WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS
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Memo

To:	Clare Wilson	**From:**	Ben Hughes
Organisation:	Wimmera CMA	**Date:**	20/10/2015
Job Title:	Warracknabeal and Brim Flood Investigation		
Subject	Mitigation Options Assessment		

1. BACKGROUND

The townships of Warracknabeal and Brim are located in Western Victoria on Yarriambiack Creek, within the Wimmera River catchment and Wimmera CMA management area. During high flows in the Wimmera River, flow is distributed along Yarriambiack Creek between Glenorchy and Horsham, near Longerenong.

During January 2011 large flows on the Wimmera River were observed, leading to a large flow distribution to Yarriambiack Creek, causing widespread flooding along the creek. Prior to floodwater arriving at Warracknabeal and Brim significant effort was put into the construction of earthen levees and sandbagging. These levees prevented significant flood damage from occurring in Warracknabeal, where the number of properties inundated above floor during the 1% AEP design event was estimated at 79[1]. It is understood this was reduced to approximately 5 in the January 2011 event with the aid of the temporary mitigation works implemented. Some of the levees constructed during January 2011 in both Warracknabeal and Brim remain in place; some have been moved and more formally constructed and maintained by Yarriambiack Shire Council.

Water Technology was commissioned by Wimmera CMA to undertaken the Warracknabeal and Brim Flood Investigation. This study will assess a range of design flood events for the purpose of delineating planning layers (LSIO and FO), assessing mitigation options, annual average damage assessments and Yarriambiack Flood Emergency Plan updates.

Design flow estimates for Yarriambiack Creek at the Wimmera Highway Bridge streamflow gauge have indicated this event was between 1% and 0.5% AEP event. An important assumption in the design flood mapping for this study is the incorporation of the levees that have been formalised by Yarriambiack Shire Council, these have been included in the design hydraulic model topography as discussed in the Design Modelling Report (3532-01R03V01).

Modelling of the 1% AEP event has shown approximately 14 properties with dwellings or commercial premises are flooded above floor (23 buildings including multiple buildings per allotment) in Warracknabeal and none in Brim with the incorporation of the weir upgrades and levee construction completed by Yarriambiack Shire Council since the January 2011 event. Floor levels used in this

[1] Water Technology - Warracknabeal and Beulah Flood Study (2007)

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analysis are based on those collected during the Warracknabeal and Beulah Flood Study[1], additional floor levels were also captured during this project by Price Merrett.

During the 0.5 % AEP event the number of properties inundated above floor across the study area increases dramatically to 56.

The 1% AEP extent covering the study area is shown in Figure 1-1, with a closer perspective of Warracknabeal shown in Figure 1-2 and Brim shown in Figure 1-3.

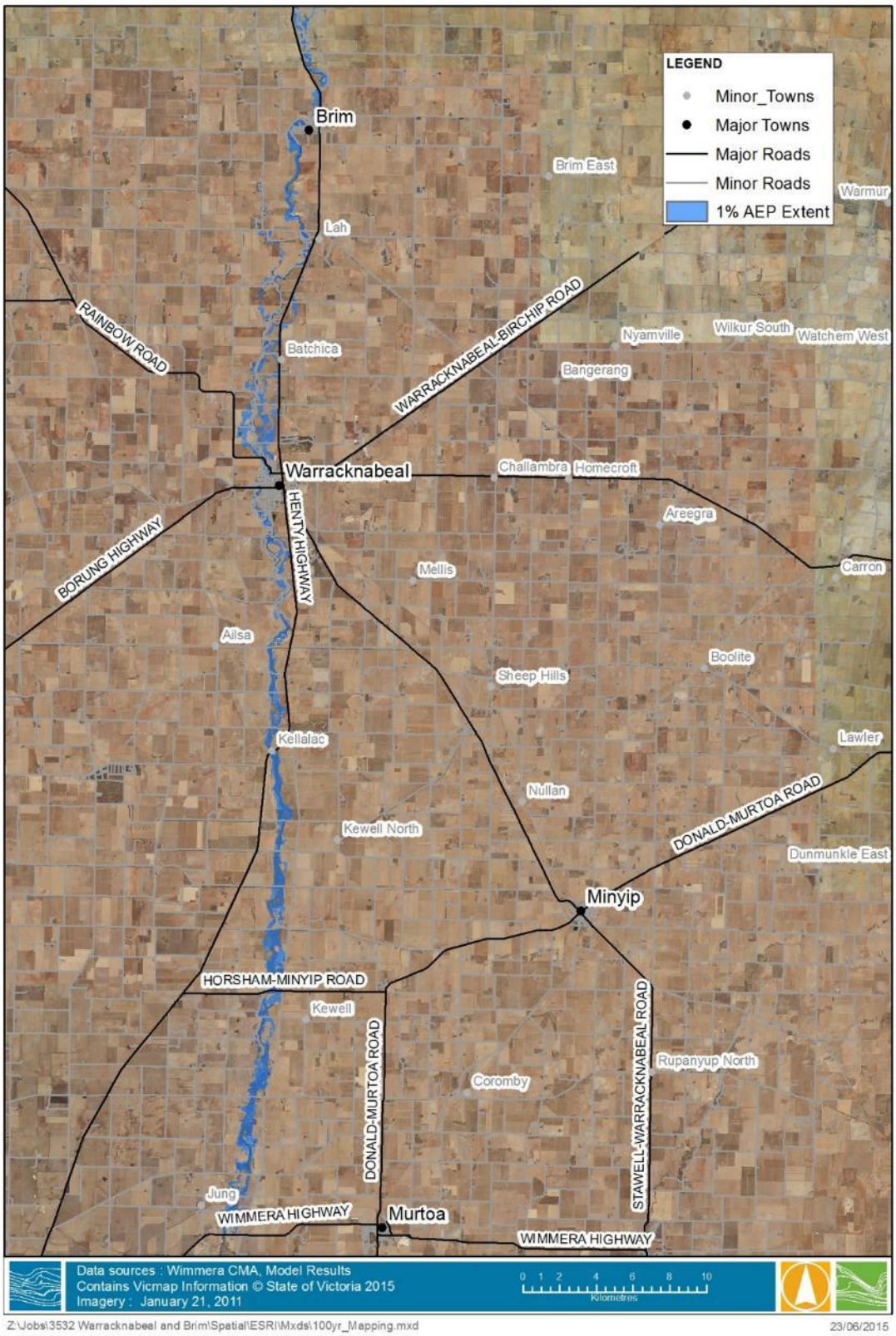

Figure 1-1 Yarriambiack Creek 1% AEP flood extent

Figure 1-2 Yarriambiack Creek 1% AEP flood extent – Warracknabeal and impacted properties

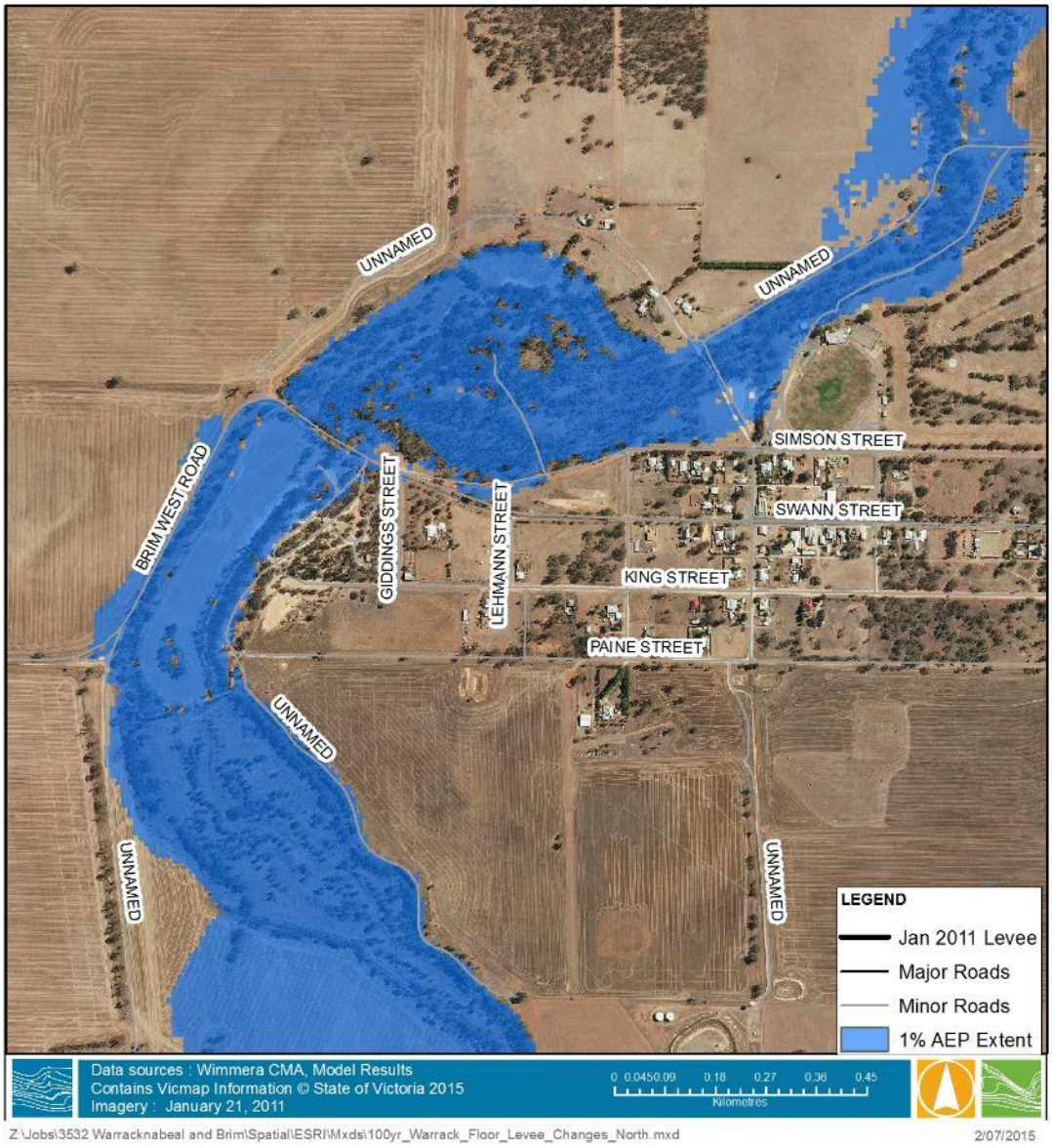

Figure 1-3 Yarriambiack Creek 1% AEP flood extent – Brim

2. PURPOSE AND OVERVIEW

The purpose of this Memo is to detail the assessment of mitigation options for the properties along Yarriambiack Creek within the project study area from the Wimmera Highway at Jung to Galaquil Road north of Brim. Each and every mitigation option suggested over the course of the project was assessed based on its potential to reduce flood damages. The options assessed were made up of community suggestions as well as options suggested by the Project Steering Committee, Wimmera CMA, Yarriambiack Shire Council and Water Technology.

The mitigation assessment was separated into four stages, these were as follows:

- Prefeasibility Assessment - to determine the potential for a mitigation option to reduce flood damage at reasonable cost and feasibility;
- Detailed Hydraulic Modelling Assessment - to determine what reduction in flood levels and extents could be achieved;
- Damages Assessment – to determine the reduction in damages that could be achieved by the chosen mitigation options
- Cost Benefit Analysis – to compare the reduction in flood damage and costs of the chosen mitigation options over a period of time to assess the economic performance of the options.
- Concept design of the recommended mitigation option.

3. PREFEASIBILITY ASSESSMENT

3.1 Overview

Each option was assessed to determine its feasibility and to highlight any property which may be negatively impacted by the construction of the option. The mitigation solutions were described separately for Warracknabeal, Brim and regional properties. Discussion of levee options for Warracknabeal was included in more detail given the number of properties involved. The full list of suggested mitigation measures is summarised below in Table 3-1 and shown in

Table 3-1 Suggested mitigation options

Option No.	Detail	Source
Warracknabeal		
1	Removal of remnant levee formalised by YSC (See Figure 4-1)	Steering committee/Community
2	Construction of a permanent levee that protects Warracknabeal in a 1% AEP flood event in a similar alignment to constructed during January 2011 (See Figure 4-1)	Steering committee/Community
3	Construction of a levee that protects Warracknabeal in a similar alignment to that constructed during January 2011 with a combination of both temporary and permanent sections.	Steering committee
4	Removal of vegetation and large debris along Yarriambiack Creek and upstream of Warracknabeal Weir	Community
5	Construction of a drain to the west of Warracknabeal to reduce stormwater flooding along Asquith Reserve	Steering Committee
6	Improved drainage to the east of Warracknabeal to reduce stormwater flooding (See Figure 3-2)	Wimmera CMA/Council
7	Pump to transport water around Warracknabeal	Steering Committee
8	A levee upstream of Warracknabeal along Ailsa Road or Moloneys Road acting like a retarding basin to reduce the peak flow rate.	Community

Brim		
9	Removal of vegetation and large debris along Yarriambiack Creek and upstream of Warracknabeal Weir	Community
10	Improved drainage to the east of Brim to reduce stormwater flooding	Community
Rural areas		
11	Improve roads/crossings/access to reduce isolation and cut off road connection to residential buildings.	Wimmera CMA

3.2 Assessment Criteria

Each mitigation option was assessed against a number of criteria; potential reduction in flood damage, cost of construction, feasibility of construction and environmental impact. The score for each criterion was based on a ranking system of 1 to 5, with 1 being the worst score and 5 the best. Each criteria score was then weighted according to the weighting shown in Table 3-2 below. The reduction in flood damage was the most heavily weighted criteria as this is really the main objective for all flood mitigation. Table 3-3 reviews and scores each mitigation option against the four criteria and calculates a total score for each option. The options with the higher scores indicate the more appropriate mitigation solutions for each location. While these options were reviewed and recorded individually it is important to consider a combination of options when developing a flood mitigation scheme.

Table 3-2 Prefeasibility assessment criteria

Score	Reduction in Flood Damages	Cost ($)	Feasibility/Constructability	Environmental Impact
Weighting	**2**	**1**	**0.5**	**0.5**
5	Major reduction in flood damage	Less than $50,000	Excellent (Ease of construction and/or highly feasible option)	None
4	Moderate reduction in flood damage	$50,000 – $100,000	Good	Minor
3	Minor reduction in flood damage	$100,000 – $500,000	Average	Some
2	No reduction in flood damage	$500,000 – $1,000,000	Below Average	Major
1	Increase in flood damage	Greater than $1,000,000	Poor (No assess to site and/or highly unfeasible option)	Extreme

3.3 Assessment

Each of the suggested mitigation options was assessed using the outlined assessment criteria, and is discussed in Table 3-3.

Table 3-3 Prefeasibility assessment criteria

No.	Mitigation Option	Criteria					Score
		Reduction in Flood Damages	Cost ($)	Feasibility/Constructability	Environmental Impact	Comments	
Warracknabeal							
1	Removal of remnant levee formalised by YSC	1	1	5	5	Removal of the remaining levee would increase flood damages and increase the work required to construct a similar levee in the future. However it may increase the amenity of Yarriambiack Creek for some Warracknabeal residents. (See Figure 4-1)	8
2	Construction of a levee that protects Warracknabeal 1% AEP flood event in a similar alignment to constructed during January 2011 (See Figure 4-1)	5	1	2	4	Replicating the January 2011 levee for Warracknabeal would offer the same level of protection, reducing the number of properties inundated significantly. However a permanent levee along the full length would be expensive given the lack of space along the required levee alignment and would likely involve major road works. (See Figure 4-1)	14
3	Construction of a levee that protects Warracknabeal in a similar alignment to that constructed	5	2	3	4	Replicating the January levee along Yarriambiack Creek then leaving road crossings and other areas where a permanent levee is expensive or has an adverse impact on amenity of Yarriambiack Creek will reduce the number of properties inundated significantly. It will also be cheaper than a full	15.5

No.	Mitigation Option	Criteria					Score
		Reduction in Flood Damages	Cost ($)	Feasibility/Constructability	Environmental Impact	Comments	
	during January 2011 with a combination of both temporary and permanent sections.					permanent levee scenario. However, it will leave YSC with a large amount of flood response work preceding a flood event which could be time consuming and expensive. (See Figure 4-1)	
4	Removal of vegetation and large debris along Yarriambiack Creek and upstream of Warracknabeal weir	2	4	2	1	Removal of vegetation and large debris along Yarriambiack Creek and around the Warracknabeal weir is unlikely to have a significant impact on flood levels. The weir is the largest influencing factor on water levels and the capacity increases post January 2011 have reduced its impact. Vegetation removal would be required on a large scale to have any noticeable impact on flood levels and this is unlikely to be approved by Council, CMA, DELWP or the Community.	9.5
5	Construction of a drain to the west of Warracknabeal to reduce stormwater flooding along Asquith Reserve	3	4	5	4	Asquith Reserve is impacted by a stormwater catchment to the south west. This could be directed into Yarriambiack Creek. Since January 2011, YSC have completed localised stormwater improvement works. The potential to reduce flood damages through improved drainage will be assessed conceptually as part of the Warracknabeal stormwater modelling.	14.5

No.	Mitigation Option	Criteria					Score
		Reduction in Flood Damages	Cost ($)	Feasibility/Constructability	Environmental Impact	Comments	
6	Improved drainage to the east of Warracknabeal to reduce stormwater flooding	3	4	5	4	East of Warracknabeal the Borung Highway causes a significant restriction to overland flow to the north. During the January 2011 event extensive inundation was caused. Improved conveyance from south to north of the Highway would reduce stormwater flood damage. This will be assessed conceptually as part of the Warracknabeal stormwater modelling (See Figure 3-1)	14.5
7	Pump to transport water around Warracknabeal	2	3	1	5	The 1% AEP flow at Warracknabeal is around 50 m^3/s, this flowrate could not be passed around Warracknabeal via a pump as it is too large.	10
8	A levee upstream of Warracknabeal along Ailsa Road or Moloneys Road acting as a flow rate control.	4	2	2	4	A levee running along either Ailsa or Moloneys Road with a flow control structure limiting flow in Yarriambiack Creek has the potential to reduce flood damage in Warracknabeal, however it would increase agricultural flood damage upstream of the	12.5
Brim							
9	Removal of vegetation and large debris along	2	4	2	1	There are very low flood damages for Brim with no dwellings flooded above or below floor for the 1% AEP event. Vegetation removal is expected to cause a minimal change	9.5

