development in the study area is considered low. As part of development requirements, new developments will need to introduce fill to a depth that is acceptable for residential construction as well as provide suitable flood clearance and adequate subsoil drainage.

2.5 Wetlands and Environmental Assets

Wetlands and environmental assets present in the study area are presented in Figure 5.

The Department of Biodiversity, Conservation and Attractions maintains a database of high value wetlands on the Swan Coastal Plain. Current mapping indicates there are high value wetlands (conservation category and resource enhancement) present within the study area including at:

- Brickwood Reserve in the south-eastern section of the study area;
- Cardup Reserve on the southern boundary of the study area;
- Abernethy Road bushland in the western part of the study area;
- Land between the South Western Highway and rail line north of Cardup Brook;
- Along the course of Cardup Brook in the southern part of the study area
- Along the course of Wungong River in the north eastern corner of the study area
- Along the course of Birrega Main Drain in the northern part of the study area

Brickwood Reserve is a Bush Forever Site (No: 321) and noted as containing "one of the largest and most intact examples of a critically endangered threatened ecological community, protected under Federal and State policies, on the Swan Coastal Plain" (SSJ, 2009).

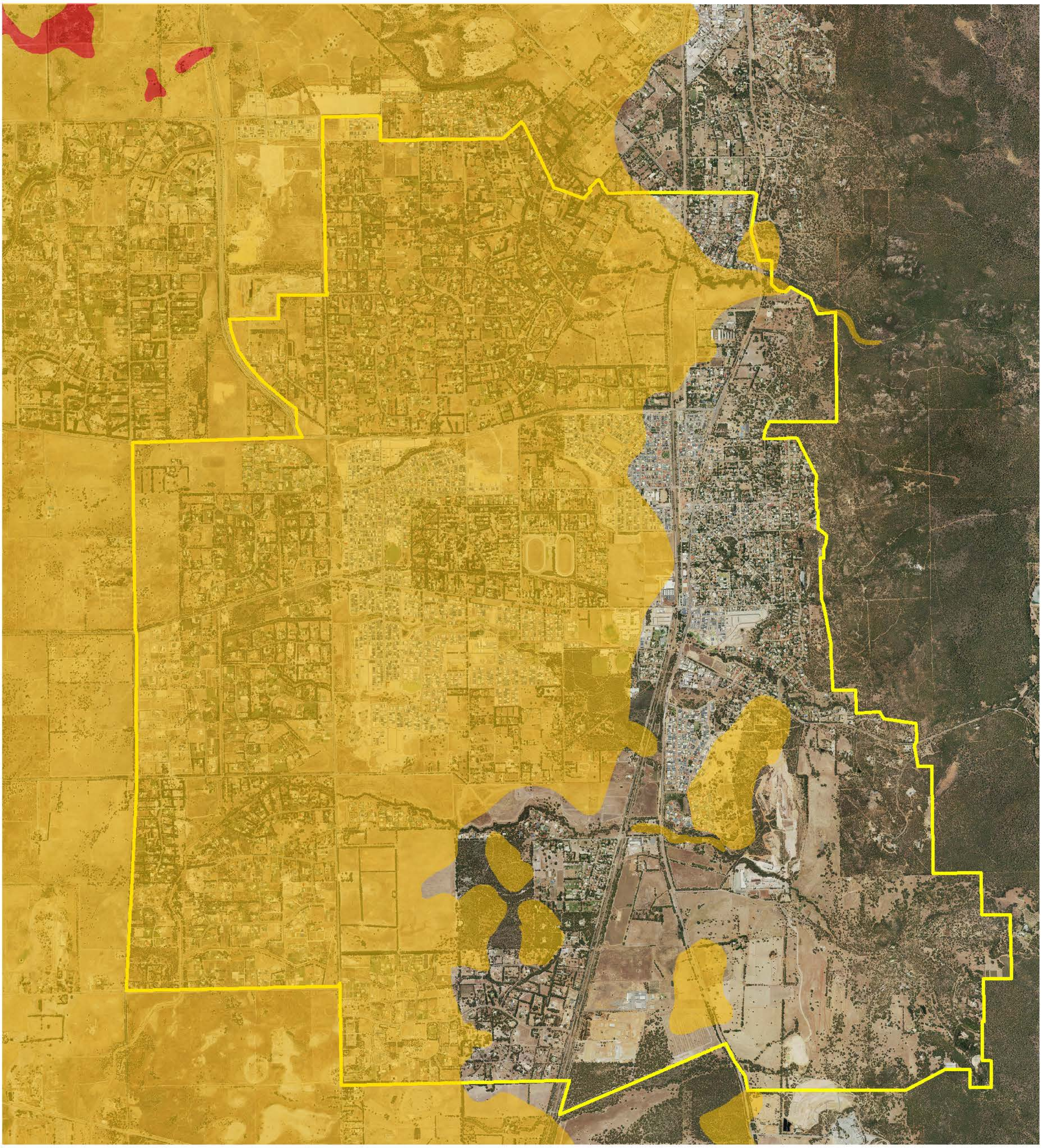
Brickwood Reserve and Briggs Park Management Plan (SJ Shire) was prepared in 2009 to guide and prioritise the use and management of the reserve, recognising the likely pressures associated with the surrounding urban expansion of Byford. The protection of the important environmental values of this reserve is a key objective of this DWMS.

Cardup Nature Reserve, which lies on the southern boundary of the study area, is classified as Bush Forever Site 352 and contains at least four priority taxa. A section of the Cardup Brook to the north of Cardup Nature Reserve is listed as Bush Forever Site 351.

Abernethy Road bushland which is south of Abernethy Road and west of Hopkinson Road is listed as Bush Forever Site 65.

Remnant vegetation between the rail line and South Western Highway north of Cardup Brook is listed as Bush Forever Site 350.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure 4 - Acid Sulfate Soil Risk



Legend

DWMS Study Area

Acid Sulfate Soil Risk:

High to moderate risk

Moderate to low risk

Scale 1: 50,000 at A4

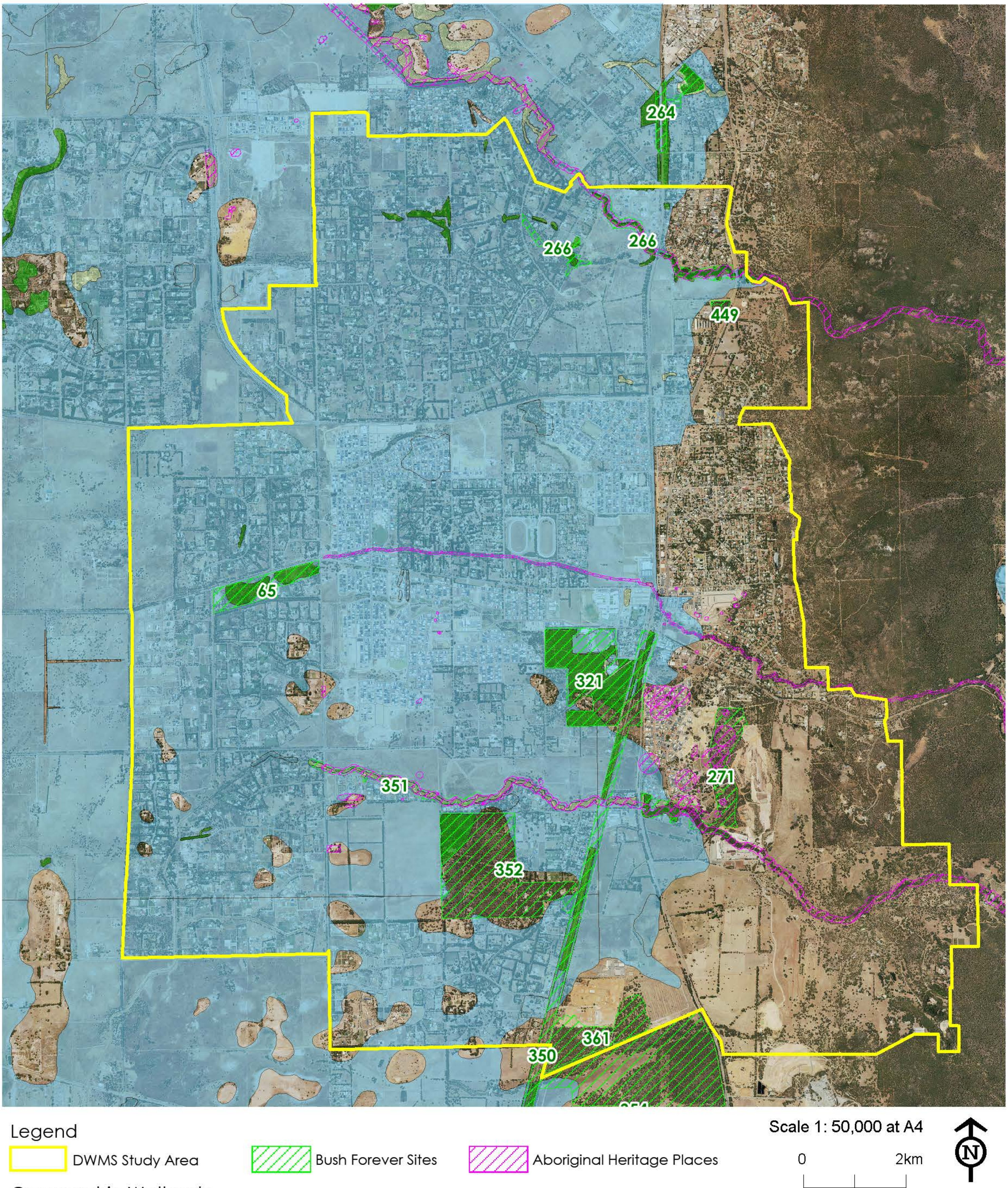
0 2km

N

urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure 5 - Wetlands and Environmental & Social Assets



urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

Two old shale quarries at the base of the scarp in the south eastern portion of the study area carry permanent water and have some conservation value but are not listed as high value wetlands. The area west of these quarries and along Cardup Brook to South Western Highway are listed as Bush Forever Site 271.

Reserves along the Wungong River and Birrega Main Drain in the north eastern corner of the study area are listed as Bush Forever Site 266.

Remnant vegetation in Oscar Bruns Reserve, in the north eastern corner of the site adjacent to South Western Highway is listed as Bush Forever Site 449.

2.6 Social considerations

The Department of Planning, Lands and Heritage have registered two Aboriginal Heritage Sites and one other Aboriginal Heritage Place in the study area which are mapped in Figure 5. These sites are in the southern portion of the site close to Cardup Brook and Cardup Reserve. However, it is noted that there may be other sites located in the study area that have not been registered. Prior to construction of individual developments, assessment should be undertaken by a qualified consultant to determine whether a more thorough Aboriginal heritage investigation of the area needs to be undertaken for any specific location to identify unregistered sites.

2.7 Surface water

Several watercourses traverse the site in a generally westerly direction from the scarp as shown in Figure 6. These watercourses include Wungong River, Birrega Main Drain Oaklands Drain, Beenyup Brook and Cardup Brook. Of these, Wungong River, Cardup Brook and Beenyup Brook are the most ecologically significant. Each of these watercourses is highly incised and their beds are usually a few metres below the surrounding land surface.

Most of the site, drains via Oaklands Drain, Beenyup Brook and Cardup Brook which ultimately discharge to the Birrega Main Drain. These watercourses eventually discharge to the Serpentine River system, which links to the Peel Harvey Estuary. A small portion of the site directly drains to the upper catchment of the Birrega Main Drain and an even smaller portion drains to the Wungong River which ultimately discharges to the Southern River and on into the Swan Canning River system.

To the west of Hopkinson Road, surface drainage consists of rural open drains. Some of these drains are declared and managed by the Water Corporation. They were originally designed to carry specified flows that would comply with the Department of Agriculture and Food's requirement that inundation of rural land should last no longer than three days. More recent monitoring and modelling, carried out by the Water Corporation, have indicated that this design criterion is approximately equivalent to the two-year average recurrence interval for main drains and the six-month interval for sub-drains.

The surface water drainage system comprises numerous small catchments draining from east to west. The upper catchments of the Darling Range foothills are well defined with steep catchment slopes, whereas the lower catchments are less defined.

The Byford area is known to experience regular water logging in the low-lying areas to the west of the study area. This inundation is due to a combination of persistent winter rainfall elevating the shallow water table, which rises to the surface and inundates vast areas of the flat terrain, as well as poor drainage, with insufficient capacity that does not allow runoff to leave the area. There is also potential for wetlands within the study area to receive additional flood water from outside their natural catchment by overtopping of drains and watercourses.

There are several local depressions east and west of the South Western Highway, which result in local perching of surface water after a large rainfall event.

The Department of Water and Environmental Regulation's *Birrega and Oaklands flood modelling and drainage study* (Hall et al, 2015) indicates that large areas of the Study Area are susceptible to flooding under an ARI 100yr rainfall event. The central spine of the Study Area is most at risk to widespread flooding, particularly along major roads. The western edge of the Study Area was not shown to flood under ARI 100yr conditions; however confined areas of ponded water were modelled throughout the area. The eastern side of the Study Area was categorized by long thin flooded areas protruding from the main body of flood water. The flooded areas were most prominent over roads traversing in an east west direction and rural properties.

2.7.1 Surface water quality

Limited surface water quality data is available within the study area. The Snapshot survey of the Serpentine, Murray and Harvey catchments of the Peel-Harvey Estuary (Wilson & Paling, 2002) included 10 sites within the Byford catchment. Samples were recorded for October 2001 and September 2002 but were only reported for 2002.

Four sites were in Oaklands drain, one at Hopkinson Road and one on each of the three upstream branches. There were two sites on the Cardup Brook, one at Hopkinson Road and one close to the railway. Beenyup Brook was also served by two sites, again at Hopkinson Road, and close to the railway. The two remaining sites were at the Hopkinson Road end of two of the minor drains between Beenyup Brook and Cardup Brook.

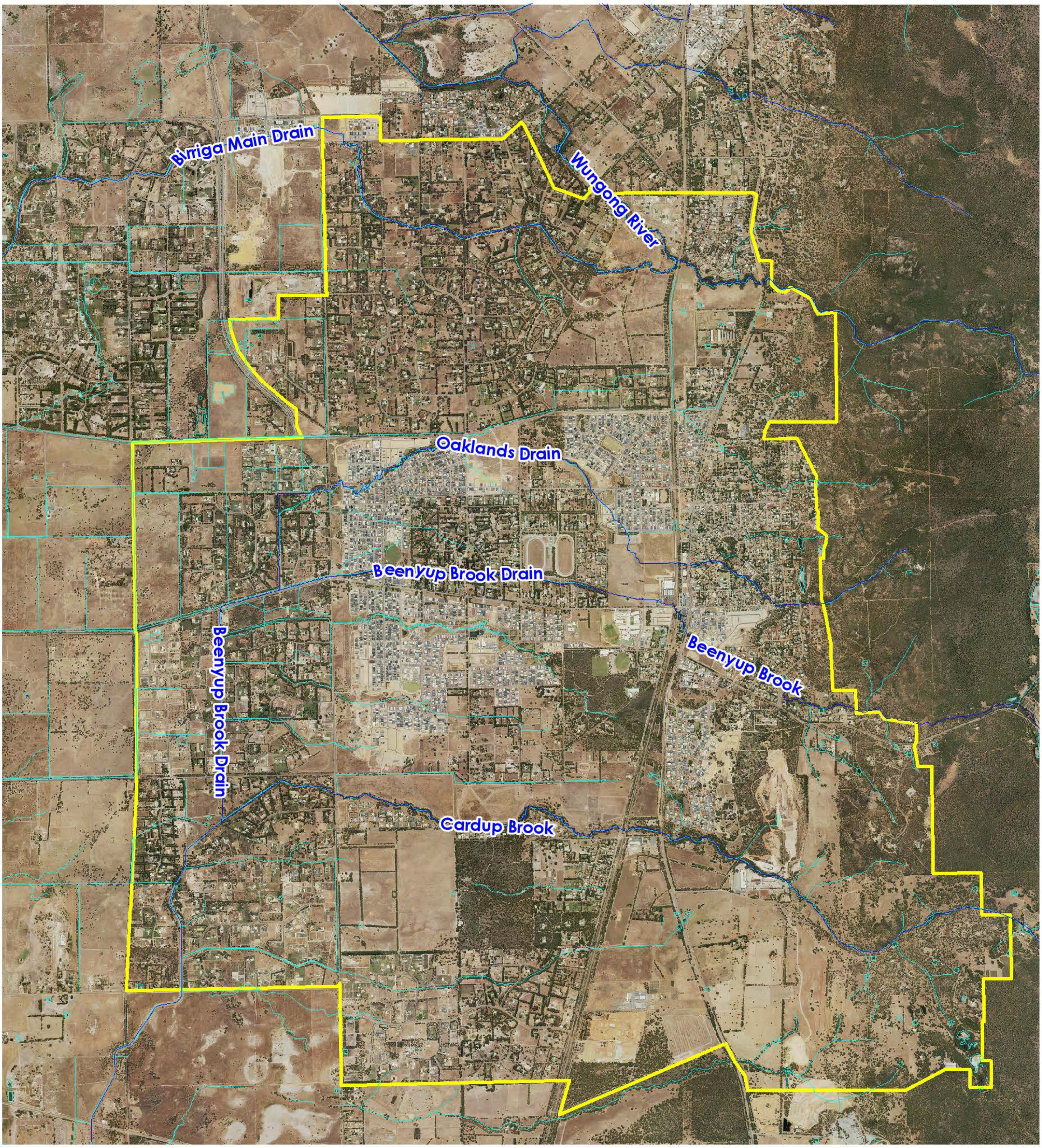
Total phosphorous concentrations recorded at most of the sites in the Byford catchment were below 0.065 mg/L. This was the target concentration suggested by the Byford urban stormwater management strategy (PB 2003), although the downstream end of Beenyup Brook recorded total phosphorus concentrations in the range 0.065-0.20 mg/L and the downstream ends of both minor drains recorded total phosphorus concentrations greater than 0.20 mg/L.

Total nitrogen concentrations recorded in two of the upstream branches of Oaklands drain were below 1.2 mg/L, which was the target concentration suggested by the *Byford urban stormwater management strategy* (PB 2003). Total nitrogen concentrations in the third branch and the downstream end were in the range 1.2-3.0 mg/L. Beenyup Brook was also below 1.2 mg/L upstream but was greater than 3.0 mg/L at its downstream location. In Cardup Brook, this trend was reversed with total nitrogen concentrations greater than 3.0 mg/L recorded upstream and less than 1.2 mg/L downstream. One of the minor drains was in the range 1.2-3.0 mg/L and the other was greater than 3.0 mg/L.

Water quality in Beenyup Brook in Byford Town Centre was tested on an opportunistic basis in 2009 and 2010 (by BGE and Emerson Stewart). Total nitrogen concentrations ranged from 0.8 to 5mg/L with a median of 1.1 mg/L reported in the *Lot 1 Abernethy Road LWMS* (ES, 2011). Total phosphorous concentrations ranged from 0.01 to 0.05 mg/L with a median of 0.01 mg/L.

Surface water quality in the Byford Townsite area was also measured at two sites for *The Glades at Byford LWMS* (JDA, 2009). Results presented indicate average total nitrogen concentration of 1.02 mg/L and average total phosphorous concentrations of 0.07 mg/L and 0.09 mg/L.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure 6 - Surface Water



Legend

- DWMS Study Area
- Major Watercourses
- Other Watercourses and Waterbodies

Scale 1: 50,000 at A4

0 2km

N

urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

2.8 Groundwater

Geotechnical and groundwater investigations have been undertaken several parties in the study area. Results from field measurements typically indicate that groundwater levels are shallow across the study area, varying between 0 – 6 m below natural surface level. Near Beenyup Brook for example, Department of Water data indicate groundwater varies between 1 – 5.4 m below natural surface level.

There are approximately 150 private groundwater bores in the study area, the majority of which target groundwater in sand lenses at the base of the Guildford clay at 17.5 – 25 m below natural surface level. For details of current groundwater allocations in Byford townsite, the Department of Water should be contacted directly.

Because of the local geology, groundwater in the study area is often perched during the winter months. The installation of improved surface and subsurface drainage systems is likely to quickly export this perched water into the drainage system, rather than allowing it to sit and gradually subside. This is likely to result in reduced deep aquifer recharge and increased drain baseflows.

Groundwater modelling has been recently completed in the study area by the Department of Water and Environmental Regulation (DWER) and presented in a series of three *Lower Serpentine Hydrological Studies* reports (Hall et al 2015). Maximum and Minimum groundwater levels predicted by this modelling study for the base (S0) scenario are presented in Figure 7.

2.8.1 Groundwater quality

There is limited groundwater quality data readily available for the study area although data has been collected in support of several water management strategies and plans.

The Byford urban stormwater management strategy stated that shallow groundwater quality monitoring shows low levels of total phosphorous and very small concentrations of ortho-phosphorous in the groundwater. Total nitrogen concentrations were moderate, with moderate concentrations of nitrate and nitrite.

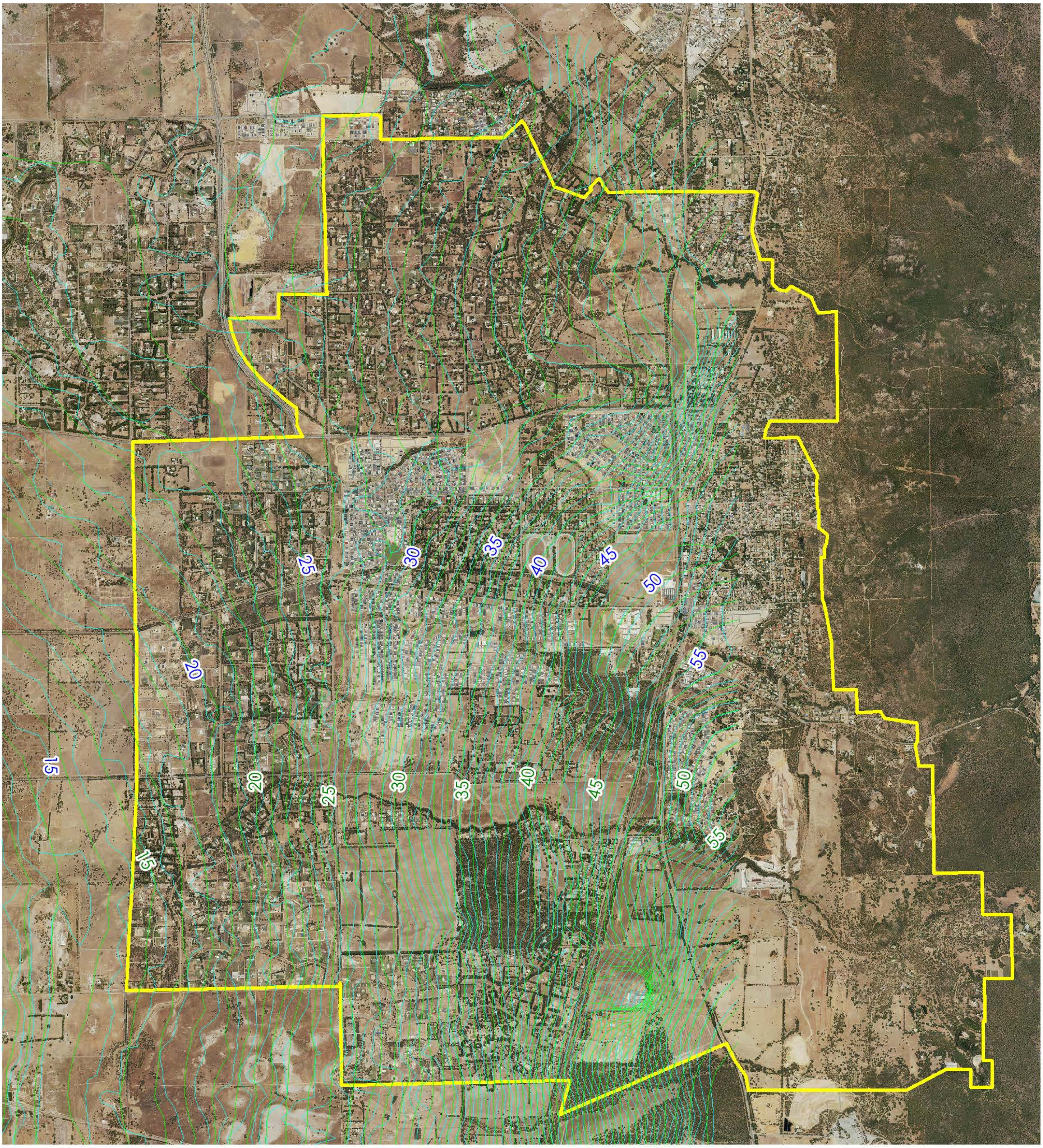
The report states that although these concentrations exceed relevant water quality guidelines, these concentrations are relatively low compared to other typical sites on the Swan Coastal Plain with historically pastoral or horticultural land uses.

Regarding salinity of groundwater within the study area, CyMod Systems (2007) found that the surface superficial groundwater is generally fresh or slightly brackish, whilst the groundwater of the Leederville aquifer is generally fresh (<1000 mg/L TDS).

Groundwater quality in Byford Town Centre was tested in 2009 (by BGE and Emerson Stewart). Total nitrogen concentrations ranged from 0.2 to 6.9mg/L with a median of 1.5 mg/L reported in the *Lot 1 Abernethy Road LWMS* (ES, 2011). Total phosphorous concentrations ranged from 0.01 to 0.88 mg/L with a median of 0.11 mg/L.

Groundwater quality in the Byford Townsite area was also measured at several sites for *The Glades at Byford LWMS* (JDA, 2009). Results presented indicate average total nitrogen concentrations ranging from 0.93 mg/L to 6.4 mg/L and average total phosphorous concentrations from 0.04 mg/L to 0.40 mg/L.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure 7 - Groundwater



Legend

DWMS Study Area

Groundwater Minimum (mAHD)

Groundwater Maximum (mAHD)

Scale 1: 50,000 at A4

0 2km

N

urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

3 PROPOSED DEVELOPMENT

3.1 Key elements of the structure plan

The proposed Byford District Structure Plan, as shown in Figure 8, has a larger area study area than the previous Byford Townsite Structure Plan including the Byford trotting complex area and rural residential and special rural areas surrounding the townsite. Largely, land uses are consistent with previous local planning with the following key changes noted:

- Creation of a new Mixed Business & Industrial Park south of Cardup Brook
- Creation of three new Development Investigation Areas

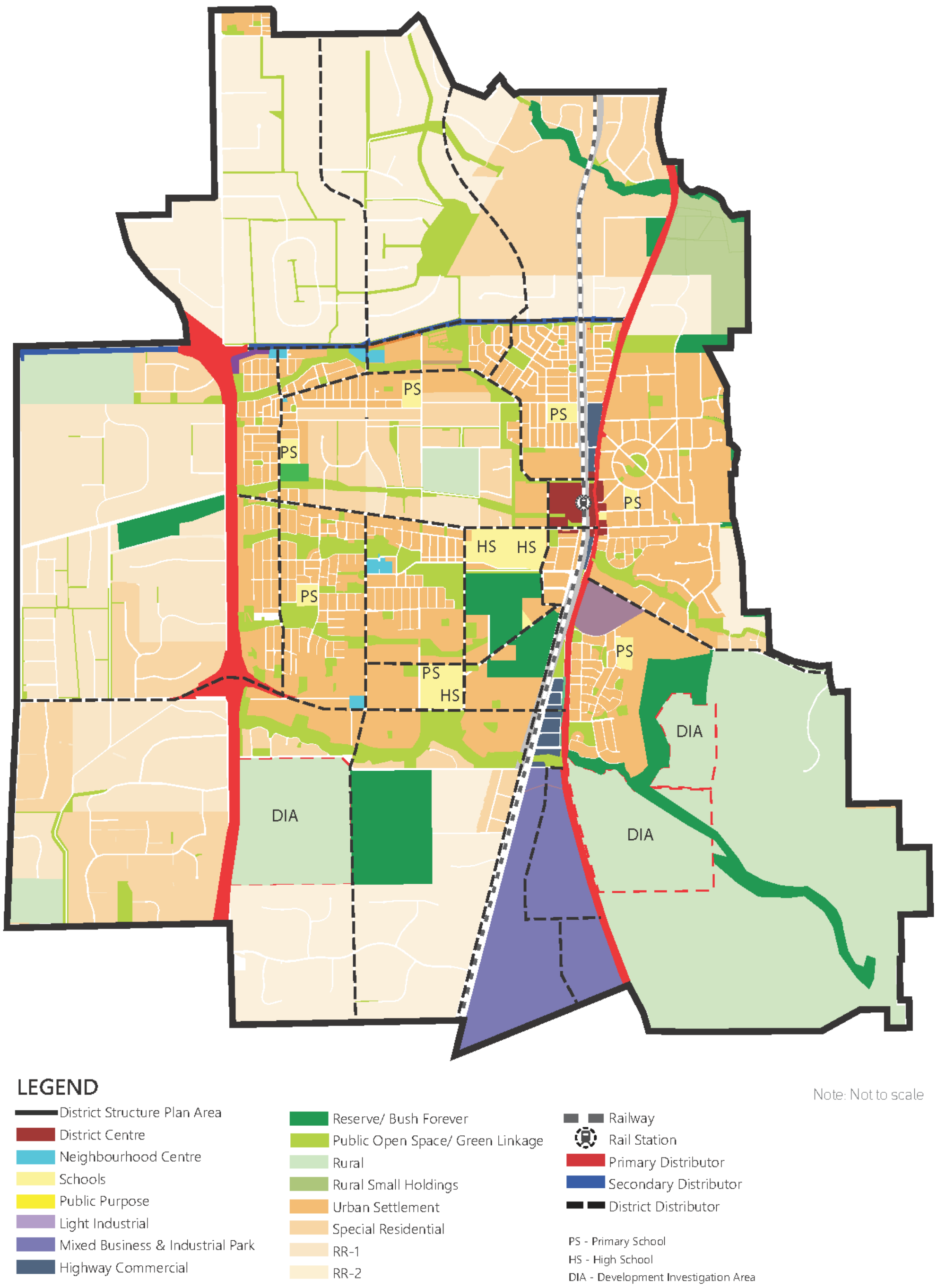


Figure 8: Byford District Structure Plan (SSJ, 2018)

4 PROTECTION OF ENVIRONMENTAL ASSETS

The following strategies have been developed to protect and enhance the value of environmental assets in the Byford structure plan area.

- Minimise changes to hydrology to prevent impacts on watercourses and wetlands
- Manage and restore watercourses and wetlands
- Assess and manage impacts on native flora and fauna
- Assess and manage impacts on Aboriginal Heritage Sites
- Investigate opportunities to mitigate for the potential impacts of climate change

4.1 Minimise changes to hydrology to prevent impacts on watercourses and wetlands

Changes in land use from rural to urban may lead to local increases in peak flows and volumes of runoff due to increases in impervious area (Figure 9a). Large increases in peak flows and volumes have the potential to adversely impact on receiving environments by causing erosion and increasing the period of inundation of vegetation.

Surface water management must ensure that urban development does not increase the peak flows discharging to receiving environments although there may be increases in total runoff volumes (Figure 9b). Development must also ensure that watercourses and wetlands do not dry out due to over abstraction of water resources or lowering of groundwater levels

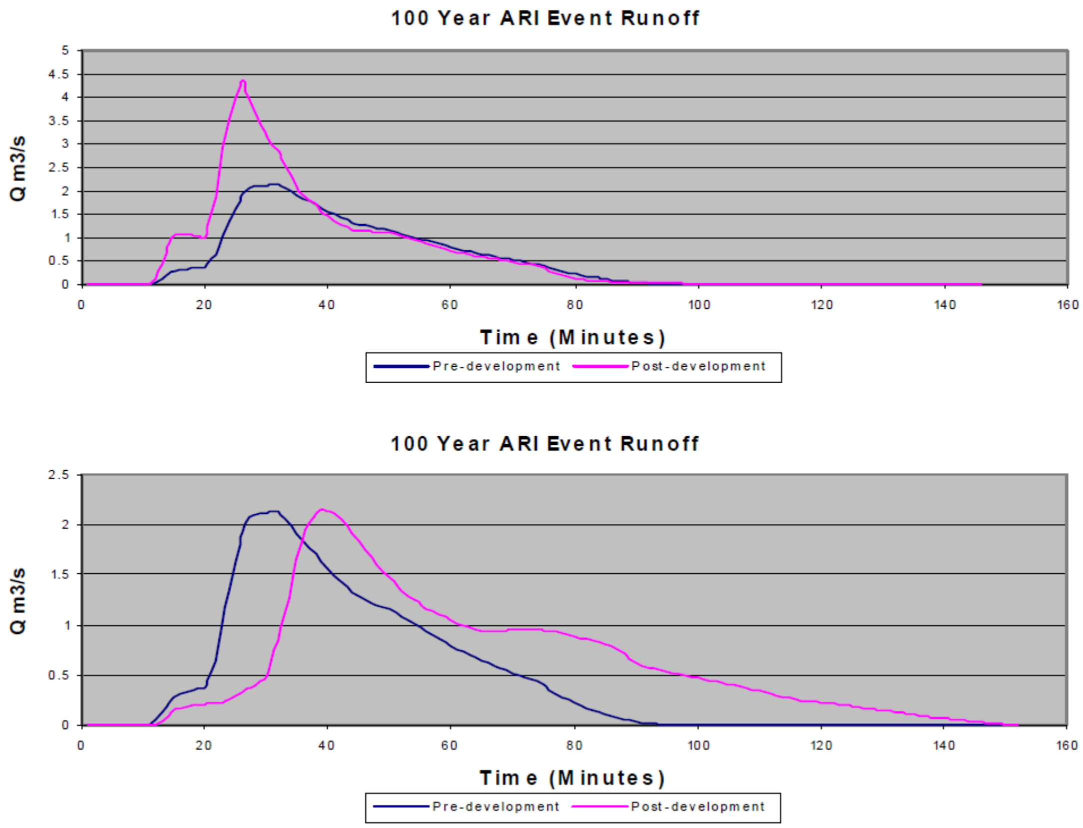


Figure 9a and b: Typical pre- and post-development runoff hydrograph comparison showing a: uncompensated and b: compensated post-development flows (Source: DWER, 2008)

As discussed in sections 2.5 and 2.7 there are several high value wetlands and significant watercourses in the study area. The preservation of pre-development flow rates and hydraulic grade lines along the main watercourses in developing areas is expected to ensure that the potential for development impacts to these systems will be minimised.

The addition of imported fill and subsurface drainage as a part of development will control groundwater levels and soil wetness and therefore reduce the extent of inundated areas throughout the study area. In addition, improvements to surface water drainage will result in less extensive surface inundation, which will be confined to predetermined locations within public open space areas and multiple use corridors. The location of subsoil drainage inverts at or above the locally determined average annual maximum groundwater level is expected to prevent impacts to high value wetlands and watercourses caused by local groundwater control.

4.2 Manage and restore watercourses and wetlands

There are high value wetlands and significant watercourses in the study area. All high value (conservation and resource enhancement) wetlands and significant watercourses are expected to be retained, protected and managed for conservation purposes. This should include restoration, revegetation and reservation of appropriate buffers and corridor widths. Various guidelines are available for all aspects of wetland and watercourse protection and restoration and are published by the Department of Water and Environmental Regulation (DWER) and Department of Biodiversity, Conservation and Attractions (DBCA).

4.3 Assess and manage impacts on native flora and fauna

There are several declared rare and priority flora species within the study area. Detailed flora and fauna assessments are required to be undertaken as part of more detailed levels of planning to ensure that development and subdivision is cognisant of and sensitive to the protection of native flora and fauna.

4.4 Assess and manage impacts on Aboriginal Heritage Sites

As discussed in section 2.5 of this report, the Department of Planning, Lands and Heritage (DPLH) has identified Aboriginal Heritage Places in the study area (Figure A-4). Prior to construction of individual developments, assessment should be undertaken by a qualified consultant to determine whether a more thorough Aboriginal Heritage investigation of the area needs to be undertaken for any specific location to identify unregistered sites.

4.5 Investigate opportunities to mitigate for the potential impacts of climate change

Development could help to mitigate the potential impacts of climate change by careful design of drainage infrastructure.

For example, discharge of drainage flows from surrounding developed areas into treatment areas or naturalised constructed wetlands (not constructed lakes) could provide valuable recharge to groundwater stores surrounding the wetland. Additionally, when combined with overland flow paths, this arrangement may help to maintain periodic inundation cycles and even allow for future redirection of additional flow into the wetland should the need arise.

5 URBAN WATER USE

The key objectives for urban water use are to:

- Achieve highest-value use of fit-for-purpose water, considering all available forms of water for their potential as a resource
- Maintain opportunities for future generations by using water more efficiently. This is best achieved by combining several approaches such as raising community awareness, regulation, market mechanisms to facilitate recognition of the true value of water and financial incentives/assistance to facilitate change

5.1 Potable water use

Reticulated potable water supply systems are present in Byford Townsite and other urban areas in the study area. Many of the rural areas are, however, in locations where there is no existing reticulated water supply system. The Water Corporation undertakes water services planning and allocates funds for infrastructure upgrades on the basis of land use planning information. Where a development proposal requires drinking water headworks infrastructure, for which the Water Corporation has not allocated funds to suit the developer's schedule, prefunding of the works may be necessary.

Connection to a reticulated scheme water supply is not always possible for rural residential areas. State planning policy 2.5; rural planning policy (2016) recognises that there may be alternative service delivery models proposed and provides the following guidance:

water supply shall be as follows:

- *where lots with an individual area of four hectares or less are proposed and a reticulated water supply of sufficient capacity is available in the locality, the precinct will be required to be serviced with reticulated potable water by a licenced service provider, including water for firefighting. Should an alternative to a licenced supply be proposed it must be demonstrated that a licenced supply is not available; or*
- *where a reticulated supply is demonstrated to not be available, or the individual lots are greater than four hectares, the WAPC may consider a fit-for purpose domestic potable water supply, which includes water for firefighting. The supply must be demonstrated, sustainable and consistent with the standards for water and health; or*
- *the development cannot proceed if an acceptable supply of potable water cannot be demonstrated;*

5.2 Fit for purpose water

An appropriate fit-for-purpose water source for irrigation of public open spaces and schools must be confirmed and secured at the local structure plan/local water management strategy stage of planning.

Groundwater is used extensively in the study area as a fit for purpose water supply for public open space irrigation, agriculture and commercial/industrial purposes as well as for private uses (garden and stock watering) which are exempt from licensing.

Groundwater availability reporting and licensing is based on groundwater management areas and subareas proclaimed under the *Rights in Water and Irrigation Act 1914* which have been defined by the Department of Water and Environmental Regulation based on natural catchment boundaries in some cases and administrative boundaries in others. Land to the east of the South Western Highway and north of Beenyup Road is within the unproclaimed Karri groundwater management area whilst the remainder of the site is split between the Perth and Serpentine groundwater management areas. To the north of Thomas Road, the study area falls within the Perth groundwater management area, and to the south the Serpentine groundwater management area.

An allocation limit is the annual volume of water set aside for consumptive use from a water resource. This includes water available for licensing and water for uses exempt from licensing (including stock and domestic 'backyard' bores). Exempted groundwater use within the study area is expected to be significant but there is little reliable consumption information available.

Allocation limits have been set for all aquifers present in the Perth and Serpentine groundwater management areas and water remains available for allocation in all aquifers except the Perth Leederville Confined.

Based on current allocation limits and availability, it appears that there is sufficient groundwater allocation available to provide for future public open space irrigation demands. However, it is important to note that allocation limits may be reduced in response to climate change impacts and other groundwater management issues. At the same time, sustainable yield from the superficial aquifer in the study area is significantly restricted due to clay soils. Developments affected by this issue may require numerous shallow, low-yielding bores and/or require a supplementary irrigation source.

Design Criteria

- avoid the use of imported scheme water for irrigation of public open space or domestic gardens
- prioritise all available on-site water resources for use and/or re-use without discounting them on a water quality or seasonal availability basis, but rather identifying fit-for-purpose options and developing strategies for water quality improvement
- investigate the beneficial use of all water resources before considering draining surface and/or groundwater
- maximise opportunities for stormwater harvesting and re use
- investigate opportunities for groundwater use and re-use schemes including aquifer storage and recovery and managed aquifer recharge
- investigate opportunities for wastewater re-use
- raise community awareness of water management issues to ensure recognition of the true value of water

6 STORMWATER MANAGEMENT STRATEGY

The key objectives for surface water management are:

- protection of receiving environments from the impacts of urban runoff
- protection of infrastructure and assets from flooding and inundation

6.1 Floodplain management

In Western Australia, the State Government is responsible for the development of appropriate standards and strategic approaches for floodplain management and to ensure that they are applied in a coordinated and integrated fashion. The role involves the provision of expert technical advice by the Department of Water and Environmental Regulation (DWER), land-use planning through the Department of Planning, Lands and Heritage (DPLH) and the provision of effective flood emergency response management and planning though the Department of Fire and Emergency Services (DFES).

DWER is the State Government's lead agency in floodplain mapping and providing floodplain development advice. In accordance with the Water Agencies Act 1984, its function is to 'develop plans for and provide advice on flood management'. The department provides advice on development on floodplains with the objective of promoting the wise use of floodplains while minimising the flood risk and damage. It provides advice to the Department of Planning on land-use planning, to local government on development conditions and to other agencies to ensure appropriate development on floodplains.

DWER has undertaken floodplain modelling and mapping for the study area which is presented in the *Birrega Oaklands Flood Modelling and Drainage Study* (Hall et al, 2015). Model results are presented in several forms, which include:

- Flood extent mapping: Simulated maximum levels and flood extent for the 1% AEP and other events.
- Detailed floodplain mapping based on the 1% AEP event is provided on request by the Department of Water and Environmental Regulation.
- Main drain long-sections illustrating peak flood levels and discharge for the Oaklands Main Drain and sections of the Birrega Main Drain.

Results are reported for the entire hydraulic model domain, which is larger than the study area of this report. Note that locations within the Byford region have been developed and drainage works undertaken since the model's topographic LiDAR dataset was flown, and as such any flooding reported in this area should be disregarded.

An overview of the floodplain mapping for the 1% AEP event is shown in Figure 10, and detailed floodplain mapping is provided by DWER on request.

Modelling indicates that widespread shallow inundation would occur over much of the study area in a 1% AEP event and is particularly significant in areas outside the Byford Townsite area west of Hopkinson Road. Within the Byford Townsite area, the most significant flooding is predicted to occur in the Town Centre Precinct.

Key findings of the *Birrega Oaklands Flood Modelling and Drainage Study* which are particularly relevant to the study area include:

The capacity of Birrega and Oaklands Main Drains to convey drainage water without influencing downstream landholders: The regular breaks and lateral culverts in the drains mean that additional discharge to the drain upstream could result in increased downstream flooding.

The importance of floodplain storage: The study area contains large areas of floodplain storage which help mitigate peak flood flows and total flood volumes. Consideration of the floodplain storage should be taken into account in the development process – as reducing or eliminating these storage areas will probably result in additional discharge to the main drains, which in turn could result in more extensive downstream flooding or levee bank overtopping.

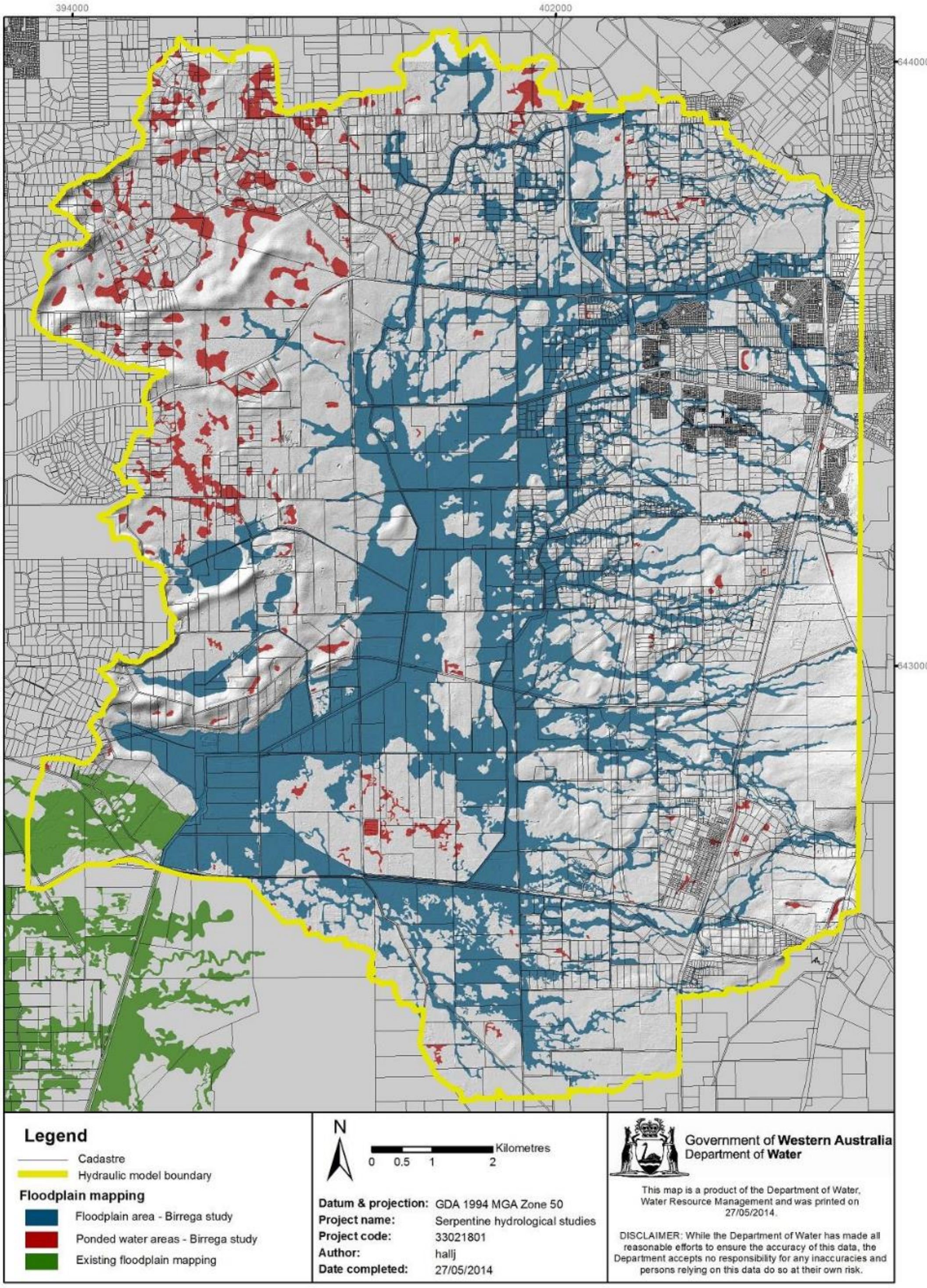


Figure 10: Detailed 1%AEP floodplain mapping and ponded areas (Source: Hall et al, 2015)

6.2 Surface water quality management

The environmental values of downstream waterways within and surrounding the study area must be upheld.

Maintaining pre-development discharge rates and volumes from developed catchments is expected to prevent the majority of contaminants from reaching the waterways by ensuring that the majority of flows from high-frequency events are detained or infiltrated on site.

Provided that the initial flow of more significant events is subject to the same detention and treatment received by high-frequency events, surface runoff that occurs during more significant events represents a lower risk to downstream water quality. This is because nutrients and other contaminants that represent a threat to downstream water quality are typically transported within the 'first flush' of an event.

Design Criteria

- Manage — retain and/or detain and treat (if required) — stormwater runoff from constructed impervious surfaces generated by the first 15 mm of rainfall at-source as much as practical.
  - At-source means that lot runoff is managed within lots and road runoff is managed within road reserves and the stormwater has not entered a piped or lined channel conveyance system.
  - Where site conditions do not allow for the full runoff to be managed at-source, manage as much as practical at-source, subject to the pre-development hydrology. Convey the remaining runoff from the lot or road reserve via overland flow wherever practical.
  - At-source treatment using a stormwater quality treatment system may be required depending on the pre-development environment and the post-development land uses. Determine if at-source stormwater quality treatment is required based on the:
    - quality of pre-development surface water and groundwater
    - quality of post-development stormwater and groundwater (mobilised or discharged)
    - potential pathways towards receiving environments, by considering factors such as soil types, depth to groundwater and horizontal distance to receiving environments
    - requirements of receiving environments.
- Install off-line stormwater quality treatment systems at the outlet of pipes or lined channels that directly convey small rainfall event runoff from constructed impervious surfaces.
- Ensure the emptying time of stormwater management systems is based on the type of system, requirements for prevention of disease vector and breeding of nuisance insects, and requirements for useability of systems post-rainfall. Table 1provides emptying times adapted from recommendations from the *Stormwater Management Manual for WA* (DWER, 2004-07) and *Australia Runoff Quality* (Engineers Australia, 2006).

Table 1: Criteria for emptying time of a stormwater storage system for different AEP

Annual Exceedance Probability	63.2% (1 Exceedance per Year)	50%	20%	10%	5%	2%	1%
Maximum emptying time in days	0.5	1.0	1.5	2.0	2.5	3.0	3.5

Section 8 provides additional information on the Shire's preferred approach to provision of water quality treatment systems and strategies.

6.3 Surface water quantity management

6.3.1 Minimise changes in hydrology to prevent impacts on receiving environments

Urbanisation results in increased impervious area. Increased rates and volumes of stormwater runoff must be managed to protect infrastructure and assets from flooding and inundation, while water quantity and quality must be managed to protect wetlands and waterways from risk of increased inundation and contaminant loads.

Surface water management must ensure that urban development does not increase the peak flows discharging to receiving environments. Surface water quantity management is not only restricted to preventing runoff from increasing due to development but must also manage the maintenance or even restoration of desirable environmental flows and/or hydrological cycles where potential impacts on significant ecosystems such as wetlands are identified.

Design criteria

- Maintain pre-development peak flow rates and total volume runoff from the outlets of the development area for the critical 1 exceedance per year (EY) event.

6.3.2 Manage surface water flows to protect infrastructure and assets

Design criteria

- Design stormwater management systems to provide serviceability, amenity and road safety during minor rainfall events.
- Maintain the 1%AEP pre-development flood regime (flood level, peak flow rates and storage volumes) at identified critical locations.
- Implement the Byford Town Centre Precinct flood management strategy presented in Figure 13.
- Detailed flood modelling, including definition of floodways is provided in Appendix A, section A.8.
- Floodways may not be developed or obstructed in any way and are entirely separate from subcatchment scale detention volumes required to manage surface water flows resulting from future land use change which are presented in Appendix A.
- Developments adjacent to floodways should ensure finished floor levels at a minimum of 0.5 m above the 1% AEP flood level.
- The existing cross-sectional area of waterways must be maintained, and restoration of waterways is essential. In some cases, channel realignments and channel profile modifications may be carried out provided it is demonstrated that the pre-development cross-sectional area has been preserved. A permit may be required to alter beds and banks of waterways under the *Rights in Water and Irrigation Act 1914*.
- Flood retention and/or detention systems, where required, must be designed to avoid impacting on functionality of public open spaces.
- Defined major arterial roads should remain passable in the 1% AEP event. This requirement applies to but is not confined to Abernethy Road, Kardan Boulevard, Thomas Road and South Western Highway. The local authority should be contacted to identify other roads where this requirement applies.
- Minor roads should remain passable in the 20% AEP event.

Hydrologic and hydraulic modelling of the study area using InfoWorks Integrated Catchment Model (ICM) has been undertaken and is presented in Appendix A. This modelling builds upon modelling previously undertaken for the Byford Townsite area incorporating several significant updates:

- Expanded study area to include development outside of the Byford Townsite;
- Hydrological parameters (catchment loss rates) adjusted consistent with those adopted for the *Birrega Oaklands flood modelling and drainage study* (DoW, 2015);
- Hydraulic system elements and structures modified to reflect changes to the system that have been constructed or approved in UWMPs or engineering design plans; and
- Hydraulic system elements and structures modified to reflect any survey information that could be obtained within the timeframes of the project.

