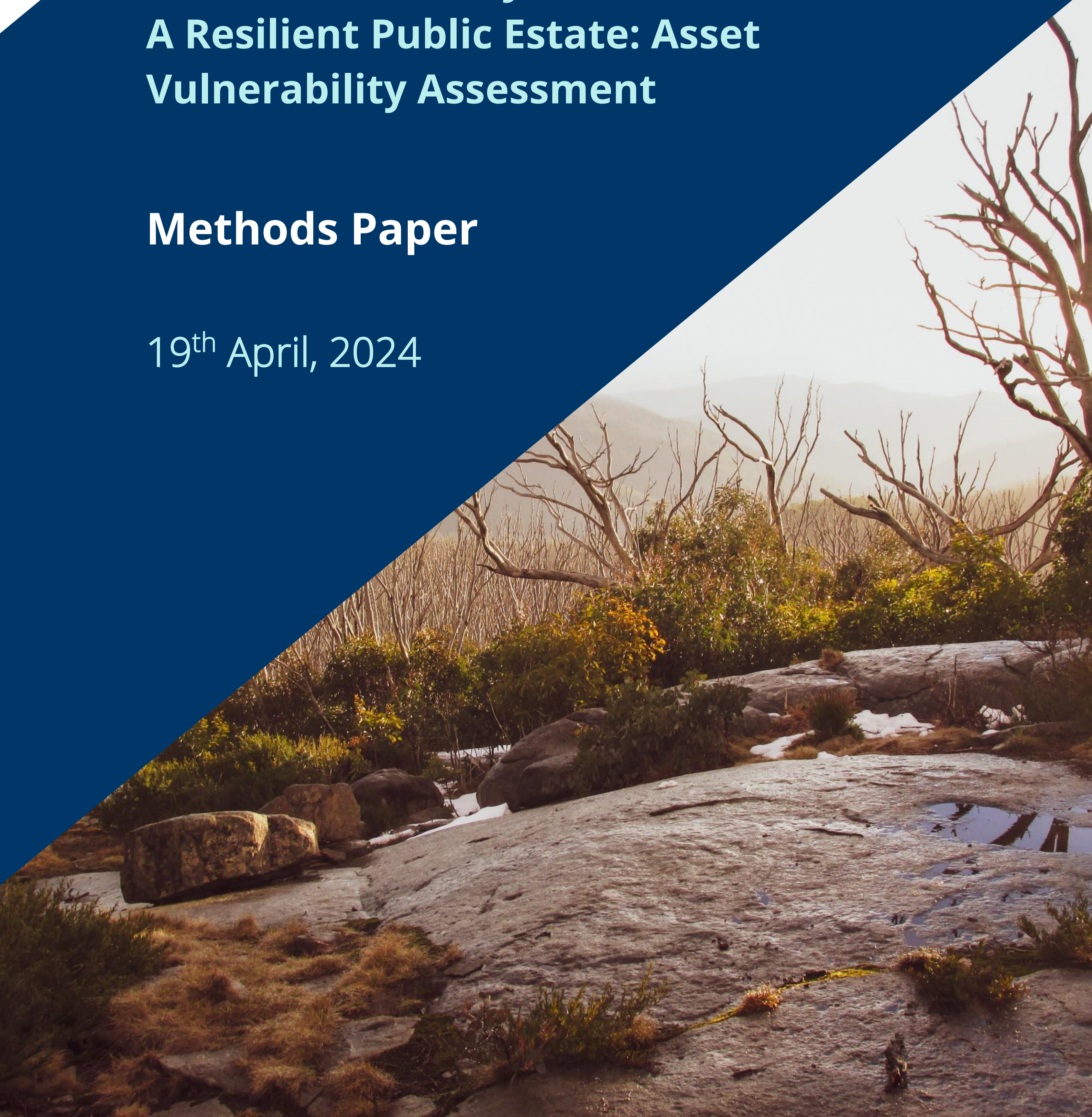
Goulburn Murray Climate Alliance – A Resilient Public Estate: Asset Vulnerability Assessment

Methods Paper

19th April, 2024



About this Document

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Spatial Vision acknowledges First Nations people as the First Peoples of Australia and the Traditional Custodians of its lands and waters. We pay respect to the deep connection First Nations people hold with Country, and celebrate the continuing effect of cultural knowledge and practices on Country and communities across Australia.

We pay our respect to Elders past and present, whose knowledge and leadership has protected Country and allowed First Nations spirituality, culture and kinship to endure through the ages.

Contents

1. This document

This report presents the high-level vulnerability assessment approach applied to agreed council assets as part of the ‘Resilient Public Estate Project’ undertaken with the Goulburn Murray Climate Alliance (GMCA). This region wide component of the project is termed to Asset Vulnerability Assessment (AVA) component. This high-level assessment approach is part one of a two-part vulnerability assessment and is equivalent to what is generally termed a first pass assessment climate change study in that it comprises a high-level generic assessment based on an agreed set of asset attributes. This part one assessment was applied on a GMCA region wide basis.

A more detailed part two vulnerability assessment, or second pass assessment, was undertaken in the form of case studies. These case studies included a detailed review of anticipated costs in relation to specific climate related impacts, and an evaluation of adaptation and replacement options to reduce projected climate change costs.

2. Background

2.1. This project

To better plan for likely climate change related impacts, council staff need to better understand the anticipated changes in the climate and the associated flow on effects. This change in the climate can be expressed in terms of climatic variables, such as days over 35°C per month, or in terms of flood recurrence such as 1 in 100-year events

Spatial views of where change is likely to occur, such as which areas are more likely to be flooded, or be subjected to a greater number of heatwaves, are required to identify the likely impact of the anticipated changes.

By utilising the most recent climate projections from CSIRO and DEECA, as well as region wide inundation, the level of change across the GMCA region can be identified. Critically, this change needs to be defined relative to an appropriate baseline or reference period so that future exposure to change and associated impacts can be accurately identified.

Therefore, a key first step in this project was the suitable collation and standardisation of data, including climate and climate projection data, and relevant council climate event or event modelling data.

2.2. Understanding likely change

Vulnerability is a function of exposure to climate factors, sensitivity to change and capacity to adapt to that change. To suitably identify or model the likely vulnerability of a particular asset requires an understanding of how sensitive a particular asset is to different levels of change, and whether there are factors, such as asset condition, that increase or reduce the impact of the anticipated change.

It is important that key attributes of an asset that influence its sensitivity, such as the materials it is built from, the design standard under which it was built, or its age, are identified so that the likely impact of an identified level of exposure to change can be expressed in terms of the likely impact this change will have on an asset. These attributes essentially define an asset and are generally unable to be changed.

In addition, there are factors about an asset that you can change, such as its maintenance level, or barriers built to protect an asset. These can be termed adaptation activities (or adaptive capacity factors). Bringing these together in a well-defined and consistently applied framework is critical in determining and assigning a meaningful impact and vulnerability rating to an asset.

Each council asset type will be influenced by, and have different levels of sensitivity to, particular hazards. A key aspect of this vulnerability assessment was to determine the likely exposure over time to hazards (such as heat waves).

The first pass assessment, or high-level assessment applied in this study used spatial analysis to assign a high-level vulnerability assessment rating to key assets for climate variables.

This approach is further detailed in this document.

2.3. Case studies

More detailed vulnerability assessments were undertaken in the form of case studies, which are viewed as a second pass assessment process in this project.

