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# ASSESSING THE IMPACT OF SPATIAL PLANNING ON DISASTER RISK REDUCTION

## UNHaRMED policy case for Tasmania

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# 1 INTRODUCTION

Australia is subject to significant impacts from natural hazards, the risk of which is increasing due to population growth and climate change (e.g. Newman et al., 2017). Tasmania is not immune to these risks and has been impacted by bushfires and floods in recent years. In the future, threats that we think of primarily as mainland problems, such as drought and heatwave, are will increasingly affect Tasmania.

If we could, it would be cheaper, and cause less harm, to deal with some of these threats in advance so we could withstand them better. The difficulty is knowing how to prioritise what to plan for, and how to make best use of available resources, which are generally scarce. This difficulty can be addressed by developing a risk reduction strategy, which requires a good understanding of current and future risks.

The projected increase in risk, together with the awareness of the complexity of the underlying dynamics affecting this risk, has led to the recognition that there is an urgent need to better understand the components of disaster risk and their dynamics. In response, over the past ten years, the University of Adelaide and the Research Institute for Knowledge Systems, supported and funded by the Bushfire & Natural Hazard Cooperative Research Centre (BNHCRC), have developed a decision support system (UNHaRMED - **U**nified **N**atural **Ha**zard **R**isk **M**itigation **E**xploratory **D**ecision Support System) to assist government agencies to better understand how risks arising from multiple natural hazards change over space and time under different plausible future conditions (e.g. climate change, population growth, economic development), as well as the relative effectiveness of different risk reduction strategies (e.g. structural measures, land use planning, land management, building code changes etc.). Its development has been supported by the inputs of many stakeholders around Australia, including Tasmanian State Government agencies such as State Growth and Parks and Wildlife Services, shaping what the tool should be able to do and what it should look like.

The current report demonstrates the use potential of UNHaRMED in understanding how risk changes over time and in space by embedding foresight into risk assessment and risk reduction focusing on the following objectives:

1. To assess the impact of spatial planning on the reduction of (future) risk due to multiple hazards: bushfire, coastal inundation, coastal erosion, landslip and riverine flooding.
2. To explore how UNHaRMED could make best use of available hazard data, with a special focus on hazards not currently incorporated in UNHaRMED.
3. To reflect on the role of UNHaRMED in supporting risk assessment and risk reduction.

This report first introduces the UNHaRMED system (Section 2), the study area (Section 3) and the application of UNHaRMED to the Tasmanian case study (Section 4), followed by the approach taken to assess the impact of zoning on risk reduction (Section 5) and the results obtained (Section 6). The report concludes with the main findings, lessons learnt and suggestions for further work (Section 7).

# 2 UNHARMED

UNHaRMED is a software tool developed by the University of Adelaide and RIKS as a spatial Decision Support System (DSS) for natural hazard risk reduction planning, funded by the BNHCRC. It consists of dynamic spatial exposure models (land use, assets) and multiple hazard models to consider how risk changes into the future, both spatially and temporally.

UNHaRMED was developed through an iterative, stakeholder-focused process to ensure the system is capable of providing the analyses required by policy and planning professionals in the planning, emergency management and risk assessment fields. The development process involved a series of interviews and workshops with potential end users across governmental and non-governmental organisations in South Australia, Tasmania, Victoria and Western Australia, aligning risk reduction options, policy relevant indicators and future uncertainties to be included, such that the system can sit within existing policy processes. This has resulted in a tool that considers how land use and values at stake change over time, how various hazards interact with these changes, and what the effectiveness of a variety of risk reduction measures is.

Land use changes are simulated based on a number of different drivers. These include external factors, such as population growth and projected increase of urban area, which determine the demand for different land uses. The land uses for every location are determined based on these demands and a set of socio-economic factors (e.g., will a business flourish in this location?), policy options (e.g., are there policy rules in effect that restrict new housing development in this location?) and biophysical factors (e.g., is the soil suited to agriculture here?). Different values at stake (e.g., buildings, infrastructure, agricultural production), as well as their susceptibility to different natural hazards, are then associated with the different land use classes. Natural hazards such as bushfire, earthquake, coastal inundation and riverine flooding can then interact with these land uses and values at stake. Each hazard is considered and modelled differently, depending on its underlying physical processes, as detailed in the UNHaRMED documentation (van Delden et al., 2022).

A simplified version of the system diagram developed for UNHaRMED is shown in Figure 1, which includes exposure, hazard risk and impact models, as well as the way they interact with the external drivers, risk reduction options and indicators. Socio-economic drivers affect land use, whereas climate drivers affect hazards such as bushfire and flooding (see e.g., Hamers et al., 2024). Risk reduction options can affect exposure (e.g. land use planning), hazard magnitude (e.g. the construction of levees can reduce flooding and prescribed burning can reduce bushfires) and vulnerability (e.g. building hardening and changes in building codes can affect infrastructure vulnerability).

UNHaRMED is developed in the Geonamica software environment (Hurkens et al., 2008) and comes as a stand-alone software application. The system comes with the Map Comparison Kit (MCK) for analysis of model results. UNHaRMED and the MCK use data formats that are compatible with standard GIS packages, such as ArcGIS.

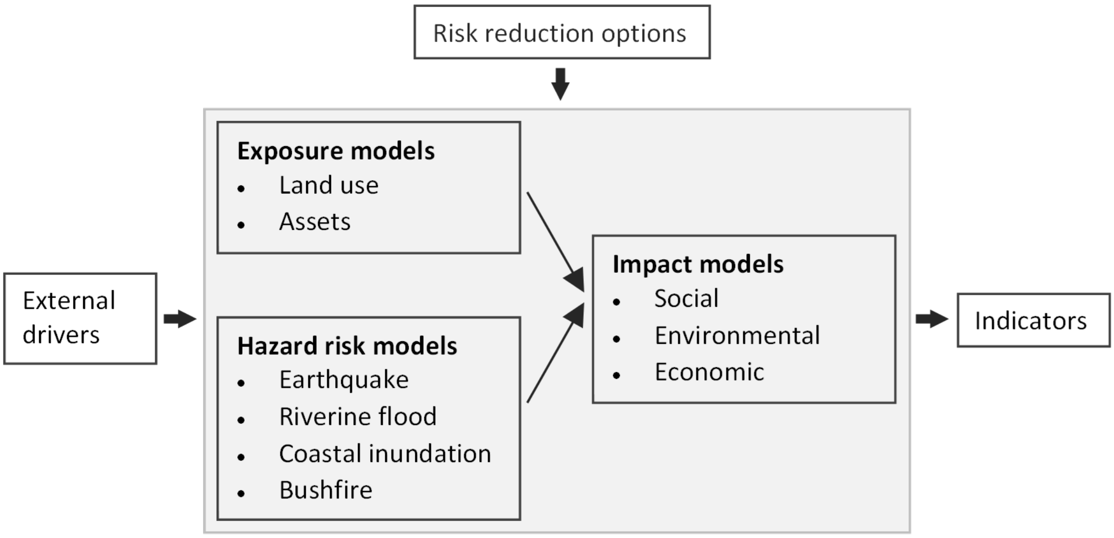

FIGURE 1: MODELLING COMPONENTS FOR INCLUSION WITHIN THE INTEGRATED MODELLING FRAMEWORK OF UNHARMED.

# 3 STUDY AREA

The model area considered is the main island of Tasmania plus its main islands. Figure 2 shows the areas of the LGAs included in the model area and Figure 3 the land uses selected for the application of UNHaRMED to Tasmania.

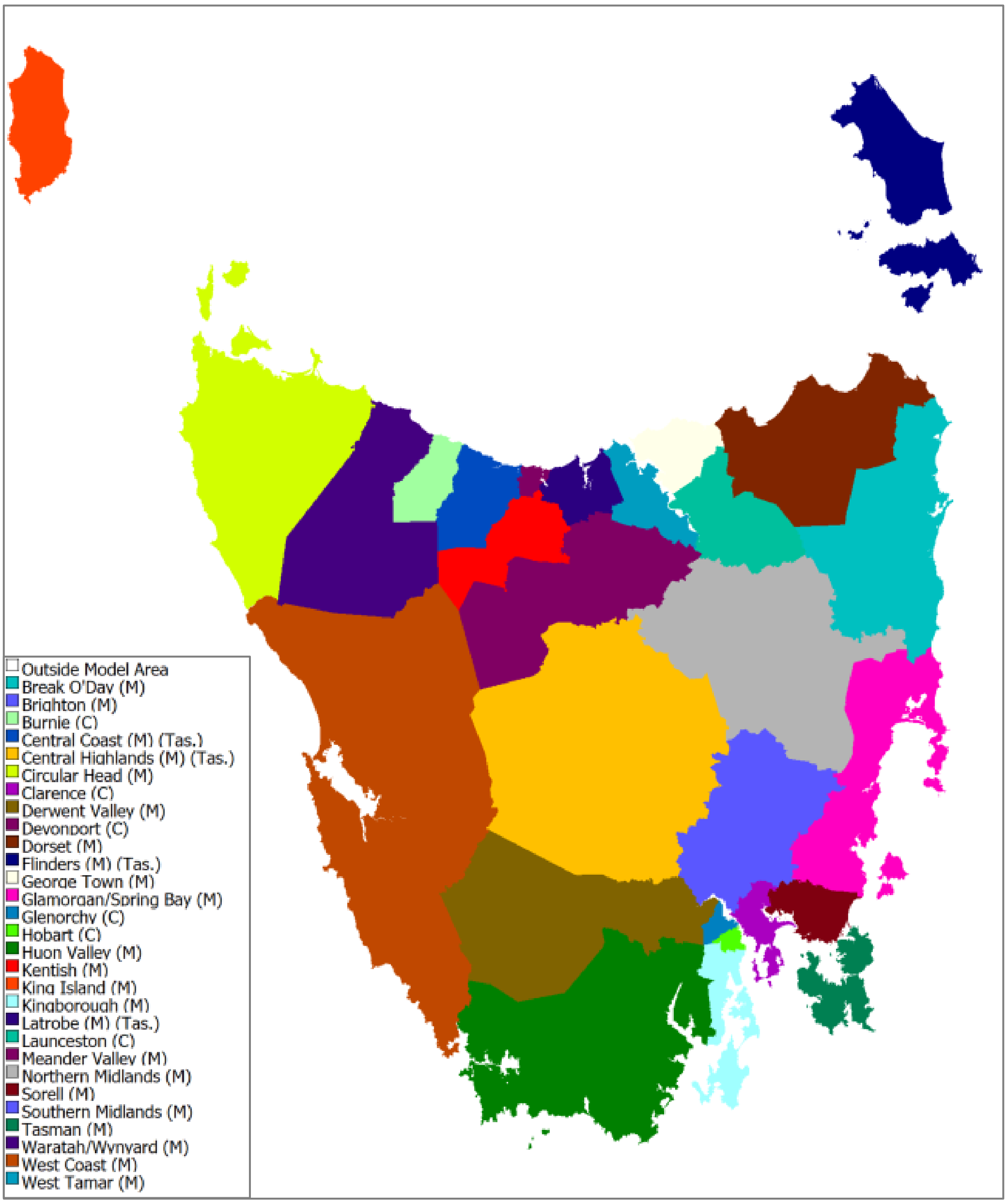

FIGURE 2: TASMANIAN STUDY AREA WITH INCLUDED LOCAL GOVERNMENT AREAS.