Key outputs from this modelling are provided in Appendix A at critical locations as a guide to developers and should be refined and located during local structure planning via the local water management strategy and finalised during subdivision scale planning via the urban water management plan. Outputs include:

For areas which are not subject to currently approved LWMS and/or UWMP documents:

- Subcatchment scale peak discharge flows, volumes and times of concentration for critical 1EY, 20% AEP and 1% AEP events.
- Subcatchment scale detention volumes required to manage surface water flows for critical 20% AEP and 1% AEP events based on land use change in accordance with the Byford District Structure Plan.

For the entire study area:

- Mapping of predicted 20% and 1% AEP flood inundation extents including peak levels and flows at critical locations.
- Critical 1EY, 20% AEP and 1% AEP event longitudinal sections for significant watercourses are provided to assist with the design of subdivisional drainage and may be used to accurately determine flows and levels.

It is important to note that modelling assumes that the first 15mm of rainfall (from allotments and also from the road network) is retained at source, so this volume is not included in indicative flood detention volumes.

Subcatchment scale discharge flows presented are not within main waterways and do not include flows generated by upstream subcatchments. Discharge criteria are set for whole subcatchments at the point at which they connect to main waterways as shown in Figure 11.

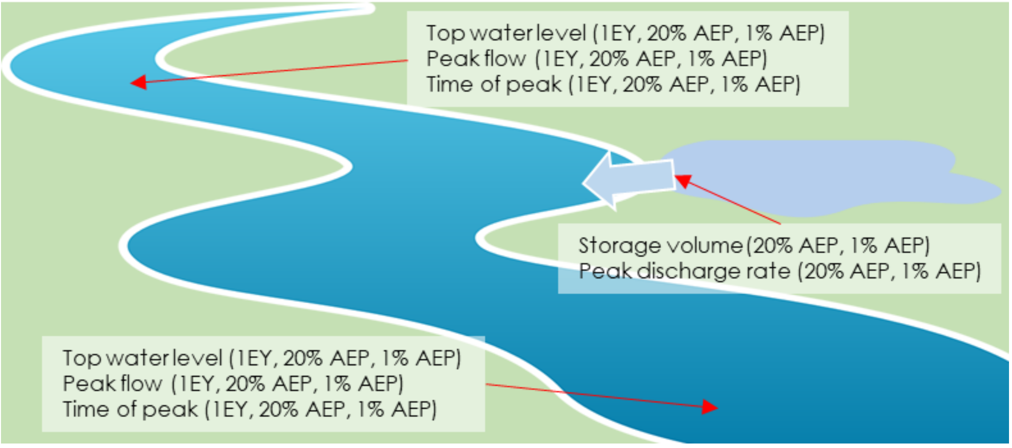


Figure 11: Schematic presentation of information for subcatchments and main waterways

Overview mapping of the Byford district stormwater management strategy is presented in Figure 12. Detailed flood maps and longitudinal sections of significant watercourses for critical duration 1EY, 20% AEP and 1% AEP flood events are provided in Appendix C.

A flood management strategy has been specifically developed to address flood risk in the Town Centre precinct. This strategy is presented in Figure 13. Key elements of the proposed Byford Town Centre strategy include:

- Re-alignment of the drainage corridor connecting Beenyup Brook to Oaklands drain.
- Upgrades to culverts on Oaklands drain at Thatcher Road and Larsen Road to prevent flooding of Larsen Road

Otherwise the drainage system remains as constructed and/or previously designed and approved through relevant LWMS's and UWMP's. Table 2 provides top water levels, peak flows and the approximate time of the peak flow at several locations throughout the study area.

This strategy has reviewed, and incorporated drainage designs presented in a previously approved Local Water Management Strategies and Urban Water Management Plans including specified stormwater storage volumes. It is acknowledged that there may be opportunities to rationalise previously approved storage volumes through optimised drainage system designs including using online storage within multiple use corridors. Any proposals to reduce previously approved storage volume provision must demonstrate that peak discharges can be managed within the arterial drainage system, to the satisfaction of the Shire of Serpentine Jarrahdale in consultation with Department of Water and Environmental Regulation. Table 2 provides peak flow timing information at key locations within the arterial system to assist with this process.

There are several areas within the study area that are proposed for future development but are not yet the subject of any approved local water management strategy or urban water management plan. Table 3 provides storage volumes by subcatchment to guide potential future development in these areas as well as in areas not currently proposed for development which include:

- Land reserved for the future Tonkin Highway – there is substantial natural storage provided in land that has been reserved for the future Tonkin Highway. In future, when the highway is constructed, it will be necessary to provide equivalent storage to prevent downstream flooding.
- Rural and rural residential land outside the Byford townsite – there are several areas of rural and rural residential that are subject to flooding and therefore provide natural flood storage. Any future development of these areas will be required to provide equivalent storage to prevent downstream flooding.

Table 2: Top water levels, peak flows and timing of peaks at critical locations

Location	1EY (63.2% AEP, S10-3h))			20% AEP (S7-3h)			1% AEP (S2-3hr)		
	Top water level (mAHD)	Peak flow (m3/s)	Time of peak (H:M:S)	Top water level (mAHD)	Peak flow (m3/s)	Time of peak (H:M:S)	Top water level (mAHD)	Peak flow (m3/s)	Time of peak (H:M:S)
1. Oaklands drain d/s George Road (north)	49.4	2.8	2:30:00	49.4	4.0	2:55:00	49.5	8.9	3:10:00
2. Oaklands drain d/s George Road (south)	51.3	1.2	2:50:00	51.3	1.4	3:00:00	51.4	2.0	3:00:00
3. Oaklands drain d/s Evans Road	42.3	6.8	2:50:00	42.3	10.0	3:05:00	42.4	15.5	3:15:00
4. Oaklands drain u/s Malarkey Road	30.7	6.9	2:20:00	30.7	9.9	1:45:00	30.7	19.0	0:55:00
5. Thomas Road drain u/s Malarkey Road	30.3	2.4	3:50:00	30.6	4.3	4:15:00	31.2	9.2	4:00:00
6. Oaklands drain d/s Malarkey Road	29.9	9.2	3:40:00	30.0	13.8	2:50:00	30.2	28.6	1:40:00
7. Oaklands drain at Hopkinson Road	25.6	6.5	4:35:00	25.8	12.5	3:40:00	26.0	31.2	3:00:00
8. Beenyup Brook d/s South Western Hwy	59.0	6.6	2:35:00	59.1	10.4	2:50:00	59.3	18.8	3:00:00
9. Beenyup Brook d/s Town Centre	47.7	3.4	2:45:00	47.9	3.6	3:05:00	48.1	3.5	3:15:00
10. Beenyup Brook to Oaklands drain link	48.4	3.2	2:45:00	48.8	5.4	3:05:00	49.5	9.2	3:15:00
11. Beenyup Brook at Hopkinson Road	25.8	2.6	3:10:00	26.1	3.9	3:15:00	26.5	7.0	3:15:00
12. Brickwood drain u/s Doley Road	35.2	1.2	3:00:00	35.4	2.9	3:25:00	36.1	6.2	3:30:00
13. Brickwood drain at Hopkinson Road	27.0	1.4	3:25:00	27.4	3.6	3:45:00	27.9	7.4	4:20:00
14. Doley Drain at Hopkinson Road	26.6	2.2	3:15:00	26.8	4.0	3:15:00	27.4	9.4	3:20:00
15. Cardup Brook d/s South Western Hwy	55.7	3.4	2:10:00	55.8	4.0	1:15:00	55.9	20.7	0:40:00
16. Cardup Brook at Hopkinson Road	27.1	2.6	3:25:00	27.5	3.9	3:15:00	28.3	10.6	3:20:00
17. Birrega Main Drain at Wungong South (N)	35.3	0.1	3:00:00	35.4	0.7	3:05:00	35.7	3.0	3:15:00
18. Birrega Main Drain at Wungong South (S)	34.1	0.0	3:40:00	34.2	0.2	3:50:00	34.3	0.2	3:05:00
19. Birrega Main Drain at Masters Road	29.6	0.1	2:55:00	30.0	0.3	3:45:00	30.6	3.4	3:45:00
20. Birrega Main Drain at Hopkinson Road	25.8	0.4	2:45:00	26.3	1.1	4:20:00	26.8	1.8	3:05:00
21. Birrega Branch Drain at Hopkinson Road	26.8	0.5	2:50:00	27.1	0.8	3:00:00	27.9	0.9	3:00:00

Location	1EY (63.2% AEP, S10-3h))			20% AEP (S7-3h)			1% AEP (S2-3hr)		
	Top water level (mAHD)	Peak flow (m3/s)	Time of peak (H:M:S)	Top water level (mAHD)	Peak flow (m3/s)	Time of peak (H:M:S)	Top water level (mAHD)	Peak flow (m3/s)	Time of peak (H:M:S)
22. Birrega Branch Drain 2 at Kargotich Road	21.6	1.3	3:00:00	21.7	2.2	3:20:00	21.9	5.0	3:20:00
23. Birrega Branch Drain 3 at Kargotich Road	18.7	5.2	5:40:00	18.9	7.7	3:40:00	19.5	15.0	3:45:00
24. Birrega Branch Drain 4 at Kargotich Road	16.8	0.7	2:30:00	16.9	1.9	2:45:00	17.3	7.7	3:00:00
25. Birrega Branch Drain 5 at Kargotich Road	15.5	0.0	0:00:00	15.6	0.4	3:30:00	15.9	2.1	3:35:00
26. Orton Road Drain at South Western Hwy	59.2	0.3	2:50:00	59.6	0.5	2:55:00	59.9	1.0	3:15:00
27. Brickwood Drain at South Western Hwy	56.9	0.7	3:35:00	57.2	0.9	3:10:00	57.4	1.0	3:00:00
28. Brickwood Drain at Glades Confluence	41.2	1.1	2:45:00	41.3	2.0	3:00:00	41.3	2.7	3:00:00
29. Beenyup Brook d/s Abernethy Road	56.4	6.5	2:40:00	56.5	9.9	2:55:00	56.6	16.0	3:10:00
30. Doley Drain at Warrington Road	43.9	0.3	2:45:00	44.1	0.3	3:10:00	44.6	0.9	3:20:00
31. Doley Drain at Doley Road	37.0	0.8	2:50:00	37.1	0.9	3:00:00	37.3	1.2	3:05:00
32. Norman Drain at South Western Hwy	77.6	0.5	2:30:00	77.7	2.0	3:00:00	78.0	8.5	3:00:00
33. Norman Drain at Railway	47.3	4.2	2:30:00	47.6	6.3	2:45:00	48.2	10.6	3:00:00
34. Norman Drain at Hopkinson Road	27.9	0.9	3:05:00	28.6	1.3	3:00:00	29.4	4.6	3:05:00
35. Oaklands Drain at Kargotich Road	17.1	8.7	4:40:00	17.8	12.9	4:10:00	18.4	16.8	3:10:00
36. Oaklands Drain d/s Norman Drain	16.6	10.2	4:30:00	16.8	15.0	4:50:00	16.9	19.0	4:45:00
37. Cardup Drain at Railway	51.7	2.9	2:30:00	51.9	3.9	2:45:00	52.1	5.7	3:00:00
38. Cardup Drain at Hopkinson Road	25.9	0.4	4:05:00	26.3	0.6	3:35:00	27.2	-5.1	5:10:00
39. Oaklands Drain d/s bifurcation	21.3	3.4	5:40:00	21.5	3.6	3:15:00	22.2	4.4	3:20:00
40. Oaklands Drain d/s Cardup Brook	19.5	8.0	3:50:00	19.8	12.1	3:25:00	21.1	16.4	3:05:00
41. Orton Road Drain at Warrington Road	47.4	0.5	3:05:00	47.5	0.9	3:10:00	47.6	1.3	3:45:00
42. Orton Road Drain at Doley Road	38.6	0.6	3:15:00	38.7	1.1	3:25:00	38.8	1.6	3:20:00
43. Thomas Road Drain North at Railway	40.7	1.6	3:05:00	40.7	1.6	3:20:00	40.7	1.7	3:15:00

Location	1EY (63.2% AEP, S10-3h))			20% AEP (S7-3h)			1% AEP (S2-3hr)		
	Top water level (mAHD)	Peak flow (m3/s)	Time of peak (H:M:S)	Top water level (mAHD)	Peak flow (m3/s)	Time of peak (H:M:S)	Top water level (mAHD)	Peak flow (m3/s)	Time of peak (H:M:S)
44. Thomas Road Drain at Railway	42.0	0.3	3:05:00	42.1	0.4	3:25:00	42.1	0.4	3:20:00
45. Wungong River at South Western Hwy	42.9	0.9	3:00:00	43.0	1.6	3:10:00	43.2	4.6	3:10:00
46. Wungong River nr Keenan Street	35.4	2.3	2:40:00	35.6	4.8	2:55:00	36.1	11.9	3:05:00
47. Wungong River at Rowley Road	29.8	2.3	3:00:00	30.0	5.6	3:10:00	30.3	15.9	3:20:00

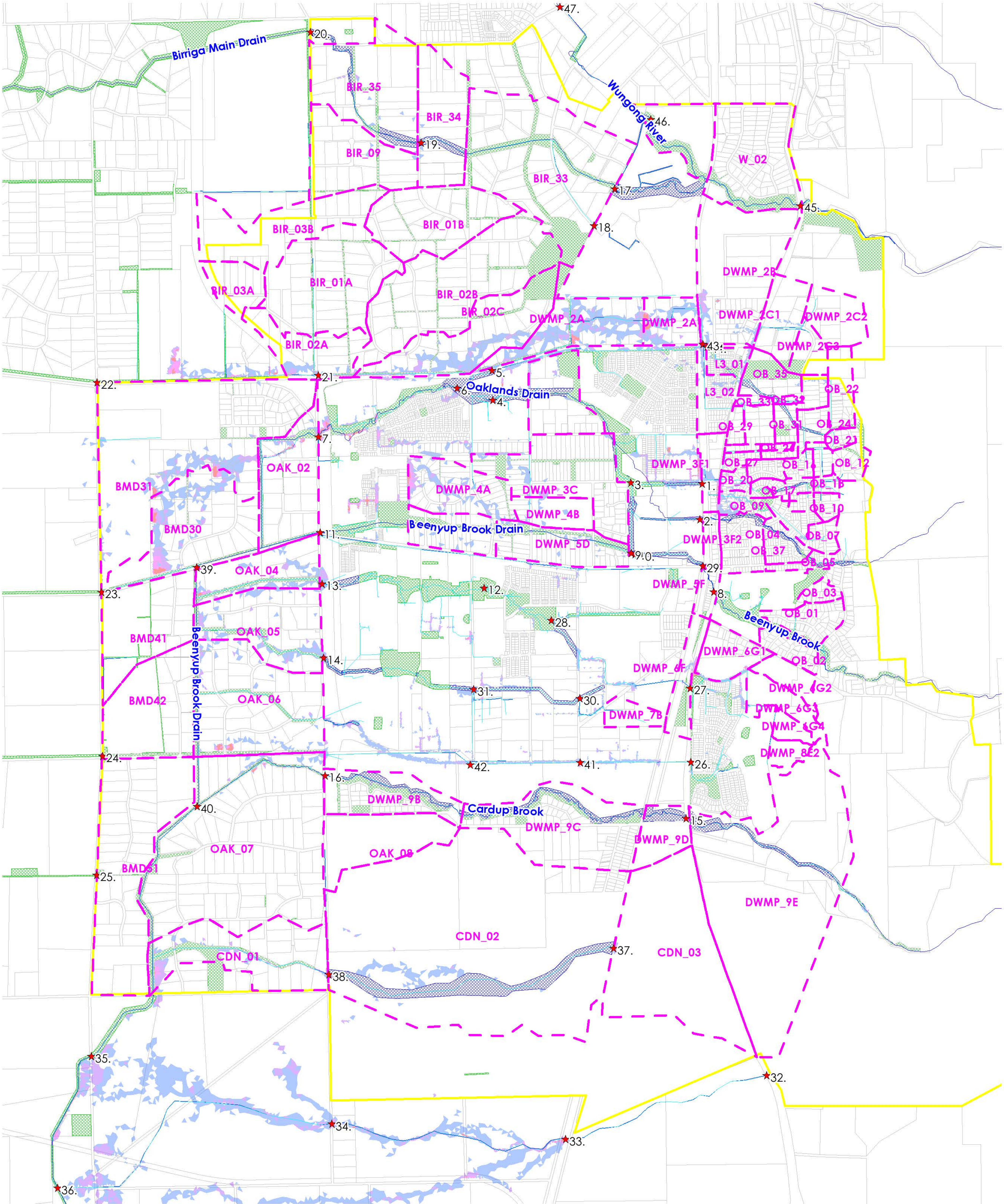
Table 3: Subcatchment details for undeveloped areas

Subcatchment id	20% AEP		1% AEP	
	Storage volume (m³)	Peak discharge rate (m³/s)	Storage volume (m³)	Peak discharge rate (m³/s)
OB_22	17	0.117	33	0.126
OB_21	6	0.177	20	0.174
OB_24	37	0.410	213	1.246
OB_34	480	0.293	868	0.372
OB_26	69	0.116	197	0.295
OB_25	256	0.244	661	0.536
OB_27	122	0.341	547	0.266
OB_28	65	0.172	311	0.306
OB_19	48	0.277	201	0.292
OB_13	336	0.265	487	0.213
OB_12	0	0.389	0	1.180
OB_10	0	0.463	0	0.969
OB_11	32	0.182	80	0.186
OB_08	281	0.258	583	0.264
OB_07	145	0.443	304	0.306
OB_16	127	0.260	482	0.233
BIR_33	0	0.500	811	2.782
BIR_34	290	0.346	1,316	1.809
BIR_35	1,912	0.144	14,144	0.840
BIR_09	250	0.503	7,046	2.149
BIR_02C	10,184	0.720	39,396	2.995
BIR_02B	194	0.145	2,479	0.934
BIR_02A	4,246	0.286	48,288	1.631
BIR_01A	0	1.208	3,101	4.502
BIR_01B	0	1.208	0	4.502
BIR_03A	0	1.053	41,275	4.535
BIR_03B	0	1.053	25,773	4.535
BMD30	20,940	0.367	61,031	1.843
BMD31	14,865	1.466	94,079	4.762
BMD41	17	0.602	10,653	1.999
BMD42	0	1.417	11,507	5.942
BMD51	0	0.702	18,834	3.031

Subcatchment id	20% AEP		1% AEP	
	Storage volume (m^3)	Peak discharge rate (m^3/s)	Storage volume (m^3)	Peak discharge rate (m^3/s)
OB_15	28	0.332	169	0.777
DWMP_6F	1,150	1.240	2,534	3.311
GL_82	0	0.412	0	1.329
OB_01	0	1.388	0	3.200
OB_02	0	0.911	0	2.031
DWMP_5F	34	0.710	670	1.550
DWMP_5D	3,723	1.251	7,813	2.412
DWMP_5C	1,495	0.736	3,408	3.086
DWMP_9E	37,233	3.702	82,280	9.612
DWMP_9D	28,190	0.865	51,760	1.959
DWMP_9C	125	1.180	23,263	6.370
DWMP_9B	0	0.013	18,058	0.045
DWMP_8E2	0	0.006	0	0.014
DWMP_6G4	0	0.558	0	1.270
DWMP_6G3	42	0.519	113	1.989
DWMP_6G2	0	1.202	16	2.078
OB_03	0	0.535	0	1.165
DWMP_7B	0	0.302	582	0.624
OB_32	408	0.075	705	0.090
DWMP_6G1	965	0.094	1,882	0.427
OB_35	2,315	0.566	4,497	1.876
DWMP_2C3	105	0.311	222	1.070
L3_01	1,973	0.638	4,298	1.575
DWMP_2C1	589	0.909	1,553	3.388
OB_30	30	0.457	149	1.298
OB_29	36	0.393	247	0.887
OAK_08	0	1.468	146	4.434
CDN_03	349	1.848	3,118	2.908
CDN_02	22,143	4.299	31,844	9.642
OB_05	518	0.289	923	0.791
OB_37	2,442	0.508	4,203	1.600
OB_04	1,386	0.660	2,693	2.379
DWMP_3F2	473	0.391	808	0.523

Subcatchment id	20% AEP		1% AEP	
	Storage volume (m³)	Peak discharge rate (m³/s)	Storage volume (m³)	Peak discharge rate (m³/s)
BM_02	3,700	2.437	9,789	6.189
OAK_02	14,678	0.914	62,548	1.757
OAK_04	9,495	0.579	15,274	2.236
OAK_05	17,490	0.762	30,532	2.468
OAK_06	14,059	1.379	70,552	2.779
OAK_07	6,293	1.631	74,118	3.211
CDN_01	20,425	1.108	68,140	3.158
OB_09	2,105	0.225	4,267	0.229
OB_31	138	0.541	609	1.295
OB_14	1,281	0.216	1,784	0.592
OB_17	199	0.152	647	0.396
OB_18	25	0.166	709	0.462
OB_20	1,093	0.414	2,101	0.943
DWMP_3F1	2,306	0.329	5,552	0.390
OB_33	224	0.175	578	0.480
DWMP_2C2	0	1.320	67	3.430
DWMP_2B	5,192	0.246	11,476	1.105
DWMP_2A1	7,834	0.553	16,959	1.524
DWMP_2A	19,495	1.317	54,336	2.145
L3_02	1,360	0.778	3,169	2.010
DWMP_3C	3,823	1.226	10,498	2.407
DWMP_4B	1,418	0.681	3,349	1.785
DWMP_4A	9,706	0.826	15,988	1.079
W_02	27	2.577	46	7.673
W_05	365	1.022	833	1.080
OB_23	19	0.079	85	0.209

Shire of Serpentine Jarrahdale - Byford DWMS
Figure 12 - Byford district stormwater strategy



Legend:

- DWMS Study Area
- Major Watercourses
- Modelled other drains and watercourses
- Existing POS and drainage reserves

20% AEP flood depth (m):

- >0.5
- 0.3 to 0.5
- 0.1 to 0.3
- 0.03 to 0.1

- Critical flow and top water level locations (Table 2)
- Reporting subcatchments (Table 3)
- Recommended new drainage reserves

Scale 1: 30,000 at A3

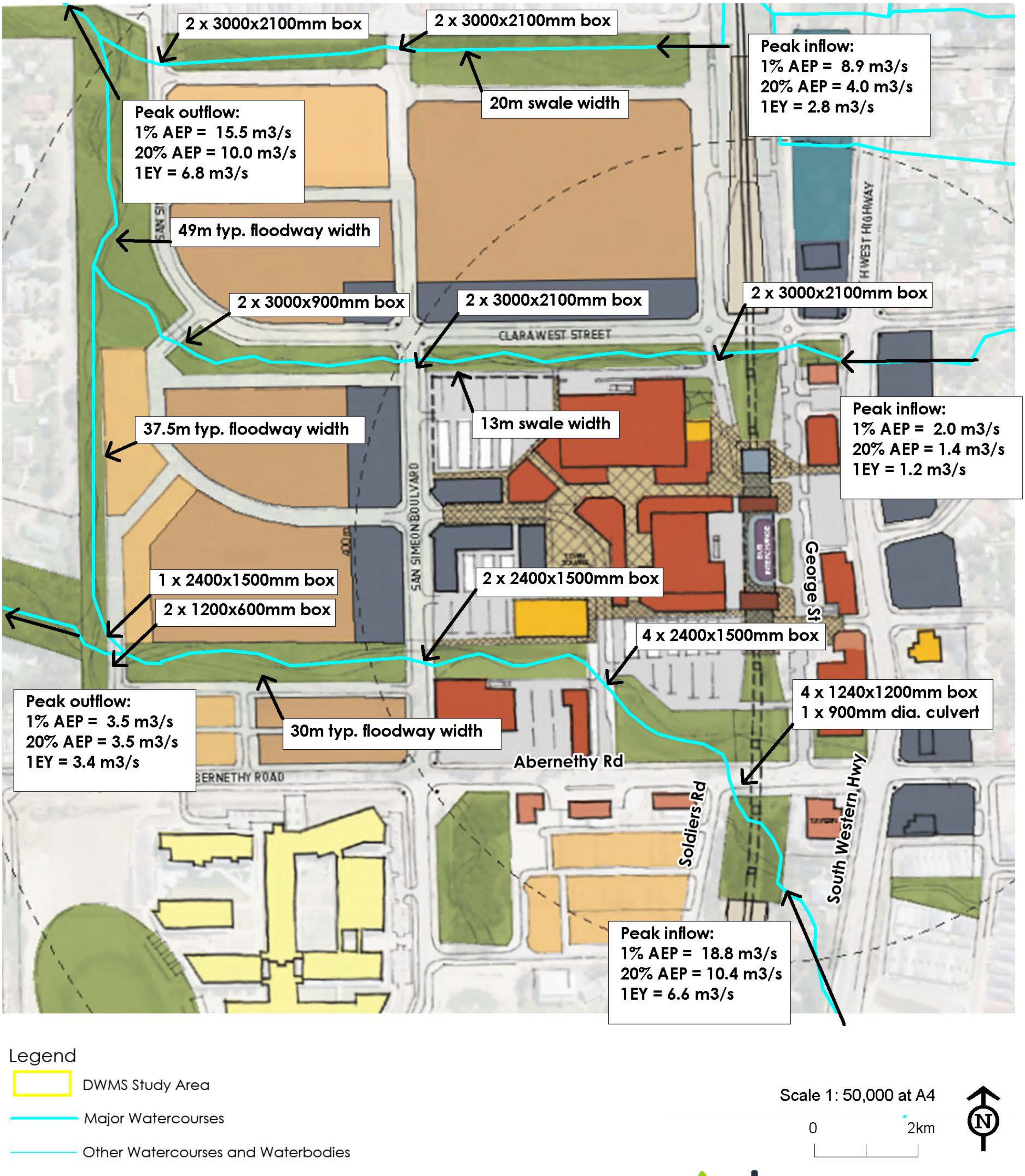
0 600m

N

urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure 13 - Byford Town Centre Precinct - Arterial stormwater management strategy



urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

7 GROUNDWATER MANAGEMENT STRATEGY

The key objectives for groundwater management are:

- protecting infrastructure and assets from flooding and inundation by high seasonal groundwater levels, perching and/or soil moisture
- protecting groundwater dependent ecosystems from the impacts of urban runoff
- managing and minimising changes in groundwater levels and groundwater quality following development/redevelopment

7.1 Glossary of groundwater terms

Capillary fringe	Part of the unsaturated zone, where soil voids are filled (or almost filled) with water due to capillary rise
Controlled groundwater system	A groundwater system that is subject to control or management through the provision of drainage infrastructure
Controlled groundwater level (CGL)	The invert level of groundwater controlling infrastructure
Groundwater	Water in the soil voids of the saturated zone
Groundwater level	The non-static top of the saturated zone (can include locally perched groundwater)
Perched groundwater	Groundwater that occurs above the regional water table, as a distinct saturated zone embedded within the unsaturated zone due to the presence of an aquiclude or aquitard
Engineered phreatic surface	The non-static top of the saturated zone in a controlled groundwater system
Engineered phreatic crest level	The highest point on the controlled phreatic surface
50% AEP phreatic surface	The phreatic surface that will be exceeded in 50% of years (50% chance each year).
20% AEP phreatic surface	The phreatic surface that will be exceeded in 20% of years (20% chance each year).
Saturated zone	The part of the soil profile where voids are completely filled with water.
Seasonally perched groundwater	Perched groundwater that is seasonally connected to the underlying water table
Unsaturated zone	The part of the soil profile where voids are only partially filled with water.
Water table	The non-static top of the saturated zone (generally does not include locally perched groundwater)

7.2 Groundwater quantity management

7.2.1 Manage groundwater levels to protect infrastructure and assets

When considering development of a site with shallow groundwater there are a number of responses that can be applied:

1. Don't develop, accept that the land value is not sufficient to make its development feasible and allow the land to remain in, or be restored to its natural state.
2. Develop the land in a way that is sympathetic to the existing hydrology and soil conditions of the site, accepting that this will result in portions of some lots and open spaces being seasonally inundated or waterlogged.
3. Drain and/or fill to adapt the land sufficiently for urban development to occur.

Hydrologically sympathetic development

Lower density residential developments or industrial areas where lower levels of public amenity may be acceptable and could even be seen as an advantage, enable people to live and work close to and surrounded by natural wetland ecosystems. This type of development can be established without extensive fill.

In this circumstance, larger residential lots and public open spaces can and have been designed with an acceptance of seasonal waterlogging with buildings and other areas that need to remain dry throughout the year elevated to prevent inundation and protect from flooding. Elevation of these areas could be achieved with sand 'pads' or 'stumps' (Figure 14).

This type of development has previously occurred in Western Australia, typically in rural and agricultural areas. Recently however, building and development practices have moved away from this methodology with close to universal adoption of 'brick & tile' houses with filled and flattened lots.

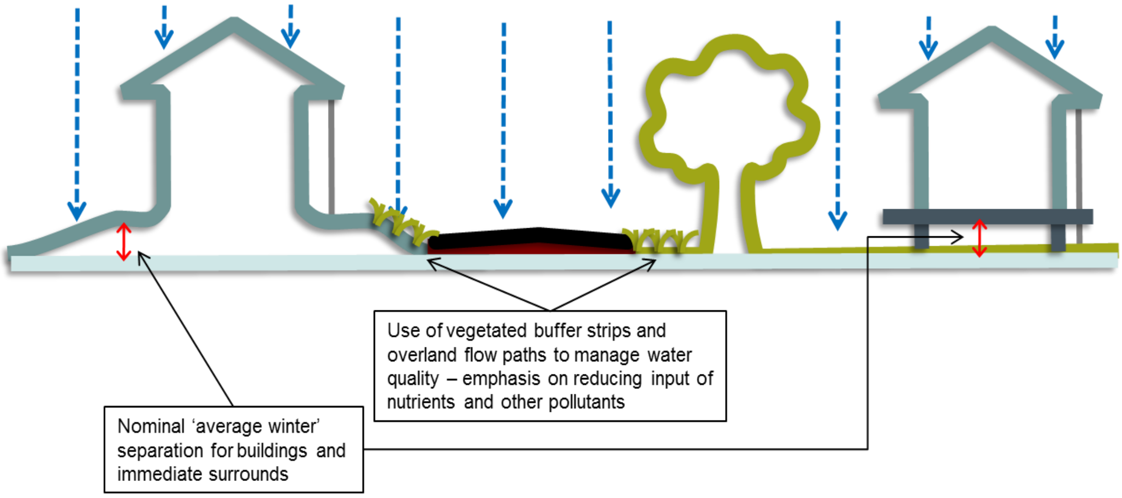


Figure 14: Options for a 'limited fill' development

Design considerations necessary for this type of development include:

- Provision of sufficient low-lying land retained to manage groundwater at pre-development levels and to accommodate stormwater flooding
- Grading of lots to minimise standing water and prevent breeding of mosquitos and other nuisance insects

- Maintenance of high water quality standards to maintain healthy natural wetland ecosystems that will biologically control nuisance insects
- Provision of suitable road access to facilitate vehicle and pedestrian movement throughout the winter and during flooding events

In particular, it is critical to gain community acceptance and understanding of the design intent and to ensure that muddy backyards and open spaces in the winter do not become a 'problem' inherited by the relevant local authority.

When 'no development' is the right answer

Provided that a parcel of land has not been reserved to reflect its particular value or significance and assuming that services and infrastructure suitable to the proposed land use can be provided, in theory it can be 'developed'.

In practice, the ability of a parcel of land to be developed successfully may be limited by many factors and any proponent of development will inevitably undertake some 'due-diligence' investigations to determine the feasibility of development of a particular site.

The presence of shallow groundwater on a site is one of many considerations for the developer that affect the way that the development can proceed and has implications for the cost of materials and construction. The presence of shallow groundwater should not be seen as something that precludes development. Where the site has sufficient strategic value, through being close to key transport links, employment centres, economic opportunities or desirable locations for recreation, then the potentially higher cost of providing the required site conditions for the preferred land use and the management of any environmental impacts can be justified.

Development with subsoil drains and fill

Medium or high density urban development and commercial areas generally require the use of active groundwater management strategies to provide the high levels of amenity that are expected in urban areas.

These developments will generally apply imported fill to artificially create 'dry-land'. Then to avoid subsequent groundwater rise caused by increased recharge that is a recognised outcome of water sensitive urban development; subsoil drainage may be installed.

In order to drain and fill a site, work must be undertaken to determine the level to which you can drain, and then the separation you require from the groundwater and other influences.

Design criteria

- Where a strategy of subsoil drainage and fill is proposed to control groundwater levels for development design criteria and modelling methodologies provided in the Institute of Public Works Engineers Australia *Specification: Separation distances for groundwater controlled urban development* will apply

7.2.2 Manage the shallow aquifer to protect the value of groundwater resources

The Department of Water recently released *Water Resource Considerations when Controlling Groundwater Levels in Urban Development* (2013). This paper outlines a process for determining an acceptable minimum level for subsoil drainage systems with appropriate consideration of potential water resource and environmental impacts.

The Department of Water expects that a suitable Controlled Groundwater Level (CGL) is defined as a critical part of any local water management strategy and/or urban water management plan. The CGL should be determined to provide appropriate protection to local and regional water resources including wetlands, watercourses and groundwater aquifers.

Design criteria

- The establishment of a CGL requires the endorsement of the Department of Water and Environmental Regulation as the state's groundwater resource manager. Further guidance is provided in *Water resource considerations when controlling groundwater levels in urban development* (DWER, 2013).
- The CGL should be established with due consideration of the likely presence and depth of impermeable soils leading to localised permanent or seasonally perched groundwater.

7.3 Groundwater quality management

7.3.1 Maintain and, if possible, improve groundwater quality (median winter concentrations)

The environmental values of groundwater within, and surrounding, the study area must be upheld.

Design criteria

- Implement water sensitive urban design strategies to treat water from directly connected impervious areas prior to its discharge to waterways, wetlands and groundwater.
- Install water quality treatment systems at controlled groundwater level subsoils and drains and/or at outlet points, unless investigations demonstrate that treatment is not required. See Water resource considerations when controlling groundwater levels (DoW 2013e) for guidance.
- Where appropriate, field investigations must be undertaken to identify acid sulphate soils. Any reduction in groundwater level should not expose acid sulphate soils to the air, as this may cause groundwater contamination. If field investigations identify acid sulphate soils, further advice should be sought from the Department of Water and Environmental Regulation.
- Contaminated sites must be managed in accordance with the Contaminated Sites Act 2003.

8 COMMITMENT TO WATER SENSITIVE URBAN DESIGN

In order to meet the design criteria for management of surface water and groundwater quality, it is necessary to use a combination of water sensitive urban design strategies.

In addition, water sensitive urban design strategies, contribute to management of urban heat island effects, reduce risks of flooding on housing and infrastructure while maximising the potential for stormwater to be treated as a resource.

8.1 Urban heat island effects

The urban heat island effect is an important urban issue. The urban heat island effect is a phenomenon where local temperatures in built-up, low vegetation areas are increased in comparison to surrounding areas due to heat absorption and radiation of built materials. Tree canopy provides relief from urban heat due to transpiration. Increasing tree canopy can reduce the urban heat island effect and provide cooler urban areas.

The CRC for Water Sensitive Cities has conducted research into the benefits of greening in urban areas. Findings show a single tree can reduce ambient air temperature under its canopy by 1.2 °C. This translates to a Universal Thermal Climate Index (UTCI) temperature difference, which reflects human physiological reactions to temperature (i.e. how much cooler an individual feels), of 7°C. In a streetscape where tree canopy is present, ambient air temperature under the tree canopy can be reduced by 1°C, while the UTCI temperature difference is 12°C (Coutts *et al.* 2015).

The adoption of water sensitive urban design principles in planning and development can assist in minimising urban heat island through the integration of blue and green infrastructure into lots, streets and open spaces. Recommended strategies that can contribute to reduced urban heat island effects include:

- Raingardens and tree-pits
- Green roofs and living walls
- Vegetated conveyance systems

8.2 Hierarchy of preferred approaches to water sensitive urban design

Structural and non-structural best management practice strategies must be used in combination to achieve the required stormwater treatment outcomes.

8.2.1 Structural strategies

Key principles for the selection of water sensitive urban design strategies in Byford are:

- Retain, restore and protect existing watercourses and water bodies as integrated elements of the water management system.
- Minimise directly connected impervious area by:
  - Retaining and establishing pervious surfaces wherever possible
  - Providing for runoff from impervious surfaces to flow overland via vegetated surfaces wherever possible prior to discharge into downstream receiving environments

Recommended strategies which satisfy these principles include:

Residential lot scale:

- front of lot raingardens and tree-pits
- on-site soakage devices, where appropriate, with overflow outlets (detention)
- water-wise and nutrient-wise landscaping
- porous pavements
- amended topsoils
- rainwater tanks for harvesting, detention and re-use
- greywater systems for garden irrigation

Commercial lot scale:

- on-site detention and/or retention
- water-wise and nutrient-wise landscaping
- maximised permeable surfaces including green roofs
- porous pavements
- amended topsoils
- landscaped infiltration structures (raingardens and tree-pits)
- hydrocarbon management and sediment traps
- rainwater tanks for harvesting, detention and re-use
- greywater systems for garden irrigation

Estate scale:

- infiltration measures
- sediment traps
- porous pavements (car parking)
- retention of existing waterways and restoration of a pre-development ecology and channel morphology in new and existing waterways
- vegetated conveyance systems (living streams and swales)
- use of imported fill material with a high phosphorous retention capability
- minimised use of retention/detention areas integrated within public open space

8.2.2 Non-structural strategies

Although urban development has been rapid in Byford, the area retains a rural character and has significant environmental values. Development should contribute to the maintenance of community understanding and participation in Byford's sustainability. The following non-structural water sensitive urban design strategies can be applied as a part of development to support this objective:

- interpretive signage
- garden education programs
- native species planting initiatives
- publishing a water-sensitive urban design web-page for the estate
- inviting residents to engage with existing community catchment groups
- development of waterwise community gardens

9 IMPLEMENTATION

9.1 Requirements for following stages

It is strongly recommended that proponents meet with the Shire of Serpentine-Jarrahdale to discuss proposed water management strategies and to gain further guidance on site-specific requirements at commencement of any water management strategy or plan.

In accordance with *Better Urban Water Management* (WAPC 2008) the implementation of this strategy will be through the land use planning process with proponents of development required to develop water management strategies and plans at each planning stage to support and inform their planning proposals, environmental investigations, engineering, landscaping and urban designs as follows.

1. A District Water Management Strategy is required to support a region scheme amendment for future urban or industrial development not proposed by the Byford District Structure Plan (2018), consistent with *Better Urban Water Management* (WAPC, 2008).

2. A local water management strategy is required to support a local scheme amendment or the preparation of any local structure plan, whichever is the earlier consistent with *Better Urban Water Management* (WAPC, 2008), *Interim: Developing a Local Water Management Strategy* (DWER, 2008) and the *Byford District Water Management Strategy*.

3. Where no approved local water management strategy exists, any application for subdivision in greenfield areas, or where more than 30 lots are proposed in infill or brownfield areas, must be accompanied by a draft urban water management plan, consistent with the Department of Water and Environmental Regulation's *Urban Water Management Plans: Guidelines for preparing plans and for complying with subdivision conditions* (DWER, 2008) and the *Byford District Water Management Strategy*, and developed in consultation with the local government, with advice as necessary from DWER.

4. Where an approved local water management strategy exists, the preparation and implementation of an urban water management plan will be required as conditions of urban or industrial subdivision. In this case, the subdivision application should be supported by a brief document which outlines a broad strategy for water management that has been previously agreed with the Shire. The urban water management plan is to be consistent with the Department of Water and Environmental Regulation's *Urban Water Management Plans: Guidelines for preparing plans and for complying with subdivision conditions* (DWER, 2008) and the *Byford District Water Management Strategy*, and developed in consultation with the Shire of Serpentine-Jarrahdale with advice as necessary from DWER.

5. Engineering drawings submitted to council for approval must be supported by clear and auditable documentation, providing details of proposed staging and implementation of the surface and groundwater quantity and quality management strategy.

Proposals should address groundwater and surface water management, water conservation and efficiency; and water reuse and recycling in an integrated manner, focussing on key issues identified in this strategy.

Proponents of development should demonstrate that their proposals and designs are consistent with the strategies and design criteria presented in this strategy, as well as satisfying other requirements of other relevant agencies.

9.2 Review of District Water Management Strategy

It is intended that the District Water Management Strategy be reviewed within ten years or earlier if deemed necessary until development has occurred consistent with the Byford Structure Plan.

9.3 Monitoring strategy

Monitoring and site investigations should always be targeted at addressing a specified problem. For instance, if the problem is shallow groundwater then the monitoring program should be targeted to understanding groundwater levels in particularly low-lying or vulnerable parts of the site. If the problem is around understanding a sensitive wetland then the monitoring program should be targeted to capture information about the wetland including both surface and groundwater inputs and outputs. Finally, in some circumstances minimal monitoring may be acceptable, provided targeted site investigation is undertaken and correlated to already available data from the nearest long-term monitoring site.

Early consultation is recommended to assist with definition of monitoring and investigation work.

9.3.1 Predevelopment monitoring

In low-lying shallow groundwater and clay soil environments such as those prevalent in the study area there is a need to fully understand the seasonal, inter-annual and long-term variability of the local groundwater system and the following questions need to be answered:

Does the local groundwater level reflect the district or regional scale superficial aquifer or is there a localised perching effect due to low in-situ soil permeability and/or the presence of impermeable materials in the soil profile?

- Localised perching can be permanent or seasonal depending on the extent and level of the impermeable layer. It is critical to develop an understanding of the relationship between the local groundwater system and the geotechnical conditions.
- Local wetlands and waterways may be sustained by a local perched groundwater system or the district or regional scale superficial groundwater system
- Shallow perched groundwater systems are sensitive to changes to the pre-developed water balance, such as a focus on 'at source' infiltration, or importation of irrigation water.
- Poorly draining in-situ soils can limit the ability for water to enter the groundwater system. It is important to understand the extent to which locally generated stormwater contributes to the groundwater system or runs off.

How close to the natural surface does the pre-development groundwater rise during an average winter?

- These are the conditions that are likely to be experienced frequently and can impact on the amenity and liveability of the subdivision, in particular reducing the functionality of public open spaces as well as being potentially damaging to infrastructure.

How close to the natural surface does the groundwater rise during a wet winter?

- These are less frequent occurrences and may not have occurred at all in recent history, but it remains important to understand how groundwater will behave under them so that the urban form can be designed appropriately.

To answer these questions groundwater level monitoring needs to be undertaken and capture at least two winters locally so that this data can be correlated to the nearest available longer-term record and the long-term patterns can be understood.

Where there is a locally perched groundwater system it is important to consider the extent to which local groundwater levels may be disconnected from the regional groundwater system on a seasonal, annual or inter-annual basis. Monitoring programs should be tailored to include this consideration potentially using paired deep and shallow bores.

Where subsoil drainage is likely to be used to manage a shallow groundwater system the following additional questions will need to be considered:

What level is acceptable for installation of subsurface drainage (CGL)?

- The definition of an acceptable CGL should be undertaken consistent with *Water resource considerations when controlling groundwater levels in urban development* (DWER, 2013) in consultation with the Shire of Serpentine-Jarrahdale and for approval by DWER in their role as water resource managers.
- This process generally considers the impact to the regional or district scale superficial aquifer and the wetlands and watercourses that it sustains and may require significant additional monitoring and investigation work.
- There is also a risk of impacts to local wetlands and watercourses as well as potential for significant groundwater export from locally perched systems and these effects need to be fully understood to be managed.

What is the potential water quality impact from stormwater and groundwater that will be discharged from the drainage system?

- It is critical to gain an understanding of the in-situ soil and groundwater quality that will be mobilised by the system so that an appropriate level of treatment can be provided.
- Where historic land uses indicate a risk of contamination or there is a known contaminated site present within or in proximity to the site, additional investigations will be necessary.
- Additionally, it is necessary to understand water quality in the receiving environment so that any impacts in the future can be properly identified and understood.

To answer these questions, surface water and groundwater quality information needs to be collected. The data must be sufficient to provide an understanding of seasonal trends and recent enough to capture the current status of the site and surrounding land uses. Generally, this will require sampling to be undertaken on at least four to six occasions timed to provide at least one sample per season.

9.3.2 Establishment of trigger values

Site specific trigger values should be established following completion of any predevelopment monitoring program. Trigger values should be established applying procedures consistent with *ANZECC and ARMCANZ 2000* using local reference data where possible to derive the 80th percentile and applying default trigger values from regional reference data as a fall-back.

9.3.3 Post-development monitoring

The key objectives of post-development monitoring are to:

- Determine the quantity and quality of groundwater and surface water on site and downstream of the site post-development;
- Ascertain whether the quantity and quality of groundwater and surface water has significantly changed post-development; and
- Establish the performance of water quality systems that have been installed by the developer and to determine whether they are successful. Where water quality systems are found to be less effective than is desirable, they will act as 'lessons learnt' for future subdivisions.

9.3.4 Monitoring specification

Post-development monitoring should commence 2 years after titling of lots and continue for a duration of not less than 3 years.

Surface water

Surface water monitoring sites should be selected to address the key objectives of post-development monitoring outlined above. Monitoring should include but not necessarily be limited to:

- Flow
- Quality
- Visual inspection and photographic record of drainage outlets and water quality treatment systems. Any outflows observed at these locations during inspection should be sampled opportunistically to coincide with other sampling.
- Visual inspection and photographic record of overland flowpaths to detect the occurrence of any maintenance and management issues such as the deposition of waste, sediment, and the presence of mosquitoes or algal growth.

The specific methodology for flow data collection may vary from site to site and does not necessarily include continuous monitoring. However, flow monitoring should be undertaken with site specific consideration of an appropriate methodology for estimation of contaminant loads to receiving environments.

Surface water sampling should be undertaken fortnightly from August to October (i.e. six fortnightly monitoring events) to capture peak winter baseflows, and once in March to capture the first baseflows post-summer.

Surface water samples should be submitted to a NATA-accredited laboratory in accordance with Australian Standards and analysed for the following parameters:

- In situ pH, electrical conductivity (EC), dissolved oxygen, temperature;
- pH
- Total suspended solids (TSS);
- Total nitrogen (TN) and total dissolved nitrogen (TDN)
- Ammonia (NH4);
- Nitrate and nitrite (Nox-N);
- Total phosphorous (TP); and
- Filterable reactive phosphorous (FRP).

The following additional parameters should be included in the laboratory analysis on an annual basis:

- Major anions (chloride, bromide and sulphate);
- Major cations (calcium, magnesium, sodium and potassium); and
- Iron (Fe) and aluminium (Al).

Groundwater

Groundwater monitoring sites should be selected to address the key objectives of post-development monitoring outlined above. Monitoring should include but not necessarily be limited to:

- Levels
- Quality

Monitoring of groundwater levels and the collection of groundwater samples should be undertaken on a quarterly basis.

Groundwater samples should be submitted to a NATA-accredited laboratory in accordance with Australian Standards and analysed for the following parameters:

- In situ pH, electrical conductivity (EC), dissolved oxygen, temperature;
- pH
- Total suspended solids (TSS);
- Total nitrogen (TN) and total dissolved nitrogen (TDN);
- Ammonia (NH4);
- Nitrate and nitrite (Nox-N);
- Total phosphorous (TP); and
- Filterable reactive phosphorous (FRP).

The following additional parameters should be included on an annual basis:

- Major anions (chloride, bromide and sulphate);
- Major cations (calcium, magnesium, sodium and potassium); and
- Iron (Fe) and aluminium (Al).

9.3.5 Reporting

The Shire of Serpentine-Jarrahdale should be advised of any trigger value exceedances immediately. The Shire of Serpentine-Jarrahdale requires annual reports to be provided for all post development monitoring programs. Monitoring data should be provided in electronic format, preferably as an excel spreadsheet. Reports should include:

- Summary tables, graphs and maps presenting spatial and temporal variations of flow and quality;
- Estimation of contaminant loads to the downstream environment based on collected water quality and flow data;
- Discussion of findings including investigations undertaken in response to trigger value exceedances;
- Recommendations for modified monitoring regime and/or trigger values where required; and
- Presentation of site inspection findings including photographs and field notes
- Groundwater bore construction logs.

9.4 Action plan

Table 4: Actions and responsibilities for implementation of the strategy

Action	Responsibility	Timing
Development of water management documents	Proponents of development	As part of the planning and development process
Assessment of DWMS and LWMS documents	DWER in consultation with the Shire of Serpentine-Jarrahdale	In accordance with statutory planning process timeframes
Assessment of UWMP documents and subdivision designs	Shire of Serpentine-Jarrahdale in consultation with DWER	In accordance with statutory planning process timeframes

10 REFERENCES AND RESOURCES

ANZECC & ARMCANZ, 2000. Australian and New Zealand guidelines for fresh and marine water quality, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Bureau of Meteorology, 2012, Climate data online: web based resource {http://www.bom.gov.au/climate/data/}, Commonwealth of Australia 2012, Bureau of Meteorology

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) Australian Rainfall and Runoff: A Guide to Flood Estimation, © Commonwealth of Australia (Geoscience Australia), 2016.

Bolland, M, 1998, *Soils of the Swan Coastal Plain*, Department of Agriculture and Food Western Australia, Perth.

CyMod Systems Pty Ltd. 2007, Local scale groundwater modelling to assess effects of climatic variations and planned development, Department of Water.

Department of Biodiversity, Conservation and Attractions 2004, *River restoration manual*, Perth

Department of Water and Environmental Regulation (DWER), 2004-07. Stormwater management manual for Western Australia, Perth.

DWER, 2004 and 2007, Statewide river water quality assessment, web-based resource { http://www.water.wa.gov.au/idelve/srwqa/}, Department of Water, Perth, Western Australia

DWER, 2007. Interim position statement: constructed lakes, Perth.

DWER, 2008, *Byford townsite drainage and water management plan*, Department of Water, Perth

DWER, 2008. Urban water management conditions – guidelines for compliance, Perth.

DWER, 2010, *Hydrological and nutrient modelling of the Swan Canning coastal catchments*, Department of Water, Perth

DWER, 2011, *Treatment and management of soils and water in acid sulfate soil landscapes,* Perth

DWER, 2013, Guidelines for District Water Management Strategies

DWER, 2013, Better Urban Water Management Guidance Note Series

DWER, 2017, *Decision process for stormwater management in Western Australia*, Perth

Engineers Australia, 2006, Australian Runoff Quality

Environmental Protection Authority (EPA), 2004. Revised draft environmental protection (Swan Coastal Plain wetlands) policy 2004, Perth.

EPA, 2008, *Water quality improvement plan for the rivers and estuary of the Peel-Harvey system – phosphorus management*, Perth

EPA, 2009, Swan Canning *water quality improvement plan*, Perth

Government of Western Australia, 1992. Environmental protection (Peel Inlet- Harvey Estuary) policy 1992, Government Gazette Perth.

Hall, J 2015, Birrega and Oaklands flood modelling and drainage study, Water Science Technical Series, report no. 71, Department of Water, Western Australia.

Institute of Engineers Australia 2001, *Australian rainfall and runoff, a guide to flood estimation*

Institute of Engineers Australia 2006, *Australian runoff quality guidelines*

Marillier, B, Hall, J & Kretschmer, P, 2012a, *Lower Serpentine hydrological studies– conceptual model report,* Water Science Technical Series, report no. 45, Department of Water, WA

Marillier, B, Hall, J & Kretschmer, P, 2012b, *Lower Serpentine hydrological studies– model construction and calibration report,* Water Science Technical Series, report no. 46, Department of Water, Western Australia

Marillier, B, Hall, J & Kretschmer, P, 2012c, *Lower Serpentine hydrological studies – land development, drainage and climate change scenarios report (2012.),* Water Science Technical Series, report no. 48, Department of Water, Western Australia

Parsons Brinkerhoff, 2003. Byford urban stormwater management strategy

Parsons Brinkerhoff, 2005. Byford urban stormwater management strategy – developer guidelines, Serpentine Jarrahdale Shire.

