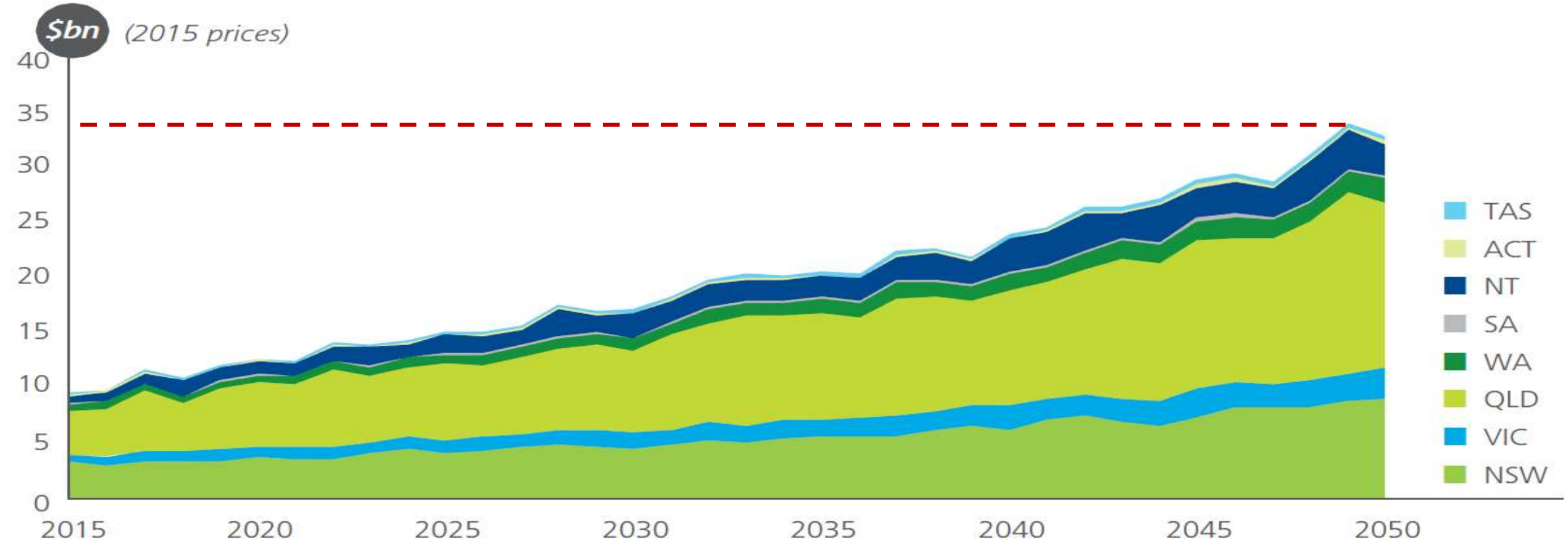
A Spatio-Temporal Decision Support System for Natural Hazard Risk Reduction Policy Assessment and Planning

Holger R. Maier, Graeme A. Riddell, Hedwig van Delden, Jeffrey P. Newman, Aaron C. Zecchin, Roel vanHout, James Daniell, Andreas Schäfer, Graeme C. Dandy, Charles P. Newland

MOTIVATION

NATURAL DISASTERS ARE EXPENSIVE

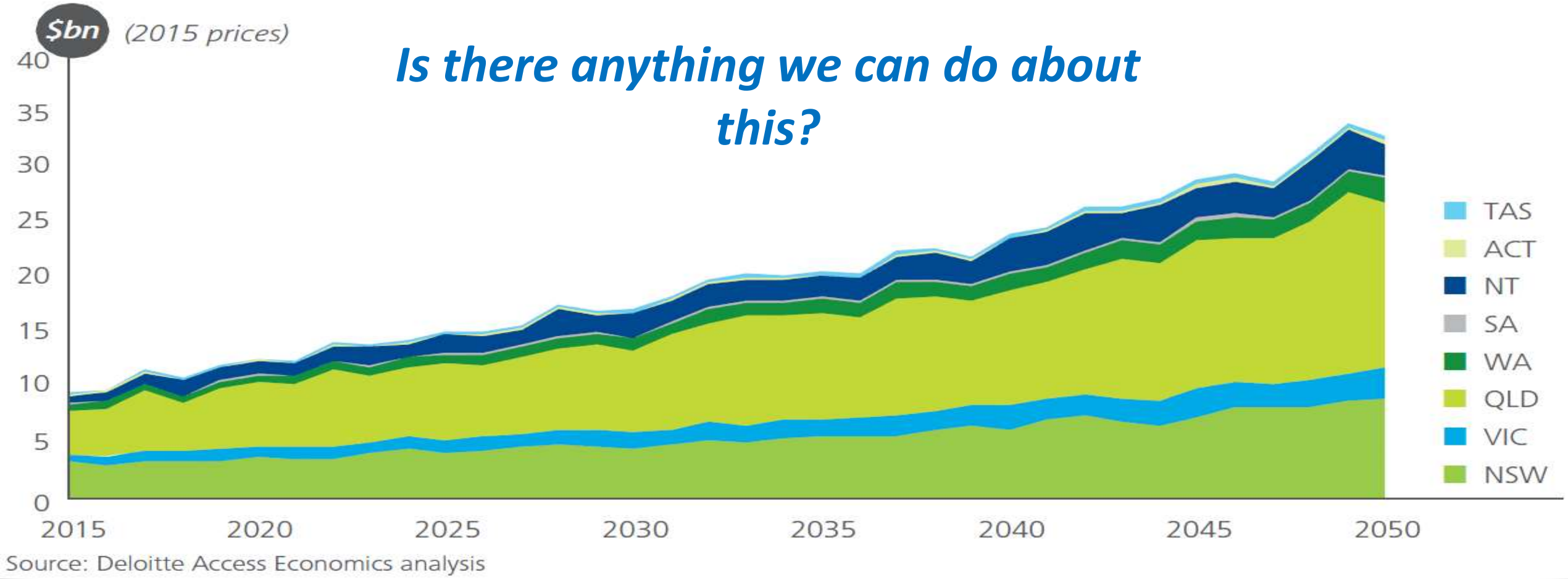
Chart ii: 2015–50 forecast of the total economic cost of natural disasters, identifying costs for each state



Source: Deloitte Access Economics analysis

NATURAL DISASTERS ARE EXPENSIVE

Chart ii: 2015–50 forecast of the total economic cost of natural disasters, identifying costs for each state



Is there anything we can do about this?