No.	Mitigation Option	Criteria					Score
		Reduction in Flood Damages	Cost ($)	Feasibility/Constructability	Environmental Impact	Comments	
	Yarriambiack Creek and upstream of Warracknabeal Weir					to flood levels and would not be well accepted by the community.	
10	Improved drainage to the east of Brim to reduce stormwater flooding	3	4	4	5	Improving stormwater drainage to the east of Brim would reduce flood damage. A stormwater catchment south of the township is unable to discharge under the Henty Highway to the north due to what appears to be undersized culverts. The potential to reduce flood damages through improved drainage will be assessed conceptually as part of the Brim stormwater modelling	14.5
Rural Areas							
11	Improve roads/crossings/ access to reduce isolation and cut off road connection to residential buildings.	2	3	3	5	There are several properties that are isolated during a major flood event and one property flooded above floor. Improving access will not reduce flood damage for these properties but could improve the ability to assist others and allow people to evacuate prior to the peak of a flood.	13

Using the prefeasibility assessment above, the 11 mitigation options were ranked by weighted score. Their ranking is shown below in Table 3-4

Table 3-4 Weighted prefeasibility mitigation scores

Rank	Option No.	Mitigation Option	Weighted Score
1	**3**	Construction of a levee that protects Warracknabeal in a similar alignment to that constructed during January 2011 with a combination of both temporary and permanent sections.	15.5
2	**5**	Construction of a drain to the west of Warracknabeal to reduce stormwater flooding along Asquith Reserve	14.5
3	**6**	Improved drainage to the east of Warracknabeal to reduce stormwater flooding	14.5
4	**10**	Improved drainage to the east of Brim to reduce stormwater flooding	14.5
5	**2**	Construction of a levee that protects Warracknabeal 1% AEP flood event in a similar alignment to constructed during January 2011 (See Figure 2-1)	14
6	**11**	Improve roads/crossings/ access to reduce isolation and cut off road connection to residential buildings.	11
7	**8**	A levee running along either Ailsa or Moloneys Road with a flow control structure limiting flow in Yarriambiack Creek has the potential to reduce flood damage in Warracknabeal, however it would increase agricultural flood damage upstream of the	12.5
8	**4**	Removal of vegetation and large debris along Yarriambiack Creek and upstream of the weir	9.5
9	**9**	Removal of vegetation and large debris along Yarriambiack Creek and upstream of the weir at Brim	9.5
10	**7**	Pump to transport water around Warracknabeal	8
11	**1**	Removal of remnant levee formalised by YSC	8

Based on the above ranking, a levee option for flood mitigation in Warracknabeal was identified as viable and considered for further investigation. Several localised drainage options were also highlighted for further consideration at part of the projects conceptual stormwater modelling. These options were not assessed in the flood damages assessment or flood mitigation measures.

The top five options are discussed in more detail in the following sections.

3.4 Stormwater Inundation improvements

Two of the proposed mitigation options were related to inundation via stormwater. These options were at Asquith Reserve and south of the Borung Highway east of Warracknabeal and are shown in Figure 3-1. Stormwater inundation at Asquith Reserve has been alleviated by drainage enlargements and the installation of one way stormwater outlets post the January 2011 event[2]. These changes will be reviewed during the stormwater modelling component of this project.

Stormwater inundation south of the Borung Highway is largely caused by a blockage to overland flow at the highway. The inundation observed during January 2011 event is shown in Figure 3-2. There may be options to add additional drainage culverts under the highway and improving the passage of overland flow. This will be assessed as part of the Warracknabeal stormwater modelling.

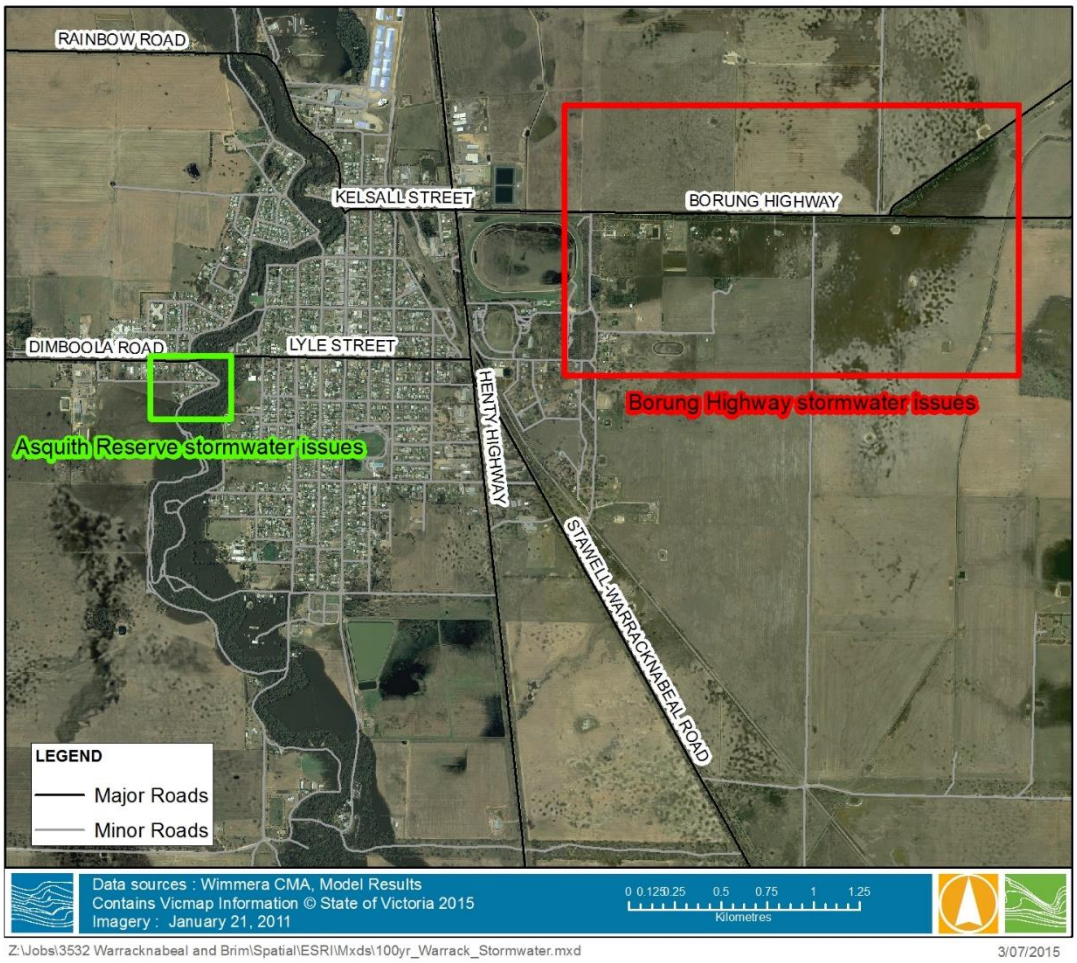

Figure 3-1 Warracknabeal stormwater issues

[2] Pers. Com. Yarriambiack Shire Council – Bernie Naylor

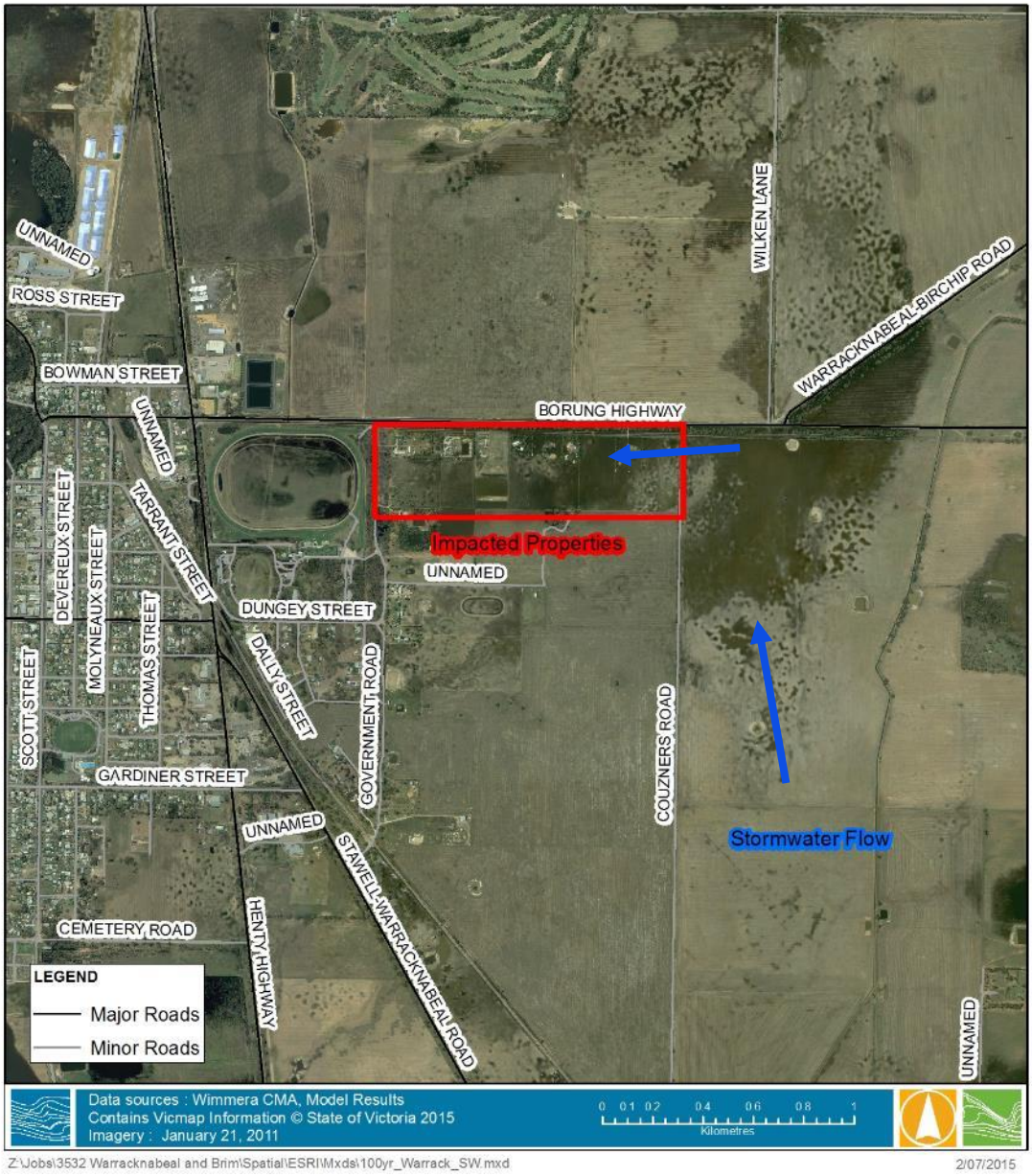

Figure 3-2 Inundation east of Warracknabeal during the January 2011 event caused by the Borung Highway restricting overland flow

4. HYDRAULIC MODELLING ASSESSMENT

4.1 Overview

Avoidable flood damages within the study area are largely concentrated in Warracknabeal. There are several regional properties outside of Warracknabeal that are impacted above and below floor, however these properties are a significant distance from other built assets and individual mitigation (i.e. private levees) at these properties is unlikely to cause adverse flood impacts. The existing conditions design modelling and the January 2011 event showed no properties are impacted above or below floor in Brim, resulting in no requirement for flood mitigation.

Warracknabeal has the highest level of avoidable flood damage and the only location within the study area where a mitigation scheme will benefit numerous properties. As a result the mitigation modelling undertaken in this project focused on the township itself. This is not to say that rural dwellings outside of Warracknabeal can't be protected by individual levees, but they have not been assessed in this study.

4.2 January 2011 Mitigation

As mentioned previously a significant levee was constructed protecting Warracknabeal during January 2011. Portions of this levee have since been formalised and included in the design modelling. The January 2011 levee and the formalised sections of levee are shown in Figure 4-1.

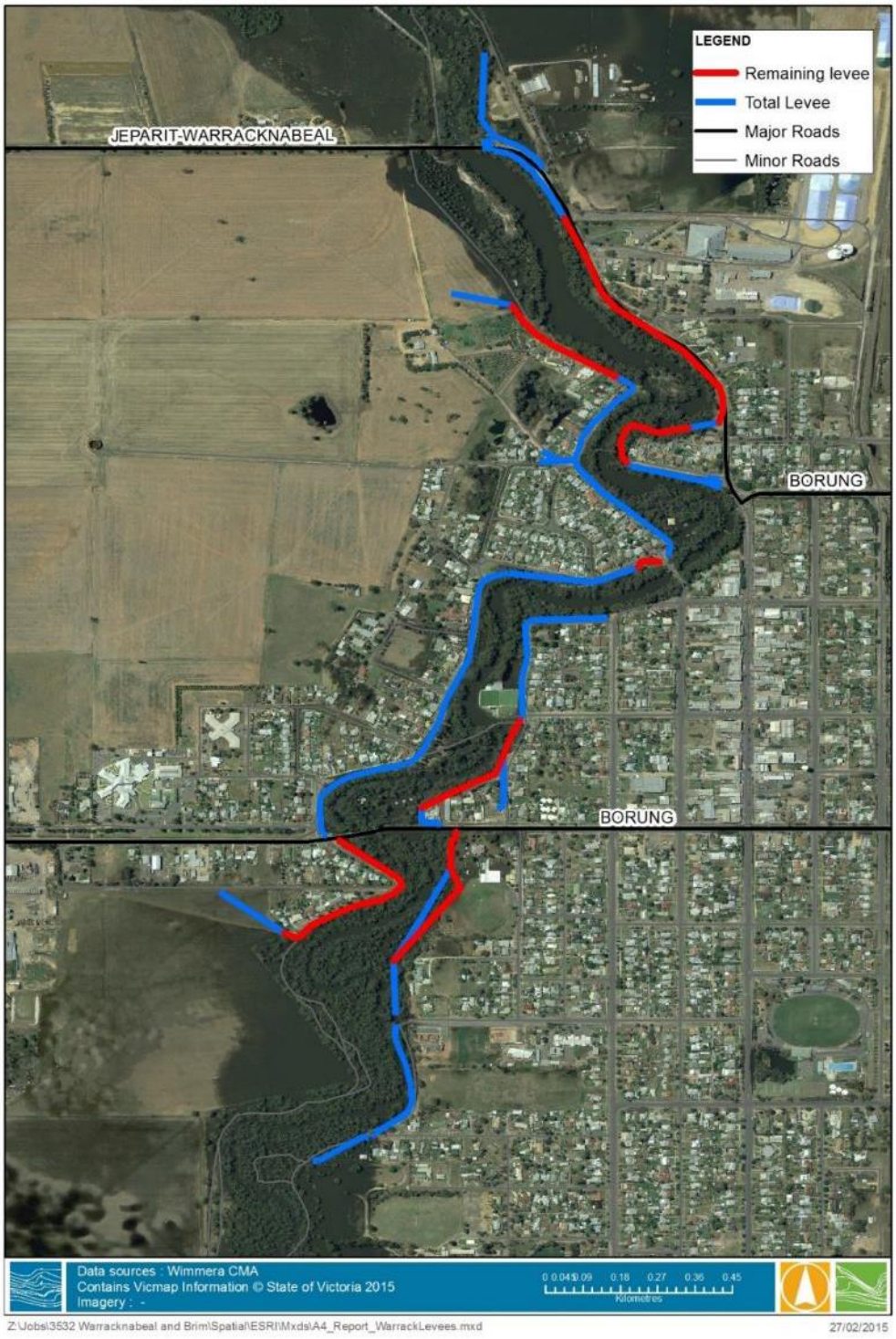

Figure 4-1 January 2011 temporary levees and current remnant sections of levee

To test the impact of the levee constructed during January 2011 during a 1% AEP event, the levee was incorporated into the 1% AEP flood model. In the Warracknabeal existing conditions modelling (with current remnant levees), there are 23 buildings flooded above floor, and 103 below floor (including all buildings surveyed). Including the entire January 2011 levee in the modelling reduced this to just 1 building flooded above floor and two below, as shown in Figure 4-2.

