CENTRAL BENDIGO FLOOD STUDY – FINAL REPORT

FEBRUARY 2022

PREPARED FOR

City of Greater Bendigo

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A	Draft Study Report
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LIST OF ABBREVIATIONS

AAD	Annual Average Damages
AEP	Annual Exceedance Probability
ARR	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
CBD	Central Business District
CoGB	City of Greater Bendigo
DEM	Digital Elevation Model
DTM	Digital Terrain Model
LiDAR	Light Detection and Ranging
NCCMA	North Central Catchment Management Authority
NPV	Net Present Value
RCP	Representative Concentration Pathway
RFFE	Regional Flood Frequency Estimation
RoG	Rain-on-Grid
SA	Source-Area Boundary
SES	State Emergency Services
WMS	Water Modelling Solutions

1 INTRODUCTION

1.1 BACKGROUND

The study area is focused on Central Bendigo, which is traversed by Bendigo Creek and Back Creek. The suburb of Bendigo (Postcode 3550) has a population of approximately 5,500 residents and a significant visiting working population, with the Bendigo CBD being an important regional commercial and retail hub. Bendigo is predominately a residential area and has undergone steady growth in recent years with a number of new multi-lot residential developments, including several in close proximity to Bendigo Creek. The extents of the study area are illustrated in Figure 1-1.

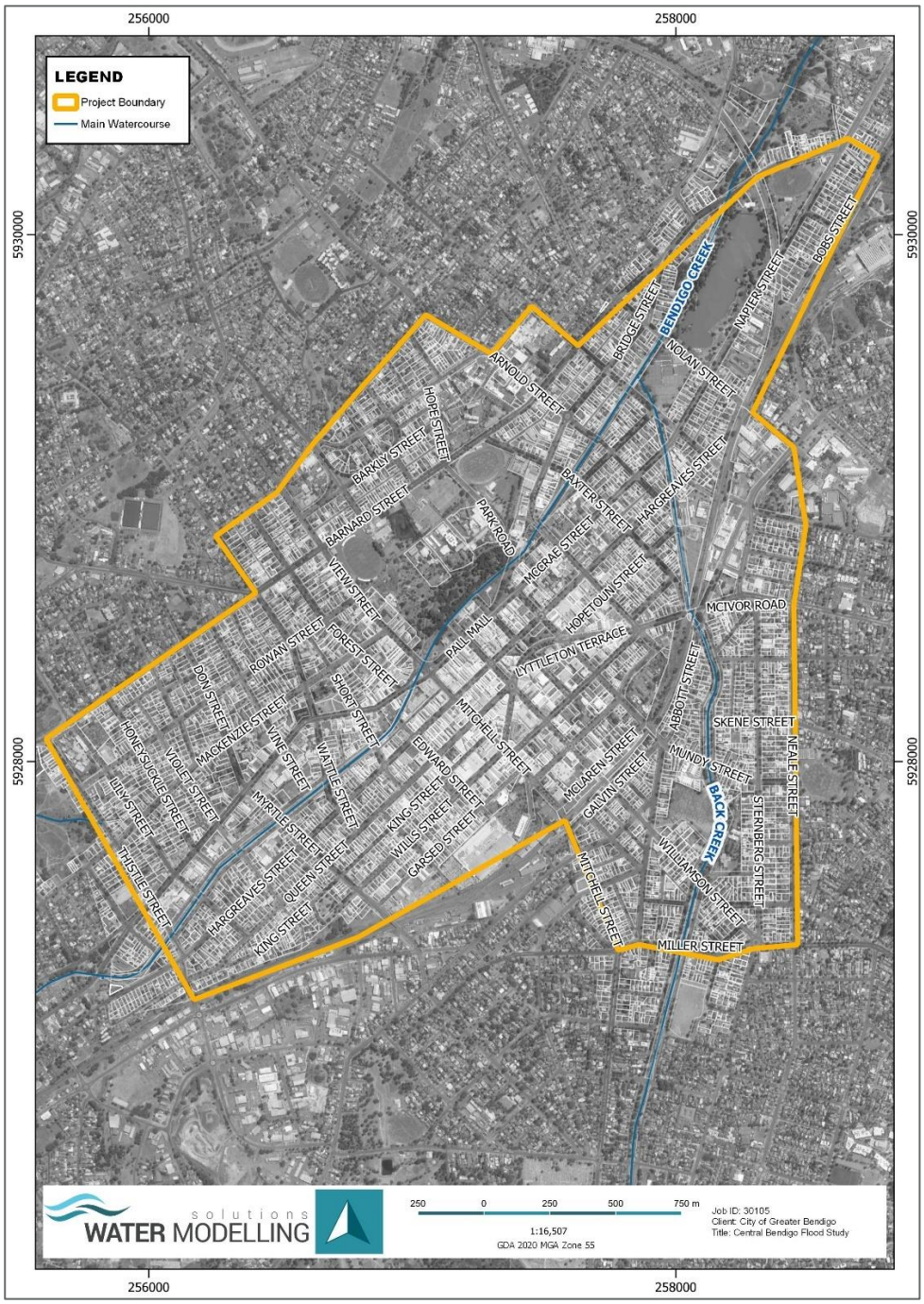

Figure 1-1 Study Extents

Bendigo Creek flows through the study area from south to north towards Huntly and is heavily modified as a result of habitation and extensive historical mining activity through the area. There are extensive sections of lined channel within the study area, some of which is bluestone and subject to heritage overlays. Back Creek also traverses the eastern portion of the study area and flows into Bendigo Creek a short distance north of Bendigo CBD.

The study area was a subject of comprehensive flood investigation in 2013 –Bendigo Urban Flood Study (BUFS). The study determined that significant flood risk occurred through this area with numerous properties inundated in the 1% AEP event. The study investigated several mitigation options which could improve flood risk across Central Bendigo including increasing the creek capacity as well as several levee options.

The study area possesses environmental, social, economic, and recreational values that make the area a popular place for a wide variety of activities and development. It is important that the environmental and social impacts of any proposed mitigation options are considered as part of a thorough assessment.

1.2 EXISTING FLOOD RISK

The preliminary stages of the study involved determining the existing level of flood risk throughout Central Bendigo. This included updating and modifying existing models to represent current conditions and to ensure consistency with current best practice. This process ensured the modelling complied with relevant guidelines including Australian Rainfall and Runoff 2019. Details regarding the model updates can be found the in the Central Bendigo Flood Study Template Report (*Water Modelling Solutions, 2021*). The modelling of existing conditions determined that significant areas of the study area are susceptible to riverine inundation across a range of flood events.

The damages assessment found that in the 1% AEP event, 374 residential buildings and 138 commercial buildings are subject to above floor flooding. The results of the damages assessment for existing conditions are summarised below in Table 1-1. Flood maps for the 1% AEP flood event as well as all other modelled AEPs under existing conditions are provided in Appendix A.

Table 1-1 Flood Damages Summary - Existing Conditions

		Annual Exceedance Probability (AEP)				
		20%	10%	5%	2%	1%
Properties Flooded Above Floor Level	Residential Properties	0	10	51	221	374
	Commercial Properties	0	8	44	82	138
	Total Properties Flooded	0	18	95	303	512
Total Tangible Damage Cost		**0**	**$174,267**	**$2,929,127**	**$12,192,558**	**$30,245,980**

2 TEMPLATE REPORT

The following sections summarise findings from the Central Bendigo Flood Study Template Report (Water Modelling Solutions, 2021). For full details of modelling methodology for both the hydrology and hydraulics refer to the original template report documentation (WMS, 2021)

2.1 HYDROLOGY

The existing RORB model utilised within the BUFS Study was revised and modified to meet the requirements of the Central Urban Flood Study (CBFS), predominantly by providing additional print points relevant to locations for input into the hydraulic model, updating the fraction imperviousness for the project area and updating rainfall data obtained from ARR Data Hub. Following preliminary hydrologic modelling it was determined that the Thistle St Basin tributary located at the southwest corner of the project area would be included as part of this study in order to account for all overland flows within the project boundary. The model for the Kangaroo Flat and Golden Square Flood Mitigation Study (KF&GS) was modified only for the 6 subareas contributing to the Thistle Street tributary.

Hydrologic modelling has been carried out by using the procedures outlined in Australian Rainfall and Runoff 2019 (ARR2019) by adopting a joint Monte Carlo (MC) end ensemble approach. The Monte Carlo analysis output in RORB provides peak flows based on fitting a probability distribution to the range of modelled results at each location of interest whilst the Ensemble Analysis was modelled in RORB to determine which combination of parameters and temporal patterns produced a peak flow closest to the Monte Carlo peak and produced output suitable for input to the hydraulic model.

The following sections summarise highlights of the analysis carried out and discusses the results.

2.2 MODEL PARAMETERS

2.2.1 Fraction Impervious (FI)

Fraction Impervious values were updated from the original BUFS RORB model using the latest aerial imagery and site visit observations. The adopted FI values are consistent with recommendations in ARR2019 and the Melbourne Water MUSIC guidelines.

As per ARR2019, subareas within RORB are separated into Directly Connected Impervious Fraction (DCIF), Indirectly Connected Impervious Fraction and Pervious Area (PA). To determine the value for each of the impervious fractions, the following rules were adopted.

- Directly Connected Impervious Fraction (DCIF) assumed to be 60% of overall FI values (standard industry assumption).
- Indirectly Connected Impervious Fraction (ICIF) assumed to be 40% of overall FI value.
- Pervious fraction is the remaining fraction once the impervious fraction is subtracted.

2.2.2 Design Losses

An extensive calibration of the losses adopted for the BUFS study was completed utilising multiple historical events from gauge data and achieved fair representation of gauges historical data. Due to the accuracy of the calibration, these losses were subsequently adopted for the KF&GS study and hence considered appropriate for CBFS and are outlined in Table 2-1. These have been deemed to be more robust than using standard, regional losses. For more information on the calibration process in the BUFS study refer to the BUFS report (Water Technology 2013).

Table 2-1 Adopted Design Losses

Parameter	Adopted Initial Loss (mm)	Adopted Continuing Loss (mm/h)
Directly Connected	1.5	0.0
Indirectly Connected	15.4	2.5
Pervious	22.0	3.5

2.3 DESIGN FLOW SUMMARY

The key results from the hydrological modelling are summarised in Table 2-2 and show the adopted critical durations and associated temporal patterns for both Back Creek and the Thistle Street catchment. Based on this summary three durations were selected for modelling which provide the key durations at each of the major inflow locations.

For Bendigo Creek design flows were adopted from the KFGS TUFLOW model. There is less than 1% difference between the KFGS and CBFS design flows at the Bendigo/Back Creek confluence and hence it was deemed reasonable to adopt the KFGS TUFLOW design flows at the inflow location. This ensures the impacts of local hydraulics at the inflow location, which includes the deep, lined channel and upstream High St Road bridge, are accounted for. This approach also ensures consistent hydraulic model results and mapping between the KFGS and CBFS studies where they interface.

The adopted 1% AEP design flows and hydrological model runs are shown in Table 2-2.

Table 2-2 1% AEP Design Flow Summary

Location	RORB Monte Carlo 1% AEP Peak Flow (m^3/s)	Critical Duration	Adopted Temporal Pattern	Adopted Ensemble 1% AEP Flow (m^3/s)
Bendigo Creek	**109.29** – adopted from KFGS TUFLOW model output			
Back Creek	58.42	2hr	25	**59.73**
Thistle Street Tributary	13.76	45min	26	**13.89**

2.4 HYDRAULICS

2.4.1 1% AEP Modelling Results

The results of the 1% AEP modelling are presented in the range of maps in Appendix A. They include maps of 1% AEP water levels and depths. Gridded data of water levels, depths and afflux will also be provided to Council and the Project Control Group.

Key differences in the 1% AEP modelling results between the current modelling and BUFS results are described below:

- Some significant reduction in levels and extents can be observed within the results, most notably at Charing Cross on Bendigo Creek. This is directly attributable to the representation of bridges adopting 2D layered flow constrictions in place of 1D culverts and associated cross-sections as previously adopted within the BUFS model. Adoption of LFC's is in line with the most recent release of TUFLOW and is considered best practice for representation of larger hydraulic structures. Details of LFC's applied are outlined thoroughly in the CBFS Template Report (WMS, 2021) with adoption of LFC's allowing better integration between the 1D and 2D domain. Several locations have been impacted including the areas around Thistle Street, Myrtle Street, Charing Cross, Mundy Street, McIvor Road and McCrae Road. An example of where the adoption of LFC's has resulted in reduction of flood extent is shown in Figure 2-1 with a comparison of BUFS and CBFS flood heights along the length of the location of the bridge located on McIvor Road.

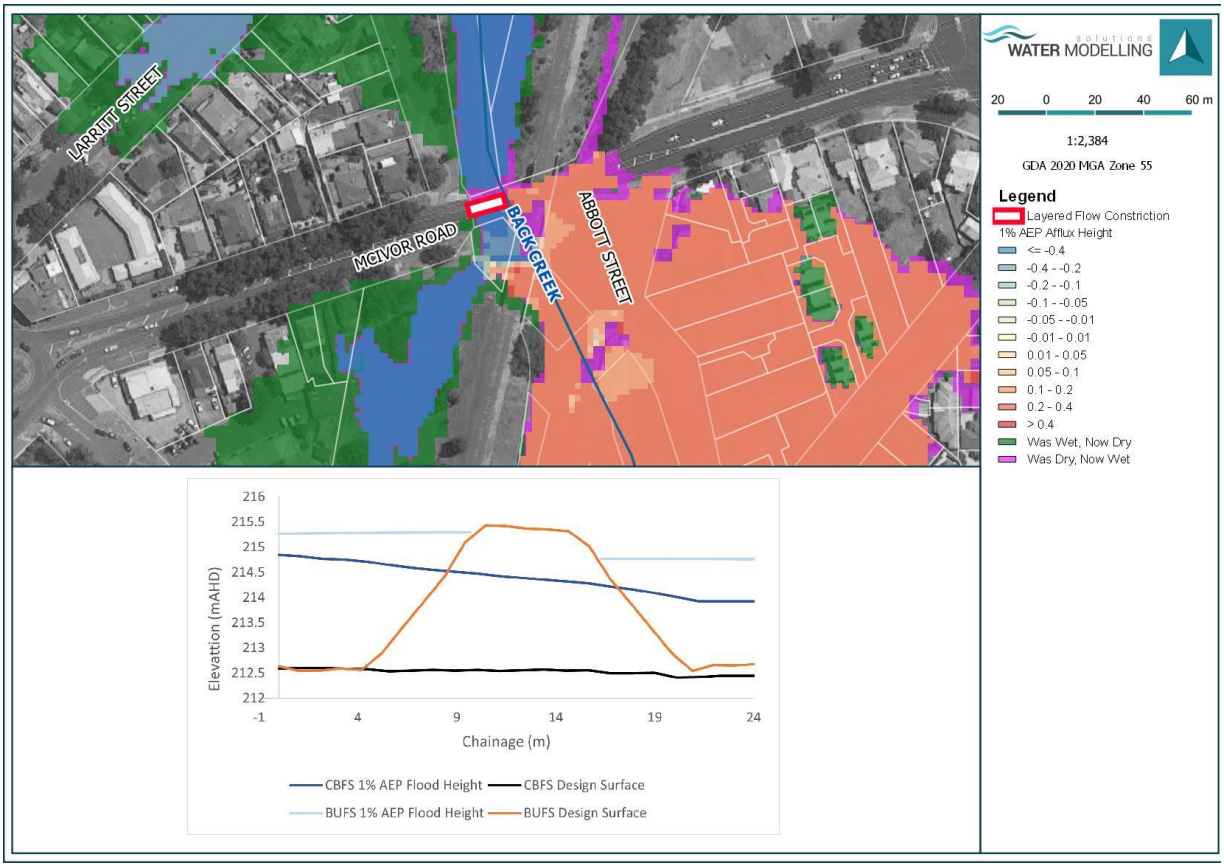

Figure 2-1 Comparison of BUFS and CBFS Hydraulic Structures Treatment

- Updates to hydrology showed reductions in peak flows to Back Creek. This was considered acceptable for adoption into the TUFLOW model as difference in flows less than 10% and depths and flood extents reflecting those observed in the KF&GS flood study and the BUFS.
- Updates to LiDAR has resulted in several surface changes leading to reductions in flood extent. Figure 2-2 illustrates an increase in elevation between the BUFS design surface and the CBFS design surface adjacent to Back Creek resulting in an overall reduction to the flood extent.

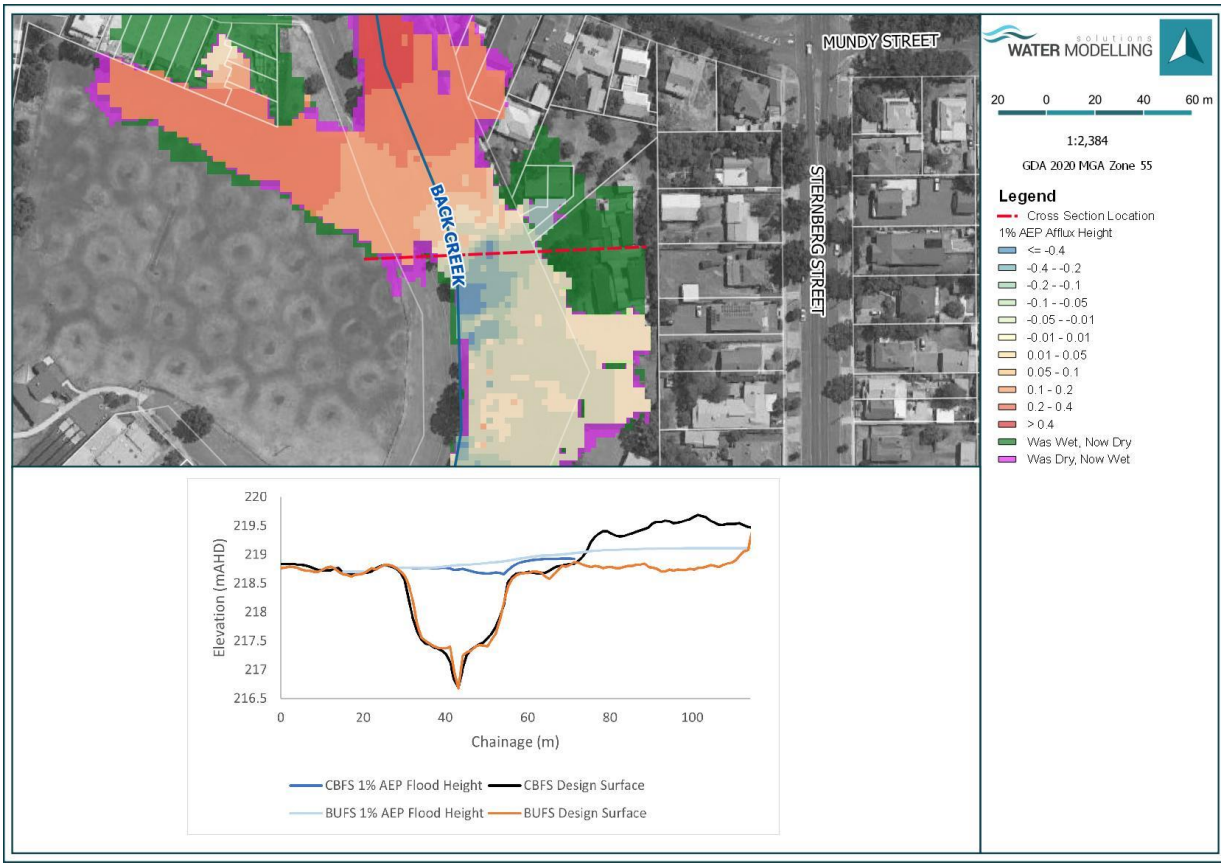

Figure 2-2 Comparison of BUFS and CBFS Surface Elevation

- The roughness values for the waterways have been represented in more detail with additional categories added for waterways with moderate and minor-moderate vegetation. The most typical value applied in the BUFS model along waterways was 0.035, while 0.025 has been the value adopted for the paved sections of channel and 0.03 for unlined sections of channel. Values were applied based on-site visits and recent aerial imagery. In many sections of Bendigo Creek this has resulted in decreased roughness allowing faster conveyance of inflows.
- Additional modelling results for the Thistle Street Basin tributary which was not included within the BUFS model.

Overall, the results show similar overland flow paths to the 1% AEP BUFS with the differences in depths and extents predominantly attributable to updates to design hydrology, changes to topography (newly flown LiDAR) as well as some localised changes as a result of updated and improved schematisation of bridges through the model.

2.4.2 Climate Change Sensitivity Testing

2.4.2.1 Background

CSIRO has released climate change scenarios based on four scenarios greenhouse gas representative concentration pathways (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) for the year 2090. The RCP represents the potential concentration of greenhouse gasses within the atmosphere at a given year. RCP 4.5 and RCP 8.5 have been adopted for the climate change assessment of the CBFS which has become typical for flood studies. RCP 4.5 assumes emissions peak around 2040 and then slowly decline thereafter. RCP 8.5 is the most severe emissions case and assumes emissions continue to rise throughout the 21st century and into the 22nd. The adoption of a medium and high greenhouse gas projection provides an appropriate level of testing to understand the sensitivity of flooding in Central Bendigo with regards to current climate change prediction.

A climate change sensitivity has been undertaken for critical durations of the 1% AEP storm event. The ARR2019 datahub recommends rainfall intensity increase of 9.2% for RCP 4.5 and 20.2% for RCP 8.5 values for the study area. The resulting intensities for the 1% AEP event are outlined in Table 2-3 compared to existing intensities.

Table 2-3 Climate Change IFD Comparison – 1% AEP

Critical Duration	Current Depth (mm)	2090_RCP4.5 Depth (mm)	2090_RCP8.5 Depth (mm)
45min	49.8	54.38	59.76
60min	54.9	59.95	65.88
120min	61.8	67.49	74.16
180min	66.4	72.51	79.68
360min	72.6	79.28	87.12

Critical durations and associated temporal patterns identified for existing conditions were adopted for the 1% AEP climate change scenarios and are outlined in Table 2-4.

