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

Project Report

19th April, 2024

About this Document

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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.

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Acronyms

AEP	Annual Exceedance Probability
AR6	Assessment Report 6
AVA	Asset Vulnerability Assessment
BMO	Bushfire Management Overlay
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEECA	Department of Energy, Environment and Climate Action
GCM	Global Circulation (Climate) Models
GMCA	Goulbourn Murray Climate Alliance
IPCC	Intergovernmental Panel on Climate Change
LGA	Local Government Area
MJA	Marsden Jacob Associates
RCP	Representative Concentration Pathway
SV	Spatial Vision
VCP19	Victorian Climate Projections 2019

1. This document

This report presents key findings and a description of key project outputs from the high-level vulnerability assessment applied to agreed assets as part of the Goulburn Murray Climate Alliance (GMCA) A Resilient Public Estates project. The project was undertaken to assist councils in the region better understand how climate change and associated extreme weather events may impact key member council infrastructure such as roads, buildings, open spaces and bridge assets, and how this in turn relates to income and expenditure.

The work described in this report focusses on the first part of a two-phased 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. The 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.

This project report is supported with a separate Methods Report that provides a detailed description of the high-level vulnerability assessment approach applied in this part of the project on a GMCA-region wide basis.

2. Background

2.1. This project

The GMCA region of Victoria has recently experienced a range of climate and extreme weather events driven by climate change, including drought, flooding, bushfires and heat waves. With the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6 stating that *'every increment of global warming will intensify multiple and concurrent hazards'*[1], it is critical that local governments take action to better plan for likely climate change related impacts on their key assets. A critical first step in this process is for council staff 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 the increase of days over 35°C per month or change in annual rainfall, or in terms of flood recurrence such as 1% Annual Exceedance Probability (AEP) flooding 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 heat waves, 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. This was then used as a foundation to assess the vulnerability of critical assets, such as buildings, roads, bridges and open spaces, to climate hazards, like heat waves, both now and into the future.

The participating GMCA member councils in this study were: Alpine Shire Council, Benalla Rural City, Greater Shepparton City Council, Indigo Shire Council, Mitchell Shire Council, Moira Shire Council, Murrindindi Shire Council, Strathbogie Shire Council, Towong Shire Council, Rural City of Wangaratta and City of Wodonga.

A Resilient Public Estate project encompassed a two-phase approach in understanding how climate change will impact key council assets and how, in turn, related councils' services, income and expenditure will be impacted so councils can appropriately plan for the future. These two phases are briefly described below.

First Pass Asset Vulnerability Assessment

The first pass asset vulnerability assessment phase of the project involved using individual asset characteristics and surrounding environmental characteristics to assign a likely estimate of an asset's sensitivity to individual climate change scenarios (wet, dry, and hot), and features of the asset impacting its adaptive capacity to such change. Overlayed with the current and future climate hazard exposures, individual asset's vulnerability scores were generated for the current state as well as three climate models, two carbon emission scenarios and four future timeframes (2030, 2050, 2070 and 2090). This process resulted in a total of 25 vulnerability scores being generated for each individual asset for each climate variable.

The assets of focus included key council owned or managed buildings, roads, bridges, and open spaces. This report provides details related to this phase of the project.

[1] IPCC AR6 Summary for Policy Makers

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.

The two developed case studies use a scenario (or set of scenarios) 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.

The 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 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 heat waves pose major health risks to local communities, especially to infants and the elderly
    - Climate change is likely to increase the frequency and severity of heat waves

- ○ 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.

In addition to the two detailed case studies a set of guidelines were developed to support Councils assess climate change adaptation options. The guidelines include:

- Identifying and prioritising climate change risks and assessing hazards
- Clarifying roles and responsibilities
- Establishing objectives
- Identify options & pathways and triggers
- Assessing options
- Dealing with risk & uncertainty
- Selecting the preferred option & implementing
- Monitoring & review

The two phase 2 case studies and related guidelines were undertaken and prepared as separate project reports by Marsden Jacob Associates (MJA).

3. Stakeholder Consultation

Successful delivery of the Asset Vulnerability Assessment project involved significant consultation and engagement with GMCA and relevant local government staff. The primary group for consultation was the Project Working Group (PWG), which comprised of one member of each GMCA member Council. The group was tasked to assist in coordinating the project internally and liaising with GMCA and the consultants (SV and MJA).

For a full list of those consulted during the project see Appendix 1.

3.1. Project Working Group workshops

Workshops were held with the PWG members at key stages of the project. These workshops were focussed on obtaining feedback on interim project outputs and involved presenting the project status and outputs to participants. They were attended by the PWG members and other relevant staff.

Workshop	Workshop Date	Workshop Purpose
Workshop 1	22nd March 2023	• Outline proposed scope, deliverables and overall approach for project
Workshop 2	31st May 2023	• Provide project progress update • Opportunity for Councils to provide feedback on asset data • Present climate change projection data and extreme event related data
Workshop 3	30th August 2023	• Update on the QGIS Viewer • Review the revised regional asset vulnerability assessment • Review nominated case studies for which adaptation options are to be evaluated
Workshop 4	27th November 2023	• MJA update on the chosen case studies and the process going forward
Workshop 5	14th February 2024	• Present regional asset vulnerability assessment outputs and methodology • Provide update on case studies

3.2. Asset Scoring Workshops

Two workshops were held with asset managers from all councils to discuss and receive feedback on the sensitivity and adaptive capacity scoring of the asset attributes and contextual information. These sessions also provided an opportunity for asset managers to review the contextual information used as sensitivity and capacity considerations, and to suggest additional contextual parameters that could be used as sensitivity and/or adaptive capacity measures.

Workshop Dates	Findings
12th October 2023 17th October 2023	• Adjustment of sensitivity and adaptive capacity scoring based on feedback from asset managers • Identification of other possible contextual sensitivity and/or capacity measures • The outcomes and advice presented in these sessions were incorporated into the Asset Vulnerability Assessment methodology and tables used in the application of the method.

3.3. QGIS Training and Mentoring Sessions

QGIS training and mentoring for council staff was undertaken to build internal capability in the use of project output data to ensure it can be incorporated into decision making processes. Recordings of both the training sessions and the mentoring sessions were provided as resources for current and future council staff.

Session	Dates	Purpose	Resources
Introduction to QGIS Training	18th July 2023 19th July 2023	To introduce QGIS as a spatial viewer and build capacity in its use to explore data	Session recording Course material
QGIS Climate Viewer Mentoring	2nd August 2023 3rd August 2023	To build capability in using climate change data to support decision making	Session recording User Guide documentation (including worked examples)
QGIS Climate Viewer Mentoring – Updated view	20th March 2024 21st March 2024	To build capability in using climate change data to support decision making	Session recording Updated User Guide documentation (including worked examples) Development of Excel Spreadsheet Tool User Guide

4. Vulnerability assessment approach overview

4.1. 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 are likely to 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 in relation to climate variables.

4.2. 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 1 presents how a Vulnerability Assessment Framework was applied in the GMCA project. This framework has been developed by the Intergovernmental Panel on Climate Change (IPCC 2001, IPCC 2007) and previously applied in multiple climate change vulnerability assessments (Spatial Vision 2013, 2021) (Spatial Vision 2020).

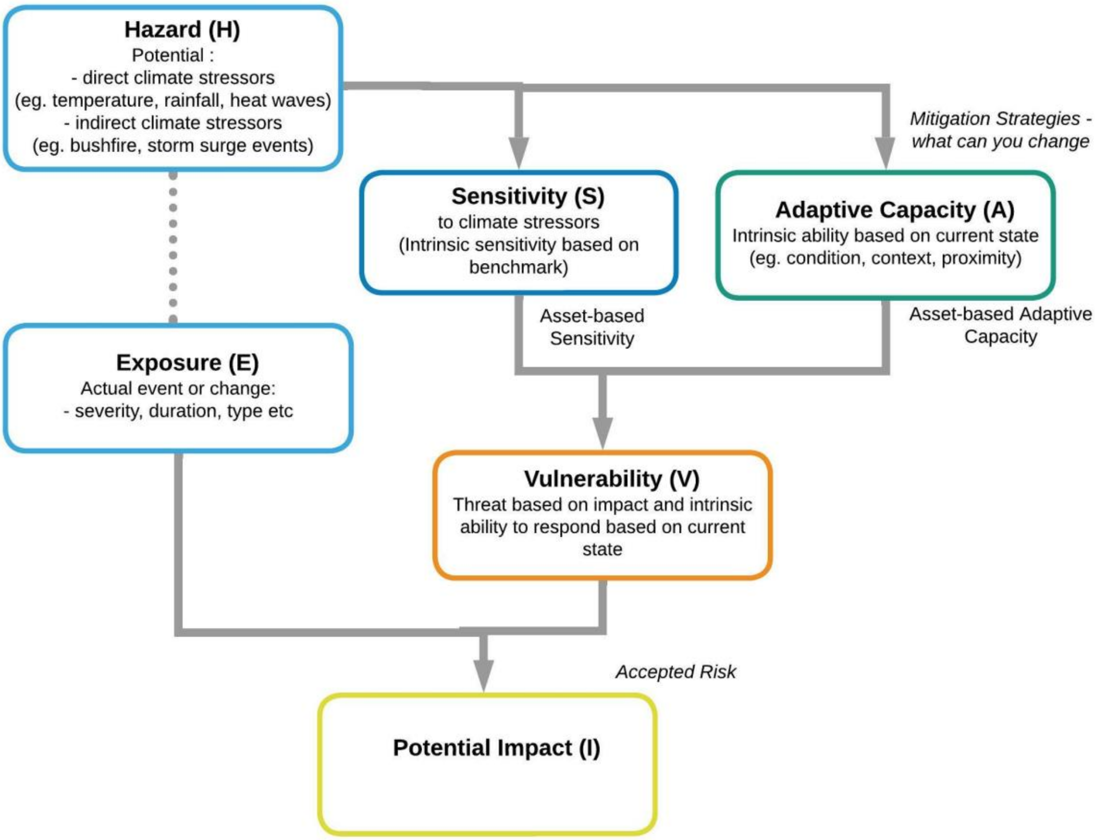

Figure 1. High-level conceptual framework applied in this study, building on the earlier AVA work

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 is likely to experience 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 economic and social challenges, for example.