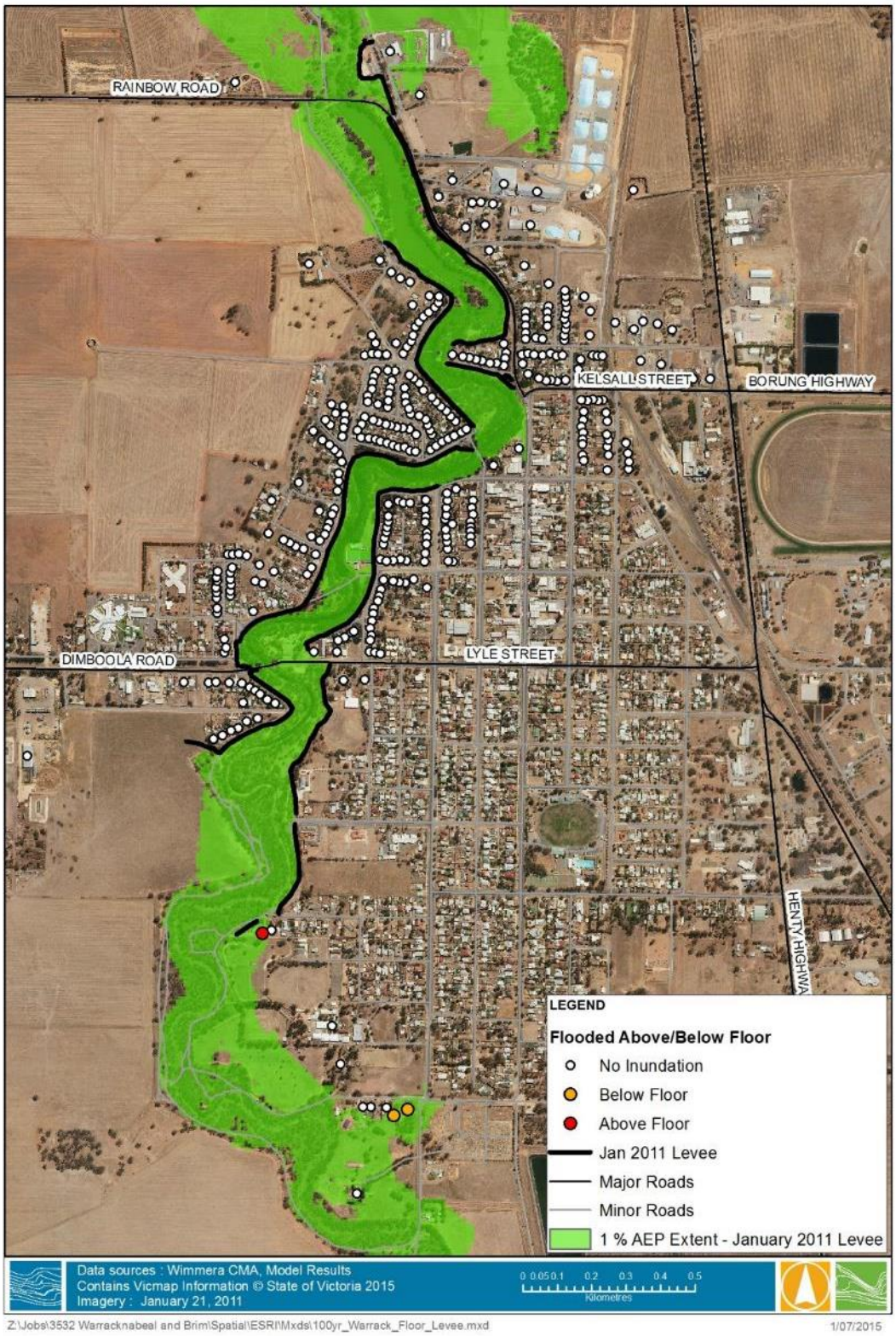

Figure 4-2 Yarriambiack Creek 1% AEP flood event with the January 2011 Levee

The total levee as constructed in January 2011 reduces the extent of inundation through the Warracknabeal township. The levees act to reduce the flow area available to convey floodwater through the township so water levels inside the levees along Yarriambiack Creek is increased. A difference between the existing and January 2011 water levels was determined as:

*Difference in Water Level (*Figure 4-3*) = January 2011 Levee Scenario – Existing Conditions Scenario*

The result shows positive values where there is an increase in water level and negative values where there is a decrease. The difference between the January 2011 and Existing Conditions Scenarios is shown in Figure 4-3.

Implementing the full January 2011 levee alignment results in a maximum increase in water levels of 0.2 m immediately downstream of the Warracknabeal Weir. Several industrial buildings are protected, as shown in Figure 4-4. This localised increase does not appear to impact on any buildings. There is also an increase between the levee banks of 0.15 m, as shown in Figure 4-5.

Increases in water levels downstream of Lyle Street (north) have impacted on the bowling green and the caravan park. Floor levels for these locations were not surveyed as part of the original Warracknabeal and Beulah Flood Study[1] and whether or not buildings are flooded above or below floor is unknown.

The one building (shed) remaining flooded above floor in Wood Street has a water level increase of 0.03 m. During January 2011 this property is understood to have been protected by a private levee. This has not been included in the January 2011 levee scenario. There is no increase in water levels at the two buildings flooded below floor.

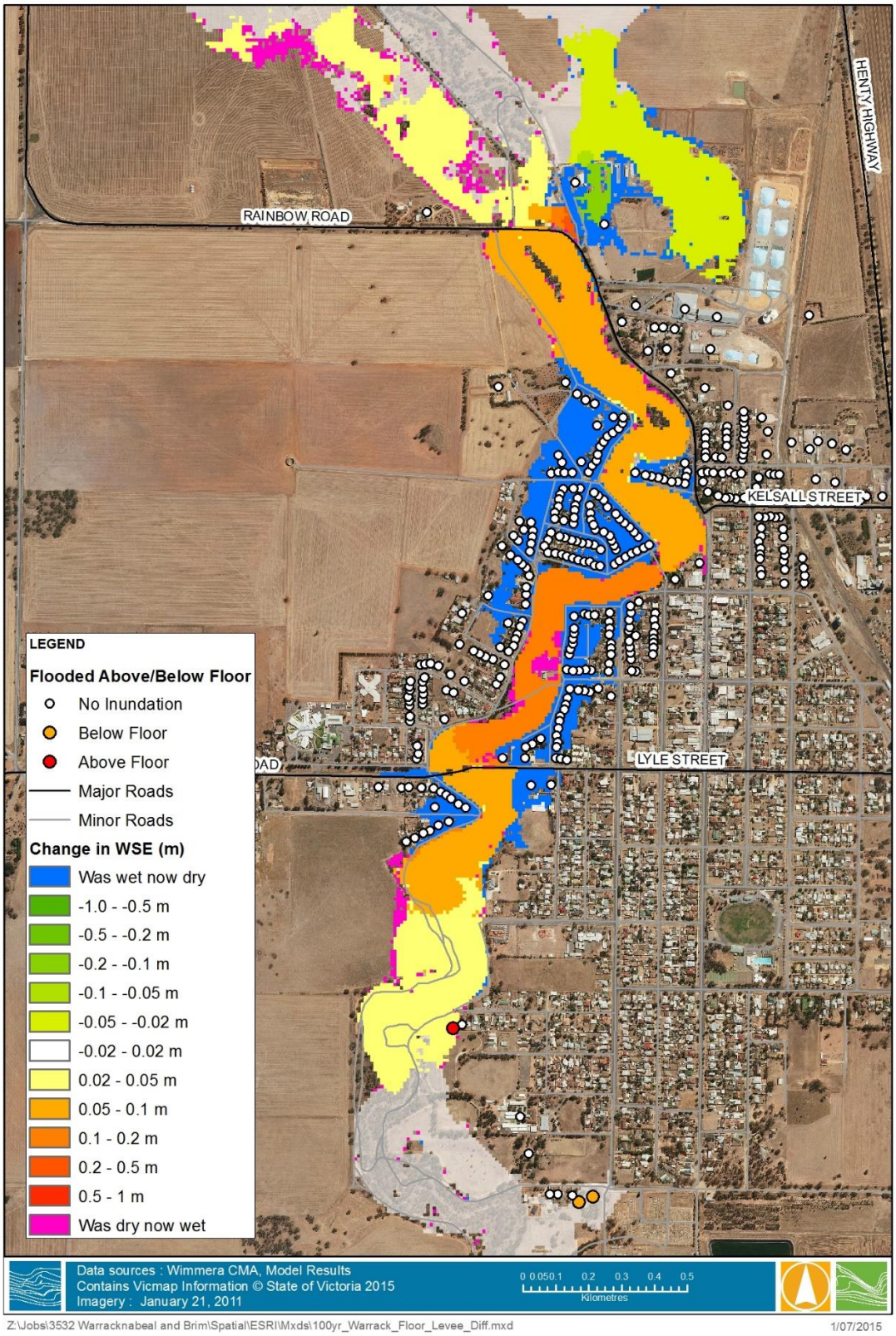

Figure 4-3 **Yarriambiack Creek 1% AEP event - Change in water levels due to the construction of the full January 2011 levee alignment**

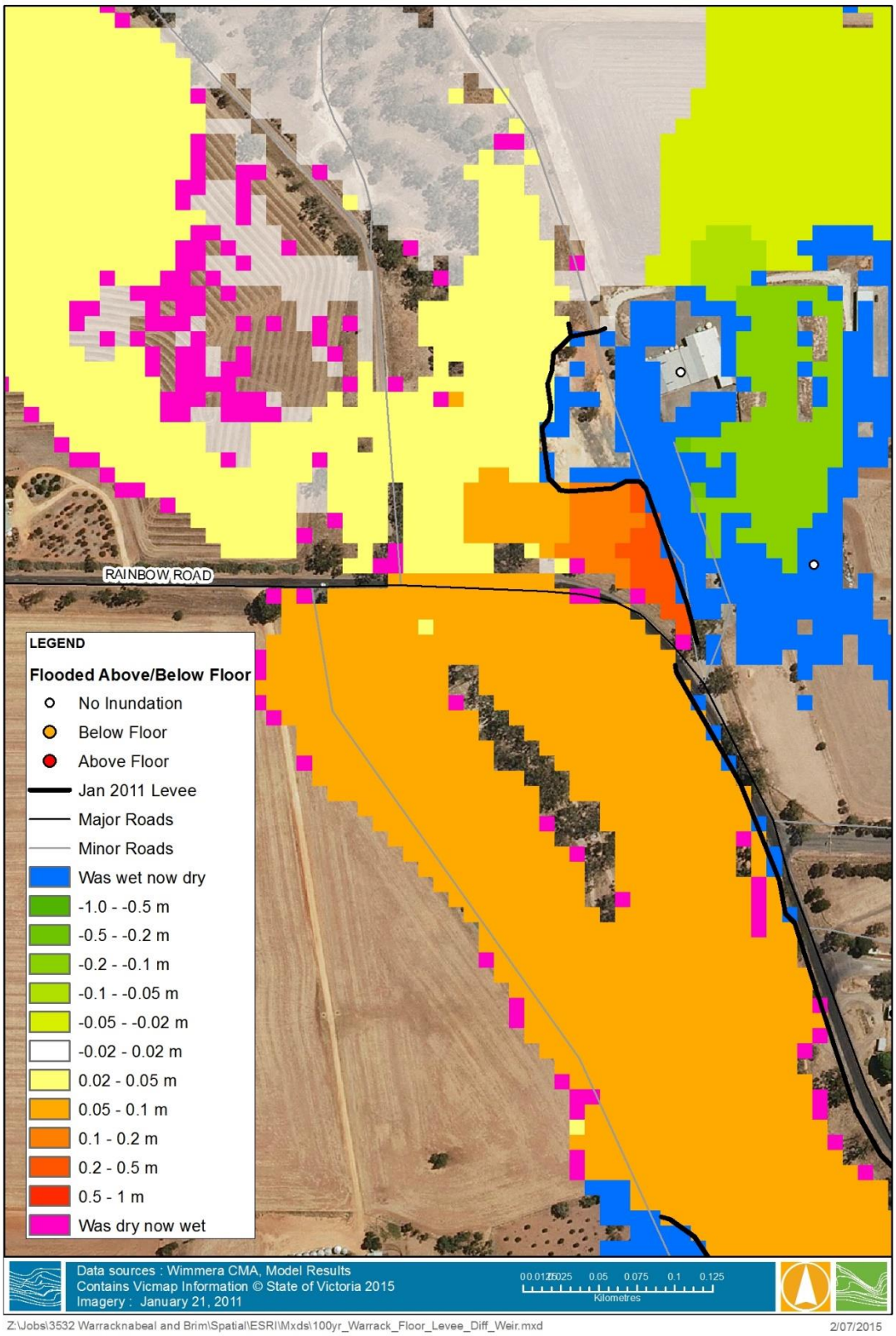

Figure 4-4 **Yarriambiack Creek 1% AEP event - Change in water levels due to the construction of the full January 2011 levee alignment, downstream of Warracknabeal Weir**

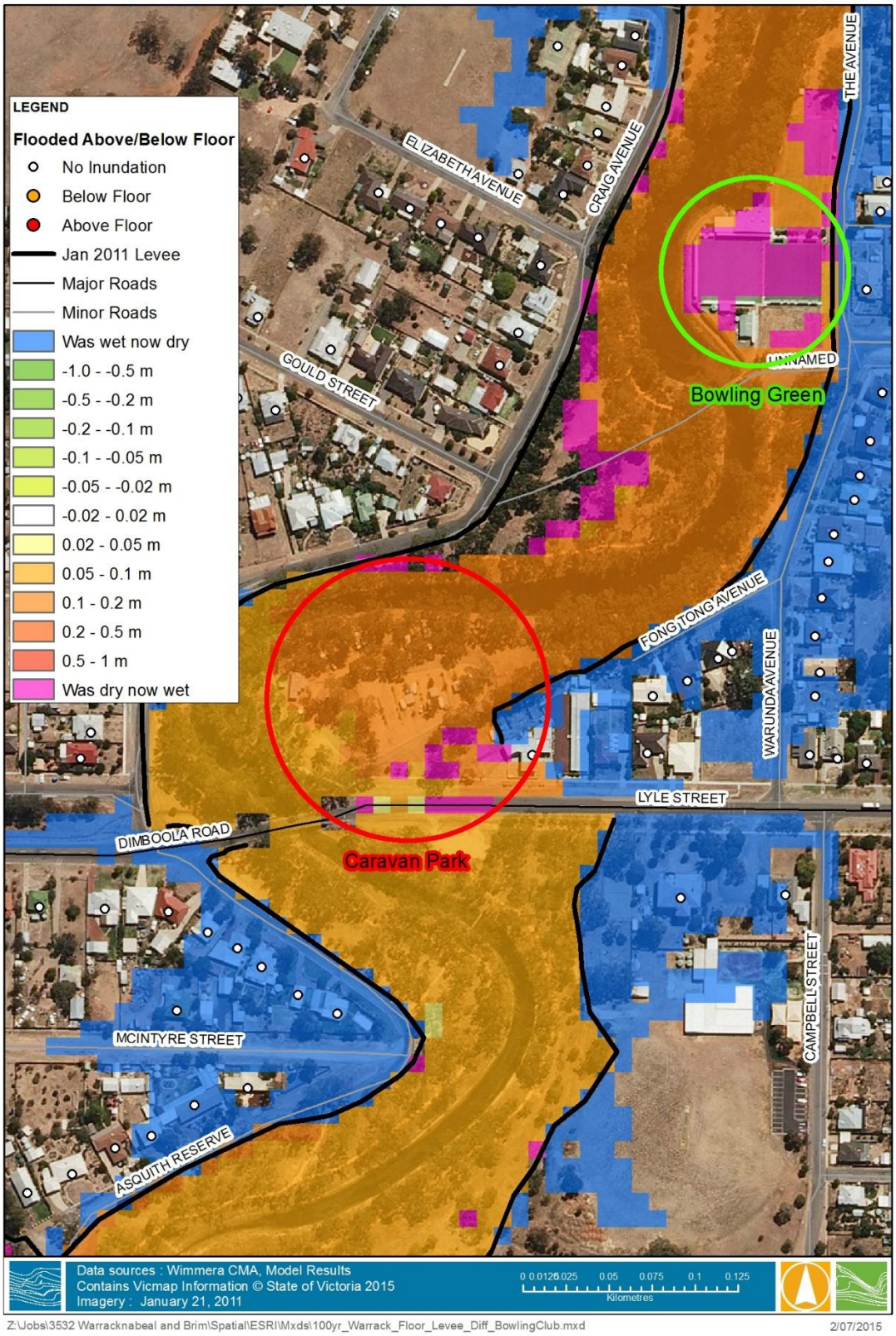

Figure 4-5 **Yarriambiack Creek 1% AEP event - Change in water levels due to the construction of the full January 2011 levee alignment, downstream of Lyle Street**

4.3 Hydraulic model assessment

4.3.1 Overview

The water level comparison between the existing and January 2011 levee scenario assisted in understanding potential for improvements in the levee alignment. A series of potential options for improvement were developed by the Project Steering Committee, Wimmera CMA and Water Technology, these potential improvements are shown below:

- Changing the levee alignment to include the Warracknabeal Bowls Club (Figure 4-6)
- Increase the levee length to better protect the industrial area north of Warracknabeal (Figure 4-7)
- Private levee for single building flooded above floor (Figure 4-8)
- Private levee for two buildings flooded below floor (Figure 4-9)
- Structure capacity increases

The options were assessed using the calibrated hydraulic model to determine their impact on the properties they protect and those that remain unprotected.

Several other scenarios were run as a sensitivity test to determine their impact, these were:

- Blocking several major structures on Yarriambiack Creek
- A reduction in floodplain storage downstream of Warracknabeal Weir

Each model scenario is discussed in the following sections.