Table 2-4 Critical Durations for Climate Change Scenario

Location	Critical Duration	Adopted Temporal Pattern	Adopted Ensemble 1% AEP Flow (m^3/s)
Bendigo Creek	6 hour	26	122.4
Back Creek	2 hour	25	61.6
Thistle Street Tributary	45 minute	22	14.8

2.4.2.2 Results

An overall increase in peak water level was observed throughout the entire study area due to the increased rainfall intensities for both rainfall events. The highest increase in flood heights were observed within and adjacent to the creek with an overall increase in flood extents throughout the project site.

The RCP 8.5 climate change scenario increased flood heights throughout the creek extents with higher increases observed at bridge crossings. Increases in flood extents is most evidenced at the confluence of the Thistle Street Tributary and Bendigo Creek. Significant increases in flood heights (approximately 600mm) are observed south of McIvor Road on Back Creek.

The RCP 4.5 climate change scenario similarly shows increased flood heights and extents but to a lesser magnitude than the RCP 8.5 climate change scenario with increased flood extents and heights generally concentrated at hydraulic constrictions within the respective Creek.

Results for the climate change scenarios can be found in Appendix B

3 PRELIMINARY OPTIONS MODELLING

3.1 SUMMARY OF FIRST ROUND COMMUNITY CONSULTATION

The first round of community consultation occurred over a 9-week period from the 21st of June to 20th August 2021. It included the following:

- A survey in both hard-copy and online format which asked for historic observations of flooding as well as mitigation ideas for testing. These have been collated in a spreadsheet which is included in Appendix C.
- An online mapping portal which presented the draft 1% AEP modelling results and allowed users to add comments and mitigation ideas. The mapping portal will be used further when it comes to presenting the results of mitigation modelling.
- Due to COVID19 restrictions at the time, in person workshops were moved to two online zoom sessions with the initial session occurring on the 10th of August and the second on the 17th of August. The workshops allowed the current flood risk to be presented, questions to be asked and then feedback and mitigation ideas to be gathered. With consideration to the limitations due to COVID19, we consider the workshop attendance and level of engagement to be successful under extremely difficult circumstances and a reflection of the adaptability, well-planned and targeted consultation strategy developed by Make a Change Australia in partnership with WMS. Statistics of the first consultation round are summarised in Table 3-1.

Table 3-1 First Round Consultation Results

Direct Communication Emails	Approximately 160 emails
Flyer Distribution/One-One Conversations	52 businesses and organisations
Letterbox Drop	Approximately 4,000 properties
Jumpleads Newsletter Feature Distributions	Approximately 6,000 emails
Social Media Reach	Approximately 8,300
Media Responses	3 x Newspaper articles, 1 x radio interview
Workshop Registrations	31 (Week 1) & 23 (Week 2)
Workshop Attendance	14 (Week 1) & 10 (Week 2)
Survey Responses	23

During the period of consultation, a total of 82 mitigation options and comments were collated from suggestions by the community as well as internal consultation between CoGB, North Central Catchment Management Authority (NCCMA) and WMS. The full list included a number of duplicate or very similar options as well as a number of general comments not related to specific locations. From this list a total of 36 options were found to be appropriate for modelling, either for preliminary mitigation modelling or for sensitivity testing. The full list of options and modelling results for these options can be found in the CBFS Mitigation Summary Report (Water Modelling Solutions, 2021).

The outcomes from the preliminary modelling for the 36 options was reviewed by the project control group with six options (or combination of options) selected for detailed modelling. Selection criteria was based on effectiveness in reducing flood risk, consequential adverse impacts, environmental risks, construction costs and overall feasibility.

4 DETAILED MITIGATION MODELLING

4.1 OVERVIEW

This section presents on overview of the detailed mitigation modelling for 6 options (or combinations of options) aimed at reducing flood risk within Central Bendigo. Locations for each of the detailed mitigation options are illustrated in Figure 4-1. Concept plans of each of the mitigation options can be found in Appendix E.

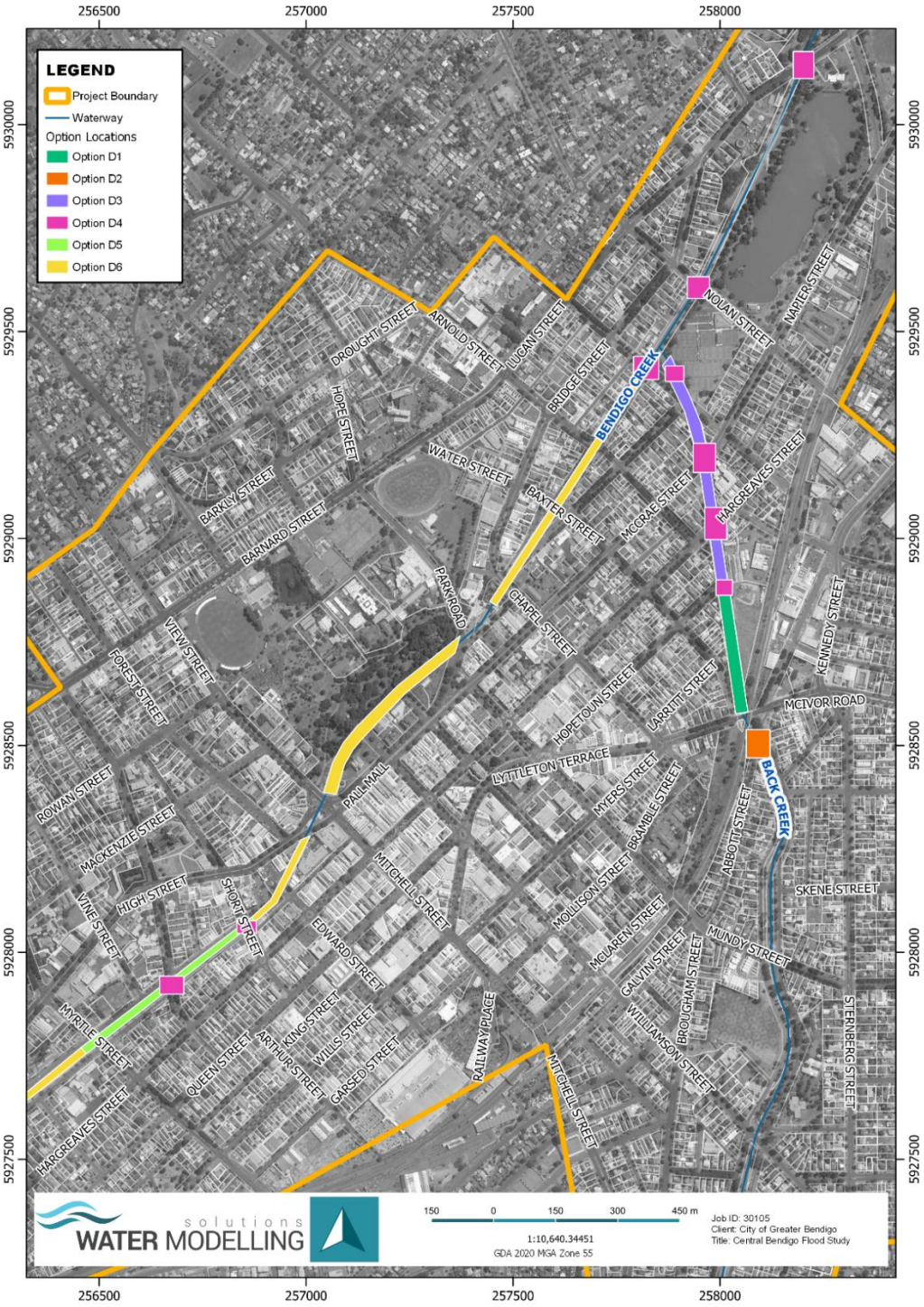

Figure 4-1 Detailed Mitigation Option Locations

4.1.1 Hydraulic Impacts

The full range of design events were modelled for each mitigation option and the hydraulic impact of each option is described for the 1% and 10% AEP events with maps for each of these events included. The maps compare the results of mitigated conditions to existing conditions, with differences in flood levels shown, highlighting areas which become flood-free or become flooded as a result of the mitigation option. The full range of design AEP flood maps can be found in Appendix A.

4.1.2 Environmental and Heritage Impacts

A desktop environmental and heritage impact assessment for each of the mitigation options has been undertaken to identify constraints that may impact the proposed design. Environmental, planning, and Aboriginal cultural sensitivity overlays were obtained from Vicmap to aid in the investigation.

4.1.3 Damages Assessment

The Annual Average Damages (AAD) were determined for existing conditions as well as each of the mitigation options. AAD determines the monetary impacts of the modelled flood events to existing commercial and residential properties and allows a direct comparison between existing conditions and mitigation options and is used as a means of assessing the mitigation options from a flood damages and benefit-cost perspective.

The damages assessment was used to determine AAD for each option, with the approach consistent with Melbourne Water methodology and design curves. The assessment considers the category of the building (i.e., residential or commercial), area of the floor flooded as well as damages to vehicles and roads.

Floor level survey was not available, and so floor levels were assumed to be 300mm above the existing surface level which is a typical industry assumption. This methodology was confirmed with CoGB prior to commencement of the damages assessment. It should be noted that secondary buildings, outbuildings and garages have not been included within this damages assessment.

Results from the damages assessment for existing conditions are outlined in Table 4-1.

Table 4-1 Existing Conditions – Damages Assessment

		Annual Exceedance Probability (AEP)				
		20%	10%	5%	2%	1%
Properties Flooded Above Floor Level	Residential Properties	0	10	51	221	374
	Commercial Properties	0	8	44	82	138
	Total Properties Flooded	0	18	95	303	512
Total Tangible Damage Cost		0	$174,267	$2,929,127	$12,192,558	$30,245,980

4.1.4 Preliminary Costing

All options have undergone preliminary costing at a concept design level. The following have been used to determine mitigation option costs:

- Melbourne Water's standard rates for earthworks and pipe/culvert construction costs.
- Rawlinson's Handbook Rates
- VicRoads regarding bridge and culvert works costs
- Experience in costing mitigation works in other flood studies
- Comments from City of Greater Bendigo regarding initial costings.

In addition, the following assumptions have been made with regards to the costing:

- A 600 mm freeboard in 1% AEP storm event has been adopted for all levees.
- 5% administration fees, 15% engineering fees, 30% contingency adopted across all options.
- 1.5% maintenance has been assumed.

The costings are recommended to be revised as part of the next phase of functional and detailed design.

4.2 DETAILED MITIGATION OPTIONS

4.2.1 Option D1 – Increased Creek Capacity and Levee in Back Creek downstream of McIvor Road

4.2.1.1 Location and Description

Option D1 is located north of McIvor Road Bridge on Back Creek and is a combination of multiple mitigation options. Option D1 aims to increase the conveyance underneath Hopetoun Street Bridge by increasing the capacity of Back Creek by lowering the creek bed as illustrated in Figure 4-2. A 700mm average height levee located on the western side of Back Creek commencing north of McIvor Road and concluding at Hopetoun Street prevents flows from breaking out of Back Creek at this location due to the downstream Hopetoun Street Bridge constriction. A one-way valve has been adopted at the downstream end of Larritt Street drainage line to prevent surcharging onto Larritt Road. The location of Option D1 is illustrated in Figure 4-2.

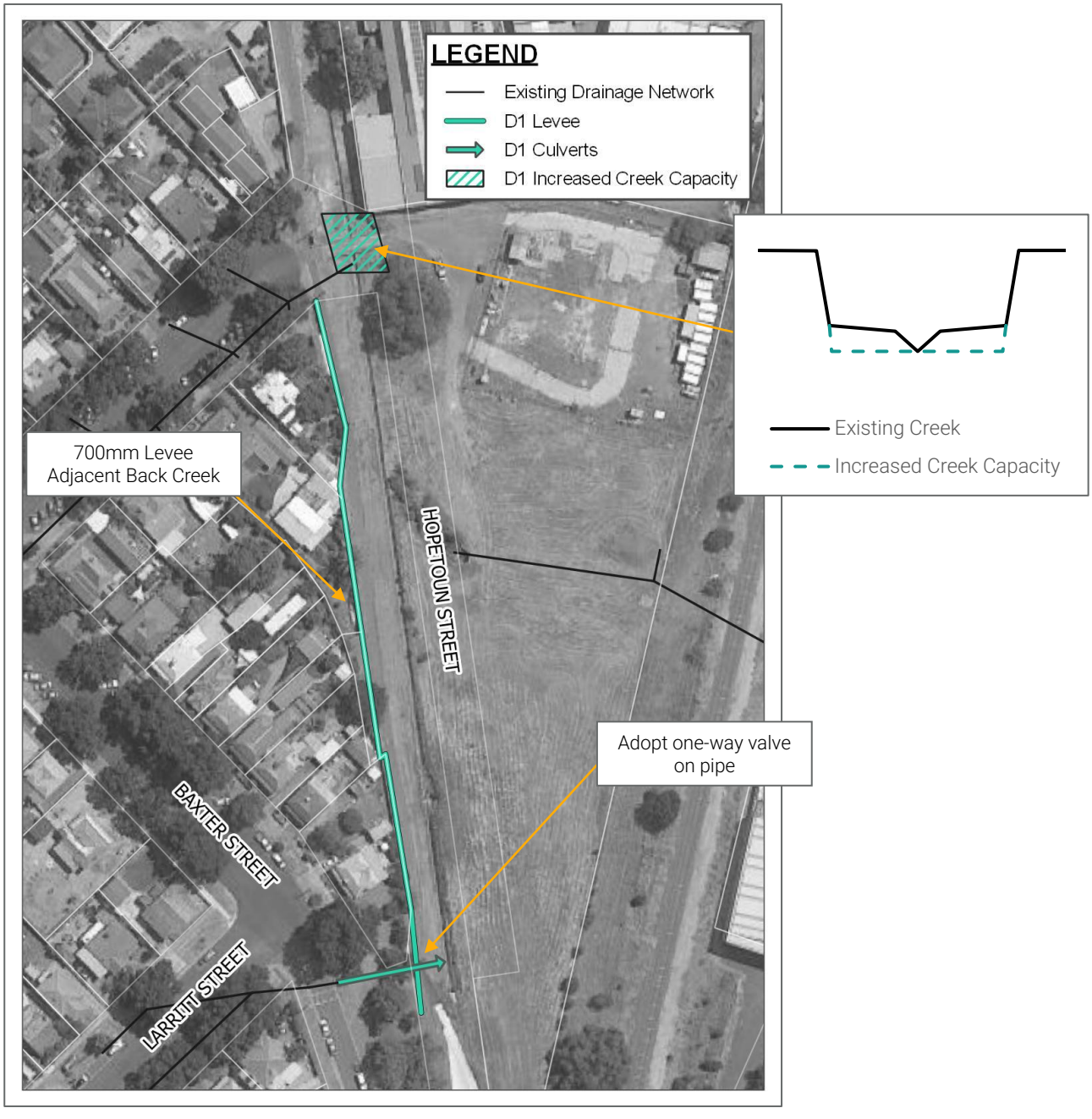

Figure 4-2 Option D1 - Location

4.2.1.2 Flood Impacts

Option D1 was modelled for the full range of design events. The 1% AEP showed elimination of flood extents (I.e., properties are no longer inundated) for properties located near Baxter Street on the western side of the proposed levee. Significant reductions in flood depths extent downstream to Hargreaves Street and Tramways Avenue with reductions in depth ranging from 10mm – 200mm. Adopting Option D1for the 1% AEP event resulted in 12 properties previously at risk now flood free and 35 properties with significantly reduced flood depths. Some increased in flood depths (approximately 16mm) are observed on the eastern side of the Back Creek, opposite the location of the levee. This area is undeveloped and therefore increases in flood depths at this location have no negative impacts to property. The 10% AEP event showed similar although not as significant benefits with 5 previously at-risk properties flood free.

The 1% and 10% AEP flood depth difference is illustrated in Figure 4-3 and Figure 4-4 respectively.

4.2.1.3 Environmental and Heritage Impacts

The bridge works, levee and pipe upgrade for Option D1 are located within both a Heritage Overlay as well as an Aboriginal Heritage Sensitive Overlay thus a cultural heritage assessment would be required as part of the next stage of design. Additionally, Hopetoun Street Bridge is located within the Design & Development Overlay. Mapping of the location of Option D1 relative to the environmental and heritage overlays is illustrated in Figure 4-5.

4.2.1.4 Damages Assessment

To determine the benefit of Option D1 from a reduction in flood damages, a damages assessment has been undertaken for residential and commercial buildings to determine annual average damages (AAD) from flooding. The AAD for Option D1 was calculated as $1,765,670, a reduction of $138,233, compared to existing conditions. The proposed works reduce the total number of floors flooded by 14 in the 1% AEP event. Table 4-2 summarises the results of the flood damages assessment for Option D1.

Table 4-2 Option D1 - Damages Assessment

		Annual Exceedance Probability (AEP)				
		20%	10%	5%	2%	1%
Properties Flooded Above Floor Level	Residential Properties	0	6	29	197	360
	Commercial Properties	0	8	44	82	138
	Total Properties Flooded Above Floor	0	14	73	279	498
Reduction in above floor flooded properties		0	4	22	24	14
Total Tangible Damage Cost		**$0**	**$129,997**	**$2,416,488**	**$11,229,988**	**$29,111,139**

4.2.1.5 Preliminary Costing

Preliminary costing has been undertaken for Option D1. Table 4-3 shows an estimation of the cost of Option D1 inclusive of engineering, administration and contingency costs.

Table 4-3 Option D1 - Preliminary Costing

Description	Total	Estimated Annual Maintenance
Preliminaries/Contractor's on cost	$60,000	
Demolition and Site Preparation	$500	
Creek Works	$30,105	
Drainage	$5,000	$25
Levee	$104,030	$1,560
Landscaping	$3,750	
Final Clean Up	$5,000	
Estimate Total	$208,385	$1,585
Contingency Sum allowance (30% of estimated cost)	$62,515	
Engineering fees (15% of estimated cost)	$31,257	
Administration fees (5% of estimated cost)	$10,419	
Apparent Contract Total	$312,577	