SKM, 2007. Byford floodplain management Strategy, Department of Water.

Taylor Burrell Barnett, 2005. Byford structure plan, Serpentine Jarrahdale Shire.

Western Australian Planning Commission (WAPC), 2002. Bush Forever information sheet, Perth.

WAPC, 2003. Planning bulletin No. 64: acid sulphate soils.

WAPC, 2006. State planning policy No 2.9: Water Resources.

WAPC, 2008, *Better urban water management,* Western Australian Planning Commission, Perth, WA

WAPC, 2015. State planning policy No 3.7: Planning for Bushfire.

WAPC, 2015 (Draft). Liveable neighbourhoods.

WAPC, 2016. State planning policy No 2.5: Rural Planning.

10.1 Local structure plans

A full current list of local structure plans can be accessed via the Shire of Serpentine Jarrahdale website << http://www.sjshire.wa.gov.au/what-we-do/planning-and-building/structure-plans/>> (link correct at 25 January 2018)

10.2 Local water management strategies and urban water management plans

A large number of Local Water Management Strategies (LWMS) and Urban Water Management Plans (UWMP) have been prepared to support local structure planning and subdivisions within the study area. The following list is not exhaustive but provides a summary of most of the reports that have been previously approved in the study area:

- Byford Town Centre Local Water Management Strategy (GHD, 2014)
  - Lot 1 Abernethy Road, Byford UWMP (Wave International, 2016)
  - Lot 2 Abernethy Rd, Byford UWMP (JDA, 2015)
  - Lot 4 Abernethy Road, Byford - UWMP (True Civil Consulting, 2018)
  - Lot 5 Abernethy Road, Byford UWMP (GHD, 2017)
  - Lot 15 Abernethy Road, Byford UWMP (RPS, 2016)
- Lots 1,2 & 63 Thomas Road, Larsen Road, Byford (Byford Central) DNMP (Cardno, 2006)
- Lots 4&5 Abernethy Road, Byford (Byford West) DNMP (Cardno, 2007)
- Byford Main Precinct Local Structure Plan (The Glades): LWMS (JDA, 2005)
  - The Glades at Byford: Stages 6, 7 & 8a UWMP (JDA 2011)
  - The Glades at Byford: Woodland Grove North UWMP (JDA 2013)
  - The Glades at Byford: Icaria Stages 1 to 4 UWMP (JDA, 2014)
  - The Glades at Byford: Icaria Stages 5 to 10 UWMP (JDA, 2014)
  - The Glades at Byford: Woodland Grove South UWMP (JDA 2013)
  - The Glades at Byford: Stage 2 UWMP (JDA, 2009)
  - The Glades at Byford: Stage 9 & High School Precinct UWMP (JDA, 2011)
  - The Glades at Byford: Stage 8 UWMP (JDA, 2012)
  - The Glades Cardup Brook, East and West Precinct, UWMP (JDA, 2016)
- Lot 9 Abernethy Road (Kalimna Estate) LWMS (DEC, 2009)
  - Lot 9 Abernethy Rd, Byford, UWMP (DEC, 2010)
- Redgum Brook Estate DNMP (GHD, 2008)
  - Redgum Brook Estate (Northern Section) LWMS (GHD, 2014)
  - Redgum Brook Estate Stages 9-12, UWMP (GHD, 2015)
  - Redgum Brook – East of Kardan Boulevard, UWMP (GHD, ???)
  - Redgum Brook Stage 10A, 10B and Stage 13 UWMP (GHD, 2014)
- Larsen Road Estate (Marri Park), Byford UWMP (Cardno 2008)
- Grange Meadows, Byford UWMP (BPA Engineering, 2013)
- Lot 9500 Thomas Road, Byford (Byford Meadows) LWMS (HyD2o, 2014)
  - Lot 9500 Thomas Road, (Byford Meadows), Stage 1 UWMP (Hyd2o, 2014)
  - Lot 9500 Thomas Road, (Byford Meadows), Stage 2(a&b) UWMP (Hyd2o, 2015)
  - Lot 9500 Thomas Road, (Byford Meadows), Stage 2c UWMP (Hyd2o, 2016)
  - Byford Meadows (Remaining Stages), UWMP (Hyd2o, 2017)
- Byford, Doley Road Precinct Local Water Management Strategy (EE, 2016)
  - Parcel Property Landholding, Byford (Doley Precinct) UWMP (Urbaqua, 2017)
  - Lot 8, 9 & 23 Warrington Road, Byford (Doley Precinct) UWMP (Cardno 2017)
- Lot 2 Nettleton Road, Byford (Brook @ Byford) LWMS (JDA, 2009)
  - Lot 2 Nettleton Road, Byford (Brook @ Byford) LWMS Addendum (Hyd2o, 2012)
  - Lot 2 Nettleton Road, Byford (Brook @ Byford) Stage 1 UWMP (Hyd2o, 2013)
  - The Brook @ Byford Stages 1-3 UWMP (EE, 2016)
- L1, L3 & L128 South Western Highway, Byford - LWMS (GHD, 2012)
- Town Planning Scheme 2 Amendment 77 (Byford on the Scarp) DNMP (Gilbert Rose Consulting, 1999)
  - Byford on the Scarp – Stages 4, 5 & 6 UWMP (JDA, 2008)
  - Byford on the Scarp – Stage 7 UWMP (EE, 2014)
  - Byford on the Scarp – Stage 8a UWMP (EE, 2016)

APPENDIX A – STORMWATER MODELLING IN INFOWORKS ICM

InfoWorks ICM is a hydraulic modelling package used to simulate stormwater drainage systems. The software package is capable of hydrological modelling of the complete urban water cycle, including stormwater drainage master planning or studies, assessments of flooding in urban drainage systems and hydraulic response of the stormwater network infrastructure to the changes in the land use. The hydraulic software component can resolve open channel and closed conduit flows and model the effect of backwater and reverse flow. The model is used predominantly for calculations of event-based simulations; therefore, the initial conditions are usually set to the worst-case scenario.

Time-varying surface runoff generated by the runoff routing model discharges into the hydraulic network. The hydraulic network consists of interconnected nodes (manholes, outfalls and storage basins) and links (weirs, pipes, culverts and open channels).

InfoWorks ICM is an evolution of InfoWorks CS which was used to develop the original *Byford Townsite DWMP* (DWER 2008) model. The model retains the same 1-Dimensional computational system although stability has been improved and has been integrated with a 2-Dimensional flexible mesh overland flood routing module which can be specified over the whole model domain or at targeted locations where significant breakout flow is known to occur.

The 'base model' presented in sections A.1 to A.4 and Figure A.1 of this report has been constructed using InfoWorks ICM to enable direct comparison to the previous post-development Byford Townsite DWMP model. The 'current system model' presented in sections A.5 to A.7 and Figure A.2 of this report includes the following modifications:

- Expanded study area to include development outside of the Byford Townsite structure plan area;
- Hydrological parameters (catchment loss rates) adjusted consistent with those adopted for the *Birrega Oaklands flood modelling and drainage study* (DWER, 2015);
- Hydraulic system elements and structures modified to reflect changes to the system that have been constructed or approved in UWMPs or engineering design plans; and
- Hydraulic system elements and structures modified to reflect any survey information that can be obtained within the timeframes of the project.

To provide an understanding of the individual impacts of the various updates, a version of the base model incorporating updated hydrological parameters has been developed and both of these models (base and base with revised parameters) have been run with the following design rainfall events:

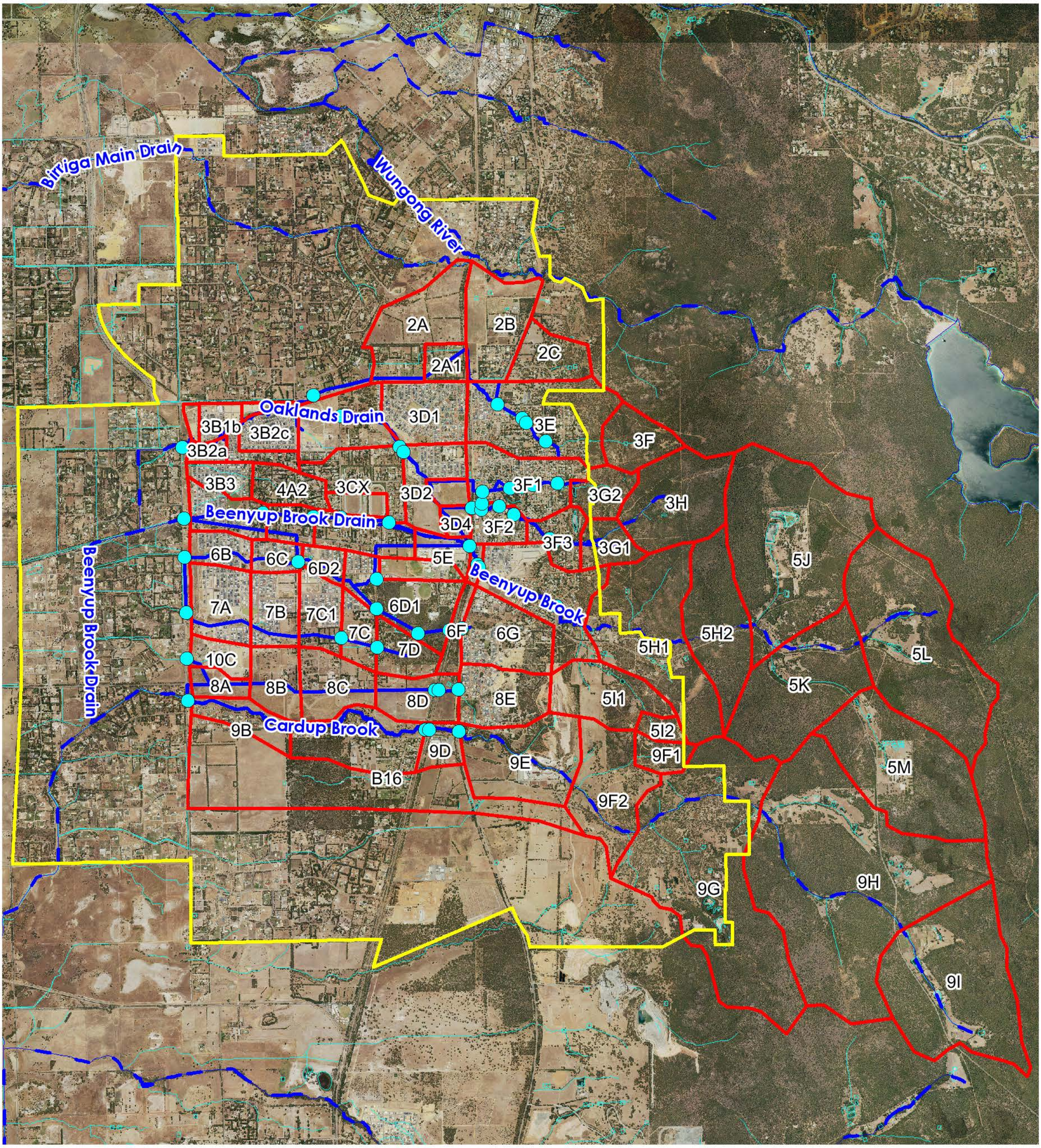
- AR&R 1996 - 1h, 3h, 6h, 12h, 24h, 48h and 72h durations for 5y and 100y ARI; and
- AR&R 2016 – 1h, 3h, 6h, 12h, 24h, 48h and 72h durations for 20% and 1% AEP.

It is recognised that the 5y ARI event is not directly comparable to the 20% AEP. However, it is noted that the 5y ARI is the appropriate event for calibration with previous modelling and the 20% AEP is the appropriate event for application of the 2016 AR&R methodology. Hence these two design events have been selected for use and are presented comparatively in this report.

Finally, the completed 'current system' model incorporating all updates has been run with the following events and was used to develop the stormwater management strategy presented in section 6 of this DWMS:

- AR&R 2016 – 1h, 3h, 6h, 12h, 24h, 48h and 72h durations for 20% and 1% AEP.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure A1 - Model layout, base model



Legend

- DWMS Study Area
- Modelled drain/watercourse
- Modelled subcatchment
- Modelled structures (culverts/bridges)

Scale 1: 60,000 at A4

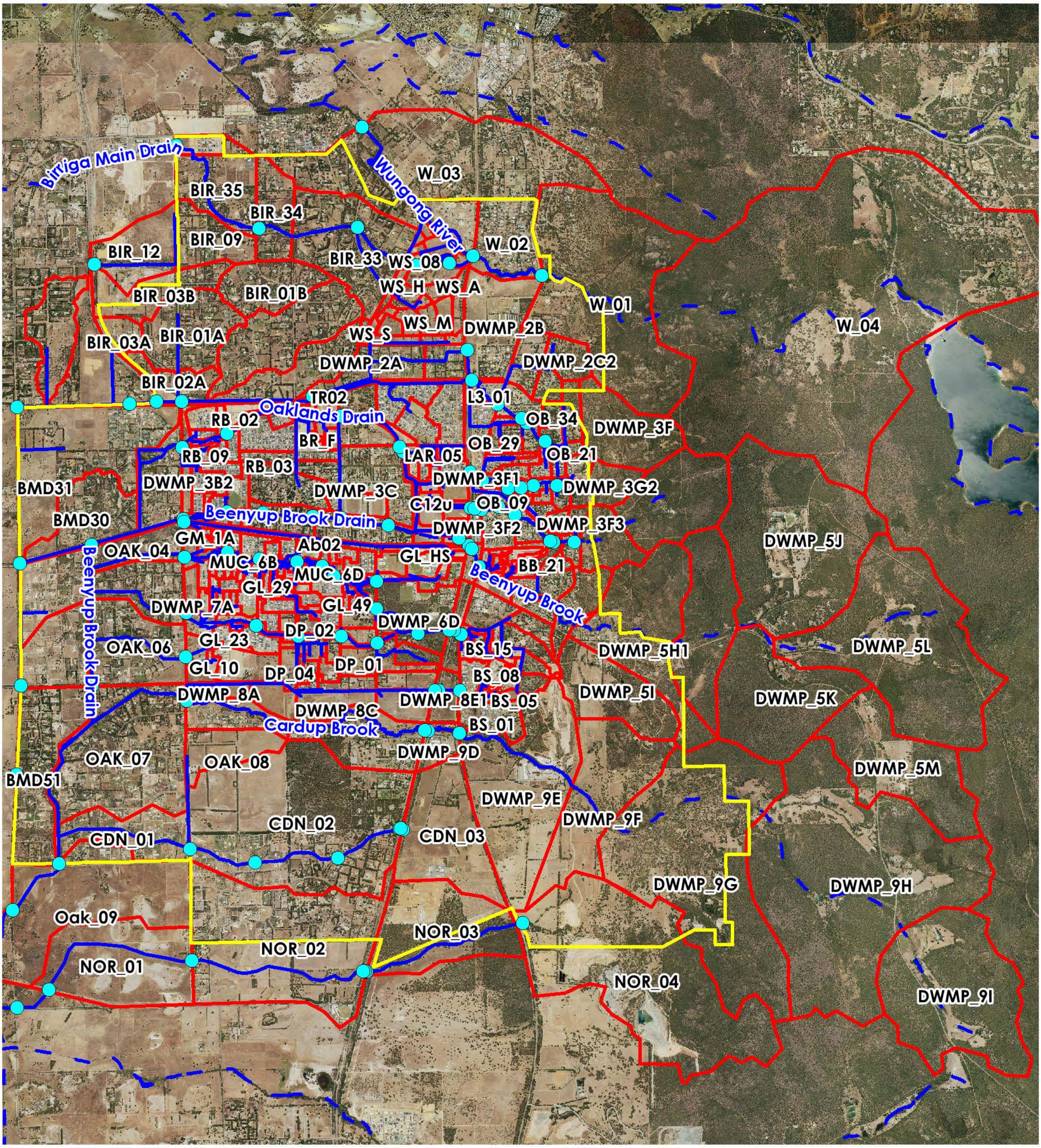
0 1.2km

N

urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure A2 - Model layout, current system model



Legend

- DWMS Study Area
- Modelled structures
- Modelled drains/watercourses
- Modelled subcatchments

Scale 1: 60,000 at A4

0 1.2km

N

urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

A.1 Initial modelling assumptions

The following assumptions developed for the original *Byford Townsite DWMP* (DWER 2008) have been retained in the base model:

- Peak winter groundwater levels (controlled groundwater levels) applied as starting water levels in basins and as baseflows in drains.
- Design rainfall events applied to whole catchment with universal start time.
- 100-year flood levels taken from *the Byford floodplain management strategy* SKM, 2007) applied as constant tailwater at the Hopkinson Road end of each modelled waterway.
- Infiltration modelled at a constant rate of 4 mm/hour.
- Catchment parameterisation (pervious/impervious breakdown, catchment slope, roughness, losses) adapted from *Byford floodplain management strategy* (SKM, 2007).

A.2 Base model hydraulics

The InfoWorks ICM base model has been developed consistent with the original *Byford Townsite DWMP* (DWER 2008). The hydraulic model consists of a combination of piped drainage, channels with cross-sections derived from 2008 LiDAR data and culvert structures.

All hydraulic components of the system including local detention basins and culvert structures have been modelled in the base model as developed for the original *Byford Townsite DWMP* (DWER, 2008). Table A1 presents the significant culvert structures that have been included within the base model consistent with the original *Byford Townsite DWMP* (DWER, 2008).

The InfoWorks ICM base model has been established applying Manning's roughness coefficients to modelled conduits summarised in Table A2 and consistent with the original *Byford Townsite DWMP* (DWER 2008).

Table A1: Modelled hydraulic structures – base model

Location X	 Y	Shape	Diameter/ width (mm)	Height (mm)	Invert level (mAHD)	Number of barrels
403208.5	6435653	Rect	3600	1900	24.3	1
403229.3	6434846	Rect	3700	1560	24.5	1
403239.8	6434410	Circ	455		26.5	2
403253.7	6433783	Rect	1200	500	26.0	1
403262.8	6433262	Circ	720		26.5	2
403273.1	6432784	Rect	1800	1500	26.0	1
404128.2	6434914	Circ	900		30.2	3
404524.3	6434359	Circ	750		34.0	2
404696.5	6434870	Circ	900		34.7	3
404696.9	6436247	Rect	3200	1200	30.1	1
405008.4	6434863	Rect	1210	920	38.2	2
405010	6436013	Rect	1880	1220	31.8	1
405015.2	6433493	Circ	450		38.6	2
405415.5	6433829	Rect	1200	450	44.2	1

Location X	Y	Shape	Diameter/ width (mm)	Height (mm)	Invert level (mAHD)	Number of barrels
405416.3	6434165	Circ	450		44.1	2
405419.4	6433387	Circ	450		42.6	2
405555.7	6434803	Rect	1500	600	44.4	2
405674.3	6435663	Rect	1220	1220	37.7	1
405721.7	6435606	Rect	1220	1200	38.6	1
405888.7	6433545	Rect	1500	600	51.0	1
405948.4	6432459	Circ	600		52.0	2
405965.5	6432457	Circ	1700		50.4	1
406015.3	6432454	Circ	1700		50.9	1
406075.1	6432908	Circ	300		56.0	3
406118.2	6432906	Rect	1220	920	56.6	1
406240.7	6433588	Rect	1200	450	54.4	2
406294.5	6433581	Rect	1220	920	55.9	1
406346.6	6432438	Circ	900		54.9	1
406381.3	6433607	Circ	380		57.2	2
406470.4	6434539	Rect	1240	1200	55.7	4
406493.3	6434972	Rect	4000	1200	47.7	1
406560.8	6434328	Rect	7500	1500	60.2	1
406577.9	6434299	Rect	4500	1500	60.5	1
406604.7	6434949	Circ	900		54.5	3
406610.4	6435019	Circ	900		54.4	1
406618.1	6435153	Rect	1520	640	54.3	2
406789.4	6436146	Circ	900		66.0	2
406809.9	6434986	Circ	900		58.5	1
406926.3	6435191	Circ	900		62.7	1
406969.5	6434893	Circ	750		64.1	1
407055.4	6435204	Circ	900		66.7	1
407064.5	6435984	Circ	600		78.3	2
407113.2	6435934	Circ	600		82.0	2
407189.3	6435228	Circ	900		72.0	1
407334.3	6435724	Circ	600		92.5	2
407381.5	6434623	Circ	750		75.0	1
407422.1	6434579	Circ	750		77.0	1
407462.3	6433851	Circ	1100		73.5	3
407467.3	6435252	Circ	300		77.5	1

Table A2: Culvert roughness coefficients (Manning's N)

Drain Type	Manning's coefficient of roughness
Maintained open drain	0.030
Unmaintained open drain	0.050
Circular culvert	0.012
Rectangular culvert	0.013
Over road flood route	0.015
Over land flood route	0.035

A.3 Base model hydrology

The InfoWorks CS model of Byford townsite developed for the *Byford Townsite DWMP* (DWER 2008) used a constant infiltration model to generate rainfall runoff and the SWMM single non-linear reservoir routing model to provide inflows to the hydraulic component of the model. This has been maintained in the new InfoWorks ICM base model.

Each subcatchment in the study area is subdivided into pervious and impervious areas that have surface roughness, initial losses and infiltration losses applied according to land use and consistent with the *Byford Townsite DWMP* (DWER 2008) as shown in Table A3.

Land uses have been retained from the original *Byford Townsite DWMP* (DWER 2008) post-development model (Table A4). The percentage of impervious area for individual catchments was calculated from existing land use and the district structure plan; summarised in Table A5.

Table A3: InfoWorks model runoff area properties

Land use	Surface roughness (Manning's N)		Initial loss (mm)		Infiltration loss (mm/hour		Fixed runoff coefficient	
	Perv	Imperv	Perv	Imperv	Perv	Imperv	Perv	Imperv
Upper forested	0.080	0.015	10	1.5	n/a	n/a	0.2 – 10y 0.5 – 100y 0.4 – 100y (design)	1.0
Rural pasture	0.050	0.015	10	1.5	4	0	n/a	n/a
Existing urban	0.025	0.015	10	1.5	4	0	n/a	n/a
Constructed urban	0.025	0.015	10	15	4	0	n/a	n/a

Table A4: InfoWorks model land use surface breakdown

Land use category	Pervious area 1 (%)	Effective impervious area 2 (%)
Roads	30%	70%
Mixed business	25%	75%
Neighbourhood centres	45%	55%
Town centres	40%	60%
Residential (R20-R60)	50%	50%
Rural residential (R2)	100%	0%
Schools	50%	50%

Note: Effective impervious areas presented in this table are for modelling at the catchment scale and are not to be used for individual lot runoff calculations.

Table A5: InfoWorks model catchment properties for base model scenario

Subcatchment ID	Total area (ha)	Vector slope (%)	Catchment width (m)	% Impervious
10C	24.672	1.4	300.0	38.486
2A	95.713	1.5	800	3.05
2A1	20.593	2	250	29.799
2B	79.625	4.1	800	1.518
2C	44.476	11.8	600	1.539
3B1a	7.153	1.8	300	28.681
3B1b	18.029	1.8	300	28.681
3B1c	6.053	1.8	300	28.681
3B2a	10.392	1.8	181.9	31.57
3B2b	15.68	1.8	223.4	28.8
3B2c	29.11	1.8	304.4	21.37
3B3	24.579	1.8	300	28.8
3C	68.051	1.4	700	21.37
3CX	56.251	2	750	47.953
3D1	65.07	3.4	800	38.265
3D2	49.011	2.1	600	26.702
3D3	12.82	2.1	200	33.162
3D4	11.409	2.5	200	27.361
3E	136.379	10.8	1200	42.017
3F	45.228	26.3	1100	0
3F1	80.81	5.6	850	53.969
3F2	27.055	3.8	500	60.001
3F3	31.54	13	750	47.97
3G1	30.298	24.6	700	0
3G2	33.347	24.3	900	0
3H	109.757	16.4	950	0
4A2	34.352	1.8	600	54.024
4B	16.631	2	250	5.989
5B	40.298	1.6	400	26.976
5C	22.714	1.7	300	36.151
5D	47.859	2	400	34.95
5E	21.189	2.1	300	31.609
5F	6.314	3.8	200	20.449
5G	108.901	8.1	900	35.969

Subcatchment ID	Total area (ha)	Vector slope (%)	Catchment width (m)	% Impervious
5H1	182.568	17.1	1100	0
5H2	108.331	13.2	800	0
5I1	74.415	17.1	700	0
5I2	13.563	19.8	300	0
5J	268.448	8.8	1200	0
5K	163.319	11	900	0
5L	246.591	5.4	1100	0
5M	188.239	5.8	1000	0
6B	26.896	1.8	500	28.798
6C	19.783	1.9	300	31.791
6D1	77.237	2.1	450	15.11
6D2	16.049	1.5	250	29.278
6E	20.92	1.8	350	39.315
6F	17.8	3.6	300	5.331
6G	74.373	4.3	850	0
7A	57.144	1.2	500	33.378
7B	46.18	1.4	500	40.158
7C	29.356	1.8	450	39.404
7C1	40.884	1.3	500	40.196
7D	34.041	1.9	300	24.176
8A	18.977	1.3	250	23.179
8B	44.054	1.5	400	39.852
8C	54.599	1.5	500	37.906
8D	47.806	1.9	500	42.541
8E	65.206	6.6	800	1.765
9B	37.144	2	400	4.672
9C	85.439	3.9	600	11.069
9D	22.645	4	300	4.19
9E	113.147	9.5	1000	0
9F1	22.219	27	700	0
9F2	101.466	21.1	1100	0
9G	355.666	15.7	1900	0
9H	463.327	10.4	2200	0
9I	232.132	5.7	1800	0
B16	224.573	2	1500	0

A.4 Base model validation

Peak flows and levels generated by the InfoWorks ICM base model at various critical locations within the major waterways were compared to peak post-development flows presented in Table 6.2 of the original *Byford Townsite DWMP* (DWER 2008). This comparison is presented in Table A6 and Table A11.

In general, the base model flows and levels compare well to those generated by the original *Byford Townsite DWMP* (DWER 2008) with a small number of discrepancies. Notable level differences (>100mm) are observed at locations 1 and 14 while notable flow differences (>5%) are observed at locations 4 and 14.

Where the new model predicts lower flows and levels, such as at location 14 on Beenyup Brook, it is thought likely that discrepancies are a result of improved model performance with artificial peaks in the 2008 model being caused by minor instabilities. Differences on Oaklands drain however, where the new model predicts higher flows, but similar levels is likely to be associated with small differences in the hydraulic configuration of the model in this location and not reflective of the overall performance of the models compared to each other.

Table A6: Base model peak flow comparison to Byford Townsite DWMP (DWER, 2008) post-development model

Location	5-year ARI peak flows		100-year ARI peak flows	
	Base model	2008 DWMP	Base model	2008 DWMP
1. Oaklands drain d/s George Road (north)	5.5	5.5	10.2	10.2
2. Oaklands drain d/s George Road (south)	2.3	2.4	10.7	10.7
3. Oaklands drain d/s Evans Road	10.7	10.7	34.4	34.5
4. Oaklands drain d/s Briggs Road	11.0	11	35.1	30.2
5. Oaklands drain at Thomas Road and Masters Road	9.5	9.5	25.7	25.7
6. Oaklands drain d/s Malarkey Road	20.9	20.8	62.0	59.3
7. Oaklands drain at Hopkinson Road	15.8	15.7	51.5	48.9
8. Beenyup Brook d/s South Western Hwy	8.1	8.1	31.2	31.2
9. u/s end piped Beenyup Brook d/s Abernethy Road	2.8	2.8	3.1	3.1
10. u/s end swale from Beenyup Brook to Oaklands drain	5.2	5.2	16.1	16.1
11. u/s end swale down Abernethy Rd from Beenyup Brook to Trib 6	0.0	0	11.5	11.5
12. overland flow down Warrington Road	0.0	0	1.3	1.3
13. overland flow down Doley Road	0.0	0	2.7	2.7
14. Beenyup Brook at Hopkinson Road	5.5	8.1	9.6	9.6
15. Tributary 6 u/s Briggs Road (Extn)	1.4	1.4	3.4	3.4

Location	5-year ARI peak flows		100-year ARI peak flows	
	Base model	2008 DWMP	Base model	2008 DWMP
16. Tributary 6 at Hopkinson Road	1.6	1.6	6.8	6.7
17. Tributary 7 at Hopkinson Road	2.1	2	5.1	5.1
18. Cardup Brook d/s South Western Hwy	5.8	5.8	23.5	23.5
19. Cardup Brook at Hopkinson Road	9.4	9.4	33.3	33.2

Table A7: Base model top water level comparison to Byford Townsite DWMP (DWER, 2008) post-development model

Location	5-year ARI top water level		100-year ARI top water level	
	Base model	2008 DWMP	Base model	2008 DWMP
1. Oaklands drain d/s George Road (north)	53.2	53.2	53.3	53.5
2. Oaklands drain d/s George Road (south)	51.8	51.8	52.0	52
3. Oaklands drain d/s Evans Road	44.3	44.3	44.6	44.6
4. Oaklands drain d/s Briggs Road	32.7	32.7	32.9	32.9
5. Oaklands drain at Thomas Road and Masters Road	30.9	30.9	31.1	31.1
6. Oaklands drain d/s Malarkey Road	29.8	29.8	30.2	30.2
7. Oaklands drain at Hopkinson Road	26.4	26.4	27.0	26.9
8. Beenyup Brook d/s South Western Hwy	58.5	58.5	58.7	58.7
9. u/s end piped Beenyup Brook d/s Abernethy Road	56.5	56.5	56.6	56.6
10. u/s end swale from Beenyup Brook to Oaklands drain	56.5	56.5	56.6	56.6
11. u/s end swale down Abernethy Rd from Beenyup Brook to Trib 6	56.3	56.3	56.8	56.8
12. overland flow down Warrington Road	44.5	44.5	45.4	45.4
13. overland flow down Doley Road	34.5	34.5	35.5	35.5
14. Beenyup Brook at Hopkinson Road	25.6	26	26.0	26.3
15. Tributary 6 u/s Briggs Road (Extn)	41.6	41.6	41.7	41.7
16. Tributary 6 at Hopkinson Road	27.5	27.6	27.7	27.7
17. Tributary 7 at Hopkinson Road	27.0	27.1	27.2	27.2
18. Cardup Brook d/s South Western Hwy	55.1	55.1	57.1	57.1
19. Cardup Brook at Hopkinson Road	27.6	27.6	27.9	27.9

A.4.1 Results comparison to Birrega Oaklands flood modelling and drainage study

The *Birrega Oaklands flood modelling and drainage study* (DoW, 2015) provides a table (5-9) which compares peak flows at three locations to the Byford DWMP (DWER, 2008). Table A8 provides a comparison of these flows with those predicted by the base model.

It is noted that the base model compares reasonably well to the Birrega Oaklands model for the Oaklands drain and Cardup Brook sites with some minor discrepancies. However, the base model predicts much larger 100-year ARI peak flows for the Beenyup Brook site. The completion of a drainage survey in the Byford old townsite and a thorough review of LiDAR data has revealed the presence of a large sump/storage area on the Beenyup Brook course upstream of Old Brickworks Road which was not modelled in the base model. It is thought that this storage area may largely account for the discrepancy in flows at this location.

Table A8: Birrega Oaklands model peak flow comparison to base model

Location	Base model		Birrega Oaklands study	
	5-year ARI	100-year ARI	5-year ARI	100-year ARI
1. Oaklands drain d/s George Road (north)	5.5	10.2	4.2	11.7
2. Beenyup Brook d/s South Western Hwy	8.1	31.2	5.4	26.8
3. Cardup Brook d/s South Western Hwy	5.8	23.5	8.0	22.7

A.5 Revised parameterisation

Hydrological parameters (catchment loss rates) have been adjusted consistent with those adopted for the *Birrega Oaklands flood modelling and drainage study* (DoW, 2015). Adjustments include adoption of a revised infiltration loss rate of 2.9 mm/h (70mm/day), revised runoff coefficients for the upper forested catchments and the addition of a new catchment land use definition; Foothills. Revised parameters are presented in Table A9.

Table A9: InfoWorks model runoff area properties – revised

Land use	Surface roughness (Manning's N)		Initial loss (mm)		Infiltration loss (mm/hour)		Fixed runoff coefficient	
	Perv	Imperv	Perv	Imperv	Perv	Imperv	Perv	Imperv
Upper forested	0.080	0.015	0	1.5	n/a	n/a	0.13 – 5y/20% 0.19 – 100y	1.0
Foothills	0.050	0.015	0	1.5	n/a	n/a	0.26 – 5y/20% 0.42 – 100y	1.0
Rural pasture	0.050	0.015	10	1.5	2.9	0	n/a	n/a
Existing urban	0.025	0.015	10	1.5	2.9	0	n/a	n/a
Constructed urban	0.025	0.015	10	15	2.9	0	n/a	n/a

A.5.1 Results comparison to base model

Peak flows generated by the InfoWorks ICM base model with revised parameterisation were compared to peak flows generated by the original base model at various critical locations within the major waterways. This comparison is presented in Table A10 and Table A11.

Because the change in parameterisation reduces the upper forested pervious area runoff coefficient but introduces a new land use category and reduces the infiltration loss rate applied to other pervious areas the effects on various locations in the model are inconsistent. However, in general, the combined effect of these changes has increased peak flows and levels. This effect is apparent in results presented below in Table A10 and Table A11.

Table A10: Base model peak flow comparison to base model with revised parameters

Location	5-year ARI peak flows		100-year ARI peak flows	
	Base model	Base model (revised param.)	Base model	Base model (revised param.)
1. Oaklands drain d/s George Road (north)	5.5	6.0	10.2	10.5
2. Oaklands drain d/s George Road (south)	2.3	3.9	10.7	11.7
3. Oaklands drain d/s Evans Road	10.7	15.7	34.4	36.9
4. Oaklands drain d/s Briggs Road	11.0	16.3	35.1	37.6
5. Oaklands drain at Thomas Road and Masters Road	9.5	12.3	25.7	27.4
6. Oaklands drain d/s Malarkey Road	20.9	29.2	62.0	66.2
7. Oaklands drain at Hopkinson Road	15.8	27.5	51.5	53.8
8. Beenyup Brook d/s South Western Hwy	8.1	11.1	31.2	32.2
9. u/s end piped Beenyup Brook d/s Abernethy Road	2.8	2.9	3.1	3.1
10. u/s end swale from Beenyup Brook to Oaklands drain	5.2	8.2	16.1	16.2
11. u/s end swale down Abernethy Rd from Beenyup Brook to Trib 6	0.0	0.0	11.5	11.9
12. overland flow down Warrington Road	0.0	0.0	1.3	1.3
13. overland flow down Doley Road	0.0	0.0	2.7	2.9
14. Beenyup Brook at Hopkinson Road	5.5	6.3	9.6	10.2
15. Tributary 6 u/s Briggs Road (Extn)	1.4	1.8	3.4	3.5
16. Tributary 6 at Hopkinson Road	1.6	1.6	6.8	8.3
17. Tributary 7 at Hopkinson Road	2.1	3.2	5.1	10.1
18. Cardup Brook d/s South Western Hwy	5.8	10.4	23.5	28.1
19. Cardup Brook at Hopkinson Road	9.4	12.6	33.3	27.5

Table A11: Base model top water level comparison to base model with revised parameters

Location	5-year ARI top water level		100-year ARI top water level	
	Base model	Base model (revised param.)	Base model	Base model (revised param.)
1. Oaklands drain d/s George Road (north)	53.2	53.2	53.3	53.3
2. Oaklands drain d/s George Road (south)	51.8	51.9	52.0	52.0
3. Oaklands drain d/s Evans Road	44.3	44.4	44.6	44.6
4. Oaklands drain d/s Briggs Road	32.7	32.8	32.9	32.9
5. Oaklands drain at Thomas Road and Masters Road	30.9	31.0	31.1	31.2
6. Oaklands drain d/s Malarkey Road	29.8	29.9	30.2	30.3
7. Oaklands drain at Hopkinson Road	26.4	26.6	27.0	27.0
8. Beenyup Brook d/s South Western Hwy	58.5	58.6	58.7	58.7
9. u/s end piped Beenyup Brook d/s Abernethy Road	56.5	56.6	56.6	56.6
10. u/s end swale from Beenyup Brook to Oaklands drain	56.5	56.6	56.6	56.6
11. u/s end swale down Abernethy Rd from Beenyup Brook to Trib 6	56.3	56.3	56.8	56.8
12. overland flow down Warrington Road	44.5	44.5	45.4	45.4
13. overland flow down Doley Road	34.5	34.5	35.5	35.5
14. Beenyup Brook at Hopkinson Road	25.6	25.8	26.0	26.1
15. Tributary 6 u/s Briggs Road (Extn)	41.6	41.6	41.7	41.7
16. Tributary 6 at Hopkinson Road	27.5	27.6	27.7	27.7
17. Tributary 7 at Hopkinson Road	27.0	27.1	27.2	27.2
18. Cardup Brook d/s South Western Hwy	55.1	55.1	57.1	56.9
19. Cardup Brook at Hopkinson Road	27.6	27.7	27.9	27.9

A.5.2 Results comparison to Birrega Oaklands flood modelling and drainage study

Table A12 provides a comparison of *Birrega Oaklands flood modelling and drainage study* (DoW, 2015) peak flows at selected locations with those predicted by the base model and base model with revised parameterisation.

In all cases, the effect of the parameterisation changes have been to increase peak flows and levels. This suggests that the peak flows presented in the *Birrega Oaklands flood modelling and drainage study* (DoW, 2015) were not reduced in comparison to earlier work because of hydrological parameter changes and may in fact be caused by hydraulic differences. Because the Birrega Oaklands model is a 2D model it is able to more accurately represent overland flow paths and catchment storage areas.

Table A12: Birrega Oaklands model peak flow comparison to base model with revised parameters

Location	Base model		Base model (revised param.)		Birrega Oaklands study	
	5-year ARI	100-year ARI	5-year ARI	100-year ARI	5-year ARI	100-year ARI
1. Oaklands drain d/s George Road (north)	5.5	10.2	6.0	10.5	4.2	11.7
2. Beenyup Brook d/s South Western Hwy	8.1	31.2	11.1	32.2	5.4	26.8
3. Cardup Brook d/s South Western Hwy	5.8	23.5	10.4	28.1	8.0	22.7

A.6 Australian Rainfall & Runoff 2016 methodology

Design rainfall events were derived from the Bureau of Meteorology's 2016 Intensity Frequency Durations combined with temporal patterns from the 2016 release of Australian Rainfall and Runoff (ARR16) for 1h, 3h, 6h, 12h, 24h, 48h and 72h durations at 1Exceedance per Year (1EY), 20% AEP, 10% AEP and1% AEP. Critical events were selected for presentation from the following groupings:

1. ARR16: 1EY; 1h(S1-10), 3h(S1-10), 6h(S1-10), 12h(S1-10), 24h(S1-10), 48h(S1-10) and 72h(S1-10).
2. ARR16: 20%AEP; 1h(S1-10), 3h(S1-10), 6h(S1-10), 12h(S1-10), 24h(S1-10), 48h(S1-10) and 72h(S1-10).
3. ARR16: 1%AEP; 1h(S1-10), 3h(S1-10), 6h(S1-10), 12h(S1-10), 24h(S1-10), 48h(S1-10) and 72h(S1-10).

The selected critical events are:

- For peak flow (at key culvert locations):
  - 1EY – 3h (S8) *[3h (S10 is very close second]*
  - 20%AEP – 6h(S10) *[3h (S10 is very close second]*
  - 1%AEP – 3h(S2)
- For detention volumes:
  - 1EY – 3h (S8) *[3h (S10 is very close second]*
  - 20%AEP – 6h(S10) *[3h (S10 is very close second]*
  - 1%AEP – 3h(S2)

A.6.1 Results comparison to base model

Peak flows in critical 20% AEP and 1% AEP events generated by the InfoWorks ICM base model applying the revised AR&R2016 methodology were compared to peak flows generated by the original base model at various critical locations within the major waterways. This comparison is presented in Table A13 and Table A14.

It is noted that the 20% AEP is not the same as the 5-year ARI but rather the 4.48-year ARI. However, for the purposes of this investigation, the comparison of these events is considered a reasonable simplification.

Adoption of the Australian Rainfall & Runoff 2016 methodology has resulted in small and quite variable changes when the 5-year ARI and 20% AEP events are compared, there is no across the board change.

The comparison of the 100-year ARI event to the 1% AEP event however, results in a much more consistent increase in peak flows throughout the model, with some increases being quite significant as observed in Table A13 and Table A14 below.

Table A13: Base model peak flow comparison to base model with AR&R 2016 methods

Location	5-year ARI/20% AEP peak flows		100-year ARI/1% AEP peak flows	
	Base model	Base model (AR&R 2016)	Base model	Base model (AR&R 2016)
1. Oaklands drain d/s George Road (north)	5.5	4.1	10.2	16.0
2. Oaklands drain d/s George Road (south)	2.3	2.3	10.7	17.4
3. Oaklands drain d/s Evans Road	10.7	11.1	34.4	50.2
4. Oaklands drain d/s Briggs Road	11.0	11.5	35.1	52.6
5. Oaklands drain at Thomas Road and Masters Road	9.5	8.1	25.7	30.9
6. Oaklands drain d/s Malarkey Road	20.9	19.6	62.0	70.2
7. Oaklands drain at Hopkinson Road	15.8	15.0	51.5	53.3
8. Beenyup Brook d/s South Western Hwy	8.1	8.7	31.2	45.4
9. u/s end piped Beenyup Brook d/s Abernethy Road	2.8	2.8	3.1	3.2
10. u/s end swale from Beenyup Brook to Oaklands drain	5.2	5.9	16.1	17.6
11. u/s end swale down Abernethy Rd from Beenyup Brook to Trib 6	0.0	0.0	11.5	21.7
12. overland flow down Warrington Road	0.0	0.0	1.3	1.9
13. overland flow down Doley Road	0.0	0.0	2.7	7.1
14. Beenyup Brook at Hopkinson Road	5.5	5.5	9.6	13.4
15. Tributary 6 u/s Briggs Road (Extn)	1.4	1.3	3.4	4.0
16. Tributary 6 at Hopkinson Road	1.6	1.1	6.8	9.5
17. Tributary 7 at Hopkinson Road	2.1	2.1	5.1	9.7
18. Cardup Brook d/s South Western Hwy	5.8	6.1	23.5	26.2
19. Cardup Brook at Hopkinson Road	9.4	9.1	33.3	36.7

Table A14: Base model top water level comparison to base model with AR&R 2016 methods

Location	5-year ARI/20% AEP top water level		100-year ARI/1% AEP top water level	
	Base model	Base model (AR&R 2016)	Base model	Base model (AR&R 2016)
1. Oaklands drain d/s George Road (north)	53.2	53.2	53.3	53.3
2. Oaklands drain d/s George Road (south)	51.8	51.8	52.0	52.0
3. Oaklands drain d/s Evans Road	44.3	44.3	44.6	44.7
4. Oaklands drain d/s Briggs Road	32.7	32.7	32.9	33.0
5. Oaklands drain at Thomas Road and Masters Road	30.9	30.9	31.1	31.2
6. Oaklands drain d/s Malarkey Road	29.8	29.8	30.2	30.3
7. Oaklands drain at Hopkinson Road	26.4	26.4	27.0	27.0
8. Beenyup Brook d/s South Western Hwy	58.5	58.5	58.7	58.8
9. u/s end piped Beenyup Brook d/s Abernethy Road	56.5	56.5	56.6	56.6
10. u/s end swale from Beenyup Brook to Oaklands drain	56.5	56.5	56.6	56.6
11. u/s end swale down Abernethy Rd from Beenyup Brook to Trib 6	56.3	56.3	56.8	57.0
12. overland flow down Warrington Road	44.5	44.5	45.4	45.4
13. overland flow down Doley Road	34.5	34.5	35.5	35.8
14. Beenyup Brook at Hopkinson Road	25.6	25.6	26.0	26.5
15. Tributary 6 u/s Briggs Road (Extn)	41.6	41.6	41.7	41.7
16. Tributary 6 at Hopkinson Road	27.5	27.5	27.7	27.7
17. Tributary 7 at Hopkinson Road	27.0	27.0	27.2	27.2
18. Cardup Brook d/s South Western Hwy	55.1	55.1	57.1	57.2
19. Cardup Brook at Hopkinson Road	27.6	27.6	27.9	27.9

A.6.2 Results comparison to Birrega Oaklands flood modelling and drainage study

Table A15 provides a comparison of *Birrega Oaklands flood modelling and drainage study* (DoW, 2015) peak flows at selected locations with those predicted by the base model and base model applying the revised AR&R2016 methodology.

Minor variable changes are observed when the 5-year ARI and 20% AEP events are compared. Whilst the comparison of the 100-year ARI event to the 1% AEP event results in consistently increased peak flows throughout the model, with increases in Beenyup Brook being the largest.

Table A15: Birrega Oaklands model peak flow comparison to base model with AR&R 2016 methods

Location	Base model		Base model (AR&R 2016)		Birrega Oaklands study	
	5-year ARI	100-year ARI	5-year ARI	100-year ARI	5-year ARI	100-year ARI
1. Oaklands drain d/s George Road (north)	5.5	10.2	4.1	16.0	4.2	11.7
2. Beenyup Brook d/s South Western Hwy	8.1	31.2	8.7	45.4	5.4	26.8
3. Cardup Brook d/s South Western Hwy	5.8	23.5	6.1	26.2	8.0	22.7

A.7 Current system model development

In order to provide an up-to-date assessment of the performance of urban and rural drainage systems in the study area a substantial number of changes have been made to the both the hydrological and hydraulic structure of the model. These changes include:

- Expanded study area to include development outside of the Byford Townsite structure plan area;
- Catchment delineation modified to reflect updated survey information (Old Townsite) and changes to the system that have been constructed or approved in UWMPs or engineering design plans;
- Hydraulic system elements and structures modified to reflect changes to the system that have been constructed or approved in UWMPs or engineering design plans;
- Hydraulic system elements and structures modified to reflect any survey information that can be obtained within the timeframes of the project; and
- Integration of a 2D flood-flow surface to improve representation of overland flood flows and catchment storage.

Figure A.2 provides an overview of the current system model layout.

A.7.1 Current system hydrology

Catchment delineation

Catchments upstream of the Byford Townsite area (rural, hills catchments) remain largely unchanged although some minor boundary realignment has been necessary for some catchments where they adjoin developed or developing areas.

Catchments within the Byford Townsite have been altered and there are a large number of new catchments. Catchment delineation in this area has been undertaken utilising a combination of LiDAR ground elevation data, survey information (where available), site inspection, and review of water management documents including D-SPEC drawings, LWMS and UWMPs.

Catchments outside of the base model domain, principally to the north and east of Byford Townsite have been added to provide full coverage of the Byford District Structure Plan area.

In these areas, where development has not significantly altered ground levels, LiDAR ground elevation data has been used as the principal data source coupled with site inspection.

Figure A.3 provides an overview of the principal data sources used in different parts of the study area.

Land use

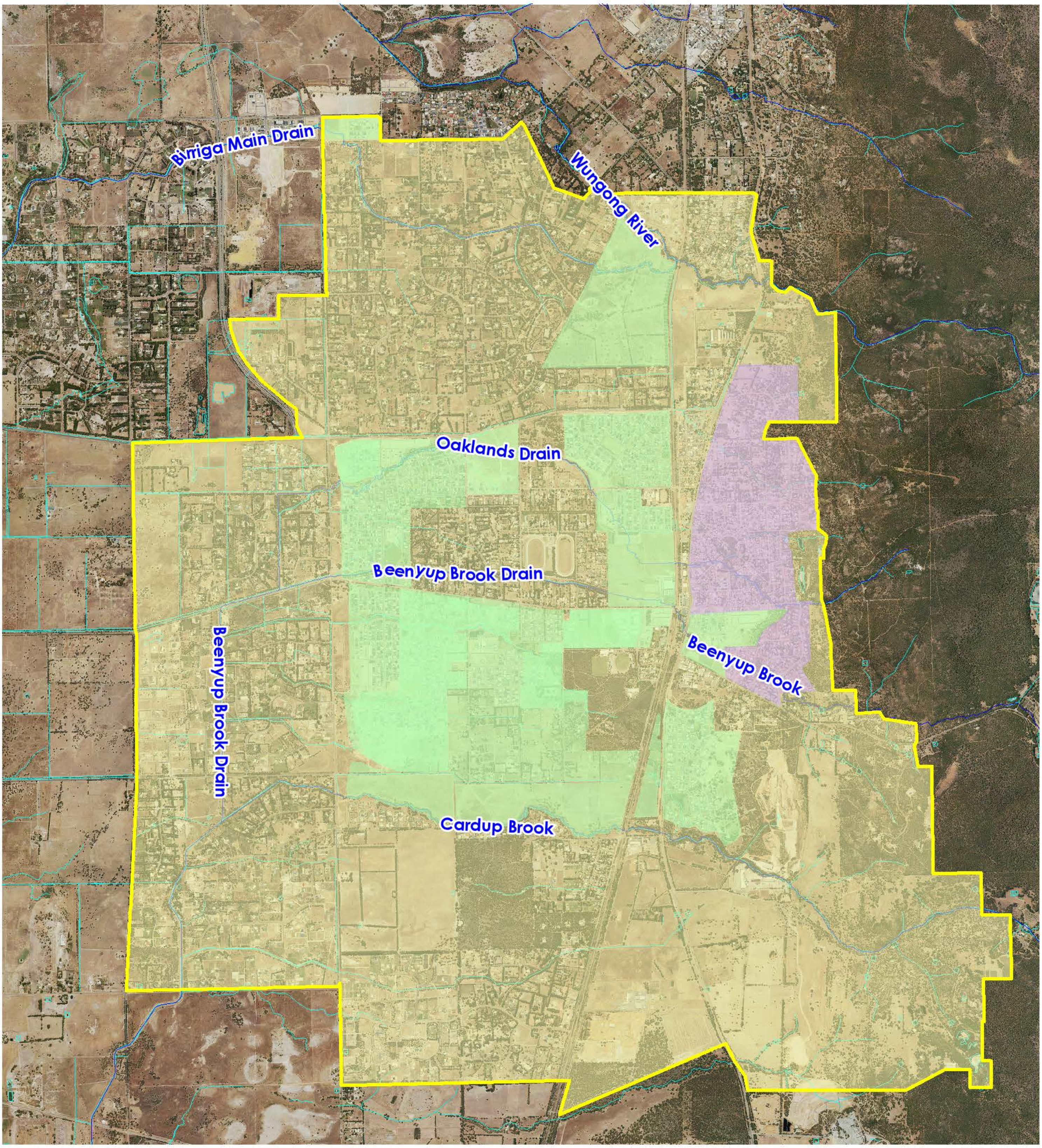
Land uses throughout the model domain have been reviewed and updated based on recent aerial imagery and planning information including:

- Byford District Structure Plan (Draft, 2018)
- Shire of Serpentine-Jarrahdale Town Planning Scheme No. 2
- Approved local structure plans and subdivision plans

Figure A.4 provides an overview of the land uses applied in the current system model.