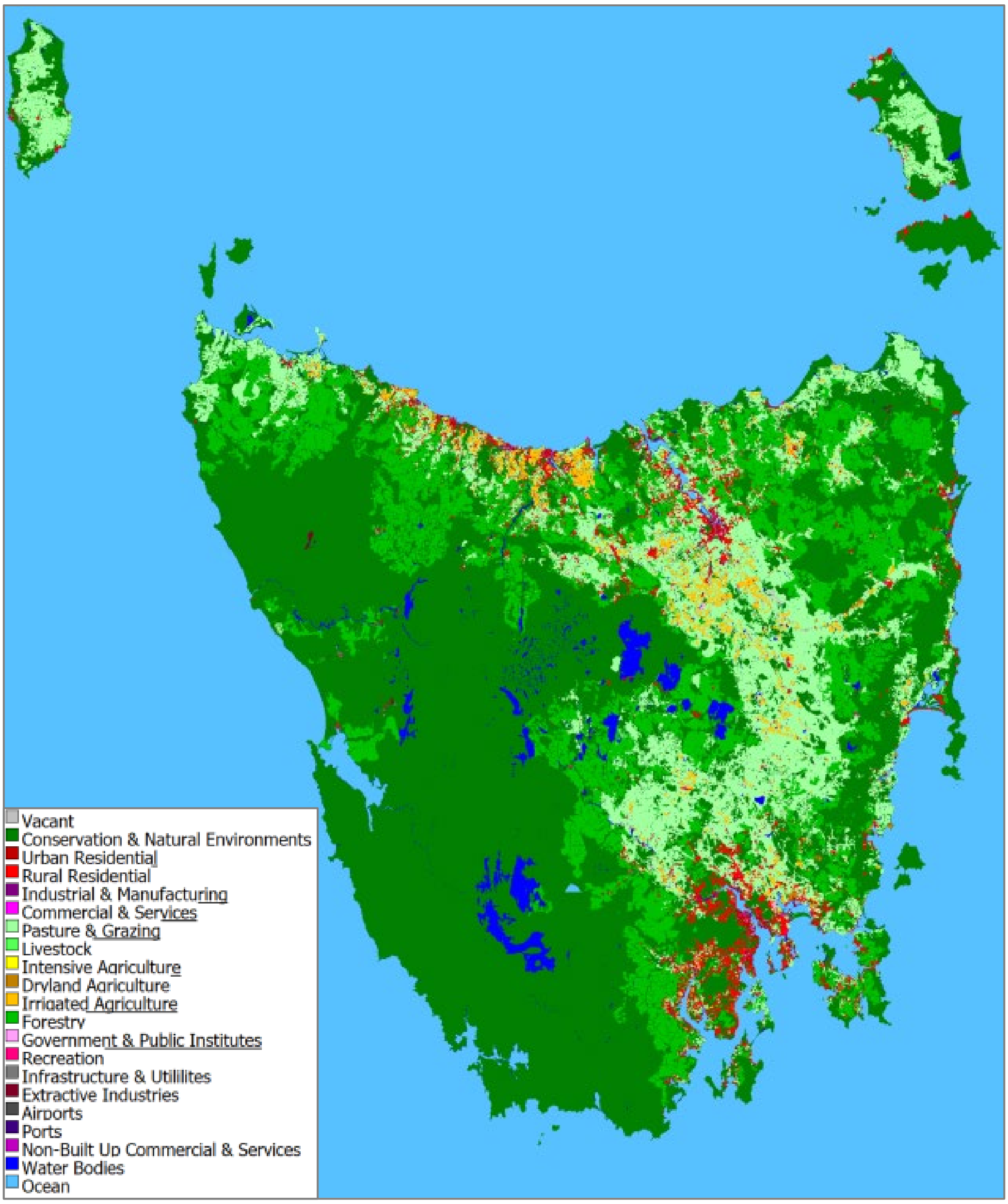

FIGURE 3: LAND USES SELECTED FOR THE TASMANIAN APPLICATION.

# 4 UNHARMED FOR TASMANIA

## 4.1 MODEL CONFIGURATION

For this report, we make use of the components of UNHaRMED that are used in the calculation of coastal inundation and bushfire risk. All calculate risk through the concepts of hazard, exposure and vulnerability, although details of each aspect vary per hazard.

Coastal inundation risk is calculated on an annual basis. For each year the *hazard* is represented through a set of inundation maps for different average recurrence intervals (ARIs). The *exposure* information is calculated based on the land use at each location as simulated by the land use model, and the related residential, commercial and industrial building stock and its monetary value, as determined by the building stock model. Agricultural value is assigned to the various agricultural classes simulated by the land use model. Using dedicated *vulnerability* curves for different types of agriculture, buildings and infrastructure, the expected risk is calculated based on the exposed assets and inundation levels for the various ARIs at each location (100x100 m cell). Inundation maps are calculated exogenously to UNHaRMED and can be included for different years (to simulate climate change impacts) and mitigation options.

In the calculation of bushfire risk, the bushfire *hazard* magnitude is provided through the bushfire likelihood map, which is calculated for each year and each location (100x100 m cell) as a function of fire behaviour (defined by fuel load and the potential rate-of-spread), ignition potential, and suppression capability. The *exposure* information is calculated based on the land use at each location as simulated by the land use model, and the related residential, commercial and industrial building stock and its monetary value, as determined by the building stock model – similar to the exposure information used in the calculation of coastal inundation. Using the Bushfire Attack Level (BAL) specific *vulnerability* of each building type to withstand a fire of a certain intensity, the bushfire likelihood, intensity and the value at stake at each location, the overall bushfire risk can be calculated, expressed as an average annual building damage for each 100x100 m cell.

Further details about the models included are given in the UNHaRMED technical specification document (Van Delden et al., 2022).

## 4.2 MODEL APPLICATION

This section provides an overview of the data, data processing and calibration of the Tasmanian application of UNHaRMED, structured along the main building blocks of the system used in this study: Land use (1), Building stock (2), Coastal inundation risk (3) and Bushfire risk (4).

The models included in UNHaRMED for calculating coastal inundation and bushfire risk make use of the following input maps:

- Land use map (1)

- Building stock map per NEXIS building type (2)
- Building stock map per BAL type (2)
- Coastal inundation hazard maps (3)
- *Vegetation map (TASVEG 4.0)* (4)
- Slope map (1, 4)
- Time since last fire (TSLF) map (4)
- *Suppression capability map* (4)
- Prescribed burn map(s) and/or future burn map(s) (4)
- Climate maps (for different years and climate scenarios) (4):
    - Daily maximum temperature
    - Daily average relative humidity
    - Daily minimum winter temperature
    - Daily maximum wind speed

Key parameters used in the UNHARMED application for Tasmania are:

- *Land use model parameters* (1)
- Future land use demands (1)
- *Building stock model parameters* (2)
- Vulnerability curves per NEXIS building type (3)
- Vulnerability curves per BAL type (4)
- *Ignition potential parameters* (4)
- *Parameters to calibrate the average annual damage* (4)

And socio-economic projections:

- Land use area per land use class from 2016 – 2050 (1)
- *Distribution of building types in newly developed urban areas* (2)

Information on the input for the exposure components of UNHaRMED is given in Section 4.2.1 for land use, and Section 4.2.2 for building stock. Information on inputs to the bushfire risk model are provided in Sections 4.2.3 Climate and 4.2.4. Fuel Age and information on the vulnerability curves for calculating bushfire and coastal inundation risk is provided in 4.2.5 Vulnerability curves. In addition to the data preparation discussed in these sections, maps in italics in the list above were provided by the Tasmania Parks and Wildlife Service. Parameters listed in italics in the list above are set as part of the calibration.

### 4.2.1 Land use

Inputs to the land use model are a set of maps: land use, infrastructure, base maps for zoning and base maps for suitability, together with land use demand projections, a set of interaction rules representing behavioural aspects and parameters to convert infrastructure maps and base maps for zoning and suitability into components contributing to the potential allocation of different land uses.

Land use maps were sourced from the Tasmanian government[1].

#### Land use demand

Assumptions on future (area) demand for different socio-economic land uses were derived from the Tasmanian growth strategy (State of Tasmania, 2015), together with current densities of different urban land uses, which were derived from the current and historic land use maps and the current and historic population from the Australian Bureau of Statistics[2].

#### Human behaviour

Human behaviour (in terms of land use allocation actions) is analysed within the model using historical land use maps and considering the changes between them. This is used to calibrate the inertia of a land use to remain as is, its ease of conversion to other land uses and its relative attractiveness to other uses.

#### Accessibility

Accessibility typically relates to the infrastructure networks that enable an activity to meet its mobility and access needs from a cell.

For the Tasmanian model, four types of accessibility were considered as inputs to the model:

- Arterial highways
- Roads
- Vehicular tracks
- Rail lines

Transport networks were sourced from the Tasmanian State Government[3] and processed for the geographical extent of the model.

#### Suitability

Suitability relates to the physical characteristics of the land to support an activity in that cell.

Currently, slope is the only suitability factor included. Relevant data were sourced from the Tasmanian State Government[4]. To ensure consistency in input data, the

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[1] https://www.thelist.tas.gov.au/app/content/data

[2] Census | Australian Bureau of Statistics (abs.gov.au)

[3] https://www.thelist.tas.gov.au/app/content/data

[4] https://www.thelist.tas.gov.au/app/content/data

slope map from the land use model is also used in the bushfire likelihood component of the bushfire risk model.

### Zoning

Several zoning plans are included within the model and determine, for a given location, whether a particular land use is actively stimulated, allowed, weakly restricted or strictly restricted in that location.

The following zoning strategies are included within the model in its current set up:

- Interim Planning Scheme (IPS)
- Flinders Island IPS
- Ramsar wetlands
- World Heritage Area
- Conservation areas as provided by the land use map

Zoning data were selected in collaboration with the Tasmanian UNHaRMED project manager, sourced from the Tasmanian State Government[5] and processed for the model extent.

## 4.2.2 Building stock

The NEXIS dataset provides information on building stock exposure (per building type) at an SA1 and SA2 Statistical Area level. To disaggregate building stock to a 100 m cell raster, the following process is applied: The Land use map from UNHaRMED is used to determine the number of cells to which the building stock Urban Land Use (ULU) types may be distributed within each Statistical Area (SA2 level for Residential and SA1 level for Commercial and Industrial). Within each statistical area the corresponding building stock(s) are evenly distributed amongst the relevant ULU cells. The total contents value and total structural value are handled using the same approach and disaggregated from SA level to cell level. The resulting total value at stake is the sum of the structural and content value of all buildings at each cell, as shown in Figure 4.

Next, the average structural value and average contents value within each LGA are calculated using the different building stock values and number of ULU cells by the relevant LGA areas.