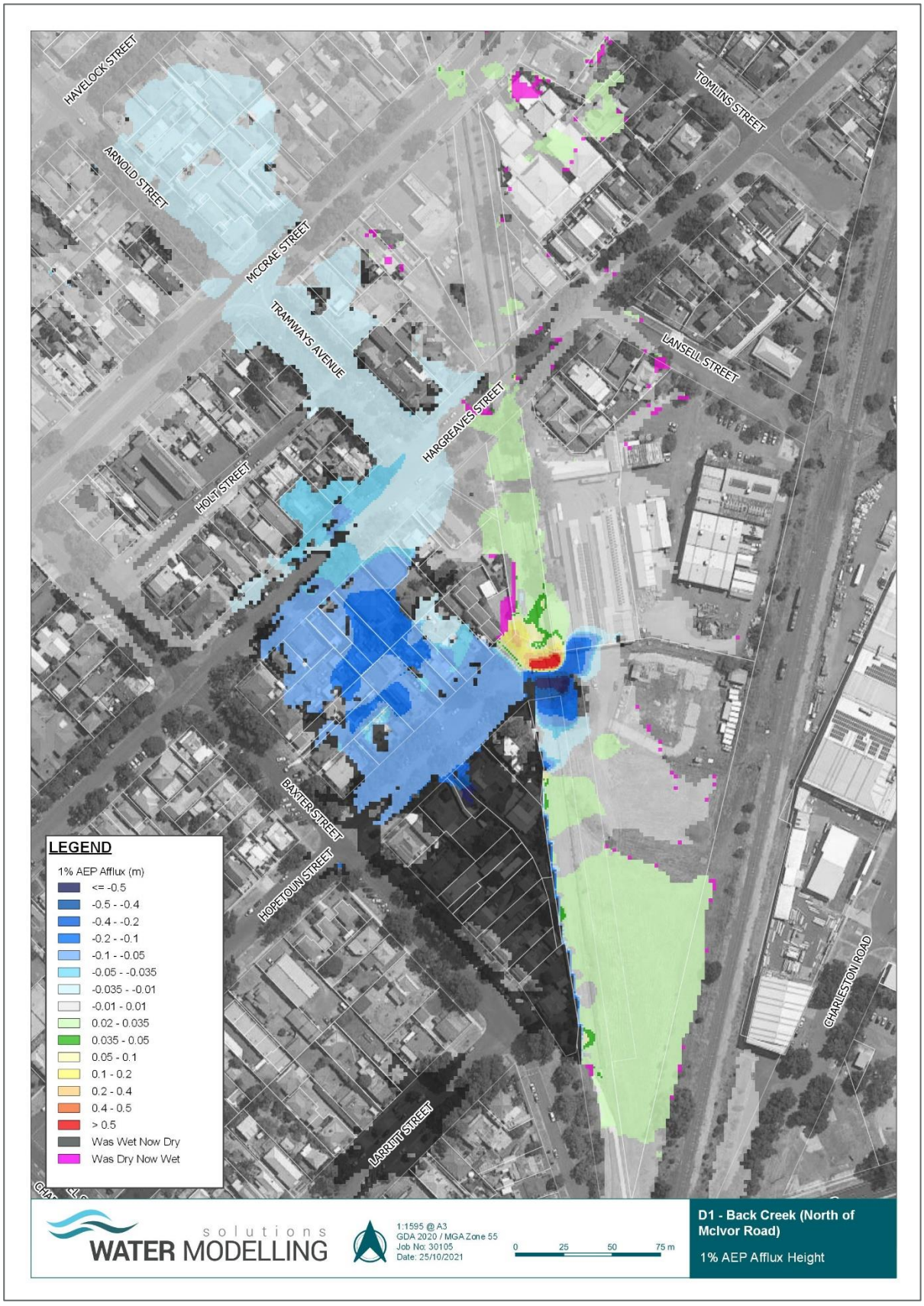

Figure 4-3 Option D1 - 1% AEP Afflux Height

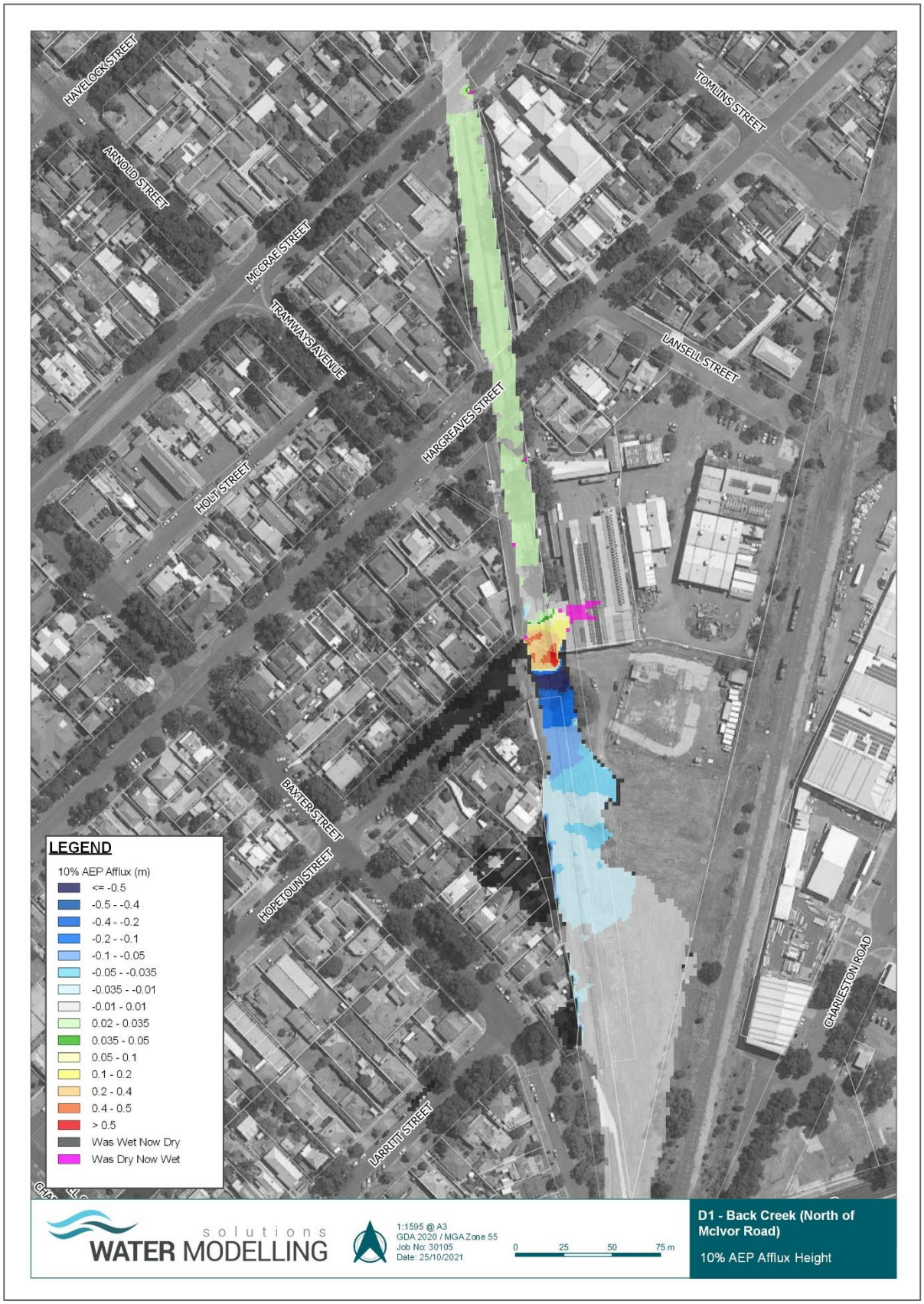

Figure 4-4 Option D1 - 10% AEP Afflux Height

Figure 4-5 Option D1 - Heritage Overlays

4.2.2 Option D2 – Additional Culverts underneath Abbotts Street Bridge

4.2.2.1 Location and Description

Option D2 is located at Abbotts Street Bridge and includes the adoption of 2 x 1.8m x 1.8m box culverts on either side of the existing bridge abutments increasing the conveyance underneath Abbotts Street Bridge. Previous iterations of the detailed analysis adopted levees on each embankment of Back Creek, upstream of Abbotts Street Bridge. Ongoing discussions found although there were significant benefits from a flood mitigation perspective, adoption of levees with the required height would not be feasible from a constructability and public approval perspective thus the levees were omitted from Option D2.

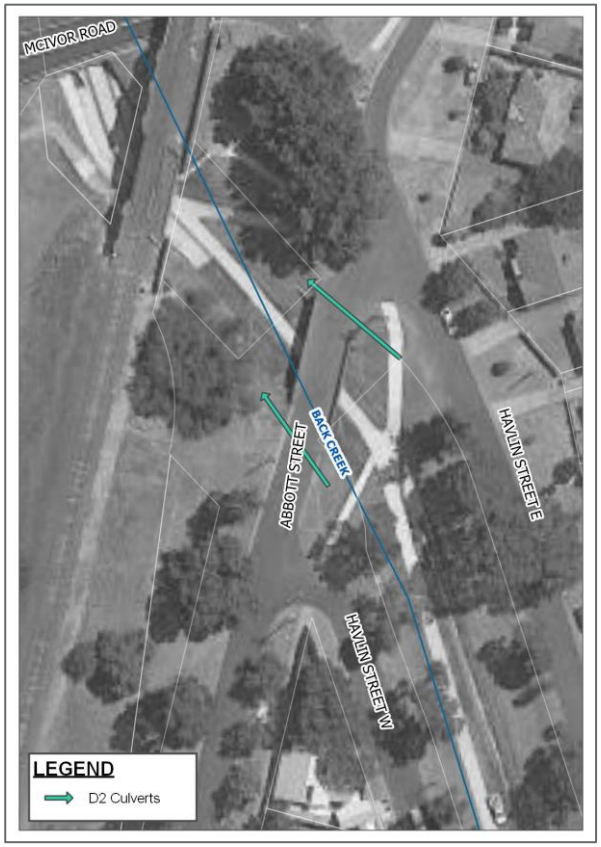

Figure 4-6 Option D2 - Location

4.2.2.2 Flood Impacts

Option D2 was modelled for the full range of design events. The 1% AEP event showed some increases in flood height at both the upstream and downstream end of the each of the culverts due to increase creek capacity at either end. No overall benefits or adverse impacts to adjacent properties in the 1% AEP flood event was observed. The 10% AEP event showed very minor decreases in flood height on Abbotts Street and Havlin Street (approximately 15mm).

The 1% and 10% AEP flood depth difference is illustrated in Figure 4-7 and Figure 4-8 respectively.

4.2.2.3 Environmental and Heritage Impacts

Abbotts Street bridge is located within an Aboriginal Heritage Sensitive Overlay thus a cultural heritage assessment would likely be required as part of the next stage of design. Mapping of the location of Option D2 relative to the environmental and heritage overlays is illustrated in Figure 4-9.

4.2.2.4 Damages Assessment

To determine the benefit of Option D2 from a flood damages perspective, a damages assessment has been undertaken for residential and commercial buildings. The AAD for Option D2 was calculated as $1,903,895, reducing the AAD by $8 compared to existing conditions. This negligible change in damages reflects the minimal impacts to flood depths and extents outside of Back Creek. Table 4-4 summarises the results of the flood damages assessment for Option D2.

Table 4-4 Option D2 - Damages Assessment

		Annual Exceedance Probability (AEP)				
		20%	10%	5%	2%	1%
Properties Flooded Above Floor Level	Residential Properties	0	10	51	221	374
	Commercial Properties	0	8	44	82	138
	Total Properties Flooded Above Floor	0	18	95	303	512
Reduction in above floor flooded properties		0	0	0	0	0
Total Tangible Damage Cost		**$0**	**$173,448**	**$2,922,566**	**$12,191,500**	**$30,268,732**

4.2.2.5 Preliminary Costing

Preliminary costing has been undertaken for Option D2. Table 4-5 shows an estimation of the cost of Option D2 inclusive of engineering, administration and contingency costs.

Table 4-5 Option D2 - Preliminary Costing

Description	Total	Estimate Annual Maintenance
Preliminaries/Contractor's on cost	$107,500	
Demolition and Site Preparation	$25,000	
Creek Works	$6,750	
Drainage	$107,500	
Final Clean Up	$5,000	
Estimate Total	$251,750	$1,612
Contingency Sum allowance (30% OF LUMP SUM)	$75,525	
Engineering fees (15% of estimated cost)	$37,762	
Administration fees (5% of estimated cost)	$12,587	
Apparent Contract Total	**$377,625**	

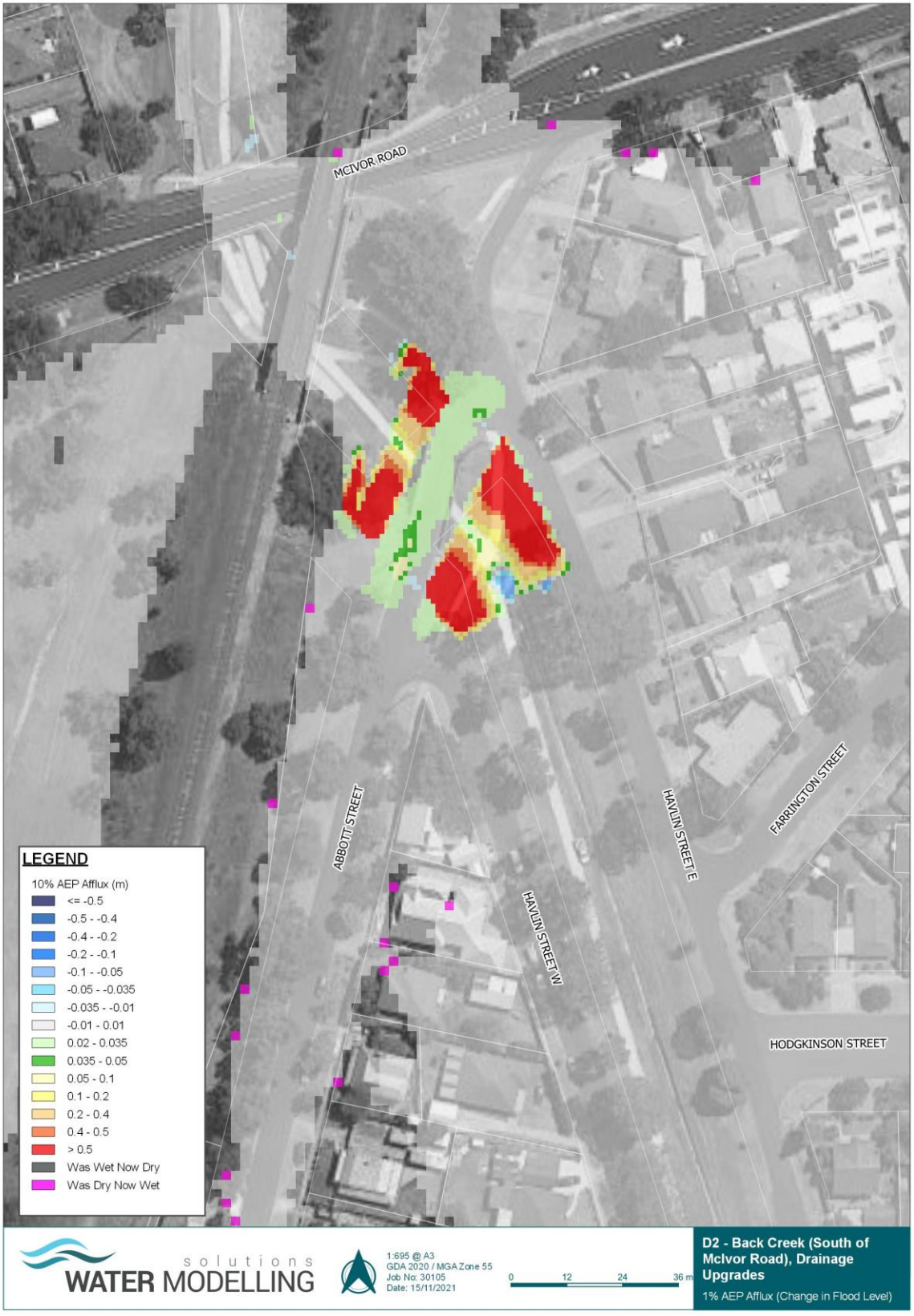

Figure 4-7 Option D2 - 1% AEP Afflux Height

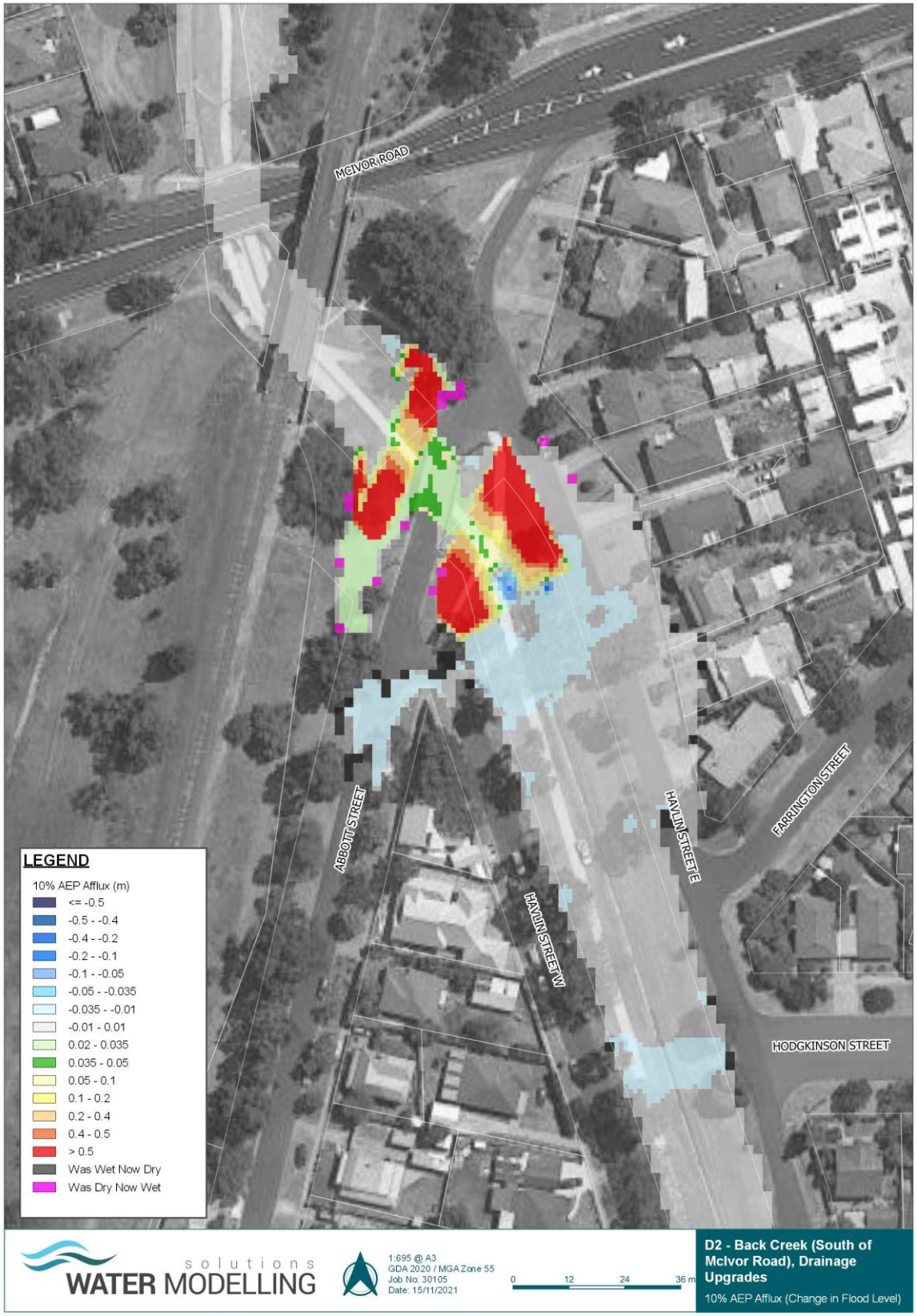

Figure 4-8 Option D2 - 10% AEP Afflux Height

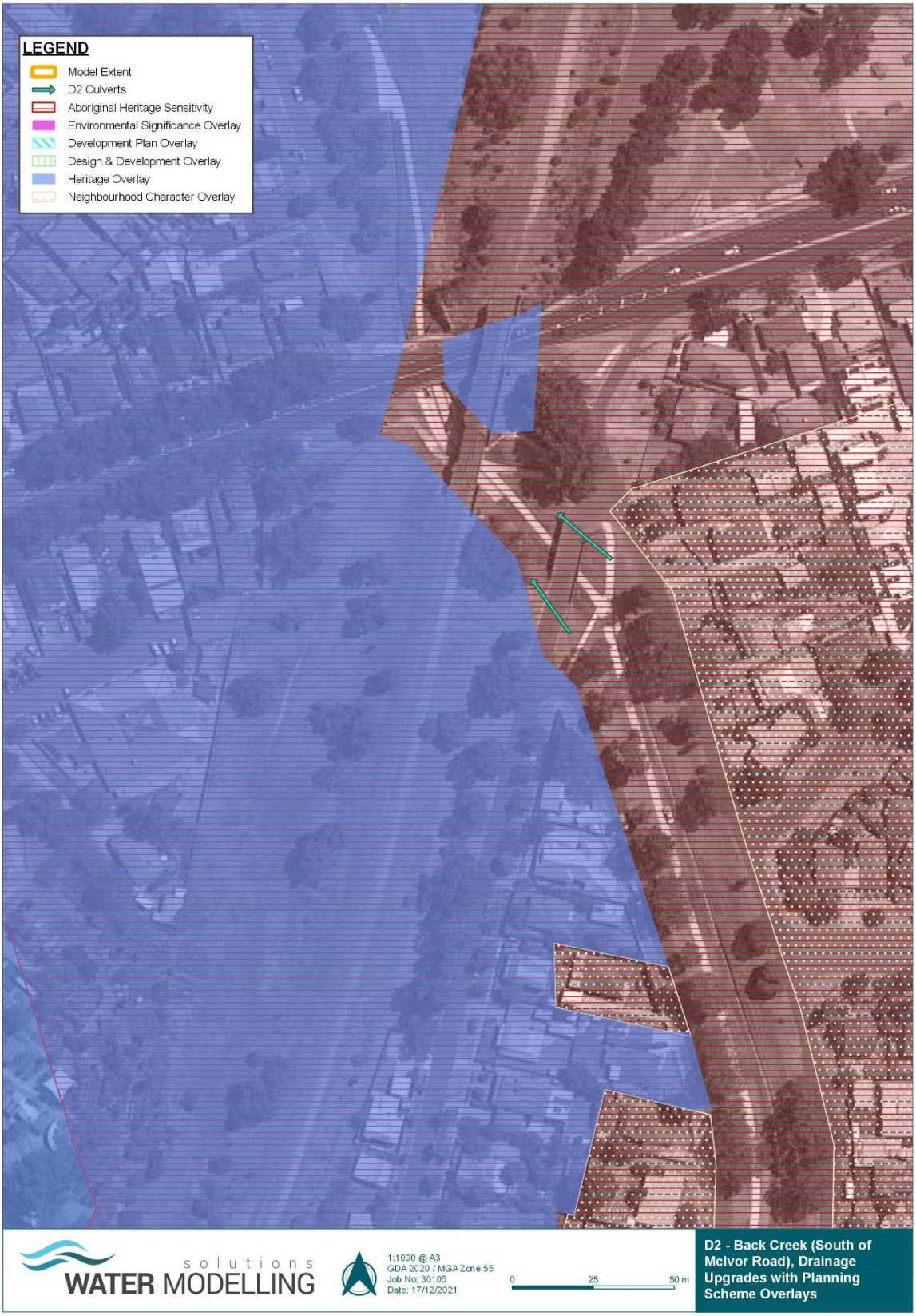

Figure 4-9 Option D2 - Heritage Overlays

4.2.3 Option D3 – Increased Capacity of Back Creek from McIvor Road to Confluence of Back Creek and Bendigo Creek

4.2.3.1 Location and Description

Option D3 is located on Back Creek commencing 50m upstream from Hopetoun Street bridge and extending 600m downstream to conclude at the confluence of Back Creek and Bendigo Creek. The option aims to increase the channel capacity within the concrete lined section of Back Creek by lowering the height of the creek bed to equal the level of the low flow drain traversing the centreline of Back Creek. The location of Option D3 and the modifications to the Creek bed are illustrated in Figure 4-10.

Figure 4-10 Option D3 - Location

4.2.3.2 Flood Impacts

Option D3 was modelled for the full range of design events. The 1% AEP showed an overall reduction in flood extents on either side of Back Creek adjacent to the location of Option D3 with significant reductions in flood depth at properties located on Baxter Street, Hopetoun Street, Hargreaves Street, Tramways Avenue, McCrae Street, Tomlins Street, Arnold Street, Havelock Street, Napier Street and Bayne Street reductions in depth ranging from 10mm – 500mm. Adoption of Option D3 would result in 91 at risk properties with significantly reduced flood depths and 6 previously at-risk properties no longer inundated for the 1% AEP event. Decreased impacts for the 10% AEP event were observed with 4 previously at-risk properties with significantly reduced flood depths and 6 previously at-risk properties no longer inundated.

The 1% and 10% AEP flood depth difference is illustrated in Figure 4-11 and Figure 4-12 respectively.

4.2.3.3 Environmental and Heritage Impacts

Option D3 lies within several heritage overlays including the Aboriginal Heritage Sensitive Overlay, Heritage Overlay and Neighbourhood Character Overlay thus a cultural heritage assessment would likely be required as part of the next stage of design. The Option also intersects with the Design and Development Overlay. Mapping of the location of Option D2 relative to the environmental and heritage overlays is illustrated in Figure 4-13.

4.2.3.4 Damages Assessment

To determine the benefit of Option D3 from a flood damages perspective, a damages assessment has been undertaken for residential and commercial buildings. The AAD for Option D3 was calculated at $1,617,297, reducing the AAD by $286,606 compared to existing conditions. The proposed works reduce the total number of floors flooded by 17 in the 1% AEP event. Table 4-6 summarises the results of the flood damages assessment for Option D3.

Table 4-6 Option D3 – Damages Assessment

		Annual Exceedance Probability (AEP)				
		20%	10%	5%	2%	1%
Properties Flooded Above Floor Level	Residential Properties	0	2	27	175	357
	Commercial Properties	0	8	44	82	138
	Total Properties Flooded Above Floor	0	10	71	257	513
Reduction in above floor flooded properties		0	8	24	46	-1
Total Tangible Damage Cost		**$0**	**$32,900**	**$2,115,844**	**$9,945,855**	**$27,809,763**

4.2.3.5 Preliminary Costing

Preliminary costing has been undertaken for Option D3. Table 4-7 shows an estimation of the cost of Option D1 inclusive of engineering, administration and contingency costs.

