

Costs and benefits of climate adaptation for council-owned roads in Greater Melbourne

Adaptive Community Assets (Phase 3)

August 2025



Natural Capital
Economics



Natural Capital Economics, part of the Alluvium Group recognises and acknowledges the unique relationship and deep connection to Country shared by Aboriginal and Torres Strait Islander people, as First Peoples and Traditional Owners of Australia. We pay our respects to their Cultures, Country and Elders past and present.

Artwork by Melissa Barton. This piece was commissioned by Alluvium and tells our story of caring for Country, through different forms of waterbodies, from creeklines to coastlines. The artwork depicts people linked by journey lines, sharing stories, understanding and learning to care for country and the waterways within.

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Executive Summary

The Adaptive Community Assets project aims to develop high-level estimates of the costs and benefits of adapting council assets in Greater Melbourne to the impacts of climate change. Phase 3 (this report) of the project focuses on council roads. It examines the costs of adapting these assets to the climate hazards of bushfires, coastal and inland flooding, and heatwaves. It also evaluates the benefits by estimating the value of damages that could be avoided through adaptation.

The analysis finds that climate-related damages to roads are expected to increase significantly over time. Under a “do nothing differently” scenario, average annual damages could potentially triple by 2100.

The economic viability of various adaptation options was assessed based on the benefits of avoided road damage, with many found not to be economically viable on that basis alone. However, the options assessed are expected to deliver additional benefits beyond avoided damage, such as reduced travel costs. As such, a broader assessment that incorporates these benefits is expected to strengthen the case for investment and may result in some options becoming economically viable. This is particularly true in instances where the benefits from avoided damage offset a significant proportion of the overall cost of adaptation.

Furthermore, the results show that benefit-cost ratios generally increase over time. This is driven by the rising value of avoided damages resulting from climate change impacts, relative to the cost of adaptation. This sees the economic justification for investing in adaptation options becoming progressively stronger in the future.

More regular maintenance emerged as a particularly promising strategy for protecting roads from inland flooding. It was found to deliver \$1.1 in benefits for every dollar invested under present day conditions, under the central estimates, with benefits potentially reaching up to \$3 for every dollar spent. These benefits are expected to increase over time.

Upgrading drainage systems at the time of renewal and the use of ground and pavement stabilisation also show potential as economically viable options for protecting roads from inland flooding. The CBA results indicate BCRs ranging from 0.40 to 1.60 for upgrading drainage systems and from 0.39 to 1.48 for ground and pavement stabilisation, in present day. The range in BCR outcomes indicates that there is a need to consider their use on a case-by-case basis to ensure economic viability. These initiatives are expected to already be in use by some councils and can be relatively simple to embed into existing asset management functions.

The results of this study highlight the need for a broader consideration of impacts to strengthen the case for investment. This approach can support more balanced investment decisions, help maximise returns by prioritising options with significant co-benefits, provide support for broader council objectives, and reduce the risk of maladaptation.

The findings also suggest that councils must strike a balance between preparing for long-term climate risks and avoiding unnecessary or premature investments. It is expected that embedding adaptation into existing asset management regimes, where decisions on adaptation investment are aligned with major asset refurbishment and replacement investment will support councils to make well-informed and economically sound adaptation decisions.

Finally, making informed adaptation decisions remains challenging due to limited data, complex hazard interactions, and the difficulty of quantifying indirect and intangible impacts. As a result, councils are likely to require ongoing and increased support to make well-informed adaptation decisions.

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1 Introduction

The Adaptive Community Assets project aims to develop high-level estimates of the costs and benefits associated with adapting council-owned assets in Greater Melbourne to the impacts of climate change. In this context:

- costs refer to the upfront and ongoing incremental expenses of implementing climate adaptation options
- benefits represent the reduction in direct costs incurred by councils due to climate-related impacts
- the impacts of climate change are defined as changes in the frequency and severity of climate hazard events—specifically bushfires, heatwaves, inland flooding, and coastal flooding¹ projected for both the near future (~2050) and the distant future (~2100).

The project has been undertaken in phases, including:

- Phase 1—the development of a cost-benefit analysis (CBA) framework for councils to use to assess the net-benefit of investing in climate adaptation options.
- Phase 2—implementing steps 1 to 3 of the CBA framework to provide a “first pass” assessment of the value of direct damages from climate hazards to council owned assets (buildings, roads, drainage, natural assets, and built assets in open space) across Greater Melbourne, without adaptation (i.e. the base case or “do nothing differently” scenario).
- Phase 3 (this report)—implementing steps 4 and 5 of the CBA Framework to develop high-level estimates of the costs and benefits of adapting the roads owned by the 32 councils in Greater Melbourne. This phase focuses specifically on the benefits of avoided direct damage costs.

The CBA Framework and reports from the previous phases of the project are available on the Eastern Alliance for Greenhouse Action’s (EAGA) website (www.eaga.com.au/projects/adaptive-community-assets/).

An overview of the CBA Framework is provided in Figure 1.

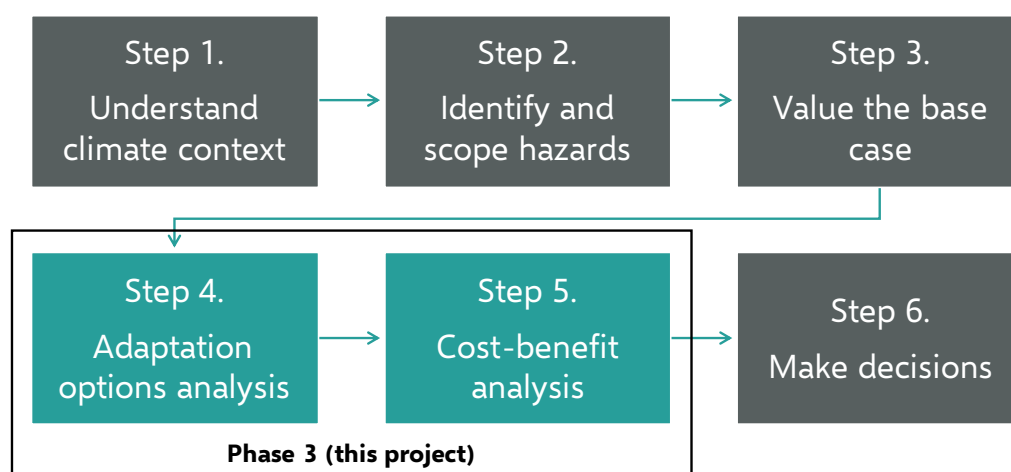


Figure 1. Overview of the Cost-Benefit Analysis Framework, including scope of phase 3

¹ Includes temporary inundation from storm-tide inundation and permanent inundation from sea level rise.

2 Approach

The CBA Framework provides a structured approach for councils to use to evaluate and compare climate adaptation initiatives. In a CBA, the total benefits of an initiative are weighed against the total costs, in monetary terms, to determine the overall net-benefit. CBA is the preferred economic assessment approach of the Victorian Government for evaluating initiatives as part of developing business cases (DTF, 2013).

To facilitate the use of CBA, the CBA Framework includes references to risk and adaptation analysis, which forms an input into the CBA. In addition, the CBA Framework provides resources which can be drawn on to complete the CBA, where there are information gaps or insufficient detail available. An overview of the components of the CBA Framework are shown in Figure 3.

What does this phase of the project cover?

This phase of the project (phase 3) focuses on implementing steps 4 and 5 of the CBA Framework for adaptation options related to road assets. It also incorporates revisions to step 3 for road assets, where newer or more detailed information has become available since the previous phase of the project was undertaken.

2.1 Step 3: Develop and value the base case

The base case represents the outcome if climate change adaptation is not implemented (i.e. the status quo or business-as-usual) It also provides a “do nothing differently” scenario against which adaptation initiatives can be assessed. For the project, the base case reflects direct tangible damages to assets (i.e. damage to assets and the cost of repair). Indirect tangible and intangible impacts have not been incorporated.

Under the base case, damages to council assets are quantified in terms of average annual damage (AAD), which reflects the average damage per year that would occur over a very long period. This approach is like how insurance companies value risk and takes account of the fact that damages from climate hazards will differ from year to year. AAD estimates are calculated for each of the three planning horizons of present day, nearer future (~2050), more distant future (~2100). The nearer future planning horizon was chosen to assist with immediate decision making (e.g. asset adaptation) as many policies and projects are evaluated over timeframes of less than 30 years. The more distant future scenario was chosen to illustrate how the severity of climate change impacts may increase over time with increasing concentrations of greenhouse gas emissions.

The framework used to estimate the base case for the project is shown in Figure 2.