Land use descriptions and parameterisation are consistent with the base model (Table A4). The percentage of impervious area for individual catchments in the current system model are presented in Table A16.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure A3 - Principal data sources for model updates



Legend

DWMS Study Area

Data source:

- Old Byford Survey
- Water Management Documents
- LiDAR and site inspection

Scale 1: 50,000 at A4

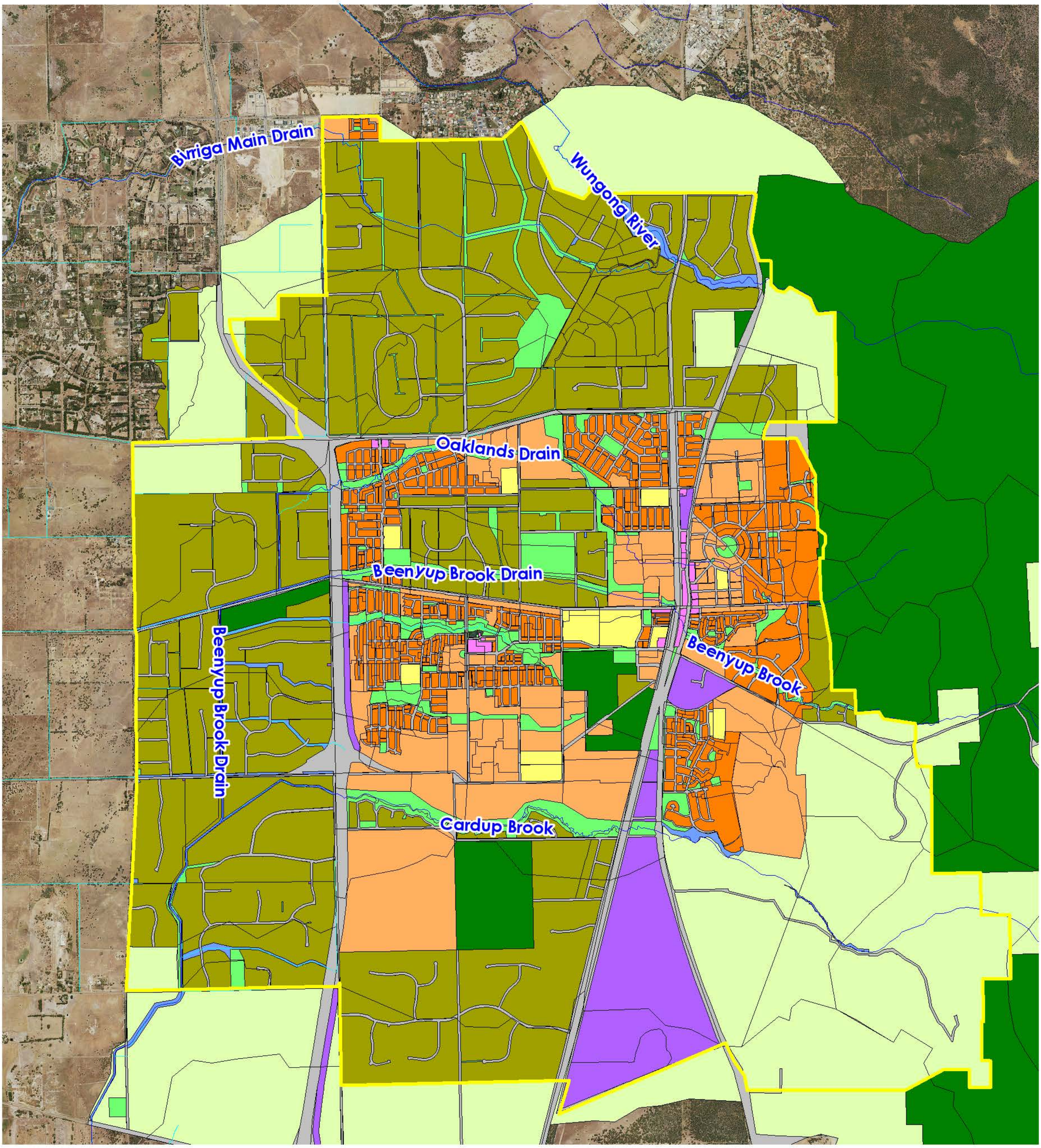
0 2km

N

urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure A4 - Modelled land uses



Legend

DWMS Study Area

Scale 1: 50,000 at A4

0 2km

N

Landuse categories:

Residential	Rural	Drainage / waterway
Development	POS	Town/local Centre
School	Conservation	Mixed Business
Rural Residential	Road	

urbaqua land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

Table A16: InfoWorks model catchment properties for current system model scenario

Subcatchment ID	Total area (ha)	Vector slope (%)	Catchment width (m)	% Impervious
DWMP_2A	43.410	0.015	800.0	5.604
DWMP_2A1	18.872	0.020	250.0	8.970
DWMP_2B	77.394	0.041	800.0	9.063
DWMP_2C2	20.542	0.118	600.0	1.793
MUC_3B	7.430	0.018	300.0	38.244
RB_02	7.281	0.018	300.0	58.399
DWMP_3B1	4.811	0.018	300.0	67.885
DWMP_3B2	8.471	0.018	181.9	69.705
RB_03	9.738	0.018	223.4	17.960
RB_04	21.539	0.018	304.4	54.970
BM_02	32.611	0.014	700.0	41.247
DWMP_3C	62.412	0.019	750.0	7.124
DWMP_3F	77.951	0.263	1100.0	0.610
DWMP_3F1	11.907	0.056	850.0	70.172
DWMP_3F2	6.399	0.038	500.0	66.959
DWMP_3F3	6.182	0.130	750.0	50.101
DWMP_3G1	37.063	0.246	700.0	3.439
DWMP_3G2	29.543	0.243	900.0	10.213
DWMP_3H	101.696	0.164	950.0	0.000
DWMP_4A	35.696	0.018	600.0	5.146
DWMP_4B	16.631	0.020	250.0	3.423
MUC_5A	3.949	0.016	400.0	17.419
DWMP_5C	23.548	0.017	300.0	5.767
DWMP_5D	32.971	0.020	400.0	4.789
DWMP_6D	53.155	0.021	450.0	10.080
MUC_6D	3.080	0.015	250.0	3.510
DWMP_6F	16.668	0.036	300.0	60.444
DWMP_6G2	11.701	0.043	850.0	60.441
DWMP_8A	12.152	0.013	250.0	62.348
DWMP_8C	24.382	0.015	500.0	60.245
DWMP_8D	20.142	0.019	500.0	60.207
DWMP_9B	36.816	0.020	400.0	18.753
DWMP_9C	74.316	0.039	600.0	6.446
DWMP_9D	19.586	0.040	300.0	61.716
DWMP_9E	205.602	0.095	1000.0	17.251
DWMP_9F	140.232	0.211	1100.0	1.352
DWMP_9G	379.307	0.157	1900.0	0.898

Subcatchment ID	Total area (ha)	Vector slope (%)	Catchment width (m)	% Impervious
DWMP_9H	494.404	0.104	2200.0	0.390
DWMP_9I	229.579	0.057	1800.0	0.575
CDN_02	345.238	0.020	1500.0	18.480
BB_06	0.465	0.019	38.5	56.256
BB_07	0.811	0.016	50.8	59.634
BB_01	0.712	0.015	47.6	55.979
BB_02	0.718	0.098	47.8	57.362
BB_03	1.356	0.000	65.7	59.068
BB_04	0.923	0.001	54.2	56.299
BB_05	0.223	0.016	26.6	69.473
BB_09	4.042	0.007	113.4	55.644
BB_19	4.336	0.009	117.5	59.781
BB_22	1.175	0.025	61.2	55.212
BB_23	0.431	0.012	37.0	4.314
BB_24	1.433	0.006	67.5	57.783
BB_25	0.352	0.037	33.5	0.783
OB_01	15.570	0.081	222.6	50.996
MUC_5G	3.102	0.014	99.4	0.477
MUC_5H	3.066	0.000	98.8	3.714
OB_02	9.680	0.081	175.5	52.950
DWMP_5G	11.558	0.081	191.8	43.816
BB_20	5.586	0.012	133.3	60.193
BB_21	3.084	0.081	99.1	1.616
BB_26	1.502	0.000	69.1	2.088
OB_03	5.485	0.081	132.1	50.813
DWMP_5H1	151.649	0.171	1100.0	2.407
DWMP_5H2	111.847	0.132	800.0	1.036
DWMP_5I	86.297	0.171	700.0	9.534
DWMP_5J	285.259	0.088	1200.0	1.248
DWMP_5K	155.704	0.110	900.0	1.535
DWMP_5L	302.476	0.054	1100.0	1.299
DWMP_5M	148.011	0.058	1000.0	1.101
BB_28	2.450	0.013	88.3	57.173
DWMP_5F	7.296	0.038	200.0	65.897
DWMP_8B	16.760	0.015	400.0	60.836
BS_01	26.339	0.066	800.0	43.273
DP_01	13.032	0.000	203.7	56.647
DP_02	7.058	0.000	149.9	60.273
DWMP_7D	11.683	0.019	300.0	61.146

Subcatchment ID	Total area (ha)	Vector slope (%)	Catchment width (m)	% Impervious
DWMP_8D2	14.465	0.019	500.0	60.233
DP_03	4.351	0.000	117.7	59.960
DP_04	8.682	0.006	166.2	61.184
DWMP_7B	9.833	0.000	176.9	13.155
DP_05	1.684	0.007	73.2	60.000
DP_06	3.311	0.000	101.0	61.151
DP_07	5.266	0.012	129.5	60.000
DP_08	10.022	0.013	178.6	55.581
DP_09	1.573	0.000	70.8	69.015
DP_10	5.054	0.013	126.8	60.000
DP_11	3.292	0.001	102.4	60.000
DP_12	2.124	0.002	82.2	60.000
DP_13	4.891	0.013	124.8	61.448
BS_08	6.174	0.008	140.2	49.472
BS_09	0.114	0.000	19.0	69.741
BS_10	1.454	0.039	68.0	53.432
BS_04	0.484	0.009	39.2	60.366
BS_14	0.879	0.026	52.9	49.702
BS_15	0.608	0.006	44.0	24.396
BS_16	0.884	0.008	53.0	54.936
BS_17	1.994	0.000	79.7	55.851
BS_18	0.521	0.033	40.7	56.324
BS_19	2.021	0.024	80.2	46.327
BS_20	1.080	0.024	58.6	55.658
BS_21	0.555	0.006	42.0	57.829
BS_22	0.438	0.023	37.3	59.260
BS_23	0.534	0.028	41.2	57.851
BS_05	4.604	0.000	121.1	52.122
BS_06	1.343	0.000	65.4	41.566
BS_26	0.234	0.000	27.3	56.998
BS_27	3.656	0.036	107.9	56.545
BS_28	1.353	0.055	65.6	21.972
BS_12	1.533	0.060	69.9	49.745
BS_07	0.360	0.022	33.9	55.377
BS_03	5.986	0.060	138.0	45.355
DWMP_8E2	6.801	0.060	147.1	59.991
DWMP_6G4	6.149	0.060	139.9	60.000
DWMP_6G3	15.651	0.060	223.2	57.741
BS_24	1.131	0.001	60.0	52.275

Subcatchment ID	Total area (ha)	Vector slope (%)	Catchment width (m)	% Impervious
BS_25	1.354	0.006	65.6	51.795
BS_11	0.388	0.056	35.1	57.743
BS_13	1.103	0.034	59.3	50.000
DWMP_8E1	17.962	0.000	239.1	72.518
BS_02	11.402	0.020	190.5	52.473
OB_04	18.430	0.000	242.2	60.968
OB_05	4.725	0.000	122.6	59.629
OB_06	6.749	0.043	146.6	53.163
OB_07	6.231	0.071	140.8	53.031
OB_08	8.147	0.051	161.0	52.388
OB_09	7.494	0.029	154.4	52.646
OB_10	4.495	0.234	119.6	52.096
OB_11	2.874	0.028	95.6	55.132
OB_12	8.013	0.000	159.7	42.016
OB_13	3.110	0.070	99.5	51.294
OB_14	3.440	0.000	104.6	52.428
OB_15	3.821	0.015	110.3	52.991
OB_16	4.779	0.007	123.3	54.190
OB_17	2.167	0.000	83.0	55.673
OB_18	2.717	0.000	93.0	40.230
OB_19	5.554	0.011	133.0	54.714
OB_20	4.554	0.021	120.4	61.180
OB_21	3.825	0.001	110.3	53.622
OB_22	14.514	0.020	214.9	48.812
OB_23	0.967	0.000	55.5	55.013
OB_24	8.038	0.000	160.0	54.073
OB_25	2.526	0.028	89.7	55.204
OB_26	1.538	0.000	70.0	59.756
OB_27	3.690	0.027	108.4	55.882
OB_28	1.872	0.025	77.2	62.295
OB_29	4.260	0.022	116.4	62.277
OB_30	8.420	0.000	163.7	60.119
OB_31	6.480	0.021	143.6	48.874
OB_32	1.544	0.007	70.1	63.349
OB_33	2.488	0.000	89.0	63.471
OB_34	6.660	0.015	145.6	53.868
OB_35	15.000	0.000	218.5	32.327
DWMP_2C1	23.060	0.099	270.9	9.780
DWMP_2C3	11.046	0.000	187.5	22.414

Subcatchment ID	Total area (ha)	Vector slope (%)	Catchment width (m)	% Impervious
L3_01	8.083	0.018	160.4	49.044
BIR_02C	59.856	0.003	436.5	7.110
BIR_02B	99.489	0.009	562.7	5.065
BIR_02A	32.337	0.004	320.8	20.708
BIR_01A	77.656	0.000	497.2	5.041
BIR_03A	17.214	0.005	234.1	17.095
BIR_01B	55.914	0.000	421.9	5.336
BIR_03B	55.349	0.005	419.7	2.762
BIR_09	47.384	0.001	388.4	5.997
BIR_12	58.695	0.001	432.2	1.113
W_01	311.123	0.006	995.2	0.724
W_02	61.846	0.289	443.7	25.050
W_03	278.768	0.005	942.0	0.724
W_04	1010.825	0.006	1793.8	0.000
GL_09	25.418	0.013	284.4	58.221
GL_10	3.189	0.039	100.7	62.863
DWMP_10A	14.226	0.011	212.8	68.167
GL_11	0.710	0.014	47.5	58.834
GL_13	2.149	0.015	82.7	57.043
GL_17	10.290	0.007	181.0	55.643
GL_23	5.132	0.024	127.8	57.378
GL_24	1.602	0.001	71.4	31.514
DWMP_7A	16.947	0.000	232.3	68.727
WS_09	1.393	0.006	66.6	0.000
WS_10	2.404	0.000	87.5	0.841
WS_07	1.854	0.001	76.8	0.000
WS_01	4.453	0.000	119.1	0.460
WS_02	4.121	0.000	114.5	0.000
WS_03	0.519	0.004	40.6	0.673
WS_04	0.306	0.004	31.2	0.000
WS_08	1.568	0.008	70.6	0.000
WS_05	0.151	0.000	21.9	0.000
WS_11	2.897	0.003	96.0	7.945
WS_06	2.899	0.026	96.1	0.000
W_05	28.624	0.006	301.9	36.736
BIR_33	124.142	0.003	628.6	3.507
BIR_34	44.671	0.002	377.1	2.279
BIR_35	69.695	0.000	471.0	3.919
OAK_08	43.595	0.001	372.5	61.119

Subcatchment ID	Total area (ha)	Vector slope (%)	Catchment width (m)	% Impervious
OAK_07	196.622	0.001	791.1	7.858
OAK_06	92.734	0.001	543.3	17.570
OAK_05	56.964	0.001	425.8	11.007
OAK_04	35.507	0.003	336.2	11.250
OAK_02	50.283	0.003	400.1	14.650
GL_26	0.959	0.000	55.3	56.529
GL_27	0.347	0.019	33.3	60.000
GL_28	1.463	0.012	68.2	56.227
GL_29	3.376	0.019	103.7	56.804
GL_30	1.618	0.013	71.8	58.124
GL_69	0.240	0.016	27.7	59.357
GL_31	0.903	0.005	53.6	51.110
GL_32	1.527	0.009	69.7	59.845
GL_33	3.451	0.011	104.8	56.454
GL_34	0.985	0.011	56.0	55.799
GL_35	6.172	0.014	140.2	40.152
BW_01	1.284	0.004	63.9	55.509
BW_02	1.424	0.018	67.3	55.783
BW_03	2.751	0.017	93.6	31.297
BW_04	0.848	0.001	52.0	54.019
BW_05	3.243	0.000	101.6	56.533
BW_07	1.628	0.006	72.0	56.418
BW_09	2.604	0.012	91.0	55.489
BW_10	2.559	0.006	90.2	55.880
BW_11	1.890	0.009	77.6	57.618
BW_12	1.667	0.061	72.8	55.383
BW_13	1.992	0.000	79.6	58.578
MUC_7B	1.695	0.000	73.5	1.632
MUC_7A	4.770	0.000	123.2	21.822
GL_36	1.279	0.012	63.8	58.381
GL_37	0.491	0.002	39.5	55.412
GL_38	1.942	0.000	78.6	50.716
GL_39	2.022	0.001	80.2	62.604
GL_71	0.398	0.002	35.6	69.981
GL_40	1.736	0.007	74.3	58.161
GL_73	0.342	0.005	33.0	45.279
GL_72	0.665	0.026	46.0	29.347
MUC_6B	1.917	0.007	78.1	1.488
GL_42	1.912	0.007	78.0	1.035

Subcatchment ID	Total area (ha)	Vector slope (%)	Catchment width (m)	% Impervious
MUC_6C	1.475	0.013	68.5	0.445
GL_44	2.508	0.003	89.4	54.991
GL_47	1.563	0.013	70.5	55.964
GL_49	1.822	0.079	76.2	56.670
GL_50	1.286	0.040	64.0	2.551
GL_59	2.106	0.004	81.9	57.289
GL_74	0.530	0.004	41.1	69.682
GL_60	3.855	0.018	110.8	56.979
GL_61	1.326	0.013	65.0	61.542
MUC_6E	2.317	0.007	85.9	37.543
GL_62	0.851	0.000	52.1	1.115
KAL_03	3.447	0.005	104.7	53.481
KAL_04	1.424	0.001	67.3	48.255
KAL_05	3.638	0.009	107.6	58.387
KAL_07	10.204	0.005	180.2	55.819
KAL_13	6.216	0.007	140.7	54.224
KAL_16	0.528	0.007	41.0	19.938
KAL_22	1.224	0.010	62.4	15.630
KAL_23	1.495	0.000	69.0	56.115
DWMP_6B	7.724	0.000	156.8	71.538
GL_63	0.719	0.009	47.8	50.161
GL_64	0.891	0.000	53.3	48.806
BR_E	13.824	0.017	209.8	42.173
RB_09	4.543	0.025	120.2	52.497
RB_06	9.052	0.002	169.7	50.390
RB_07	3.005	0.006	97.8	42.945
RB_08	2.845	0.018	95.2	58.326
MUC_3A	3.604	0.000	107.1	4.802
OB_36	21.945	0.081	264.3	18.168
DWMP_6G1	19.263	0.009	247.6	74.296
OB_37	10.884	0.000	186.1	56.523
GL_65	5.248	0.002	129.2	47.342
GL_66	4.684	0.004	122.1	58.907
GL_70	0.981	0.001	55.9	3.028
GL_67	8.163	0.016	161.2	46.532
GL_68	3.304	0.006	102.5	42.031
BW_14	2.783	0.068	94.1	56.582
BW_15	1.882	0.083	77.4	57.623
MUC_6A	2.626	0.005	91.4	39.287

Subcatchment ID	Total area (ha)	Vector slope (%)	Catchment width (m)	% Impervious
BW_16	2.769	0.076	93.9	56.777
BTC_A	6.875	0.030	147.9	60.084
BTC_B	1.483	0.022	68.7	60.037
BTC_C	4.620	0.039	121.3	60.000
BTC_E	3.401	0.022	104.0	60.061
BTC_D	2.156	0.003	82.9	60.000
MUC_5F	0.877	0.017	52.8	61.242
C2d	1.349	0.000	65.5	60.573
C12u	4.077	0.000	113.9	60.000
C5d	6.236	0.000	140.9	60.000
C13u	4.492	0.000	119.6	60.064
MUC_3F	6.131	0.032	139.7	12.826
C11d	2.669	0.000	92.2	44.841
Kalimna DOS	10.899	0.003	186.3	20.533
BC_Central	16.113	0.001	226.5	48.750
BC_East	24.599	0.006	279.8	54.472
BC_West	21.592	0.024	262.2	49.797
MUC_3E	4.672	0.000	121.9	16.018
Marri Gr School	4.670	0.012	121.9	51.335
LAR_04	0.755	0.003	49.0	58.142
LAR_06	7.297	0.009	152.4	57.861
LAR_01	2.659	0.010	92.0	56.898
LAR_07	3.360	0.010	103.4	55.558
LAR_05	1.395	0.008	66.6	54.013
LAR_03	1.739	0.011	74.4	58.228
LAR_02	2.578	0.010	90.6	55.315
L3_02	17.278	0.000	234.5	60.953
TR12	1.344	0.000	65.4	67.826
TR04	3.597	0.001	107.0	65.083
TR02	4.094	0.002	114.1	67.970
Stage 4_S56	1.889	0.011	77.5	57.729
RB_10	4.068	0.285	113.8	57.058
RB_11	4.939	0.018	125.4	56.710
BR_C	3.356	0.014	103.4	60.000
BR_D	2.428	0.015	87.9	60.206
BR_School	3.859	0.002	110.8	50.051
BR_G	4.246	0.024	116.3	60.293
BR_F	1.167	0.004	61.0	59.789
BR_B	3.834	0.008	110.5	60.303

Subcatchment ID	Total area (ha)	Vector slope (%)	Catchment width (m)	% Impervious
MUC_3C	1.495	0.000	69.0	60.107
MUC_5B	1.664	0.000	72.8	4.243
MUC_5D	4.251	0.041	116.3	60.000
MUC_5E	0.666	0.000	46.0	60.000
Ab01b	3.724	0.000	108.9	47.599
Ab01c	3.266	0.000	102.0	63.347
Ab02	3.288	0.009	102.3	62.055
Ab03	4.470	0.008	119.3	62.044
GM_1A	1.745	0.008	74.5	52.989
Ab05	2.182	0.000	83.3	68.928
GL_HS	3.210	0.011	101.1	50.025
GL10	1.367	0.436	66.0	50.000
L15_A	1.543	0.016	70.1	19.463
L15_B	1.138	0.003	60.2	58.956
L15_C	1.174	0.010	61.1	56.943
L15_D	0.673	0.001	46.3	61.896
Ab01a	1.238	0.013	62.8	71.142
RB_12	3.685	0.014	108.3	55.467
GM_1B	2.444	0.007	88.2	55.406
GM_2	4.479	0.011	119.4	57.872
GM_3	3.631	0.001	107.5	57.668
GL_75	2.526	0.011	89.7	49.021
GL_76	2.318	0.000	85.9	50.577
GL_77	5.151	0.008	128.0	47.218
GL_78	9.490	0.012	173.8	48.604
GL_79	5.267	0.022	129.5	57.926
GL_80	8.503	0.001	164.5	50.039
GL_HS2	9.914	0.001	177.6	49.851
GL81	2.194	0.003	83.6	56.190
GL_82	9.680	0.000	175.5	34.588
War_01	8.068	0.005	160.3	60.096
War_02	2.701	0.002	92.7	62.044
GL_81	6.816	0.018	147.3	51.247
GL_83	5.647	0.000	134.1	55.768
GL_84	9.641	0.006	175.2	53.108
GL_85	8.758	0.005	167.0	53.663
BMD28	55.655	0.002	420.9	3.977
BMD27	73.550	0.001	483.9	13.535
BMD31	166.384	0.003	727.7	7.197

Subcatchment ID	Total area (ha)	Vector slope (%)	Catchment width (m)	% Impervious
BMD30	73.081	0.003	482.3	8.291
BMD41	55.068	0.001	418.7	6.988
BMD42	60.858	0.075	440.1	9.323
BMD51	106.943	0.002	583.4	3.310
MUC_7F	1.154	0.000	60.6	60.000
MUC_7E	3.204	0.000	101.0	60.027
MUC_7D	2.341	0.000	86.3	60.000
MUC_7C	1.657	0.000	72.6	59.997
DP_14	1.493	0.000	68.9	60.056
DP_15	5.779	0.000	135.6	60.712
DP_16	2.909	0.000	96.2	60.655
WS_A	4.309	0.003	117.1	4.624
WS_B	5.176	0.003	128.4	0.000
WS_G	11.677	0.000	192.8	0.000
WS_H	3.688	0.000	108.4	0.000
WS_D	5.045	0.000	126.7	0.000
WS_12	1.212	0.003	62.1	0.000
WS_C	2.035	0.003	80.5	0.000
WS_J	5.875	0.083	136.7	5.059
WS_L	7.801	0.092	157.6	0.000
WS_M	6.423	0.092	143.0	0.000
WS_O	6.946	0.067	148.7	0.000
WS_E	1.947	0.000	78.7	0.000
WS_P	5.487	0.067	132.2	0.000
WS_F	2.172	0.000	83.1	0.000
WS_R	2.331	0.001	86.1	0.000
WS_S	3.182	0.001	100.6	0.000
WS_K	2.711	0.083	92.9	3.689
WS_N	2.792	0.092	94.3	0.242
WS_Q	5.681	0.067	134.5	0.008
BMD10	11.817	0.000	193.9	57.047
NOR_04	351.694	0.000	1058.1	2.591
NOR_01	148.540	0.006	687.6	12.324
CDN_03	122.824	0.100	625.3	74.509
CDN_01	66.440	0.001	459.9	16.076
NOR_02	284.277	0.092	951.3	7.880
NOR_03	131.795	0.207	647.7	44.347
Oak_09	202.581	0.016	803.0	10.158

A.7.2 Current system hydraulics

Channel and structure dimensions throughout the model domain have been reviewed.

Channels, and structures upstream of the Byford Townsite area (rural, hills catchments) remain largely unchanged although some minor realignment has been necessary for some channels where they adjoin developed or developing areas.

Channels, pipes and structures within the Byford Townsite have been altered and there are a large number of new hydraulic elements. System definition in this area has been undertaken utilising a combination of LiDAR ground elevation data, survey information (where available), site inspection, and review of water management documents including D-SPEC drawings, LWMS and UWMPs.

Channels, and structures outside of the base model domain, principally to the north and east of Byford Townsite have been added to provide full coverage of the Byford District Structure Plan area. In these areas, where development has not significantly altered ground levels, LiDAR ground elevation data has been used as the principal data source for channel cross section definition coupled with site inspection to provide dimensions for structures.

Table A17 presents the significant structures that have been included within the current system model. Photographs for selected structures (indicated by an *) are provided in Appendix B.

Table A17: Modelled hydraulic structures – current system model

Site ref	Location	X	Y	Shape	Width (mm)	Height (mm)	Invert (mAHD)	Barrels	Source	Image	Field ref
1	Wungong R - SW Hwy	407288.2	6437608.4	Bridge	10000	2500	42.60	1	Observed		
2	Wungong R - Railway	406508.2	6437826	Bridge	10000	2000	39.70	1	Observed		
3	Wungong R - Rowley Rd	405252.7	6439291.8	Bridge	10000	2000	29.40	1	Observed	y	1.23
4	Birrega MD - Dalray CtE	406238.8	6437748.4	RECT	900	450	38.00	2	UWMP		
5	Birrega MD - Dalray CtW	405869	6437720.7	RECT	1200	600	35.80	4	UWMP		
6	Birrega MD - Wungong Sth Rd	405199.7	6438154.1	CIRC	600	600	32.50	4	Observed	y	1.22
7	Birrega MD - Masters Rd	404079.5	6438142.1	CIRC	700	700	29.40	4	Observed	y	1.21
8	Birrega MD - Hopkinson Rd	403143.1	6439077.6	CIRC	900	900	25.20	1	Observed	y	1.1
9	Thomas Rd Drn - Linton St	407324.5	6435727.1	CIRC	600	600	73.66	2	Survey		
10	Thomas Rd Drn - Stanley Rd	407120.8	6435935.3	CIRC	600	600	61.81	2	Survey		
11	Thomas Rd Drn - Pound Cl	407062.4	6435988.7	CIRC	600	600	59.13	2	Survey		
12	Thomas Rd Drn - SW Hwy	406789.4	6436145.7	CIRC	900	900	50.75	2	DWMP		
13	Thomas Rd Drn - Thomas Rd	406498.2	6436415	CIRC	600	600	40.50	2	DWMP		
14	Thomas Rd Drn - Railway	406443.2	6436763.6	CIRC	600	600	35.80	1	DWMP		
15	Thomas Rd Drn - Thomas Rd	404692.2	6436240.1	RECT	3200	1200	30.09	2	DWMP		
16	Birrega BD - Tonkin Hwy	402213.3	6437729.9	Bridge	5000	1000	25.10	1	Aerial image		
17	Birrega BD - Hopkinson Rd	403207.3	6436174.4	RECT	900	900	26.20	1	Observed	y	1.4
18	Birrega BD - Tonkin Hwy	402920.7	6436176.5	RECT	1200	1200	24.80	1	Observed	y	1.5
19	Birrega BD - Ballak Pl	402616	6436150.1	CIRC	1050	1050	24.40	1	Observed	y	1.5
20	Birrega BD - Kargotich Rd	401335.8	6436112.8	Bridge	5000	1500	21.10	1	Observed	y	1.6
21	Oaklands Drn - Old Brickworks Rd	407655.2	6434580.5	CIRC	300	300	89.48	1	Survey		

Site ref	Location	X	Y	Shape	Width (mm)	Height (mm)	Invert (mAHD)	Barrels	Source	Image	Field ref
22	Oaklands Drn - Beenyup Rd	407420.7	6434579.3	RECT	900	600	79.80	1	Survey		
23	Oaklands Drn - Bower Pl	407386.5	6434593.8	CIRC	750	750	78.03	1	Survey		
24	Oaklands Drn - South Cr	406984.8	6434896.3	CIRC	750	750	63.35	1	Survey		
25	Oaklands Drn - Edward Cr	406802.8	6434982	CIRC	900	900	58.46	1	Survey		
26	Reservoir Drn - Stevenson Pl	407461.9	6435226.5	CIRC	375	375	79.26	1	Survey		
27	Reservoir Drn - Helen Cr	407192.5	6435225.7	CIRC	900	900	71.34	1	Survey		
28	Reservoir Drn - John Cr	407054.9	6435195.5	CIRC	900	900	65.84	1	Survey		
29	Reservoir Drn - Park Rd	406910.2	6435190.6	CIRC	900	900	61.00	1	Survey		
30	Reservoir Drn - SW Hwy	406617.3	6435282.8	CIRC	900	900	52.59	1	Survey		
31	Reservoir Drain - Railway	406475.1	6435373.2	Bridge	3500	500	51.40	1	Aerial image		
32	Oaklands Drn - SW Hwy	406604.7	6434948.6	CIRC	900	900	55.50	3	UWMP	Y	1.15
33	Oaklands Drn - Railway	406481.8	6434972.3	Bridge	4000	1200	53.25	1	UWMP	Y	1.15
34	Oaklands Drn - George St	406528.9	6434965.9	RECT	1200	600	54.60	3	UWMP	y	1.15
35	Oaklands Drn - Thatcher Rd	405721.7	6435605.8	RECT	1220	1200	37.97	1	UWMP		
36	Oaklands Drn - Larsen Rd	405674.3	6435663.3	RECT	1220	1220	37.60	1	UWMP		
37	Oaklands Drn - Briggs Rd	405010	6436012.8	RECT	1880	1220	32.40	1	UWMP		
38	Oaklands Drn - Kardan Bvd	403720	6435812.3	RECT	1200	1200	25.50	3	Observed	y	1.14
39	Oaklands Drn - Hopkinson Rd	403208.5	6435653.1	RECT	3600	1900	24.34	1	DWMP		
40	Beenyup Brk - Old Brickworks Rd	407489.7	6433818.3	CIRC	1200	1200	72.73	3	Survey		
41	Beenyup Brk - SW Hwy	406579.2	6434299.6	Bridge	13030	1200	59.13	1	Observed	y	1.2
42	Beenyup Brk - Railway	406494.1	6434503.1	Bridge	4200	1200	55.85	1	Observed	y	1.2
43	Beenyup Brk - Abernethy Rd	406463.2	6434546.2	RECT	1240	1200	55.70	4	Observed	y	1.16

Site ref	Location	X	Y	Shape	Width (mm)	Height (mm)	Invert (mAHD)	Barrels	Source	Image	Field ref
44	Beenyup Brk - Won Niche Rd	406352	6434627.7	RECT	2400	1500	53.36	4	Observed	y	1.3
45	Beenyup Brk - Thatcher Rd	405547.2	6434770.1	RECT	1500	600	44.40	2	DWMP		
46	Beenyup Brk - Briggs Rd	405013.7	6434855.8	RECT	1210	920	38.60	2	DWMP		
47	Beenyup Brk - Malarkey Rd	404691.1	6434872.7	CIRC	900	900	34.80	3	DWMP		
48	Beenyup Brk - Renaud Wy	404123.9	6434915	CIRC	900	900	30.00	3	DWMP		
49	Beenyup Brk - kardan Bvd	403719.8	6434922.9	RECT	1200	750	28.50	7	UWMP		
50	Beenyup Brk - Hopkinson Rd	403225.5	6434844.6	RECT	3700	1560	25.20	1	Observed	y	1.24
51	Abernethy Rd Drn - Abernethy Rd	403228.7	6434813.5	CIRC	300	300	25.90	2	Observed	y	1.24
52	Oaklands Drn - Abernethy Rd	402179.7	6434547.8	Bridge	5000	1500	20.25	1	Observed	y	1.8
53	Birrega BD - Bifurcation	402179.7	6434547.8	WIER	2000	1500	20.50	1	Observed	y	1.8
54	Oaklands Drn - Orton Rd	402192	6432956	Bridge	5000	1500	18.80	1	Observed	y	1.9
55	Oaklands Drn - Gossage Rd	401813.1	6430935.4	RECT	1200	1800	15.90	3	Observed	y	1.10
56	Brickwood Drn - Warrington Rd	405415.5	6433829.2	RECT	1200	450	43.41	1	Observed	y	1.20
57	Brickwood Drain N - Warrington Rd	405413.9	6434137.4	CIRC	450	450	44.00	2	UWMP		
58	Brickwood Drn - Mead St	404934.3	6434193.7	RECT	1200	450	38.40	4	Observed	y	1.20
59	Brickwood Drn - Woolandra Dr	404800	6434307.5	RECT	1200	450	36.70	4	UWMP		
60	Brickwood Drn - Doley Rd	404515.5	6434361.2	RECT	1200	450	34.40	4	Observed	y	1.20
61	Brickwood Drn - Kokoda Bvd	404087.4	6434390.4	RECT	1200	450	30.50	4	UWMP		
62	Brickwood Drn - Tourmaline Bvd	403723.9	6434466.3	RECT	900	900	28.19	4	Observed	y	1.20
63	Brickwood Drn - Hopkinson Rd	403239.8	6434410.1	CIRC	455	455	26.00	3	DWMP		
64	Brickwood Drn - SW Hwy	406374.8	6433536.4	CIRC	380	380	57.20	2	DWMP		
65	Brickwood Drn - Railway	406289.7	6433584.4	RECT	1220	920	55.92	1	DWMP		

Site ref	Location	X	Y	Shape	Width (mm)	Height (mm)	Invert (mAHD)	Barrels	Source	Image	Field ref
66	Brickwood Drn - Soldiers Rd	406240.7	6433587.6	RECT	1200	450	54.45	2	DWMP		
67	Brickwood Drn - Turner Rd	405888.7	6433544.6	RECT	1500	600	48.80	1	DWMP		
68	Doley Precinct Drn - Warrington Rd	405419.4	6433387.3	CIRC	450	450	45.80	2	DWMP		
69	Doley Precinct Drn - Lawrence Wy	405015.2	6433492.6	CIRC	450	450	40.50	2	UWMP		
70	Doley Precinct Drn - Doley Rd	404524.1	6433516	RECT	1200	600	36.15	1	UWMP		
71	Doley Precinct Drn - Kokoda Bvd	404052.5	6433637.7	CIRC	1200	1200	31.91	2	UWMP		
72	Doley Precinct Drn - Hopkinson Rd	403253.7	6433782.9	RECT	1200	500	25.40	1	DWMP		
73	Glades Drn - Hopkinson Rd	403252.7	6433278.1	CIRC	720	720	26.20	2	DWMP		
74	Orton Rd Drn - SW Hwy	406359.1	6432899.8	CIRC	600	600	58.40	1	DWMP		
75	Orton Rd Drn - Railway	406117.9	6432898.5	Bridge	1220	920	55.60	1	DWMP		
76	Orton Rd Drn - Soldiers Rd	406074.1	6432896.1	CIRC	300	300	54.95	3	DWMP		
77	Cardup Brk - SW Hwy	406358.8	6432416.4	CIRC	900	900	54.61	1	DWMP		
78	Cardup Brk - Railway	406000.9	6432439.4	CIRC	1700	1700	51.21	1	DWMP		
79	Cardup Brk - Soldiers Rd	405962.6	6432449.4	CIRC	1700	1700	50.75	1	DWMP		
80	Cardup Brk - Hopkinson Rd	403265.6	6432787.6	RECT	1800	1500	26.00	1	Observed	y	1.25
81	DWMP 2018	401372.2	6434340	Bridge	5000	1500	17.80	1	Observed	y	1.7
82	Birrega BD - Orton Rd/Kargotich Rd	401382.2	6432953.1	Bridge	5000	1000	16.50	1	Observed	y	1.11
83	Birrega BD - Kargotich Rd	401331.5	6431946.7	Bridge	5000	1000	15.40	1	Observed	y	1.12
84	Oaklands Drn - Kargotich Rd			Bridge				1	Observed	y	2.2
85	Oaklands Drn - Railway			Bridge				1	Aerial image		
86	Cardup Drn - Railway			CIRC	1100	1100		3	Observed	y	2.10
87	Cardup Drn - Walk trail			CIRC	600	600		2	Observed	y	2.10

Site ref	Location	X	Y	Shape	Width (mm)	Height (mm)	Invert (mAHD)	Barrels	Source	Image	Field ref
88	Cardup Drn - Soldiers Rd			CIRC	750	750		2	Observed	y	2.10
89	Cardup Drn - Pollard Cross			CIRC	750	750		2	Observed	y	2.11
90	Cardup Drn - Baigup Loop			CIRC	600	600		1	Observed	y	2.13
91	Cardup Drn - Hopkinson Rd			RECT	1200	700		2	Observed	y	2.14
92	Norman Drn - SW Hwy			CIRC	1800	1800		2	Observed	y	2.9
93	Norman Drn - Railway			Bridge				1	Observed	y	2.8
94	Norman Drn - Walk trail			CIRC	600	600		2	Observed	y	2.8
95	Norman Drn - Soldiers Rd			CIRC	1800	1800		1	Observed	y	2.8
96	Norman Drn - Hopkinson Rd			CIRC	900	900		2	Observed	y	2.7
97	Norman Drn - Railway			Bridge				1	Aerial image		
98	Norman Drn - Kargotich Rd			CIRC	750	750		2	Observed	y	2.5

A.7.3 2-Dimensional domain

To provide improved understanding of flood water behaviour within the study area, an integrated 2-dimensional model domain has been added to the current system model. This domain allows excess water to exit the hydraulic model, flow overland across a 2-dimensional surface and re-enter the hydraulic model further downstream as appropriate.

The 2-dimensional domain has been developed as a terrain-sensitive triangular mesh from a LiDAR ground elevation model (2008) updated to reflect the elevation of developed and developing areas with imported fill. An assumption of 1.5m fill has been applied to all lots (residential, commercial and industrial) developed since 2008. Roads, public open spaces, multiple use corridors and rural areas have been retained at 2008 elevations.

It should be noted that this methodology does not provide a perfectly realistic post-development ground model for the study area. However, it is useful to provide a somewhat improved understanding of flood water behaviour in urban parts of the study area, and rural parts of the study area are expected to be well represented by 2008 elevations. In future, to provide improved model performance, consideration should be given to undertaking an update to the LiDAR elevation model.

10.2.1 Critical duration assessment

Design rainfall events were derived from the Bureau of Meteorology's 2016 Intensity Frequency Durations combined with temporal patterns from the 2016 release of Australian Rainfall and Runoff (ARR16) for 1h, 3h, 6h, 12h, 24h, 48h and 72h durations at 1Exceedance per Year (1EY), 20% AEP, 10% AEP and1% AEP. Critical events were selected for presentation from the following groupings:

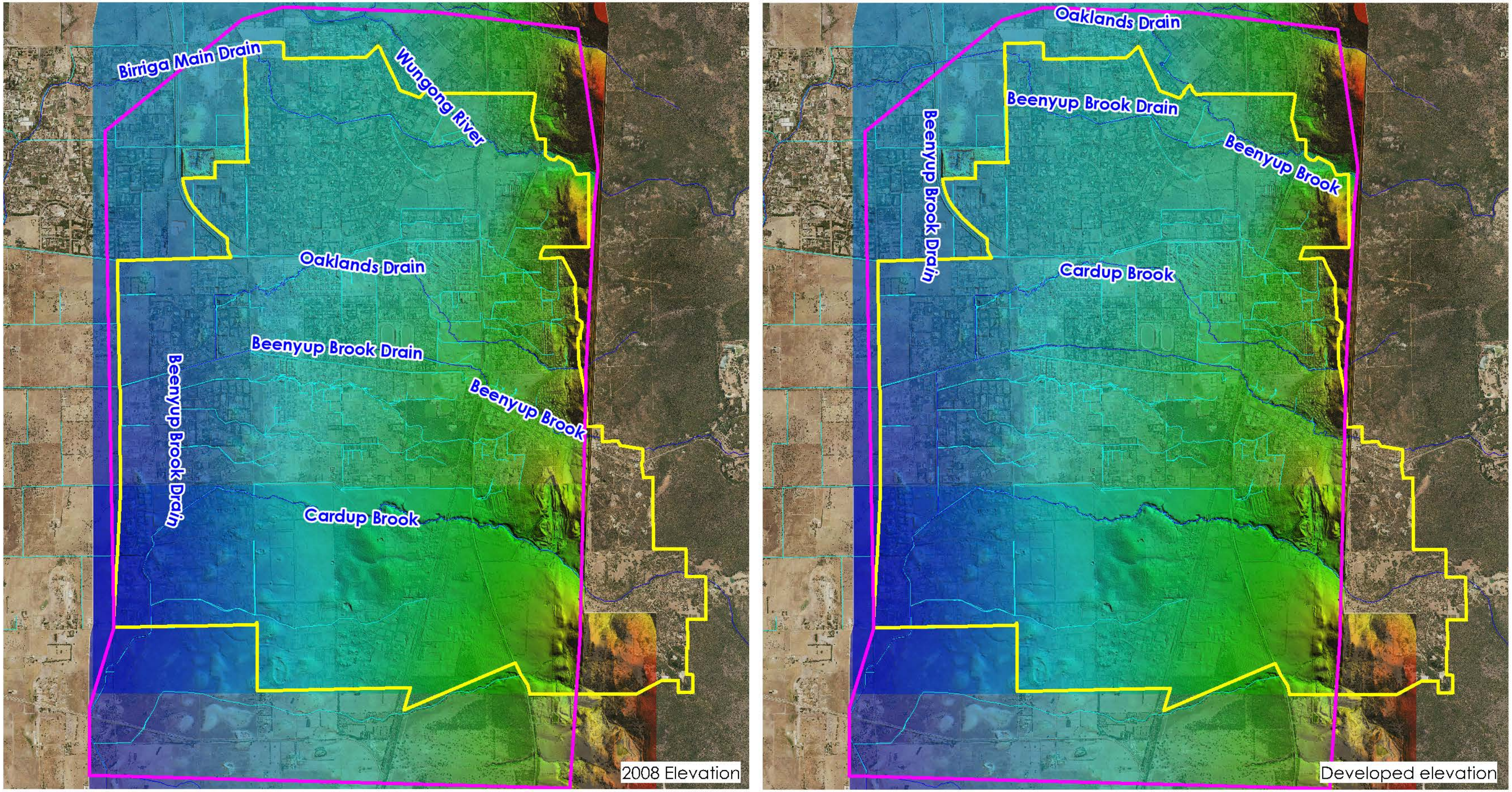
4. ARR16: 1EY; 1h(S1-10), 3h(S1-10), 6h(S1-10), 12h(S1-10), 24h(S1-10), 48h(S1-10) and 72h(S1-10).
5. ARR16: 20%AEP; 1h(S1-10), 3h(S1-10), 6h(S1-10), 12h(S1-10), 24h(S1-10), 48h(S1-10) and 72h(S1-10).
6. ARR16: 1%AEP; 1h(S1-10), 3h(S1-10), 6h(S1-10), 12h(S1-10), 24h(S1-10), 48h(S1-10) and 72h(S1-10).

The selected critical events are:

- For peak flow (at key culvert locations):
    - 1EY – 3h (S10)
    - 20%AEP – 3h(S7)
    - 1%AEP – 3h(S2)
- For detention volumes:
    - 1EY – 3h (S10)
    - 20%AEP – 3h(S7)
    - 1%AEP – 3h(S2)

It is interesting to note that the revisions to the model have resulted in a general shortening of the critical duration from 3-6 hours in the base model to 1-3 hours in the current system model. This is largely due to the extent of additional development in the system and reflects a generally shorter time of concentration for drainage within those developments. For this reason, to ensure that peak catchment flows are captured, analysis and design using the current system model has included the 20% AEP – 6h(S10) and the 1% AEP – 1h (S2) which are the critical events at these durations.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure A5 - 2-Dimensional model domain and ground model



Legend
DWMS Study Area
2-Dimensional model domain

Scale 1: 75,000 at A4
0 1.5km
N

urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

A.7.4 Results comparison to base model

Peak flows generated by the InfoWorks ICM current system model applying revised hydrological parameters and the revised AR&R2016 methodology were compared to peak flows generated by the original base model at various critical locations within the major waterways. This comparison is presented in Table A18 and Table A19.

Differences in peak flows and levels are observed at all sites. It is important to note that whilst similar locations have been presented in these tables, in several cases the modelled network has changed significantly and therefore a direct comparison is not strictly possible. This is particularly the case for flood levels where large differences may be caused by non-identical locations. Explanatory notes relating to the key differences at each of the selected sites follow:

1. Oaklands drain d/s George Road (north)
    - 20% AEP flow is reduced from the upstream catchment which includes a large area of the old townsite.
    - Survey information from the upstream catchment combined with the addition of 2D overland flow routing has improved representation of catchment storage in this area.
    - 1% AEP flow is increased because of overland flooding from the south re-entering the system just upstream of this site.
2. Oaklands drain d/s George Road (south)
    - 20% AEP flow is reduced from the upstream catchment which includes a large area of the old townsite.
    - Survey information from the upstream catchment combined with the addition of 2D overland flow routing has improved representation of catchment storage in this area.
    - 1% AEP flow is reduced because of overland flooding to the north re-entering the system just upstream of site 1.
3. Oaklands drain d/s Evans Road
    - Flow at this location is reduced for reasons consistent with the results at sites 1 and 2 above.
4. Oaklands drain u/s Malarkey Road
    - Flow at this location is reduced for reasons consistent with the results at sites 1, 2 and 3 above.
5. Thomas Road drain u/s Malarkey Road
    - Flow at this location is reduced from the upstream catchment which is mostly rural residential.
    - The addition of 2D overland flow routing has improved representation of catchment storage in this area.
6. Oaklands drain d/s Malarkey Road
    - Flow at this location is reduced for reasons consistent with the results at sites 4 and 5 above.
7. Oaklands drain at Hopkinson Road
    - Flow at this location is reduced for reasons consistent with the results at sites 4, 5 and 6 above.
8. Beenyup Brook d/s South Western Hwy
    - 20% AEP flow is slightly increased from the upstream catchment resulting from changes to catchment delineation, rainfall patterns and hydrological parameters.
    - 1% AEP is significantly reduced resulting from incorporation of the Old Brickworks Road Sump which contains a significant volume of storage in this event.
    - This reduction removes any need to upgrade the Abernethy Road culverts.

9. Beenyup Brook d/s Byford Town Centre
   - The flow through the old trotting track area is slightly reduced, alleviating flood risk in this section of Byford.
10. Beenyup Brook to Oaklands drain link
    - 20% AEP flow towards the Oaklands drain is increased because of reduced flow through the trotting track area. This could be amended if required although it has little impact on the downstream Oaklands system which has been designed to accommodate larger flows.
    - 1% AEP flow towards the Oaklands drain is reduced consistent with reductions noted at sites 8 and 9 from the upstream catchment.
11. Beenyup Brook at Hopkinson Road
    - Flows at this site are reasonably consistent with previous modelling.
12. Brickwood drain u/s Doley Road
    - Flows are slightly increased from the upstream catchment resulting from changes to catchment delineation, rainfall patterns and hydrological parameters.
    - The downstream MUC has the capacity to accommodate this additional flow.
13. Brickwood drain at Hopkinson Road
    - Flows at this site are reasonably consistent with previous modelling.
14. Doley drain at Hopkinson Road
    - Flows at this site are increased because of changes in overland flow distribution between Orton Road drain and Doley drain. This has also resulted in some reduction in Cardup Brook flows at Hopkinson road which ultimately receives flow from Orton Road drain.
15. Cardup Brook d/s South Western Hwy
    - Flows are significantly reduced resulting from incorporation of 2D overland flow routing which has enabled representation of a significant volume of storage upstream of South Western Hwy and the Railway, neither of which are overtopped.
16. Cardup Brook at Hopkinson Road
    - Flow is reduced for reasons consistent with results at site 15 above as well as through overland flow changes identified for site 14 above.

Table A18: Current system model peak flow comparison to base model

Location	5-year ARI/20% AEP peak flows		100-year ARI/1% AEP peak flows	
	Base model	Current system model	Base model	Current system model
1. Oaklands drain d/s George Road (north)	5.5	4.0	10.2	8.9
2. Oaklands drain d/s George Road (south)	2.3	1.4	10.7	2.0
3. Oaklands drain d/s Evans Road	10.7	10.0	34.4	15.5
4. Oaklands drain u/s Malarkey Road	11.0	9.9	35.1	19.0
5. Thomas Road drain u/s Malarkey Road	9.5	4.3	25.7	9.2
6. Oaklands drain d/s Malarkey Road	20.9	13.8	62.0	28.6
7. Oaklands drain at Hopkinson Road	15.8	12.5	51.5	31.2

Location	5-year ARI/20% AEP peak flows		100-year ARI/1% AEP peak flows	
	Base model	Current system model	Base model	Current system model
8. Beenyup Brook d/s South Western Hwy	8.1	10.4	31.2	18.8
9. Beenyup Brook d/s Byford Town Centre	2.8	3.6	3.1	3.5
10. Beenyup Brook to Oaklands drain link	5.2	5.4	16.1	9.2
11. Beenyup Brook at Hopkinson Road	5.5	3.9	9.6	7.0
12. Brickwood drain u/s Doley Road	1.4	2.9	3.4	6.2
13. Brickwood drain at Hopkinson Road	1.6	3.6	6.8	7.4
14. Doley Drain at Hopkinson Road	2.1	4.0	5.1	9.4
15. Cardup Brook d/s South Western Hwy	5.8	4.0	23.5	20.7
16. Cardup Brook at Hopkinson Road	9.4	3.9	33.3	10.6

Table A19: Current system model top water level comparison to base model

Location	5-year ARI/20% AEP top water level		100-year ARI/1% AEP top water level	
	Base model	Current system model	Base model	Current system model
1. Oaklands drain d/s George Road (north)	53.2	49.4	53.3	49.5
2. Oaklands drain d/s George Road (south)	51.8	51.3	52.0	51.4
3. Oaklands drain d/s Evans Road	44.3	42.3	44.6	42.4
4. Oaklands drain u/s Malarkey Road	32.7	30.7	32.9	30.7
5. Thomas Road drain u/s Malarkey Road	30.9	30.6	31.1	31.2
6. Oaklands drain d/s Malarkey Road	29.8	30.0	30.2	30.2
7. Oaklands drain at Hopkinson Road	26.4	25.8	27.0	26.0
8. Beenyup Brook d/s South Western Hwy	58.5	59.1	58.7	59.3
9. Beenyup Brook d/s Abernethy Road	56.5	47.9	56.6	48.1
10. Beenyup Brook to Oaklands drain link	56.5	48.8	56.6	49.5
11. Beenyup Brook at Hopkinson Road	56.3	26.1	56.8	26.5
12. Brickwood drain u/s Doley Road	44.5	35.4	45.4	36.1
13. Brickwood drain at Hopkinson Road	34.5	27.4	35.5	27.9
14. Doley Drain at Hopkinson Road	25.6	26.8	26.0	27.4

Location	5-year ARI/20% AEP top water level		100-year ARI/1% AEP top water level	
	Base model	Current system model	Base model	Current system model
15. Cardup Brook d/s South Western Hwy	41.6	55.8	41.7	55.9
16. Cardup Brook at Hopkinson Road	27.5	27.5	27.7	28.3

A.7.5 Results comparison to Birrega Oaklands flood modelling and drainage study

Table A20 provides a comparison of *Birrega Oaklands flood modelling and drainage study* (DoW, 2015) peak flows at selected locations with those predicted by the base model and current system model. Additional locations, outside the base model domain are included based flows obtained from longitudinal sections presented in *Birrega Oaklands flood modelling and drainage study* (DoW, 2015).