Table 4-7 Option D3 – Preliminary Costing

Description	Total	Estimated Annual Maintenance
Preliminaries/Contractor's on cost	$50,000	
Creek Works	$667,690	
Final Clean Up	$7,500	
Estimate Total	$725,190	
Contingency Sum allowance (30% of estimated cost)	$217,557	
Engineering fees (15% of estimated cost)	$108,778	
Administration fees (5% of estimated cost)	$36,259	
Apparent Contract Total	**$942,747**	

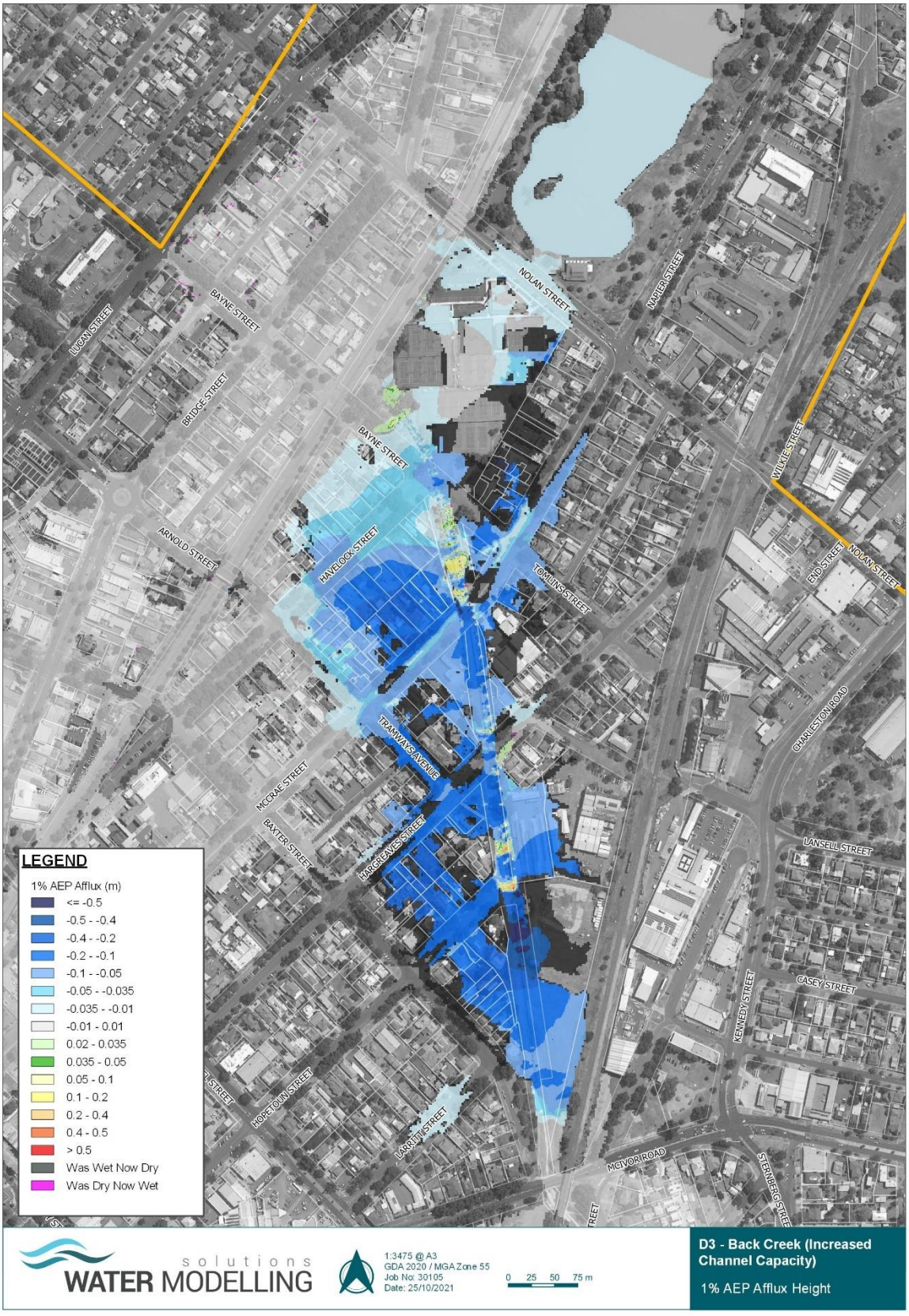

Figure 4-11 Option D3 - 1% AEP Afflux Height

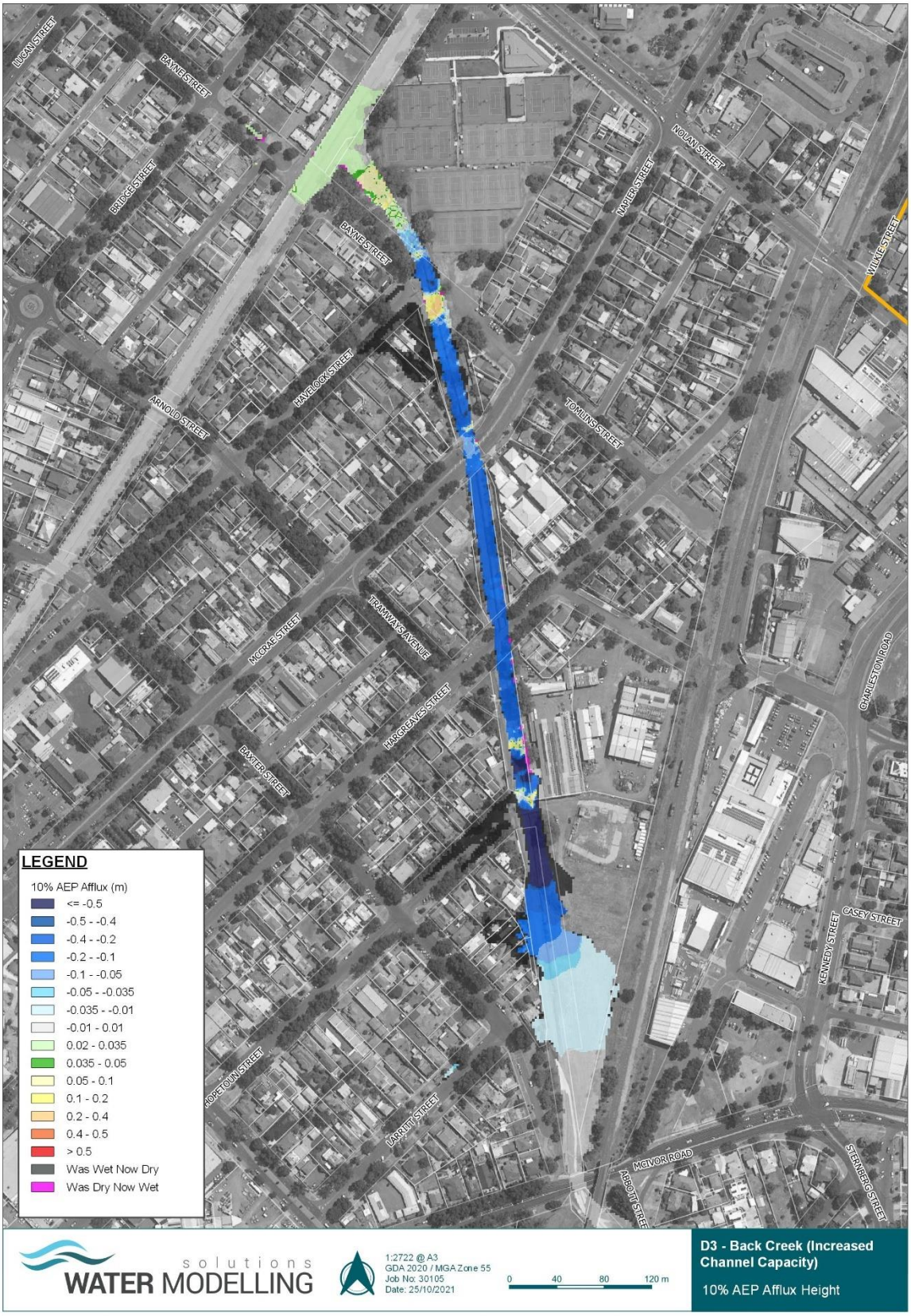

Figure 4-12 Option D3 - 10% AEP Afflux Height

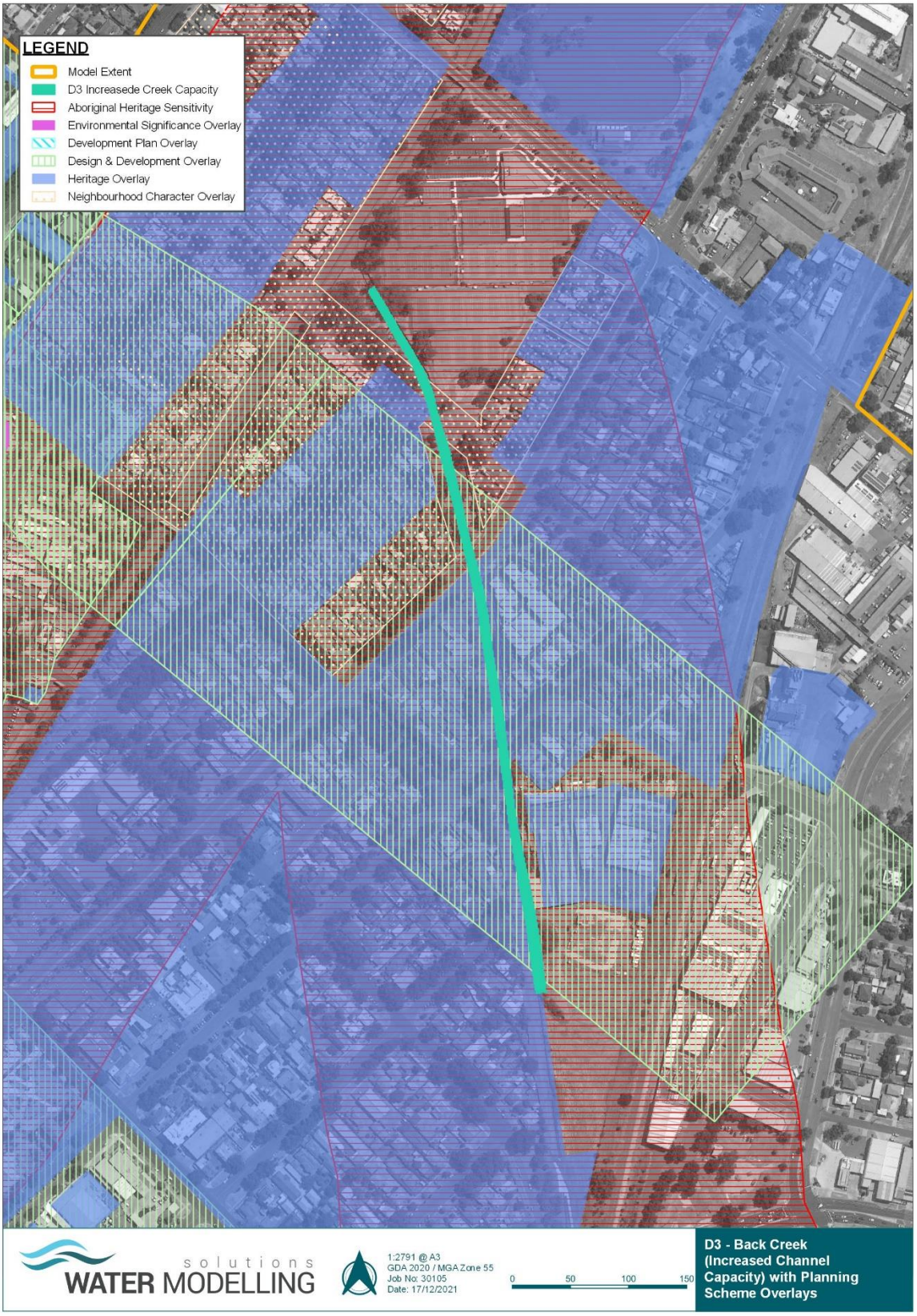

Figure 4-13 Option D3 - Heritage Overlays

4.2.4 Option D4 – Increased Capacity of Underneath Bridges in Back Creek and Bendigo Creek

4.2.4.1 Location and Description

Option D4 involves increasing the conveyance underneath a number of bridges. Numerous bridges in the existing conditions scenario were identified as causing constriction of flows in both Back Creek and Bendigo Creek contributing to overtopping of the creek embankments. A sensitivity analysis was conducted in preliminary model runs to identify individual bridges which were causing inundation of properties in the 1% AEP flood event. Bridges identified as resulting in constrictions within each of the creeks are illustrated in Figure 4-14 and include:

- Back Creek
  - Hopetoun Street Bridge
  - Pedestrian Crossing upstream of Hargreaves Street
  - Hargreaves Street Bridge
  - McCrae Street Bridge
  - Pedestrian Crossing upstream of Bendigo/Back Creek confluence
- Bendigo Creek
  - Thistle Street Bridge
  - Myrtle Street Bridge
  - Wattle Street Bridge
  - Short Street Bridge
  - Bayne Street Bridge
  - Nolan Street Bridge
  - Weeroona Street Bridge

To increase the conveyance capacity beneath the identified bridges, the eastern half of the creek bed within the section of creek underlying the bridges was lowered to the level of the low flow drain as illustrated in Figure 4-15. A levee was adopted 30m downstream of McCrae Street on the eastern side of Back Creek with a length of 81m and an average height of 1.7m as illustrated in Figure 4-15.

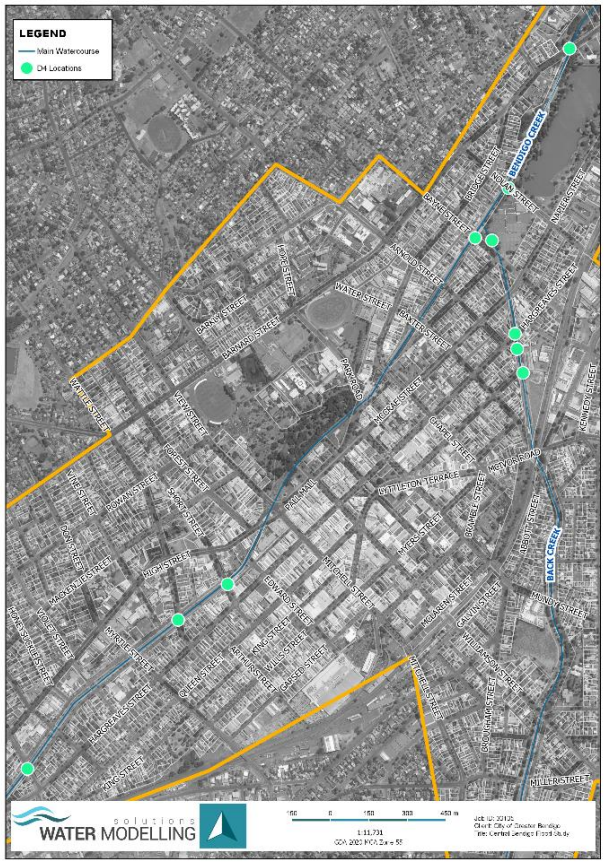

Figure 4-14 Option D4 - Locations

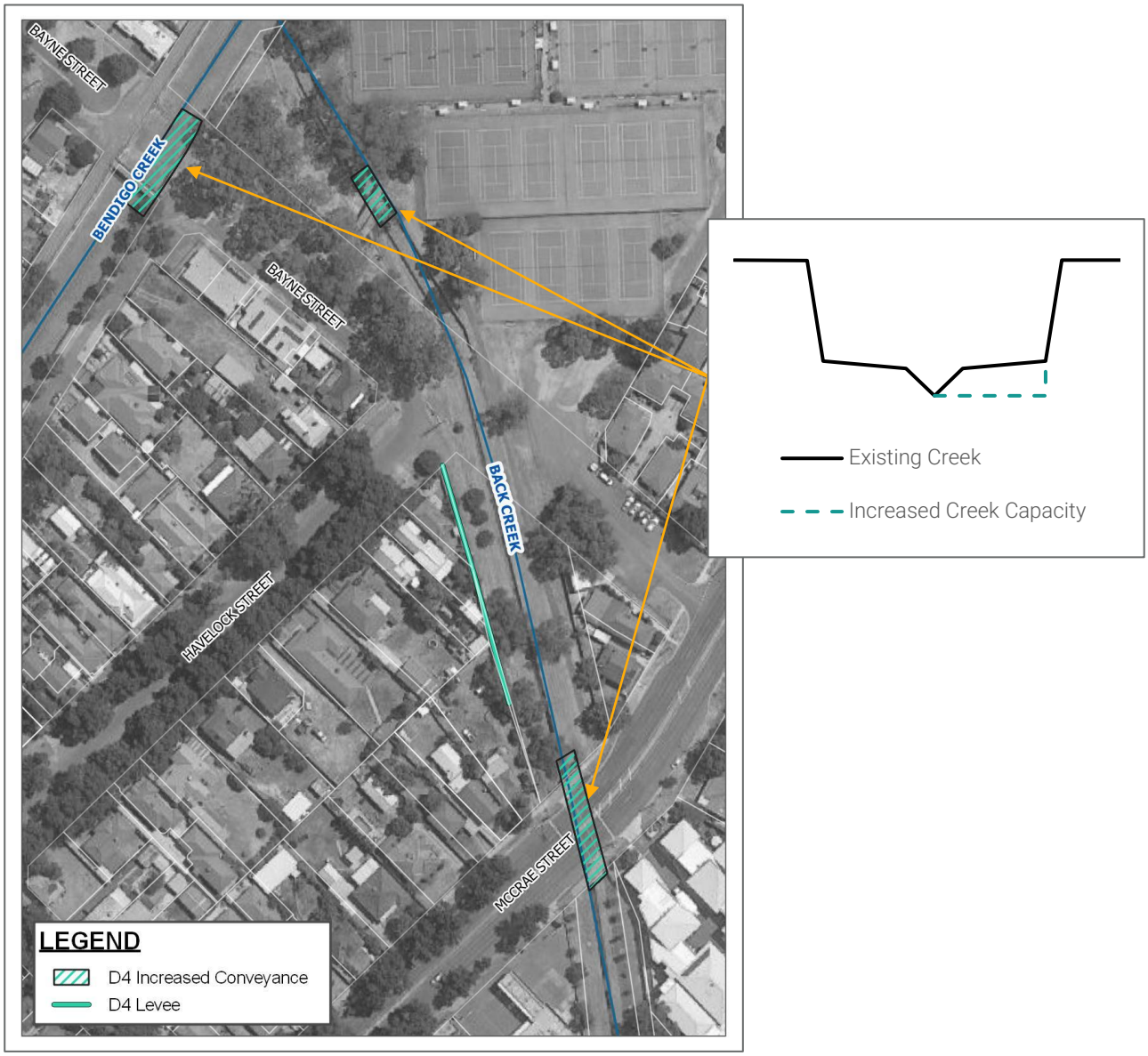

Figure 4-15 Example of Option D4

4.2.4.2 Flood Impacts

Option D4 was modelled for the full range of design events. The 1% AEP showed significant reductions in extents and depths adjacent to bridges with increased conveyance. Most notable reductions in flood impacts are observed adjacent to Thistle Street Bridge and all identified bridges located on Back Creek with flood heights reducing up to 370mm. Option D4 results in 139 previously at-risk properties with significantly reduced flood depths. Some adverse impacts are observed at 16 properties on Bayne Street and Lucan Street (adjacent to confluence of Bendigo Creek and Back Creek) with depths increased marginally (approximately 15mm). It is anticipated that this slight increase can be resolved by increasing the volumetric capacity of Bendigo Creek at Bayne Street Bridge.

Flood impacts were decreased marginally for the 10% AEP event with reduced flood depths of 4 previously at-risk properties located on Baxter Street, North of McIvor Road Bridge.

The flood depth difference for the 1% AEP event is illustrated in Figure 4-16 and Figure 4-17 with the 10% AEP flood depth difference illustrated in Figure 4-18 and Figure 4-19 respectively.

4.2.4.3 Environmental and Heritage Impacts

Overlays intersecting with locations of Option D4 vary depending on the Bridge location. All bridge locations intersect with the Aboriginal Heritage Sensitive Overlay with the Heritage Overlay and Neighbourhood Character Overlay intersected at several locations. Cultural Heritage Assessments would likely be required if this option progresses to design, particularly given the excavation and ground disturbance that would be involved. The Option also intersects with the Design and Development Overlay. Mapping of the location of Option D2 relative to the environmental and heritage overlays is illustrated in Figure 4-20 and Figure 4-21.

4.2.4.4 Damages Assessment

To determine the benefit of Option D4 from a flood damages perspective, a damages assessment has been undertaken for residential and commercial buildings. The AAD for Option D4 was calculated as $1,696,305, reducing the AAD by $207,598 compared to existing conditions. The proposed works reduce the total number of floors flooded by 9 in the 1% AEP event. Table 4-8 summarises the results of the flood damages assessment for Option D4.

Table 4-8 Option D4 – Damages Assessment

		Annual Exceedance Probability (AEP)				
		20%	10%	5%	2%	1%
Properties Flooded Above Floor Level	Residential Properties	0	5	32	194	365
	Commercial Properties	0	8	44	81	138
	Total Properties Flooded Above Floor	0	13	76	275	503
Reduction in above floor flooded properties		0	5	19	28	9
Total Damage Cost		**$0**	**$69,989**	**$2,220,950**	**$10,621,113**	**$28,733,766**

4.2.4.5 Preliminary Costing

Preliminary costing has been undertaken for Option D4. Table 4-9 shows an estimation of the cost of Option D4 inclusive of engineering, administration and contingency costs.

