in association with

Upper Avoca River Flood Investigation

Flood Damages and Structural Mitigation Options Report

IS297900-RPT-005-Mitigation-RevA

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Pyrenees Shire Council

Cover image courtesy of ABC (2010), Avoca River floods in Victoria, https://www.abc.net.au/news/2010-09-04/avoca-river-floods-in-victoria/2248938

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Definitions

Annual Exceedance Probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 cubic metres per second has an AEP of five per cent, it means that there is a five per cent chance (i.e. a 1 in 20 chance) of a peak discharge of 500 cubic metres per second being equalled or exceeded in any one year (also see average recurrence interval).
Australian Height Datum (AHD)	National survey datum corresponding to about mean sea level.
Average Annual Damages (AAD)	The average annual damage is the average cost in dollars per year that would occur in a particular area from flooding over a long period of time.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrence of a flood as big as or larger than the selected event. For example, flood with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Benefit-cost ratio	Measure used to assess the economic viability of a mitigation measure.
Catchment	The catchment at a particular point is the area of land that drains to that point.
Design flood	A theoretical flood representing a specific likelihood of occurrence (for example the 1% AEP flood).
Flood behaviour	The pattern / characteristics / nature of a flood.
Flood depth	The height or elevation of floodwaters above ground level.
Flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum).
Hydraulics	The term given to the study of water flow in rivers, estuaries and coastal systems.
Hydrograph	A graph showing how a river or creek's discharge changes with time.
Hydrology	The term given to the study of the rainfall-runoff process in catchments.
LiDAR	Remote (airplane) sensing method that uses light in the form of a pulsed laser to measure distance to the Earth. This is used to generate detailed 3D topographical information across an area.
Peak flood level, flow or velocity	The maximum flood level, flow or velocity occurring during a flood event at a particular location.
RORB	Runoff routing computer model for hydrologic analysis of catchment runoff.
TUFLOW	Fully two-dimensional and one-dimensional unsteady flow hydraulic computer modelling software.
Velocity	The speed at which the floodwaters are moving. Typically, modelled velocities in a river or creek are quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section if a one-dimensional solution is used; and depth average if a two-dimensional solution is used.

Abbreviations

AAD	Average Annual Damages
ARR 2019	2019 release of Australian Rainfall & Runoff
BCR	Benefit-cost ratio
BoM	Bureau of Meteorology
Council	Pyrenees Shire Council
DELWP	Department of Environment, Land, Water and Planning
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EIA	Effective Impervious Area
GSAM	Generalised Southeast Australia Storm Method
GSDM	Generalised Short-Duration Method
m AHD	meters Australian Height Datum
FFA	At-Site Flood Frequency Analysis
LiDAR	Light Detection and Ranging
m/s	Metres per second (a measure of speed / velocity).
m^3/s	Cubic metres per second (a measure of flow).
NCCMA	North Central Catchment Management Authority
NDRGS	Natural Disaster Resilience Grant Scheme
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PRG	Project Reference Group
RCP	Representative Concentration Pathway
RFFE	Regional Flood Frequency Estimate
RRV	Regional Roads Victoria
The Investigation	Upper Avoca River Flood Investigation
The Catchment	Upper Avoca River catchment to the Investigation downstream boundary
TIA	Total Impervious Area

1. Introduction

This Draft Flood Damages and Structural Mitigation Options Report details the existing conditions flood damages assessment, pre-feasibility structural mitigation options assessment and detailed assessment of the five selected structural mitigation options for the Upper Avoca River Flood Investigation (the Investigation).

This report builds on the project inception and site visit, data review and validation, and existing conditions flood modelling and mapping tasks of the Investigation as documented in:

- Data Review Report (Jacobs 2020a)
- Flood Modelling Report (Jacobs 2020b)
- Flood Mapping Report (Jacobs 2020c)

The focus of this report is the assessment of structural mitigation options (physical works) that can be used to reduce the flood risk in the Upper Avoca River catchment. Non-structural mitigation options such as community education and awareness, and planning controls are not assessed but the outputs of this Investigation will be used for this purpose. The flood warning feasibility assessment is documented separately.

1.1 Investigation background

The Upper Avoca River area has a long history of flooding, including experiencing three significant flood events over the past decade in 2010, 2011 and 2016. However, to date, there has not been a detailed flood assessment completed for this area. To address this a flood study of the Upper Avoca River to inform flood intelligence and planning scheme maps for Amphitheatre, Avoca and Natte Yallock and the rural areas in between was identified as a high regional priority in the North Central Regional Floodplain Management Strategy 2018-2028 (NCCMA 2018).

In response the Pyrenees Shire Council (Council) has received funding from the Victorian and Commonwealth Governments through the Natural Disaster Resilience Grants Scheme (NDGRS), and in partnership with the North Central Catchment Management Authority (NCCMA) have engaged Jacobs to undertake the Upper Avoca River Flood Investigation.

The focus of this Investigation is to assess riverine flooding in the Upper Avoca River catchment with the main objectives to:

- Define flood related controls in the Pyrenees Shire Council Planning Scheme
- Develop flood intelligence products and inform emergency response planning
- Investigate opportunities for flood mitigation works and activities
- Assist in the preparation of community flood awareness and education products
- Assess feasibility for improved flood warning arrangements
- Support the assessment of flood risk for insurance purposes

1.2 Catchment and investigation area description

The Investigation area (Figure 1.1) is located in the upper reaches of the Avoca River where it flows from the hills of the Great Dividing Range ranges onto the Avoca River floodplain where it remains relatively confined until it breaks out into the wider floodplain north of Charlton. To Archdale Junction (the downstream limit of the Investigation), there is contributing catchment of approximately 1,000 km^2.

The Avoca River is the primary waterway in the catchment area, forming in the hills south of Amphitheatre and flowing north, with several tributaries that join it prior to Archdale Junction, including:

- Homebush Creek
- Brown Hill Creek
- Cherry Tree Creek
- Middle Creek
- Redbank Creek
- Mountain Creek
- Wild Dog Creek
- Sardine Gully
- Fiddlers Creek
- Number One Creek
- Number Two Creek
- Sugarloaf Creek
- Rutherford Creek
- Green-hill Creek
- Forrest Creek
- Glenlogie Creek
- Amphitheatre Creek

In total the Investigation covers an area of approximately 300 km^2 from upstream of Amphitheatre to Archdale Junction, covering the townships of Amphitheatre, Avoca and Natte Yallock as shown in Figure 1.1. These towns have populations of 248, 1,193 and 188 respectively as of the 2016 census. High-resolution modelling was undertaken for the townships (which are referred to as town models), with coarser modelling adopted for the broader area (which is referred to as the regional model).

Figure 1.1: Upper Avoca Flood Investigation Overview

2. Existing conditions flood damages assessment

The flood damage assessment is an important component of the Investigation as it enables floodplain managers and decision makers to gain an understanding of the monetary cost of flooding. The information determined in the damages assessment is also used to inform the selection of mitigation measures via a cost benefit analysis. As the objective of the structural mitigation options assessment detailed in this report is to mitigate flood impacts in the township areas, the flood damages assessment has been setup to focus on the damages to the towns.

As shown in Table 2.1 flood damages can be categorised as either tangible or intangible, depending on the difficulty of assigning a monetary value to a particular item. Tangible flood damages are those which can easily be assigned a monetary value such as damages to buildings. Intangible flood damages are those which cannot be easily assigned a monetary value such as environmental and social costs. Flood damages can be further divided into direct or indirect costs. Each flood damage category is discussed in more detail below.

Table 2.1: Categories of damage (Jacobs 2018)

Direct		Indirect	
Tangible	**Intangible**	**Tangible**	**Intangible**
▪ Damage to buildings and contents ▪ Damage to infrastructure ▪ Damage to crops ▪ Damage to inventories and consumer goods ▪ Costs due to displaced households	▪ Loss of life ▪ Physical and mental health ▪ Loss of memorabilia and irreplaceable items ▪ Loss of ecosystem services	▪ Production and income losses ▪ Clean-up costs ▪ Costs of evacuation ▪ Increased travel costs	▪ Increased vulnerability of people and communities ▪ Disruption of community ▪ Inconvenience caused by the disruption of utility services

2.1 Flood damage assessment methodology

A summary of the procedure for calculating flood damages is:

- Prepare the appropriate relationships between flooding and the assigned monetary value of damages (Section 2.2)
- Gather the required input information detailing the characteristics of the buildings and infrastructure that will be assessed. This includes data such as floor level (where available), building type and size and road type
- Determine the design flood event impacts on individual buildings, properties and roads. For this assessment the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% Annual Exceedance Probability (AEP) and Probable Maximum Flood (PMF) design flood events have been used
- Produce the total estimated tangible direct damages for each design flood event across
- Assume tangible indirect damages and intangible damages based on the magnitude of tangible direct damages
- Determine the average annual damages (AAD)

2.2 Economic inputs

The AAD approach is built on economic inputs that quantify flood damage in monetary terms. The derivation and assumptions of economic inputs are described in Jacobs (2018) for the following categories of flood damage:

- Direct (tangible) damages - comprise the physical impact of the flood, for example, damages to structure and contents of buildings, agricultural enterprises and regional infrastructure
- Indirect (tangible) damages - comprise losses from disruption of normal economic and social activities that arise as a consequence of the physical impact of the flood; for example, costs associated with emergency response, clean-up, community support, as well as disruption to transport, employment and commerce
- Intangibles - or 'non-market' impacts, comprise losses which cannot always be quantified in monetary terms (since market prices cannot be used). For example, loss in biodiversity, physical injury or increased stress levels for residents following a major flood event affecting their homes.

2.2.1 Direct damages

Economic assumptions have been developed for direct damages to the following categories of assets:

- Buildings (structure, contents, external costs and clean-up)
- Roads

2.2.1.1 Building damages

The assessment of damage to buildings is based on relationships between above floor flood depth and damages as shown in Table 2.3 and Figure 2.1. For this Investigation buildings are separated into two categories; residential and commercial, where the impacted community facilities such as sports club rooms and the Natte Yallock Primary School have been categorised as commercial.

The residential building damages relationships are developed by the New South Wales (NSW) Office of Environment (OEH), escalated to 2020 dollars The NSW OEH curves account for damage to structures, contents, external costs, clean-up costs and temporary accommodation. It has been assumed that the residential buildings are single storey/low set buildings with a floor area of 120 m^2. The curves express absolute damage relative to the above floor depth of flooding. Consistent with NSW OEH guidance, the damage curves have been escalated to 2020 dollars using the Australian Bureau of Statistics Average Weekly Earnings.

Commercial building damages are based on depth damage data used by US Federal Emergency Management Agency (FEMA), escalated to 2020 dollars. The damage is presented per square metre (in Australian dollars and based on Australian cost data). Building area is capped at 1,000 m^2 per building.

For flooded buildings where floor level survey was not available, a floor level of 300 mm above ground level has been assumed.

For commercial and public buildings, it has been assumed that once a building is inundated above floor level that entire building area is inundated.

Table 2.2: Building above floor flood depth – damage assumptions

Above floor flood depth (m)	Residential building damages ($/building)	Commercial/public building damages ($/m^2/building)
-0.5	$12,261	$6
-0.4	$12,261	$6
-0.3	$12,261	$6
-0.101	$12,261	$6
-0.1	$12,261	$8
-0.05	$12,261	$10
0	$32,358	$12
0.1	$32,737	$39
0.2	$72,218	$66
0.3	$75,720	$120
0.4	$79,223	$174
0.5	$82,726	$202
0.6	$86,228	$229
0.7	$89,731	$256
0.8	$93,234	$280
0.9	$96,736	$304
1	$100,239	$328
1.1	$103,741	$351
1.2	$107,244	$374
1.3	$110,747	$396
1.4	$114,249	$417
1.5	$117,752	$436
1.6	$121,255	$456
1.7	$124,757	$476
1.8	$128,260	$496
1.9	$131,763	$516
2	$135,265	$541
2.5	$138,768	$568
3	$142,556	$686

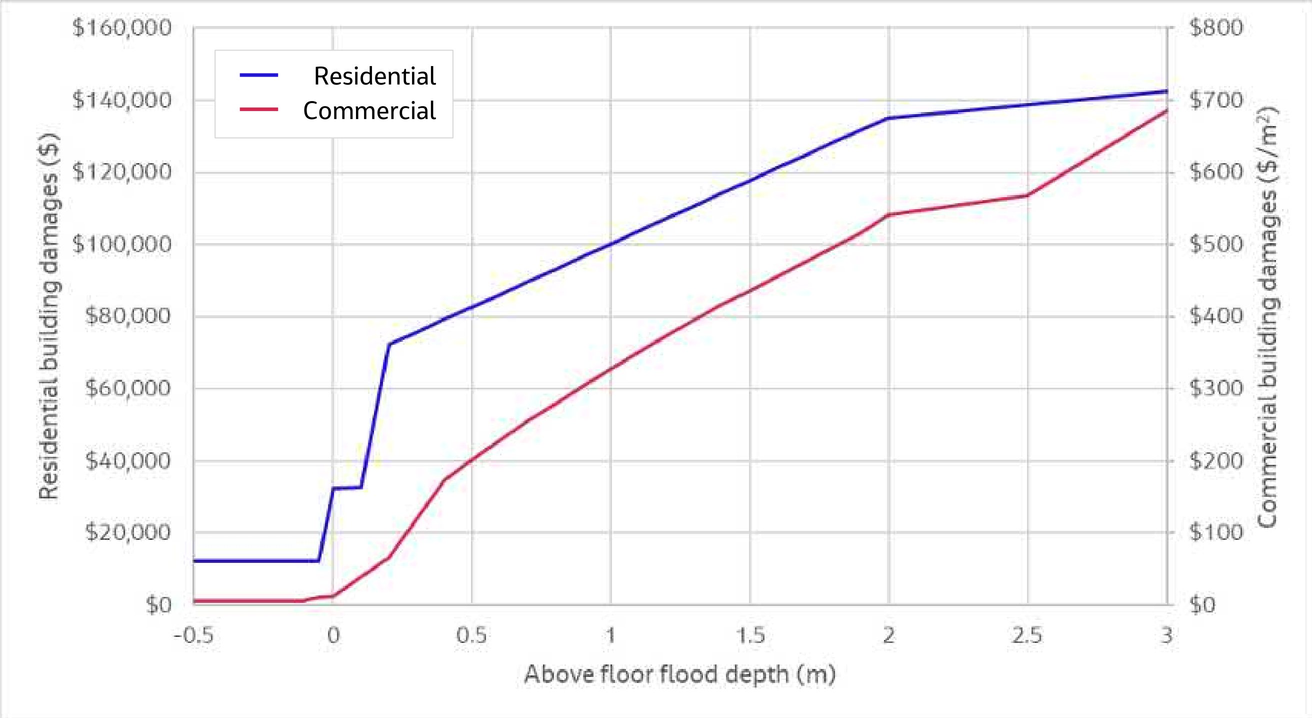

Figure 2.1: Building above floor flood depth – damage curves

2.2.1.2 Road damages

Road damages are calculated using cost per length of road flooding. The cost parameters are conventional parameters originally published in the Rapid Appraisal Method (RAM) for Floodplain Management (DNRE 2000) and escalated to today's dollars using the Australian Bureau of Statistics Consumer Price Index.

Updating the values to 2020, the revised estimates of damage are shown in Table 2.3. Note that these standard values are a proxy for all road, bridges and drainage infrastructure.

Table 2.3: Road damages cost assumptions

Road type	Road Damage ($/km inundated)
Major	$103,300
Minor	$31,450
Unsealed	$14,195

2.2.1.3 Avoca Public Park damages

Council has provided advice that when the Avoca oval playing surface is fully inundated, clean-up and playing surface rehabilitation costs are estimated to be $150,000.

2.2.2 Indirect damages

Indirect but tangible damages stem from disruption and/or additional costs to normal economic and social activities that arise from direct damages of flooding. For instance, costs associated with public clean-up, loss of public services, emergency responses and transport network impacts. These types of damages are generally positively related with the magnitude of a flood's direct physical damages.

Indirect damages are assumed to be 30% of total direct damages (building, property and road). This is consistent with the previous assessment and Melbourne Water's current AAD Tool. This was informed by the Floodplain Management – Economic Appraisal Guidelines (Jacobs 2018).

2.2.3 Intangible damages

Intangible damages are assumed to be 100% of total direct damages. Intangible damages are comprised of non-physical and unpriced damages that result from direct and indirect impacts. These include but are not limited to the following:

- Physical health (including loss of life)
- Psychological health impacts (e.g. mental health impacts, trauma, concerns of future floods and loss of confidence in authorities and services)
- Social impacts (loss of community and irreplaceable societal memorabilia)
- Cultural and heritage impacts
- Flora and fauna impacts

Jacobs' literature review as part of the Flood Risk Reduction (FRR) Recommendations Report found that intangible impacts are at least equal to direct damages. This was the conclusion of the Deloitte (2016) economic cost of the social impact of natural disasters. Moreover, a social survey in Scotland (Werritty et al., 2007) concluded that intangible impacts were more important, larger and longer lasting than tangible (direct +indirect) impacts. Consequently, the AAD tool assumes that intangible damages amount to 100% of direct damages (residential + commercial + industrial + road damages).

2.3 Existing conditions average annual damages

Average annual damages (AAD) are the average damages per year that would occur in a particular area from flooding over an extended period of time. Estimation of AAD provides a basis for comparing the effectiveness of different management measures using a transparent and repeatable method (i.e. the reduction in the AAD) using benefit cost analysis.

AADs are calculated as the area under the probability-damage curve (Figure 2.2), estimated by determining the flood damages for each of the design events assessed. As the most frequent event assessed is the 20% AEP event, it is assumed that 50% (1 in 2) AEP will cause zero damages, and defines the lower limit of the curve. The probability damage curve is interpolated to account for events with a probability between the 20% and 50% AEP. To define the upper limit of the curve the PMF has been assigned an AEP of 0%.

AAD for Amphitheatre, Avoca and Natte Yallock are presented in Table 2.4, Table 2.5 and Table 2.6 respectively and the breakdown from each set of damages. The existing conditions flood damages have been calculated using the outputs from the detailed Town hydraulic models.

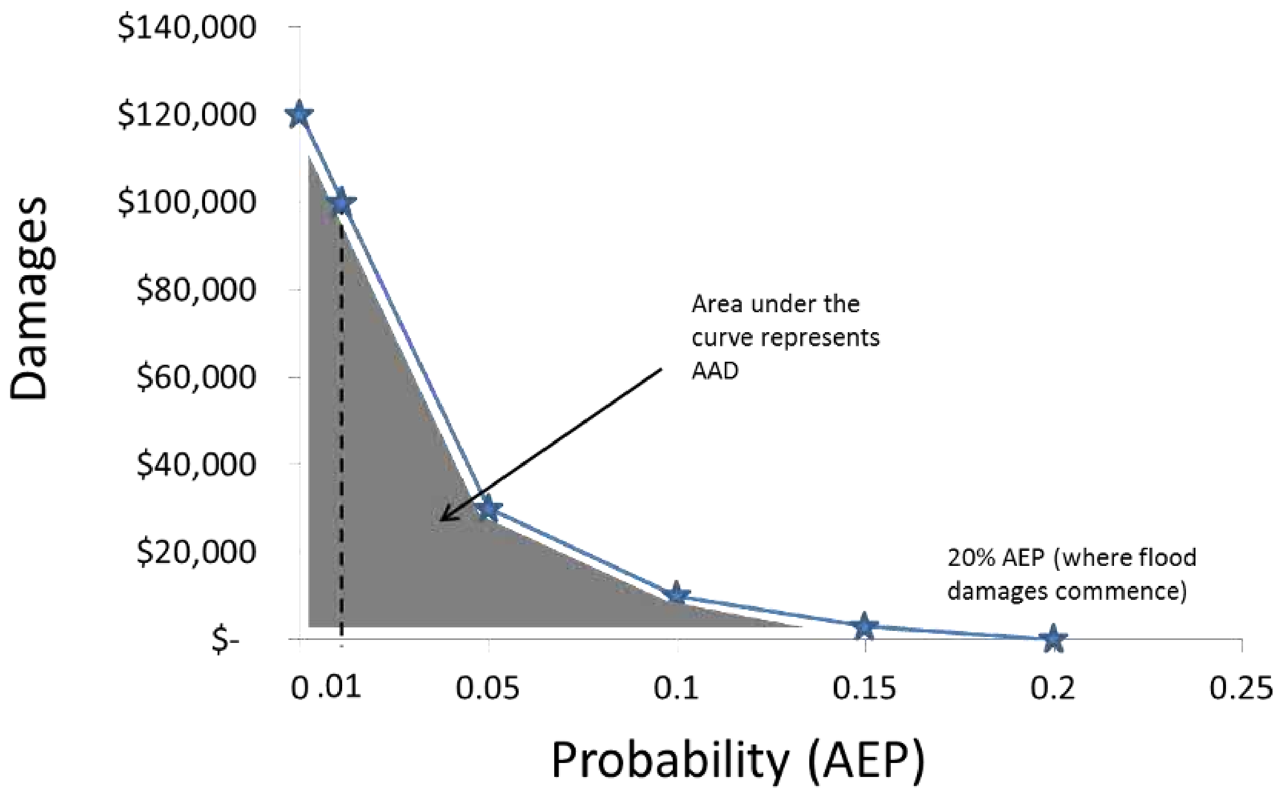

Figure 2.2: Example damage probability curve used for calculating AAD (Jacobs 2018)

Table 2.4: Amphitheatre existing conditions damages summary

AEP	Building direct tangible damages	Road direct tangible damages	Indirect tangible damages	Intangible damages	Contribution to AAD
PMF	$2,067,000	$668,000	$820,000	$2,735,000	**$6,290,000**
0.2%	$25,000	$184,000	$63,000	$209,000	**$480,000**
0.5%	$12,000	$171,000	$55,000	$183,000	**$421,000**
1%	$12,000	$162,000	$52,000	$174,000	**$401,000**
2%	-	$152,000	$46,000	$152,000	**$350,000**
5%	-	$135,000	$40,000	$135,000	**$310,000**
10%	-	$126,000	$38,000	$126,000	**$290,000**
20%	-	$91,000	$27,000	$91,000	**$209,000**
Average Annual Damages					**$95,000**

Table 2.5: Avoca existing conditions damages summary

AEP	Building direct tangible damages	Road direct tangible damages	Avoca Public Park	Indirect tangible damages	Intangible damages	Total damages
PMF	$20,834,000	$1,358,000	$150,000	$6,703,000	$22,342,000	**$51,386,000**
0.2%	$1,213,000	$480,000	$150,000	$553,000	$1,843,000	**$4,239,000**
0.5%	$954,000	$462,000	$150,000	$470,000	$1,566,000	**$3,602,000**
1%	$741,000	$445,000	$150,000	$401,000	$1,335,000	**$3,071,000**
2%	$571,000	$414,000	$150,000	$341,000	$1,135,000	**$2,611,000**
5%	$362,000	$340,000	$150,000	$256,000	$852,000	**$1,960,000**
10%	$285,000	$303,000	$150,000	$221,000	$737,000	**$1,696,000**
20%	$61,000	$225,000	$150,000	$131,000	$436,000	**$1,002,000**
Average Annual Damages						**$558,000**

Table 2.6: Natte Yallock existing conditions damages summary

AEP	Building direct tangible damages	Road direct tangible damages	Indirect tangible damages	Intangible damages	Contribution to AAD
PMF	$1,693,000	$1,134,000	$848,000	$2,827,000	$6,502,000
0.2%	$684,000	$973,000	$497,000	$1,657,000	$3,810,000
0.5%	$566,000	$877,000	$433,000	$1,443,000	$3,318,000
1%	$479,000	$808,000	$386,000	$1,287,000	$2,959,000
2%	$440,000	$728,000	$350,000	$1,167,000	$2,685,000
5%	$360,000	$643,000	$301,000	$1,004,000	$2,308,000
10%	$348,000	$623,000	$291,000	$971,000	$2,233,000
20%	$332,000	$526,000	$257,000	$858,000	$1,974,000
Average Annual Damages					**$760,000**

3. Pre-feasibility structural mitigation options assessment

A pre-feasibility structural mitigation options assessment has been undertaken to identify the structural mitigation options for detailed assessment. The pre-feasibility assessment was undertaken in two stages:

1) Identification of potential structural mitigation options throughout the preceding tasks of the project as detailed in Jacobs (2020a) from the following sources:
    - Local community at community meetings 1 and 2 and the community surveys
    - Project Reference Group (PRG) at PRGs meetings 1 and 2
    - Project team (Council, NCCMA and Jacobs)
2) Presentation of all the potential structural mitigation options to the PRG at PRG Meeting 3 (held on 12 September 2020), for selection of options for detailed assessment based on the following criteria:
    - Likely improvements in flood risk
    - Economic feasibility
    - Social considerations
    - Environmental considerations

A description of the structural mitigation options identified, and the results of the pre-feasibility assessment is presented in Table 3.1.