Full details on the high-level vulnerability assessment approach applied in this part of the project are provided in a separate Methods Report.

5. Climate change findings – general observations

5.1. Climate change - Australia

The sixth assessment report of the United Nations Intergovernmental Panel on Climate Change (IPCC), the latest of its major assessments (released in early August 2021) has found the globe's ocean, lands and air temperatures are rising, and the human influence is "unequivocal". Its findings confirm that Australia as a whole, and regions such as those covered by GMCA, will experience the changes outlined in this section.

Fire and heat

- Australia's land area has warmed by about 1.4°C in the 110 years since 1910.
- The year-to-year changes in temperatures are now above anything that could have been caused by natural variation.
- The report says land and ocean across the world was 1.09°C hotter between 2011 and 2020 than it was in preindustrial times, taken as the period between 1850 and 1900. All the warming was caused by human activities.
- There are now more incidents of extreme heat and less cold extremes, and the report says those trends for Australia will continue.
- Australia's fire season has lengthened since 1950 and the number of days with extreme fire danger has increased.
- "The intensity, frequency and duration of fire weather events are projected to increase throughout Australia (high confidence)," says the report.
- As global temperatures rise from 1.5°C to 2°C and beyond, heatwaves, droughts, floods, and other impacts become more widespread.

Floods and droughts

- The IPCC report is less confident about changes in rainfall and drought in Australia, but there is medium confidence that heavy rainfall and river floods will increase in the future.
- But in the south and east of the continent, rainfall has generally decreased and the instances of droughts affecting ecosystems and agriculture have risen.
- Across the east of the continent, the average rainfall in cool seasons will fall, but there is medium confidence that there will be more extreme downpours. Droughts are projected to increase at 2°C of warming.
- The most pronounced changes in rainfall have been seen in the south-west of Australia, where higher greenhouse gases have seen significant loss of rainfall, which is very likely to continue, even if emissions are cut drastically.

5.2. GMCA region climate changes

5.2.1. Use of climate model outcomes

The Victorian Climate Projections 2019 (VCP) initiative provides information about the state's future climate based on the best available climate science. This AVA project had drawn on the outputs from three of the six global circulation models (GCMs) that were dynamically downscaled to produce local-scale climate projections data for Victoria.

CSIRO and DEECA climate scientists have advised that each model represents a single possible future with no one model 'more likely' or 'better' than any other model. They also provided guidance on selecting a smaller range of models to assist with decision making. In providing this advice they also note that "given the deep uncertainty about the far future, projections should only be used as a guide when managing future risk, and it's important to remember that changes above or below the projected ranges could still occur in individual years".

In line with this advice, the AVA project has selected the following three models that represent the range of possible futures for both temperature and rainfall:

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

Carbon emission future scenarios in terms of Representative Concentration Pathway (RCP) emissions scenarios of 4.5 and 8.5 (RCP 4.5 and RCP 8.5), are also explored.

The anticipated climate futures from these various models and different carbon emission scenarios for the GMCA region are provided as data outputs in this project, and views of one climate future (ACCESS 1.0, RCP 8.5) are presented in the following sections of this report.

5.2.2. Temperature and rainfall changes

A summary of the anticipated climate changes for the GMCA region is presented in this section. Maps and statistics are presented for the maximum consensus model (ACCESS 1.0) for a high carbon emission scenario of RCP 8.5, for the year 2050, although for a more comprehensive understanding of possible climate futures the spatial outputs for this project should be interrogated.

Heat-related climate hazards

With the expected increases in temperature across the GMCA region, and across Victoria, heat-related hazards are likely to become more frequent and with higher intensities. Climate hazards relating to increasing temperature include maximum daily temperatures, days above key temperature thresholds such as 35°C and heat wave events. These key climate hazards associated with increasing temperatures for the maximum consensus model at a high carbon emission scenario of RCP 8.5 are presented in Table 1.

Under this climate scenario, key insights include:

- Maximum temperature across the region is expected to increase by approximately 5.5°C to 2090.
- Under all climate future models and carbon emission scenarios we see an increase in temperature, and frequency of associated heat related climate events.

- The number of annual heat wave events increases significantly into the near-to-mid futures of 2030 and 2050, with almost three individual heat wave events expected to occur annually by 2050. For a *hotter and drier than current* climate future under an extreme carbon emission scenario, this value is projected to be increase to four events annually.
- The number of days above 35°C in 2050 is expected to increase by more than double that of the 1981-2010 baseline across the GMCA region.

Table 1. Heat-related climate hazards change over time - ACCESS 1.0, RCP 8.5. (Annual statistics)

	Baseline	2030	2050	2070	2090
Maximum temperature	19.7°C	21.1°C	22.3°C	23.3°C	25.2°C
Minimum Temperature	7.4°C	8.5°C	9.3°C	10.1°C	11.2°C
Days >35°C	9.9 days	12.9 days	22.2 days	29.3 days	48.7 days
Heatwave events	0.2 events	1.5 events/yr	2.9 events/yr	3.9 events/yr	6.6 events/yr

Figure 2 presents selected map views based on Table 1 of heat-related climate hazard change to 2050. The map views show how areas in the north of the GMCA region will experience the greatest change.

Figure 3 highlights the areas across the GMCA region currently designated as areas that may be at risk to bushfire. The bushfire management overlay (BMO) covers large extents of Towong Shire, Alpine Shire, Murrindindi Shire, Indigo Shire, and Wangaratta Rural City, although all LGAs in the GMCA region have areas at risk of bushfire.

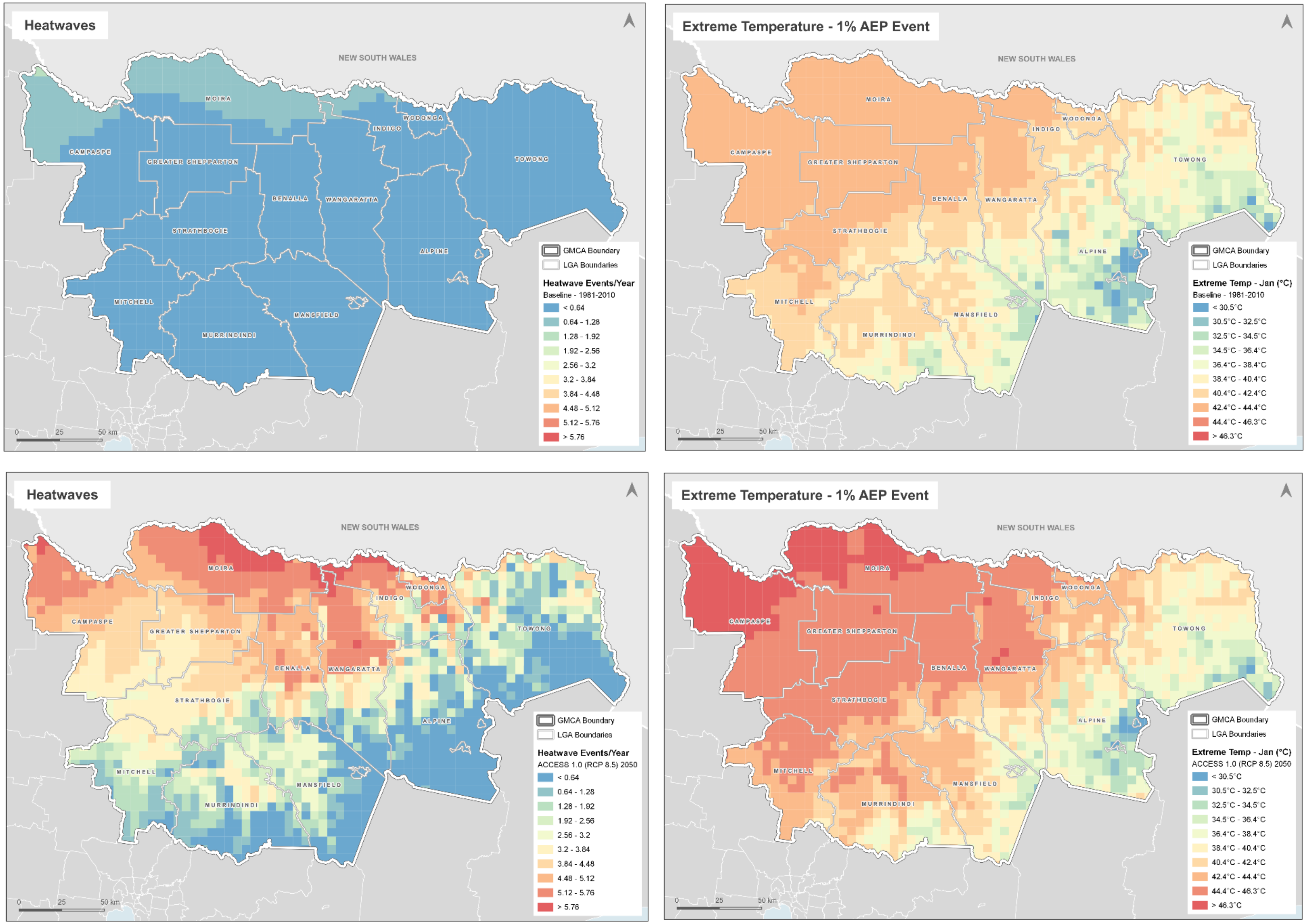

Figure 2. Heatwave (left - top and bottom) and extreme temperature (right - top and bottom) for the 1981-2010 baseline (top maps) and ACCESS 1.0 RCP 8.5 2050 future (bottom maps)

