Government of Western Australia
Department of Water and Environmental Regulation

East of Kwinana and Pinjarra-Ravenswood planning investigation area

Flood risk management land capability assessment

Department of Water and Environmental Regulation

Drainage and Water Management Plan technical series No. 1

September 2021

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September 2021 (edited December 2023)

FIRST 116017

Acknowledgements

The Department of Water and Environmental Regulation would like to thank the following for their contribution to this publication: Terry Kefalianos, Rachel Forrest, Melinda MacKay, Tim Sparks, Simon Rodgers, Renee Dixon and Feifei Tong.

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Summary

The East of Kwinana and Pinjarra-Ravenswood planning investigation area (PIA) was identified in the Perth and Peel @ 3.5 million frameworks as requiring further investigation of drainage and flood risk. In 2019, the Department of Planning, Lands and Heritage asked the Department of Water and Environmental Regulation (the department) to do a land capability assessment based on flooding for the East of Kwinana and Pinjarra-Ravenswood PIA. The assessment will inform the Department of Planning, Lands and Heritage's comparative analysis of East of Kwinana and Pinjarra-Ravenswood in 2021.

The department adopted a floodplain risk management approach to analyse and provide advice on flooding in the East of Kwinana and Pinjarra-Ravenswood PIA. The primary standards for floodplain risk management in Australia are documented in the Australian Emergency Manual Series, consisting of the Australian Disaster Resilience Handbook Collection and related guidance. There are no urban flood levees in Western Australia and, consequently, no local guidance for the management of levees. In the absence of Western Australian guidance, *Levee Management Guidelines* by the Victorian Government have been used (Victorian Department of Environment, Land, Water and Planning 2015).

The department's flood modelling approaches are consistent with national guidance outlined in *Australian Rainfall and Runoff: A guide to flood estimation* (Ball et al. 2019). Flood modelling that underpins the flooding advice has been found fit-for-purpose by local and national experts in the field of catchment and floodplain modelling.

This report should be read in combination with the technical report *East of Kwinana flood modelling and drainage study: Supporting local water management and future development* prepared by the department.

East of Kwinana

Flooding risks in the East of Kwinana sector of the PIA (East of Kwinana) have been identified in two previous modelling studies and were the base for the most recent East of Kwinana flood modelling and drainage study. This study provided a fit-for-purpose tool to investigate development options to inform the subregional planning frameworks as part of Perth and Peel @ 3.5 million.

East of Kwinana has three precincts:

- Oldbury and Oakford
- North East Baldivis north of Mundijong Road
- North East Baldivis south of Mundijong Road.

The natural landscape of the area is characterised by flat terrain with large natural surface depressions to allow for ponded water to be stored – also described as a palusplain. There is a mix of sands and clays, and groundwater is shallow across most of the area.

East of Kwinana sits within the Birrega, Oaklands and Peel floodplains on the Swan Coastal Plain. Flooding of this area is complex. There are several areas of natural landscape depressions in and around the PIA where the landscape flattens from the slopes of the upper catchment. The landscape depressions fill during rainfall events and act as a natural

attenuation of flood flows. The introduction of a rural drainage network, specifically the Birrega Main Drain, contrary to the natural direction of flow, increases the complexity of flooding in the southern precincts.

The most complex flooding in East of Kwinana is in the North East Baldivis north of Mundijong Road precinct. The natural direction of flood flows follows the slope of the landscape in a westerly direction through this precinct. The Birrega Main Drain provides a minor diversion of flows in a southerly direction, contrary to the natural fall of the landscape. When the Birrega Main Drain reaches capacity in a one-in-100-year (1:100-year) flood, floodwaters will flow into the North East Baldivis north of Mundijong Road precinct and continue in a westerly direction towards the Peel Main Drain. The landscape of North East Baldivis north of Mundijong Road is the relief point of the catchment, temporarily storing flood waters before they reach the Peel-Harvey estuary via the Peel Main Drain and Serpentine River.

There are earthen spoil banks along the Birrega Main Drain adjacent to the North East Baldivis north of Mundijong Road precinct. The design, construction and maintenance of the spoil banks indicate that an uncontrolled failure of these banks in a large flood is likely. This would cause a rapid change in flooding behaviour in the precinct and have catastrophic consequences for human life, property and essential infrastructure if floodwaters aren’t adequately planned for.

The department’s assessment shows that, across the three East of Kwinana precincts, the developable area with 1:100-year flood protection ranged from 90% for North East Baldivis south of Mundijong Road, 81% for Oldbury and Oakford and 55% for North East Baldivis north of Mundijong Road. Using a varied approach to flood standards for North East Baldivis north of Mundijong road allows for up to 65% of the precinct to be developed, which includes 35% of the precinct with 1:100-year flood protection and 30% of the precinct with one-in-20-year (1:20-year) flood protection suitable for non-residential purposes. The department has established flood criteria for development proposals should any precinct be identified for future development in the subregional planning frameworks.

Pinjarra-Ravenswood

The Pinjarra-Ravenswood sector of the PIA has six precincts in and around the Murray River floodplain, east of the Peel-Harvey estuary:

- Furnissdale
- South East Furnissdale
- Pinjarra
- South East Yunderup
- North Ravenswood
- South Ravenswood.

The area is dominated by flooding from the Murray River and Peel-Harvey estuary and in the palusplain where surface depressions in the natural landscape are important for attenuating flood waters. The flooding risk in the Pinjarra-Ravenswood sector is high but is not as complex as those found in some precincts of East of Kwinana.

Flooding of the Murray River and Peel-Harvey estuary was analysed in 2017 and forms the basis of the flood-related land capability assessment for the precincts dominated by riverine and estuary flooding. Flooding of the palusplain was identified in the recent flood and drainage studies of North Ravenswood and South Ravenswood precincts.

The developable area with 1:100-year flood protection is 100% in Furnissdale and South East Furnissdale, 86% in South Ravenswood, 77% in South East Yunderup, 74% in North Ravenswood and 69% in Pinjarra. The department has established flood criteria for development proposals should any precinct be identified for future development in the subregional planning frameworks.

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1 Background

In March 2018, the Government of Western Australia (State Government) released the Perth and Peel @ 3.5 million subregional frameworks (Western Australian Planning Commission, 2018). The frameworks define the urban form for the next 30 years, with the aim of supporting a population of 3.5 million. They help determine where new homes and jobs will be located, make best use of existing and proposed infrastructure and protect important environmental assets.

The frameworks aim to limit unsustainable urban sprawl and encourage greater housing diversity to meet changing community needs. They provide guidance and certainty to the State Government, local government and the development sector.

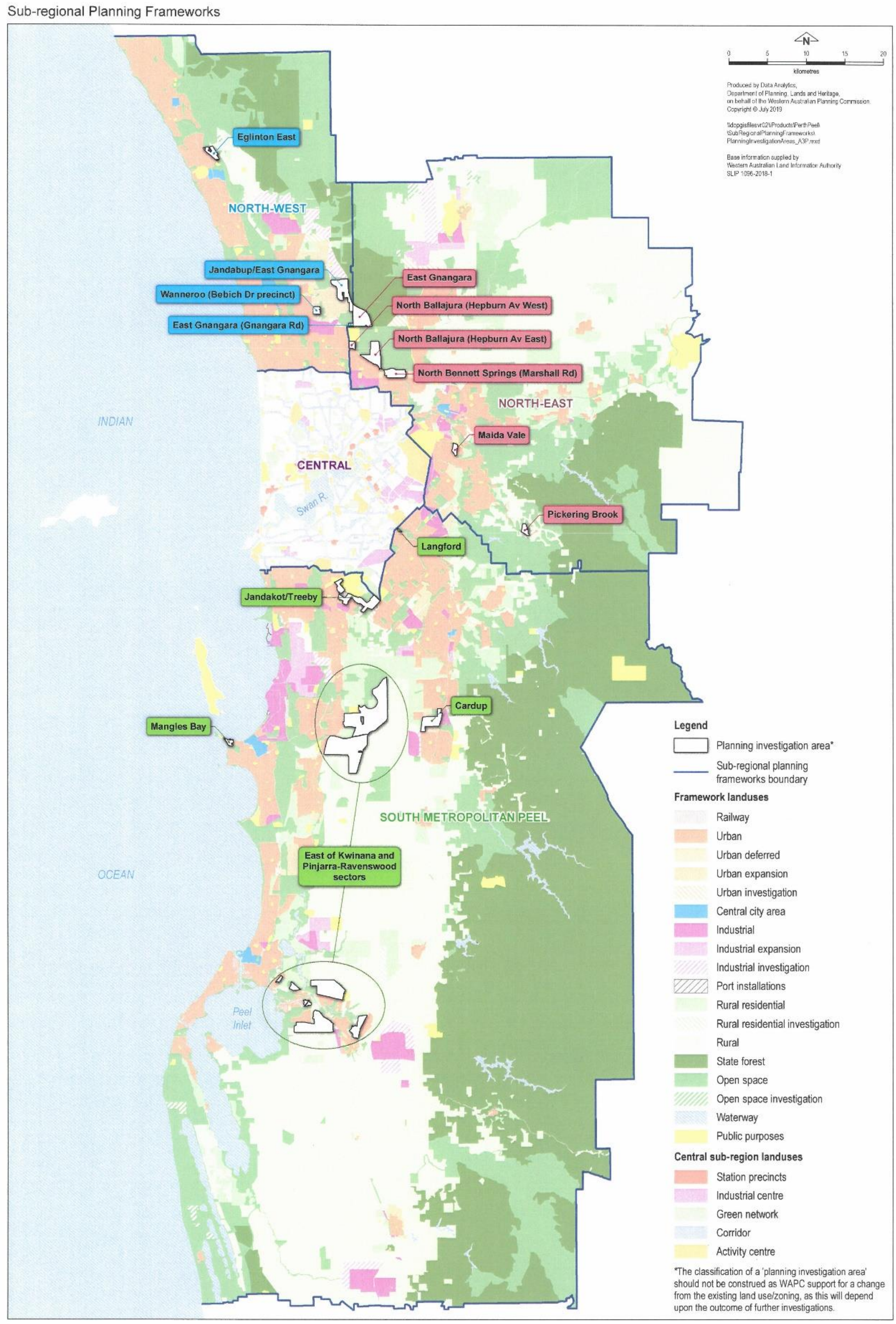
There is a monitoring and review process for the frameworks to ensure they remain contemporary and responsive to government priorities and community need. A comprehensive review will start in 2021. This will be led by the Department of Planning, Lands and Heritage (DPLH).

1.1 Planning investigation areas

The frameworks identify 15 planning investigation areas (PIAs) where further detailed planning needs to be undertaken to determine whether any possible change from the current zoning could be supported.

In August 2018, the Western Australian Planning Commission adopted a work program to progress investigations into all PIAs across Perth and Peel. In 2019, DPLH asked the Department of Water and Environment Regulation (the department) for a land capability assessment based on flooding for the East of Kwinana and Pinjarra-Ravenswood sectors of the PIA identified in the Perth and Peel @ 3.5 million frameworks.

The *South Metropolitan Peel Sub-regional Planning Framework* identified two PIAs that required further investigation for drainage and flood risk: East of Kwinana and Pinjarra-Ravenswood and Cardup (Figure 1). The land in these areas is predominantly zoned rural and is geographically large with complex flood behaviour that may impact the amount of land that can be developed with flood protection.



Source: *Perth and Peel planning investigation areas* (Department of Planning Lands and Heritage, 2019)

Figure 1 Locality map of the PIA

1.2 Purpose

The aim of the department's work is to provide independent expert advice to the DPLH on how to maximise land capability from a flooding perspective and inform a decision about the best use of all land in both the East of Kwinana and Pinjarra-Ravenswood sectors.

Two key flood-related questions need to be answered:

- Can the land be developed without unacceptable impacts to neighbouring land?
- How much land can be provided at an appropriate flood standard for the land use that is being sought?

The focus of the first question is to undertake detailed flood modelling on a catchment scale that includes the development areas. This is to quantify and assess the impacts downstream from and adjacent to the development precincts that would occur from development within the precincts.

The focus of the second question is to gain a conceptual understanding of development inside the site, so that a reasonable estimate for the developable area for different land uses, based on flooding, can be made. If a particular land use is required or desired, the aim is to determine the area of land that can be provided at an appropriate flood standard for that use and other potential uses for the remainder of the land which cannot provide the required flood standard. In some cases, a mix of land uses with different flood protection standards was considered.

1.3 Independence of advice

The department's role is to balance the benefits and flood risk aspects of occupying and using the floodplain to provide advice on appropriate requirements and flood-related constraints to land capability.

It should be noted that the department has:

- no decision-making role in the land planning process
- no ownership or operation of flooding and drainage infrastructure
- no responsibility for emergency management operations.

The department provides independent advice to decision-makers based on science and flood risk management consistent with national standards and practice.

1.4 Floodplain risk management across Australia

The department adopted a floodplain risk management approach to analyse flooding and provide expert advice consistent with local Western Australian guidelines and national best practice. The primary standards for floodplain risk management in Australia are sponsored by the Australian Government's Attorney-General's Department and are documented as part of the Australian Emergency Manual Series. This consists of a handbook collection and associated guidance documents. The handbook collection is developed and reviewed by national consultative committees representing a range of state and territory agencies, governments, organisations and individuals involved in disaster resilience.

Many jurisdictions have developed more detailed guidance on specific aspects of floodplain risk management in response to historic development at hazardous locations in those jurisdictions. These documents provide additional information and guidance in the selection, formulation and implementation of various risk management measures.

Information on scientific approaches and appropriate methodologies for flood estimation is provided by *Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia* (Ball et al. 2019).) and the supporting project reports.

In addition to local Western Australian guidelines, key documents used in undertaking this floodplain risk and land capability assessment are:

- *Australian Disaster Resilience Handbook 7; Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia* (Australian Institute for Disaster Resilience 2017)
- *Australian Disaster Resilience Guideline 7-2; Flood Emergency Response Classification of the Floodplain* (Australian Institute for Disaster Resilience 2017)
- *Australian Disaster Resilience Guideline 7-3; Flood Hazard* (Australian Institute for Disaster Resilience 2017)
- *Australian Disaster Resilience Guideline 7-5; Flood Information to Support Land-use Planning* (Australian Institute for Disaster Resilience 2017)
- *Australian Disaster Resilience Practice Note 7-7; Considering Flooding in Land-use Planning Activities* (Australian Institute for Disaster Resilience 2017)
- *Flood Emergency Planning for Disaster Resilience* (Australian Institute for Disaster Resilience 2020)
- *Australian Disaster Resilience Handbook 4 Evacuation Planning* (Australian Institute for Disaster Resilience 2017)
- *Levee Management Guidelines* (Victorian Department of Environment, Land, Water and Planning 2015)
- *Floodplain Development Manual: the management of flood liable land* (New South Wales Government 2005)

- *Planning for stronger more resilient floodplains. Part 1 - Interim measures to support floodplain management in existing planning schemes* (The State of Queensland – Queensland Reconstruction Authority 2011
- *Planning for stronger more resilient floodplains. Part 2 - Measures to support floodplain management in future planning schemes* (The State of Queensland – Queensland Reconstruction Authority 2012)
- *Australian Rainfall and Runoff: A Guide to Flood Estimation* (Commonwealth of Australia Geoscience Australia 2019).

Floodplain risk management is a discipline that applies a risk-based approach to considering the social and economic advantages of occupying and using the floodplain in contrast to the harmful effects of flooding. The aim is to:

- reduce the social and financial costs of occupying the floodplain
- increase the sustainable benefits of using the floodplain.

The floodplain risk management approach considers the existing flood risk of a site under current uses, the potential future flood risk of intensifying uses on and around that site and the residual risk that remans once all practical risk minimisation approaches have been implemented. Risk minimisation measures are categorised into three different types of approaches that:

- manage flood behaviour – such as flood infrastructure or mitigation works
- manage the use of the land – such as land planning and building controls
- manage the response of people – such as emergency management, awareness and preparedness.

Floodplain risk management considers benefits and limitations across the three risk minimisation approaches listed above under existing and future conditions. The guidelines listed at the start of this section provide the framework for the flood risk management approach adopted in this assessment.

1.5 Documentation of advice

The department's advice has been divided into varying levels of detail and is underpinned by a suite of documents as summarised in Figure 2. Advice for the various land planning precincts is available as follows:

- North East Baldivis north of Mundijong Road – see Section 3.9
- North East Baldivis south of Mundijong Road – see Section 3.12
- Oldbury and Oakford, cumulative impacts and flood criteria – see Section 3.14
- Pinjarra-Ravenswood – see Section 4.8.

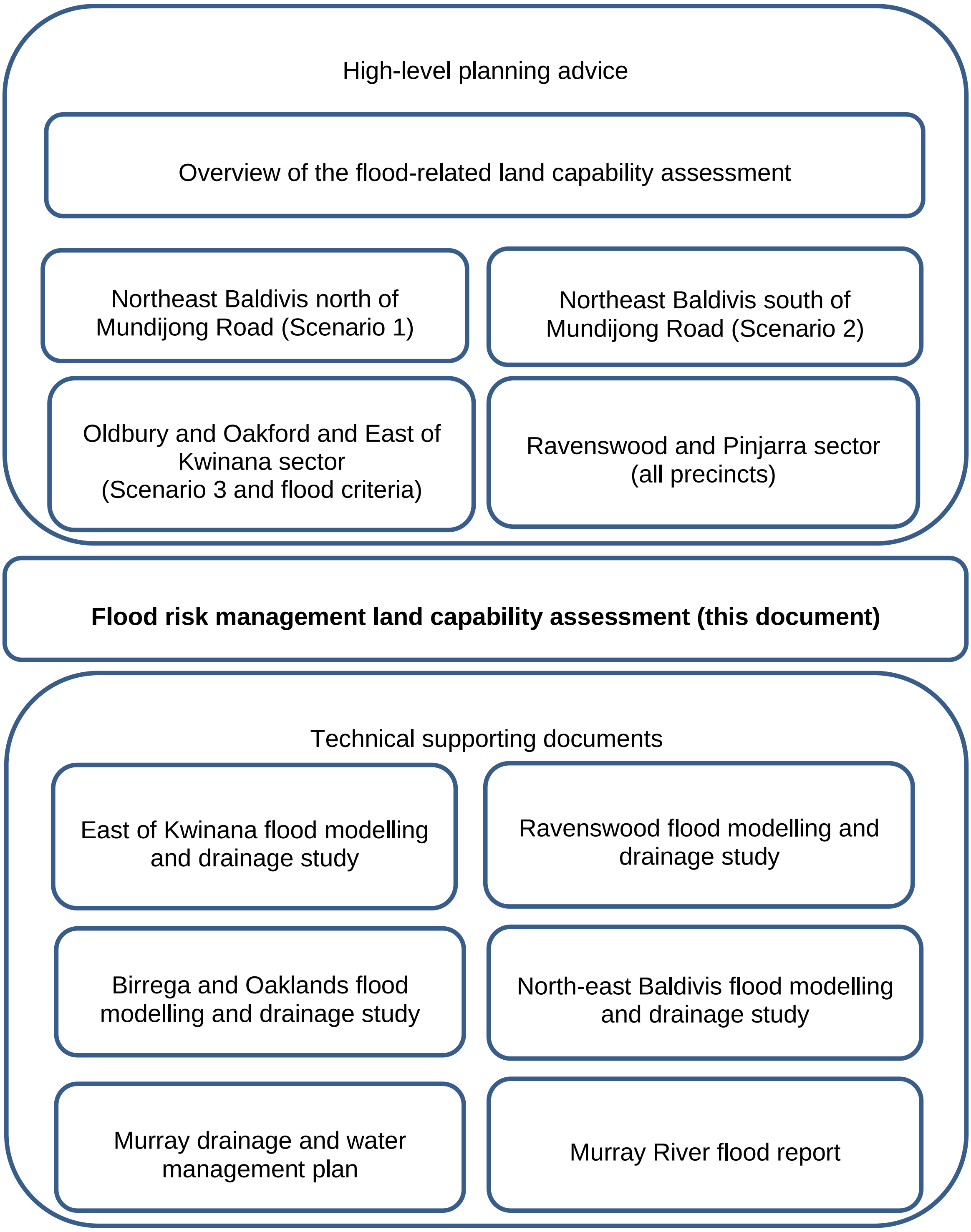


Figure 2 Supporting documents

2 Flood-related land capability analysis

As outlined in Section 1.2, the department's flood-related land capability analysis used detailed catchment-scale flood modelling to:

1. quantify and assess the impacts of developing the PIA on surrounding land
2. determine how much of the PIA could be developed with flood protection in a 1% annual exceedance probability (AEP; 1:100-year) flood.

The differing landscapes and complexities of flooding mechanisms in the PIA require the use of different approaches. In some areas, purpose-built flood models were compiled, and multiple development approaches were tested. In other areas, more simplistic analysis using existing flooding information was sufficient.

East of Kwinana is within the Birrega, Oaklands and Peel main drainage catchments. For assessment purposes, East of Kwinana was divided into three precincts outlined in Figure 3. Existing studies – *Birrega and Oaklands flood modelling and drainage study* (DWER 2015) and *North-East Baldivis flood modelling and drainage study* (DWER 2015) – were used to prioritise the precincts in order of relative flood complexity:

1. North East Baldivis north of Mundijong Road precinct (most complex)
2. North East Baldivis south of Mundijong Road
3. Oldbury and Oakford precinct (least complex).

The existing studies were updated as a part of the *East of Kwinana flood modelling and drainage study* (DWER 2021), as discussed in Section 2.1.1 below, to provide a fit-for-purpose flood model to investigate development options. The precincts and East of Kwinana flood model extent are depicted in Figure 3.

Groundwater information is available through surface water and groundwater interactions modelling documented in the department's Lower Serpentine hydrological studies series. This information was used to guide decisions about groundwater and invert levels for flood infrastructure.

Climate change was indirectly considered in this project through model sensitivity scenarios. These include the discharges from the adjacent drains to East of Kwinana under different spoil bank failure scenarios and the inflows to East of Kwinana under different design rainfalls. Climate change would need to be considered in more detail as part of any land use change proposal.

For assessment purposes, the Pinjarra-Ravenswood area was divided into six precincts: North Ravenswood, South Ravenswood, Pinjarra, South East Yunderup, South East Furnissdale and Furnissdale, outlined in Figure 3.

The precincts were prioritised in order of relative flood complexity, with the North Ravenswood and South Ravenswood precincts requiring an update to existing flood information using more detailed flood modelling approaches, and the remaining areas being adequately captured in the *Murray River flood report: Flood Risk Damage Assessment* (DOW 2017). The updated flood modelling for North Ravenswood and South Ravenswood is documented in the *Ravenswood flood modelling and drainage study* (DWER 2021, unpublished).

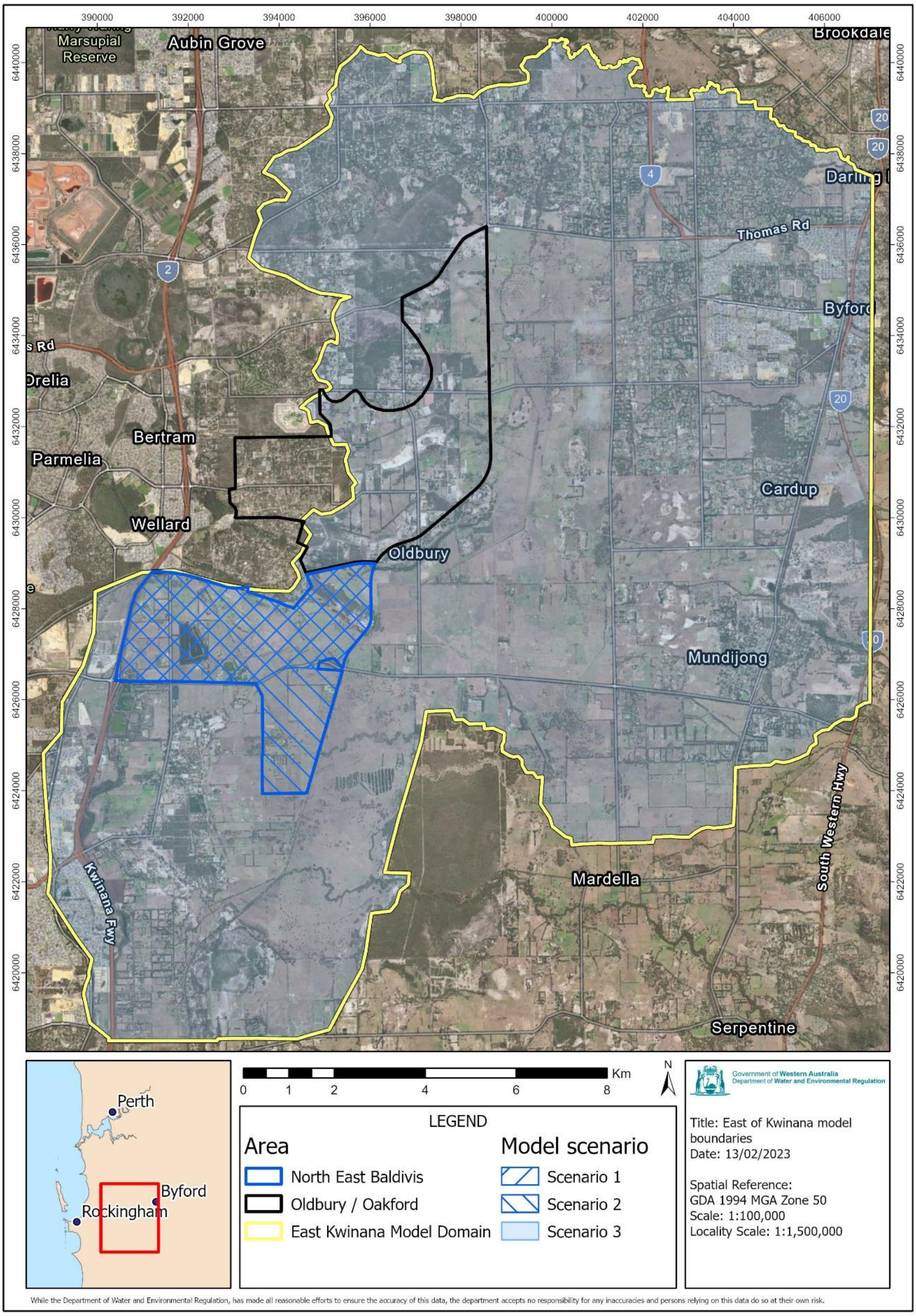


Figure 3 East of Kwinana model boundaries

2.1 East of Kwinana approach to flood capability

The department established a logical framework of flood modelling scenarios to investigate East of Kwinana, as outlined in Figure 4 below. For each of the precincts, the following was determined:

1. the pre-development base case
2. the amount of land with flood protection
3. the flood criteria that land use change proposals will need to address.

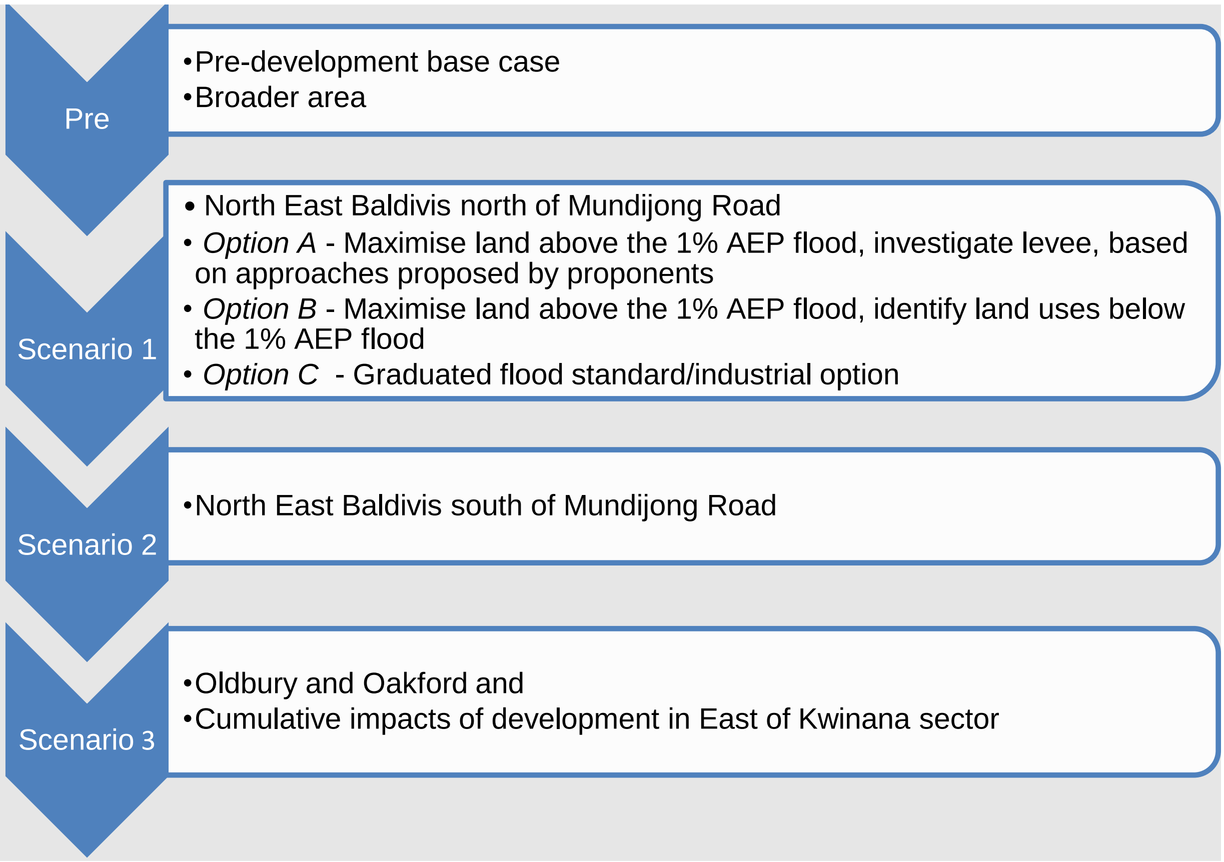


Figure 4 Flood modelling framework for investigating East of Kwinana

2.1.1 Pre-development base case

The pre-development base case establishes the flooding risk under the existing rural land use and allows for an understanding of how water in the catchment currently behaves (both inside and outside the sector). The pre-development base case was established for all precincts in East of Kwinana and was used for comparison with development scenarios and any future land use change proposals.

East of Kwinana is covered by two existing flood studies for the Birrega and Oaklands catchment and the North East Baldivis catchment. These studies were developed using the 1987 edition of *Australian Rainfall and Runoff* (Institute of Engineers Australia 1987) and consist of coupled dynamic one-dimensional and two-dimensional flood models using the

Mike Flood software package. The resolution of these models was 20 m and 10 m, respectively.

These two models were merged into a single large model called the East of Kwinana model domain shown as the yellow boundary on Figure 3. The East Kwinana model was transferred to the latest Mike Flood software package using the latest graphical processing unit (GPU) technology. Substantial improvements were also made to the flood model including:

- The approaches and parameters were updated consistent with the 2019 edition of *Australian Rainfall and Runoff* (Ball et al. 2019).
- The use of 'flexible mesh' permits the model resolution to be adjusted as needed based on the significance of the area to flood behaviour and decision-making. This allows a higher level of detail to be considered in key areas that affect decision-making.
- Use of the latest GPU technology has significantly reduced the model run time from about 3–4 days for a gridded model down to 9–11 hours for the current model, thus allowing the rapid assessment of multiple options.
- The resolution for waterways within the Birrega and Oaklands catchments was increased to improve model accuracy.
- The model was calibrated to the 1987 flood and shows that the model can accurately predict real on ground flooding based on observed rainfall.

The pre-development flood model has been peer reviewed by experts external to the department for quality assurance purposes and has confirmed that the model has been appropriately constructed and is fit for the purposes of this project.

A local area model of the North East Baldivis north of Mundijong Road precinct was also developed for Scenario 1. This finer scale model was appropriate for representing the details of the hydraulic controls in the post-development terrains.

The department developed these flood models to identify the flooding and inundation risks for the PIAs. The modelling work undertaken is state-of-the-art two-dimensional flood modelling that is appropriate for these complex and high-risk sites, to inform the high-level planning investigation analysis for DPLH. It is appropriate that government undertakes this modelling work to:

- have at its disposal a tool for considering alternative land uses and strategies across multiple precincts in the region
- provide appropriate flooding criteria for district level planning.

2.1.2 Post-development scenarios

Three post-development scenarios were defined to determine the flood-related land capability of the three precincts East of Kwinana. This allowed a logical progression from the most complex and highest flood risk precinct, being North East Baldivis north of Mundijong Road, to North East Baldivis south of Mundijong Road and then to the least complex and lower flood risk Oldbury and Oakford precinct. There are three reasons for this approach with respect to flood risk management:

1. Ensure that development of one precinct does not depend on development of another precinct.
2. Ensure that development in one precinct does not further constrain development in another precinct.
3. Inform the planning process to set appropriate criteria and approaches for industry should a precinct be deemed suitable for land use change.

2.1.3 Scenario 1 North East Baldivis north of Mundijong Road precinct

The North East Baldivis north of Mundijong Road precinct was identified as the most complex precinct with highest flood risk in East of Kwinana. Three different approaches to the development of the land were considered to inform the flood-related capability:

Scenario 1 Option A – levee approach: maximise the developable area by using a purpose-built flood levee to prevent upstream flood waters entering the precinct when developed. In the past, numerous proponent-driven proposals used a similar approach; therefore, this approach was included in this assessment. Option A included removing the existing spoil bank on the Birrega Main Drain adjacent to the precinct and construction of a flood levee based on modern engineering standards for earth embankments.

Scenario 1 Option B – traditional approach: maximise land above the pre-development base case 1% AEP flood, while maintaining a reasonable use for land below the 1% AEP flood. This option included the removal of spoil banks and no flood levee.

Scenario 1 Option C – varied flood protection: maximise land available for development through varied flood protection standards There was a substantial portion of land in the precinct that is below the 1% AEP flood. Therefore, this option took the approach that land use will be limited to industrial only and flood-prone land will be distributed among the privately owned land to maximise the land available for private use. For example, half of each private lot might be above the 1% AEP flood and suitable for industrial buildings while the other half would be below the 1% AEP flood and its use limited to open hard stand industrial activities. Flooding would be allowed on private industrial land with a graduated land use from the lower to the higher parts of each site.

2.1.4 Scenario 2 North East Baldivis south of Mundijong Road precinct

Flooding in the North East Baldivis south of Mundijong Road precinct is less complex than in the North East Baldivis north of Mundijong Road precinct. This meant one approach to the development of the land was considered to inform the flood-related land capability. A similar approach to Scenario 1 was adopted in that the pre-development base case includes failure of the spoil bank adjacent to the Birrega Main Drain on the eastern boundary of the precinct. The post-development approach was like Scenario 1 Option B. The spoil banks were removed and flooding through the site was permitted based on the identified pre-development base case of spoil bank failure while maximising land available for development.

2.1.5 Scenario 3 Oldbury and Oakford precinct and East of Kwinana

Flooding in the Oldbury and Oakford precinct is the least complex of all the East of Kwinana precincts which meant that, rather that undertake post-development flood modelling, a criteria approach based on the flooding mechanisms of the area was used. A geographic information system analysis was used to determine the flood-related land capability.

This scenario also considered flood criteria for the broader East of Kwinana sector. Cumulative impacts were considered and incorporated into the criteria established for industry should a precinct be deemed suitable for land use change.

2.2 Pinjarra-Ravenswood approach to land flood capability

The flooding risk in this sector of the PIA is high but is not as complex as those found in some precincts of East of Kwinana. The approach to quantifying flooding and analysing the risks varies depending on the specific flood mechanism or mix of flood mechanisms within each development precinct. This is discussed in Section 4.2.

There are six precincts within the Pinjarra-Ravenswood sector: North Ravenswood, South Ravenswood, Pinjarra, South East Yunderup, South East Furnissdale and Furnissdale.

2.3 Summary of flood-related land capability

The flood-related land capability assessment for all precincts of the East of Kwinana and Ravenswood-Pinjarra PIA is summarised in Table 1 below. Further explanation of the land capability and the supporting documentation is provided in subsequent sections of this report.

Table 1 Flooding related land capability comparative analysis

		East of Kwinana					Pinjarra-Ravenswood					
Precinct		**North East Baldivis north of Mundijong Road (Scenario 1A)**	**North East Baldivis north of Mundijong Road (Scenario 1B)**	**North East Baldivis north of Mundijong Road (Scenario 1C)**	**North East Baldivis south of Mundijong Road (Scenario 2)**	**Oldbury and Oakford**	**Furnissdale**	**South East Furnissdale**	**Pinjarra**	**South East Yunderup**	**North Ravenswood**	**South Ravenwood**
Landscape		• Mix of sand and clay • Groundwater is at or near to the surface across most of the area • Flat terrain with large natural surface depressions to allow for ponded water to be stored • Palusplain					• Mix of sand and clay • Flat terrain with rural pastures on a floodplain that slopes towards the Murray River and the Peel-Harvey estuary • Groundwater is at or near to the surface across most of the area					
Dominant flood process		Flooding of the Peel and Birrega floodplain					Flooding from the Murray River				Flooding from the Murray River and local catchments	Flooding from the Murray River, Peel Estuary and local catchments
Flood criteria	**Maintain peak flow rate and flood levels**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Maintain flood storage	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓*	✓*
	Development excluded from floodway	n/a	n/a	n/a	n/a	n/a	n/a	n/a	✓	✓	n/a	✓
Flood-related land capability	**With 1:100-year flood protection (% of precinct) (ha)**	n/a	55% (548)	Industrial and residential 30% (318) Industrial only 35% (366)	90% (355)	84% (1297)	100% (33)	100% (79)	69% (190)	77% (41)	74% (574)	86% (711)
	Without 1:100-year flood protection (% of precinct) (ha)	n/a	45% (476)	35% (375)	10% (38)	16% (250)	0%	0%	31% (84)	23% (12)	26% (198)	14% (120)
Fill (vertical separation for flood protection) (m^3)		n/a	8,800,000	5,500,000	4,600,000	Not applicable[1]	20,000[1]	152,000[1]	700,000[2]	473, 000	733,000[2] May be subject to change based on district planning	1,780,000[2]
Additional information		The department does not recommend using a levee to enable land to be developed							Land can become isolated. Emergency planning is critical.		*Further investigations to show local 1:100-year flooding between the precinct and the Murray River will not increase when compared to the pre-development base case	

3 East of Kwinana sector of the planning investigation area

3.1 Flooding in the landscape

The natural landscape between Orton Road and the southern end of Leary Road (see Figure 5) is characterised by flat terrain with large natural surface depressions to allow for ponded water to be stored (palusplain). There is a mix of sands and clays, and groundwater is mostly shallow. East of Kwinana sits within the Birrega, Oaklands and Peel floodplains on the Swan Coastal Plain. The natural landscape in this area contains a series of large storages to attenuate flows as the channel slopes flatten. Flooding in these storages tends to be volumetrically driven and the timing of flows is just as important as the peak discharge.

Water Corporation operates a rural drainage network in the area. The function of the drainage network is to drain water ponding on rural land within 72 hours of a rainfall event. Although the drainage network may provide some flood-mitigating benefits, it is not designed or constructed to provide flood protection. Observations from past floods and previous flood studies have shown that the rural drainage network should not be relied upon to protect adjacent areas from flooding.

The introduction of the Birrega Main Drain contrary to the natural direction of flow has also increased the complexity of flooding by introducing behaviour consistent with the major-minor drainage principle. This principle is typically applied to urban drainage networks. However, the alignment of the Birrega Main Drain also sees this principle operate within the North East Baldivis north of Mundijong Road precinct, albeit at a much larger scale. When the conveyance capacity of the Birrega Main Drain is exceeded, floodwaters will overflow into the North East Baldivis north of Mundijong Road precinct which behaves as the relief point, temporarily storing flood waters and attenuating flows.

There are distinctive hydraulic properties and subsequent catchment responses in this area that place a constraint to land capability. The Birrega and Peel floodplains between Orton Road and the southern end of Leary Road are flat when compared to the upstream catchment slopes. The lack of channel slope in the central portions of the catchment means that water is not conveyed as efficiently compared to the channel slopes further upstream. As upstream runoff reaches this part of the catchment, flow is obstructed by sand mounds to the west and must traverse through a relatively flat landscape in a southerly direction towards the Serpentine River. Because of the changes in channel slope, the conveyance capacity of the flood channels drops and this necessitates storing floodwaters on the floodplain.

The middle portions of the catchment, between Orton Road and the southern end of Leary Road, contain large natural storages. The effect of these storages is to attenuate flood flows between the steeper upstream channels, which have a higher conveyance efficiently, and the downstream channels, which are flatter and have a lower conveyance efficiency. Flooding in this area tends to have a lower velocity and be more volumetrically driven. It represents the difference between faster upstream flood water arriving in this area and the ability of the downstream channels to convey this water further downstream.

Human occupation of the floodplain has introduced additional hydraulic structures which have divided this area into a series of cascading storages generally as shown in Figure 5 below. However, the basic functioning of the floodplain remains unchanged. Flooding in this area is not only determined by the peak discharge but also the timing of discharge during a flooding event.

East of Kwinana is in the middle of the cascading storages. Development of this land not only needs to contend with the possibility of an early discharge causing detrimental downstream impacts but must also with the possibility that early discharge from upstream development will detrimentally impact the land capability within the precincts. This impact may come from upstream urban development, or it may come from landfill and earthworks activity within the rural areas which can be approved under the existing planning arrangements. To maintain the hydraulic properties of this part of the catchment, there cannot be any additional discharge on either the rising limb or the peak of the pre-development base case hydrograph. It is not enough for upstream development to retain the pre-development peak discharge in the post-development scenario. It is also necessary to retain the floodplain storage properties to ensure that there is no early discharge of floodwaters.

Care should be taken when considering landfill within these storages as loss of storage and attenuation capacity will increase the discharge to downstream channels and increase flooding on downstream land. The limits to landfill do not just relate to downstream impacts as the loss of attenuation will also impact flood levels in the channels and is also limited by the conveyance capacity of these channels. Filling in the floodplain will not abate the need to attenuate flows because of a flattening of the channel slopes. A degree of flow attenuation would still be required, and flooding could occur on top of the fill to obtain the required flow attenuation.

The introduction of landfill will not abate the need for flow attenuation and flooding may occur on downstream land and on top of the fill. Landfill within these storages is not an effective flood mitigation measure.

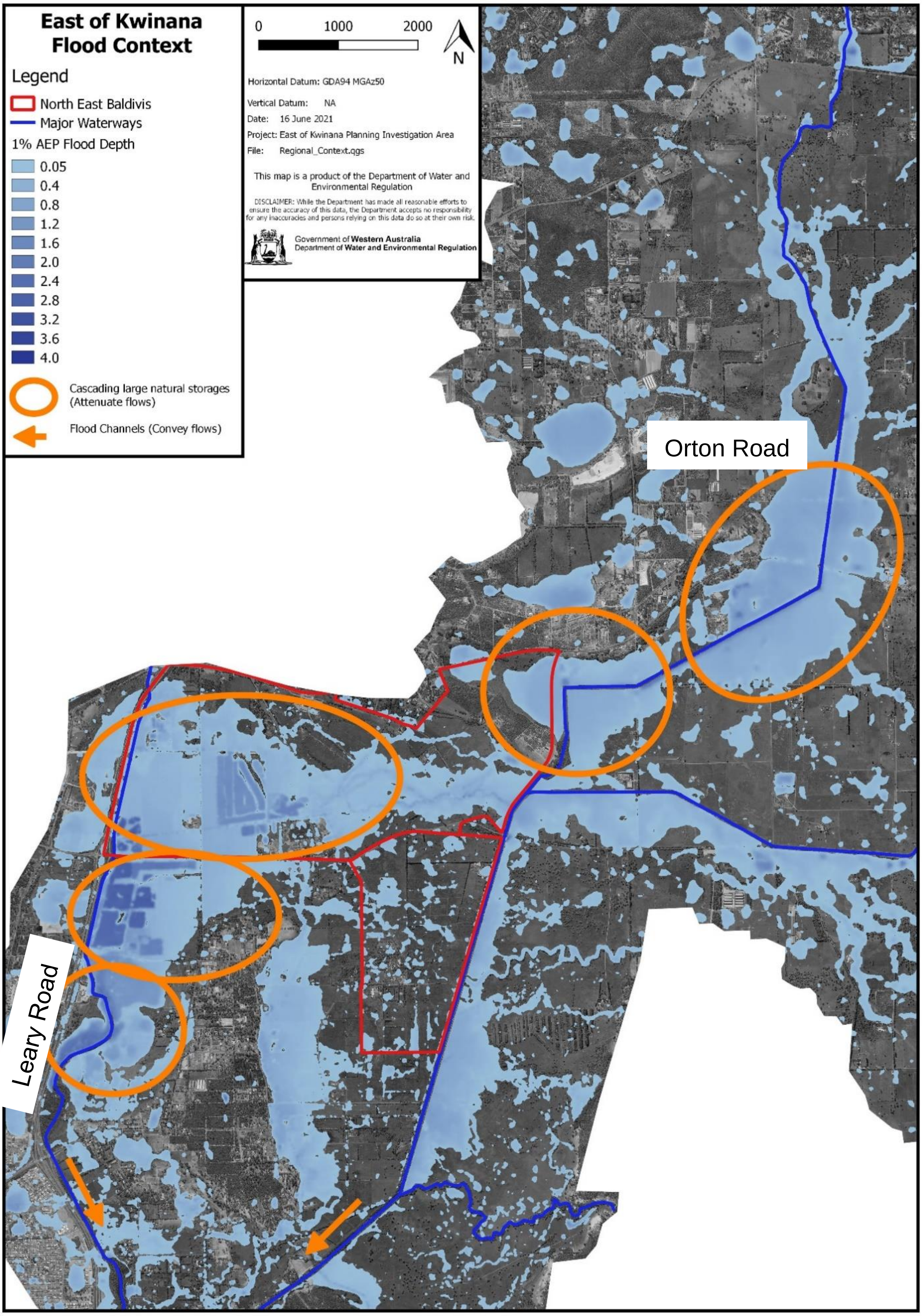


Figure 5 Northeast Baldivis flood context

3.2 Criteria for post-development assessment

Post-development impacts will be considered within the whole context of acceptable practices and targets for development, and proposals should satisfy the following criteria:

1. post-development peak discharge not to exceed pre-development peak discharge
2. post-development floodplain storage to be no less than pre-development floodplain storage, as increased early discharge ahead of the peak this high in the catchment will increase flooding on downstream land.

The appropriateness of proposals should be tested using flood models covering sufficient land outside the development proposal to demonstrate acceptable external impacts.

The tolerances to acceptable external flood level increases are as follows:

1. flood level increases up to 3 cm on the Peel floodplain and up to 5 cm on the Birrega and Oaklands floodplains
2. higher flood level increases could be considered within waterways and waterbodies and in very close proximity to waterways (e.g. within 20 m)
3. flood level increases at existing homes and structures not to exceed 1 cm.

Acceptable tolerance includes consideration of cumulative impacts in the catchment, incremental differences in flood levels between different flood probabilities and the location where the impacts occur.

Flood studies in Western Australia were initially undertaken during the 1980s and included the definition of a floodway. The floodway was defined as representing where the total cumulative impact of development reached a threshold of increasing flood levels by 15 cm. It has been accepted practice in Perth for the past four decades that the total cumulative impact of all development should not exceed 15 cm anywhere in the catchment.

Increases in flood levels also correspond to increases in the frequency of flooding and property damage experienced by landowners. For example, if a flood level increases by the difference between the 1% and 2% AEP floods, the impact to the landowner is that the 1% AEP flood is now a 2% AEP flood. This doubles the frequency of flood inundation. The variation of flood levels between different AEPs is relatively greater on the Birrega and Oaklands floodplain and smaller on the Peel floodplain. This means that the threshold of acceptable flood level increases is greater on the Birrega and Oaklands floodplains (5 cm) and smaller on the Peel floodplain (3 cm).

The location where the impact occurs also plays a role in the acceptability of the impact because of the potential to affect people and damage property. Existing development such as residential buildings or private property has the least tolerance to changes in flood levels (1 cm) compared to the floodplain. Waterways and waterbodies have the greatest tolerance to flood level increases compared to the floodplain and existing buildings.