Table 4-9 Option D4 - Preliminary Costing

Description	Total	Estimated Annual Maintenance
Preliminaries/Contractor's on cost	$77,000	
Creek Works	$434,045	
Levee	$70,065	$1,051
Final Clean Up	$12,000	
Estimate Total	$593,110	$1,051
Contingency Sum allowance (30% of estimated cost)	$177,933	
Engineering fees (15% of estimated cost)	$88,967	
Administration fees (5% of estimated cost)	$29,656	
Apparent Contract Total	**$889,665**	

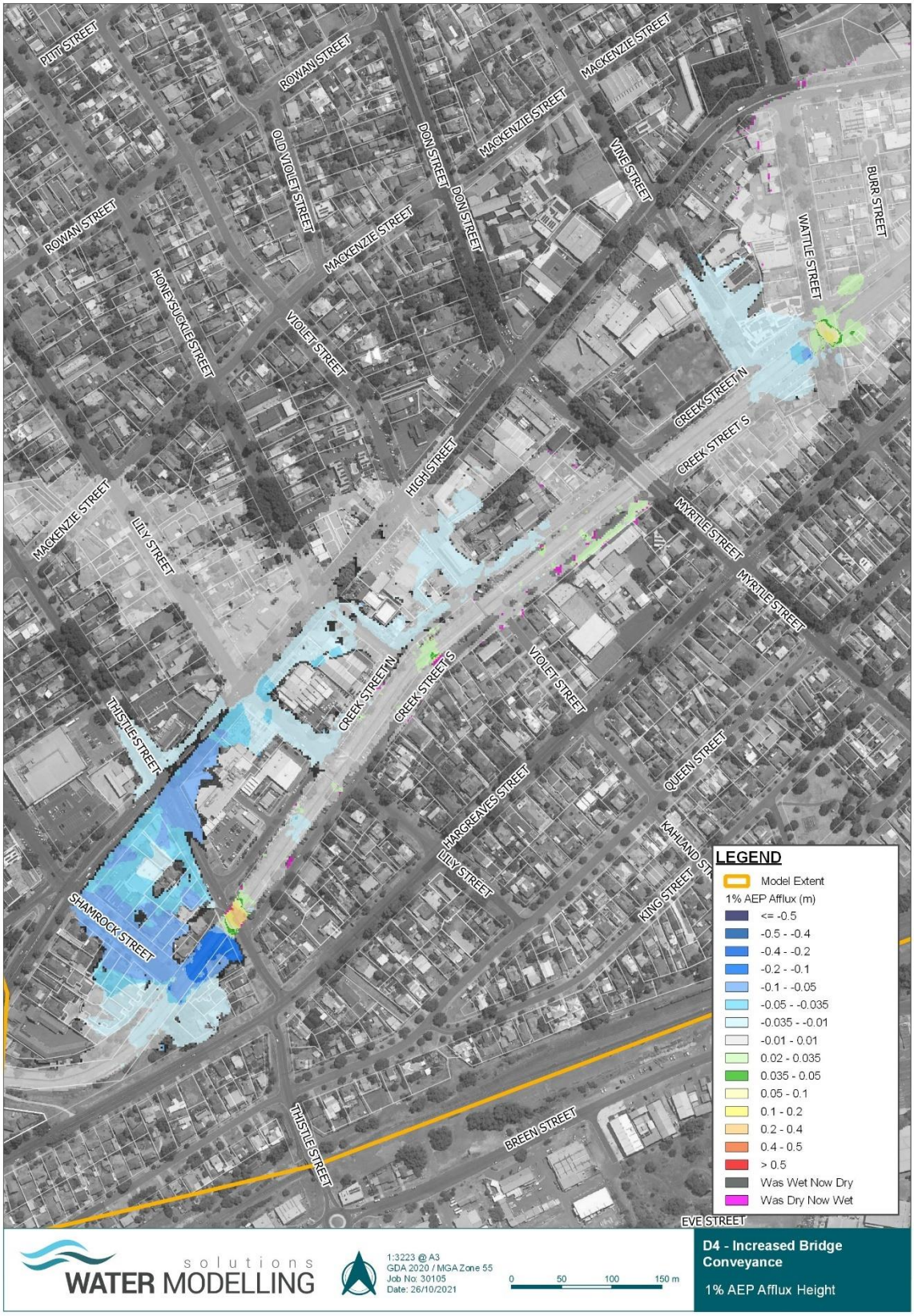

Figure 4-16 Option D4 - 1% AEP Afflux Height (South)

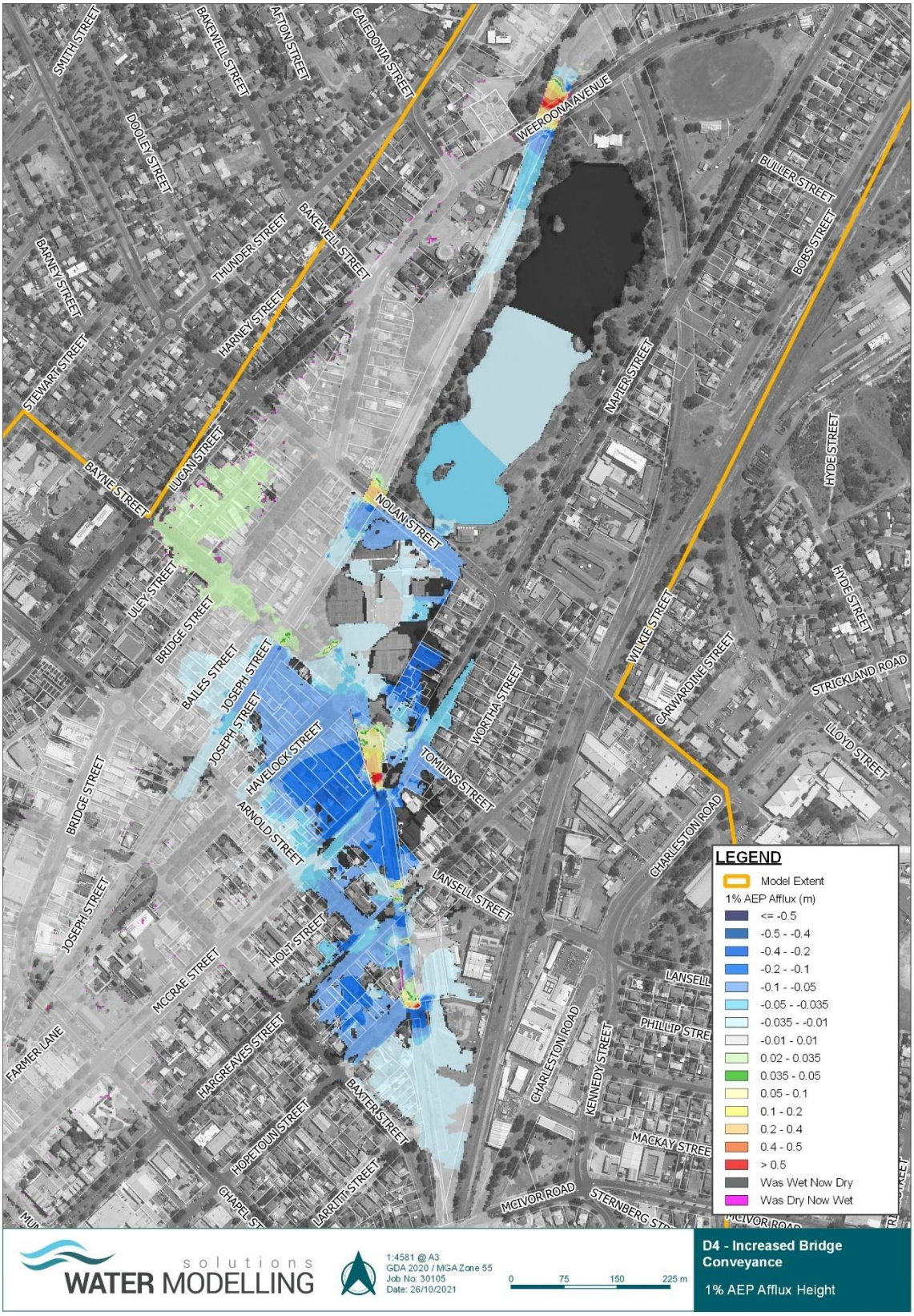

Figure 4-17 Option D4 - 1% AEP Afflux Height (North)

Figure 4-18 Option D4 - 10% AEP Afflux Height (South)

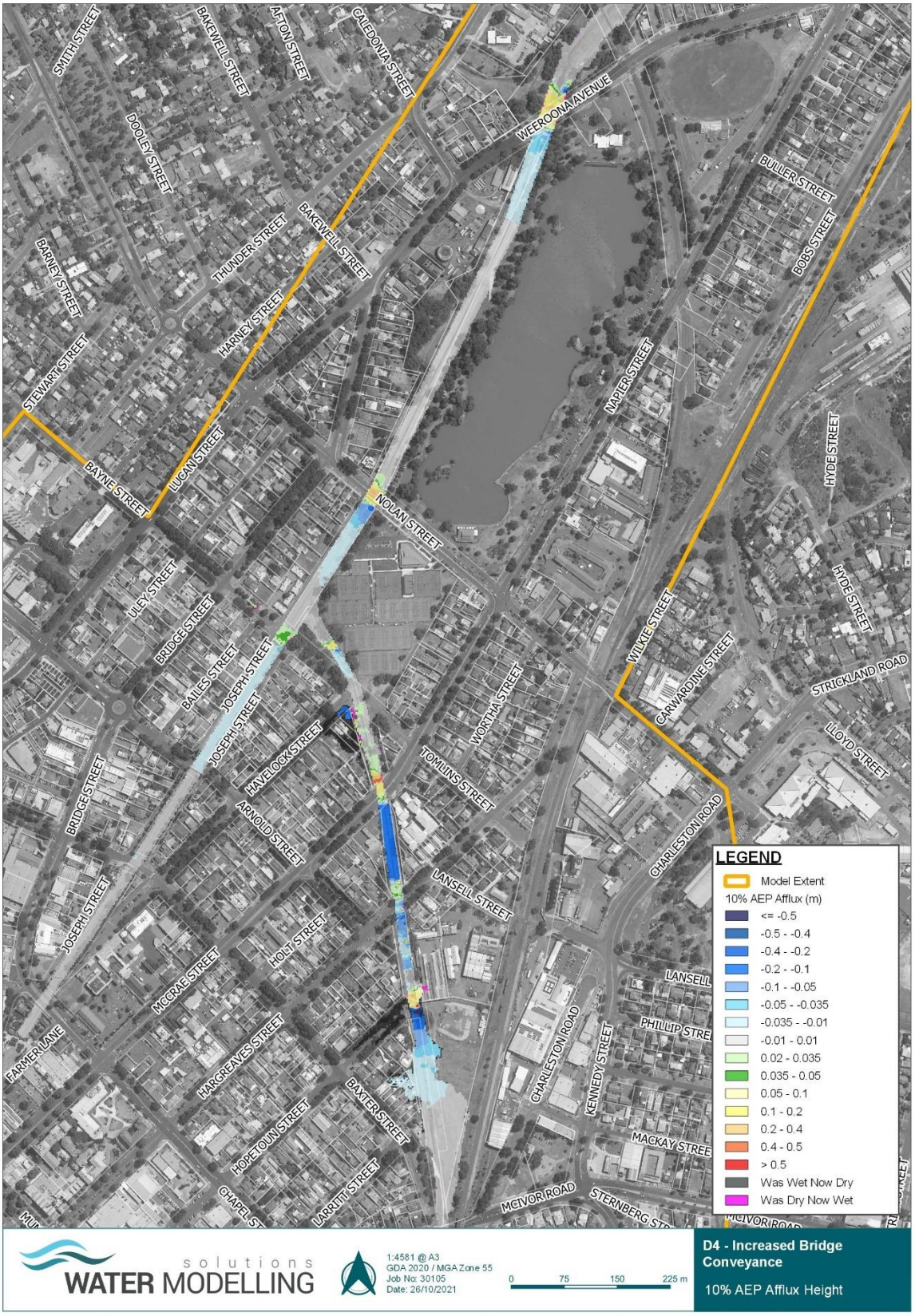

Figure 4-19 Option D4 - 10% AEP Afflux Height (North)

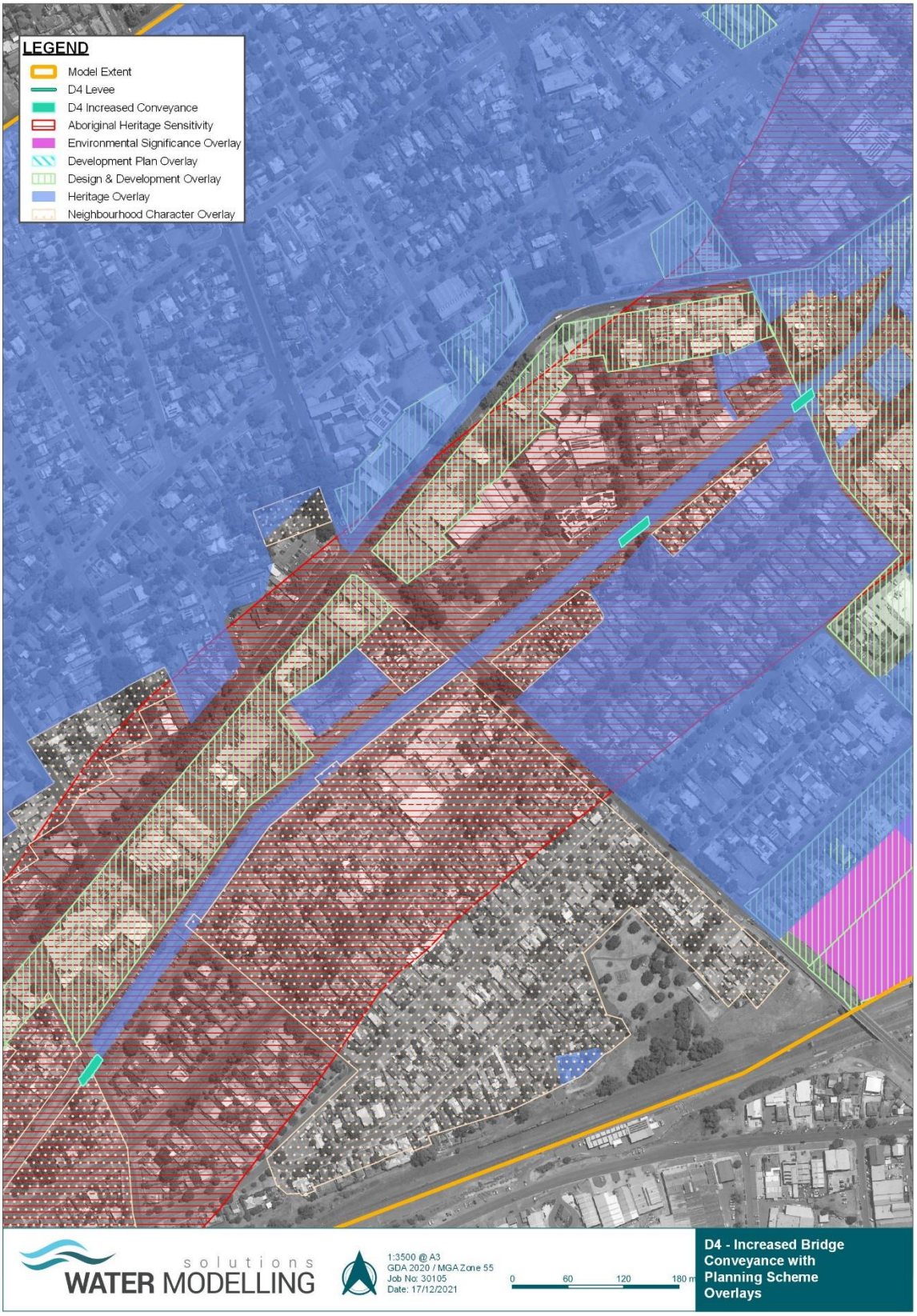

Figure 4-20 Option D4 - Heritage Overlays (Bendigo Creek)

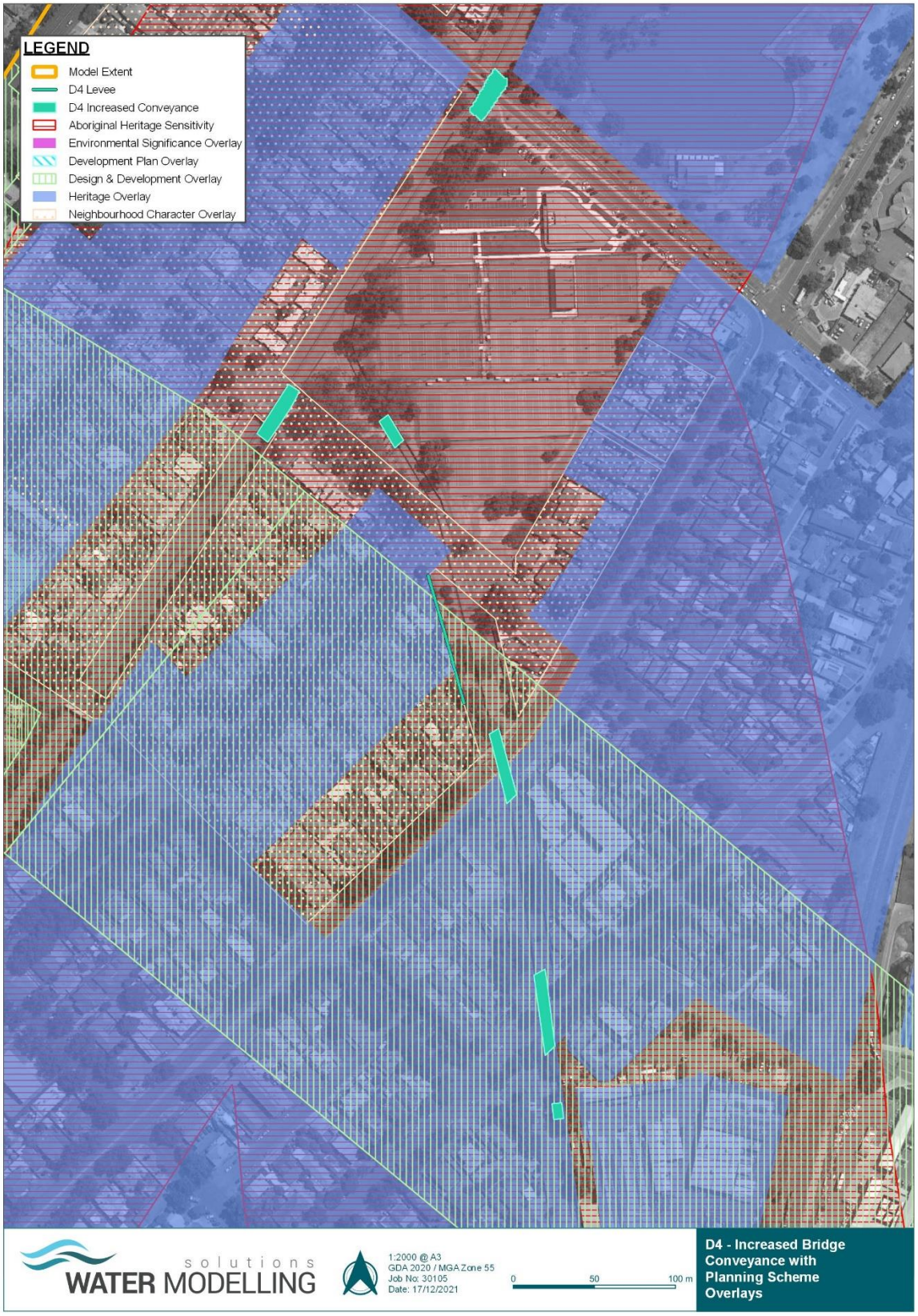

Figure 4-21 Option D4 - Heritage Overlays (Back Creek)

4.2.5 Option D5 – Increased Capacity of Bendigo Creek with Levees from Myrtle Street to Short Street

4.2.5.1 Location and Description

Option D5 increases the conveyance underneath Myrtle Street Bridge and Short Street Bridge as well as increasing the volumetric capacity of Bendigo Creek by lowering the creek bed to the level of the low flow drain as illustrated in Figure 4-22. Lowering of the creek commences approximately 30 upstream from Myrtle Street Bridge and concludes approximately 20m downstream of Short Street Bridge. Levees have been adopted on either side of Bendigo Creek between Myrtle Street and Short Street to prevent overtopping of the creek embankments with an average height of 1.1m for the levee located on the northern embankment and 1.0m for the levee located on the southern embankment.

The location of Option D5 is illustrated in Figure 4-22.

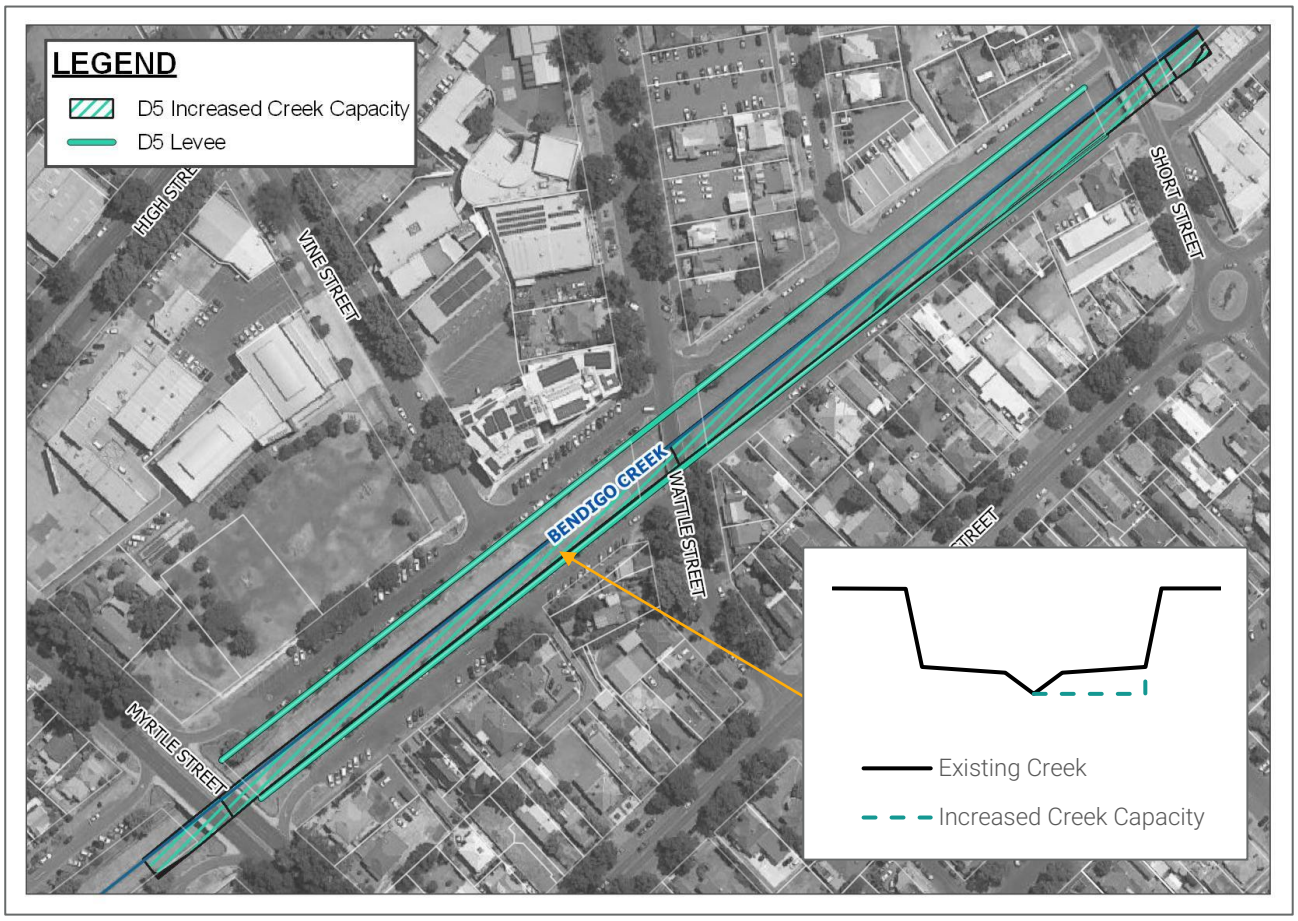

Figure 4-22 Option D5 - Location

4.2.5.2 Flood Impacts

Option D5 was modelled for the full range of design events. The 1% AEP event showed significant reductions in extents and depths either side of Bendigo Creek, directly adjacent to the location of Option D5 with 4 properties previously at risk now flood free and 78 properties with significantly reduced flood depths. Some increased flood depth was observed upstream of Myrtle Street Bridge with nine properties impacted adversely. It is anticipated that this increase can be resolved with further increased capacity in Bendigo Creek further upstream of Myrtle Street Bridge.