Table 3.1: Pre-feasibility structural mitigation options assessment

Option	Description	Detailed assessment
Avoca Public Park bund	Bunds around the perimeter of the Avoca Public Park to reduce the frequency and depth of flooding. At present there is a small bund along the fence line on MacKintosh Street and the Duke Street entrance. Due to the flood clean-up and oval remediation costs incurred after each flood event, the detailed assessment of this option was specified in the scope of the Investigation. **Likely changes to flood risk** ▪ Bunds can reduce frequency, depth and velocity of inundation within park ▪ Likely to increase flood levels in properties adjacent to park, requiring consideration of the bund level adopted **Economic feasibility** ▪ Relatively low construction costs ▪ Reduces ongoing flood clean-up and oval remediation costs **Social considerations** ▪ Reduces closure time of community asset **Environmental considerations** ▪ Negligible environment impacts	✓
Channel clearing (tree and debris removal)	Channel clearing (tree and debris removal) along the Avoca River. Channel clearing can be undertaken by removing vegetation or debris (fallen trees, branches, etc) along reaches of the river or removing specific flow obstructions. The overall clearing of channel can be tested in the hydraulic model by reducing the channel roughness parameter, but the removal of individual obstructions cannot. This option was chosen for detailed assessment to test the sensitivity of channel roughness on floodplain levels. However, the removal of individual obstructions can be considered as required. **Likely changes to flood risk** ▪ Channel clearing unlikely to provide significant improvements in lower floodplain flood level as channel conveys limited flow in comparison to floodplain ▪ May have result in flood impacts on properties downstream of channel clearing ▪ Clearing of individual obstructions in critical specific locations can improve flood levels and breakout flows locally **Economic feasibility** ▪ Relatively low costs	✓

Option	Description	Detailed assessment
	Social considerations ▪ Potentially contentious within communities given possible environmental impacts **Environmental considerations** ▪ Removal of aquatic species habitat ▪ May contribute to channel bank erosion	
Upper catchment reservoir or weir	Construction of a reservoir or weir in the upper catchment to store flood water with the aim of reducing downstream flood flows. This option was not chosen for detailed assessment due to the significant construction and ongoing costs. **Likely changes to flood risk** ▪ Large volumes of flood flow storage required to reduce flood risks downstream ▪ Likely to provide more benefits in upper catchment where existing flood risks are lower **Economic feasibility** ▪ Very high construction costs ▪ Requires responsible authority to undertake ongoing maintained and operations arrangements to ensure storage safety ▪ Land acquisition required **Social considerations** ▪ Land acquisition required ▪ Can be incorporated into a recreation feature. However, for storage to function it must be kept empty or at low storage levels minimising its use for recreations such as fishing and water sports ▪ Potentially contentious within communities given possible environmental impacts **Environmental considerations** ▪ Significant change in environmental type in area of storage, for example from a dry riverine environment to a permanent waterbody or wetland type environment ▪ May result in changes to downstream water cycle ▪ Sediment and scouring will need to be managed during construction	✗

Option	Description	Detailed assessment
Construction and maintenance of local drainage infrastructure	Maintain existing and construct new local drainage infrastructure to manage stormwater or local flooding. The scope of this Investigation is on riverine flooding, as a result the flood models have not been set-up to assess local drainage infrastructure so have not been considered for detailed assessment. **Likely changes to flood risk** ▪ Effective in managing stormwater and local flooding ▪ Will not provide significant improvements during riverine flood events **Economic feasibility** ▪ Relatively low costs ▪ Reduces clean-up and maintenance costs **Social considerations** ▪ Effective in managing stormwater and local flooding which due to its frequency often presents the most nuisance to people's daily lives **Environmental considerations** ▪ Negligible environment impacts	✘
Raise levee banks along the Avoca River	Raising of the levee banks along the Avoca River from upstream of Natte Yallock through the township to contain more flow within the channel and reduce breakout flows across the floodplain. This option was chosen for detailed assessment as it has the potential to reduce flood risk in Natte Yallock. It should also be noted that there are sections of the existing Avoca River levees that are degrading and may need maintenance. **Likely changes to flood risk** ▪ Reduced breakout flows leading to lower flood levels across the lower floodplain ▪ Likely will result in reduced flow travel times and increased flood levels downstream of raised levee banks ▪ Increased consequences of a levee failure **Economic feasibility** ▪ Medium construction costs ▪ Ongoing maintenance costs to ensure levee integrity **Social considerations**	✓

Option	Description	Detailed assessment
	▪ Minimal social impacts as levee banks are already in place **Environmental considerations** ▪ Reduced environmental benefit for floodplains from inundation such as sediment disposition ▪ Increased flow in channel may result in increased channel erosion during flood events	
Flow training levees upstream of Natte Yallock	A series of levees or bunds upstream (south) of Natte Yallock to divert Avoca River breakout flows around the township, in particular on the western side of the Avoca River. This option was chosen for detailed assessment as it has the potential to reduce flood risk in Natte Yallock. **Likely changes to flood risk** ▪ Potential for significant reduction in flood risk for Natte Yallock ▪ Will increase flood levels and velocities outside of the area protected by the levees but can be designed to not impact on existing buildings **Economic feasibility** ▪ Medium construction costs ▪ Ongoing maintenance costs to ensure levee integrity **Social considerations** ▪ May need to be located on private property **Environmental considerations** ▪ Flood flow distribution across the floodplain will be changed ▪ Areas of increased flow may require additional works to manage erosion	✓
Excavation of Avoca River channel to increase flow capacity	Excavate the Avoca River channel to increase its flow capacity and reduce breakout flows across the floodplain. This option was not chosen for detailed assessment due to the likely limited improvements in flood risk and the significant environmental impact. **Likely changes to flood risk** ▪ Reduced breakout flows leading to lower flood levels across the floodplain ▪ Major increase in channel size required to significantly reduce flood levels across floodplain **Economic feasibility**	✗

Option	Description	Detailed assessment
	▪ High construction costs ▪ High maintenance costs **Social considerations** ▪ Potentially contentious within communities given possible environmental impacts **Environmental considerations** ▪ Significant environmental impact on channel reaches excavated ▪ May result in changes to natural water cycle	
Silt removal (dredging) of upper reaches of Avoca River	Silt removal or maintenance dredging in the upper reaches of the Avoca River to increase capacity of the channel. Broad silt removal has not chosen for detailed assessment due to the likely limited improvements in flood risk part of this investigation. If individual hydraulic structures such as culverts and bridges are blocked by siltation, desilting should be considered. **Likely changes to flood risk** ▪ Unlikely to provide significant food risk reduction in large events ▪ Cleaning of blocked structures can provide local improvements in flood conditions, in particular at crossings **Economic feasibility** ▪ Low but ongoing costs **Social considerations** ▪ Improved access during floods if blocked structures are cleaned **Environmental considerations** ▪ If broad channel dredging undertaken significant environmental impact ▪ Negligible environmental impact if blocked structures cleaned	✘
Construct culvert at Barry Road (Amphitheatre)	Construct culvert at Barry Road, Amphitheatre to manage stormwater or local flooding. The scope of this Investigation is on riverine flooding, as a result the flood models have not been set up to assess local drainage infrastructure so have not been considered for detailed assessment. **Likely changes to flood risk** ▪ Effective in managing stormwater and local flooding	✘

Option	Description	Detailed assessment
	▪ Will not provide significant improvements during riverine flood events **Economic feasibility** ▪ Relatively low costs ▪ Reduces clean-up and maintenance costs **Social considerations** ▪ Effective in managing stormwater and local flooding which due to its frequency often presents the most nuisance to people's daily lives **Environmental considerations** ▪ Negligible environment impacts	
Moonambel – Natte Yallock Road bermed corner lowering and tree removal	Lowering of the bermed corner on Moonambel – Natte Yallock west of Natte Yallock township and clearing of trees adjacent to the corner and trees at the corner of Maryborough – St Arnaud Road and Henderson Lane with the aim of allowing more water to bypass the township to the west. This option has been chosen for detailed assessment because the community have specific concerns that it contributes to the flood risk in Natte Yallock. The bermed corner is required to maintain the trafficability design requirements of the road but this option can be used to determine if a design solution that replicates natural flow conditions provides a benefit to the township. **Likely changes to flood risk** ▪ Will reinstate the natural flow path but may not have a significant influence on flood behaviour in the township during major flood events **Economic feasibility** ▪ Potentially costs restrictive given road has recently been upgraded ▪ Economic losses if road cannot meet its trafficability requirements **Social considerations** ▪ Negligible social impacts **Environmental considerations** ▪ It is understood that the trees proposed to be cleared are relatively new planting but may require vegetation offsets	✓

Option	Description	Detailed assessment
Permanent or temporary levees to protect Natte Yallock Recreation Reserve	Permanent or temporary levees across the southern boundary (entrance) to the Natte Yallock Recreation Reserve to prevent damage to the carpark area. It is believed that the damage occurs during local storm events which are not considered in this riverine flood investigation, but mitigation of this issue is being addressed through other upgrade works. **Likely changes to flood risk** ▪ High flow velocities that damaging carpark are experienced during local storm events ▪ Reduced flood velocities across recreation reserve car park ▪ Likely to result in increased flood levels on private properties along Reserve Road ▪ If temporary levees used across reserve entrance, may not be able to be deployed in time during local storm events **Economic feasibility** ▪ Medium cost to construct ▪ Bund requires ongoing maintenance costs ▪ Reduces carpark and other facility clean-up and maintenance costs **Social considerations** ▪ Reduces closure time of community asset ▪ Negligible social impacts **Environmental considerations** ▪ Negligible environmental impacts	✘
Increase Sunraysia Hwy flood immunity north of Avoca	Increase Sunraysia Hwy flood immunity north of Avoca by increasing cross-road drainage capacity or raising road grade. The flood mapping indicates that the road is inundated to shallow depths, less than 300 mm in the 1% AEP event. This option has not been chosen for detailed assessment as part of this investigation, but flood immunity should be considered in future road upgrades. **Likely changes to flood risk** ▪ Reduces road safety risk ▪ Maintains emergency and other critical service vehicle access during flood events **Economic feasibility** ▪ Medium construction costs (Regional Roads Victoria managed road)	✘

Option	Description	Detailed assessment
	▪ Improves road clean-up and maintenance costs **Social considerations** ▪ Enable communities to remain connected during flood events **Environmental considerations** ▪ Negligible environment impacts ▪ Sediment and scouring will need to be managed during construction	
Controls on location and type of crops	Controls on the location, type and timing of crops in the floodplain to reduce flood levels and/or the redirection of flows from normal flow paths. Observations provided by the community and the results of the September 2016 calibration event modelling indicate that flood behaviour in the lower floodplain is sensitive to the crops present during a flood event. This option is outside the scope of this structural mitigation option assessment but can be considered further.	✘

4. Detailed structural mitigations assessment

This section describes the assessment of the five structural mitigation options selected for detailed assessment:

- Avoca Public Park bund
- Channel clearing (tree and debris removal)
- Raise levee banks along the Avoca River
- Flow training levees upstream of Natte Yallock
- Moonambel – Natte Yallock Road bermed corner lowering and tree removal

4.1 Assessment methodology

For each structural mitigation option, a description of the proposed works, an assessment of the effectiveness in reducing the risk of flooding, the economic benefit and the social and environmental advantages and disadvantages has been provided.

4.1.1 Flood level impact mapping

In order to determine the effectiveness of a structural mitigation option in reducing flood risk, flood impact mapping is used to compare the reduction (or increase) in peak flood levels as a result of the works. This achieved by subtracting the post mitigation model peak flood levels from the existing conditions peak flood levels. The resulting maps are referred to as flood impact maps where, the yellow colour indicates no change in flood level within a +/- 0.01 m tolerance, reductions in flood level are shaded with greens and increases in flood level are shaded with oranges/reds. A magenta colour indicates a region where flooding currently occurs, but would no longer occur if the option was implemented, and a blue colour indicates a region where flooding currently does not occur but would if the option was implemented.

4.1.2 Economic assessment (benefit-cost ratio)

The economic viability of a scheme is initially assessed by calculating the monetary benefit-cost ratio (BCR). A benefit-cost ratio of 1.0 indicates that the monetary benefits are equal to the monetary costs. A ratio greater than 1.0 indicates that the benefits are greater than the costs while a ratio less than 1.0 indicates that the costs are greater than the benefits.

In floodplain management, a BCR substantially less than 1.0 may still be considered viable because the economic analysis does not include all of the benefits gained by flood mitigation works.

To calculate the BCR the following steps are undertaken:

1) Calculate the benefit (difference) in AAD between pre and post mitigation works scenarios (refer to Section 2)
2) Calculate the cost of the mitigation works; capital and operational (maintenance) costs
3) Convert the benefits and costs into total present value across the financial life of the mitigation option
4) Calculate the BCR

$$BCR = \frac{Total\ Present\ Value\ Benefit}{Total\ Present\ Value\ Cost}$$

As summarised above the, to calculate the BCR, the annual financial benefit and cost of the mitigation works summed over the financial project life and converted to present value. For this investigation a financial project life of 30 years was adopted. This does not mean that the projected structural life of the scheme is only 30 years as some works could be effective in reducing flood damages for many more years to come, especially if well maintained.

The total benefits and costs are represented in present value which is the current value of future money. To calculate the present value a discount rate of 7% has been adopted. This discount rate is consistent with the Department of Treasury and Finance's recommendations for Category 2 (Provision of goods and services in traditional core service delivery areas of government where benefits attributed to the project are more easily translated to monetary terms) presented in the Economic Evaluation for Business Cases Technical guidelines (DTF 2013).

It is important to recognise that the BCR represent only the economic assessment that must be considered in respect to the viability of an option. While intangible damages (and subsequent benefits) are include in AAD calculations, other issues such as social and environmental impacts, although difficult to quantify, must be included in the complete assessment.

4.1.2.1 Cost estimates

In order to undertake a BCR an estimate of the total cost of each option has been completed. At this concept stage, these costs are a best estimate with a large degree of uncertainty. The mitigation works costs include capital costs and ongoing maintenance costs. The cost estimates which are presented in Appendix A include the following:

- Construction costs
- Engineering and design costs (7%-10%)
- Project Management / Administration (7%-10%)
- Contingency (35%)
- Ongoing maintenance (2% per annum for levee/bunds)

4.2 Avoca Public Park bund

The proximity of the Avoca Public Park to the nearby Avoca River has rendered it subject to frequent flooding, with the 2010, 2011 and 2016 floods causing notable damage. These events correspond to the oval becoming inundated from approximately the 20% AEP events, resulting in considerable expense, with maintenance and repairs costing an estimated $150,000 by Council.

While primarily impacted by out of bank flow from the Avoca River that crosses Faraday Street from the east, the Avoca Public Park is also impacted by inundation from the north and to a lesser extent local flows from the west.

A bund is proposed to reduce the frequency of this inundation, with the assessed alignment running along the Avoca Public Park's eastern boundary (along Faraday Street) and northern boundary (along Vinoca Road) along with raising the access track on the western boundary, as shown in Figure 4.1.

The proposed bund is set to the 20% AEP flood level resulting in a height of approximately 0.8m and is positioned such that floodwaters from the river are trained along the eastern then northern perimeter of the oval, to join those flows from the west. The bund extends across the Faraday Street entrance requiring a regrading of the entrance to go over the bund (temporary levees could also be used to block the entrance).

The access track that runs along the western edge of the Avoca Public Park is proposed to be raised by approximately 1m to the 20% AEP flood level.

Other arrangements of the levee were trialled, including an alignment along the western border of the sports ground, and being raised to the 10% AEP flood level. These were found to provide insufficient benefit given the additional cost and resulted in significant flood level impacts on surrounding properties.

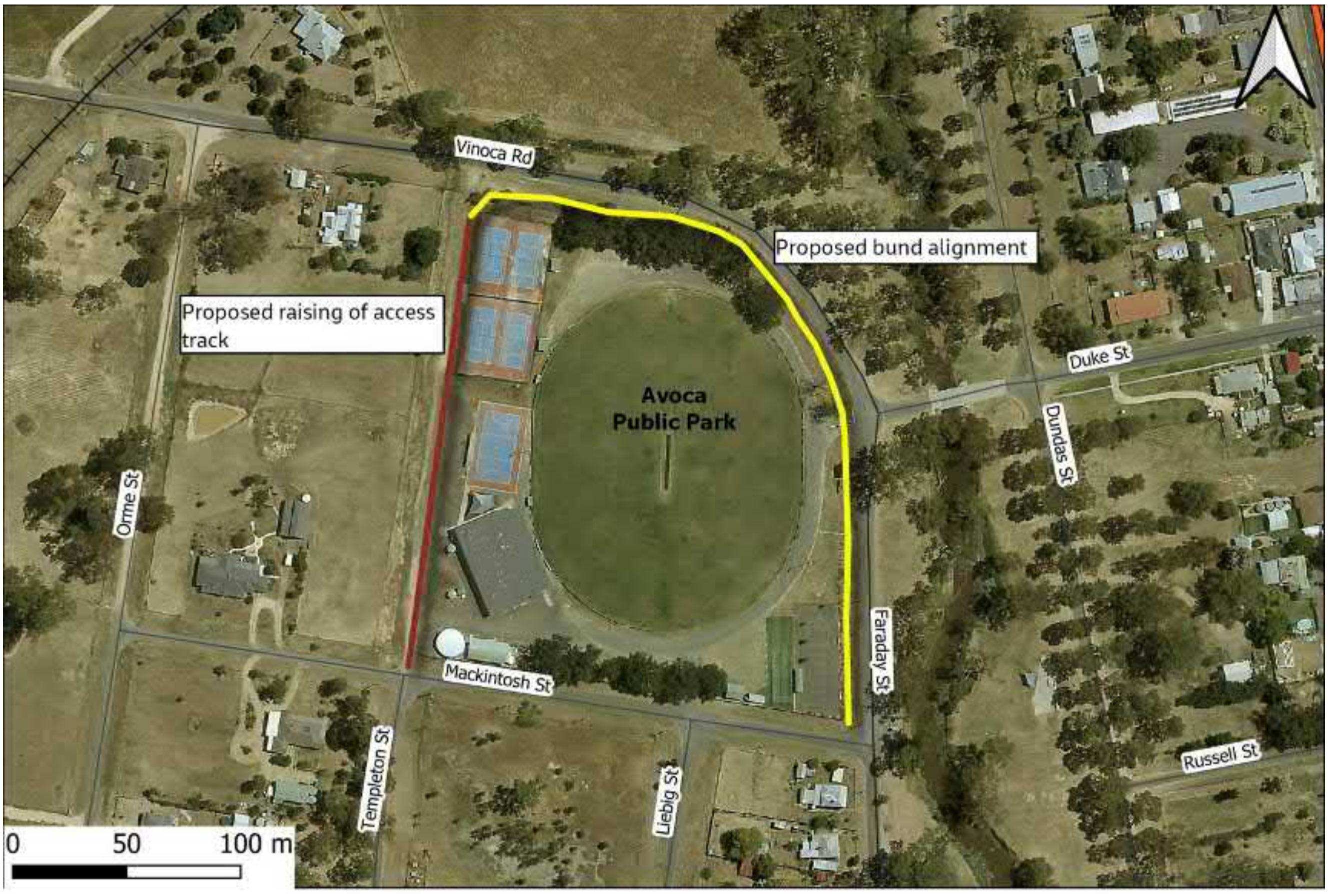

Figure 4.1: Avoca Public Park bund layout

4.2.1 Flood impacts

The peak flood level impact maps for each modelled AEP event are presented in Appendix C.

The modelling indicates that the levee would provide a barrier to flow in the 20% AEP design event and reduce inundation and velocities in the 10% AEP and rarer events.

On the river / eastern side of the levee, modelled peak water levels are increased as expected. These impacts are predominately upstream of the Duke Street crossing, with minor increases in inundated area. Within the 1% AEP event, impacts are approximately 30 mm east of the river, affecting some property backyards and the Avoca Chinese Garden but does not impact on existing buildings.

The levee results in impacts on residential properties south of the Avoca Public Park on Faraday Street. Here the river is overtopped in the 1% AEP event and westward flows cross Faraday Street through three properties. With the addition of the bund, peak 1% AEP flood levels are increased by 13 mm impacting on an existing residential building and in the 2% AEP event a new flowpath through these properties is created. Local drainage works along Faraday Street and Mackintosh Street could be used to mitigate these impacts.

4.2.2 Economic assessment

The damages for the Avoca Public Park bund for each design flood event are summarised in Appendix B. The AAD is $474,000, which is a reduction of $84,000 from the existing conditions AAD of $558,000. Using an estimated capital cost of $550,000 and annual maintenance costs of $11,000 the BCR is 1.39. The benefit cost analysis is summarised in Table 4.1.

Table 4.1: Avoca Public Park bund BCR summary

Item	Existing conditions	Mitigated conditions
AAD	$558,000	$474,000
Benefit (Per Annum)		$84,000
Total Benefit (Present Value)		$873,000
Capital Cost		$550,000
Maintenance (per annum)		$11,000
Total Cost (Present Value)		$629,000
BCR		**1.39**

4.2.3 Advantages and disadvantages

Key advantages and disadvantages are summarised in the following Table 4.2.

Table 4.2: Avoca Public Park bund key advantage and disadvantages

Advantages	Disadvantages
Modelled removal of floodwaters within the Avoca Public Park within the 20% AEP event.	Increases in modelled flood levels outside of the levee, impacting properties which may require additional local mediation works.
Decreases in modelled flood levels west of the Avoca Public Park.	
BCR of greater than 1 (1.39).	
Relatively minor impact to visual amenity or land disruption given all works can be incorporated into existing park landscaping works.	

4.2.4 Recommendations

1) Further investigate a bund to protect the Avoca sports ground
2) Undertake floor level and detailed topographic survey of impacted properties along Faraday Street south of the Avoca Public Park to more accurately define increase in flood risk and identify potential localised remedial works

4.3 Channel clearing (tree and debris removal)

Breakout flows that result in flooding upstream of Natte Yallock could be exacerbated by high debris loads within the river. As described in Section 3, there are significant drawbacks to broadscale channel clearing, however its impacts on flood behaviour can be tested in the flood model by reducing the channel roughness. A 'smoother' channel, reflecting less build-up of vegetation and debris, would be expected to have an increased flow capacity reducing overbank flow breakouts.

A scenario was tested where the Manning's roughness was reduced in the Avoca River between Avoca and the Natte Yallock downstream end of the Natte Yallock township from a value of 0.06 to 0.04.

4.3.1 Flood impacts

The peak flood level impact maps for each modelled AEP event are presented in Appendix D.

As anticipated, reducing the roughness lowers modelled flood levels in all modelled flood events downstream of Avoca. However, downstream of Natte Yallock the size of the Avoca River channel is restricted so when the additional flow hits this point it slows and deepens, resulting impacts propagating upstream, causing widespread flooding across Natte Yallock township itself. In the 1% AEP flood event this increases peak flood levels by 250 mm on the eastern side of Natte Yallock. Similar behaviour is observed in the other modelled design events.

This highlights the concept that increasing channel flow capacity generally transfers the flood risk downstream, as opposed to reducing the flood risk for the whole community/catchment.

Given the significant impact on residential properties a BCR analysis was not undertaken.

4.3.2 Advantages and disadvantages

Key advantages and disadvantages are summarised in Table 4.3.

Table 4.3: Channel clearing (tree and debris removal) key advantage and disadvantages

Advantages	Disadvantages
Decrease in modelled water levels downstream of Avoca township and in the wider floodplain.	Increase in modelled water levels throughout Natte Yallock township, impacting residential properties.
Reduction in overbank flooding in multiple locations.	Potentially contentious within communities given possible environmental impacts.
Relatively inexpensive compared to other options.	Increased flow velocity may result in channel erosion.

4.3.3 Recommendations

1) Broadscale clearing of the Avoca River channel is not recommended.
2) Channel clearing of individual blockages, particularly at critical locations such as upstream of bridges, can be further investigated.

4.4 Raise levee banks along the Avoca River

Widespread flooding of Natte Yallock, particularly on the western side of town, is predominately a result of breakout flows from the Avoca River overtopping the banks and existing levees, both within the township and up to 10 km upstream. An identified measure to address these breakout flows is to ‘build-up’ the levee banks either side of the River, effectively increasing the capacity of the channel.

The modelled levees were set to the 1% AEP flood level plus 300 mm freeboard, and run along both banks from Mills Lane near the Mountain Creek confluence (about 60% of the distance between Avoca and Natte Yallock) past the last property within Natte Yallock, terminating as the River forks and opens to the floodplain. The levee alignment is shown in Figure 4.2.

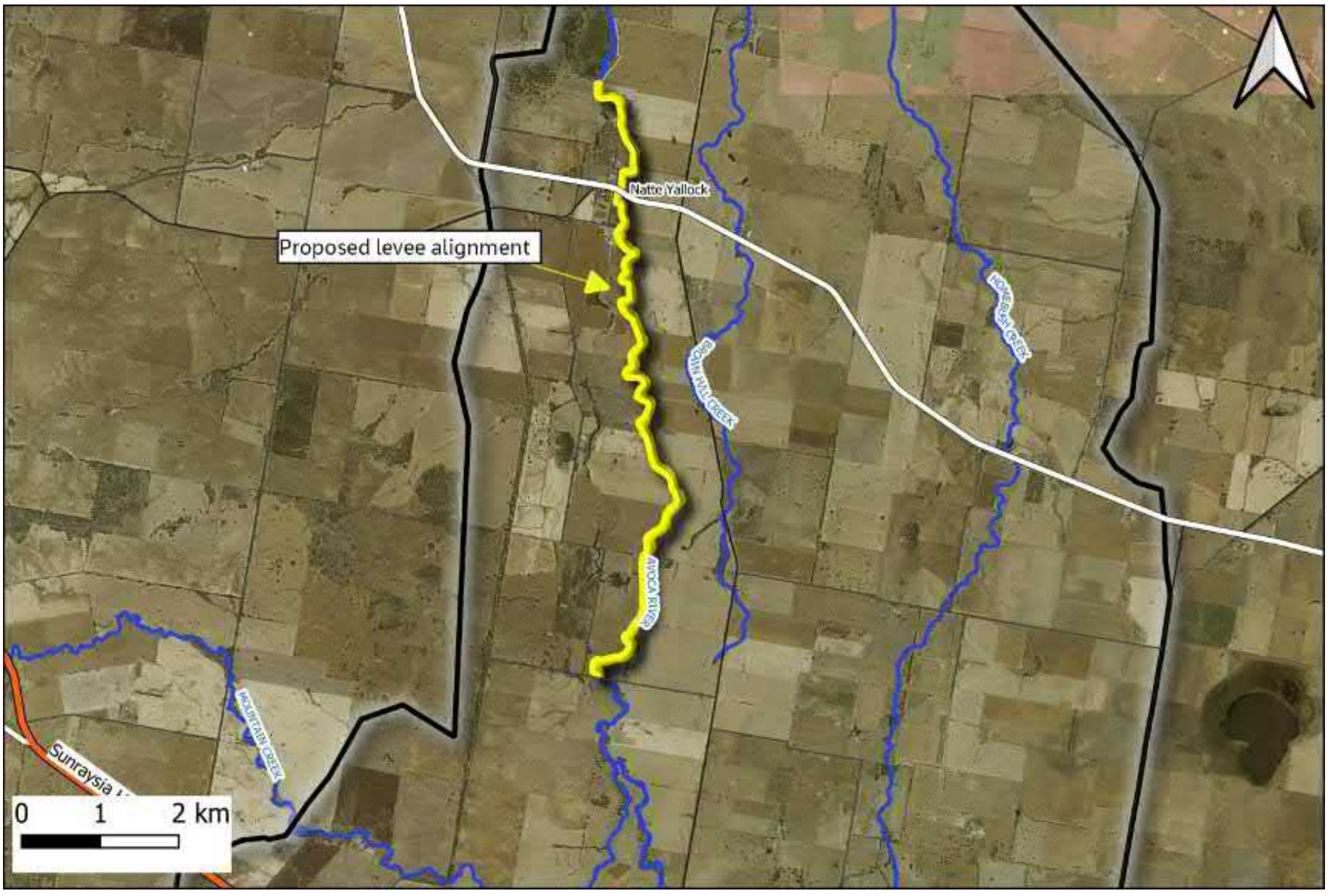

Figure 4.2: Raised levee banks alignments

4.4.1 Flood impacts

The peak flood level impact maps for each modelled AEP event are presented in Appendix E.

Raising the bank levels reduces the flood level to the west of the Avoca River in all modelled flood events with the exception of the PMF. This results in peak flood reductions in the Natte Yallock township either side of the Avoca River of up to 100 mm. However, by raising the levee banks on both sides of the river the flood levels in the channel are increased including upstream of the extent of the levees. This results in additional breakout flows across the eastern floodplain causing broad increases flood extent and flood in all events up to the 0.2% AEP event.

4.4.2 Economic assessment

The damages for the Avoca Public Park bund for each design flood event are summarised in Appendix B. The AAD is $683,000, which is an increase of $177,000 from the existing conditions AAD of $506,000. Please note that the existing conditions AAD differs to that presented in Section 2.3 as the regional model was used to assess this option given its spatial extent. This will not impact the results of the economic assessment as the relative difference between pre and post mitigation options is used.

Using an estimated capital cost of $4,400,000 and annual maintenance costs of $88,000 the BCR is -0.37. The benefit cost analysis is summarised in Table 4.4.

Table 4.4: Raise levee banks along the Avoca River BCR summary

Item	Existing conditions	Mitigated conditions
AAD	$506,000	$683,000

Item	Existing conditions	Mitigated conditions
Benefit (Per Annum)		-$177,000 (increase in AAD)
Total Benefit (Present Value)		-$1,854,000
Capital Cost		$4,400,000
Maintenance (per annum)		$88,000
Total Cost (Present Value)		$5,033,000
BCR		**-0.37**

4.4.3 Advantages and disadvantages

Key advantages and disadvantages are summarised in Table 4.5.

Table 4.5: Raise levee banks along the Avoca River key advantage and disadvantages

Advantages	Disadvantages
Reduction in peak flood levels in the Natte Yallock township.	Significant increases in peak flood level and extent on the eastern floodplain.
	Results in an overall increase in AAD.
	Potential for increased channel erosion due to heightened velocities

4.4.4 Recommendations

1) It is not recommended to pursue this option due the negative impacts on flood levels and increased AAD.
2) If sections of the existing levee are degrading, they should be assessed for remediation works.

4.5 Flow training levees upstream of Natte Yallock

An option identified to reduce widespread flooding through Natte Yallock (western floodplain) is to construct a series of levees upstream of the town to divert flows west of the township. Unlike the raising of the Avoca River levee banks option, these would allow a degree of breakout flow to occur from the Avoca River, and instead divert the flow to less sensitive areas.

The arrangement assessed involves a combination of a training levee running east-west, situated approximately 1.5km south of the township to the west of the river and to mitigate subsequent increased flood levels in the Avoca River the levee banks on each side of the river were raised, as shown in Figure 4.3. Levee heights were set to provide 300 mm of freeboard above the modelled 1% AEP flood level.