Source: Deloitte Access Economics analysis

PREVENTION IS BETTER THAN CURE

"Better to build a fence at the top of a cliff, than park an ambulance at the bottom"

Helen Clark 2015 Sendai

RISK REDUCTION & MITIGATION

"Better to build a fence at the top of a cliff, than park an ambulance at the bottom"

Helen Clark 2015 Sendai

Where to put the fence?

How high should it be?

When to build it?

RISK REDUCTION & MITIGATION

"Better to build a fence at the top of a cliff, than park an ambulance at the bottom"

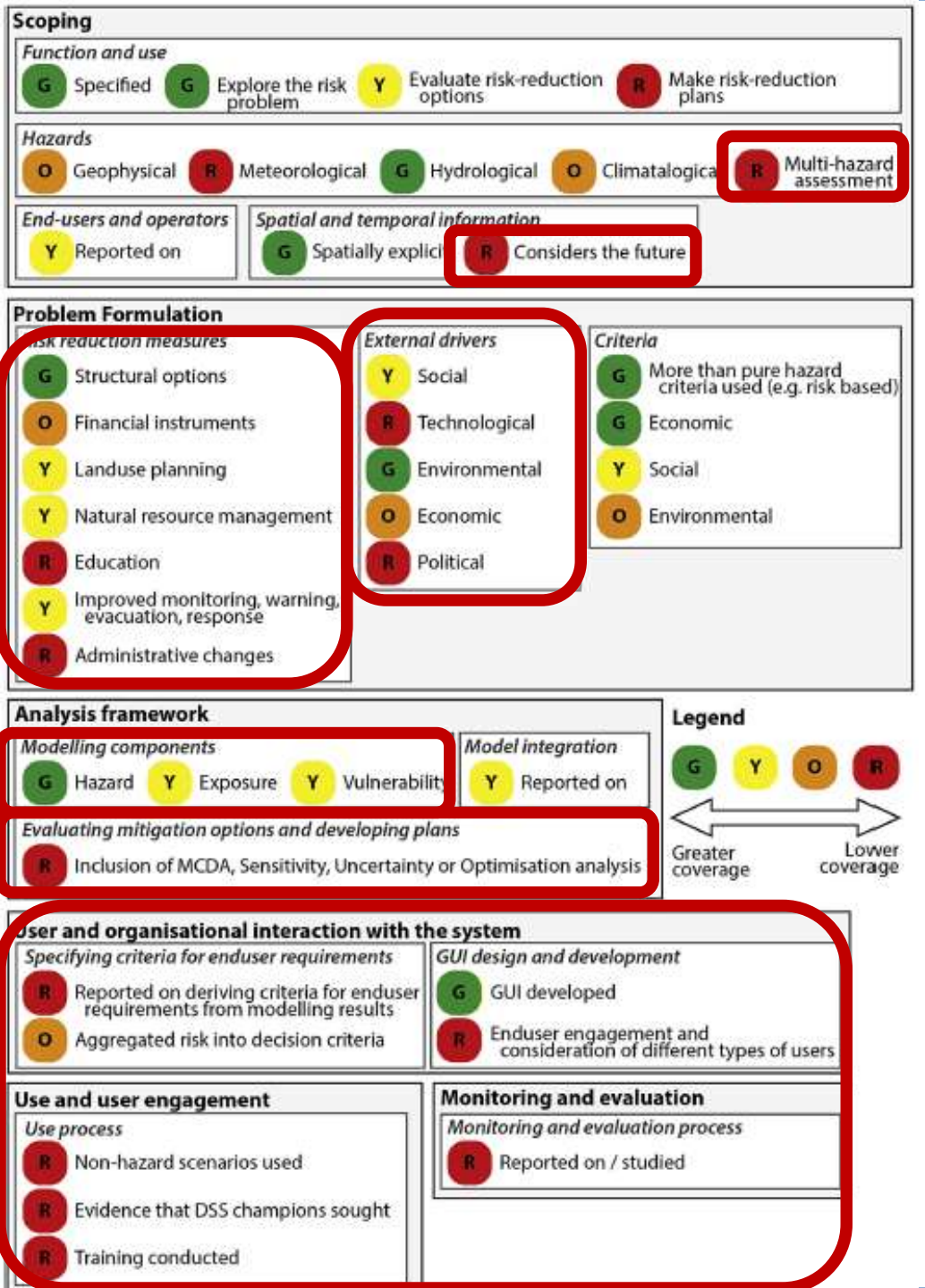
Helen Clark 2015 Sendai

Evidence!

Where to put the fence?

How high should it be?

When to build it?



RESEARCH GAPS

Newman J.P., Maier H.R., Riddell G.A., Zecchin A.C., Daniell J., Schaefer A., van Delden H., Khazai B., O'Flaherty M.J. and Newland C.P. (2017) **Review of literature on decision support systems for natural hazard risk reduction: Current status and future research directions**, *Environmental Modelling and Software*, **96**, 378-409, DOI:10.1016/j.envsoft.2017.06.042