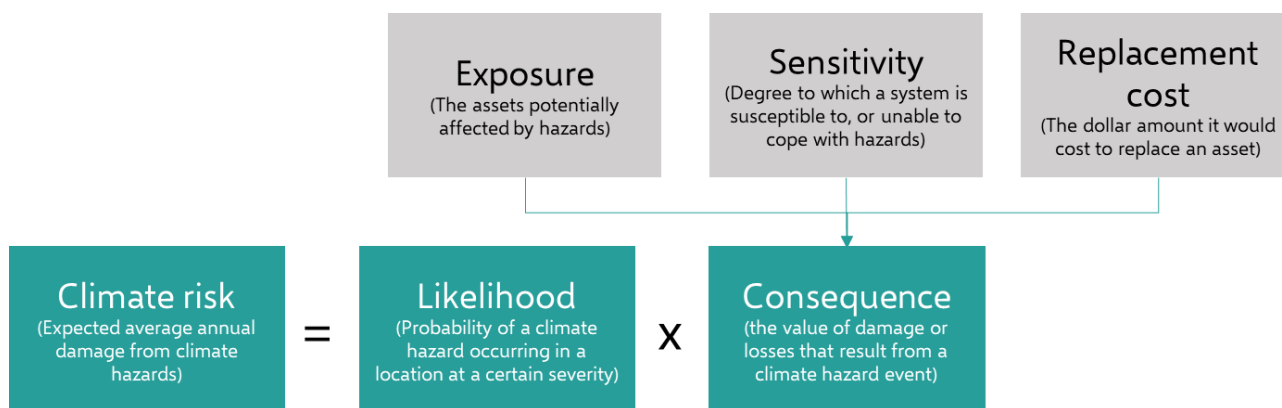


Figure 2. Framework for estimating the base case

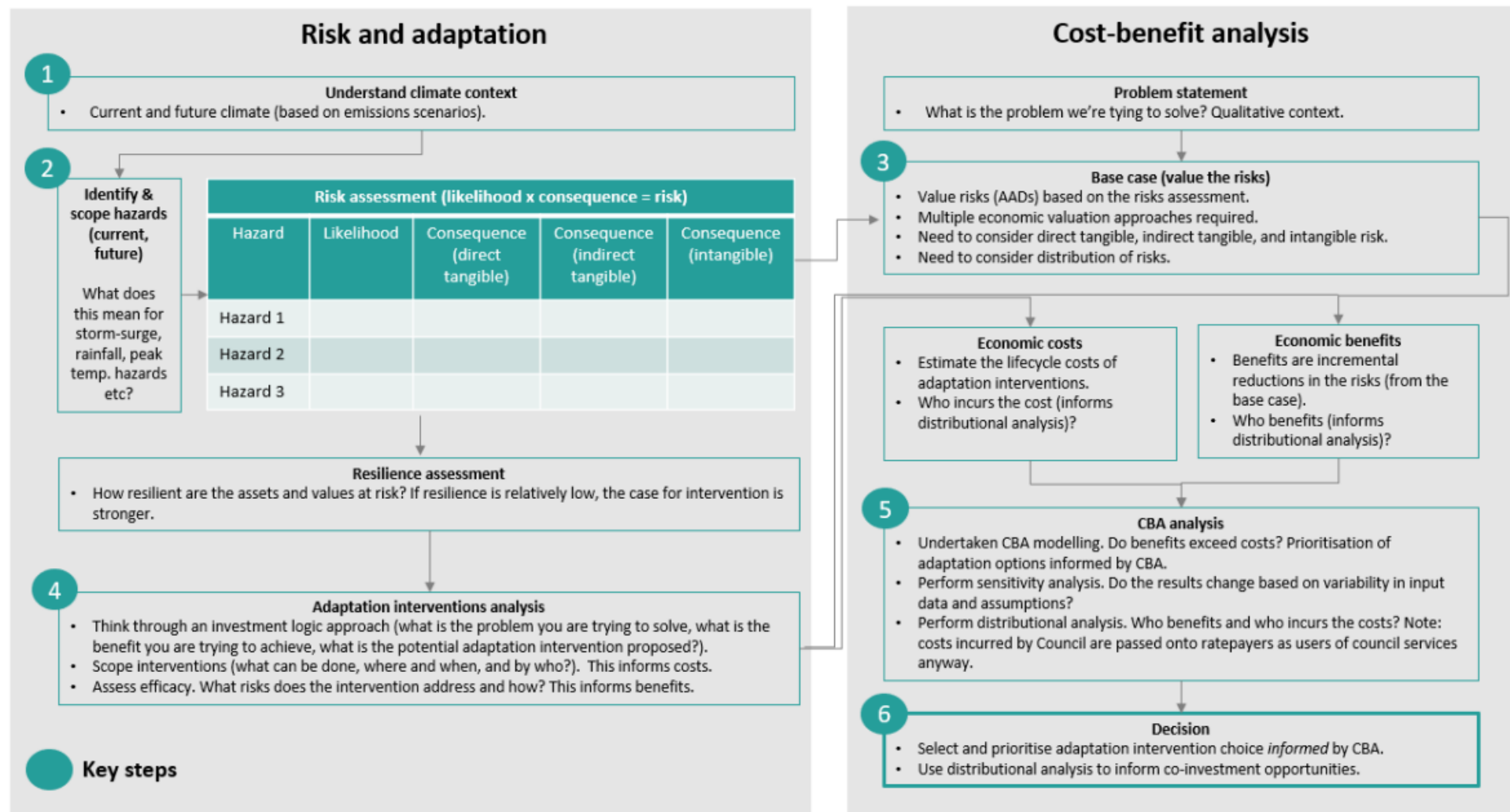


Figure 3. Overview of the CBA framework components

Revisions to the base case inputs and assumptions for road assets

The base case has been updated to incorporate newer or more detailed information that was unavailable or unable to be incorporated in the previous phase of the project completed in March 2023. This includes broadening the scope to consider impacts from a wider spectrum of hazard events. This will support more robust estimates of the cost of the “do nothing differently” scenario and the benefits of adaptation.

Enhanced data and inputs for modelling

A summary of the changes made to the base case between phase 2 of the project and phase 3 is provided in Table 1. Further information on the updates to the base case is provided in Appendix A.

Table 1. Base case inputs and assumptions for roads (Phase 2 of project versus Phase 3)

Input	Inputs and assumptions	
	Phase 2	Phase 3
Exposure	The exposure of road assets to each climate hazard was assessed using spatial analysis to identify where asset footprints intersect with hazard extents. Data on roads (as distinct from other road assets such as footpaths) was not available for Darebin, Glen Eira, Monash, and Wyndham.	The exposure analysis from Phase 2 also underpins Phase 3. For Darebin, Glen Eira, Monash, and Wyndham, road exposure to hazards was estimated using road length data from the Victorian Local Government Grants Commission (2024) and average exposure levels from similar councils where hazard extents overlap the council area. Additionally, exposure results were adjusted based on the assumption that only roads with traffic volumes of fewer than 1,000 vehicles per day are considered “exposed” to heatwaves. This reflects the greater resilience of roads engineered for higher traffic volumes to elevated temperatures. A summary of the exposure analysis results for each council is provided in Appendix A.
Sensitivity	The sensitivity of road assets was informed by guidance from IPWEA (2021), which considers the type of assets and its construction materials. Sensitivity values were tested and refined through a memo to council representatives.	The sensitivity of road assets to different climate hazards was refined based on a more detailed understanding of the likely damages from climate hazard events. The refined assumptions are presented in Appendix A.
Replacement cost	Replacement costs of roads were based on Rawlinsons Australian Construction Handbook (2021), as well as information collected from councils in phase 1.	Replacement costs for roads have been updated based on available data from Local Government Victoria’s (2024) Know Your Council - Local Government Performance Reporting. The updated unit rates are presented in Appendix A.
Likelihood	Where possible, the likelihoods of hazards aligned with the assumptions which underpin the hazard extents (i.e. the likelihood of the modelled event). Where this information was unavailable, changes in likelihood due to climate change were informed by projected changes in key climate variables.	The likelihood of heatwaves is proportionate to the change in mean temperature in Greater Melbourne in 2090 as opposed to the average number of heatwaves expected to occur. This change is made to accommodate the updated approach to estimating consequences for heatwaves. Likelihood assumptions for other hazards remain consistent with phase 2.

Incorporating a wider spectrum of hazard events

In Phase 2, the base case analysis was limited to inland and coastal flood events with a 1% annual exceedance probability (AEP) due to data constraints. In Phase 3, this limitation has been addressed by incorporating a broader range of hazard scenarios.

For inland flooding, damage cost estimates have been included for events with 10%, 5%, 2%, and 0.2% AEPs. These estimates were derived by applying scaling factors to the 1% AEP damage costs. The upper bound of these estimates aligns with proportions observed in Arup (2023), while the lower bound is conservatively set at 50% of those values.

For coastal flooding, damage costs have been estimated for 5% and 2% AEP storm-tide inundation events. These estimates are based on the percentage change in inundation area between events, relative to the 1% AEP event, as reported by McInnes et al. (2022), under a 0.8m sea level rise scenario. The upper bound reflects the observed change in inundation extent, while the lower bound is again set conservatively at 50% of this value.

This expanded approach enables a more comprehensive understanding of potential costs under the base case scenario as well as the benefits of adaptation. Further details on how the costs and benefits a wider spectrum of hazard events has been incorporated is provided in Appendix A.

Base case results for roads

The revised base case for roads is presented in Figure 4 alongside the base case estimates from phase 2. The revisions to the base case in phase 3 see AADs increase significantly for each planning horizon². This is driven by the incorporation of a broader range of hazard events for inland and coastal flooding. AADs estimates related to heatwaves and bushfire have declined, due to the revisions to the input assumptions. This includes changes to the assumptions about how sensitive road assets are to damage from these hazards.

Under the revised base case, present day AADs for roads are estimated to be in the range of \$120-\$260 million, with AADs increasing to between \$180-\$370 million in the nearer future (~2050) and to between \$360-\$750 million in the more distant future (~2100). This is an increase in AADs of about 50% in the nearer future and 200% in the more distant future from present day.

²

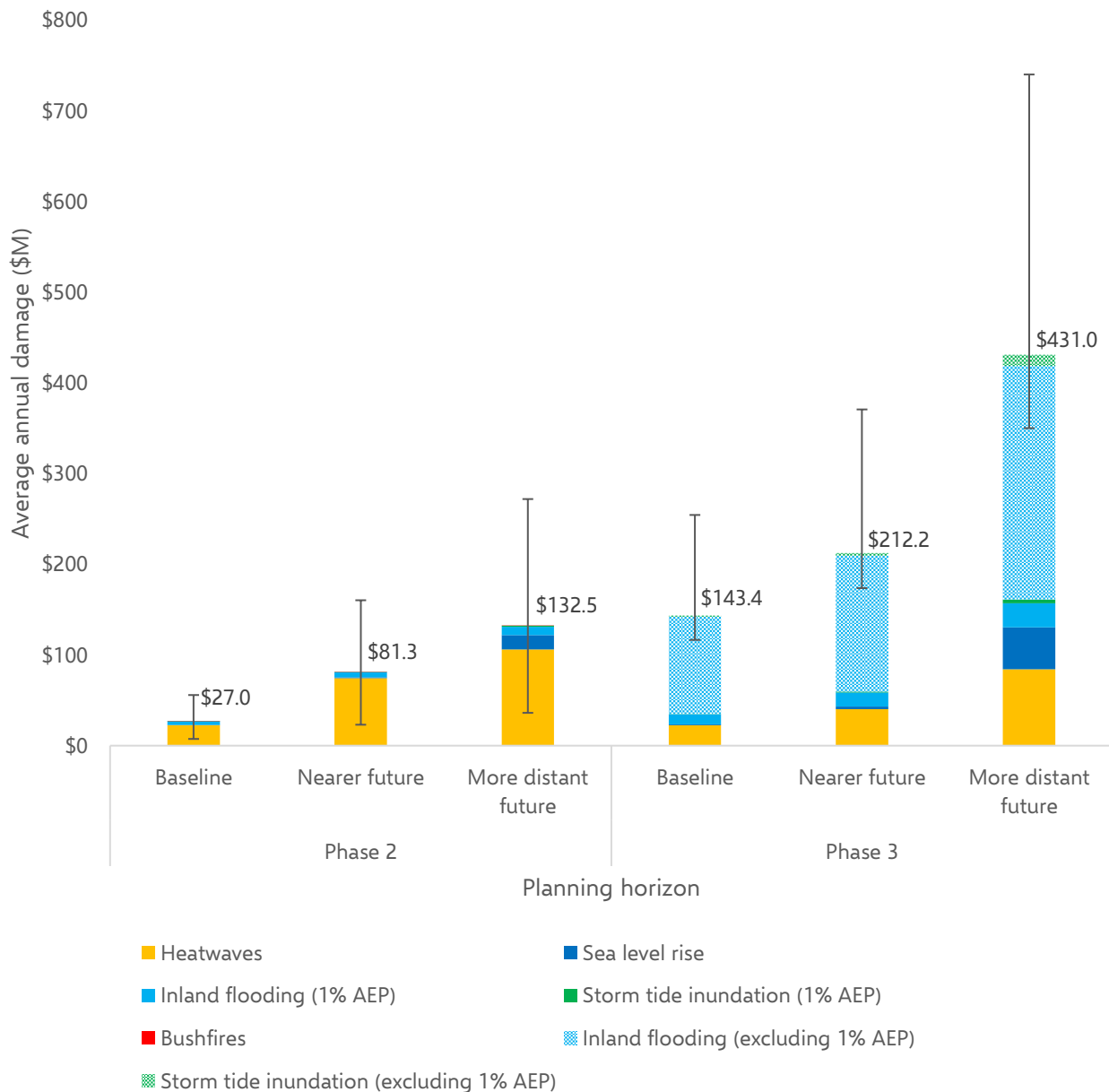


Figure 4. Average annual damages from climate hazards to roads in Greater Melbourne under the base case (i.e. “do nothing differently”)