3.3 Spoil banks

A rural drainage network owned by Water Corporation has been constructed within the catchment to manage and convey inundation on agricultural land within 72 hours after a rainfall event. The network is not classified as a flood protection asset in Water Corporation's operational licence. As a part of the construction and maintenance of this network, spoil material has been stockpiled adjacent to the rural drainage channels. These stockpiles, known as spoil banks, consist of material removed from the drains including sand, silt, rubbish and vegetation. These stockpiles do not include formally constructed foundations. There is no compacted or engineered structural core. Engineering-grade and formally compacted material has not been used and there is a range of material including organic matter scattered randomly within the stockpiles. There is no maintenance or surveillance scheme in place consistent with the operation of a flood protection levee asset.

Some sections of the spoil bank adjacent to the North East Baldivis north of Mundijong Road precinct may have been modified to attempt to create a rural levee. This work was undertaken about 100 years ago with no regular maintenance or upkeep. There are no urban flood levees in Western Australia and consequently no local guidance for the management of levees. In the absence of Western Australian guidance, *Levee Management Guidelines* by the Victorian Government have been used (Victorian Department of Environment, Land, Water and Planning 2015). These guidelines list a series of 'essential principles' for levees:

- A levee protects property, not lives.
- A levee is an expensive structure that needs to be appropriately managed.
- A levee cannot be relied on to provide flood protection if it has not been diligently maintained and if people are not trained and available to manage it during floods.
- A levee is built to protect assets that exist at the time, but the presence of a levee will usually encourage further development behind it. The higher the risk, the higher the degree of sophistication required for the flood protection system.
- A levee should have minimal impact on the flood storage and conveyance capacity of the floodplain on which it is built.

Although past attempts may have been made to construct a rural levee, the following is noted:

- The age of the construction renders design plans unreliable.
- Material compaction is non-existent or unreliable.
- Design and construction documentation is substandard by modern requirements.
- The design and construction were never intended to provide urban flood protection and only limited rural flood protection.
- The design and construction do not meet modern standards for urban flood levees.
- There is no long-term maintenance or surveillance record to demonstrate long-term stability and to identify potential latent defects or instabilities.

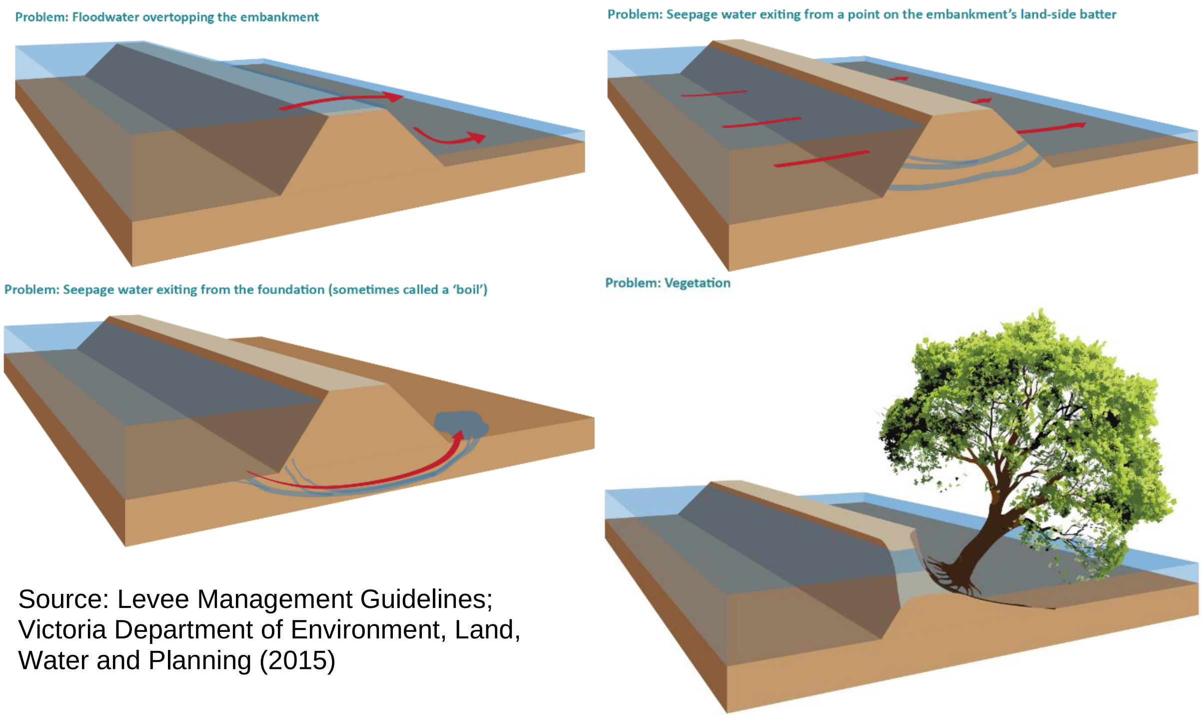
In discussions with Water Corporation, as the asset owner, it was noted that experience with levees of similar age demonstrated that design information and compaction was either non-existent or unreliable and could not be relied upon to provide appropriate flood protection.

While, in the past, attempts at construction of rural levees may have been made, these areas would not fit the requirements of modern engineered structural embankments. The potential for failure of these levees is fundamentally the same as for spoil banks. Spoil banks should not be considered as levees but rather as stockpiles of refuse material. There is anecdotal evidence of spoil banks failing during the 1987 (2% AEP) flood, and failure during larger floods such as a 1% AEP flood is highly likely based on:

- the history of their construction
- advice from the asset owner
- on-ground conditions
- the lack of appropriate historical maintenance and surveillance.

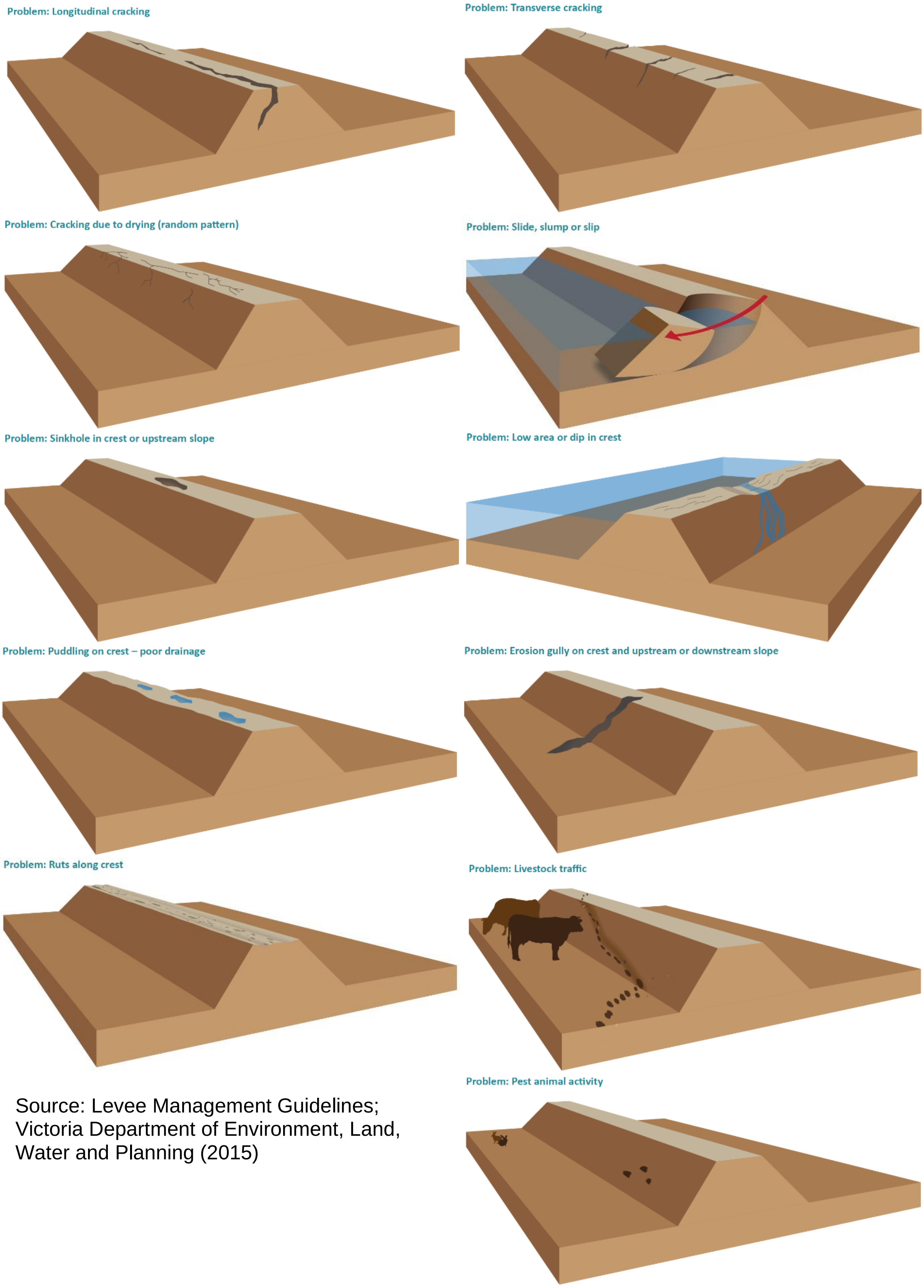
3.3.1 Spoil bank failure assessment

The potential for spoil bank failure was assessed considering common failure mechanisms known to practitioners and identified in documents including the *Levee Management Guidelines* (The State of Victoria Department of Environment, Land, Water and Planning 2015) and the *Flood emergency planning for disaster resilience handbook* (Australian Government 2017). Typical failure mechanisms considered by the desktop assessment are provided in Figure 6. A sample of common failure mechanisms and problems that may also be present on-site is provided in Figure 7. This list is not exhaustive and other problems and failure mechanisms specific to the on-ground circumstances will be present.



Source: Levee Management Guidelines; Victoria Department of Environment, Land, Water and Planning (2015)

Figure 6 Sample of failure mechanisms considered by desktop assessment



Source: Levee Management Guidelines; Victoria Department of Environment, Land, Water and Planning (2015)

Figure 7 Additional common problems and failure mechanisms with levees

A desktop assessment of the spoil banks adjacent to the Birrega and Oaklands main drains was based on criteria adapted from Australian Government guidance and guidelines from other jurisdictions around Australia. Failure of the spoil banks was considered likely if one or more of the following failure criteria were met:

- overtopping of the spoil bank initiating erosion
- structural failure because of build-up of a large amount of water on one side of the spoil bank
- large trees or vegetation causing damage weakening the structure, initiating internal voids and erosion or toppling over during a flood and initiating failure
- exposed or eroding bank within or adjacent to the drain.

The desktop assessment focused on situations where the criteria identified above were obviously visible in terrain data, aerial photography and flooding information. Site visits and on-site assessment were considered and undertaken in some locations. Historical information was used to validate the desktop assessment. Failure locations identified in the desktop assessment are identified in Figure 8 . A total of 41 locations were identified as meeting one or more of the failure criteria.

In collaboration with Water Corporation, it was identified that during the 1987 flood, failures of the spoil banks were observed at the following locations:

- Birrega Main Drain at Duck Pool adjacent to North East Baldivis north of Mundijong Rd precinct: Overtopping and circumvention of the spoil bank at Duck pool adjacent to eastern boundary of the North East Baldivis north of Mundijong Road precinct
- Birrega Main Drain adjacent to North East Baldivis south of Mundijong Road precinct: failure of the spoil back on the western side of the Birrega Main Drain
- Oaklands Main Drain upstream of East of Kwinana: failure of the spoil bank on the western side of the Oaklands Main Drain outside of East of Kwinana about 5 km upstream (east) of the North East Baldivis north of Mundijong Road precinct.

The spoil bank desktop assessment identified the most likely locations where failures could occur using four criteria and validated results against information available from the 1987 flood. The approximate locations of the observed failures and overtopping of the spoil banks, including an indicative direction of flow, is provided in Figure 8 below. Failures in the 1987 event matched locations identified in the desktop assessment. The criteria for failure were set at the minimum threshold necessary to include the failure locations observed in the 1987 flood. Two of the three 1987 failures occurred in the North East Baldivis north of Mundijong Road and North East Baldivis south of Mundijong Road precincts.

Given spoil bank failures were observed during a 2% AEP flood (1987) at some locations, it was concluded that failures will occur in the 1% AEP flood. The spoil bank adjacent to the North East Baldivis north of Mundijong Road precinct has an equal or greater likelihood of failure during a 1% AEP flood compared with the locations which were observed to fail in a 2% AEP flood.

Comprehensive visual inspections, ground penetrating radar (GPR) and geotechnical investigations were considered for added information when assessing the spoil banks against the failure criteria. Comprehensive visual inspections are difficult in vegetated areas and latent subsurface defects can easily be overlooked. GPR has limited capacity to provide information on characteristics such as the degree of compaction or to identify defects in deep places such as the foundations. It is likely that there are latent defects that would not be picked up by visual inspection or GPR. Geotechnical investigations can easily miss latent defects (which can initiate failure) and the homogeneity of the material quality and compaction in between geotechnical sampling cannot be assumed because of the history of construction and maintenance. Furthermore, geotechnical investigations themselves pose the risk of forming, triggering or accelerating failure because of latent defects.

Guidelines for the management of levees and other similar structural embankments (such as the *Levee Management Guidelines*, Victoria 2015) emphasise the need for long-term maintenance and surveillance to demonstrate long-term stability and safety. Features identified by visual inspection, GPR or geotechnical investigations may not appear to be significant during a one-off investigation. A regular long-term surveillance and maintenance program may identify subtle changes over time which could indicate a critical latent defect that could contribute to spoil bank failure.

The lack of appropriate design, construction certification and a continuous and long-term maintenance and surveillance program indicates that the spoil banks should not be relied on for flood protection in a 1% AEP flood. Further, advice from the asset owner is that the spoil banks were not intended and should not be relied on to provide a flood protection function in a 1% AEP flood.

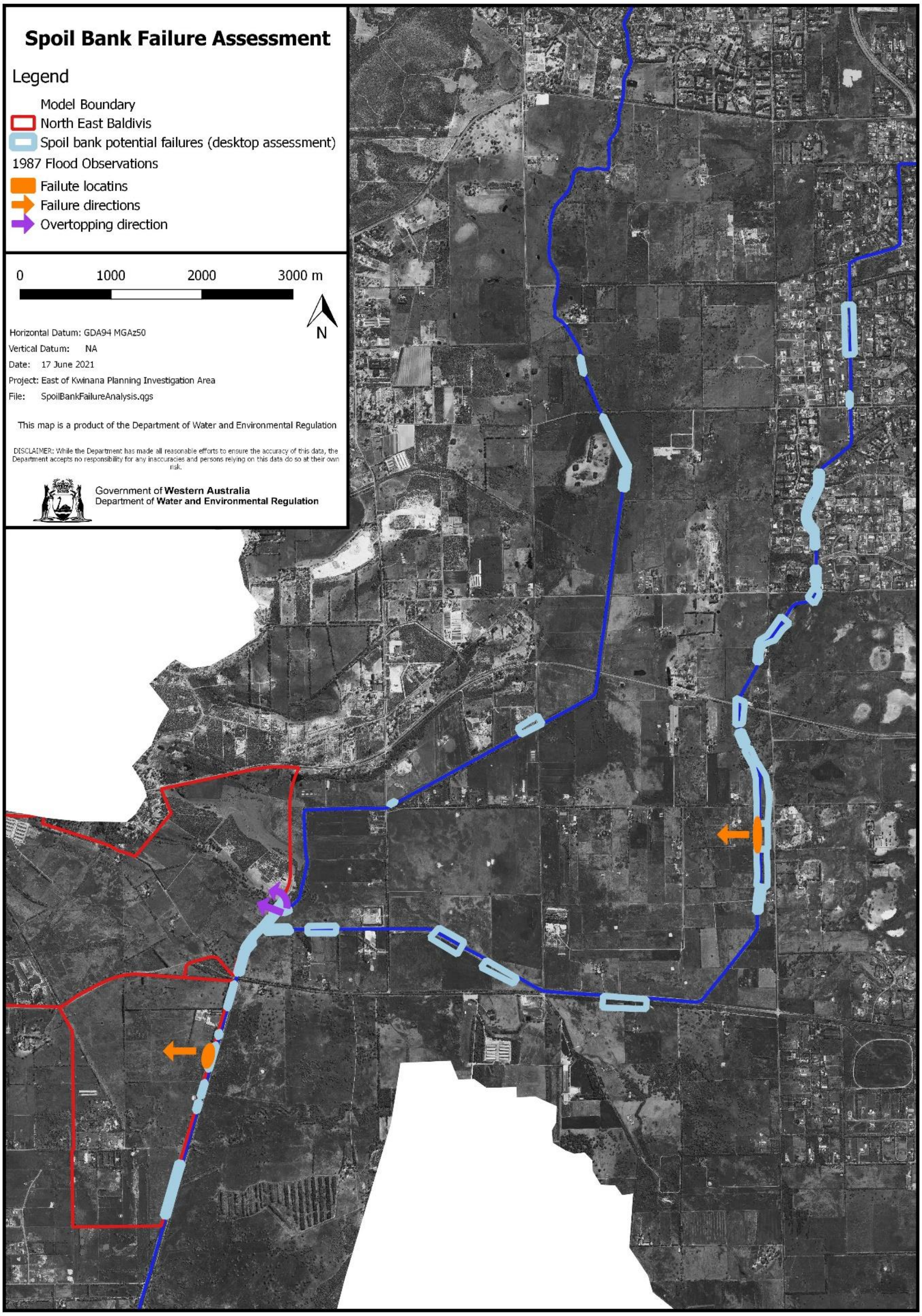


Figure 8 Spoil bank failure assessment and failures observed in 1987 flood

3.3.2 Spoil bank failure and pre-development base case

Previous studies including the *Birrega and Oaklands flood modelling and drainage study* (DWER 2015) and the *North-east Baldivis flood modelling and drainage study* (DWER 2015) also included spoil bank failures in their pre-development base case. A comparison of the inflows to the North East Baldivis north of Mundijong Road precinct from this study and the previous studies is provided in Table 2 below. The *Birrega and Oaklands flood modelling and drainage study* (DWER 2015) indicates a substantially higher peak inflow to the North East Baldivis north of Mundijong Road precinct as this includes failure of the spoil banks for a substantial length along both the Birrega and Oaklands main drains. In section 7.4 of the *Birrega and Oaklands flood modelling and drainage study* (DWER 2015), it was recommended that future urban development consider the following matters:

- the potential for failure of the levee banks on the Birrega and Serpentine main drains
- the capacity of Birrega and Oaklands main drains to convey drainage water without influencing downstream landholders
- the importance of floodplain storage.

The rationale for the inflows adopted by the *North-east Baldivis flood modelling and drainage study* (DWER 2015) are not clear; however, the similarity of inflows with the current study suggests that a similar approach may have been taken.

Table 2 North East Baldivis north of Mundijong Road pre-development spoil bank failure

Study	Pre-development Inflow (m^3/s)
Current study	73.1
Birrega and Oaklands flood modelling and drainage study (failure of spoil banks for a substantial length)	143.5
North-east Baldivis flood modelling and drainage study	64.8

In accordance with recommendations published by the department in 2015, consideration has been given to the potential for failure of the spoil banks (along with the second and third recommendations listed above). This study and flood risk assessment has been carried out in a manner consistent with the recommendations published in 2015.

Sensitivity testing was undertaken on the length of the spoil bank failure and determined that there was little difference to subsequent decision-making if the failure was limited to half the spoil bank length. Additional detail of the spoil bank sensitivity analysis is provided in Section 3.7.2.

The spoil bank failure assessment (Section 3.3.1) concluded that there are many areas along the rural drainage network where failure could occur. Joint probability of failure at multiple locations was considered and deemed highly complex as the uncertainty of where and when this would occur was too high and did not justify the added complexity.

The location of spoil bank failure that has the greatest impact on flooding within a precinct is immediately adjacent to the precinct. Therefore, it was determined that when considering development of a precinct, failure of the spoil bank would only be considered immediately adjoining that precinct.

For example, failures along the western bank of the Oaklands Main Drain substantially increase the floodwaters arriving at North East Baldivis precinct. However, the adopted failures were limited to locations immediately adjacent the development precinct of interest that had met the criteria for failure risk identified in Section 3.3.1.

Pre-development base case flooding for the 1% AEP is depicted for the regional flood model in Figure 9 and Figure 10 and for the local model in Figure 11. This is the base case to which all land use change proposals in Scenario 1 should be compared.

The department has systematically considered the locations, likelihood and consequence of spoil bank failure for the floodplain. A pre-development base case with 73 m^3/s represents the median risk position that recognises the likelihood of spoil bank failure and provides a reasonable balance between the economic use of the land and the risk to property damage and human life.

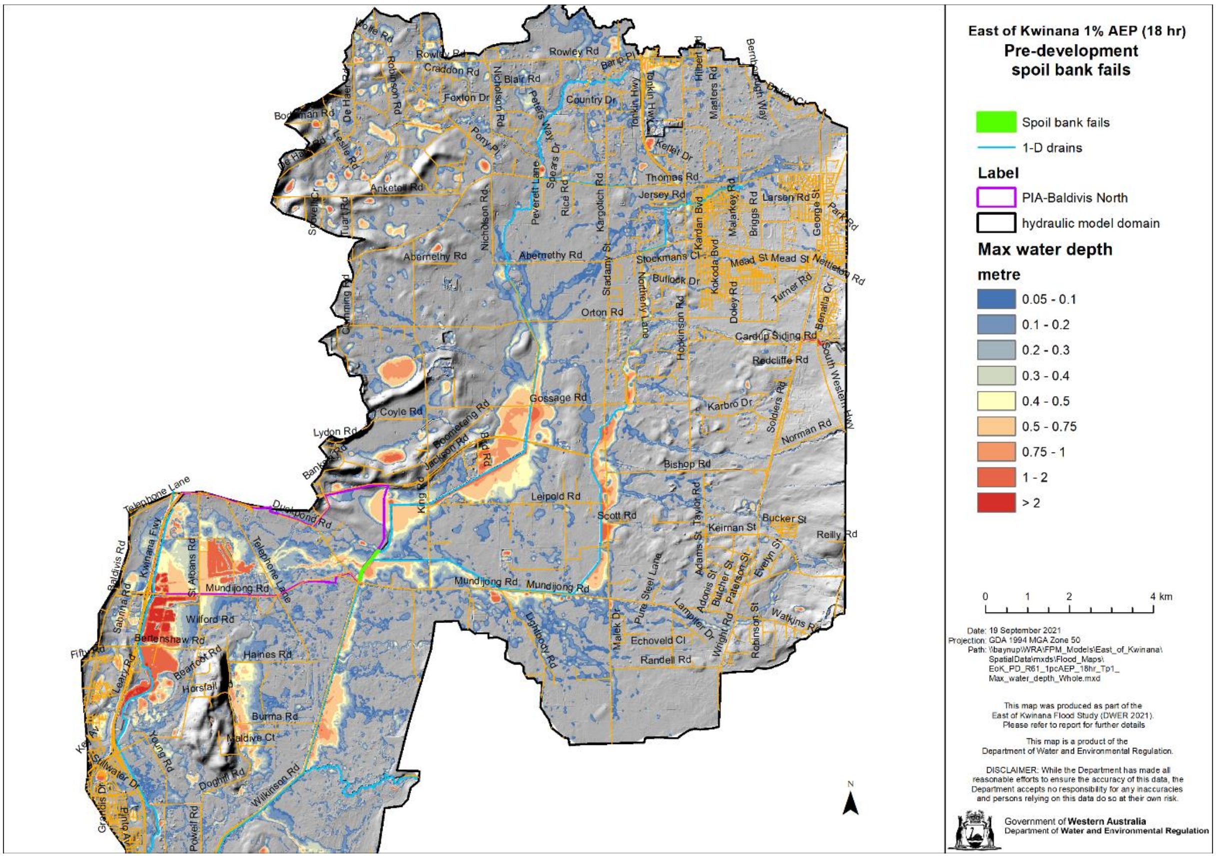


Figure 9 East of Kwinana pre-development 1% AEP flood map (regional)

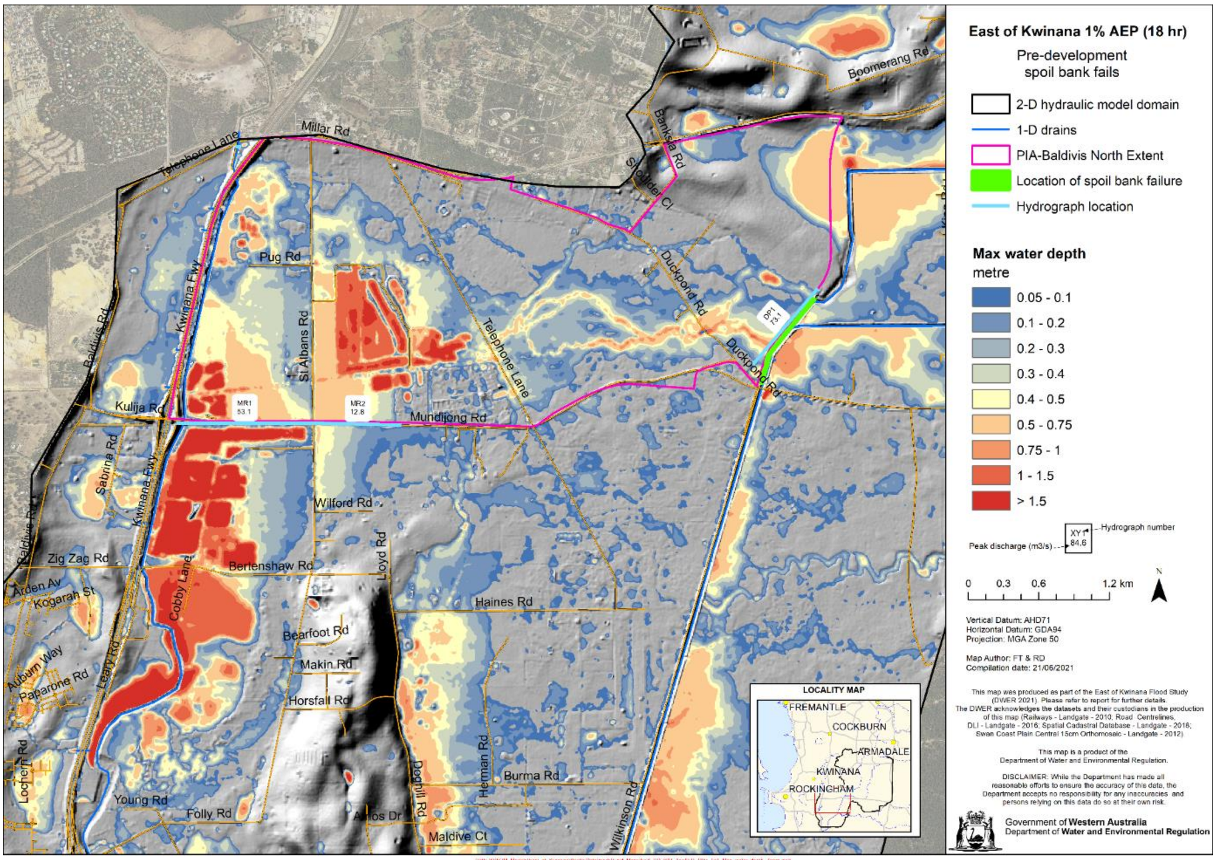


Figure 10 Pre-development 1% AEP flood map (spoil bank fails)

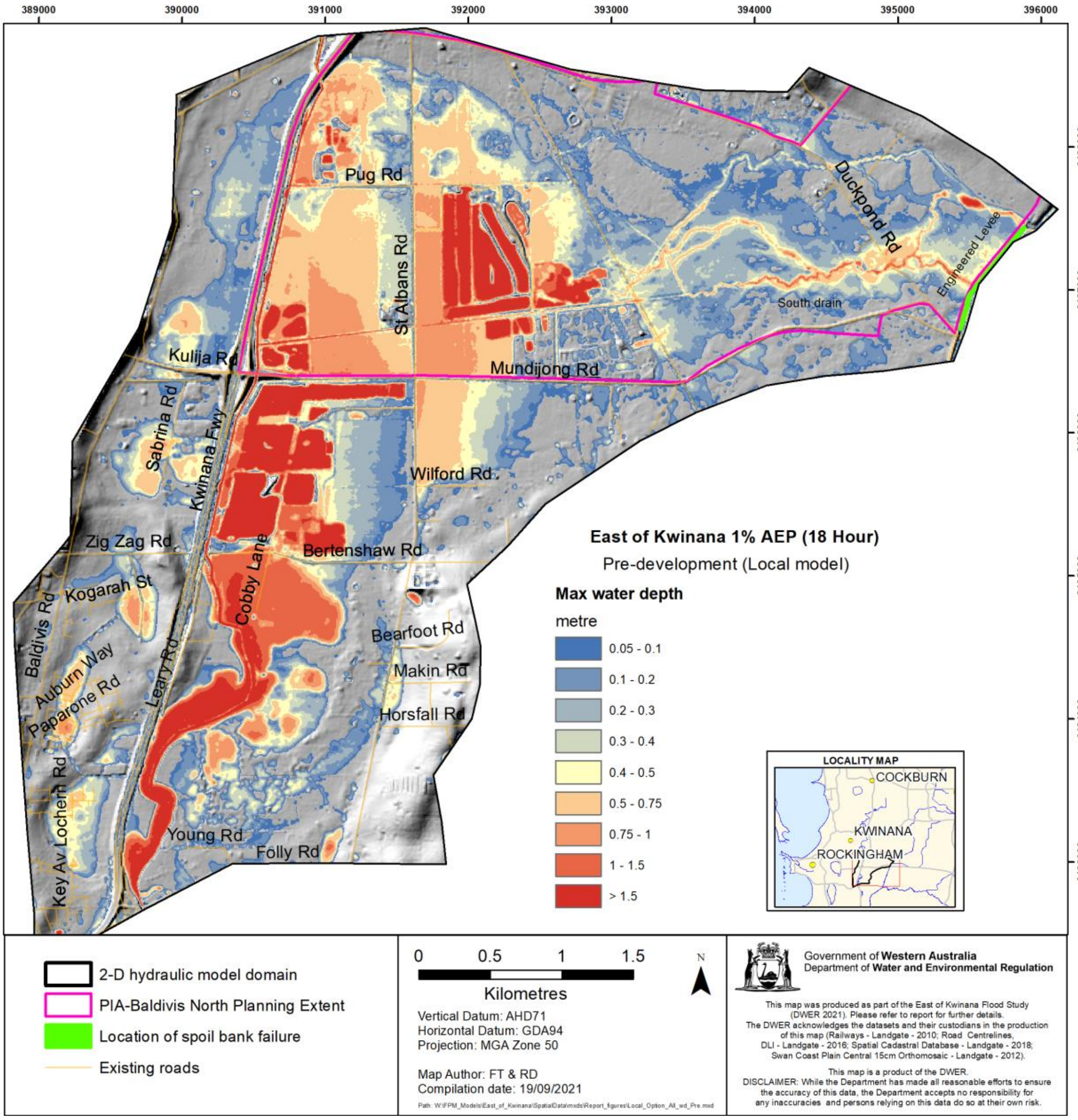


Figure 11 Local model 1% AEP pre-development flood map

3.3.3 Using a spoil bank as a levee

Proponent-driven levee proposals often retain the spoil bank as a levee on the banks of the Birrega Main Drain. Attempts to modify and reuse the historical spoil bank as the key structural component protecting human life overlook important safety aspects for modern levees documented in a variety of guidelines including the *Levee Management Guidelines* (Victoria 2015) and the *Flood emergency planning for disaster resilience handbook* (Australian Government 2017).

Basic engineering principles dictate that destabilising the toe of an embankment will progressively destabilise the entire embankment. When the embankment is within the waterway, it is subject to erosive forces that damage the toe and destabilise the entire structure. Erosion protection measures are proposed; however, the erosion protection often falls short of what would be required to provide appropriate protection in such a harsh environment. The environmental impacts of measures are often overlooked and long-term maintenance requirements are ignored. It is unnecessary to locate the embankment in the erosive forces of the main drain when there is space available to provide separation.

The existing spoil bank should not be adapted or reused as an urban flood levee because of the probability of a latent defect in the spoil bank resulting in failure, and the proximity to the Birrega Main Drain initiating erosion. The loss of human life is reasonably foreseeable and can be attributed to the decision to reuse the spoil bank as an urban flood levee.

3.4 North East Baldivis north of Mundijong Road – urban levee approach (Scenario 1 Option A)

The objective of Scenario 1 Option A is to identify the impacts of developing the land using an urban levee to prevent upstream flood waters from entering the precinct when developed. The department does not support the use of urban flood levees to facilitate new development; however, there have been proponent-driven proposals in the past that adopted a similar approach. Therefore, this approach was included in this assessment.

Under normal circumstances, elements would not be included in the flood modelling and analysis if they contradicted the department’s policy, were considered unachievable or would impact human life or safety. The objective is to ensure that model inputs represent a situation that is as realistically representative of the likely post-development scenario as possible. The objective of this option was to demonstrate the likely impacts of developing a proposal based on previous proponent-driven proposals; therefore, this scenario prioritised proponent-driven approaches over the department’s policies and accepted practices to allow for assessment of the impacts of this approach.

3.4.1 Pre-development base case

The assessment of the spoil banks against the failure criteria and validation using historical data (Section 3.2) found that the spoil bank adjacent to the Birrega Main Drain is likely to fail during the 1% AEP flood and cannot be relied upon to provide flood protection for the 1% AEP flood in the North East Baldivis north of Mundijong Road precinct. Sensitivity testing on the length of the spoil bank failure determined that there was little difference to subsequent decision-making if the failure was limited to half the spoil bank length. Additional detail of the spoil bank sensitivity analysis is provided in Section 3.7.2.

The pre-development base case for the North East Baldivis north of Mundijong Road precinct includes the failure of the spoil bank for the entire length immediately adjoining the eastern boundary of the precinct.

Pre-development flooding within the North East Baldivis north of Mundijong Road precinct was assessed to characterise the pre-development flood function as described in section 5.2 of *Managing the floodplain: a guide to best practice in flood risk management in Australia* (AIDR 2017) and summarised in Figure 16. The flood function is divided into ‘flood conveyance’ (also referred to as floodway), ‘flood storage’ and ‘flood fringe’.

3.4.2 Post-development flood levee

At present there are no significant urban flood levees in the Perth metropolitan area and there is limited capacity within the local industry or within government institutions to adequately oversee the design, construction and operation of an urban flood levee or the emergency response.

Given urban flood levees are not used in Western Australia, the department has considered national guidance, including the *Levee Management Guidelines* (Victoria 2015) and the Australian disaster resilience (Australian Institute for Disaster Resilience, 2017-2020) guidance and applied it to the urban flood levee approach for North East Baldivis north of Mundijong Road precinct.

This section provides additional information on some of the critical requirements that would need to be implemented if an urban flood levee is proposed. In addition to the matters discussed in this section, there will need to be significant capacity building, management systems and governance arrangements put in place prior to the construction of an urban flood levee.

3.4.2.1 Assessment of an urban flood levee

Levees are assessed based on the consequences of failure and not the likelihood of failure. A brief explanation of this concept is provided in Section 3 of the *Levee Management Guidelines* (Victoria 2015). Further information about appropriate methodologies can be found in various standards and guidelines addressing the construction of earth embankments and the consequences of failure. All urban flood levees are considered to pose a 'high hazard' (Victoria 2015) and the assessment of any flood levee would proceed on that basis. The following provides a high-level introduction to the approach by which urban flood levees will be assessed and an appropriate design considered. It is not intended to be a comprehensive description and should not be viewed as an indication of support for this option, but an indication of the fundamental approach for the sake of transparency in decision-making.

The 1% AEP flood is a commonly used flood standard in Australia for property protection because it is accepted that the cost of mitigating larger floods (including the opportunity cost of not developing land) generally exceeds the value of the property that is being protected. However, this argument cannot be made regarding safety and human life. All reasonable steps must be taken to ensure the safety of human life and, given that floods greater than the 1% AEP flood can and do occur, it is necessary to consider larger floods.

Flood levees are identified as special environments in *Flood emergency planning for disaster resilience* (AIDR 2020) and are recognised as posing a unique danger to human life. The levee crest height must incorporate a 0.5 m freeboard above the 1% AEP flood as a minimum to ensure that a 1% AEP flood standard is provided for downstream property protection. However, human safety is assessed based on much larger floods. The largest flood that can occur is the Probable Maximum Flood (PMF) and is the nationally accepted standard for consideration of safety for human life. Consideration of human safety is required up to the PMF; however, this does not mean that mitigation of property damage in the PMF is required. Safety considerations for an urban flood levee must include with and without levee failure for both the PMF and the flood that peaks at the crest and fails at the time of the peak. The hazard that is identified by scenarios like this subsequently forms the basis for determining the levee design standards, emergency management response downstream and the ongoing management of the levee.

Consideration of the developable area is not limited to property damage and inundation for the 1% AEP flood but includes the risk to human life for all potential flood scenarios up to and including the PMF. The developable area may be limited by the formation of hazardous conditions should levee failure occur rather than the area of the 1% AEP flood inundation should failure not occur.

Maintaining the flood function of the floodplain is a key objective of best practice in flood risk management. Retaining the flood function of the North East Baldivis north of Mundijong Road precinct for both the 1% AEP flood and the PMF is a specific requirement of national standards and best practice flood risk management (Australian Disaster Resilience Handbook 7, Section 5.2).

This has historically been recognised in North East Baldivis north of Mundijong Road. The spoil bank adjacent to the Birrega Main Drain does not provide flood protection for the 1% AEP flood and allows for the retention of the natural flood function of the floodplain through this area. The flood function through the North East Baldivis north of Mundijong Road precinct has been defined in Section 3.5.1 below including the definition of a floodway (flow conveyance area).

In the assessment of any levee proposal, it will be necessary to maintain a floodway through the development no less than that defined in Figure 18 and may be greater than this area depending on the safety and failure hazard assessment. There will also need to be an appropriate setback of private development from the levee to account for localised hazardous conditions during a failure. This is required irrespective of the inundation extent determined for situations where failure does not occur.

3.4.2.2 Appropriate design of an urban flood levee

As discussed in Section 3.3.3, the levee would need to be a substantial distance from the waterway to provide adequate protection from erosive conditions and accommodate both environmental and recreational requirements for the waterway foreshore. That is, trees and recreational infrastructure would not be permitted on or near the levee as they would create conditions during a flood that would initiate failure of the levee. There would need to be sufficient setback between the levee and the waterway to accommodate environmental and recreational requirements for the foreshore. There would subsequently be a large, engineered structure between the residential development and the foreshore reserve. The construction of an entirely new levee would be required, complying with modern structural design standards, internal and external levee erosion protection measures and appropriate construction and compaction.

3.4.2.3 Ongoing management of an urban flood levee

Given that there are no significant urban flood levees in the Perth metropolitan area at present, institutional arrangements required to appropriately maintain and operate the levee and undertake emergency response is very limited. The design, funding, ownership, maintenance and operation of the levee and associated flood warning systems, community education programs, evacuation procedures and ownership of residual flood risk need to be agreed to by all relevant State Government and local authorities and agencies at the district planning stage.

The institutional arrangements that would need to be put in place are:

- installation of gauging and monitoring technology by Water Corporation and local government at the levee to detect and alert of conditions that may lead to failure
- incorporating of potential levee failure forecasting in flood forecasting by the Bureau of Meteorology
- establishment of a safety and evacuation plan by the impacted local governments and the Department of Fire and Emergency Services (DFES)
- establishment of alert criteria and communication protocols between the Bureau of Meteorology, DFES, Water Corporation and the local governments impacted.
- seamless integration of telemetry, forecasting, communication and emergency response across multiple government agencies.

In addition to the levee construction and institutional arrangements discussed above, *Flood emergency planning for resilience* (Australian Institute of Disaster Resilience 2020) requires emergency management and evacuation arrangements to be put in place and ongoing community education and awareness programs to be undertaken. The requirements that will need to be put in place include the following:

1. There would need to be a community facility (preferably to the north) on high ground which can function as an emergency evacuation centre which can both accommodate the impacted residents and can be readily accessed by roads heading in a constant uphill direction perpendicular to the flow of flood waters.
2. There would need to be a notification on property titles and planning certificates identifying the potential hazards of a levee failure owing to the uniqueness of the situation in the Perth metropolitan area.
3. When impacted residents first move into their homes there will need to be individual notification and instruction on evacuation warnings and the action required. This instruction would need to be repeated at regular intervals as a refresher for existing residents and notification of new residents.

Even then it should be noted that the timeframes to effect an emergency response and the nature of the flooding may require the prediction of hazardous conditions and implementation of an emergency response well in advance as a precautionary measure. This would mean that there may be false positives on a semi-regular basis, possibly as frequent as every 10 years. For example, the threat of dangerous conditions forming may necessitate an evacuation of residents (knocking on hundreds of doors) late at night or in the early hours of the morning for an emergency that may or may not subsequently occur. The resulting false positives would gradually reduce the effectiveness of any emergency response through either the perception of 'crying wolf' or a reluctance to implement repeated emergency responses within short time intervals of each other despite the repeated development of hazardous conditions.

The commencement of potentially hazardous conditions and the need for evacuation would occur during the storm event at a time when the hazard situation is dynamic and the response is reactionary. Emergency services will be under great pressure to respond to fallen trees, cordon off downed power lines and flooded roads, perform hazardous flood rescues, etc. It is during this time that a significant contingent of resources would need to be diverted from rescue efforts to affect an evacuation of North East Baldivis north of Mundijong Road, leaving residents in the broader area with limited emergency-response capacity.

3.4.2.4 Justification for an urban flood levee

Urban flood levees typically exist to protect development that was historically placed on inappropriate land. They are implemented as a measure of last resort when relocating an existing town or suburb or preventing further development places too great a burden on the existing community. Urban flood levees require significant engineering design, construction and maintenance. They also require advanced flood prediction and emergency management systems that recognise the unique danger that they pose to human safety and life.

Urban flood levees are inherently dangerous and only used to protect communities that are already in danger, not as a justification to deliberately place people in danger.

There is no existing urban development in the North East Baldivis north of Mundijong Road precinct and the use of an urban flood levee would be placing people in harm's way.

3.4.3 General approach

Development of the urban flood levee approach (Scenario 1 Option A) was based on layouts and concepts typically put forward by various proponents in the North East Baldivis north of Mundijong Road precinct.

Information from proponent-driven proposals was cross referenced with the available light detection and ranging (LIDAR) terrain to create a logical and spatially correct scenario. The final terrain is the best possible representation of proponent-driven proposals but also accounts for the physical properties of the pre-development LIDAR terrain at the proposal's perimeter. Several aspects in the terrain purposefully departed from proponent-driven proposals and are documented below. The final terrain used in the flood modelling is depicted in Figure 12.

Figure 12 Scenario 1 Option A terrain adopted by the department for flood modelling

3.4.4 Upstream extension

Proponent-driven proposals typically only cover a portion of the precinct depending on their land ownership. Should development of the precinct proceed, the entire precinct would need to be included, not just individual land holdings. Therefore, the department's terrain covers the entire North East Baldivis north of Mundijong Road precinct and was developed to be consistent with approaches in proponent-driven proposals.

The only exception to this was the large natural storage area at the north-east end of the precinct, outside the flood conveyance area. Flooding would constrain the development of the land largely because of conservation of floodplain storage. Several layouts could be adopted if the floodplain storage was conserved. For this reason, the pre-development landform was retained for the flood modelling as the developable area could be established by using the pre-development floodplain storage target as a design criterion.

This option includes a flood levee to be consistent with proponent-driven proposals; however, consistent with Section 3.4.2.2, a new levee has been included with a nominal distance of 70 m between the embankment toe and the waterway. This provides appropriate separation between the levee and the Birrega Main Drain, allowing for environmental and foreshore buffers and recreational infrastructure.

Proponent-driven proposals typically include several shortcomings which have been addressed as a part of Scenario 1 Option A. The first relates to the use of the private water park facility as a flood-compensating basin. Proponent-driven proposals often assume that the entire private water park facility can be retained and used as a compensating basin. These proposals often exacerbate existing flooding on the site and introduce potential urban water quality impacts. The effect of these assumptions is to render the water park facility unsuitable for the current use and with very limited recreational value in the post-development.

The second issue relates to interception of groundwater. The department has a range of groundwater information, including a groundwater model, for this area. Proponent-driven proposals often cut into the groundwater, potentially mobilising significant quantities of groundwater. Proposals in this area will need to be consistent with the department groundwater modelling. This will impact development invert levels, ground levels and fill requirements. Figure 13 illustrates high groundwater levels within the precinct in September 2020 and Figure 39 depicts groundwater inundation of this proposal when discussing fill requirements.

Figure 13 Groundwater levels at North East Baldivis in September 2020

3.4.5 Flood modelling and results

The Scenario 1 Option A terrain was incorporated into both the regional and the local models to simulate the impact of this option on flooding outside of the North East Baldivis north of Mundijong Road precinct. The regional model was used to simulate the upstream impacts on the Birrega and Oaklands catchment to the east, while the local model was used to determine flooding within the precinct as well as on the Peel Main Drain to the west of the site. The 1% AEP 18-hour duration rainfall pattern from the regional model was used to determine the development impacts outside the site as this is the critical duration for the broader catchment. A range of durations between one hour and 24 hours was simulated using the local model to determine flooding within the site.

The peak of peaks from the local model is shown in Figure 14 while the impacts outside the development area are shown in Figure 15 for the critical duration resulting from the regional flooding.

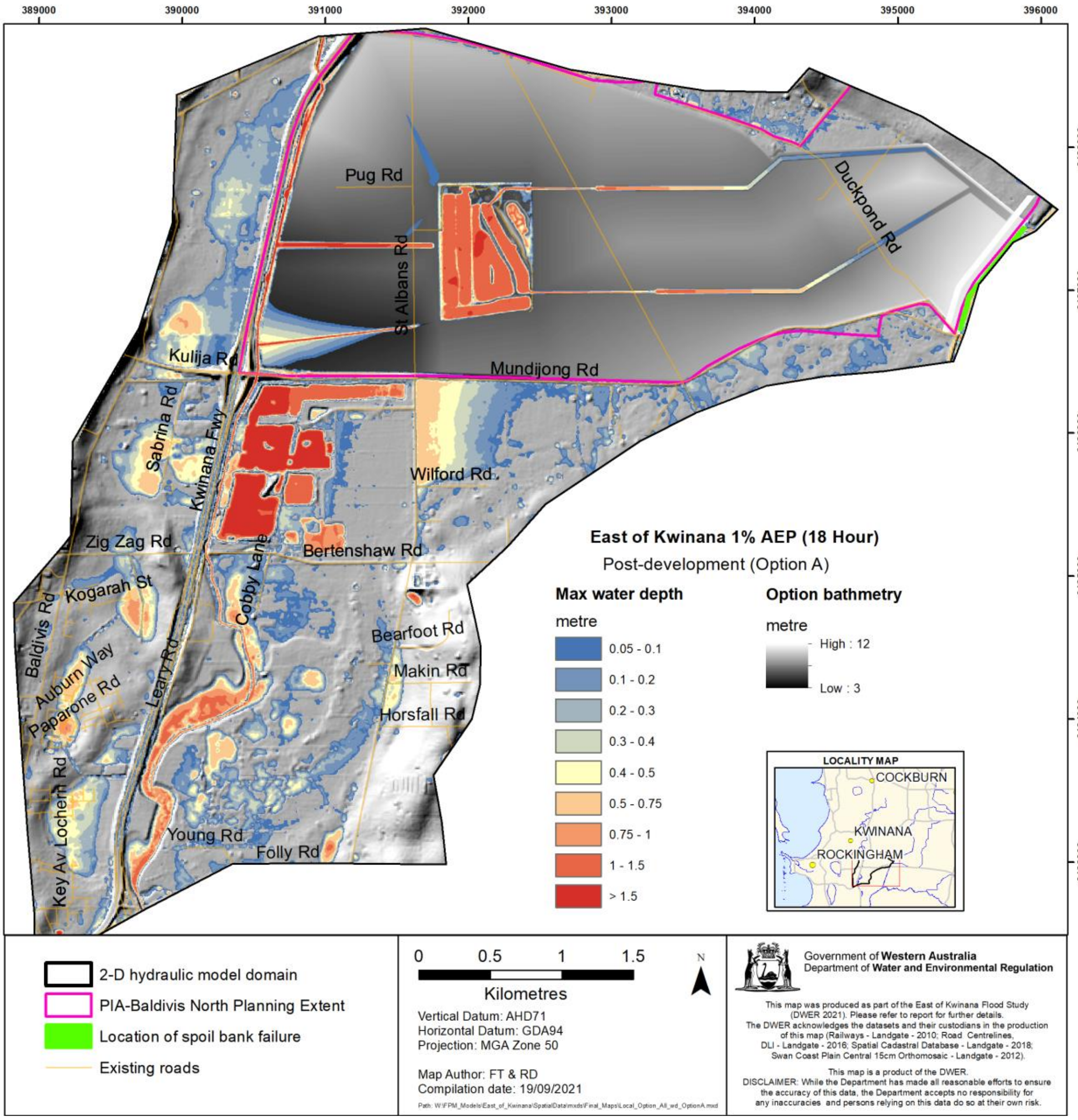


Figure 14 East of Kwinana 1% AEP Scenario 1 Option A local flood map

Figure 15 shows that Scenario 1 Option A detrimentally increases flooding over an area that extends for about 5 km upstream and 5 km downstream (10 km in total) along the Birrega Main Drain on the eastern side of the proposed development. Flooding is reduced for about 3 km downstream of the Peel Main Drain towards the south-west of the development. The significant increases in flooding towards the east of the site indicates that the proposal may be transferring development potential from the eastern side into the development site and to the south-west of the site. The area where flooding increases on the western side is substantially larger than the area where flooding is reduced on the eastern side. In fact, much of the flood level reductions are within water bodies and would be unlikely to improve the development potential of that land. This suggests that developing Option A may reduce the total amount of developable area within the broader locality.