No significant benefits or adverse impacts were observed for the 10% AEP event.

The 1% and 10% AEP flood depth difference is illustrated in Figure 4-23 and Figure 4-24 respectively.

4.2.5.3 *Environmental and Heritage Impacts*

Option D5 lies within several heritage overlays including the Aboriginal Heritage Sensitive Overlay, Heritage Overlay and Neighbourhood Character Overlay thus a cultural heritage assessment would be required as part of the next stage of design. The Option also intersects with the Design and Development Overlay. Mapping of the location of Option D5 relative to the environmental and heritage overlays is illustrated in Figure 4-25.

4.2.5.4 *Damages Assessment*

To determine the benefit of Option D5 from a flood damages perspective, a damages assessment has been undertaken for residential and commercial buildings. The AAD for Option D5 was calculated at 1,867,929, reducing the AAD by $35,974 compared to existing conditions. The proposed works reducing the total number of floors flooded by 2 in the 1% AEP event. Table 4-10 summarises the results of the flood damages assessment for Option D4.

Table 4-10 Option D5 – Damages Assessment

		Annual Exceedance Probability (AEP)				
		20%	10%	5%	2%	1%
Properties Flooded Above Floor Level	Residential Properties	0	10	51	221	376
	Commercial Properties	0	7	44	81	134
	Total Properties Flooded Above Floor	0	17	95	302	510
Reduction in above floor flooded properties		0	1	0	1	2
Total Tangible Damage Cost		**$0**	**$171,868**	**$2,843,134**	**$12,027,281**	**$29,664,926**

4.2.5.5 *Preliminary Costing*

Preliminary costing has been undertaken for Option D5. Table 4-10 shows an estimation of the cost of Option D5 inclusive of engineering, administration and contingency costs.

Table 4-11 Option D5 - Preliminary Costing

Description	Total	Estimated Annual Maintenance
Preliminaries/Contractor's on cost	$62,500	
Demolition and Site Preparation	$8,800	
Creek Works	$564,480	
Levee	$565,915	$8,489
Final Clean Up	$10,000	
Estimate Total	$1,211,695	$8,489
Contingency Sum allowance (30% of estimated cost)	$363,509	
Engineering fees (15% of estimated cost)	$181,754	
Administration fees (5% of estimated cost)	$60,585	
Apparent Contract Total	**$1,817,543**	

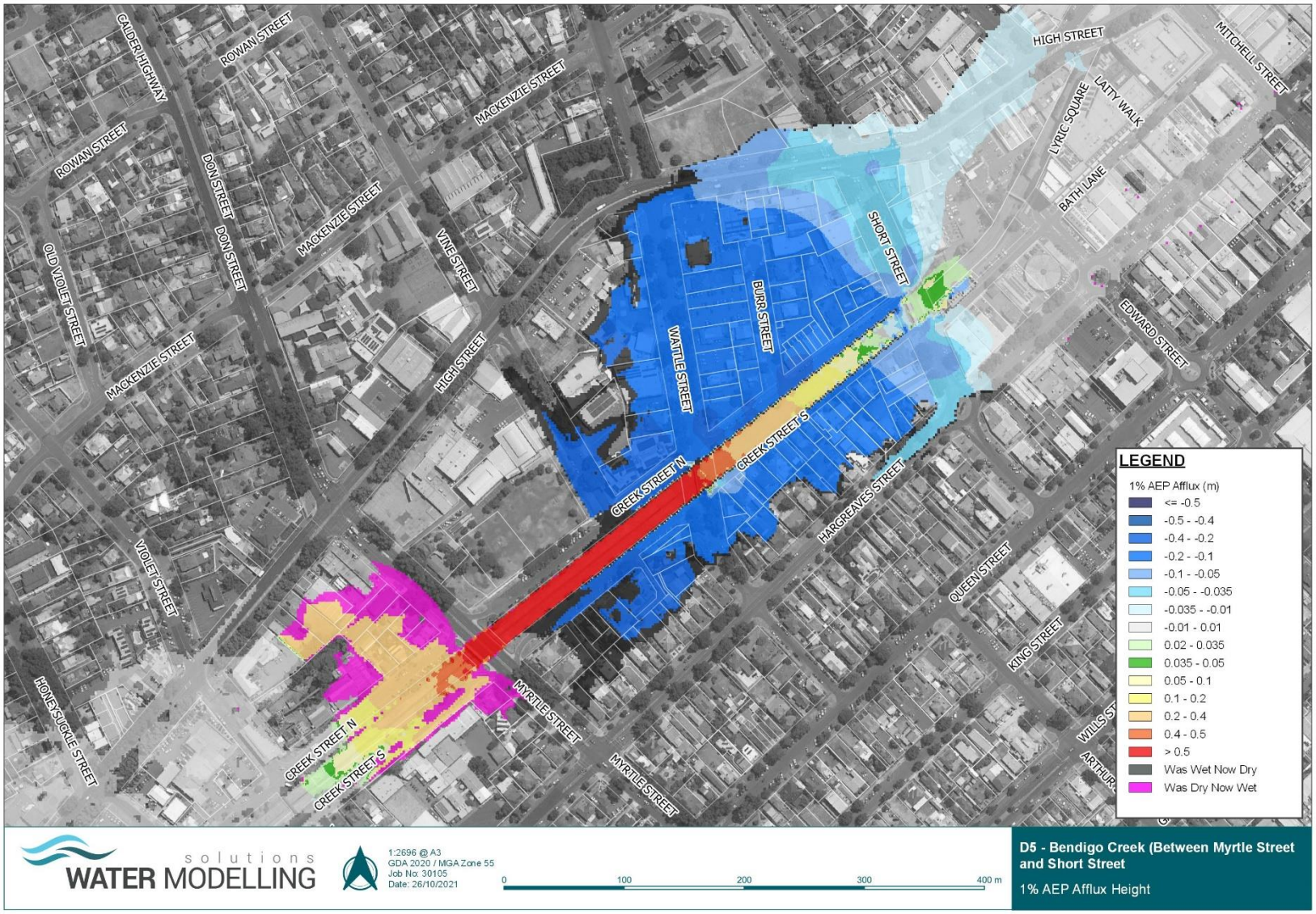

Figure 4-23 Option D5 - 1% AEP Afflux Height

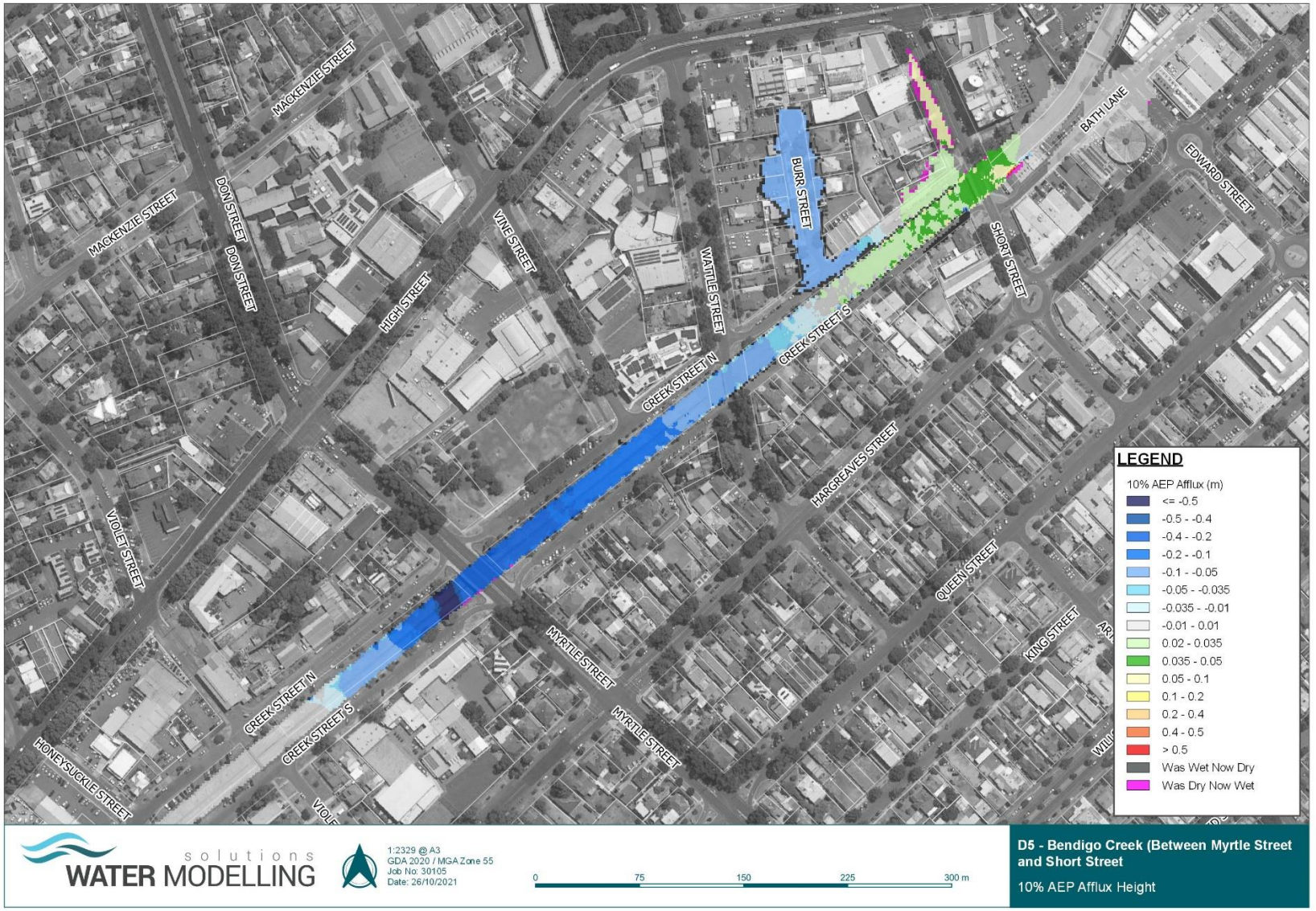

Figure 4-24 Option D5 - 10% AEP Afflux Height

Figure 4-25 Option D5 - Heritage Overlays

4.2.6 Option D6 – Increased Capacity of Bendigo Creek from Thistle Street to Confluence of Back and Bendigo Creek

4.2.6.1 Location and Description

Option D6 increases the capacity of Bendigo Creek by lowering eastern side of creek to match the invert height of the existing low flow drain (as illustrated in Figure 4-26). Option D6 commences 50m downstream from High Street and concludes 30m upstream of the confluence of Bendigo Creek and Back Creek.

The location of Option D5 is illustrated in Figure 4-26.

Figure 4-26 Option D6 - Location

4.2.6.2 Flood Impacts

Option D6 was modelled for the full range of design events. The 1% AEP event showed significant reductions in flood depths for 202 previously at-risk properties. Significant increases in flood depths can be observed around Charing Cross and slight increases to flood

depths are observed corner of Bayne Street and Lucan Street (adjacent to confluence of Bendigo Creek and Back Creek). It is anticipated that the increases adjacent to the confluence of Bendigo Creek and Back Creek can be resolved the detailed design process. The increases in flood heights centred around Charing Cross are significant, caused by the constriction of the creek in the channel underneath High Street.

Some adverse impacts are observed at 16 properties on Bayne Street and Lucan Street (adjacent to confluence of Bendigo Creek and Back Creek) as well as adjacent to the High Street underpass with flood depths increased marginally. It is anticipated that this slight increase can be resolved by increasing the volumetric capacity of Bendigo Creek at Bayne Street Bridge and High Street.

No significant benefits or adverse impacts were observed for the 10% AEP event.

The flood depth difference for the 1% AEP event is illustrated in Figure 4-27 and Figure 4-28 with the 10% AEP flood depth difference illustrated in Figure 4-29 and Figure 4-30 respectively.

4.2.6.3 Environmental and Heritage Impacts

Option D6 lies within several heritage overlays including the Aboriginal Heritage Sensitive Overlay, Heritage Overlay and Neighbourhood Character Overlay thus a cultural heritage assessment would be required as part of the next stage of design. The Option also intersects with the Design and Development Overlay. Mapping of the location of Option D6 relative to the environmental and heritage overlays is illustrated in Figure 4-31.

4.2.6.4 Damages Assessment

To determine the benefit of Option D6 from a flood damages perspective, a damages assessment has been undertaken for residential and commercial buildings. The AAD for Option D6 was calculated at $1,875,188, reducing the AAD by $28,715 compared to existing conditions. The proposed works reduce the total number of floors flooded by 10 in the 1% AEP event. Table 4-12 summarises the results of the flood damages assessment for Option D6.

Table 4-12 Option D6 - Damages Assessment

		Annual Exceedance Probability (AEP)				
		20%	10%	5%	2%	1%
Properties Flooded Above Floor Level	Residential Properties	0	10	51	217	369
	Commercial Properties	0	4	46	75	133
	Total Properties Flooded Above Floor	0	14	97	292	502
Reduction in above floor flooded properties		0	4	-2	11	10
Total Tangible Damage Cost		**$0**	**$163,332**	**$3,246,646**	**$11,542,392**	**$29,488,495**

4.2.6.5 *Preliminary Costing*

Preliminary costing has been undertaken for Option D6. Table 4-13 shows an estimation of the cost of Option D6 inclusive of engineering, administration and contingency costs.

Table 4-13 Option D6 - Preliminary Costing

Description	Total	Estimated Annual Maintenance
Preliminaries/Contractor's on cost	$65,000	
Creek Works	$2,801,260	
Final Clean Up	$10,000	
Estimate Total	$2,876,260	
Contingency Sum allowance (30% of estimated cost)	$862,878	
Engineering fees (15% of estimated cost)	$431,439	
Administration fees (5% of estimated cost)	$143,813	
Apparent Contract Total	$4,314,390	

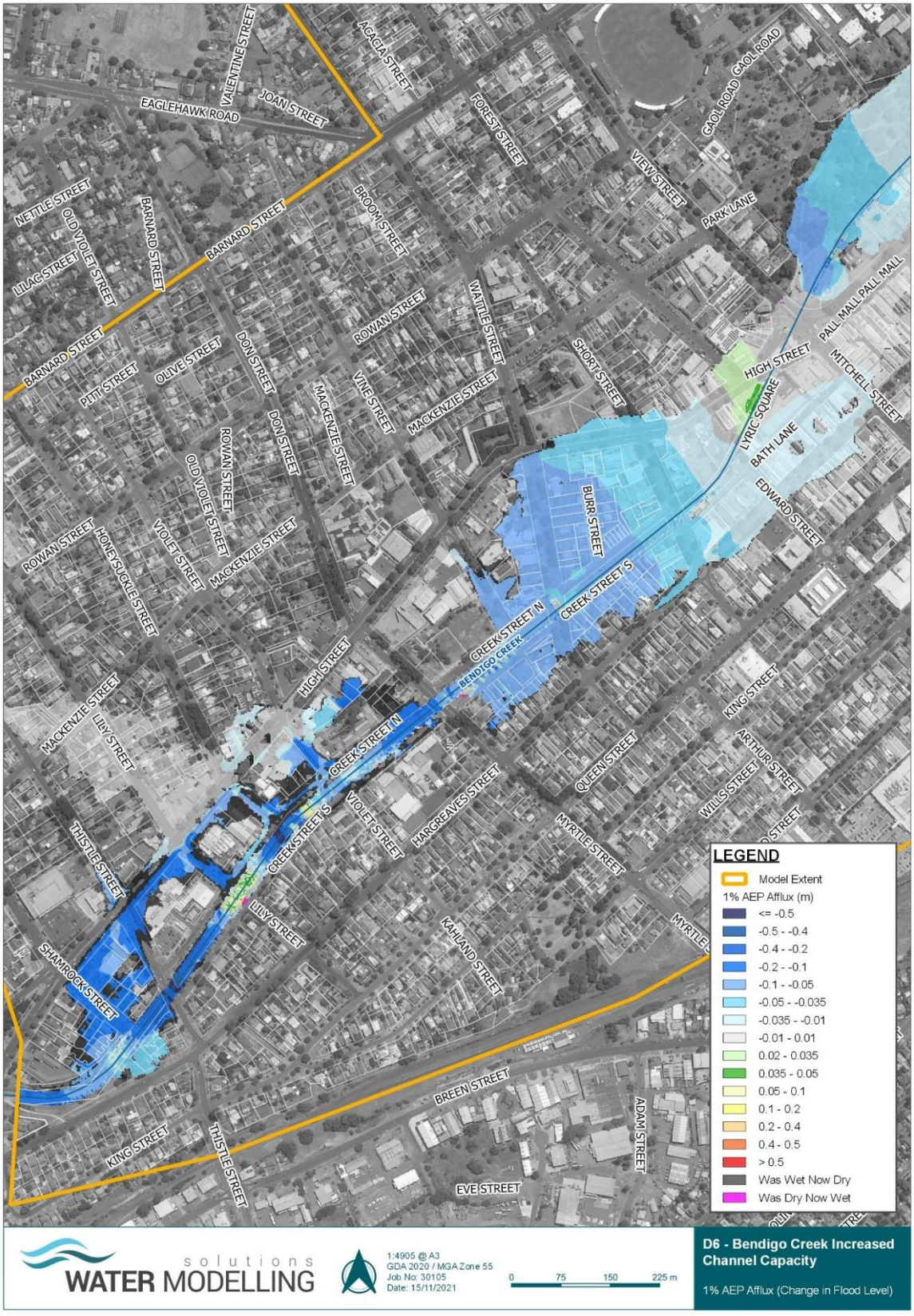

Figure 4-27 Option D6 - 1% AEP Afflux Height (South)

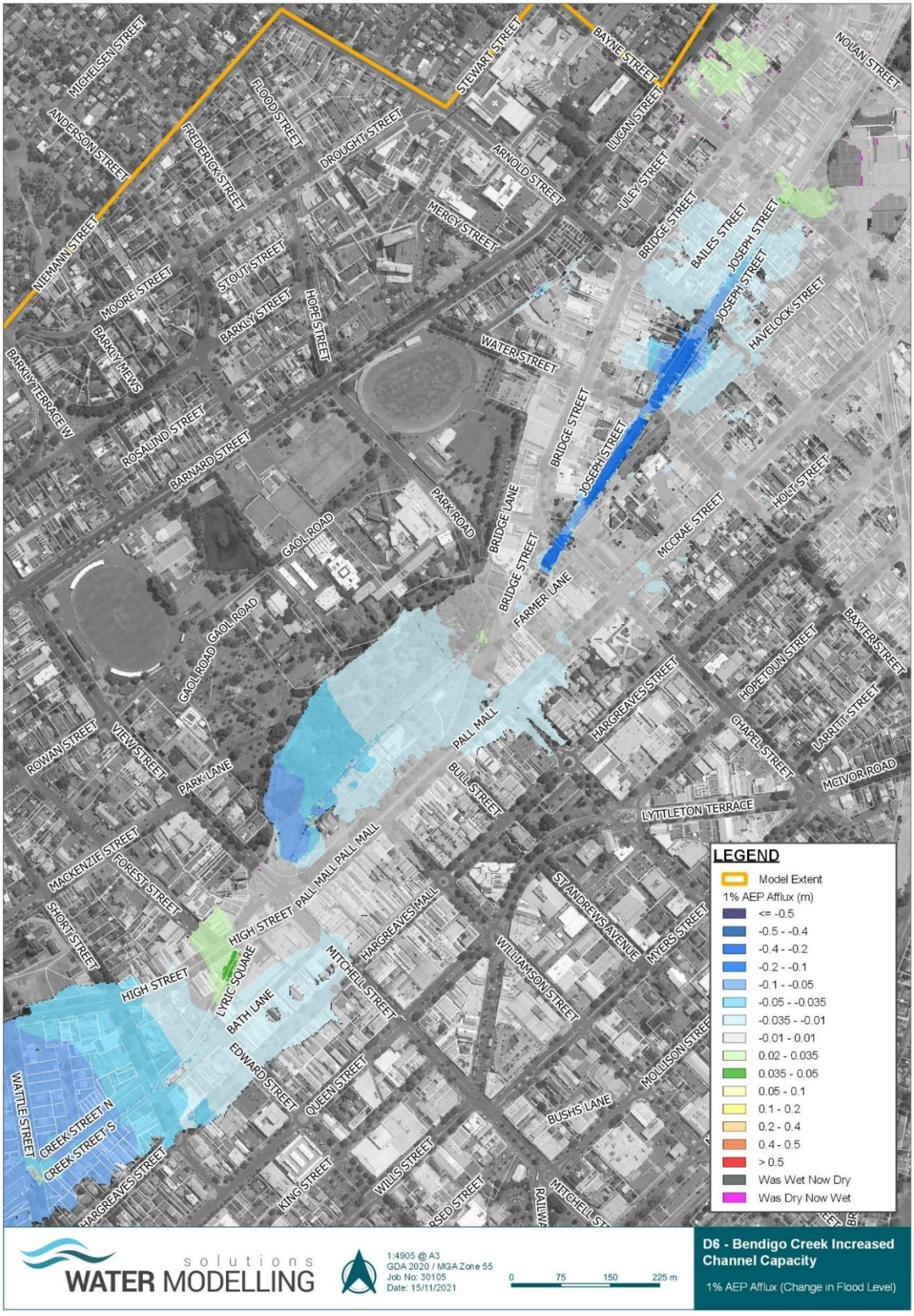

Figure 4-28 Option D6 - 1% AEP Afflux Height (North)