2.2 Step 4: Adaptation intervention analysis

Adaptation options to reduce damages to council roads from climate hazards were identified through desktop research, stakeholder interviews, and a survey of local councils. A range of these options are presented in Table 2. The options presented reflect many of the commonly identified measures across the research and engagement activities. However, they do not represent an exhaustive list of all possible adaptation strategies.

Table 2 also includes a high-level assessment of the suitability of each option for implementation across Greater Melbourne. This assessment is based on responses from the local council survey³. As highlighted by

³ This assessment is based on the weighted average of responses to the survey question: “What proportion of roads in your council could the following adaptation options be applied to?” Respondents could select from the following options: Not feasible for any roads, 1–10%, 11–25%, 26–50%, 51–75%, 76–100%, and Unsure. For the analysis, a weighted average was calculated using the midpoint of each selected range. Responses marked as Unsure were excluded from the calculation.

Infrastructure Victoria (2024), adaptation is not a *one-size-fits-all* proposition; therefore, it is expected that the suitability of adaptation options will vary significantly between councils, including between metropolitan councils and interface councils (those forming a ring around metropolitan Melbourne). However, the results of the survey do not enable difference between regions to be reliably quantified—therefore, only a single suitability rating is provided for each option.

Table 2. Adaptation options for roads and their suitability for Greater Melbourne

Adaptation options	Suitability for implementation to roads in Greater Melbourne	Relative suitability rating
Heatwaves and more extreme temperatures		
Increase use of binders with higher softening points	Improves heat resilience; expected to be widely applicable across the region.	High
Increase asphalt thickness	Enhances durability; more suited to metro areas with more asphalt roads; may increase heat retention (i.e. heat island effect)	Moderate
Increase the solar reflectance of pavements	May reduce surface temperatures; glare and durability concerns; limited evidence of reduced damages to roads.	Moderate
Introduce road shading with trees	Cools surface and improves amenity; root damage risk to roads; limited evidence of reduced damages to roads.	High
Inland flooding and coastal flooding		
Upgrade drainage systems at time of renewal	High priority for councils; highly variable costs; site-dependent feasibility.	High
Apply water sensitive urban design measures (WSUD)	Reduces runoff; offers co-benefits; space constraints in dense areas.	Moderate to high
Ground and pavement stabilisation	Strengthens roads; chemical concerns in urban areas; may be affected by dry soils.	Low to moderate
Raise road elevation	Can redirect floodwaters, including to properties; limited suitability.	Low
Conduct more regular maintenance	Widely applicable; improves resilience; resource dependent.	High
Bushfires		
Fire resistant roadside planting	Low direct risk to roads from bushfires suggesting limited suitability; may protect roadside assets, access, and evacuation routes.	Low to moderate
Establish roadside fire breaks		Low to moderate

Costs of adaptation options

Table 3 presents indicative costs for implementing adaptation options for roads in Greater Melbourne. This includes estimates of the:

- incremental upfront costs (i.e. capital costs), and
- incremental ongoing costs (i.e. operating and maintenance costs).

The costs represent the incremental (additional) expenditure required to implement each option, relative to a business-as-usual scenario. Estimates are provided as a range to reflect uncertainty. All figures have been

adjusted to 2025 values. Actual costs will vary depending on factors such as road type, location, and site-specific characteristics.

For road design modifications, the accuracy of the cost estimates is not sufficient to determine incremental changes in costs across each planning horizon with any reliability. As a result, only a single cost range is presented, rather than attempting to differentiate costs over time, which could give a misleading impression of precision.

Table 3. Indicative costs of adaptation options for roads

Adaptation option	Input	Value	Comment	Reference
Heatwaves and more extreme temperatures				
Increase use of binders with higher softening points	Upfront cost	\$2 – \$23 / sqm	Assumes 5-20% uplift in the cost of pavement materials ¹ .	Chinowsky, et al., 2013
	Ongoing cost	\$0	Assumes no additional maintenance is required	
Increase asphalt thickness	Upfront cost	\$15 – \$34 / sqm	Assumes 30% uplift in the cost of pavement materials ¹ . This is proportional to change in thickness required	Knott et al., 2019
	Ongoing cost	\$0	Assumes no additional maintenance is required	
Increase the solar reflectance of pavements	Upfront cost	\$4 - \$8 /sqm	Based on cost of applying reflective sealant	Civil road works (2025)
	Ongoing cost	\$3 - \$6 / sqm	Reapplication assumed every 3 years	
Introduce road shading with trees	Upfront cost	\$205 - \$410 / m	Costs per tree have been converted to a per meter basis based on the assumption of 1 tree being planted every 10–20 m on both sides of the road	Mosaic Insights & Natural Capital Economics (2023)
	Ongoing cost	\$116 – 233 / m	Lifecycle maintenance cost	
Inland flooding and coastal flooding				
Upgrade drainage systems at time of renewal	Upfront cost	\$102 - \$880 / m	Assumes 20% uplift in drainage replacement cost	VPA (2019); Bass Coast Shire Council (2024); Arup (2023),
	Ongoing cost	\$0	Assumes no additional maintenance is required	
Apply water sensitive urban design measures	Upfront cost	\$350 - \$1,000 / m	Based on indicative costs from council	Arup (2023); Pers comms from councils
	Ongoing cost	\$199 - \$568 / m	Based on the proportionate cost of maintenance required for street trees	
Ground and pavement stabilisation	Upfront cost	\$25 - \$150 / sqm	Based on lime and foam bitumen stabilisation	Pers comms from councils; Arup (2023)
	Ongoing cost	\$0	Assumes no additional maintenance is required	
Raise road elevation	Upfront cost	\$750 - \$2,250 / m	Based on raising road by 1 metre	URS (2014); SGS Economics (2009)

Adaptation option	Input	Value	Comment	Reference
	Ongoing cost	\$0	Assumes no additional maintenance is required	
Conduct more regular maintenance	Upfront cost	\$0	Assumed no addition upfront cost	Arup (2023); Local Government Victoria's (2024)
	Ongoing cost ²	\$4 – \$14 / sqm	Equivalent to 25% of pavement resealing cost every 3 year ³	
Bushfires				Bushfires
Fire resistant roadside planting	Upfront cost	\$400 - \$600 / m	Assumes 5 sqm of planting either side of the road.	Arup (2023)
	Ongoing cost	\$400 - \$600 / m	Required every 10 years	
Establish roadside fire breaks	Upfront cost	\$800 - \$1,200 / m	Assumes a 5 sqm firebreak either side of the road.	
	Ongoing cost	\$800 - \$1,200 / m	Required every 5 years	

¹ According to SPARC Hub (2023), the cost of asphalt is estimated at \$50 per square meter for a 75 mm thick layer and \$115 per square meter for a 175 mm thick layer.

² Analysis assumes that implementing more frequent maintenance will prevent the need for periodic resealing, which is assumed to occur once between years 10 and 26 of the asset life. This is considered a conservative approach, with all other maintenance and rehabilitation costs assumed to remain unchanged.

³ According to Local Government Victoria (2024), the cost of resealing sealed local roads ranges from \$16 to \$56 per square meter.

Efficacy of adaptation options

Table 4 presents indicative efficacy estimates of the adaptation options for roads in Greater Melbourne. The efficacy estimates reflect the effectiveness of adaptation options at reducing physical damage to roads from the relevant climate hazard.

The efficacy rates used in this study are based on relatively simple assumptions and the best available information at the time of assessment. To account for uncertainty, wide bounds have been applied to these estimates. It is important to keep these underlying assumptions in mind when interpreting the CBA results presented in this report. Robust evidence on efficacy rates remains a key challenge for organisations developing adaptation business cases.

Table 4. Indicative efficacy of adaptation options for roads

Adaptation options	Efficacy	Comments
Heatwaves and more extreme temperatures		
Increase use of binders with higher softening points	50% - 100%	Assumed to prevent as much as half of damage related to extreme temperatures and heatwaves.
Increase asphalt thickness	50% - 100%	As above.
Increase the solar reflectance of pavements	15% - 33%	Based on surface temperature reductions observed by Edge Environment (2020) & Kawakami and Kubo (2008, as cited in WRI, 2012). This is considered an optimistic estimate ¹ .
Introduce road shading with trees	15% - 33%	As above. Edge Environment (2020) found shading one third of the road surface can achieve a cooling effect comparable to the most effective cool pavement treatments.
Inland flooding and coastal flooding		

Adaptation options	Efficacy	Comments
Upgrade drainage systems at time of renewal	29%-58%	Upper bound assumes roads are resilient to flood events up to 10% AEP under current and future conditions, with the lower bound set at 50% of this efficacy rate. This is based on City of Melbourne (2024) designing new council drains for a 10% AEP capacity with an additional 18.5% allowance for increased rainfall intensity due to climate change.
Apply water sensitive urban design measures	29%-58%	As above.
Ground and pavement stabilisation	50% - 99%	Upper bound based on Arup (2023) estimates for foam bitumen stabilisation, with the lower bound set at 50% of this value
Raise road elevation	50% - 100%	Assumes elevation increase is sufficient to prevent 50% to 100% of flood-related damage.
Conduct more regular maintenance	25% - 50%	Upper bound based on Arup (2023) which assumes more regular maintenance can halve flood-related damage, with the lower bound set at 50% of this value. Work undertaken by the World Bank (2017) supports this assumption ² .
Bushfires		
Fire resistant roadside planting	0%	Direct risk to roads from bushfires is minimal. These measures may reduce damage from falling debris and roadside infrastructure but not from fire itself.
Establish roadside fire breaks	0%	

¹ In a study conducted in Adelaide, Edge Environment (2020) report a maximum surface temperature reduction of 15% using a cool road sealant, compared to conventional asphalt. Comparatively, Kawakami and Kubo (2008) observed surface temperature reductions of 33% for asphalt coated with solar reflective technology versus uncoated asphalt.