Flows predicted by the current system model are generally reduced, with the exception of site 1, where a substantial adjustment of overland flow paths has resulted in a localised increase that is not reflected further downstream (see section A.7.4 above for details).

The significant flow reductions observed in the Beenyup and Cardup Brooks are generated through the combination of detailed 1-dimensional and 2-dimensional modelling upstream of South Western Highway where large storage areas have been identified. The Birrega Oaklands model, although capable of reflecting the available storage through its 2-dimensional surface, operates with a 10m fixed grid size resulting in premature overtopping of the Highway at Cardup Brook and Old Brickworks Road at Beenyup Brook.

Table A20: Birrega Oaklands model top water level comparison to current system model

Location	Base model		Current system model		Birrega Oaklands study	
	5-year ARI	100-year ARI	20% AEP	1% AEP	5-year ARI	100-year ARI
1. Oaklands drain d/s George Road (north)	5.5	10.2	4.0	8.9	4.2	11.7
2. Beenyup Brook d/s South Western Hwy	8.1	31.2	10.4	18.8	5.4	26.8
3. Cardup Brook d/s South Western Hwy	5.8	23.5	4.0	7.8	20.7	22.7

A.8 Current system detailed modelling results

Detailed flood maps and longitudinal sections of significant watercourses for critical duration 1EY, 20% AEP and 1% AEP flood events are provided in Appendix C.

Critical 1EY, 20% AEP and 1% AEP event longitudinal sections for significant watercourses are provided to assist with the design of subdivisional drainage and may be used to accurately determine flows and levels.

APPENDIX B – SITE INSPECTION PHOTOGRAPHS AND NOTES

Structure No 3: Site 1.23 – Wungong River at Rowley Road

Structure No 6: Site 1.22 – Birrega Drain at Wungong South Road

Structure No 7: Site 1.21 – Birrega Drain at Masters Road

Structure No 8: Site 1.1 – Hopkinson Road at Darling Downs

Structure No 17: Site 1.4 – Thomas Road, Hopkinson Road Intersection

Structure No 19: Site 1.5 – Thomas Road, Ballak Place Intersection

Structure No 30: Site 1.15 – Oaklands Drain at South Western Highway

Structure No 30a: Site 1.15 – Oaklands Drain at George Street

Structure No 31: Site 1.15 – Oaklands Drain at Railway

Structure No 36: Site 1.14 – Redgum Brook Multiple Use Corridor at Kardan Boulevard

Structure No 39: Site 1.2 – Beenyup Brook at South West Highway

Structure No 40: Site 1.2 – Beenyup Brook at Railway

Structure No 41: Site 1.16 – Beenyup Brook at Abernethy Road

Structure No 42: Site 1.3 – Beenyup Brook at Won Niche Street

Structure No 49: Site 1.24 – Beenyup Brook at Hopkinson Road

Structure No 50: Site 1.24 – Beenyup Brook Subdrain at Abernethy Road

Structure No 51: Site 1.8 – Oaklands Drain at Abernethy Road

Structure No 52: Site 1.8 – Oaklands Drain Bifurcation

Structure No 53: Site 1.9 – Oaklands Drain at Orton Road

Structure No 54: Site 1.10 – Oaklands Drain at Gossage Road

Structure No 56: Site 1.20 – Glades Multiple Use Corridor at Warrington Road

Structure No 58: Site 1.20 – Glades Multiple Use Corridor at Mead Street

Structure No 60: Site 1.20 – Glades Multiple Use Corridor at Doley Road

Structure No 62: Site 1.20 – Glades Multiple Use Corridor at Tourmaline Boulevard

Structure No 80: Site 1.25 – Cardup Brook at Hopkinson Road

Structure No 81: Site 1.7 – Birrega Subdrain at Abernethy Road, Kargotich Road Intersection

Structure No 82: Site 1.11 – Birrega Subdrain at Orton Road, Kargotich Road Intersection

Structure No 83: Site 1.12 – Birrega Subdrain at Kargotich Road

Structure No 84: Site 2.1 – Rowley Road at Darling Downs

Structure No 84: Site 2.2 – Oaklands Drain at Kargotich Road

Structure No 86: Site 2.10 – Cardup Drain at Railway

Structure No 87: Site 2.10 – Cardup Drain at Railway walk trail

Structure No 88: Site 2.10 – Cardup Drain at Soldiers Road

Structure No 89: Site 2.11 – Cardup Drain at Pollard Cross

Structure No 90: Site 2.13 – Cardup Drain at Baigup Loop

Structure No 91: Site 2.14 – Cardup Drain at Hopkinson Road

Structure No 92: Site 2.9 – Norman Drain at South West Highway

Structure No 93: Site 2.8 – Norman Drain at Railway

Structure No 94: Site 2.8 – Norman Drain at Railway walk trail

Structure No 95: Site 2.8 – Norman Drain at Soldiers Road

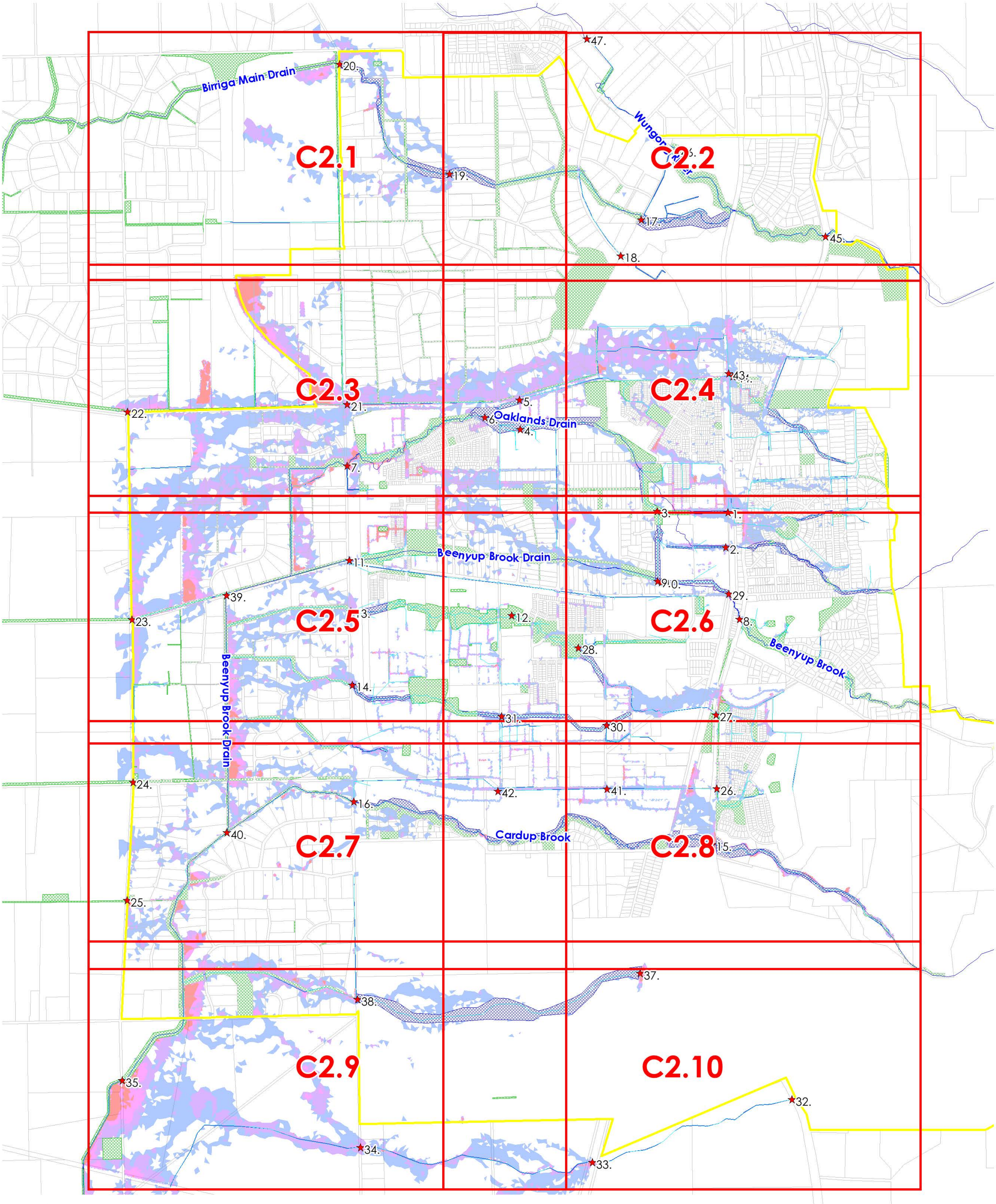
Structure No 96: Site 2.7 – Norman Drain at Hopkinson Road

Structure No 98: Site 2.5 – Norman Drain at Kargotich Road

APPENDIX C – DETAILED FLOOD MAPPING AND LONGITUDINAL SECTIONS

- Figure C1: Flood mapping overview
- Figure C2.1-10: Detailed flood mapping
- Figure C2.11-20: Longitudinal sections – 20% AEP
- Figure C2.21-30: Longitudinal sections – 1% AEP

Shire of Serpentine Jarrahdale - Byford DWMS
Figure C1 - Flood mapping overview



Legend:

- DWMS Study Area
- Major Watercourses
- Modelled other drains and watercourses
- Existing POS and drainage reserves

1% AEP flood depth

- >0.5
- 0.3 to 0.5
- 0.1 to 0.3
- 0.03 to 0.1

- Critical flow and top water level locations (Table 2)
- Reporting subcatchments (Table 3)
- Recommended new drainage reserves

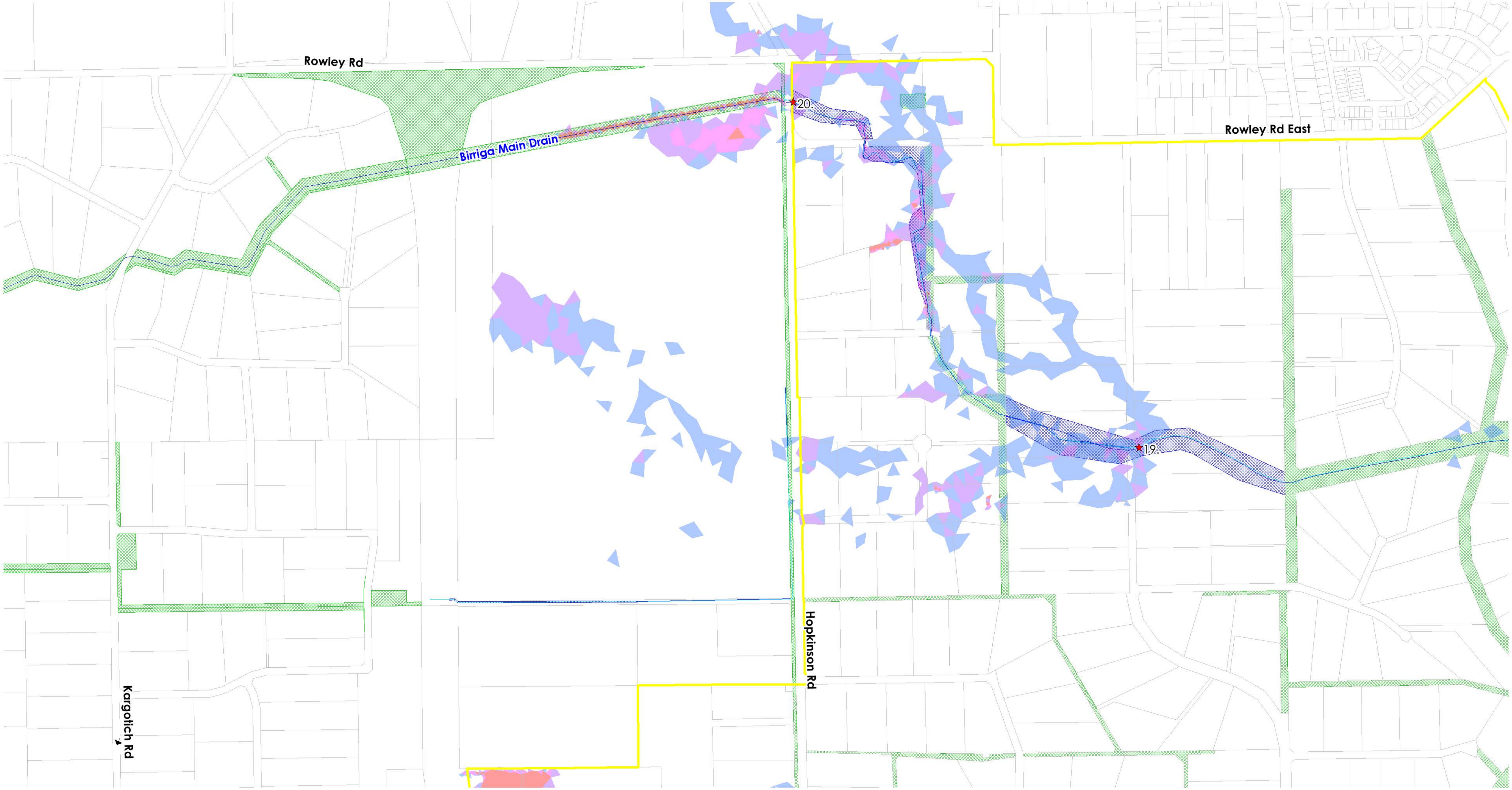
Scale 1: 30,000 at A3

0 600m

N

urbaqua
land and water solutions

Shire of Serpentine Jarrahdale - Byford DWMS
Figure C2.1 - Detailed flood mapping



Legend:

- DWMS Study Area
- Major Watercourses
- Modelled other drains and watercourses
- Existing POS and drainage reserves

1% AEP flood depth

- >0.5
- 0.3 to 0.5
- 0.1 to 0.3
- 0.03 to 0.1

- Critical flow and top water level locations (Table 2)
- Reporting subcatchments (Table 3)
- Recommended new drainage reserves

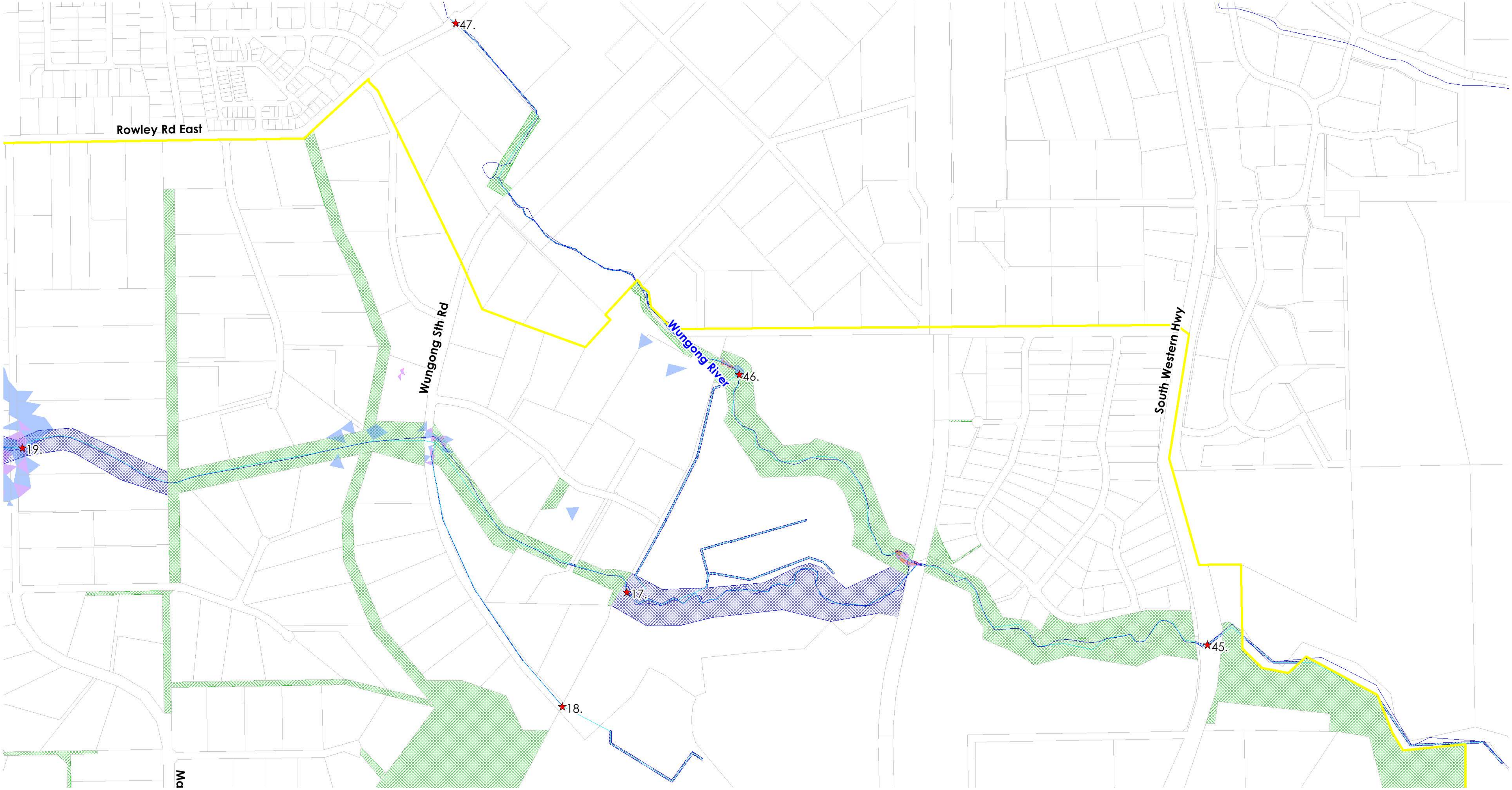
Scale 1: 10,000 at A3

0 200m

urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure C2.2 - Detailed flood mapping



Legend:

- DWMS Study Area
- Major Watercourses
- Modelled other drains and watercourses
- Existing POS and drainage reserves

1% AEP flood depth

- >0.5
- 0.3 to 0.5
- 0.1 to 0.3
- 0.03 to 0.1

- Critical flow and top water level locations (Table 2)
- Reporting subcatchments (Table 3)
- Recommended new drainage reserves

Scale 1: 10,000 at A3

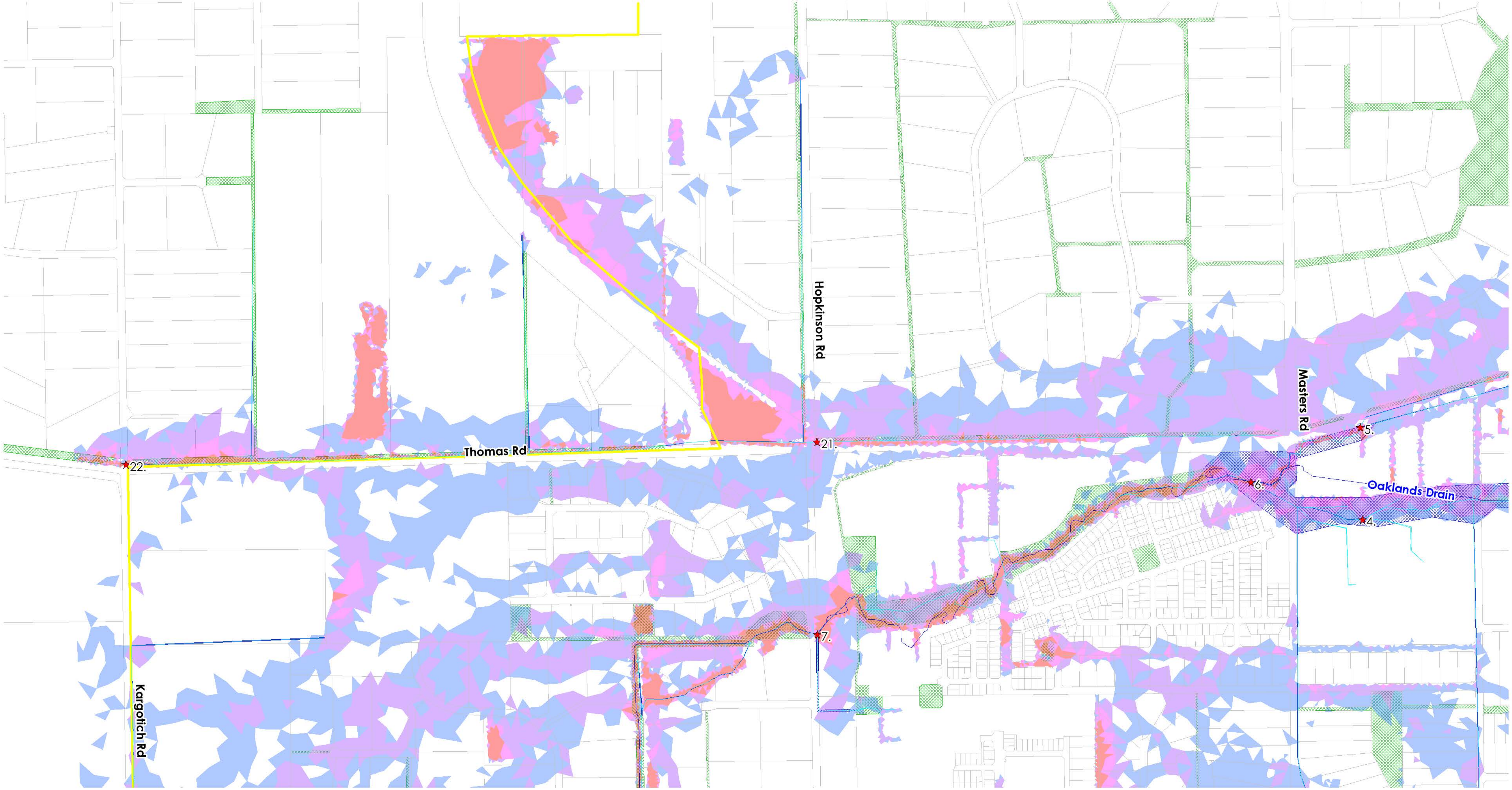
0 200m

N

urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure C2.3 - Detailed flood mapping



Legend:

- DWMS Study Area
- Major Watercourses
- Modelled other drains and watercourses
- Existing POS and drainage reserves

1% AEP flood depth

- >0.5
- 0.3 to 0.5
- 0.1 to 0.3
- 0.03 to 0.1

- Critical flow and top water level locations (Table 2)
- Reporting subcatchments (Table 3)
- Recommended new drainage reserves

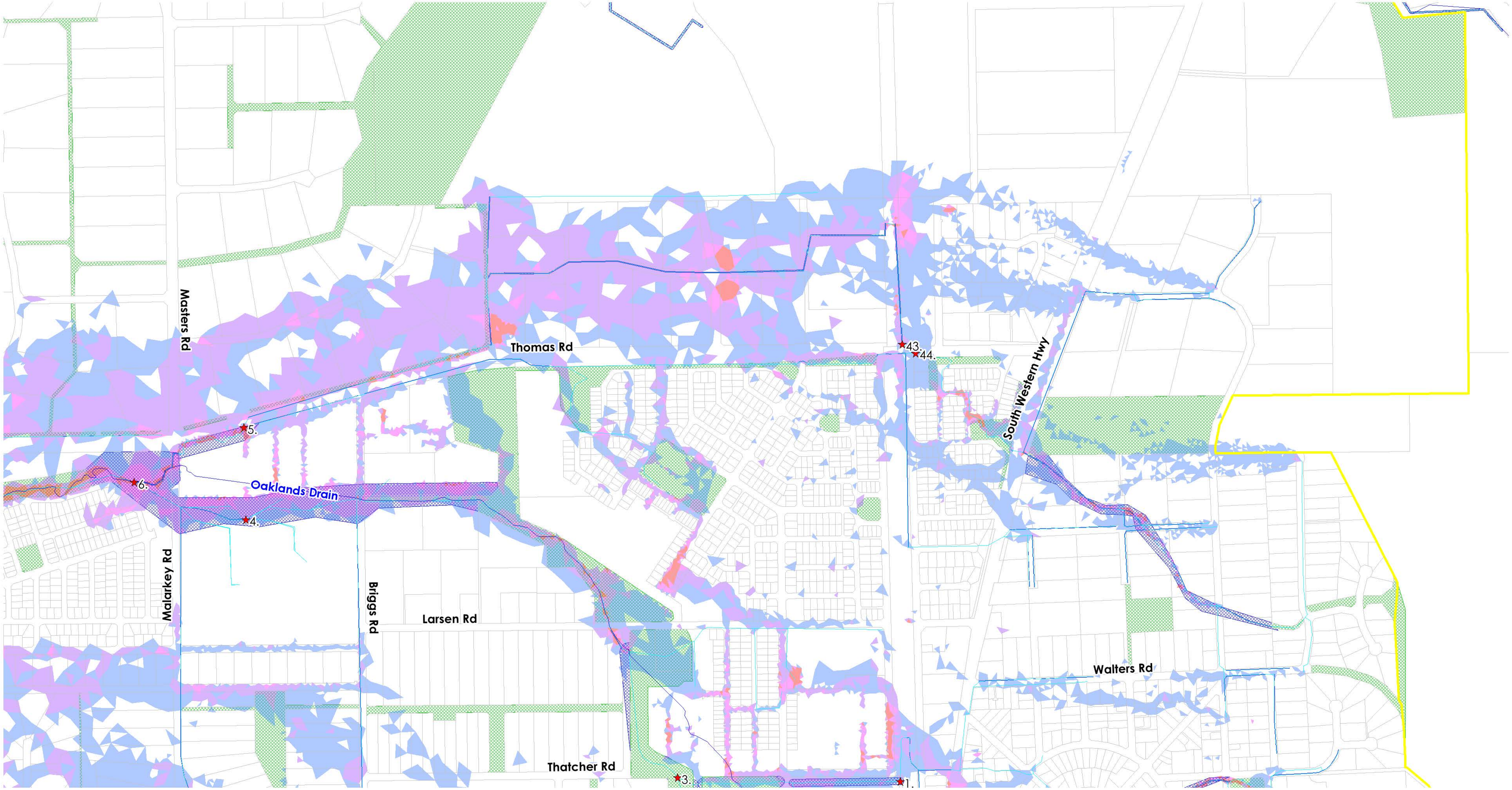
Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

Scale 1: 10,000 at A3

0 200m

urbaqua
land and water solutions

Shire of Serpentine Jarrahdale - Byford DWMS
Figure C2.4 - Detailed flood mapping



Legend:

- DWMS Study Area
- Major Watercourses
- Modelled other drains and watercourses
- Existing POS and drainage reserves

1% AEP flood depth

- >0.5
- 0.3 to 0.5
- 0.1 to 0.3
- 0.03 to 0.1

- Critical flow and top water level locations (Table 2)
- Reporting subcatchments (Table 3)
- Recommended new drainage reserves

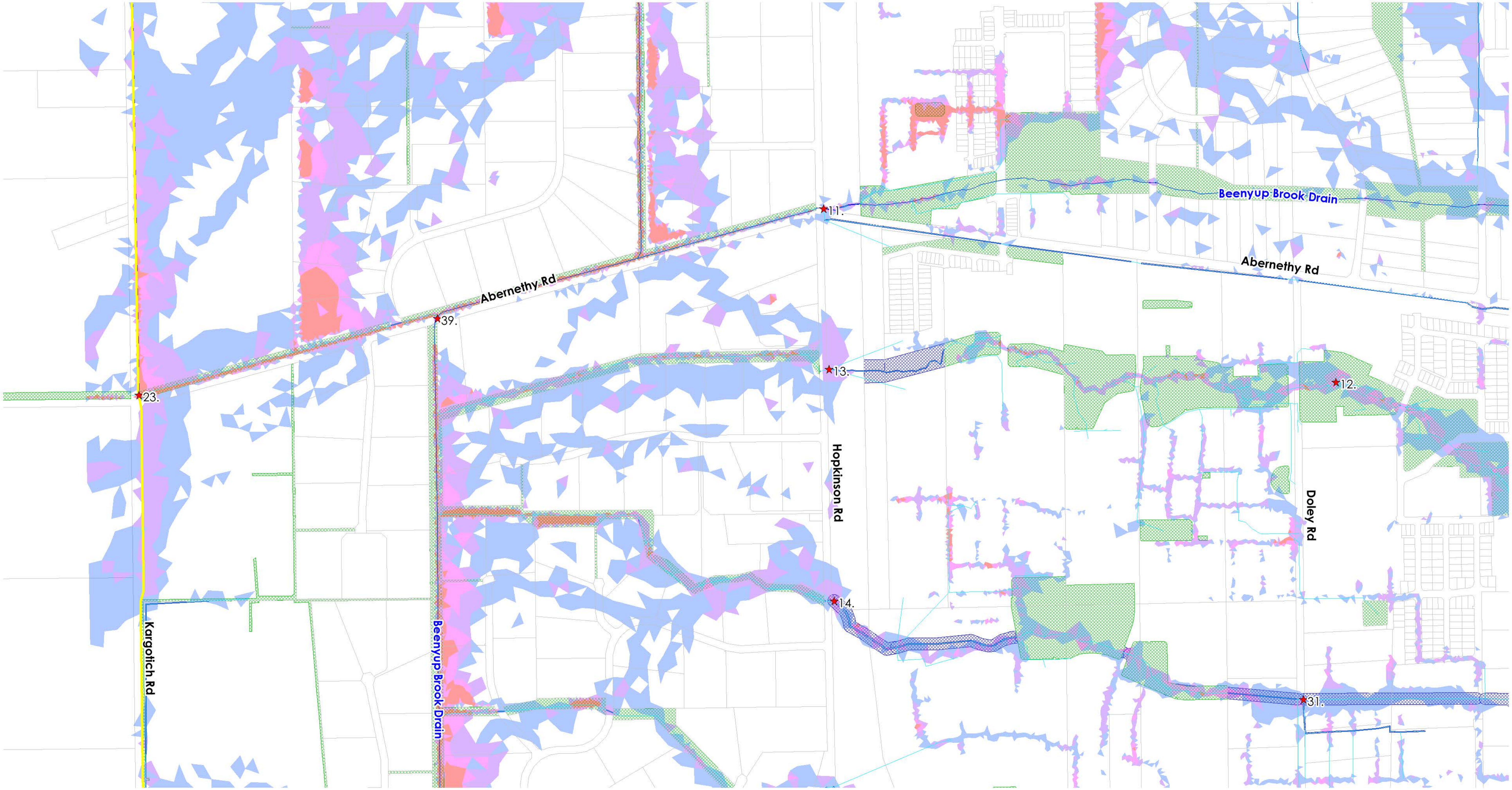
Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

Scale 1: 10,000 at A3

0 200m

urbaqua
land and water solutions

Shire of Serpentine Jarrahdale - Byford DWMS
Figure C2.5 - Detailed flood mapping



Legend:

- DWMS Study Area
- Major Watercourses
- Modelled other drains and watercourses
- Existing POS and drainage reserves

1% AEP flood depth

- >0.5
- 0.3 to 0.5
- 0.1 to 0.3
- 0.03 to 0.1

- Critical flow and top water level locations (Table 2)
- Reporting subcatchments (Table 3)
- Recommended new drainage reserves

Scale 1: 10,000 at A3

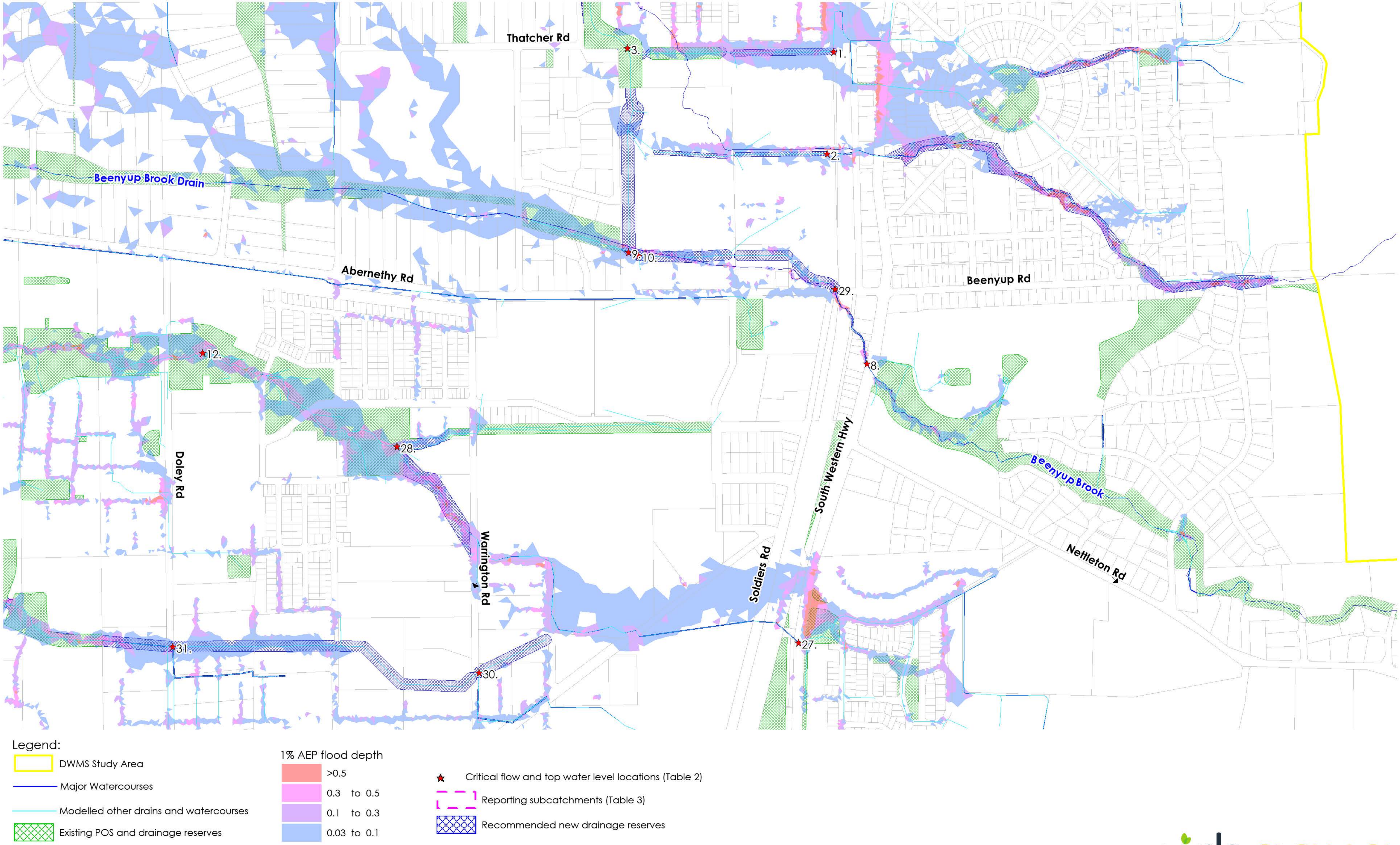
0 200m

N

urbaqua
land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

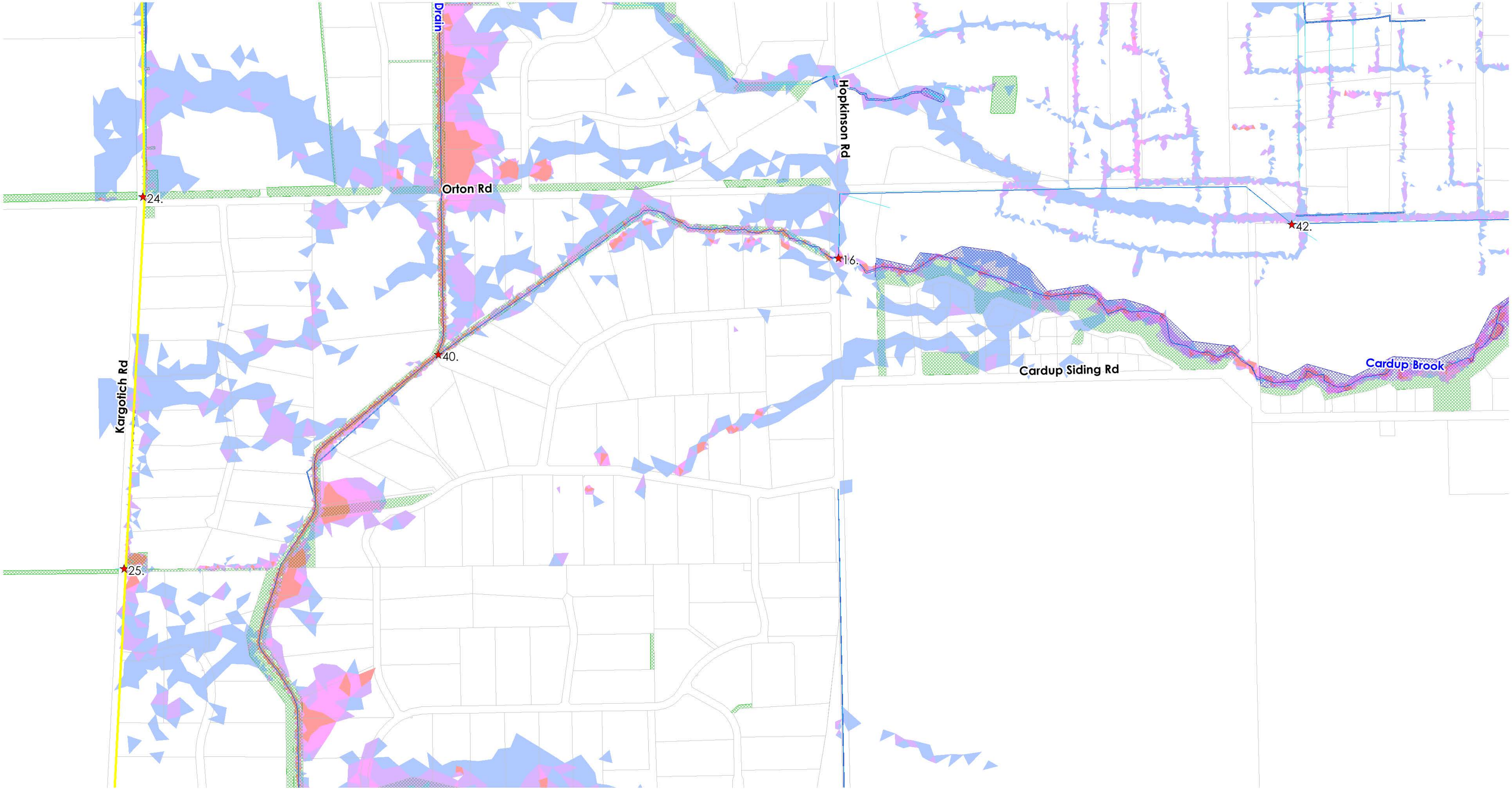
Shire of Serpentine Jarrahdale - Byford DWMS
Figure C2.6 - Detailed flood mapping



Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

urbaqua land and water solutions

Shire of Serpentine Jarrahdale - Byford DWMS
Figure C2.7 - Detailed flood mapping



Legend:

- DWMS Study Area
- Major Watercourses
- Modelled other drains and watercourses
- Existing POS and drainage reserves

1% AEP flood depth

- >0.5
- 0.3 to 0.5
- 0.1 to 0.3
- 0.03 to 0.1

- Critical flow and top water level locations (Table 2)
- Reporting subcatchments (Table 3)
- Recommended new drainage reserves

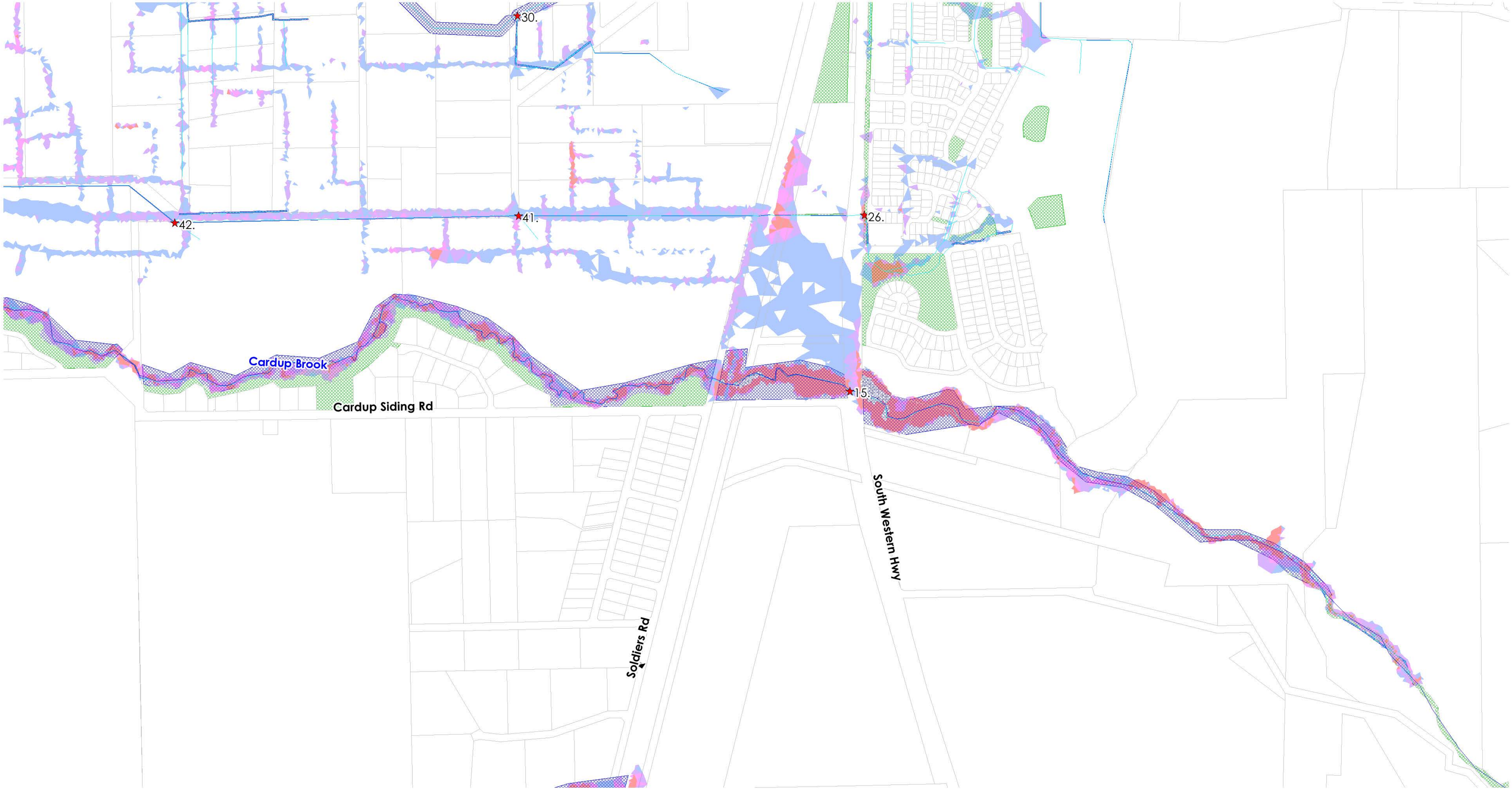
Scale 1: 10,000 at A3

0 200m

urbaqua land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

Shire of Serpentine Jarrahdale - Byford DWMS
Figure C2.8 - Detailed flood mapping



Legend:

- DWMS Study Area
- Major Watercourses
- Modelled other drains and watercourses
- Existing POS and drainage reserves

1% AEP flood depth

- >0.5
- 0.3 to 0.5
- 0.1 to 0.3
- 0.03 to 0.1

- Critical flow and top water level locations (Table 2)
- Reporting subcatchments (Table 3)
- Recommended new drainage reserves

Scale 1: 10,000 at A3

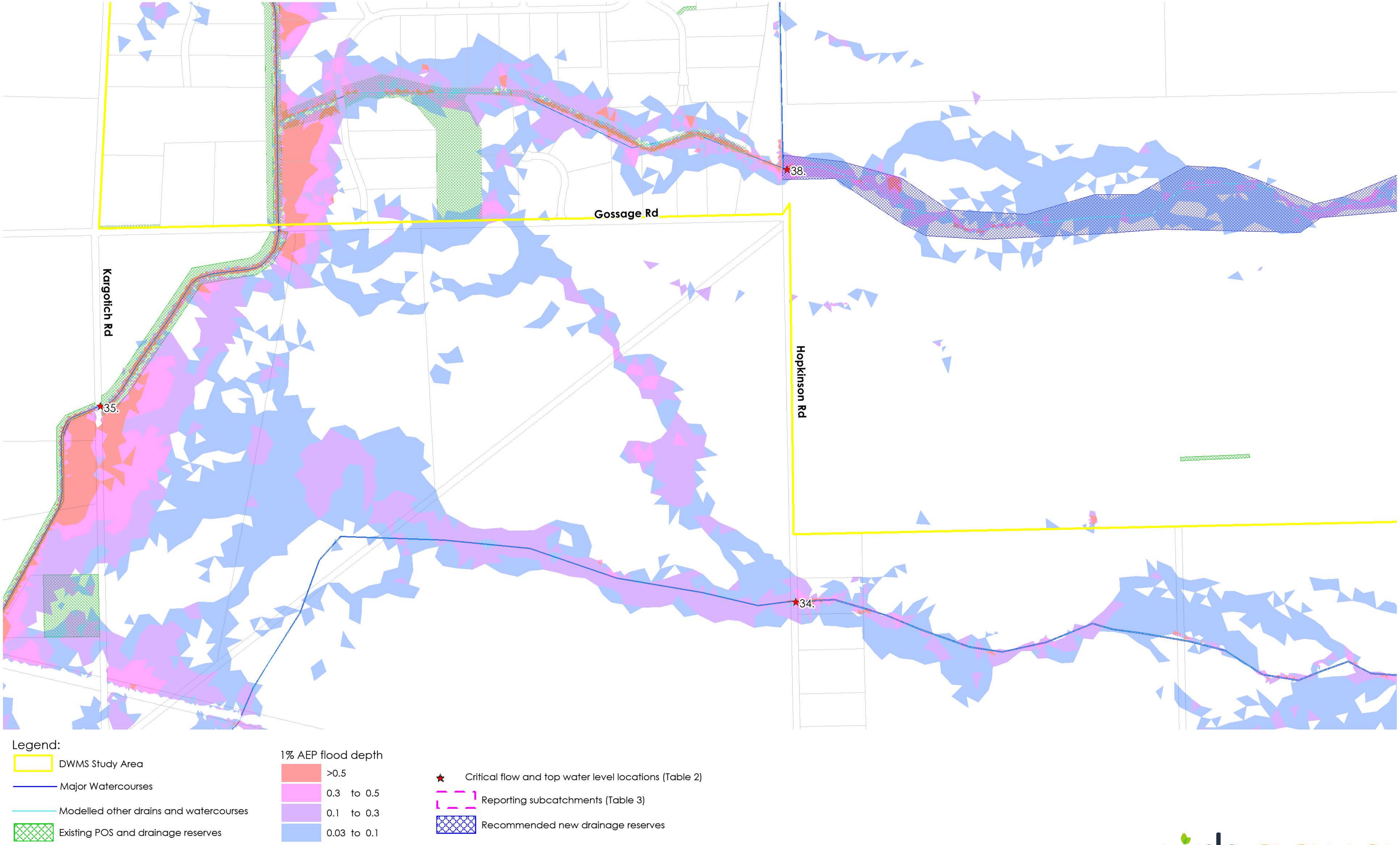
0 200m

N

urbaqua land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

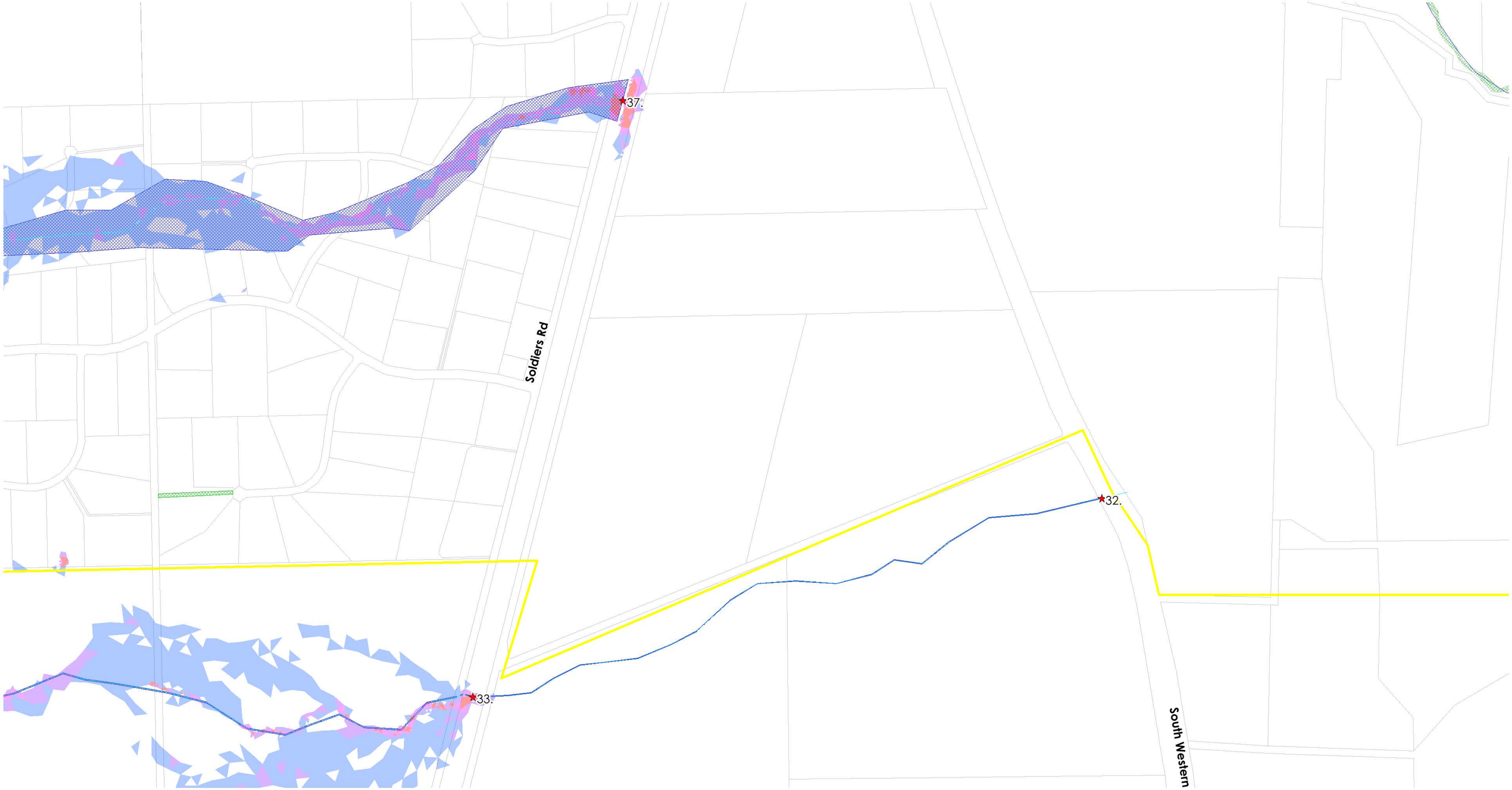
Shire of Serpentine Jarrahdale - Byford DWMS
Figure C2.9 - Detailed flood mapping



Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.

urbaqua land and water solutions

Shire of Serpentine Jarrahdale - Byford DWMS
Figure C2.10 - Detailed flood mapping



Legend:

- DWMS Study Area
- Major Watercourses
- Modelled other drains and watercourses
- Existing POS and drainage reserves

1% AEP flood depth

- >0.5
- 0.3 to 0.5
- 0.1 to 0.3
- 0.03 to 0.1

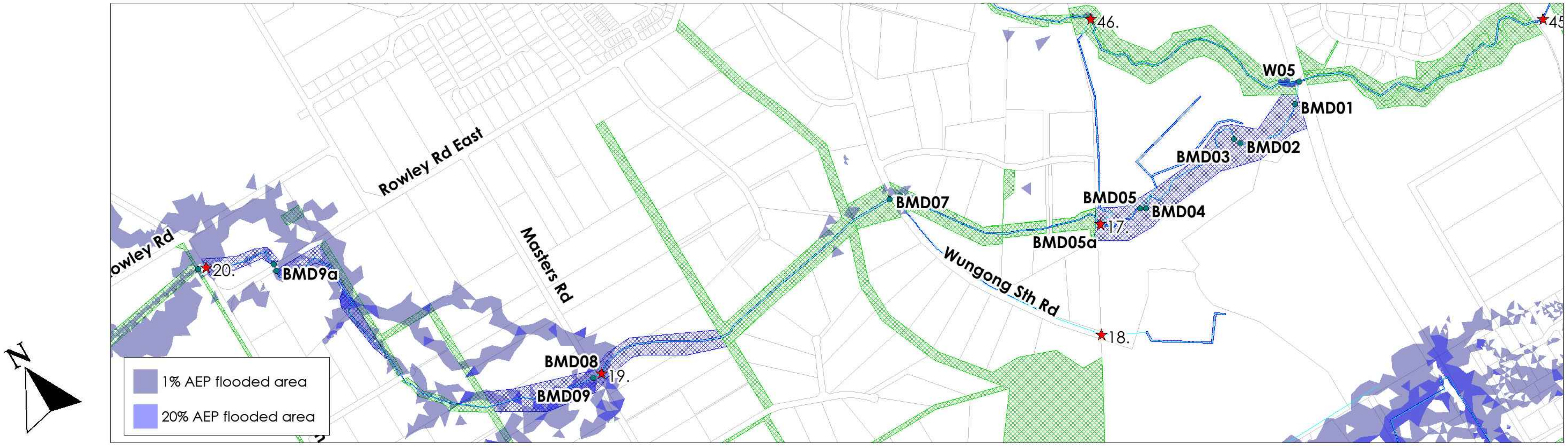
- Critical flow and top water level locations (Table 2)
- Reporting subcatchments (Table 3)
- Recommended new drainage reserves

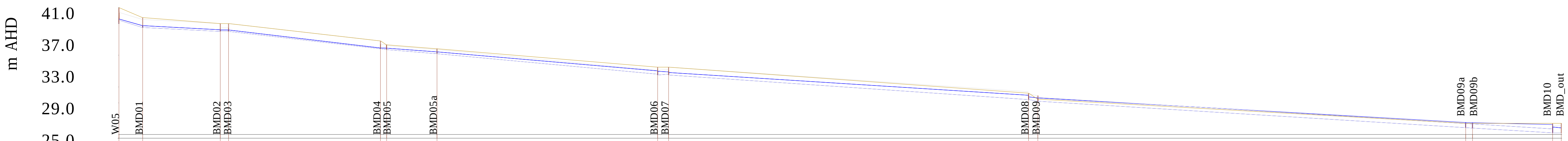
Scale 1: 10,000 at A3

0 200m

urbaqua land and water solutions

Data source: Landgate, Shire of Serpentine-Jarrahdale, DWER. Created by: HB Projection: MGA: zone 50.