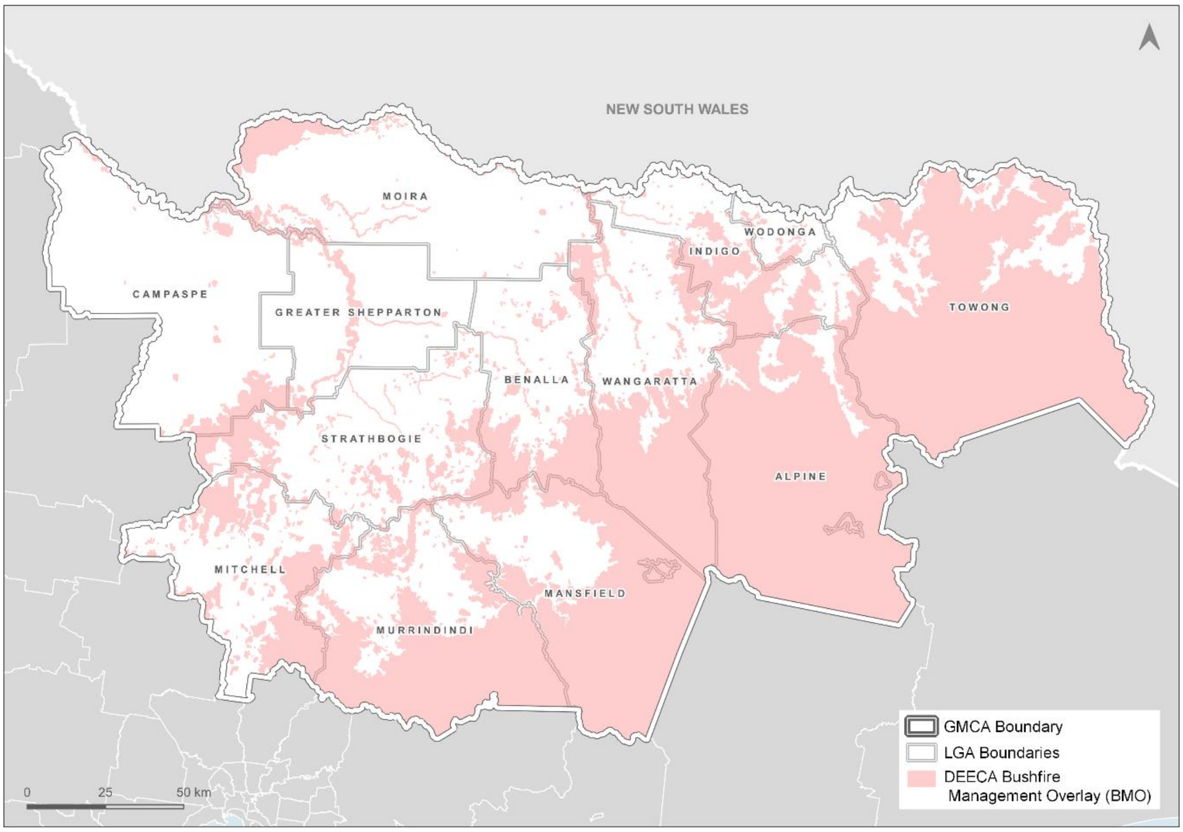

Figure 3. BMO extent across the GMCA region

Rainfall-related climate hazards

Rainfall variation across the GMCA region is generally irregular and inconsistent between models. However, some trends include:

- Decrease in rainfall trending over time
- Days with significant rainfall (>10mm) will decrease, however when these extreme rainfall events occur the volume of rain will increase at least until 2070

Table 2. Rainfall-related climate hazards change over time - ACCESS 1.0, RCP 8.5. (Annual statistics)

	Baseline	2030	2050	2070	2090
Total annual rainfall (mm)	826.1mm	761.7mm	766.3mm	754.0mm	615.3mm
Days >10mm (annually)	25.5 days	22.2 days	22.2 days	22.1 days	17.8 days
Extreme rainfall event – 1% AEP (mm)	38.6 mm	39.6 mm	39.9 mm	42.5 mm	37.9 mm

Figure 4 presents the 1% AEP flooding extent across the GMCA region. Flooding is concentrated along the major flood and stream networks.

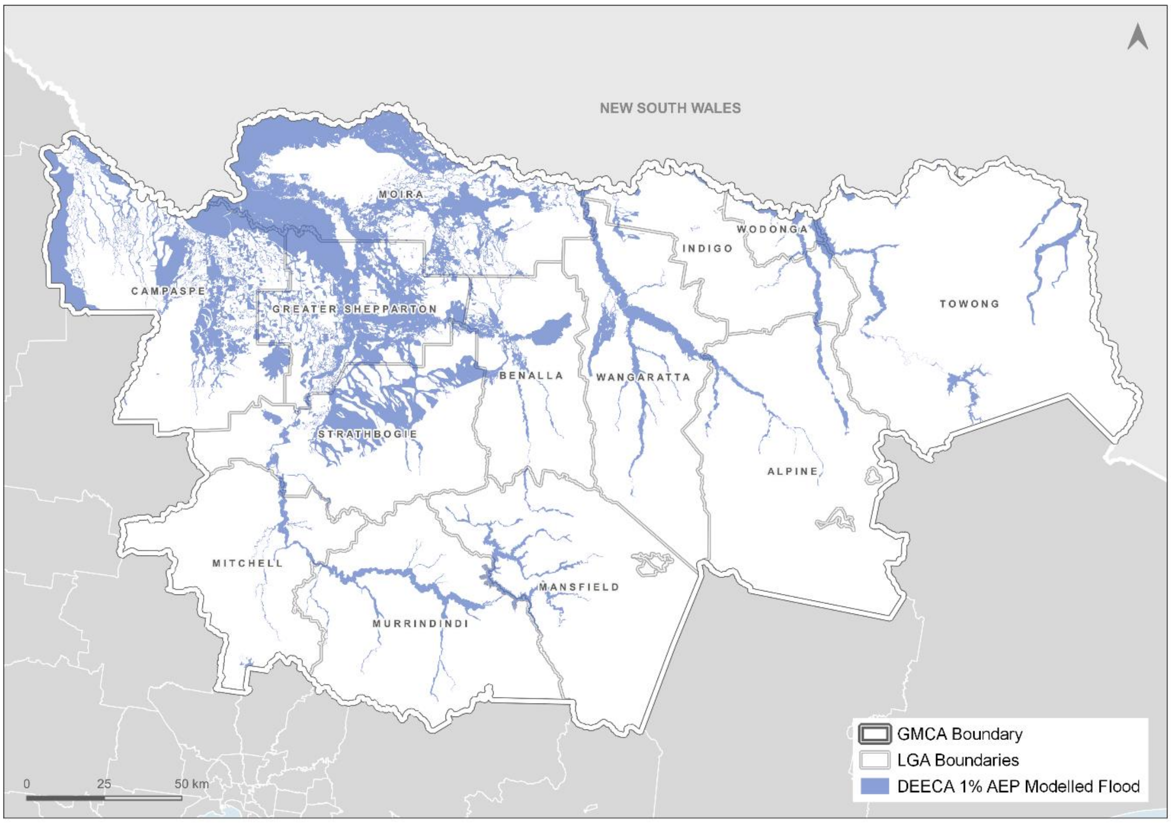

Figure 4. 1% AEP flooding extent across the GMCA region

Figure 5 presents selected map views based on Table 2 of rainfall-related climate hazard change to 2050. The map views show how areas in the north of the GMCA region will experience the greatest change.