Figure 4-29 Option D6 - 10% AEP Afflux Height (South)

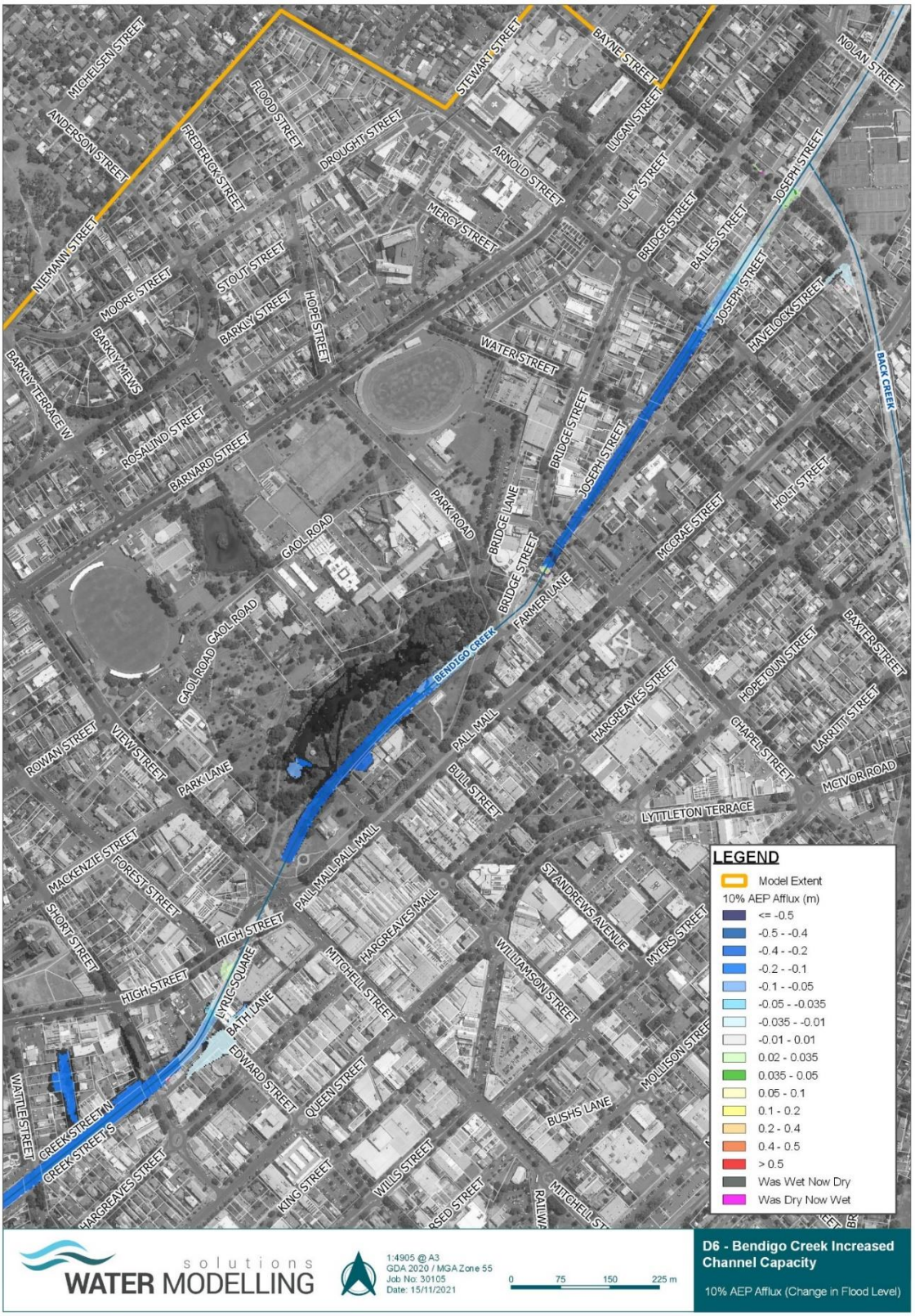

Figure 4-30 Option D6 - 10% AEP Afflux Height (North)

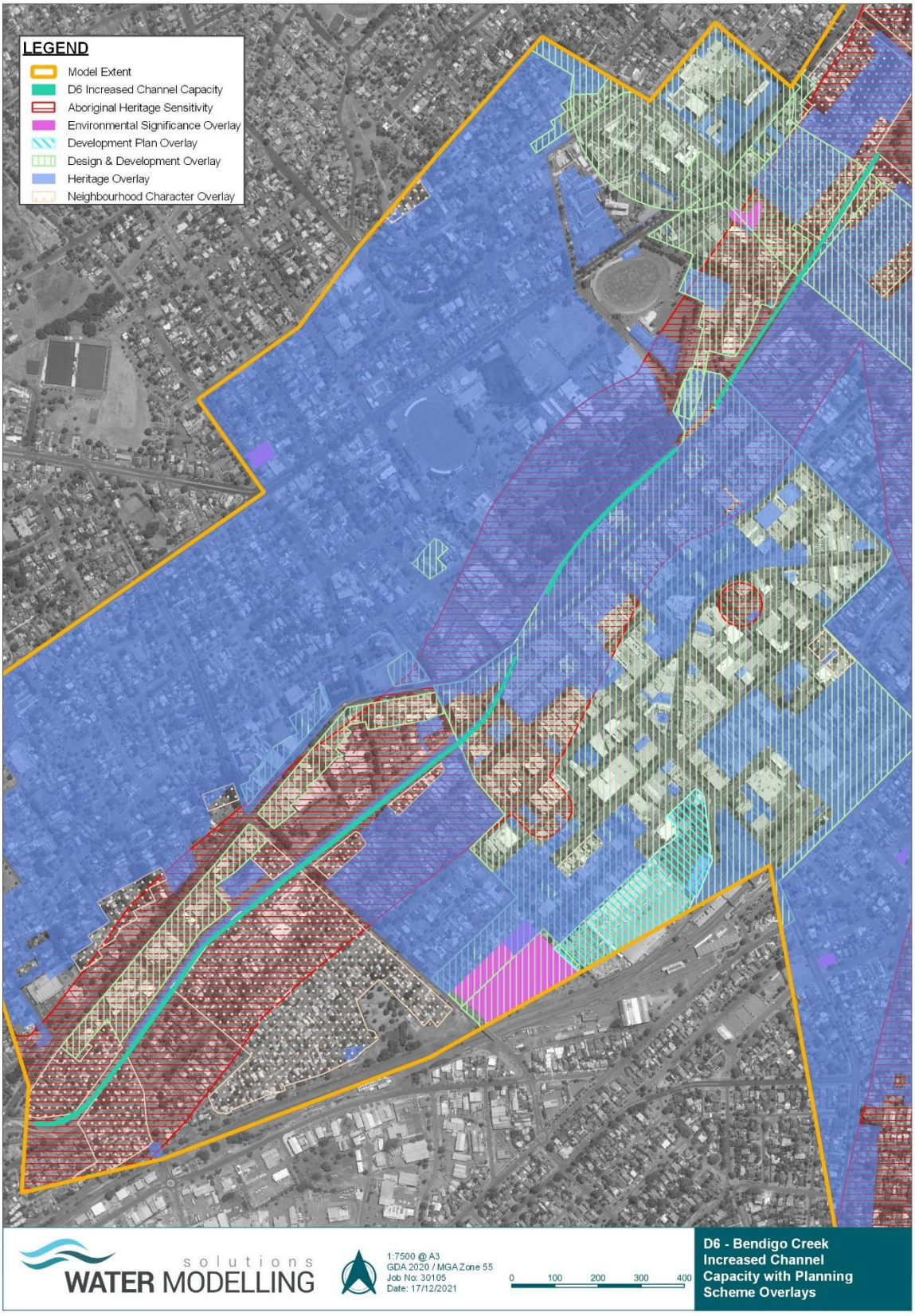

Figure 4-31 Option D6 - Heritage Overlays

5 FEASIBILITY DISCUSSION

5.1 DAMAGES ASSESSMENT

The damages assessment shows that a number of mitigation options achieve a significant impact in reducing flood damages and Average Annual Damage (AAD) through the study area. Mitigation Option D2 achieves the least reduction, whilst Option D3 and D4 achieves the greatest reduction. A summary of the AAD for existing conditions and each mitigation package is shown in Table 5-1. The three options with the greatest reduction in AAD are shown in bold.

The damages assessment for the mitigation options has been compared to the damages assessment for existing conditions which is summarised below, in order to understand the benefit in terms of the reduction in average annual across the range of design events.

Table 5-1 Mitigation Options AAD Summary

Options	Average Annual Damage	Reduction in AAD
Existing Conditions	*$1,903,903*	
Option D1	**$1,765,670**	**$138,233**
Option D2	$1,903,895	$28,715
Option D3	**$1,617,297**	**$286,606**
Option D4	**$1,696,305**	**$207,598**
Option D5	$1,867,929	$35,974
Option D6	$1,875,188	$1,903,903

5.2 BENEFIT COST

A benefit-cost analysis has been undertaken based on the damages assessment and costings described tin the previous sections and is exclusive of engineering and administration fees. The results are summarised in Table 5-2 below. It can be seen that the Benefit Cost Ratio varies across all options, and two options are below the ratio of 1 which is generally the minimum required for a scheme to be considered to have strong feasibility i.e., for every dollar spent on the scheme, at least a dollar is saved in terms of reduced flood damage. The analysis assumes 50-year design life for all works.

The three strongest options show BCRs of 6,89, 4.02 and 3.54, which are all considered very high for flood mitigation works, and indicative of exceptionally strong feasibility.

The three options with the highest benefit-cost ratio are shown in bold in the table below.

Table 5-2 Cost Benefit Ratio Summary (assumes 50-year design life)

Levee Option	Capital Cost Estimate	Annual Maintenance	Reduction in AAD	Benefit			Benefit Cost Ratio		
				11% NPV	7% NPV	4% NPV	11% NPV	7% NPV	4% NPV
Option D1	**$270,901**	**$4,064**	**$138,233**	**$1,216,127**	**$1,865,809**	**$2,918,569**	**4.49**	**6.89**	**10.77**
Option D2	$327,275	$4,909	$28,715	-$44,424	-$68,157	-$106,613	-0.14	-0.21	-0.33
Option D3	**$942,747**	**$14,141**	**$286,606**	**$2,469,651**	**$3,788,992**	**$5,926,887**	**2.62**	**4.02**	**6.29**
Option D4	**$771,043**	**$11,566**	**$207,598**	**$1,776,859**	**$2,726,096**	**$4,264,263**	**2.30**	**3.54**	**5.53**
Option D5	$1,575,204	$23,628	$35,974	$111,905	$171,687	$268,559	0.07	0.11	0.17

Levee Option	Capital Cost Estimate	Annual Maintenance	Reduction in AAD	Benefit			Benefit Cost Ratio		
				11% NPV	7% NPV	4% NPV	11% NPV	7% NPV	4% NPV
Option D6	$3,739,138	$56,087	$1,903,903	-$248,103	-$380,646	-$595,421	-0.07	-0.10	-0.16

It is noted that Option D1 has the highest benefit cost ratio with a BCR of 5.89 (assuming 7% NPV). Option D3 has the second highest benefit cost ratio with a BCR of 4.02 (assuming 7% NPV), while also providing the second largest reduction in AAD.

Intangible damages have also been included as part of this assessment and relate to the social cost of flooding and are much more difficult to quantify. Intangible damages include the impacts of isolation, disruption to family, physical ill-health and psychological ill-health. Intangible damages have been assumed to be of an equal value to tangible damages within each assessment, which is consistent with Melbourne Water damages assessment methodology.

5.3 COMMUNITY SUPPORT

5.3.1 Summary of Second Round Community Consultation

The second round of community consultation occurred over a 5-week period from the 16th of November to 20th December 2021. It included the following:

- A survey in both hard-copy and online format which asked for feedback on suggested mitigation options. These have been collated in a spreadsheet which is included in Appendix C.
- An online mapping portal which presented the locations of the 6 mitigation options
- An in-person workshop as well as an online workshop the following week,

Statistics of the first consultation round are summarised in Table 5-3.

Table 5-3 Second Round Consultation Results

Direct Communication Emails	Approximately 160 emails
Flyer Distribution/One-One Conversations	19 local businesses
Letterbox Drop	Approximately 5,000 properties
Social Media Reach	Approximately 7,400
Media Responses	1 x Newspaper articles, 1 x radio interview
Pop up Engagement Sessions	20 face to face conversations with community members
Workshop Registrations	24 (In Person) & 27 (Online)
Workshop Attendance	17 (In Person) & 13 (Online)
Survey Responses	19

5.3.2 Consultation Results

The results of the detailed mitigation modelling were presented to the community during the second round of consultation within the face to face and online community consultation sessions. Responses taken from the online survey, paper survey and comments from both the online and face to face workshops of the options are summarised in Table 5-4. It is noted that Options D1, D3 and D4

all had the strongest community support, which mirrors the strong feasibility of these three options found in the benefit-cost analysis.

Table 5-4 Summary of Community Feedback on Proposed Mitigation Options

Option ID	No. of positive responses / show of support	No. of negative responses / opposition
Option D1	10	-
Option D2	2	1
Option D3	12	-
Option D4	9	-
Option D5	3	1
Option D6	2	3

Option D3 was the most well-received mitigation option with a total of 12 positive responses. Community was most concerned with impacts to heritage from removal of bluestone paving, potential for increase flood volumes due to increased creek capacity as well as some opposition to construction of levees.

6 SUMMARY AND RECOMMENDATIONS

Based on the analyses completed within this report as well as community feedback, the following options should be considered for further investigation and could be combined into a single, staged mitigation scheme at an overall cost of approximately $2.15 million:

- Option D1 - Increased Creek Capacity and Levee in Back Creek downstream of McIvor Road
- Option D3 - Increased Capacity of Back Creek from McIvor Road to Confluence of Back Creek and Bendigo Creek
- Options D4 - Increased Capacity Underneath Bridges in Back Creek and Bendigo Creek

All three options above had a high benefit-cost ratio, strong support from the community with no opposition and all resulted in a significant reduction in Average Annual Damages (AAD) as outlined in Table 6-1.

To fully understand the net benefit and impacts of the above options combined together into a single mitigation scheme, it is recommended that the options be modelled jointly within one scenario.

It is also recommended that, because assumed floor level were adopted for the purpose of this study, in order to improve the damages and benefit-cost assessment, a floor level survey of properties which are impacted and benefit from the proposed works should be completed. Additionally, a feature and topographical survey along the alignment of the proposed works to further improve the feasibility assessment from a constructability perspective. These could be undertaken as part of the next stage of design.

Table 6-1 Recommended Options- Analysis Summary

	Community Support/Community Opposition	Benefit Cost Ratio (7% NPV)	Reduction in AAD	Overall Cost
D1	10/0	6.89	$138,233	$312,577
D3	12/0	4.02	$286,606	$942,747
D4	9/0	3.54	$207,598	$889,665

7 REFERENCES

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

Water Technology (2013). Bendigo Urban Flood Study Report, prepared for City of Greater Bendigo

Water Modelling Solutions (2019), Kangaroo Flat Golden Square Flood Mitigation Study Report, prepared for City of Greater Bendigo.

Water Modelling Solutions (2021), Central Bendigo Flood Study – Template Report, prepared for City of Greater Bendigo.

Water Modelling Solutions (2021), Central Bendigo Flood Study – Mitigation Summary Report, prepared for City of Greater Bendigo.

APPENDIX A

EXISTING CONDITIONS –FLOOD MAPS

APPENDIX B

CLIMATE CHANGE – 1% AEP FLOOD MAPS

APPENDIX C

COMMUNITY CONSULTATION SUMMARY

C.1 FIRST ROUND OPTIONS AND COMMENTS SUMMARY

The following table summarises comments and suggested options from the online community consultation workshops, online and hard copy survey forms as well as mitigation options suggested within a workshop between project personnel. Additional notes for each of the mitigation options can be found in

Note: Option ID's beginning with 'M' denote a mitigation options and Option ID's beginning with 'C" denote a general comment.

Table C- 1 First Community Consultation Feedback Summary

Option ID	Option Details	Source of the Idea
M1	Clean out the creek from White Hills to Epsom	Community (Online Export 20210714)
M2	Renaturalisation of whole length of Back Creek	CoGB
M3	Revegetate and develop the Bendigo Creek and surrounds and feeder waterways with more natural based pond retention and reeds holding up / slowing down water and creating lovely environments, cooler spaces with greenery and water and habitat for fauna.	Community (Online Export 20210813)
M4	Removal of all bridges	CoGB
M5	1 x bridge removal	WMS
M6	1 x bridge removal	WMS
M7	Removal of bridge at McIvor Road intersection	WMS
M8	Channel widening at constrictions (i.e., increase depth under bridges to depth of invert of low channel)	CoGB
M9	Increased bridge heights	Community (Online Export 20210714)
C10	Consider the whole system not just central	Community (Online Export 20210714)
M11	Repair this area (41 High Street), allow water to flow and escape	Community (Online Export 20210714)
C12	Stop COGB approval of fill works in floodway areas	Community (Online Export 20210726)

Option ID	Option Details	Source of the Idea
M13	Reinstating Coliban water race behind all properties abutting GBNP to slow water down from entering properties, or construction of proper drainage systems. I have spent $20k to try and reduce the risk of flooding to my property.	Community (Online Export 20210809)
C14	Maintenance of storm water infrastructure, retention and detention basins do decrease the community's concerns about flooding. Proactive works with long term benefits have been what locals are very happy with.	Community (Online Export 20210813)
M15	reduce run off in the catchment areas with the use of dams, porous surface paving, public awareness and by charging an extra fee for those building or paving in the catchment area.	Community (Online Export 20210813)
M16	Inlets in Atkinson Street reconfigured and enlarged	Community (Online Export 20210820)
C17	I would like to see council doing more with mitigating direct storm water drainage connection the creek. Slowing the inputs at many small points will possibly limit larger impacts downstream	Community (Online Export 20210820)
M18	Remove any flow restrictions within the Bendigo Creek e.g., at bridges etc.	Community (Online Export 20210820)
M19	Increase creek capacity downstream by clearing/shaping creek.	Community (Online Export 20210820)
M20	Utilise storage capacity (4 million cubic metres) downstream of Leans Rd if mining approval granted.	Community (Online Export 20210820)
M21	Return creek to chain of ponds waterway effect	Community Consultation (20210810)
C22	I'm wondering if purchasing property & creating water retention within this study area has been considered. There's rather a lot of high value land that's blue on the map. I'm thinking large scale water retention devices with dams that would be kept empty until there's a flood event, with floodgates to hold back high water. Issue would be buying old properties with the intent to demolish them in favour of a creek level paddock in the CBD. Expensive and unpopular but would help - if enough could be bought.	Community Consultation (20210810)
M23	What about raising the walls? Flood levees to Huntly. Flood levee as high/low bike/walk paths	Community Consultation (20210810)
M24	Lower Rosalind Park.	Community Consultation (20210810)

Option ID	Option Details	Source of the Idea
M25	The bluestone floor has ground water seepage and the concrete walls in some locations are in poor condition. would replacing the floor and battering the walls give more protection against possible flooding.	Community Consultation (20210810)
M26	Could you consider deepening the creek and revegetating to create further cross section and space for flood waters?	Community Consultation (20210810)
M27	Could large pipes be placed under the creek that are designed to take high flow deeper down (possibly into old mines?)	Community Consultation (20210810)
M28	Would you consider the old gas works to be another retention basin?	Community Consultation (20210810)
C29	Pumps or Lochs	Community Consultation (20210817)
M30	Crusoe Reservoir needs to be bigger	Community Consultation (20210817)
C31	Gets out but can get back into the creek?	Community Consultation (20210817)
M32	Increasing Creek Capacity particularly through constrained areas	Community Consultation (20210817)
M33	Looking at opportunities to get water back into the creek once it's broken out. Pipe upgrades? Road regrading?	Community Consultation (20210817)
M34	Consider impact of levees and their location, can we locate them to minimise adverse impacts	Community Consultation (20210817)
M35	Levee near Shamrock St to prevent breakout	Community Consultation (20210817)
M36	Long breakout along Bridge St and back into creek via Arnold and Bailes St, any opportunities to assist water back into creek.	Community Consultation (20210817)
M37	Upstream storage or basins on Back Creek	Community Consultation (20210817)
C38	Improved planning overlays to limit cumulative fill as development occurs	Community Consultation (20210817)
M39	New stormwater drainage diversion drains	Hard Copy Survey

Option ID	Option Details	Source of the Idea
M40	Increase capacity under bridge south of McIvor Road Bridge	WMS
M41	Storage basin in southern corner of parcel near tram depot (i.e., south of stormwater pipe)	CoGB
M42	Combination of Storage basin at tram depot + levee near Baxter Street	CoGB
M43	Increase depth of eastern side of Back Creek to invert of low flow channel from McIvor Street to the confluence of Back Creek and Bendigo Creek. Lowered surface to be lined.	CoGB
M44	Enlarging Thistle Street Basin	WMS
M45	Build up northern side of open drain near Peppergreen Farm (on Bendigo Creek near Thunder Street)	WMS
M46	Increase capacity of low flow channel with naturalised scenario	CoGB
M47	Diversion pipe from Laritt Street down Baxter Street into Hopetoun Street (i.e., no direct connection from Laritt to Back Creek to mitigate localised flood depths due to pipes surcharging)	CoGB
M48	One-way valves along Laritt Street to resolve localised flooding	WMS
M49	Back Creek Levee 1: Levee on eastern side of Back Creek near Havlin Street East to mitigate inundation of Business and apartment blocks along Back Creek	WMS
M50	Back Creek Levee 2: Localised levee protection south of McIvor Road on eastern side of Creek	WMS
M51	Back Creek Levee 3: Localised levee protection south of McIvor Road on Western side of Creek	WMS
M52	Back Creek Levee 4: Flood wall on western side of Back Creek to protect properties on Baxter Street	WMS
M53	Back Creek Levee 5: Eastern side of Creek south of Hargreaves Street	WMS