Node	Chainage (m)	ground (m AHD)	20% level (m AD)
W05	0	41.000	39.558
BMD01	75	39.743	38.731
BMD02	319	39.000	38.211
BMD03	346	39.000	38.173
BMD04	825	36.800	35.912
BMD05	844	36.300	35.891
BMD05a	1003	35.800	35.416
BMD06	1700	33.500	33.037
BMD07	1734	33.500	32.806
BMD08	2870	30.200	29.965
BMD09	2900	29.464	29.619
BMD09a	4249	26.400	26.513
BMD09b	4271	26.400	26.494
BMD10	4524	26.400	26.253
BMD_out	4551	26.400	

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	20% flow (m3/s)
1000	1000	39.400	38.500	0.13465
1000	1000	38.500	38.000	0.23944
900	450	38.000	38.000	0.08698
1000	1000	38.000	35.800	0.17221
1200	600	35.800	35.700	0.05807
4000	500	35.700	35.200	0.49328
4000	500	35.200	32.600	0.67278
600	600	32.500	32.600	0.20753
5000	1000	32.500	29.400	1.27660
700	700	29.400	29.200	0.31439
2000	500	29.200	25.876	1.08849
2000	500	25.876	25.822	1.02841
2000	500	25.822	25.200	1.03685
900	900	25.200	25.200	1.12856

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.11 - Birrega Drain - 20% AEP

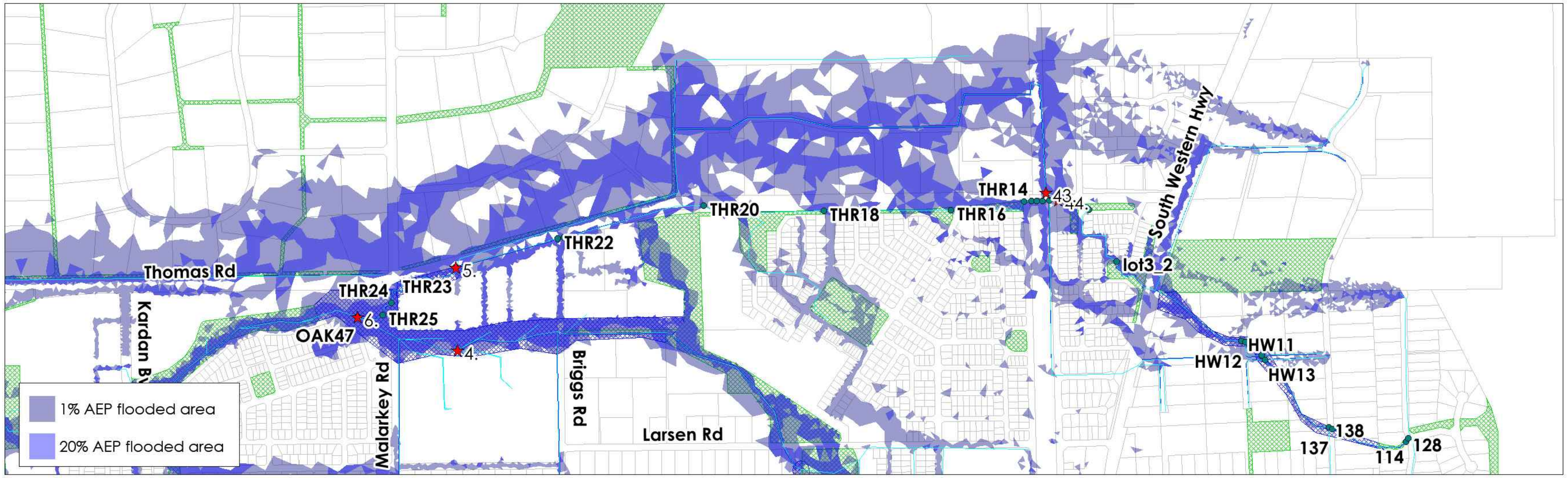
ISSUE	DATE	DESIGN	CHECK
A	18 Jun 2018	AN	HB

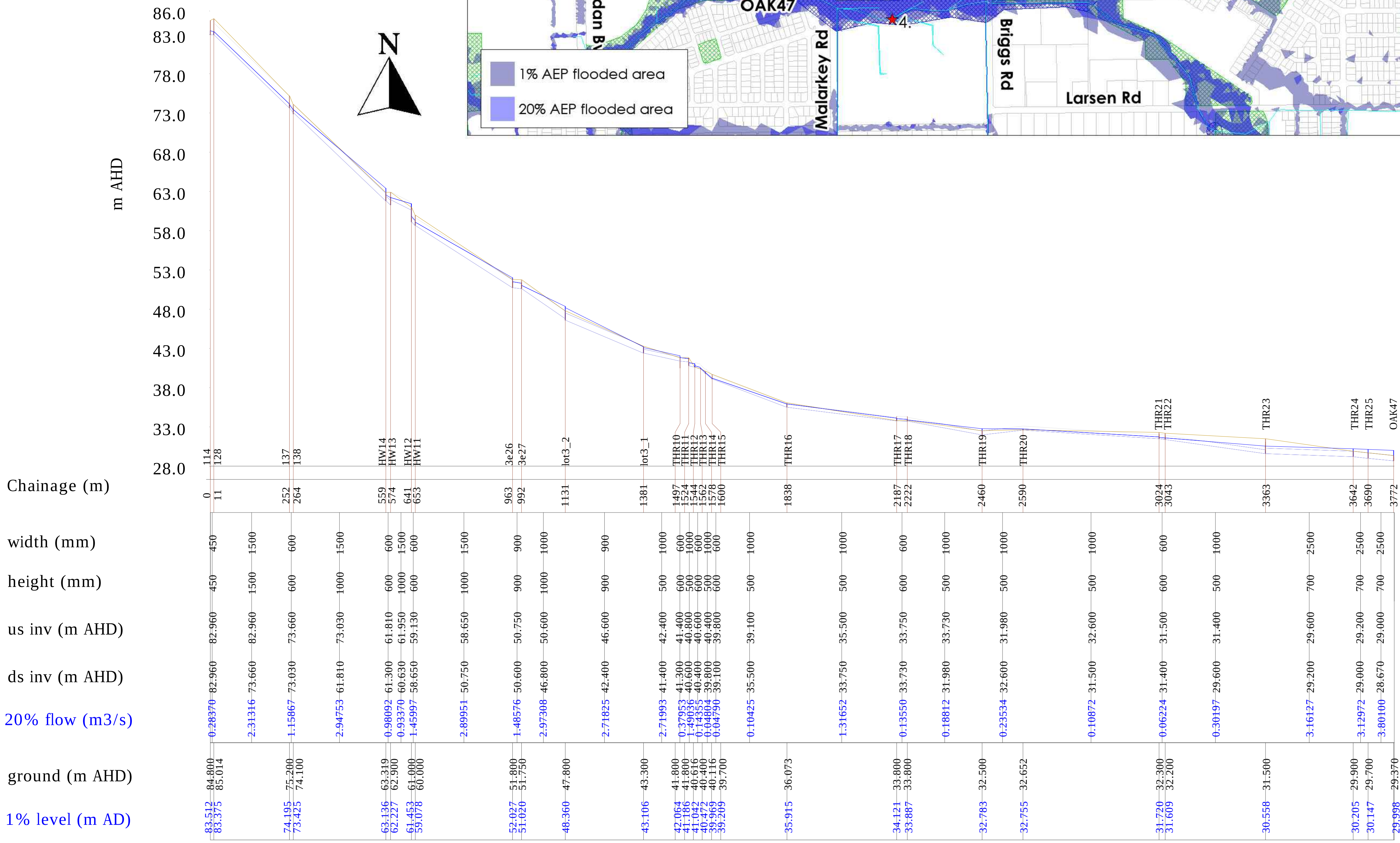
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua
land and water solutions





Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.12 - Oaklands Drain North - 20% AEP

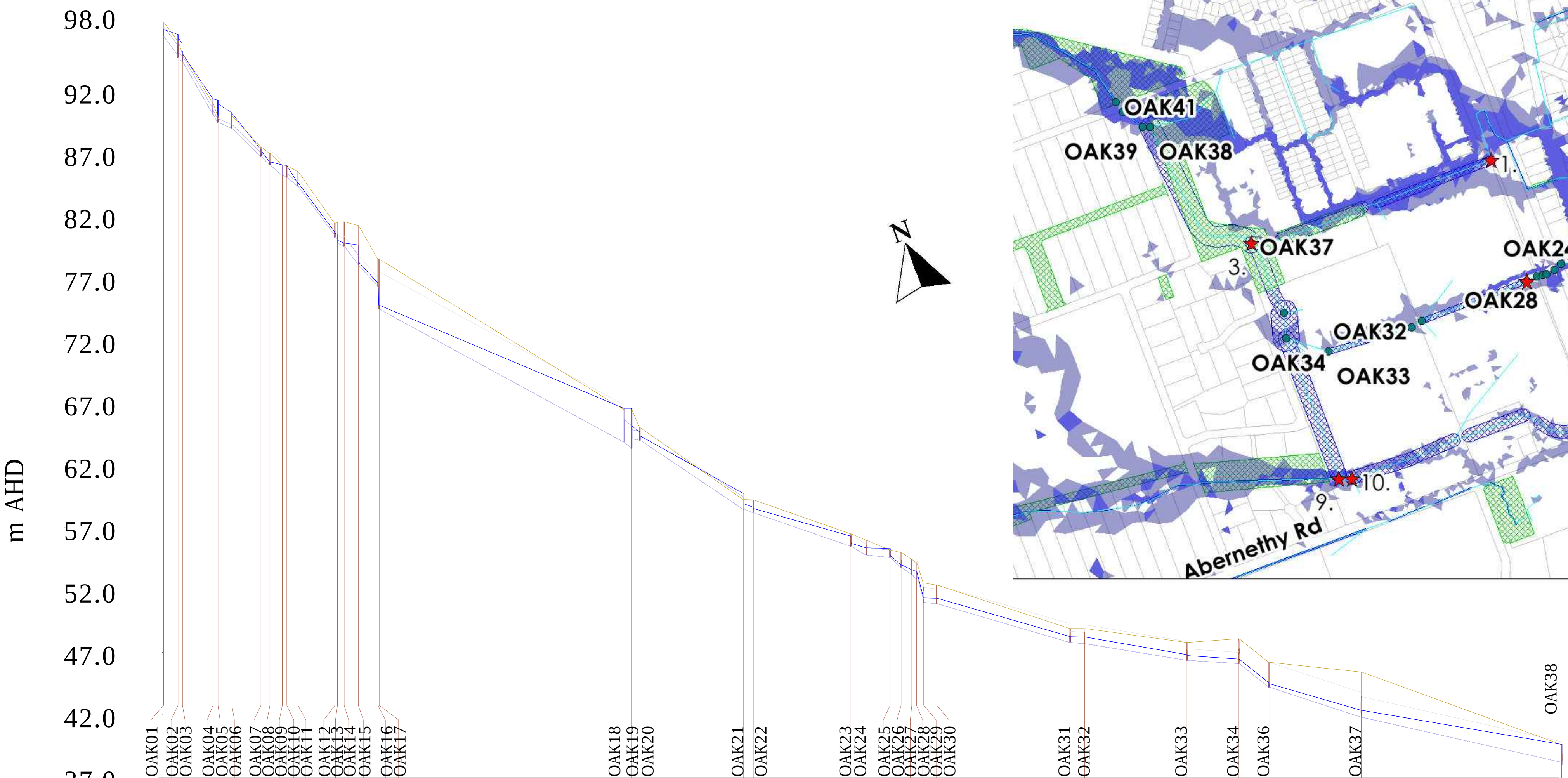
ISSUE	DATE	DESIGN	CHECK
A	19 Jun 2018	AN	HB

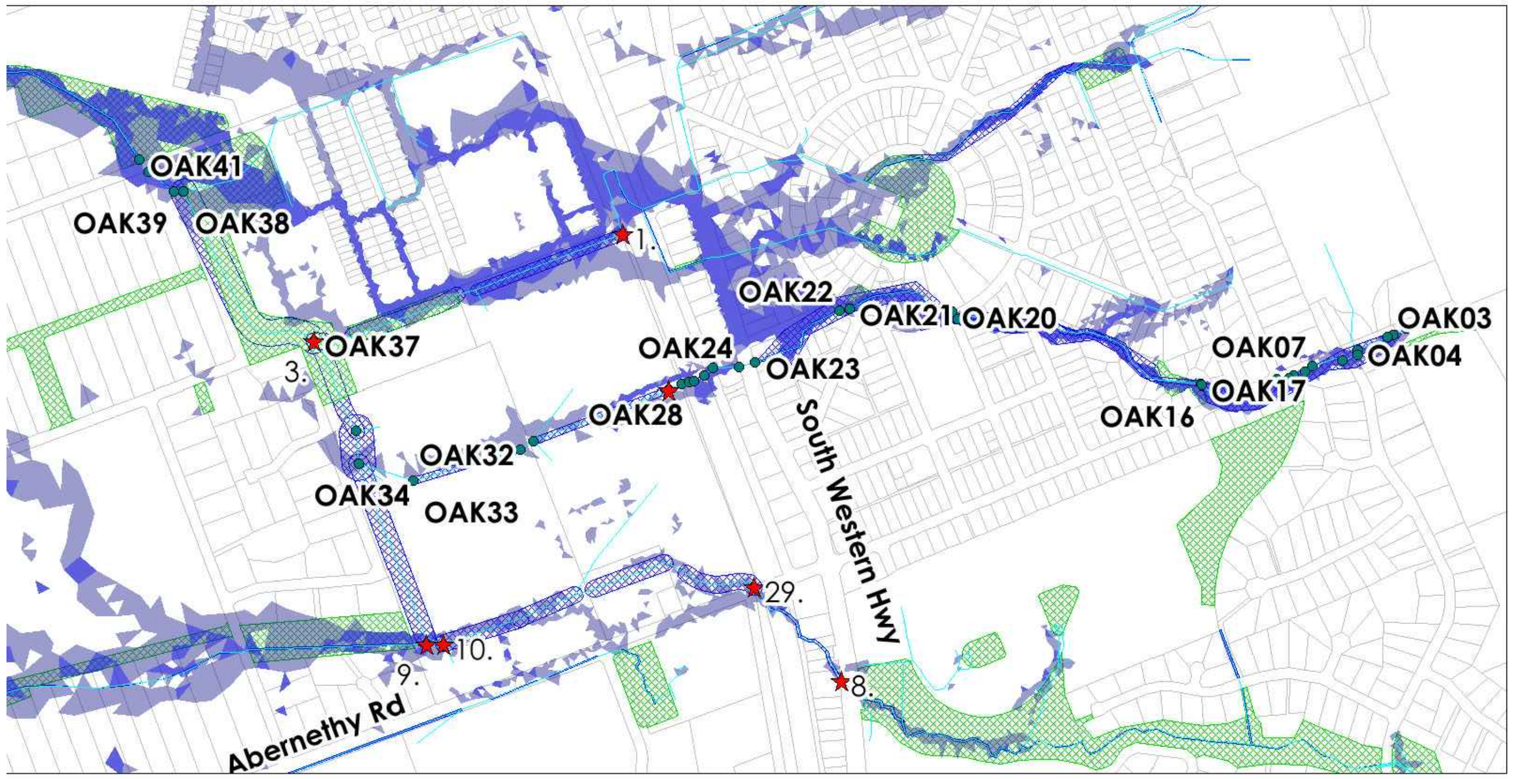
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua land and water solutions





Node	Chainage (m)	ground (m AHD)	20% level (m AD)
OAK01	0	97.500	96.922
OAK02	29	96.000	96.541
OAK03	38	95.000	95.164
OAK04	99	91.000	91.390
OAK05	109	90.000	91.266
OAK06	137	90.000	90.259
OAK07	195	87.500	87.319
OAK08	213	87.000	86.306
OAK09	238	86.085	86.075
OAK10	247	85.993	86.070
OAK11	269	85.530	84.621
OAK12	343	81.390	80.584
OAK13	349	81.466	80.524
OAK14	362	81.513	79.792
OAK15	390	81.212	79.664
OAK16	430	78.525	76.503
OAK17		78.500	74.829
OAK18	923	66.458	66.557
OAK19	939	66.414	66.556
OAK20	955	65.000	64.351
OAK21	1163	59.254	59.753
OAK22	1182	59.220	58.521
OAK23	1378	56.500	56.327
OAK24	1408	56.000	55.373
OAK25	1457	55.200	55.320
OAK26	1479	55.000	54.014
OAK27	1500	54.450	53.623
OAK28	1509	54.200	53.482
OAK29	1524	52.560	51.392
OAK30	1550	52.400	51.343
OAK31	1818	48.900	48.272
OAK32	1847	48.900	48.234
OAK33	2052	47.800	46.740
OAK34	2156	48.100	46.458
OAK36	2216	46.200	44.491
OAK37	2401	45.430	42.347
OAK38	2803	39.600	39.621

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	20% flow (m3/s)
1000	800	96.360	94.880	3.20837
450	450	94.660	94.340	1.05892
450	450	94.340	90.140	0.97669
300	300	90.140	89.480	0.24373
300	300	89.480	89.010	0.20140
300	300	89.010	86.753	0.22843
300	300	86.753	86.070	0.22915
1000	1200	86.070	85.210	0.35138
900	900	85.220	85.080	0.35297
300	300	85.080	84.360	0.25385
300	600	84.360	80.450	0.25397
450	450	80.280	80.120	0.25406
900	600	79.800	79.550	0.51402
1000	780	79.550	78.090	0.51367
750	750	78.030	76.350	0.56695
750	750			
10000	3000	74.500	63.840	1.09502
1000	1820	63.840	63.350	1.45908
750	750	64.100	64.000	1.99528
2000	1000	64.000	58.460	2.65565
900	900	58.460	58.200	1.03097
2000	1000	58.200	55.500	1.12915
900	900	55.500	54.800	0.37555
500	600	54.800	54.600	1.12902
900	600	54.600	53.800	0.39071
5000	1200	53.800	53.250	1.38425
4000	1200	53.250	52.900	1.38315
1000	1200	53.250	51.250	1.38315
2400	1200	51.000	50.900	0.69154
13000	1500	50.900	47.800	1.38188
3000	900	47.800	47.700	0.83313
13000	1500	47.700	46.369	1.66497
3000	900	46.369	46.100	0.83001
62800	2000	46.100	44.200	6.90343
30000	2000	44.200	41.800	6.98707
49000	1650	41.800	38.200	10.04325

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.13 - Oaklands Drain - 20% AEP (Sheet 1 of 4)

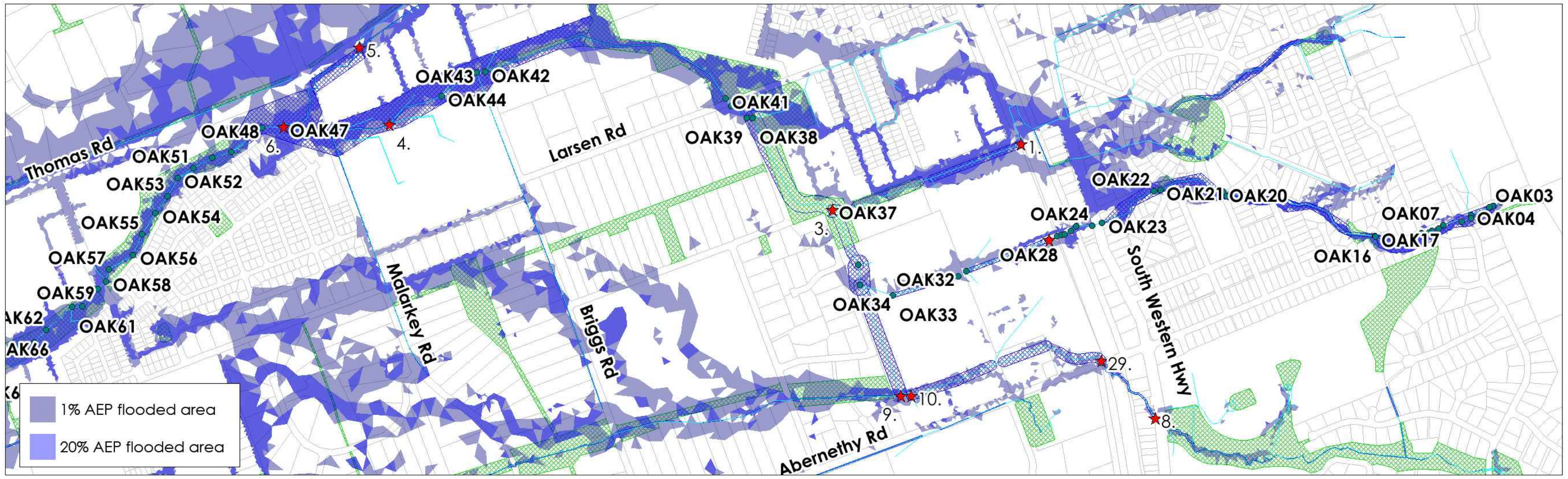
ISSUE	DATE	DESIGN	CHECK
A	19 Jun 2018	AN	HB

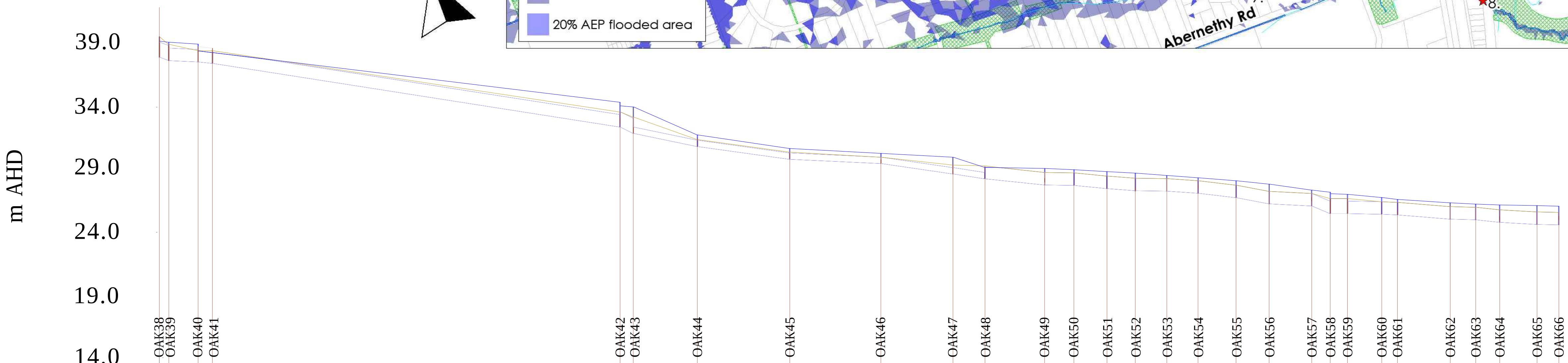
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

land and water solutions





Node	Chainage (m)	ground (m AHD)	20% level (m AD)
OAK38	2803	39.600	39.621
OAK39	2822	39.000	39.176
OAK40	2881	38.500	39.016
OAK41	2909	38.500	38.340
OAK42	3722	33.600	33.784
OAK43	3749	33.200	33.665
OAK44	3877	31.400	31.778
OAK45	4061	30.400	30.697
OAK46	4243	30.000	30.312
OAK47	4387	29.370	29.632
OAK48	4451	29.300	29.190
OAK49	4570	28.780	29.095
OAK50	4628	28.750	29.002
OAK51	4694	28.500	28.853
OAK52	4750	28.330	28.738
OAK53	4813	28.290	28.537
OAK54	4876	28.120	28.356
OAK55	4952	27.770	28.120
OAK56	5017	27.270	27.849
OAK57	5102	27.100	27.379
OAK58	5140	26.700	27.210
OAK59	5174	26.700	27.046
OAK60	5242	26.450	26.783
OAK61	5274	26.400	26.638
OAK62	5379	26.060	26.356
OAK63	5430	26.000	26.255
OAK64	5477	25.800	26.191
OAK65	5552	25.630	26.135
OAK66	5596		

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	20% flow (m3/s)
1220	1200	37.970	37.720	3.24597
2000	1000	37.700	37.600	9.42160
1220	1220	37.600	37.480	2.84347
2500	1000	37.480	32.400	8.80329
1880	1220	32.400	31.900	4.67979
1000	500	31.900	30.848	3.05772
1000	500	30.848	29.840	1.82640
1000	500	29.840	29.500	1.30190
1000	500	29.500	28.670	1.47821
1000	500	28.670	28.280	2.53206
1000	1000	28.280	27.780	3.28232
1000	1000	27.780	27.750	4.38717
1000	1000	27.750	27.500	5.37052
1000	1000	27.498	27.330	5.08790
1000	1000	27.330	27.290	6.63235
1000	1000	27.290	27.120	6.70125
1000	1000	27.120	26.770	6.81549
1000	1000	26.770	26.270	7.28445
1000	1000	26.270	26.100	7.99779
1000	1000	26.100	25.500	7.36908
1200	1200	25.500	25.500	2.03356
1000	1000	25.500	25.450	6.71308
1000	1000	25.450	25.400	7.25548
1000	1000	25.400	25.060	6.11449
1000	1000	25.060	25.000	5.53252
1000	1000	25.000	24.800	5.40666
1000	1000	24.800	24.630	5.24465
1000	1000	24.630	24.600	5.08376

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.13 - Oaklands Drain - 20% AEP (Sheet 2 of 4)

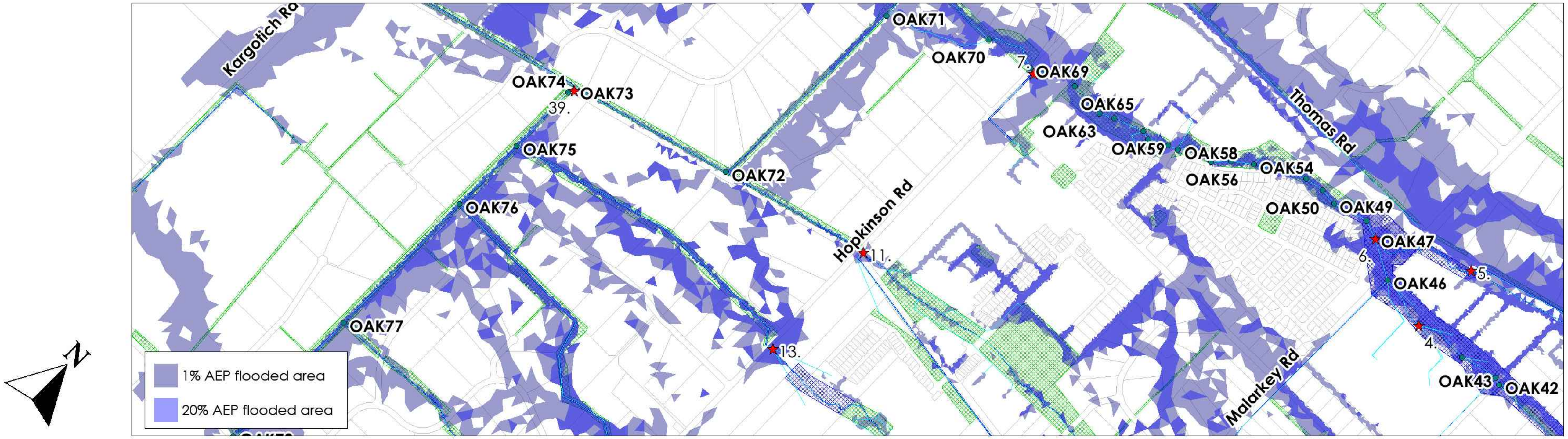
ISSUE	DATE	DESIGN	CHECK
A	19 Jun 2018	AN	HB

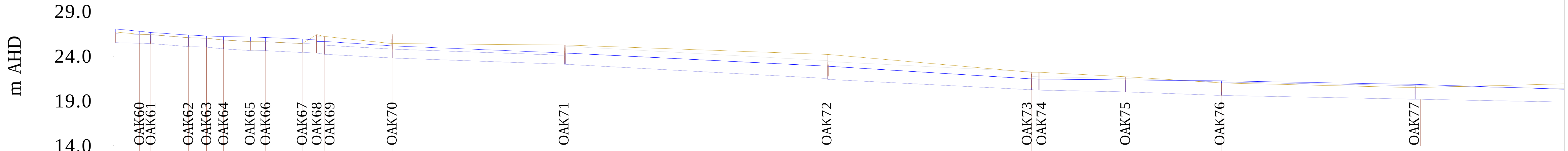
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua land and water solutions





Node	Chainage (m)	ground (m AHD)	20% level (m AD)
OAK60	5242	26.450	26.783
OAK61	5274	26.400	26.638
OAK62	5379	26.060	26.356
OAK63	5430	26.000	26.255
OAK64	5477	25.800	26.191
OAK65	5552	25.630	26.135
OAK66	5596	25.600	26.084
OAK67	5698	25.400	25.914
OAK68	5739	26.400	25.797
OAK69	5760	26.200	25.635
OAK70	5950	25.400	25.138
OAK71	6434	25.255	24.354
OAK72	7171	24.182	22.872
OAK73	7741	22.200	21.454
OAK74	7762	22.200	21.439
OAK75	8005	21.700	21.350
OAK76	8274	21.000	21.250
OAK77	8815	20.492	20.837

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	20% flow (m3/s)
1000	1000	25.500	25.450	6.71308
1000	1000	25.450	25.400	7.25548
1000	1000	25.400	25.060	6.11449
1000	1000	25.060	25.000	5.53252
1000	1000	25.000	24.800	5.40666
1000	1000	24.800	24.630	5.24465
1000	1000	24.630	24.600	5.08376
1000	1000	24.600	24.400	5.31968
1000	1000	24.400	24.340	6.05687
3600	1900	24.340	24.220	6.74438
2000	1000	24.220	23.797	7.12482
2000	1000	23.797	23.100	5.74213
2000	2000	23.100	21.500	7.08827
2000	2000	21.400	20.250	9.83062
5000	1500	20.250	20.200	3.57488
2000	1500	20.200	20.000	3.56768
2000	1500	20.000	19.600	4.61034
2000	1500	19.600	19.200	6.43371
2000	1500	19.200	18.800	7.85620

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.13 - Oaklands Drain - 20% AEP (Sheet 3 of 4)

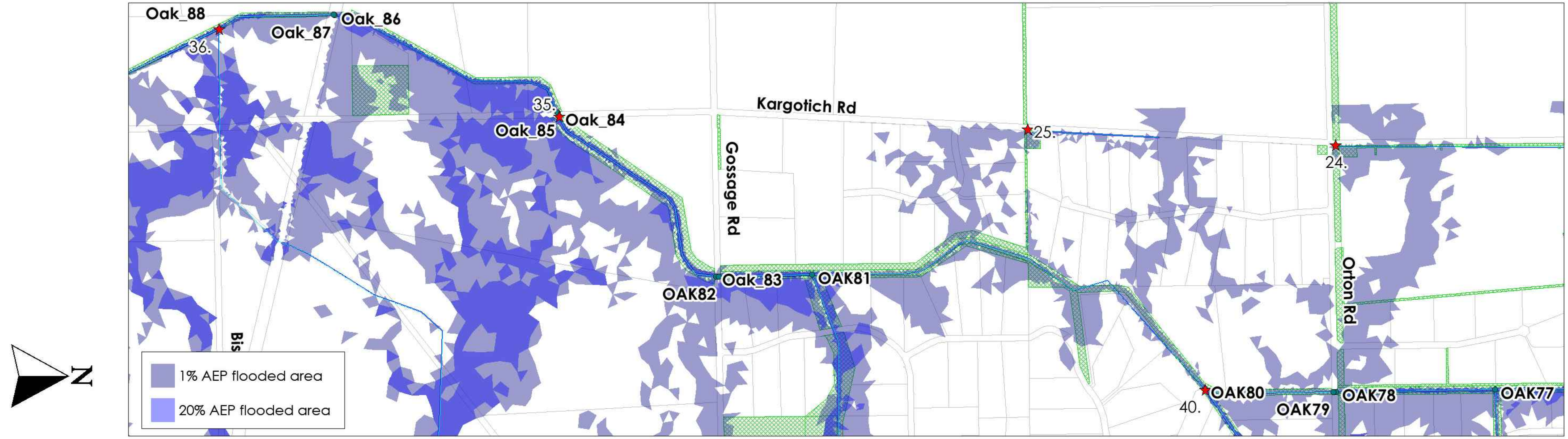
ISSUE	DATE	DESIGN	CHECK
A	20 Jun 2018	AN	HB

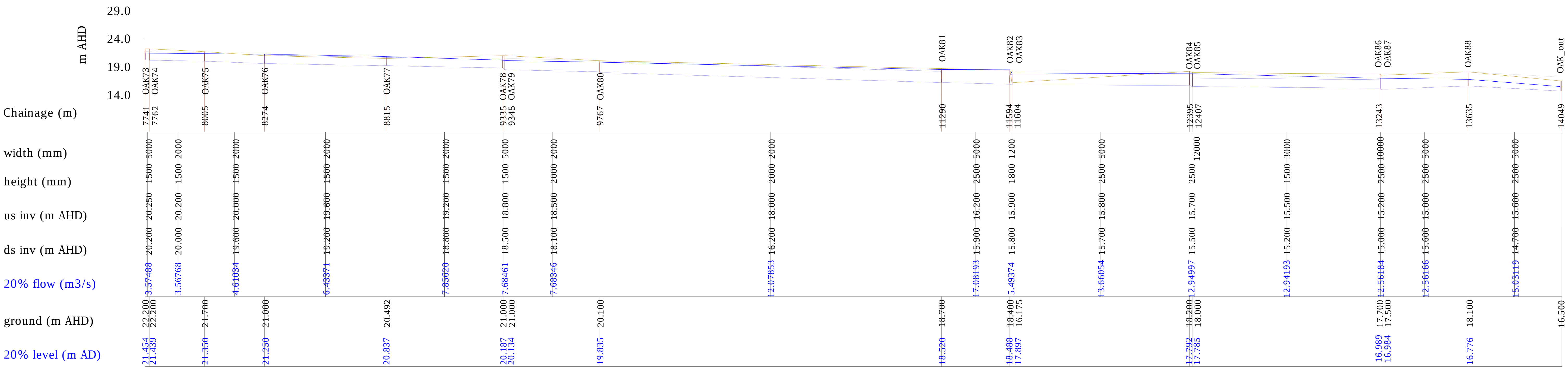
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua
land and water solutions





Shire of Serpentine-Jarrahdale - Byford DWMS

Figure C2.13 - Oaklands Drain - 20% AEP (Sheet 4 of 4)

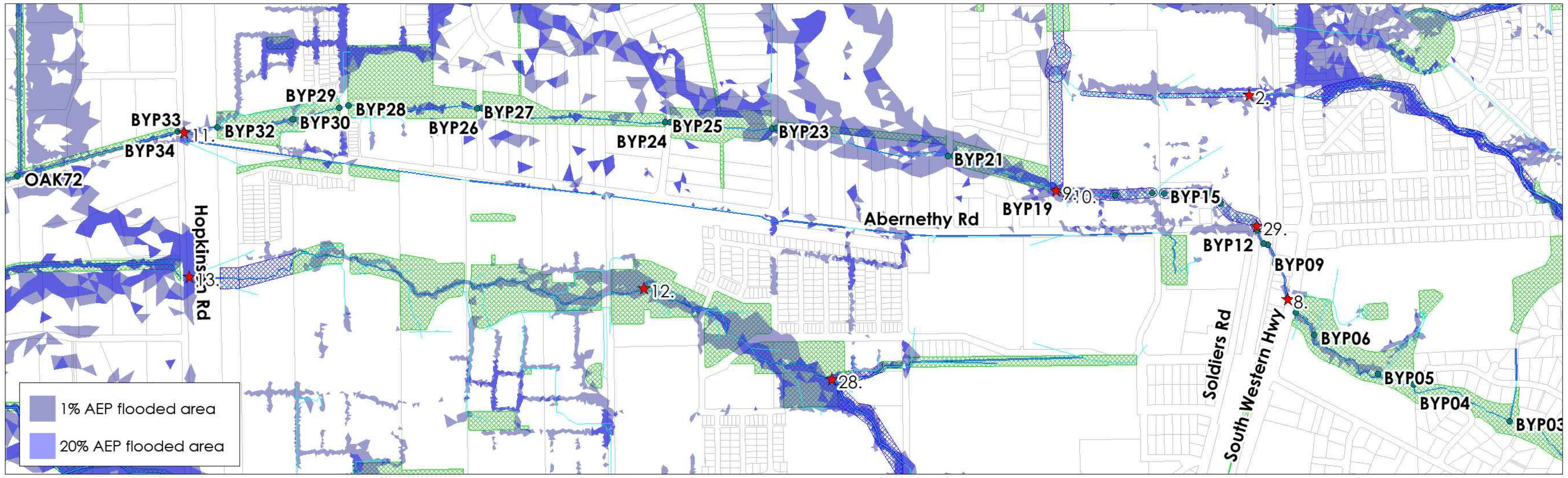
ISSUE	DATE	DESIGN	CHECK
A	19 Jun 2018	AN	HB

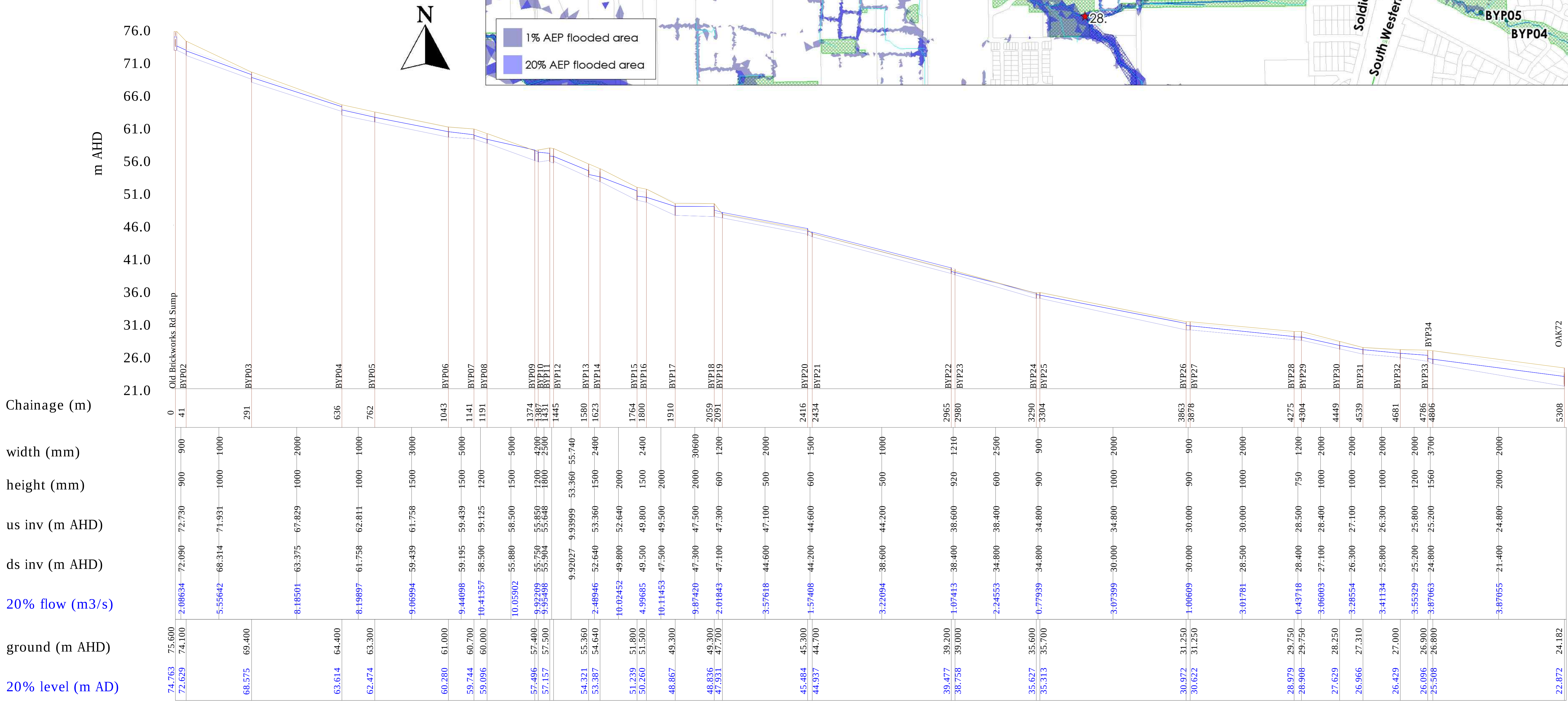
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua land and water solutions





Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.14 - Beenyup Brook - 20% AEP

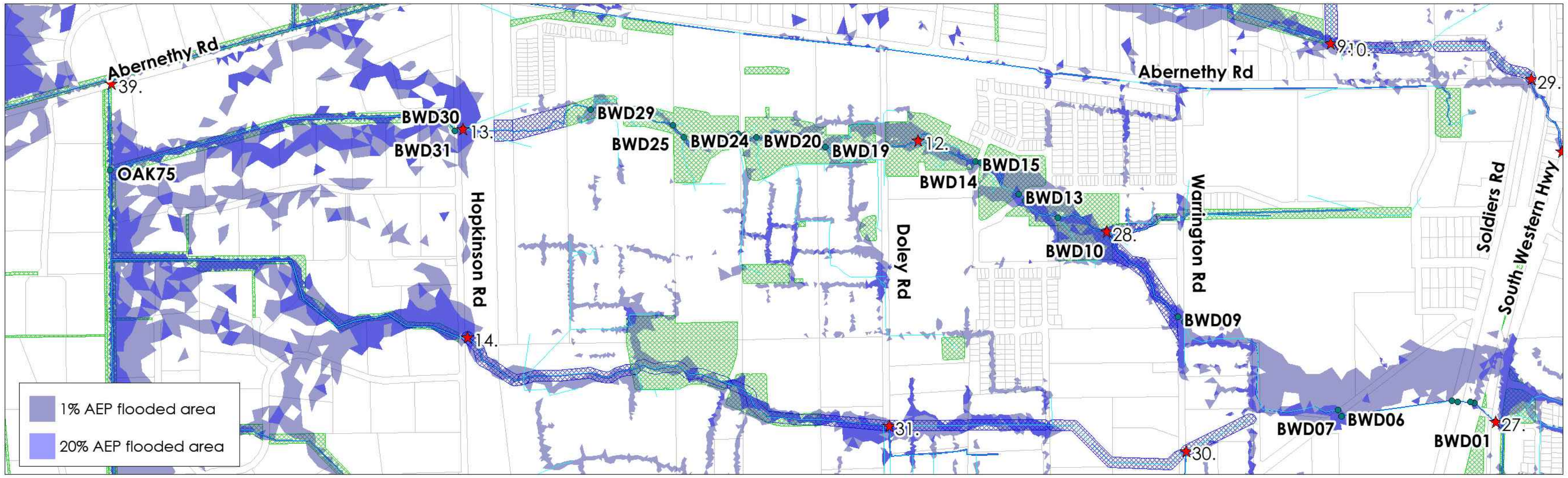
ISSUE	DATE	DESIGN	CHECK
A	18 Jun 2018	AN	HB

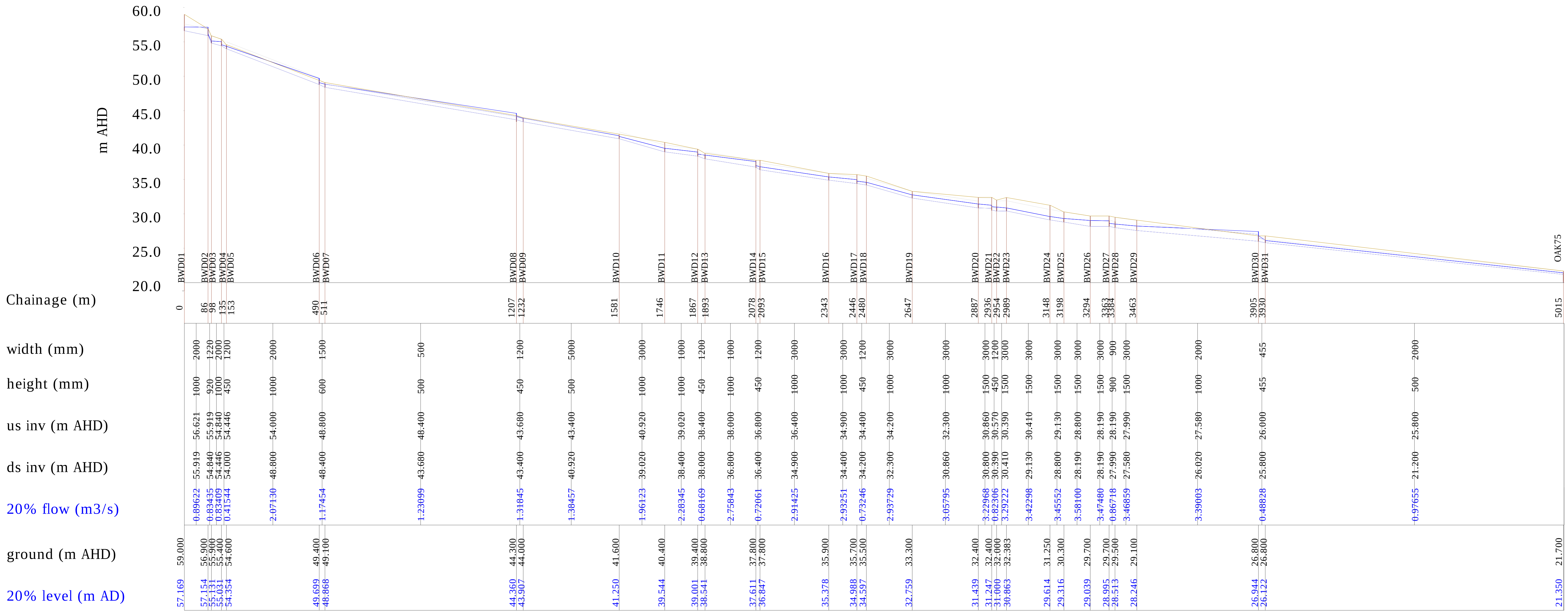
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua
land and water solutions





Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.15 - Brickwood Drain - 20% AEP

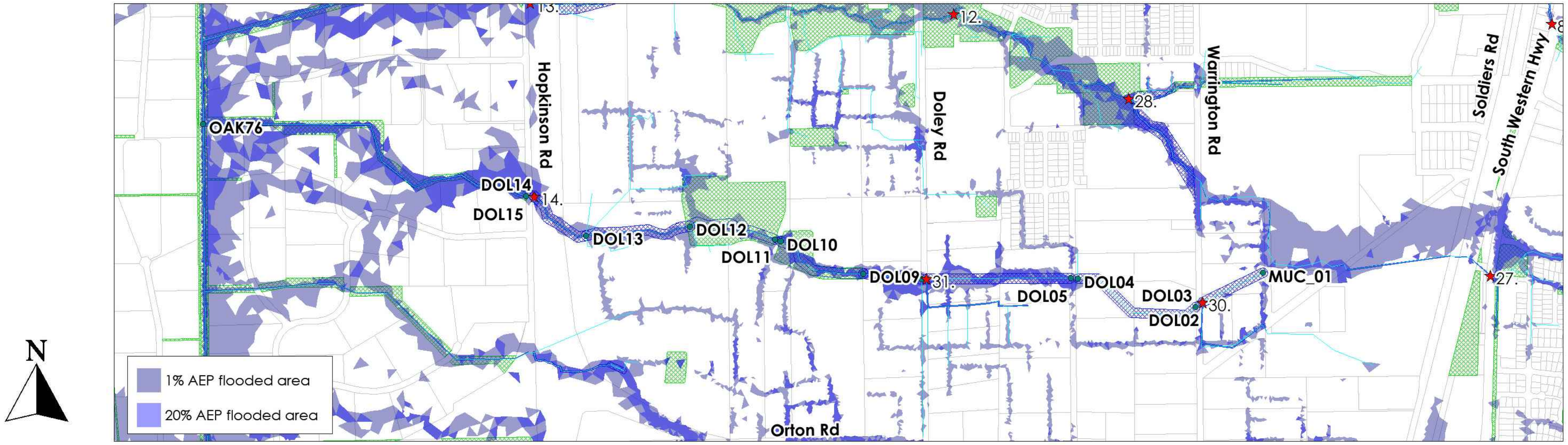
ISSUE	DATE	DESIGN	CHECK
A	18 Jun 2018	AN	HB