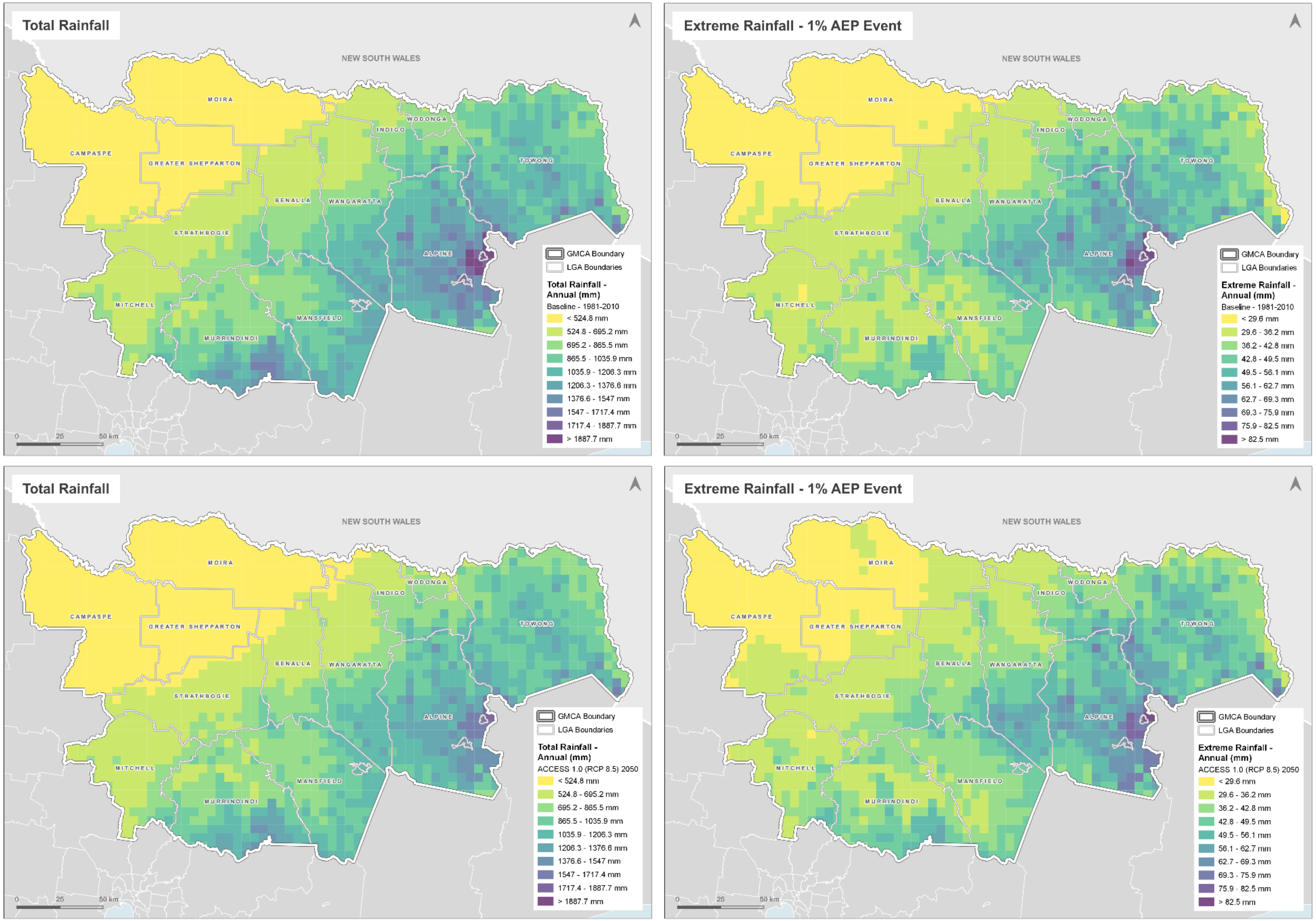

Figure 5. Total annual rainfall (left – top and bottom) and extreme rainfall (right – top and bottom) for the 1981-2010 baseline (top maps) and ACCESS 1.0 RCP 8.5 2050 future (bottom maps)

6. Asset vulnerability assessment findings

The vulnerability assessment analysis required spatial and attribute data related to the assets of concern: buildings, roads, bridges, and open space. Three scenarios for which vulnerability was calculated were:

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

As spatial data was unable to be gathered in a timely manner, nor consistently, for all member councils, state-wide spatial data was used in its place, and the analysis incorporated contextual environmental factors in addition to any asset attribution information available for the assets.

This section provides an overview of the vulnerability assessment applied to assets across the GMCA region, and broad findings at an LGA scale.

6.1. Climate impact and vulnerability application

The assessment assigned vulnerability ratings for each climate scenarios (wet, dry and hot) based on an assigned sensitivity of an asset to the anticipated change in key hazards. Adaptive capacity assigned at the asset level was then used in combination with the assessed impact to determine a final vulnerability assessment rating.

The results of this process for three climate models were then used to assign climate model-based vulnerability ratings for an asset, and this was repeated for each combination of the four future time points under consideration (2030, 2050, 2070, and 2090), and for each RCP scenario (RCP 4.5 and RCP 8.5).

Hence, each asset had a vulnerability assigned based on multiple climate change variables, for three global climate models, four time points, and two carbon emission futures, which resulted in a significant number of vulnerability ratings for individual assets.

The spatial data generated through this process provides individual asset-level vulnerability scores for all climate futures and carbon emission scenarios, as well as aggregates suburb-level summaries of the vulnerabilities.

As asset vulnerability can vary between different climate variables, scores were determined for 'wet', 'hot' or 'dry' climate scenarios. The table below identifies which of the scenarios were applied for each asset type.

Table 3. Climate scenarios for which vulnerability scores were determined for each asset type

	WET SCENARIO	HOT SCENARIO	DRY SCENARIO
BUILDINGS	•		
ROADS	•	•	
BRIDGES	•		
OPEN SPACE	•	•	•

LGA-level summaries of the vulnerability analysis were also generated and are presented in this section. The results presented include the results for a baseline climate and near to mid future climate of 2050 for a carbon emission scenario of RCP 8.5. For a more comprehensive understanding of the vulnerabilities, it is noted that the findings for all three climate models and the two carbon emission scenarios need to be considered.

LGA averages presented in the next section represent the 'average vulnerability of all the asset type within the LGA'.

6.2. Buildings

Vulnerability scores for a 'wet' scenario were calculated for almost 2000 building assets across the GMCA region. The three LGAs with the highest average vulnerability (for each column) are highlighted in orange.

Some key insights include:

- Benalla Rural City has the highest average building vulnerability of 35% followed by Strathbogie Shire at 32.4% for 2050.
- Benalla Rural City and Moira Shire have a large change (~10% increase) in average vulnerability from the current to 2050 future
- The suburb with the highest average vulnerability for buildings in 2050 is Fawcett (78.4%) in Murrindindi Shire, noting that there is only one building analysed in this suburb.

Table 4. LGA-level average vulnerability scores for buildings

LGA Name	Total Buildings	Wet Scenario		
		Vulnerability Current (Score)	Vulnerability 2050 (ACCESS 1.0 RCP 8.5)	% Change
ALPINE SHIRE	162	19.9%	21.2%	+1.30%
BENALLA RURAL CITY	88	24.1%	35.0%	+10.9%
GREATER SHEPPARTON	209	19.9%	27.2%	+7.3%
INDIGO SHIRE	141	23.0%	27.6%	+4.6%
MITCHELL SHIRE	205	19.9%	29.1%	+9.2%
MOIRA SHIRE	187	19.6%	29.2%	+9.6%
MURRINDINDI SHIRE	214	21.7%	30.7%	+9.0%
STRATHBOGIE SHIRE	102	25.1%	32.4%	+7.3%
TOWONG SHIRE	133	18.8%	22.0%	+3.2%
WANGARATTA RURAL CITY	169	20.2%	26.3%	+6.1%
WODONGA CITY	99	16.4%	16.4%	+0.0%

Figure 6 presents a map view of suburb level average vulnerability ratings assigned to buildings for 2050 under a wet scenario. It shows how the Campaspe Shire has some of the most highly impacted areas.

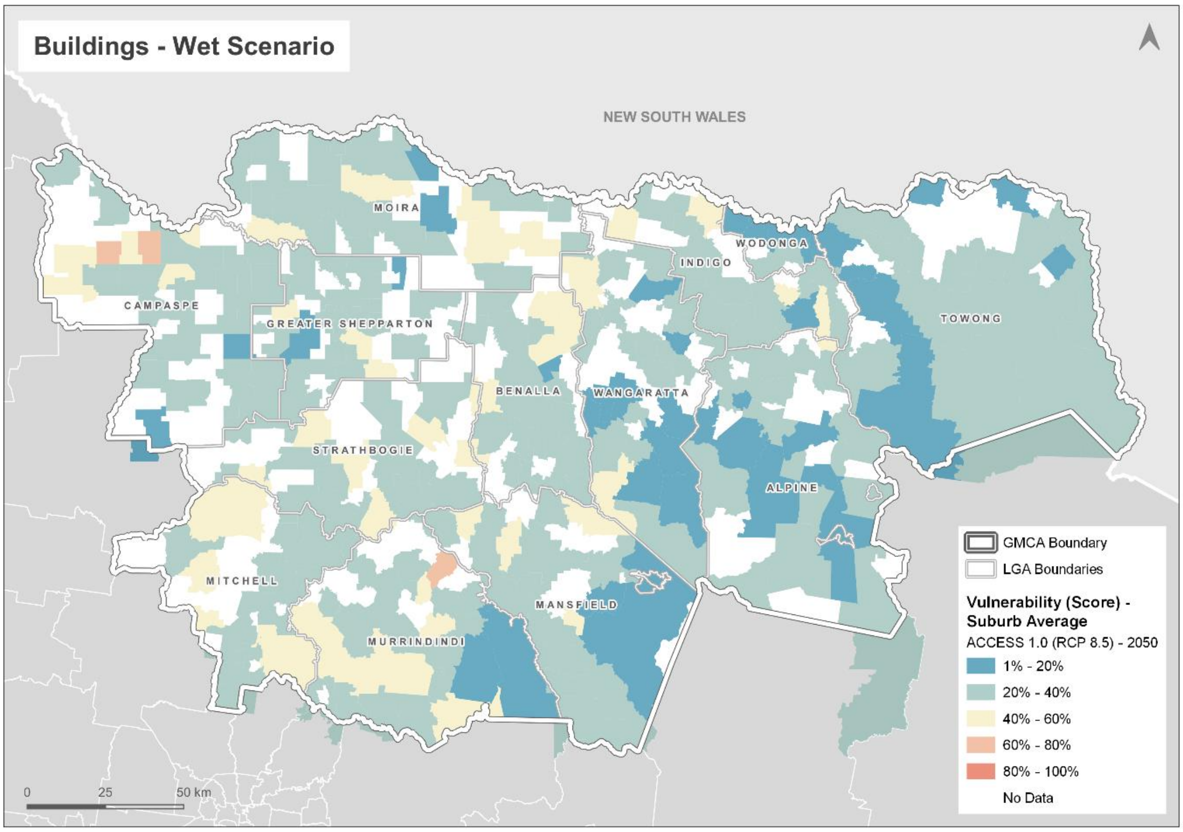

Figure 6. Suburb-level average vulnerability scores (wet scenario) for building assets at 2050 under an ACCESS 1.0 RCP 8.5 climate future

6.3. Roads

Vulnerability scores were calculated for road assets across the GMCA region, for a 'hot' and a 'wet' scenario. The three LGAs with the highest average vulnerability (for each column) are highlighted.

Some key findings include:

- For a 'hot' scenario, all LGAs have an average vulnerability of 50% or more by 2050.
- For a 'hot' scenario, Greater Shepparton, Mitchell Shire and Wodonga City have the highest average road vulnerabilities – both currently and for 2050. Wodonga City has the highest average road vulnerability in 2050 at ~76%.
- For a 'wet' scenario, Mitchell Shire, Murrindindi Shire, and Towong Shire have the highest average road vulnerabilities for the 2050 future.