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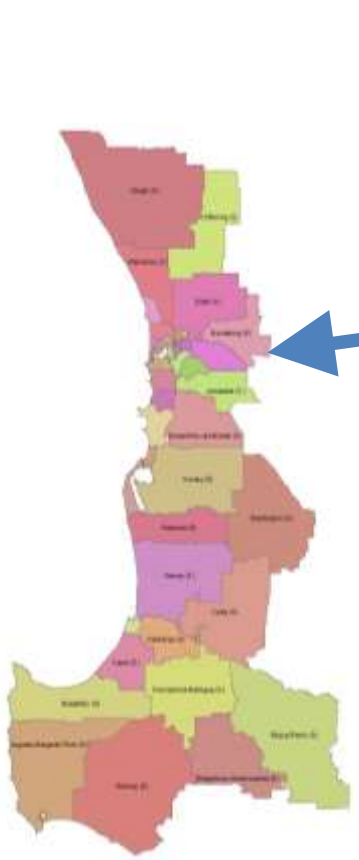
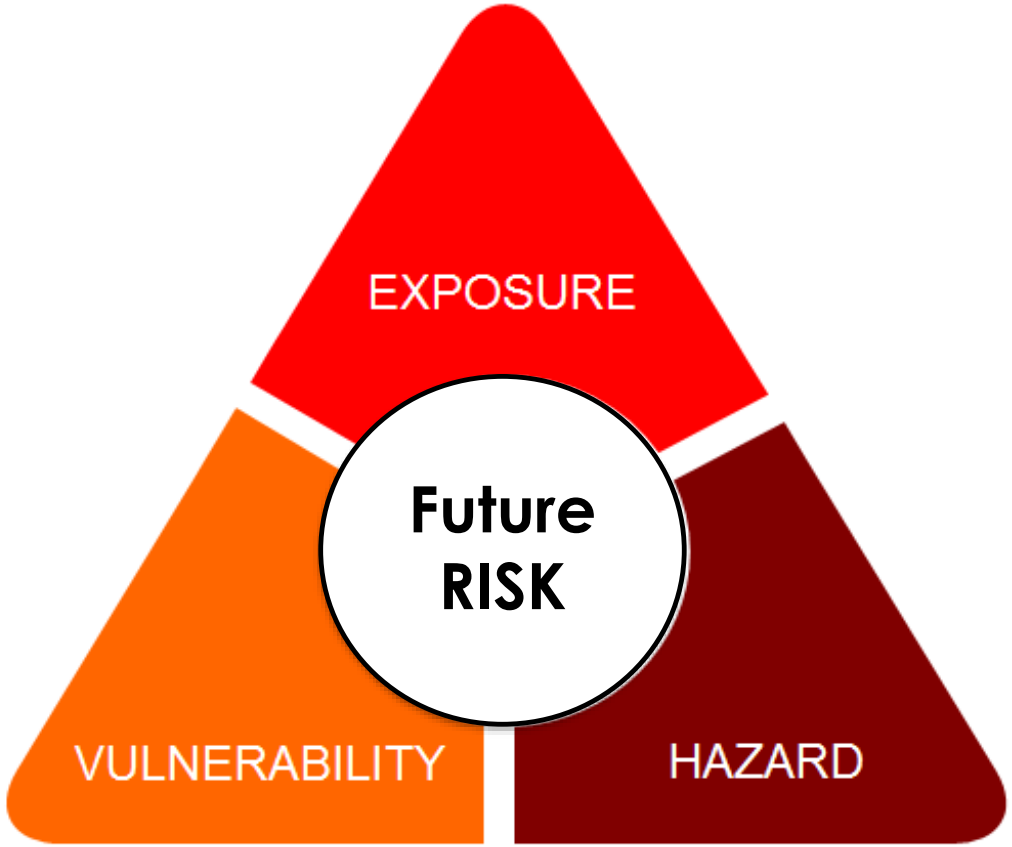