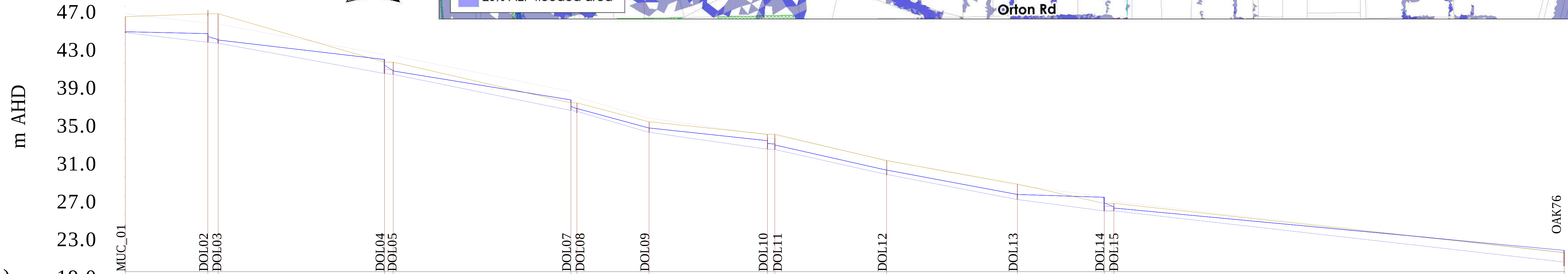
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A
Datum: N/A

urbaqua
land and water solutions





Node	Chainage (m)	ground (m AHD)	20% level (m AD)
MUC_01	0	45.900	44.306
DOL02	218	46.200	44.113
DOL03	245	46.200	43.422
DOL04	683	41.100	41.377
DOL05	706	41.100	40.174
DOL07	1175	36.800	37.116
DOL08	1191	36.800	36.204
DOL09	1382	34.800	34.142
DOL10	1694	33.500	32.822
DOL11	1713	33.500	32.349
DOL12	2008	30.700	29.702
DOL13	2353	28.230	27.132
DOL14	2582	26.200	26.501
DOL15	2607	26.200	25.708
OAK76	3795	21.000	21.250

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	20% flow (m3/s)
32000	2000	44.200	43.200	0.00154
450	450	43.200	43.100	0.32943
32000	2000	43.100	39.900	0.65885
450	450	39.900	39.800	0.47716
32000	2000	39.800	36.000	0.99812
1200	600	36.150	35.755	0.94950
2000	1500	35.900	33.690	1.06593
2000	1500	33.690	31.910	2.26807
1200	1200	31.910	31.870	1.14507
2000	1500	31.880	29.250	3.06405
3000	1500	29.250	26.600	3.31928
4000	1500	26.600	25.400	4.17039
1200	500	25.400	25.400	1.76874
5000	1000	25.400	20.000	1.76874

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.16 - Doley Precinct Drain - 20% AEP

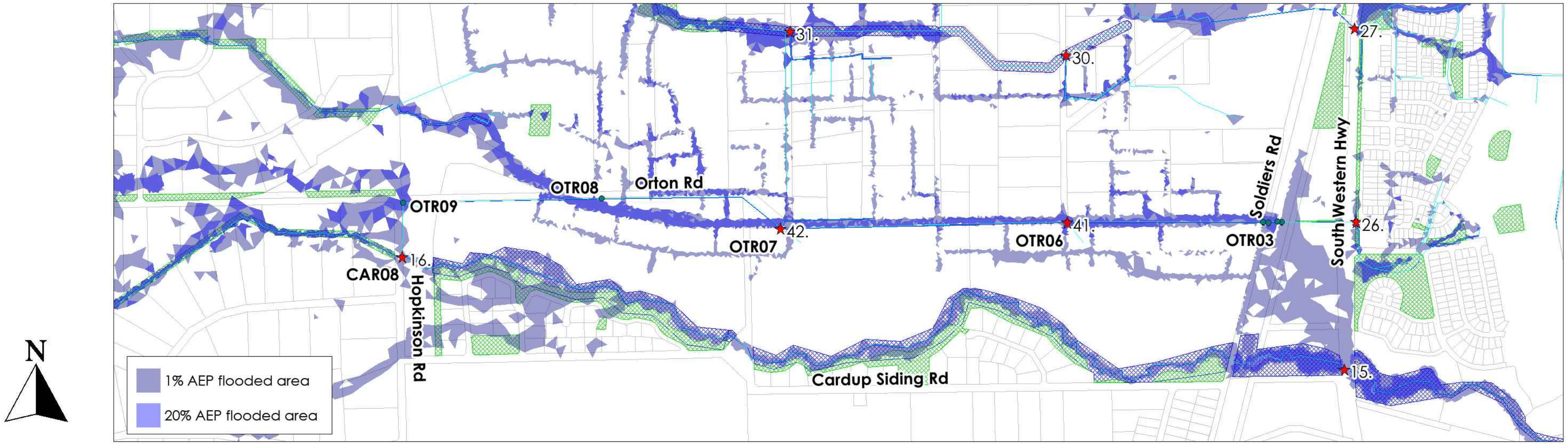
ISSUE	DATE	DESIGN	CHECK
A	20 Jun 2018	AN	HB

DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A
Datum: N/A

urbaqua land and water solutions



Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.17 - Orton Rd Drain - 20% AEP

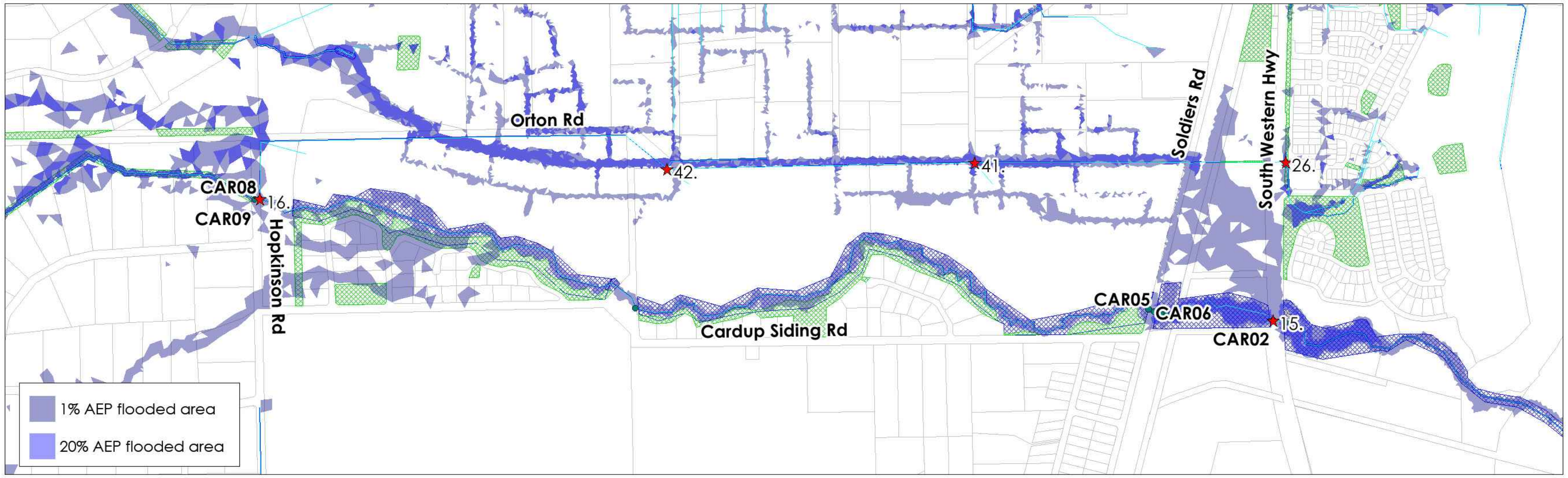
ISSUE	DATE	DESIGN	CHECK
A	20 Jun 2018	AN	HB

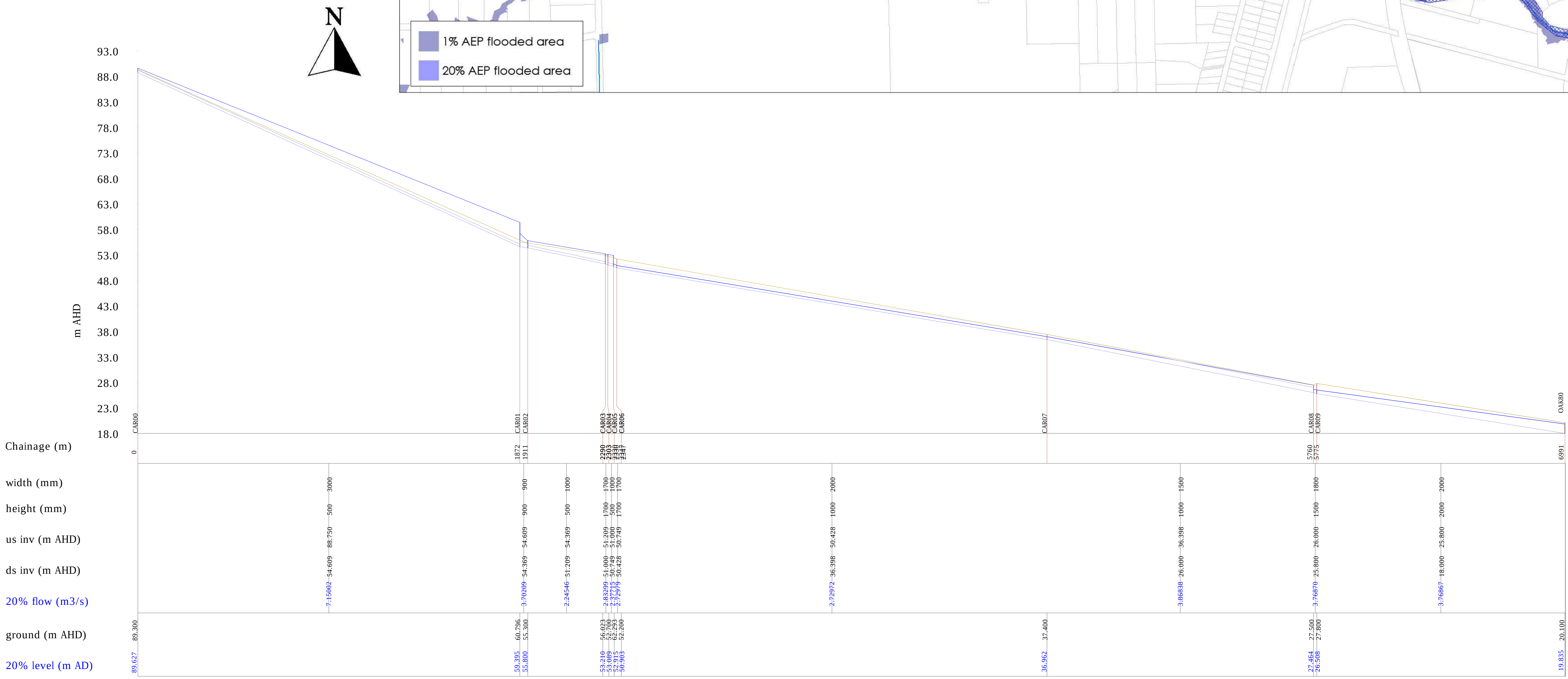
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A
Datum: N/A

urbaqua
land and water solutions





Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.18 - Cardup Brook - 20% AEP

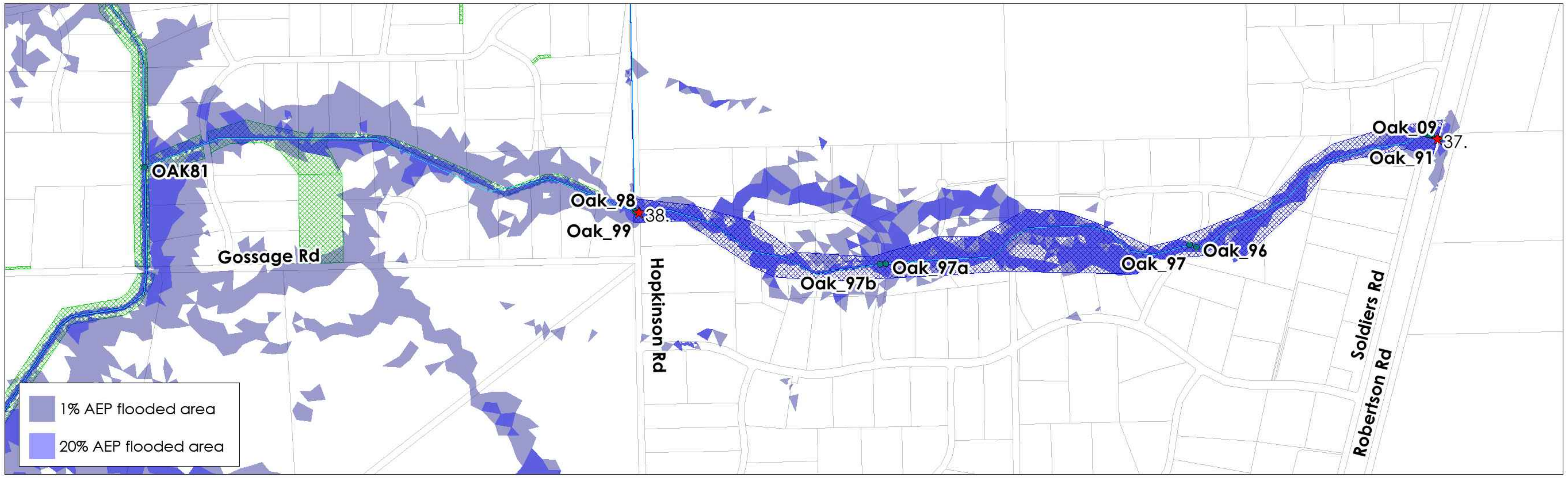
ISSUE	DATE	DESIGN	CHECK
A	20 Jun 2018	AN	HB

DATA SOURCES
Landgate
Depart of Planning

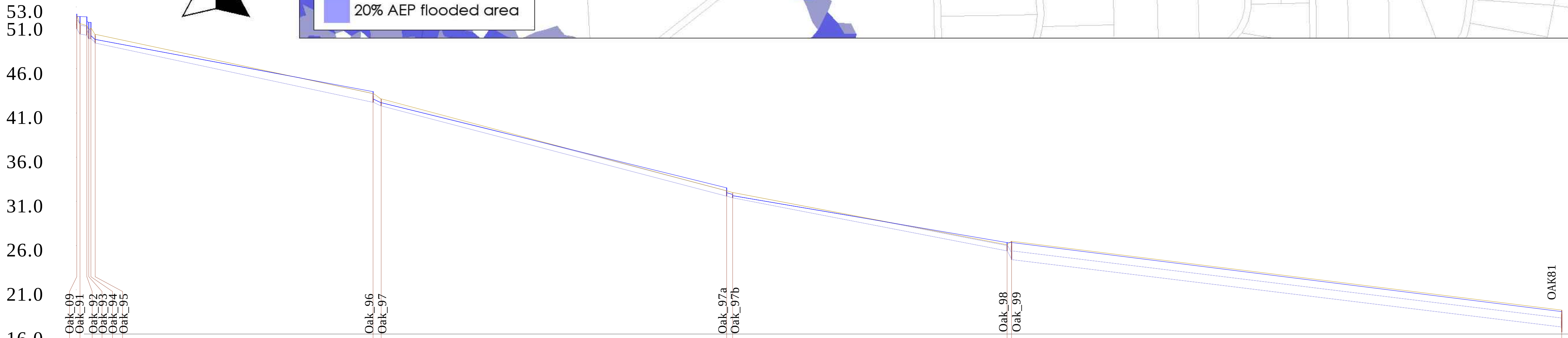
N.T.S

Projection: N/A | Datum: N/A

urbaqua
land and water solutions



N



Node	Chainage (m)	ground (m AHD)	20% level (m AD)
Oak_09	0	52.000	52.204
Oak_91	9	51.100	51.800
Oak_92	28	50.900	51.749
Oak_93	34	50.400	51.261
Oak_94	40	50.600	51.042
Oak_95	52	49.900	49.322
Oak_96	837	43.200	43.350
Oak_97	860	42.600	42.155
Oak_97a	1836	32.200	32.528
Oak_97b	1853	32.000	31.630
Oak_98	2628	26.100	26.345
Oak_99	2641	26.500	26.343
OAK81	4195	18.700	18.520

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	20% flow (m3/s)
1100	1100	50.520	49.930	1.84800
1000	1000	49.930	49.800	3.94723
600	600	49.800	49.400	0.80848
1000	1000	49.400	49.400	3.49337
750	750	49.400	49.000	0.82855
1000	1000	48.900	42.200	1.75647
750	750	42.200	41.800	0.70428
2000	600	41.800	31.600	1.56942
600	600	31.600	31.400	0.50663
2000	600	31.400	25.400	0.59416
1200	700	25.400	24.500	0.59981
1500	1000	24.400	16.800	7.25917

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.19 - Cardup Drain - 1% AEP

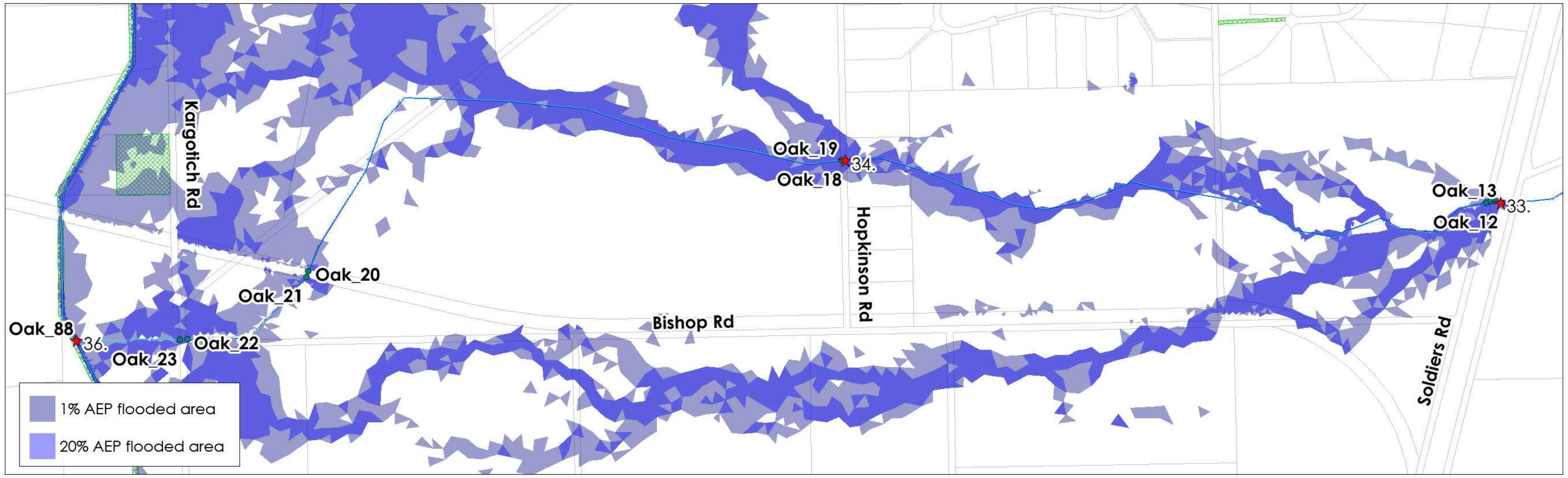
ISSUE	DATE	DESIGN	CHECK
A	20 Jun 2018	AN	HB

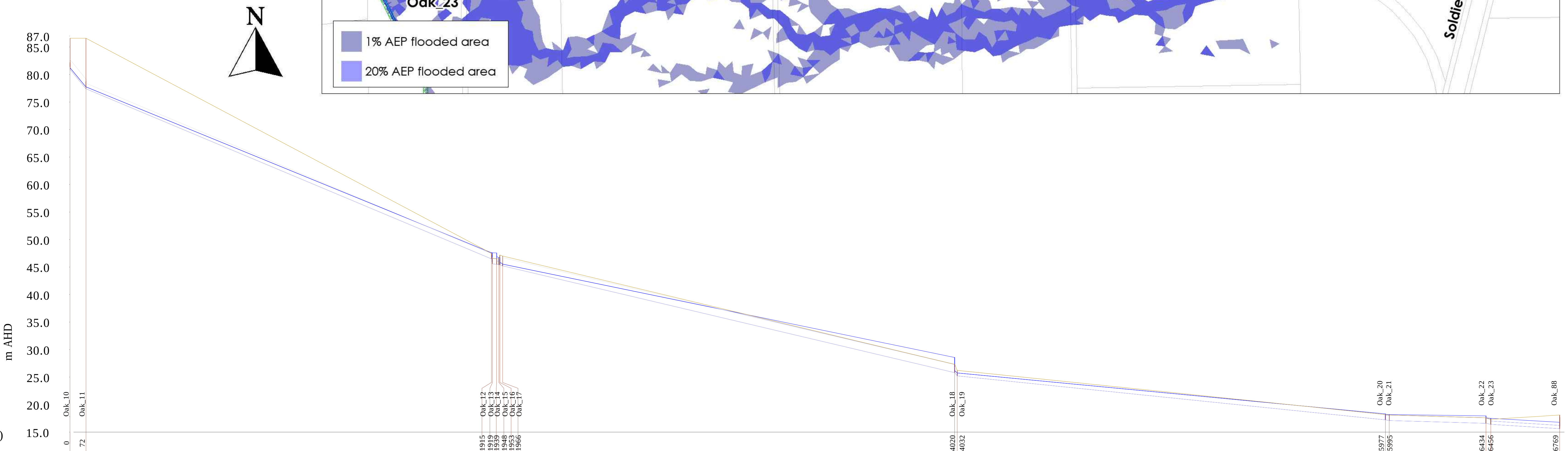
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua
land and water solutions





width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	20% flow (m3/s)
1800	1800	80.900	77.400	0.98832
2000	1000	77.400	46.500	1.97409
9500	1000	46.500	45.600	2.71706
2000	1000	45.600	45.500	6.25211
600	600	45.500	45.500	0.88316
2000	1000	45.500	45.400	1.50550
1800	1800	45.400	45.200	1.51523
3000	1500	45.200	25.800	1.52829
900	900	25.800	25.200	1.34880
2000	1000	25.200	17.200	2.85590
4000	900	17.200	17.100	4.39377
1000	1000	17.100	16.600	4.38430
900	900	16.600	16.400	1.41768
1000	600	16.400	15.600	2.84209

Node	Chainage (m)	ground (m AHD)	20% level (m AD)
Oak_10	0	86.600	81.837
Oak_11	72	86.600	77.741
Oak_12	1915	47.500	47.618
Oak_13	1919	46.600	47.531
Oak_14	1939	46.500	47.531
Oak_15	1948	46.500	46.683
Oak_16	1953	47.200	46.720
Oak_17	1966	47.000	45.514
Oak_18	4020	27.300	28.555
Oak_19	4032	26.200	25.740
Oak_20	5977	18.200	18.300
Oak_21	5995	18.100	18.192
Oak_22	6434	17.600	17.922
Oak_23	6456	17.300	17.483
Oak_88	6769	18.100	16.776

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.20 - Norman Drain - 20% AEP

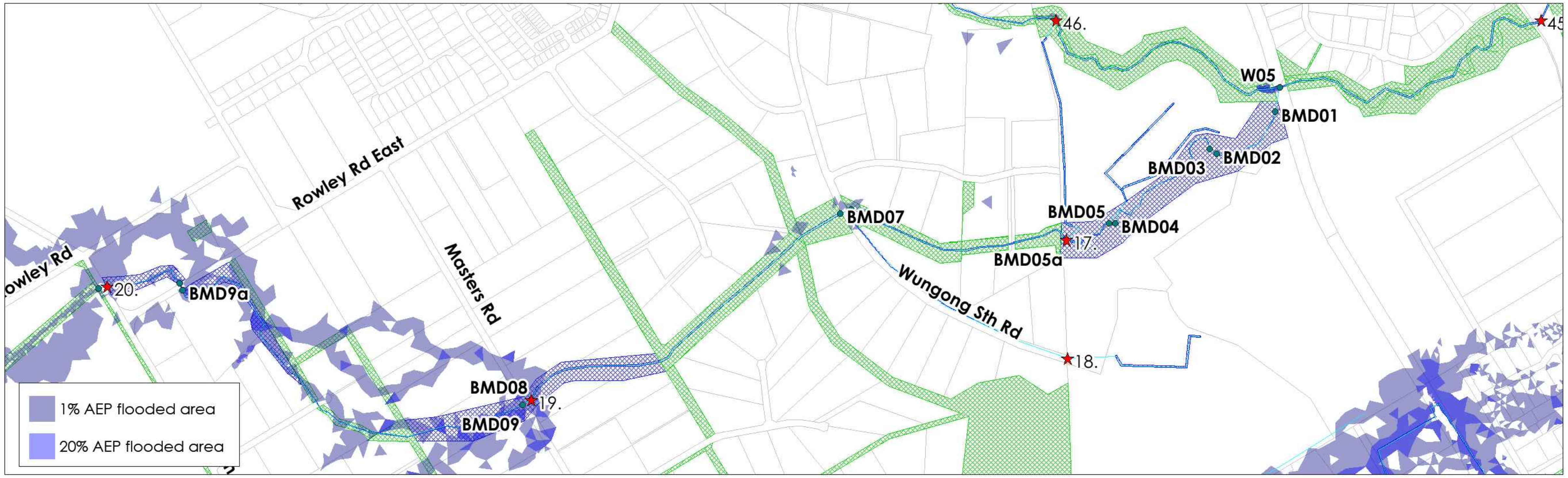
ISSUE	DATE	DESIGN	CHECK
A	18 Jun 2018	AN	HB

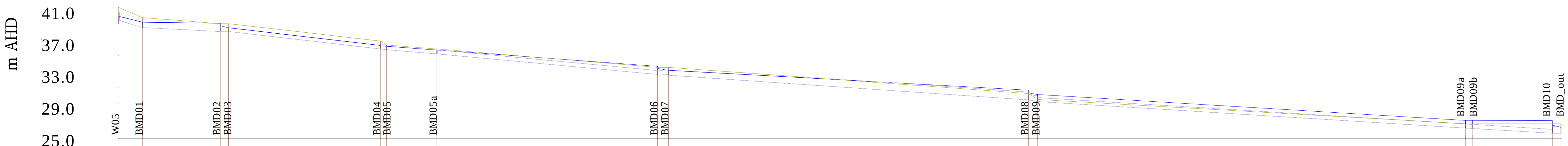
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua land and water solutions





Node	Chainage (m)	ground (m AHD)	1% level (m AD)
W05	0	41.000	39.913
BMD01	75	39.743	39.184
BMD02	319	39.000	39.034
BMD03	346	39.000	38.475
BMD04	825	36.800	36.260
BMD05	844	36.300	36.160
BMD05a	1003	35.800	35.680
BMD06	1700	33.500	33.633
BMD07	1734	33.500	33.137
BMD08	2870	30.200	30.316
BMD09	2900	29.464	29.534
BMD09a	4249	26.400	26.818
BMD09b	4271	26.400	26.816
BMD10	4524	26.400	26.790
BMD_out	4551	26.400	

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	1% flow (m3/s)
1000	1000	39.400	38.500	2.47702
1000	1000	38.500	38.000	2.81052
900	450	38.000	38.000	0.84754
1000	1000	38.000	35.800	1.69506
1200	600	35.800	35.700	0.46347
4000	500	35.700	35.200	2.45084
4000	500	35.200	32.600	2.95123
600	600	32.500	32.600	0.55305
5000	1000	32.500	29.400	5.00255
700	700	29.400	29.200	0.84698
2000	500	29.200	25.876	2.02580
2000	500	25.876	25.822	0.98155
2000	500	25.822	25.200	1.03179
900	900	25.200	25.200	1.78230

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.21 - Birrega Drain - 1% AEP

ISSUE	DATE	DESIGN	CHECK
A	18 Jun 2018	AN	HB

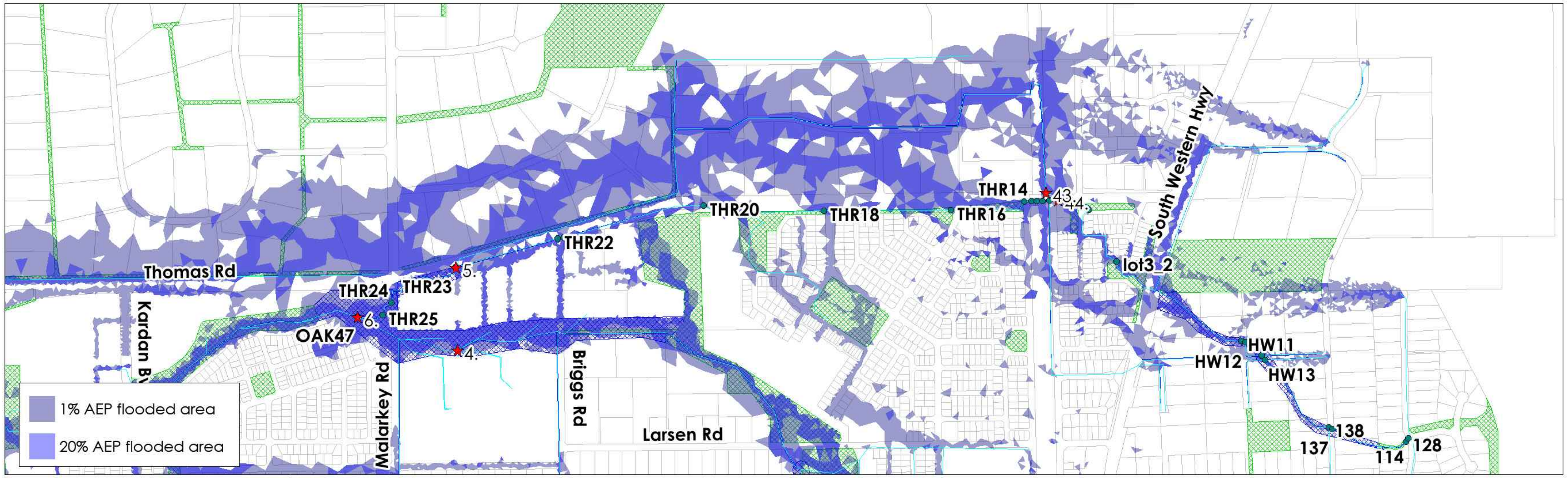
DATA SOURCES
Landgate
Depart of Planning

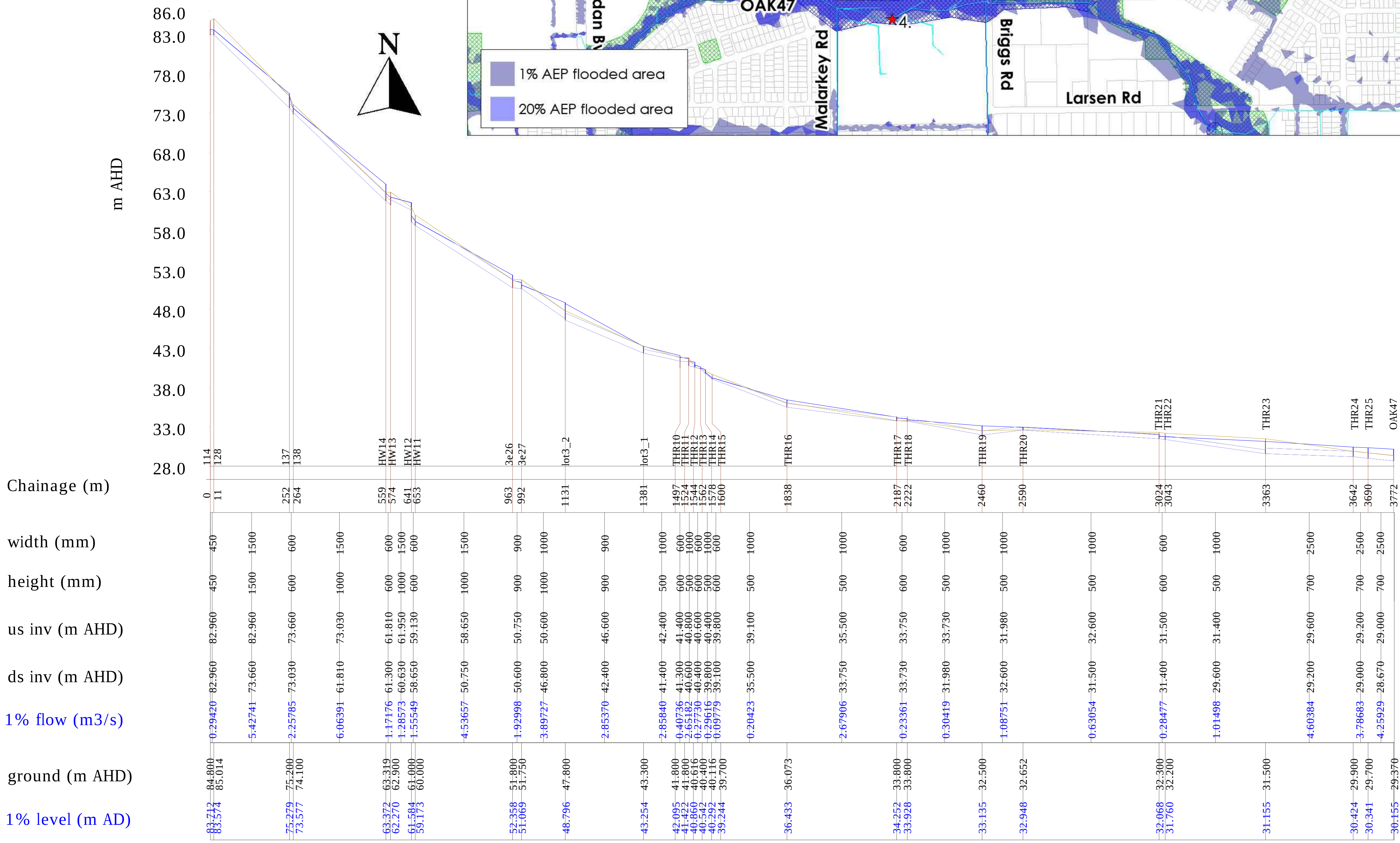
N.T.S

Projection: N/A

Datum: N/A

urbaqua
land and water solutions





Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.22 - Oaklands Drain North - 1% AEP

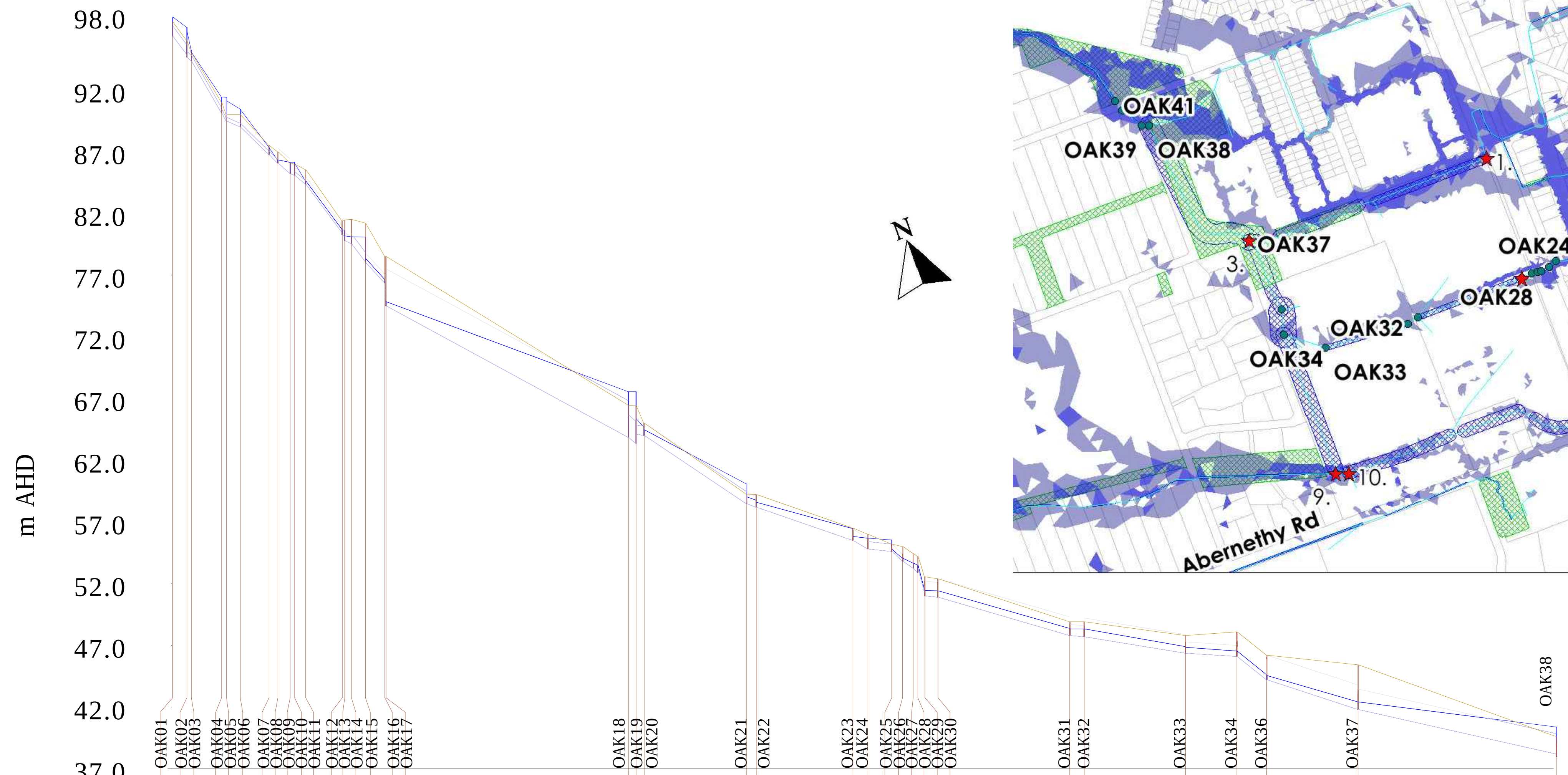
ISSUE	DATE	DESIGN	CHECK
A	19 Jun 2018	AN	HB

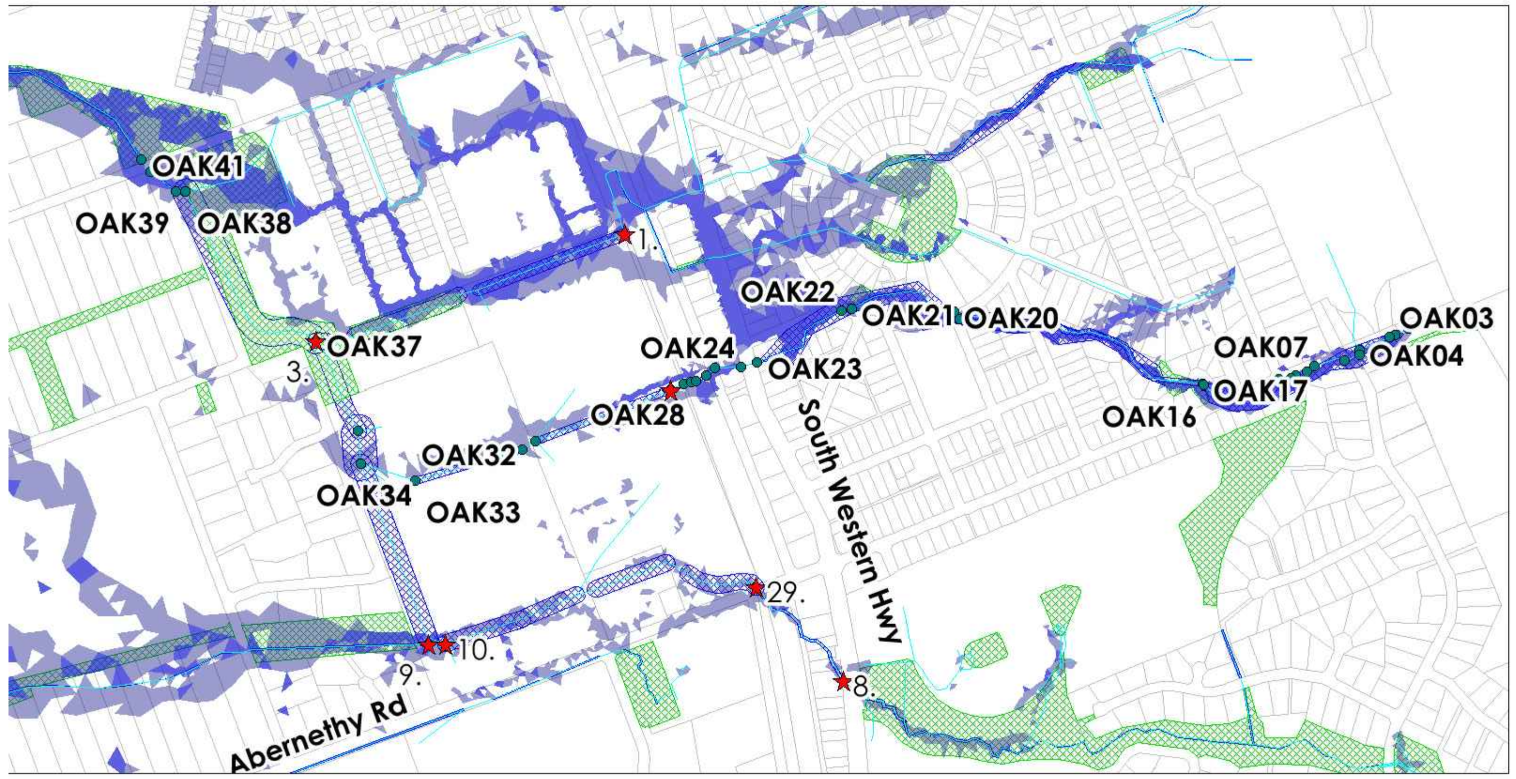
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua land and water solutions





Nodes

Node	Chainage (m)	ground (m AHD)	1% level (m AD)
OAK01	0	97.500	97.701
OAK02	29	96.000	96.316
OAK03	38	95.000	95.098
OAK04	99	91.000	91.436
OAK05	109	90.000	91.421
OAK06	137	90.000	90.454
OAK07	195	87.500	87.376
OAK08	213	87.000	86.337
OAK09	238	86.085	86.137
OAK10	247	85.993	86.130
OAK11	269	85.530	84.624
OAK12	343	81.390	80.682
OAK13	349	81.466	80.630
OAK14	362	81.513	80.096
OAK15	390	81.212	80.086
OAK16	430	78.525	76.525
OAK17		78.500	74.850
OAK18	923	66.458	67.545
OAK19	939	66.414	67.544
OAK20	955	65.000	64.456
OAK21	1163	59.254	60.080
OAK22	1182	59.220	58.593
OAK23	1378	56.500	56.461
OAK24	1408	56.000	55.681
OAK25	1457	55.200	55.533
OAK26	1479	55.000	54.040
OAK27	1500	54.450	53.677
OAK28	1509	54.200	53.511
OAK29	1524	52.560	51.497
OAK30	1550	52.400	51.424
OAK31	1818	48.900	48.376
OAK32	1847	48.900	48.333
OAK33	2052	47.800	46.836
OAK34	2156	48.100	46.536
OAK36	2216	46.200	44.541
OAK37	2401	45.430	42.420
OAK38	2803	39.600	40.375

Conduits

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	1% flow (m3/s)
1000	800	96.360	94.880	6.92845
450	450	94.660	94.340	1.23069
450	450	94.340	90.140	0.74708
300	300	90.140	89.480	0.27475
300	300	89.480	89.010	0.20154
300	300	89.010	86.753	0.23389
300	300	86.753	86.070	0.23768
1000	1200	86.070	85.210	0.46619
900	900	85.220	85.080	0.42593
300	300	85.080	84.360	0.25924
300	600	84.360	80.450	0.25986
450	450	80.280	80.120	0.26098
900	600	79.800	79.550	0.76534
1000	780	79.550	78.090	0.76257
750	750	78.030	76.350	0.81708
750	750			
10000	3000	74.500	63.840	1.91951
1000	1820	63.840	63.350	2.41878
750	750	64.100	64.000	2.47976
2000	1000	64.000	58.460	4.85920
900	900	58.460	58.200	1.55704
2000	1000	58.200	55.500	1.70876
900	900	55.500	54.800	0.55888
500	600	54.800	54.600	1.68110
900	600	54.600	53.800	0.52250
5000	1200	53.800	53.250	1.84689
4000	1200	53.250	52.900	1.94449
1000	1200	53.250	51.250	1.98289
2400	1200	51.000	50.900	0.99124
13000	1500	50.900	47.800	1.98097
3000	900	47.800	47.700	1.16442
13000	1500	47.700	46.369	2.44466
3000	900	46.369	46.100	1.21165
62800	2000	46.100	44.200	11.39890
30000	2000	44.200	41.800	11.49357
49000	1650	41.800	38.200	15.50623

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.23 - Oaklands Drain - 1% AEP (Sheet 1 of 4)

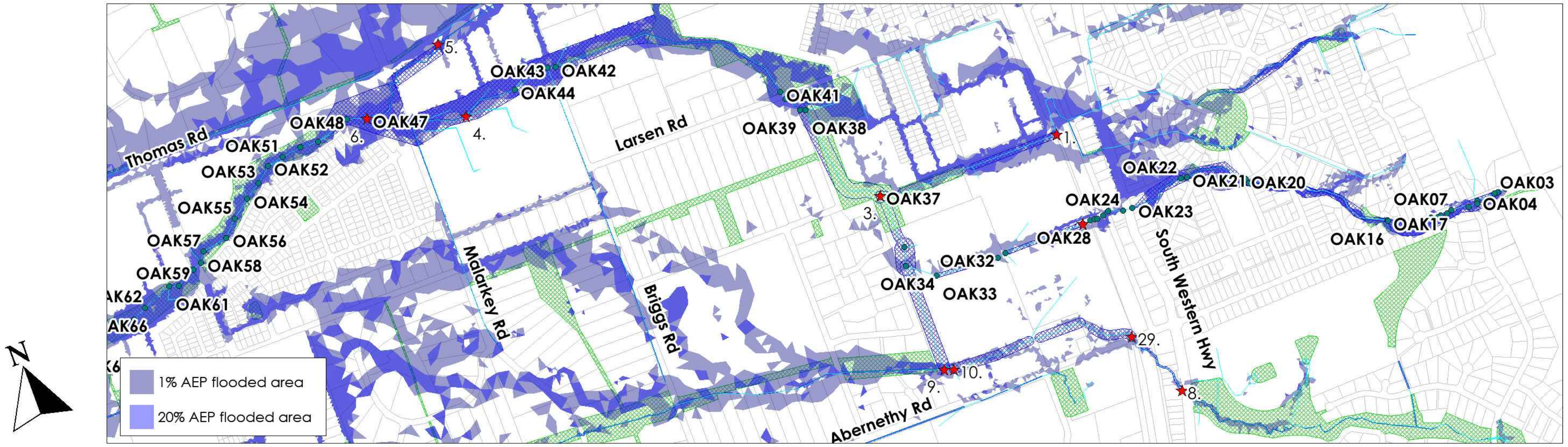
ISSUE	DATE	DESIGN	CHECK
A	19 Jun 2018	AN	HB

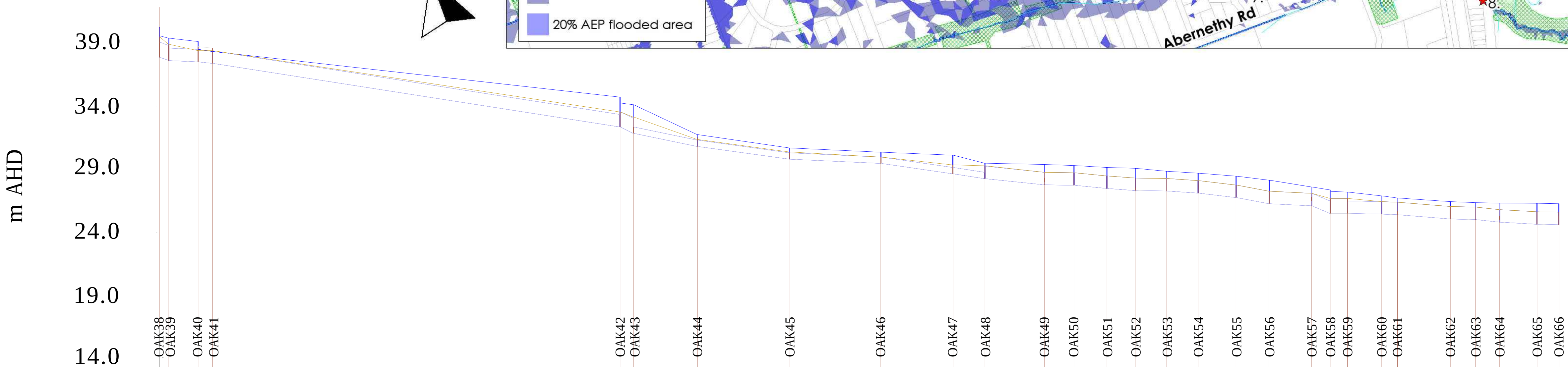
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua
land and water solutions





Node	Chainage (m)	ground (m AHD)	1% level (m AD)
OAK38	2803	39.600	40.375
OAK39	2822	39.000	39.507
OAK40	2881	38.500	39.231
OAK41	2909	38.500	38.427
OAK42	3722	33.600	33.875
OAK43	3749	33.200	33.730
OAK44	3877	31.400	31.803
OAK45	4061	30.400	30.730
OAK46	4243	30.000	30.386
OAK47	4387	29.370	29.792
OAK48	4451	29.300	29.502
OAK49	4570	28.780	29.413
OAK50	4628	28.750	29.327
OAK51	4694	28.500	29.173
OAK52	4750	28.330	29.097
OAK53	4813	28.290	28.868
OAK54	4876	28.120	28.709
OAK55	4952	27.770	28.475
OAK56	5017	27.270	28.156
OAK57	5102	27.100	27.615
OAK58	5140	26.700	27.384
OAK59	5174	26.700	27.213
OAK60	5242	26.450	26.907
OAK61	5274	26.400	26.734
OAK62	5379	26.060	26.449
OAK63	5430	26.000	26.368
OAK64	5477	25.800	26.329
OAK65	5552	25.630	26.304
OAK66	5596		

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	1% flow (m3/s)
1220	1200	37.970	37.720	4.60377
2000	1000	37.700	37.600	12.34386
1220	1220	37.600	37.480	3.50151
2500	1000	37.480	32.400	10.98694
1880	1220	32.400	31.900	6.03433
1000	500	31.900	30.848	3.17579
1000	500	30.848	29.840	1.83915
1000	500	29.840	29.500	1.30552
1000	500	29.500	28.670	1.67403
1000	500	28.670	28.280	2.55735
1000	1000	28.280	27.780	3.26894
1000	1000	27.780	27.750	4.86792
1000	1000	27.750	27.500	5.53922
1000	1000	27.498	27.330	5.21518
1000	1000	27.330	27.290	6.95992
1000	1000	27.290	27.120	6.64150
1000	1000	27.120	26.770	6.81861
1000	1000	26.770	26.270	7.75455
1000	1000	26.270	26.100	8.81786
1000	1000	26.100	25.500	8.68412
1200	1200	25.500	25.500	2.02798
1000	1000	25.500	25.450	7.25396
1000	1000	25.450	25.400	8.08344
1000	1000	25.400	25.060	6.22531
1000	1000	25.060	25.000	5.69363
1000	1000	25.000	24.800	5.55016
1000	1000	24.800	24.630	5.27052
1000	1000	24.630	24.600	5.25000