Table 5. LGA-level averaged vulnerability scores for roads

LGA Name	Hot Scenario			Wet Scenario		
	Vulnerability Current (Score)	Vulnerability 2050 (ACCESS 1.0 RCP 8.5)	% change	Vulnerability Current (Score)	Vulnerability 2050 (ACCESS 1.0 RCP 8.5)	% change
ALPINE SHIRE	32.6%	58.5%	25.9%	37.1%	40.4%	3.3%
BENALLA RURAL CITY	30.3%	54.0%	23.7%	30.5%	41.1%	10.6%
GREATER SHEPPARTON	35.1%	62.7%	27.6%	31.7%	41.9%	10.2%
INDIGO SHIRE	31.5%	56.4%	24.9%	32.7%	37.6%	4.9%
MITCHELL SHIRE	34.9%	62.2%	27.3%	30.6%	44.5%	13.9%
MOIRA SHIRE	28.7%	50.3%	21.6%	28.3%	40.4%	12.1%
MURRINDINDI SHIRE	30.3%	54.3%	24%	34.6%	49.7%	15.1%
STRATHBOGIE SHIRE	28.6%	51.4%	22.8%	30.6%	40.4%	9.8%
TOWONG SHIRE	29.7%	53.2%	23.5%	35.1%	42.6%	7.5%
WANGARATTA RURAL CITY	31.8%	56.7%	24.9%	32.3%	41.2%	8.9%
WODONGA CITY	42.8%	75.9%	33.1%	30.2%	30.6%	0.4%

Figure 7 and Figure 8 present map views of suburb level average vulnerability ratings assigned to roads for 2050 under a hot scenario and wet scenario, respectfully. These views show selected suburbs or sub-regions of each LGA are more likely to be impacted than other areas.

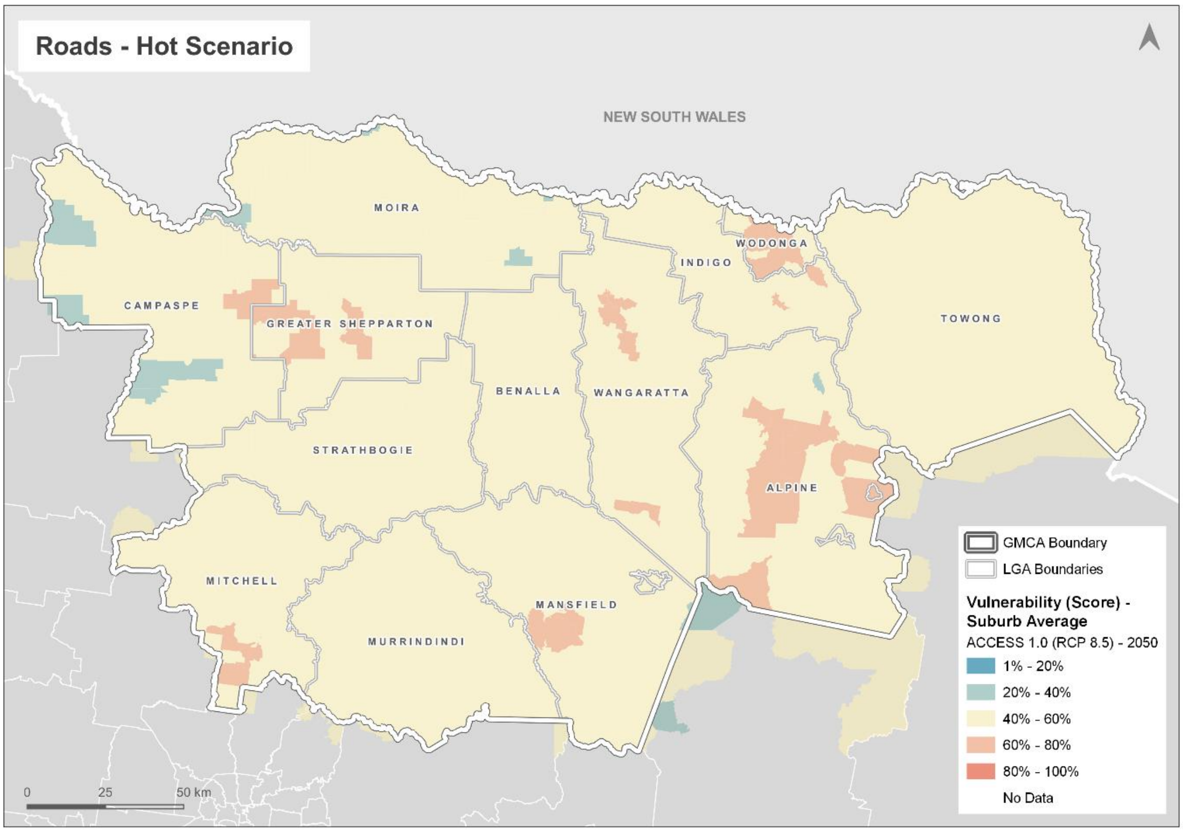

Figure 7. Suburb-level average vulnerability scores (hot scenario) for roads assets at 2050 under an ACCESS 1.0 RCP 8.5 climate future

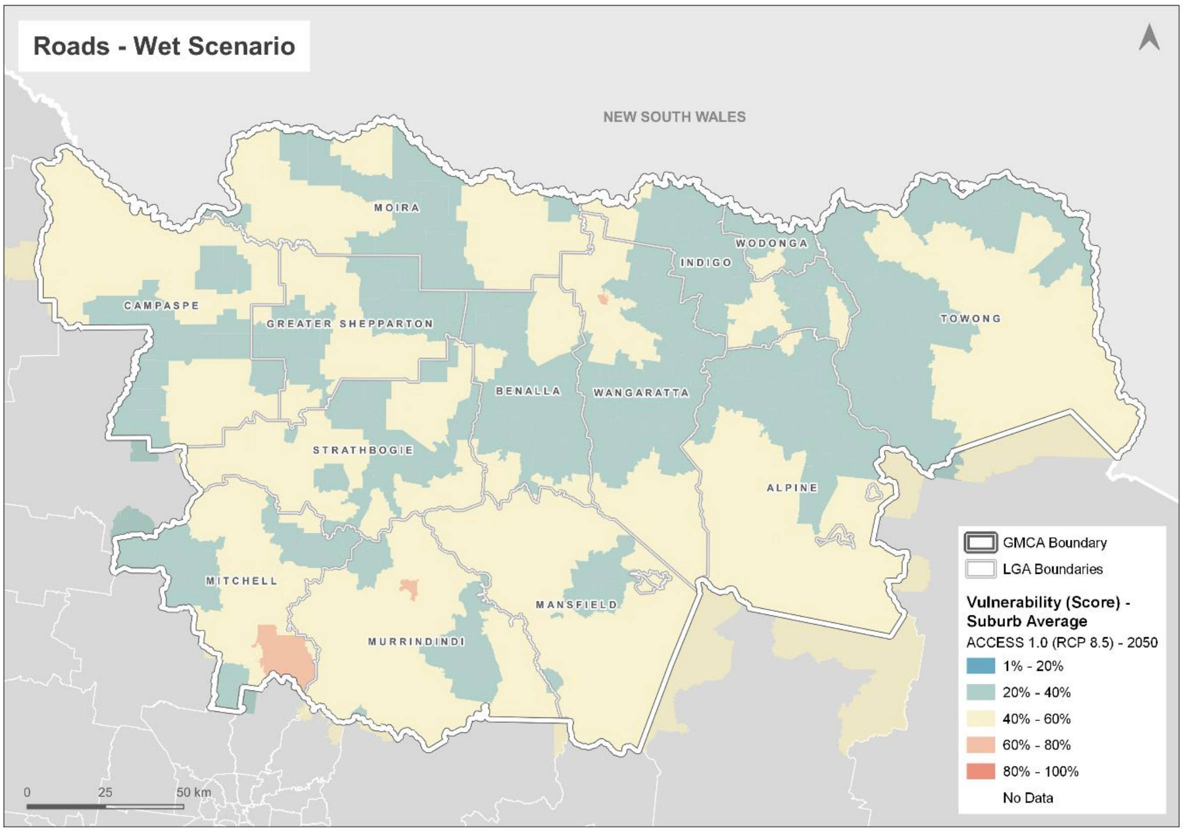

Figure 8. Suburb-level average vulnerability scores (wet scenario) for roads assets at 2050 under an ACCESS 1.0 RCP 8.5 climate future

6.4. Bridges

Vulnerability scores were calculated for 1,078 bridge assets across the GMCA region, for a 'wet' scenario. The three LGAs with the highest average vulnerability (for each column) are again highlighted in orange.

Some key findings include:

- Average bridge vulnerability on an LGA level is generally lower than other asset types analysed in this project
- Greater Shepparton has the highest average bridge vulnerability under the current (baseline) climate (14.3%) and in 2050 (18.5%) – the later average bridge vulnerability which it shares with Murrindindi Shire.

Table 6. LGA-level averaged vulnerability scores for bridges

LGA Name	Total Bridges	Wet Scenario		
		Vulnerability Current (Score)	Vulnerability 2050 (ACCESS 1.0 RCP 8.5)	% change
ALPINE SHIRE	50	12.0%	12.7%	0.7%
BENALLA RURAL CITY	91	11.6%	15.5%	3.9%
GREATER SHEPPARTON	85	14.3%	18.5%	4.2%
INDIGO SHIRE	83	11.7%	13.4%	1.7%
MITCHELL SHIRE	137	11.3%	16.6%	5.3%
MOIRA SHIRE	87	11.7%	16.6%	4.9%
MURRINDINDI SHIRE	103	12.7%	18.5%	5.8%
STRATHBOGIE SHIRE	137	10.8%	13.8%	3.0%
TOWONG SHIRE	111	12.5%	14.9%	2.4%
WANGARATTA RURAL CITY	132	12.2%	15.8%	3.6%
WODONGA CITY	62	11.1%	11.2%	0.1%

Figure 9 presents a map view of suburb level average vulnerability ratings assigned to bridges for 2050 under a wet scenario. This view shows there is very little difference in overall vulnerability assigned for bridges across the GMCA region.