The initial BAL ratings of the building stock at each cell, required for determining the vulnerability of buildings subject to a certain fire intensity[6], are determined by comparison against the Fire Intensity Potential map, and the age of the building stock at each cell. Buildings from Pre-1980 are automatically assigned a BAL value 'Low'. All other buildings obtain the lowest BAL value required to withstand the current Fire Intensity or Radiant Heat Flux Potential at the location. This Radiant Heat Flux Potential map (kW/m$^2$) is obtained by conversion from the Fire Behaviour Potential (kW/m)[7].

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[5] https://www.thelist.tas.gov.au/app/content/data

[6] Bushfire Attack Level – AS 3959

[7] A more detailed description of how this building stock map has been created, with the accompanying R code, may be provided on request.

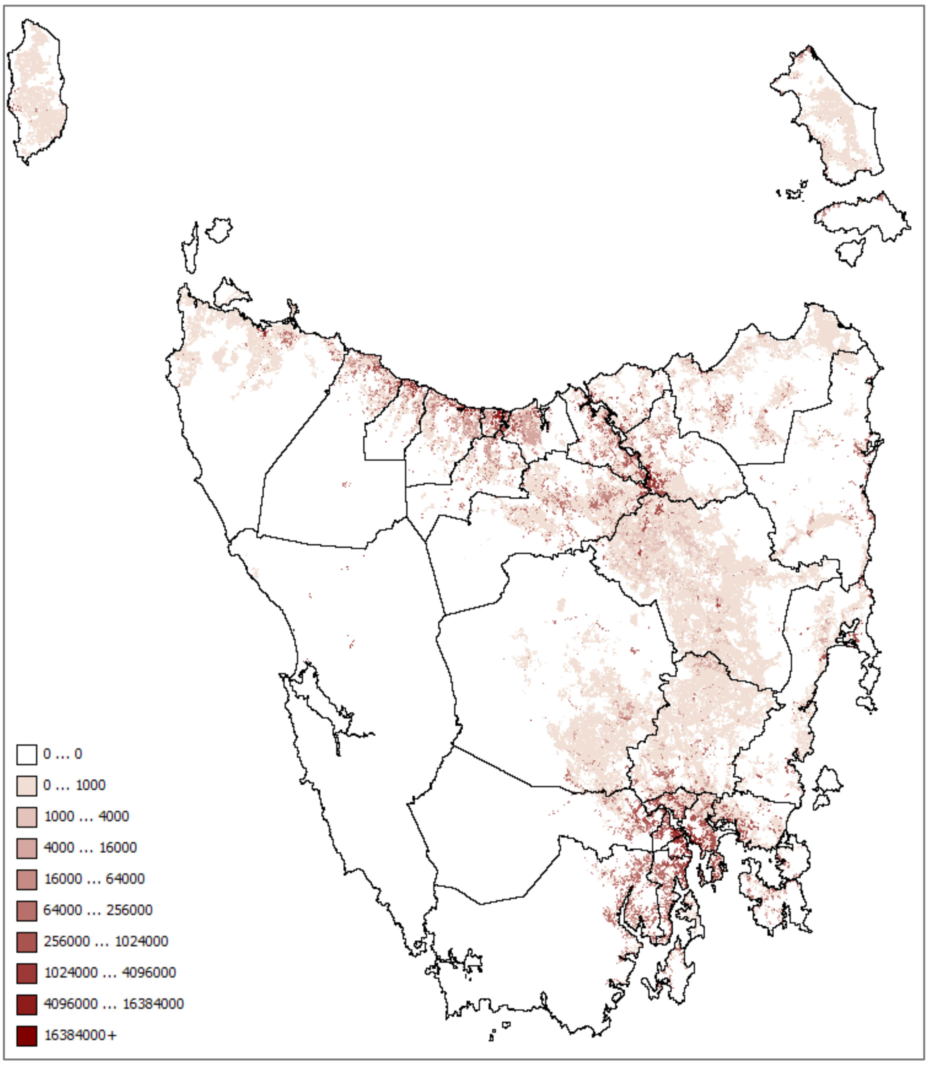

FIGURE 4: VALUES AT STAKE OF AGRICULTURAL LAND AND RESIDENTIAL, COMMERCIAL, AND INDUSTRIAL BUILDINGS IN 2018 ($).

### 4.2.3 Climate

The current climate (i.e., not future projected climate) data have been sourced from Tasmania Parks and Wildlife Service. Information on future climate projections was sourced from the CSIRO Climate Change Australia website[8]. This website provides climate model data from 47 global climate models (GCMs), which have been assessed for Australia for four IPCC greenhouse gas emissions scenarios (RCP 2.6, 4.5, 6.0, and 8.5).

Use was made of projected changes in climate relative to the IPCC 1986-2005 baseline. Annual, seasonal, and monthly data are available at 20-year time slices centred on 2030, 2050, 2070 and 2090. These data are presented as projected ranges of change (in %) based on the 10-90th percentile of the model range and for individual models. For any given region, time period, and emissions scenario, these models can be used to represent "best case", "worst case" and "maximum consensus" scenarios.

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[8] https://www.climatechangeinaustralia.gov.au/en/

The pre-processing of the future climate projection data for inclusion in the Bushfire Model Block can be divided into 3 steps.

Step 1: Identify the most relevant global climate model

The Projection Builder tool[9] was used to identify which climate model would be the most relevant for each UNHaRMED application region (worst-case conditions). The Bushfire Model Block calculates fire behaviour over the summer months, so the season considered for future climate projections was set to December - February (DJF). The climate variables of interest were: Maximum Daily Temperature, Minimum Daily Temperature, Humidity, and Wind Speed. As the Projection Builder offers the possibility to identify the "best case", "worst case", and "maximum consensus" scenario models, the following parameters were selected to define these scenarios:

Best case:

- Little change in December - February (DJF) Wind Speed
- Small increase in December - February (DJF) Maximum Daily Temperature
- Little change in December - February (DJF) Humidity

Worst case:

- Increase in December - February (DJF) Wind Speed
- Large increase in December - February (DJF) Maximum Daily Temperature
- Decrease in December - February (DJF) Humidity

This process was repeated for each time slice and emissions scenario of interest. Once all the queries had been submitted, a summary of the "worst case" and "maximum consensus" scenario models was created to identify the most appropriate climate model for the time-slices considered.

Step 2: Download the gridded change datasets for each climate variable

The relative gridded change datasets for each of the four climate variables and time slices of interest were downloaded from the Climate Change Australia archive. These gridded datasets are available in NetCDF format and cover the entire globe. A description of the files and information contained within each grid can be accessed through the website[10].

Step 3: Re-process the gridded change datasets to the Tasmanian extent and format required by UNHaRMED

The relative gridded change datasets were re-projected and resampled to the resolution and extent of the case-study area and re-processed to actual change datasets to be combined with the current climate input maps (baseline). As a result, new climate maps were produced for each time slice and emissions scenario of interest.

### 4.2.4 Fuel age

Fuel age, in combination with the vegetation type, is an important factor in determining fuel load.

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[9] https://www.climatechangeinaustralia.gov.au/en/projections-tools/climate-futures-tool/projections-builder/

The initial fuel age map was determined based on historic fires in the modelled region[10] using the following approach:

1. Load the historical fire scar map (use both planned burns and bushfire records).
2. Identify the maximum fuel age as the longest time since any fire has occurred in the region (this will become the background value if no fires occurred on a given cell).
3. For each record, calculate the interval (in years) between the fire ignition date and the desired simulation date (e.g., 2022).
4. Convert the modified shapefile to a raster layer (select the column that contains the fuel age value calculated in Step 3) and apply the background value calculated in Step 2 to all other cells.

### 4.2.5 Vulnerability curves

Vulnerability or damage curves are set per building type for calculating coastal inundation risk and per BAL type for bushfire risk. Annex I provides an overview of the vulnerability curves applied in the risk calculation of coastal inundation and bushfire.

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[10] https://discover.data.vic.gov.au/dataset/fire-history-records-of-fires-primarily-on-public-land-showing-the-fire-scars

# 5 APPROACH TO ASSESS IMPACT OF ZONING ON RISK REDUCTION

As mentioned in Section 1, the aim of the this study was to assess the impact of spatial planning on the reduction of (future) risk due to multiple hazards. For this purpose, we designed four different planning scenarios and assessed their impact on future risk. As the Tasmanian stakeholders expressed interest in also considering hazards not included in UNHaRMED (Riddell et al., 2016), we explored to what extent such hazards could be taken into account using relevant information available from the Tasmanian government.

In collaboration with the UNHaRMED project manager and the experts and stakeholders she has interacted with, the following spatial planning options were defined:

- S0 – No codes: no specific codes to restrict development in hazard-prone areas;
- S1 – Current spatial planning overlays for restricting development in hazard-prone areas;
- S2 – Proposed spatial planning overlays for restricting development in hazard-prone areas;
- S3 – Proposed spatial planning overlays and a bushfire overlay based on UNHaRMED fire behaviour and a coastal inundation overlay based on coastal inundation maps incorporated in UNHaRMED.

An overview of all spatial plans incorporated in the different scenarios is presented in Table 1. While all scenarios incorporate plans for general development (Interim Planning Scheme (IPS) and Flinders Island IPS) and conservation (Conservation areas as per land use map 2015, Ramsar wetlands and World Heritage Area), only scenarios S1, S2 and S3 include dedicated plans to limit urban development and high value agriculture in hazard prone areas.

Risk assessment has been undertaken for the following hazards: landslip, riverine flooding, coastal erosion, coastal inundation, and bushfire. For the first three hazards, the incorporated contingency table is used to assess the current and future area of different land use types in hazard prone areas. For the final two hazards, coastal inundation and bushfire, UNHaRMED also calculates the damage in monetary values in dedicated model components.

As details of the spatial plans and their implementation are critical for interpreting the results, these aspects will be discussed together with the results in the next section.

TABLE 1: OVERVIEW OF SPATIAL PLANS INCORPORATED IN THE VARIOUS PLANNING SCENARIOS.

| Zoning base map | **S0 No codes** | **S1 Current overlays** | **S2 New codes** | **S3 New codes + UNHaRMED** |
|---|---|---|---|---|
| IPS | X | X | X | X |
| Flinders island IPS | X | X | X | X |
| Conservation areas as per land use map 2015 | X | X | X | X |
| Ramsar wetlands | X | X | X | X |
| World Heritage area | X | X | X | X |
| Bushfire current code | - | X | - | - |
| Bushfire new code | - | - | X | X |
| Bushfire UNHaRMED | - | - | - | X |
| Coastal erosion | - | X | - | - |
| Coastal erosion new | - | - | X | X |
| Coastal inundation current | - | X | - | - |
| Coastal inundation new | - | - | X | X |
| Coastal inundation UNHaRMED | - | - | - | X |
| Riverine flood 1% AEP | - | X | X | X |
| Landslip current | - | X | - | - |
| Landslip new | - | - | X | X |

# 6 RESULTS AND DISCUSSION

This section discusses the risk assessment for the individual hazards and concludes with a cross-hazard assessment and reflection on the obtained results.