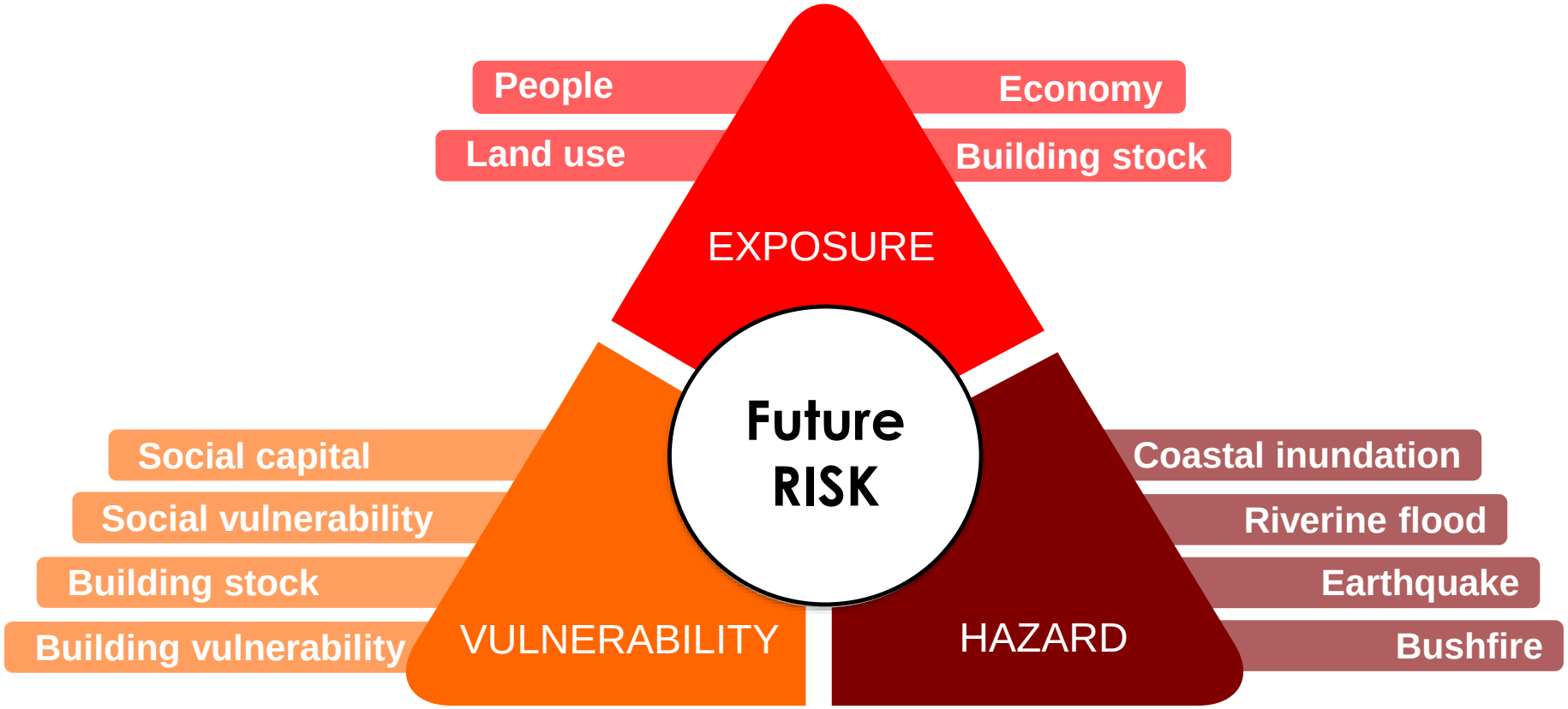
Perth

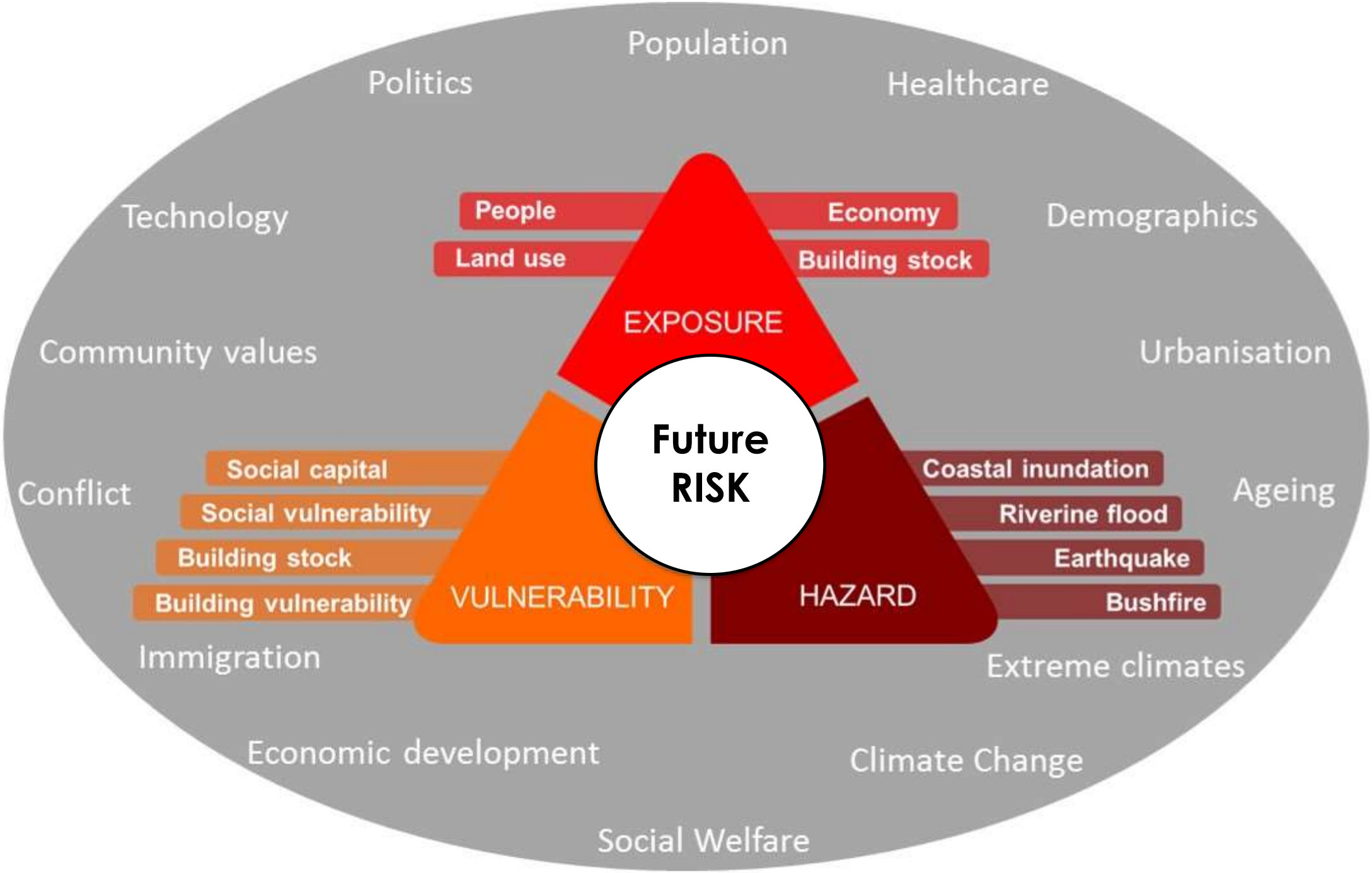
Adelaide

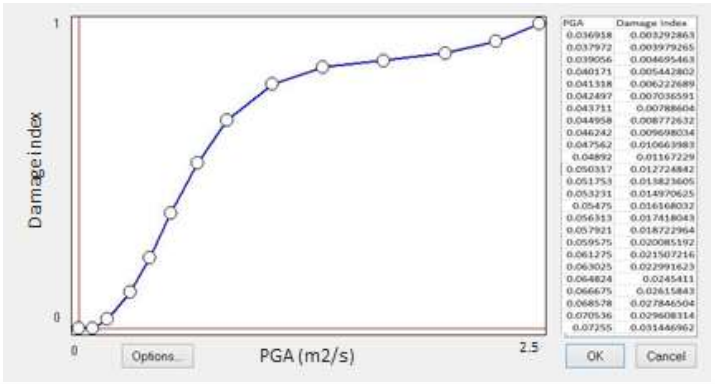
Melbourne

Tasmania


EXPOSURE
Future
RISK
VULNERABILITY
HAZARD


People
Economy
Land use
Building stock
EXPOSURE
Future
RISK
Social capital
Social vulnerability
Building stock
Building vulnerability
VULNERABILITY
HAZARD
Coastal inundation
Riverine flood
Earthquake
Bushfire