These case studies use a scenario (or set of) to describe how a particular extreme weather event that is exacerbated by climate change, impacts a particular location and how the impacts can be reduced through adaptation measures. The results are aimed at assisting higher level decision making by council officers and managers rather than finer level planning decisions.

These case studies:

- Provide a focus for effort to achieve a more detailed vulnerability assessment, economic/financial review of options and costings, and hence the provision of a more valuable set of outcomes.
- Support the building of skills and provide mentoring in how to formulate and evaluate options to reduce likely impacts in a particular location through adaptation measures.
- Provide the focus of discussion and insight.
- Provide practical exemplars for future reference.
- Provide the basis of mentoring sessions that will aim to transfer longer term capability in the assessment approaches pursued.

The case studies aim to:

- ensure there are practical actions LGAs can take
- step through the process with practical and relevant examples
- package up the process so that it can be reapplied and is translatable by Council staff

Case studies apply the full vulnerability assessment processes identified where there is support data, and the financial implications of Business as Usual (BAU) and adaptation approaches. A key output of these case studies is the delivery and imparting of skills in the application of these processes to allow councils to run and update these assessments if data is updated or if more data is sourced.

A description of these second pass case studies is provided in a separate document. They comprise:

- Murrindindi Shire Council: Costs and benefits of upgrading Thornton bridge.
  Where this case study considers:
    - Major flooding on the Goulburn River risks sweeping the Thornton bridge off its pads

  - Climate change will increase the likelihood of major flooding occurring on the Goulburn River
  - A possible levee to protect Thornton township from flooding could also increase risk to the bridge
  - The bridge and road are important for local tourism and freight access
  - A bridge upgrade could also be combined with riparian revegetation

- City of Greater Shepparton: economic benefits of increasing tree canopy cover.
  Where this case study considers:
  - Extreme heat and heatwaves pose major health risks to local communities, especially to infants and the elderly
  - Climate change is likely to increase the frequency and severity of heatwaves
  - Increasing tree canopy has been demonstrated to reduce the ambient temperature and severity of extreme temperature days in built up areas.
  - This case study will assess the health and other benefits of increasing tree cover in Shepparton through its Urban Forest Strategy.

2.4. Extreme weather events and climate change projection data

While extreme weather events are not readily modelled in the latest climate science and down-scaled modelling available through the CSIRO, the latest modelling outcomes are used to help contextualise key trends in the climate data that directly influence likely extreme weather events for the region. For example, the locations where daily rainfall is anticipated to exceed a particular threshold at a future date under a particular scenario are identified.

2.5. Planning for climate change and its impacts

Having identified the anticipated impact of change, the key issue for councils is what to do about it. As previously noted, these issues were explored in the more detailed second pass vulnerability assessments undertaken in the form of case studies. These case studies will include a review of anticipated costs in relation to specific climate related impacts.

3. Our vulnerability assessment approach

3.1. Use of climate change modelling data

The asset vulnerability assessment approach applied in this project uses the most recent climate projections for Victoria the Victorian Climate Projections 2019. The Victorian Government worked with CSIRO to provide dynamically downscaled 5km x 5km statewide projections for six Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) global climate models. This application ready data has been applied in this project.

These modelled climate variables and associated impacts, as outlined in the previous chapter, were processed into a vulnerability rating.

3.2. Vulnerability method overview

The concepts and definitions adopted in this project draw on elements of the overall vulnerability assessment method as outlined and adopted in: *Guidelines for Developing a Climate Change Adaptation Plan and Undertaking an Integrated Climate Change Vulnerability Assessment; November 2012; Local Government Association of South Australia.*

Underpinning the broader concepts around an overall vulnerability assessment method are the approaches developed by the IPCC, 2007. These methods describe how likely exposure to climate scenarios, and sensitivity and adaptive capacity of assets and systems to these climate changes, are used to assess the likely impact and vulnerability of assets and systems to these changes.

The broader conceptual framework on which these vulnerability assessment approaches are based is presented in Figure 1.

Solid lines indicate direct affective relationships between biophysical components (such as the impact of climate change on direct climate variables, or of non-climate variables on exposure to climatic variables). Dashed lines indicate the effects of human activity, including the impacts of climate change, and adaptation and mitigation activities (adapted from: Capon et al 2013, and developed by Brunckhorst, 2011).

This approach generates an impact rating based on the assessed inherent sensitivity of an asset to different climate change parameter exposure scenarios. The adaptive capacity of an asset in relation to impacts is also assessed and used to assign asset vulnerability, where adaptive capacity primarily relates to attributes that can be altered, such as the condition or context of an asset.

Spatial datasets depicting assets are utilised in the application of this process.

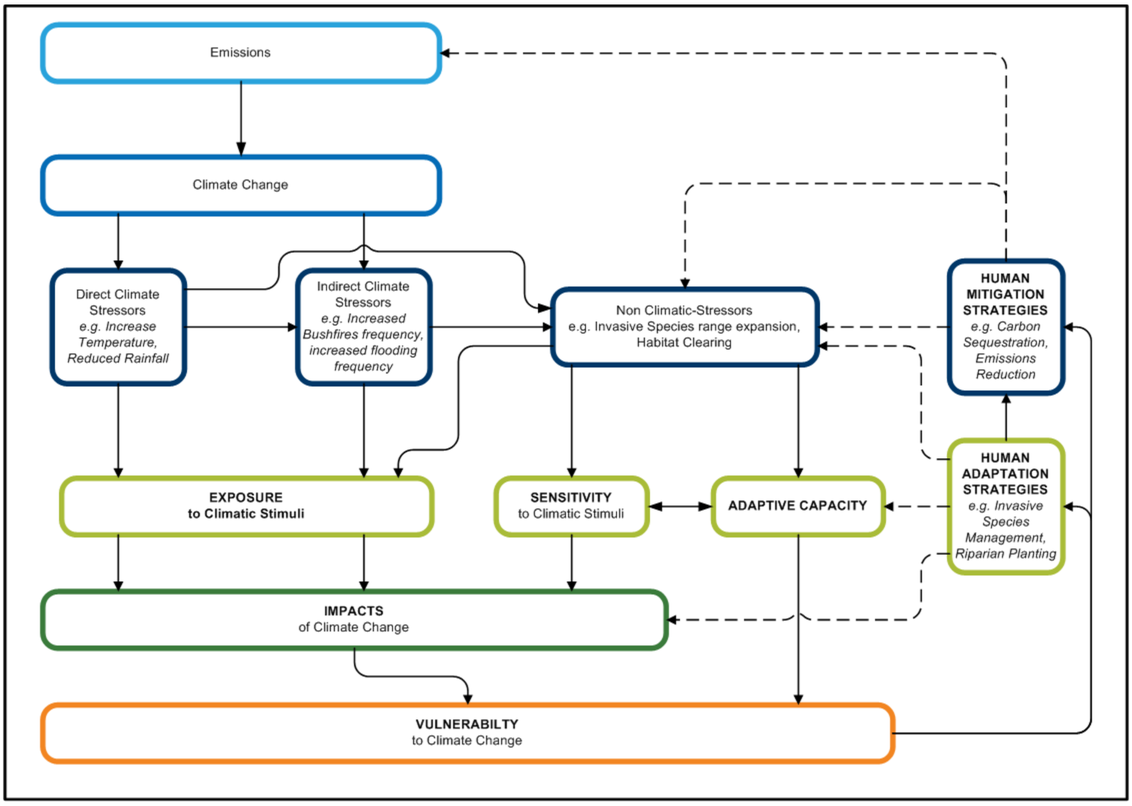

Figure 1. High-level conceptual framework for assessing vulnerability to climate change, showing relationships between exposure, sensitivity, impacts, adaptive capacity, and vulnerability (Source: Copan 2014)

3.3. Asset vulnerability assessment (AVA) – first pass approach

A first pass asset vulnerability assessment involves using individual asset characteristics to assign a likely estimate of an asset's sensitivity to individual climate change variables, and features of the asset impacting its adaptive capacity to such change. Suitable asset attribute information is required to support such an assessment.