## 6.1 LANDSLIP RISK

Landslip risk was assessed by calculating the current (2016) and future (2050) area of different land use classes in the areas marked as low, medium, medium-high or high on the landslip map provided by the Tasmanian government in Figure 5b. Options to restrict urban development in areas prone to landslip were either none (scenario S0), a map with the current landslip overlay shown in Figure 5a (scenario S1) or a map with the new landslip overlay shown in Figure 5b (scenarios S2 and S3).

Areas listed as high or medium-high in relation to landslip were set as strictly restricted for new urban development, with the exception of rural residential, which was set to weakly restricted for medium-high areas. All other areas prone to landslip were set as weakly restricted for all urban land uses.

Comparing the results from the current situation and the different scenarios (Tables 2a-e), we see that there is a high increase in urban area (from 46,161 ha to 51,443 ha) over the 2016–2050 period due to an increase in urban development in areas prone to landslides. The alternative scenarios S1, S2 and S3 are all able to reduce development in areas prone to landslides belonging to classes high and medium high to levels similar to those at present. The slight increase in urban development in those areas in scenario S1 compared to present conditions is due to the landslip map for this scenario not being completed yet for all LGAs.

Tables 2a-e also show a substantial difference in urban development in the areas marked by low or medium on the landslide hazard map. This difference can be explained through restrictions imposed on these locations due to the other hazard maps in scenario S3.

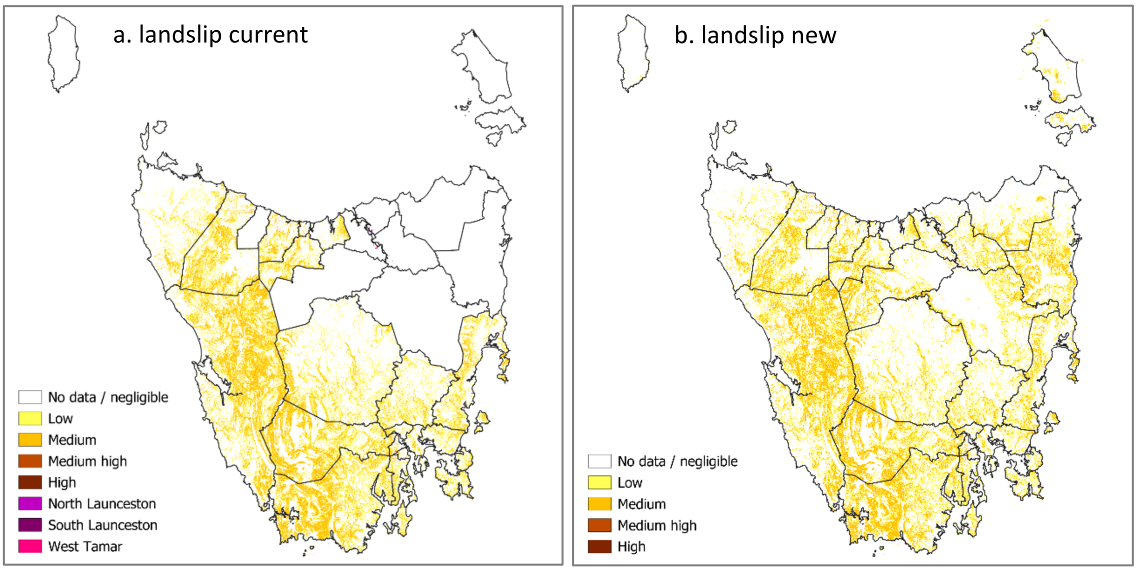


FIGURE 5: LANDSLIP HAZARD MAPS A) CURRENT AND B) NEW. MAP A IS USED AS THE ZONING BASE MAP IN SCENARIO 1, AND MAP B IN SCENARIOS 2 AND 3. MAP B IS ALSO USED IN THE ASSESSMENT OF LANDSLIP RISK.

TABLES 2A-E: AREA OF VARIOUS URBAN LAND USE TYPES (HA) IN AREA PRONE TO LANDSLIP (VARIOUS RISK CATEGORIES). TABLES ARE PROVIDED PER SCENARIO: A - 2016, B - S0 2050, C - S1 2050, D - S2 2050, E - S3: 2050.

| **Table A: 2016**<br>**RISK** | **Urban Residential** | **Rural Residential** | **Industrial & Manufacturing** | **Commercial & Services** | **Government & Public Institutes** | **Total urban area** |
|---|---|---|---|---|---|---|
| **Low** | 2,082 | 29,899 | 87 | 80 | 94 | 32,242 |
| **Medium** | 1145 | 12,465 | 64 | 25 | 69 | 13,768 |
| **Medium-high** | 24 | 38 | 4 | 0 | 7 | 73 |
| **High** | 35 | 42 | 0 | 0 | 1 | 78 |
| **Total** | 3,286 | 42,444 | 155 | 105 | 171 | 46,161 |

| **Table B: S0 BAU 2050**<br>**RISK** | **Urban Residential** | **Rural Residential** | **Industrial & Manufacturing** | **Commercial & Services** | **Government & Public Institutes** | **Total urban area** |
|---|---|---|---|---|---|---|
| **Low** | 2,427 | 32,998 | 119 | 154 | 128 | 35,826 |
| **Medium** | 1,351 | 13,800 | 78 | 103 | 99 | 15,431 |
| **Medium-high** | 29 | 58 | 4 | 0 | 7 | 98 |
| **High** | 36 | 51 | 0 | 0 | 1 | 88 |
| **Total** | 3,843 | 46,907 | 201 | 257 | 235 | 51,443 |

| Table C: S1 2050<br>RISK | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **Low** | 2,369 | 32,379 | 114 | 162 | 132 | 35,156 |
| **Medium** | 1,338 | 13,546 | 78 | 119 | 98 | 15,179 |
| **Medium-high** | 25 | 47 | 4 | 0 | 7 | 83 |
| **High** | 35 | 42 | 0 | 0 | 1 | 78 |
| **Total** | 3,767 | 46,014 | 196 | 281 | 238 | 50,496 |

| Table D: S2 2050<br>RISK | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **Low** | 2,350 | 32,114 | 113 | 179 | 116 | 34,872 |
| **Medium** | 1,324 | 13,359 | 77 | 128 | 96 | 14,984 |
| **Medium-high** | 24 | 39 | 4 | 0 | 7 | 74 |
| **High** | 35 | 42 | 0 | 0 | 1 | 78 |
| **Total** | 3,733 | 45,554 | 194 | 307 | 220 | 50,008 |

| Table E: S3 2050 | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **Low** | 2,136 | 30,841 | 99 | 161 | 108 | 33,345 |
| **Medium** | 1,173 | 12,880 | 71 | 116 | 100 | 14,340 |
| **Medium-high** | 24 | 40 | 4 | 0 | 7 | 75 |
| **High** | 35 | 42 | 0 | 0 | 1 | 78 |
| **Total** | 3,368 | 43,803 | 174 | 277 | 216 | 47,838 |

## 6.2 RIVERINE FLOOD RISK

Riverine flood risk was assessed by calculating the current (2016) and future (2050) area of different land use classes in the areas marked as prone to flooding during a 1% AEP flood event (Figure 6). Scenario S0 did not include a flood overlay, the other scenarios (S1, S2, and S3) all strictly restricted future urban development in the 1% AEP flood zone area, with the exception of the land use class rural residential, for which limited restrictions were included.

Results show a large increase in urban development (from 3,245 ha to 4,299 ha) in the flood prone area over the 2016-2050 period (Table 3). The alternative scenarios S1, S2, and S3 show no increase in the urban residential, industrial & manufacturing, commercial & services and government & public institutes land use classes over the 2016-2050 period due to the strict zoning regulations applied.

We do see an increase in rural development in these scenarios, although substantially less than in the scenario without the flood overlay (S0). The difference in rural development in the flood prone area in the different alternative scenarios can be explained by the overlays for the other hazards.

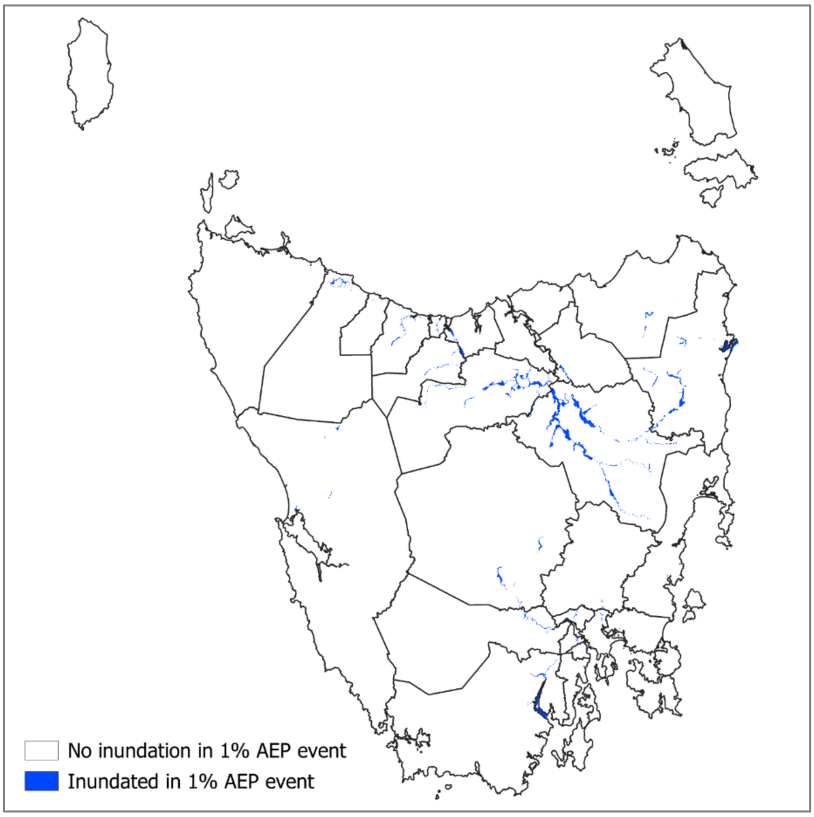


FIGURE 6: RIVERINE FLOOD MAP INDICATING THE EXPECTED INUNDATED AREAS DURING A 1% AEP FLOOD EVENT. THE FLOOD MAP IS USED AS THE ZONING BASE MAP IN SCENARIOS 1, 2 AND 3 AND IN THE ASSESSMENT OF FLOOD RISK.

TABLE 3: AREA OF VARIOUS URBAN LAND USE TYPES (HA) IN AREA PRONE TO RIVERINE FLOODING FOR DIFFERENT GROWTH SCENARIOS.

| Scenario | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **2016** | 877 | 1,996 | 137 | 58 | 177 | 3,245 |
| **S0: 2050** | 1,155 | 2,754 | 146 | 67 | 177 | 4,299 |
| **S1: 2050** | 877 | 2,492 | 137 | 58 | 177 | 3,741 |
| **S2: 2050** | 877 | 2,463 | 137 | 58 | 177 | 3,712 |
| **S3: 2050** | 877 | 2,425 | 137 | 58 | 177 | 3,674 |

## 6.3 COASTAL EROSION RISK

Coastal erosion risk was assessed by calculating the current (2016) and future (2050) area occupied by various land use types in the area prone to coastal erosion. The assessment was made according to the classification listed on the new coastal inundation map (Figure 7b). The assessment was limited to the classes low, medium and high, as these were found most relevant.