Population
Politics
Healthcare
Technology
Demographics
People
Economy
Land use
Building stock
EXPOSURE
Community values
Urbanisation
Future
RISK
Social capital
Social vulnerability
Building stock
Building vulnerability
VULNERABILITY
HAZARD
Coastal inundation
Riverine flood
Earthquake
Bushfire
Conflict
Ageing
Immigration
Extreme climates
Economic development
Climate Change
Social Welfare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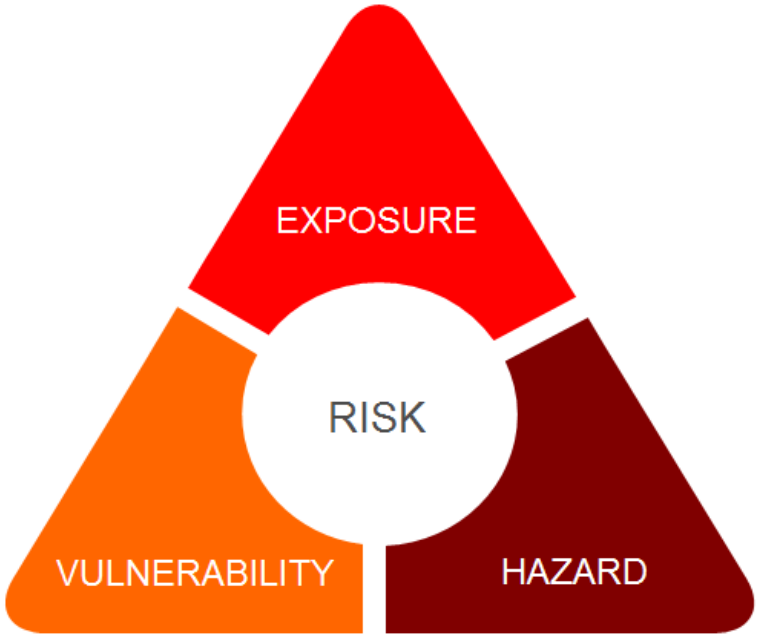
EXPOSURE
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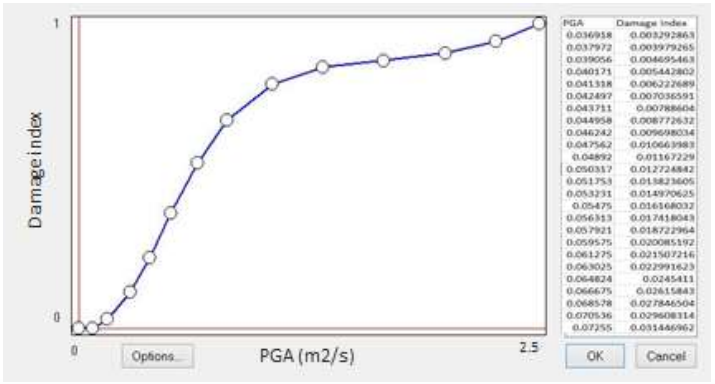
VULNERABILITY
HAZARD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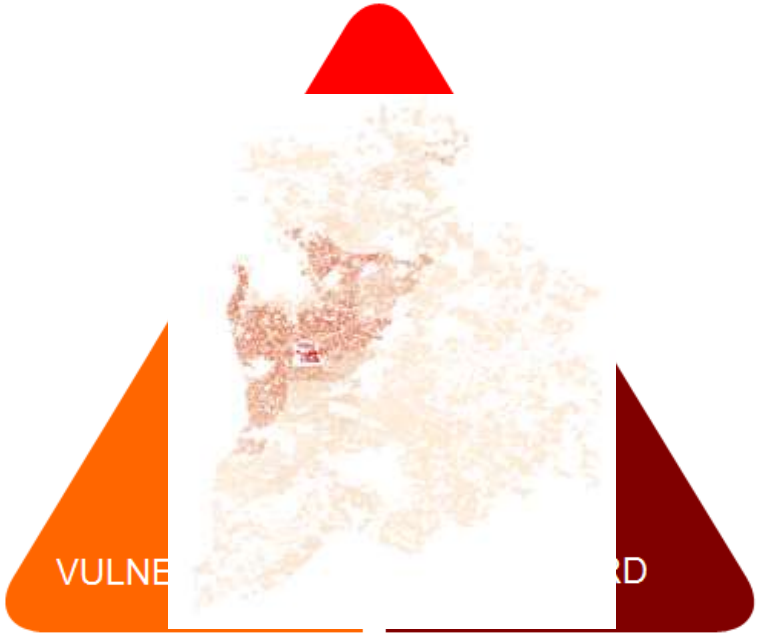
VULNE
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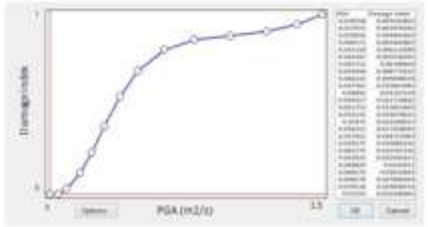
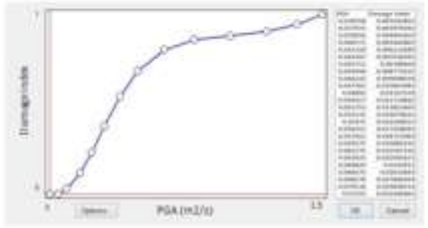
Integrated Model