Figure 4-6 **Yarriambiack Creek 1% AEP flood event – Potential levee option at the Warracknabeal Bowling Club**

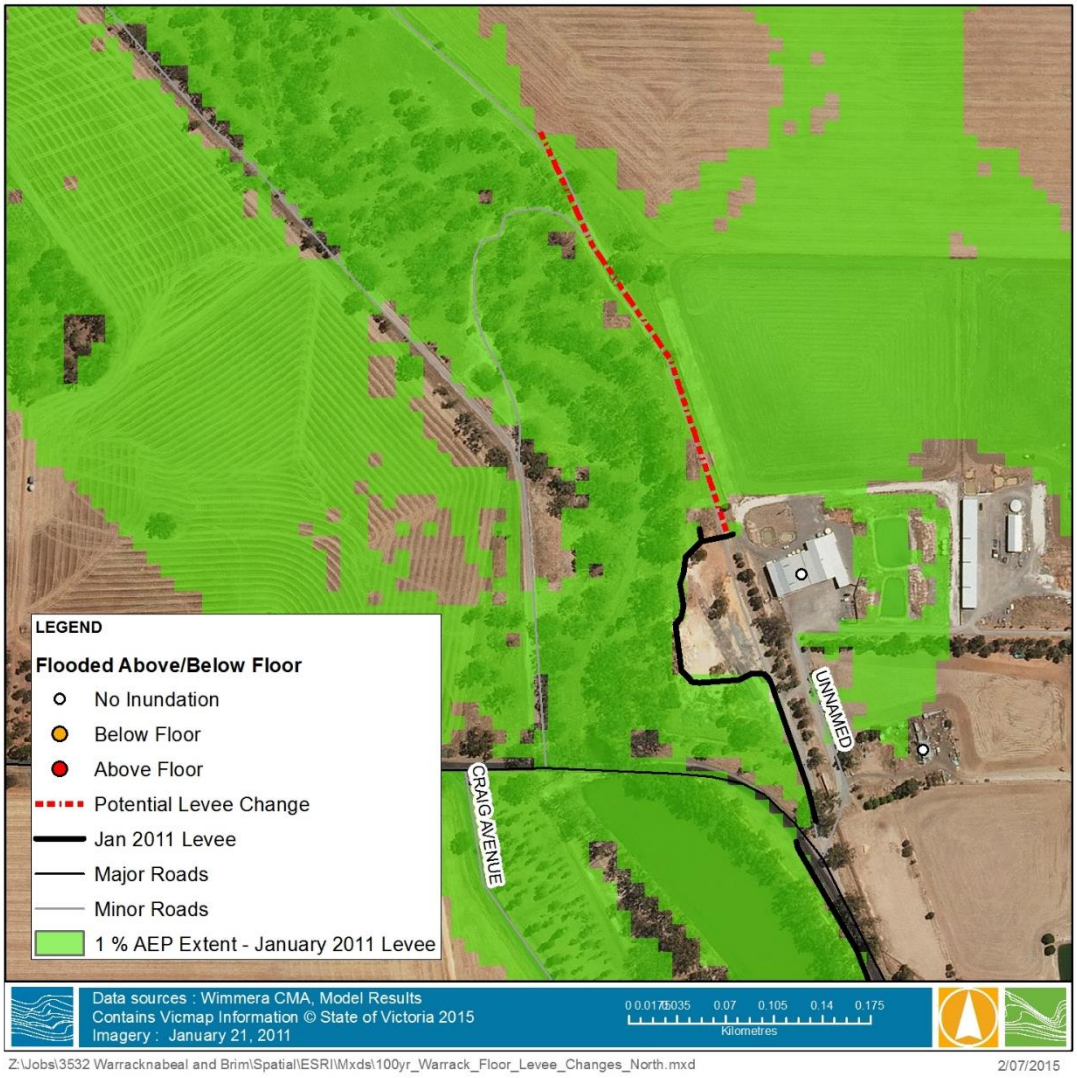

Figure 4-7 Yarriambiack Creek 1% AEP flood event – Potential levee option north of Warracknabeal

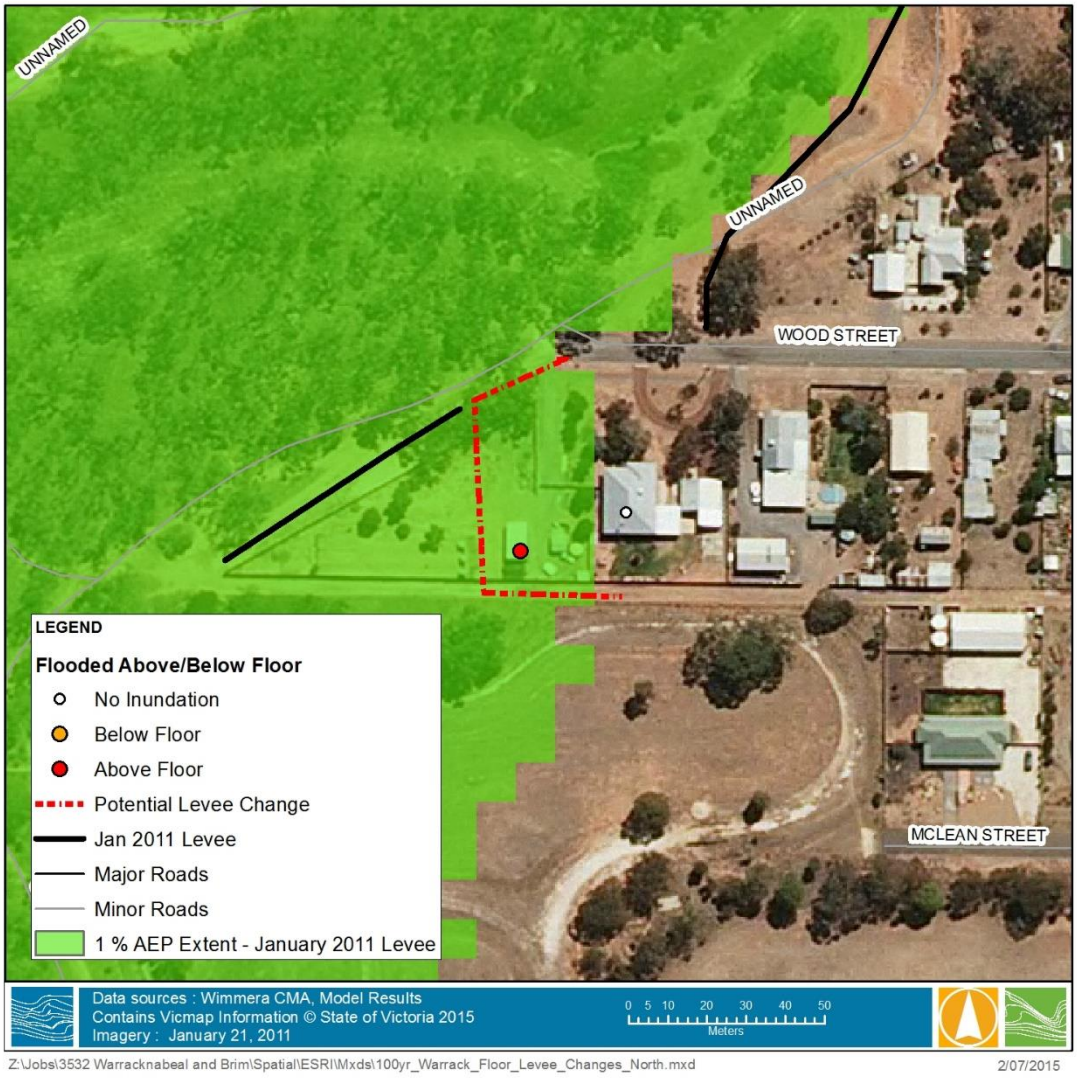

Figure 4-8 **Yarriambiack Creek 1% AEP flood event – Potential levee changes at the building flooded above floor**

Figure 4-9 Yarriambiack Creek 1% AEP flood event – Potential levee changes at the buildings flooded below floor

4.3.2 Hydraulic Modelling

Removal of remnant levees

Removal of the remnant and formalised Yarriambiack Shire Council levees was modelled to understand the impact of the remaining levees. The modelling was used to determine what a flood could look like without any mitigation measures in place (excluding the size increase at the Warracknabeal Weir).

A comparison of the existing conditions (remnant levees remaining) and removed remnant levee scenarios is shown in Figure 4-10 with a closer perspective of the southern and northern levees shown in Figure 4-11 and Figure 4-12 respectively.

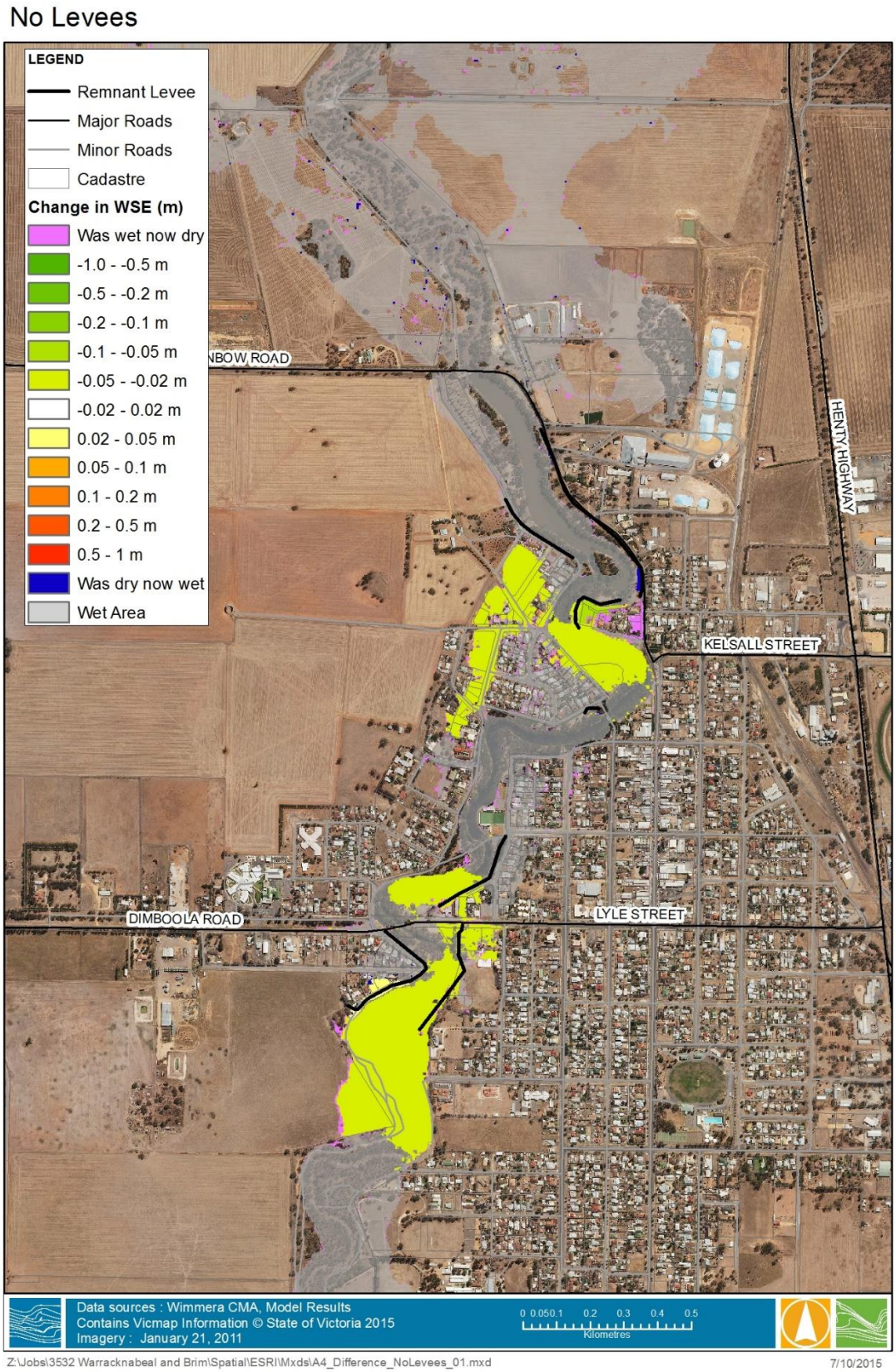

Figure 4-10 Change in water levels as a result of removing the remnant levees

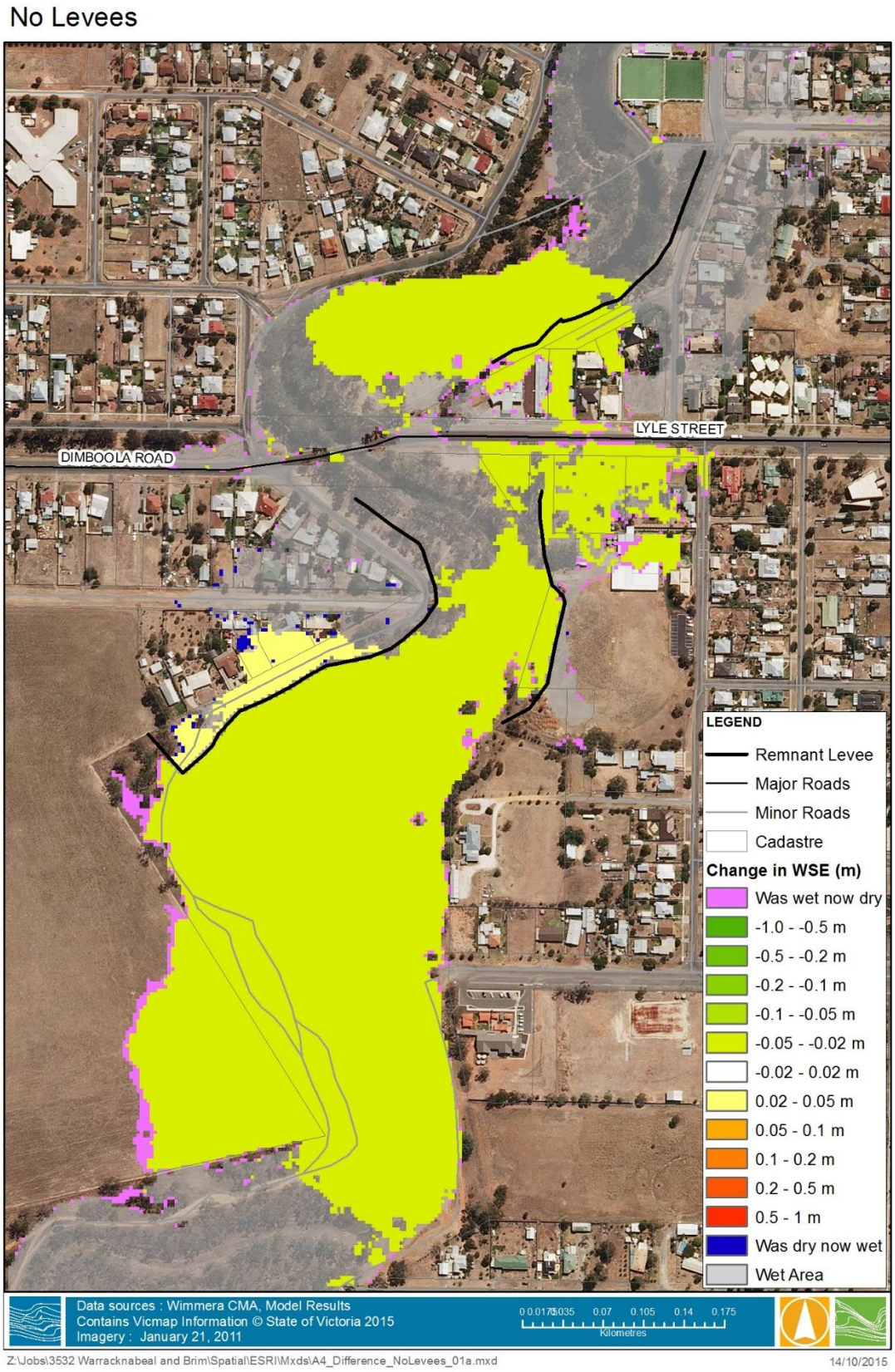

Figure 4-11 Change in water levels as a result of removing the remnant southern levees

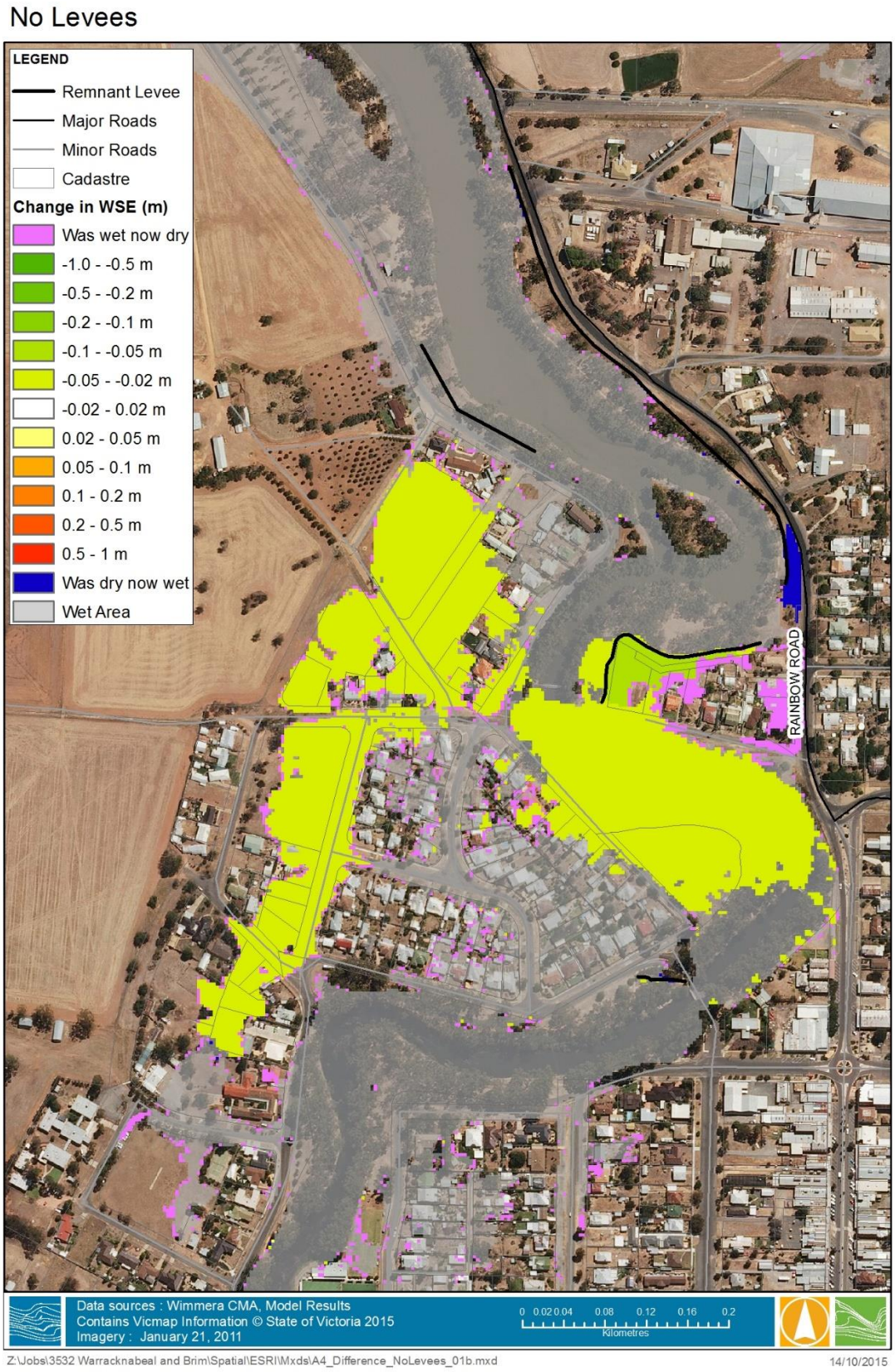

Figure 4-12 Change in water levels as a result of removing the remnant northern levees

The removal of the remnant levees has resulted in a general reduction in water levels in Yarriambiack Creek and the floodplain. This is due to the remnant levee system having gaps in it, with water outflanking the existing remnant levees. These remnant levees are currently not providing full protection and when water outflanks them it gets trapped behind them, so removing them actually lowers water levels. The majority of the remnant levees are also not high enough to prevent overtopping of the 1 % AEP event.