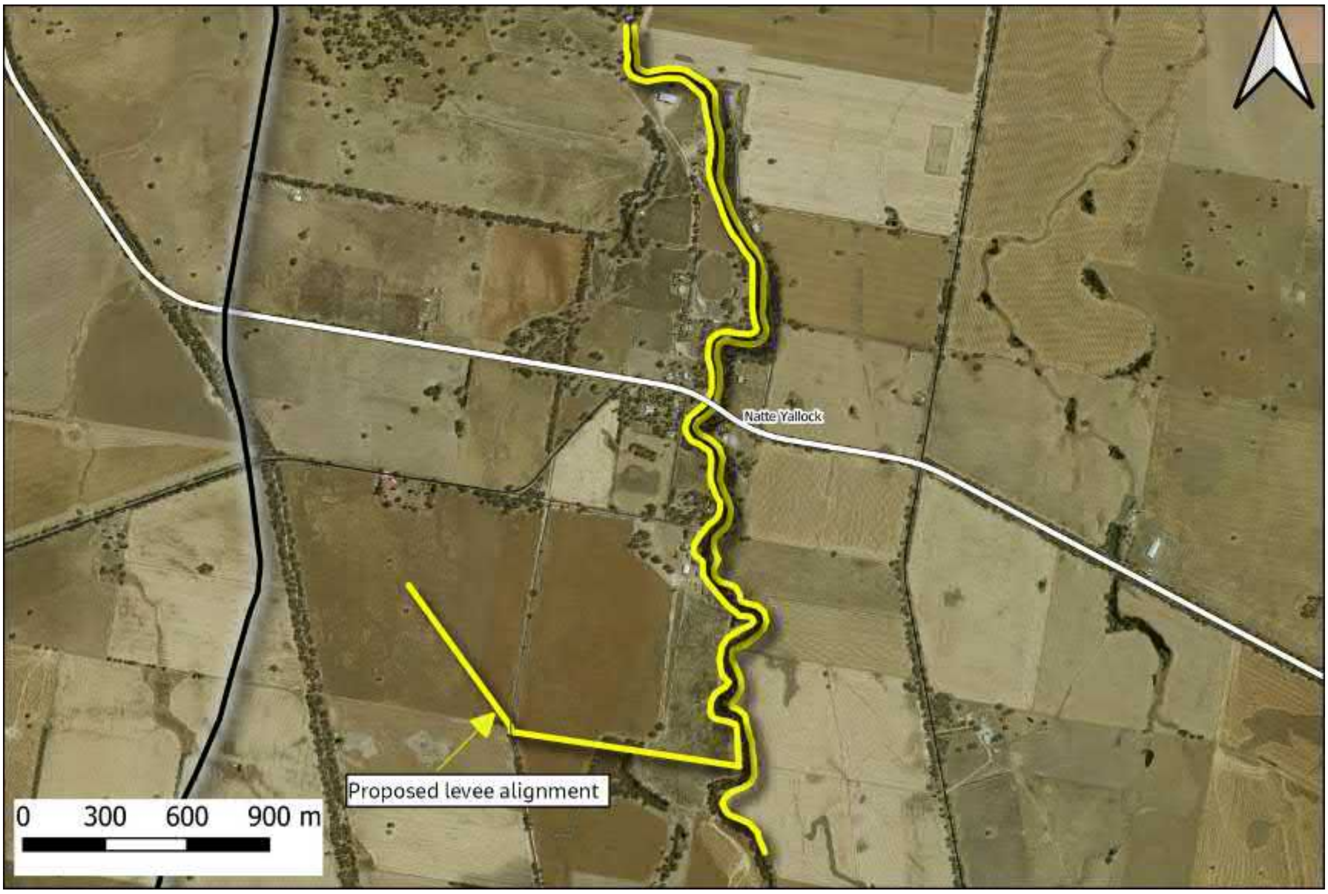

Figure 4.3: Proposed flow training levees upstream of Natte Yallock

4.5.1 Flood impacts

The peak flood level impact maps for each modelled AEP event are presented in Appendix F.

Within the 1% AEP event, this option reduces peak flood levels by up to 105 mm on the western side of the Avoca River and eliminates the inundation on the residential properties adjacent to the eastern bank of the Avoca River. These improvements are replicated in all modelled flood events.

Outside of the levee, as river flow is diverted westward, modelled peak water depths are increased by 600-800 mm in the 1% AEP. These increases in flood depth are likely to be overstated as a result of “glass-walling” against the model boundary where no topographical information was available. However, there is a residence and associated buildings located on Moonambel-Natte Yallock Road east of Three Chains Road that lies outside of the model extent but would likely be subject to increased flood levels.

Additional flow is also pushed onto the eastern floodplain resulting in increases in peak flood level of up to 100 mm.

4.5.2 Economic assessment

The damages for the Flow training levees upstream of Natte Yallock for each design flood event are summarised in Appendix B. The AAD is $428,000, which is a reduction of $78,000 from the existing conditions AAD of $506,000. Please note that the existing conditions AAD differs to that presented in Section 2.3 as the regional model was used to assess this option given its spatial extent. This will not impact the results of the economic assessment as the relative difference between pre and post mitigation options is used.

Using an estimated capital cost of $2,330,000 and annual maintenance costs of $47,000 the BCR is 0.37. The benefit cost analysis is summarised in Table 4.6.

Table 4.6: Flow training levees upstream of Natte Yallock BCR summary

Item	Existing conditions	Mitigated conditions
AAD	$506,000	$428,000
Benefit (Per Annum)		$78,000
Total Benefit (Present Value)		$1,042,000
Capital Cost		$2,330,000
Maintenance (per annum)		$47,000
Total Cost (Present Value)		$2,796,000
BCR		**0.37**

4.5.3 Advantages and disadvantages

Key advantages and disadvantages are summarised in Table 4.7.

Table 4.7: Flow training levees upstream of Natte Yalloc key advantage and disadvantages

Advantages	Disadvantages
Reduced peak flood levels within Natte Yallock.	Relatively high construction costs resulting in BCR of less than one.
	Assessed levee alignment is within private land.
	Increased peak flood levels outside of the levees, including flowpaths far to the east and west of Natte Yallock.
	Ongoing maintenance of levee required to ensure integrity.

4.5.4 Recommendations

1) It is not recommended to pursue this option due to the limited reductions in peak flood levels and low BCR.
2) Where appropriate local levees/bund to protect specific areas and assets can be further investigated.

4.6 Moonambel – Natte Yallock Road bermed corner lowering and tree removal

West of Natte Yallock, the Moonambel-Natte Yallock Road has a bermed corner which has been identified by the local community as potentially contributing to flood risk in Natte Yallock. The bermed corner supports trafficability design requirements of the road, but is believed to disturb the natural flow conditions of this region by diverting flows that would otherwise bypass the township to the west back towards the township. Upgrades to the road were made relatively recently, presenting some challenges in proposing the berm's removal. Adjacent to the corner, trees have been planted relatively recently, and are also considered to be detrimental to flood flows. Additional recent tree plantings have occurred downstream of Maryborough-St Arnaud Road.

As shown in Figure 4.4 the flood model was used to assess the impacts on flood behaviour if the bermed corner is regraded to adjacent ground levels and the trees are removed.

Figure 4.4: Moonambel - Natte Yallock Road bermed corner and tree removal

4.6.1 Flood impacts

The peak flood level impact maps for each modelled AEP event are presented in Appendix G.

As shown in flood impact maps for all modelled events there is negligible impacts on peak flood levels beyond the immediate vicinity of the regraded corner on Natte Yallock – Moonambel Road. This is highlighted by reductions of only up to 6 mm been observed in the Natte Yallock township area in the 1% AEP flood event which is within the flood impact mapping limits of 10 mm.

This indicates that in the riverine flood events assessed in this Investigation that reducing these impediments to flow; bermed corner and trees do not impact peek flood levels.

4.6.2 Economic assessment

The damages for the Moonambel - Natte Yallock Road bermed corner and tree removal for each design flood event are summarised in Appendix B. The AAD is $506,000, which within the rounding error is the same as the existing conditions AAD. Please note that the existing conditions AAD differs to that presented in Section 2.3 as the regional model was used to assess this option given its spatial extent. This will not impact the results of the economic assessment as the relative difference between pre and post mitigation options is used.

Using an estimated capital cost of $1,159,000 and the BCR is 0 due there been no reduction in AAD. The benefit cost analysis is summarised in Table 4.8.

Table 4.8: Moonambel – Natte Yallock Road bermed corner lowering and tree removal BCR summary

Item	Existing conditions	Mitigated conditions
AAD	$506,000	$506,000
Benefit (Per Annum)		-
Total Benefit (Present Value)		-
Capital Cost		$1,159,000
Maintenance (per annum)		-
Total Cost (Present Value)		$1,159,000
BCR		**0**

4.6.3 Advantages and disadvantages

Key advantages and disadvantages are summarised in the following table.

Advantages	Disadvantages
Reinstates floodplain to “natural” topography.	Bermed corner required to trafficability requirements.
	Limited reductions in peak flood level and AAD.
	Reduction in native vegetation associated with tree removal.

4.6.4 Recommendations

1) It is not recommended to pursue this option due to the limited reductions in peak flood levels, and low BCR and it has been demonstrated not to provide a benefit.

5. Recommendations

This Flood Damages and Structural Mitigation Options Report details the existing conditions flood damages assessment and, the pre-feasibility and detailed structural mitigation options assessment.

Following the detailed assessment of the five selected mitigation options it is recommended that a bund to protect the Avoca Public Park from inundation is further investigated. While the other selected mitigation did not result in significant improvements in flood risk as assessed it is also recommended that:

- Where required channel clearing of individual blockages, particularly at critical locations such as upstream of bridges should be investigated.
- Remediation works should be investigated for sections of the existing Avoca River bank levee that are degrading.
- Where appropriate public or private local levees/bund to protect specific areas and assets can be further investigated.

6. References

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Appendix A. Structural mitigation options cost estimates

Avoca Public Park bund

Item	Quantity	Unit	Unit cost	Fee estimate
Demolition allowance - 5 crew days	5	Days	$3,500	$17,500
Disposal allowances	1	Item	$3,500	$3,500
Imported Filling, earthen bund - quantity is approx 400m x .8m high x 5 wide x 1/2 = 800m^2, allow 1,000m^3 - rate includes for supply, cart, place, shape batter	1,000	m^3	$70	$70,000
Imported Filling, entrance - quantity is approx 200m x 1m high x 5 wide = 1,000m^3 - rate includes for supply, cart, place, shape batter	1,000	m^3	$70	$70,000
Landscape for earthen bund / grassing	2,000	m^2	$10	$20,000
Gravel Road surface for entrance	900	m^2	$25	$22,500
Tree planting	10	No.	$200	$2,000
Fencing	250	LM	$ 80	$20,000
Feature Fencing	100	LM	$150	$15,000
Entrance Gates	1	Item	$20,000	$20,000
Reinstate signage, etc	1	Set	$10,000	$10,000
Total Trade Cost				**$270,500**
Contractor's Costs	25%			$67,625
Construction Estimate				**$338,125**
Engineering, Design, etc	10%			$33,813
Owners Costs / Project Management	10%			$33,813
Land Acquisition & Easements	Not Required			
Total Base Budget				$405,750
Contingency	35%			$142,013
Total Fee Estimate				**$547,763**
Rounded Total Fee Estimate				**$550,000**
Maintenance per annum	**2%**			**$11,000**

Raise levee banks along the Avoca River

Item	Quantity	Unit	Unit cost	Fee estimate
Demolition allowance - 25 crew days	25	Days	$3,500	$87,500
Disposal allowances	1	Item	$15,000	$15,000
Imported Filling - quantity is approx 20,000m x .5m x 5m = approx 50,000m^3 - rate includes for supply, cart, place, shape batter - cheaper rate for bulk works	50,000	m^3	$30	$1,500,000
Landscape to levee / grassing	100,000	m^2	$5	$500,000
Gravel Road surfaces	1,000	m^2	$25	$25,000
Tree Planting	100	No	$200	$20,000
Fencing	2,500	LM	$50	$125,000
Total Trade Cost				**$2,272,500**
Contractor's Costs	25%			$568,125
Construction Estimate				**$2,840,625**
Engineering, Design, etc	7%			$198,844
Owners Costs / Project Management	7%			$198,844
Land Acquisition & Easements	Not Required			
Total Base Budget				$3,238,313
Contingency	35%			$1,133,409
Total Fee Estimate				**$4,371,722**
Rounded Total Fee Estimate				**$4,400,000**
Maintenance per annum	**2%**			**$88,000**

Flow training levees upstream of Natte Yallock

Item	Quantity	Unit	Unit cost	Fee estimate
Demolition allowance - 10 crew days	10	Days	$3,500	$35,000
Disposal allowances	1	Item	$10,000	$10,000
Imported Filling Diversion Levee - quantity is approx 1500m x 1m x 5m x 1/2 = approx 3,750m^3 - rate includes for supply, cart, place, shape batter	3,750	m^3	$50	$187,500
Imported Filling River Levee - quantity is approx 7500m x .6m x 5m = approx 22,500m^3 - rate includes for supply, cart, place, shape batter - cheaper rate for bulk works	22,500	m^3	$30	$675,000
Landscape to levee / grassing	45,000	m^2	$5	$225,000
Gravel Road surfaces	750	m^2	$25	$18,750
Tree Planting	50	No	$200	$10,000
Fencing	1,000	LM	$50	$50,000
Total Trade Cost				**$1,211,250**
Contractor's Costs	25%			$302,813
Construction Estimate				**$1,514,063**
Engineering, Design, etc	7%			$105,984
Owners Costs / Project Management	7%			$105,984
Land Acquisition & Easements	Not Required			
Total Base Budget				$1,726,031
Contingency	35%			$604,111
Total Fee Estimate				**$2,330,142**
Rounded Total Fee Estimate				**$2,330,000**
Maintenance per annum	**2%**			**$46,600**

Moonambel – Natte Yallock Road bermed corner lowering and tree removal

Item	Quantity	Unit	Unit cost	Fee estimate
"Demolition allowance, tree removals - 10 crew days, 2.5 days per hectare - 40,000m2, 40 hectares"	100	Days	$2,500	$250,000
Disposal allowances	1	Item	$25,000	$25,000
Road re-grading - 6.5m to 7.5m road corridor with shoulders, increase to 8.5m for sweeping bend, for road safety. - 200m x 9m = up to 2,000m^2 - no allowance for active traffic management. Road closure / road closed to through traffic for the duration of works. Seek alternate route.	2,000	m^2	$180	$360,000
Landscape / grassing	750	m^2	$5	$3,750
Gravel Road surfaces	200	m^2	$25	$5,000
Tree Planting	10	No	$200	$2,000
Total Trade Cost				**$645,750**
Contractor's Costs	25%			$161,438
Construction Estimate				**$807,188**
Engineering, Design, etc	7%			$56,503
Owners Costs / Project Management	7%			$56,503
Land Acquisition & Easements	Not Required			
Total Base Budget				$920,194
Contingency	35%			$322,068
Total Fee Estimate				**$1,242,262**
Rounded Total Fee Estimate				**$1,240,000**

Appendix B. Structural mitigation options AAD

Avoca Public Park bund

AEP	Building direct tangible damages	Road direct tangible damages	Avoca Public Park	Indirect tangible damages	Intangible damages	Total damages
PMF	$20,836,000	$1,358,000	$150,000	$6,703,000	$22,344,000	**$51,391,000**
0.2%	$1,216,000	$480,000	$150,000	$554,000	$1,846,000	**$4,246,000**
0.5%	$975,000	$462,000	$150,000	$476,000	$1,588,000	**$3,651,000**
1%	$761,000	$444,000	$150,000	$407,000	$1,355,000	**$3,117,000**
2%	$577,000	$415,000	$150,000	$343,000	$1,142,000	**$2,627,000**
5%	$358,000	$341,000	$150,000	$255,000	$849,000	**$1,952,000**
10%	$260,000	$302,000	$150,000	$214,000	$712,000	**$1,637,000**
20%	$48,000	$214,000	$0	$79,000	$263,000	**$604,000**
Average Annual Damages						$474,000

Existing conditions (Regional Model)

AEP	Building direct tangible damages	Road direct tangible damages	Indirect tangible damages	Intangible damages	Contribution to AAD
PMF	$1,546,000	$1,124,000	$801,000	$2,671,000	**$6,143,000**
0.2%	$512,000	$983,000	$448,000	$1,495,000	**$3,437,000**
0.5%	$406,000	$913,000	$396,000	$1,319,000	**$3,034,000**
1%	$316,000	$816,000	$340,000	$1,132,000	**$2,603,000**
2%	$254,000	$704,000	$288,000	$958,000	**$2,204,000**
5%	$131,000	$581,000	$214,000	$712,000	**$1,639,000**
10%	$98,000	$560,000	$197,000	$658,000	**$1,513,000**
20%	$60,000	$455,000	$154,000	$515,000	**$1,184,000**
Average Annual Damages					$506,000

Raise levee banks along the Avoca River (Regional Model)

AEP	Building direct tangible damages	Road direct tangible damages	Indirect tangible damages	Intangible damages	Contribution to AAD
PMF	$1,630,000	$1,126,000	$827,000	$2,756,000	**$6,339,000**
0.2%	$624,000	$976,000	$480,000	$1,600,000	**$3,681,000**
0.5%	$581,000	$955,000	$461,000	$1,536,000	**$3,534,000**
1%	$501,000	$918,000	$426,000	$1,419,000	**$3,264,000**
2%	$389,000	$849,000	$371,000	$1,238,000	**$2,848,000**
5%	$246,000	$728,000	$292,000	$973,000	**$2,239,000**
10%	$246,000	$679,000	$277,000	$924,000	**$2,125,000**
20%	$196,000	$506,000	$211,000	$703,000	**$1,616,000**
Average Annual Damages					$683,000

Flow training levees upstream of Natte Yallock (Regional Model)

AEP	Building direct tangible damages	Road direct tangible damages	Indirect tangible damages	Intangible damages	Contribution to AAD
PMF	$1,400,000	$1,100,000	$750,000	$2,500,000	**$5,749,000**
0.2%	$448,000	$962,000	$423,000	$1,410,000	**$3,242,000**
0.5%	$361,000	$906,000	$380,000	$1,267,000	**$2,914,000**
1%	$249,000	$831,000	$324,000	$1,080,000	**$2,484,000**
2%	$156,000	$716,000	$262,000	$873,000	**$2,008,000**
5%	$37,000	$585,000	$187,000	$622,000	**$1,430,000**
10%	$25,000	$553,000	$174,000	$578,000	**$1,330,000**
20%	$0	$405,000	$122,000	$405,000	**$933,000**
Average Annual Damages					$428,000

Moonambel – Natte Yallock Road bermed corner lowering and tree removal (Regional Model)

AEP	Building direct tangible damages	Road direct tangible damages	Indirect tangible damages	Intangible damages	Contribution to AAD
PMF	$1,543,000	$1,124,000	$800,000	$2,666,000	**$6,133,000**
0.2%	$497,000	$983,000	$444,000	$1,480,000	**$3,404,000**
0.5%	$404,000	$913,000	$395,000	$1,318,000	**$3,030,000**
1%	$315,000	$816,000	$339,000	$1,131,000	**$2,602,000**
2%	$251,000	$704,000	$287,000	$955,000	**$2,197,000**
5%	$131,000	$581,000	$214,000	$712,000	**$1,638,000**
10%	$97,000	$560,000	$197,000	$656,000	**$1,510,000**
20%	$60,000	$455,000	$154,000	$515,000	**$1,184,000**
Average Annual Damages					$506,000