Options to restrict development in areas prone to coastal erosion were either none (scenario S0), a map with the current coastal erosion overlay shown in Figure 7a (scenario S1) or a map with the new coastal erosion overlay shown in Figure 7b (scenarios S2 and S3). The two coastal erosion overlays indicate very similar locations as being prone to coastal erosion, however, some deviations can be found between both maps.

Areas listed as highly prone to coastal erosion were set as strictly restricted for all new urban development, while areas listed as being medium prone to coastal erosion strictly restricted new development of industrial & manufacturing, commercial & services and government & public institutes, and weakly restricted urban and rural residential development. In locations with low coastal erosion risk, weak restrictions were imposed on all urban land uses except rural residential.

Comparing the results from the current situation and the different scenarios (Tables 4a-e), we see very few differences across the different scenarios. Some reduction can be observed in rural residential in scenarios S1, S2 and S3.

Coastal erosion risk was not found relevant in the context of the agricultural classes and hence no results are provided for these classes.

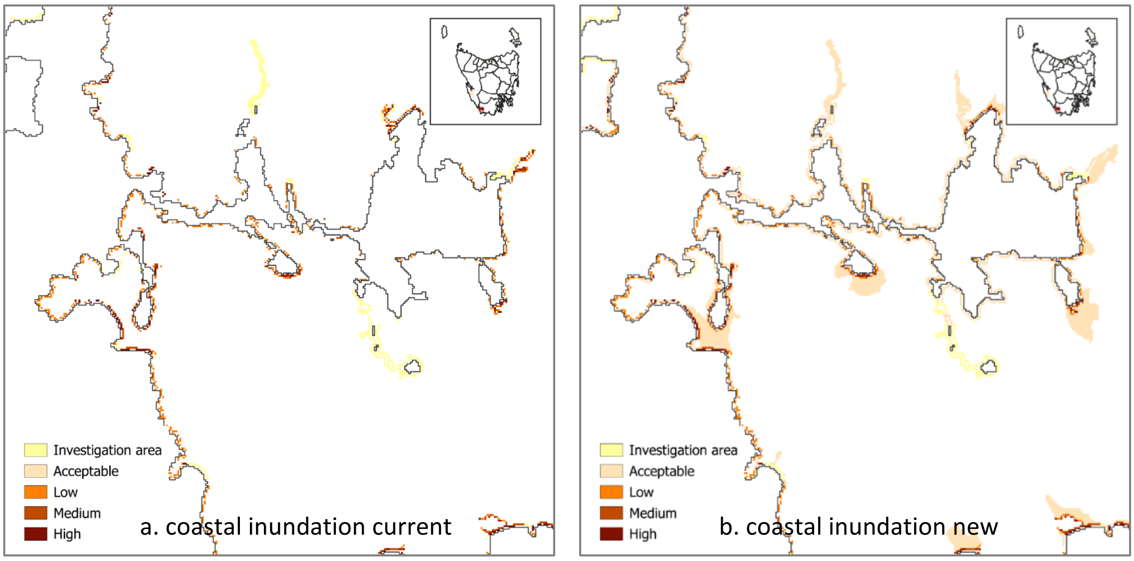


FIGURE 7: COASTAL EROSION HAZARD MAPS A) CURRENT AND B) NEW. MAP A IS USED AS ZONING BASE MAP IN SCENARIO 1, MAP B IN SCENARIOS 2 AND 3. MAP B IS ALSO USED IN THE ASSESSMENT OF COASTAL INUNDATION RISK.

TABLES 4A-E: AREA OF VARIOUS URBAN LAND USE TYPES (HA) IN AREAS PRONE TO COASTAL EROSION (VARIOUS RISK CATEGORIES). TABLES ARE PROVIDED PER SCENARIO: A - 2016, B - S0 2050, C - S1 2050, D - S2 2050, E - S3: 2050.

| Table A: 2016<br>RISK | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **Low** | 152 | 226 | 10 | 1 | 9 | 398 |
| **Medium** | 154 | 219 | 4 | 4 | 11 | 392 |
| **High** | 103 | 157 | 2 | 3 | 4 | 269 |
| **Total** | 409 | 602 | 16 | 8 | 24 | 1,059 |

| Table B: S0 BAU 2050<br>RISK | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **Low** | 159 | 258 | 11 | 2 | 9 | 439 |
| **Medium** | 156 | 222 | 4 | 4 | 11 | 397 |
| **High** | 102 | 150 | 2 | 3 | 4 | 261 |
| **Total** | 417 | 630 | 17 | 9 | 24 | 1,097 |

| Table C: S1 2050<br>RISK | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **Low** | 154 | 253 | 10 | 1 | 10 | 428 |
| **Medium** | 155 | 224 | 4 | 4 | 11 | 398 |
| **High** | 102 | 145 | 2 | 3 | 4 | 256 |
| **Total** | 411 | 622 | 16 | 8 | 25 | 1,082 |

| Table D: S2 2050<br>RISK | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **Low** | 155 | 240 | 11 | 1 | 9 | 416 |
| **Medium** | 156 | 217 | 4 | 4 | 11 | 392 |
| **High** | 102 | 146 | 2 | 3 | 4 | 257 |
| **Total** | 413 | 603 | 17 | 8 | 24 | 1,065 |

| Table E: S3 2050<br>RISK | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **Low** | 154 | 229 | 10 | 1 | 9 | 403 |
| **Medium** | 155 | 216 | 4 | 4 | 11 | 390 |
| **High** | 102 | 145 | 2 | 3 | 4 | 256 |
| **Total** | 411 | 590 | 16 | 8 | 24 | 1,049 |

## 6.4 COASTAL INUNDATION RISK

Coastal inundation risk was assessed by calculating the current (2016) and future (2050) area occupied by various land use types in the area prone to coastal inundation.

For coastal inundation risk, two assessments were made:

1. The first assessment was made by calculating current and future land use in areas indicated as having low, medium and high inundation risk on the new coastal inundation map (Figure 8b).
2. The second assessment was made by calculating current and future land use in areas expected to be flooded during a 1/20, 1/50, 1/100, 1/2000 or 1/20000 flood event in 2050 (Figure 8c). In addition, the damage (A$) was calculated.

The first assessment was chosen to align with the assessment of the other hazards, the second assessment was chosen to align with the monetary damage calculation of UNHaRMED.

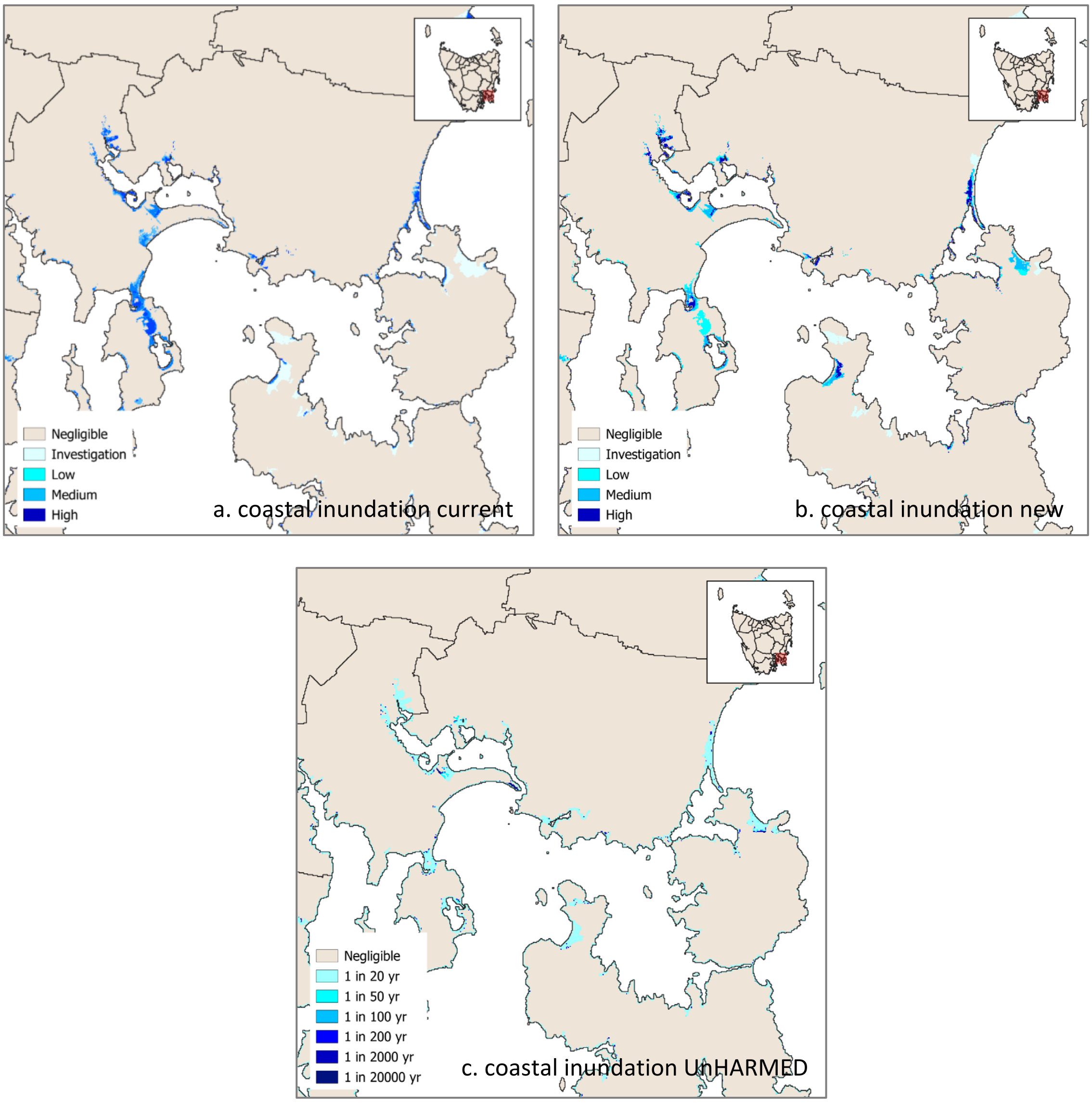
Options to restrict development in areas prone to coastal inundation were either none (scenario S0), a map with the current coastal inundation overlay shown in Figure 8a (scenario S1), a map with the new coastal inundation overlay shown in Figure 8b (scenario S2) or a combination of the map with the new coastal inundation overlay and a map showing the coastal inundation for different return periods in 2050 as used in UNHaRMED (scenario S3). The two coastal inundation overlays indicate very similar locations as being prone to coastal inundation, however, some deviations can be found between both maps. The map from UNHaRMED also shows overlap with the overlays, but as this map is calculated using a different inundation model, more differences can be found.