3.4.6 Maintaining the floodway

Maintaining the flood function of the floodplain is a key objective of best practice flood risk management. Retaining the flood function of the North East Baldivis north of Mundijong Road precinct for both the 1% AEP flood and the PMF is a specific requirement of national standards and best practice in Australian Disaster Resilience Handbook 7: *Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia*, Section 5.2 (AIDR 2017).The floodplain is defined for North East Baldivis north of Mundijong Road in Section 3.5.2 below, including the definition of a floodway (flow conveyance area). Scenario 1 Option A was based on proponent-driven proposals for urban flood levees and does not retain the floodway through the precinct.

To ensure the flood function of the floodplain through the North East Baldivis north of Mundijong Road precinct is maintained, a floodway should be retained in all land change proposals for the precinct.

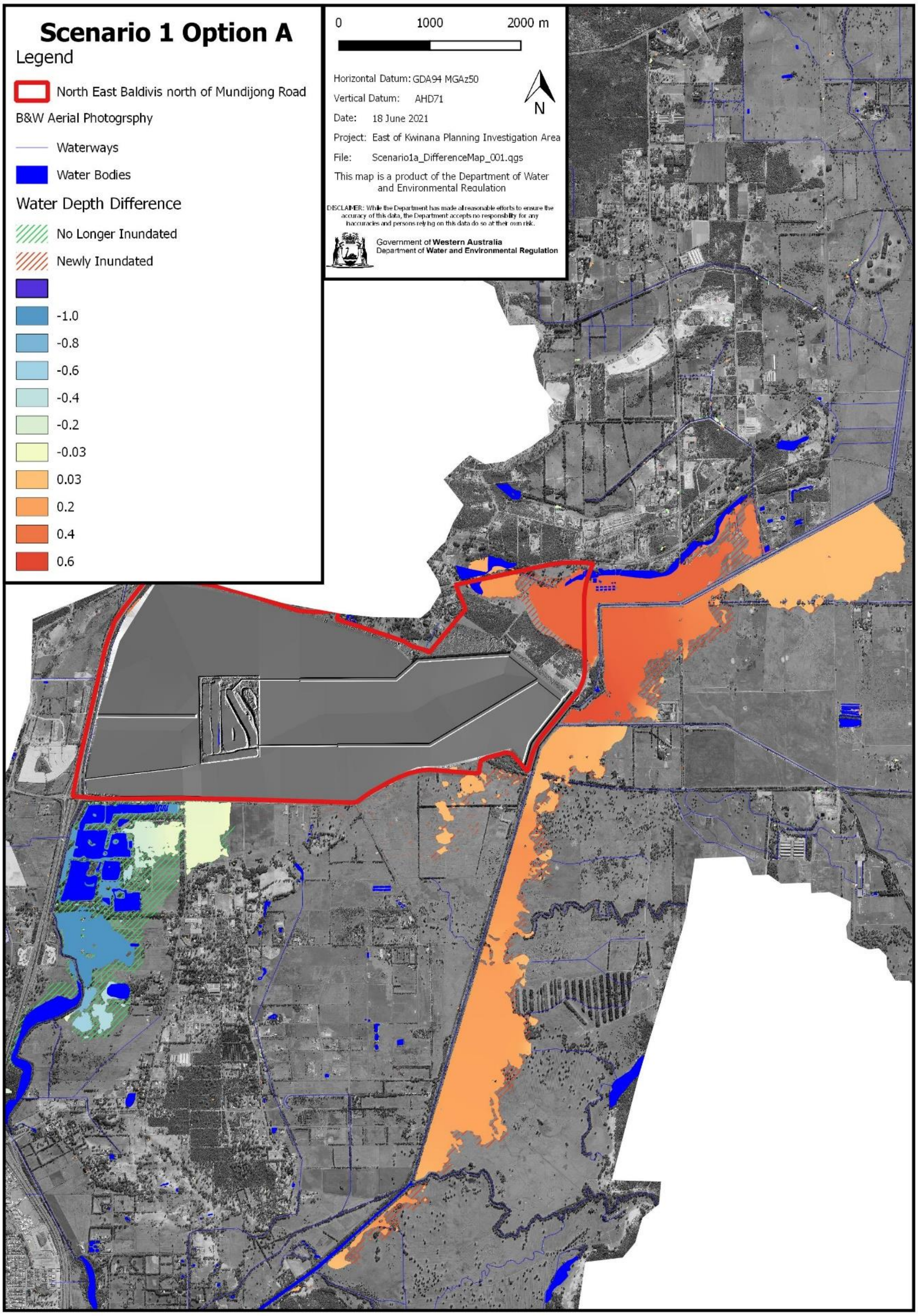


Figure 15 Scenario 1 (Option A) water depth difference map

3.5 North East Baldivis north of Mundijong Road – traditional approach (Scenario 1 Option B)

The objective of the traditional approach to flood management (Scenario 1 Option B) was to maximise the area of land above the 1% AEP while accommodating pre-development flooding through the site and ensuring that flooding of land below the 1% AEP still permitted the use of that land for other purposes including a public use at a minimum. The difference between Option A and Option B was that Option A aimed to exclude external flooding from the North East Baldivis north of Mundijong Road precinct while Option B aimed to accommodate flooding that could be reasonably expected under pre-development conditions.

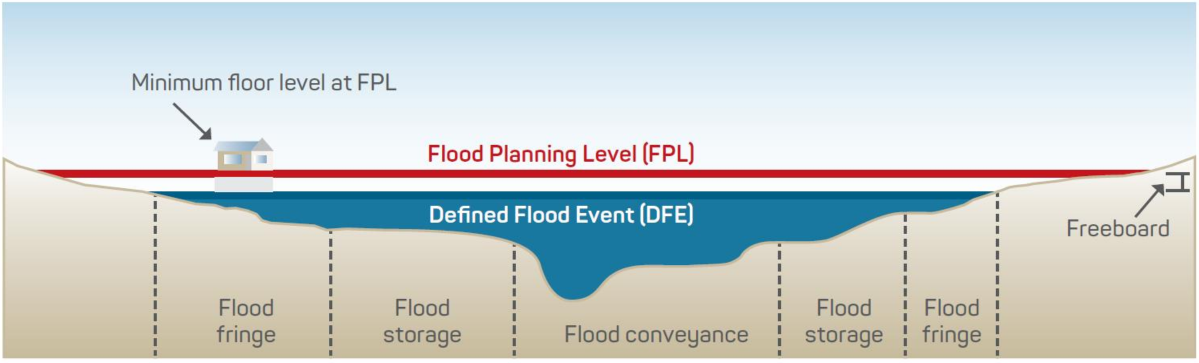
3.5.1 Pre-development base case

The pre-development base case for the North East Baldivis north of Mundijong Road precinct includes failure of the spoil bank for the entire length immediately adjoining the eastern boundary of the precinct.

Formulation of Scenario 1 Option B started with further understanding the nature of flooding and flood constraints within the area of interest. Figure 9, Figure 10 and Figure 11 depict the maximum depth of inundation and peak discharge under pre-development conditions. Figure 17 below depicts the maximum velocity within the precinct. The velocity shows that the eastern portion of the precinct consists of a waterway with a distinctive flow path forming a floodway. However, the western portion of the site consists of a very low velocity and, combined with very flat flood levels, this indicates that the area primarily consists of a large flood storage. The existing water park facility is located at the interface between the waterway and the flood storage area. The spike in velocity on the north-eastern corner of the water park suggests that it is causing a significant redistribution of flood flows and therefore the water park facility is obstructing the floodway.

Pre-development flooding within the North East Baldivis north of Mundijong Road precinct was assessed to characterise the pre-development flood function as described in section 5.2 of *Managing the floodplain: a guide to best practice in flood risk management in Australia* (AIDR 2017) and summarised in Figure 16. The flood function is divided into flood conveyance (also referred to as floodway), flood storage and flood fringe.

A preliminary assessment was undertaken of the floodway extent. Floodways are typically described as the area where most of the water flows and, if obstructed, would detrimentally increase upstream flood levels or significantly redistribute flows in the floodplain. The preliminary floodway extent has been defined through the examination of floodplain velocities, the velocity depth product, unit flow distribution across the floodplain and channel banks. The preliminary hydraulic categorisation including the pre-development floodway definition is provided in Figure 18. A total of seven cross-section samples were used to assess the unit flow distribution across the site which revealed that the floodway represents about 65% of the peak flow in the floodplain. Three examples of the unit flow distribution (cross-section of the velocity depth product) are provided in Figure 19.



Source: Figure 2.*1 Managing the floodplain: a guide to best practice in flood risk management in Australia* (AIDR 2017)

Figure 16 Hydraulic categorisation of floodplains

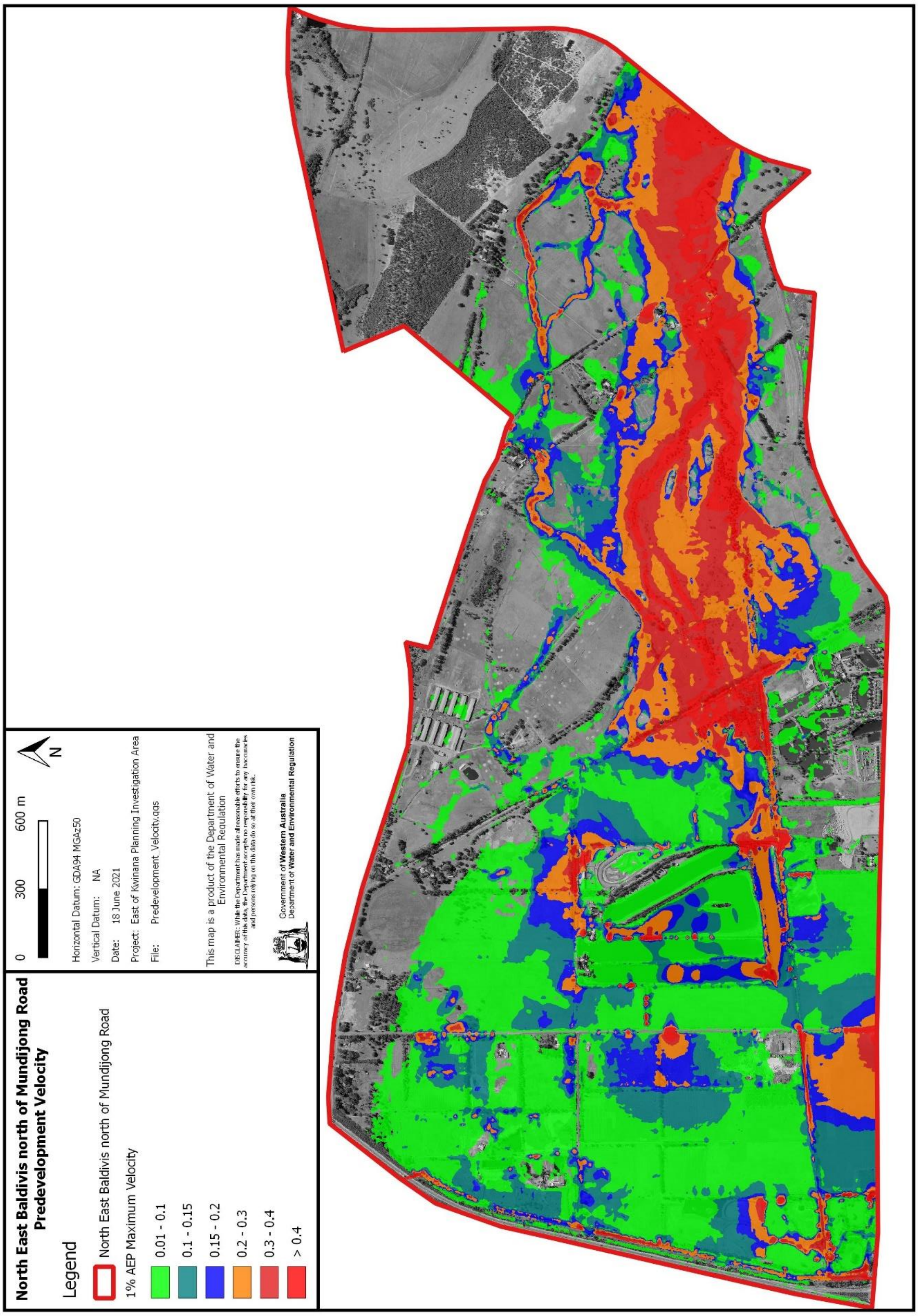


Figure 17 Pre-development velocity

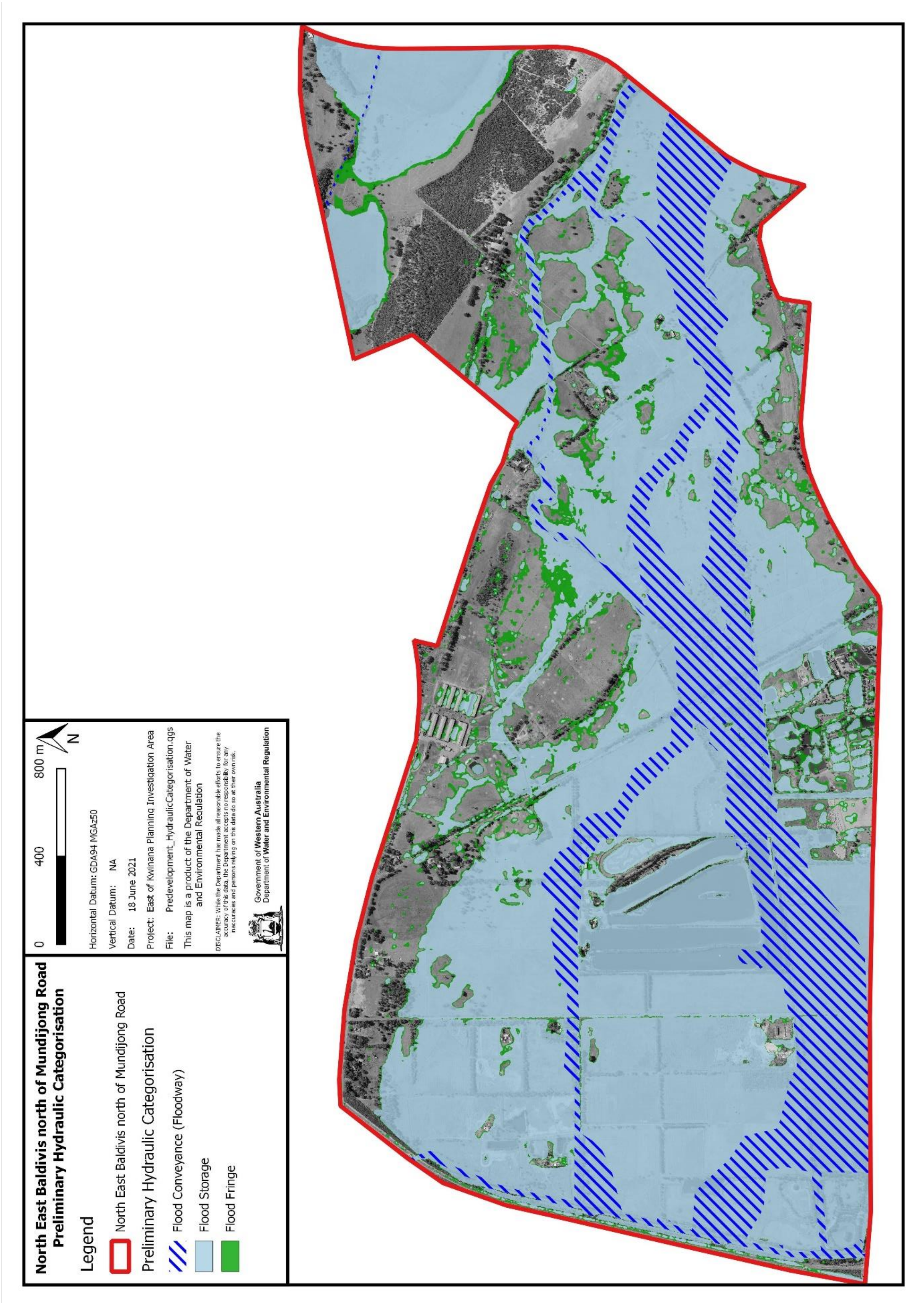


Figure 18 Pre-development hydraulic categorisation

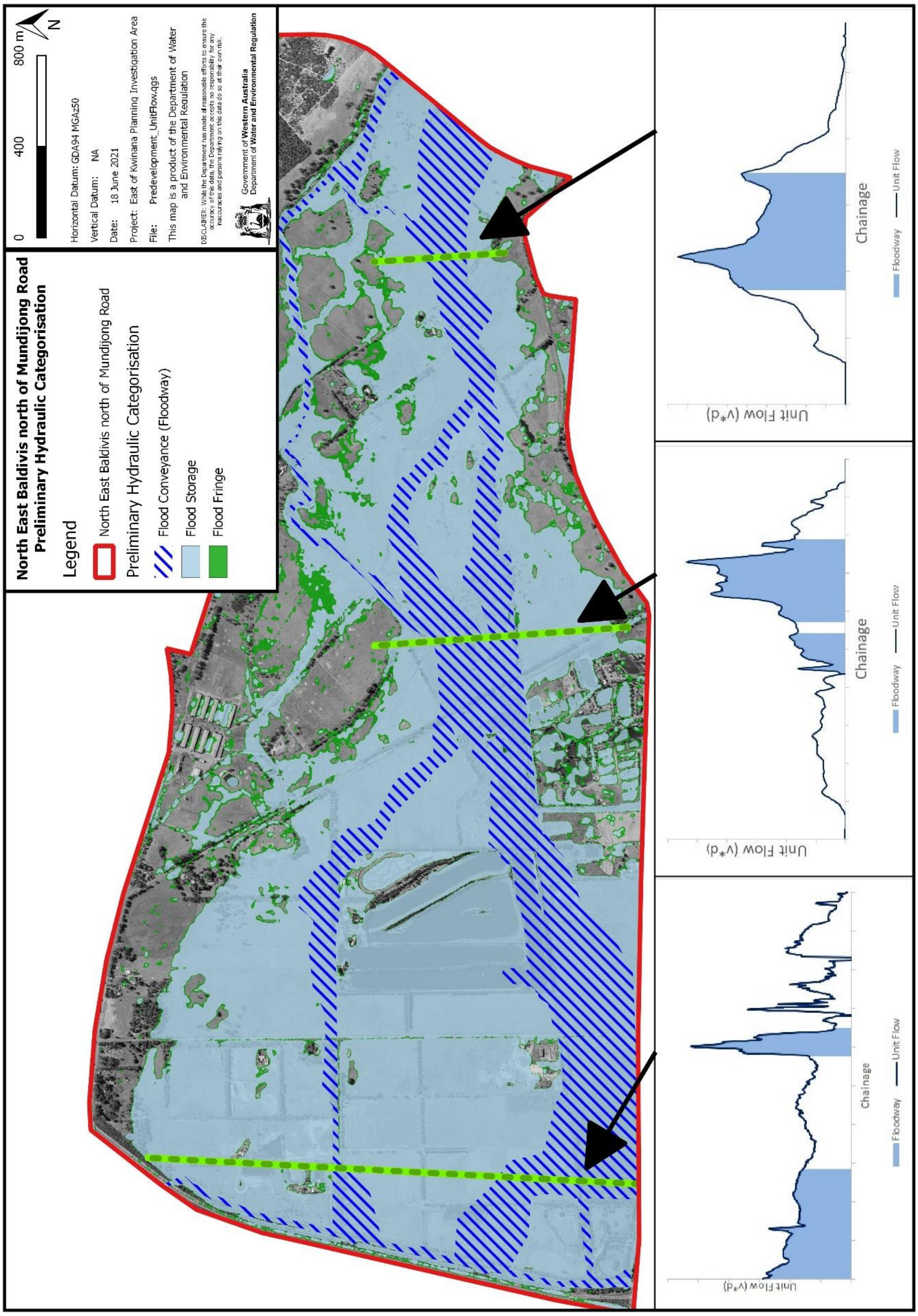


Figure 19 Pre-development 1% AEP sample unit flow distribution

3.5.2 Initial concept formulation

The general approach to development in Scenario 1 Option B is to remain sympathetic to the pre-development environment and flooding regime. That is, to incorporate a central flood corridor through the precinct and a large storage in the lower (western) end. In the pre-development environment flood flows discharge from the site via both the Peel Main Drain and overtopping of Mundijong Road and this was retained in Option B.

Formulation of the Option B layout started by dividing the pre-development flooding into seven (7) cells as shown in Figure 20. The cell boundaries were determined by interrogation of the longitudinal water level profile, flooding extent and existing topographical features. The purpose of the cells is to ensure that the pre-development floodplain storage in each cell is retained within that cell in the post-development Option B terrain. The benefits of using the cells are as follows:

- facilitate the formulation of Scenario 1 Option B
- relate the post-development flood mitigation required for a cell to the pre-development flooding in that cell
- allow cells to be mixed and matched between Option B and Option C thus giving flexibility to adopt different approaches across the precinct.

Each cell was required to maintain the pre-development flood storage. It was proposed to achieve this through the introduction of hydraulic controls. This was represented conceptually as embankments in the terrain with the embankment crest and breaks in the embankment representing the hydraulic controls.

The storage area and target storage depth were determined through consideration of the typical depth in the storage and the incremental benefit of decreasing the land area and increasing the flood depth. The adopted storage level and area for cells 2–6 was ultimately based on a typical flood depth of 1.2 m within the flood corridor, excluding the waterbodies where the depth was greater. This represents a threefold increase to flood depth in the post-development compared to pre-development. Beyond this flood depth the incremental benefit of reduced land take versus increased flood depth significantly diminished and the hazard within the flood corridor significantly increased.

The hydraulic controls were partly incorporated in the terrain by setting the embankment crest at the target levels. However, the hydraulic controls representing gaps in the embankments were not incorporated into the terrain as these would be determined through iterations of the hydraulic modelling.

The approach to cell 1 varied from the other cells in that the target flood level for that cell was also constrained by the flood levels in the Birrega Main Drain. In addition, there were areas of land within the flood corridor where the depth of flooding was shallow. However, access to this land was limited because of the alignment of the existing waterways on the site. These shallow flood areas were significantly impacted by other constraints such as isolation and not suitable for development.

The approach to cell 7 varied from the other cells in that the target flood level for that cell was also constrained by the level of the Kwinana Freeway. The creation of an embankment crest higher than the freeway road level was considered a high-risk proposition from the perspective of human safety and potential damage to the freeway. Limiting the target flood level to below the freeway carriageway was considered low risk as any failure of the embankment would not inundate the carriageway and could be contained within the Peel Main Drain corridor and discharged in a controlled manner through the Peel Main Drain. In addition, a hydraulic control was proposed to allow floodwaters to overtop Mundijong Road. The preliminary Scenario 1 Option B concept is shown in Figure 21.

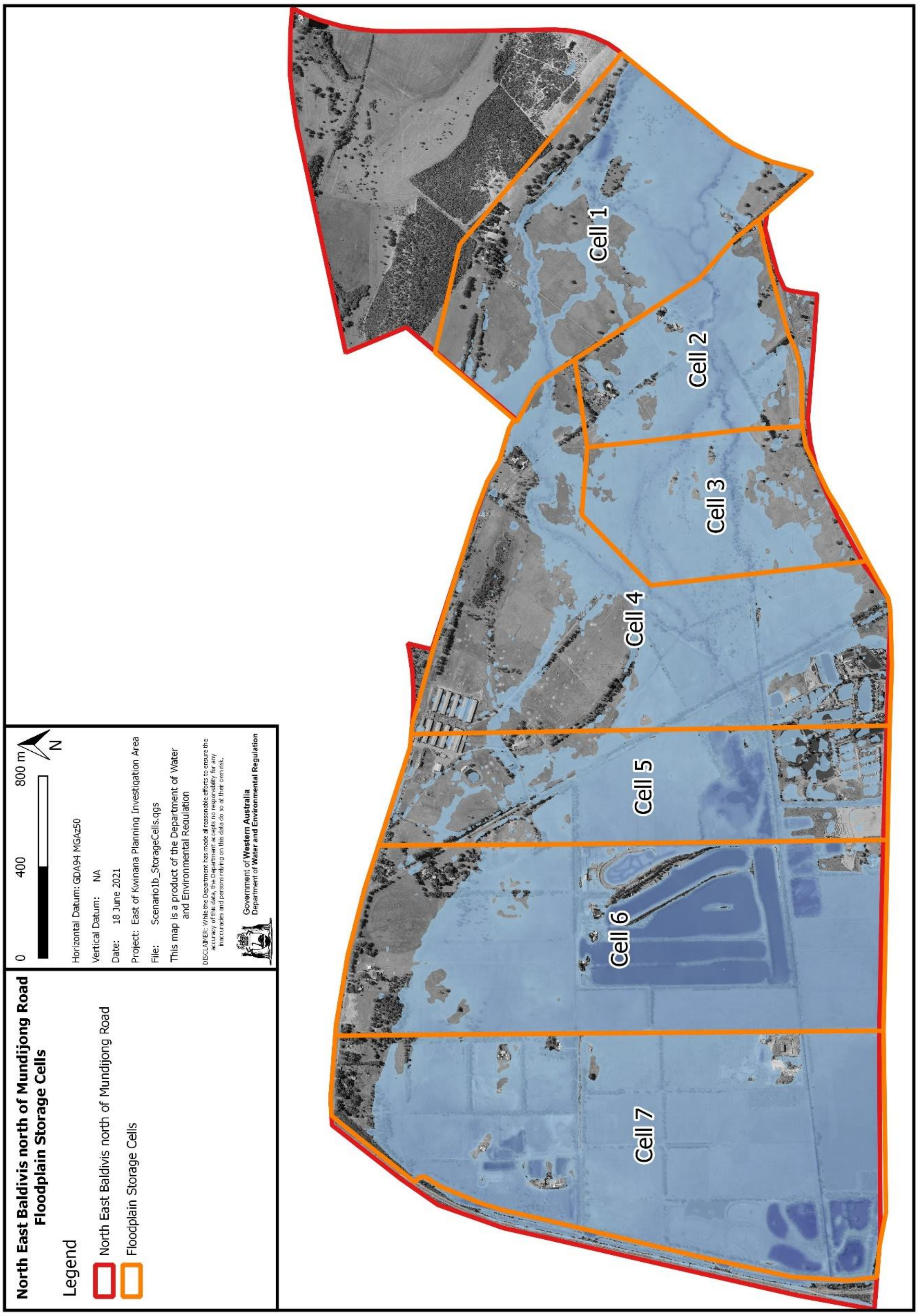


Figure 20 Pre-development 1% AEP floodplain storage cells

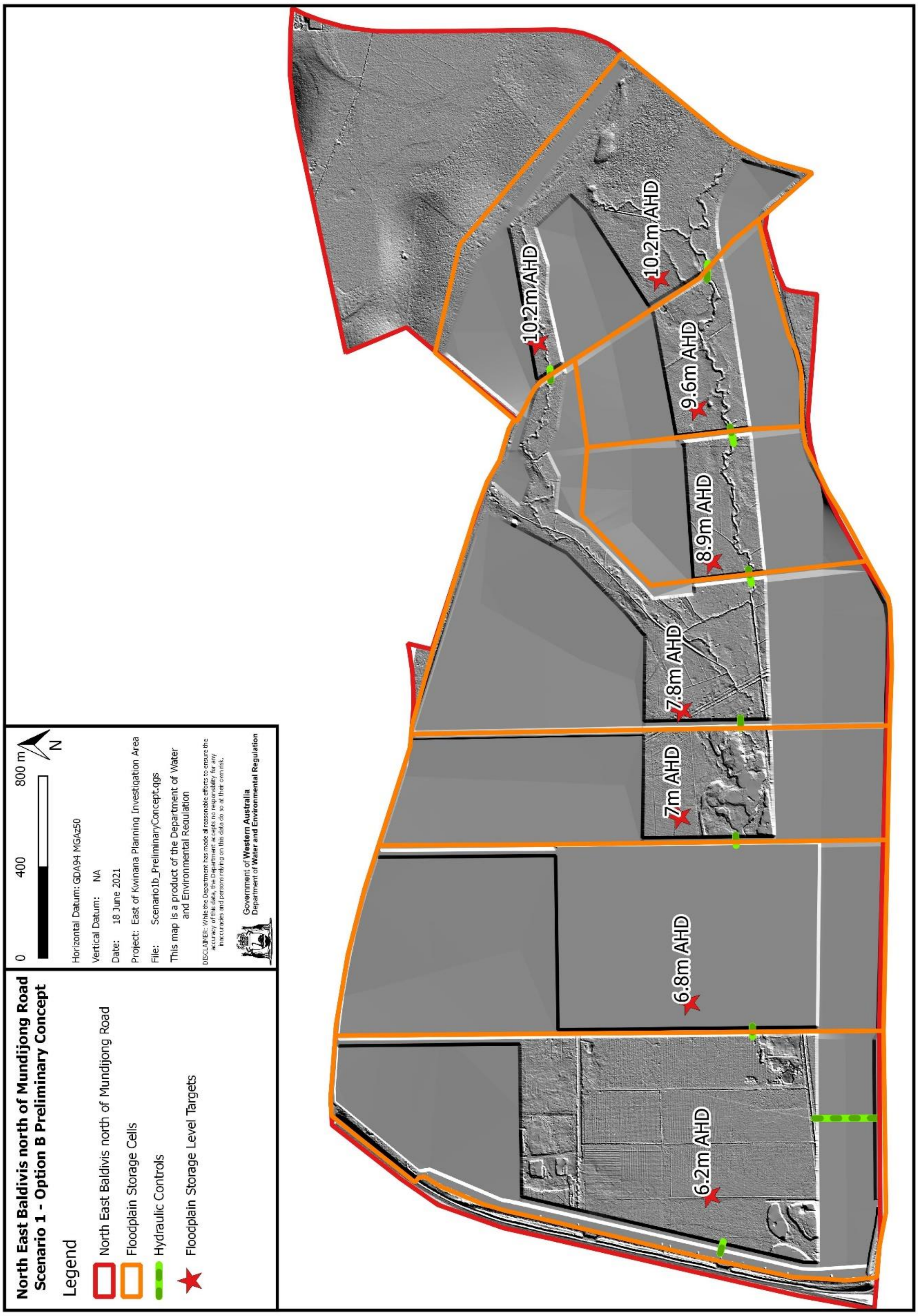


Figure 21 Preliminary Scenario 1 Option B concept

3.5.3 Initial flood modelling Scenario 1 Option B

During the initial flood modelling simulations, it became clear that there were difficulties with the conceptual layout at the western downstream end of the precinct, including both the discharge over Mundijong Road and the discharge into the Peel Main Drain. The hydraulic control facilitating flow over Mundijong Road did not have the capacity to convey post-development flows of similar magnitude as pre-development flows. This resulted in excessive discharges and flood levels within the Peel Main Drain placing the Kwinana Freeway at risk and potentially detrimentally impacting other land. Several attempts were made to resize and reposition this hydraulic control, but it was ultimately determined that a broader flood connection to Mundijong Road was required to maintain pre-development conveyance. A portion of the developable area in the south-west corner of cell 7 was relocated to the northern end of the flood corridor to provide greater access for discharge over Mundijong Road.

These alterations were successful in providing conveyance access for floodwaters to maintain pre-development discharge over Mundijong Road and via the Peel Main Drain. The effect of this change was to also reduce the flood level in cell 7 from the target 6.2 m Australian Height Datum (AHD) down to the pre-development 5.6 m AHD. This resulted in a reduction of floodplain storage within cell 7. Further analysis of flood modelling results showed that while floodplain storage in cells 6 and 7 dropped by about 34%, this was compensated by increases to floodplain storage in cells 1 to 5. The overall result was a net 1% increase in floodplain storage as well as a 7% reduction in the peak downstream discharge compared to the pre-development case.

A consequence of the altered spatial layout was that the embankment at the western edge of the precinct was no longer required as the post-development flood level in cell 7 was the same as the pre-development flood level in the Peel Main Drain. This is considered a beneficial outcome as it removed the need for a substantial element of engineered infrastructure. Further detail of the flood modelling results is provided in Section 3.5.5 below.

3.5.4 Modified Scenario 1 Option B Plus

Scenario 1 Option B was modified to test whether a controlled spillway over Mundijong Road would increase flood levels in cell 7 and increase the area in the precinct with in 1:100-year flood protection. Scenario 1 Option B Plus includes the following modifications to Scenario 1 Option B:

- provide a formalised spillway for discharge over Mundijong Road
- confine the spillway over Mundijong Road to an area in line with existing water bodies for safety reasons
- reintroduce the Western embankment
- reinstate the cell 7 height target of 6.2 m AHD
- maintain floodplain storage
- provide additional developable area.

The additional developable area was distributed between cell 7 and cell 6 to provide a more consistent flood corridor. The revised Scenario 1 Option B Plus terrain is depicted in Figure 22.

Flood modelling simulations of the modified Scenario 1 Option B Plus indicated a recurrence of the difficulties experienced during the initial flood modelling. That is, insufficient discharge over Mundijong Road and excessive discharge into the Peel Main Drain. As with the flood modelling for the initial Scenario 1 Option B, flood levels in the Peel Main Drain peaked at 6.2 m AHD, like the flood levels within cell 7, placing the Kwinana Freeway at risk. While it may be possible to adjust the hydraulic controls in the flood model to reproduce the pre-development discharges, this was not done as the flood modelling exercise exposed a flaw in the concept as follows.

The conceptual approach significantly confines the Peel Main Drain into a narrow corridor at the western end of the site. Flooding within this corridor and the resultant impacts on the Kwinana Freeway would be sensitive to the discharge patterns from the development into the Peel Main Drain. Hydraulic controls would need to be finely tuned, and a small variation to the anticipated behaviour would likely result in significant impacts to both the Peel Main Drain and the Kwinana Freeway. While it may be possible to configure these hydraulic controls for the particular flood and temporal pattern adopted in the modelling exercise, the impacts would likely recur should the modelling exercise adopt alternative temporal or spatial rainfall patterns. The random nature of rainfall means that any future real-world floods would undoubtably produce a different spatial and temporal pattern, likely resulting in detrimental impacts on the Peel Main Drain and the Kwinana Freeway.

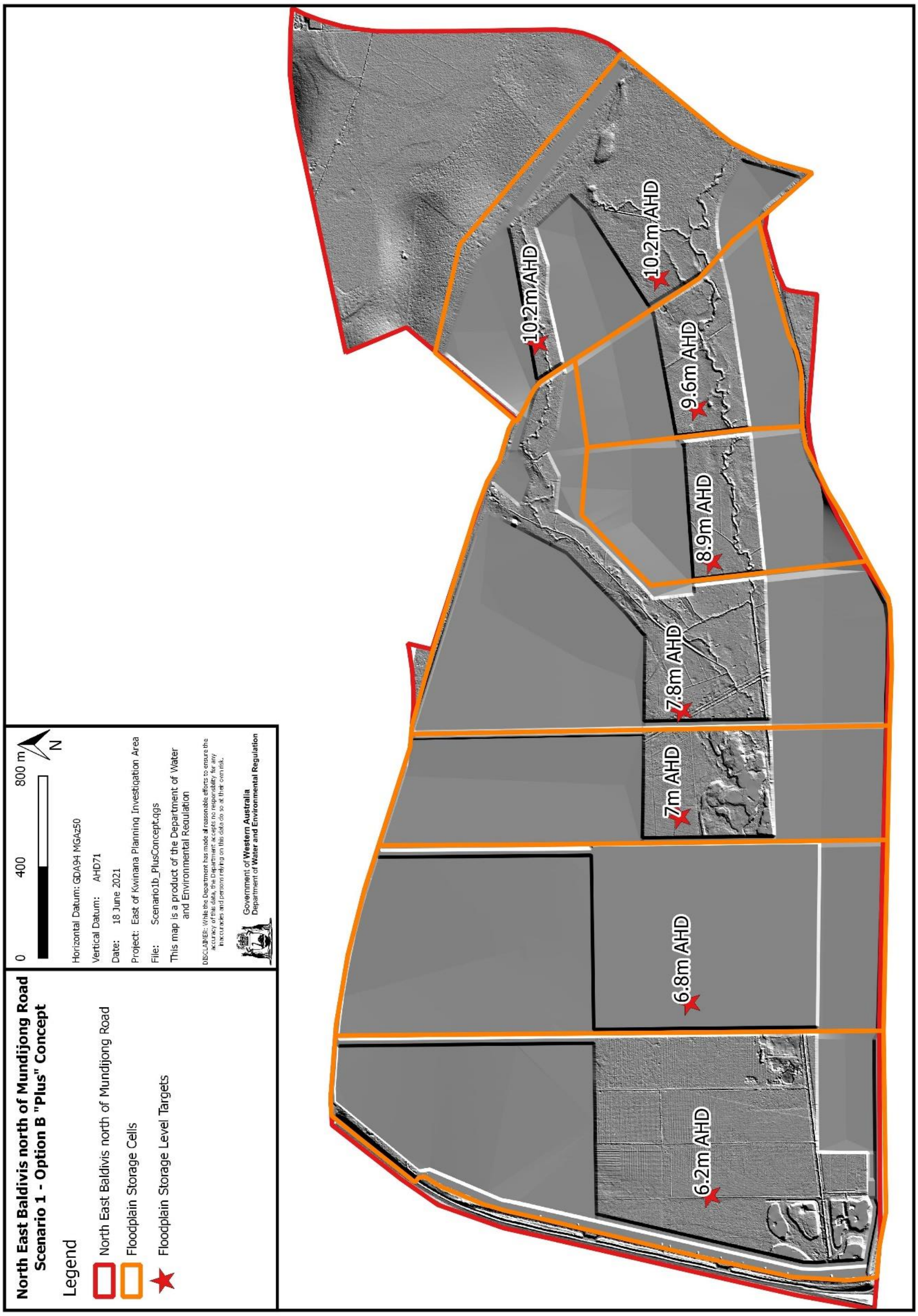


Figure 22 Scenario 1 Option B Plus concept

3.5.5 Summary of Scenario 1 Option B flood modelling results

Information about flood modelling results for Scenario 1 Option B and Scenario 1 Option B Plus has been provided in Table 3, Table 4, Figure 23 and Figure 24 below.

A summary of the peak flows has been provided in Table 3 including pre-development flows and relative differences. Peak discharges for Scenario 1 Option B were about 7% lower than pre-development peak discharges. Peak discharges for Scenario 1 Option B Plus increased by 29% in the Peel Main Drain; however, the combined discharge crossing Mundijong Road including the water overtopping the road resulted in a net reduction of 12% to the peak discharge value.

Floodplain storage is summarised in Table 4 and includes a breakdown of pre-development and post-development storage based on the seven cells depicted in Figure 20 Pre-development 1% AEP floodplain storage cells.

Scenario 1 Option B results showed that the peak discharge crossing Mundijong Road (including both the Peel Main Drain and flows overtopping the road) reduced by 7% and the overall floodplain storage increased by 1%. While the overall floodplain storage remained about equal, the breakdown based on storage cells shows that floodplain storage in the upstream cells increased while storage in the downstream cells reduced. This varied from the initial thinking that each cell would be self-contained; however, this variance is considered justified because of the difficulty in obtaining developable area in the downstream western cells.

The results for Scenario 1 Option B Plus showed that the peak discharge in the Peel Main Drain increased by 29%; however, the combined discharge crossing Mundijong Road, including the water overtopping the road, resulted in a net reduction of 12% to the peak discharge value. The overall floodplain storage also increased by 12%.

The results show that further refinement of the options may be possible. The following sections discuss the scope for optimising Scenario 1 Option B at the district planning stage should the option be pursued. In addition, the anticipated developable area as well as the risks and benefits of both options is discussed.

Table 3 Scenario 1 Option B peak discharge summary

Location	Pre-development (m^3/s)	Scenario 1B (m^3/s)	Scenario 1B Plus (m^3/s)
Inflow			
Birrega	73.1	73.1	73.1
Peel Main Drain	9.3	9.3	9.3
Outflow			
Peel Main Drain (PMD)	20.5	18.6 (-9%)	26.4 (29%)
Mundijong Road inc. PMD	73.3	68.4 (-7%)	64.8(-12%)

Table 4 Scenario 1 Option B summary of 1% AEP floodplain storage

Cell	Pre-development (ML)	Scenario 1B (ML)	Scenario 1B Plus (ML)
1	203	291 (43%)	291 (43%)
2	131	206 (58%)	206 (58%)
3	125	186 (48%)	186 (48%)
4	225	411 (83%)	411 (83%)
5	309	372 (20%)	377 (22%)
6	1311	1286 (-2%)	1142 (-13%)
7	1307	891 (-32%)	1426 (9%)
Overall	**3611**	**3643 (1%)**	**4040 (12%)**

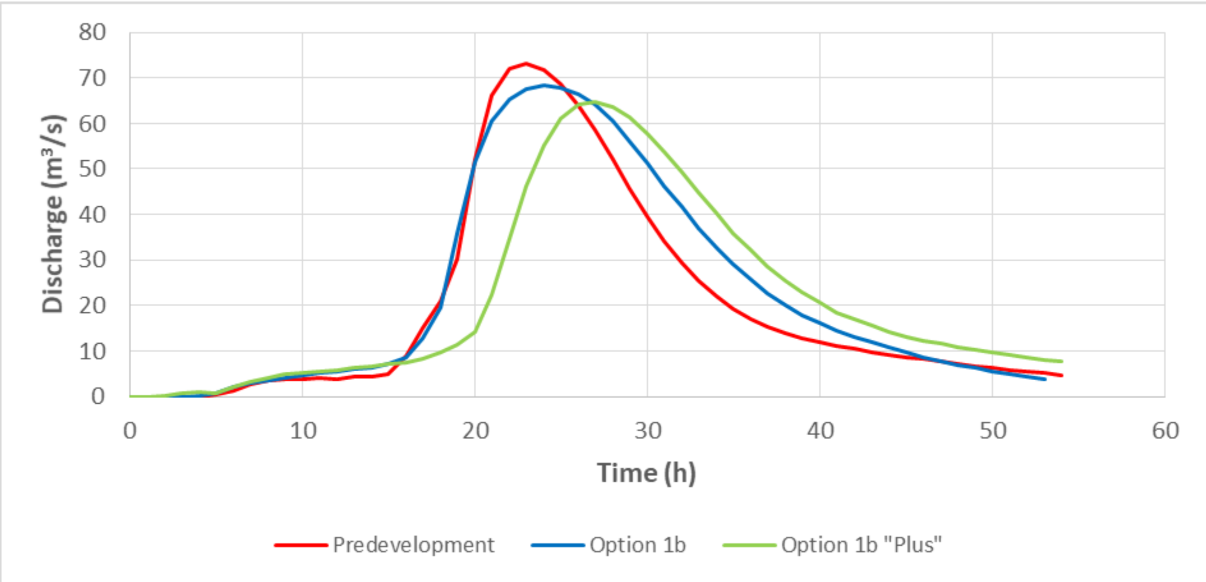


Figure 23 Scenario 1 Option B total discharge at Mundijong Road

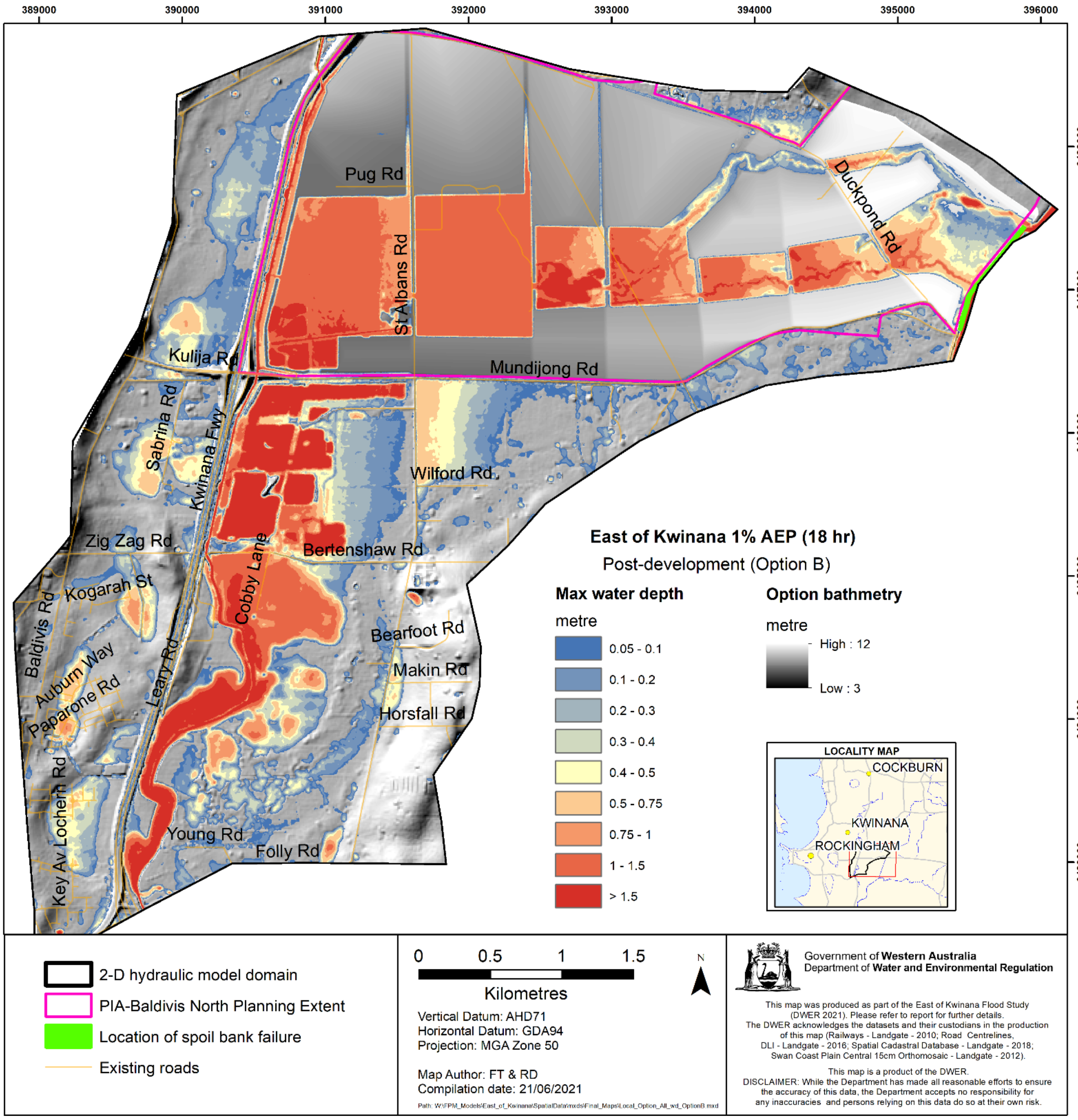


Figure 24 Scenario 1 Option B Plus flood modelling results

3.5.6 Scenario 1 Option B northern waterway corridor optimisation

In addition to the central flood corridor, a northern waterway corridor was retained primarily for environmental reasons. At present, no information is available regarding any on-ground portions of the northern waterway with potentially significant environmental value. However, the natural waterway alignment clearly visible in the aerial photography is considered to have environmental value. Formulation of Scenario 1 Option B has adopted a precautionary approach to this issue and included the northern waterway in the post-development scenario. Should further investigations determine that the northern waterway could be removed, there is potential to incorporate flooding from the northern corridor into the central corridor.