Shire of Serpentine-Jarrahdale - Byford DWMS

Figure C2.23 - Oaklands Drain - 1% AEP (Sheet 2 of 4)

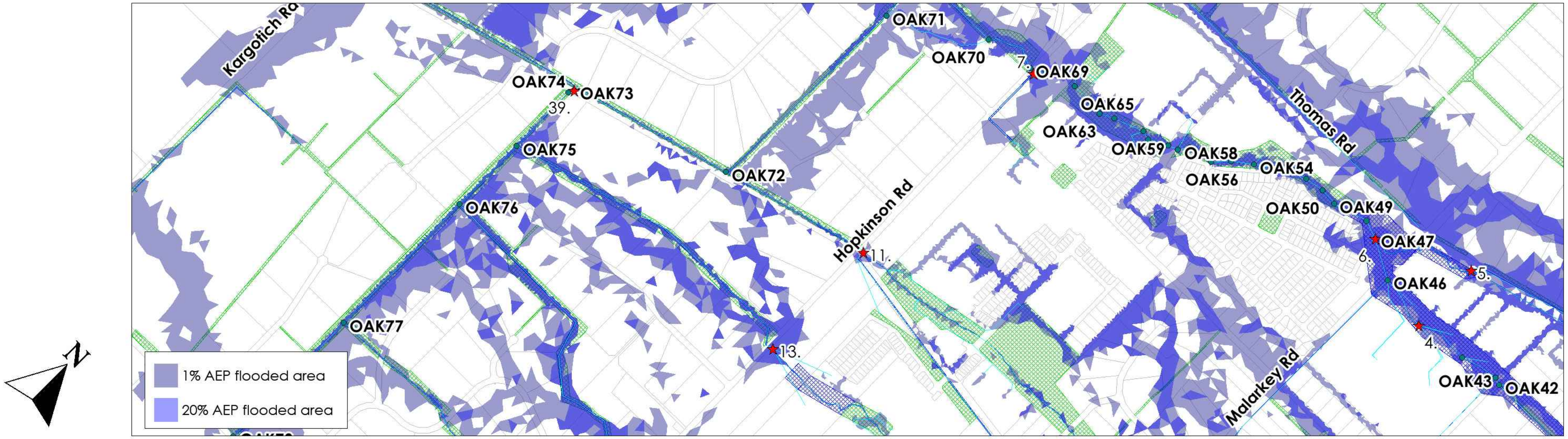
ISSUE	DATE	DESIGN	CHECK
A	19 Jun 2018	AN	HB

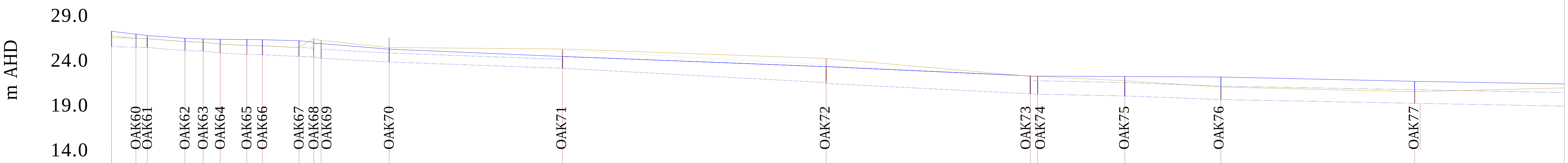
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua land and water solutions





Node	Chainage (m)	ground (m AHD)	1% level (m AD)
OAK60	5242	26.450	26.907
OAK61	5274	26.400	26.734
OAK62	5379	26.060	26.449
OAK63	5430	26.000	26.368
OAK64	5477	25.800	26.329
OAK65	5552	25.630	26.304
OAK66	5596	25.600	26.275
OAK67	5698	25.400	26.169
OAK68	5739	26.400	26.000
OAK69	5760	26.200	25.840
OAK70	5950	25.400	25.229
OAK71	6434	25.255	24.403
OAK72	7171	24.182	23.271
OAK73	7741	22.200	22.231
OAK74	7762	22.200	22.210
OAK75	8005	21.700	22.171
OAK76	8274	21.000	22.127
OAK77	8815	20.492	21.632

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	1% flow (m3/s)
1000	1000	25.500	25.450	7.25396
1000	1000	25.450	25.400	8.08344
1000	1000	25.400	25.060	6.22531
1000	1000	25.060	25.000	5.69363
1000	1000	25.000	24.800	5.55016
1000	1000	24.800	24.630	5.27052
1000	1000	24.630	24.600	5.25000
1000	1000	24.600	24.400	5.37274
1000	1000	24.400	24.340	7.31329
3600	1900	24.340	24.220	7.88713
2000	1000	24.220	23.797	8.32936
2000	1000	23.797	23.100	6.16132
2000	2000	23.100	21.500	7.76097
2000	2000	21.400	20.250	16.53037
5000	1500	20.250	20.200	4.36759
2000	1500	20.200	20.000	4.36706
2000	1500	20.000	19.600	5.47500
2000	1500	19.600	19.200	7.44195
2000	1500	19.200	18.800	9.86135

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.23 - Oaklands Drain - 1% AEP (Sheet 3 of 4)

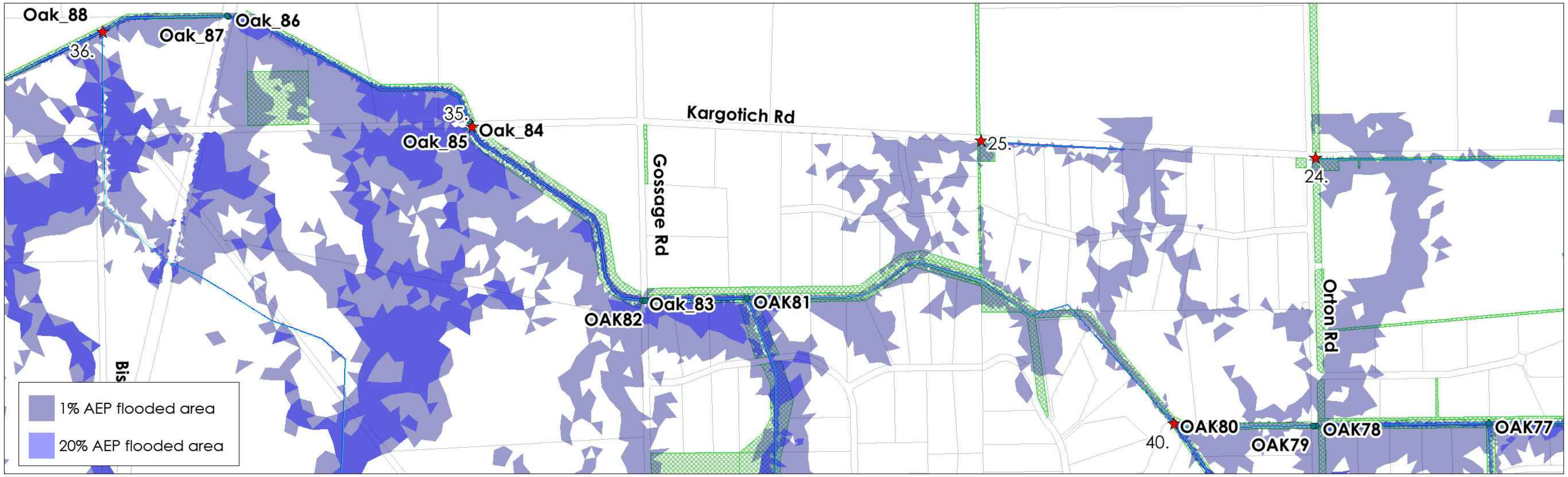
ISSUE	DATE	DESIGN	CHECK
A	19 Jun 2018	AN	HB

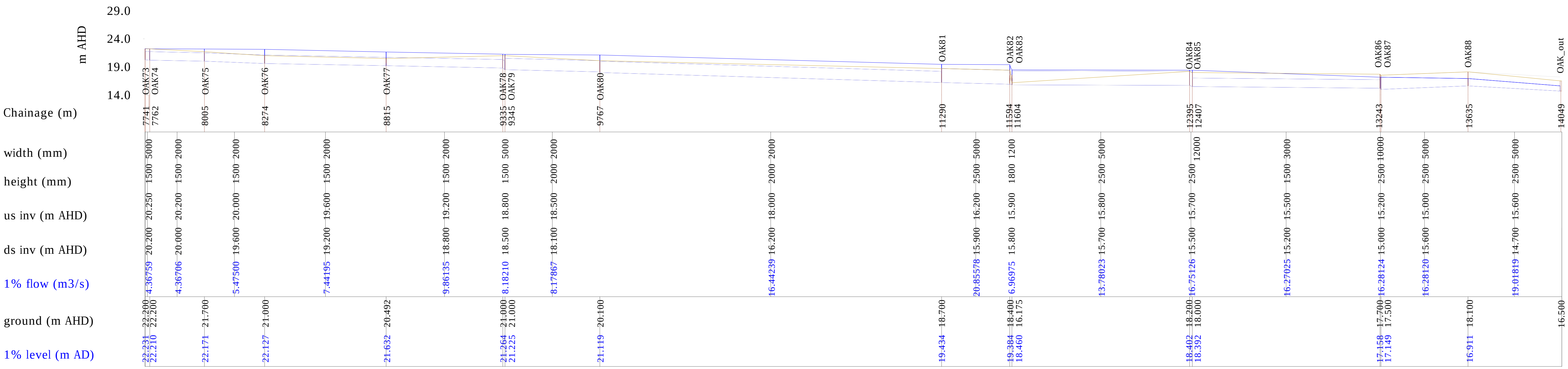
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua
land and water solutions





Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.23 - Oaklands Drain - 1% AEP (Sheet 4 of 4)

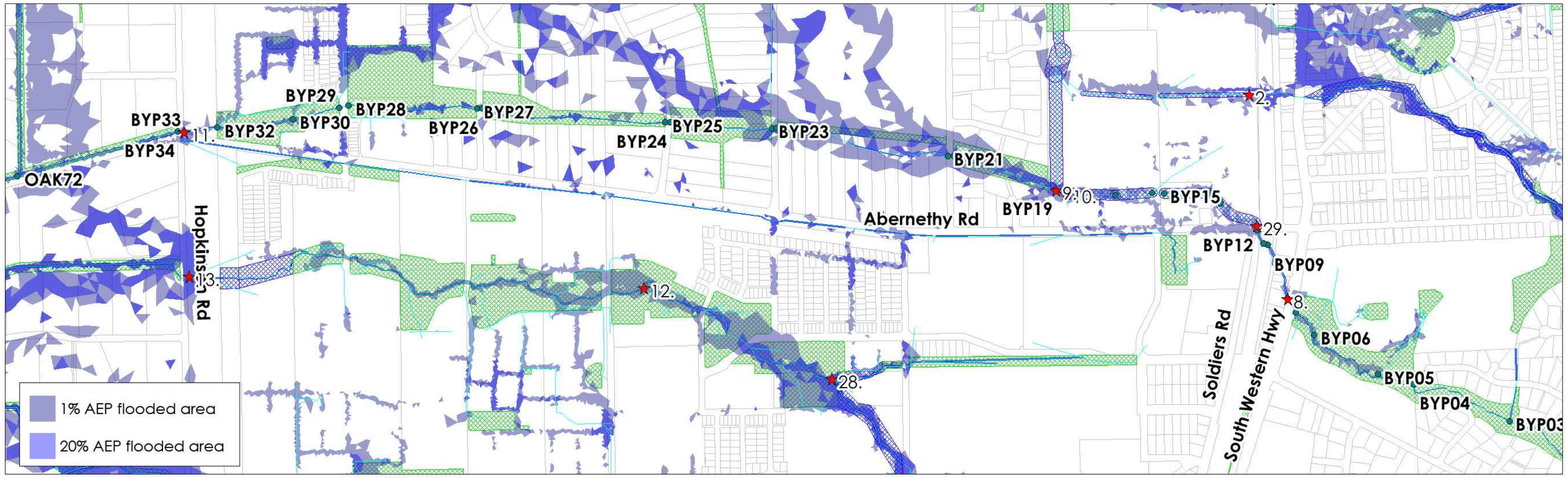
ISSUE	DATE	DESIGN	CHECK
A	19 Jun 2018	AN	HB

DATA SOURCES
Landgate
Depart of Planning

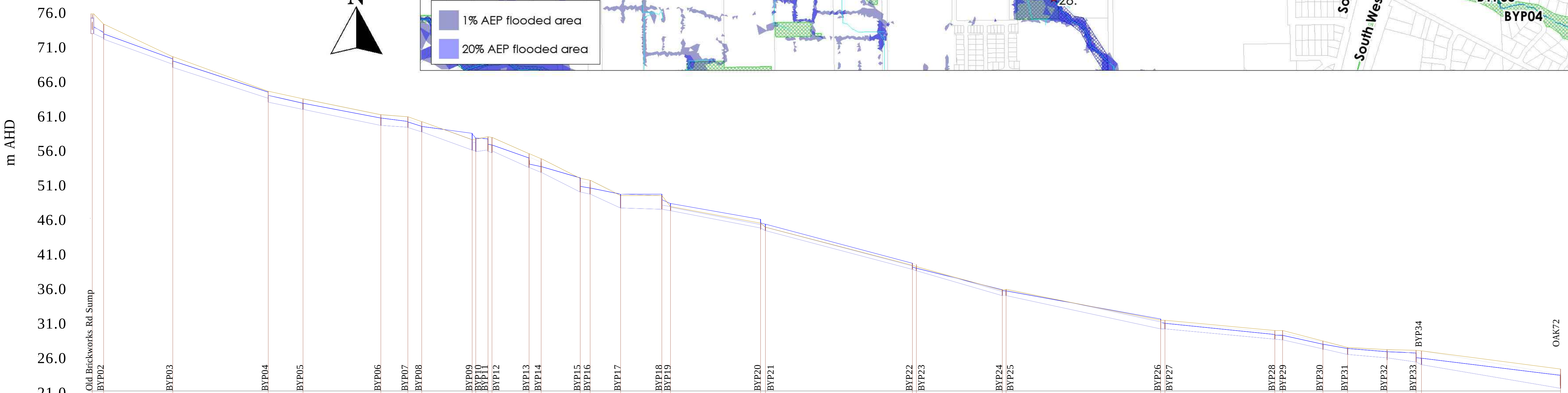
N.T.S

Projection: N/A | Datum: N/A

urbaqua land and water solutions



N



Node	Chainage (m)	ground (m AHD)	1% level (m AD)
Old Brickworks Rd Sump	0	75.600	75.001
BYP02	41	74.100	72.709
BYP03	291	69.400	68.760
BYP04	636	64.400	63.789
BYP05	762	63.300	62.663
BYP06	1043	61.000	60.522
BYP07	1141	60.700	59.957
BYP08	1191	60.000	59.298
BYP09	1374	57.400	57.921
BYP10	1387		57.621
BYP11	1431	57.500	57.485
BYP12	1445		56.604
	30600		
BYP13	1580	55.360	54.742
BYP14	1623	54.640	53.495
BYP15	1764	51.800	51.856
BYP16	1800	51.500	50.371
BYP17	1910	49.300	49.505
BYP18	2059	49.300	49.491
BYP19	2091	47.700	48.145
BYP20	2416	45.300	45.401
BYP21	2434	44.700	45.154
BYP22	2965	39.200	39.328
BYP23	2980	39.000	38.766
BYP24	3290	35.600	35.678
BYP25	3304	35.700	35.485
BYP26	3863	31.250	31.427
BYP27	3878	31.250	30.803
BYP28	4275	29.750	29.178
BYP29	4304	29.750	29.064
BYP30	4449	28.250	27.788
BYP31	4539	27.310	27.163
BYP32	4681	27.000	26.684
BYP33	4786	26.900	26.517
BYP34	4806	26.800	25.749
OAK72	5308	24.182	23.271

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	1% flow (m3/s)
900	900	72.730	72.090	2.69959
1000	1000	71.931	68.314	7.18174
2000	1000	67.829	63.375	13.30791
1000	1000	62.811	61.758	13.64563
3000	1500	61.758	59.439	15.19356
5000	1500	59.439	59.195	16.17821
	1200	59.125	58.500	18.75562
5000	1500	58.500	55.880	17.66467
4200	1200	55.850	55.750	14.22606
2500	1800	55.648	55.904	15.44418
				3.99204
55.740	53.360	9.93999	9.92027	15.93556
2400	1500	53.360	52.640	3.99800
	2000	52.640	49.800	15.96336
2400	1500	49.800	49.500	7.96571
	2000	49.500	47.500	15.62611
	2000	47.500	47.300	14.59589
1200	600	47.300	47.100	2.47859
2000	500	47.100	44.600	3.52906
1500	600	44.600	44.200	2.41167
1000	500	44.200	38.600	2.90637
1210	920	38.600	38.400	1.09713
2500	600	38.400	34.800	2.33501
900	900	34.800	34.800	0.84901
2000	1000	34.800	30.000	5.29725
900	900	30.000	30.000	1.64772
2000	1000	30.000	28.500	
1200	750	28.500	28.400	0.77022
2000	1000	28.400	27.100	5.38343
2000	1000	27.100	26.300	5.65854
2000	1000	26.300	25.800	5.93146
2000	1200	25.800	25.200	6.18922
3700	1560	25.200	24.800	6.99665
2000	2000	24.800	21.400	6.93981

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.24 - Beenyup Brook - 1% AEP

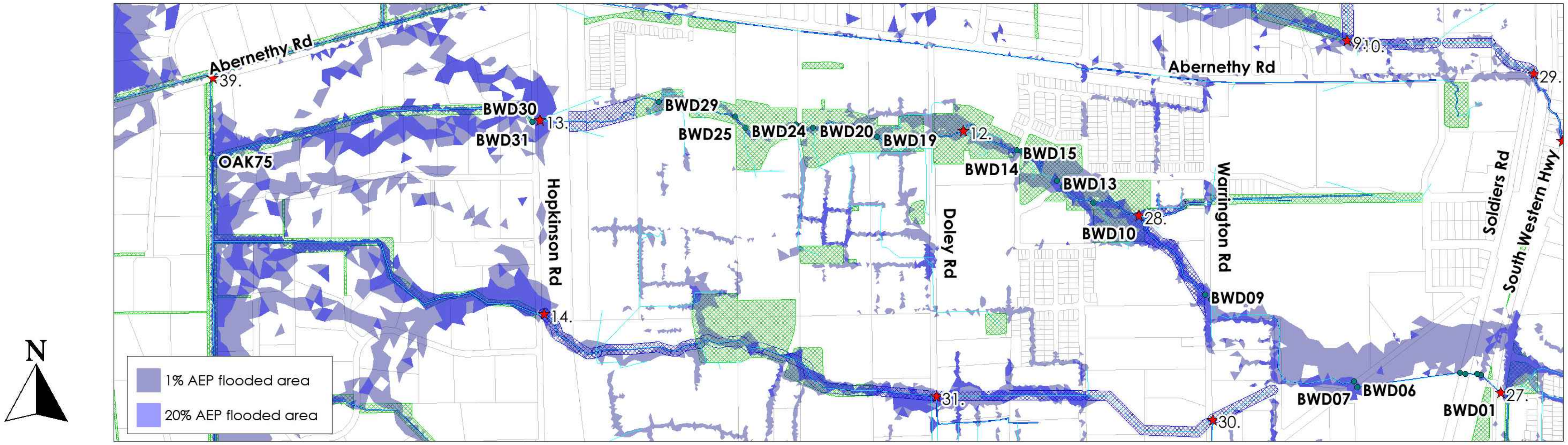
ISSUE	DATE	DESIGN	CHECK
A	18 Jun 2018	AN	HB

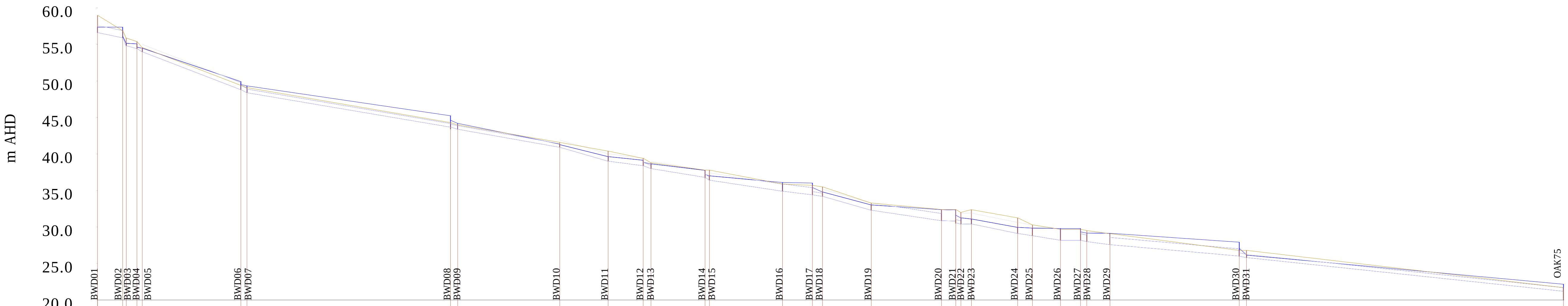
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua
land and water solutions





Node	Chainage (m)	ground (m AHD)	1% level (m AD)
BWD01	0	59.000	57.382
BWD02	86	56.900	57.375
BWD03	98	55.900	55.161
BWD04	135	55.400	55.085
BWD05	153	54.600	54.487
BWD06	490	49.400	49.556
BWD07	511	49.100	49.321
BWD08	1207	44.300	44.484
BWD09	1232	44.000	44.194
BWD10	1581	41.600	41.296
BWD11	1746	40.400	39.638
BWD12	1867	39.400	39.151
BWD13	1893	38.800	38.655
BWD14	2078	37.800	37.766
BWD15	2093	37.800	37.011
BWD16	2343	35.900	36.091
BWD17	2446	35.700	36.015
BWD18	2480	35.500	34.792
BWD19	2647	33.300	33.020
BWD20	2887	32.400	32.382
BWD21	2936	32.400	32.374
BWD22	2954	32.000	31.225
BWD23	2989	32.383	31.105
BWD24	3148	31.250	29.953
BWD25	3198	30.300	29.848
BWD26	3294	29.700	29.807
BWD27	3363	29.700	29.792
BWD28	3384	29.500	29.171
BWD29	3463	29.100	29.152
BWD30	3905	26.800	27.016
BWD31	3930	26.800	26.155
OAK75	5015	21.700	22.171

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	1% flow (m3/s)
2000	1000	56.621	55.919	56.621
1220	920	55.919	54.840	55.919
2000	1000	54.840	54.446	54.840
1200	450	54.446	54.000	54.446
2000	1000	54.000	48.800	54.000
1500	600	48.800	48.400	48.800
500	500	48.400	43.680	48.400
1200	450	43.680	43.400	43.680
5000	500	43.400	40.920	43.400
3000	1000	40.920	39.020	40.920
1000	1000	39.020	38.400	39.020
1200	450	38.400	38.000	38.400
1000	1000	38.000	36.800	38.000
1200	450	36.800	36.400	36.800
3000	1000	36.400	34.900	36.400
3000	1000	34.900	34.400	34.900
1200	450	34.400	34.200	34.400
3000	1000	34.200	32.300	34.200
3000	1000	32.300	30.860	32.300
3000	1500	30.860	30.800	30.860
1200	450	30.570	30.390	30.570
3000	1500	30.390	30.410	30.390
3000	1500	30.410	29.130	30.410
3000	1500	29.130	28.800	29.130
3000	1500	28.800	28.190	28.800
3000	1500	28.190	28.190	28.190
900	900	28.190	27.990	28.190
3000	1500	27.990	27.580	27.990
2000	1000	27.580	26.020	27.580
455	455	26.000	25.800	26.000
2000	500	25.800	21.200	25.800

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.25 - Brickwood Drain - 1% AEP

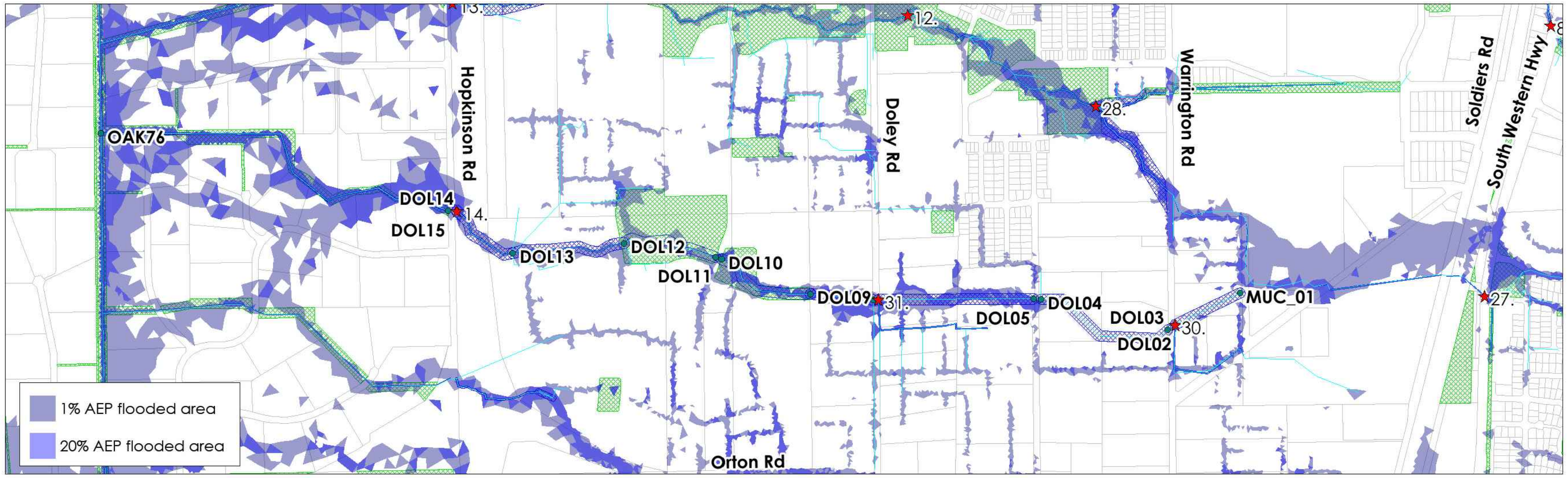
ISSUE	DATE	DESIGN	CHECK
A	18 Jun 2018	AN	HB

DATA SOURCES
Landgate
Depart of Planning

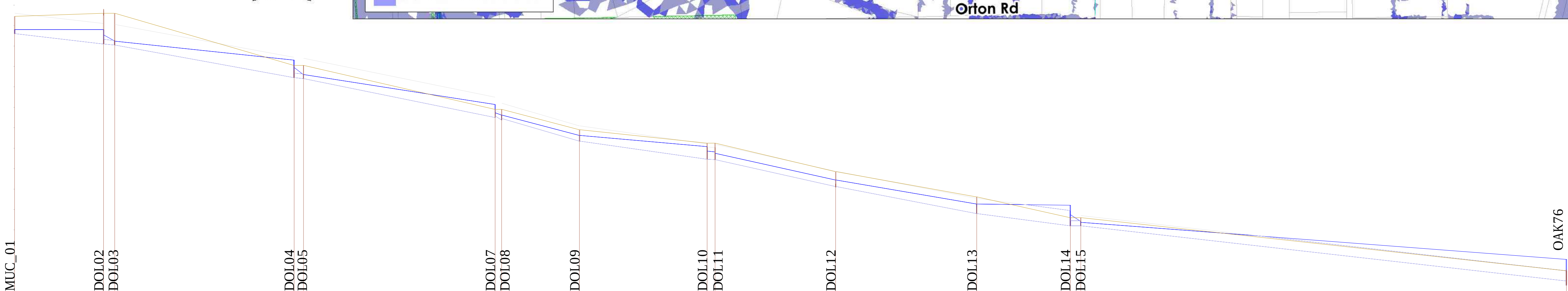
N.T.S

Projection: N/A | Datum: N/A

urbaqua
land and water solutions



N



Node	Chainage (m)	ground (m AHD)	1% level (m AD)
MUC_01	0	45.900	44.609
DOL02	218	46.200	44.609
DOL03	245	46.200	43.465
DOL04	683	41.100	41.622
DOL05	706	41.100	40.195
DOL07	1175	36.800	37.276
DOL08	1191	36.800	36.247
DOL09	1382	34.800	34.255
DOL10	1694	33.500	33.162
DOL11	1713	33.500	32.498
DOL12	2008	30.700	29.891
DOL13	2353	28.230	27.528
DOL14	2582	26.200	26.634
DOL15	2607	26.200	25.754
OAK76	3795	21.000	22.127

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	1% flow (m3/s)
32000	2000	44.200	43.200	0.00667
450	450	43.200	43.100	0.44529
32000	2000	43.100	39.900	0.89058
450	450	39.900	39.800	0.52635
32000	2000	39.800	36.000	1.16088
1200	600	36.150	35.755	1.18895
2000	1500	35.900	33.690	1.55673
2000	1500	33.690	31.910	3.72489
1200	1200	31.910	31.870	1.94691
2000	1500	31.880	29.250	5.60039
3000	1500	29.250	26.600	6.90071
4000	1500	26.600	25.400	9.36997
1200	500	25.400	25.400	2.23242
5000	1000	25.400	20.000	2.29585

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.26 - Doley Precinct Drain - 1% AEP

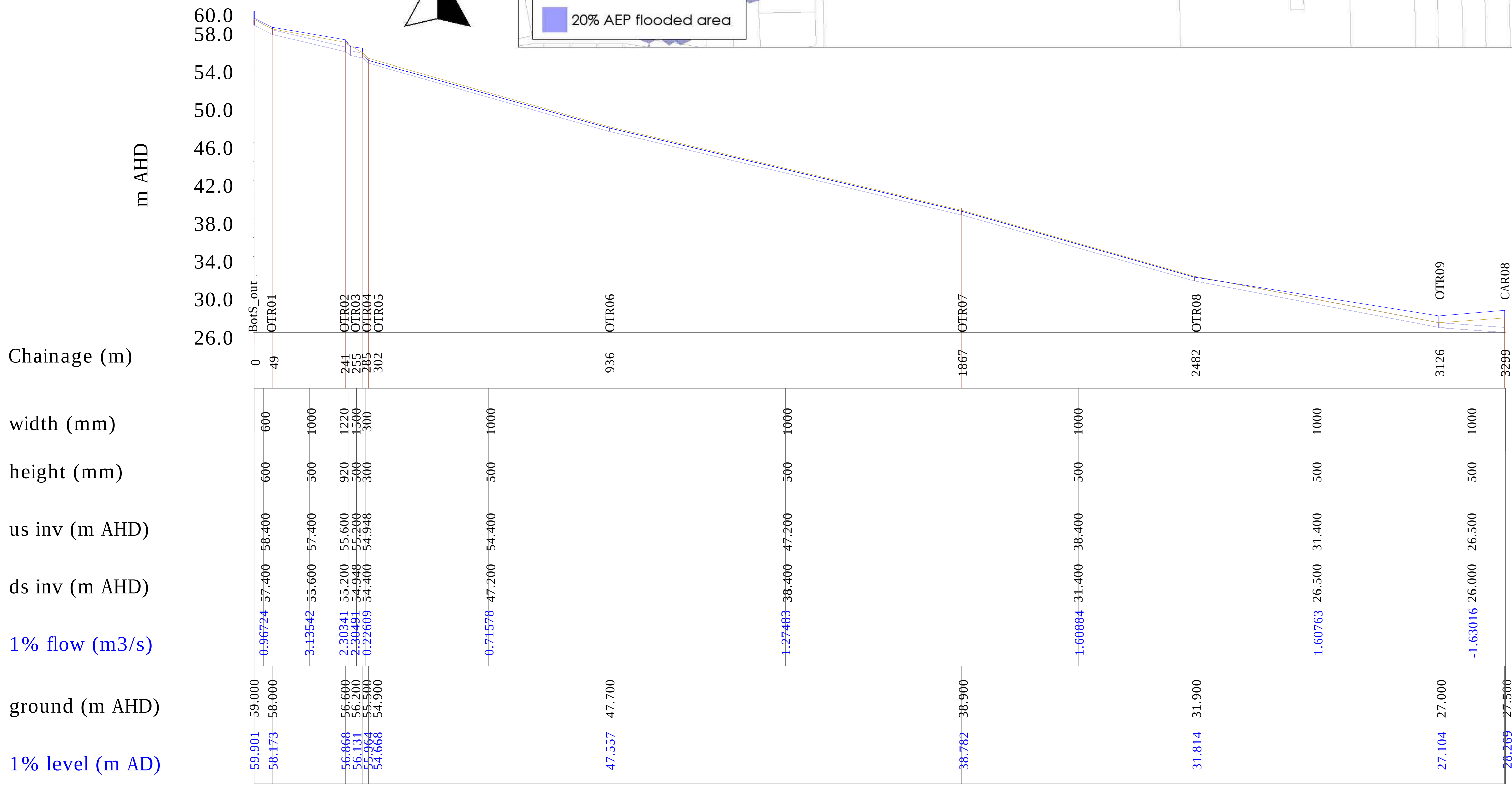
ISSUE	DATE	DESIGN	CHECK
A	20 Jun 2018	AN	HB

DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A | Datum: N/A

urbaqua land and water solutions



Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.27 - Orton Rd Drain - 1% AEP

ISSUE	DATE	DESIGN	CHECK
A	20 Jun 2018	AN	HB

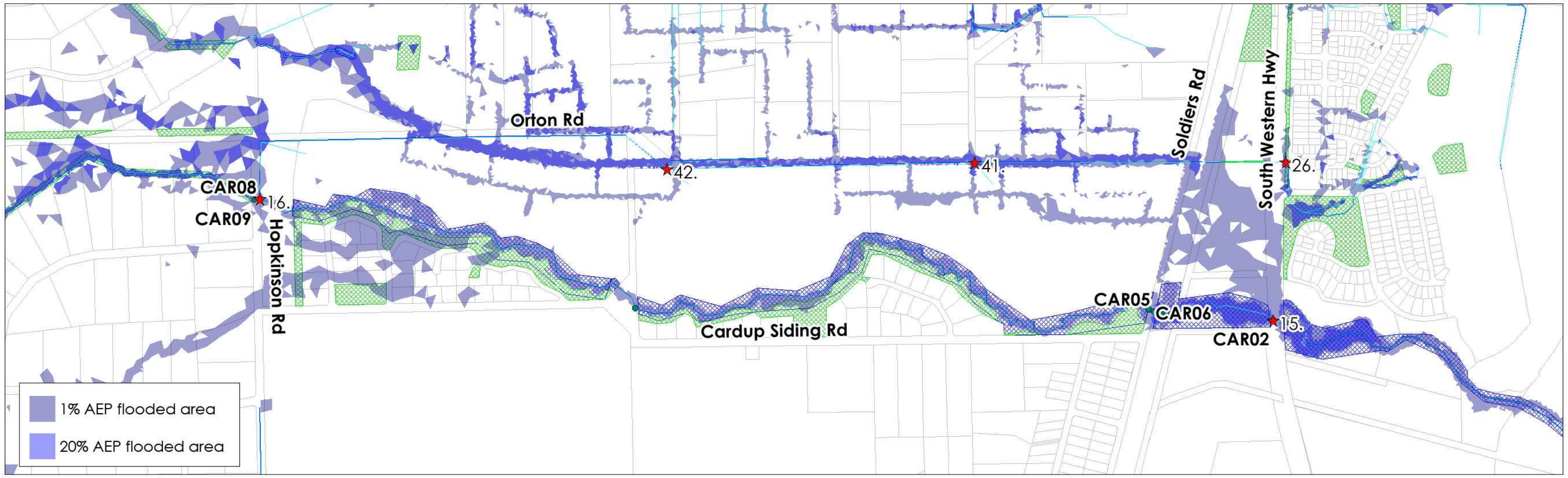
DATA SOURCES
Landgate
Depart of Planning

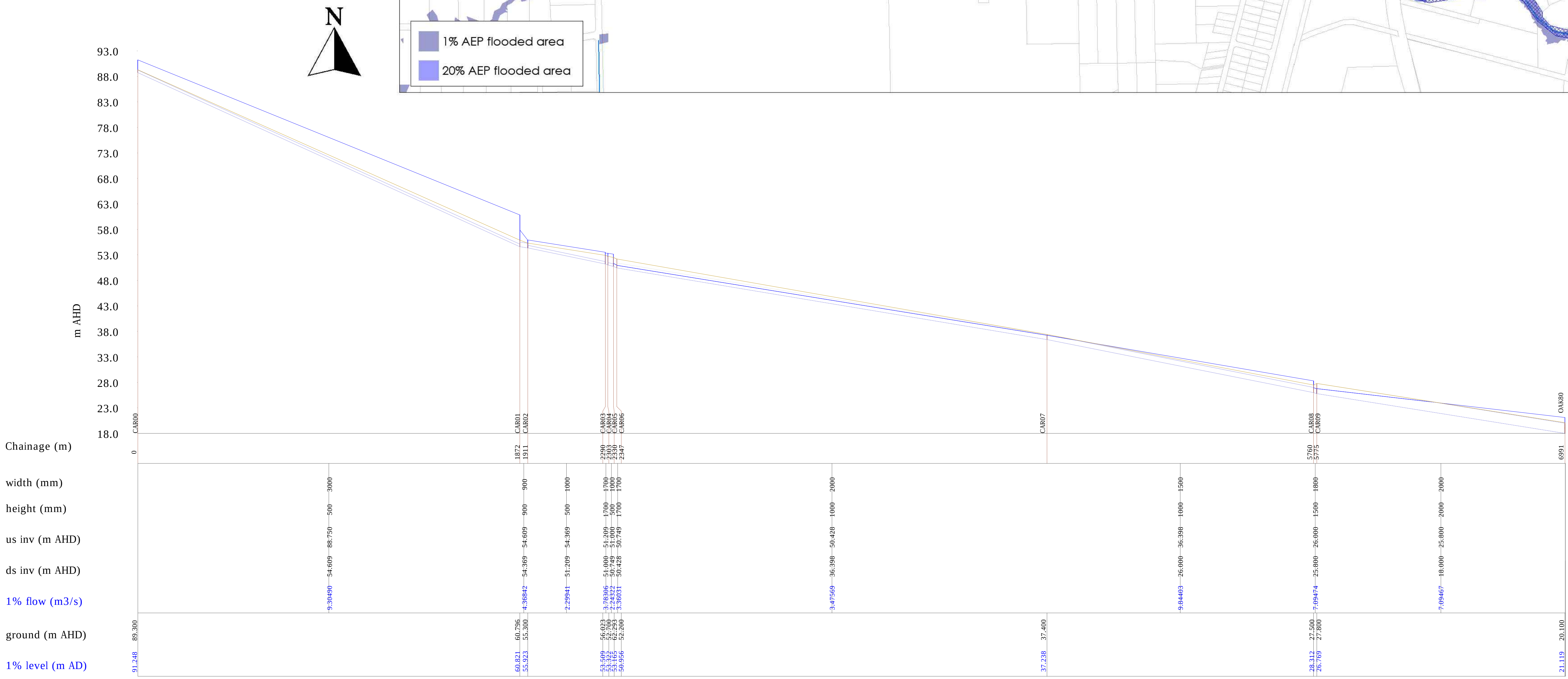
N.T.S

Projection: N/A

Datum: N/A

urbaqua land and water solutions





Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.28 - Cardup Brook - 1% AEP

ISSUE	DATE	DESIGN	CHECK
A	20 Jun 2018	AN	HB

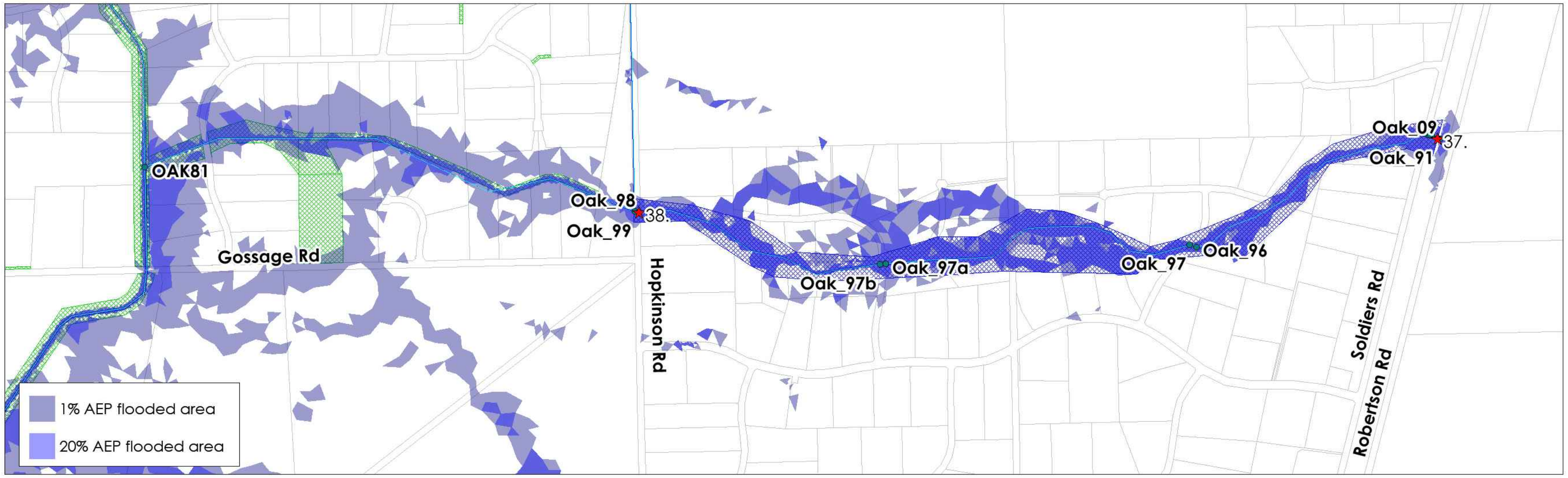
DATA SOURCES
Landgate
Depart of Planning

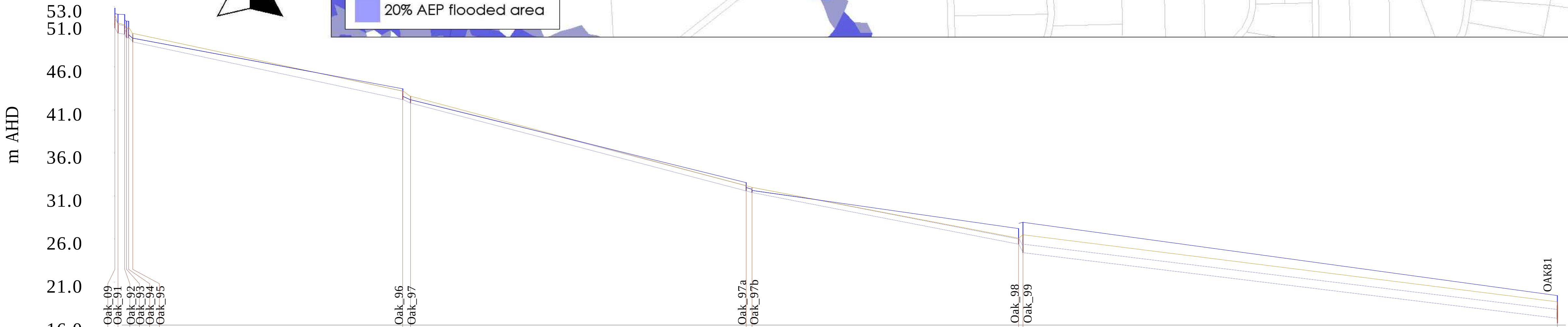
N.T.S

Projection: N/A

Datum: N/A

urbaqua
land and water solutions





Node	Chainage (m)	ground (m AHD)	1% level (m AD)
Oak_09	0	52.000	52.276
Oak_91	9	51.100	51.870
Oak_92	28	50.900	51.821
Oak_93	34	50.400	51.522
Oak_94	40	50.600	51.110
Oak_95	52	49.900	49.335
Oak_96	837	43.200	43.418
Oak_97	860	42.600	42.174
Oak_97a	1836	32.200	32.257
Oak_97b	1853	32.000	31.641
Oak_98	2628	26.100	26.538
Oak_99	2641	26.500	27.080
OAK81	4195	18.700	19.434

width (mm)	height (mm)	us inv (m AHD)	ds inv (m AHD)	1% flow (m3/s)
1100	1100	50.520	49.930	2.90826
1000	1000	49.930	49.800	5.65317
600	600	49.800	49.400	0.89095
1000	1000	49.400	49.400	3.77469
750	750	49.400	49.000	0.88567
1000	1000	48.900	42.200	1.90848
750	750	42.200	41.800	0.74607
2000	600	41.800	31.600	1.72559
600	600	31.600	31.400	0.52739
2000	600	31.400	25.400	0.64508
1200	700	25.400	24.500	-2.56306
1500	1000	24.400	16.800	9.64154

Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.29 - Cardup Drain - 1% AEP

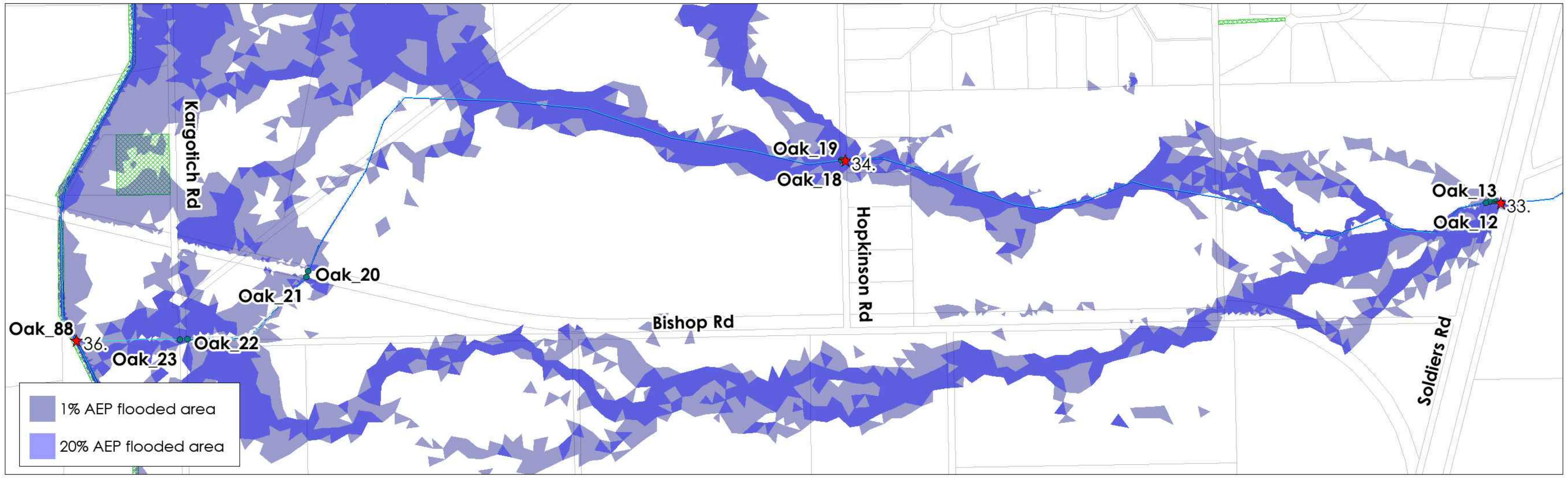
ISSUE	DATE	DESIGN	CHECK
A	20 Jun 2018	AN	HB

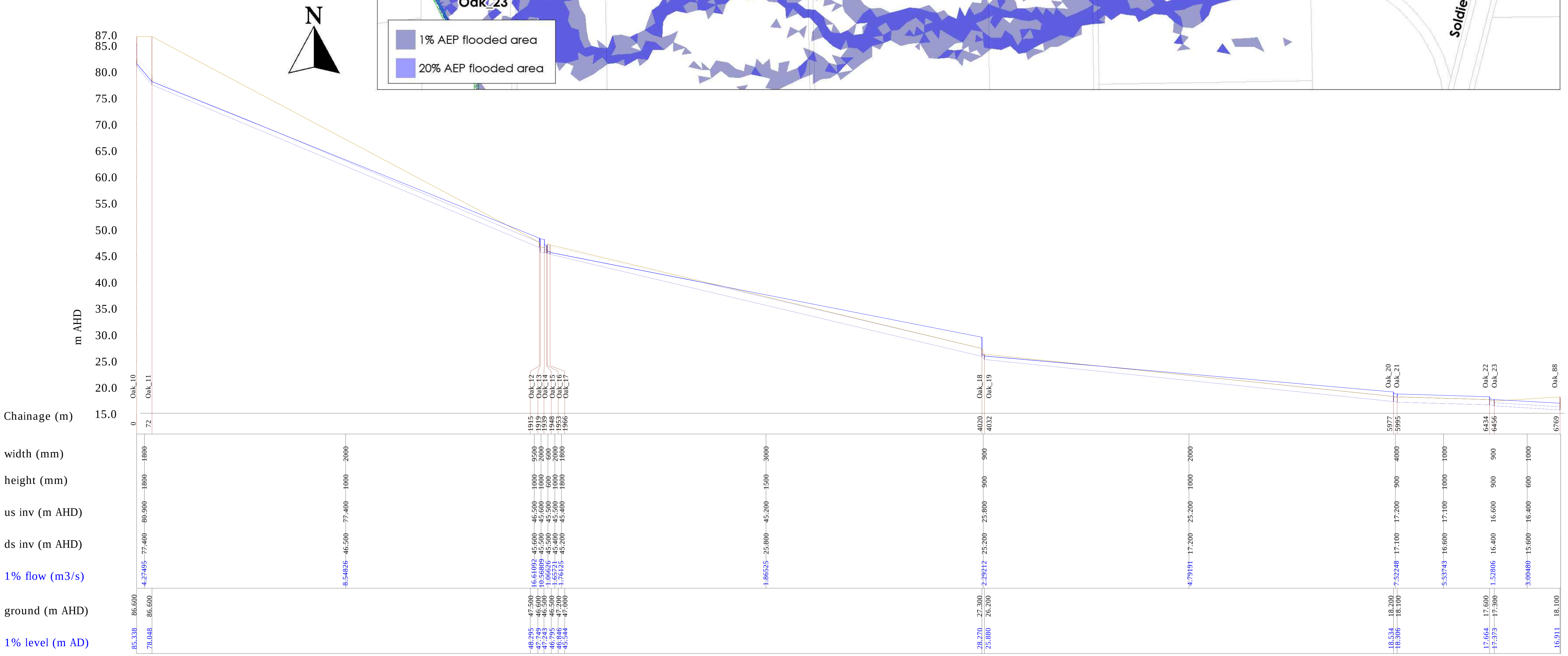
DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A
Datum: N/A

urbaqua
land and water solutions





Shire of Serpentine-Jarrahdale - Byford DWMS
Figure C2.30 - Norman Drain - 1% AEP

ISSUE	DATE	DESIGN	CHECK
A	20 Jun 2018	AN	HB

DATA SOURCES
Landgate
Depart of Planning

N.T.S

Projection: N/A

Datum: N/A

urbaqua
land and water solutions

Client: Shire of Serpentine-Jarrahdale

Report	Version	Prepared by	Reviewed by	Submitted to Client	
				Copies	Date
Preliminary draft	V1	HBr	SSh	Electronic	March 2018
Draft for consultation	V2	HBr	SSh	Electronic	June 2018
Final for advertising	V3	HBr	SSh	Electronic	June 2018

Urbaqua
land & water solutions
Suite 4/226 Carr Place
p: 08 9328 4663 | f: 08 6316 1431
e: info@urbaqua.org.au
www.urbaqua.org.au