Bowling Club Levee

The Warracknabeal Bowling Club in not inundated during the 1% AEP design modelling, however modelling with the inclusion of the January 2011 levee has shown the constriction the levee causes increases flood levels in this area, as shown in Figure 4-5 exacerbating inundation. The increase in water levels causes an increase in inundation extent with the bowling greens now inundated. There are two buildings at the Bowling Club, north and south of the greens. The northern building is around 190 mm lower than the southern building and is showing as flooded below floor (100 mm below floor level).

To protect the Bowling Club from inundation a levee was modelled along the edge of Yarriambiack Creek. The inclusion of the levee only caused a minor increase in water levels upstream when compared to the January 2011 levee scenario at 0.025 m. When compared to the existing conditions scenario an increase of 0.133 m was observed immediately upstream of the Bowling Club.

A comparison of the modelled water levels with the inclusion of the Bowling Club levee (as a modification to the January 2011 level) and the existing condition is shown in Figure 4-13.

The lack of increase in water levels upstream of the Bowling Club is due to the lack of floodplain conveyance across the site when it is inundated.

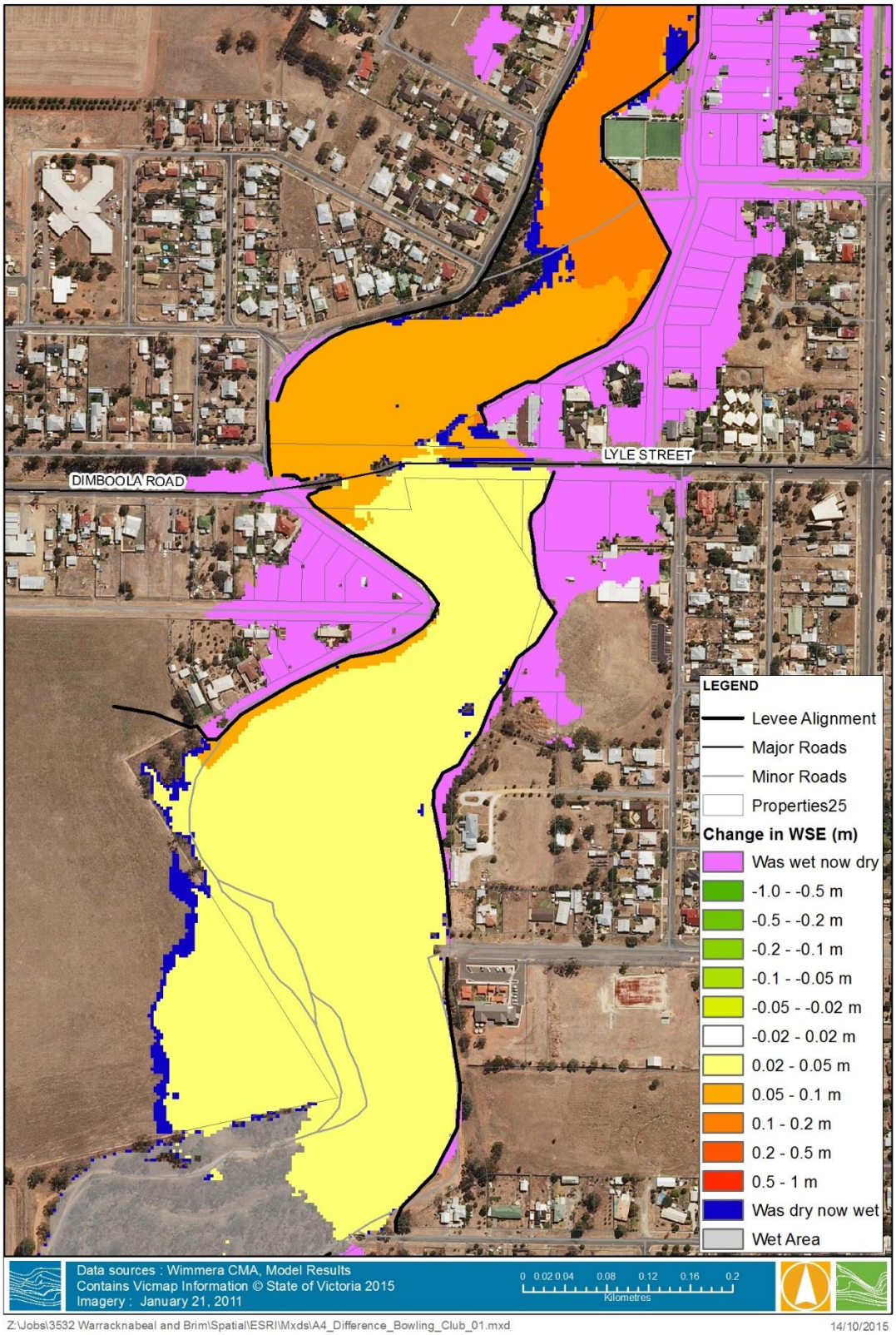

Figure 4-13 Change in water levels - The inclusion of a levee around the Bowling Club as a modification to the January 2011 levee compared to existing conditions

Joinery Levee

The joinery downstream of the Warracknabeal weir is inundated by water breaking out from Yarriambiack Creek and flowing into a low area across the site.

A levee was modelled along the western side of an unnamed road running east of Yarriambiack Creek. The levee then changed direction to the east to run along an existing internal road.

The levee alignment and change in water levels with the addition of the levee protecting the joinery is shown in Figure 4-14.

The proposed levee prevents inundation of the joinery with water now breaking out of Yarriambiack Creek to the west and flowing around the levee at the northern end. Similar to the January 2011 levee there is an increase in water levels in the immediate vicinity of the levee, however the increases are only relatively isolated. Upstream of the Warracknabeal Weir the increases are marginally over 0.02 m and decrease to zero.

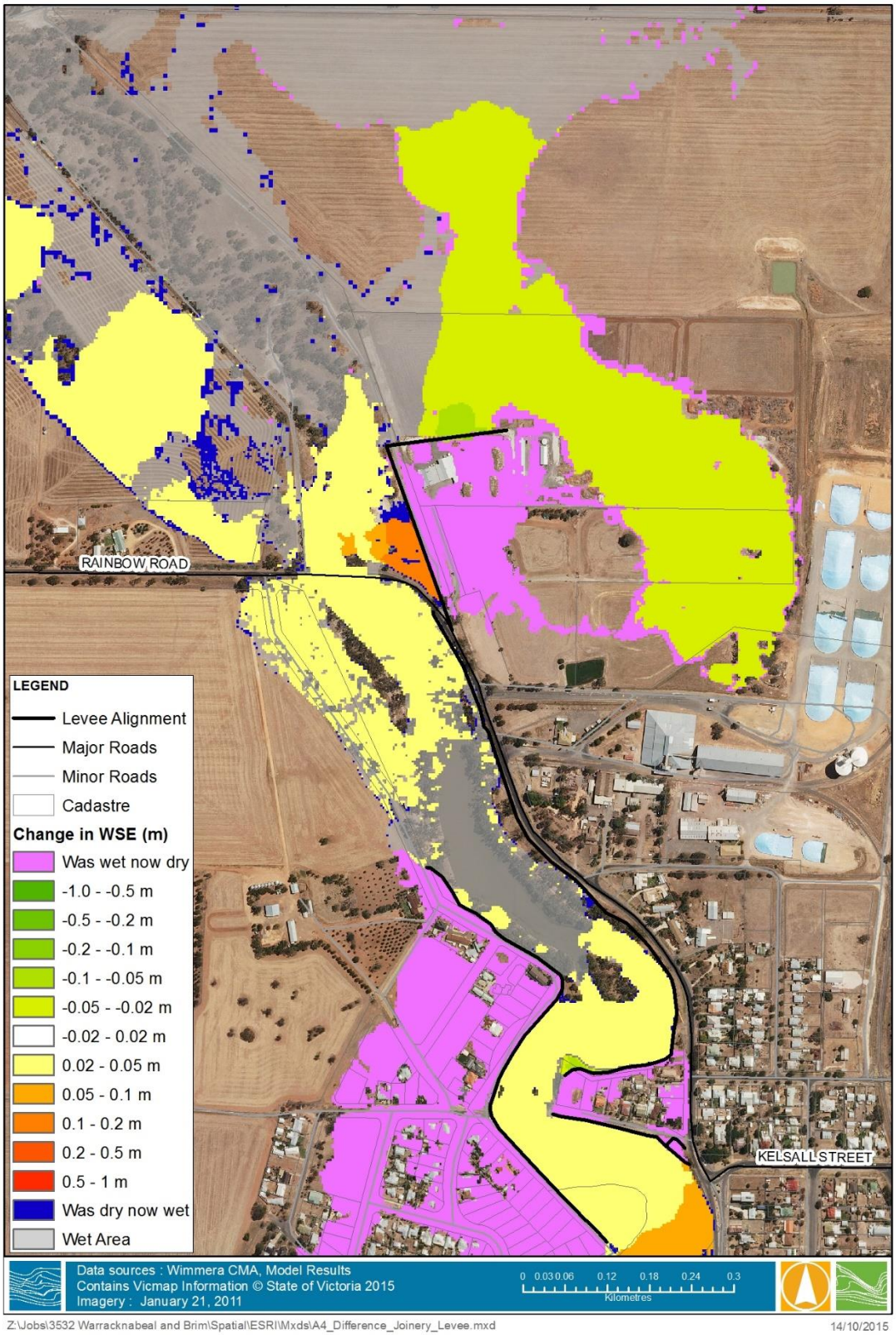

Figure 4-14 Change in water levels - The inclusion of a levee protecting the joinery as a modification to the January 2011 levee compared to existing conditions

Increased Structure Capacity

To test the impact of increasing structure capacity in Yarriambiack Creek through Warracknabeal the two major structures; Dimboola Road and Jamouneau Street were completely removed, simulating the lagest possible capacity increase. The Warracknabeal Weir has already undergone significant works to increase its capacity.

The opened structures and change in water levels as a result of the opening is shown in Figure 4-15.

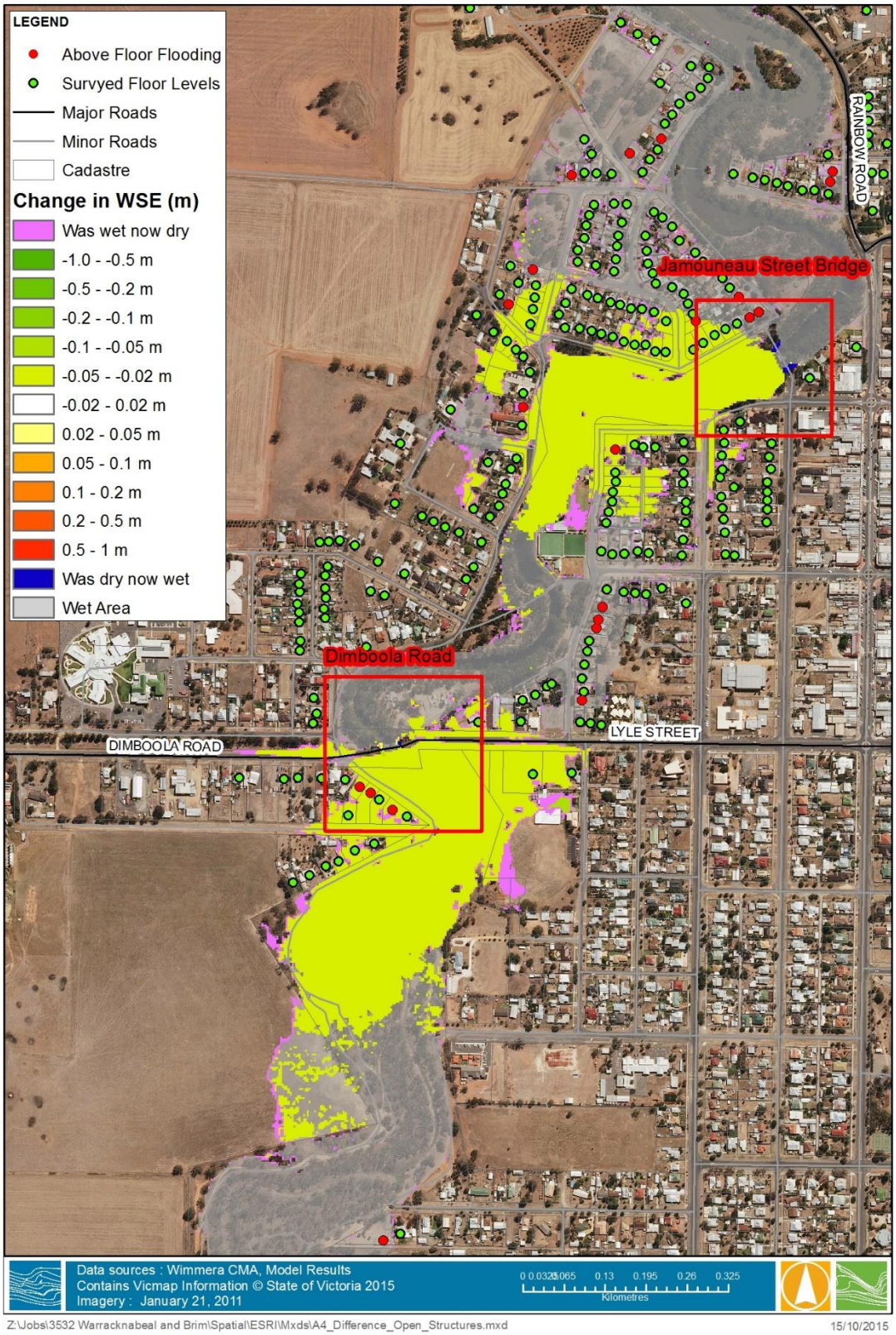

Figure 4-15 Change in water levels – Opening Yarriambiack Creek structures in Warracknabeal

Opening of the Yarriambiack Creek structures at Dimboola Road and Jamouneau Street had caused a relatively localised reduction in water levels upstream of each location. In both cases this reduction was around 0.03 m.

Upstream of Jamouneau Street the reduction in flood levels impacts on two buildings flooded above floor, one each in Kokoda Avenue and The Avenue. Both are flooded above floor in excess of 0.15 m and remain flooded above floor on the structure opening scenario.

Upstream of Dimboola Road the reduction in flood levels impact on three neighbouring buildings flooded above floor on Asquith Reserve Road. One of these is a shed inundated by 0.19 m. The other two buildings are dwellings flooded above floor by 0.04 m and 0.02 m. The reduction in flood levels due to opening Dimboola Road is 0.035 m, alleviating above floor flooding at one property. However, practically speaking, with the reduced flood level only marginally below the floor level, it is likely to be impacted to above floor level by wave action from traffic.

Reduction in Floodplain Storage DS of Warracknabeal Weir

To assist in understanding the impact that uncontrolled levee construction could have on floodplain water levels and extents a reduction in floodplain storage was modelled north of Warracknabeal Weir. In this section of Yarriambiack Creek there has been some levee construction in the past in an attempt the prevent inundation of agricultural land. The reduction in storage was modelled as a levee either side of Yarriambiack Creek.

The levee alignments and the change in water levels due to the loss of floodplain storage downstream of the Warracknabeal Weir is shown in Figure 4-16 with a closer perspective of the Warracknabeal township shown in Figure 4-17.

The loss of floodplain storage downstream of Warracknabeal Weir caused an approximate 0.12 m increase in water level immediately upstream of the weir pool. This increase dissipates to zero at around the Bowling Club. The increase in water levels has caused an increase in inundation extent, this is most prominent on the eastern side of Yarriambiack Creek where additional commercial and residential areas are inundated.

Within the area of water level increases there are 13 buildings flooded above floor in the 1% AEP existing conditions results. Each of these buildings is flooded to a greater depth varying from 0.05 to 0.07 m. There are also an additional 13 buildings flooded above floor as a result of the loss of floodplain storage.

The buildings flooded above floor in existing conditions are shown in Figure 4-17 with green markers, additional buildings flooded above floor in the reduction in storage scenario are shown with red markers.