A preliminary assessment has been undertaken of floodplain storage in the northern corridor and the likely area that could be gained and lost should this corridor be removed. The results of this assessment are summarised on Figure 29 which shows that about 33 ha of land could be gained by removing the northern corridor, with the floodplain storage consolidated into the central corridor resulting in a loss of about 11 ha of land. The net result would be a gain of about 22 ha (2%) of land. It should be noted that this has been determined using a simple volumetric calculation and no flood modelling simulations have been undertaken for the option of one consolidated central flood corridor.

3.5.7 Scenario 1 Option B Plus potential reduction in floodplain storage

Given that the results for Scenario 1 Option B Plus showed a substantial reduction in the peak discharge and increase floodplain storage, it may be possible to further optimise this scenario and increase the developable area. A volumetric assessment indicated that maintaining the pre-development floodplain storage could result in an additional 38 ha (3.6%) of land in cells 6 and 7. This brought the corridor’s northern boundary in cells 6 and 7 to align with the corridor’s northern boundary of cell 5.

This assessment was based entirely on a volumetric calculation and no further flood modelling was undertaken. This was because of the impacts of Scenario 1B Plus on the Kwinana Freeway and the risks discussed in Section 3.5.4.

The additional developable area was assigned to cells 6 and 7 rather than other cells in recognition of the difficulties in obtaining developable area in these lower cells.

3.5.8 Proponent-driven Option B approaches

Proponent-driven proposals for development in the North East Baldivis north of Mundijong Road precinct have also included options for removal of the spoil bank. The recommendation as outlined in Sections 3.1 and 3.2 is to retain the pre-development floodplain storage volume. Because of proponent-driven proposals, it was decided to include flood modelling that investigates the impact of permitting a loss in floodplain storage.

The Scenario 1 Option B concept was altered consistent with other proponent-driven proposals for the North East Baldivis north of Mundijong Road precinct. The local flood model developed as a part of the *East of Kwinana flood modelling and drainage study* used to assess Option A and the department’s Option B was also used to assess the proponent-driven Option B.

Proponent-driven proposals typically place the downstream limit of the flood model immediately downstream of the development boundary at Mundijong Road. It is then assumed that discharging the flood waters as quickly and as early as possible will not have a detrimental impact, provided that the post-development peak discharge does not exceed the pre-development peak discharge.

Proponent-driven proposals in this location overlook a basic physical property; that is, the conservation of mass. If the post-development peak discharge is not to exceed the pre-development peak discharge and the pre-development floodplain storage will not be retained, the only way this can be physically accomplished is to discharge more water earlier. If a site is in the downstream-most reaches of a catchment near the ocean outlet, an early discharge could be accommodated without detrimental impact. However, this is not the case in the North East Baldivis north of Mundijong Road precinct as the site is located higher in the catchment and it is not acceptable practice to discharge floodwaters early into the Peel Main Drain in this situation.

In effect, proponent-driven proposals conclude that there is no downstream impact based on the false assumption that discharging more floodwaters quicker and earlier than pre-development does not cause a downstream impact.

3.5.9 Proponent-driven Option B layouts

Limitations on the use of land in a precinct without flood protection is described section 3.15. Proponent-driven layouts typically retain and expand the existing ski park, occupying a substantial area of open space with limited recreational values. The land without flood protection would need to come into public ownership and extensive and ongoing maintenance would need to be provided by the local authority to fulfill both recreational and flood functions. The Serpentine Hydrological Studies (DWER 2012–15) show that the ski park intersects groundwater which creates a local groundwater depression and water quality risks when groundwater enters the waterbody. The local authority responsible for management of the land without flood protection would need to manage the water quality of the waterbody in addition to the recreational and flood functions.

Secondly, proponent-driven layouts typically require a substantial upgrade to the Peel Main Drain culvert crossing at Mundijong Road. This culvert will likely need to be much larger than the land corridor assigned to the Peel Main Drain and accommodate floodwaters substantially greater than what could be physically conveyed by the Peel Main Drain flood channel.

The hydraulic constraints posed by Mundijong Road have already been discussed in Section 3.5.3 and the need for an additional discharge crossing is discussed further in Section 3.7. Upgrading of the Peel Main Drain culverts at Mundijong Road would inevitably require the creation of a new culvert discharging into private property downstream or the redirection of substantial flows from an upgraded culvert back into private property downstream. The development of the North East Baldivis north of Mundijong Road precinct would be dependent on first securing additional downstream discharge capacity with the landowner(s) of downstream private property. This matter was discussed by the department and DPLH during the initial formulation of Option B. It was determined that formulation of an option in this manner was not appropriate; therefore, the department incorporated flexibility into the department’s Scenario 1 Option B layout to remove this dependency.

As per the approach adopted for the urban flood levee (Scenario 1 Option A) and discussed in Section 3.4, the typical proponent-driven layout is not considered realistic to implement. However, given that the objective is to explore the impacts of concepts as put forward by proponents, this scenario prioritised proposed proponent approaches over the department’s policies, DPLH requirements and national standards and practice.

3.5.10 Formulation of a post-development proponent-driven Option B terrain

A post-development terrain was developed based on the horizontal layout and flood depths identified in proponent-driven proposals. It is not necessary to match the precise invert levels of proponent-driven proposals because the upstream and downstream ground levels provide a constraint to the possible inverts. It is the basic storage and conveyance properties that ultimately dominate the flood response. There is sufficient information in proponent-driven proposals to determine the storage and conveyance properties of the proposal without knowing the precise terrain levels.

Based on the approach described in proponent-driven proposals and discussed in Section 3.5.8, proposals often optimise hydraulic controls to efficiently discharge floodwaters earlier without exceeding the pre-development peak discharge. Given the basic catchment characteristics described in Section 1 and criteria for post-development assessment outlined in Section 3.2, optimising the hydraulic controls in this manner means that flood storage is lost from the site and flooding is increased on downstream land.

The department's objective is to maintain the 1% AEP pre-development flood regime to prevent increased flooding on downstream landowners. Thus, the department's hydraulic controls will undoubtedly be different to the hydraulic controls from proponent-driven proposals. The hydraulic controls adopted by the department retained a greater flood volume on the site to minimise impacts, resulting in higher flood depths within the flood corridors as compared to proponent-driven proposals. The aim was to reduce downstream impacts by limiting the early flow release from the site, and the department gave priority to this objective ahead of limiting the peak discharge value.

3.5.11 Flood model results of the proponent-driven Option B

Post-development flood modelling was undertaken using the local flood model depicted in Figure 11 and the 1% AEP 18-hour duration which has previously been identified as the critical duration. Post-development flooding within the site is depicted in Figure 26 below.

The discharge at Mundijong Road is shown in Figure 25 which compares the pre-development and the department's Option B discharge hydrographs with the proponent-driven Option B discharge hydrograph. As discussed in Section 3.5.10, the department's aim is to maintain the 1% AEP pre-development flood regime to prevent detrimental impacts on landowners outside the planning investigation. The department prioritised this aim even though the post-development peak discharge exceeded the pre-development peak discharge.

The post-development floodplain storage of the proponent-driven Option B has been calculated and summarised in Table 5 below. The proponent-driven floodplain storage is compared to the pre-development floodplain storage determined by the department. However, this has been clipped to match the extent of the proponent-driven Option B to facilitate a direct comparison.

The land flood capability of the proponent-driven Option B is summarised in Table 6 below and compared to the department's Option B. The department's Option B land flood capability has been clipped to match the same extent as the proponent-driven Option B to facilitate a direct comparison. This shows that the proponent-driven Option B has increased the developable area by 17%; however, this has come with a 25% loss of floodplain storage.

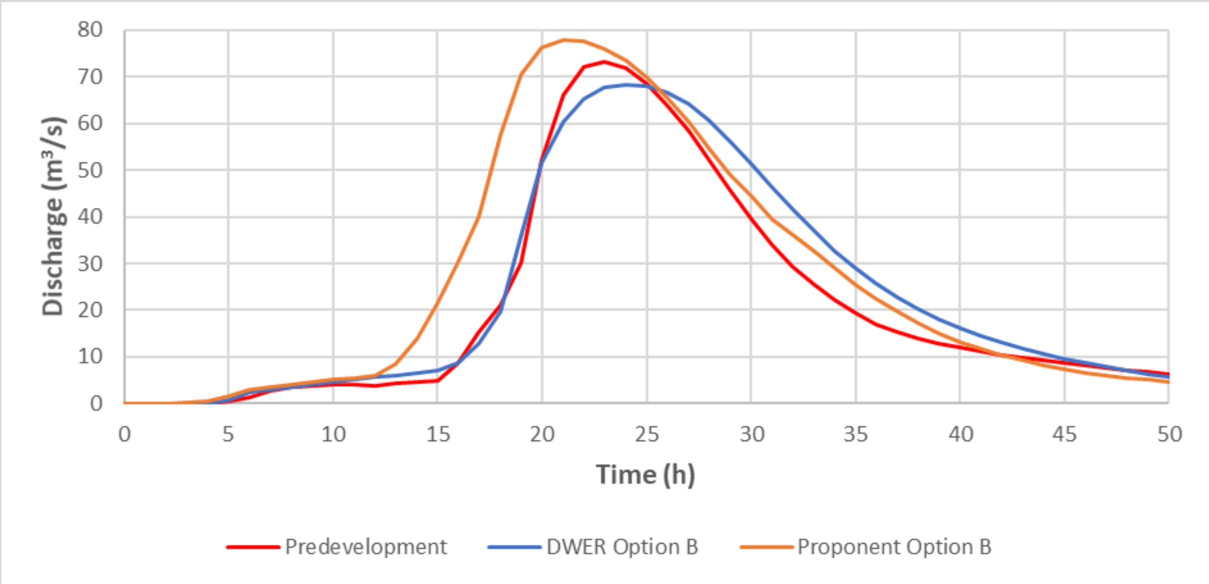


Figure 25 Proponent-driven Option B total discharge at Mundijong Road

Table 5 Proponent-driven Option B floodplain storage comparison

Pre-development (ML)	Post-development (ML)	Difference (%)
3611*	2709	- 25

*Note: This is a subset of the department's Option B floodplain storage clipped to the same extent as the proponent-driven Option B to facilitate a direct comparison.

Table 6 Proponent-driven Option B land flood capability comparison

	Minor constraint (ha)	Significant constraint (ha)
Proponent-driven Option B	561 (72%)	215 (28%)
Department's Option B*	455 (56%)	344 (44%)

*Note: This is a subset of the department's Option B land flood capability clipped to the same extent as the proponent-driven Option B to facilitate a direct comparison.

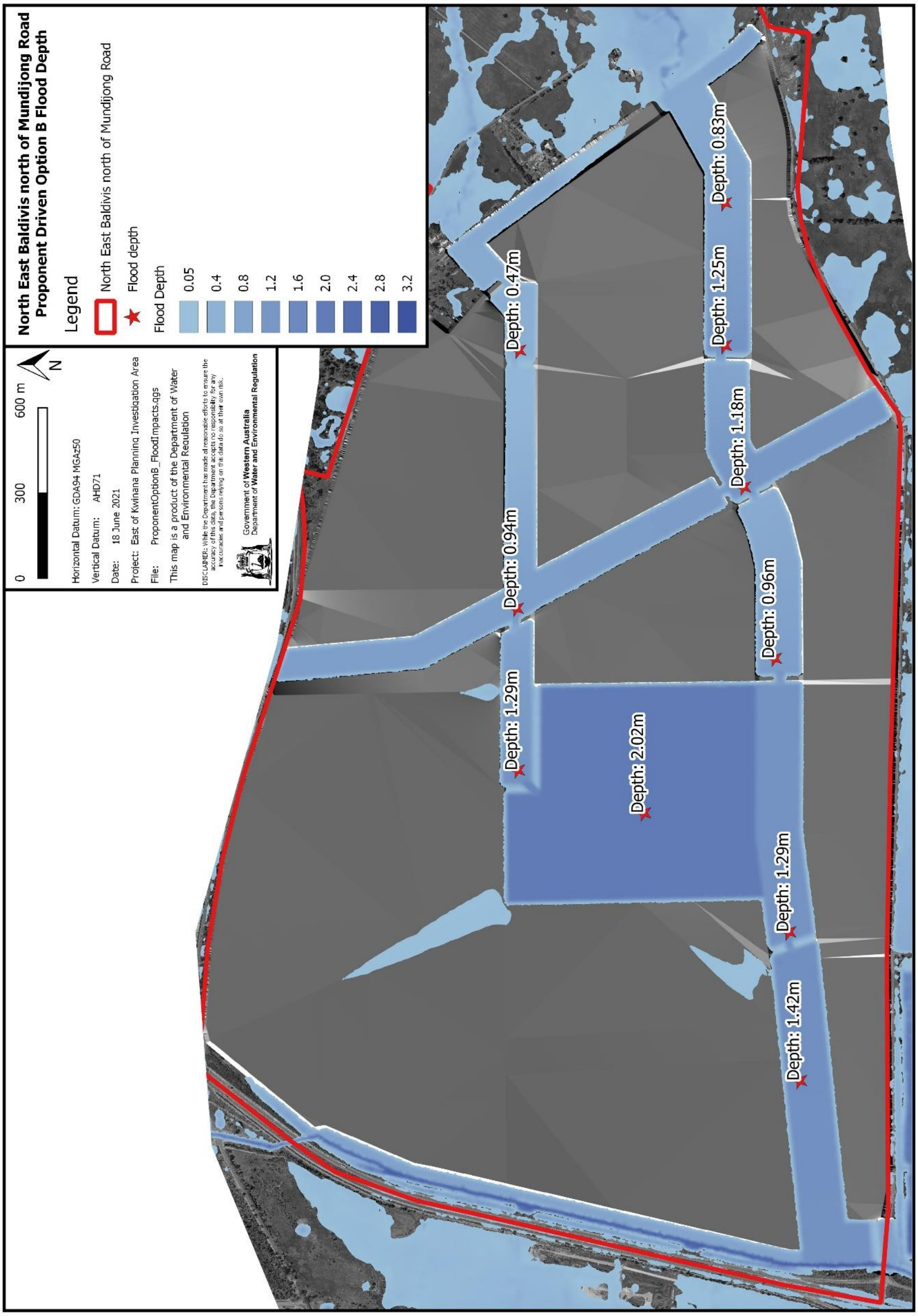


Figure 26 Proponent-driven Option B flood extent and depth.

3.5.12 Flood impacts of the proponent-driven Option B

The impact of the proponent-driven Option B on downstream land has been assessed and is summarised in Figure 27 below. The first matter to note is that extensive tests have been undertaken to assess and rule out the influence of the downstream boundary condition in the model results and the conclusions reached. The impacts depicted in the figure represent the flood impact of the proponent-driven Option B proposal.

The most notable impact of the proponent-driven Option B is to increase downstream flooding over a substantial area of downstream land holders. Mundijong Road and Bertenshaw Road represent significant hydraulic structures, and the floodplain in this area behaves as a series of cascading storages with relatively flat flood levels in between these roads.

The flood level increase between Mundijong Road and Bertenshaw Road (ignoring the waterbodies) is typically in the order of 4.3 cm, and flood level increases between Bertenshaw Road and the southern end of Leary Road is typically in the order of 9 cm. It has been previously determined in Section 3.2 that the threshold of acceptable impacts is 3 cm for the Peel floodplain and 5 cm for the Birrega floodplain. The flood impact of the proponent-driven Option B is located within the Peel floodplain and is in excess of the 3 cm threshold determined acceptable for that area. Furthermore, the impact is also substantially above the 5 cm threshold determined for the Birrega floodplain. The increase to flood levels means that within the floodplain of the Peel Main Drain, land which is above the 1% AEP flood in the pre-development will be inundated by floods more frequent than the 5% AEP flood in the post-development. That is an increase in excess of 500% to the frequency of flooding experienced by downstream property owners.

The other matter of note is that the impacts of the development project for a substantial distance downstream and, rather than abating, the impacts worsened further downstream. There are two mechanisms which lead to this result. The first mechanism is that the width and area of the floodplain contracts so the change in volume represents a greater change in flood level. The second mechanism is to note that towards the southern end of Leary Road, the flood mechanism changes. Downstream of this point, the Peel floodplain is largely confined to the Peel Main Drain channel and is conveyance driven. The flood storage between Bertenshaw Road and the southern end of Leary Road is the last storage in the chain and will bear the brunt of early flow releases from upstream land as discharge from this location is limited by the conveyance capacity of the Peel Main Drain.

3.5.13 Potential optimisation of the proponent-driven Option B

Consideration was given to the potential to reduce the impacts of the proponent-driven Option B. There are several aspects to this optimisation as follows. The first issue to note is the shortcomings identified in Section 3.5.9 which would need to be addressed. The second issue to note is that the flood depths within the flood corridors are substantial, potentially increasing the required volume of fill and making integration of the level changes into the urban form difficult. The third issue to note is that the potential to increase storage volume by increasing flood levels is substantially limited because of the road levels of the Kwinana Freeway. Depending on groundwater constraints, it is more likely that the potential storage volume in this layout has been overstated rather than understated and downstream impacts may be greater.

The other aspect considered was that it may be possible to optimise the hydraulic controls to manipulate the rising limb of the hydrograph to minimise the impact. It may be possible to optimise one rainfall temporal pattern and onflow hydrograph. This would be a more difficult task where ten temporal patterns and inflow hydrographs are concerned but may be theoretically possible. However, such an attempt is beyond the technical accuracy and capability of current flood modelling techniques and places a greater reliance on numerical modelling than is reasonable. In reality, rainfall is a random natural phenomenon and the possible rainfall patterns and flow combinations is almost limitless. Furthermore, such an approach by proponent-driven proposals ignores cumulative impacts and makes the following errors:

- assumes that the cumulative impact of multiple developments equals the sum of the individual proposals
- ignores equity among landowners.

Accepting the proponent-driven Option B approach and a 25% floodplain storage loss has two implications. Firstly, for reasons of equity, the upstream landowners, including those with a rural zoning, could also reduce floodplain storage by a comparable volume. This would increase the flooding experience in the North East Baldivis north of Mundijong Road precinct and reduce the developable area in that precinct. Secondly, losing a comparable floodplain storage volume downstream would further confine the floodplain and the impacts of the North East Baldivis north of Mundijong Road precinct on downstream flood levels would be greater.

Mitigating the impacts of losing floodplain storage would require a substantial investment to upgrade main drainage infrastructure from the North East Baldivis north of Mundijong Road precinct for a substantial distance towards the ocean discharge point. In the absence of a large infrastructure investment, the conservation of floodplain storage would be required.

3.5.14 Impact of floodplain storage on Scenario 1 Option B developable area

The department has undertaken a number of investigations and produced several flood models for this area over the past 10 years. In the process of doing this, the department has gained an understanding of the broader flood characteristics of the area and how they relate to the landscape. This was discussed in Section 1 and as a part of this project, the understanding of catchment response was further investigated and confirmed. The approach adopted by Option B was tested using multiple configurations with varying floodplain storage properties.

The effect of floodplain storage on catchment response is clearly visible in the discharge from the North East Baldivis north of Mundijong Road precinct. Figure 28 shows the pre-development discharge in comparison with the variations to floodplain storage in the Option B concept. The department's Option B most closely retains the storage and conveyance properties of the pre-development and, other than some minor refinements for optimisation, most closely resembles the pre-development discharge. The department's Option B Plus results in a 12% floodplain storage gain and the effects of this can be seen in the discharge at Mundijong Road. The proponent-driven Option B, on the other hand, results in a 25% loss of floodplain storage. The effects of this on the discharge can be seen in Figure 28 and on downstream flooding can be seen in Figure 27.

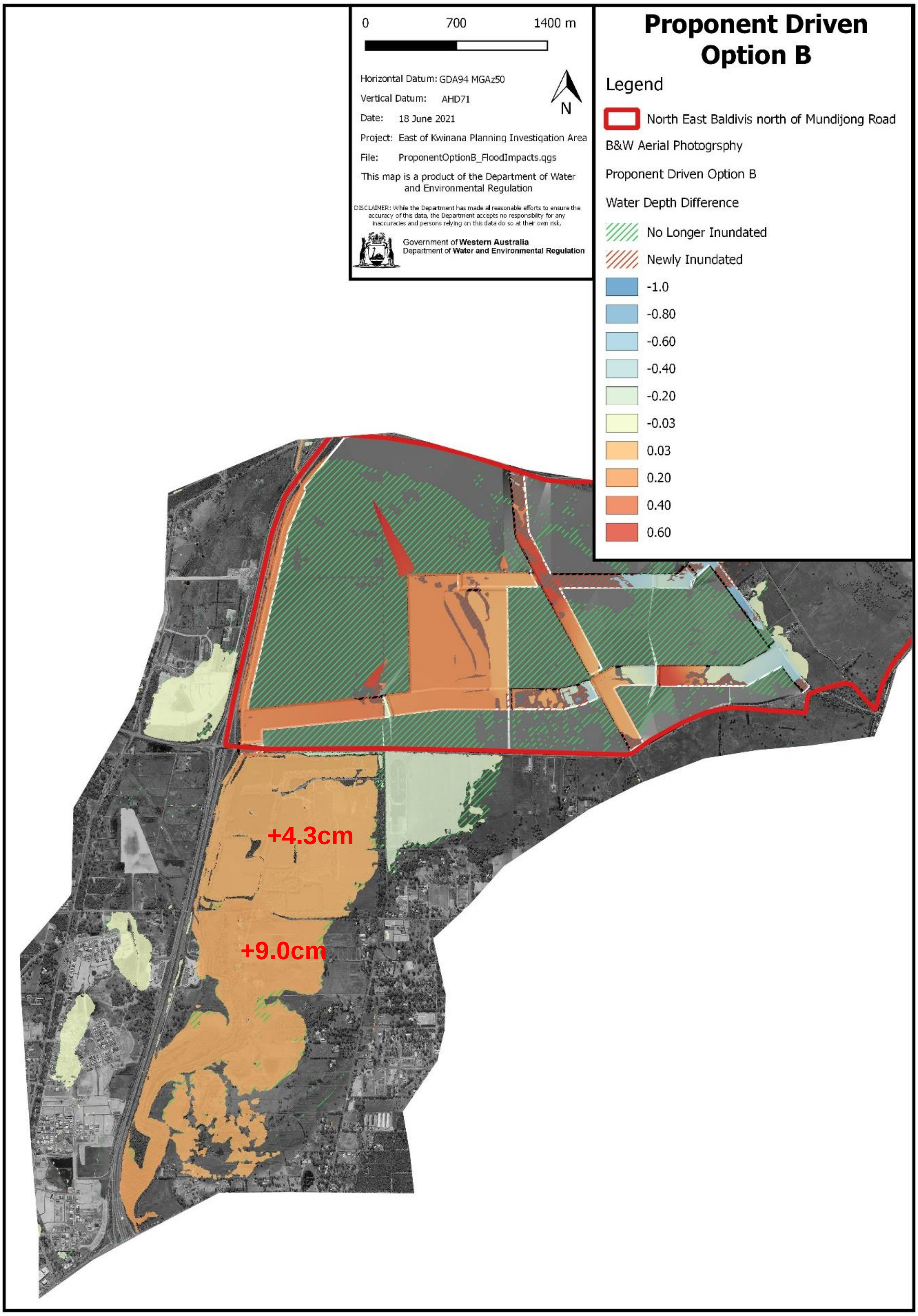


Figure 27 Proponent-driven Option B flood impacts

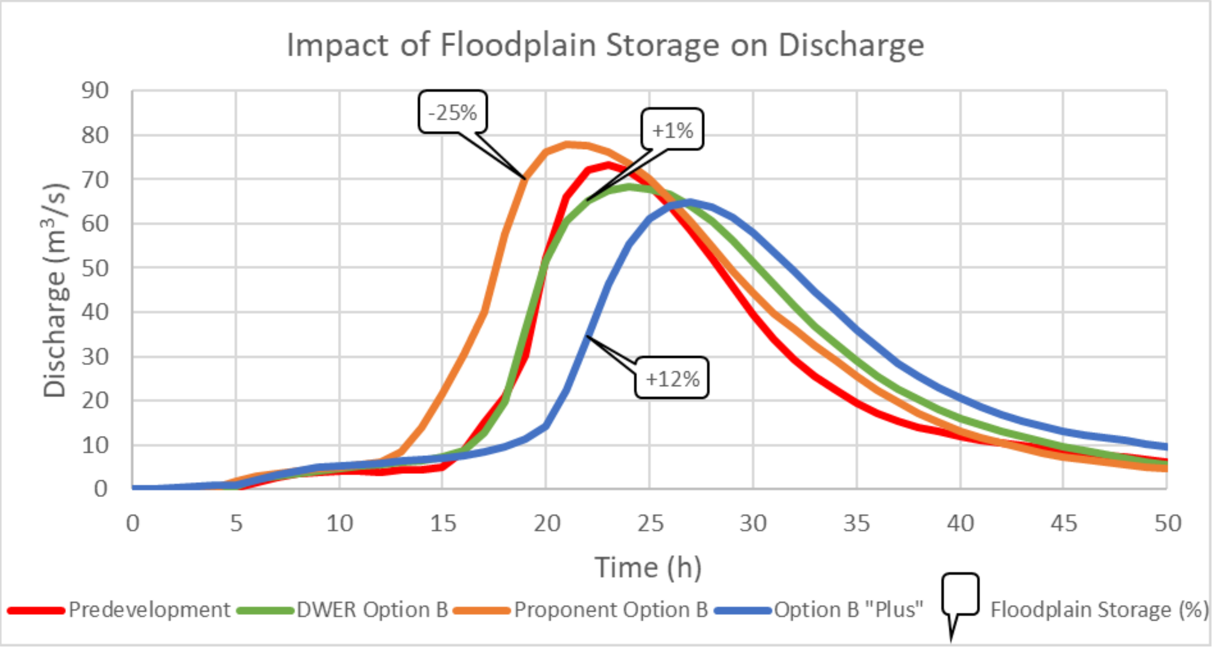


Figure 28 Impact of floodplain storage on discharge

3.5.15 Scenario 1 Option B flood-related land capability assessment

The flood-related land capability assessment resulted in a percentage of land that could be developed with flood protection above the 1:100-year event. The Scenario 1 Option B land capability is summarised in Figure 29. Flood protection for the 1% AEP could be provided to about 55% of the land which would subsequently be available for most urban uses including residential or industrial development. The remaining 45% of the land would be subject to flooding with significant limitation on the acceptable uses.

The adoption of Scenario 1 Option B Plus (providing a controlled spillway over Mundijong Road and to increase flood levels in cell 7) would increase the developable area by about 2–4%; however, it would require a levee embankment about 1.7 km long. Because of the technical limitations discussed in Section 3.5.4, this would carry a significant risk of detrimental impacts on the Peel Main Drain and the Kwinana Freeway. The results of flood modelling for Scenario 1 Option B showed that the natural characteristics of the land and flooding lent itself to about 55% of the land being suitable for urban purposes. Further, engineered solutions would come with significant increases to cost, complexity and risk for a marginal gain of developable area.

In addition, the scope for further optimisation was considered. It was determined that additional developable areas could be obtained through further optimisation at the district planning stage. This would be in the order of an additional 2–6% and substantial increases beyond this are unlikely.

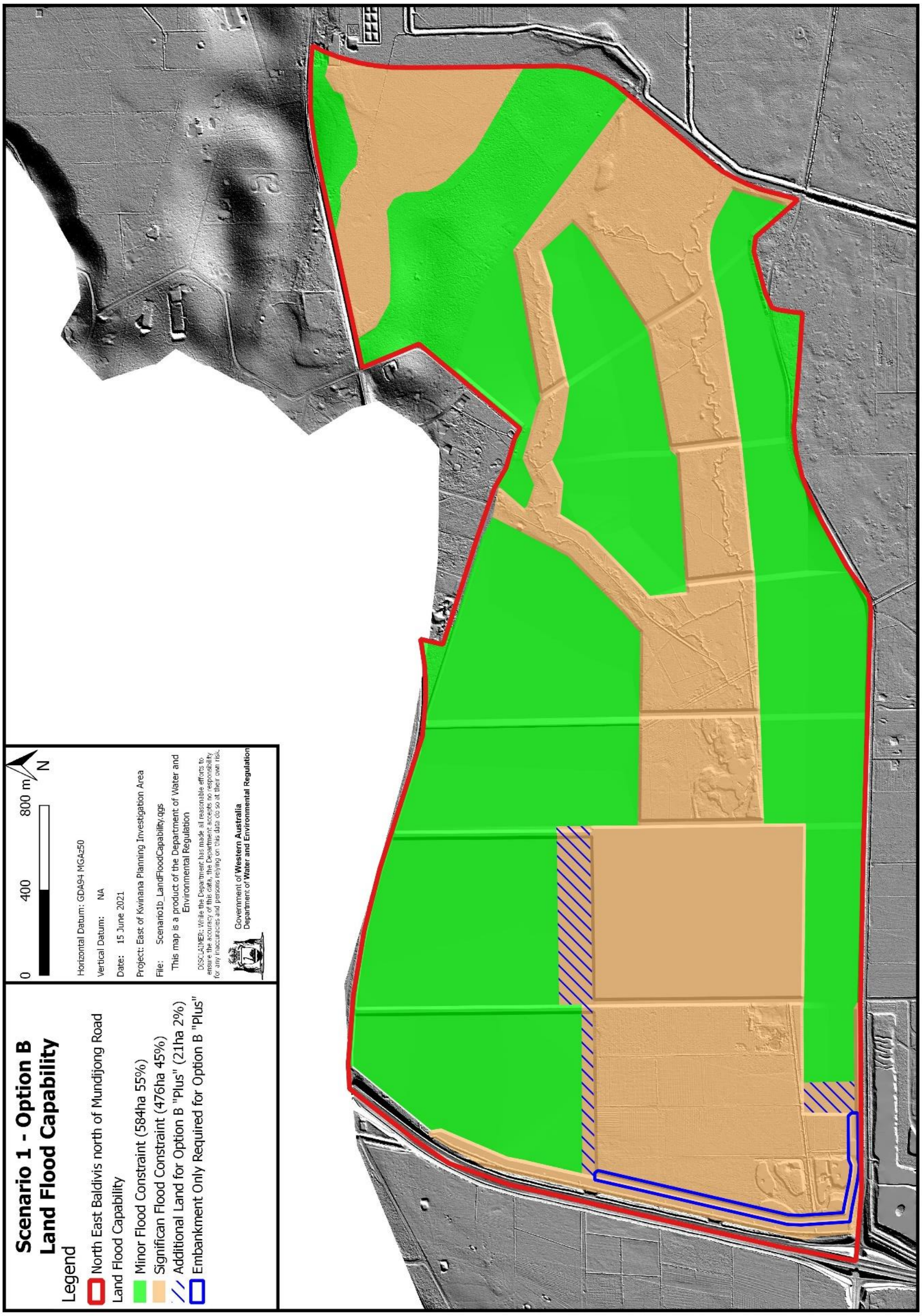


Figure 29 Scenario 1 Option B flood-related land capability assessment

3.6 North East Baldivis north of Mundijong Road – risk-based approach to flood protection (Scenario 1 Option C)

The objective of Scenario 1 Option C was to maximise the use of the available land by restricting development to industrial uses and permitting flooding of areas that have the capacity to tolerate more flooding with minimal damage to private and public infrastructure. Scenario 1 Option C differed from Option B in that industrial development was thought to be more tolerant of flooding risks because:

- the lots are generally larger; thus, there would be a lower number of stakeholders to manage and coordinate emergency response
- there would not be substantial numbers of people sleeping in the area
- industrial infrastructure that is more tolerant of flooding could be built
- emergency response to flooding could be implemented in workplace health and safety documentation for the sites.

Whereas Scenario 1 Option B sought to keep mainstream flooding away from development, Scenario 1 Option C sought to maximise the developable area by integrating flooding within the built form.

3.6.1 Concept formulation

The concept is very similar to Scenario 1 Option B in that the storage cells, basic layout, target flood levels and floodplain storage from that scenario were retained. Scenario 1 Option C differs in that it permits flooding of the development area, both roadways and private industrial lots in the 1% AEP flood.

The criteria for inundation of private industrial lots were as follows:

- Half the lot would be set at the 1% AEP flood level and accommodate an industrial building.
- Half the lot would be located below the 1% AEP flood level and accommodate other outdoor uses such as car parks or hard stand areas.
- The outdoor inundated area would be no greater than 0.5m below the 1% AEP flood level and above the 5% AEP flood level.
- A minimum 5% AEP flood standard would be required for outdoor car parking, hardstand areas and industrial roads.

The Scenario 1 Option B terrain was altered to place industrial land below the 1% AEP flood and an equivalent area of industrial land above the 1% AEP flood. At the same time, the flood corridor width was reduced to ensure that the 1% AEP floodplain storage for Scenario 1 Option C was the same as Scenario 1 Option B, based on achieving the same 1% AEP flood level. The approach of progressively lowering the terrain was undertaken for each storage cell until one of the following criteria prevented further extension of the industrial land into the flood corridor:

- the 1% AEP flood depth of 0.5 m on industrial land was reached
- industrial land was at the 5% AEP flood level calculated for Scenario 1B
- the 5% AEP floodplain storage calculated for Scenario 1B was reached
- there was no longer enough land available for industrial development below the 1% AEP flood
- potential environmental constraints prevented further reduction to corridor width.

Essentially, this option required a four-way calculation to formulate a terrain which maintained the flood level and floodplain storage criteria for both the 1% and 5% AEP floods.

Where development spanned across a large distance in the north–south direction, additional local drainage channels were added in a north–south orientation to allow the movement of floodwaters and the spatial distribution of land above the 1% AEP flood level. It should be noted that this is only a conceptual approach applied to the flood modelling exercise and not indicative of a district structure plan layout. At the district planning stage, it would only be necessary for the road layout to allow the ingress of floodwater into all the identified storage areas regardless of the final road layout selected.

For most of the cells, it was the flood depth criteria (0.5 m below the 1% AEP flood) which determined the lower limit of industrial land, rather than the 5% AEP flood. The only exceptions to this were cells 1 and 7, at the upstream and downstream extremities, where the depths were impacted by external flooding constraints.

The 5% AEP floodplain storage limit was not reached except for cell 7 where floodplain storage was lost for the 5% AEP flood. This was considered acceptable as many of the other cells had the capacity to accept additional floodplain storage and the overall floodplain storage could be maintained; therefore, priority was given to maximising the developable area in the cell. However, this could add complexity during detailed design as two-stage hydraulic controls may be required. The first stage would ensure that industrial land in cell 7 would not be inundated in the 5% AEP flood while the second stage provided the required performance for the 1% AEP flood.

The flood depth and the availability of industrial land was the limiting factor for developable area in cell 1, along with isolation issues that prevented small pockets of shallow inundation from being developed. Environmental constraints, rather than flooding constraints, impacted the corridor width and developable area for cells 2, 3, 4 and 5. The availability of land for industrial use below the 1% AEP flood limited the developable area in cell 6.

Constraints to development in cell 7 were varied and multiple factors played a role in determining developable area. The concept sought to maintain pre-development overflows towards Mundijong Road but to also provide a hydraulic control immediately upstream of Mundijong Road rather than depend on the road crest to provide hydraulic control. Given the proposal was based on the Scenario 1 Option B, the downstream embankment adjacent to the Peel Main Drain was removed as it was not needed to achieve the flood level and storage targets.

The low-lying nature of cell 7 presented difficulties in obtaining appropriate grades for local drainage infrastructure. Should this option be pursued, further engineering investigations would be recommended to determine whether local drainage or other gravity-based infrastructure would be feasible in such a flat environment.

The terrain for Scenario 1 Option C is depicted in Figure 30 and it should be emphasised that this is only a conceptual layout. A real on-ground proposal following this concept would not be required to retain the same horizontal layout but would need to ensure that the discharge and storage criteria were retained along with the capacity to convey floodwaters into and out of the storages distributed throughout the built form.

3.6.2 Scope for a Scenario 1 Option C Plus option

Consideration was given to a potential Scenario 1 Option C Plus based on the approach adopted for Scenario 1 Option B Plus and a terrain was developed. However, any benefits obtained by increasing the flood level in cell 7 were consumed by the need to provide a minimum grade for drainage of the industrial land and no additional developable area was obtained. It was therefore concluded that a Scenario 1 Option C Plus option would not be included in the flood modelling.

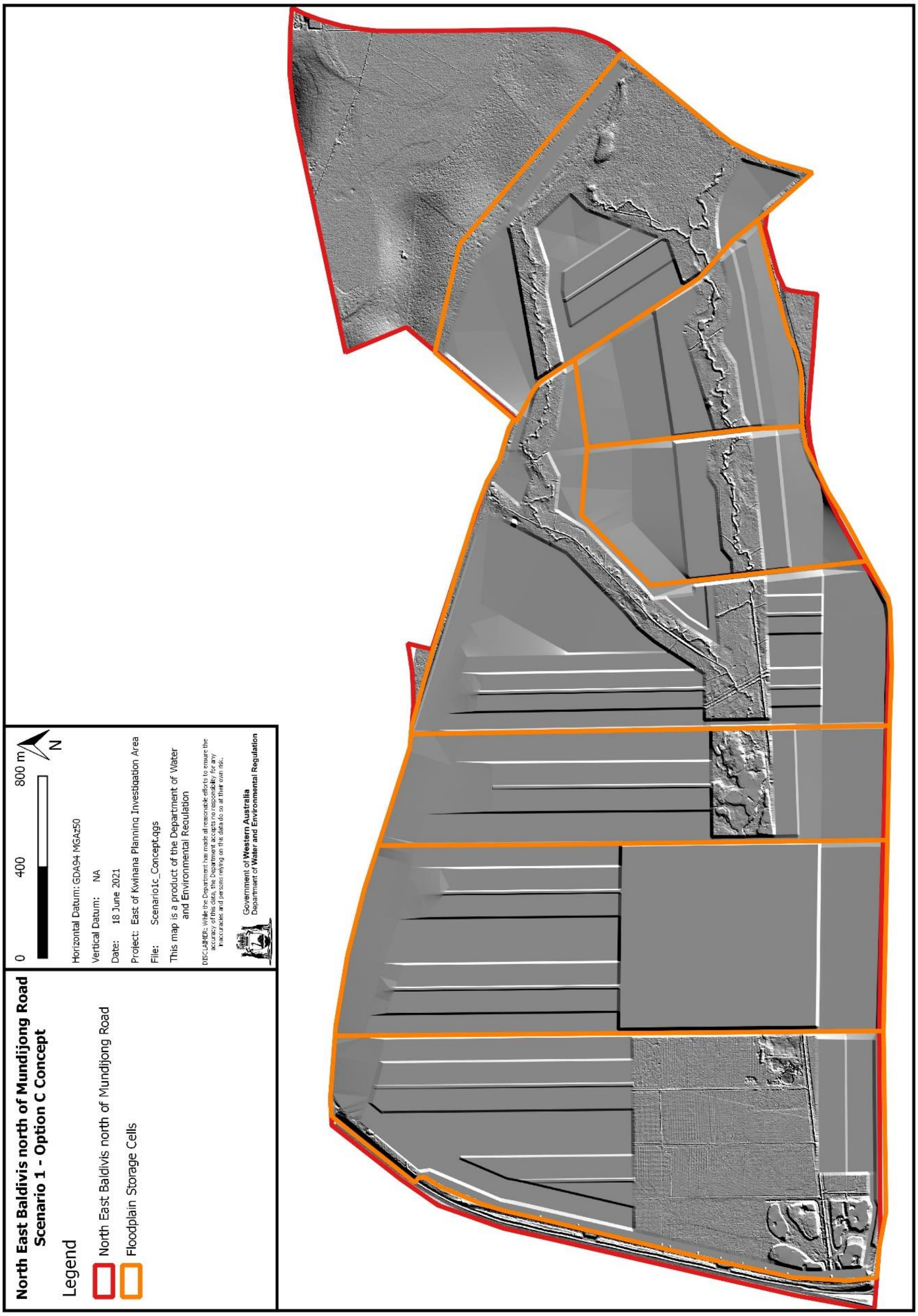


Figure 30 Scenario 1 Option C concept

3.6.3 Summary of Scenario 1 Option C flood modelling results

Flood modelling was undertaken for the 1% and 5% AEP floods and the maximum flood depth is depicted in Figure 31 below. The results show inundation of industrial land at some locations for the 5% AEP flood. The depth of this inundation is shallow – typically 0.1 m or less. It is likely that this inundation could be eliminated with some minor modifications to the terrain or hydraulic controls.

A summary of the peak flows has been provided in Table 7 including pre-development flows and relative differences. Peak discharges for Scenario 1 Option C increased by 42% in the Peel Main Drain; however, the combined discharge crossing Mundijong Road including the water overtopping the road resulted in a net reduction of 11% to the peak discharge value.

The redistribution of flows towards the Peel Main Drain and the overall reduction in peak discharge appears to be linked to the downstream hydraulic controls for water overtopping Mundijong Road. Both Scenario 1 Option B Plus and Option C attempted to manage water overtopping Mundijong Road by providing a hydraulic control at Mundijong Road independent of the road crest and about 0.1m higher than the road crest. Both options resulted in a substantial redistribution of flows towards the Peel Main Drain and reinforced the depiction in Figure 18 that a substantial portion of the floodway overtops Mundijong Road.

Floodplain storage and flood levels are summarised in Table 8 and show that the overall floodplain storage exceeds pre-development by 3%. As with previous scenario modelling, the floodplain storage in cells 6 and 7 dropped while increasing in cells 1–5. This indicates that cells 1–5 have been used to provide mitigation benefits and increase the developable area in cells 6 and 7. This appears to be an important requirement to obtain developable area in the western portions of the precinct, and splitting the precinct into smaller areas is not recommended.

Discharge hydrographs at Mundijong Road are provided in Figure 32 for pre-development and post-development Scenario 1 Option C, indicating a significant reduction in peak discharge. Additional detail provided in Table 9 compares the discharge from Scenario 1 Option C, Scenario 1 Option B Plus and pre-development. The floodplain storage volume for Scenario 1 Option C is like that of Scenario 1 Option B; however, the peak discharge for Scenario 1 Option C is below the pre-development peak and like Scenario 1 Option B Plus. A comparison of the discharge hydrographs for Scenario 1 Option B Plus and Scenario 1 Option C (Figure 33) shows that while the two have similar peaks, the shape of the hydrographs is different. Scenario 1 Option C appears to discharge higher flows earlier in the flood than Scenario 1 Option B Plus while retaining similar peaks, even though Scenario 1 Option C has a floodplain storage volume closer to Scenario 1 Option B than Scenario 1 Option B Plus. The discharge from cells 6 to cell 7 is depicted in Figure 34 and this figure (along with Figure 33) indicates the point where inundation of the industrial land starts.

The shape of the Scenario 1 Option C hydrograph implies less storage attenuation and more conveyance lower in the floodplain, and less conveyance and more storage attenuation higher in the floodplain. This is likely a combination of restricting flows over Mundijong Road, the redistribution of flows towards the Peel Main Drain and the relocation of floodplain storage from lower in the floodplain to higher in the floodplain. This suggests there is a limit to how much the flood depth can be increased, and the flood extent reduced, to maximise the developable area. This is discussed further in Section 3.6.4 (below).

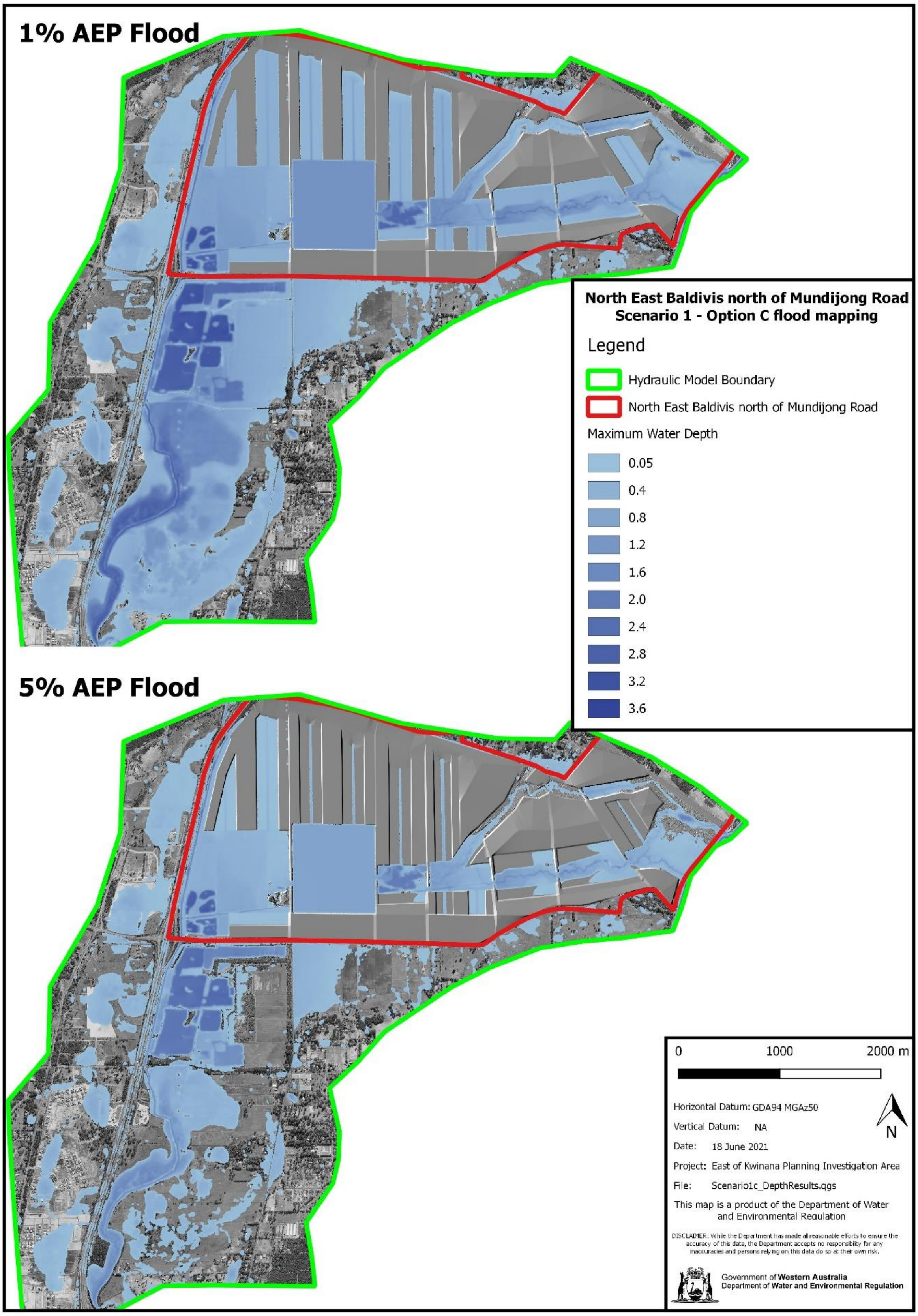


Figure 31 Scenario 1 Option C flood mapping

Table 7 Scenario 1 Option C peak discharge summary

Location	Pre-development (m^3/s)	Option C (m^3/s)
Inflow		
Birrega	73.1	73.1
Peel Main Drain	9.3	9.3
Outflow		
Peel Main Drain (PMD)	20.5	29.1 (42%)
Mundijong Road inc. PMD	73.3	65.3 (-11%)

Table 8 Scenario 1 Option C summary of 1% AEP floodplain storage and levels.