² In assessment of resilient transport policies to reduce asset losses in Fiji, World bank (2017) assumed that improved road maintenance would remove all asset losses due to flood events with a return period of 20 years or less. For reference, the base case estimates shows that flood events with a return period of 20 years or less account for 80% of the AAD to roads in Greater Melbourne from inland flooding.

2.3 Step 5: Cost-benefit analysis

The CBA has been undertaken to assess the economic viability of investing in each adaptation option. The analysis was conducted for a representative 1 km section of road affected by each hazard type, over a 40-year evaluation period. A discount rate of 7% was applied consistently across all planning horizons.

Table 5 presents a summary of the CBA results for both present day and more distant future scenarios. The results are shown across a low and high range to reflect uncertainty in the model inputs. Specifically, the table includes:

- the present value cost of implementing and maintaining each adaptation option,
- the present value of benefits from avoided damages, and
- the benefit-cost ratio (BCR), indicating the level of benefits generated per dollar invested—an option is required to have a BCR above 1 to be economically viable.
- commentary and observations related to the results.

The full results of the CBA are presented in Appendix B. The adaptation options for bushfires have not been assessed as part of the CBA as direct damages to roads from bushfires are expected to be limited and rare.

Table 5. Cost-benefit analysis results for a 1-kilometre road affected by each hazard (p10 and p90 estimates⁴)

Adaptation option	Planning horizon	Present value cost (\$'000)	Present value benefit (\$'000)	Benefit-cost ratio	Commentary
Heatwaves and more extreme temperatures					
Increase use of binders with higher softening points	Present day	\$69 - \$183	\$7 - \$18	0.05 - 0.19	The CBA results indicate that the use of binders and thicker asphalt are not economically viable adaptation options, based on avoided damages to roads. The use of binders is found to have lower implementation costs that thicker asphalt but similar levels of effectiveness in reducing damages. This combination results in a more favourable BCR for the use of binder, making it the more preferred option of the two.
	More distant		\$20 - \$50	0.14 - 0.53	
Increase asphalt thickness	Present day	\$190 - \$298	\$7 - \$18	0.03 - 0.08	
	More distant		\$20 - \$51	0.08 - 0.22	
Increase the solar reflectance of pavements	Present day	\$210 - \$280	\$2 - \$6	0.01 - 0.02	Increasing the solar reflectance of pavements and shading roads with trees do not present as viable options for reducing road damages, based on their current costs and levels of efficacy. While these measures may not be economically justified solely for damage reduction, they could still contribute to broader council objectives, such as urban cooling and improved public amenity. In this context, any reduction in road damage should be considered an additional co-benefit, rather than the primary driver for investment.
	More distant		\$6 - \$16	0.02 - 0.07	
Introduce road shading with trees	Present day	\$419 - \$545	\$2 - \$6	0.00 - 0.01	
	More distant		\$6 - \$16	0.01 - 0.03	
Inland flooding					
Upgrade drainage systems at time of renewal	Present day	\$277 - \$709	\$215 - \$618	0.40 - 1.60	Upgrading drainage systems and implementing WSUD measures are both potentially viable climate adaptation options, based on avoided damages to roads. Drainage upgrades may be suitable for both present day and future implementation, while WSUD measures are more likely to be viable in the longer term. However, both approaches exhibit a wide range in costs, contributing to a high degree of uncertainty regarding their viability across different sites in Greater Melbourne.
	More distant		\$432 - \$1,268	0.80 - 3.28	
Apply water sensitive urban design measures	Present day	\$741 - \$1,174	\$215 - \$618	0.22 - 0.69	
	More distant		\$431 - \$1,264	0.45 - 1.42	
Both approaches are expected to deliver a range of co-benefits, including reduced flood damages to nearby properties, decreased stormwater runoff, and improved water quality. The selection of these options may ultimately depend on site-specific constraints and alignment with broader council objectives.					

⁴ Percentiles describe a range that a statistic falls into. The 10th (P10) and 90th (P90) percentiles represent the values below which 10% and 90% of the results fall. Therefore, the values presented, exclude the highest and lowest 10% of values to provide a robust estimate of the spread

Adaptation option	Planning horizon	Present value cost (\$'000)	Present value benefit (\$'000)	Benefit-cost ratio	Commentary
Conduct more regular maintenance	Present day	\$132 - \$373	\$185 - \$535	0.66 - 2.92	Conducting more regular maintenance has the potential to be a viable adaptation option across all planning horizons, based on avoided damages to roads and avoided maintenance costs. This stems from relatively low costs combined with consistent benefits in terms of reduced damage. This approach may offer an efficient strategy for managing inland flood risk.
	More distant		\$371 - \$1,093	1.34 - 5.97	
Ground and pavement stabilisation	Present day	\$529 - \$1,222	\$366 - \$1,054	0.39 - 1.48	Ground and pavement stabilisation emerges as a potentially viable adaptation option under present day conditions and becomes increasingly viable in more distant future scenarios. This is largely due to the expectation of higher damage costs in the future, which enhances the economic justification for investment.
	More distant		\$736 - \$2,162	0.78 - 3.03	
Coastal flooding (storm-tide inundation)					
Upgrade drainage systems	Present day	\$277 - \$709	\$154 - \$508	0.29 - 1.29	Adaptation options for storm-tide inundation are found to be less viable compared to the same options assessed for inland flooding. This difference arises despite the same implementation costs, due to a lower level of avoided damages in coastal scenarios. As a result, the BCRs for coastal flooding adaptation options are lower, indicating reduced economic efficiency and making these investments harder to justify under current assumptions.
	More distant		\$154 - \$509	0.29 - 1.30	
Apply water sensitive urban design measures	Present day	\$741 - \$1,174	\$134 - \$441	0.14 - 0.49	This finding is partly driven by the underlying exposure analysis and assumptions used in the assessment. Notably, the inland flooding results capture damages from more frequent events (i.e. 10% AEPs). In contrast to inland flooding, the analysis also assumes that the frequency of storm-tide events will remain constant, potentially underestimating future risk and the benefits of adaptation.
	More distant		\$135 - \$445	0.14 - 0.50	
Conduct more regular maintenance	Present day	\$132 - \$373	\$80 - \$260	0.29 - 1.41	
	More distant		\$80 - \$262	0.29 - 1.42	
Ground and pavement stabilisation	Present day	\$529 - \$1,222	\$158 - \$514	0.17 - 0.71	
	More distant		\$158 - \$518	0.17 - 0.71	
Coastal flooding (sea level rise)					
Raise road (0.25 meter)	Present day	\$364 - \$638	\$342 - \$1,230	0.67 - 2.67	The growing cost of adaptation over time, combined with stable benefits, results in a lower BCR in the more distant future. This highlights how the increasing financial burden of implementing adaptation measures under worsening conditions, while the value of avoided damages does not rise proportionally, can reduce the viability of a given adaptation option.
Raise road (1.0 meter)	More distant	\$1,091 - \$1,914		0.22 - 0.89	

The CBA results indicate that many adaptation options are not economically viable under present day or future conditions when considering only the direct benefits to councils. However, these direct benefits are expected to represent only a portion of the total value of adaptation. Therefore, to strengthen the investment case, it will be necessary to incorporate indirect and intangible benefits, such as avoided travel disruptions. Notably, several options show potential to deliver a substantial portion of the benefits needed to justify their costs. This significantly reduces the extent of additional benefits required, suggesting that the inclusion of broader benefits could make the case for investment considerably more compelling. This is further explored in a scenario below.

The results indicate that BCRs will increase over time. This trend is largely driven by the rising value of avoided damages resulting from climate change impacts. Assuming adaptation costs remain relatively stable in real terms, this indicates that the economic justification for investing in adaptation measures becomes progressively stronger in the future. Although not incorporated into this analysis, the value of co-benefits of adaptation options may also increase with time.

Among the options assessed, conducting more regular maintenance appears to be the most promising, demonstrating the potential for economic viability both in the present day and in the more distant future, when addressing inland flood risk. This suggests it may be an efficient and practical strategy for councils moving forward. However, the results also indicate, that this option may not be viable when risks are lower, such as instances where roads are affected by storm-tide inundation only. The results indicate that direct benefits could reach up to \$3 for every \$1 invested, when addressing inland flooding risk in present day, with benefits increasing through time.

Upgrading drainage systems at the time of renewal and the use of ground and pavement stabilisation both show potential as viable options for protecting roads from inland flooding—measures already in use by some councils. Upgrading drainage systems may also provide a viable option for addressing damages from storm-tide inundation. The CBA results indicate BCRs ranging from 0.40 to 1.60 for upgrading drainage systems and from 0.39 to 1.48 for ground and pavement stabilisation, in present day. The results indicate that there is a need to consider their use on a case-by-case basis to ensure economic viability. Again, as with most other adaptation options, the benefits of these two options are expected to grow over time due to the increasing damages to roads with climate change.

Raising roads to address sea level rise is likely to be viable in the short term, but its viability declines over time as the level of adaptation required increases, making it less cost-effective in future scenarios. Many councils also suggest this option is unfeasible for most roads. These results do not consider the benefits from avoiding damages from storm-tide inundation.

Implementing WSUD initiatives are not found to be economically viable when assessed solely on the basis of avoided road damage costs, in present day. However, these initiatives are often pursued to achieve broader objectives beyond road protection. Therefore, while the observed benefits may not be sufficient on their own to justify investment today, they can contribute to a stronger overall case when considered alongside wider outcomes such as flood mitigation, improved water quality, and urban cooling.

This broader value proposition also applies to other adaptation options, including tree planting for shade and drainage system upgrades. Importantly, the benefits of WSUD in protecting roads from inland flooding may be sufficient to justify investment under certain conditions in the more distant future.

Scenario analysis

To provide further insights, three distinct scenarios related to inland flooding impacts on roads across Greater Melbourne were analysed. These scenarios include:

- the benefits of conducting more regular maintenance on flood-affected roads
- the costs associated with adopting a 'build back better' approach
- the indirect cost of road closures.