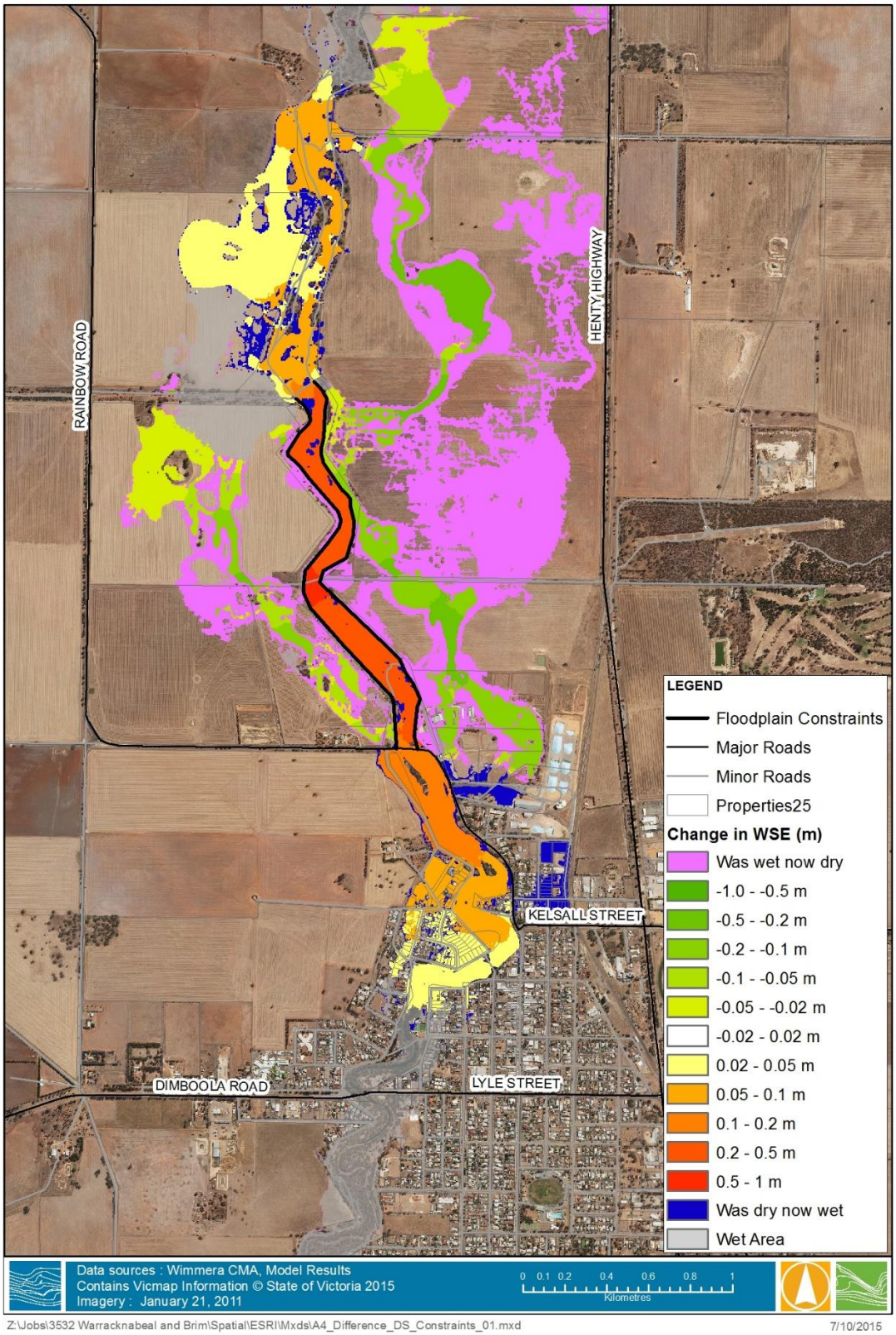

Figure 4-16 Change in water levels – Loss of floodplain storage downstream of Warracknabeal Weir

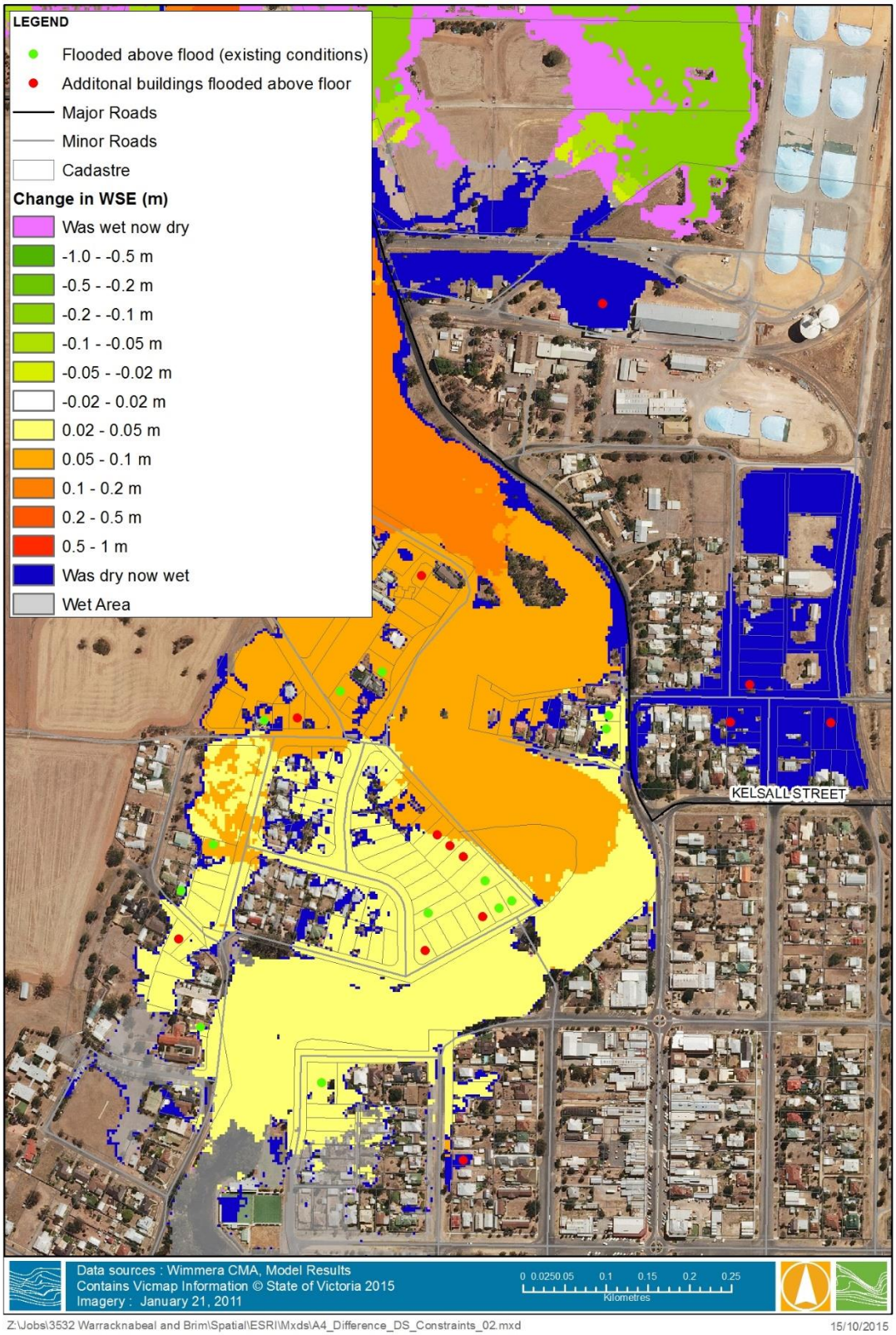

Figure 4-17 Change in water levels in Warracknabeal – Loss of floodplain storage downstream of Warracknabeal Weir

Individual Levee Protection

There are three buildings to the south of Warracknabeal impacted by floodwater in the 1% AEP event with the inclusion of the levee along the same alignment as January 2011. One shed is flooded above floor and two houses below floor. Protecting these properties was modelled with the inclusion of separate levees. The levee alignments and change in water levels due to their construction is shown in Figure 4-18. It is important to note the shed flooded above floor was flooded marginally deeper (less than 0.02cm) with the January 2011 levee scenario.

The inclusion of private levels reduced the area of inundation protecting both the shed flooded above floor and the dwellings flooded below floor. The northern levee protecting the shed caused an isolated increase of 0.02 m and a marginal increase in inundation extent. The southern levee did not cause any increase in water levels or extents.

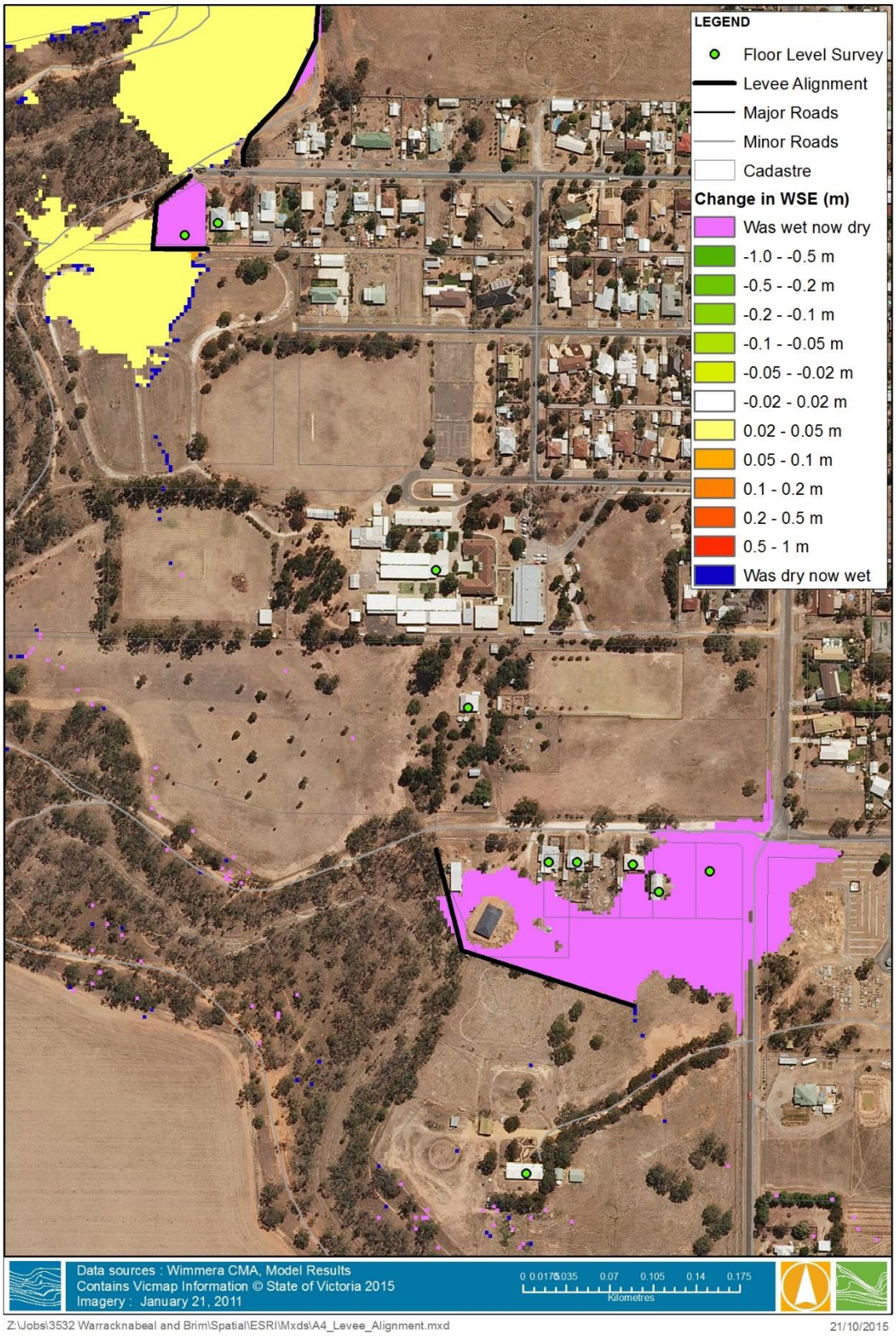

Figure 4-18 Change in water levels – Levees protecting three dwellings on the southern edge or Warracknabeal

Combined Mitigation Package

Several of the modelled mitigation measures were combined into a mitigation package. The combined option aimed to not negatively impact any private built assets in Warracknabeal while reducing the number of properties flooded above and below floor to as low as possible.

The combined mitigation package included levees similar to that constructed during January 2011 with the following modifications:

- A levee protecting the industrial area north of Warracknabeal
- Modification to the levee protecting the Bowling Club
- Two private levees protecting the areas south of Warracknabeal

The combined mitigation scenario and 1% AEP inundation extent is shown in Figure 4-19 with a comparison of the combined mitigation package and existing conditions water levels and properties flooded above and below floor in Warracknabeal shown in Figure 4-20. Under the combined mitigation package no buildings are flooded above or below floor.

Combined Mitigation Package is the recommended mitigation option for Warracknabeal. More detail around the mitigation package, levee alignments and heights is discussed in Section 0.

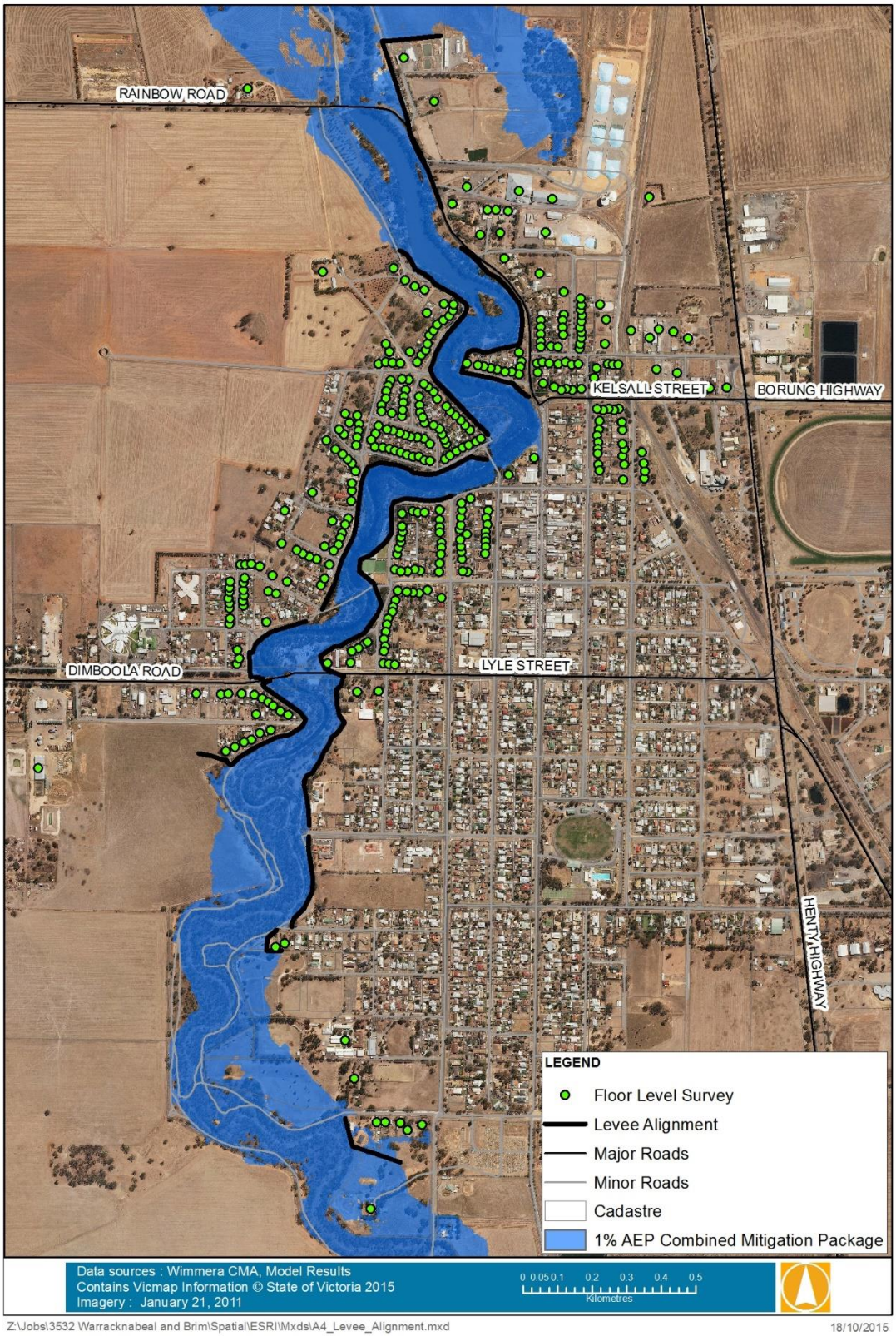

Figure 4-19 Inundation extent and levee alignments for the combined mitigation package