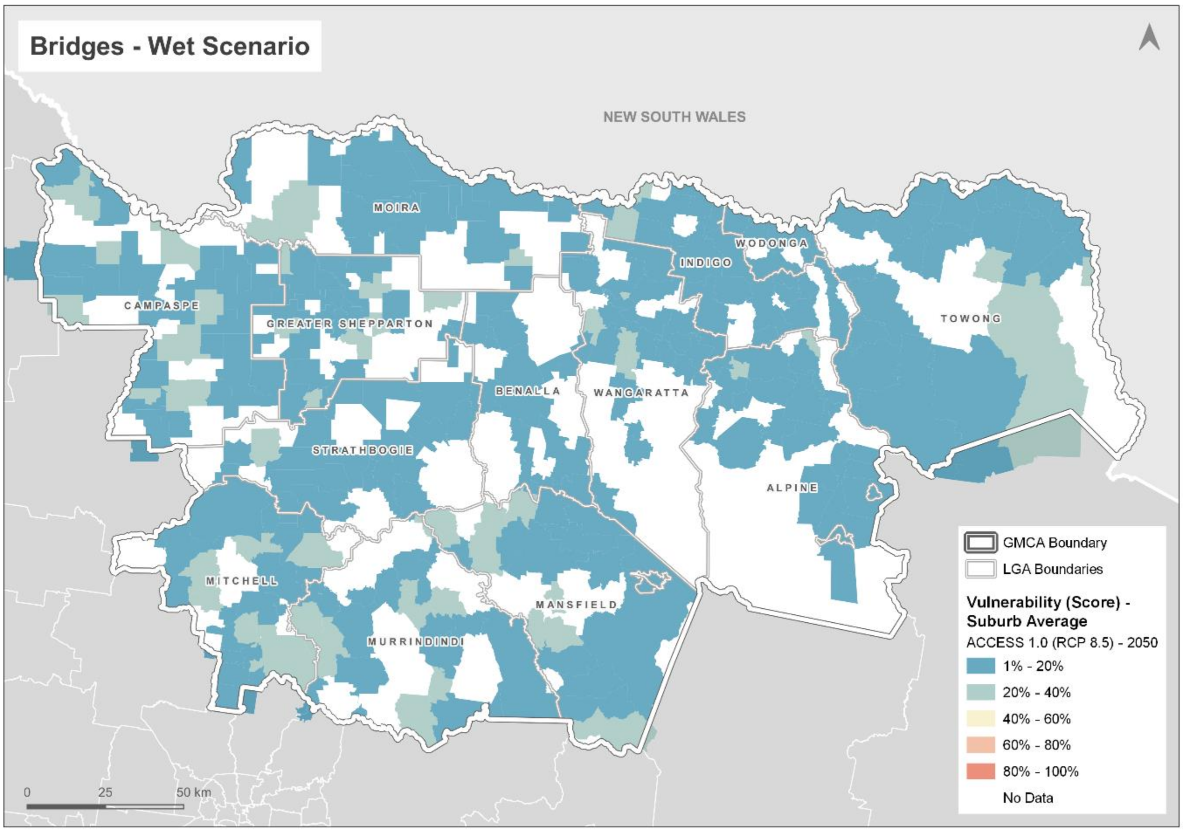

Figure 9. Suburb-level average vulnerability scores (wet scenario) for bridge assets at 2050 under an ACCESS 1.0 RCP 8.5 climate future

6.5. Open Space

Vulnerability scores were calculated for open space assets across the GMCA region, for a 'hot, 'wet' and 'dry' scenario. The three LGAs with the highest average vulnerability (for each column) are again highlighted.

Some key insights include:

- Greater Shepparton, Moira Shire and Towong Shire have the highest average vulnerability for open space, for all three scenarios by 2020.
- Open space assets are most vulnerable in 'hot' scenarios.

Table 7. LGA-level averaged vulnerability scores for open space assets

LGA Name	Hot Scenario			Wet Scenario			Dry Scenario		
	Current	2050[2]	% change	Current	2050	% change	Current	2050	% change
ALPINE SHIRE	21.6%	39.1%	17.5%	18.2%	19.2%	1.0%	19.7%	29.0%	9.3%
BENALLA RURAL CITY	23.5%	42.0%	18.5%	24.2%	35.4%	11.2%	23.9%	34.3%	10.4%
GREATER SHEPPARTON	28.0%	50.4%	22.4%	27.6%	36.8%	9.2%	26.1%	36.6%	10.5%
INDIGO SHIRE	24.5%	44.1%	19.6%	22.1%	26.9%	4.8%	23.2%	32.4%	9.2%
MITCHELL SHIRE	26.0%	46.7%	20.7%	22.5%	32.9%	10.4%	24.1%	33.7%	9.6%
MOIRA SHIRE	30.2%	53.2%	23.0%	26.4%	39.6%	13.2%	28.0%	39.2%	11.2%
MURRINDINDI SHIRE	23.9%	43.0%	19.1%	21.5%	30.5%	9.0%	22.4%	32.2%	9.8%
STRATHBOGIE SHIRE	26.5%	47.8%	21.3%	24.9%	32.3%	7.4%	24.7%	34.6%	9.9%
TOWONG SHIRE	29.9%	53.8%	23.9%	27.2%	30.8%	3.6%	28.3%	39.7%	11.4%
WANGARATTA RURAL CITY	24.8%	44.6%	19.8%	22.1%	30.5%	8.4%	23.4%	33.2%	9.8%
WODONGA CITY	24.4%	43.9%	19.5%	19.8%	19.8%	0%	20.9%	29.3%	8.4%

Figure 10, Figure 11, Figure 12 present map views of suburb level average vulnerability ratings assigned to open space for 2050 under a hot scenario, wet scenario and dry scenario, respectfully. These views show under a hot scenario and dry scenario areas in the north and alpine regions are the most impacted. Under a wet scenario the results are more evenly distributed although there appears slightly more areas in the north impacted.

[2] ACCESS 1.0 RCP 8.5 future scenario presented for all 2050 values in table

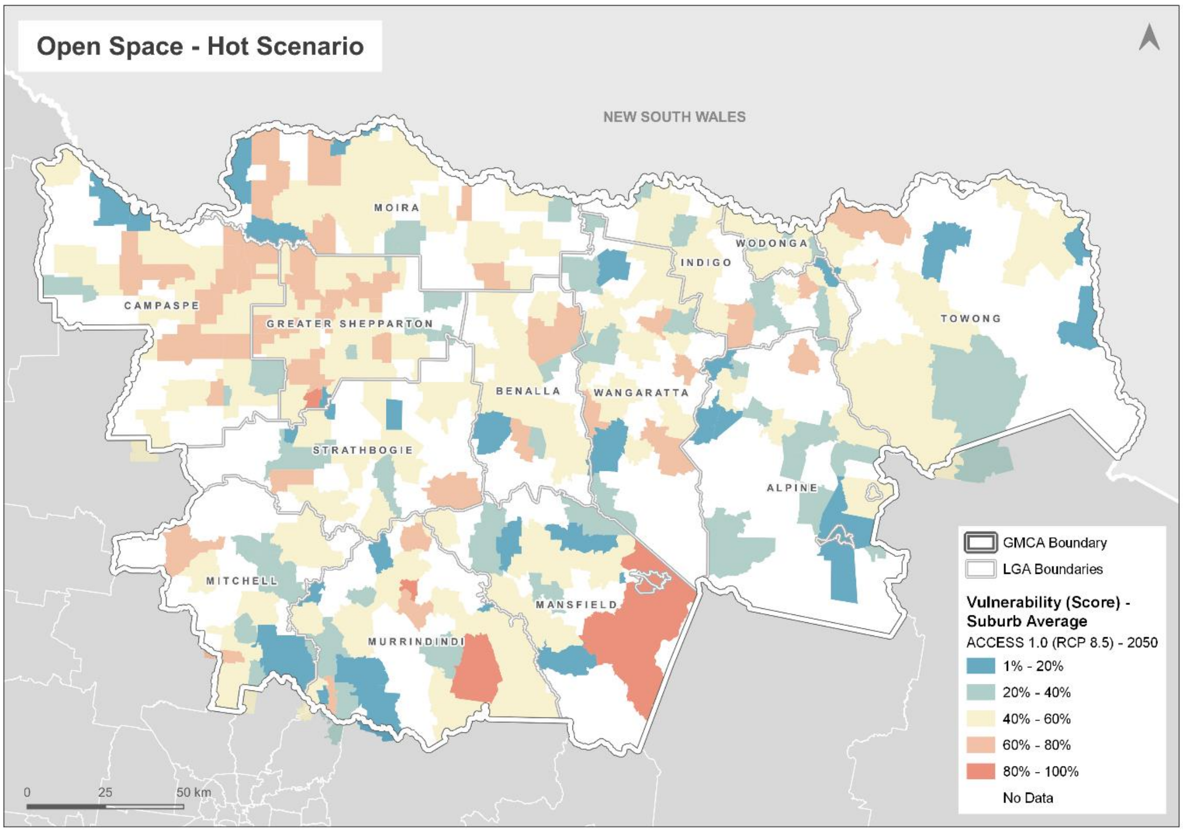

Figure 10. Suburb-level average vulnerability scores (hot scenario) for open space assets at 2050 under an ACCESS 1.0 RCP 8.5 climate future