A review of how individual asset attributes are used to support such an assessment was undertaken and agreed with Council staff. The final approach adopted for each asset type and climate change variable was presented and discussed with the Project Working Group prior to implementation.

Figure 2 presents how a Vulnerability Assessment Framework was applied in the GMCA project. As indicated, this framework has been developed by the International Panel on Climate Change (IPCC 2001, IPCC 2007) and previously applied in multiple climate change vulnerability assessments (Spatial Vision 2013, 2021) (Spatial Vision 2020).

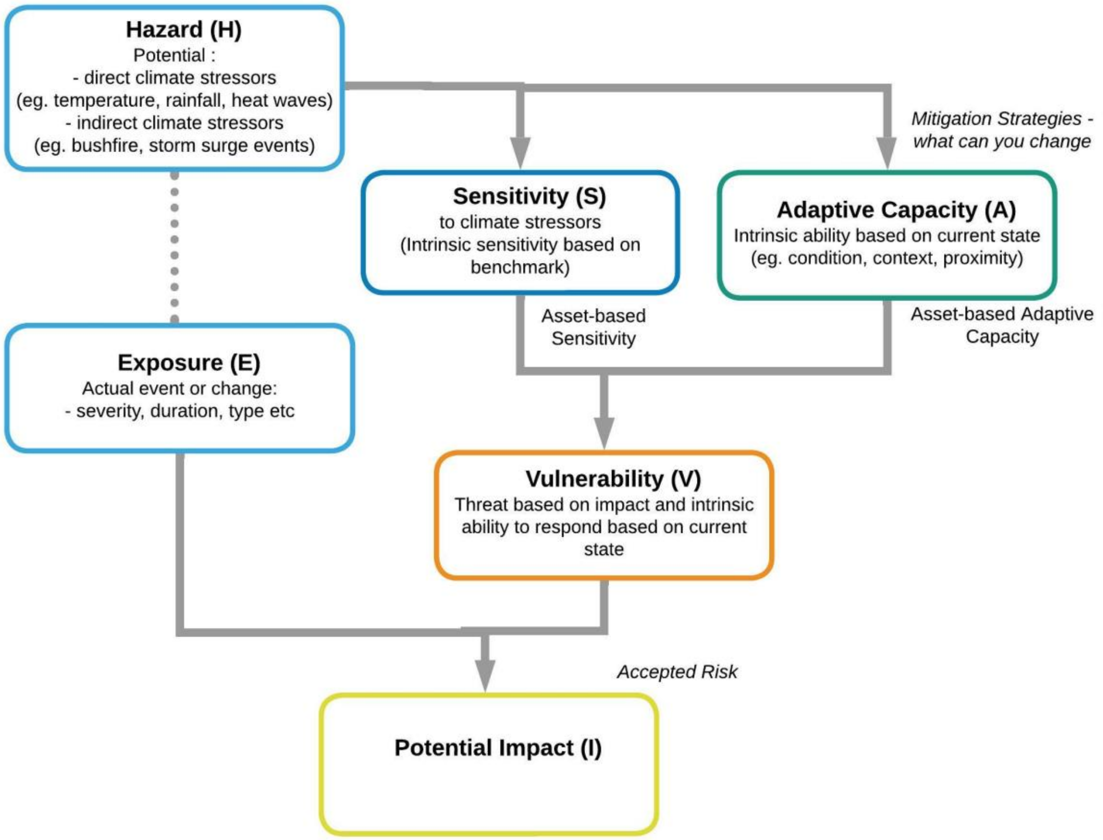

Figure 2. Proposed high-level conceptual framework to be adopted in this study building on the earlier AVA work

Key definitions relating to this framework are:

Vulnerability: the degree to which a system is susceptible to, or unable to cope with **shocks and stresses.** Vulnerability is a function of the character and magnitude of shocks and stresses to which a system is exposed, its sensitivity, and its adaptive capacity

Resilience: the ability of a system to deal with **shocks and stresses,** while retaining the same basic structure and functioning's, the capacity for self-organisation, and the capacity to adapt to stress and change

Climate Resilience: the ability of a system to **absorb** and recover from **climatic shocks and stresses**, whilst positively **adapting** and **transforming** their structures and means for living in the face of long-term change and uncertainty

Exposure: relates to the influences or stimuli that impact on a system. Exposure is a measure of the predicted changes in the climate for the future scenario assessed. It includes both direct variables (such as increased temperature), and indirect variables or related events.

Hazard: refers to a process, natural or otherwise, that has the potential to impact on a given area to a degree that assets associated with that location may be at risk. In the context of coastal areas, these hazards are primarily naturally driven and can include processes such as storms and sea level rise. However, anthropogenic influences on these processes are indirectly increasing the impact of the hazards.

Impact: refers to the effect on the natural or built environment to hazards, including extreme events such as storms and other climate events. It relates to the exposure of an asset to a particular hazard and the sensitivity of that asset to that exposure.

Sensitivity: reflects the responsiveness of a system to climatic variables, and the degree to which changes in climate might affect that system in its current form. Sensitive systems are highly responsive to climate and can be significantly affected by small climate changes. This term is often used interchangeably with the term susceptibility.

Capacity: broadly relates to intrinsic or inherent factors to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Risk: can be defined as the potential to lose or gain something of value based on actions or inactions. A risk assessment, or analysis, is the process in which these potential risks are evaluated, and the projected consequences are defined based on this action or inaction.

The AVA framework has been employed over many applications and has been altered to adapt to new understandings within applied climate studies. This variation on the AVA approach centres on risk as a central concept and splits hazard and exposure to focus on what the hazard (or shock) is and where and how severe the exposure (or stressor) is.

The hazard (or threat) is separate from exposure (the event or change over time), and the hazard informs the likely vulnerability based on sensitivity and capacity of an asset or system to respond in relation to the hazard. The potential impact or risk therefore results from the combination of the vulnerability of an asset or systems and the actual exposure (or event) it experiences in terms of its severity, duration, and spatial extent.

An assessment of risk in relation to climate change should not only concentrate on factors that relate directly to climate change, as has been the approach with the AVA framework, but it should also incorporate other pathways and options that a system may take. According to the IPCC, not only does the severity of a disaster depend on climate events, but it is also dependent on exposure and vulnerability which arise from non-climatic factors. These include exposure to food security and water supply challenges, for example.

4. Climate data inputs and assumptions

4.1. Climate hazard and exposure data

Several climate change related variables and impacts were assessed to identify 'high risk' or priority assets within the GMCA Study Region. These climatic related variables include:

- Temperature (minimums and maximums)
- Extreme temperature and heat waves.
- Rainfall (monthly and seasonal)
- Extreme rainfall and rainfall deficiencies (Dryness Index)
- Overland flooding

The following sections explore each of these variables in more detail, primarily around the use of data and available sources that were leveraged in the process of a climate impact and vulnerability assessment.

4.2. Flooding and inundation

Flooding and inundation impacts were considered in the GMCA project but have not directly been incorporated or assigned to likely climate futures. Inundation data that was available for use in this project includes modelled flood extent information as per Victorian Planning Overlays and other modelled flood extents.