Option ID	Option Details	Source of the Idea
M54	Back Creek Levee 6: Eastern side of creek between Hargreaves and McCrae	WMS
M55	Back Creek Levee 7: Western side of creek between Hargreaves and McCrae	WMS
M56	Back Creek Levee 8: Localised flood wall north-eastern side of tram crossing at Hopetoun Road	WMS
M57	Back Creek Levee 9: Flood wall/levee on eastern side of creek north of Napier Street	WMS
M58	Back Creek Levee 10: Flood wall/levee on western side of creek between McCrae Street and Havelock Street	WMS
M59	Back Creek Levee 11: Flood wall/levee on western side of creek between Havelock Street and creek confluence	WMS
M60	Bendigo Creek Levee 1: Northern side of creek at Shamrock Street	WMS
M61	Bendigo Creek Levee 2: Southern side of creek upstream from Thistle Street Bridge	WMS
M62	Bendigo Creek Levee 3: Northern side of creek from Wattle Street to Myrtle Street	WMS
M63	Bendigo Creek Levee 4: Southern side of creek from Wattle Street to Myrtle Street	WMS
M64	Bendigo Creek Levee 5: Southern side of creek from Short Street to Edward Street	WMS
M65	Bendigo Creek Levee 6: Northern side of creek from Short Street to Edward Street	WMS
M66	Bendigo Creek Levee 7: Northern side of creek from Edward Street to High Street	WMS
M67	Bendigo Creek Levee 8: Southern side of creek from Charing X to Sidney Myer Place	WMS
M68	Bendigo Creek Levee 9: Northern side of creek from Charing X to Sidney Myer Place	WMS
M69	Bendigo Creek Levee 10: Southern side of creek from Sidney Myer Place to William Vahland Place	WMS

Option ID	Option Details	Source of the Idea
M70	Bendigo Creek Levee 11: Northern side of creek from William Vahland Place to Park Road	WMS
M71	Bendigo Creek Levee 13: Southern side of creek between Baxter and Arnold Street	WMS
M72	Bendigo Creek Levee 14: Northern side of creek between Baxter and Arnold Street	WMS
M73	Bendigo Creek Levee 15: Southern side of creek between Arnold Street and Bayne Street	WMS
M74	Bendigo Creek Levee 16: Northern side of creek between Arnold Street and Bayne Street	WMS
M75	Bendigo Creek Levee 17: Southern side of creek between south of Nolan Street	WMS
M76	Bendigo Creek Levee 18: Northern side of creek north of Nolan Street to No. 132 Bridge Street	WMS
M77	Bendigo Creek Levee 19: Northern side of creek from No. 132 Bridge Street to Gas Works	WMS
M78	Bendigo Creek Levee 20: Northern side of creek from Nolan Street to Gas Works (M76 + M77)	WMS
M79	Park Road Levee: Western side, north of Creek to prevent overland flows going north	WMS
M80	Bayne Street Levee: Northern side of Bendigo Creek to prevent overtopping of Creek	WMS
M81	Roughness Sensitivity: Adopt Mannings of 0.04 north of Weeroona Avenue on Bendigo Creek	CoGB
M82	Increase capacity of low flow channel for full length of Bendigo Creek	CoGB

C.2 SECOND ROUND COMMUNITY FEEDBACK

The following table summarises comments and feedback from the online survey as well as hard copy surveys received within the face to face community consultation and pop up sessions.

Table C- 2 Second Community Consultation Feedback Summary

ID	Which of these options do you support? Please list them and provide any reasoning as to why you support them.	Are there any options which you are opposed to? Please list them and if possible include why you are opposed to them.	Are there any options that have not been considered which you feel should have been?	Is there any other feedback you would like to provide regarding the study?
1	I fully support options D1, D3 and D4. Not only will they help protect my property but they appear to be good value for the protection they provide to many properties. Also being on Back creek this will cause very limited disturbance to Bendigo.	While i hope that all of the options get completed this will be unlikely, Options D5 and D6 provide good benefit but they are costly and working through town will be difficult and hard on the city during the works. Also bluestone is such a great feature	No, options are comprehensive	Good study, great to see some more work being completed on flooding in Bendigo. I really hope to see some or all of these projects go ahead before we get another significant event.
2	I support options D1, D3 and D4 these will help protect my neighbourhood. I use the creek walking track daily and all these options provide protection while keeping the walking track.	The bluestone in the creek is beautiful and if work is to be done it needs to be redone.		
3	D1, D3 and D4		No	No
4	D1, D3, D4			
5	D1 D3 D4	Reduce flood risk		
6	Option 3 for me personally would be better. I also think down from the lake would benefit a big clean out	No. If it is better for everyone it's okay.	Clean out downstream	From McCrae Street to foot bridge near back of tennis courts needs wall put up
7	Nil	All options submitted will only create more flooding problems downstream	I feel that the best option would be to start downstream form Epsom and remove any obstructions or high points in the creek to allow the flow to be unrestricted therefore allowing some of the options to work without creating additional flooding downstream from Back Creek Junction	The solution is to treat the problem as a complete package and not little spot fires
8	Nil support for options 1-6	A holistic approach is needed to address the flood issues. By trying to fix in segments only causes issues somewhere else	Get the creek flowing properly further downstream i.e. Epsom, Huntly and beyond and the bulk of Central Bendigo flood issues with addressed along with proper regular maintenance by council as a backup	Bandaid approach will not work. The creek needs to be looked at in its entirety to not temporarily fix one problem only to create another further downstream.

ID	Which of these options do you support? Please list them and provide any reasoning as to why you support them.	Are there any options which you are opposed to? Please list them and if possible include why you are opposed to them.	Are there any options that have not been considered which you feel should have been?	Is there any other feedback you would like to provide regarding the study?
9	I prefer solutions with low visual impact and that do not affect access to the creek. Because of this, I prefer D3-lowering the eastern side of Back Creek to the level of the existing low flow drain. I don't like levees.			Living next to Back Creek and across from the tram depot, I am concerned about the depot's expansion next year onto the area behind that is currently regularly subject to inundation from Back Creek. Without substantial mitigation in addition to what is proposed, this expansion will push extra water from Back Creek onto surrounding residential properties. So I hope this is also taken into account in short-term strategies being considered.
10	None of the options assist downstream of Bayne St, other than D4 which only helps to reduce water across the bridges themselves.	None opposed, they are ok for Back Creek and upstrem form Bayne St (Bendigo Creek). Issue is that no proposed options will assist my address.	1) Increase flow downstream from Howard St. This will reduce 'Back-up'. 2) Reduced development upstream => less run off	IS there consideration for piping outflow from Back Creek From junction with bendigo Ck up past Howard Street
11	None at this stage	All, because it will only create more problems further downstream.	The problem needs fixing downstream before you start upstream	you are trying to put the "cart before the horse"with your proposals.
12	All options appear to address specific bloackage points at various locations within the bendigo and back creeks but has not acknowledged the build up of water downstream of bendigo that prevents water from escaping	Yes option D5 and D6. Increased capacoty to hold more water within the creeks does not increase the flooding creeks ability to effectively deal with flood water. There is no overflow management plan offered to indicated hwo theincreased water volume is abel to flow through the creek and effectively escape downstream of Bendigo.	Increased capacity to hold more water does not assist the bendigo Creek to effectively drain its flooding water.	Re: Bendigo Creek and Back Creek junctions: all current options are suggesting increasing capacty and flow upstream of the bendigo and Back creek are a solution to flooding dangers? No options have acknowldged the impact that a greater flow of water wull cause at this junction. Nor is there acknowldgement or plan identified to suggest how this increased volume of floodwater will be able to escape downstram of this junction. The areas downstream from junction do not have capcity to absorb current flooding - increasing water capacity upstream will not solve the problem.
13	Whichever option will benefit Lucan street area	options appear to not benefit my area (Lucan Street)	Unfortunatly my background is not engineered focus, however reviewing drainage and infrastructre in my area would be an option	

ID	Which of these options do you support? Please list them and provide any reasoning as to why you support them.	Are there any options which you are opposed to? Please list them and if possible include why you are opposed to them.	Are there any options that have not been considered which you feel should have been?	Is there any other feedback you would like to provide regarding the study?
14	I do not support any of the 6 options.	They do not offer any mitigation of flooding around the convergence of bendigo /back creek.	The council needs to start at epsom & Huntly and take action to properly clear and maintain the banks of the creek to allow the flood water to drain.	Sectioning the study into separate pieces will only slow the decision making process. Council should allocate annual funding for flood mitigation as the problem is only going to get worse with the ongoing building of residentsces around the catchment area.
15	None	N/A	I feel that the Creek/s need to be looked at as a whole otherwise the flooding problem will continue to be a problem, just in a different area.	If debris is removed on a regular basis it will alleviate the possibility of flooding of the creek.
16	They do not appear to assist this area	Have looked clearly and they appear to add to the flooding downstream.	Previously discussed, limiting further development in this area. Increasing the flow downstream and continuing maintenance regularly.	Reviewing the downstream area needs to be a priority to start.
17	d2, d1		Getting rid of as much water as possible from lake weerona area so bendigo creek is as free as possibe to run uninterupted.	
18	D1, D3, D4, D5. Combine with beautification, urben developments, walking and cycling seperated paths.	D2- Not effective. D6- Heritage and general impact. Too costly.	Combine with urban development where lowered floodplain can be incorporated into development (Med density)	Great Session Thanks. A difficult area to address due to confined space.
19	D3- in combination with a 'renaturalisation' approach. D6- in combination with Reim Bendigo Creek principles	Substancial Levees		
20	Option 3		Continous, ongoing clearing of "debris"of bendigo Creek beyond ….	….. Need to be controlled. Failure ….. critical drainage propsals are adequate & not add to existing problem
21	All. Start with the one that protects the most properties first. And prioritise accorindingly. Priority: D4, D3, D6, D5, D1, D2	None. All need implementing!	Lowering the entirety of the creek bed.	WaterS]shed drainage needs improving so that fewer roads are inundated.

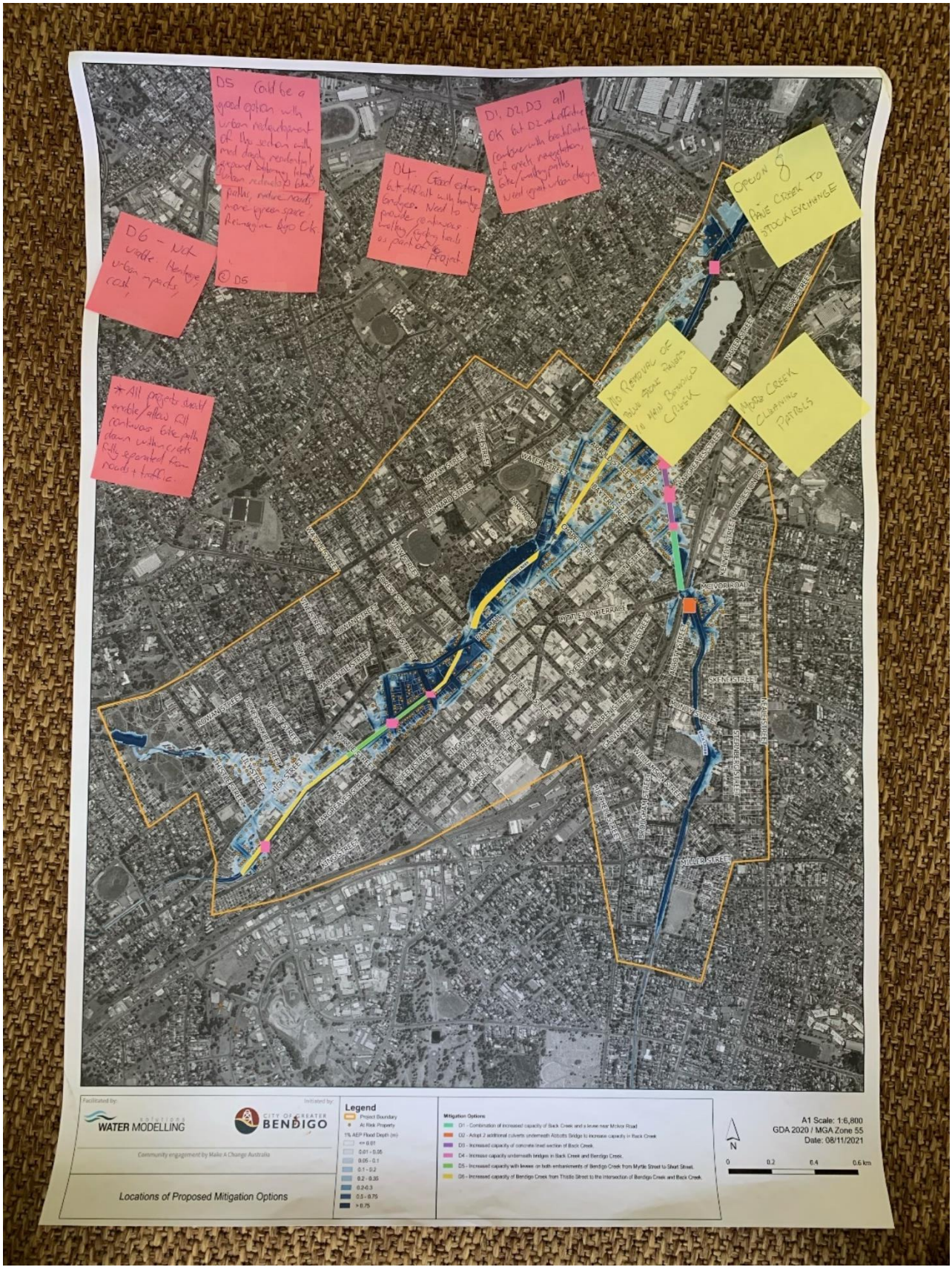

Figure C- 1 Consultation Workshop Comments – Group 1

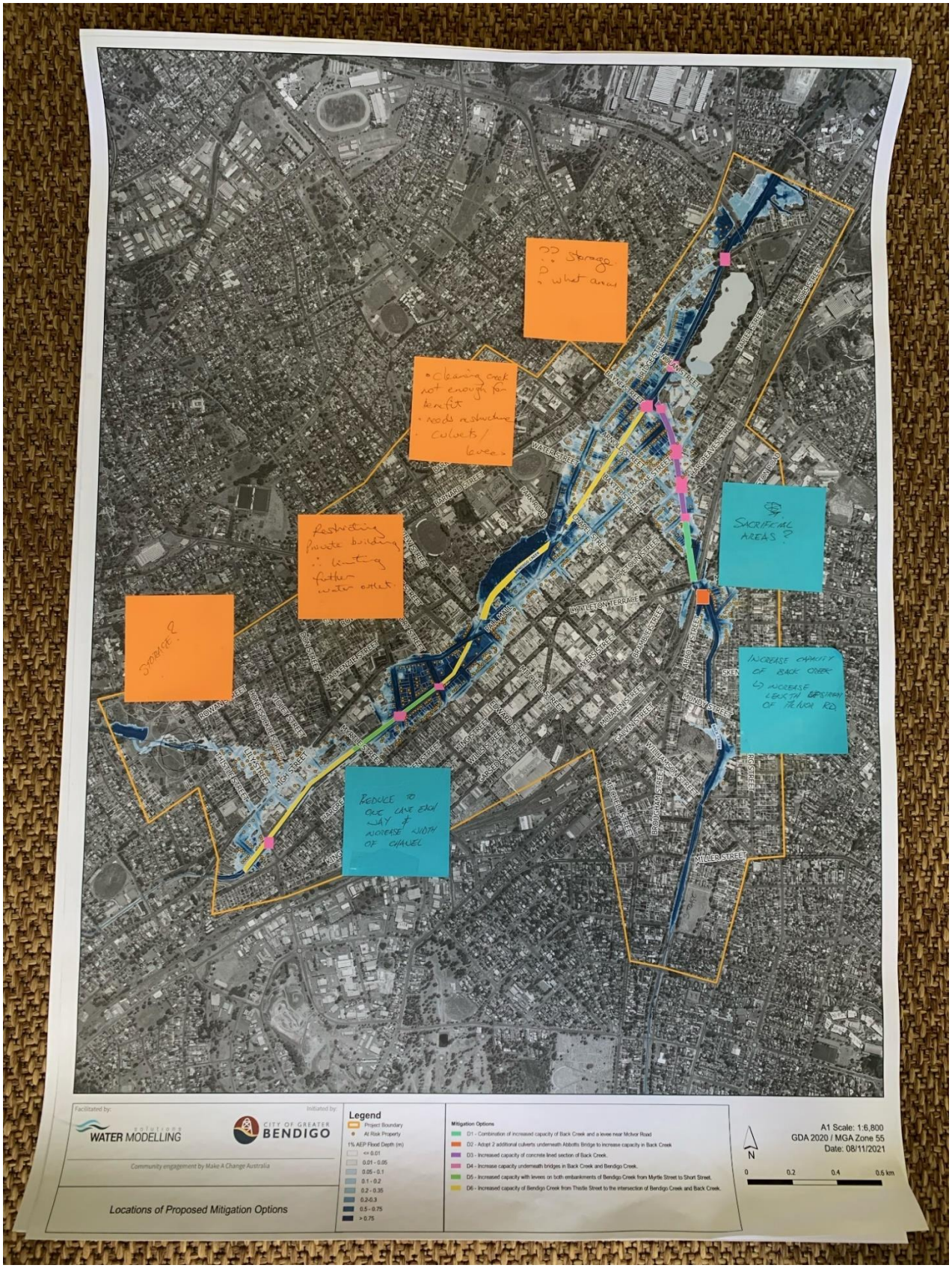

Figure C- 2 Consultation Workshop Comments – Group 2

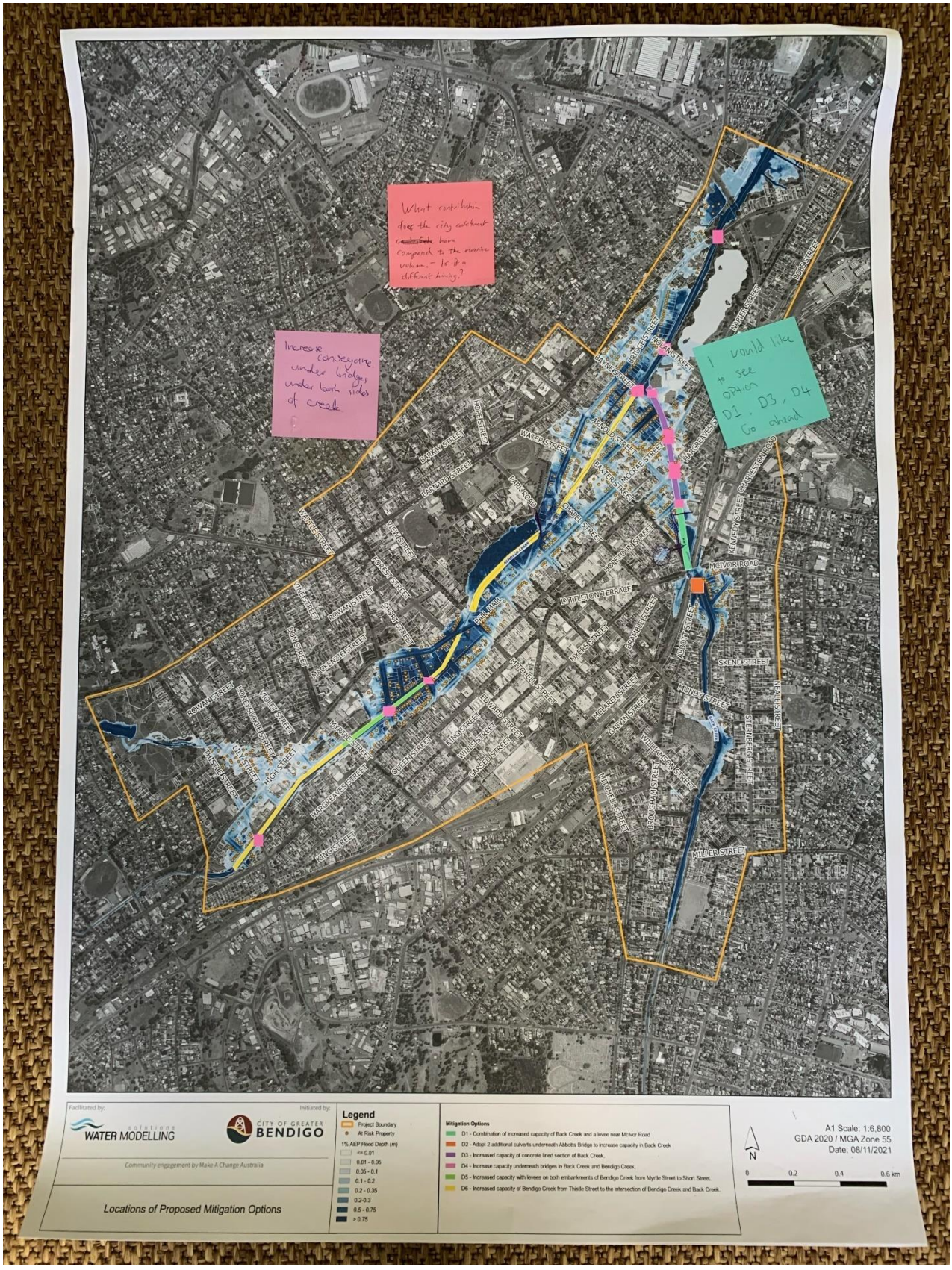

Figure C- 3 Consultation Workshop Comments – Group 3

APPENDIX D

MITIGATION OPTIONS – CONCEPT PLANS

APPENDIX E

MITIGATION OPTIONS – FLOOD MAPS