Cell	Floodplain Storage (ML)		Flood Levels (m AHD)	
	Pre-development	Option C	Target	Option C
1	203	282 (38%)	10.2	10.1
2	131	183 (40%)	9.6	9.5
3	125	232 (85%)	8.9	9.0
4	225	441 (96%)	7.8	7.8
5	309	340 (10%)	7	6.9
6	1311	1094 (-17%)	6.8	6.6
7	1307	1162 (-11%)	5.8	5.8
Overall	**3611**	**3732 (3%)**		

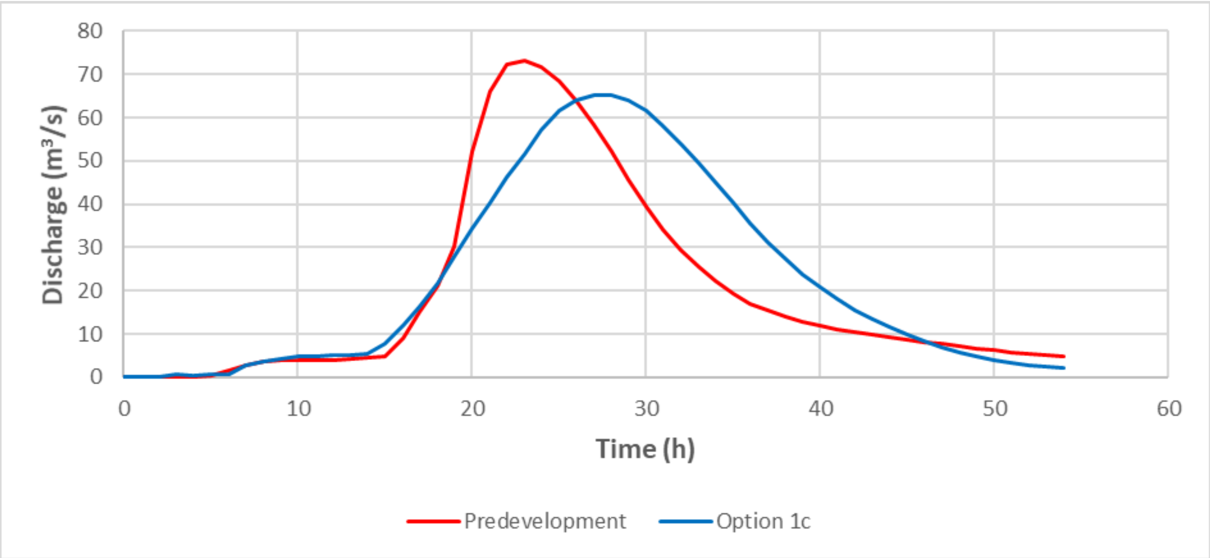


Figure 32 Scenario 1 Option C total discharge at Mundijong Road

Table 9 Comparison of storage and discharge of Scenario 1 options

	Discharge (m^3/s)	Storage (ML)
Pre-development	73.3	3611
Scenario 1 Option B	68.4 (-7%)	3643 (1%)
Scenario 1 Option B Plus	64.8 (-12%)	4040 (12%)
Scenario 1 Option C	65.3 (-11%)	3732 (3%)

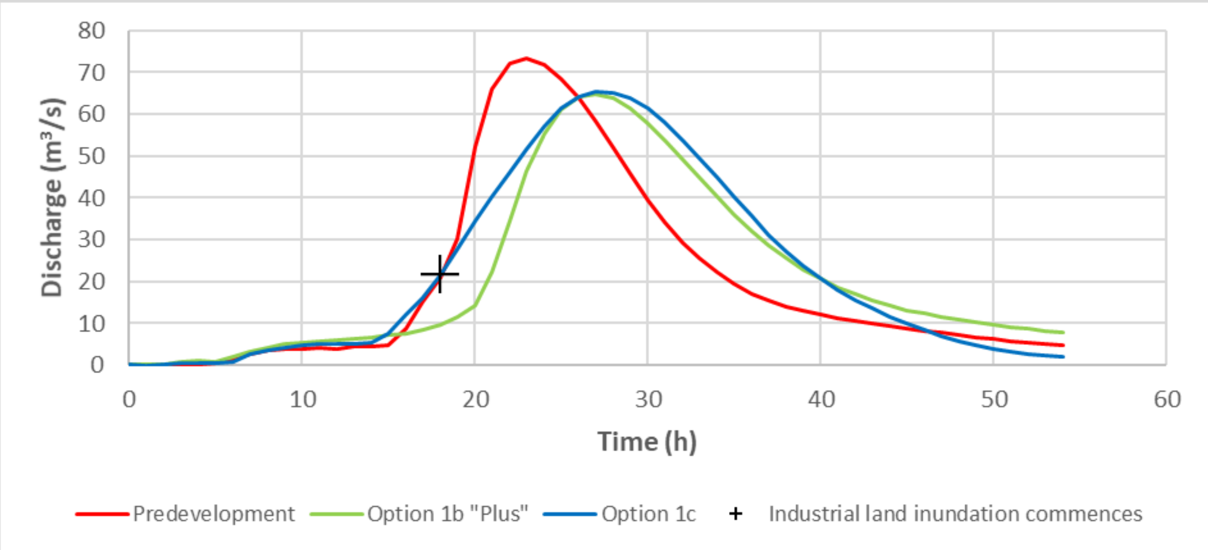


Figure 33 Scenarios 1 Option B Plus and Option C discharge at Mundijong Road.

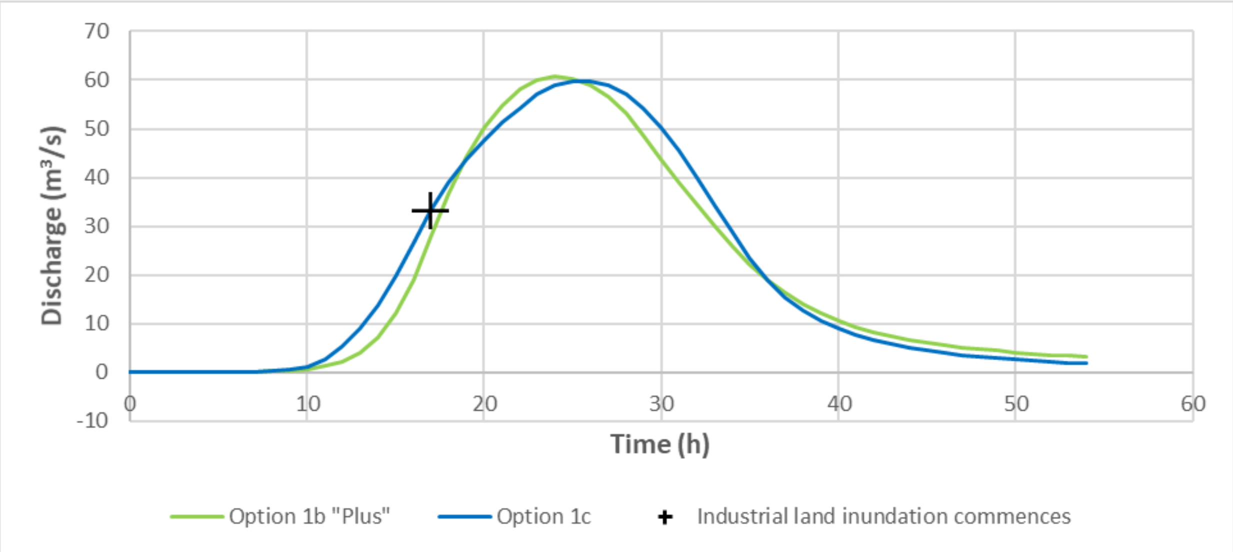


Figure 34 Cell 6 discharge for Scenario 1 Option B Plus and Option C

3.6.4 Potential optimisation

There are several ways in which in which Option C could be optimised to increase the developable area. The northern waterway corridor could be removed as described in Section 3.5.6 with an additional 3% gain in developable area.

Given that the peak discharge for Scenario 1 Option C is like Scenario 1 Option B Plus, it may be possible to gain an additional 4% in developable area by reducing floodplain storage as discussed in Section 3.5.7; however, two significant barriers make the potential for optimisation uncertain.

Firstly, as discussed in Section 3.6.1, the western end of the precinct is very flat and presented significant difficulties in obtaining sufficient grades for drainage. As noted in Section 3.6.2, an attempt was made to further optimise the developable area. However, the result of this was to resolve the difficulties in drainage grades rather than increase the developable area.

Secondly, as noted in Section 3.6.3, the concept produces less storage at shallower depths, resulting in higher discharge earlier in the storm, and more storage at higher depths, resulting in reduced peak discharge. Further optimisation to increase the developable area has the potential to result in a high early discharge. Discharging additional floodwaters early in the flood is typically permitted in the lowest reaches of a catchment, much closer to the ocean discharge, and is not an acceptable practice in locations this high in the catchment (like East of Kwinana). If an exception was made to normal practice and a higher early discharge is permitted, the measure of detrimental impacts is not merely maintaining post-development discharge to match pre-development but also ensuring than flood level increases downstream because of the high early discharge are not detrimental. This issue has already been discussed in Section 3.11 when characterising the landscape and in Section 3.5.8 when discussing proponent-driven Option B and, as demonstrated in Section 3.5.12, can result in a downstream impact.

It should also be noted that the point where inundation of industrial land starts plays an important role in the potential for optimisation. As shown in Figure 33, inundation of industrial land (circa 5% AEP flood level) is the trigger point at which significant attenuation of the discharge starts. To increase the total developable area, it would be necessary to fill land below this level and create a high early discharge. Optimisation after (or above) this point involves reducing the depth and extent of flood inundation permitted on industrial land but does not increase the total developable area.

Another potential optimisation method was to increase the permitted inundation depth for industrial land beyond the adopted 0.5 m limit. This would significantly limit the ability to obtain vehicular access to enclosed spaces and would be more appropriate for larger-scale industrial operations dealing with materials and equipment of either lower value or lower susceptibility to flood damage. During the formulation of Option C it was noted that, for most of the site, environmental considerations were impacting the ability to obtain developable land. Furthermore, it was also noted that while the depth limit largely determined the developable area, the 5% AEP flood was close to inundating industrial land and minimal additional developable area would be gained by increasing the depth of inundation permitted on industrial land.

3.6.5 Implementation of development constraints on private industrial lots

While additional developable area could be obtained by permitting portions of industrial land below the 1% AEP flood, the demand for development in Perth to date has not necessitated this practice. Should Scenario 1 Option C be pursued, the North East Baldivis north of Mundijong Road precinct would be the first situation in Perth where such an approach has been adopted.

Essentially, the new industrial lots would be sold as flood-prone land with constraints on how the land can be developed and used. These constraints would include, but not be limited to, the following:

- Buildings and other enclosed spaces would effectively be limited to half the site (a by-product of the floodplain storage requirement).
- Office floor levels and other enclosed floors not requiring vehicular access would need to be above the 1% AEP flood plus 0.5 m freeboard (i.e. 1 m above the surrounding ground level).
- Industrial floor spaces requiring vehicular access would need to be set at the 1% AEP flood level with no freeboard (i.e. 0.5 m above the surrounding ground level) to facilitate vehicular access ramps.
- Building components (including industrial floor spaces) below the 1% AEP flood plus 0.5 m freeboard would need to be constructed from flood-compatible building materials and techniques, (i.e. can be inundated by floodwaters without damage).
- There would need to be appropriate containment of materials that might become hazardous or floating debris during flooding.
- Materials sensitive to flood damage would need to be stored above the 1% AEP flood plus 0.5 m freeboard (e.g. 0.5 m off the floor inside buildings that do not have freeboard).
- Emergency planning and evacuation for the site would need to include flood emergency situations.

While the above approach is common in other jurisdictions in Australia, this would be the first time this approach had been adopted in Perth. As a result, there would be capacity building constraints to implementation such as:

- the ability of approval authorities to enforce a nonstandard approach
- the capacity of approval authorities to assess compliance and ensure appropriate implementation
- the capacity of local industry to formulate and construct proposals consistent with the flooding constraints.
- knowledge and awareness by future property owners of the flood risk and the limitations this poses on the construction and operation of industrial development on the land.

It is recommended that the approval authorities should have legally enforceable non-standard planning controls in place and the capacity to assess proposals against these controls. Prospective property owners should be clearly informed of the flood risk and the constraints for the development and use of the land. Local private industry would need to develop the capacity to design and construct solutions within these constraints and property owners would need to develop the capacity to operate within these constraints. Ultimately, the demand for industrial land in this area would need to outweigh the constraints and costs of providing and operating industrial development on flood prone land.

3.6.6 Scenario 1 Option C flood-related land capability assessment

The flood-related land capability for Scenario 1 Option C is summarised in Figure 35. Protection for the 1% AEP flood is reduced from 55% of the land in Option B down to 30% in Option C. Industrial development is permitted on 35% of the land that is also flood prone, with limitations placed on industrial development to mitigate flood damage to the development. The total developable area is 65% for Option C compared to 55% for Option B. A comparison between Option B and Option C showed that, in Option C, protection for the 1% AEP flood is foregone for 25% of the land to gain an additional 10% in the total developable area.

The formulation of Option C was significantly impacted by the flat nature of the topography at the western end of the precinct, and the ability to obtain sufficient grades for drainage infrastructure was a challenge in this area. There is the potential for further optimisation at the district planning stage in the order of 2–6%; however, this would be challenging because of the flat topography at the precinct’s western end.

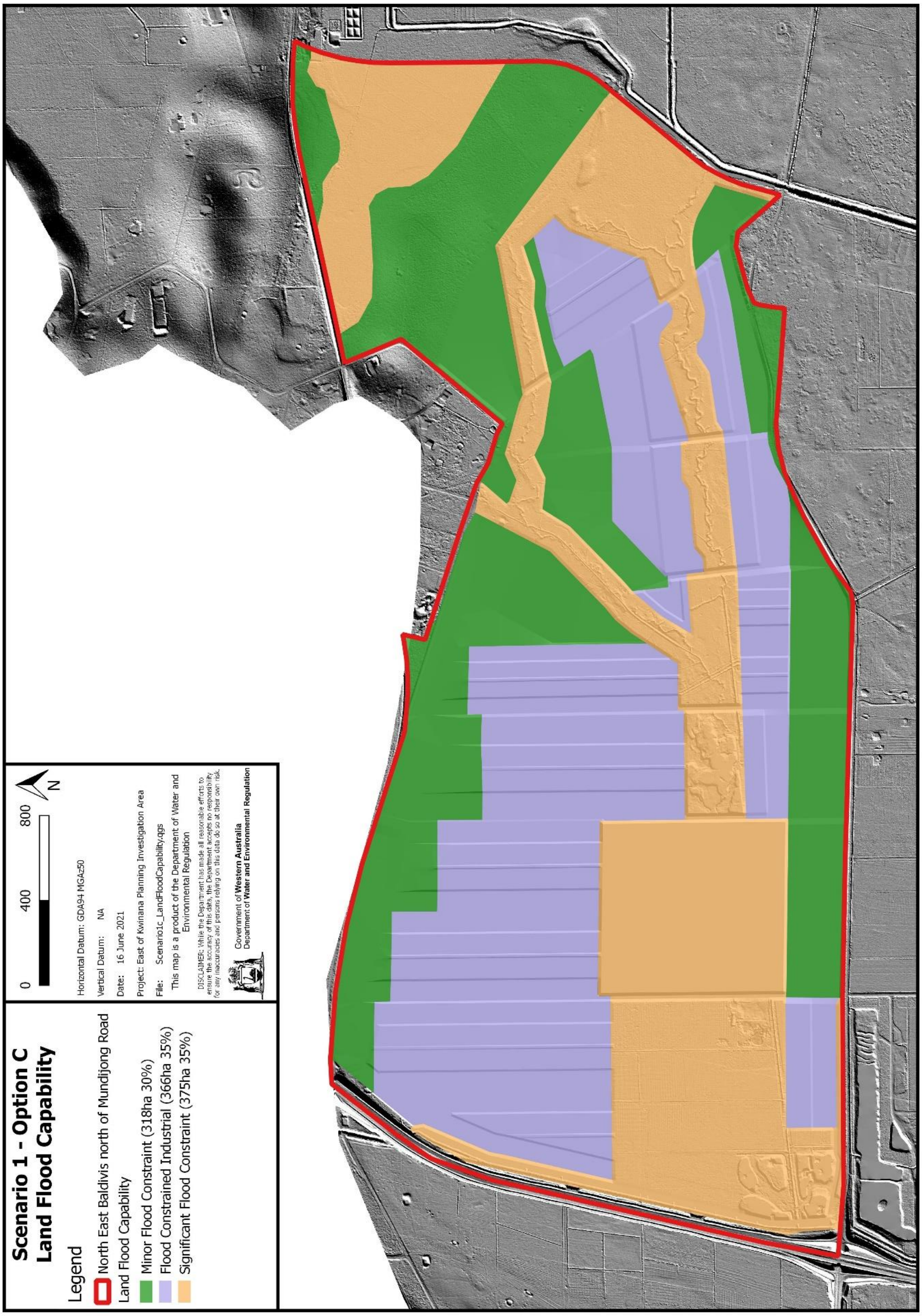


Figure 35 Scenario 1 Option C land flood capability assessment

3.7 Additional considerations for North East Baldivis north of Mundijong Road (Scenario 1)

3.7.1 Additional drainage capacity at Mundijong Road

Under pre-development conditions, most of the 1% AEP flood discharges over Mundijong Road. During the formulation and testing of the options, it became clear that discharge over Mundijong Road impacted the potential layout of development and in some options the redistribution of flows towards the Peel Main Drain was noted.

Diversion of flows to the Peel Main Drain, rather than overtopping Mundijong Road, may be beneficial but there is a risk of detrimental impacts. The Peel Main Drain crossing of Mundijong Road is in a constrained position away from the main area of flood discharge. Major infrastructure upgrades would be required to redirect all flows through the Peel Main Drain. This may not be appropriate and a second drainage crossing of Mundijong Road may be required.

This study retained discharge over Mundijong Road but limited the extent of the overtop and noted where a redistribution of flows towards the Peel Main Drain occurred. It should also be noted that the Peel Main Drain culvert crossing at Mundijong Road has not been included in this study and any redistribution of flows towards the Peel Main Drain is based on the channel capacity not the culvert capacity.

The location and configuration of the discharge has implications for district structure planning regardless of the adopted development option. Upgrading of Mundijong Road to support development is likely, and flooding of the road may not be compatible with the access requirements for the future development. Should development of the land proceed, additional investigations would be required at the district planning stage. These investigations would need to consider the appropriate discharge configuration, including the proportion of discharge over Mundijong Road through the Peel Main Drain or additional drainage crossings.

However, the extent of flooding constraints in the southwest corner of the precinct means that the configuration of the outlet does not impact the total developable area determined by this study. While the precise configuration of outlets is detail for consideration at district structure planning, the quantum of developable land determined by this study would not change and is considered reliable.

3.7.2 Sensitivity to key parameters and assumptions

The sensitivity of key parameters and assumptions was tested to determine whether these aspects of the flood modelling impacted decision-making. The sensitivity testing looked at the impacts of the uncertainty on both the flood modelling and on decision-making.

3.7.2.1 Roughness, losses and inundation

The sensitivity of the flood model to roughness, losses and inundation was tested as a part of the *East of Kwinana flood modelling and drainage study* (DWER 2021) and the following provides a brief overview. Sensitivity tests were run on the pre-development regional flood model. The results of the sensitivity tests were analysed for discharges at key locations along with impacts on flood levels where the flood depth exceeded 50 mm. The analysis considered the overall flood model performance but also focused in on the sensitivity within the North East Baldivis north of Mundijong Road precinct. The analysis showed that the flood modelling results were not sensitive to the tested parameters at either the regional level or within the North East Baldivis north of Mundijong Road precinct.

Table 10 below summarises the sensitivity of the regional flood model in comparison to the inflows from the Birrega Main Drain and the average change to flood levels for the North East Baldivis north of Mundijong Road precinct. The results across the broader regional model displayed less sensitivity than the results below.

Table 10 Pre-development model sensitivity to roughness, losses and inundation.

Sensitivity case	Percentage change to inflows from the Birrega	Average change to flood levels
Roughness sensitivity		
Roughness up 10%	-5%	-12 mm
Roughness down 10%	+3%	+12 mm
Losses sensitivity		
Infiltration up 10%	-7%	-15 mm
Infiltration down 10%	+6%	+16 mm
Inundation sensitivity		
No groundwater inundation	-5%	-2 mm
Annual average maximum groundwater level inundation	+2%	+ 6mm

3.7.2.2 Spoil bank failure 1% AEP flood

Assessment of the spoil banks for potential failure was discussed in Section 3.3 and it was concluded that the spoil bank is likely to fail during the 1% AEP flood. More specifically, it was concluded that anywhere between 50–80% of the spoil bank length could fail.

A range of spoil bank failure configurations were assessed to identify the impact that various potential failures may have on inflows to the North East Baldivis north of Mundijong Road precinct. The configurations tested were as follows:

- failure of the entire length adjacent to the development precinct
- failure of 50% of the length at the northern position
- failure of 50% of the length in a southern and central position.

The first and second configurations produced very similar inflows, but the third configuration resulted in a reduction to the peak inflow from 73.7 to 63.1 m^3/s (17%). The flood modelling results showed that when the length of spoil bank failure was halved, the tendency was to increase the velocity through the breach rather than reduce the inflow. The impact of this was assessed and summarised in Table 11 below which presents the impact of half the spoil bank failure (by length) versus failure of the entire spoil bank.

The impact of the chosen configuration on developable area was assessed based on recovering additional developable land at the western end of the precinct (cells 6 and 7) and at the eastern end of the precinct (cell 1). A mix of land at these two locations was used to maximise the estimate of additional developable area. The sensitivity analysis showed that whether the spoil bank failed over half of its length or all its length made little difference to the developable area that could be obtained.

Table 11 Spoil bank partial failure versus total failure sensitivity

	Predicted change
Peak inflow	-17%
Average level difference	-70 mm
Floodplain Storage difference	-5%
Developable area difference	+23 ha (+2%)

3.7.2.3 Spoil bank failure 5% AEP flood

A sensitivity analysis was done on the 5% AEP flood with and without failure of the spoil bank using the regional pre-development flood model. This revealed that downstream flood levels within existing waterbodies varied substantially. On land outside of the waterbodies, there was little variation in flood levels, with the maximum recorded increase being 23 mm (see Figure 36). Flood levels within the precinct varied substantially depending on failure of the spoil bank; however, the 5% AEP flood was contained within the 1% AEP flood and was not impacting the estimation of developable area.

It is unknown whether the spoil bank would fail during the 5% AEP flood; however, this does not impact on the developable area within the North East Baldivis north of Mundijong Road precinct or on downstream land outside of waterbodies.

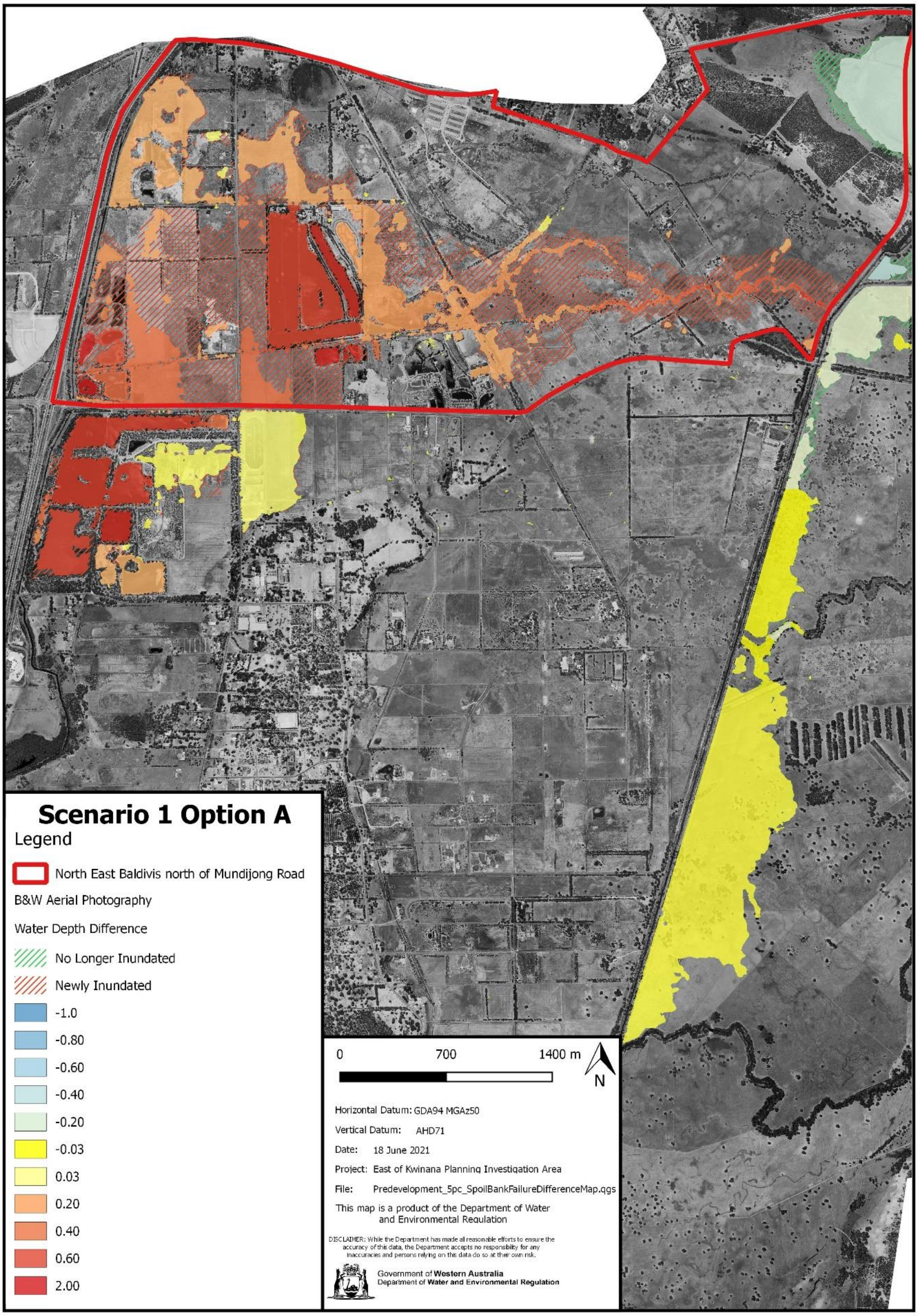


Figure 36 Pre-development 5% AEP flood spoil bank failure sensitivity

3.7.2.4 Potential low-height inflow crest

Consideration was given to the potential benefits that could be gained by limiting the post-development inflow of the 5% AEP flood. While there is no flood levee in Options B and C, consideration was given to providing a short and wide crest in the landscape on the western side of the Birrega Main Drain. The height of this crest was limited to a maximum of 0.5 m and would be implemented over a very broad width, effectively providing a low crest in the general topography rather than a high flood levee.

A crest level of 10.5m AHD was considered to limit the maximum height of the crest to 0.5 m. This would have the effect of limiting inflows from the 5% AEP and, potentially, the 1% AEP flood. This configuration was implemented in the regional model for the 1% AEP 18-hour duration. The peak inflow into the North East Baldivis north of Mundijong Road precinct was reduced from 73.1 to 47.3m^3/s which represents a 25.8m^3/s (36%) reduction.

Updated difference mapping is provided in Figure 37 which shows that while the external impacts of the low-height crest are not as great as Option A, the impacts are still considered to be detrimental. It was determined that use of a low-height crest up to 10.5m AHD would not be appropriate for use in the post-development options.

Further consideration was given to this concept by undertaking flood modelling for a low-height crest of 10.3m AHD. The 1% AEP flood had lower flood level increases of up to 10 cm compared to the 55 cm increase observed in Scenario 1 Option A, but this is still unacceptable. As summarised in Table 12 below, the impact is not as great as Scenario 1 Option A where the increased flood level would see land above the 1% AEP flood inundated by the 5% AEP flood. A crest set at 10.5 m AHD would see the frequency of inundation doubled with land inundated by a 1% AEP flood now inundated by a 2% AEP flood. A crest set at 10.3 m AHD represents a 30–60% increase to the frequency of inundation and Figure 38 shows that the impact is spread over a significant area.

Table 12 Impact of variable inflow conditions for north of Mundijong Road.

Case	Maximum flood level increase	Extent impacted
Construction of a levee (Scenario 1 Option A)	55 cm	Increases of varying depths for up to 10 km
Crest set at 10.5m AHD	29 cm	Increases of varying depths for up to 9 km
Crest set at 10.3m AHD	10 cm	Increases of varying depths for up to 8.5 km

The use of a low-height inflow crest is complicated by limitations in the accuracy of current flood modelling technology and capability. There cannot be a freeboard on the low-height inflow crest as the freeboard will result in detrimental upstream impacts. If the final constructed crest level varies by 0.1 m or the estimated flood levels vary by 0.1 m, this can have an impact on flooding for both the 1% and 5% AEP floods. In the case of upstream flooding, this may result in detrimental flood impacts for upstream land.

In the case of flooding within the North East Baldivis north of Mundijong Road precinct, this is not a significant issue for Scenario 1 Option B as development will be provided with a 1% AEP flood protection including appropriate freeboard. However, in the case of Scenario 1 Option C, the limitations in flood prediction and design for the low-height inflow crest may result in industrial development being flooded in events more frequent that the 5% AEP flood. This is because of the lack of freeboard on both the inflow crest and the industrial development.

The use of a low-height inflow crest did not provide the potential to substantially improve the developable area within the North East Baldivis north of Mundijong Road precinct. However, it did introduce uncertainty to the flood level estimation potentially resulting in:

- detrimental upstream impacts
- flooding of industrial development in Option C more frequent than the 5% AEP flood.

3.7.2.5 Option A potential inflows

Scenario 1 Option A does not permit any inflows from the Birrega Main Drain to enter the North East Baldivis north of Mundijong Road precinct. A request was made for the department to consider allowing 17 m^3/s inflow (77% reduction to pre-development inflow) via a spillway over the flood levee proposed in that option. The regional flood model for Option A was adjusted to permit 17 m^3/s inflow which is less than that considered in the previous section. The impact of this configuration is very similar to that of Option A as depicted in Figure 15, with only a minor reduction in the differences. Introducing a spillway in the 1% AEP flood allowing high velocities creates the additional risk of levee failure occurring and does not provide any significant reduction to upstream impacts.

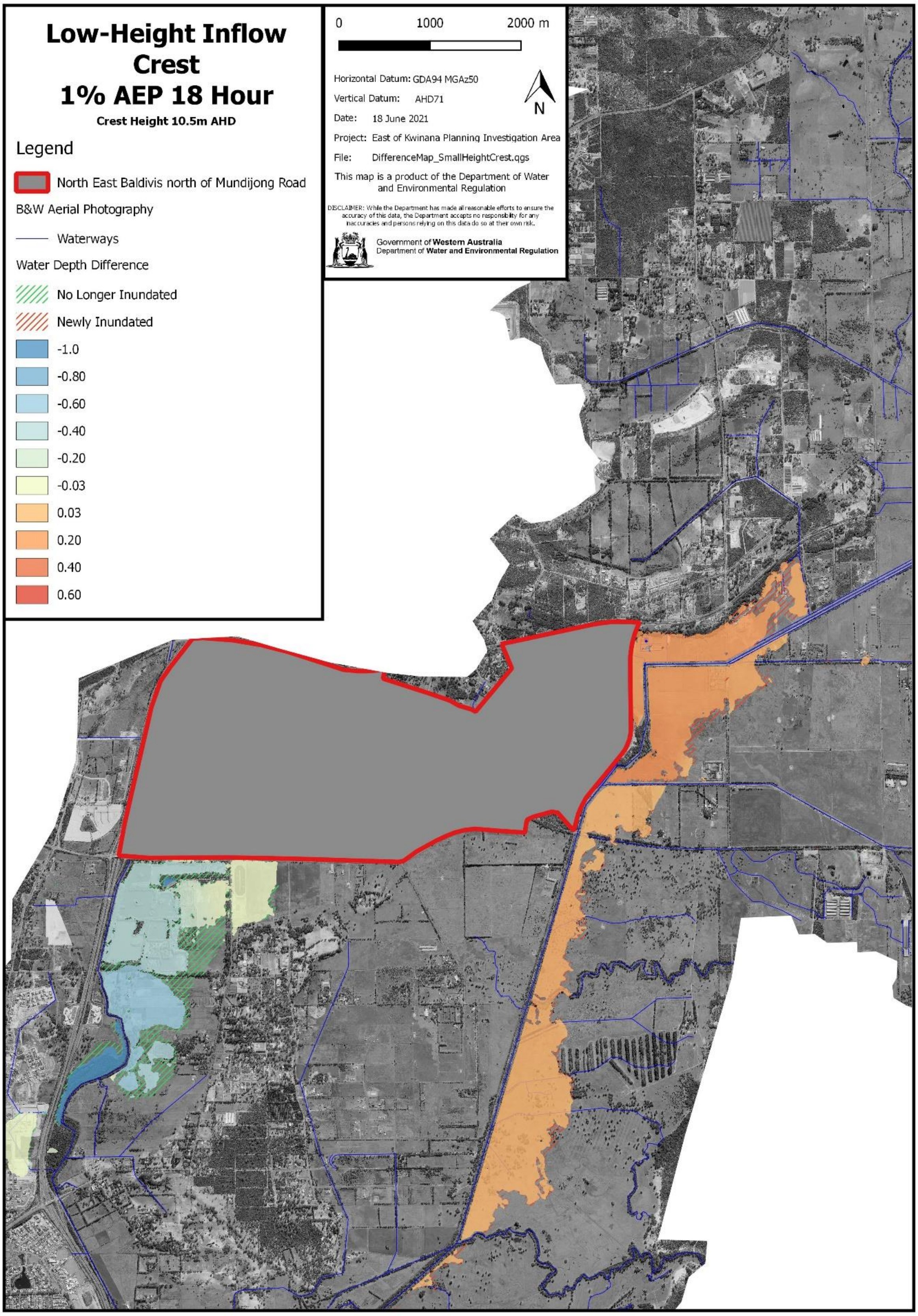


Figure 37 Pre-development 1% AEP flood low-height inflow crest at 10.5m AHD

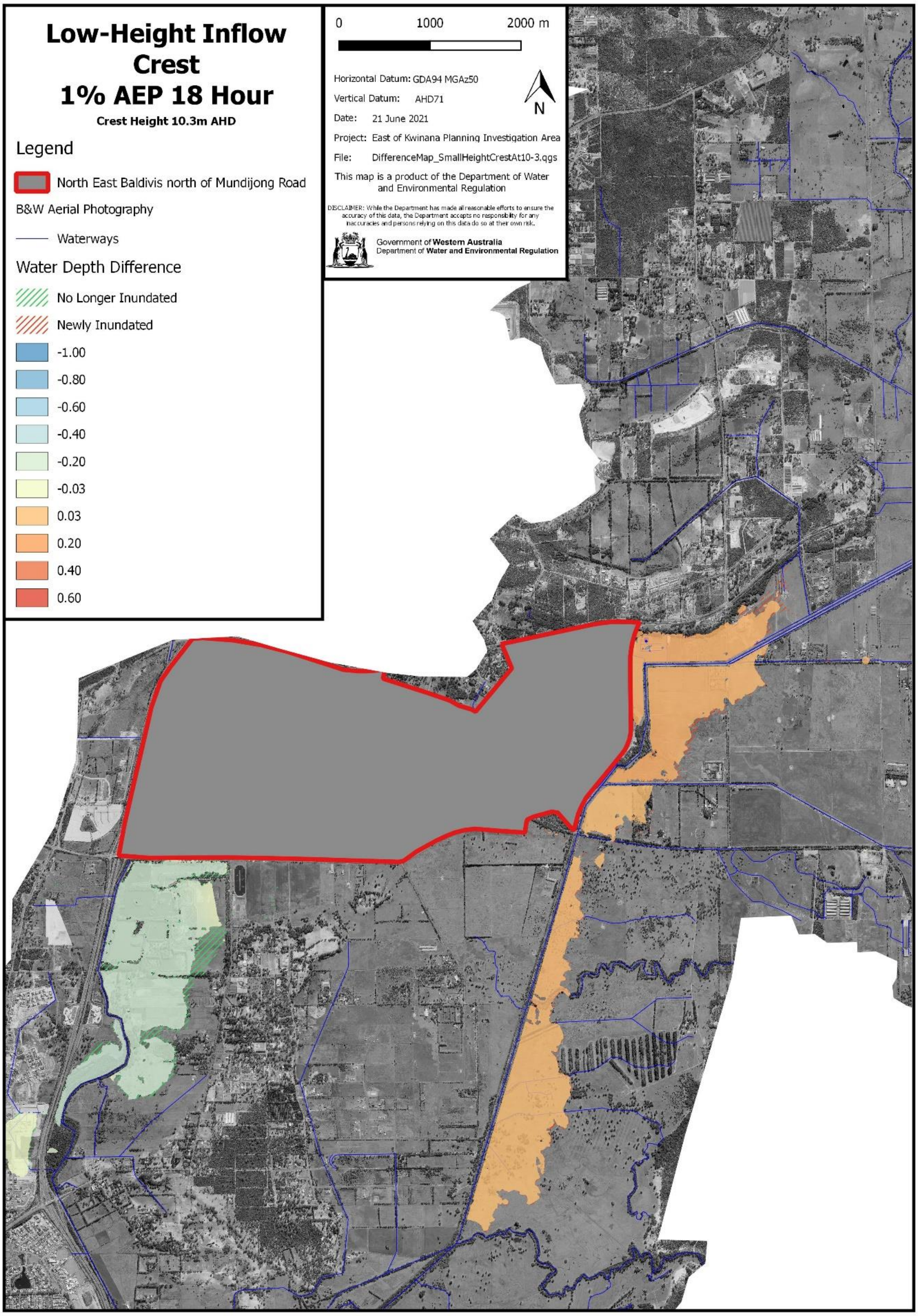


Figure 38 Scenario 2 potential 1% AEP flood low-height inflow crest at 10.3m AHD

3.8 Scenario 1 potential fill volumes for flood management

The information in this section has been provided at the request of the DPLH and care should be taken when interpreting this information. The quantity of fill was a consideration in formulating the post-development options. The post-development terrains were formulated to limit the depth of fill required to implement the conceptual approach while ensuring the land intended for development would be above the required flood levels. Further optimisation of the fill levels could be obtained in subsequent stages of planning, provided the flood protection is maintained.

The levee approach (Scenario 1 Option A Section 3.4) is not a realistic representation of cut and fill levels as it substantially cuts into existing groundwater. Extension of the concept upstream further cut into groundwater as priority was given to maintaining consistency with the proponent-driven concepts, rather than providing a more realistic representation of cut and fill. The area of development that is below the Annual Average Maximum Groundwater Level (Lower Serpentine Hydrological Studies 2012–15) base case scenario is shown in Figure 39.

For the traditional and varied standards approach (Options B, B Plus and C), the floodplain was confined until the flood inundation reached a depth between 1.2–1.4 m, representing 1.5–1.7m of fill at the interface between the development and the floodplain. The land was graded as flat as reasonably possible to minimise fill levels while ensuring sufficient grade for runoff. The flood levels at the western end of Option B were retained at a substantially higher level, consistent with Option B Plus, and no attempt was made to lower ground levels to correspond with the lower flood levels for Option B. For flood modelling purposes, it was more important to keep flood inundation away from the developable land than to optimise fill volumes. The volume of cut and fill was calculated based on the terrains developed for the purpose of flood modelling and is summarised in Table 13 below. In addition, Figure 40 indicates the difference between the pre-development and post-development ground levels.

Table 13 Scenario 1 flood terrain cut and fill volumes

	Cut	**Fill**	**Net (Fill – Cut)**	**Earthworks (Fill + Cut)**
	Millions of cubic metres			
Option B	0.2	9.0	8.8	9.2
Option B Plus	0.2	9.3	9.1	9.5
Option C	0.2	5.7	5.5	5.9

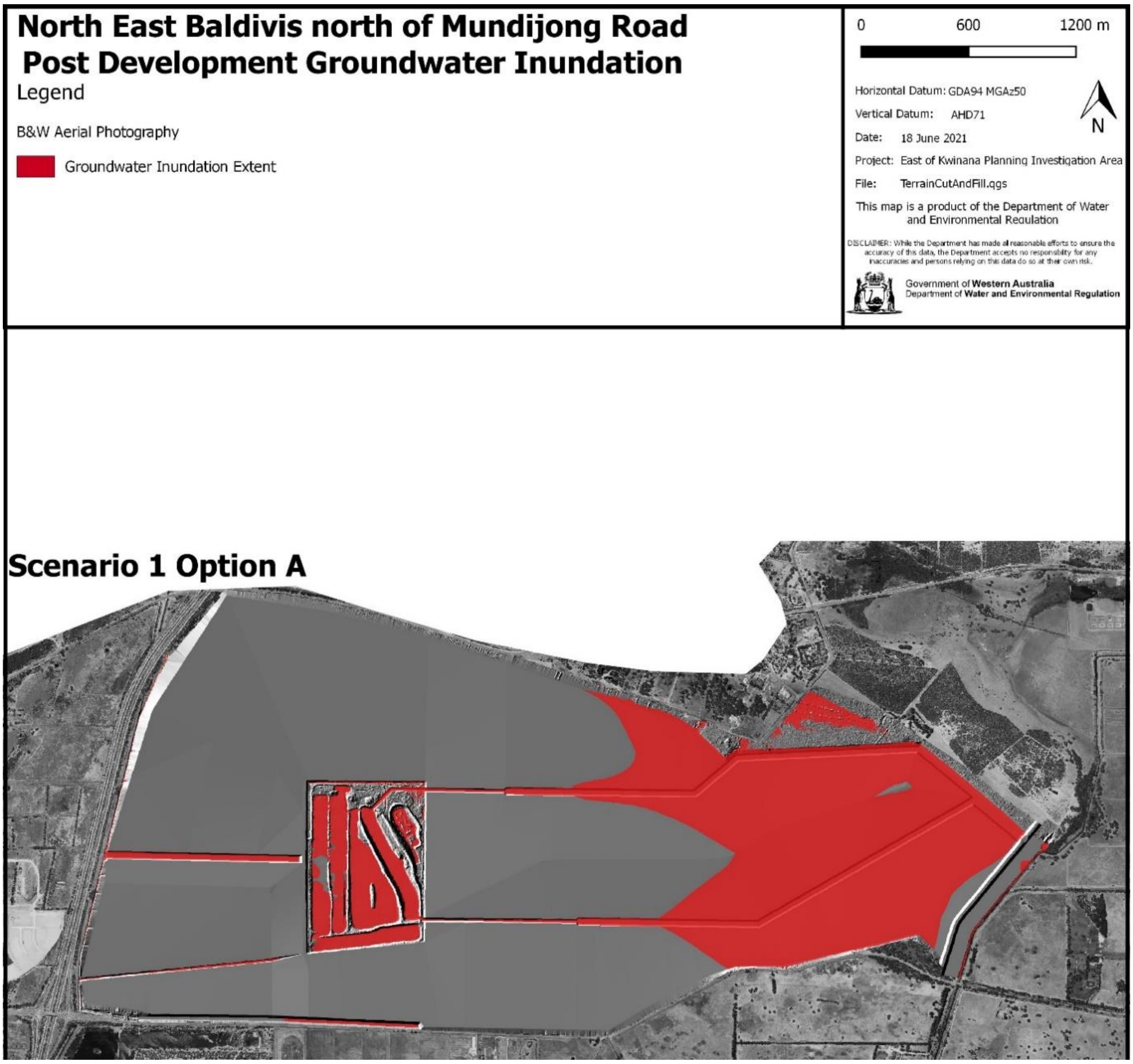


Figure 39 Scenario 1 groundwater inundation extent

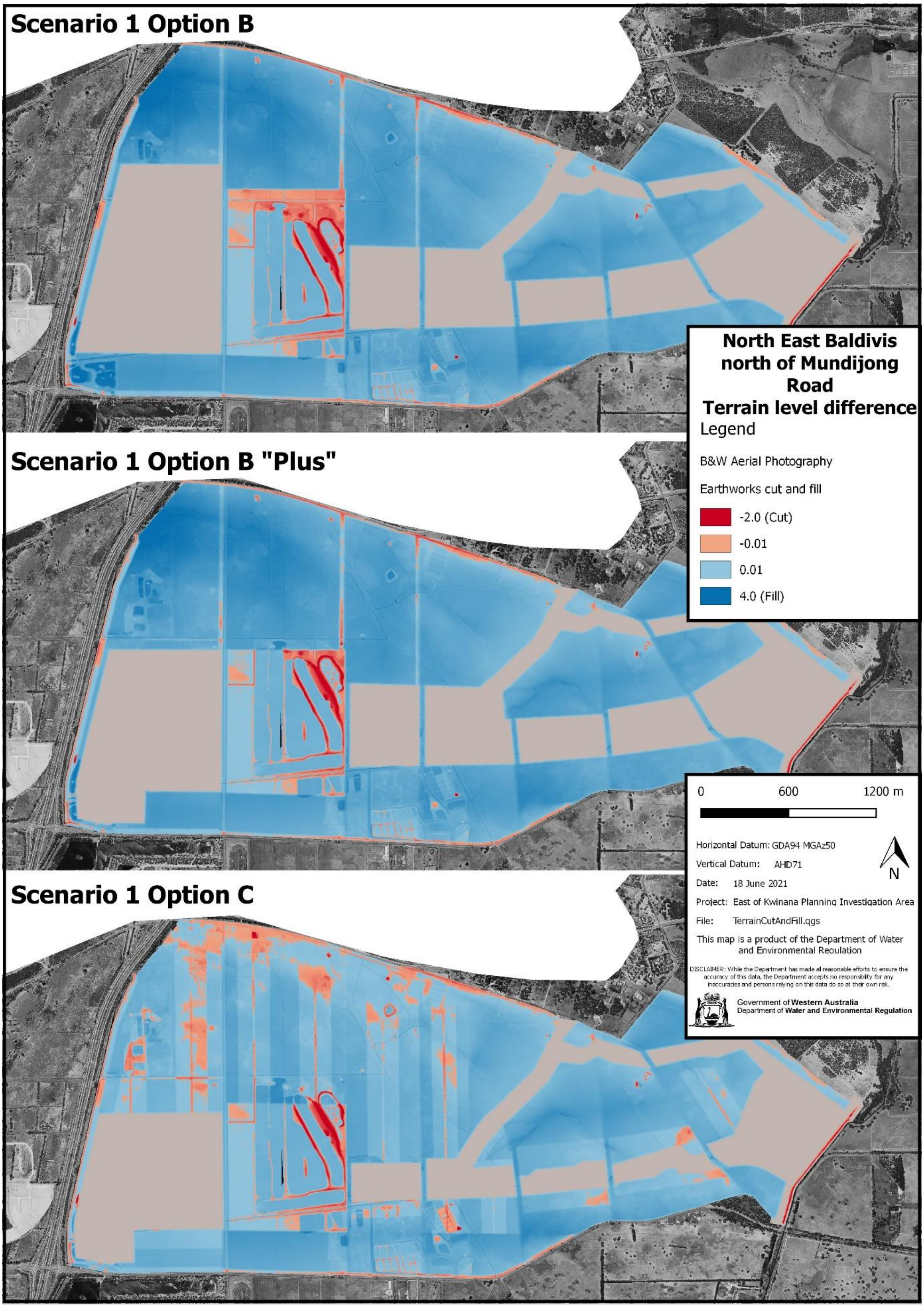


Figure 40 Scenario 1 Options B and C terrain level difference map

3.9 Advice for the North East Baldivis north of Mundijong Road precinct (Scenario 1)

3.9.1 Summary of advice

- The department has analysed flooding in the North East Baldivis north of Mundijong Road precinct of the East of Kwinana sector.
- To the east of the North East Baldivis north of Mundijong Road precinct is the Birrega Main Drain.
- The department has determined that the spoil bank adjacent to the Birrega Main Drain in this location will fail in a 1:100-year flood, flooding the North East Baldivis north of Mundijong Road precinct. This is the base case to which any future development proposal is compared.
- The department's advice is that installing a levee to develop the precinct would cause increased flooding on land for 5 km upstream and downstream in a 1:100-year event (scenario 1A). Additionally, flood levees are not fail-safe and can pose a risk to human safety and infrastructure and would not be considered best-practice flood mitigation for a greenfield site.
- The department has determined that 55% of the precinct can be developed with flood protection in the 1:100-year flood, with the remaining 45% without flood protection and, therefore, with limitations on use (scenario 1B).
- Alternatively, a total of 65% of the precinct can be developed using a 1:100-year flood standard for residential use and a 1:20-year flood standard for non-residential use. In this situation, 30% is available for residential use, 35% for non-residential use, and 35% without flood protection and with limited use (scenario 1C).
- The department focused on regional analysis and flood and inundation risk across the PIAs to determine the flood-related land capability. In this advice, limited consideration was given to groundwater management, stormwater management, water quality management or other environmental factors, policies or guidance as they relate to land use change in the PIAs. This advice should be read in conjunction with other advice for the PIA provided by the department and other agencies. Detailed investigations of water and environmental factors will be required as part of any land use change proposal.

A comparison of the analysis is presented in Table 14 below.