Areas listed as highly prone to coastal inundation of the coastal inundation overlays were set as strictly restricted for all new urban development, while areas listed as being medium prone to coastal inundation strictly restricted new development of industrial & manufacturing, commercial & services and government & public institutes, and weakly restricted new development for urban and rural residential development. In locations with low coastal inundation risk, weak restrictions were imposed on all urban land uses except rural residential.

In scenario S3, in addition to the new flood overlay, also areas prone to inundation in 2050 on the maps incorporated in UNHaRMED were strictly restricted for new development of industrial & manufacturing, commercial & services and government & public institutes, and weakly restricted for urban and rural residential development.

Looking at the results from the first assessment (Tables 5a-e), we see a reasonable increase (from 1,836 ha to 2,108 ha) over the 2016-2050 period in the total urban area in the flood zone, almost entirely due to an increase in residential development is this area. The total urban area in the flood zone is somewhat smaller in S1, somewhat smaller again in S2 and smallest across the future scenarios in S3. However, the total urban area impacted in S4 (1,894 ha) is still slightly larger than that in 2016 (1,836 ha).

Comparing the results from the current situation and the different scenarios (Tables 6a-e) from the second assessment, we also see some differences across the different scenarios, but they are less than those in the first assessment. There is an increase in the total urban area impacted from 4,177 ha to 4,439 ha over the 2016-2050 period. Scenarios S1 and S2 are both expected to result in some reduction of this area. The largest reduction can be found in Scenario S3. Here the urban area impacted (4,186 ha) is similar to the area impacted in 2016. As was the case in the first assessment, the increase in area impacted can be attributed to an increase in residential development in the flood prone area (4,177 ha). The quantitative risk assessment (Figure 9) aligns with the information in tables 6a-e, as it shows the greatest risk reduction in Scenario S3. Compared to the scenario without zoning (S0), the risk is expected to be reduced from A$ 134 M to A$ 126 M.



FIGURES 8A-C: COASTAL INUNDATION HAZARD MAPS A) CURRENT AND B) NEW. MAP A IS USED AS THE ZONING BASE MAP IN SCENARIO 1, AND MAP B IN SCENARIOS 2 AND 3. MAP B IS ALSO USED IN THE 1ST ASSESSMENT OF COASTAL INUNDATION RISK AND MAP C IN THE 2ND ASSESSMENT OF COASTAL INUNDATION RISK.

TABLES 5A-E: AREA OF VARIOUS URBAN LAND USE TYPES (HA) IN THE AREA PRONE TO COASTAL INUNDATION (VARIOUS RISK CATEGORIES) AS PER ASSESSMENT 1. TABLES ARE PROVIDED PER SCENARIO: A - 2016, B - S0 2050, C - S1 2050, D - S2 2050, E - S3: 2050.

| **Table A: 2016 RISK** | **Urban Residential** | **Rural Residential** | **Industrial & Manufacturing** | **Commercial & Services** | **Government & Public Institutes** | **Total urban area** |
|---|---|---|---|---|---|---|
| **Low** | 258 | 425 | 26 | 13 | 3 | 725 |
| **Medium** | 296 | 446 | 27 | 10 | 11 | 790 |
| **High** | 71 | 239 | 7 | 2 | 2 | 321 |
| **Total** | 625 | 1110 | 60 | 25 | 16 | 1,836 |

| **Table B: S0 BAU 2050 RISK** | **Urban Residential** | **Rural Residential** | **Industrial & Manufacturing** | **Commercial & Services** | **Government & Public Institutes** | **Total urban area** |
|---|---|---|---|---|---|---|
| **Low** | 282 | 468 | 26 | 14 | 3 | 793 |
| **Medium** | 355 | 546 | 27 | 10 | 11 | 949 |
| **High** | 92 | 263 | 7 | 2 | 2 | 366 |
| **Total** | 729 | 1,277 | 60 | 26 | 16 | 2,108 |

| **Table C: S1 2050 RISK** | **Urban Residential** | **Rural Residential** | **Industrial & Manufacturing** | **Commercial & Services** | **Government & Public Institutes** | **Total urban area** |
|---|---|---|---|---|---|---|
| **Low** | 273 | 456 | 26 | 14 | 3 | 772 |
| **Medium** | 344 | 529 | 27 | 10 | 11 | 921 |
| **High** | 78 | 257 | 7 | 2 | 2 | 346 |
| **Total** | 695 | 1,242 | 60 | 26 | 16 | 2,039 |

| **Table D: S2 2050 RISK** | **Urban Residential** | **Rural Residential** | **Industrial & Manufacturing** | **Commercial & Services** | **Government & Public Institutes** | **Total urban area** |
|---|---|---|---|---|---|---|
| **Low** | 278 | 450 | 26 | 13 | 3 | 770 |
| **Medium** | 346 | 507 | 27 | 10 | 11 | 901 |
| **High** | 71 | 244 | 7 | 2 | 2 | 326 |
| **Total** | 695 | 1,201 | 60 | 25 | 16 | 1,997 |

| **Table E: S3 2050 RISK** | **Urban Residential** | **Rural Residential** | **Industrial & Manufacturing** | **Commercial & Services** | **Government & Public Institutes** | **Total urban area** |
|---|---|---|---|---|---|---|
| **Low** | 265 | 436 | 26 | 14 | 3 | 744 |
| **Medium** | 320 | 452 | 27 | 10 | 11 | 820 |
| **High** | 71 | 248 | 7 | 2 | 2 | 330 |
| **Total** | 656 | 1,136 | 60 | 26 | 16 | 1,894 |

TABLES 6A-E: AREA OF VARIOUS URBAN LAND USE TYPES (HA) IN AREAS PRONE TO COASTAL INUNDATION (VARIOUS RISK CATEGORIES) AS PER ASSESSMENT 2. TABLES ARE PROVIDED PER SCENARIO: A - 2016, B - S0 2050, C - S1 2050, D - S2 2050, E - S3: 2050.

| Table A: 2016 RISK | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **1in20** | 189 | 482 | 15 | 4 | 5 | 695 |
| **1in50** | 19 | 27 | 2 | 0 | 1 | 49 |
| **1in100** | 1,114 | 1,969 | 85 | 32 | 52 | 3,252 |
| **1in200** | 4 | 15 | 0 | 0 | 0 | 19 |
| **1in2000** | 9 | 10 | 0 | 0 | 0 | 19 |
| **1in20000** | 43 | 35 | 36 | 8 | 21 | 143 |
| **Total** | 1,378 | 2,538 | 138 | 44 | 79 | 4,177 |

| Table B: S0 BAU 2050 RISK | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **1in20** | 199 | 538 | 15 | 4 | 5 | 761 |
| **1in50** | 21 | 33 | 2 | 0 | 1 | 57 |
| **1in100** | 1,162 | 2,052 | 89 | 41 | 52 | 3,396 |
| **1in200** | 4 | 19 | 0 | 0 | 0 | 23 |
| **1in2000** | 11 | 14 | 0 | 0 | 0 | 25 |
| **1in20000** | 69 | 43 | 36 | 8 | 21 | 177 |
| **Total** | 1,466 | 2,699 | 142 | 53 | 79 | 4,439 |

| Table C: S1 2050 RISK | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **1in20** | 204 | 525 | 15 | 4 | 5 | 753 |
| **1in50** | 23 | 30 | 2 | 0 | 1 | 56 |
| **1in100** | 1,158 | 2,047 | 88 | 38 | 53 | 3,384 |
| **1in200** | 4 | 15 | 0 | 0 | 0 | 19 |
| **1in2000** | 11 | 10 | 0 | 0 | 0 | 21 |
| **1in20000** | 51 | 46 | 36 | 8 | 21 | 162 |
| **Total** | 1,451 | 2,673 | 141 | 50 | 80 | 4,395 |

| Table D: S2 2050 RISK | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **1in20** | 200 | 509 | 15 | 4 | 5 | 733 |
| **1in50** | 22 | 29 | 2 | 0 | 1 | 54 |
| **1in100** | 1,157 | 2,023 | 88 | 38 | 52 | 3,358 |
| **1in200** | 4 | 16 | 0 | 0 | 0 | 20 |
| **1in2000** | 10 | 10 | 0 | 0 | 0 | 20 |
| **1in20000** | 46 | 40 | 36 | 8 | 21 | 151 |
| **Total** | 1,439 | 2,627 | 141 | 50 | 79 | 4,336 |

| Table E: S3 2050 RISK | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **1in20** | 189 | 496 | 15 | 4 | 5 | 709 |
| **1in50** | 19 | 27 | 2 | 0 | 1 | 49 |
| **1in100** | 1,112 | 1,959 | 85 | 32 | 52 | 3,240 |
| **1in200** | 4 | 15 | 0 | 0 | 0 | 19 |
| **1in2000** | 10 | 10 | 0 | 0 | 0 | 20 |
| **1in20000** | 48 | 36 | 36 | 8 | 21 | 149 |
| **Total** | 1,382 | 2,543 | 138 | 44 | 79 | 4,186 |

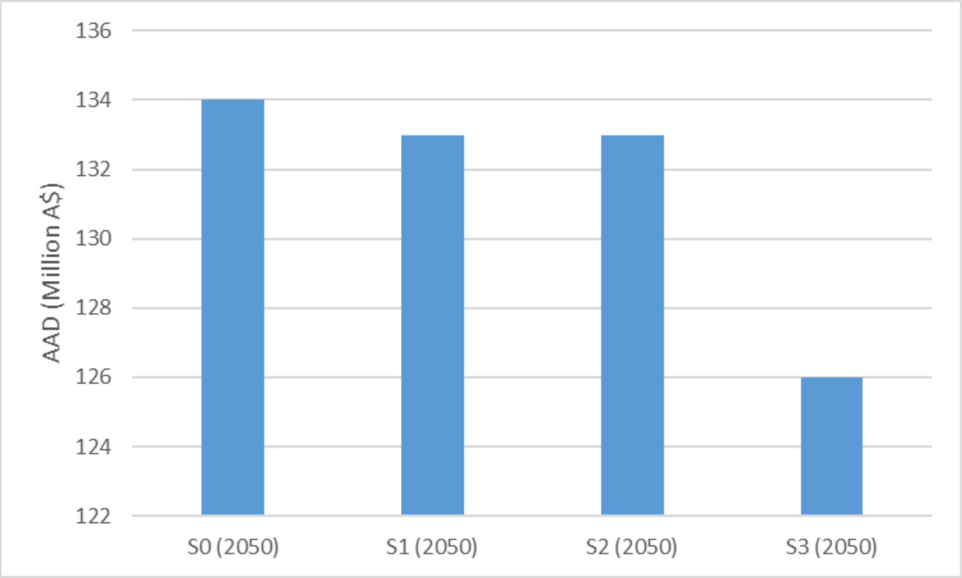


FIGURE 9: AVERAGE ANNUAL DAMAGE (AAD) FOR COASTAL INUNDATION RISK FOR DIFFERENT PLANNING SCENARIOS (2050).