Appendix C. Avoca Public Park bund flood level impact maps

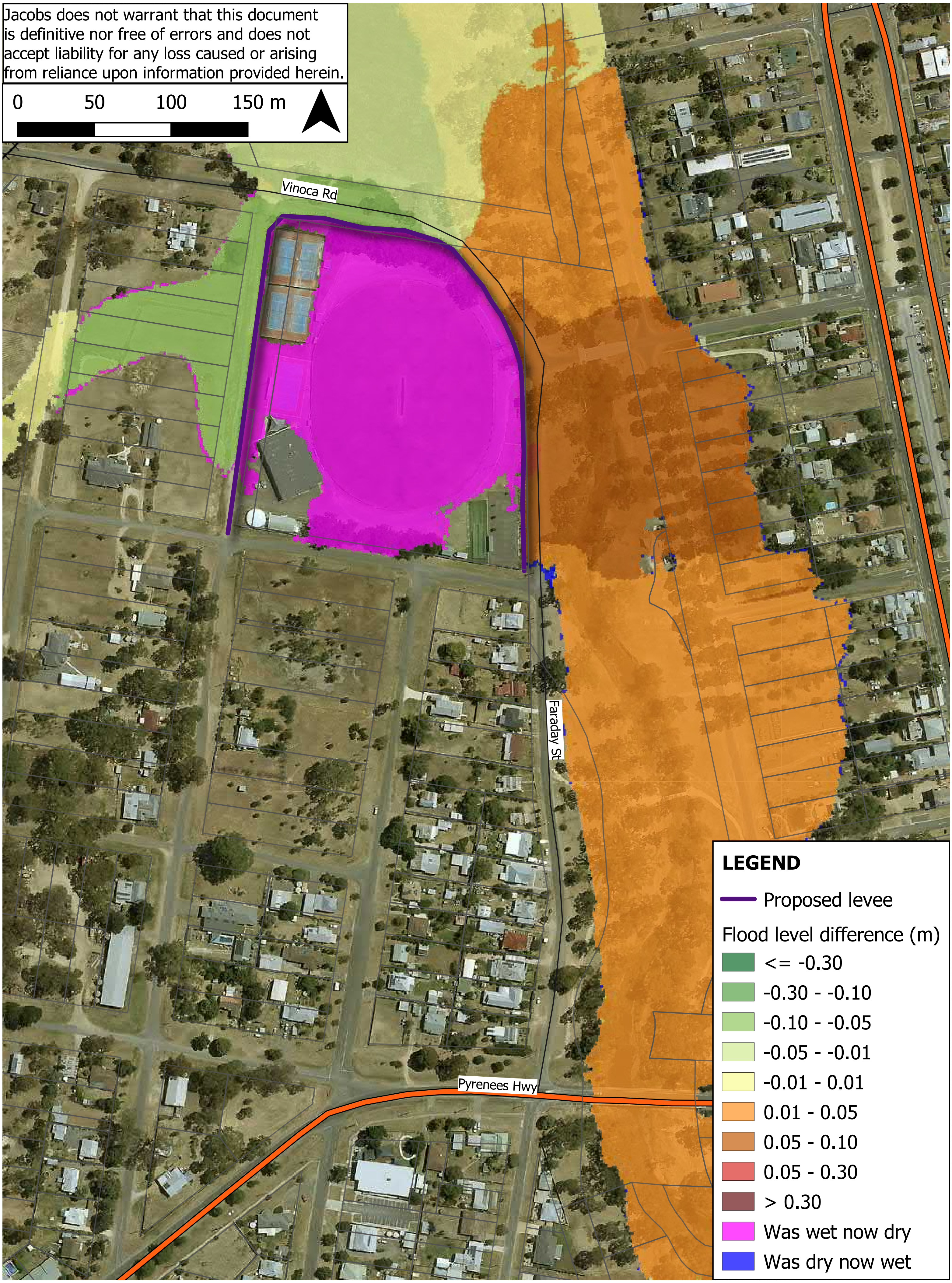

Figure C.1: 20% AEP Avoca - Levee option - flood level difference map

Jacobs

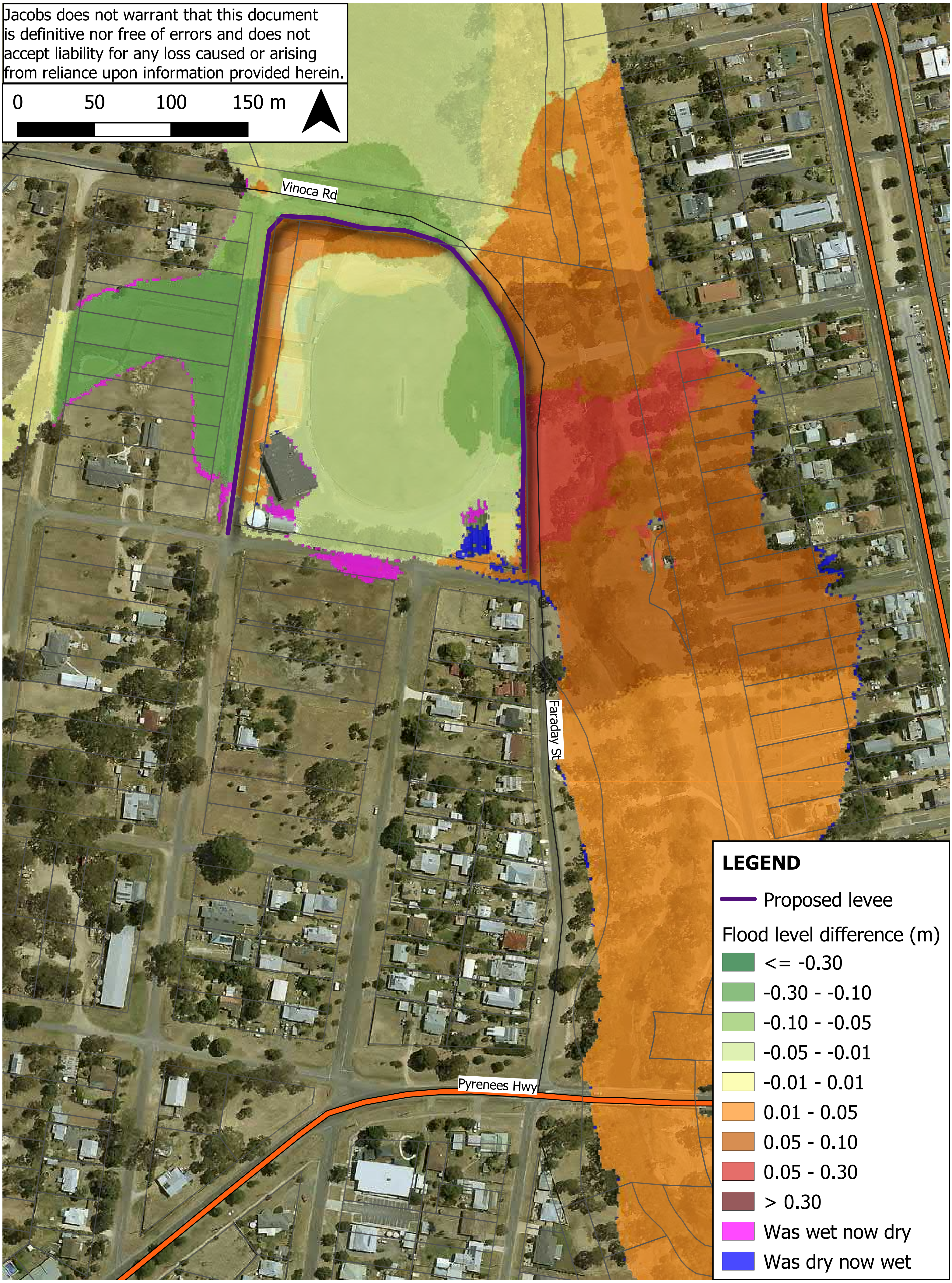

Figure C.2: 10% AEP Avoca - Levee option - flood level difference map

Jacobs

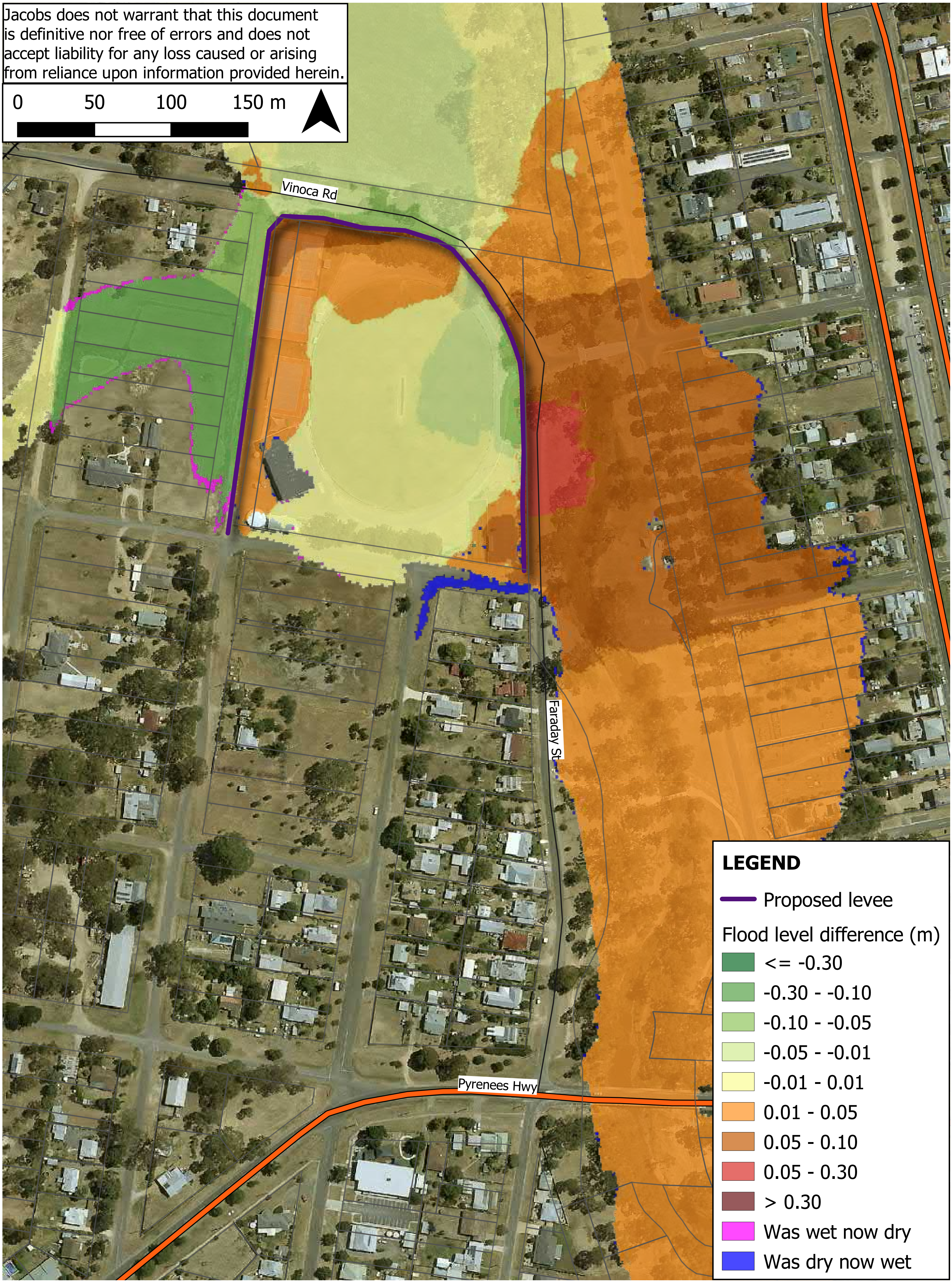

Figure C.3: 5% AEP Avoca - Levee option - flood level difference map

Jacobs

Figure C.4: 2% AEP Avoca - Levee option - flood level difference map

Jacobs

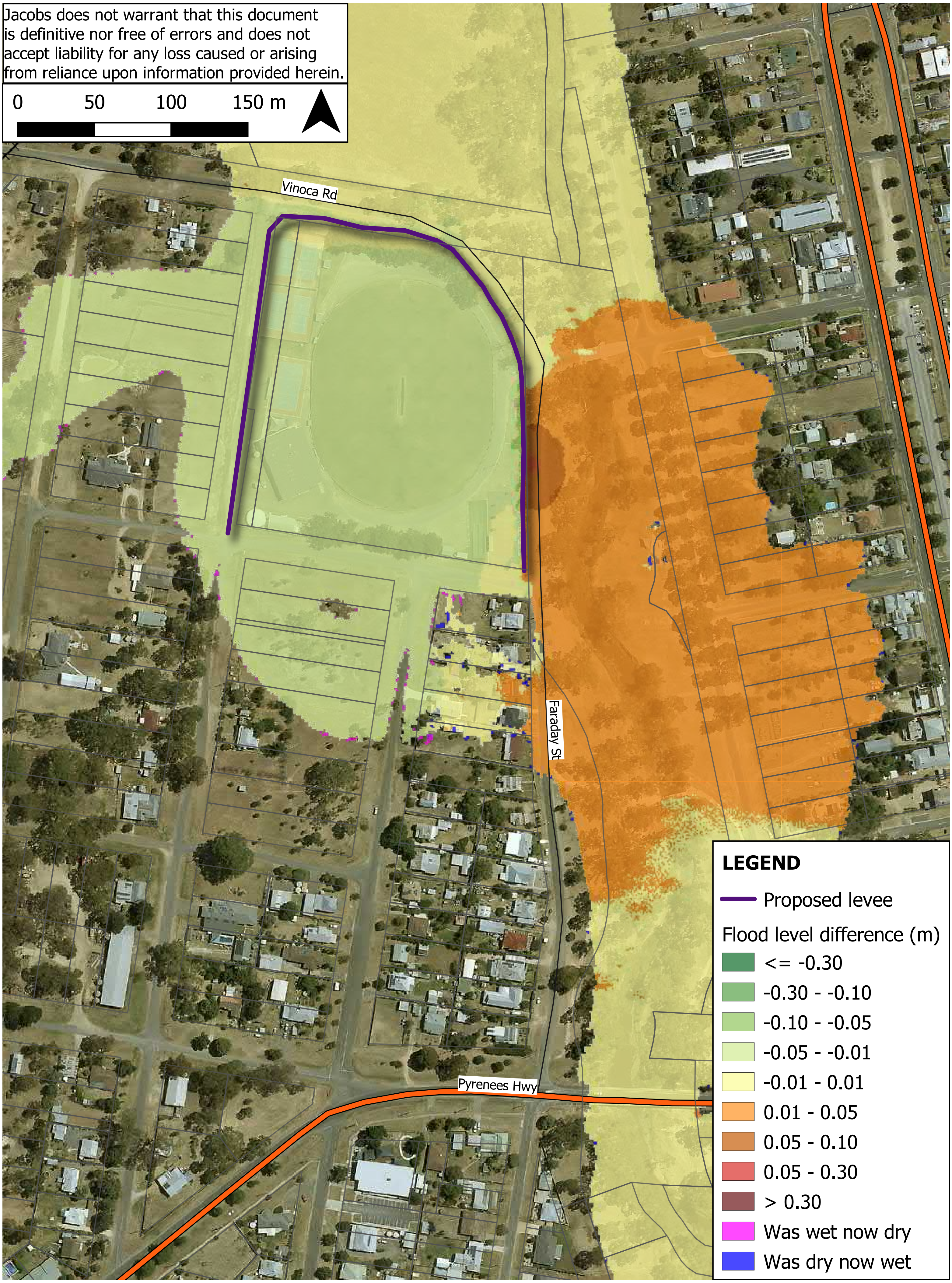

Figure C.5: 1% AEP Avoca - Levee option - flood level difference map

Jacobs

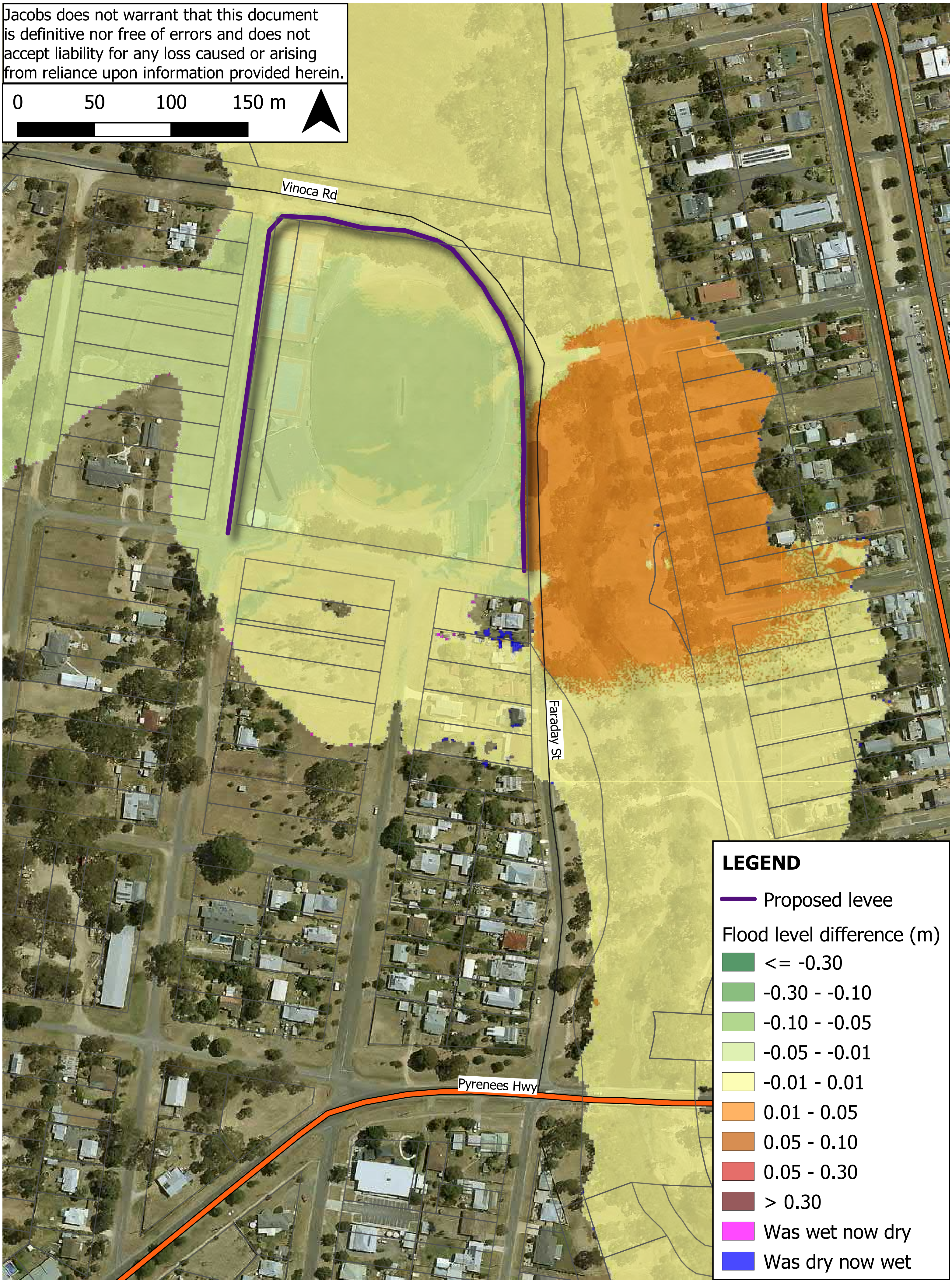

Figure C.6: 0.5% AEP Avoca - Levee option - flood level difference map

Jacobs

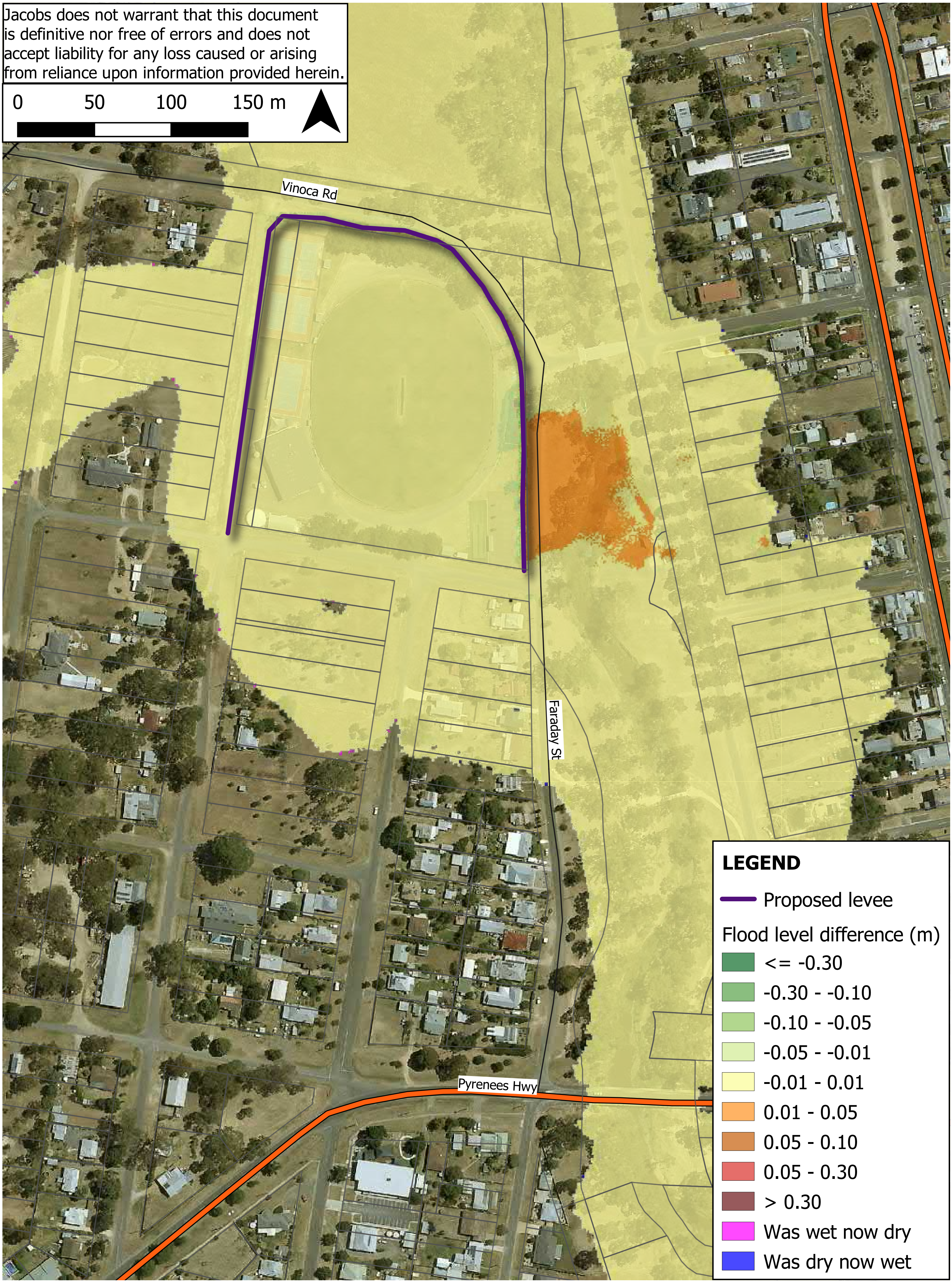

Figure C.7: 0.2% AEP Avoca - Levee option - flood level difference map

Jacobs

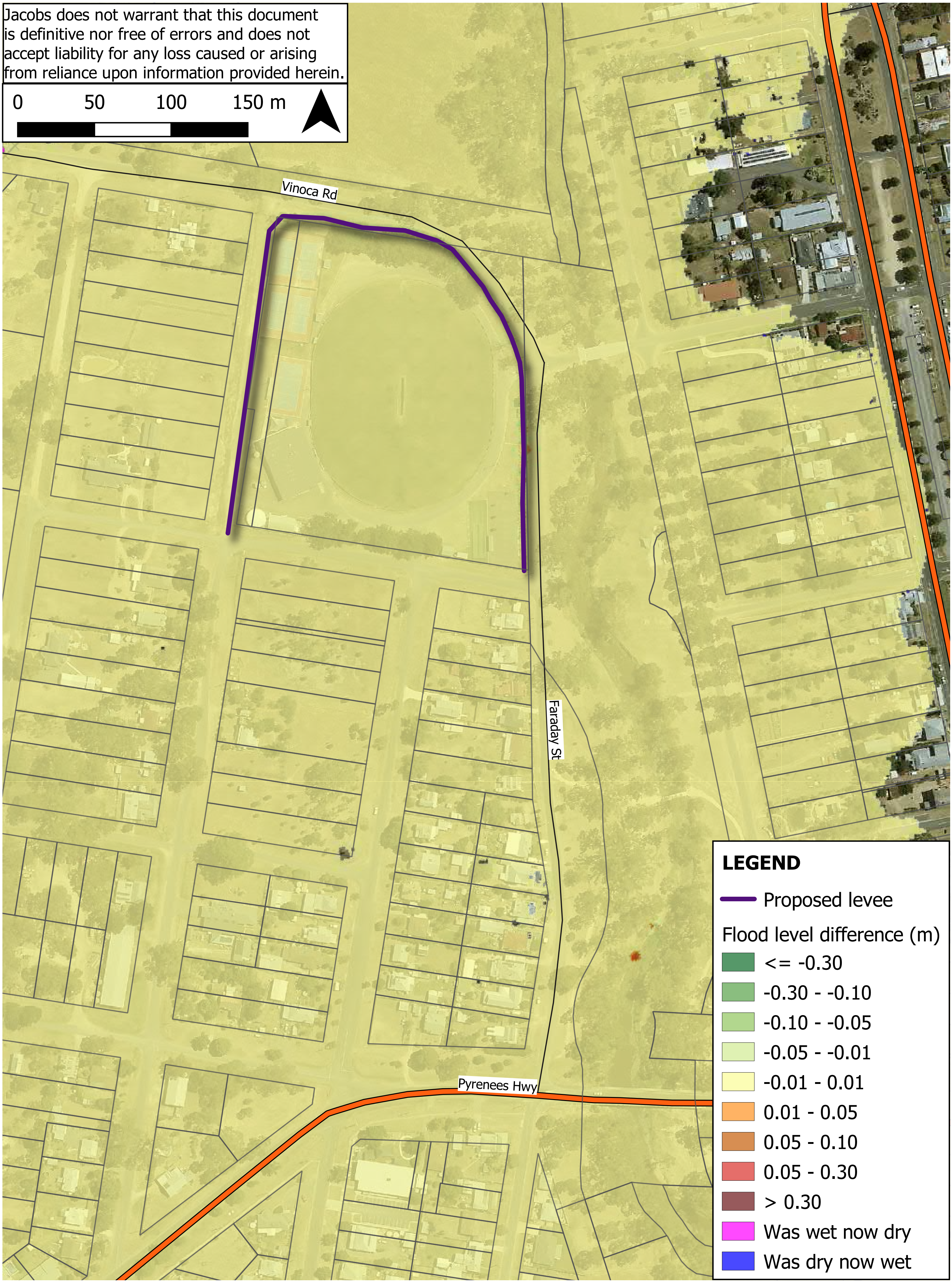

Figure C.8: PMF Avoca - Levee option - flood level difference map

Jacobs

Appendix D. Channel clearing (tree and debris removal)