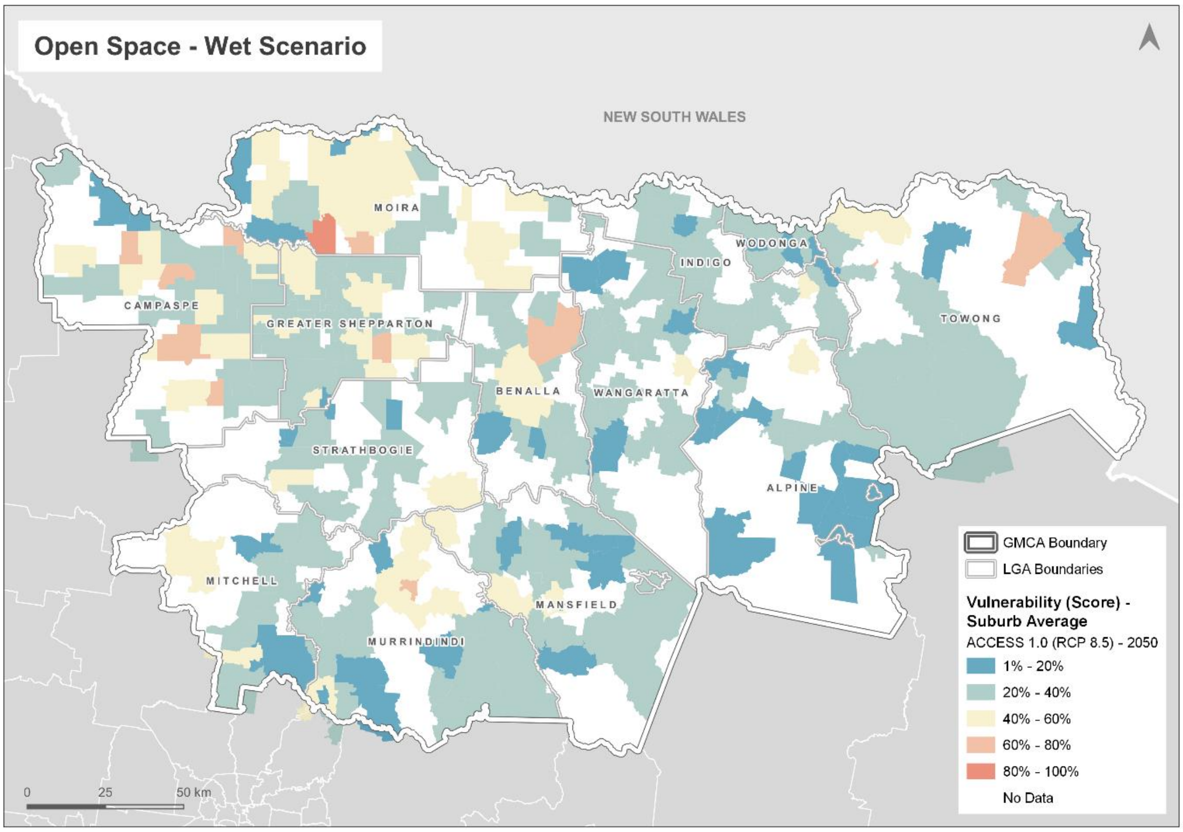

Figure 11. Suburb-level average vulnerability scores (wet scenario) for open space assets at 2050 under an ACCESS 1.0 RCP 8.5 climate future

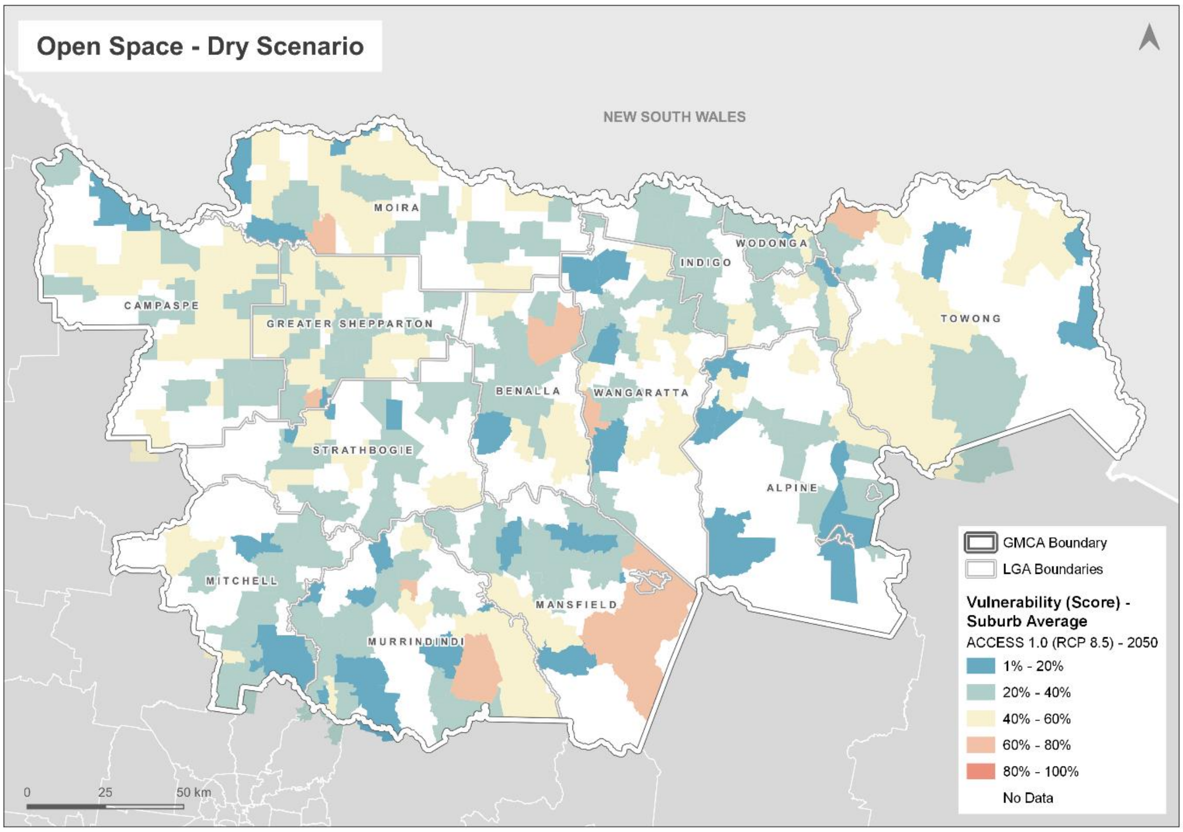

Figure 12. Suburb-level average vulnerability scores (dry scenario) for open space assets at 2050 under an ACCESS 1.0 RCP 8.5 climate future

7. Project Outputs

The project outputs for phase 1 are aimed at assisting councils in better understanding the likely climate change under various climate futures, and the likely impacts to key assets.

Figure 13 below provides a visual diagram of the project handover structure, relating to the proceeding described outputs.

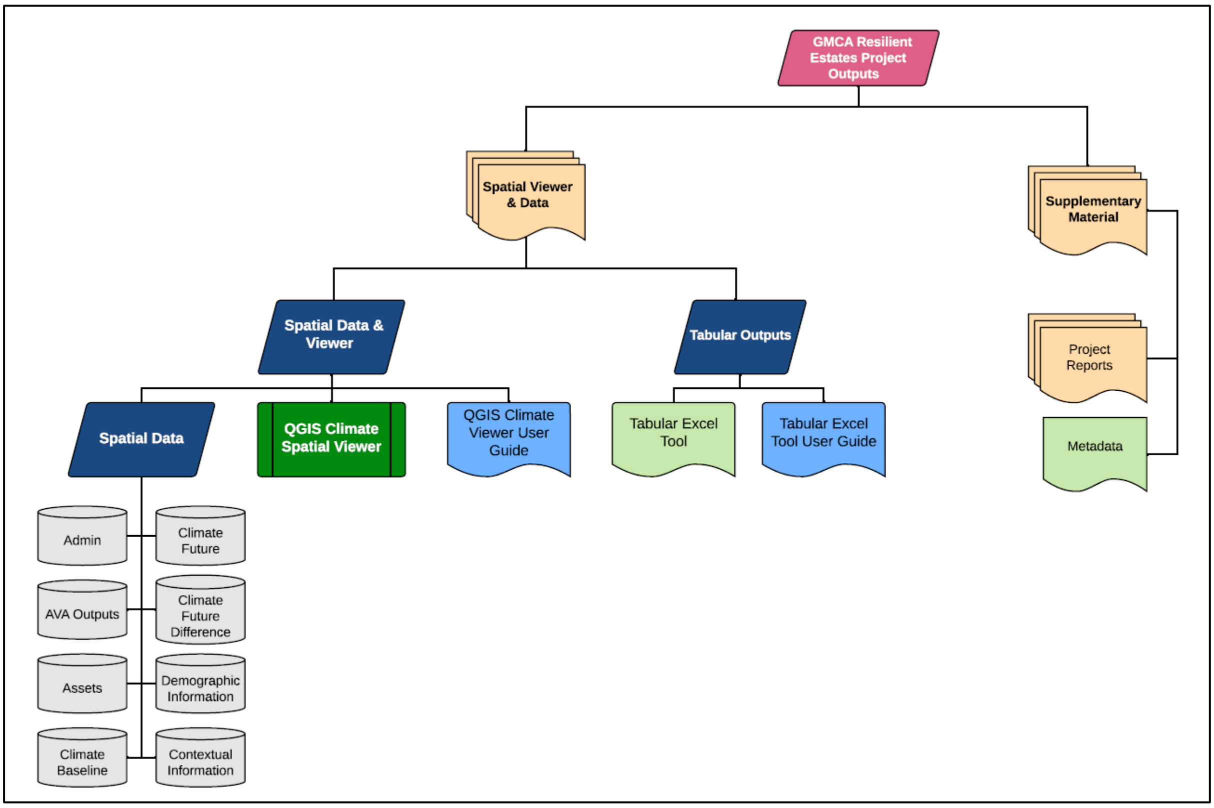

Figure 13. Diagrammatic representation of project outputs and handover folder structure

Project outputs for phase 1 include:

1. *Reports:*
   - Methods report detailing the applied methodology of the asset vulnerability assessment for phase1 of the project.
   - Project report (this report) detailing the project as a whole.