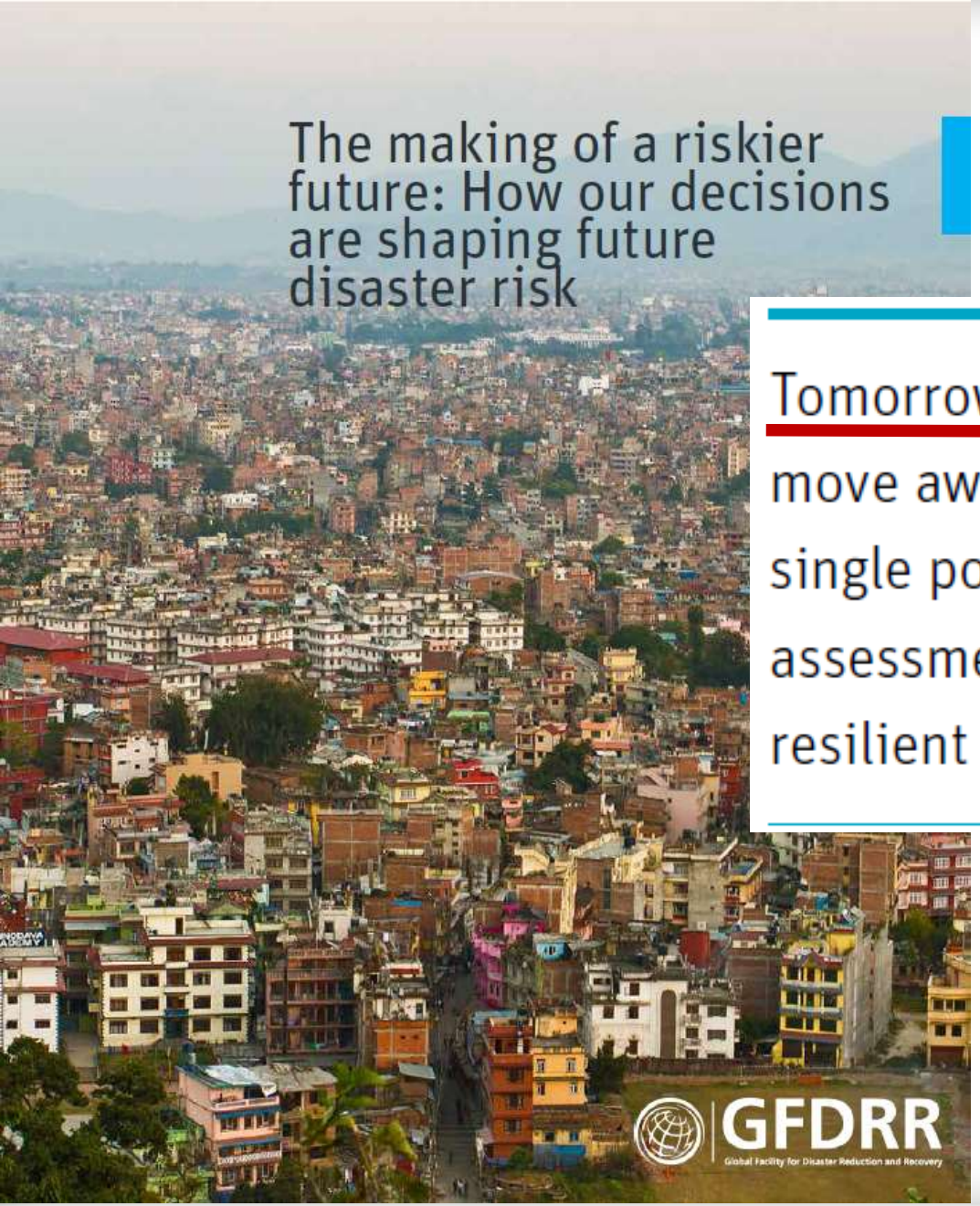


Integrated Model



Mitigation Options

- Land use planning
- Structural measures
- Building codes
- Community education



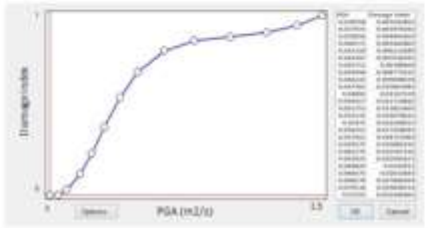
Tomorrow's risk is being built today. We must therefore move away from risk assessments that show risk at a single point in the present and move instead towards risk assessments that can guide decision makers towards a resilient future.

Global Facility for Disaster Reduction and Recovery (2016)