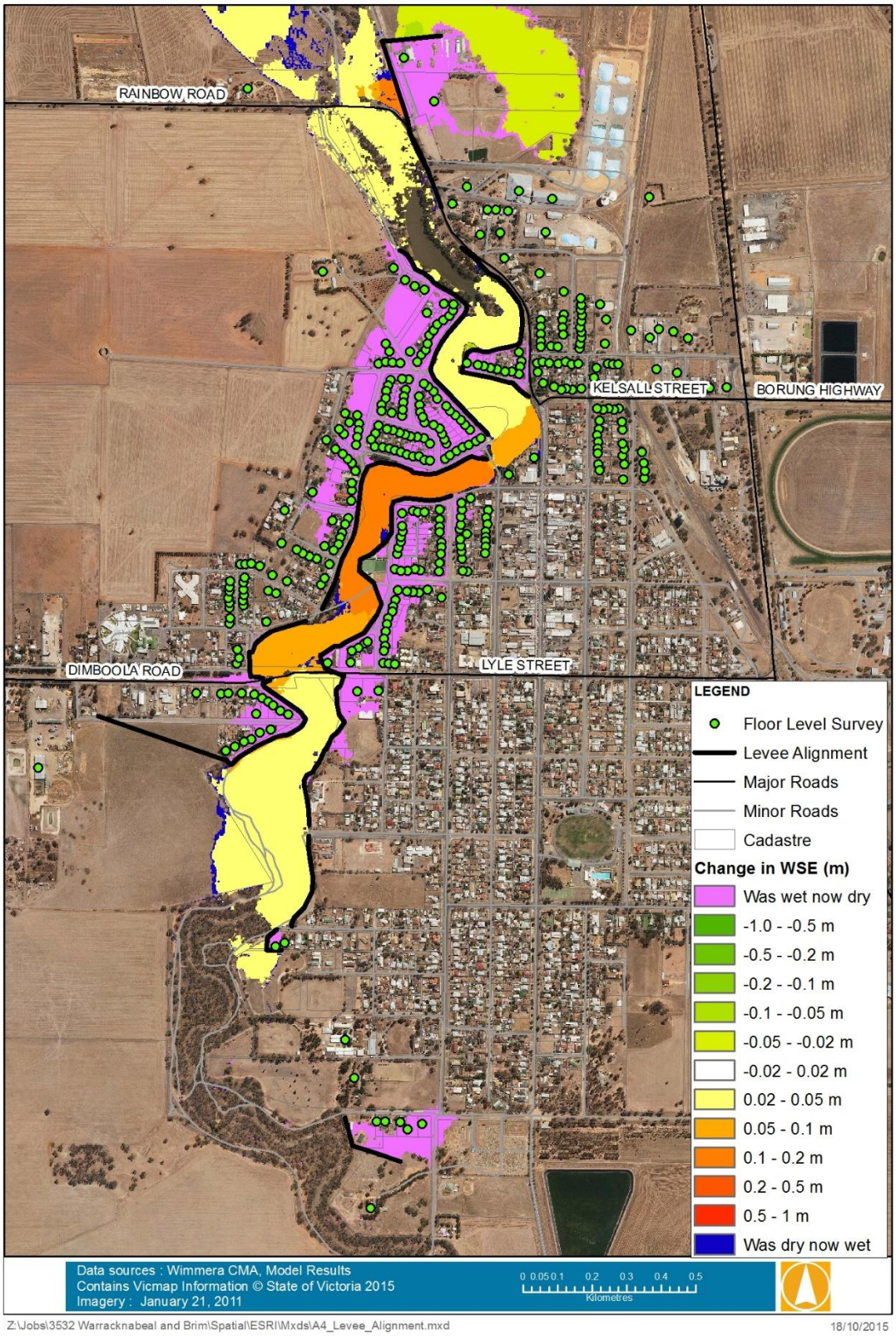

Figure 4-20 Change in water levels – Combined Mitigation Package

Levee Failure

With the construction of any flood protection levee there is a risk the levee may fail. The most likely points of levee failure are on the outside of bends where the velocity is the highest and there is a chance of the river migrating and the bank collapsing, or where there are points of weakness in the levee such as cracks, holes, poorly constructed sections, informal crossings which lower the crest over time, services such as pipes that run through the levee which have not been adequately set in, etc.

The combined mitigation package was reviewed to determine two potential points of failure, one on either side of Yarriambiack Creek. The points of failure were determined on where the levee might fail and where a potential failure could have the highest consequence in terms of property damage. The chosen failure locations and buildings flooded above and below floor in existing conditions are shown in Figure 4-21. Several buildings are flooded above and below floor downstream of each failure location highlighting high consequence for failure in those locations.

The levees were failed along an approximate 15 m length at the peak height of the 1 % AEP event, with an hour duration for the levee failure to breach to ground level. The levee failures were used as a sensitivity test that may assist in understanding the potential result of a levee failure.

The inundation extent and properties flooded above floor for Levee Failure Scenario 01 and 02 are shown in Figure 4-22 and Figure 4-23 respectively.

In the area of Levee Failure 01, the existing conditions results show 10 buildings flooded above floor (see Figure 4-21). Levee Failure Scenario 01 resulted in 29 buildings becoming flooded above floor and 55 below. All the building inundation in Warracknabeal was limited to the area of levee failure with flood water unable to re-enter Yarriambiack Creek and pooling.

In the area of Levee Failure 02, the existing conditions results show 5 buildings flooded above floor (see Figure 4-21). Levee Failure Scenario 02 resulted in 13 buildings becoming flooded above floor and 36 below. Similar to Failure Scenario 01, all the building inundation in Warracknabeal was limited to the area of levee failure with flood water unable to re-enter Yarriambiack Creek and pooling.

These results demonstrate the residual risk of living behind a levee. There is a danger that complacency may set in with residents and authorities lulled into a false sense of security, with the assumption that all risk has been removed because they are behind a levee. The reality is that larger events can occur and overtop or outflank a levee, and a levee can fail. For these reasons it is imperative that a levee system is maintained, that flood related planning conditions are in place and that communities are educated to their risk and understand what it means for them.

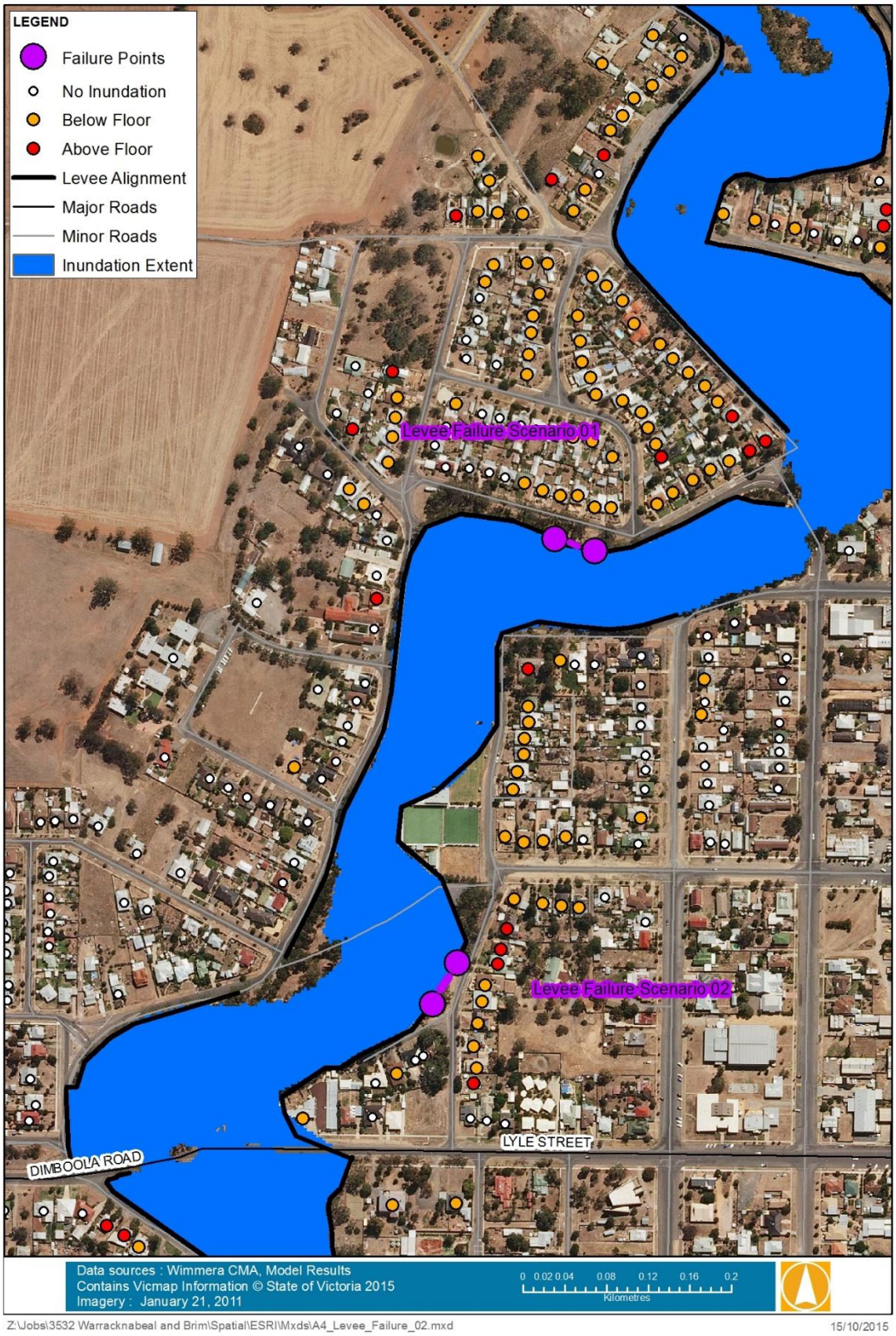

Figure 4-21 Levee failure locations

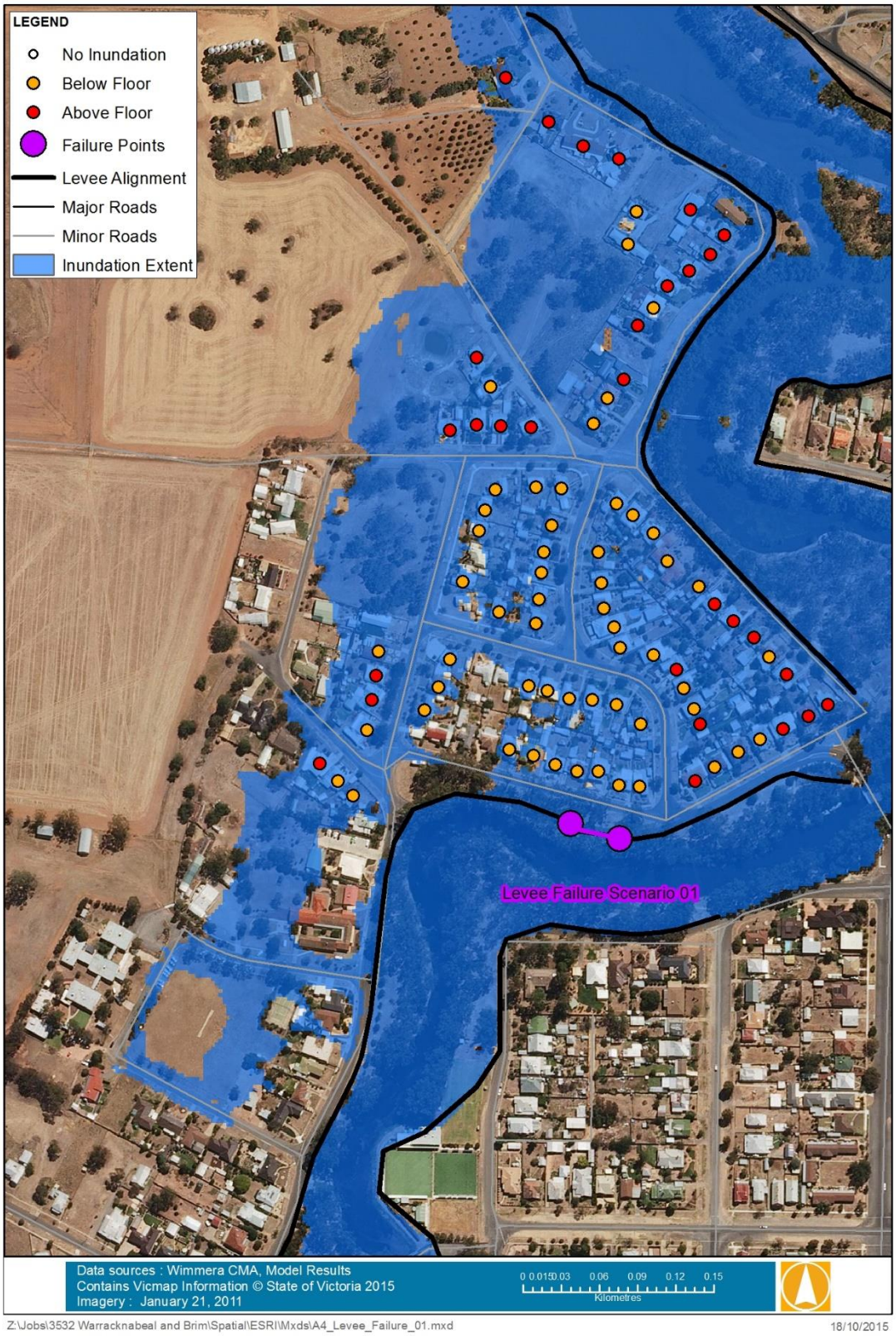

Figure 4-22 Levee Failure Scenario 01 – Inundation extent and properties flooded above floor

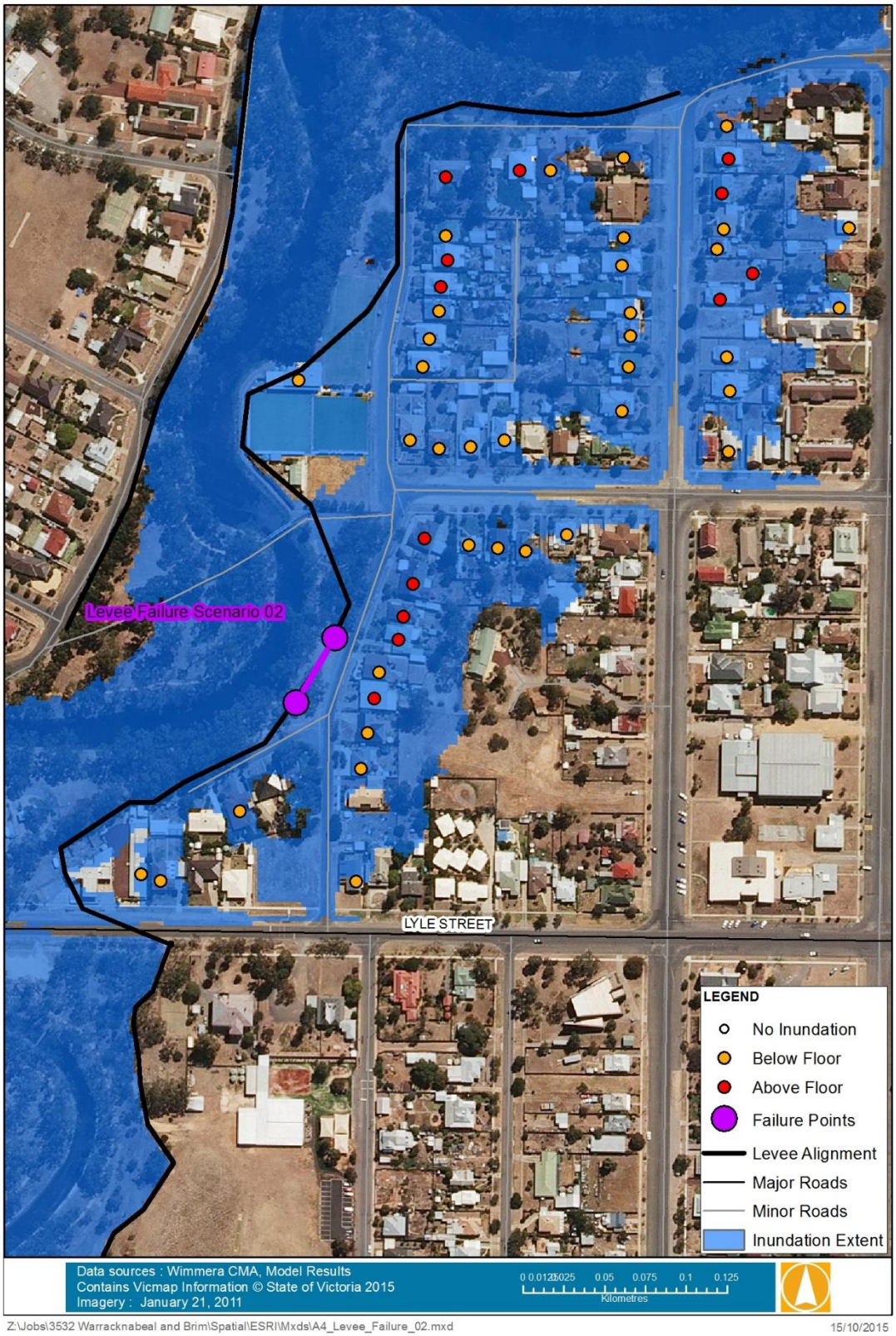

Figure 4-23 Levee Failure Scenario 02 – Inundation extent and properties flooded above floor

Structure Blockage

To assess the potential impact of structure blockage the major Yarriambiack Creek structures were blocked to 100% as a sensitivity test. The blocked structures included Dimboola Road, Jamouneau Street and the Warracknabeal Weir.

The difference in flood level caused by blockage of all three structures is shown in Figure 4-24.