This flood extent data identifies the likely area flooded for a standardised recurrence interval of 1 in 100-year event, or a 1% Annual Exceedance Probabilities (AEP). From the planning overlays the main points of data extracted included:

- Land Subject to Inundation Overlay (LSIO)
- Flood Overlay (FO)
- Special Building Overlay (SBO)
- Urban Flood Zone (UFZ)

This data was sourced from State Government and has been collated into one main flooding layer.

It is acknowledged that individual Councils, or groups of Councils, may have undertaken more detailed flood modelling for their relevant jurisdictions. This may include additional depth, extent and recurrence intervals for selected rivers and catchments. However, this highly accurate data is very location specific, and will not have consistent coverage region wide.

For use in this project full coverage is critical, hence the use of planning overlays as the key source of flood related data.

Future climate projections of flooding extent and depth can be problematic to model. Factors such as river flow velocities, local terrain and flow restriction points, localised landscape weak points and landslip areas prone to increase flow velocity, and other hydrological factors need to be accounted for if modelling future scenarios.

Projects, such as those by Melbourne Water, have begun creating flood depth analysis using a climate forcing for their jurisdictional boundaries, but currently this is only for a limited number of creeks and basins and is only for the year 2100, and only for Melbourne.

Using current recurrence intervals and AEP levels, a basic understanding of future scenario points can be obtained. It is accepted that under likely future scenarios, flooding and inundation will become more frequent due to increased sea levels and changed climate rainfall patterns.

However, the application of historical recurrence intervals in combination with future climate projections requires expert guidance.

4.3. Projected climate change and climate change related events

The first pass asset vulnerability assessment includes consideration of the following projected climate change variables that are derived from the most recent climate modelling prepared by CSIRO and made available as part of the Victorian Climate Projections 2019 Project:

- Percentage and degree increase of annual extremely hot days (defined as change that occurs to the top 1% of events)
- Percentage and millimetre change of annual extremely wet days (defined as change to events that occur to the top 1% of events)
- Percentage reduction in total annual rainfall (from baseline) as proxy for dryness in region.

These three variables form the basis of future scenarios that are assessed in this project, namely;

- Hot scenario – extreme hot days
- Wet scenario – extreme rainfall days
- Dry scenario – rainfall reduction

Each of these three scenarios wase underscored by the supporting climate projection data but was also be augmented through the use of correlating hazard data.

In creating changes from a current scenario, a baseline climate is used to quantify the percentage increase or decrease. The baseline climate data is the same as that used in the VCP2019 project which is the period 1981 to 2010.

The VCP2019 projections comprise downscaled, region wide, application-ready data derived from the most recent climate modelling prepared by CSIRO as an outcome of the IPCC 5th Assessment Report (AR5).

In relation to the application of these climate variables it is proposed that the most critical projected climate variables likely to impact the vulnerability of an individual asset by type be considered.

Preliminary thoughts on which projected climate change variables to apply to asset types on this basis and applied in this study are presented in Table 1.

The starting point for an assessment of the likely impacts of anticipated climate change on different asset types is an indicative relationship between asset types sensitively and climate change parameters. The results presented in this table, depicting asset type and climate change parameters was reviewed in conjunction with the anticipated changes for a region for a particular climate model.

The table rates the sensitivity of a broad asset group to climate change parameters. Where no sensitively is assigned, it has been assessed the asset types are unlikely to be impacted by changes in the climate change parameter. However, this can alter in light of new evidence and scale of focus.

Table 1. Initial thoughts of the two or more most critical projected climate variables likely to impact the vulnerability of individual assets by type

Asset Type	High Max Temps	More High Temp Days	Heat waves	Reduced rainfall	Extreme rain events	High Wind	Floods	Sea Level Rise
Council Building					M	H	L–H	L–H
Parks & Reserves	H	H	H	H	M	H	M–H	L–H
Street Segments	M	M	M		M		H	
Footpath	L	L	L	M	M		M	
Kerb and Channel	L	L	L	M	M		M	
Carpark	M	M	M		M			
Bridge					M	M	H	L–H
Storm Water				L	H		H	L–H
Water Features	M	M	M	M	H		M	L–H
Sewer	M	M	M	M–H	H		H	H
Drainage Reserve	L	M	M	H	H		H	M–H
Metered Light						M		
Streetlight						M		
Trees	M	H	H	H	M	H		

Application of the latest climate change data from CSIRO involved evaluating relevant annual and monthly climate variable data for agreed carbon emission scenarios. This information has also been presented in a QGIS spatial data viewer as part of the GMCA project.

4.4. Climate models and climate scenarios

The climate variables are generated for three General Circulation Modes (GCMs), representing:

1. Maximum consensus future climate (based on all six available VCP19 models (Clark et al., 2019))
2. Hotter and drier future climate
3. Warmer and wetter future climate

This approach is in line with best practice climate change modelling advice that all futures represented by each GCM are equally possible and ideally 2 or 3 different GCMs should be considered in any vulnerability evaluation. The approach applied in this project to incorporate a range of possible futures is presented in Section 6.

The three models selected to represent the range of likely futures for both temperature and rainfall projections include the NorESM1-M, HadGEM2-CC and ACCESS 1.0 GCMs, where these models have been developed by:

1. ACCESS 1.0 - CSIRO and BoM – representing a maximum consensus future
2. HadGEM2-CC - Met Office Hadley Centre – representing a hotter and drier future
3. NorESM1-M - Norwegian Climate Centre – representing a warmer and wetter future

4.5. Carbon emission futures

In terms of climate projections based on carbon emission future scenarios, GMCA expressed interest in the Representative Concentration Pathway (RCP) emissions scenarios of 4.5 and 8.5 (RCP4.5 and RCP8.5), noting that the VCP2019 projections are only available for an RCP4.5 and RCP8.5 carbon emission future. This first pass vulnerability assessment therefore presents the findings for these two RCP futures.

4.6. Time frames

The VCP2019 projections are available for the years of 2030, 2050, 2070 and 2090.

This projection data is based on a baseline climate represented by the period from 1981 to 2010. While the project compiled and reviewed the projection data for all four future time periods, there is a focus on presenting results and outputs for the period up until 2050. Inclusion of three models for two RCPs and four time points, results in a significantly large volume of data and outputs. Reporting and presentation focusses on one time-point to present the context of the results, but other points can be incorporated in to further expand discussion.

It is noted that for the period to 2030 changes in the projections for most parameters for any GCM at both RCP 4.5 and 8.5 are minimal, but for periods after, such as 2050, there are considerable differences (see below Figure 3 that shows the changes in global temperatures) (IPCC 2007).