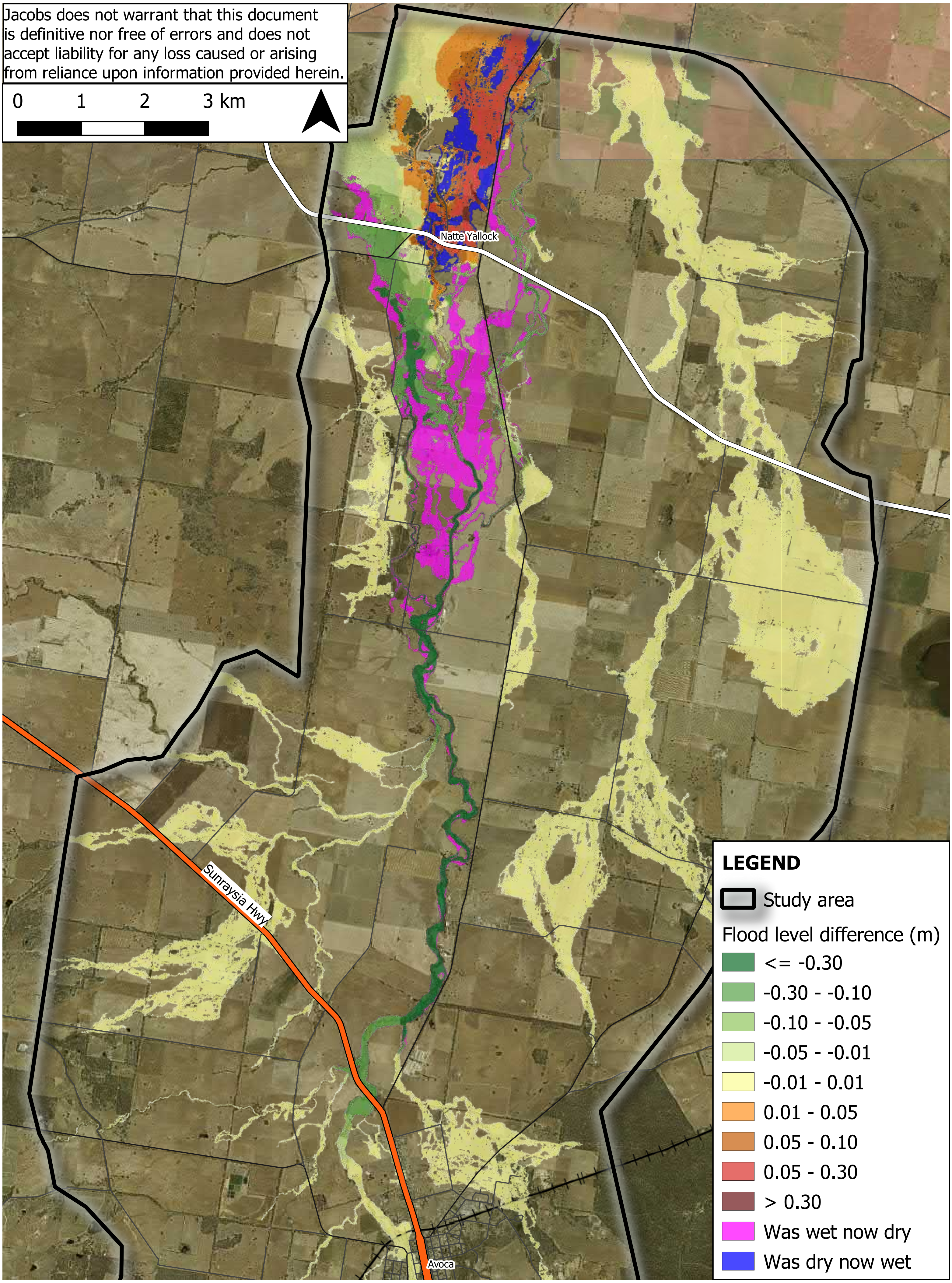

Figure D.1: 20% AEP Channel clearing option - flood level difference map

Jacobs

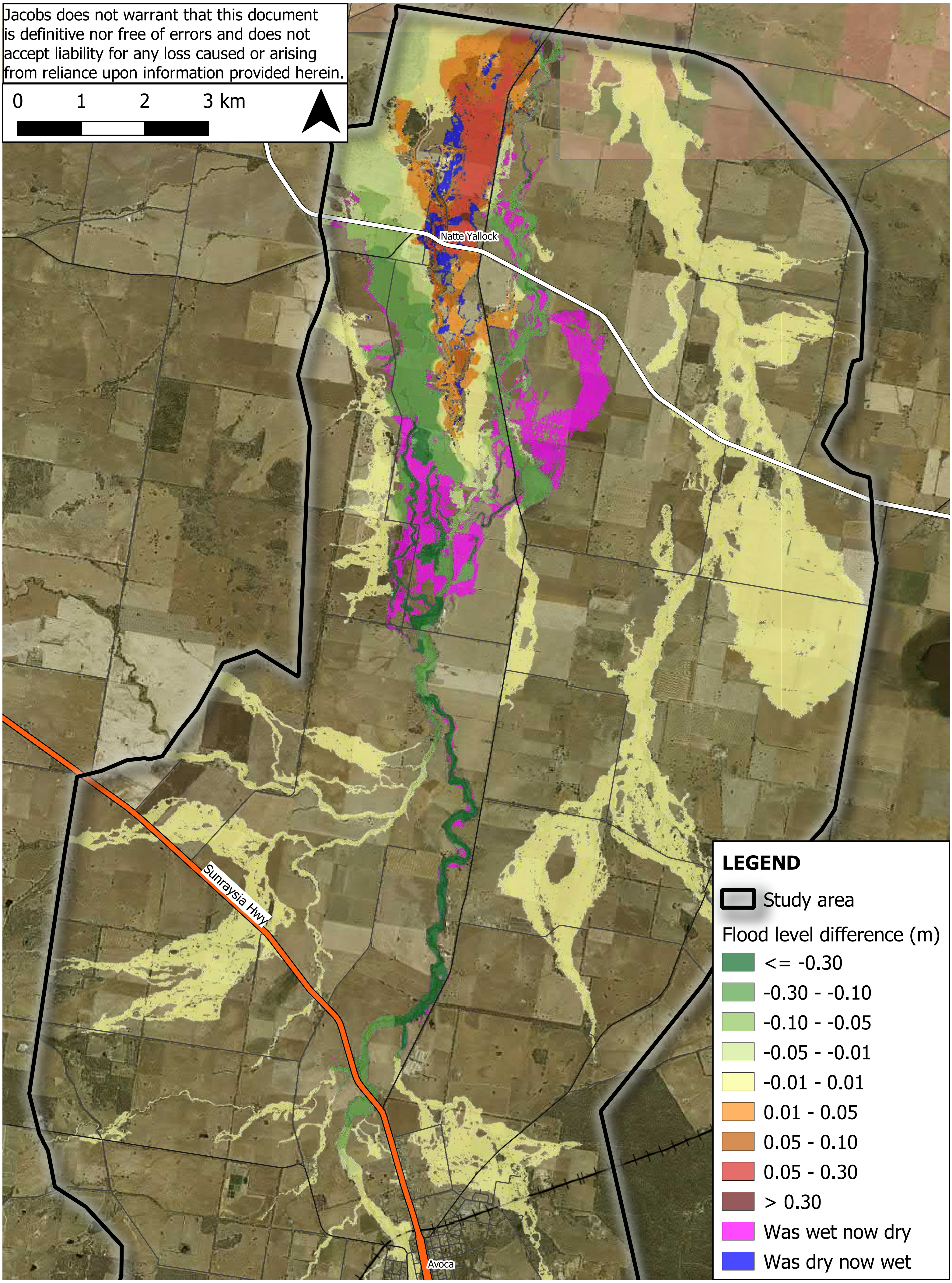

Figure D.2: 10% AEP Channel clearing option - flood level difference map

Jacobs

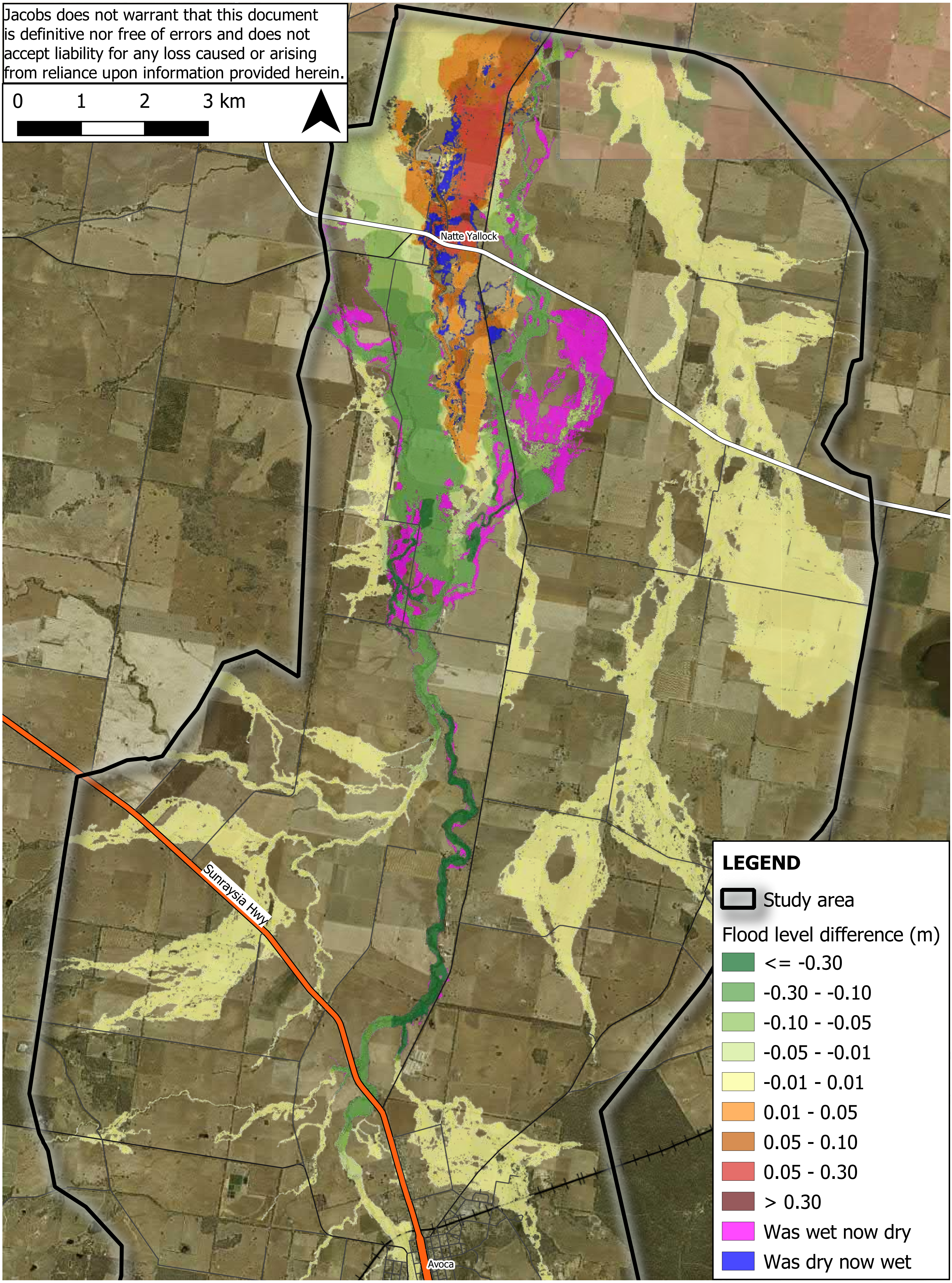

Figure D.3: 5% AEP Channel clearing option - flood level difference map

Jacobs

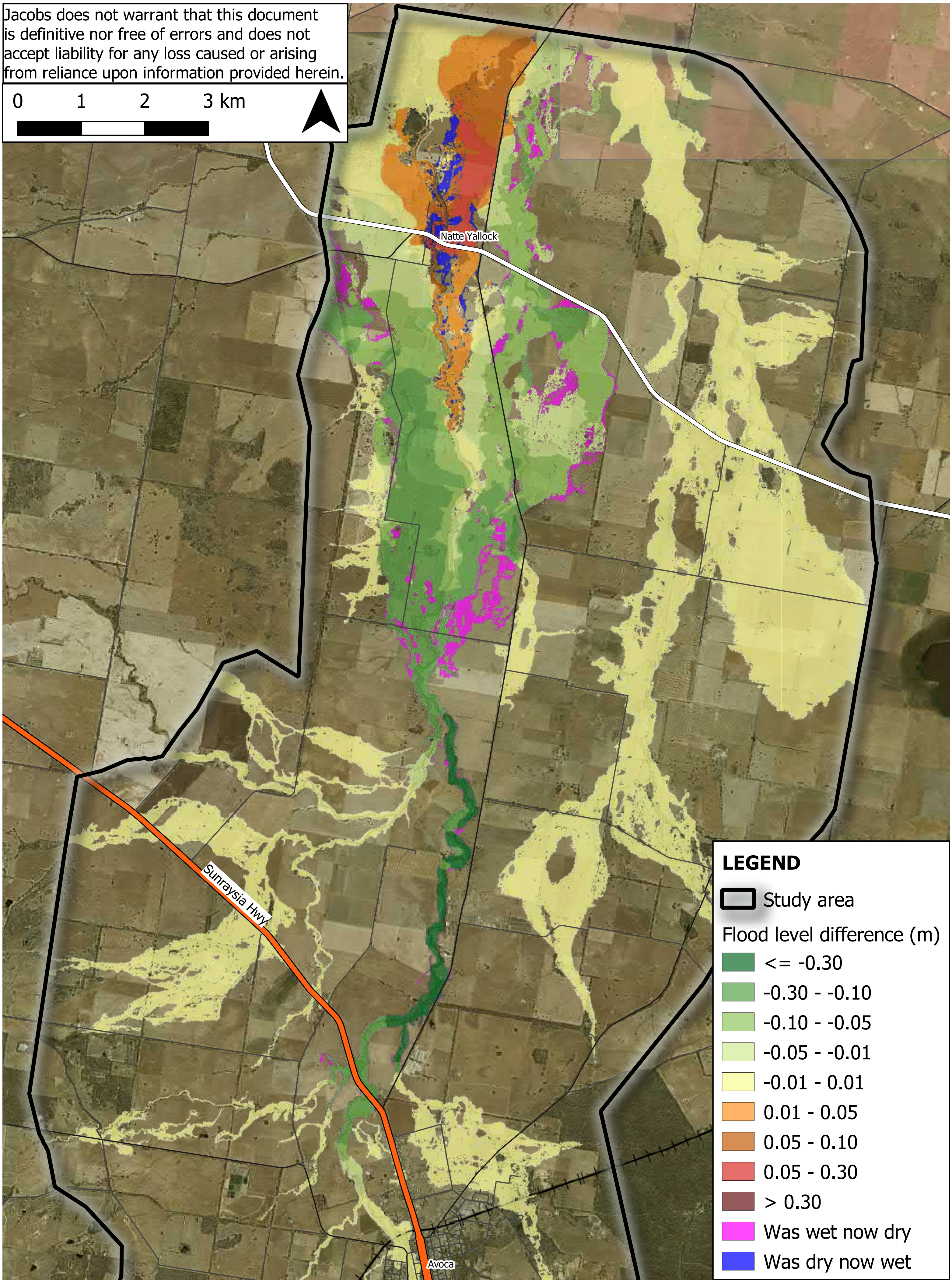

Figure D.4: 2% AEP Channel clearing option - flood level difference map

Jacobs

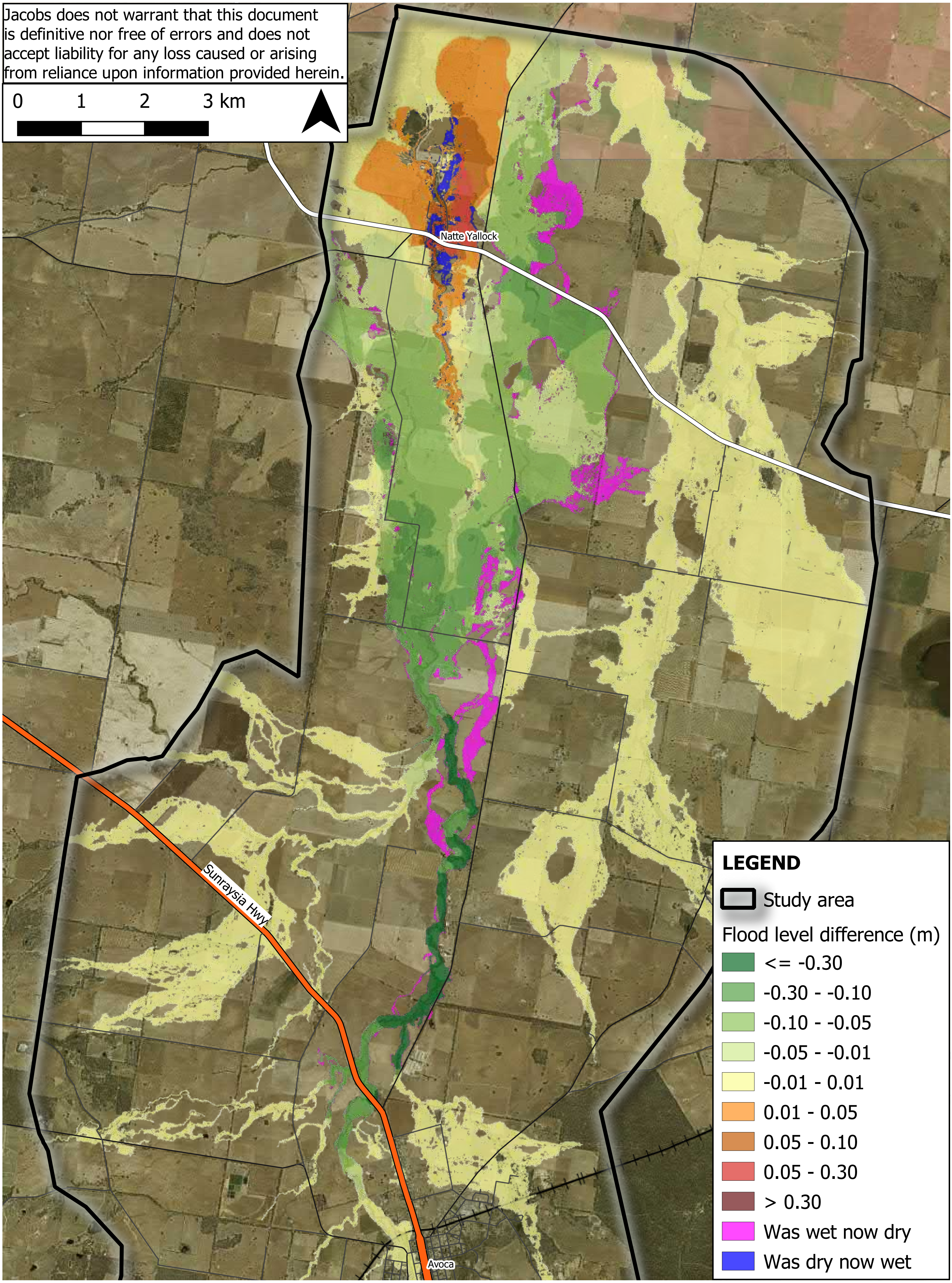

Figure D.5: 1% AEP Channel clearing option - flood level difference map

Jacobs

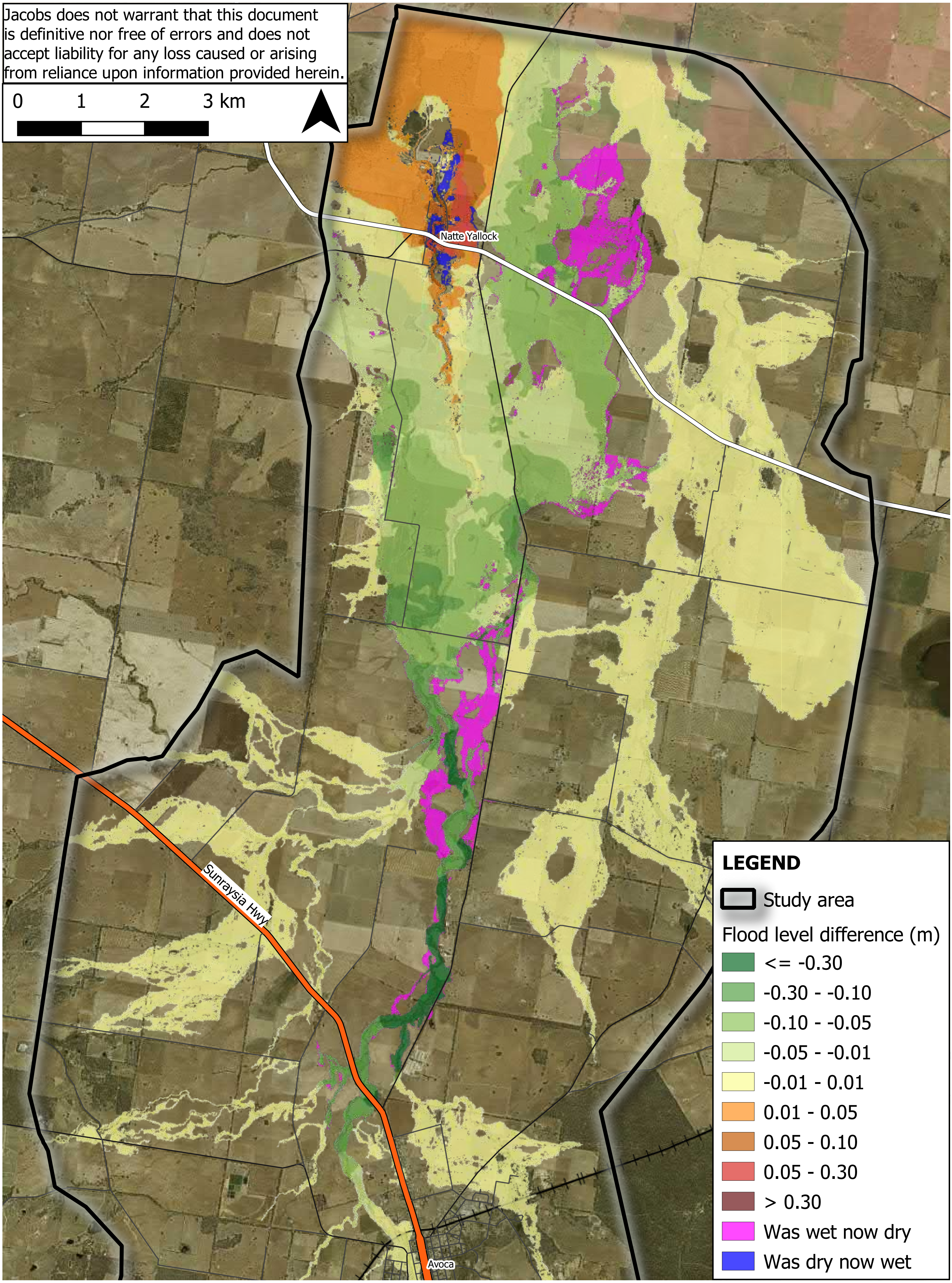

Figure D.6: 0.5% AEP Channel clearing option - flood level difference map

Jacobs

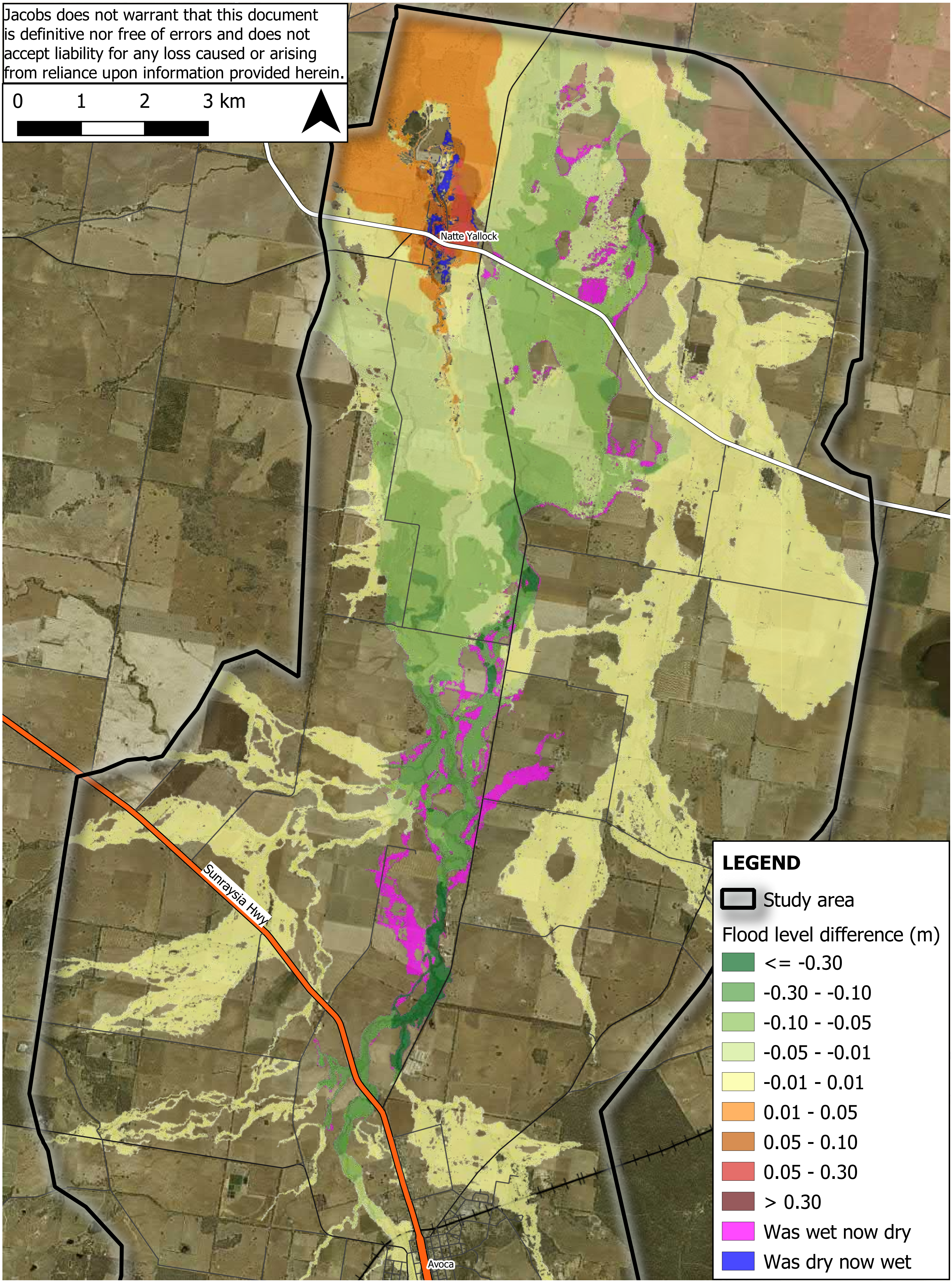

Figure D.7: 0.2% AEP Channel clearing option - flood level difference map

Jacobs

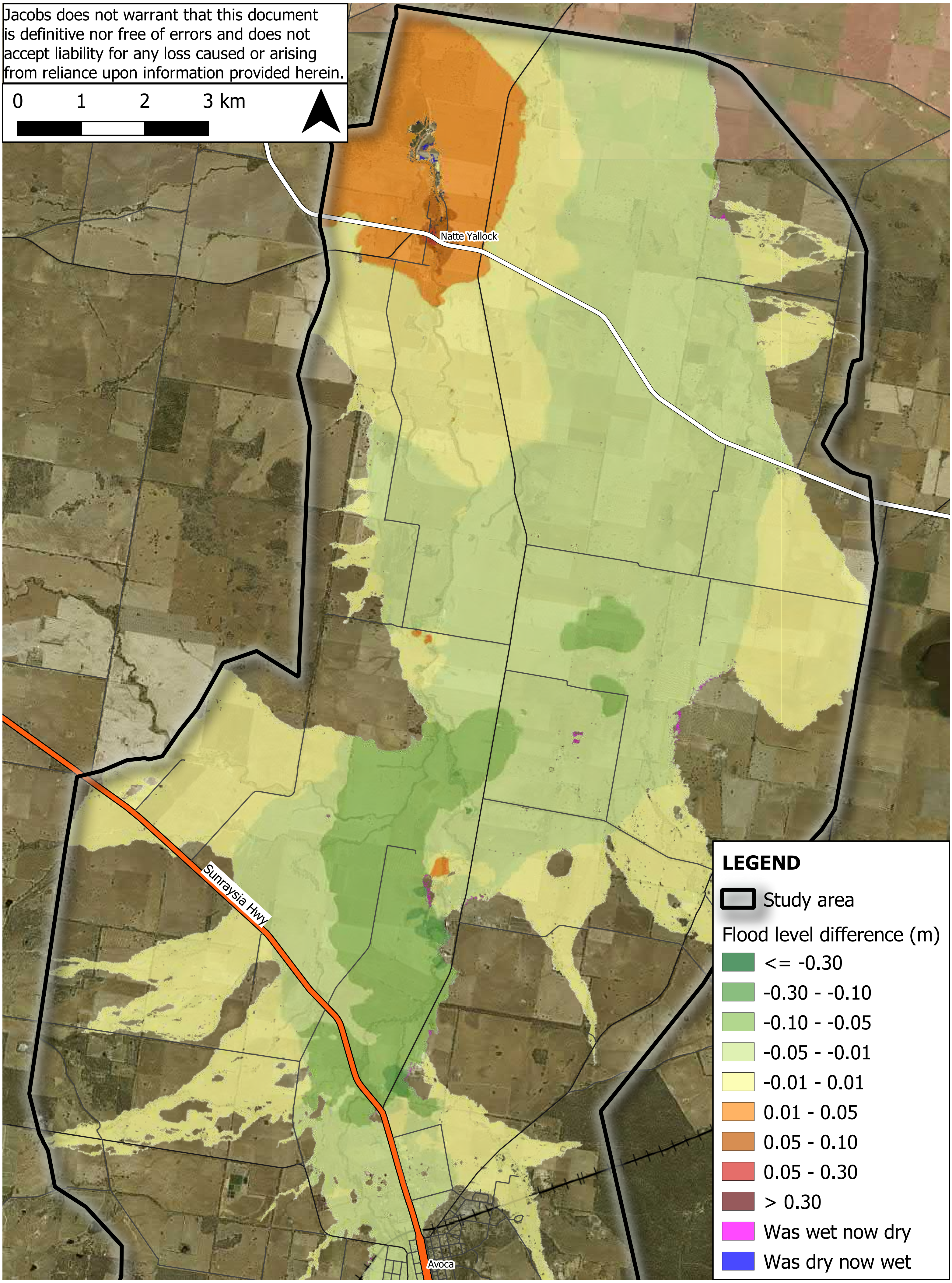

Figure D.8: PMF Channel clearing option - flood level difference map

Jacobs

Appendix E. Raise levee banks along the Avoca River flood level impact maps

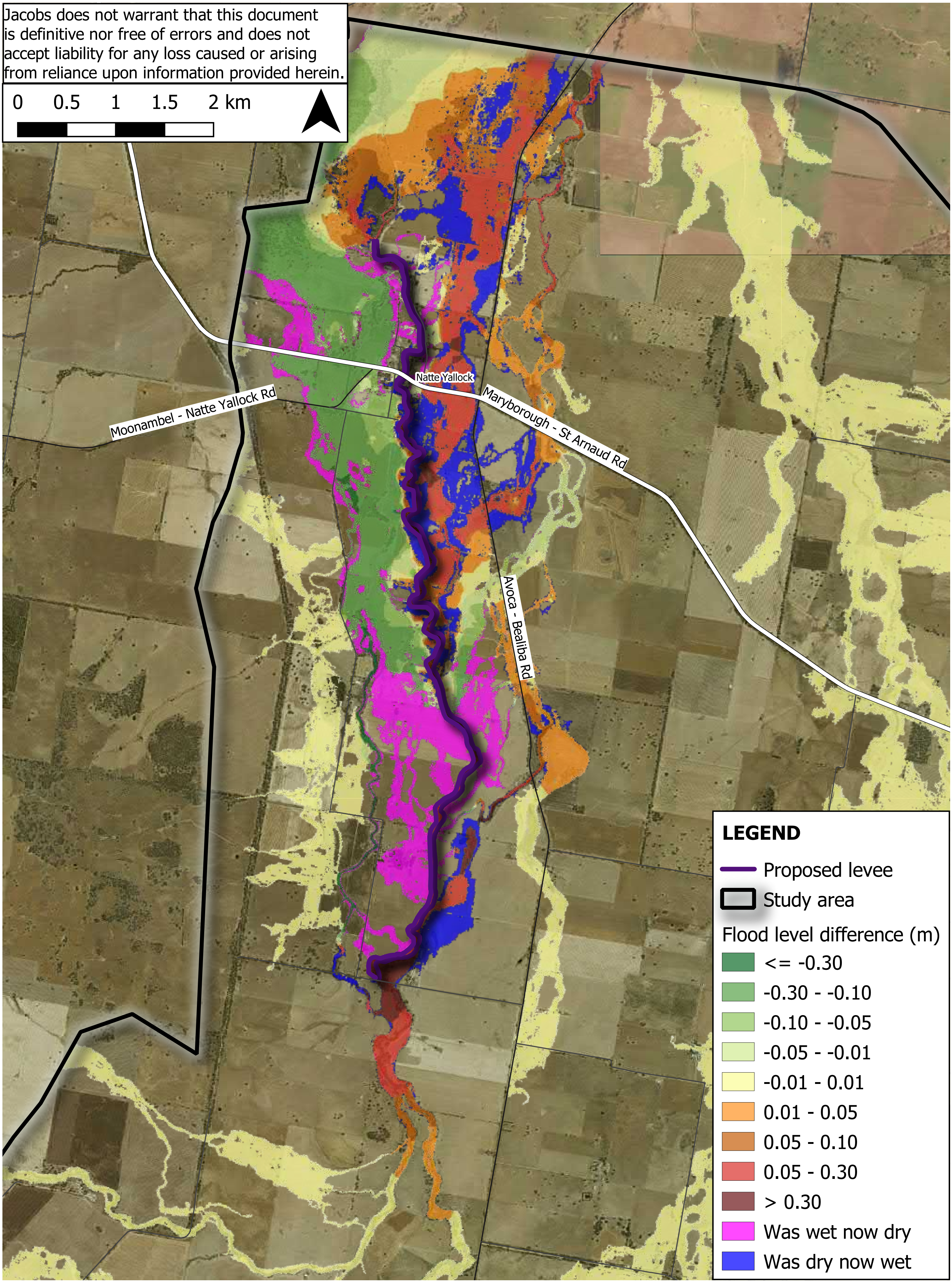