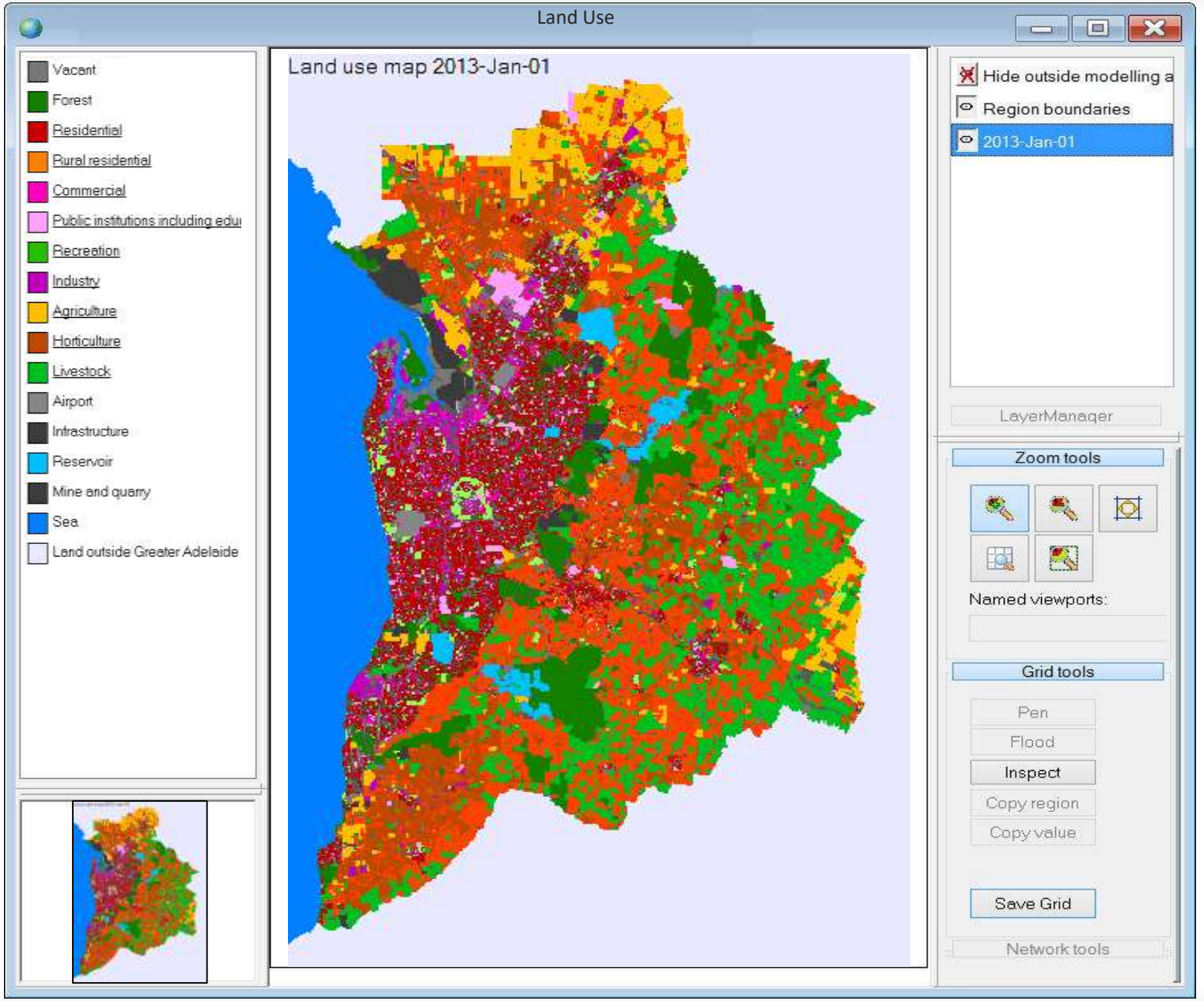
Long-Term Drivers

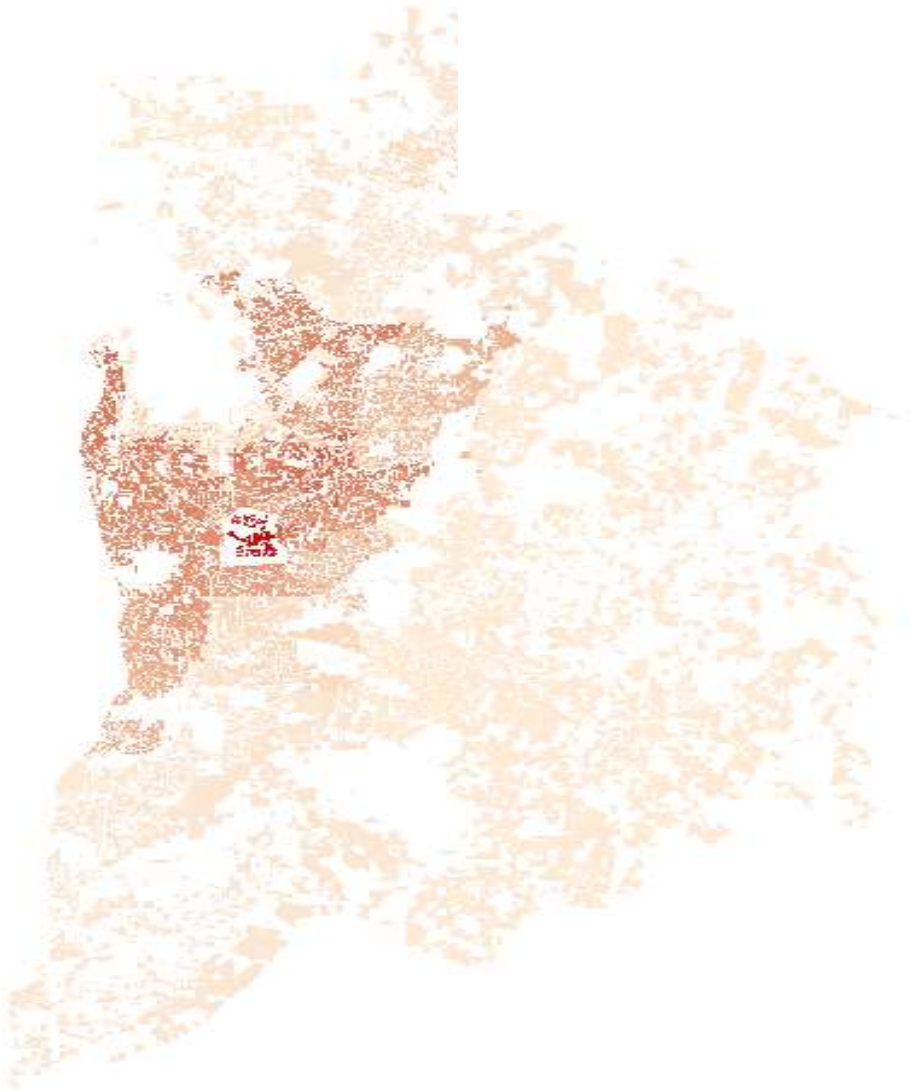
- Population growth
- Economic change
- Technological change
- Climate change