Table 14 Scenario 1 land flood capability comparison

Scenario	Proportion of the site with protection up to 1:100-year flood	Proportion of the site with protection from 1:20-year flood	Total developable areas	
			With flood protection	Without flood protection

Flood levee(1A)	Impacts on and off site for 5km upstream and downstream (in 100-year flood) and net loss of developable area in the PIA.			
1:100-year flood protection(1B)	55%	Not tested as part of this scenario	55%	45%
Varied flood protection (1C)	30%	35%	65%	35%

3.9.2 Advice

Pre-development base case for North East Baldivis north of Mundijong Road

The department advises that proposals should be compared to the department's pre-development base case which concluded the spoil bank adjacent to the Birrega Main Drain to the east of the precinct would fail in a 1:100-year flood.

The department's analysis, which was based on national standards and guidance for flood levees, determined the spoil bank adjacent to the Birrega Main Drain would fail in a 1:100-year event, flooding the North East Baldivis north of Mundijong Road precinct.

The department advises that any pre-development base case for this location should include spoil bank failure along the Birrega Main Drain in near the North East Baldivis north of Mundijong Road precinct.

Figure 10 shows the pre-development base case flooding in a 1:100-year event.

Analysis of a flood levee on Birrega Main Drain (scenario 1A)

The department advises that a flood levee on Birrega Main Drain would increase flooding outside the North East Baldivis north of Mundijong Road precinct for about 5 km upstream and 5 km downstream, which would cause impacts to neighbouring land.

The department analysed the impact of a levee on Birrega Main Drain adjacent to the precinct on neighbouring properties and compared it to the pre-development base case that includes spoil bank failure.

As shown in Figure 15, there would be an increase in flooding to land to the east of the North East Baldivis north of Mundijong Road precinct and a small reduction in flooding to land adjacent to the south west corner of the precinct (and outside the East of Kwinana sector). The area where flooding is reduced is smaller than the area where flooding is increased, representing a net loss of developable land from East of Kwinana

An engineered and constructed levee can pose significant risk to safety and human life. It is not fail-safe and planning for safe conveyance of flood water is still required. It would be a precautionary measure to have emergency planning around a major event and failure of the spoil bank.

Australian floodplain management industry practice considers levees a tool to manage flood risk for existing developments where the impact of relocating people and infrastructure is unpalatable.

The department does not recommend using a levee to enable land to be developed in a floodplain. The purpose of a levee is to protect people already living and working in an area with high flood risk, not to knowingly put people into a flood risk area.

The department advises that, should the land be deemed suitable for development as part of the subregional framework review, a flood protection levee is required to facilitate development of land in East of Kwinana. The flood levee design, funding, ownership, maintenance and operation and associated flood warning systems, community education programs, evacuation procedures and ownership of residual flood risk need to be agreed to by all relevant State and local authorities and agencies at the district planning stage.

There would need to be a high degree of occupant and community flood awareness and preparedness to understand/mitigate the risk of levee failure. This includes identifying the hazard and the required emergency response, regular information sessions for new and existing occupants and a designated evacuation facility.

Standard (1:100-year) approach to flood protection (scenario 1B)

The department advises that:

- 55% of the North East Baldivis north of Mundijong Road precinct can be developed with 1:100-year flood protection
- for land use change proposals, the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood need to be maintained to pre-development base case
- land use change proposals need to maintain pre-development base case flood storage capacity of the precinct.

Figure 24 shows that 55% of the precinct is available to be developed with 1:100-year flood protection. The remaining 45% has no protection in 1:100-year flood and would have limitations on use.

Figure 29 shows the location of the land with and without 1:100-year flood protection. The land that has no flood protection would need to be maintained to ensure there were no impediments (e.g. buildings, dense vegetation) to the flow of water in a flood.

The department tested whether engineered structures on the western edge of the site would gain more developable land within the 1:100-year flood protection standard. An extra 2% of land could be developed with 1:100-year flood protection by using large engineered structures in the western site of the precinct. This represents a small increase in total land, with 1:100-year flood protection for large infrastructure cost and maintenance.

This approach, where 55% of the precinct is has 1:100-year flood protection, is the easiest implementation of the three development scenarios the department analysed, as it is the standard approach to flood protection used in Western Australia.

Flood criteria for future land use proposals should be followed for this precinct. This includes maintaining flood storages and discharges for the 1:100-year (1% AEP) flood throughout the catchment to ensure no increase in flooding on downstream or neighbouring properties.

The 45% of land below the 1:100-year flood will need to be placed in public ownership, with an appropriate public use and maintenance plan in place by the relevant authority to ensure flood waters can be safely conveyed.

Risk-based approach to flood protection (scenario 1C)

The department advises that:

- 65% of the North East Baldivis north of Mundijong Road precinct can be developed using a 1:100-year flood standard for residential use and a 1:20-year flood standard for non-residential use
- for land use change proposals, the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood need to be maintained to pre-development base case
- land use change proposals need to maintain pre-development base case flood storage capacity of the precinct.

Figure 35 shows the North East Baldivis north of Mundijong Road precinct split between residential land that has 1:100-year flood protection and non-residential land (e.g. industrial land) that has a lower flood protection standard (1:20-year).

Figure 31 shows a total of 65% of the precinct can be developed. This is made up of 30% of the precinct with 1:100-year flood protection appropriate for residential use and 35% of the precinct with 1:20-year flood protection for non-residential use. When compared to Scenario 1 Option B, Option C transfers 25% of the site with 1:100-year flood protection to industrial only for a 10% gain in total developable area.

In the non-residential area, lots have a maximum building footprint of 50% to allow for open space (e.g. carpark) for flood waters to safely flow through the area in events greater than 1:20-year floods. Lots would require safety planning, including management of floating debris (including cars).

Implementation of this approach would require consideration of market demand for lots with low flood protection, building constraints relating to the lowered flood standard, constraints on the lots and insurance costs for lots with a reduced flood protection.

Land uses for the 35% of land below the 1:100-year flood will need to be placed in public ownership, with an appropriate public use and maintenance plan in place by the relevant authority, to ensure flood waters can be safely conveyed.

3.10 North East Baldivis south of Mundijong Road precinct (Scenario 2)

3.10.1 Pre-development base case

The spoil banks adjacent to North East Baldivis South of Mundijong Road precinct were assessed for potential failure consistent with the methodology outlined in Section 3.3 of this report. Two locations were identified as potential failure points and were referred to as the ‘upper failure’ and the ‘lower failure’. A sensitivity analysis was undertaken on the 1% AEP flood to determine the impact on flood levels within the Birrega Main Drain and flows through the North East Baldivis south of Mundijong Road precinct.

The following spoil bank failure scenarios were simulated using the regional pre-development model:

- upper failure only
- lower failure only
- combined upper and lower failures
- combined upper and lower failures and Scenario 1 spoil bank failure.

The location of these failures is shown in Figure 41 below along with inflow hydrographs for flows through the breaches. The peak flows through the breaches are summarised in Table 15 below.

The spoil bank failure assessment shows the lower failure alone resulted in a breakout of 24.5 m^3/s but, once combined with the upper failure, this drops substantially down to 6.3 m^3/s. Once the two southern spoil bank failures are combined with a failure at the North East Baldivis north of Mundijong Road precinct spoil bank, the breakout in the lower failure location drops to near zero. This indicates there would be no substantial impact on developable area by considering one failure location versus two failure locations south of Mundijong Road. No distinction could be made between the likelihood of the upper failure occurring versus the lower failure occurring at the North East Baldivis south of Mundijong Road precinct. Based on this assessment, the department eliminated the lower failure location from further consideration in the pre-development base case. The upper failure provided the greater of the two inflows in the event of a breach and would more likely represent the greater potential for post-development upstream impacts.

Table 15 Scenario 2 spoil bank failure flows

Case	Discharge (m^3/s)		
	Lower failure	**Upper failure**	**Scenario 1**
1. Upper failure only	-	35.7	-
2. Lower failure only	24.5	-	-
3. Lower and Upper failures combined	6.3	31.8	-
4. Lower and Upper failures and Scenario 1 failures combined	0.2	15.6	69.8
5. Scenario 1 failure only	-	-	73.1

The assessment also considered whether failure of the spoil bank at the North East Baldivis south of Mundijong Road precinct would benefit development in the North East Baldivis north of Mundijong Road precinct. In Table 15 above, case 4 can be used as an indication of the combined effect of the upper spoil bank failure in the North East Baldivis south of Mundijong Road precinct and a spoil bank failure in the North East Baldivis north of Mundijong Road precinct. This is compared to the spoil bank failure from Scenario 1 shown in case 5. The flows entering the North East Baldivis North of Mundijong Road precinct were not significantly reduced by introducing a failure south of Mundijong Road. It is unlikely that substantial gains could be made to the developable area in the North East Baldivis north of Mundijong Road precinct by introducing a failure in the North East Baldivis south of Mundijong Road precinct. This means that there is no development dependency between the two precincts.

Failure of the spoil bank south of Mundijong Road will increase flood levels on the floodplain of the Peel Main Drain by about 6 cm (see Figure 41). This increase to downstream flood levels had a negligible impact on flooding within the North East Baldivis north of Mundijong Road precinct as flooding in that precinct is significantly impacted by Mundijong Road acting as a hydraulic control. In addition, a flood level increase of about 7 cm was recorded behind (to the east) of the sand hill between the Birrega and Peel main drains.

Based on the spoil bank failure assessment and consistency with the approach adopted for Scenario 1, it was determined that the North East Baldivis south of Mundijong Road precinct is independent of the North East Baldivis north of Mundijong Road precinct, and the pre-development base case includes spoil bank failure on the Birrega Main Drain in the upper location only (Figure 44).

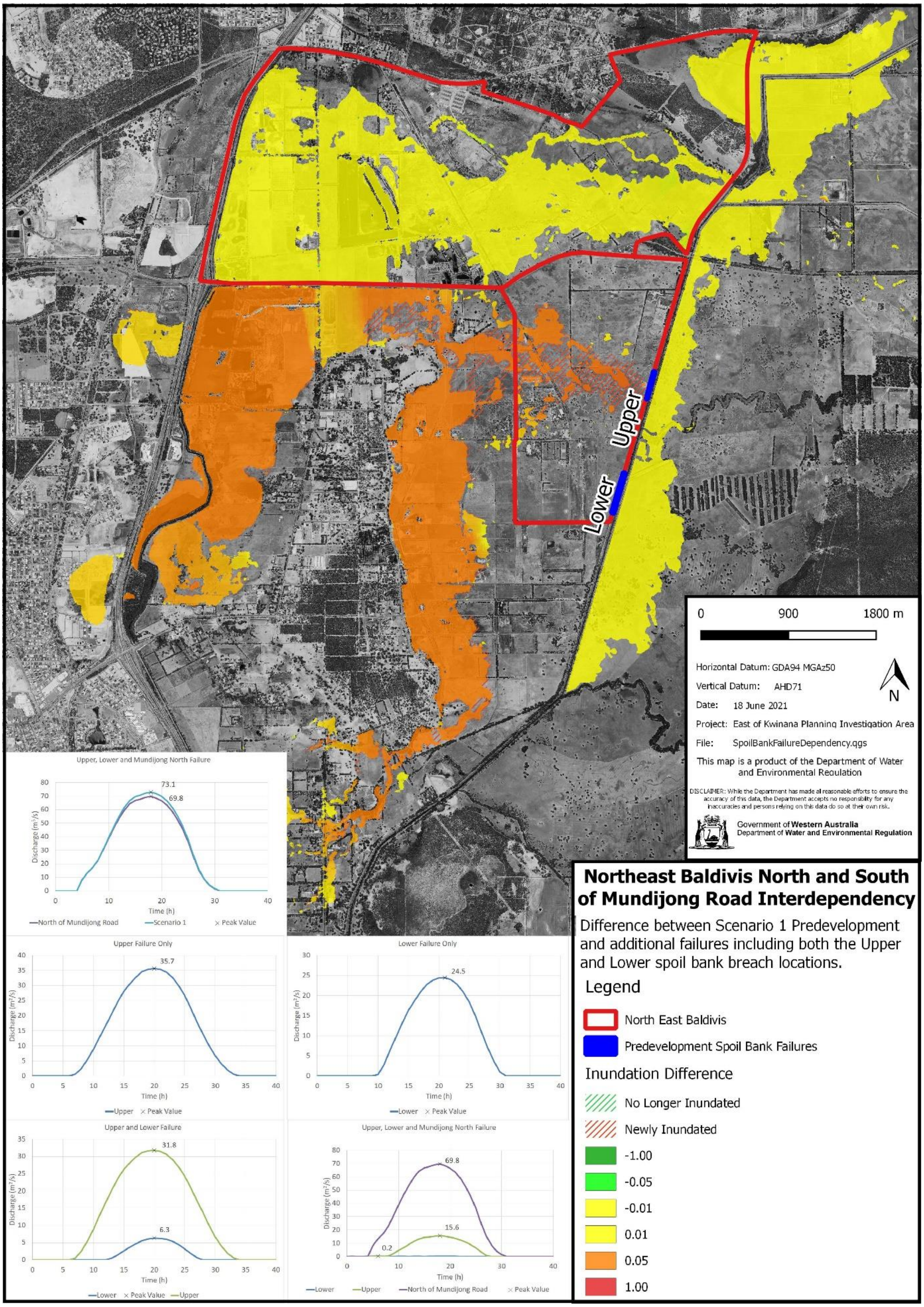


Figure 41 Scenario 2 spoil bank failure sensitivity 1% AEP flood

3.10.2 Post-development low-height inflow crest

It was observed that the North East Baldivis south of Mundijong Road precinct does not have well-defined discharge points and discharge is via broad depressions in the topography rather than drains or waterways with a clearly defined bed and banks like the Peel Main Drain. Development of the North East Baldivis south of Mundijong Road precinct therefore also considered the impact of development in smaller, more frequent, storms and the implications for existing rural downstream development. The potential for a low-height inflow crest targeting the 5% AEP flood for North East Baldivis south of Mundijong Road was considered to minimise the potential inflow of smaller events while retaining the 1% AEP pre-development inflow.

The opportunity was also taken to investigate whether the post-development impact of the low-height inflow crest for the North East Baldivis north of Mundijong Road precinct (considered in Section 3.7.2.4) could be further reduced by development in the North East Baldivis south of Mundijong Road precinct. The location and extent of the pre-development spoil bank failures remained consistent with the pre-development base cases for the North East Baldivis north of Mundijong Road precinct (Section 3.4.1) and the North East Baldivis South of Mundijong Road precinct (Section 3.10.1). Several combinations of low-height inflow crests were considered for both precincts for post-development. The cases are summarised in Table 16 below. Both the 1% and 5% AEP floods were considered, and results provided for inflows to the development precinct. These have been summarised in Table 17 below and hydrographs provided in Figure 42.

Table 16 Impact of considering development jointly for north and south of Mundijong Road.

Case	Pre-development	Post-development
Impacts of developing the North East Baldivis north of Mundijong Road precinct	North of Mundijong Road • Spoil bank fails South of Mundijong Road • Spoil bank intact	North of Mundijong Road • Crest at 10.3 m AHD South of Mundijong Road • Crest at 9.3 m AHD
Impacts of developing the North East Baldivis south of Mundijong Road precinct	North of Mundijong Road • Spoil bank intact South of Mundijong Road • Spoil bank fails	North of Mundijong Road • Crest at 10.3 m AHD South of Mundijong Road • Crest at 9.3 m AHD

Table 17 North East Baldivis inflows from developing both north and south of Mundijong Road

Case	1% AEP	5% AEP
North East Baldivis north of Mundijong Road precinct		
Pre-development • spoil bank failure north of Mundijong Road	73.1	27.9
Post-development	62.6	14.1

• north crest at 10.3 m AHD		
Post-development • north crest at 10.3 m AHD • south crest at 9.5 m AHD	59.8	13.6
North East Baldivis south of Mundijong Road precinct		
Pre-development • spoil bank failure south of Mundijong Road	35.7	Not available
Post-development • south crest at 9.5 m AHD	35.9	5.3
Post-development • north crest at 10.3 m AHD • south crest at 9.5 m AHD	16.2	2.7

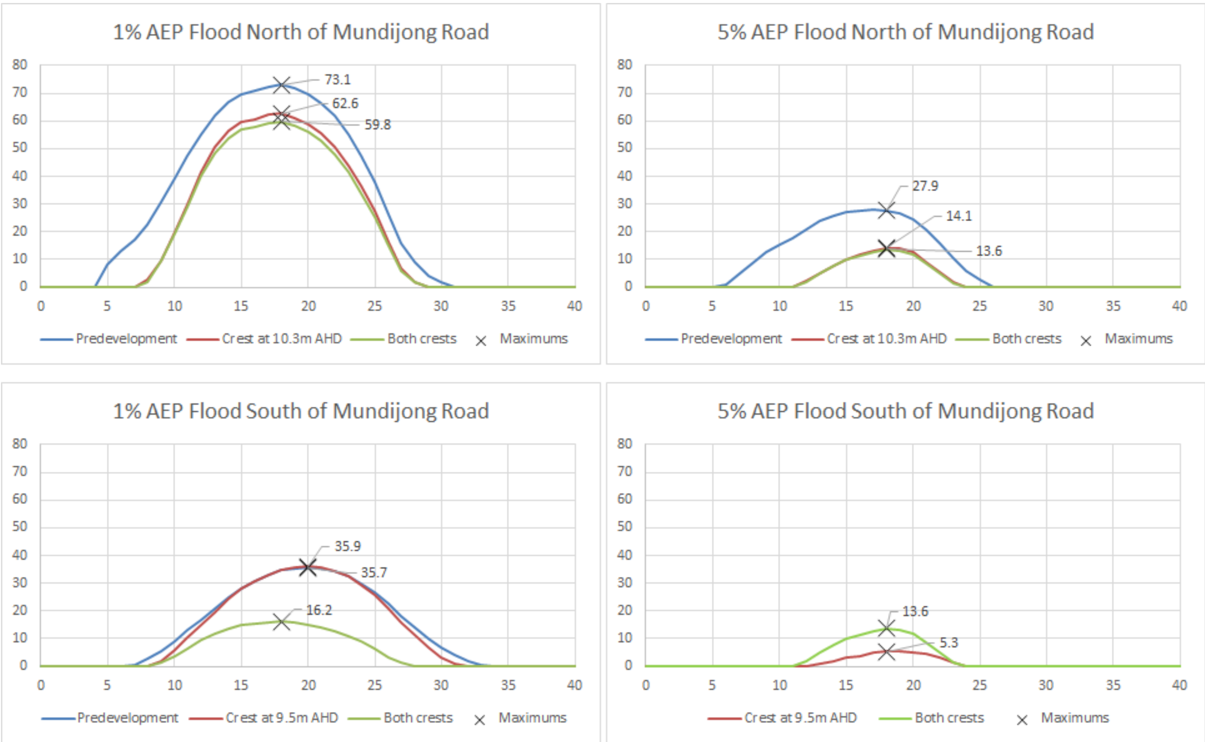


Figure 42 Scenario 2 North East Baldivis potential 1% AEP inflows with integrated development

3.10.2.1 Impact of developing North East Baldivis south of Mundijong Road on North East Baldivis north of Mundijong Road

The first matter considered was whether development of the North East Baldivis south of Mundijong Road precinct would assist in mitigating the impacts of developing the North East Baldivis north of Mundijong Road precinct. It has already been shown in Section 3.7.2.4 that use of a low-height inflow crest constructed to a level of 10.3 m AHD would result in detrimental impacts upstream but further investigation was needed to determine whether these impacts were reduced to an acceptable level with development south of Mundijong Road

The difference between a low-height inflow crest set at 10.3 m AHD in the North East Baldivis north of Mundijong Road precinct is compared to the introduction of an additional low height crest set at 9.5 m AHD in the North East Baldivis south of Mundijong Road precinct. Table 17 shows that the peak inflow to the North East Baldivis north of Mundijong Road precinct reduced by 2.8m^3/s, which is not considered to provide a significant improvement for developable area within the North East Baldivis north of Mundijong Road precinct. A review of difference mapping showed that the introduction of the low-height crest set at 9.5 m AHD for the North East Baldivis south of Mundijong Road precinct provided a very minor reduction to the impacts in North East Baldivis north of Mundijong Road. The impacts in the North East Baldivis north of Mundijong Road precinct did not significantly change from that depicted on Figure 38 with the flood level changes being 3 mm or less. The impacts for the North East Baldivis north of Mundijong Road precinct are still detrimental with increased flood levels for up to 8.5 km along the Birrega Main Drain as discussed in Section 3.7.2.4 and summarised in Table 12.

It was concluded that development in the North East Baldivis south of Mundijong Road precinct did not impact or assist development in the North East Baldivis north of Mundijong Road precinct. There was no significant improvement to developable area in linking the North East Baldivis north of Mundijong Road precinct to development with the North East Baldivis south of Mundijong Road precinct when considering the pre-development cases or the post-development scenarios.

3.10.2.2 Impact of developing North East Baldivis north of Mundijong Road on North East Baldivis south of Mundijong Road

Development of the North East Baldivis south of Mundijong Road precinct is impacted by development of the North East Baldivis north of Mundijong Road precinct. A comparison of inflows to the North East Baldivis south of Mundijong Road precinct is provided in Table 17 which shows that there was practically no difference for the 1% AEP flood peak inflow if a low-height crest set at 9.5m AHD was used. It also shows that introduction of a low-height crest set at 10.3 m AHD north of Mundijong Road provided a 19.5m^3/s (55%) reduction to the inflows for the North East Baldivis south of Mundijong Road precinct. This is considered a substantial impact and reinforces the conclusion that the natural fall of the land is through the North East Baldivis north of Mundijong Road precinct. When capability of the existing infrastructure is exceeded, the natural flow direction is through the North East Baldivis north of Mundijong Road precinct, and the inflows into North East Baldivis south of Mundijong Road are an artificial diversion caused by infrastructure design.

3.10.3 Initial concept formulation

The adopted pre-development peak inflow to the North East Baldivis south of Mundijong Road precinct included failure of the upper spoil bank only in the 1% AEP, consistent with Section 3.10.1. Because of the lack of well-defined discharge points (like the Peel Main Drain) downstream of the development precinct, it was also determined that in the post-development, a low-height inflow crest would be implemented at the location where the pre-development spoil bank failure was identified. A crest level of 9.5 m AHD was considered and would have the effect of limiting inflows from the 5% AEP as much as possible while minimising the potential to obstruct the 1% AEP flood.

It was determined that flood impacts would also be considered for land to the west of the North East Baldivis south of Mundijong Road precinct in the 5% AEP flood because of the lack of a clearly defined outlet at that location. It is unclear whether a spoil bank failure would occur during a 5% AEP flood; however, it was determined that the 5% AEP flood pre-development base case would not include failure of the spoil bank. This is because the focus is on flood impacts for land to the west of the precinct and a 5% AEP flood pre-development base case with no failure would highlight the worst-case impact on land to the west of the precinct.

This configuration was implemented in the regional flood model for the 1% AEP and 5% AEP 18-hour duration floods and forms the basis of the post-development inflows. The peak inflow to the North East Baldivis south of Mundijong Road precinct for the 1% AEP flood was the upper spoil bank failure, while for the 5% AEP flood, it was for no spoil bank failure.

Downstream discharges from the pre-development 1% AEP flood with the upper spoil bank failure was used as the pre-development base case that post-development impacts will be assessed against. Because of downstream infrastructure capacity limitations on the western side of the precinct, an additional discharge target was established for the 5% AEP flood. This discharge was based on the pre-development 5% AEP flood with no spoil bank failure. These discharges are summarised in Table 18, and Figure 43 shows the impact of these targets on flood levels. The pre-development 1% AEP flood base case is shown in Figure 44.

Table 18 Inflow targets North East Baldivis South of Mundijong Road.

	Pre-development (m^3/s)	**Post-development (m^3/s)**
1% AEP flood inflow from Birrega	35.7	35.9
5% AEP flood inflow from Birrega	0	5.3

As can be seen from Figure 43, the preliminary targets did not have a detrimental impact on the 1% AEP flood but provided a minor reduction in flood levels adjacent to the Peel Main Drain of up to 7 cm. For the 5% AEP flood, there were no detrimental impacts on the Birrega Main Drain. Impacts behind (to the east) of the sand hill between the Birrega and Peel main drains were identified in the order of 2 cm, while a small area of localised increases of up to 9 cm was identified on the western boundary. Detailed concept designs in subsequent planning stages would need to ensure that potential impacts do not occur. The land allocation to manage the 1% AEP flood is likely to provide sufficient space to address any potential impacts in smaller events. Flood level increases within the waterbodies south of Mundijong Road adjacent to the Peel Main Drain were not considered to be detrimental as they were within the existing water bodies (Section 3.2).

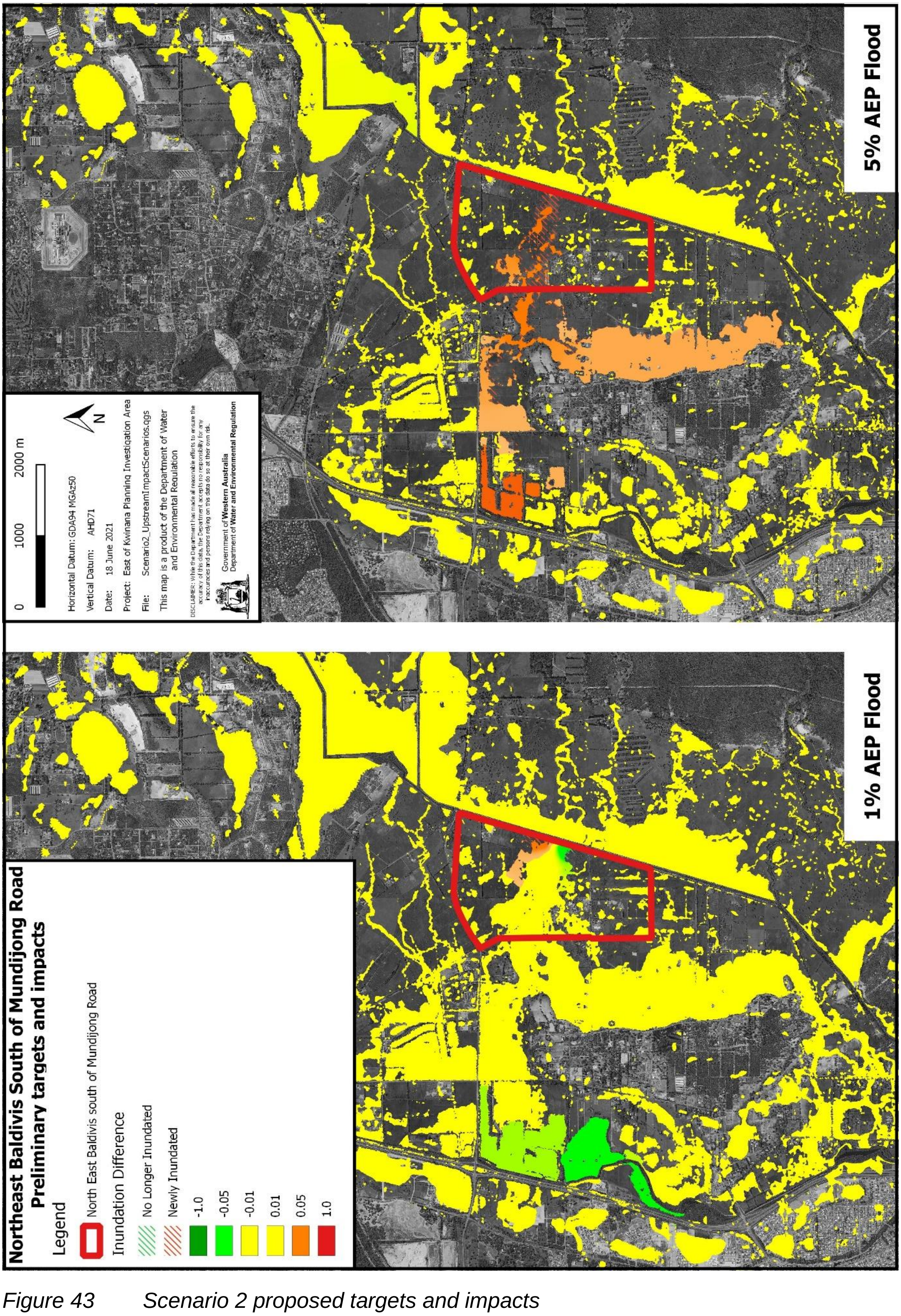


Figure 43 Scenario 2 proposed targets and impacts

Uncertainty about the performance of a low-height inflow crest was previously discussed in Section 3.7.2.4 as it related to the North East Baldivis north of Mundijong Road precinct. That is, a small change in the level of the low-height inflow crest or the calculated flood level may alter the frequency of water overflow into the development precinct. A similar uncertainty also applies to the North East Baldivis south of Mundijong Road precinct. However, in this case, the use of the low-height inflow crest is acceptable as:

- all development within the precinct will include appropriate freeboard to the 1% AEP flood and all land below the 1% AEP flood will be in public ownership
- the purpose of the low-height crest is to provide additional flood protection for downstream properties during smaller floods to facilitate local stormwater connections to the downstream environment.

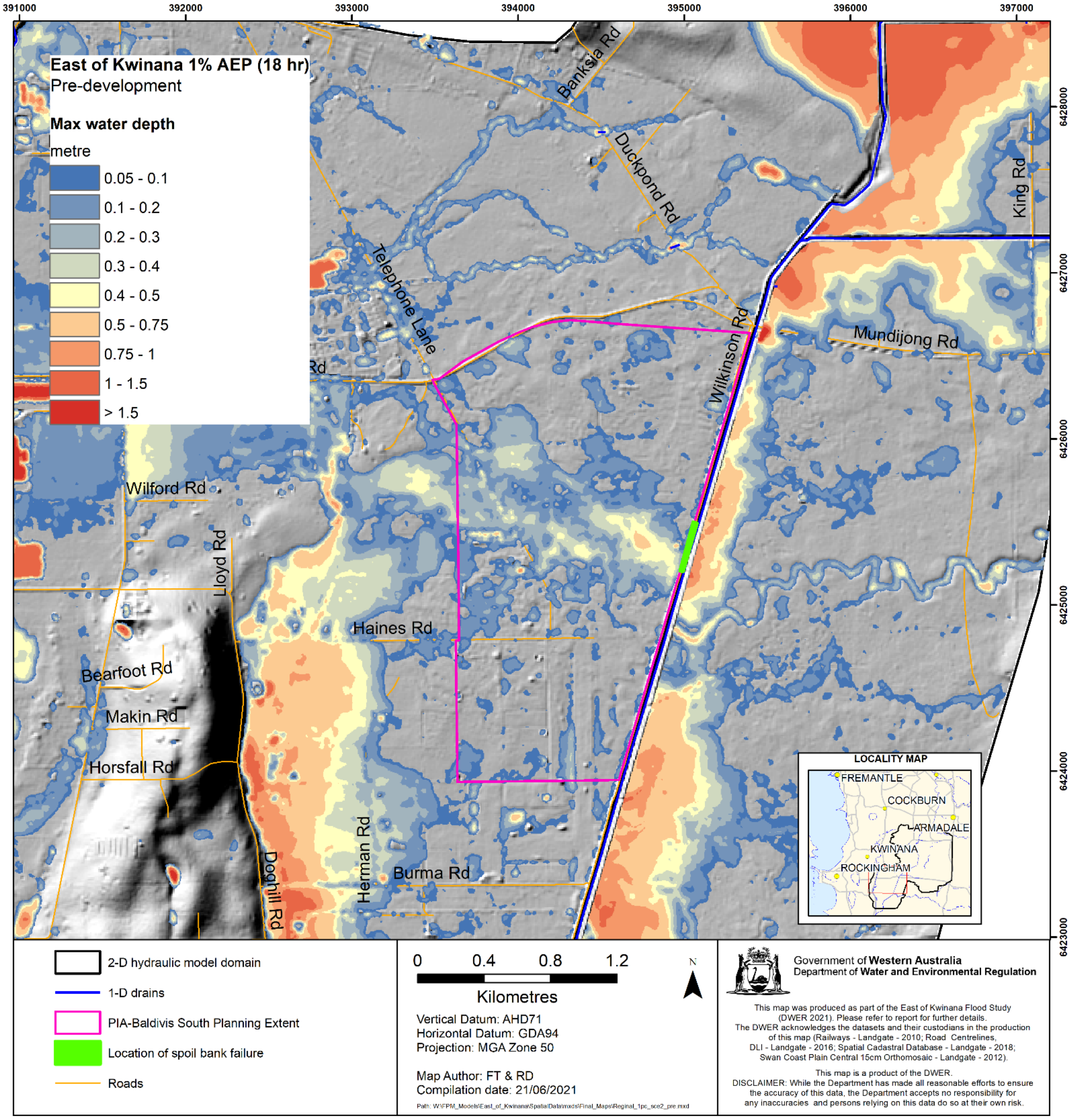


Figure 44 Scenario 2 1% AEP pre-development conditions

3.10.4 Formulation of post-development layout and terrain

Formulation of the post-development layout and terrain focused on the flood corridor that resulted from the failure of the pre-development spoil bank. A small-height crest set at 9.5 m AHD was included at the eastern end of the precinct for the post-development (as discussed in Section 3.10.3). The flood corridor was divided into three cells using a similar approach to Scenario 1, with the corresponding crests to be potentially incorporated into post-development roads or other urban features during district structure planning. The flood depth in the downstream (western-most) cell was limited to typically 1 m or less. This was done to minimise the potential safety risks of a failure and to minimise the need for using landfill as a flood mitigation measure. The low-height crest at the upstream (eastern) end was considered to provide an acceptable safety risk as failure could reasonably be contained within the flood corridor as a part of the district structure planning.

The southern portions of the precinct did not have any mainstream flood breakouts from the Birrega Main Drain or substantial flood corridors; however, there were no clearly defined discharge points from this location. A review of the topography showed three minor drainage discharge points aligned with existing road corridors in the southern portions of the precinct. The post-development layout in this area was divided into three catchments corresponding with the discharge points and a nominal post-development storage, based on the redevelopment floodplain storage, was also provided to manage these flows. It should be noted that discharge in the southern portions of the precinct only relates to local drainage flows internal to the precinct and would be the subject of further investigations at the district structure planning stage. The concept put forward in this option is intended to provide a more nominal allocation of land for consideration at the regional level for regional decision-making. The final land allocation in the southern portions of the precinct should be determined at the district structure planning stage.

As discussed in Section 3.10.1 and 3.10.2, it was determined that the North East Baldivis south of Mundijong Road and the North East Baldivis north of Mundijong Road precincts should be considered independent of each other as development of the precinct to the south of Mundijong Road did not provide any additional benefits to development of the precinct north of Mundijong Road. As a result of this decision, no post-development options were included for the North East Baldivis north of Mundijong Road precinct in Scenario 2. Furthermore, the pre-development base case for Scenario 2 does not include failure of the spoil bank at the North East Baldivis north of Mundijong Road precinct, although failure of the spoil bank at this location is very likely and would substantially reduce flooding in the North East Baldivis south of Mundijong Road precinct. This was done to demonstrate the minimum amount of developable area that could be obtained from the North East Baldivis south of Mundijong Road precinct, even though a greater amount of developable area is likely.

3.10.5 Post-development flood modelling

Flood modelling of scenario 2 was undertaken using the regional flood model and based on the 1% AEP 18-hour duration median temporal pattern. The hydraulic controls for the flood corridor resulting from the failure of the pre-development spoil bank were adjusted to meet the pre-development floodplain storage targets. No hydraulic controls were applied to the three southern flood storages associated with the internal local drainage and discharges and the water in these storages was permitted to fill up and overflow the crests.

The post-development flooding is depicted in Figure 45. The difference between the pre-development and post-development is depicted in Figure 46 which shows that flooding on the Birrega floodplain upstream (east) of the development precinct results in a maximum flood level increase of 3.5 cm. This is within the 5 cm threshold determined as the acceptable limit. This increase is the result of the small-height crest implemented on the post-development. Flood levels on the downstream (west) of the development precinct have been reduced slightly.

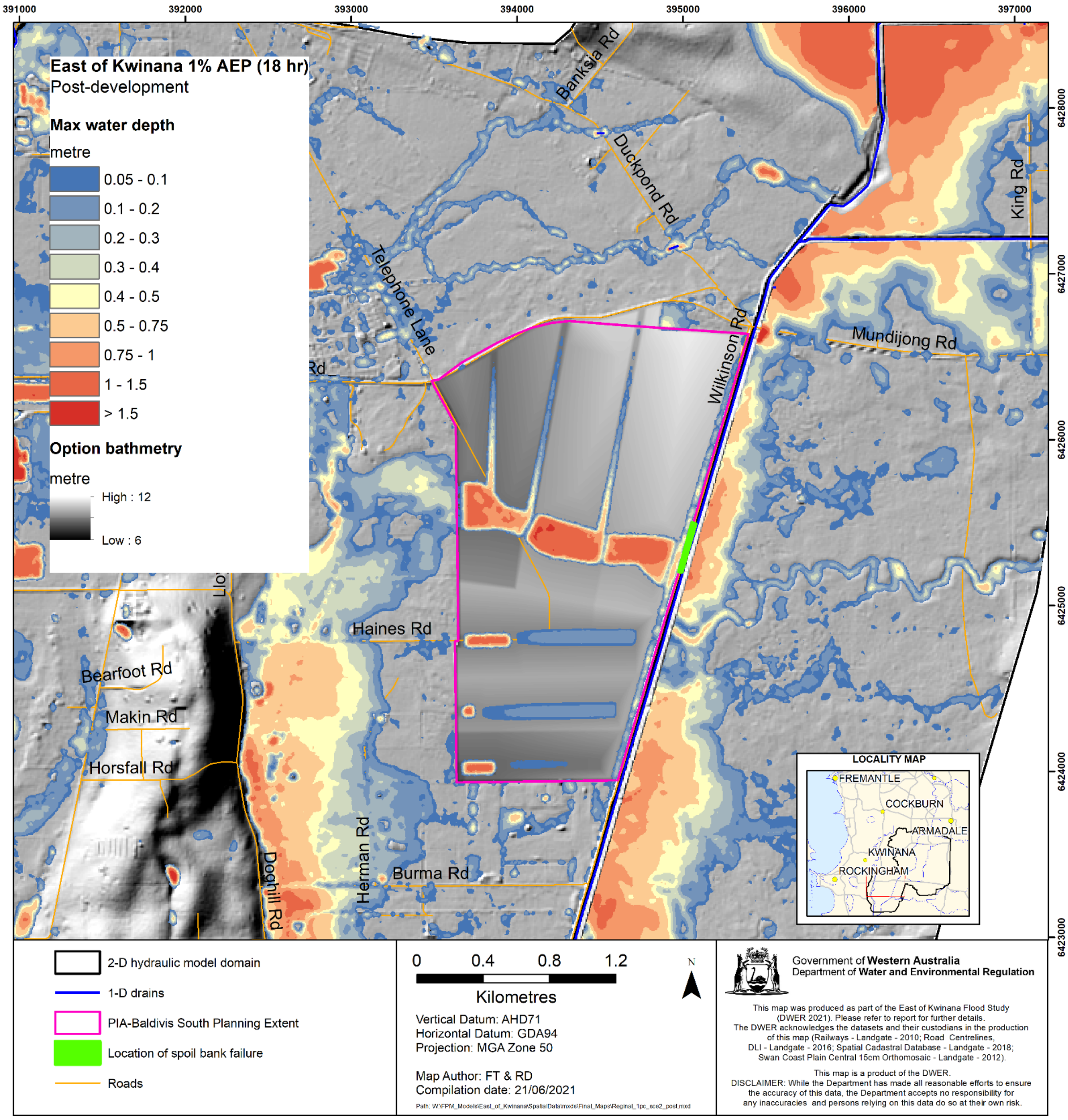


Figure 45 Scenario 2 post development flooding

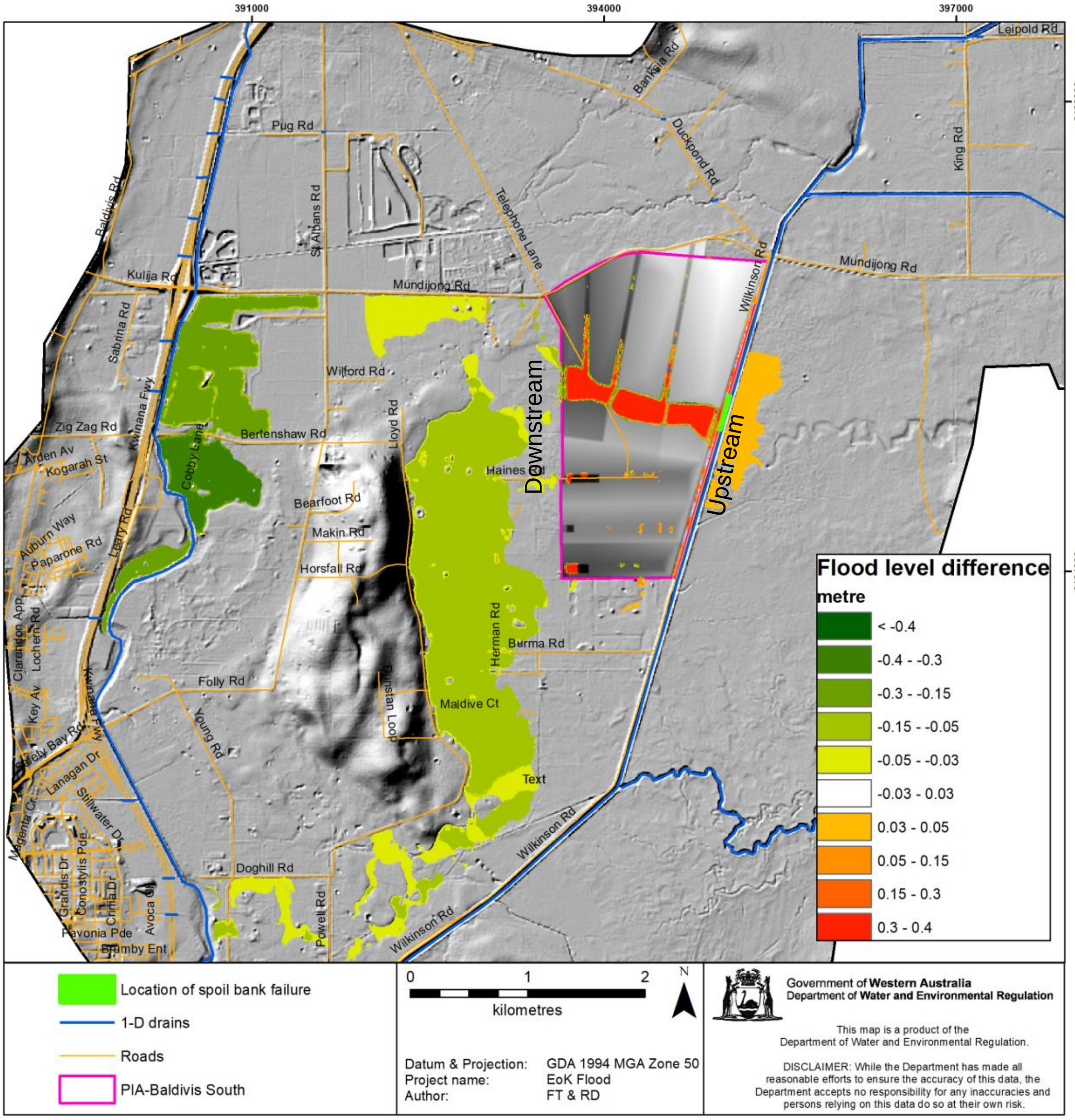


Figure 46 Scenario 2 post development impacts

The pre-development and post-development hydrographs for the flood corridor are provided in Figure 47. The hydrographs show the impact of introducing the low-crest weir on the upstream (east) side of the precinct. The flood corridor is effective at conveying flood waters through the precinct with attenuation of flooding on the rising limb.

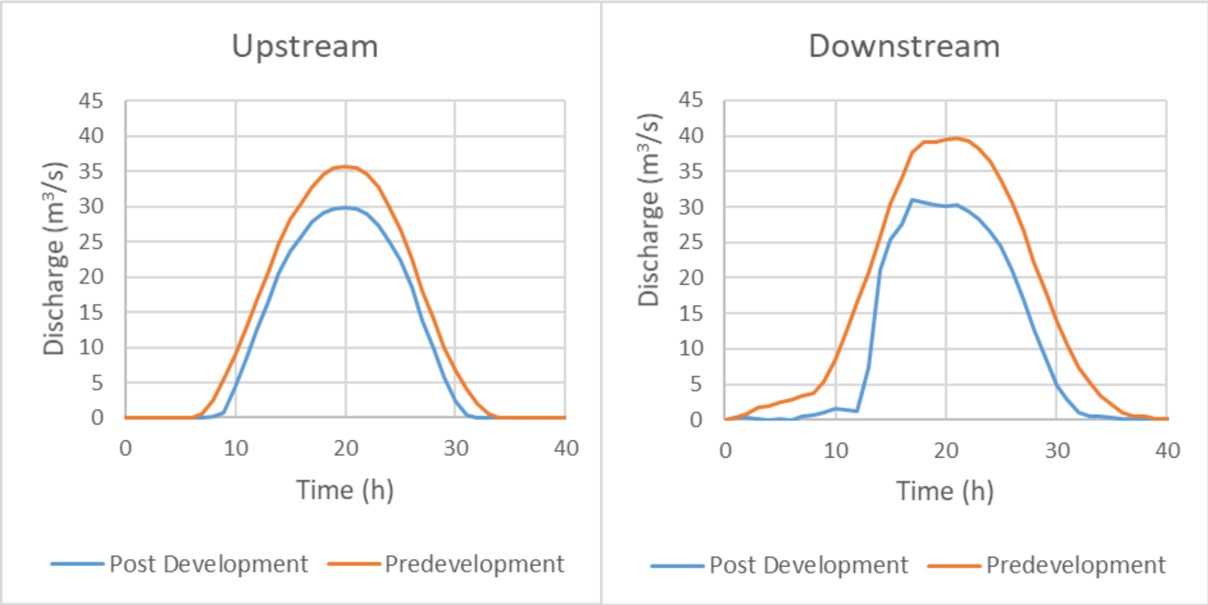


Figure 47 Scenario 2 pre-development and post development flows

3.10.6 Scenario 2 land flood capability

The land flood capability for the North East Baldivis south of Mundijong Road precinct has been assessed adopting an approach consistent with that used for the Scenario 1 options. It has been determined that about that 90% of the North East Baldivis South of Mundijong Road precinct does not have a significant flooding constraint while the remaining 10% is impacted by a significant flood constraint. As previously discussed in Section 3.10.2, should the spoil bank adjacent to the North East Baldivis north of Mundijong Road precinct fail or be removed, flooding of the North East Baldivis south of Mundijong Road precinct will be reduced and the land flood capability increased. Given that the land flood capability is already at 90% and could be higher, it was decided that no further options need to be considered for the land flood capability assessment. The land flood capability for the North East Baldivis south of Mundijong Road precinct is provided in Figure 48 below.

3.11 Scenario 2 potential fill volumes for flood management

The quantity of fill was not a significant consideration in formulating the post-development option for the North East Baldivis south of Mundijong Road precinct. Flooding will impact fill levels adjacent to the flood corridor and along the eastern boundary of the precinct adjacent to the Birrega Main Drain. Provided that the land slope away from these areas transitions at a grade flat enough to not create any levees, fill levels will predominately be determined by groundwater separation requirements rather than flooding. At the request of DPLH, the volumetric difference has been calculated between the pre-development and post-development terrains. The result was a net 4.6 million cubic metres of cut and fill and is shown in Figure 49 below. It is recommended that fill requirements be determined based on groundwater levels rather than relying on the flood model terrain alone.