Scenario 1 - Benefits of conducting more regular maintenance on roads affected by inland flooding across Greater Melbourne

To better understand the potential magnitude of benefits from more regular maintenance, we estimated the costs and benefits of applying this approach to 10% of roads affected by inland flooding in each council across Greater Melbourne. The assessment was conducted for the present day, near future, and more distant future, using central estimates from the economic model.

The results, presented in Table 6, indicate that it would cost councils approximately \$60 million to implement more regular maintenance on this 260 km length of roads. In return, this investment would deliver estimated benefits of \$70 million in the present day, \$95 million in the nearer future, and \$140 million in the more distant future, across 40 years. This represents a return of \$1.10 for every dollar invested in present day, increasing to \$1.60 and \$2.30 per dollar invested in the near and more distant future, respectively.

Importantly, the use of more regular maintenance is expected to be applicable across a much broader network of roads. As such, the benefits have the potential to be even greater. The results also do not consider the benefits of avoided damages from other hazards.

These results assume that councils are not currently conducting 'more regular' maintenance.

Table 6. Potential benefits of more regular maintenance for 10% of roads affected by inland flooding across Greater Melbourne

Council	Length of road (km)	Present value cost (\$'000)	Present value benefits (\$'000)		
			Present day	Nearer Future	More distant future
Banyule	2.0	\$470	\$533	\$737	\$1,085
Bass Coast	0.6	\$130	\$147	\$204	\$300
Bayside	7.5	\$1,766	\$2,005	\$2,771	\$4,077
Boroondara	2.3	\$545	\$619	\$856	\$1,259
Brimbank	7.2	\$1,691	\$1,919	\$2,653	\$3,903
Cardinia	30.6	\$7,160	\$8,128	\$11,234	\$16,529
Casey	53.2	\$12,460	\$14,144	\$19,550	\$28,765
Darebin	4.3	\$1,017	\$1,154	\$1,595	\$2,347
Frankston	6.0	\$1,394	\$1,582	\$2,186	\$3,217
Glen Eira	3.7	\$857	\$972	\$1,344	\$1,978
Greater Dandenong	24.4	\$5,719	\$6,492	\$8,972	\$13,202
Hobsons Bay	5.8	\$1,352	\$1,535	\$2,121	\$3,121
Hume	6.7	\$1,558	\$1,769	\$2,445	\$3,598
Kingston	7.2	\$1,675	\$1,901	\$2,628	\$3,866
Knox	7.5	\$1,764	\$2,003	\$2,768	\$4,073
Manningham	3.4	\$804	\$913	\$1,262	\$1,856

Council	Length of road (km)	Present value cost (\$'000)	Present value benefits (\$'000)		
			Present day	Nearer Future	More distant future
Maribyrnong	2.5	\$578	\$656	\$907	\$1,334
Maroondah	2.6	\$610	\$692	\$956	\$1,407
Melbourne	2.8	\$665	\$755	\$1,043	\$1,535
Melton	3.8	\$887	\$1,007	\$1,392	\$2,047
Merri-bek	5.3	\$1,248	\$1,416	\$1,957	\$2,880
Monash	6.2	\$1,456	\$1,653	\$2,285	\$3,361
Moonee Valley	3.4	\$801	\$910	\$1,257	\$1,850
Mornington Peninsula	18.0	\$4,212	\$4,781	\$6,608	\$9,723
Nillumbik	1.4	\$335	\$380	\$526	\$773
Port Phillip	8.2	\$1,915	\$2,174	\$3,004	\$4,420
Stonnington	2.0	\$479	\$544	\$752	\$1,106
Whitehorse	2.4	\$557	\$632	\$873	\$1,285
Whittlesea	3.7	\$858	\$974	\$1,346	\$1,981
Wyndham	16.7	\$3,907	\$4,435	\$6,130	\$9,020
Yarra	4.5	\$1,059	\$1,202	\$1,661	\$2,444
Yarra Ranges	7.6	\$1,790	\$2,032	\$2,808	\$4,131
Total	263.6	\$61,717	\$70,059	\$96,831	\$142,475
Benefit-cost ratio			1.1	1.6	2.3

Scenario 2 - Costs of adopting a 'build back better' approach for roads affected by inland flooding across Greater Melbourne

To better understand the cost of applying a 'build back better' approach to road infrastructure in Greater Melbourne, we estimated the annual investment required to upgrade roads affected by inland flooding. These roads represent approximately 7 percent of the total road network in the region, yet they account for around 80 percent of the total AAD, under current conditions. This concentration of risk suggests that a targeted betterment strategy could offer a cost-effective means of reducing the economic cost of climate hazards on road infrastructure.

The assessment assumes a uniform annual uplift of flood-affected roads over a 40 to 60-year period. To account for climate adaptation measures, a conservative 25 percent increase in the cost of sealed road reconstruction has been applied, based on costs presented by Local Government Victoria (2024). Under these assumptions, the estimated additional investment required ranges from \$18 to \$40 million per year. The 25 percent uplift in costs may understate the cost of adaptation.

For context, the Australian Local Government Association (ALGA, 2025) has proposed a \$400 million climate adaptation fund to support place-based climate solutions across all Australian councils. The results of this analysis, which indicate a betterment cost of between \$18 to \$40 million, suggests that while this fund could enable targeted investments such as the betterment of highly vulnerable roads, it is unlikely to be sufficient to build resilience across all infrastructure assets. Notably, the relatively modest uplift for flood-affected roads in Greater Melbourne alone could consume up to 10% of the proposed fund.

Table 7. Potential cost of applying a build back better approach to roads in Greater Melbourne affected by inland flooding

Council	Roads exposed to inland flooding		Annual cost to 'build back better'		
	% of total roads	% of total AAD	Low	Mid	High
Banyule	4%	75%	\$138	\$175	\$306
Bass Coast	1%	32%	\$38	\$48	\$85
Bayside	11%	89%	\$519	\$656	\$1,152
Boroondara	5%	80%	\$160	\$203	\$356
Brimbank	7%	85%	\$496	\$628	\$1,102
Cardinia	31%	94%	\$2,102	\$2,660	\$4,669
Casey	13%	87%	\$3,659	\$4,630	\$8,125
Darebin	8%	87%	\$299	\$378	\$663
Frankston	9%	87%	\$409	\$518	\$909
Glen Eira	8%	86%	\$252	\$318	\$559
Greater Dandenong	13%	91%	\$1,679	\$2,125	\$3,729
Hobsons Bay	6%	78%	\$397	\$502	\$882
Hume	2%	59%	\$458	\$579	\$1,016
Kingston	15%	91%	\$492	\$622	\$1,092
Knox	6%	82%	\$518	\$656	\$1,150
Manningham	6%	79%	\$236	\$299	\$524
Maribyrnong	11%	91%	\$170	\$215	\$377
Maroondah	5%	82%	\$179	\$227	\$398
Melbourne	7%	76%	\$195	\$247	\$434
Melton	3%	68%	\$260	\$330	\$578
Merri-bek	11%	91%	\$366	\$464	\$813
Monash	8%	85%	\$428	\$541	\$949
Moonee Valley	4%	77%	\$235	\$298	\$523
Mornington Peninsula	3%	68%	\$1,237	\$1,565	\$2,746
Nillumbik	2%	58%	\$98	\$124	\$218
Port Phillip	15%	90%	\$562	\$712	\$1,249
Stonnington	7%	86%	\$141	\$178	\$312
Whitehorse	4%	76%	\$163	\$207	\$363
Whittlesea	2%	63%	\$252	\$319	\$559
Wyndham	8%	82%	\$1,147	\$1,452	\$2,548
Yarra	15%	85%	\$311	\$393	\$690
Yarra Ranges	4%	71%	\$526	\$665	\$1,167
Greater Melbourne	7%	82%	\$18,122	\$22,933	\$40,243

Scenario 3 - The indirect cost of road closures

The results of the CBA suggest the need to include additional benefits to strengthen the case for investment. This may include incorporating avoided costs related to road closures. Road closures, both during and after hazard events (e.g. for repairs), can impose significant economic costs. These costs are largely driven by increased travel time and higher vehicle operating expenses.

To illustrate the potential scale of these costs a simplified economic model was developed to estimate the economic costs associated with several hypothetical road closure scenarios in Greater Melbourne. The scenarios explore how the economic cost of road closures vary depending on traffic volumes and length of diversions.

In a low-traffic scenario with a short diversion, the estimated economic cost of a road closure is found to be around \$850 per day. In contrast, a high-traffic scenario with a longer diversion results in an estimated cost of \$43,000 per day. These results show that the economic cost of road closures can increase significantly with higher traffic volumes and limited alternative routes. They also highlight the importance of including avoided road closure costs in investment assessments, particularly for roads with high traffic or where detour options are limited.

The assumptions and results of this analysis are presented in Table 8.

Table 8. Estimated economic cost hypothetical road closure scenarios

Scenario	Low traffic	Medium traffic	High traffic	Source
Assumptions				
Vehicles per day¹	500	1,000	5,000	NCE Assumption
Length of diversion (km)	1	2.5	5	NCE Assumption
Average vehicle occupancy (persons/vehicle)		1.6		Based on average occupancy of private car on urban roads (ATAP, 2021)
Average vehicles speed (km/hr)		40		NCE Assumption
Operating cost (\$/km)		\$0.88		Valued based on ATO Cents per kilometre rate for 2024-25.
Value of time (\$/hr)		\$21.2		Valued based on 40% of the seasonally adjusted full time average weekly earnings for Australia (ATAP, 2021)
Results				
Value of additional travel time per day	\$440	\$2,200	\$22,000	
Value of additional vehicle operating expenses per day	\$423	\$2,116	\$21,158	
Total cost per day	\$863	\$4,316	\$43,158	

¹Data from the Victorian Local Government Grants Commission (2024) shows that 57% of roads in Greater Melbourne carry fewer than 500 vehicles per day on average. In addition, 20% of roads have average daily traffic volumes between 500 and 1,000 vehicles, while 23% experience more than 1,000 vehicles per day.

For a subset of adaptation option related to inland flooding, we have examined how incorporating the avoided cost of road closures into the CBA affects the case for investment. This analysis assumes that each

adaptation option prevents one day of road closure per year due to avoided damage, over a 40-year period. The results are presented in Table 9 and show how the inclusion of these additional benefits can significantly strengthen the case for investment. For simplicity, only the central BCR estimates are shown, based on the present day planning horizon.