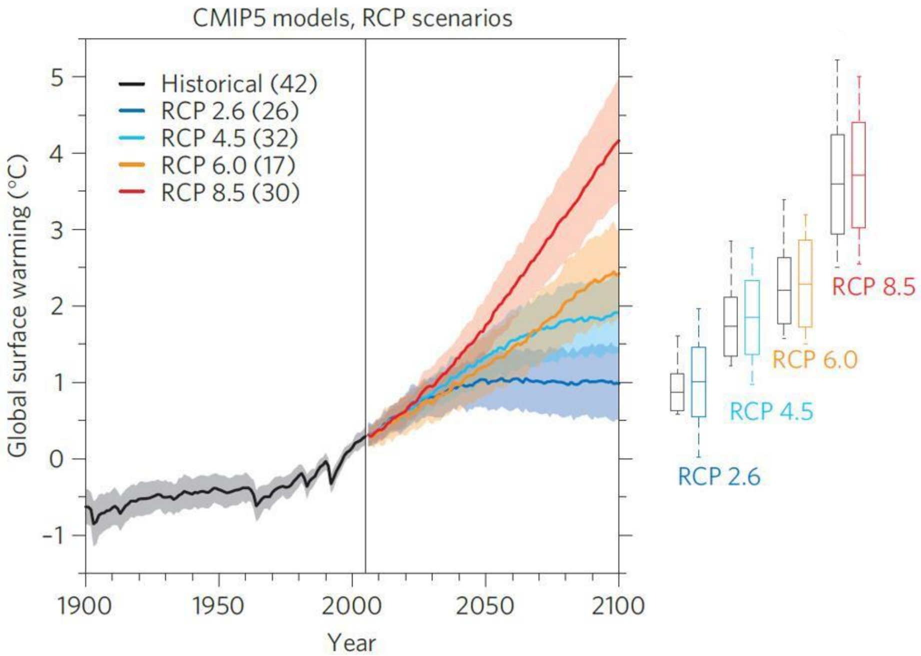

Figure 3. Relationship between four RCP scenarios, where RCPs provide standardised greenhouse gasconcentration inputs for running climate models.

5. Key asset attributes to assess vulnerability

5.1. Asset data and representation

Included within the analysis are four key asset groups;

- Buildings
- Roads
- Bridges
- Open Space

For consistency across the GMCA region and between each Council, spatial asset data has been obtained from multiple open-source data platforms and providers. Table 2 below indicates the key data sources for asset information and their spatial representation in the study. The majority of data has been sourced from the Vicmap program run by the Victorian Government. Full metadata statements and sources are provided in the data package as a spreadsheet, this also includes metadata for all data sources used in the analysis.

Table 2. Key assets and relevant data sources

Asset	Key Open Data Sources	Spatial Representation
Open Space	Vicmap – Features of Interest Public Land Management (PLM) Victorian Land Use Information System (VLUIS)	Polygon
Buildings	Vicmap – Features of Interest Open Street Maps (OSM) Public Land Management (PLM) Toilet Block Location	Point
Road	Vicmap – Transport	Line
Bridges	Vicmap – Transport Department of Transport (DTP)	Point

Also indicated in the table is the spatial representation type of each asset group. Only Open Space is represented as a polygon type due to data sources allowing for this. Buildings were initially represented as polygons, but due to some data sources applying the full cadastral lot rather than an actual building footprint, it was decided to represent all buildings as points.

5.2. Asset attribution

The vulnerability of an asset is highly dependent on multiple factors some of which are inherent to an asset and others that are external to the asset. Factors inherent to an asset can include the asset's age, material, or the level of service and use. External factors include proximity to water bodies or flood plains, or tree and vegetative cover.

For this project, these factors have been termed attributes and have been used to identify the likely sensitivity or adaptive capacity of an asset to climate change.

Due to the open-source nature of the asset information, detailed information for some assets was not available. For example, building material was not available within any of the data layers. Hence, for some assets, it is more the surrounding environment, potential exposure to a hazard of concern and context to other assets or population centres that has driven this assessment.

Application of asset attributes to be used in the vulnerability assessment based on a preliminary review of the sourced GMCA attribute data obtained for buildings, bridges, road, and open space assets is presented in Table 4. The table identifies the attributes that were identified in relation to the assignment of a sensitivity rating, and attributes that are potentially an indicator of capacity.

Table 3. Application of attributes used in vulnerability assessment based on a preliminary review of the GMCA council asset attribute data

Open Space (All Scenarios)	Buildings (Wet Scenario)	Roads (Wet and Hot Scenario)	Bridges (Wet Scenario)
Capacity Factors • Vegetation	Capacity Factors • Feature Type (level of service) • Population	Capacity Factors • Feature Hierarchy (Both)	Capacity Factors • Bridge Condition Rating
Sensitivity Factors • Feature type (Level of Service) • Feature type (Material/Surface) • Perimeter/Area ratio • Surrounding road context • Flood Overlays & Zones (Wet)	Sensitivity Factors • Vegetation • Soil - Percentage Clay • Clustering of Assets • Flood Overlays & Proximity to Water Bodies	Sensitivity Factors • Seal/Material (Both) • Household has one or more Cars (Both) • Road slope (Wet) • Flood Overlays & Zones (Wet)	Sensitivity Factors • Material • Type • Flood Overlays & Proximity to Water Bodies • Waterway Hierarchy Type
Other • Water Supply and Management • Vegetation Type	Other • Soil Type • Renewables • Evacuation Point/Refuge	Other • Transmission Lines • Vegetation • Connectivity • Vehicles Per Day	Other • Connectivity • Vehicles Per Day • Year of Construction

For some assets, attributes that indicate who manages or is responsible for a given asset are available. For example, for open space it can be determined if the park or reserve is managed by Parks Victoria, DEECA or Council. This allows for the end results to be filtered for relevancy to Council.

These attributes, that are viewed to be of value in an assessment of climate change vulnerability, have been determined through consultation with asset managers and representative for each participating Council. During this discussion, several factors and likely attributes were identified for possible inclusion in this analysis, but in the end not included. These are shown as 'Other' in the above table and were explored for application in a spatial context, but not used.

For example, under roads, transmission lines and roadside vegetation have been explored. But the context in which they would have been used, more relates to the consequence of disruption of service of the asset, rather than vulnerability of the asset itself. The criticality of an asset and the service is viewed as a secondary assessment, whereas the focus of this Asset Vulnerability Assessment is to determine the vulnerability of the asset itself.

A few other attributes also listed in the above table were explored but eventually removed from the analysis and inclusion in the framework. For example, Vehicles Per Day (VPD) under roads has been excluded as it duplicates results in the model since vehicle numbers can be assumed based on the hierarchy of road type. Hierarchy is also used to consider likely wear of a road surface, and hence possible maintenance. Using the same attribute in a similar manner but re-titled as something different would weight roads too heavily and skew results.

6. Approach in assigning final ratings

6.1. Assignment of asset vulnerability ratings

The first pass asset vulnerability assessment applied in this GMCA project involves applying a vulnerability assessment for one or more agreed projected climate change variables and associated scenarios for each asset, as presented in Table 1 and reporting on the outcome of each.

As per Section 4.3, these variables and scenarios are;

- Hot Scenario – Extreme Hot Days
    - Percentage and degree increase of annual extremely hot days (defined as change that occurs to the top 1% of events)
- Wet scenario – extreme rainfall days
    - Percentage and millimetre change of annual extremely wet days (defined as change to events that occur to the top 1% of events)
- Dry scenario – rainfall reduction
    - Percentage reduction in total annual rainfall (from baseline) as proxy for dryness in region.

Hence, for each asset class (buildings, roads, bridges and open space), up to three individual vulnerability assessments were undertaken. These results may be combined on the basis of either: the worse rating, a weighted approach, or another approach, to combining the results. In this study the average, and hence an equal weighting of results was used.

This first pass asset vulnerability assessment process was applied for the agreed projected climate change variables for each climate scenarios, for each future time point. This results in each asset having three vulnerability scores, for three projected climate change scenarios, under two RCPs under four time points.

In relation to the four time points (2030, 2050, 2070 and 2090) a key reference year of 2050 under the ACCESS 1.0 RCP 8.5 model, was used to review and present the first pass asset vulnerability assessment findings.

6.2. Relative climate changes application

For each of the three climate projection scenarios, or possible futures (RCPs), relative change from a baseline was determined rather than absolute values.