Figure E.1: 20% AEP Avoca River levee bank option - flood level difference map

Jacobs

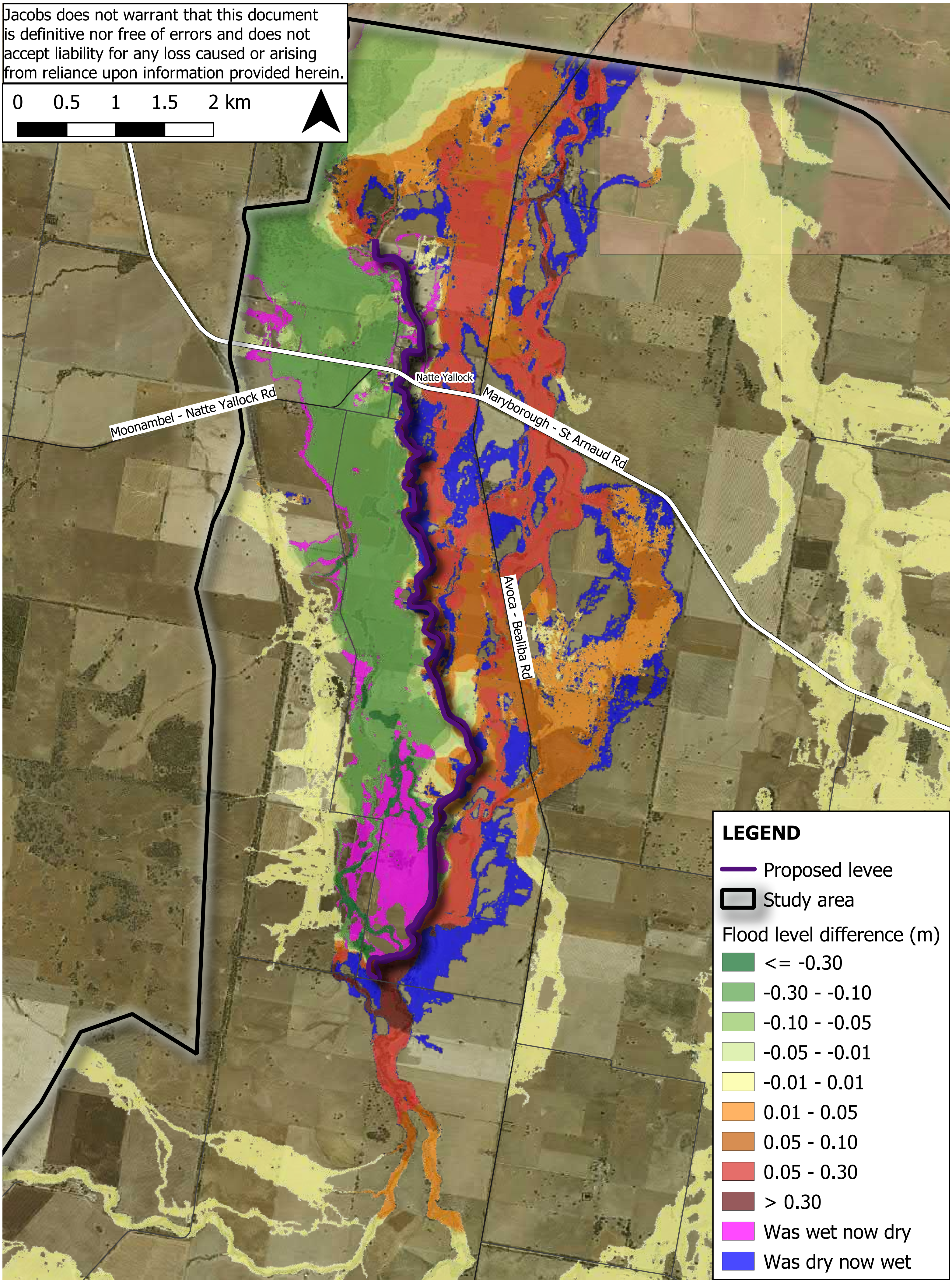

Figure E.2: 10% AEP Avoca River levee bank option - flood level difference map

Jacobs

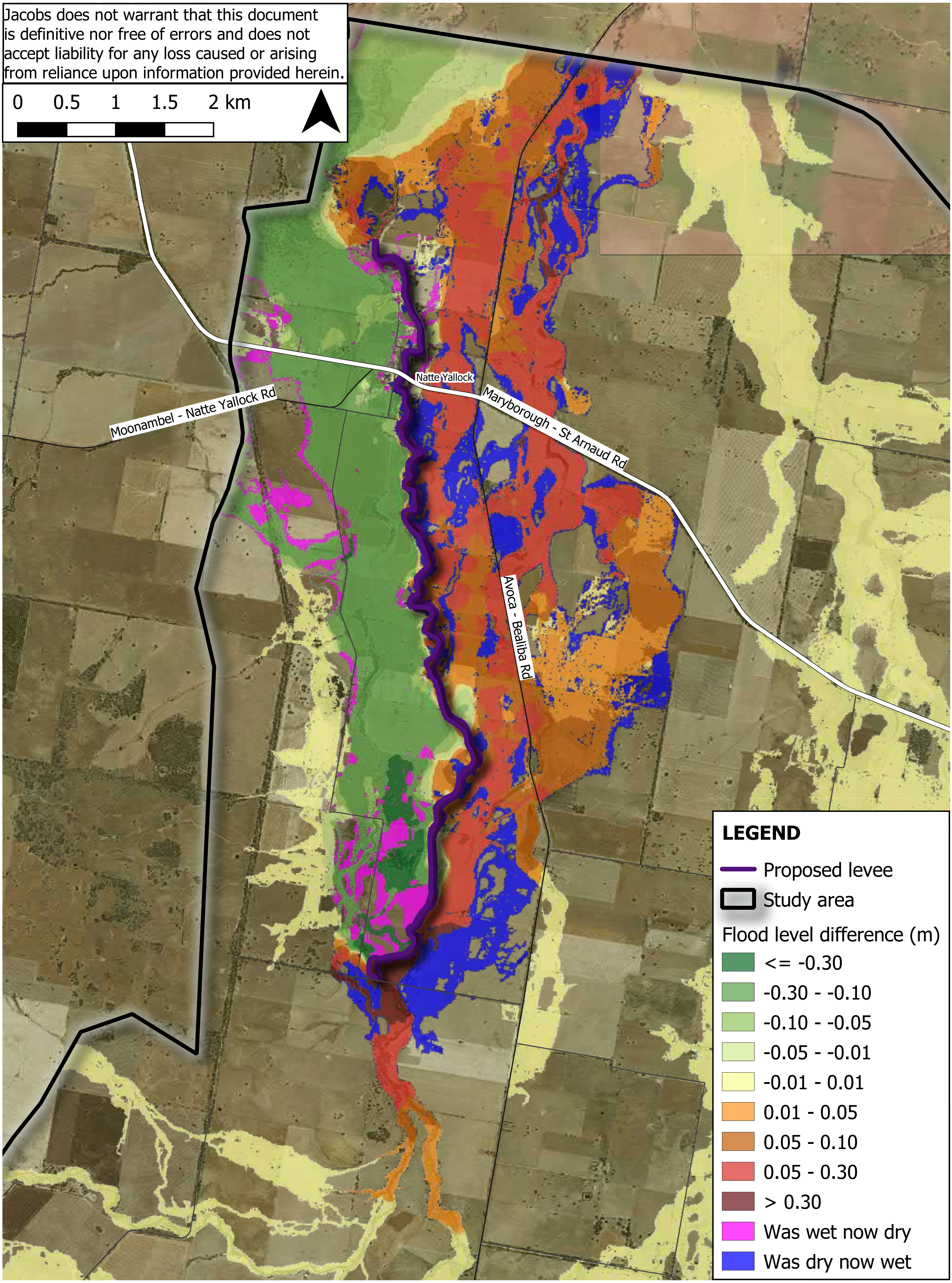

Figure E.3: 5% AEP Avoca River levee bank option - flood level difference map

Jacobs

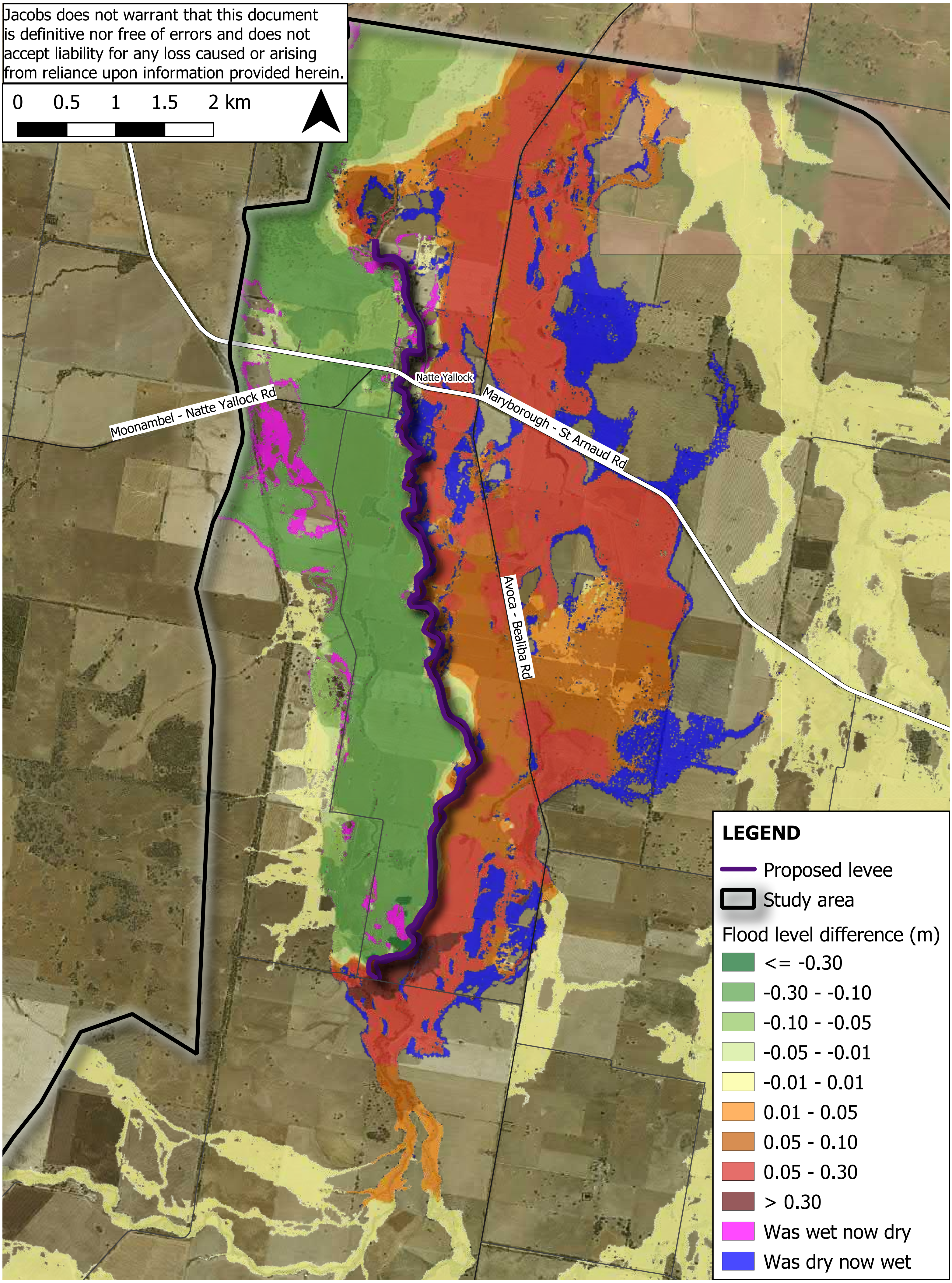

Figure E.4: 2% AEP Avoca River levee bank option - flood level difference map

Jacobs

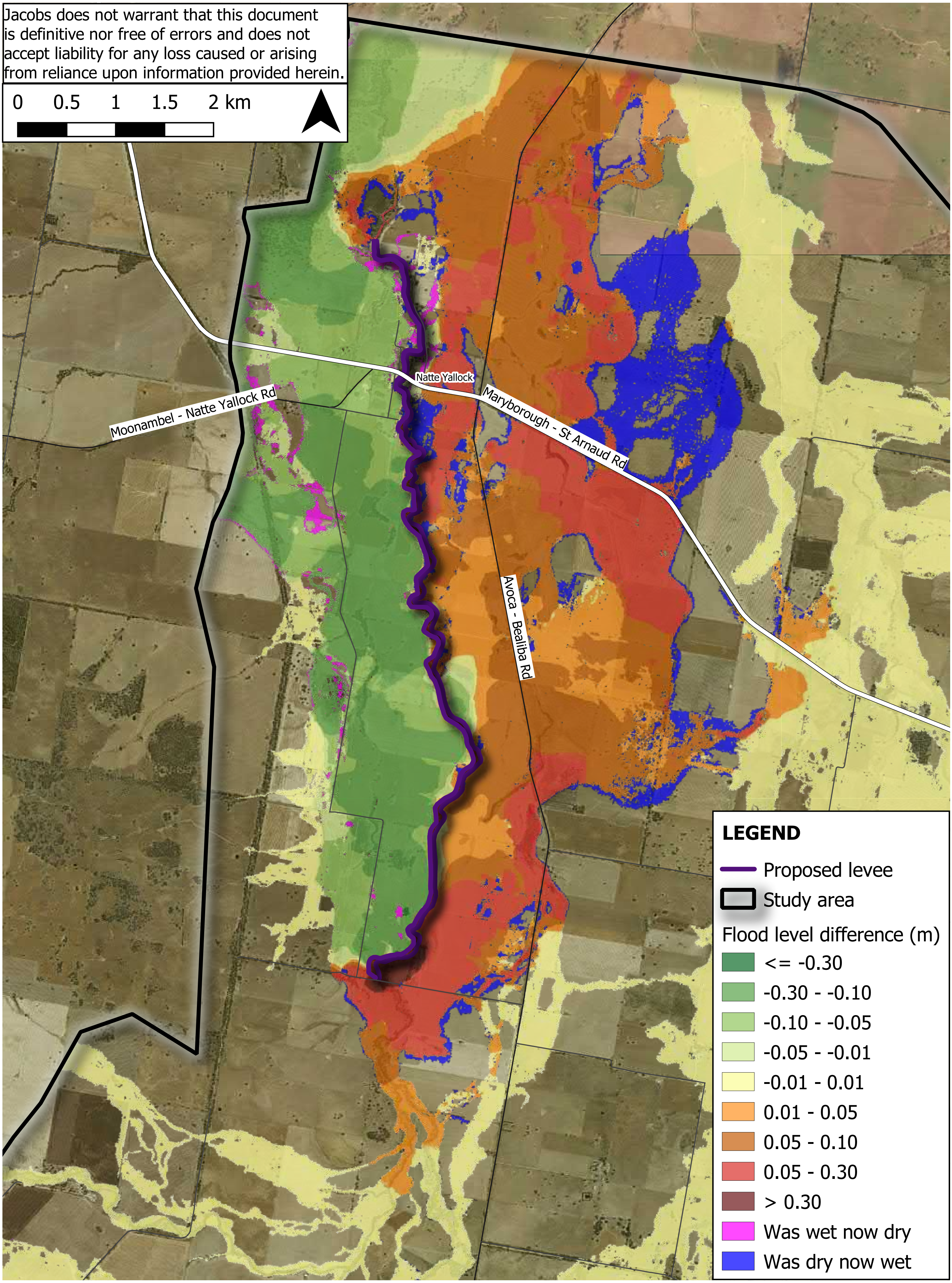

Figure E.5: 1% AEP Avoca River levee bank option - flood level difference map

Jacobs

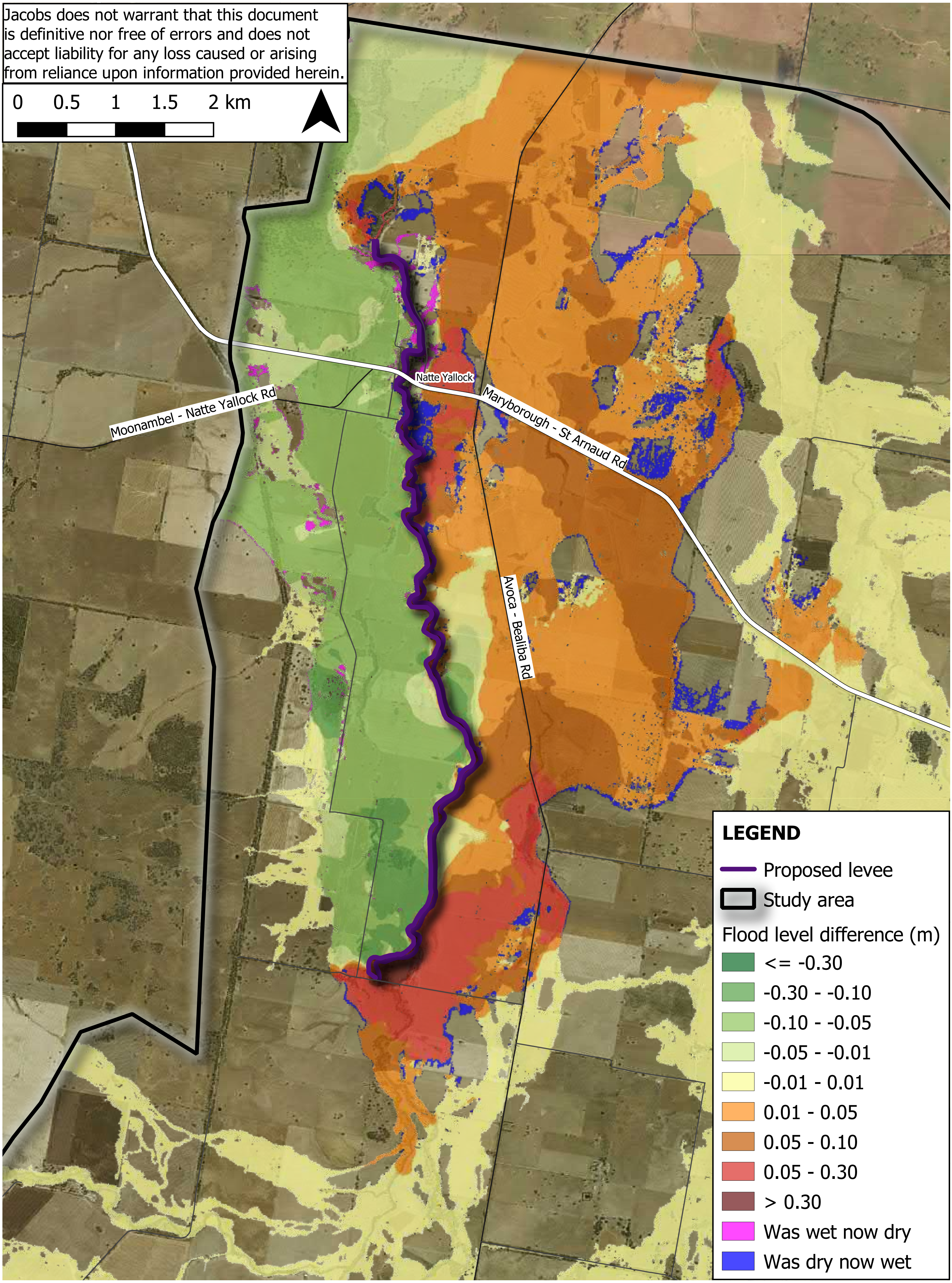

Figure E.6: 0.5% AEP Avoca River levee bank option - flood level difference map

Jacobs

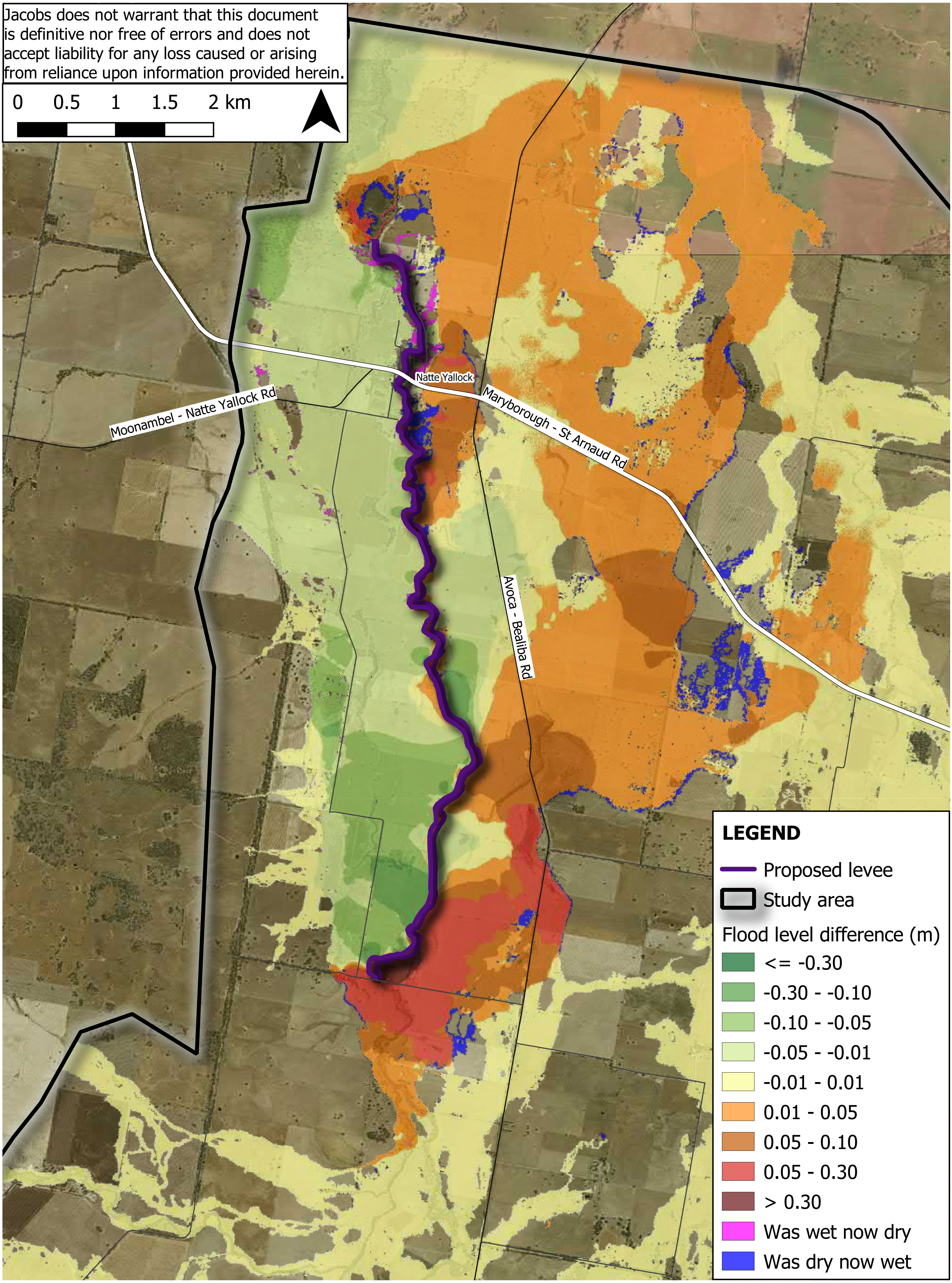

Figure E.7: 0.2% AEP Avoca River levee bank option - flood level difference map

Jacobs

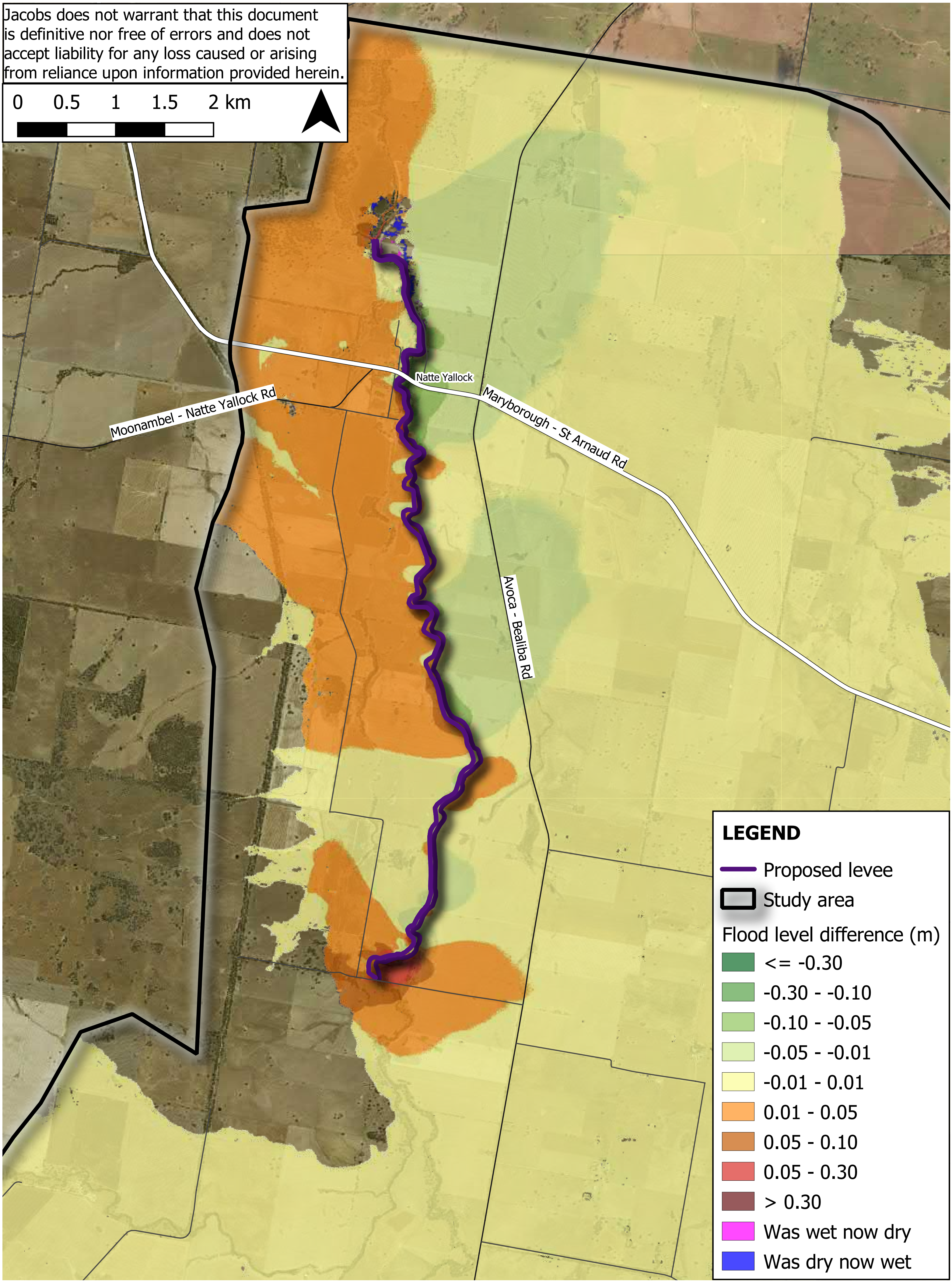

Figure E.8: PMF Avoca River levee bank option - flood level difference map

Jacobs

Appendix F. Flow training levees upstream of Natte Yallock

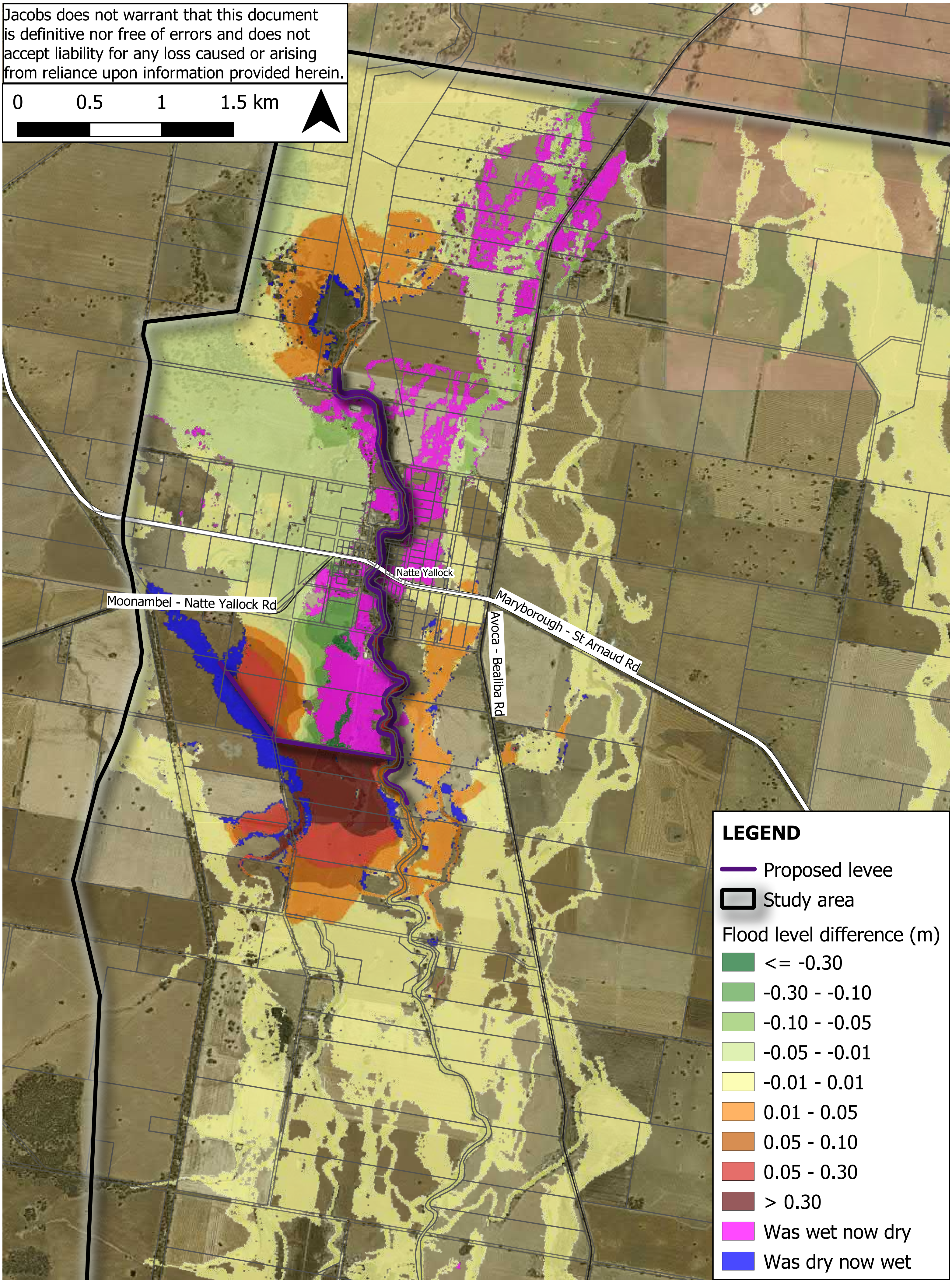

Figure F.1: 20% AEP Natte Yallock training levee option - flood level difference map