Table 9. Change in benefit-cost ratios of adaptation option with inclusion of avoided costs associated with road closure, in present day

Option	Benefit-cost ratios	Benefit cost ratio		
	excluding avoided road closures	Including benefits from avoided road closures		
Scenario	Central estimate	Low traffic	Medium traffic	High traffic
Upgrade drainage systems	0.61	0.64	0.73	1.77
Apply water sensitive urban design measures	0.43	0.44	0.51	1.22
Ground and pavement stabilisation	0.60	0.61	0.67	1.26

The results show that inclusion of avoided indirect costs under the low-traffic scenario are not sufficient to raise the value of adaptation benefits above the associated costs. The medium-traffic scenario also falls short of a positive BCR, although it provides a moderate improvement in the investment case. In contrast, under the high-traffic scenario, all adaptation options become viable, with benefits exceeding costs from a societal perspective. Including additional benefits, such as avoided intangible impacts (e.g. psychological stress) and co-benefits of adaptation measures (e.g. urban cooling), would further strengthen the case for investment.

Sensitivity analysis

Sensitivity analysis was conducted to evaluate how uncertainty in input variables affects the results. This analysis employed a Monte Carlo simulation with 30,000 iterations to explore the range of plausible outcomes. This process enabled the CBA results to be presented across a range in Table 5.

Sensitivity analysis was also used to identify which input variables most significantly influence the variability of the results. This helps determine which variables should be prioritised for refinement in future work to improve the accuracy of the BCR estimates. The analysis revealed that the following inputs contribute most significantly to BCR variability:

- replacement cost of roads—this input affects both the estimated value of damages under the base case and the avoided costs (i.e. benefits) associated with each adaptation option
- cost of each adaptation option—variability in both upfront and ongoing costs leads to significant differences in BCR outcomes
- sensitivity of roads to each hazard—this input influences the extent of damages under the base case scenario, which in turn affects the value of avoided costs (i.e. benefits) of each adaptation option
- efficacy rates—this input influences the level of damages avoided and therefore the benefits of adaptation.

Undertaking more localised studies can help reduce the uncertainty in the estimated replacement costs of roads and the cost of implementing specific adaptation measures. By narrowing these cost ranges, councils can make more informed investment decisions. However, understanding the sensitivity of road infrastructure to different climate hazards, as well as the effectiveness of various adaptation options, is inherently more

complex. This is an area where further research is likely to be required to support councils in developing robust and evidence-based adaptation assessments.

Limitations of the assessment

The CBA is designed to inform councils across Greater Melbourne, and this regional focus has shaped the methodology used. To ensure broad applicability, the analysis relies on generalised inputs, which may not fully reflect the specific adaptation needs, constraints, or conditions of individual councils or sites. Consequently, the results should be considered indicative only, and further site-specific assessments will be essential before making investment decisions.

Councils are encouraged to consider the full spectrum of climate change impacts on road infrastructure, including all relevant hazards and indirect factors such as population growth, when identifying appropriate adaptation strategies. This more comprehensive approach was not feasible for this study and will help councils to maximise benefits and minimise the risk of maladaptation. Additionally, broader community objectives should be taken into account to ensure alignment with local priorities and values.

Importantly, road design decisions must consider more than just hazard exposure, which was the primary focus of this study. Factors such as traffic volumes, road function, subgrade conditions, and material availability play a critical role in determining the suitability and cost-effectiveness of adaptation options. These engineering and operational considerations add further complexity to the decision-making process and reinforce the need for tailored, context-specific planning.

It is acknowledged that some councils may already be implementing certain adaptation measures, while other, potentially more suitable options not assessed in this study may exist. These should be explored as part of a local adaptation planning.

Comparison to Infrastructure Victoria's Weathering the Storm.

This project has drawn on the work and insights of Infrastructure Victoria's Weathering the Storm (2024), including inputs such as Arup's Economic Analysis of Adaptation for Roads (2023). Where similar adaptation options have been assessed, differences in results, including BCRs, are primarily attributable to variations in input assumptions and the scope of benefits considered. These differences include:

- Replacement costs—Arup applied a significantly higher replacement cost of \$12 million per km, compared to \$1.8 million per km used in this study. The higher cost reflects the replacement value of a major arterial road, whereas the costs in this study aims to represent the average replacement cost of local municipal roads across Greater Melbourne. The higher rate increases the relative cost of flooding and, consequently, the relative benefits from adapting roads, resulting in a stronger economic case for adaptation investment.
- Indirect and intangible impacts—Arup incorporated indirect and intangible costs and benefits into its analysis, which were excluded from this project's scope. These inclusions further strengthen the economic justification for investing in adaptation.

Furthermore, this project has also deliberately adopted a conservative approach to estimating the benefits of adaptation, given the broad study region.

3 Findings from the analysis

The findings from this analysis suggest:

1. Climate impacts and costs to roads are forecast to grow

While uncertainty remains, the direction of change is relatively clear: climate-related damages to roads are expected to increase significantly. Without adaptation, AADs could more than triple by 2100. Councils will require additional funding and planning support to respond effectively.

2. Councils need better data and support to make informed adaptation decisions

Making sound adaptation decisions is complex, especially when assessing hazards like heatwaves, where methods to quantify impacts and evaluate adaptation benefits are less developed compared to flooding. This complexity increases when multiple hazards must be considered simultaneously and is further amplified when indirect and intangible impacts, such as disruptions to transport or community wellbeing, are considered. Councils need improved data, and decision-support tools to navigate these challenges. Phase 3 contributes to this need through this report and the development of a spatial tool by CSIRO's Data61, but significant information gaps and challenges remain.

3. Councils must balance climate risks and adaptation costs

The high cost of adapting roads to future climate conditions, when many benefits may not be realised immediately, makes some options economically unviable. Councils must strike a balance between preparing for long-term climate risks and avoiding unnecessary or premature investment. Incremental approaches, such as more regular maintenance, may offer flexible and cost-effective pathways that allows councils to adapt progressively as risks evolve. Importantly, the net benefit of adaptation investments is expected to improve over time, and hence, so may the prudent decision to invest in adaptation.

The need to balance risks and costs in adaptation suggest councils would benefit from systematically embedding adaptation into existing asset management regimes, where decisions on adaptation investment are aligned with major asset refurbishment/replacement investment. For example, a rapid reassessment of risks, benefits, and costs at the time of refurbishment/replacement. Then, based on the results of that analysis, determine if adaptation investments are worthwhile. This embeds adaptation into the management of the portfolio of assets. This approach can also be used in conjunction with betterment post climate hazard event, where assets are damaged prior to their scheduled refurbishment/replacement.

In support of this finding, the Environment and Planning Committee's (2025) inquiry into climate resilience recommends that the Victorian Government support the use of a betterment approach based on findings that this approach reduces costs by minimising the need for repeated repairs.

4. More regular maintenance shows strong potential

More regular maintenance to address inland flooding has the potential to deliver economic benefits in present day, delivering between \$0.66 and \$2.92 in benefits for every dollar invested. These benefits are expected to grow in the more distant future to between \$1.34 and \$5.97 as climate-related damages increase. When the avoided impacts from other hazards, such as heatwaves and coastal flooding, are also considered, the overall value of maintenance-based adaptation strategies could be significantly higher.

The economic case for more regular maintenance is further supported by findings Infrastructure Victoria (2024) and from the Inquiry into the implications of severe weather events on the national regional, rural,

and remote road network. The Inquiry confirmed that regular maintenance is critical for reducing the impact of severe weather on road infrastructure. However, it also revealed that many local governments are struggling to implement such practices due to significant maintenance backlogs. These backlogs are compounded by constrained budgets, repeated weather-related damage, inflationary pressures, rate-capping, and shortages of skilled contractors (Standing Committee on Regional Development, Infrastructure and Transport, 2023). To unlock the full value of maintenance-based adaptation strategies, these barriers must be addressed. Strengthening asset management systems is also essential to support a shift from reactive, short-term fixes to proactive, long-term maintenance planning (Hallegatte et al., 2017).

5. Broader benefits must be considered to justify adaptation and avoid maladaptation

The benefits from avoided damages to roads can contribute a significant portion of the value needed to justify investment in adaptation. However, for many road-related options, avoided road damage alone is not enough to make the investment viable. To strengthen the case, a broader consideration of co-benefits is necessary. Measures such as WSUD are expected to deliver additional positive outcomes, including reduced flood impacts to properties, improved water quality, and urban cooling. A more holistic assessment that captures these wider benefits will support well-rounded investment decisions, help maximise potential returns, support broader council objectives, and reduce the risk of maladaptation.

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Appendix A – Revisions to the base case inputs and assumptions for road assets

Appendix provides additional information related to the revisions to the base case from phase 2.

Exposure

Exposure refers to the footprint of assets located within areas projected to be impacted by specific climate hazard events—namely bushfires, heatwaves, coastal flooding, and inland flooding. Exposure estimates are based on spatial analysis conducted during phase 2 of the project, as part of Step 2 of the CBA Framework.

During Phase 2, spatial data for roads (distinct from other road-related assets such as footpaths) was unavailable for the councils of Darebin, Glen Eira, Monash, and Wyndham. For these councils, exposure was estimated using the total length of roads reported by the Victorian Local Government Grants Commission (2024) and average exposure levels from comparable councils where hazard extents intersect the council area. These assumptions, along with the proportion of each council's roads exposed to each hazard, are detailed in Table 10.

Additionally, the exposure results have been amended to account for the greater resilience of roads designed for higher traffic volumes to heatwave conditions. Specifically, only roads with traffic volumes of fewer than 1,000 vehicles per day were considered “exposed” to heatwaves. This adjustment reflects the understanding that roads engineered for heavier traffic are typically constructed with materials and designs that better withstand elevated temperatures. Traffic volume proportions were derived from urban road data published by the Victorian Local Government Grants Commission (2024).