There is a significant increase in inundation extent north of Kelsall Street and with the maximum increase in flood levels observed upstream of the Warracknabeal Weir at around 0.2-0/0.25 m

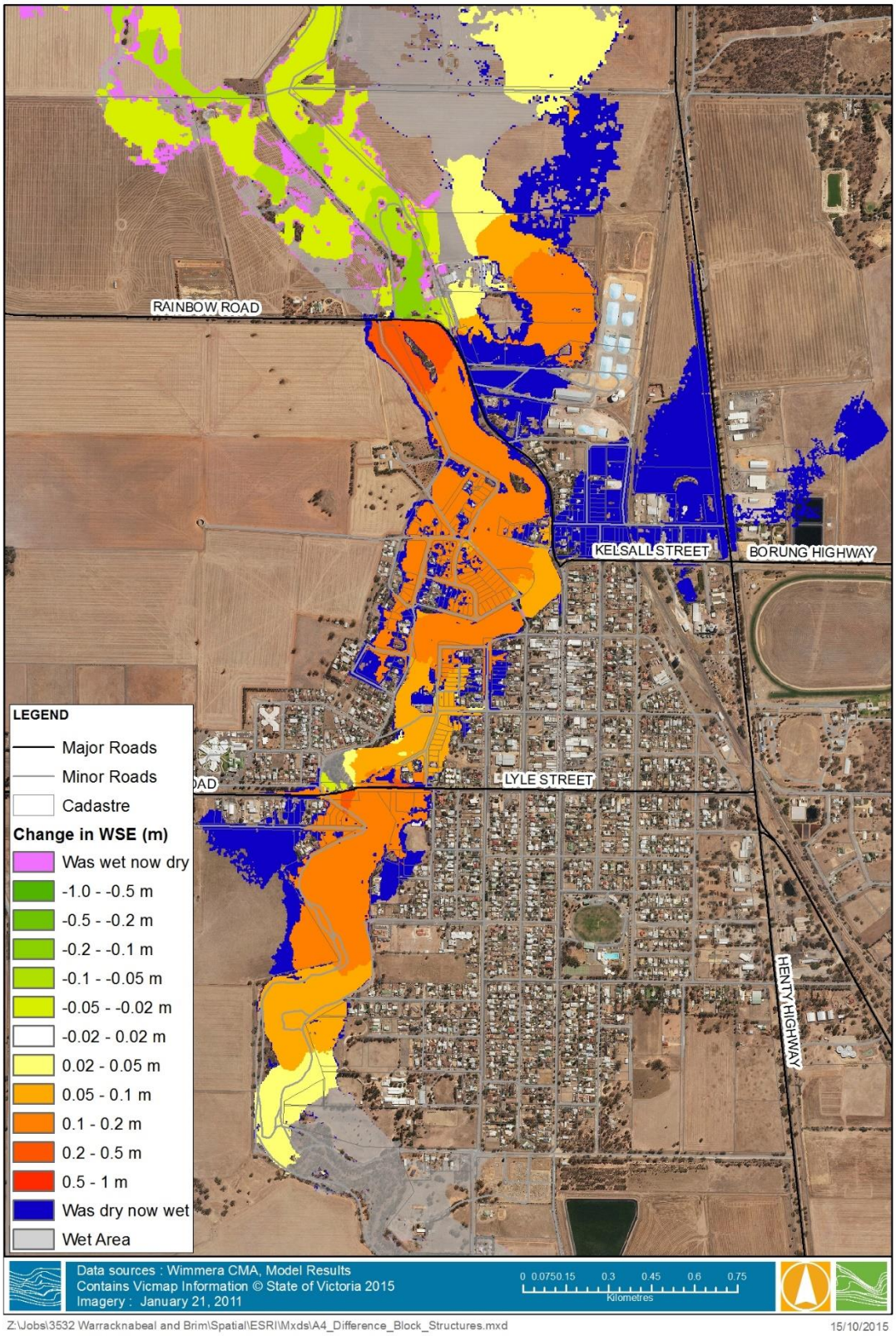

Figure 4-24 Structure Blockage – Change in flood levels as a result of the blockage

5. FLOOD DAMAGES ASSESSMENT

5.1 Overview

A flood damage assessment for the study area was undertaken using the range of design events modelled (20%, 10%, 5%, 2%, 1% and 0.5% AEP design events) for existing conditions (i.e. with current remnant levees). The damage assessment was used to determine the monetary flood damage for the design floods.

The flood damage assessment was also undertaken for Combined Option 01.

Water Technology has developed an industry best practice flood damage assessment methodology that has been previously utilised for a number of studies in Victoria, combining aspects of the Rapid Appraisal Method, ANUFLOOD and other relevant flood damage literature. The NSW Office of Environment and Heritage stage damage curves are utilised, which represent far superior damage estimates at low depths above floor and below floor than earlier stage damage curves. Water Technology utilises WaterRide to undertake the property inspection and apply the appropriate stage damage curves.

The model results for all mapped flood events were processed to calculate the numbers and locations of properties affected. This included properties with buildings inundated above floor, properties with buildings inundated below floor and properties where the building was not impacted but the grounds of the property were. In addition to the flood affected properties, lengths and damages of flood affected roads for each event were also calculated.

Agricultural damages were included in the damages assessment of the entire study area. Agricultural areas were delineated by areas classified as Farm Zone. The predominant agricultural activity along Yarriambiack Creek is broad acre cropping, a damages rate of $150/Ha was applied based on the area of inundation occurring within the Farm Zone, this value was determined from the Rapid Appraisal Method[3].

The Average Annual Damage (AAD) was determined as part of the flood damage assessment. The AAD is a measure of the flood damage per year averaged over an extended period. This is effectively a measure of the amount of money that must be put aside each year in readiness for when a flood may happen in the future.

The AAD was calculated for the entire study area and within Warracknabeal township alone. This enables the modelled mitigation options for Warracknabeal to be compared to the existing conditions damages in the township alone rather than including the broader study area agricultural damages etc.

The damages assessment shows a slightly different number of buildings flooded above and below floor to that documented in the Flood Intelligence Report and previous discussion of the number of buildings flooded above floor. This is due to the removal of sheds (unless commercial) and multiple buildings on one allotment. The damages estimates are an assessment of the average monetary damage with ancillary buildings included in these averages. The Flood Intelligence Report includes these buildings because they are significant flood response.

[3] VDNRE, 2000 – Rapid Appraisal Method

5.2 Existing Conditions

The flood damage assessment was separated into two areas; the entire study area and the Warracknabeal township. This separation was used to enable easier comparison and assessment for the Warracknabeal township alone.

The flood damage assessment for existing conditions over the entire study area is shown below in Table 5-1. The Average Annual Damages (AAD) for existing conditions is estimated at approximately **$108,000.**

The flood damage assessment for existing conditions within the Warracknabeal township alone is shown below in Table 5-2. The Average Annual Damages (AAD) for existing conditions is estimated at approximately **$37,000.**

Table 5-1 Existing conditions damages over the entire study area

ARI (years) / AEP	200yr 0.005	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2
Residential Buildings Flooded Above Floor	46	11	4	0	0	0
Commercial Buildings Flooded Above Floor	9	3	1	0	0	0
Properties Flooded Below Floor	241	166	76	9	6	4
Total Properties Flooded	**296**	**180**	**81**	**9**	**6**	**4**
Direct Potential External Damage Cost	$884,000	$479,000	$168,000	$15,000	$3000	$3,000
Direct Potential Residential Damage Cost	$2,365,000	$560,000	$181,000	$0	$0	$0
Direct Potential Commercial Damage Cost	$441,000	$15,000	$1,000	$0	$0	$0
Total Direct Potential Damage Cost	**$3,690,000**	**$1,054,000**	**$351,000**	**$15,000**	**$3,000**	**$3,000**
Total Actual Damage Cost *(0.8*Potential)*	**$2,952,000**	**$843,000**	**$281,000**	**$12,000**	**$3,000**	**$3,000**
Rural Damage Cost	**$630,000**	**$487,000**	**$330,000**	**$170,000**	**$115,000**	**$73,000**
Infrastructure Damage Cost	**$1,309,000**	**$899,000**	**$557,000**	**$291,000**	**$212,000**	**$169,000**
Total Cost	**$4,890,000**	**$2,230,000**	**$1,168,000**	**$473,000**	**$329,000**	**$244,000**

Average Annual Damage (AAD)	$108,000

Table 5-2 Existing conditions damages over the Warracknabeal township

ARI (years) / AEP	200yr 0.005	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2
Residential Buildings Flooded Above Floor	46	11	4	0	0	0
Commercial Buildings Flooded Above Floor	9	3	1	0	0	0
Properties Flooded Below Floor	238	163	73	8	3	3
Total Properties Flooded	**293**	**177**	**78**	**8**	**3**	**3**
Direct Potential External Damage Cost	$857,000	$455,000	$148,000	$13,000	$5,000	$3,000
Direct Potential Residential Damage Cost	$2,365,000	$560,000	$181,000	$0	$0	$0
Direct Potential Commercial Damage Cost	$441,000	$15,000	$1,000	$0	$0	$0
Total Direct Potential Damage Cost	**$3,663,000**	**$1,030,000**	**$331,000**	**$13,000**	**$5,000**	**$3,000**
Total Actual Damage Cost *(0.8*Potential)*	**$2,930,000**	**$824,000**	**$265,000**	**$10,000**	**$4,000**	**$2,000**
Infrastructure Damage Cost	**$441,000**	**$298,000**	**$195,000**	**$73,000**	**$58,000**	**$50,000**

Average Annual Damage (AAD)	$37,000

5.3 Combined Mitigation Package

As detailed in Section 4.3.2 the Combined Mitigation Package comprises of a series of levees either side of Yarriambiack Creek ensuring water is held within the waterway. The levees prevent all above floor and below floor inundation within the township during the 1% AEP event.

The flood damage assessment for the Combined Mitigation Package within the Warracknabeal township is shown below in Table 5-3. The Average Annual Damages (AAD) for existing conditions is estimated at approximately **$9,000.**

Table 5-3 Combined Mitigation Package damages over the Warracknabeal township

ARI (years) / AEP	200yr 0.005	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2
Residential Buildings Flooded Above Floor	0	0	0	0	0	0
Commercial Buildings Flooded Above Floor	1	1	0	0	0	0
Properties Flooded Below Floor	24	19	15	5	0	0
Total Properties Flooded	**25**	**20**	**15**	**5**	**0**	**0**
Direct Potential External Damage Cost	$93,000	$47,000	$29,000	$0	$0	$0
Direct Potential Residential Damage Cost	$0	$0	$0	$0	$0	$0
Direct Potential Commercial Damage Cost	$19,555	$7,452	$0	$0	$0	$0
Total Direct Potential Damage Cost	**$112,594**	**$54,743**	**$28,000**	**$00**	**$0**	**$0**
Total Actual Damage Cost *(0.8*Potential)*	**$90,000**	**$44,000**	**$22,000**	**$0**	**$0**	**$0**
Infrastructure Damage Cost	**$221,000**	**$175,000**	**$137,000**	**$77,000**	**$0**	**$0**
Total Cost	**$311,000**	**$219,000**	**$159,000**	**$77,004**	**$0**	**$0**

Average Annual Damage (AAD)	**$9,000**

5.4 Non – Economic Flood Damages

The previous discussion relating to flood damages has concentrated on monetary damages, i.e. damages that are easily quantified. In addition to those damages, it is widely recognised that individuals and communities also suffer significant non-monetary damage, i.e. emotional distress, health issues, etc.

There is no doubt that the intangible non-monetary flood related damage in and along Yarriambiack Creek is high. The benefit-cost analysis presented in this report has not considered this cost. Any decisions made that are based on the benefit cost ratios need to understand that the true cost of floods in and along Yarriambiack Creek is far higher than the economic damages alone. The amount of time volunteered and equipment/material cost donated by the community to construct the temporary levees during the January 2011 flood event was also high, and was not factored into the flood damages cost included above. These intangible costs have the effect of increasing the benefit-cost ratio, improving the argument for approving a mitigation scheme at Warracknabeal.

6. BENEFIT-COST ANALYSIS

A benefit-cost analysis was undertaken to assess the economic viability of the Combined Mitigation Package. An indicative benefit-cost ratio was based on the construction cost estimates and Average Annual Damages calculated above.

6.1 Mitigation Option Cost

The cost estimate for the permanent sections of the combined mitigation package is shown in Table 6-1 with temporary sections shown in

Table 6-2. Water Technology has undertaken many levee functional designs and costings, we have developed standard spreadsheets based on industry rates from Melbourne Water and Rawlinsons. A 30% contingency cost was included along with engineering and administration costs. It should be noted that these costs are based on estimated rates and should be checked during the detailed design phase.

The Victorian Levee Guidelines has standard recommendations for levee crest width (2 m), batter slopes (3:1 batter on water side, 2:1 on dry side) and clay core with cut-off trench requirements. The levee proposed meets these requirements with a 2m crest width, 3:1 batter slopes on both sides. Further detail is included in Section 7.

The levee was designed to the 1% AEP level with the inclusion of a 100mm freeboard as specified by Yarriambiack Shire Council. This is less than the 0.5% AEP level, however, temporary sections of levee and an increase in levee height will be constructed if a flood event exceeding a 1% AEP is forecast.

The costing rates were based on a number of references:

- Melbourne Water rates for earthworks and pipe construction costs;
- Melbourne Water rates for land acquisition; and
- Comparison to cost estimates for similar works for other flood studies.

An annual maintenance cost (3% of the total construction cost) was factored in for levee works. The cost of the levee has been separated into permanent and temporary portions. Permanent portions were costed with the inclusion of a clay core and cut-off trench, while temporary sections of levee were costed based on standard levee construction rates excluding topsoiling and grassing. The

The estimated capital cost of the permanent sections of levee is $494,629. The estimated cost of the temporary section of levee is $174,954.

Table 6-1 Mitigation Cost Breakdown – Permanent Works

Levee section	Length (m)	Average height (m)	Volume (m^3)	Estimated Construction Cost	Estimated Annual Maintenance Cost
1	230	0.5	522	$16,514	$495.41
2	117	0.5	254	$8,093	$242.80
3	281	0.3	452	$14,708	$441.25
4	511	0.4	933	$30,257	$907.72
5	824	0.5	1993	$62,658	$1,879.74
6	830	0.5	1895	$48,783	$1,463.50
9	824	0.5	2300	$70,966	$2,128.99
11	694	0.4	1276	$41,255	$1,237.66
13	470	0.4	553	$15,161	$454.82
Culvert and Value allowance				$10,000	$300.00
Sub-total 'A'				$318,396	$9,552
'A' x Engineering Fee @ 15%				$47,759	$1,433
Sub-total 'B'				$366,156	$10,985
'B' x Administration Fee @ 9%				$32,954	$989
Sub-total 'C'				$484,454	$14,534
'A' x Contingencies @ 30%				$95,519	$2,866
FORECAST EXPENDITURE				**$494,629**	**$14,839**

Table 6-2 Mitigation Cost Breakdown – Temporary Works

Levee section	Length (m)	Average height (m)	Volume (m^3)	Estimated Construction Cost
1	230	0.03	131	$4,806
2	117	0.06	75	$2,718
3	281	0.09	196	$7,040
4	511	0.09	361	$12,971
5	824	0.14	683	$24,161
6	830	0.09	568	$42,549
9	824			$0
11	694	0.13	565	$20,022
13	470	0.09	335	$76,547
7	150	0.19	156	$3,898
8	238	0.24	179	$4,480
10	727	0.5	1640	$24,930
12	453	0.5	997	$24,930
14	505	0.2	335	$8,367
Sub-total 'A'				$112,619
'A' x Engineering Fee @ 15%				$16,893
Sub-total 'B'				$129,512
'B' x Administration Fee @ 9%				$11,656
Sub-total 'C'				$141,168
'A' x Contingencies @ 30%				$33,786
FORECAST EXPENDITURE				**$174,954**

6.1.1 Cost Benefit Ratio

The results of the benefit-cost analysis are shown below in Table 6-3. For this analysis, a net present value model was used, applying a 6% discount rate over a 30 year project life. The benefit cost ratio should ideally be equal to or greater than 1, meaning that the long term benefit of flood mitigation equals or exceeds the long term costs.

Table 6-3 Benefit Cost Analysis

	Existing Conditions	Combined Mitigation Package
Average Annual Damage	$37,000	$9,000
Annual Maintenance Cost	-	$7,692
Annual Cost Savings	-	$28,000
Net Present Value	-	$393,747
Cost of permanent mitigation		$494,629
Cost of temporary mitigation		$174,954
Capital Cost of Mitigation	-	$669,583
Benefit-Cost Ratio	**-**	**0.59**

7. CONCEPT DESIGN

Concept design of the Warracknabeal levee arrangements were completed in consultation with Wimmera CMA, Yarriambiack Shire Council and the Project Steering Committee.

The levee comprises of 14 sections of levee, 9 permanent sections and 5 temporary sections. The section of permanent levee t has been set at the 1% AEP level plus a 0.1m freeboard. The temporary sections of levee are at the 0.5% AEP level, additionally, if an event larger than a 1% AEP event was forecast the levee height would be increased. This is included in the Flood Intelligence Report and costing in undertaken in the Benefit-Cost Analysis.

The concept design and details around each section of levee is detailed using A1 maps in Appendix A. The Appendix A mapping includes levee alignments, type of levee proposed in each section, length, max height and average height. A colour coded map of the levee heights is also included.

Details around each of the 14 levee sections are shown in

Table 7-1, the temporary levee sections are highlighted in green.

Table 7-1 Levee details

Levee Number	Length (m)	Max. Height (m) (including 100mm freeboard on permanent sections)	Average Height (m)	Notes
1	230	0.9	0.5	Permanent earthen levee protecting 2 properties from below floor inundation
2	117	0.7	0.50	Permanent earthen levee protecting one shed from above floor inundation, township levees increase inundation at this location without protection
3	280	0.8	0.3	Permanent earthen levee
4	512	0.7	0.40	Permanent earthen levee, school levee exists at a sufficient height
5	825	1.0	0.5	Permanent earthen levee, potential for road level increases, very narrow at the rear of the bowling club
6	830	0.7	0.3	Permanent earthen levee, potential to build into existing road shoulder
7	150	0.3	0.2	Temporary earthen levee, only required for events greater than 1% AEP
8	237	0.5	0.20	Temporary earthen levee, only required for events greater than 1% AEP
9	445	1.2	0.5	Permanent earthen levee, currently partially constructed
10	727	0.8	0.5	Temporary/walking track
11	694	0.9	0.5	Permanent earthen levee, potential to use road median strip
12	450	1.0	0.5	Temporary earthen levee, only required for events greater than 1% AEP
13	470	0.8	0.4	Permanent earthen levee
14	541	0.4	0.1	Temporary earthen levee, only required for events greater than 1% AEP
Total Length (m)	**6,508 m (4,403 m permanent/2,105 m temporary)**			

Regards

Ben Hughes – Senior Engineer

Water Technology Pty Ltd