Jacobs

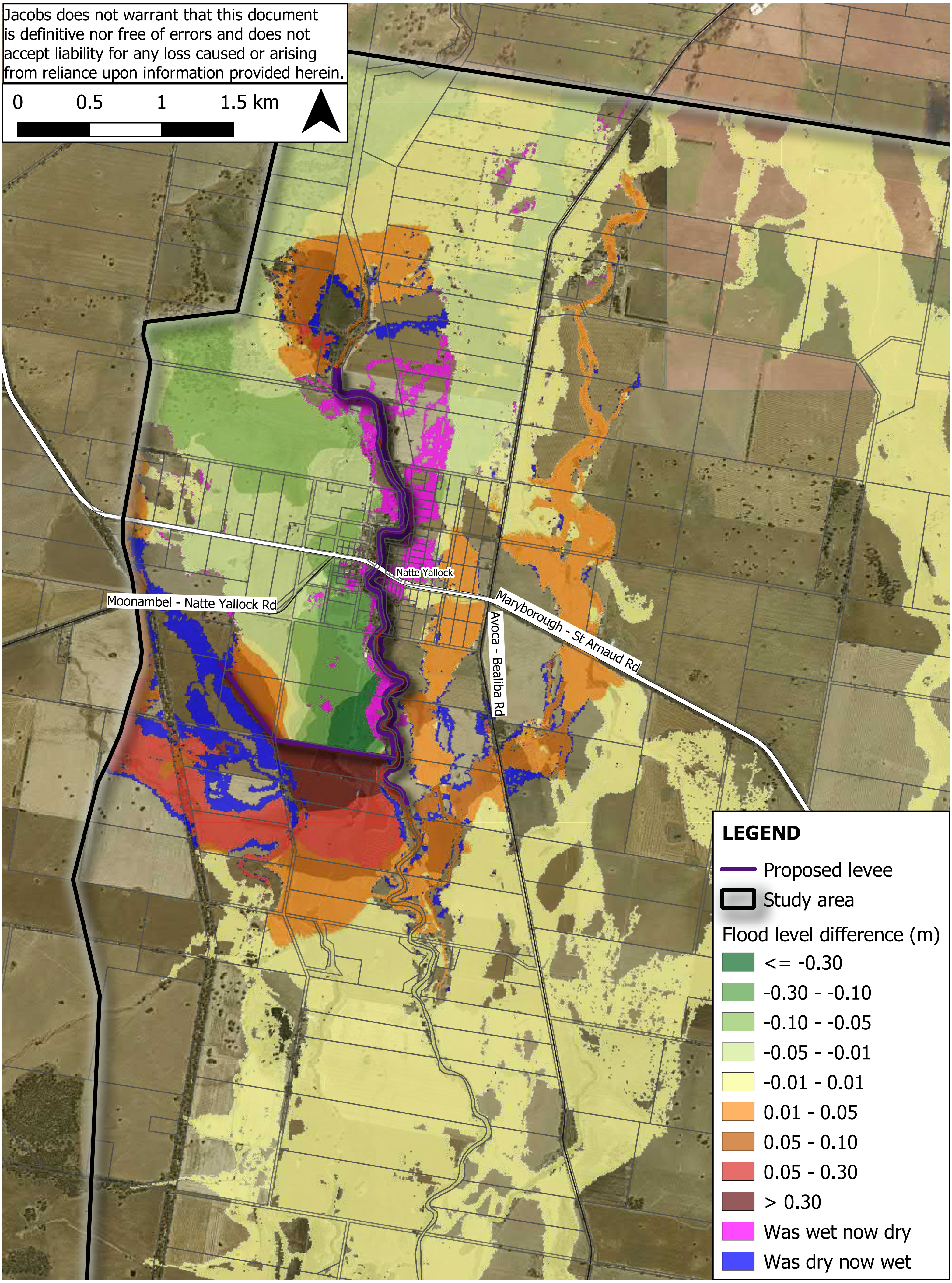

Figure F.2: 10% AEP Natte Yallock training levee option - flood level difference map

Jacobs

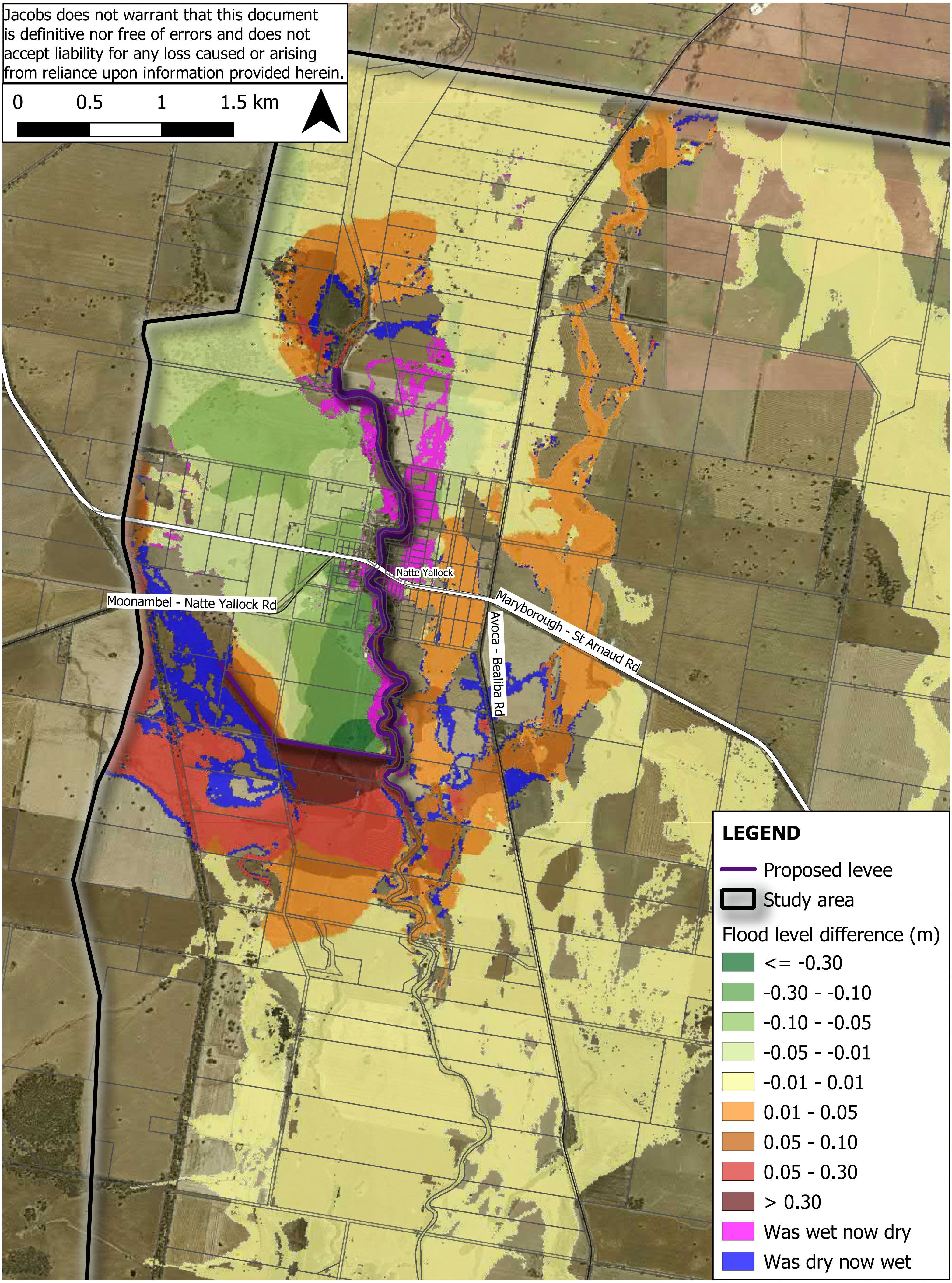

Figure F.3: 5% AEP Natte Yallock training levee option - flood level difference map

Jacobs

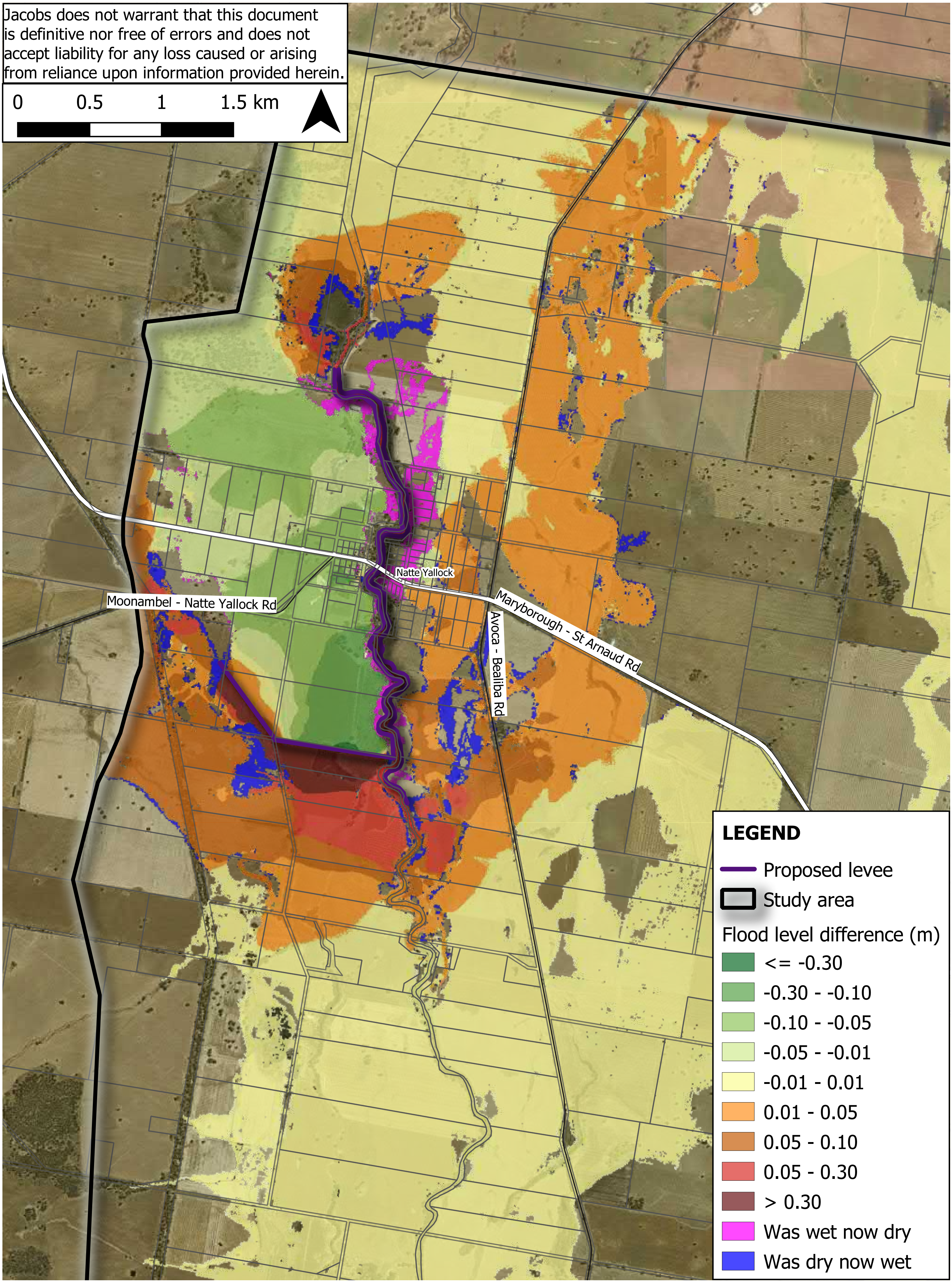

Figure F.4: 2% AEP Natte Yallock training levee option - flood level difference map

Jacobs

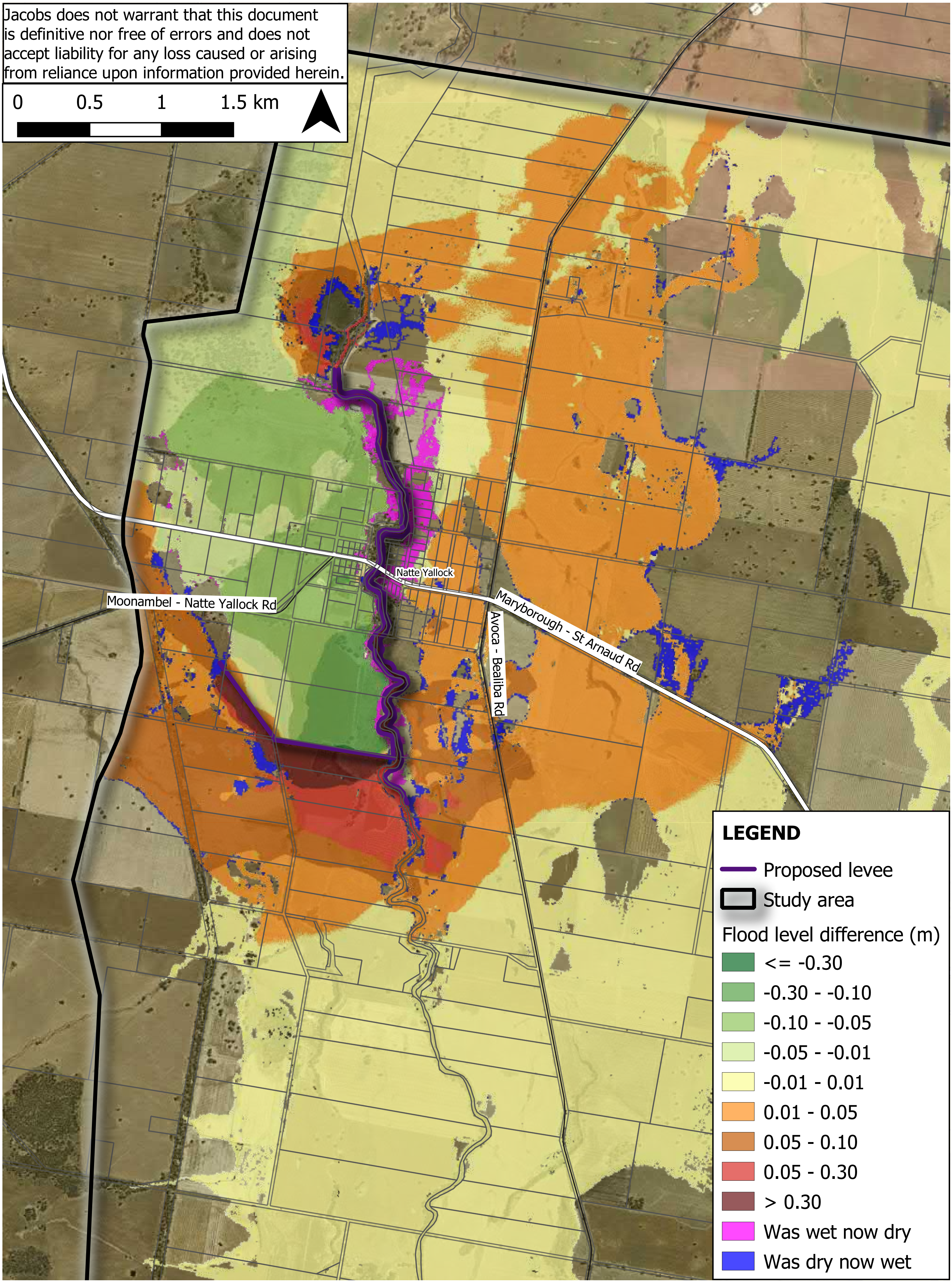

Figure F.5: 1% AEP Natte Yallock training levee option - flood level difference map

Jacobs

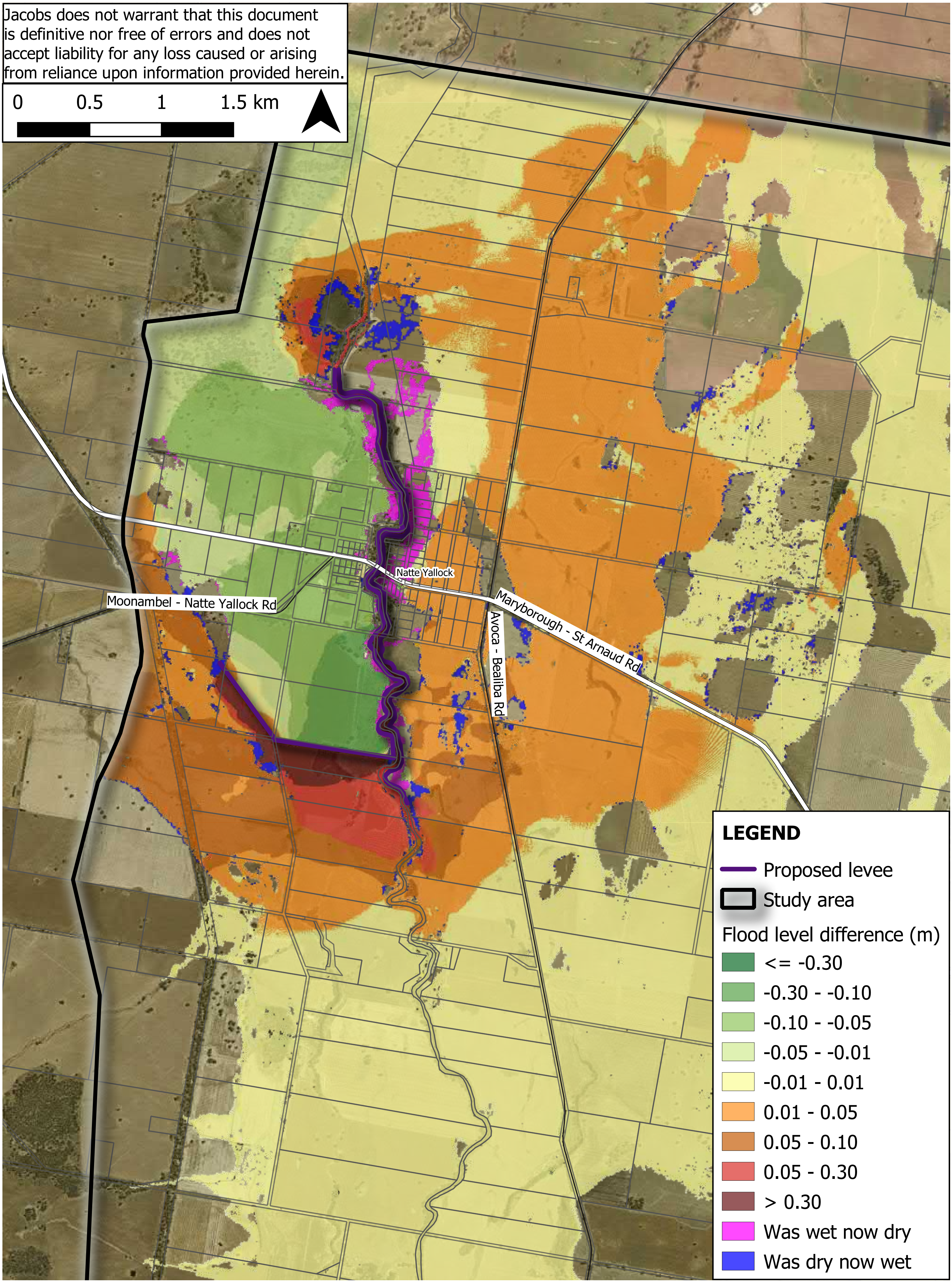

Figure F.6: 0.5% AEP Natte Yallock training levee option - flood level difference map

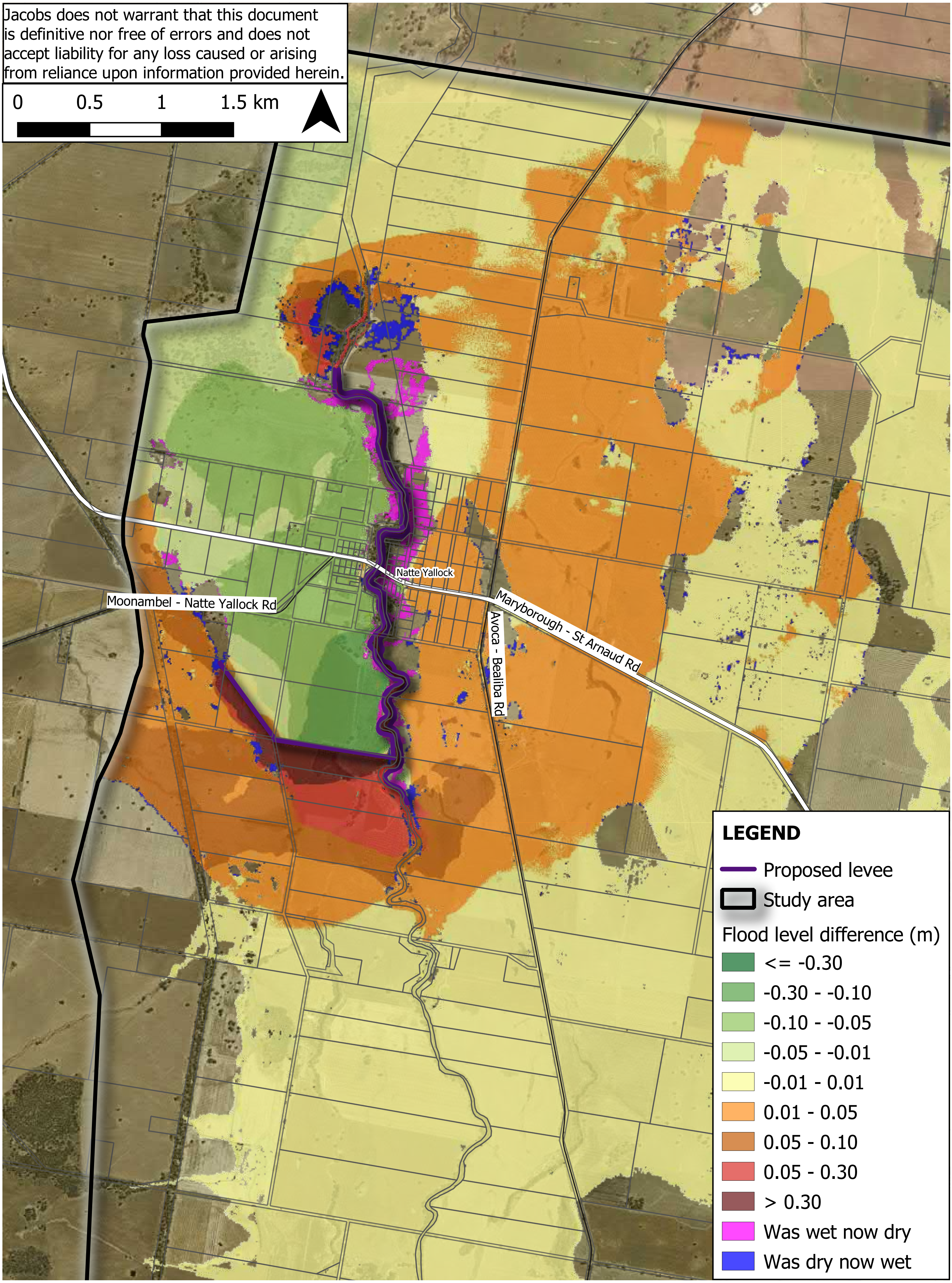

Figure F.7: 0.2% AEP Natte Yallock training levee option - flood level difference map

Jacobs

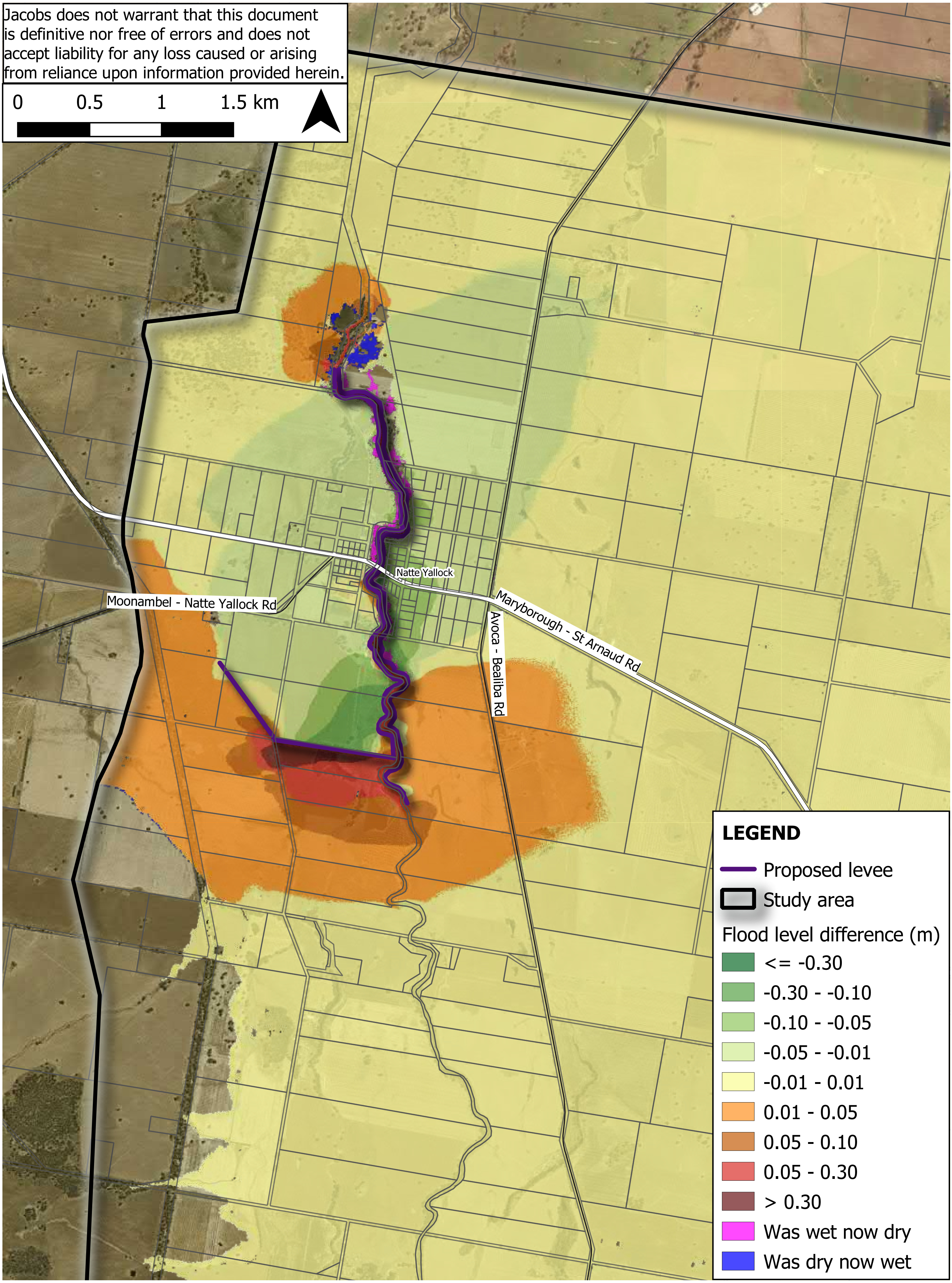

Figure F.8: PMF Natte Yallock training levee option - flood level difference map

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Appendix G. Moonambel-Natte Yallock Road bermed corner lowering and tree removal

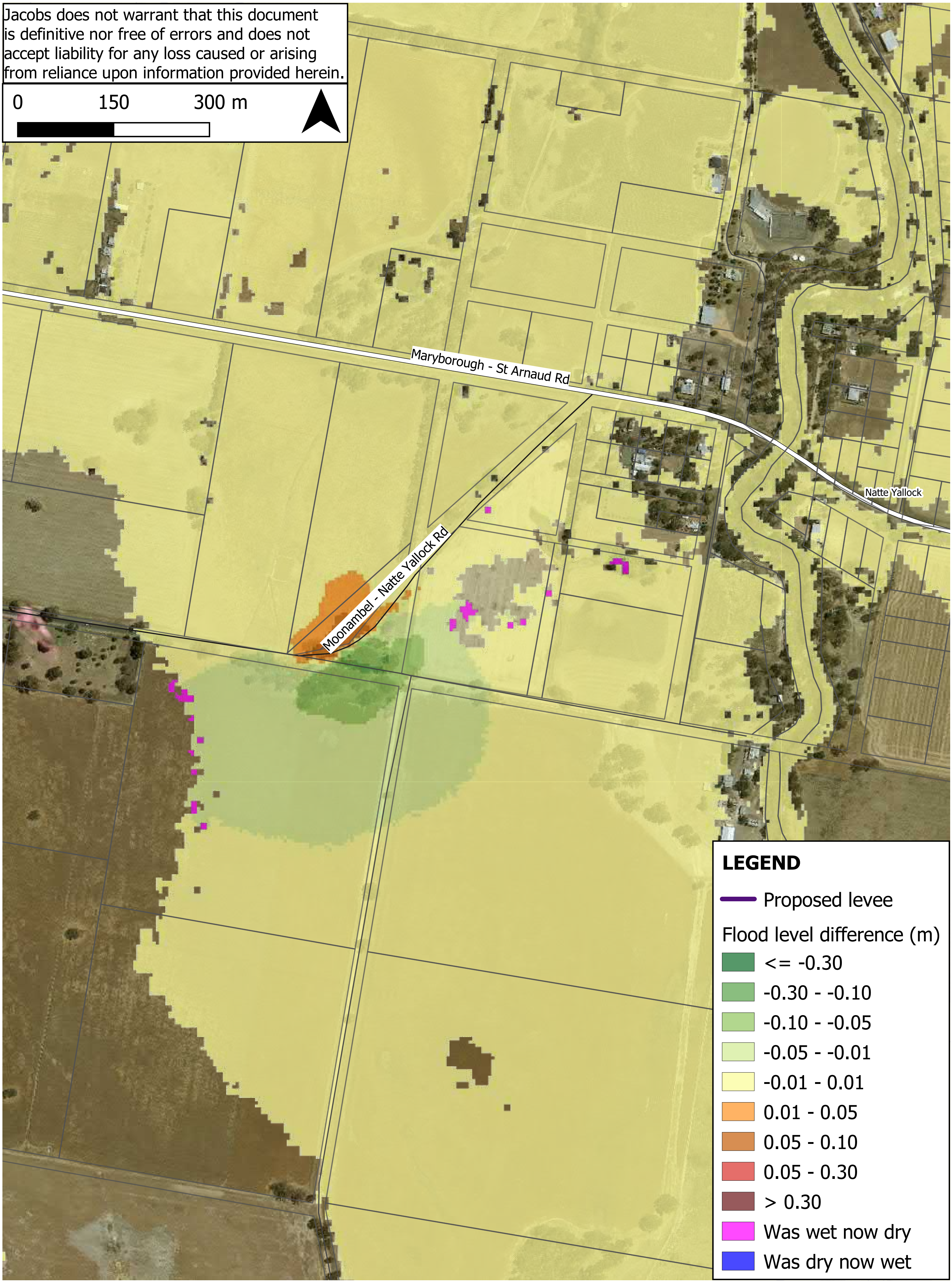

Figure G.1: 20% AEP Natte Yallock bermed corner lowering option - flood level difference map