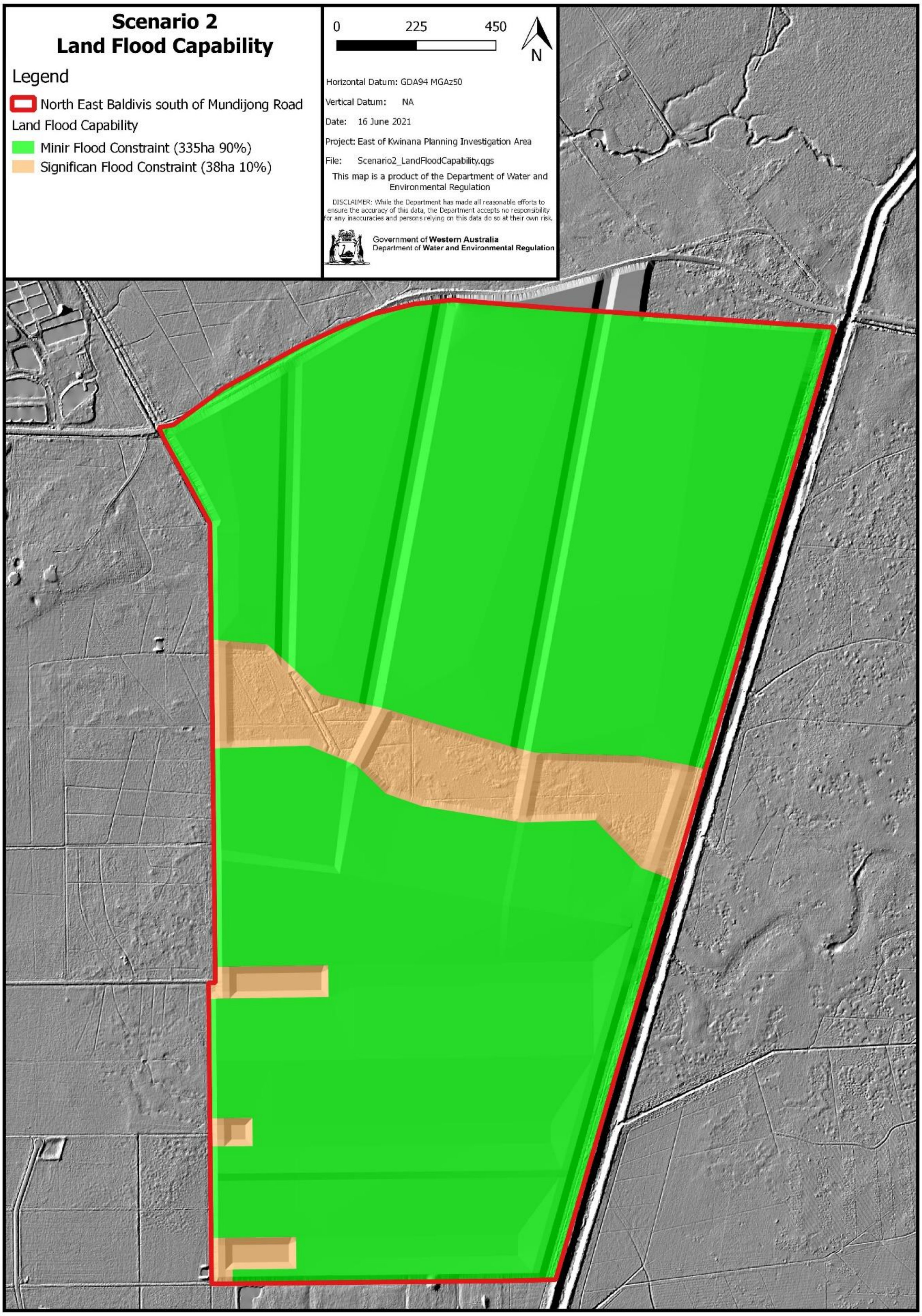


Figure 48 Northeast Baldivis South of Mundijong Road land flood capability

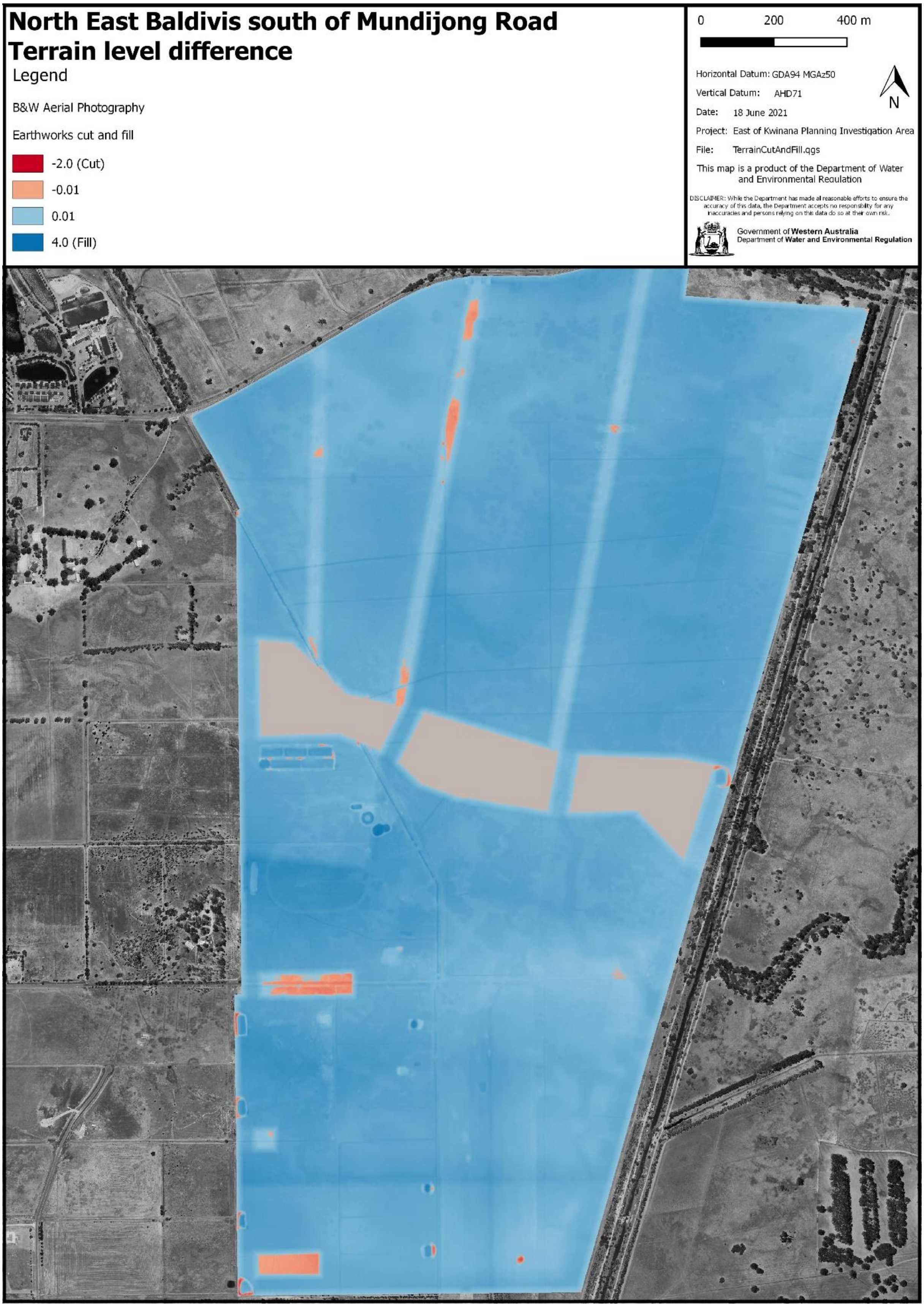


Figure 49 Northeast Baldivis South of Mundijong Road terrain level difference map

3.12 Advice for the North East Baldivis south of Mundijong Road precinct (Scenario 2)

3.12.1 Advice

Pre-development base case for North East Baldivis south of Mundijong Road

The department advises that proposals should be compared to the department's pre-development base case that concludes the spoil bank adjacent to the Birrega Main Drain to the east of the precinct will fail in a 1:100-year flood.

The Birrega Main Drain is to the east of the North East Baldivis south of Mundijong Road precinct. The department's analysis, based on national standards and guidance for flood levees, determined the spoil bank adjacent to the Birrega Main Drain will fail in a 1:100-year event and flood the North East Baldivis north of Mundijong Road precinct.

Figure 44 shows the pre-development base case flooding in a 1% AEP flood. The department advises that the pre-development base case for the North East Baldivis south of Mundijong Road precinct is to consider a failure of the spoil bank halfway along the drain as shown in Figure 44.

The base case has been developed to direct the maximum amount of water in a 1% AEP flood into the North East Baldivis south of Mundijong Road precinct to determine the minimum land flood capability of the land. This assumes that only the spoil banks adjacent to the development area fail and not at other locations. This is the same as the approach taken in the North East Baldivis north of Mundijong Road precinct.

Failure of the spoil bank in the North East Baldivis north of Mundijong Road precinct will improve flooding and increase the amount of land with 1% AEP flood protection in the North East Baldivis south of Mundijong Road precinct. This is because flood water will flow in a westerly direction through the northern precinct, reducing the water flowing through the drain adjacent to the southern precinct.

Failure of the spoil bank on the Birrega Main Drain adjacent to the North East Baldivis south of Mundijong Road precinct does not improve the flooding and land capability for the North East Baldivis north of Mundijong Road precinct, as it is upstream of the southern precinct.

The North East Baldivis North and South of Mundijong Road are treated independently to give greater flexibility for future development.

Standard approach (1:100-year) flood protection for North East Baldivis south of Mundijong Road

The department advises that:

- 90% of the south of Mundijong Road precinct can be developed with flood protection in 1:100-year flood.
- For land use change proposals, the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood need to be maintained to pre-development base case.

- Land use change proposals need to maintain pre-development base case flood storage capacity of the precinct.

Figure 48 shows that 90% of the North East Baldivis south of Mundijong Road precinct can be developed with flood protection in a 1% AEP flood, with the remaining 10% without flood protection and with limitations in use. Figure 45 shows the location of the land with and without 1% AEP flood protection.

If a levee is proposed for this precinct, the department's advice is that installing a levee to develop the precinct would cause increased flooding on surrounding land. Flood levees are not fail-safe and can pose a risk to human safety and infrastructure and would not be considered best-practice flood mitigation for a greenfield site.

Australian floodplain management industry practice considers levees a tool to manage flood risk for existing developments. The purpose of a levee is to allow time for an evacuation response for those people living and working in an area with high flood risk. The same advice was provided for North East Baldivis north of Mundijong Road.

Land uses for the 10% of land below the 1% AEP flood will need to be placed in public ownership, with an appropriate public use and maintenance plan in place by the relevant authority to ensure flood waters can be safely conveyed.

A comparison of the analysis of Scenario 1 and 2 is presented below.

Table 19 Scenario 2 land flood capability comparison

Scenario	**Proportion of the site with protection up to 1:100-year flood**	**Proportion of the site with protection from 1:20-year flood**	**Total developable areas**	
			With flood protection	**Without flood protection**
North East Baldivis north of Mundijong Road precinct (Scenario 1) (as provided 24 September 2020)				
Flood levee(1A)	Impacts on and off site for 5km upstream and downstream (1:100-year flood) and net loss of developable area in the PIA.			
1:100-year flood protection(1B)	55%	Not tested as part of this scenario	55%	45%
Varied flood protection (1C)	30%	35%	65%	35%
North East Baldivis south of Mundijong Road precinct (Scenario 2)				
1:100-year flood protection	90%	Not tested as part of this scenario	90%	10%

3.13 Oldbury and Oakford and cumulative impacts (Scenario 3)

3.13.1 Oldbury and Oakford pre-development base case

The Oldbury and Oakford precinct is in the Birrega catchment to the north of the North East Baldivis precincts. The Birrega Main Drain flows in a southerly direction to the east of the Oldbury and Oakford precinct. Figure 50 shows pre-development flooding for the 1% AEP flood. The precinct is elevated higher than the Birrega Main Drain flood extent and is not impacted by spoil bank failure.

Flooding within the precinct is mainly local overland flooding with most of the inundation within natural surface depressions. A small portion of the precinct in the south-west corner is flooded from the Birrega Main Drain in a 1% AEP flood.

3.13.2 Oldbury and Oakford land flood capability

The land flood capability for Oldbury and Oakford was determined based on the 1% AEP flood extent including all areas where the flood depth exceeded 0.05 m. This threshold was chosen as the inundated areas are primarily natural surface depressions and would be natural drainage points in a future district structure plan. Figure 51 shows 84% of the precinct can be developed with flood protection in a 1% AEP flood with the remaining 16% without flood protection.

3.13.3 Oldbury and Oakford flooding related landfill volumes

Fill volumes have not been calculated for this precinct as most of the flooding during the 1% AEP occurs within existing waterbodies. Fill volumes within this precinct will be largely determined based on the specification *Separation distances for groundwater controlled urban development* (IPWEA 2016). Additional fill may be required for flood mitigation purposes should it be determined that the natural surface depressions will not be retained.

3.13.4 Oldbury and Oakford flood criteria for development

Based on the landscape characteristics outlined in Section 1 and the extensive investigations undertaken within the Birrega catchment, the following flood criteria should be implemented in subsequent planning stages for this precinct:

- The post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood need to be maintained to pre-development base case.
- Pre-development base case flood storage capacity of the precinct needs to be maintained.

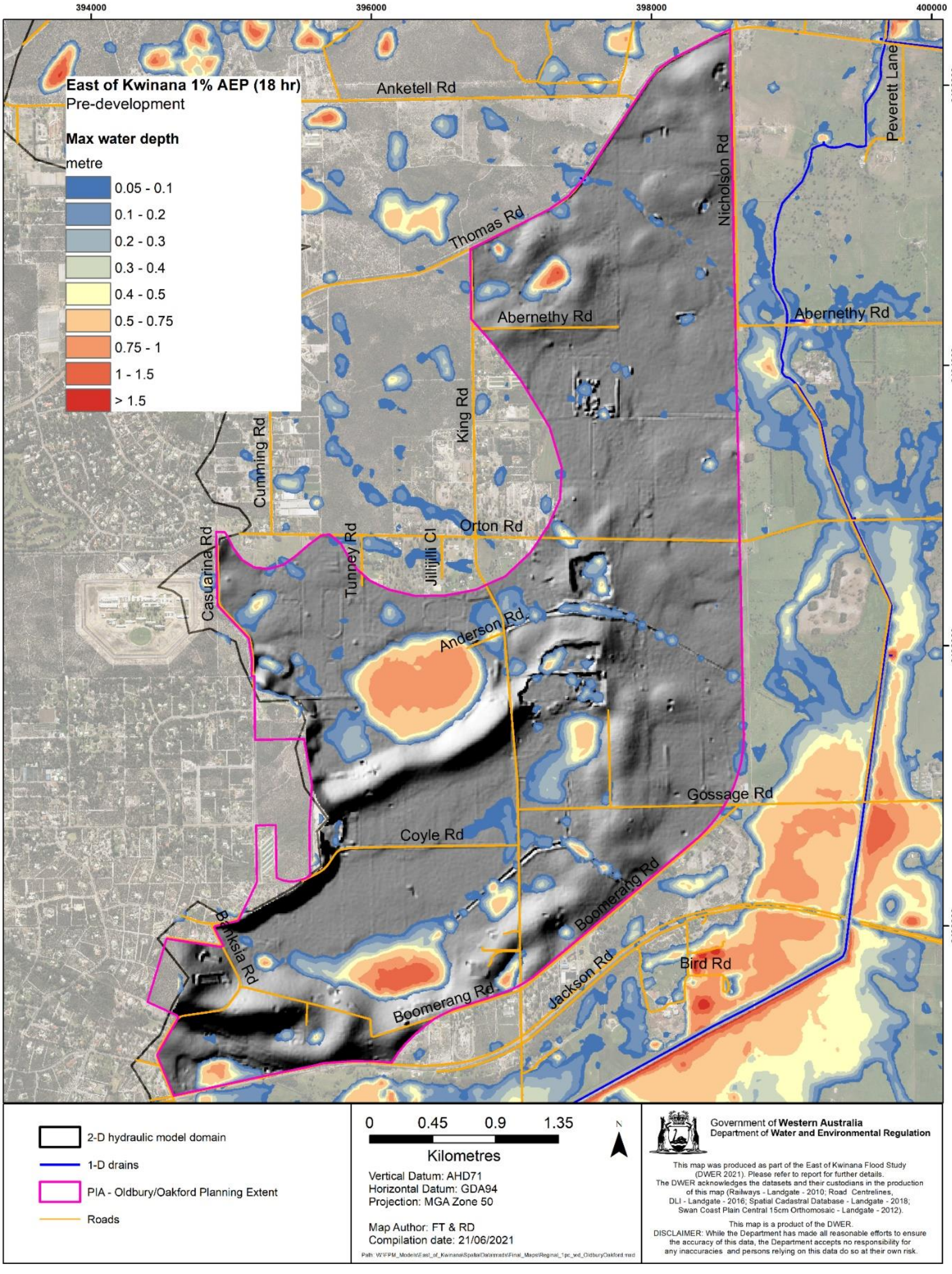


Figure 50 Oldbury and Oakford pre-development flooding

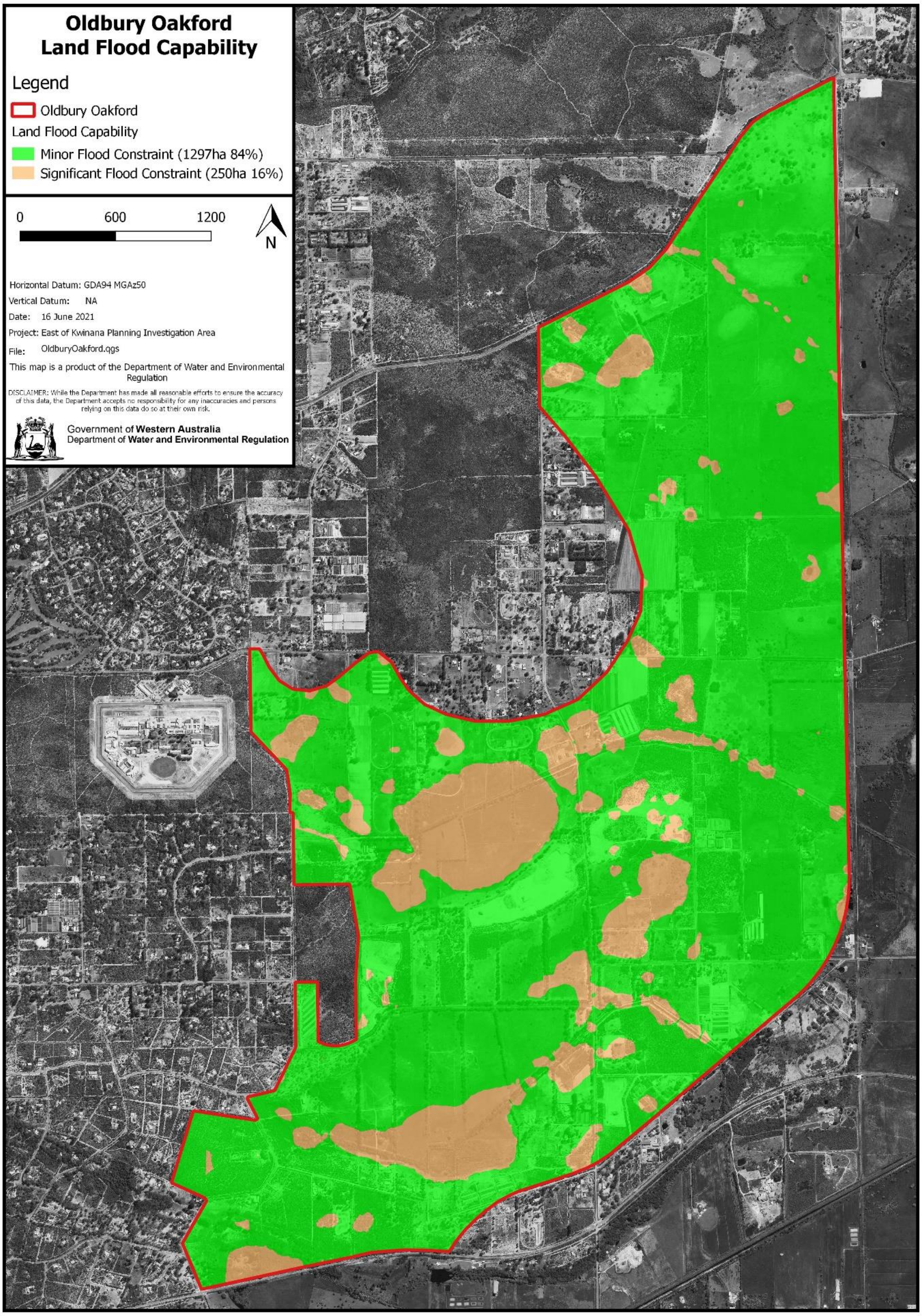


Figure 51 Oldbury and Oakford land flood capability

3.13.5 Cumulative impacts

The aim of Scenario 3 is to consider the cumulative impacts of development broadly across the entire catchment. his includes not just the remainder of the planning investigation but also other urban expansion areas as well as development permissible under the current rural planning.

The objective is to ensure appropriate and equitable flood management within the catchment to ensure that the cumulative impacts of further development are within acceptable thresholds and that the risk to human life and property is appropriately managed.

Cumulative impacts have been considered by first understanding the broader flood mechanisms within the catchment as discussed in Section 3.1 (Flooding in the landscape) and confirmed by the catchment response to the loss of floodplain storage demonstrated in Section 3.5.14 where detrimental impacts of proponent-driven proposals is shown. As has been shown in these sections, floodplain storage plays an important role in determining impacts and developable area not just at an individual precinct level but cumulatively across the entire catchment.

3.13.6 Scope for consideration of cumulative impacts and flood criteria

To understand cumulative impacts, consideration for the potential loss of floodplain storage needs to be undertaken across the entire catchment. This is not a task that could reasonably be done as a part of this investigation but would be most appropriate to be undertaken at a strategic whole-of-catchment level through a drainage and water management plan (as recommended in Section 8.2 and 8.3 of reference 1 below).

The approach is to undertake hydraulic categorisation to delineate the floodplain into its various functions as outlined in the following references:

- Australian Disaster Resilience Handbook 7; Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia; AIDR 2017; Section 5.2 and 8.3
- Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) Australian Rainfall and Runoff: A Guide to Flood Estimation, 2019; Book 1, Figure 1.5.4.

There are two steps in the process. The first is to define the floodway or flow conveyance area using an approach like that which is described in Section 3.5.1 and shown in Figure 19, which was partly validated during the Scenario 1 options testing. The difference being that the criteria would be applied across the entire catchment and multiple flow thresholds would be considered. Each flow threshold would undergo repeated testing at multiple locations across the entire catchment to define the floodway or flow conveyance area based on modern practice.

Once the flow conveyance area was defined, a range of thresholds for floodplain storage loss would be considered equally across the entire catchment to define the flood storage areas and the threshold to which flood storage loss could be tolerated.

Based on experience undertaking this type of analysis, it is advised that this process would require a substantial quantity of resources over a period of about two years to determine to what threshold floodplain storage loss may be acceptable. In Sections 3.5.8 to 3.5.14, it was shown that the proponent-driven Option B proposal with a 25% loss in floodplain storage and a 17% gain in developable area had a detrimental impact. Furthermore, it is unlikely that an analysis such as that described in this section would yield a 17% gain in developable area. Rather, the potential gain in developable area is more likely to be lower, in the order of 10%, and would likely be of limited value to decision-making in the current PIA.

Given the time and resources required to undertake this analysis, and considering its likely benefits, the department does not recommend pursuing this analysis or considering options which include the loss of floodplain storage.

The department recommends applying the following flood criteria to all development within the Birrega, Oaklands and Peel catchments:

- post-development peak discharge not to exceed pre-development peak discharge
- post-development floodplain storage to be greater than or equal to pre-development floodplain storage.

The consistent application of these two criteria will ensure that development proposals do not have detrimental impacts both on their own and cumulatively across the catchment.

3.14 Advice for the Oldbury and Oakford precinct and flood criteria for East of Kwinana (Scenario 3)

3.14.1 Advice

Oldbury and Oakford precinct

The department advises that:

- 84% of the Oldbury and Oakford precinct can be developed with flood protection in 1:100-year flood.
- For land use change proposals, the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood need to be maintained to pre-development base case.
- Land use change proposals need to maintain pre-development base case flood storage capacity of the precinct.

The department has now analysed flooding in the Oldbury and Oakford precinct of East of Kwinana. The Birrega Main Drain flows in a southerly direction to the east of the precinct. Figure 50 shows the pre-development base case flooding in a 1% AEP flood.

The department advises that failure of the spoil bank along the Birrega Main Drain does not impact flooding in the Oldbury and Oakford precinct as the precinct elevation is higher than the Birrega Main Drain flood extent.

Figure 51 shows 84% of the precinct can be developed with flood protection in a 1% AEP flood with the remaining 16% without flood protection.

Flooding in the precinct is mainly local flooding with the majority the inundation within the natural surface depressions. A small portion of the precinct in the south-west corner is flooded from the Birrega Main Drain in a 1% AEP flood.

A comparison of the flood-related land capability for the North East Baldivis north of Mundijong Road, North East Baldivis south of Mundijong Road and Oldbury and Oakford precincts are presented below.

Table 20 Scenario 3 land flood capability comparison

Scenario	Proportion of the site with protection up to 1:100-year flood	Proportion of the site with protection from 1:20-year flood	Total developable areas	
			With flood protection	Without flood protection
North East Baldivis north of Mundijong Road (Scenario 1) (as provided 24 September 2020)				
Flood levee(1A)	Impacts on and off site for 5km upstream and downstream (1:100-year flood) and net loss of developable area in the PIA.			
1:100-year flood protection(1B)	55%	Not tested as part of this scenario	55%	45%
Varied flood protection (1C)	30%	35%	65%	35%
North East Baldivis south of Mundijong Road (Scenario 2)				
1:100-year flood protection	90%	Not tested as part of this scenario	90%	10%
Oldbury and Oakford precinct (Scenario 3)				
1:100-year flood protection	84%	Not tested as part of this scenario	84%	16%

3.15 Flood criteria for all precincts in the East of Kwinana

The department advises that:

- For land use change proposals, the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood need to be maintained to pre-development base case.
- Land use change proposals need to maintain pre-development base case flood storage capacity of the precinct.
- Proposals should be compared to the department's pre-development base case established for each of the precincts.

The natural landscape of East of Kwinana is characterised by a mix of sand and clay, with shallow groundwater and flat terrain that has large natural surface depressions to allow for ponded water to be stored (palusplain). The large natural surface depressions play an important role in how flood waters flow across the palusplain to the Peel-Harvey estuary via the Birrega and Oaklands and Peel main drain systems (Figure 5). The surface depressions act as natural areas for storage of the flood waters, and these are the largest in the central section of East of Kwinana as this is where the slope flattens and the flows are reduced.

The storages within a catchment can reduce the land capability of the area. The department advises that the flood storages and discharges for the 1% AEP flood should be maintained throughout the catchment to ensure no increase in flooding on downstream or neighbouring properties. This means that the peak amount of water discharged from the proposed development (post-development) should not be more than the amount discharged from the area prior to development (pre-development).The volume of flood waters stored in the proposed development should be maintained or higher than the storage volumes prior to development.

This advice is consistent with the department's published standards. The *Decision process for stormwater management in Western Australia* (DWER 2017) requires the 1% AEP pre-development flood regime (flood level, peak flow rates and storage volumes) to be maintained for catchments that do not have a published catchment plan.

The early discharge of upstream floodwaters into the downstream areas would not be acceptable if it were to increase the flooding on the downstream areas. Furthermore, landfill within the storages is not an effective flood mitigation measure, as a loss of storage will allow for more water to be released downstream earlier and at a faster rate than naturally would have occurred, therefore increasing flooding on downstream land.

3.16 Potential uses of flood prone land in the planning investigation area

This current project represents the most comprehensive analysis undertaken to date and has gone to great lengths to seek a viable development option which is commensurate with the flooding risk at the location. The department has been asked to provide advice on the types of land uses that are considered appropriate for land that is below the 1% AEP flood. Advice is provided specifically for Scenario 1 Option B and Scenario 1 Option C. Urban development of this land requires a significant proportion of land to be placed in public ownership, placing a significant burden on government to manage a large amount of public land.

3.16.1 Scenario 1 Option B

There is a substantial proportion of land below the 1% AEP flood, and it is generally anticipated that this land should end up in public ownership. Public open space is considered the most appropriate use for the land. The greatest limitation to this use is that higher-grade playing fields should generally be located above the 5% AEP flood. Analysis has not been undertaken on how much land of an appropriate standard could be provided to accommodate higher-grade playing fields. This could be optimised by considering a low-height crest at the upstream end of the North East Baldivis north of Mundijong Road precinct. The potential for a low-height crest has already been extensively analysed and is unlikely to result in a substantial increase to the developable area. However, there may be some scope for a very minor crest to facilitate more active open-space activities.

There is scope for rural uses on flood-prone land; however, this is not considered appropriate in Scenario 1 Option B because a small pocket of rural uses among urban uses is not considered appropriate from a flood perspective. It is also unlikely to be appropriate because of other planning reasons. Moreover, ancillary structures such as rural homesteads and sheds would be difficult to implement in any great number because much of the development potential has been assigned to urban uses.

3.16.2 Scenario 1 Option C

Potential uses for flood-prone land in this option are like Scenario 1 Option B. However, as much of the land capability for the 5% AEP has already been assigned to industrial development, it would be far more difficult to obtain high-quality sports fields or other active recreational facilities in this option.

4 Pinjarra-Ravenswood sector of the planning investigation area

4.1 Characterising the landscape

The Pinjarra-Ravenswood sector is within the Murray River catchment to the east of the Peel-Harvey estuary. There are several different landscapes within the PIA and different flood mechanisms can impact development within each landscape. These landscapes and flood mechanisms are broadly characterised into three groups:

1. riverine flooding from the Murray River
2. estuarine flooding from the Peel-Harvey estuary
3. local catchment flooding of the palusplain where the surface depressions of the landscape are important for managing runoff.

The riverine and estuary landscapes were previously analysed as a part of the *Murray River flood report, flood risk damage assessment* (Department of Water, 2017). This study considered storm surge and sea level rise for the Peel Inlet and the Harvey Estuary and these matters have been incorporated to the advice for the Pinjarra-Ravenswood sector. It was also determined that conservation of floodplain storage on the Murray River floodplain was not required because of the proximity to the ocean of some of the precinct outlets in the Pinjarra-Ravenswood sector.

Flood modelling was undertaken to quantify flooding on palusplain environments in the local catchments, such as the North Ravenswood and South Ravenswood precincts. Flood criteria for each development precinct within the Pinjarra-Ravenswood sector varied depending on the landscape characteristics, the mix of differing flood mechanisms and any existing infrastructure between the development precincts and the Murray River.

4.2 Approach to land flood capability

The flooding risk in this sector is high but is not as complex as those found in some precincts of East of Kwinana. There are six precincts within the sector (Figure 52):

- North Ravenswood
- South Ravenswood
- Pinjarra
- South East Yunderup
- South East Furnissdale
- Furnissdale.

The approach to quantifying flooding and analysing the risks varies depending on the specific flood mechanism or mix of flood mechanisms within each development precinct.

The precincts were prioritised in order of relative flood complexity, with the North Ravenswood and South Ravenswood localities requiring an update of existing flood information using more detailed flood modelling approaches, and the remaining areas being adequately captured in the *Murray River flood report* (Department of Water, 2017).

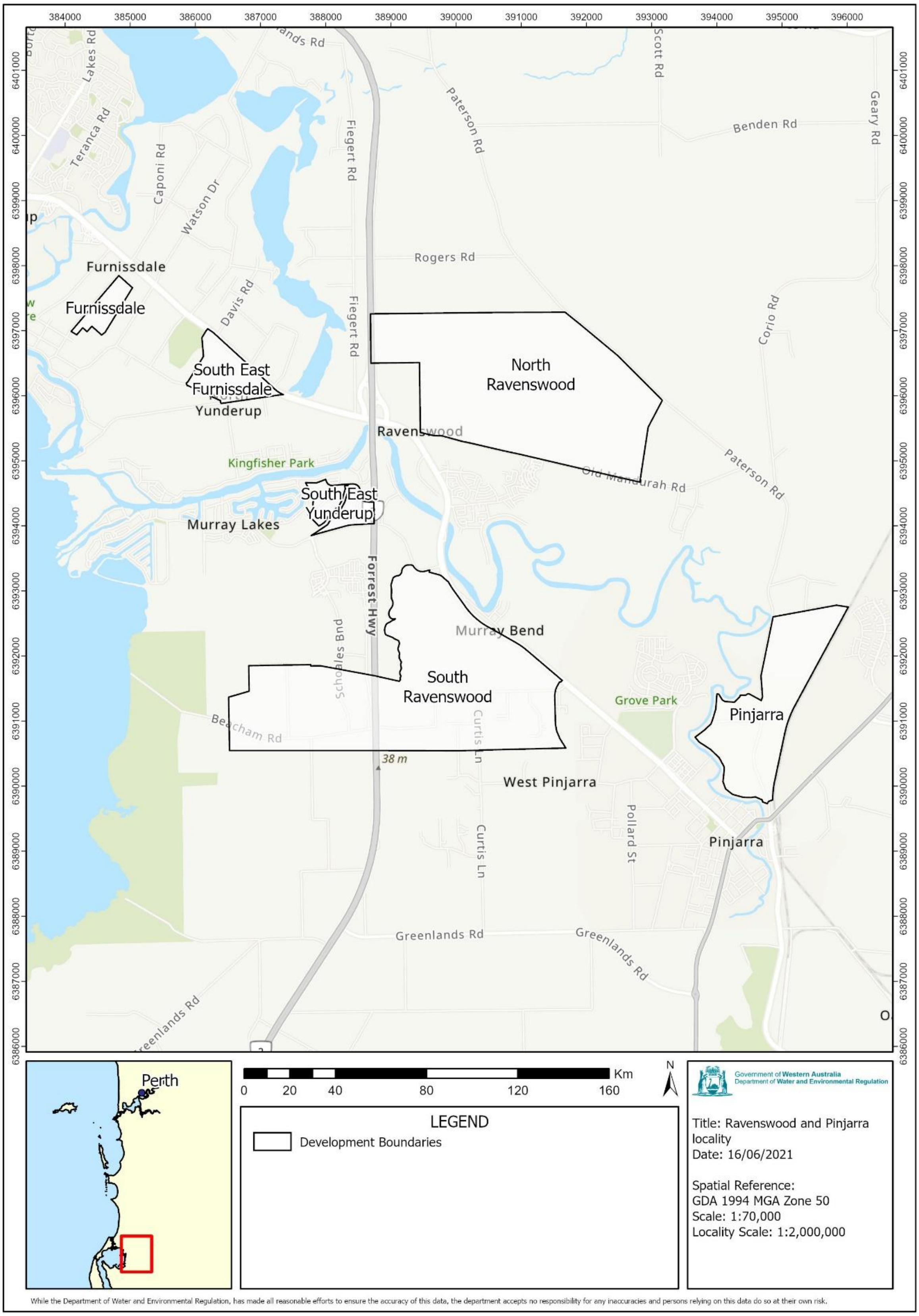


Figure 52 Pinjarra-Ravenswood PIA

4.3 North Ravenswood

The North Ravenswood precinct currently consists of rural land predominately in private ownership. The natural landscape is characterised by a mix of sand and clay with shallow groundwater and flat terrain containing large natural surface depressions. These natural depressions also allow for ponded water to be stored in large floods (palusplain). The rural land slopes gently towards the Murray River and contains rural drains installed to manage groundwater and facilitate agricultural activities rather than for flood protection.

Detailed flood modelling was undertaken as part of the planning investigation and is documented in the department's Ravenswood Flood and Drainage Studies (unpublished). Figure 53 shows the pre-development 1% AEP flood extent for North Ravenswood. The flood mechanism within the precinct is dominated by local catchment flooding. Drainage infrastructure conveys flood discharges from the development precinct to the Murray River through private land. The capacity of this infrastructure and the potential flood impact on private property between the development precinct and the Murray River plays a significant role in the land flood capability.

4.3.1 North Ravenswood land flood capability

The land flood capability for North Ravenswood was determined based on the pre-development 1% AEP flood depth and extent. A range of flood depths was considered between 0.05 m and 0.30 m to assist in defining the proportion of land which was significantly constrained by flooding. Depths were considered at increments of 0.05 m to determine the most appropriate approach to estimating constrained land. At each depth increment, the matters considered were the:

- average flood depth within constrained land should the pre-development floodplain storage be retained.
- extent of natural depressions or waterbodies clearly visible on aerial photography dated August 2021
- continuity of waterway corridors.

It was determined that a flood depth of 0.2 m represented the best fit with the natural surface sumps clearly visible on the aerial photography. This depth threshold did not provide sufficient continuity of the water corridor; however, it was considered inappropriate to adopt a shallower depth threshold for the sake of maintaining continuity. In addition to the depth threshold, the aerial photography was used to identify major overland flow paths and a nominal 60 m corridor width was used to ensure continuity. There are two bands of flooding which traverse the site in a north-west to south-east direction and the corridor approach was adopted to link the larger water bodies to the existing discharge locations.

Condensing the flood corridors into the identified area would result in a doubling of the average flood depth from 0.25 m to 0.49 m with the maximum flood depth in the order of 1.8 m. There are five discharge points between the southern boundary of the site and the Murray River. Should the capacity of these discharge channels be increased, it may be possible to reduce the floodplain storage volume and the area of flood constrained land within the precinct.

It appears that land flood constraints may be closely linked to groundwater and environmental constraints. Further consideration of environmental constraints and downstream drainage infrastructure at the district planning stage may impact the land flood capability and the overall developable area.

The North Ravenswood land flood capability is summarised in Figure 54 which shows that 26% of the land is impacted by a significant flood constraint that will limit land uses with the remaining 74% available for urban uses.

4.3.2 North Ravenswood flooding related landfill volumes

The potential fill volume for North Ravenswood was calculated based on the pre-development 1% AEP flood extent from the North Ravenswood flood model. It was assumed that filing would not be undertaken in areas identified as subject to a significant flood constraint. The calculated fill volume was based on filling land within the minor flood constraint area which is identified as subject to flooding in the pre-development state. It was assumed that this land would be filled to a level 0.55 m above the flood level. This was done to allow for:

- a 0.25 m increase to flood levels within the precinct when floodplain storage volume is confined to the flood corridors
- a 0.3 m freeboard of the fill to the future flood levels. It was assumed that any additional freeboard requirements would be applied to the building floor levels rather than the fill levels.

There is a significant degree of uncertainty in the volume calculation because of the following:

- The fill volume may be significantly greater when post-development ground levels are graded away from flood prone land.
- The fill volume may be reduced should upgrading of downstream drainage infrastructure negate the need to retain floodplain storage.
- The fill volume may increase should environmental assessment indicate that a greater proportion of developable land is possible.

It should be noted that the fill volume requirements are based on flooding constraints only and additional fill for groundwater management is likely. It is estimated that about 1.18 million cubic metres of fill would be required to provide flood protection with additional fill potentially required to maintain groundwater separation.

4.3.3 North Ravenswood flood criteria for development

The department advises that development proposals in this precinct should follow the criteria as outlined below:

- The post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood should not exceed the pre-development base case peak flow rate and flood levels at inflow and outflow locations of the precinct.
- Land use change proposals should maintain pre-development base case flood storage capacity of the 1% AEP (1:100-year) flood of the precinct so that flooding is not increased between the North Ravenswood precinct and the Murray River.

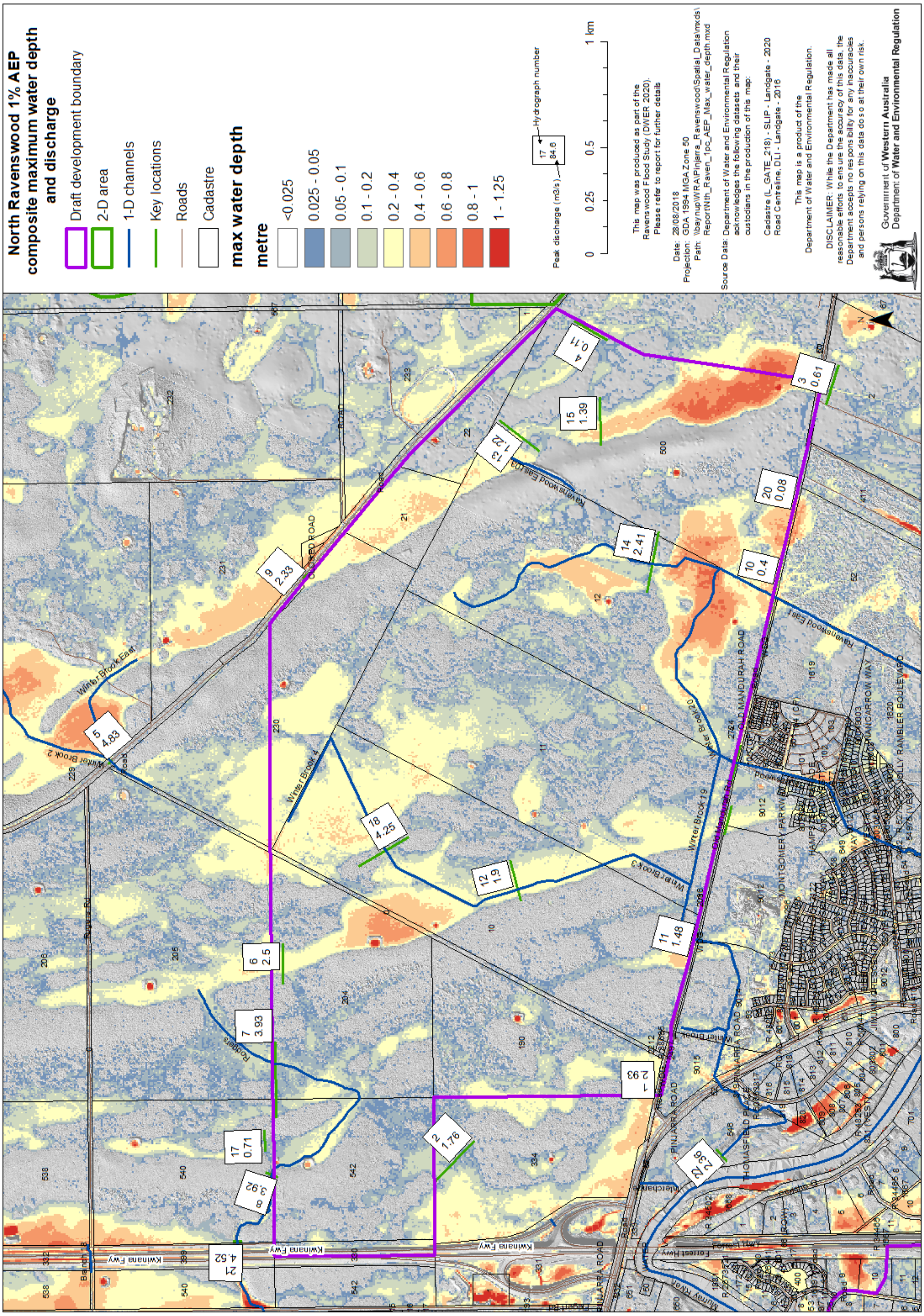


Figure 53 North Ravenswood pre-development flooding

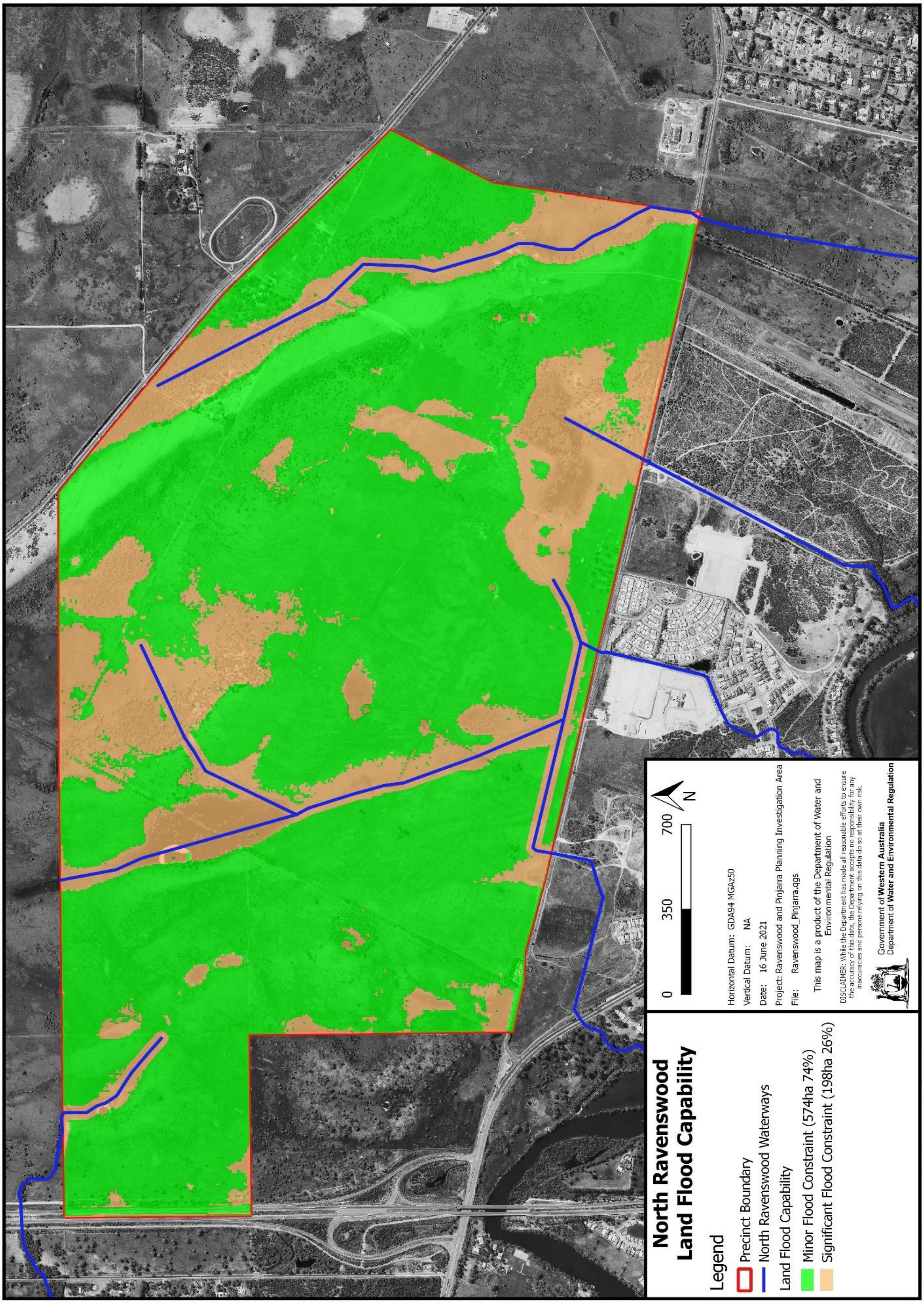


Figure 54 North Ravenswood land flood capability

4.4 South Ravenswood

Flooding within the South Ravenswood precinct is impacted by all three flood mechanisms described in Section 4.1 including riverine flooding from the Murray River, estuarine flooding from the Peel Inlet and local catchment flooding.

Detailed flood modelling was undertaken as a part of the planning investigation and is documented in the department's Ravenswood Flood and Drainage Studies (unpublished). Figure 55 shows the pre-development 1% AEP flood extent for South Ravenswood with the different flood mechanisms incorporated into a single map. Figure 56 shows the dominant flood mechanism across different parts of the floodplain. Local waterways and drainage infrastructure convey flood discharges from the development precinct to the Murray River through private land. The capacity of this infrastructure and the potential flood impact on private property between the development precinct and the Murray River should be considered in subsequent planning stages.

4.4.1 South Ravenswood land flood capability

Murray River flooding mechanisms were assessed as a part of the *Murray drainage and water management plan* (DWER 2011). After the completion of the drainage and water management plan, additional investigations confirmed that the historic floodway definition was still valid. Furthermore, because of the development site's proximity to the ocean, the conservation of floodplain storage for the Murray River floodplain is not required.

Local flooding from the Buchanans Drain catchment was assessed as a part of the *Ravenswood flood modelling and drainage study* (DWER, unpublished). A flood depth of 0.3 m from the local catchment flooding was used to identify the threshold for land with a significant flood constraint. This threshold was used as local overland flow paths through urban streets are typically considered acceptable up to a depth of 0.3 m and could be incorporated into the road layout without needing to resort to dedicated flood corridors. The different flood mechanisms were combined to determine the land flood capability.

The North Ravenswood land flood capability is summarised in Figure 57 which shows that 86% of land has flood protection above the 1% AEP and is available for development, while 14% of the land is impacted by a significant flood constraint that will limit land uses.

4.4.2 South Ravenswood flooding related landfill volumes

The potential fill volume for South Ravenswood was calculated based on the combined extent of flood inundation for both the Murray River and the local catchment flooding. It was assumed that filing would not be undertaken in areas identified as subject to a significant flood constraint. The calculated fill volume was based on filling land within the minor flood constraint area which is identified as subject to flooding in the pre-development state. It was assumed that this land would be filled to a level 0.3 m above the flood level with any additional freeboard requirements applied to the building flood levels rather than the fill levels. This analysis has not considered the potential fill requirements for maintaining groundwater separation. Additional fill may be required for groundwater management purposes.