2. *Climate data:*
   - Climate baseline and future projection data for key climate variables, for three GCMs, two carbon emission scenarios and four timeframes.
   - Data provided as 5km^2 gridded shapefiles.

3. *Vulnerability analysis outputs:*
   - Vulnerability scores on a per-asset basis for all asset types (roads, bridges, buildings, and open spaces), for the current state (i.e. not accounting for future climate changes) and for future climate changes (incorporating three GCMs, two carbon

emission scenarios and four timeframes). Asset vulnerability scores are calculated for either a 'wet', 'dry' and/or 'hot' scenarios.

- Suburb-level averages of the asset vulnerability outputs. Provides an understanding of the average vulnerability of all assets (of an asset type) within each suburb.
- LGA-level averages of asset vulnerability outputs.
- All data provided in shapefile format.

4. *QGIS Viewers:*
    - All spatial data outputs are presented and pre-symbolised within a QGIS Viewer, called the 'QGIS Climate Viewer', allowing the user to interrogate and investigate the data in a visual manner.
    - Documentation is provided to guide users on the structure and application of the output data in supporting decision-making, by outlining worked examples for key application questions.

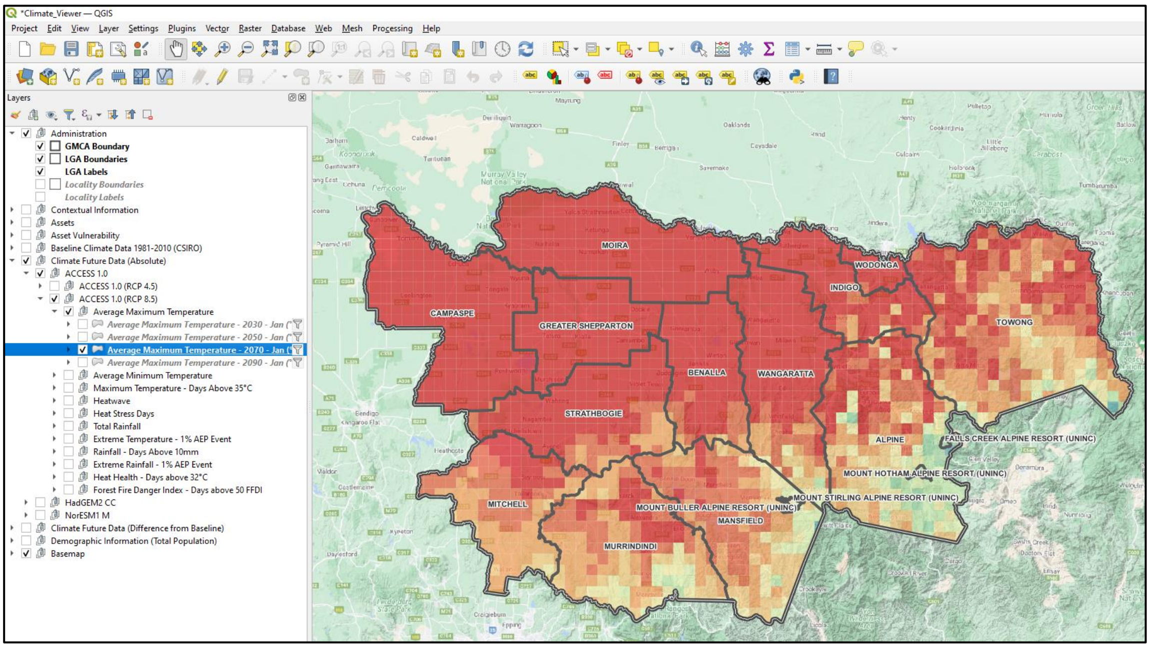

Figure 14. Screenshot of QGIS Viewer

5. *Tabular Excel Tool:*
    - Asset vulnerability assessment outputs are summarised at the suburb level within an excel spreadsheet tool. The tool allows the user to understand the average vulnerability of all assets (of an asset type) within each suburb, and filter the data by: LGA, asset type, scenario (wet, dry and/or hot), climate model, carbon emission scenario, and time frame.
    - Documentation is provided to guide users on using the tool.

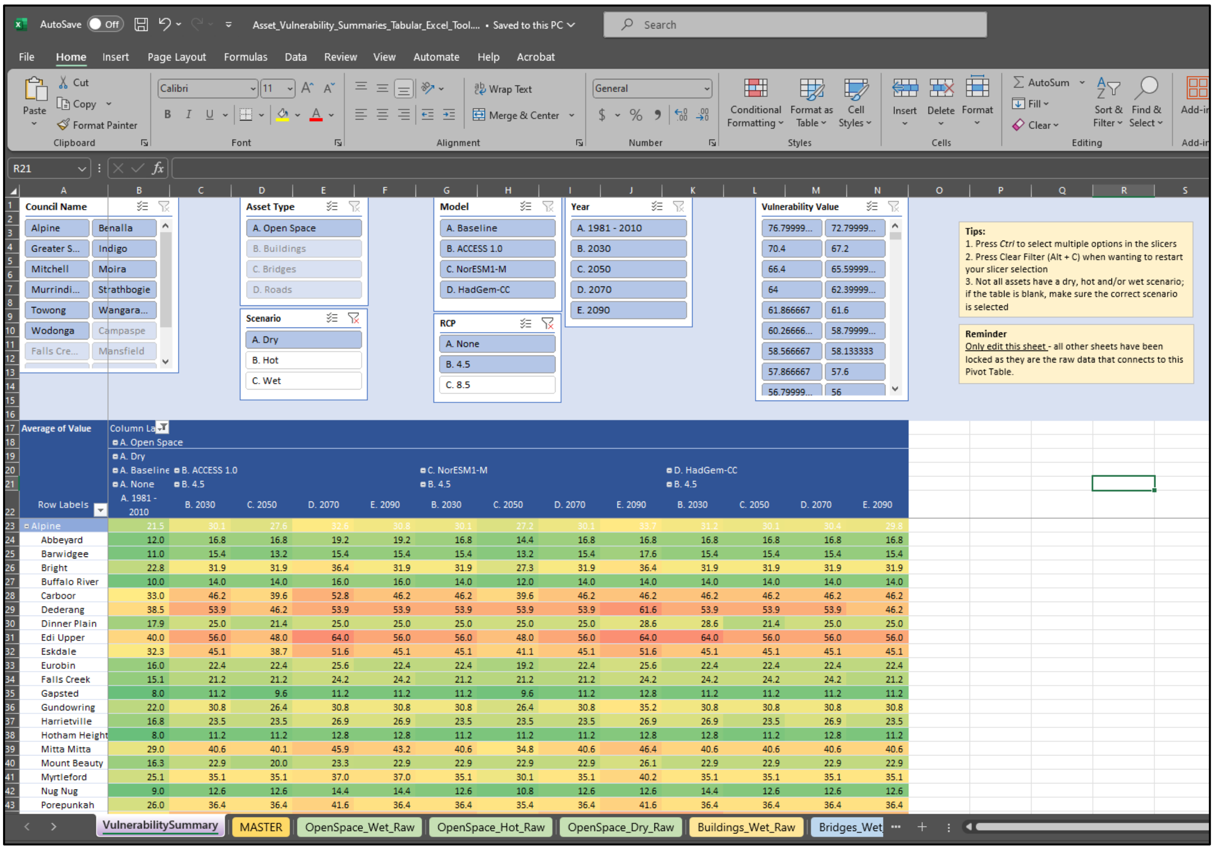

Figure 15. Screenshot of Tabular Excel Tool

6. *QGIS Training & Mentoring material:*

   - Recordings and associated material of all QGIS training and mentoring sessions are provided.

8. References

IPCC. (2001) *Climate Change 2001: Impacts, Adaptation, and Vulnerability - Technical Summary. A Report of Working Group II of the Intergovernmental Panel on Climate Change.* Review Editors: M. Manning (New Zealand) and C. Nobre (Brazil), IPCC 2001

IPCC. (2007) *Climate Change 2007 – Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC.* Cambridge University Press 2007.

Spatial Vision. (2013, 2021). *Case Study: NRM Planning for Climate Change* | Spatial Vision. Retrieved 23 April 2021, from https://spatialvision.com.au/case-study-nrm-planning-for-climate-change/

Spatial Vision. (2020). *Final Project Report – First Pass Asset Vulnerability Assessment. City of Melbourne.* Report submitted July 2020. (unpublished)

Appendix 1

List of GMCA participating councils and key staff*.

Council	Participating Council Members
Moira Shire	Deidre Andrews Luke Bramley
Indigo Shire	Sam Niedra Darryn Arnold
Towong Shire	Rachael Gadd Syed Abdullah
Alpine Shire	Bronwyn Westbrook Russell Wheaton Elsie Northey
Wangaratta Rural City	Evelina Dudzinski Clive Brooker Zaylee Saint-James Turner
Wodonga City	Robyn Nicholas Dean Shawcross Tim Clarke Daniel Alder
Benalla Rural City	Nathan Gasperoni Elise Wood Jenny Levy
Strathbogie Shire	Molly Odgers Juana McKeachie
Greater Shepparton	Marisa O'Halloran Paul Dainton Rohan Montgomery
Mitchell Shire	Narelle Liepa Jenny Hart Brendan Garrrett Saif Mahmod
Murrindindi Shire	Bronwyn Chapman Peter Bain Sanduni Kalingamudali Melissa Spinks

* Staff identified include those involved for only a selected period in addition to those who were involved for the full period.