These changes were classified into categories of change ranging from '1 Very Low' to '5 Very High', which can then be used as the basis for identifying the likely exposure of assets to various levels of climate change. This classification is shown in Table 4 as applied to each variable.

Table 4. Climate relative change classifications for temperature variables.

Change		Percentage change from baseline – Extreme Temperature (Hot Scenario)	Percentage change from baseline – Extreme Rainfall (Wet Scenario)	Percentage change from baseline – Total Annual Rainfall (Dry Scenario)	Description
Very High	5	> 15%	> 30%	< -30%	Extreme Increase (i.e., Much Hotter)
High	4	10% - 15%	15% - 30%	-30% - -20%	Major Increase (i.e., Hotter)
Moderate	3	7.5% - 10%	7.5% - 15%	-20% - -10%	Moderate Increase (i.e., Warmer)
Low	2	5% - 7.5%	5% - 7.5%	-10% - -5%	Small increase (i.e., Slightly Warmer)
Very Low	1	< 5%	< 5%	> -5%	Little to no change

This output is then fed into the exposure arm of the vulnerability framework.

6.3. Sensitivity and adaptive capacity application

Sensitivity

A key consideration for a given asset (or asset type) is what asset attributes would make any given asset more or less sensitive to a particular climate variable (such as flood events or more extreme heat days).

The rating system used assigns a score between 1 and 5. A score of ‘1’ indicates assets with a particular characteristic that makes it less sensitive (more resilient) to a particular climate variable and ‘5’ indicates assets with a particular characteristic that makes it more sensitive (or less resilient).

This sensitivity relates to particular characteristics or attributes of the asset that are essentially an intrinsic element of the asset or it’s environment that cannot be readily changed.

For example, a tree may be a particular species or age that makes it more or less sensitive to heat.

Capacity

Capacity relates to particular characteristics or attributes of the asset that can be modified through adaptive features or mitigative actions.

For example, a tree may be a well maintained, or have irrigation facilities put in that will make it more resilient to a given variable, such as heat.

The rating system used assigns a score of between 1 to 5. A score of ‘1’ indicates assets with a particular characteristic that makes it have a higher capacity (more resilient) to the variable and ‘5’ indicates assets with a particular characteristic that makes it have a low capacity (less resilient).

Table 5 identifies the sensitivity and capacity ratings and definitions assigned to asset attributes or characteristics.

Table 5. Sensitivity and Capacity ratings and definitions

Class	Description	Sensitivity	Capacity
1	Asset with negligible to no sensitivity limitations to climatic impacts, requirements for management intervention, or ideal capacity/mitigation to climatic impacts	Very low sensitivity to exposure	Very high capacity
2	Asset with minor sensitivity limitations to climatic impacts, requirements for management intervention, or high capacity/mitigation to climatic impacts.	Low	High
3	Asset with moderate sensitivity limitations to climatic impacts, requirements for land management intervention, or moderate capacity/mitigation to climatic impacts.	Moderate	Moderate
4	Marginal assets, which can be considered highly sensitive to climate impacts, or have low capacity/mitigation to climatic factors. These assets will require active management or intervention to mitigate or remove any limiting factors.	High	Low
5	Assets with extreme sensitivity limitations, or little to no capacity/mitigation measures, that may preclude its use in its current form. These assets will require active management or intervention to mitigate or remove any limiting factors.	Very high sensitivity to exposure	Very low capacity

6.4. Application to attributes

For each Council, for each assigned sensitivity or capacity attribute, values within data layers will be classified into these 1 to 5 classification systems based on values within attributes.

An example is provided in Table 6 for how an attribute of Open Space is used to assign a sensitivity rating. In this example the attribute ’Feature type’ is used as a proxy for Material and/or Ground Surface

Here, feature type can be used to indicate the general surface (or surface material), mainly pertaining to permeability. For example, concrete features such as skate parks will have lower sensitivity (with a rating of 1) to damage from prolonged dryness due to having no vegetation component but can become a heat sink and experience cracking in excessive heat, and hence has a higher sensitivity to heat (with a rating of 4).

For attribute scoring tables for other assets and their associated tables, please refer to Appendix 1

Table 6. Sensitivity classification examples for Open Space using feature type

Feature Type	Score			Assumed Material
	Hot	Dry	Wet	
Alpine Resort	2	1	1	
Athletic Field	3	2	2	Synthetic material/compact
Baseball Field	2	2	3	Grass field
Basketball Court	4	3	4	Synthetic material/compact
Bowling Green & Croquet Green	3	3	3	Grass field
Commonwealth Land	2	1	1	
Community Use Area - Building In Public Use	2	2	2	
Community Use Area	2	2	2	Mixed surfaces & variable
Community Use Area - Parklands And Gardens	4	3	3	Vegetated
Community Use Area - Recreation Reserve	3	3	3	Mixed surfaces & variable
Community Use Area - Recreation Trails	3	1	1	Vegetated & Paths
Dog Park	4	3	3	Grass fields
Gardens & Park	4	3	3	Vegetated
Historic And Cultural Features Reserve	2	1	1	Vegetated
National Park	2	1	1	Vegetated
Natural Feature Reserves	2	1	1	Vegetated
Nature Conservation Reserve	2	1	1	Vegetated
Picnic Site & Play Grounds	4	4	4	Mixed surfaces & variable
Plantation	2	1	1	Vegetated
Regional Park	2	1	1	Vegetated
Rest Area	4	3	4	Roadside (concrete, some veg)
Services and Utilities	3	3	1	Vegetated – but open & mixed use
Skate Park	4	1	2	Concrete
Sports Ground	2	2	3	Mix of all (catch-all); mix-surface
State Forest	2	1	1	
State Park	2	1	1	
Uncategorised Public Land	2	2	2	
Water Production	3	3	1	

Application of scores to any attribute group is considered in isolation to other attributes and only in relation to the exposures in questions. Links between attributes were not considered.

Once all layers are processed, an overlay process is applied which assumes all input layers are equal. The number of inputs used in the overlay process needs to be suitably managed since if there are too many layers, there can be an over-saturation of inputs. In this situation the scores may potentially even out into a similar score. It is therefore recommended to only have up to 3 attributes per type (sensitivity or adaptive capacity) to capture the critical attributes to the particular asset grouping.

6.5. Asset attribute and climate assignment quality assurance

The process for assigning a sensitivity and adaptive rating to assets involved a review of available asset attributes and an evaluation of their suitability for use in the assessment.

The next step involved applying rating values for adaptive capacity and sensitivity based on asset data attributes in relation to climatic variables.

For climatic variable ratings, the first step in the process was to assess the range of values for each climate variable and the change relative to a baseline (i.e., changes in the average rainfall). This was used together with the insights obtained from previous studies, to assign a score range appropriate for each climate variable and asset type across the GMCA project area.

How these relative changes in a climate variables relate to assets and the rating assigned for sensitivity and adaptive capacity drew on the insights obtained from previous studies from which the project team has gained a good understanding of the principles to apply and the scores to assign in such a process. This approach has been tested with relevant field experts, asset managers in previous studies and literature reviews and research undertaken in prior projects (Fussel and Klein 2006), (Spatial Vision 2013, 2021), (Spatial Vision 2020).

Importantly this process draws significantly on work undertaken in collaboration with Professor Roger Jones from Victoria University (Professorial Research Fellow, Institute for Sustainable Industries & Liveable Cities). His knowledge on urban ecology and climate risk assessment has been invaluable in framing an understanding how urban environs and assets respond to projected changes in the climate.