## 6.5 BUSHFIRE RISK

Bushfire risk was assessed by calculating the current (2016) and future (2050) area occupied by various land use types in the area prone to bushfires. The assessment was made according to the classification listed on the fire behaviour map for 2050 calculated by UNHaRMED (Figure 10b). The assessment was performed by classifying the fire behaviour map into 6 classes: negligible, medium, medium-high, high, very high, and severe.

Options to restrict development in areas prone to bushfires were either none (scenario S0), a map with the current bushfire overlay shown in Figure 10a (scenario S1), a map with the new bushfire overlay shown in Figure 10b (scenario S2) or the fire behaviour map calculated by UNHaRMED. As can be seen in Figure 10b, the new bushfire overlay lists every location except for water bodies as prone to bushfire, and the current bushfire map only covers a subsection of all LGAs. Within the subsection of LGAs covered, the current and new bushfire overlay are very similar, although not exactly the same. The fire behaviour map from UNHaRMED has 6 classes to differentiate bushfire risk, as listed above.

Areas listed as having bushfire impact on the bushfire overlays were set as weakly restricted. Areas listed as having severe and very high and high fire behaviour on the fire behaviour map were listed as strictly restricted for all new urban development and medium-high location on the fire behaviour map were set to weakly restricted for all new urban development. Other areas on the fire behaviour map had no restrictions for new urban development.

Tables 7a-e show the increase in urban development in bushfire prone areas between 2016 and 2050 from 195,048 ha to 232,064 ha. As almost the entire state is prone to bushfires, figures for total urban development in bushfire prone areas are very similar across all scenarios. What the modelling shows is that by using a differentiated zoning map (i.e. the fire behaviour map with different risk classes), it is possible to redirect future growth from areas with high, very high or severe bushfire risk. This is indicated by the smaller urban area in the higher risk classes in scenario S3 and the resulting larger urban area in the lower risk classes in the same scenario. These findings are in line with the quantitative risk assessment (Figure 11) with the AAD ranging from $ 46M in 2016 to $ 59M in 2050 and scenario 3 having the largest risk reduction potential resulting in a AAD of $ 49M.

The bushfire overlays have been added to this assessment as zoning inputs for completeness, however, it should be noted that they do not contribute in a meaningful way to the assessment and therefore their results are not discussed in detail and marked as grey in Tables 7c and &d. The new bushfire overlay marks almost the entire state in one class (bushfire impact), so using this map as an input does not provide any differentiation in the spatial allocation of urban development. The current bushfire overlay only provides information for a small number of LGAs. Because UNHaRMED performs the land use allocation by downscaling land demands from state level, there is a bias in the zoning input map with LGAs with areas listed as having bushfire impact becoming less attractive for allocation than LGAs without areas listed having bushfire impact.

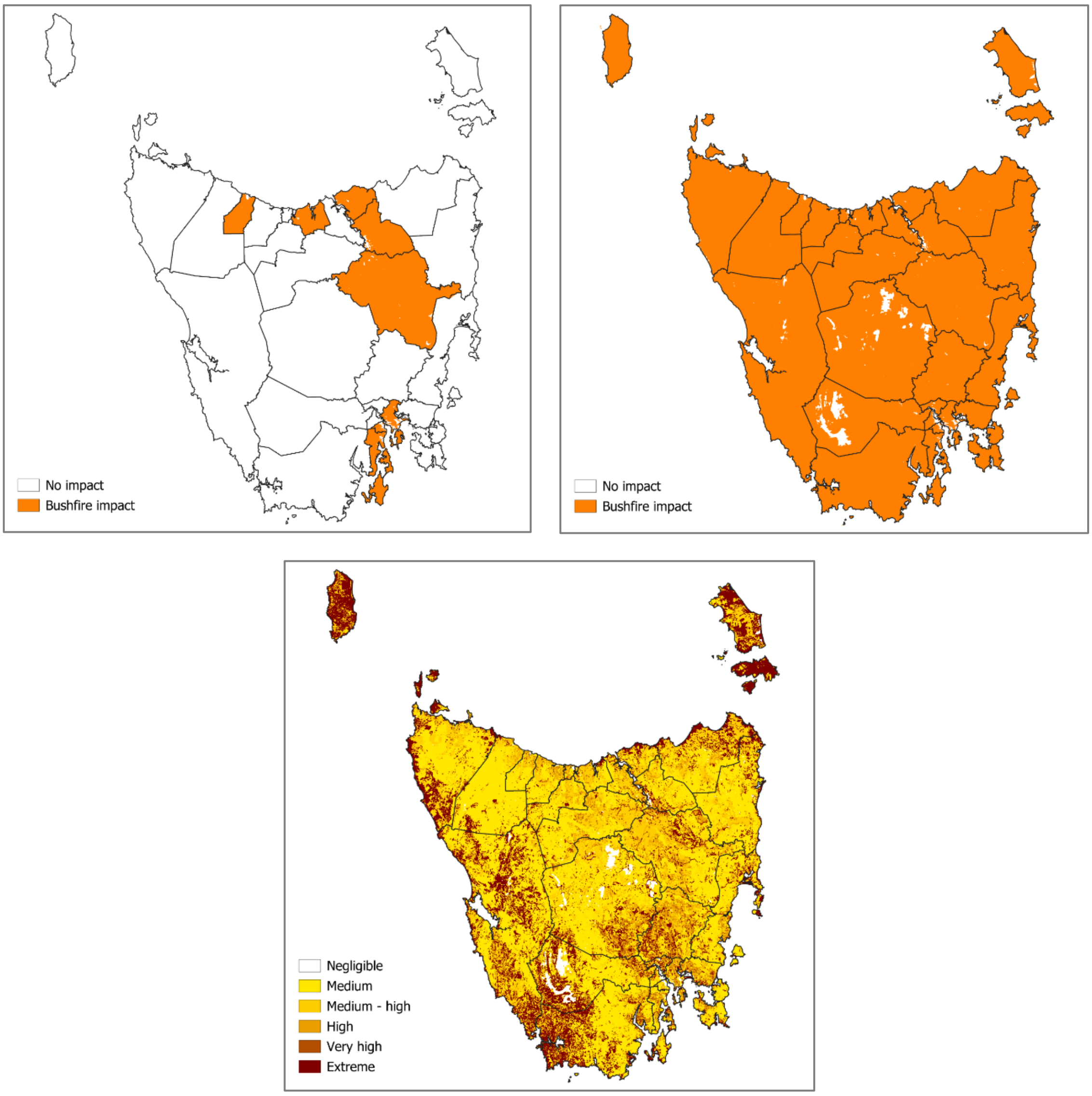


FIGURE 10: BUSHFIRE HAZARD MAPS A) CURRENT AND B) NEW. MAP A IS USED AS THE ZONING BASE MAP IN SCENARIO 1, MAP B IN SCENARIOS 2 AND 3. MAP B IS ALSO USED IN THE ASSESSMENT OF BUSHFIRE RISK.

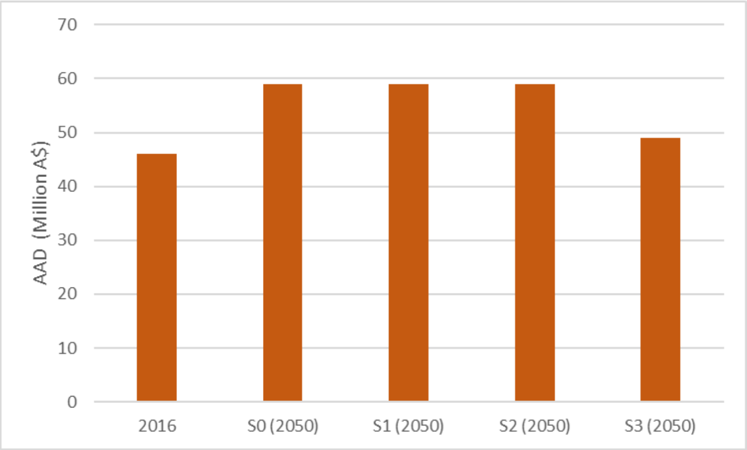


FIGURE 11: AVERAGE ANNUAL DAMAGE (AAD) FOR BUSHFIRE RISK FOR 2016 AND DIFFERENT PLANNING SCENARIOS (2050).

TABLES 7A-E: AREA OF VARIOUS URBAN LAND USE TYPES (HA) IN AREA PRONE TO BUSHFIRES (VARIOUS RISK CATEGORIES). TABLES ARE PROVIDED PER SCENARIO: A - 2016, B - S0 2050, C - S1 2050, D - S2 2050, E - S3: 2050.

| **TABLE A: 2016 RISK** | **Urban Residential** | **Rural Residential** | **Industrial & Manufacturing** | **Commercial & Services** | **Government & Public Institutes** | **Total urban area** |
|---|---|---|---|---|---|---|
| **< 10000** | 5,821 | 46,356 | 466 | 214 | 437 | 53,294 |
| **10000 ... 20000** | 6,279 | 47,060 | 683 | 352 | 891 | 55,265 |
| **20000 ... 30000** | 4,149 | 35,520 | 314 | 153 | 520 | 40,656 |
| **30000 ... 40000** | 1,161 | 13,048 | 77 | 52 | 40 | 14,378 |
| **40000+** | 3,823 | 26,900 | 370 | 115 | 247 | 31,455 |
| **Total** | 21,233 | 168,884 | 1,910 | 886 | 2,135 | 195,048 |

| **TABLE B: S0 BAU 2050 RISK** | **Urban Residential** | **Rural Residential** | **Industrial & Manufacturing** | **Commercial & Services** | **Government & Public Institutes** | **Total urban area** |
|---|---|---|---|---|---|---|
| **< 10000** | 6,004 | 48,360 | 554 | 568 | 664 | 56,150 |
| **10000 ... 20000** | 8,669 | 61,013 | 897 | 654 | 1,043 | 72,276 |
| **20000 ... 30000** | 5,729 | 44,568 | 367 | 299 | 587 | 51,550 |
| **30000 ... 40000** | 1,437 | 15,114 | 97 | 114 | 51 | 16,813 |
| **40000+** | 4,348 | 29,860 | 467 | 328 | 272 | 35,275 |
| **Total** | 26,187 | 198,915 | 2,382 | 1,963 | 2,617 | 232,064 |

| **TABLE C: S1 2050 RISK** | **Urban Residential** | **Rural Residential** | **Industrial & Manufacturing** | **Commercial & Services** | **Government & Public Institutes** | **Total urban area** |
|---|---|---|---|---|---|---|
| **< 10000** | 5,974 | 48,493 | 542 | 645 | 629 | 56,283 |
| **10000 ... 20000** | 8,772 | 61,518 | 906 | 679 | 1,013 | 72,888 |
| **20000 ... 30000** | 5,748 | 44,415 | 387 | 283 | 588 | 51,421 |
| **30000 ... 40000** | 1,417 | 14,890 | 107 | 96 | 59 | 16,569 |
| **40000+** | 4,276 | 29,600 | 451 | 254 | 324 | 34,905 |
| **Total** | 26,187 | 198,916 | 2,393 | 1,957 | 2,613 | 232,066 |