Table 10. Proportion of total road area exposed to each climate hazard by council (% of total road area)

Council	Heatwaves	Bushfires	Inland flooding		Coastal flooding	
Extent layer	No. of heatwaves	Bushfire Management Overlay	Waterway 1% ARI flood extent	Overland Flow 1% ARI flood extent	Sea level rise ¹	1-in-100 year storm-tide level ²
Banyule	66%	0.4	1.0	2.5	-	-
Bass Coast	96%	13.0	0.5	0.5	0.4	3.1
Bayside	79%	-	-	10.7	0.0	0.2
Boroondara	67%	-	0.9	3.9	-	0.0
Brimbank	72%	-	1.8	5.2	-	-
Cardinia	94%	24.1	29.8	1.1	0.1	2.4
Casey	83%	6.0	8.8	4.3	0.1	3.5
Darebin⁴	70%	-	2.4 ²	6.0 ³	-	-
Frankston	78%	13.8	2.8	6.5	0.1	3.6
Glen Eira⁴	80%	-	2.4 ²	6.0 ³	-	-
Greater Dandenong	59%	-	7.8	4.9	0.0	1.1
Hobsons Bay	73%	-	1.0	5.5	0.7	9.6
Hume	68%	1.0	0.6	1.1	-	-

Council	Heatwaves	Bushfires	Inland flooding		Coastal flooding	
Kingston	76%	-	7.6	7.6	0.6	17.8
Knox	76%	7.3	2.4	3.6	-	-
Manningham	88%	19.2	4.4	1.4	-	-
Maribyrnong	66%	-	3.1	8.1	-	1.6
Maroondah	69%	3.5	0.4	5.1	-	-
Melbourne	55%	-	4.6	2.5	3.3	16.4
Melton	87%	1.1	3.0	0.2	-	-
Monash ⁴	63%	-	2.4 ²	6.0 ³	-	-
Moonee Valley	86%	-	0.9	3.2	0.0	0.2
Moreland	66%	-	0.5	10.1	-	-
Mornington Peninsula	85%	21.3	2.7	0.8	0.1	1.1
Nillumbik	91%	67.6	1.8	0.5	-	-
Port Phillip	73%	-	-	15.2	1.7	31.5
Stonnington	67%	-	1.0	6.5	-	-
Whitehorse	62%	0.5	0.9	2.6	-	-
Whittlesea	83%	6.3	1.4	1.0	-	-
Wyndham ⁴	86%	-	2.4 ²	6.0 ³	0.5 ³	6.2 ³
Yarra	61%	-	4.8	9.7	0.1	0.4
Yarra Ranges	93%	61.5	3.0	0.9	-	-

¹Results for more distant future planning horizon

²Based on average exposure of metropolitan councils

³Based on average exposure of councils exposed to coastal flooding

⁴Total road area was converted from kilometres to square meters based on an assumed width of 10m

Sensitivity

Sensitivity refers to the degree to which assets are damaged by a hazard event. The sensitivity ratings applied to roads for each hazard are presented in Table 11. These ratings have been refined in this phase of the project.

Table 11. Sensitivity ratings applied to road assets in phase 3

Sensitivity rating	Asset damage (% of asset replacement cost)			Notes
	Low	Mid	High	
Bushfires		0%		Based on findings from desktop research and interviews, bushfires are assumed to cause no direct damage to roads. This is supported by AECOM (2023) and Arup (2023).

Sensitivity rating	Asset damage (% of asset replacement cost)			Notes
	Low	Mid	High	
Heatwaves*	16%	24%	32%	Asset damage estimates for heatwaves reflect the reduction in design life of roads in the more distant future, with damage for other planning horizons proportionate to the expected change in mean temperature in Greater Melbourne, under RCP8.5 (Clarke et al., 2019). Heatwave-related damage is assumed to accumulate over the roads design life (i.e. 30 years). The high estimate assumes that a 1°C increase in mean temperature reduces the road's design life by 10%. This assumption aligns with Beecroft's (2018) hypothetical assessment of a thick asphalt road in Perth, used here in the absence of more detailed, location-specific data
Inland flooding	15%	30%	50%	Assumes inundation depths of approximately 10cm, 20cm and 50cm for the low, mid and high scenario, respectively. Based on the range in depths observed for a 1% AEP event from DECCA (2023), and stage damage curve applied in Arup (2023).
Coastal flooding (Sea level rise)	10%	50%	90%	Midpoint estimate assumes that roads damaged by sea level rise are halfway through their useful life.
Coastal flooding (Storm-tide inundation)	15%	30%	70%	Assumes inundation depths of approximately 10cm, 20cm and 100cm for the low, mid and high scenario, respectively, with level of asset damage based on the stage damage curve applied in Arup (2023). Depths are assumed to be conservative based on range in depths observed for a 1% AEP storm at 0.0m sea level rise from DECCA (2023).

*Assumed reduction in design life in 2100

Replacement cost

The replacement cost of roads is used to estimate the cost of repairing or reconstructing roads following damage from a hazard event. The replacement cost of roads has been updated in phase 3 to reflect the latest information on the costs of sealed road reconstruction from Local Government Victoria's (2024). The latest rates are shown in Table 12.

Table 12. Replacement cost rates applied to road assets in phase 3

Asset	Cost (\$ per sqm)			Source
	Low	Mid	High	
Replacement cost of road¹	89	176	381	Based on Local Government Victoria's (2024) Know Your Council - Local Government Performance Reporting data.

¹Based on the range (p10, p50, p90) in costs of sealed road reconstruction for all 32 councils for 2022-23 and 2023-24 indexed to March 25 values based on the ABS's (2025) producer price index for road and bridge construction.

Incorporating a wider spectrum of hazard events

The rates used to estimate the cost of a broader range of hazard scenarios are presented in Table 13.. The results of the analysis for each AEP and planning horizon are presented in Figure 5.

Table 13. Assumed proportionate value of damage relative to 1% AEP event

Annual exceedance probability (AEP)	Inland flooding ¹			Storm-tide inundation ²		
	Low	Central	High	Low	Central	High
20.0%		0%			0%	
10.0%	31%	47%	63%		0%	
5.0%	38%	58%	77%	44%	66%	88%
2.0%	42%	63%	84%	47%	71%	95%
1.0%		100%		44%	66%	88%
0.2%		100%			0%	

¹Based on Arup's (2023) damage estimates for various AEPs, expressed as a percentage of the damage level observed for the 1% AEP event in the previous study. The assumed range spans from 50% to 100% of that level.

²Based on the percentage change in inundation area between events, as reported by McInnes et al. (2022), under a 0.8m sea level rise scenario. The upper bound reflects the observed change in inundation extent between the 1% AEP event, while the lower bound is again set at 50% of this value

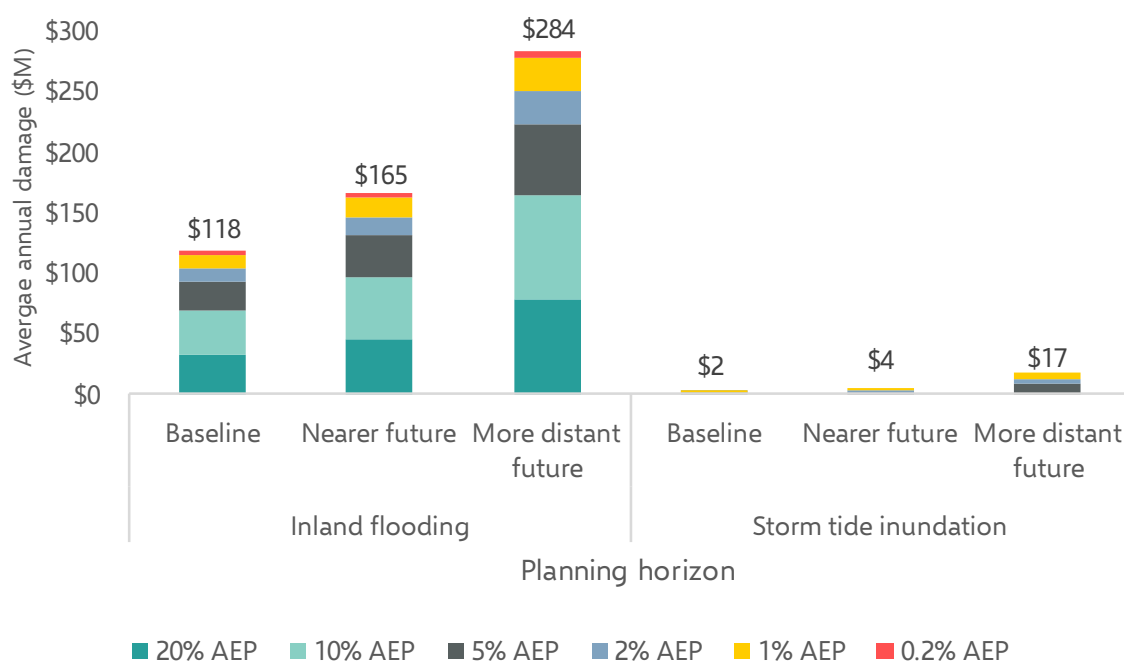


Figure 5. Extrapolated inland and coastal flood damage estimates

Base case results for roads by council

The estimates of AAD for each council, under the revised base case, are presented in Table 14.

Table 14. AAD estimates for each council, under the revised base case (\$000)

Council	Baseline			Nearer future			More distant future		
	Coastal flooding	Heatwaves	Inland flooding	Coastal flooding	Heatwaves	Inland flooding	Coastal flooding	Heatwaves	Inland flooding
Banyule		\$203-\$482	\$641-\$1,783		\$365-\$874	\$891-\$2,506		\$763-\$1,826	\$1,528-\$4,309
Bass Coast	\$65-\$206	\$303-\$720	\$178-\$490	\$295-\$974	\$545-\$1,305	\$246-\$693	\$1,460-\$4,871	\$1,140-\$2,726	\$422-\$1,190
Bayside		\$300-\$714	\$2,394-\$6,757		\$541-\$1,294	\$3,351-\$9,427	\$21-\$65	\$1,130-\$2,704	\$5,738-\$16,216
Boroondara		\$178-\$423	\$742-\$2,076		\$320-\$767	\$1,035-\$2,910		\$670-\$1,601	\$1,773-\$5,003
Brimbank		\$400-\$953	\$2,304-\$6,422		\$721-\$1,727	\$3,207-\$9,018		\$1,509-\$3,608	\$5,495-\$15,504
Cardinia	\$71-\$226	\$502-\$1,193	\$9,909-\$26,645	\$130-\$414	\$904-\$2,164	\$13,571-\$38,129	\$693-\$2,254	\$1,890-\$4,519	\$23,307-\$65,436
Casey	\$784-\$2,502	\$1,826-\$4,344	\$17,137-\$46,766	\$1,256-\$4,016	\$3,289-\$7,875	\$23,625-\$66,400	\$4,627-\$15,112	\$6,878-\$16,450	\$40,536-\$114,037
Darebin		\$194-\$462	\$1,387-\$3,859		\$349-\$837	\$1,929-\$5,424		\$731-\$1,748	\$3,306-\$9,324
Frankston	\$2-\$6	\$271-\$644	\$1,902-\$5,285	\$41-\$130	\$487-\$1,167	\$2,643-\$7,432	\$555-\$1,788	\$1,019-\$2,438	\$4,530-\$12,776
Glen Eira		\$187-\$445	\$1,168-\$3,251		\$337-\$806	\$1,625-\$4,569		\$704-\$1,684	\$2,785-\$7,854
Greater Dandenong	\$116-\$393	\$620-\$1,476	\$7,856-\$21,497	\$157-\$524	\$1,117-\$2,675	\$10,843-\$30,478	\$794-\$2,601	\$2,337-\$5,588	\$18,602-\$52,351
Hobsons Bay	\$134-\$444	\$354-\$843	\$1,839-\$5,151	\$373-\$1,222	\$638-\$1,529	\$2,565-\$7,214	\$4,727-\$15,664	\$1,335-\$3,193	\$4,394-\$12,405
Hume		\$1,428-\$3,397	\$2,129-\$5,902		\$2,572-\$6,158	\$2,956-\$8,311		\$5,378-\$12,862	\$5,067-\$14,285
Kingston	\$30-\$95	\$194-\$462	\$2,295-\$6,316	\$233-\$742	\$350-\$837	\$3,176-\$8,928	\$2,867-\$9,376	\$731-\$1,748	\$5,447-\$15,340
Knox		\$512-\$1,218	\$2,412-\$6,674		\$922-\$2,208	\$3,346-\$9,408		\$1,929-\$4,612	\$5,737-\$16,168
Manningham		\$279-\$665	\$1,108-\$3,011		\$503-\$1,205	\$1,524-\$4,284		\$1,052-\$2,517	\$2,616-\$7,356
Maribyrnong		\$79-\$188	\$788-\$2,193	\$2-\$8	\$142-\$341	\$1,096-\$3,082	\$58-\$181	\$297-\$711	\$1,878-\$5,298
Maroondah		\$178-\$424	\$828-\$2,327		\$321-\$768	\$1,157-\$3,253		\$671-\$1,605	\$1,981-\$5,595
Melbourne	\$171-\$545	\$117-\$278	\$914-\$2,497	\$525-\$1,712	\$210-\$504	\$1,261-\$3,543	\$7,752-\$25,994	\$440-\$1,052	\$2,163-\$6,086
Melton		\$543-\$1,291	\$1,226-\$3,304		\$978-\$2,341	\$1,681-\$4,724		\$2,044-\$4,889	\$2,887-\$8,107
Merri-bek		\$170-\$404	\$1,693-\$4,766		\$306-\$733	\$2,367-\$6,657		\$640-\$1,531	\$4,053-\$11,451
Monash		\$340-\$810	\$1,986-\$5,525		\$613-\$1,468	\$2,762-\$7,766		\$1,282-\$3,067	\$4,733-\$13,351