Jacobs

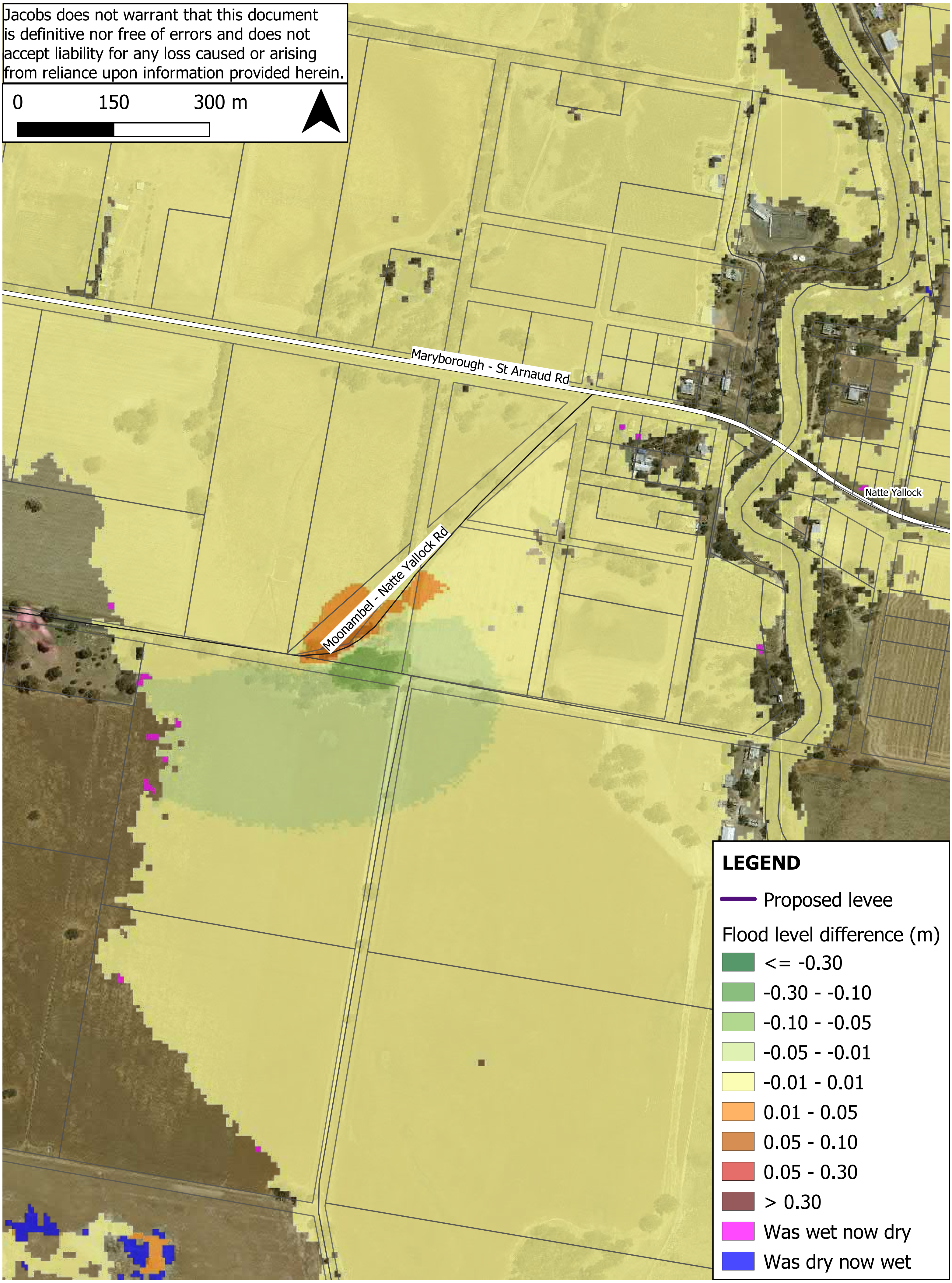

Figure G.2: 10% AEP Natte Yallock bermed corner lowering option - flood level difference map

Jacobs

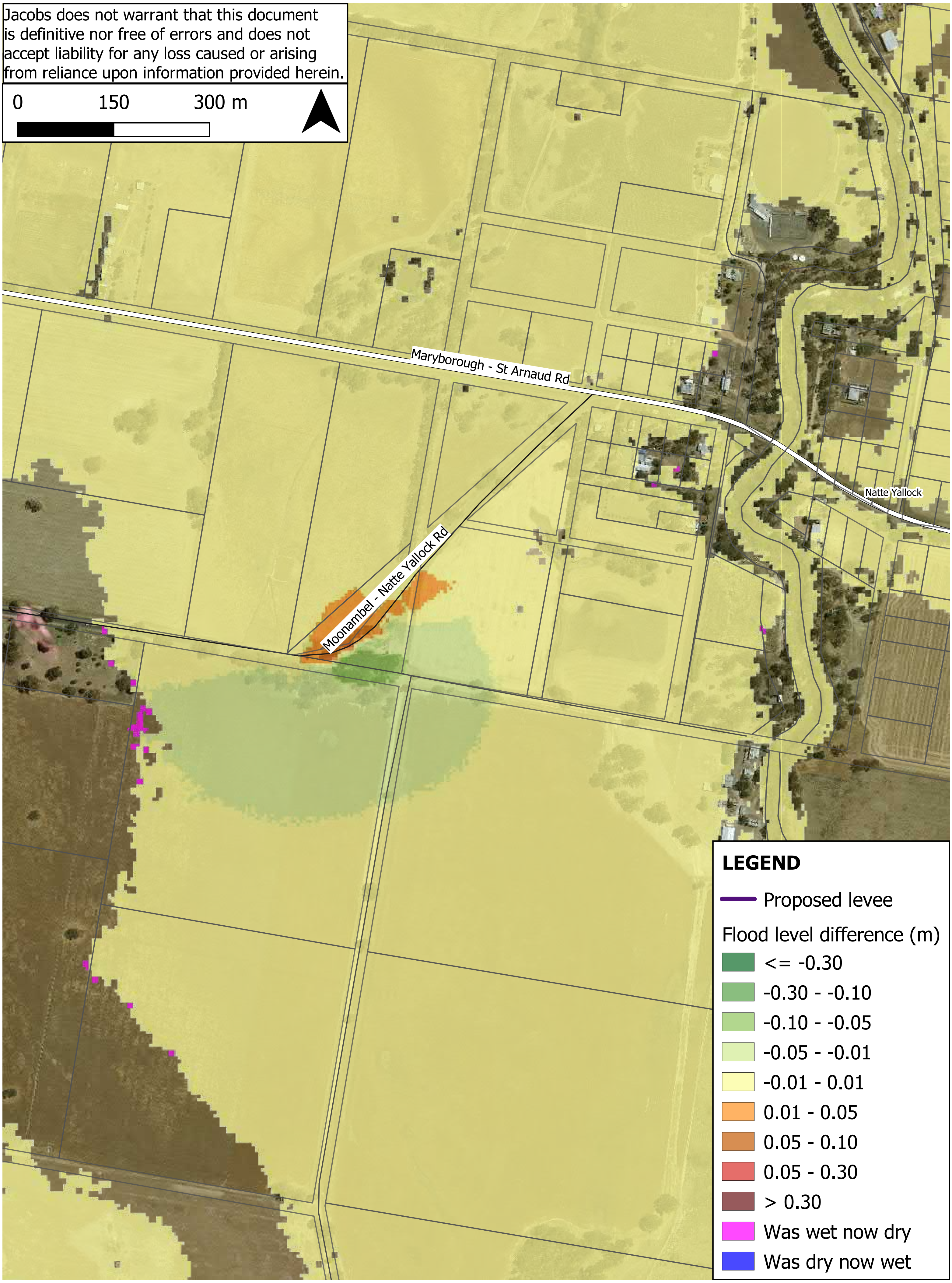

Figure G.3: 5% AEP Natte Yallock bermed corner lowering option - flood level difference map

Jacobs

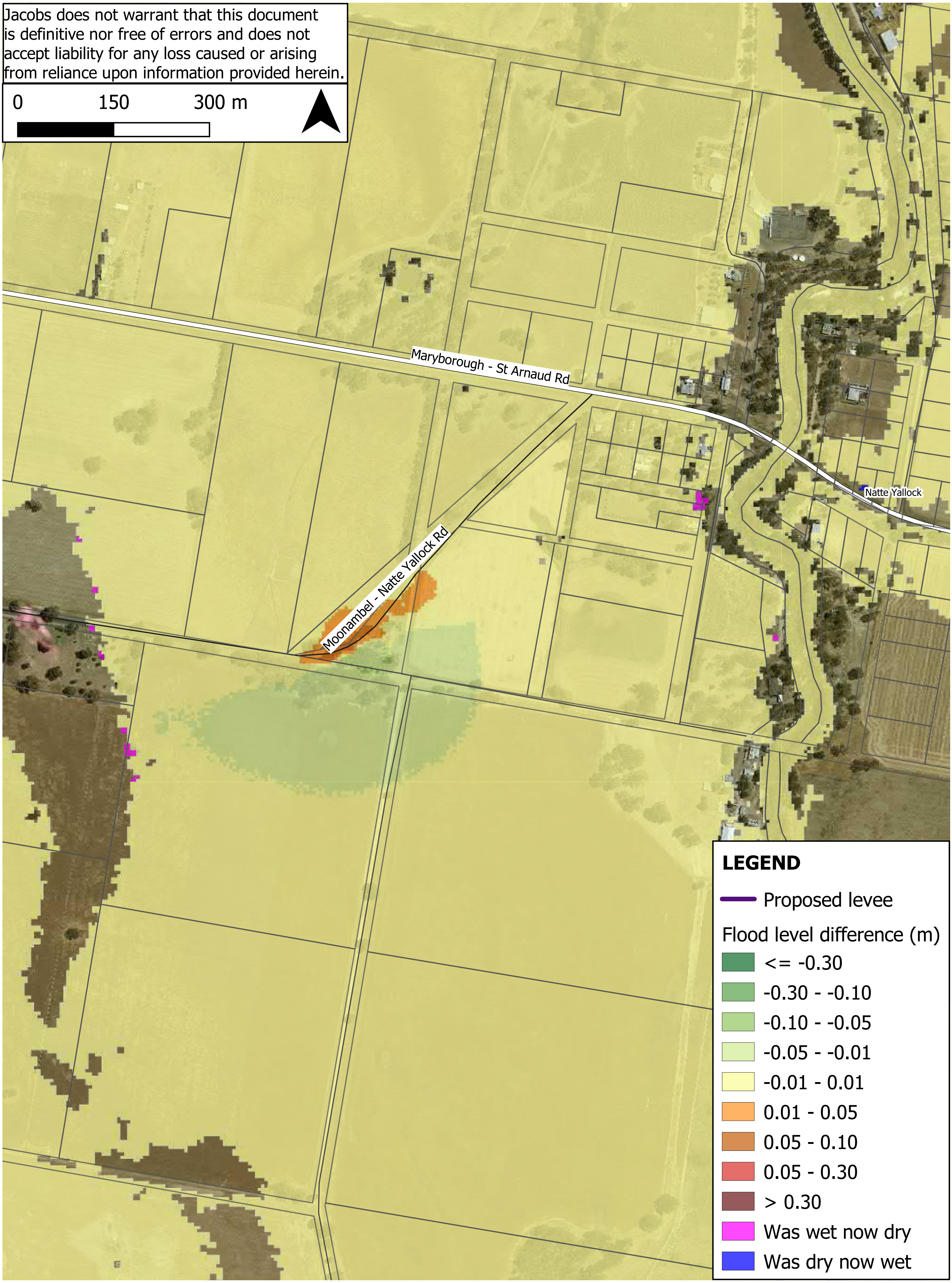

Figure G.4: 2% AEP Natte Yallock bermed corner lowering option - flood level difference map

Jacobs

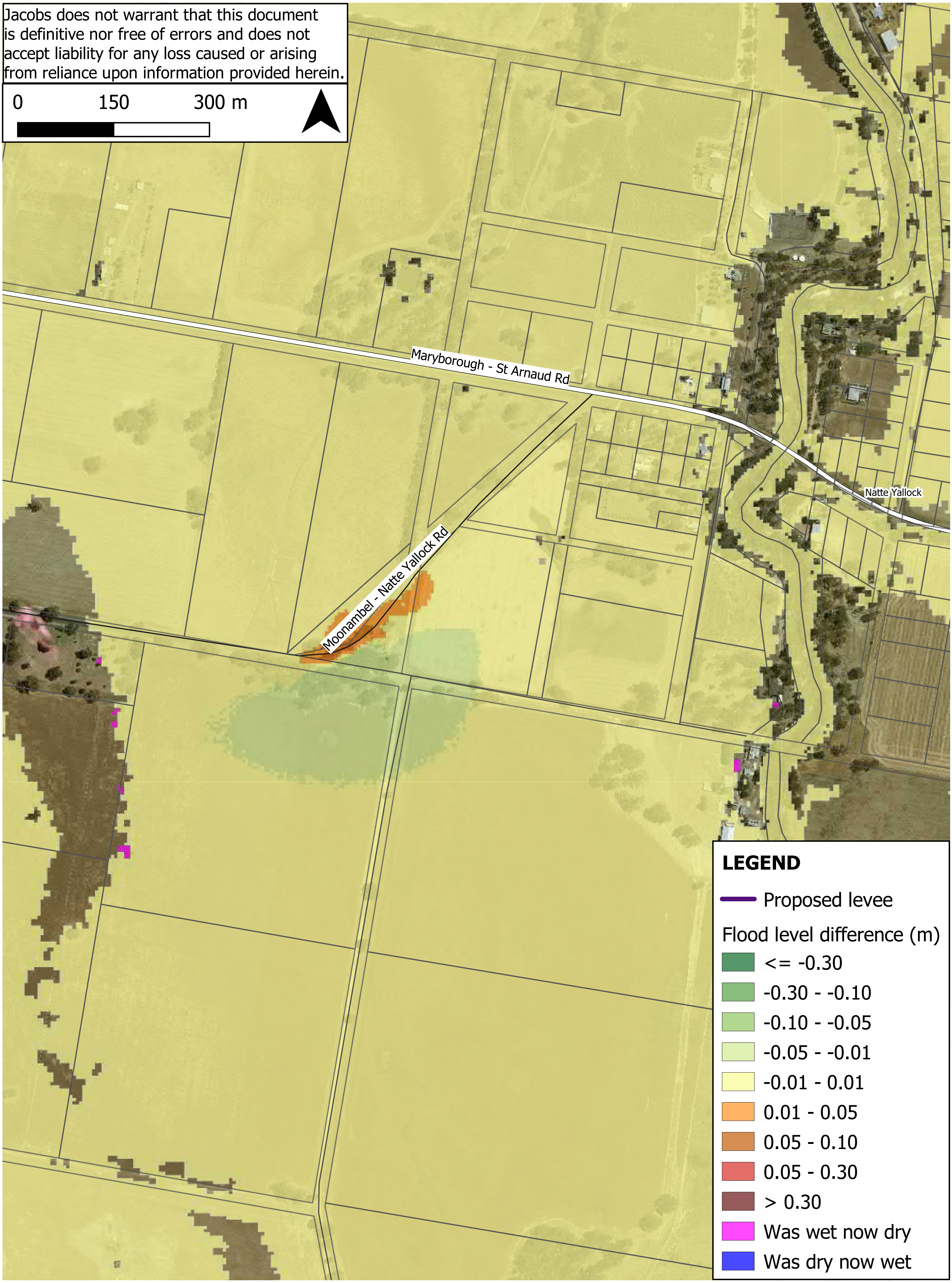

Figure G.5: 1% AEP Natte Yallock bermed corner lowering option - flood level difference map

Jacobs

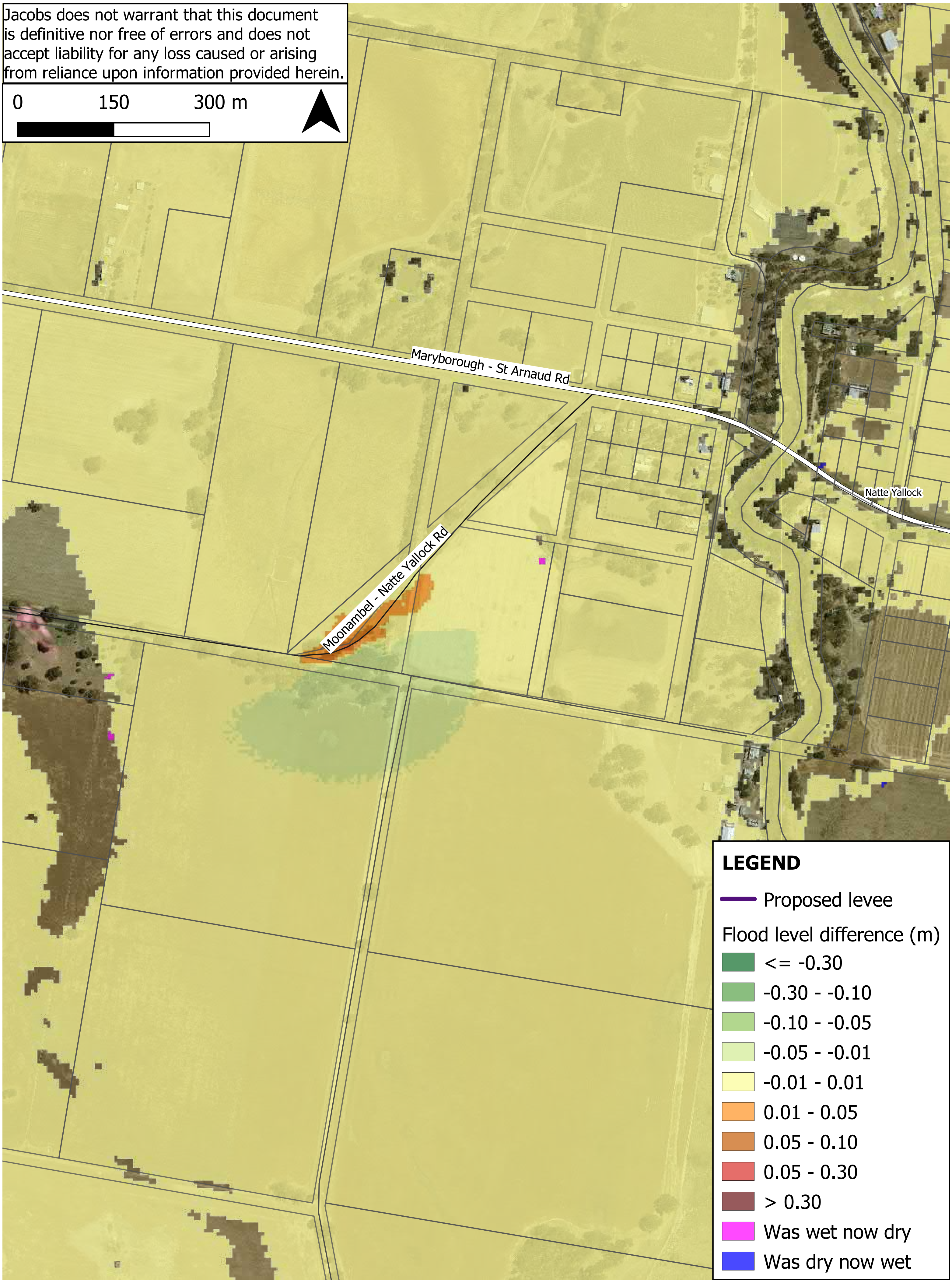

Figure G.6: 0.5% AEP Natte Yallock bermed corner lowering option - flood level difference map

Jacobs

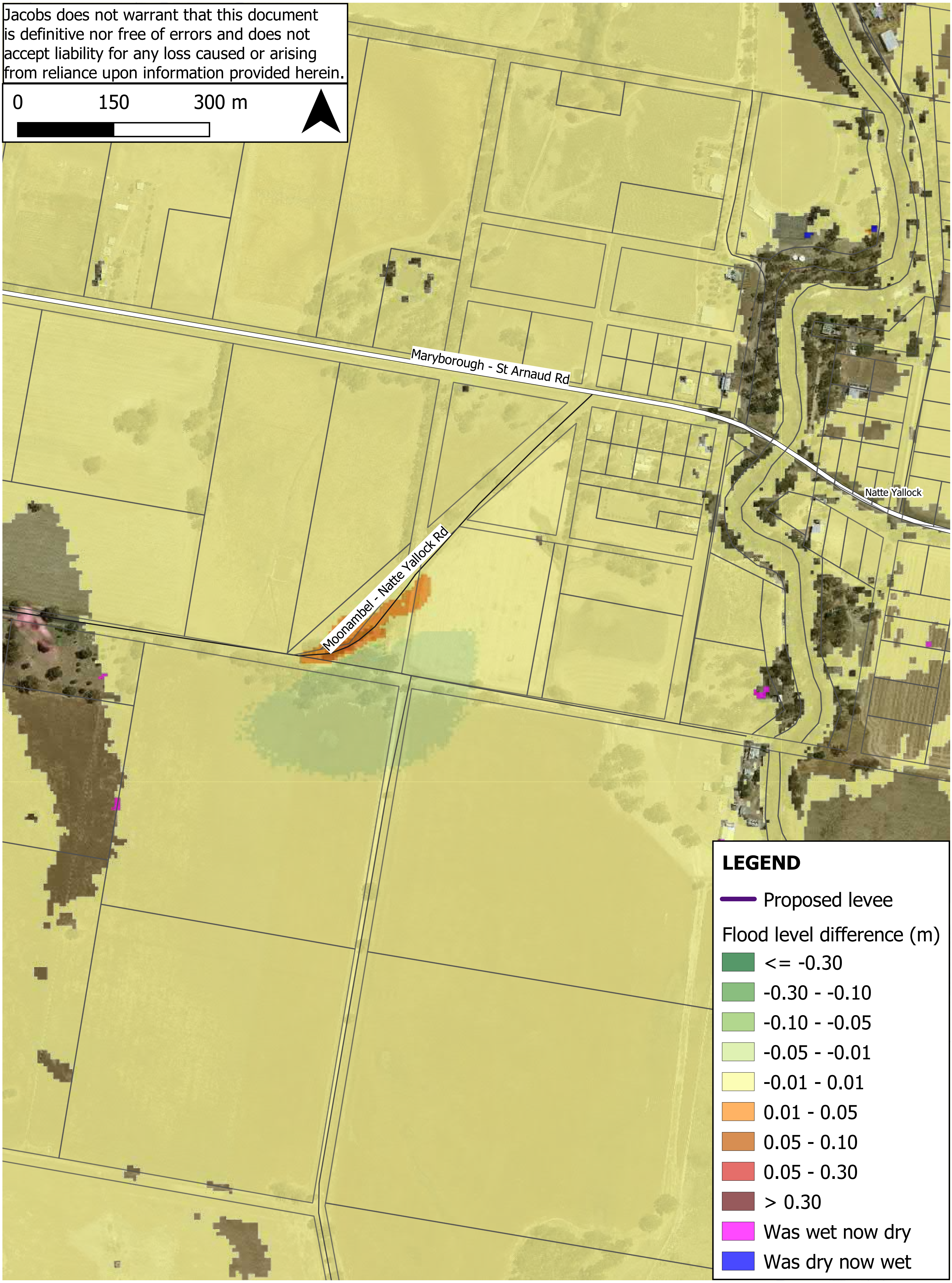

Figure G.7: 0.2% AEP Natte Yallock bermed corner lowering option - flood level difference map

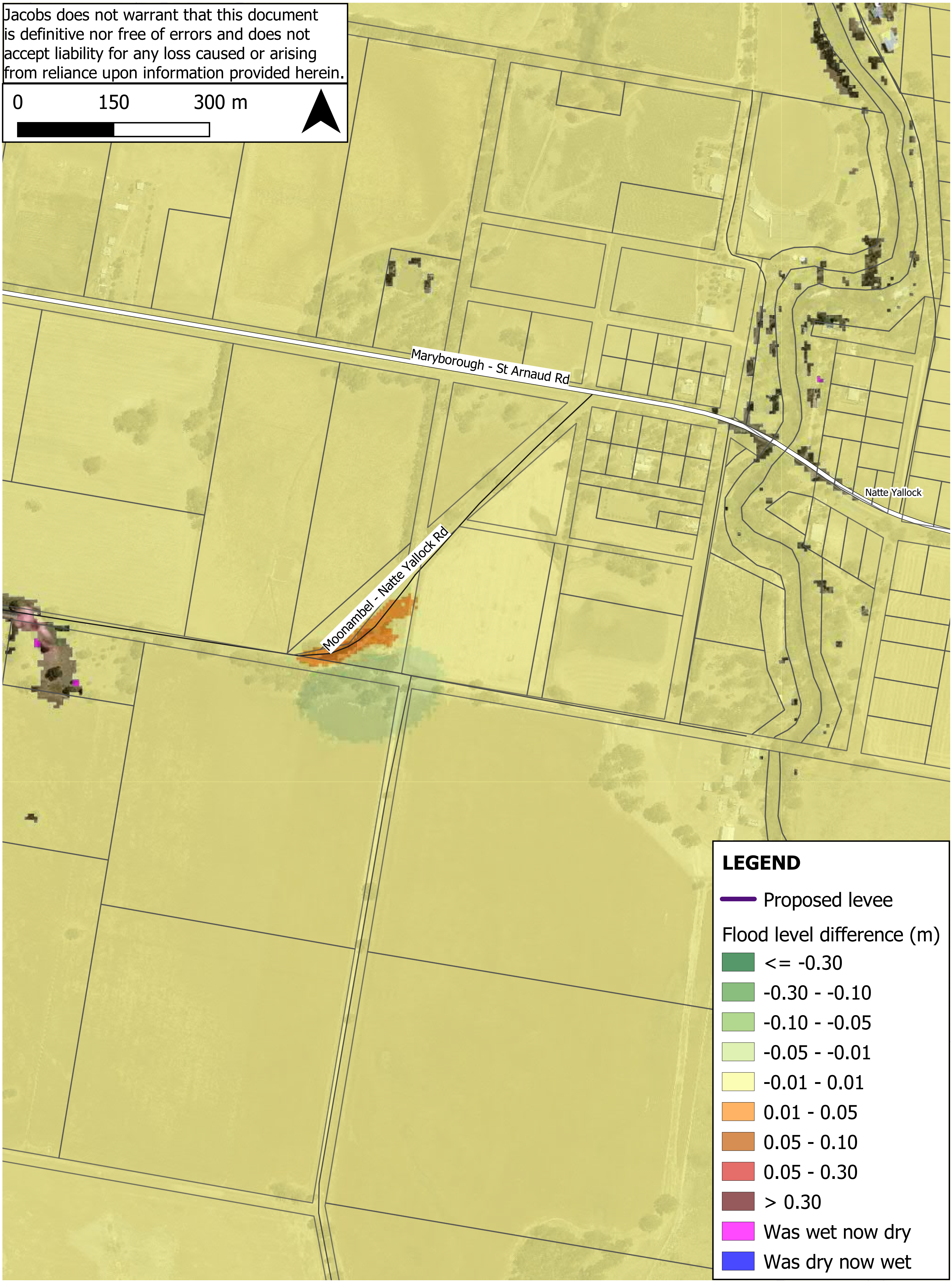

Figure G.8: PMF Natte Yallock bermed corner lowering option -flood level difference map

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