A first step in the first pass vulnerability assessment process involved a review and subsequent refinement stage following an initial application of the assessment process. This review and validation stage was viewed as critical for quality assurance purposes.

Asset sensitivity and adaptive capacity ratings assigned on the basis of asset attributes were discussed and reviewed with relevant asset managers in GMCA member councils prior to their application, to ensure local knowledge was captured in the process.

Asset data attributes

The attribute details provided for particular assets determine the level of detail contained within the sensitivity and capacity ratings. Assets with little attribute information were placed in a general category and were assessed based on more general rules with respect to their sensitivity to climate variables or their capacity factors.

More detailed sensitivity or capacity ratings were assigned where more detailed attribute information supports this based on known relationships.

This assessment approach does not replace the need for on-site evaluations to support operational response decisions.

A key outcome of the project was to provide a framework and an approach that can be reviewed and refined with new and more detailed knowledge about the likely relationships between asset attributes and climate change variables.

6.6. Data provision post project completion

The final stage of the project involved providing all datasets to GMCA LGAs with the original assigned asset attributes, in addition to asset vulnerability attributes added through the vulnerability assessment process.

This data was provided together with a supporting QGIS (GIS software) project that allows the data to be visualised, evaluated and queried. This environment also supports mentoring in the analysis process undertaken to assess and assign asset impact and vulnerability.

6.7. Climate impact and vulnerability application

The vulnerability assessment process described results in a significant number of vulnerability ratings (or range in vulnerability rating scores) for individual assets.

A key component of the process is the asset impact assessment rating for each climate variable assessed based on an assigned sensitivity of an asset to the anticipated change.

Adaptive capacity assigned at the asset level is then used in combination with the assessed impact to determine a final vulnerability assessment rating.

The results of this process for three climate models was used to assign climate model-based vulnerability ratings for an asset.

This process was repeated for each combination of the four future time points under consideration (2030, 2050, 2070, and 2090), and for each RCP scenario (RCP4.5 and RCP 8.5).

Hence, each asset has a vulnerability assigned based on multiple climate change variables, for three global climate models, four time points, and two carbon emission futures.

6.8. Proposed process in applying asset vulnerability assessment

In terms of a process to apply the AVA Part 1 outcomes, it is suggested that the maximum consensus climate model outcomes (which for the GMCA region is ACCESS 1.0) are used as a starting point, and that the outcomes under a hotter and dryer, and warmer and wetter future (based on the other climate models – HadGEM2-CC and NorESM1-M respectively) be explored in relation to this maximum consensus climate model future.

It is proposed that the vulnerability results for the year 2050 and an RCP8.5 emissions future be used as the starting point to review vulnerability assessment outcomes.

Mentoring sessions and notes for the AVA project focus on this process in relation to the application of assessment results for selected individual assets, and summary vulnerability results on a locality basis.

Appendix 1 – Asset Vulnerability Scoring

Open Space

Feature Subtype – Level of Service

Feature subtype can be used as a proxy for level of service to indicate passively managed and actively managed open space assets. It incorporates factors such as maintenance and irrigation (ex. a gardens and parks will be regularly irrigated and have a more frequent management schedule).

This is a complete listing of open space attribute types in the Goulburn Murray Climate Alliance region. But not all are assessed due to location in the GMCA region or falling within non-council managed tenure.

Due to the various sources of data that provides attribution to this asset type, some of the classifications and values listed in the below table are general in categorisation. For example, water production includes all land that encompasses reservoirs, infrastructure, and associated catchments.

Feature Type	Score
Alpine Resort	2
Athletic Field	4
Baseball Field	4
Basketball Court	4
Bowling Green & Croquet Green	3
Commonwealth Land	1
Community Use Area - Building In Public Use	3
Community Use Area	3
Community Use Area - Parklands And Gardens	2
Community Use Area - Recreation Reserve	3
Community Use Area - Recreation Trails	3
Dog Park	4
Gardens & Park	2
Historic And Cultural Features Reserve	2
National Park	1
Natural Feature Reserves	1
Nature Conservation Reserve	1
Picnic Site & Play Grounds	4
Plantation	2
Regional Park	1
Rest Area	4
Services and Utilities	3
Skate Park	4
Sports Ground	4
State Forest	1
State Park	1
Uncategorised Public Land	2
Water Production	2

Feature Subtype – Material and/or Ground Surface

Feature subtype can be used to indicate the general surface (or surface material), mainly pertaining to permeability. For example, concrete features such as skate parks will have lower sensitivity to damage from prolonged dryness due to having no vegetation component, but can become a heat sink and experience cracking in excessive heat.

Feature Type	Score			Assumed Material
	Hot	Dry	Wet	
Alpine Resort	2	1	1	
Athletic Field	3	2	2	Synthetic material/compact
Baseball Field	2	2	3	Grass field
Basketball Court	4	3	4	Synthetic material/compact
Bowling Green & Croquet Green	3	3	3	Grass field
Commonwealth Land	2	1	1	
Community Use Area - Building In Public Use	2	2	2	
Community Use Area	2	2	2	Mixed surfaces & variable
Community Use Area - Parklands And Gardens	4	3	3	Vegetated
Community Use Area - Recreation Reserve	3	3	3	Mixed surfaces & variable
Community Use Area - Recreation Trails	3	1	1	Vegetated & Paths
Dog Park	4	3	3	Grass fields
Gardens & Park	4	3	3	Vegetated
Historic And Cultural Features Reserve	2	1	1	Vegetated
National Park	2	1	1	Vegetated
Natural Feature Reserves	2	1	1	Vegetated
Nature Conservation Reserve	2	1	1	Vegetated
Picnic Site & Play Grounds	4	4	4	Mixed surfaces & variable
Plantation	2	1	1	Vegetated
Regional Park	2	1	1	Vegetated
Rest Area	4	3	4	Roadside (concrete, some veg)
Services and Utilities	3	3	1	Vegetated – but open & mixed use
Skate Park	4	1	2	Concrete
Sports Ground	2	2	3	Mix of all (catch-all); mix-surface
State Forest	2	1	1	
State Park	2	1	1	
Uncategorised Public Land	2	2	2	
Water Production	3	3	1	

Perimeter/Area Ratio

The perimeter to area ratio has been included as an indication of edge effects, which consider the increased sensitivity of fragmented areas and the boundary area between open space and other land use. Wider and less linear features are considered less sensitive. Note that the ratio breaks will be determined during analysis.

P/A Ratio	Score
1 (linear)	5
	4
	3
	2
0.1 (wide)	1

Flood – Flood overlay & zones cover

The flood overlay and flood zone extents can be used to indicate whether the asset may be inundated in the event of a flood. Flooding of an open space can cause damage to the area and its vegetation.

Flood Cover	Score
High flood overlay & flood zone cover	5
	4
	3
	2
Low flood overlay & flood zone cover	1

Surrounding Road Context – Types of Vehicles

The surrounding road types can indicate an increased sensitivity though similar effects to zoning context, including factors such as heat effects and pollution. Highways and Freeways are likely to have a higher number of travelling vehicles, and at a faster speed, than local or arterial roads. In a similar way, trucks and large vehicles travel via the freight network and B-double network. These roads will create greater vulnerability.