Council	Baseline			Nearer future			More distant future		
	Coastal flooding	Heatwaves	Inland flooding	Coastal flooding	Heatwaves	Inland flooding	Coastal flooding	Heatwaves	Inland flooding
Moonee Valley	\$10-\$33	\$304-\$723	\$1,091-\$3,047	\$18-\$60	\$547-\$1,311	\$1,520-\$4,275	\$111-\$367	\$1,145-\$2,737	\$2,604-\$7,350
Mornington Peninsula	\$196-\$662	\$2,401-\$5,713	\$5,806-\$15,758	\$377-\$1,269	\$4,326-\$10,358	\$7,985-\$22,439	\$2,322-\$7,624	\$9,046-\$21,635	\$13,705-\$38,527
Nillumbik		\$315-\$749	\$462-\$1,253		\$567-\$1,358	\$635-\$1,785		\$1,186-\$2,836	\$1,090-\$3,065
Port Phillip	\$70-\$220	\$210-\$501	\$2,596-\$7,325	\$324-\$1,031	\$379-\$907	\$3,633-\$10,220	\$7,284-\$23,998	\$793-\$1,895	\$6,221-\$17,581
Stonnington		\$99-\$236	\$652-\$1,826		\$179-\$428	\$909-\$2,557		\$374-\$895	\$1,557-\$4,397
Whitehorse		\$226-\$537	\$759-\$2,113		\$407-\$974	\$1,056-\$2,969		\$851-\$2,035	\$1,809-\$5,104
Whittlesea		\$672-\$1,600	\$1,178-\$3,228		\$1,211-\$2,900	\$1,627-\$4,573		\$2,533-\$6,058	\$2,791-\$7,855
Wyndham	\$217-\$707	\$918-\$2,185	\$5,330-\$14,827	\$597-\$1,945	\$1,655-\$3,962	\$7,411-\$20,840	\$6,797-\$22,533	\$3,460-\$8,276	\$12,701-\$35,825
Yarra	\$121-\$410	\$102-\$242	\$1,446-\$4,012	\$157-\$533	\$184-\$440	\$2,008-\$5,646	\$218-\$734	\$384-\$918	\$3,442-\$9,705
Yarra Ranges		\$981-\$2,334	\$2,466-\$6,700		\$1,767-\$4,232	\$3,393-\$9,535		\$3,696-\$8,839	\$5,823-\$16,372

Appendix B – Cost-benefit analysis results

The CBA results for both present day, near future and more distant future planning horizons are presented in Table 15.

Table 15. Cost-benefit analysis results for a 1-kilometre road affected by each hazard (p10 and p90 estimates)

Adaptation option	Planning horizon	Present value cost (\$'000)	Present value benefit (\$000)	Benefit-cost ratio
Heatwaves and more extreme temperatures				
Increase use of binders with higher softening points	Present day	\$69 - \$183	\$7 - \$18	0.05 - 0.19
	Nearer Future		\$12 - \$30	0.08 - 0.32
	More distant		\$20 - \$50	0.14 - 0.53
Increase asphalt thickness	Present day	\$190 - \$298	\$7 - \$18	0.03 - 0.08
	Nearer Future		\$12 - \$30	0.05 - 0.13
	More distant		\$20 - \$51	0.08 - 0.22
Increase the solar reflectance of pavements	Present day	\$210 - \$280	\$2 - \$6	0.01 - 0.02
	Nearer Future		\$4 - \$10	0.02 - 0.04
	More distant		\$6 - \$16	0.02 - 0.07
Introduce road shading with trees	Present day	\$419 - \$545	\$2 - \$6	0.00 - 0.01
	Nearer Future		\$4 - \$10	0.01 - 0.02
	More distant		\$6 - \$16	0.01 - 0.03
Inland flooding				
Upgrade drainage systems	Present day	\$277 - \$709	\$215 - \$618	0.40 - 1.60
	Nearer Future		\$296 - \$858	0.55 - 2.22
	More distant		\$432 - \$1,268	0.80 - 3.28
Apply water sensitive urban design measures	Present day	\$741 - \$1,174	\$215 - \$618	0.22 - 0.69
	Nearer Future		\$295 - \$856	0.30 - 0.96
	More distant		\$431 - \$1,264	0.45 - 1.42
Conduct more regular maintenance	Present day	\$132 - \$373	\$185 - \$535	0.66 - 2.92
	Nearer Future		\$254 - \$741	0.91 - 4.04
	More distant		\$371 - \$1,093	1.34 - 5.97
Ground and pavement stabilisation	Present day	\$529 - \$1,222	\$366 - \$1,054	0.39 - 1.48
	Nearer Future		\$505 - \$1,461	0.53 - 2.05
	More distant		\$736 - \$2,162	0.78 - 3.03
Coastal flooding (storm-tide inundation)				
Upgrade drainage systems	Present day	\$277 - \$709	\$154 - \$508	0.29 - 1.29
	Nearer Future		\$154 - \$509	0.29 - 1.30
	More distant		\$154 - \$509	0.29 - 1.30

Adaptation option	Planning horizon	Present value cost (\$'000)	Present value benefit (\$000)	Benefit-cost ratio
Apply water sensitive urban design measures	Present day		\$134 - \$441	0.14 - 0.49
	Nearer Future	\$741 - \$1,174	\$135 - \$445	0.14 - 0.50
	More distant		\$135 - \$446	0.14 - 0.50
Conduct more regular maintenance	Present day		\$80 - \$260	0.29 - 1.41
	Nearer Future	\$132 - \$373	\$80 - \$262	0.29 - 1.42
	More distant		\$80 - \$262	0.29 - 1.43
Ground and pavement stabilisation	Present day		\$158 - \$514	0.17 - 0.71
	Nearer Future	\$529 - \$1,222	\$158 - \$518	0.17 - 0.71
	More distant		\$157 - \$519	0.17 - 0.71
Coastal flooding (sea level rise)				
Raise road (0.25 meter)	Present day	\$364 - \$638		0.67 - 2.67
Raise road (0.5 meter)	Nearer Future	\$727 - \$1,276	\$342 - \$1,230	0.33 - 1.34
Raise road (1 meter)	More distant	\$1,091 - \$1,914		0.22 - 0.89

Appendix C – Findings from interviews

Interviews with council staff and other experts were undertaken in phase 3 to gain a more detailed understanding of the impacts of climate hazards on roads in Greater Melbourne and of potential adaptation options. Table 16 provides a summary of the findings from these interviews. The findings are presented by hazard (i.e. bushfires, heatwaves, flooding).

Table 16. Findings from interviews

Hazard	Findings
Bushfires	Impacts • Direct damage to roads is limited but includes: – Melting or oxidation of spray seal surfaces. – Destruction of signage, line markings, and guideposts. – Fallen trees damaging infrastructure and blocking roads. • Post-fire rainfall leads to: – Blocked drains. – Erosion and landslips due to soil movement and water accumulation. Adaptation Measures • Polymer-modified bitumen with higher softening points (up to 80°C). • Improved culvert liners that resist burning. • Drainage maintenance is critical post-fire to prevent erosion. • Foam bitumen stabilisation and sealing roads in fire-prone areas to ensure access.
Heatwaves	Impacts • Asphalt roads: – Softening, rutting, and “bleeding” (bitumen rising to surface). – Deformation under heavy vehicles, especially on steep roads. – Increased maintenance needs, particularly for newer roads. • Unsealed roads: – Dust generation, affecting residents and requiring mitigation (e.g., water trucks). • Combined effects of heat and traffic loads accelerate deterioration. Adaptation Measures • Heat-resistant binders (20% more expensive). • Cool road coatings (e.g., white paint) trialled but with limited durability. • Lighter aggregates to reduce heat absorption. • Preventative maintenance (e.g., sealing every 7 years). • Speed reductions and dust suppressants for unsealed roads.
Flooding	Impacts • Asphalt roads: – Potholes, edge breaks, and base layer failure due to water infiltration. • Unsealed roads: – Washouts, rutting, and sediment runoff into drains. • Drainage systems: – Often undersized for current rainfall intensities. – Blockages exacerbate road damage. • Coastal flooding:

Hazard	Findings
	- Saline water accelerates road degradation. Adaptation Measures • Drainage upgrades: - Larger pipes, sediment pits, open drains, and hay bales. - 20% capacity increase to account for climate change. • Primer layers on asphalt to waterproof surfaces. • Detention systems and rain gardens (though costly and maintenance-intensive). • McAdam pavement (asphalt over large rock) for resilience. • Pilot projects testing recycled materials (e.g., rubber, glass). • Improved maintenance schedules and AI-based monitoring proposed.