It is estimated that about 1.78 million cubic metres of fill would be required to provide flood protection, with additional fill potentially required to maintain groundwater separation.

4.4.3 South Ravenswood flood criteria for development

The department advises that development proposals in this precinct should follow the criteria as outlined below:

- The post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood should not exceed the pre-development base case peak flow rate and flood levels at inflow and outflow locations of the precinct.
- Land use change proposals should maintain pre-development base case flood storage capacity of the 1% AEP (1:100-year) flood of the precinct so that flooding is not increased between the South Ravenswood precinct and the Murray River.
- Development should be excluded from the floodway of the Murray River.

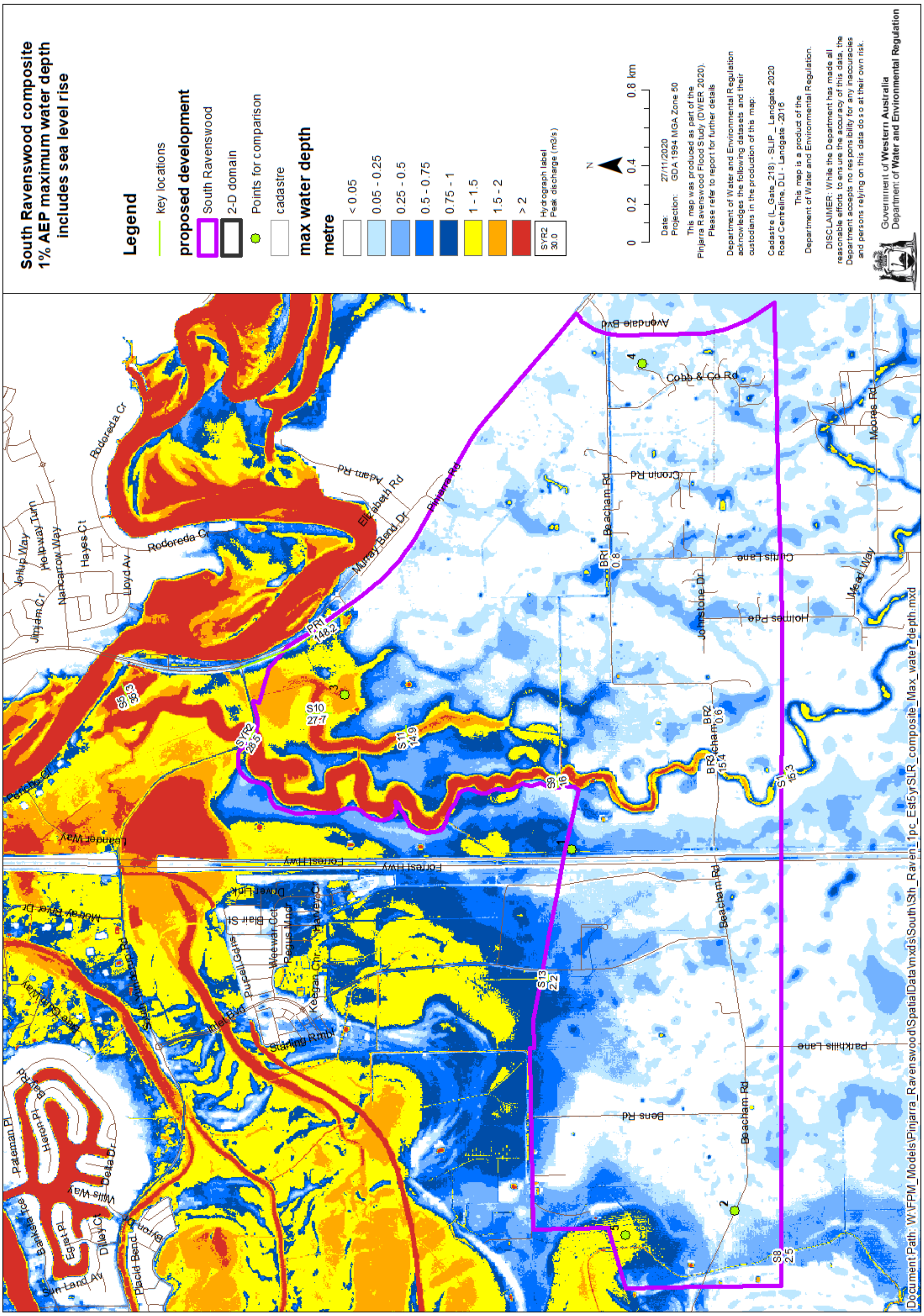


Figure 55 South Ravenswood pre-development flooding

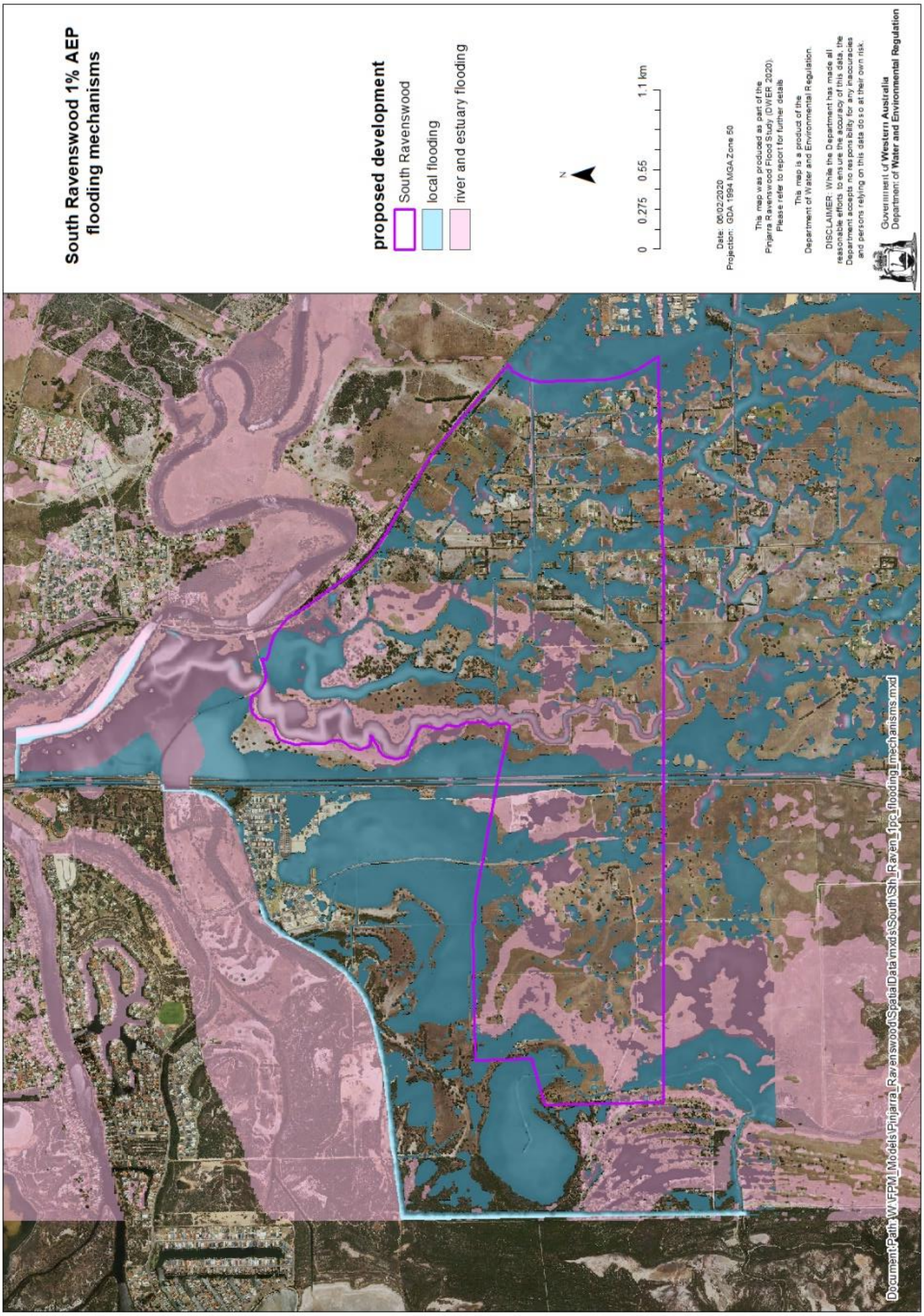


Figure 56 South Ravenswood flood mechanisms

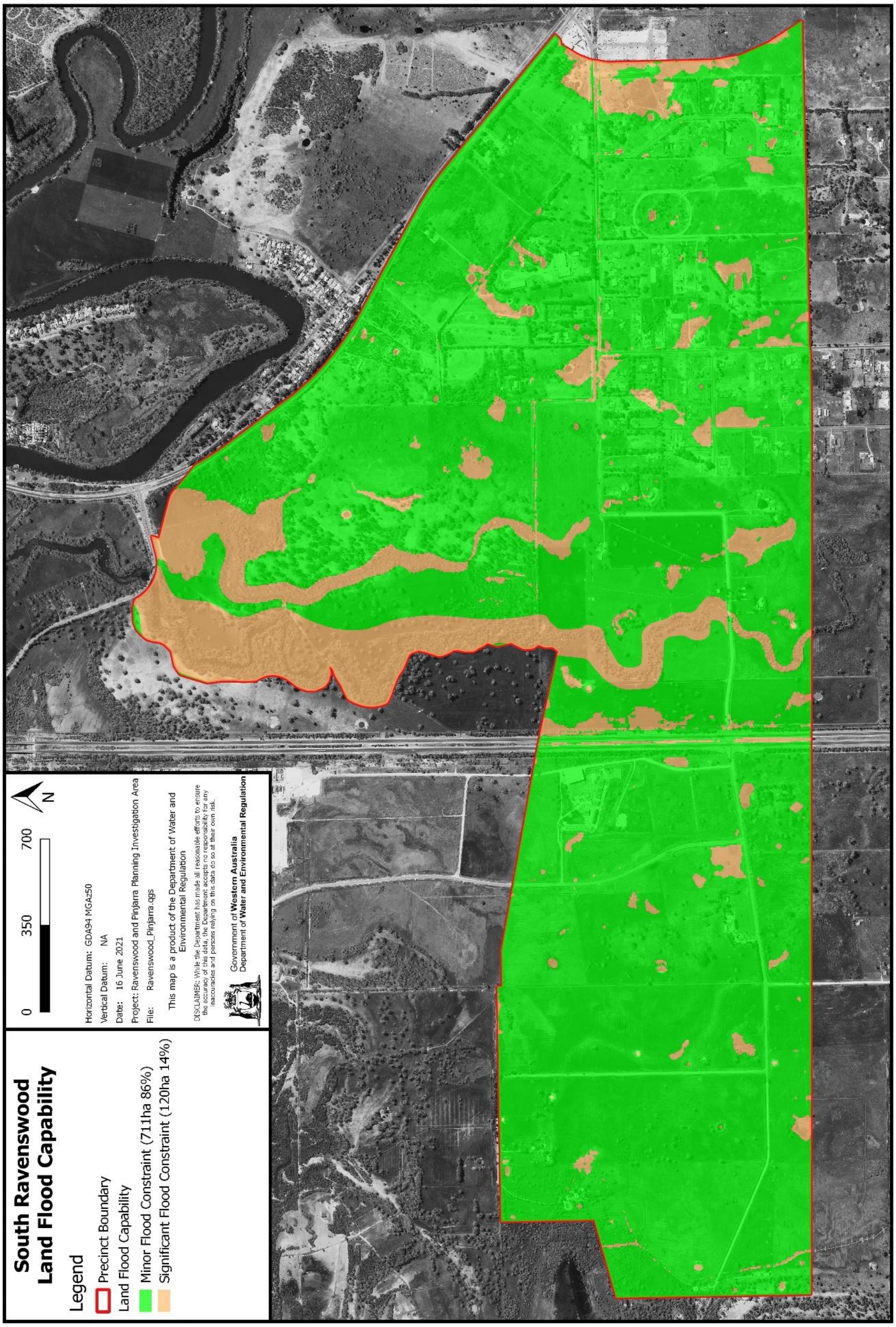


Figure 57 South Ravenswood land flood capability

4.5 Pinjarra

The dominant flood mechanism within the Pinjarra development precinct is riverine flooding from the Murray River. Flooding has been identified for three waterways within the vicinity of the Pinjarra precinct:

- Murray River
- Tate Gully
- Curtis Drain.

Flood modelling underpinning the *Murray drainage and water management plan* (DWER 2011) was reviewed along with topographical information and aerial photography. It was determined that there were no additional local waterways or flooded areas within the development precinct where the flood depth exceeded 0.3 m. The flood mapping associated with the *Murray drainage and water management plan* (DWER 2011) and the *Murray River flood report, flood risk damage assessment* (DWER 2017) provides appropriate coverage of flooding within the precinct for the planning investigation.

4.5.1 Pinjarra land flood capability

The land flood capability for the Pinjarra precinct is based on flood modelling undertaken as a part of the *Murray drainage and water management plan* (DWER 2011)*.* After the completion of the drainage and water management plan, additional investigations confirmed that the historic floodway definition was still valid. Furthermore, because development site's proximity to the ocean, the conservation of floodplain storage is not required.

Local drainage flooding appears to be minor and, for most of the land, is less than 0.3 m deep. Portions of these site are within the flood fringe of the Murray floodplain. Because of the proximity with the ocean, filling of these areas without conservation of floodplain storage is permitted. Portions of the site are within the floodway and landfill or development within these areas is not appropriate.

The land flood capability of Pinjarra was determined based on floodway delineated as a part of the *Murray River flood report, flood risk damage assessment* (DWER, 2017) (see Figure 58). Land within the floodway is identified as significantly flood constrained with limited land uses, while land that is outside the floodway or outside the floodplain is identified as a minor flood constraint. About 69% is outside the floodway and can be developed with an appropriate flood standard, with the remaining 31% of the land identified with a significant flood constraint located within the floodway. The land flood capability for the Pinjarra precinct is shown in Figure 59.

The southern portion of the Pinjarra precinct becomes isolated between the Murray River and Tate Gully – and to a lesser degree, Curtis Drain – during large floods. A significant river crossing will be required with appropriate flood projection to facilitate the orderly evacuation of people. In addition, safety and evacuation of people from this area will need to be managed through appropriate flood evacuation strategies. Sufficient capacity should be provided at public facilities in suitable locations to safely accommodate evacuated persons during flooding.

4.5.2 Pinjarra flooding related landfill volumes

Fill requirements were calculated based on filling the food fringe identified in Figure 58 with 0.3 m of additional fill added for freeboard above the 1% AEP flood level. The calculated fill volume is 700,000 cubic metres based on no fill within the floodway. Additional fill may be required (outside the floodway) depending on groundwater separation requirements.

4.5.3 Pinjarra flood criteria for development

The department advises that development proposals in this precinct should follow the criteria as outlined below:

- Development should be excluded from the floodway of the Murray River
- Land use change proposals should maintain the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood.
- Land use change proposals do not need to conserve pre-development base case flood storage capacity of the precinct as it is close to the Murray River and ocean.

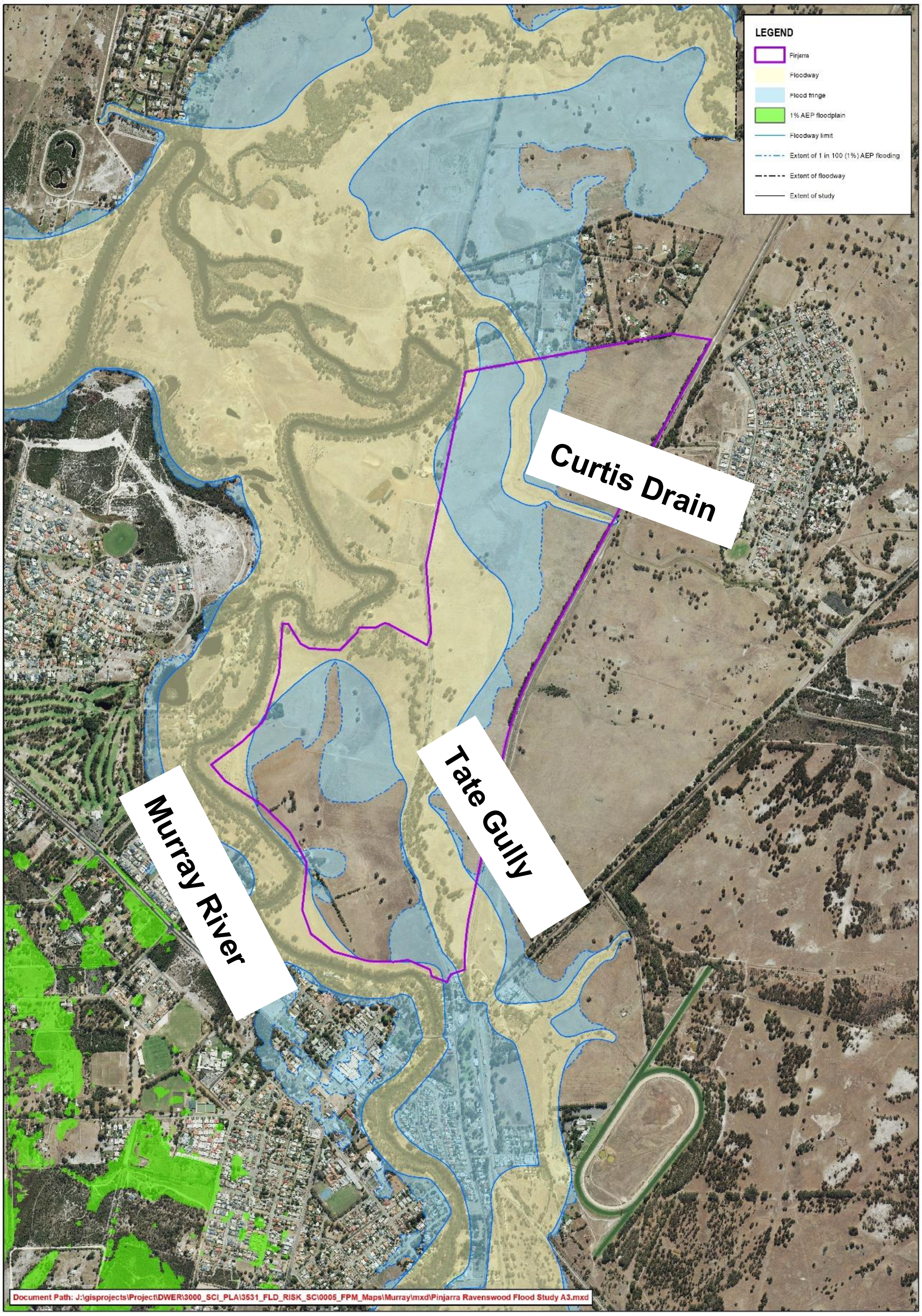


Figure 58 Pinjarra flood mapping

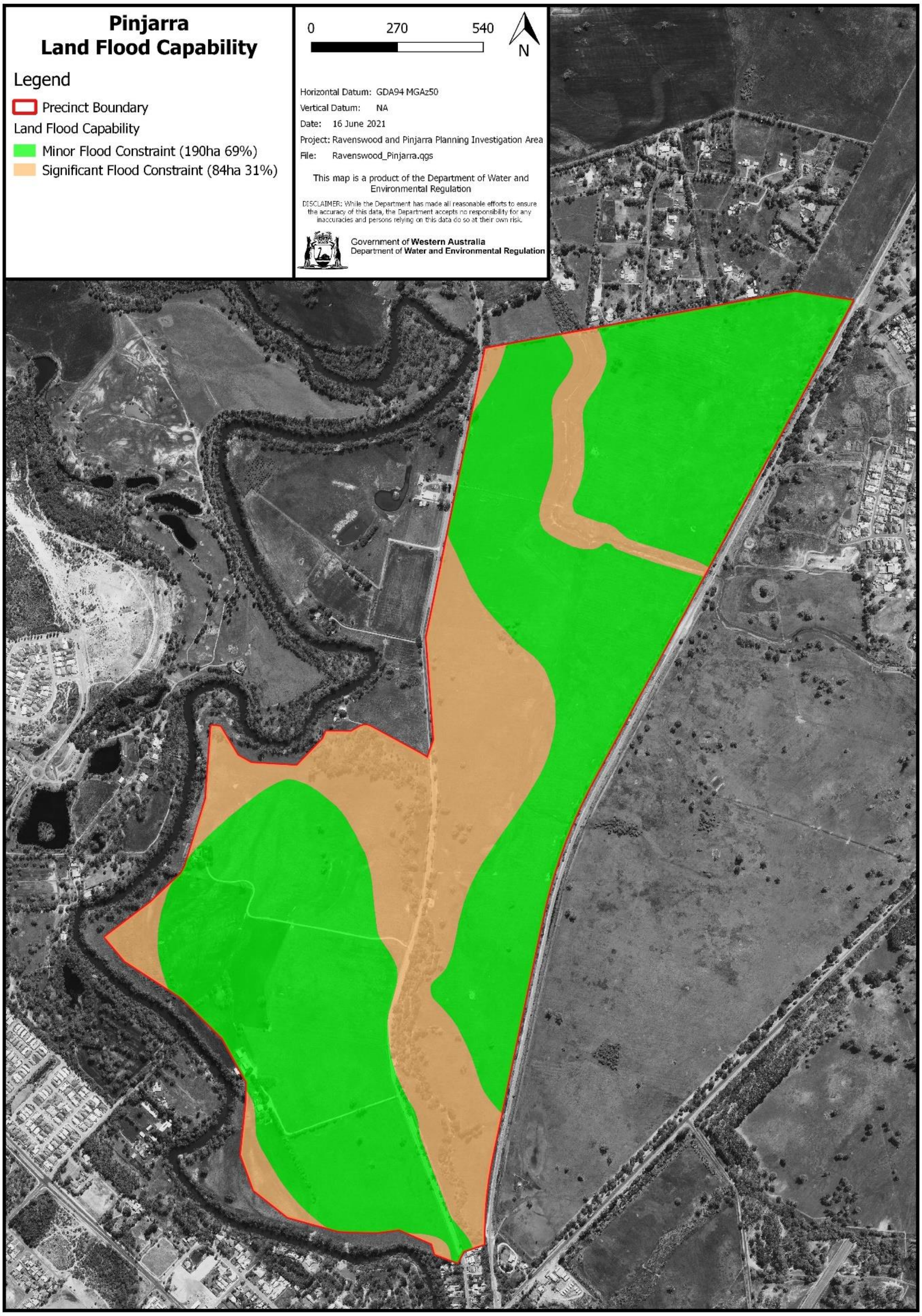


Figure 59 Pinjarra land flood capability

4.6 Furnissdale and South East Furnissdale

Flooding within the Furnissdale and South East Furnissdale development precincts is impacted by riverine flooding from the Murray River and investigated as a part of the *Murray drainage and water management plan* (DWER, 2011) and the *Murray River flood report*, flood risk damage assessment (DWER, 2017). Portions of the precincts have been identified within the flood fringe of the Murray River floodplain as shown in Figure 60 and Figure 61.

In addition, there may be local drainage matters associated with the surrounding land and local drainage infrastructure between the development precinct and the Murray River. Local drainage matters were not considered to be critical to the planning investigation and can reasonably be addressed through district and local planning.

4.6.1 Furnissdale and South East Furnissdale land flood capability

The land flood capability for Furnissdale and Southeast Furnissdale is based on flood modelling undertaken as a part of the *Murray drainage and water management plan* (DWER 2011). After the completion of the drainage and water management plan, additional investigations confirmed that the historic floodway definition was still valid. Furthermore, because of the development site's proximity to the ocean, the conservation of floodplain storage is not required.

Local drainage flooding appears to be minor and, for most of the land, is less than 0.3 m deep. Local drainage corridors will need to be considered as a part of subsequent planning stages, but at this stage there does not appear to be any specific mainstream flooding risk that would require a significant portion of land dedicated to managing that risk (see Figure 63).

Portions of these sites are within the flood fringe of the Murray River floodplain. Because of the proximity to the ocean, filling of these areas without conservation of floodplain storage is permitted.

4.6.2 Furnissdale and South East Furnissdale flooding related landfill volumes

Fill volumes within the precincts is based on flood modelling results (flood extent) from the *Murray drainage and water management plan* (DWER 2011) with a 0.3 m of additional fill added for freeboard. The calculated fill volumes for the Furnissdale and South East Furnissdale precincts is 20,000 and 152,000 cubic metres. Additional fill may be required to manage other issues such as groundwater separation.

4.6.3 Furnissdale and South East Furnissdale flood criteria for development

The department advises that development proposals in this precinct should follow the criteria as outlined below:

- Land use change proposals should maintain the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood.
- Land use change proposals do not need to conserve pre-development base case flood storage capacity of the precinct as it is close to the Murray River and ocean.

Figure 60 Furnissdale flood mapping

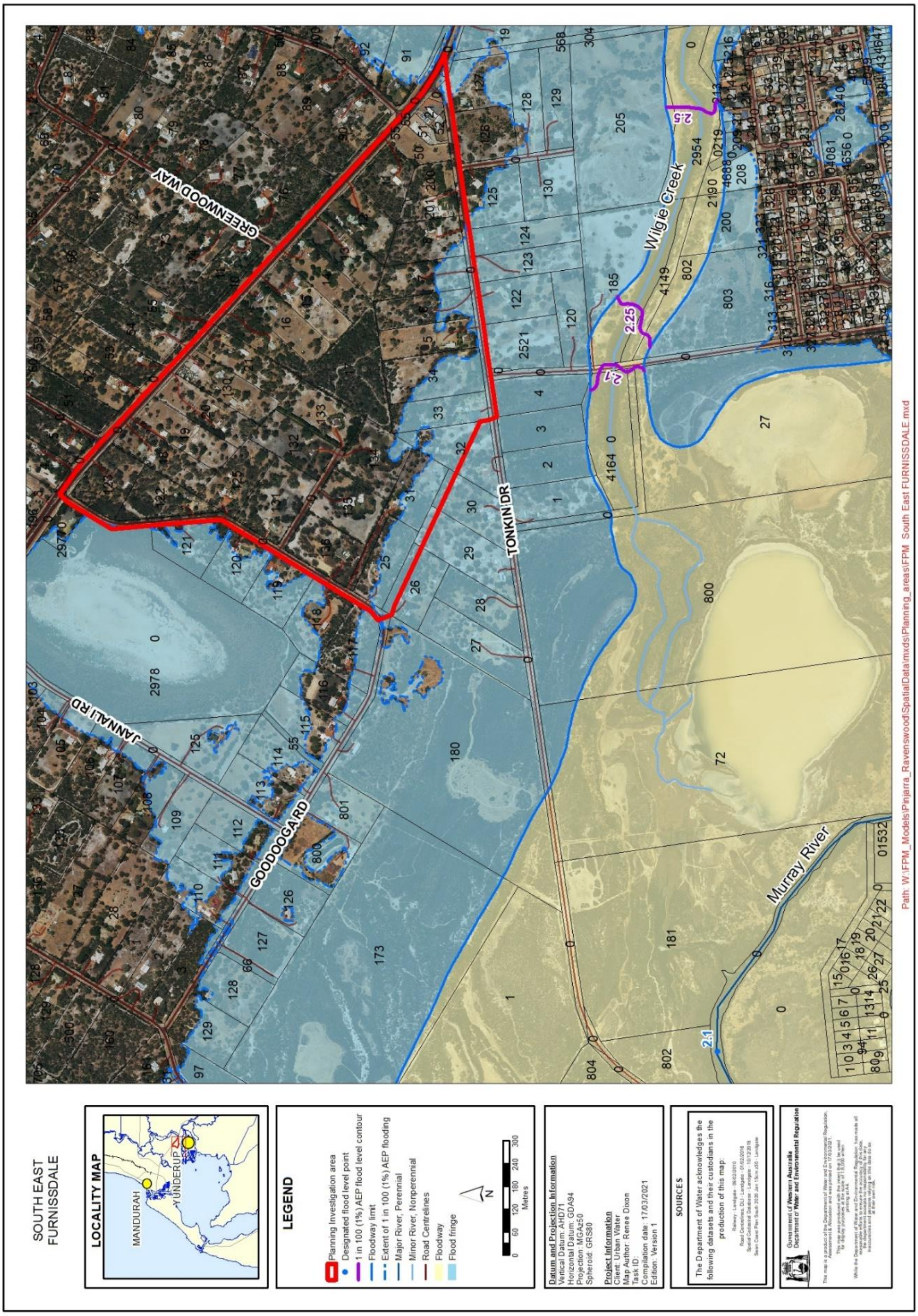


Figure 61 South East Furnissdale flood mapping

4.7 South East Yunderup

Flooding within the South East Yunderup development precincts is impacted by riverine flooding from the Murray River and investigated as a part of the *Murray drainage and water management plan* (DWER 2011) and the *Murray River flood report, flood risk damage assessment* (DWER 2017). The precinct is partially within the floodway and partially within the flood fringe as shown in Figure 62 below.

4.7.1 South East Yunderup land flood capability

The land flood capability for South East Yunderup is based on flood modelling undertaken as a part of the *Murray drainage and water management plan* (DWER 2011). After the completion of the drainage and water management plan, additional investigations confirmed that the historic floodway definition was still valid. Because of the development site's proximity to the ocean, the conservation of floodplain storage is not required.

The land flood capability is determined by the extent of the floodway with filing of the site permitted outside the floodway. About 23% of the precinct is within the floodway and use of this land is significantly constrained by flooding. The remaining 77% of the precinct is within the flood fringe and can be developed. The site does become isolated during large floods and there is a continuing safety and evacuation risk to the site. This risk will need to be managed through appropriate flood evacuation strategies. The land flood capability of the South East Yunderup precinct is shown in Figure 63 below.

4.7.2 South East Yunderup flooding related landfill volumes

Fill volumes in the Southeast Yunderup precinct were calculated on the basis that filling will only occur within the flood fringe. The indicative volume of fill required for flood protection is 473,000 cubic metres, which includes a freeboard of 0.3 m added to the fill volume.

4.7.3 South East Yunderup flood criteria for development

The department advises that development proposals in this precinct should follow the criteria as outlined below:

- Development should be excluded from the floodway of the Murray River.
- Land use change proposals should maintain the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood.
- Land use change proposals do not need to conserve pre-development base case flood storage capacity of the precinct as it close to the Murray River and ocean.

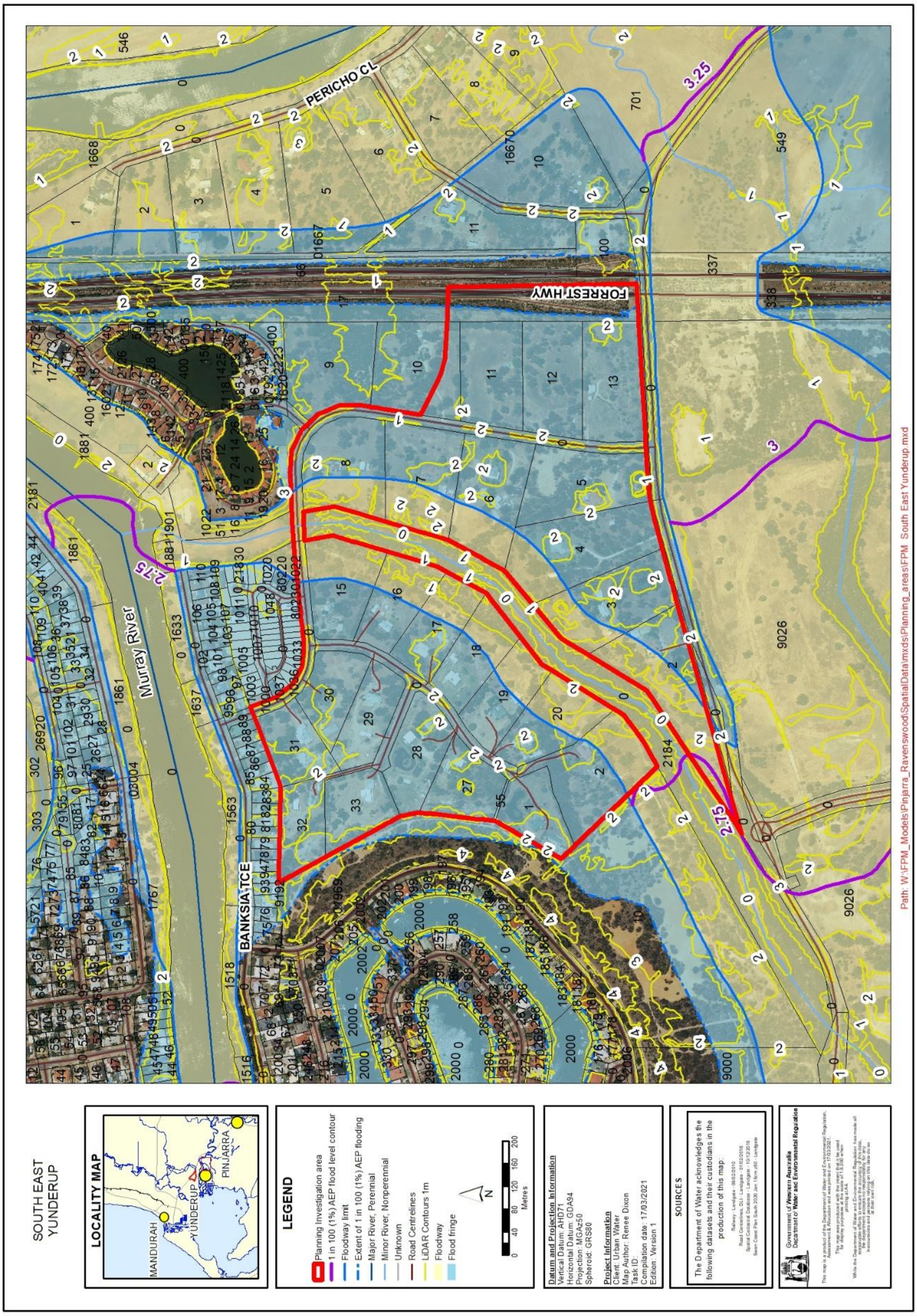
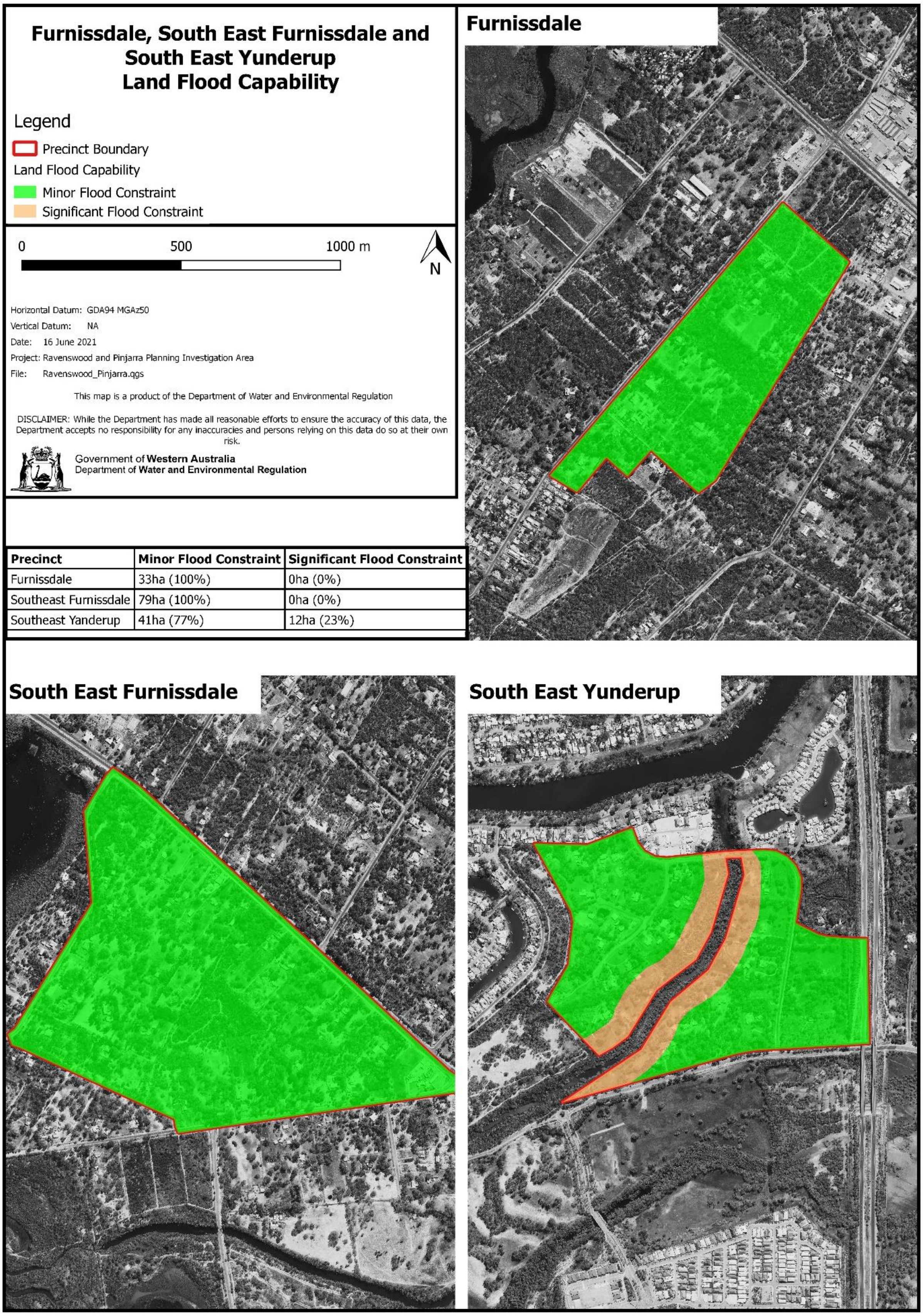


Figure 62 South East Yunderup flood mapping



Precinct	Minor Flood Constraint	Significant Flood Constraint
Furnissdale	33ha (100%)	0ha (0%)
Southeast Furnissdale	79ha (100%)	0ha (0%)
Southeast Yanderup	41ha (77%)	12ha (23%)

Figure 63 Furnissdale South East Furnissdale and South East Yunderup land flood capability

4.8 Pinjarra-Ravenswood advice

4.8.1 Context

- In 2019, DPLH asked the department to do a land capability assessment based on flooding for East of Kwinana and Pinjarra-Ravenswood PIA identified in the Perth and Peel @ 3.5million frameworks.
- The assessment will be used to inform a comparative analysis of the two sectors of the PIA by DPLH in 2021.
- The department has based the land capability assessment on two flood-related questions:
  - Can a precinct be developed without unacceptable impacts to neighbouring land?
  - How much of the precinct can be developed with varied flood protection standards?
- The department has analysed flooding in the Pinjarra-Ravenswood sector using a variety of tools based on relative flood complexity.
- The Pinjarra-Ravenswood sector is within the Murray River catchment to the east of the Peel-Harvey estuary.
- The flooding risk in this sector is high but is not as complex as those found in some precincts of East of Kwinana.
- For assessment purposes, the Pinjarra-Ravenswood sector was divided into six precincts: North Ravenswood, South Ravenswood, Pinjarra, South East Yunderup, South East Furnissdale and Furnissdale (as outlined in Figure 1).
- The precincts were prioritised in order of relative flood complexity, with the North Ravenswood and South Ravenswood precincts requiring an update of existing flood information using more detailed flood modelling approaches, and the remaining areas being adequately captured in the *Murray River flood report* (DWER 2017).
- Flooding in the Pinjarra-Ravenswood sector can broadly be characterised as either riverine flooding from the Murray River floodplain, estuarine flooding from the Peel-Harvey estuary or flooding of the palusplain where the surface depressions of the landscape are important for managing 1:100-year flooding.
- The department's flood criteria area was based on the flooding characteristics of each precinct.
- The department focused on flooding across the sectors to determine the flood-related land capability. Limited consideration was given to groundwater management, stormwater management, water quality management or other environmental factors, policies or guidance as they relate to land use change in the sector. Detailed investigations of these aspects will be required as part of any land use change proposal.

- The department uses the following guiding principles to ensure proposed development in flood-prone areas is acceptable with regard to major flooding:
  - The proposed development has adequate flood protection.
  - The proposed development does not detrimentally impact on the existing flooding regime of the general area.
- The department advises that the Murray Coastal Hazard Risk Management and Adaptation Plan (Shire of Murray in prep.) should be considered in conjunction with the advice below.
- The advice below relates to all precincts within the Ravenswood-Pinjarra sector.

4.8.2 Advice

Pinjarra-Ravenswood sector (all precincts)

The department advises that:

- land use change proposals should be compared to the department's pre-development base case established for each precinct
- land use change proposals should address the flood criteria established for each precinct
- the department's Ravenswood Flood and Drainage Studies (unpublished) should be referred to for pre-development base case.

North Ravenswood

The department advises that:

- 74% of the North Ravenswood land can be developed with 1:100-year flood protection
- for land use change proposals, the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood should not exceed pre-development base case peak flow rate and flood levels at inflow and outflow locations of the precinct
- land use change proposals should maintain pre-development base case flood storage capacity of the 1% AEP (1:100-year) flood of the precinct so that flooding is not increased between the North Ravenswood precinct and the Murray River.

The natural landscape of the North Ravenswood precinct is characterised by a mix of sand and clay with shallow groundwater and flat terrain containing large natural surface depressions to allow for ponded water to be stored in a large flood (palusplain).

The North Ravenswood precinct is rural land with pastures that gently slope south towards the Murray River. It has rural drains that do not convey major flow but were installed to prevent inundation to agricultural land. The Ravenswood townsite lies between the precinct and the Murray River. Figure 2 shows the location of the land with and without 1:100-year flood protection and is the pre-development base case for North Ravenswood precinct.

Flooding in North Ravenswood precinct is categorised as flooding of the palusplain. Much of the rainfall in a 1:100-year event is attenuated on the site in natural surface depressions before flowing to the Murray River through small rural drains and through the Ravenswood townsite. The North Ravenswood precinct is not affected by flooding from the Murray River or estuarine flooding from Peel-Harvey estuary.

Figure 3 shows that 74% of the area is available to be developed with 1:100-year flood protection. The remaining 26% has no protection in a 1:100-year flood and would have limitations on use.

The department advises that flood storage does not need to be maintained if further investigations and modelling show, to the satisfaction of the department and infrastructure managers, that local 1:100-year flooding between the precinct and the Murray River will not increase when compared to the pre-development base case. As a result, the amount of land in the North Ravenswood precinct may increase.

The department advises that about 1,180,000 cubic metres of fill will be required in the North Ravenswood precinct to ensure any future development has adequate vertical separation from 1% AEP (1:100-year) flooding. This will change if the amount of land with 1:100-year flood protection changes through more detailed proponent-led investigations.

Additional fill may be required for groundwater management (not considered in this flood-related land capability assessment).

South Ravenswood

The department advises that:

- 86% of the South Ravenswood land can be developed with 1:100-year flood protection
- for land use change proposals, the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood should not exceed pre-development base case peak flow rate and flood levels at inflow and outflow locations of the precinct
- land use change proposals should maintain pre-development base case flood storage capacity of the 1% AEP (1:100-year) flood of the precinct so that flooding is not increased between the South Ravenswood precinct and the Murray River
- development should be excluded from the floodway of the Murray River.

The South Ravenswood precinct is on the southern banks of the Murray River and eastern banks of the Peel-Harvey estuary. Buchanans Drain flows in a northerly direction through the centre of the precinct to the Murray River. The Greenlands Drain flows west to the Peel-Harvey Estuary. The landscape is characterised by rural pastures that have flat, poorly drained alluvial terrain that gently slopes to the Murray River in the north and the Peel-Harvey Estuary in the east.

Figure 4 shows the location of the land with and without 1:100-year flood protection and is the pre-development base case for South Ravenswood precinct. Figure 5 shows that 86% of the precinct can be developed with 1:100-year flood protection. The remaining 14% has no protection in a 1:100-year flood protection and would have limitations on use.

The department advises that flood storage does not need to be maintained if further investigations and modelling show, to the satisfaction of the department and infrastructure managers, that local 1:100-year flooding between the precinct and the Murray River will not increase when compared to the pre-development base case. As a result, the amount of land in the South Ravenswood precinct may increase.

Pinjarra

The department advises that:

- 69% of the Pinjarra area can be developed with 1:100-year flood protection
- development should be excluded from the floodway of the Murray River
- for land use change proposals, the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood need to be maintained
- land use change proposals do not need to conserve pre-development base case flood storage capacity of the precinct as it is close to the Murray River and ocean.

The Pinjarra precinct is on the east banks of the Murray River. Tate Gully flows in a north-westerly direction through the southern part of the precinct to the Murray River.

Figure 6 shows the location of the land with and without 1:100-year flood protection and is the pre-development base case for Pinjarra precinct. Flooding in the precinct is dominated by floodwaters from the Murray River.

Figure 7 shows that 69% of the area can be developed with 1:100-year flood protection. The remaining 31% has no protection in a 1:100-year flood protection and would have limitations on use.

The department advises that the Pinjarra precinct between the Murray River and Tate Gully (and Murray River and Curtis Drain) (Figure 6) will become isolated during floods up to and including the 1:100-year event and will become fully submerged in floods larger than the 1:100-year flood. The department advises that emergency planning, evacuation routes and rescue procedures should be established for this area as part of any land use change proposal.

The department advises that a road crossing above the 1:100-year flood level that allows for safe evacuation of people living or working in the Pinjarra precinct between the Murray River and Tate Gully (and Murray River and Curtis Drain) will be required for future land use change proposals.

Furnissdale

The department advises that:

- 100% of the Furnissdale land can be developed with 1:100-year flood protection
- for land use change proposals, the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood should be maintained
- land use change proposals do not need to maintain pre-development base case flood storage capacity of the precinct as it is close to the Murray River and ocean.

The Furnissdale precinct is to the north-east of the existing Furnissdale locality. The Serpentine River flows in a southerly direction to the Peel-Harvey estuary to the south-east of the precinct. Figure 8 shows the location of the land with and without 1:100-year flood protection and is the pre-development base case for Furnissdale precinct.

Figure 9 shows that 100% of the area is available to be developed with 1:100-year flood protection.

The south-western corner of the precinct is within the mapped flood fringe of the Serpentine River. The department advises that development can occur within the mapped flood fringe in south-western corner of the precinct with appropriate clearance between infrastructure and flood level.

South East Furnissdale

The department advises that:

- 100% of the South East Furnissdale land can be developed with 1:100-year flood protection
- for land use change proposals, the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood should be maintained
- land use change proposals do not need to maintain pre-development base case flood storage capacity of the precinct as it is close to the Murray River and ocean.

South East Furnissdale is to the north of the Murray River and to the east of the Serpentine River and the Peel-Harvey estuary. Figure 10 shows the location of the land with and without 1:100-year flood protection and is the pre-development base case for South East Furnissdale precinct.

Figure 9 shows that 100% of the area is available to be developed with 1:100-year flood protection. The southern part of the South East Furnissdale precinct is within the Murray River flood fringe in a 1:100-year flood.

The department advises that development can occur within the mapped flood fringe in the south-western corner of the precinct with appropriate clearance between infrastructure and flood level.

South East Yunderup

The department advises that:

- 77% of the South East Yunderup land can be developed with 1:100-year flood protection
- for land use change proposals, the post-development peak flow rate and flood levels of the 1% AEP (1:100-year) flood should be maintained
- land use change proposals do not need to maintain pre-development base case flood storage capacity of the precinct as it is close to the Murray River and ocean
- development should be excluded from the floodway of the Murray River.

South East Yunderup is on the southern banks of the Murray River and to the east of the Peel-Harvey estuary. Figure 11 shows the location of the land with and without 1:100-year flood protection and is the pre-development base case for South East Yunderup precinct.

Figure 9 shows that 77% of the area is available to be developed with 1:100-year flood protection. The remaining 23% has no protection in a 1:100-year flood protection and would have limitations on use.

The department advises that development should be avoided within the mapped Murray River floodway in the South East Yunderup precinct in a 1:100-year event. The department advises that development can occur within the mapped Murray River flood fringe in the north-west and south-east of the South East Yunderup precinct with appropriate clearance between infrastructure and flood level in a 1:100-year event.

The South East Yunderup precinct will become isolated during major events with floodwaters overtopping access roads to the South Yunderup area. Emergency planning is critical.