Surrounding Road Type (Class Code)	Score
Principle Freight Network (999)	4
B-Double Network (99)	4
Freeway (0)	4
Highway (1)	4
Arterial (2)	3
Sub-Arterial (3)	3
Collector Road (4)	2
Local Road (5)	2
Minor Road (6)	1
No road (null)	1

Vegetation - Tree Canopy Cover

Greater tree canopy cover can reduce sensitivity to a number of climate related scenarios by providing shade to reduce heat effects in hot and dry conditions as well as root structure and protection to reduce wetness effects. Note that exact canopy cover breaks will be determined at the time of analysis.

Canopy Cover	Score
Low Canopy Cover	4
	3
	2
High Canopy Cover	1

Buildings

Feature Subtype – Level of Service

Building subtype has been included to indicate a level of service (usage) which may indicate maintenance. Here lower values indicate lower sensitivity due to greater maintenance, while higher values indicate a high level of sensitivity.

Feature Subtype	Score
aged care	2
art gallery	1
boating club	4
child care	2
club house	4
community centre	1
community health centre	1
customer service centre	3
emergency coordination centre	1
hall	3
library	1
maternal/child health centre	1
municipal office	1
museum	1
neighbourhood house	4
neighbourhood safer place	4
public toilets	2
senior citizens	2
swimming pools	1
tourist information centre	3

Soil Type

Soil Type can be used to indicate a level of stability and permeability of the building’s foundation. ASC soil types were classified as sandy, clayey, and loamy. In wet conditions sandy soils lose structure, while in hot and dry conditions they remain relatively unaffected and therefore exhibit lower sensitivity. In hot and dry conditions clayey soils are vulnerable to expansion and cracking, and their poor drainage properties increase sensitivity in wet conditions as well. Loamy soils exhibit relatively low sensitivity across all climate scenarios.

Clay %	Score
0 - 5	1
5 – 10	2
10 – 20	3
20 – 50	4
> 50	5

Clustering of Critical Assets

The level of use and criticality of a building can depend on whether it is the only or one of many critical assets within a township. If it is the only or one of a few critical assets supporting the community, the asset will have a higher sensitivity as it will have a higher foot-traffic.

Critical assets in this context represented Council buildings that are ‘hubs’ for the community, including: libraries, community centres, halls, and community health centres.

A buffer of 5km was applied to all critical assets to act as a ‘service area’ which is an estimated reasonable distance residents would travel to use surrounding assets. Surrounding critical assets were only identified within the service area of each critical asset. Critical assets were then categorized as buildings in an Urban Centre and Locality (UCL) and those outside of an UCL. The class breaks were calculated separately for the two groups to account for population differences, and therefore the differences in the frequency of use of critical assets. Different class breaks can ensure that a population-to-asset ratio is consistent as areas outside of UCL’s have smaller populations, therefore, the importance of surrounding critical assets is also less.

Criticality	Class Breaks		Score
	Inside UCL	Outside UCL	All critical assets
Few surrounding critical assets	≤ 2	≤ 1	4
	≤ 3	≤ 2	3
	≤ 5	≤ 4	2
Many surrounding critical assets	≤ 8	≤ 6	1

Flood Overlay and Proximity to Water Bodies

The presence of a flood overlay and flood zone extents can be used to indicate whether the asset may be inundated in the event of a flood. The closest proximity for each asset to a water body is also calculated to further analyse areas at risk of inundation. Flooding of an open space can cause damage to the asset.

Flood Cover	Score
High flood overlay & flood zone cover	5
	4
	3
	2
Low flood overlay & flood zone cover	1

Roads

Road Hierarchy - Maintenance

Road hierarchy can be used as a proxy for maintenance, where more significant roads with higher usage are maintained to a higher standard, and therefore less sensitive to climate-related events.

Road Class	Score
Principle Freight Network (999)	1
B-Double (99)	1
Freeway (0)	1
Highway (1)	1
Arterial (2)	2
Sub-Arterial (3)	2
Collector Road (4)	3
Local Road (5)	3
Minor Road (6)	4
Major Track (7)	5
Minor Track (8)	5
Trail (9)	5
Paper Road (13)	5

Road Seal

Road seal can be used as a proxy for road material, which can influence the impact of climate-related scenarios on road assets. For example, asphalt is particularly sensitive to hot scenarios due to the material's inherent properties, whereas unformed roads are more sensitive to wet scenarios due to erosion/flooding risks.

Seal	Description	Score – Hot Scenario	Score – Wet Scenario
Sealed (1)	Road Sealed (sprayed seals, asphalt, or concrete)	4	3
Unsealed (2)	Road Unsealed (includes rock or processed gravel)	1	4
Unknown (3)	Unknown	2	2
Natural (4)	A formed or unformed road consisting of locally available earth material not included in unsealed	1	4

Road Slope

Roads with a steeper slope gradient are more susceptible to the impacts of runoff, erosion and landslips. This is only applicable for 'wet' hazards. Exact breaks values will be calculated during analysis.

Slope Gradient (%)	Score
Flat (0-6.25%)	1
Gently inclined (6.25-12.5%)	2
Moderately inclined (12.5-25%)	3
Steep (25-50%)	4
Very Steep (>50%)	5

Car Density and Usage

Density	Score
Very Low (0 - 0.25)	1
Low	2
Moderate	3
High	4
Very High	5

Flood – Flood overlay & zones cover

The flood overlay and flood zone extents can be used to indicate whether the asset may be inundated in the event of a flood. Flooding of an open space can cause damage to roads.

Flood Cover	Score
High flood overlay & flood zone cover	5
	4
Moderate flood overlay & flood zone cover	3
	2
Low flood overlay & flood zone cover	1

Bridge

Bridge Material

Bridge material can influence sensitivity due to certain properties inherent to each type. For example, concrete bridges have lower sensitivities than timber bridges.

Material	Score
Brick	3
Cast Iron	2
Masonry	3
Prestressed Concrete	2
Reinforced Concrete	2
Steel	1
Timber	4
Other/Unknown	2

Bridge Type

Bridge Type can indicate a number of sensitivity factors such as inherent structural factors, maintenance and the level of exposure to risks such as rivers. In particular, Major Culverts are highly susceptible to flooding, making them highly sensitive to wet conditions. Sensitivity is scored only for wet conditions.

Type	Score
Road Over Road (Grade Separation)	1
Road Over Rail (Rail Underpass)	1
Rail Over Road (Rail Overpass)	1
Road Over Perennial Watercourse	4

Road Over Seasonal Watercourse	3
Road Over Floodplain	3
Road Over Irrigation Channel	2
Murray River Bridges & Punts	3
Other/Unknown	2
Major Culvert	4

Flood Overlay and Proximity to Water Bodies

The flood overlay and flood zone extents can be used to indicate whether the asset may be inundated in the event of a flood. The closest proximity for each asset to a water body is also calculated to further analyse areas at risk of inundation. Flooding of an open space can cause damage to the asset.

Flood Cover	Score
Inside flood overlay and proximity to water bodies	5
	4
	3
	2
Outside flood overlay	1

Bridge Rating - Condition

The bridges and culverts are given a rating based on the condition of the asset. Condition can indicate a bridge’s ability to withstand climate effects such as flooding and heatwaves.

Bridge Condition (rating)	Score
Poor condition (>60)	5
45-60	4
30-45	3
15-30	2
Great condition (<15.0)	1
No Value (0)	2

Waterway Type – Risk

The proximity to a waterway may affect a bridge or culvert’s risk of enduring climate effects such as flooding and inundation. Based on the hierarchy of the watercourse, those with a higher hierarchy are more prominent watercourses and therefore, may be more affected in situations of flooding and inundation.

Waterway Hierarchy	Score
High (H)	3
Medium (M)	2
Low (L)	1

Spatial
Vision