| **TABLE D: S2 2050 RISK** | **Urban Residential** | **Rural Residential** | **Industrial & Manufacturing** | **Commercial & Services** | **Government & Public Institutes** | **Total urban area** |
|---|---|---|---|---|---|---|
| **< 10000** | 5,979 | 48,412 | 578 | 658 | 587 | 56,214 |
| **10000 ... 20000** | 8,783 | 61,723 | 922 | 593 | 1076 | 73,097 |
| **20000 ... 30000** | 5,744 | 44,300 | 364 | 313 | 576 | 51,297 |
| **30000 ... 40000** | 1,437 | 14,866 | 102 | 102 | 57 | 16,564 |
| **40000+** | 4,249 | 29,612 | 427 | 286 | 320 | 34,894 |
| **Total** | 26,192 | 198,913 | 2,393 | 1,952 | 2,616 | 232,066 |

| TABLE E: S3 2050 RISK | Urban Residential | Rural Residential | Industrial & Manufacturing | Commercial & Services | Government & Public Institutes | Total urban area |
|---|---|---|---|---|---|---|
| **< 10000** | 6,142 | 50,046 | 605 | 705 | 605 | 58,103 |
| **10000 ... 20000** | 10,897 | 73,938 | 1,019 | 937 | 1,203 | 87,994 |
| **20000 ... 30000** | 4,149 | 35,457 | 314 | 153 | 520 | 40,593 |
| **30000 ... 40000** | 1,161 | 12,994 | 77 | 52 | 40 | 14,324 |
| **40000+** | 3,823 | 26,487 | 370 | 115 | 247 | 31,042 |
| **Total** | 26,172 | 198,922 | 2,385 | 1,962 | 2,615 | 232,056 |

## 6.6 SYNTHESIS AND DISCUSSION OF FINDINGS

Results show that integrating hazard information in spatial planning can decrease the (urban) area impacted quite substantially across multiple hazards, including landslip, riverine flooding, coastal erosion, coastal inundation and bushfire.

This study has further shown that it is possible to provide information on hazards not included in UNHaRMED. The information that can be provided in this way includes the understanding of the current and future urban area that are within areas prone to one or more hazards, as calculated in this study. In addition, an assessment could be made for other land uses, such as agricultural areas or areas with high nature value. As UNHaRMED simulates the building stock, in addition to the land use change, it is also possible to provide information on the number of buildings (of different types) located in hazard prone areas.

For hazards that are included in UNHaRMED, the monetary damage value can also be quantified, as shown for coastal inundation and bushfires.

A point of caution when using (map) information on hazards not included in UNHaRMED is that the information provided does need to match with the UNHaRMED model set-up. As part of this study, we encountered three issues worth mentioning in this respect:

- Some hazard maps only had information for part of the model region (e.g. landslip current and bushfire current). As UNHaRMED allocates land use demands for the entire model region to the local grid, local differences in e.g. zoning matter for the overall spatial allocation. It is for this reason that including maps that do not cover the entire areas cause inconsistencies.
- When maps are used as base maps for zoning, it is important that there is a differentiation on the map, otherwise the map does not impact on the land use allocation. In the current study, this was the case for the new bushfire map that covered the entire state, with the exception of the water bodies.
- When designing hazard overlays, it is important that the same maps that are used for spatial planning are also used in the risk assessment. In the current study, we used information from the current hazard overlay as a zoning input in various assessments (landslip S1, coastal risk S1, coastal inundation S1, bushfire S1), while the risk was then assessed using the new hazard overlay. As

these maps do not exactly align, the locations of interest are not protected in the way they would be with a matching overlay. As a result, even though the same risk assessment approach was applied to the different maps, it is questionable how useful the comparison between the two overlays is, given the discrepancies in input maps.  Although the issue was related to the input maps in this study, in practice, it is also important that the zoning policies align with the locations at risk. In addition, an understanding that these locations might change over time due to socio-economic changes, climate change or other risk reduction measures that have been put in place (e.g. structural mitigation options for flood risk) is also critical in designing effective zoning strategies for disaster risk reduction.

For the reasons mentioned above, scenario S3 provides the most meaningful information regarding the impact of spatial planning to reduce multi-hazard risk.

# 7 CONCLUSIONS AND LESSONS LEARNT

This study has shown a potential use case of UNHaRMED in understanding current and future risk for Tasmania and using this knowledge to develop state-wide risk reduction policies. We have simulated four scenarios with different spatial plans and results indicate that integrating hazard information into spatial planning can decrease the (urban) area impacted by natural hazards quite substantially across multiple hazards, including landslip, riverine flooding, coastal erosion, coastal inundation and bushfires.

One of the objectives of this study was to explore if UNHaRMED could also provide meaningful risk assessment and risk reduction information on hazards that are not incorporated in UNHaRMED, provided relevant hazard maps are available. This study has shown that this is indeed the case. However, when performing such assessments, it is important to consider how the externally provided maps align with the way UNHaRMED works and calculates impact.

Finally, it is important to acknowledge the inconsistencies between zoning policies to mitigate risk and the actual risk mitigation that can occur in practice. Consequently, zoning policies need to align with the locations that are at risk. Furthermore, an understanding that these locations might change over time due to socio-economic changes, climate change or other risk reduction measures that have been put in place (e.g. structural mitigation options for flood risk) is critical in designing effective zoning strategies for disaster risk reduction.

The application of UNHaRMED to Tasmania has demonstrated that:

- Change in exposure is an important driver of risk.
- Change in exposure can be simulated with the land use and building stock components in UNHaRMED.
- Dynamic exposure information can be combined with information on the hazard and the vulnerability for those hazards incorporate in UNHaRMED. In this way the land uses and buildings impacted by one of more hazards can be assessed and the monetary risk (AAD) can be calculated.
- UNHaRMED can produce relevant information for hazards not currently incorporated in the system. As part of this approach, dynamic exposure information is combined with external hazard maps. In this way, the land use and buildings impacted by one or more hazards can be assessed, but the monetary risk (AAD) cannot be calculated. In addition, it is important to ensure that the available hazard data covers the entire modelled area.
- In both risk assessment options outlined above, it is possible to assess the impact of spatial planning or zoning as an option to reduce risk.
- If hazard maps are used as zoning base maps in UNHaRMED, it is important that they align with the hazard maps used in the risk assessment.
- The data requirements for UNHaRMED are significant, and the uncertainty present in the modelling results is dependent on the quality of the input data. In the absence of accurate data, reasonable assumptions can be made, but it is important to evaluate the modelling results in light of these assumptions.

- Decision support systems like UNHaRMED need to be tailored to specific decision contexts with the aid of stakeholder input. A joint participatory and modelling approach strengthens the modelling and facilitates its understanding and uptake amongst stakeholders. Moreover, it allows to incorporate important aspects relevant for the decision-making process that cannot be modelled.
- While the application of UNHaRMED offers significant flexibility, it is likely that changes to the software are required in order to meet specific end-user needs in different decision contexts.

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# ANNEX I – VULNERABILITY CURVES

## VULNERABILITY CURVES FOR BUSHFIRE RISK

All buildings with the same BAL type are expected to have a similar damage when confronted with a fire of a similar intensity expressed as radiant heat flux (RHF).

Vulnerability curves are defined based on the standards for the different BAL types, as shown in Table A-1.

TABLE A-8: BUSHFIRE VULNERABILITY CURVES FOR DIFFERENT BAL TYPES. A VALUE 0 RESEMBLES A DAMAGE INDEX OF 0, OR NO DAMAGE, A VALUE OF 1 RESEMBLES A DAMAGE INDEX OF 1, OR TOTAL DESTRUCTION. CURVES ARE LINEARLY INTERPOLATED BETWEEN DAMAGE INDEX VALUES.

| Radiant Heat Flux (kW/m²) | BAL Low | BAL 12.5 | BAL 19 | BAL 29 | BAL 40 | BAL Flame Zone |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 1 | 0 | 0 | 0 | 0 | 0 |
| 12.5 | 1 | 1 | 0 | 0 | 0 | 0 |
| 19.5 | 1 | 1 | 1 | 0 | 0 | 0 |
| 29 | 1 | 1 | 1 | 1 | 0 | 0 |
| 40 | 1 | 1 | 1 | 1 | 1 | 0 |
| 60 | 1 | 1 | 1 | 1 | 1 | 1 |

## VULNERABILITY CURVES FOR COASTAL INUNDATION RISK

The coastal inundation vulnerability curves used in this study built on the damage functions developed by the European Union Joint Research Centre (Huizinga et al., 2017). These functions are provided for different global regions, including Oceania. To align with the Australian and Tasmanian context, the functions for buildings have been adapted to reflect expected damage for low inundation depths. All damage functions for existing buildings therefore start to calculate damage from an inundation depth of 15cm (see e.g. Table A-2).

Vulnerability functions for different crop types have been adapted more drastically based on expert judgement from stakeholders across Australia.

TABLE A-2: VULNERABILITY FUNCTION FOR RESIDENTIAL BUILDINGS

| Water depth (m) | Damage factor |
|---|---|
| 0 | 0 |
| 0.15 | 0 |
| 0.5 | 0.48 |
| 1 | 0.64 |
| 1.5 | 0.71 |
| 2 | 0.79 |
| 3 | 0.93 |
| 4 | 1 |

TABLE A-3: VULNERABILITY FUNCTION FOR COMMERCIAL BUILDINGS 1-3 STORIES

| Water depth (m) | Damage factor |
|---|---|
| 0 | 0 |
| 0.15 | 0 |
| 0.5 | 0.24 |
| 1 | 0.48 |
| 1.5 | 0.67 |
| 2 | 0.86 |
| 3 | 1 |

TABLE A-4: VULNERABILITY FUNCTION FOR COMMERCIAL BUILDINGS 4-7 STORIES

| Water depth (m) | Damage factor |
|---|---|
| 0 | 0 |
| 0.15 | 0 |

| | |
|---|---|
| 2 | 0.24 |
| 4 | 0.48 |
| 6 | 0.67 |

TABLE A-5: VULNERABILITY FUNCTION FOR COMMERCIAL BUILDINGS 8+ STORIES

| **Water depth (m)** | **Damage factor** |
|---|---|
| 0 | 0 |
| 0.15 | 0 |
| 6 | 0.24 |

TABLE A-6: VULNERABILITY FUNCTION FOR INDUSTRIAL BUILDINGS

| **Water depth (m)** | **Damage factor** |
|---|---|
| 0 | 0 |
| 0.15 | 0 |
| 0.5 | 0.31 |
| 1 | 0.48 |
| 1.5 | 0.61 |
| 2 | 0.71 |
| 3 | 0.84 |
| 4 | 0.93 |
| 5 | 0.98 |
| 6 | 1 |

TABLE A-7: VULNERABILITY FUNCTION FOR AGRICULTURE

| Water depth (m) | Damage factor |
|---|---|
| 0 | 0 |
| 0.10 | 0 |
| 0.5 | 0.27 |
| 1 | 0.48 |
| 1.5 | 0.56 |
| 2 | 0.61 |
| 3 | 0.76 |
| 4 | 1 |