Integrated Model



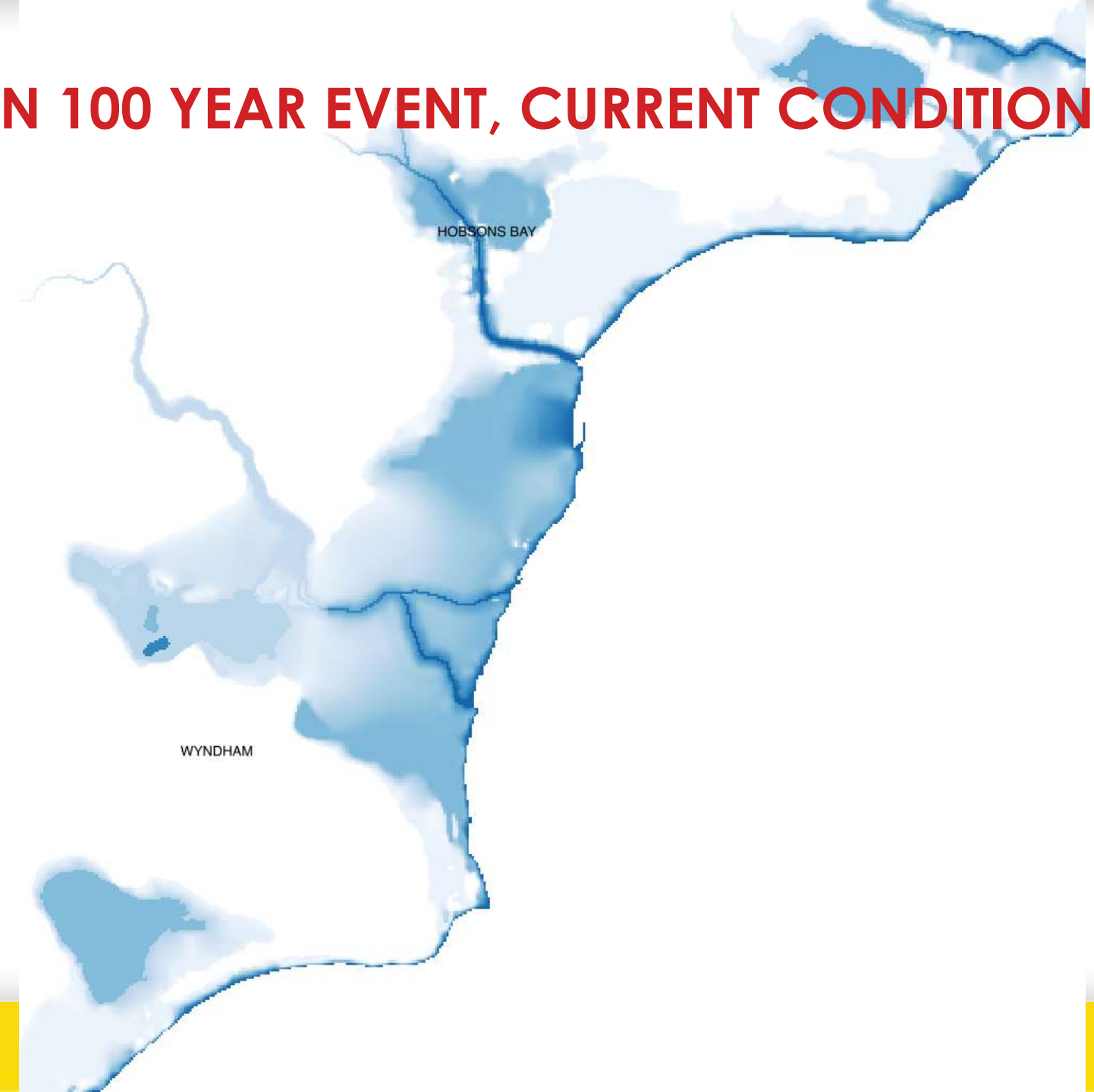
Mitigation Options


Land Use
Vacant
Forest
Residential
Rural residential
Commercial
Public institutions including edu
Recreation
Industry
Agriculture
Horticulture
Livestock
Airport
Intrastructure
Reservoir
Mine and quarry
Sea
Land outside Greater Adelaide
Land use map 2013-Jan-01
Hide outside modelling a
Region boundaries
2013-Jan-01
LayerManager
Zoom tools
Named viewports:
Grid tools
Pen
Flood
Inspect
Copy region
Copy value
Save Grid
Network tools

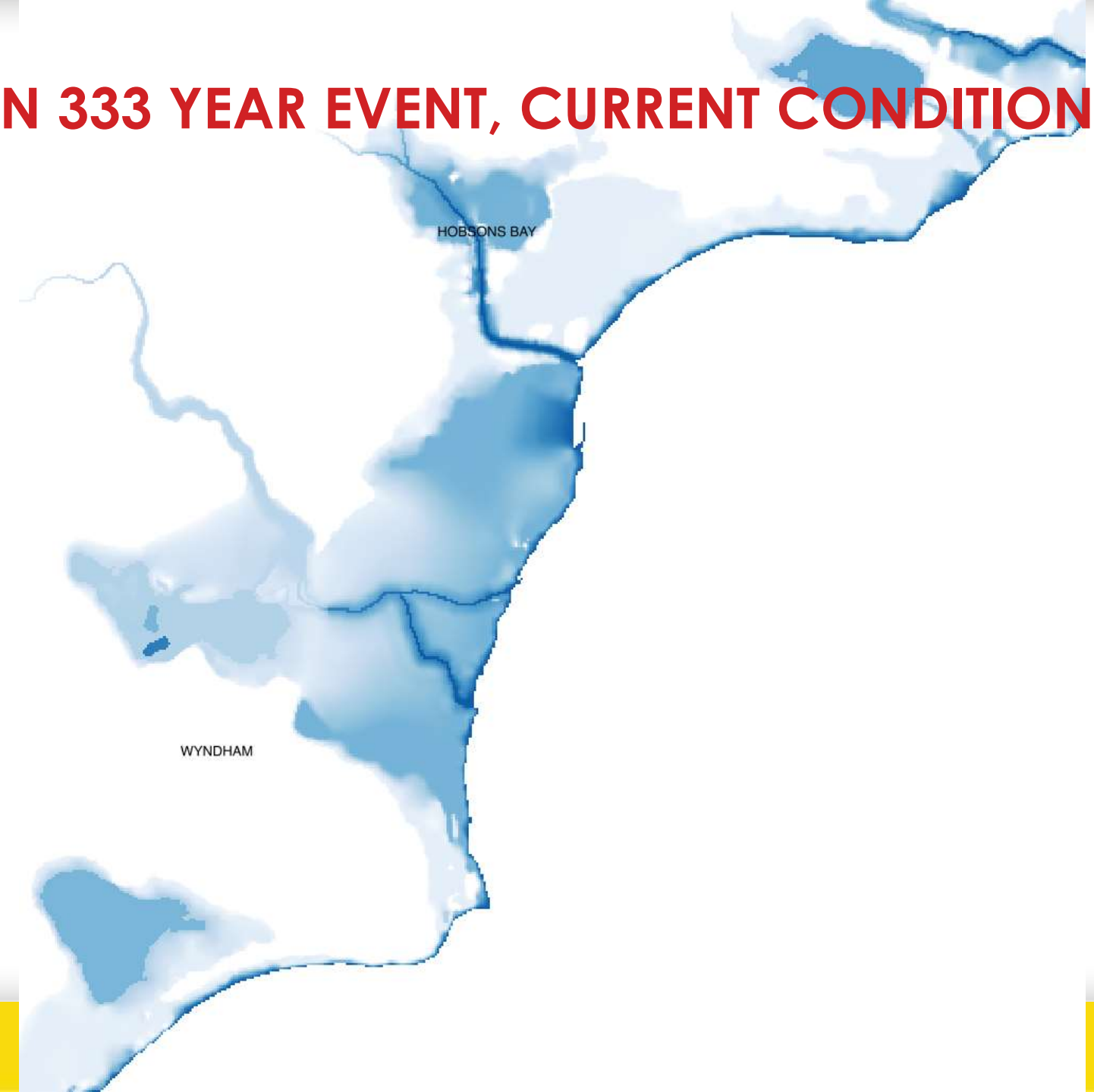


Expected average annual loss from earthquakes 2013-2050

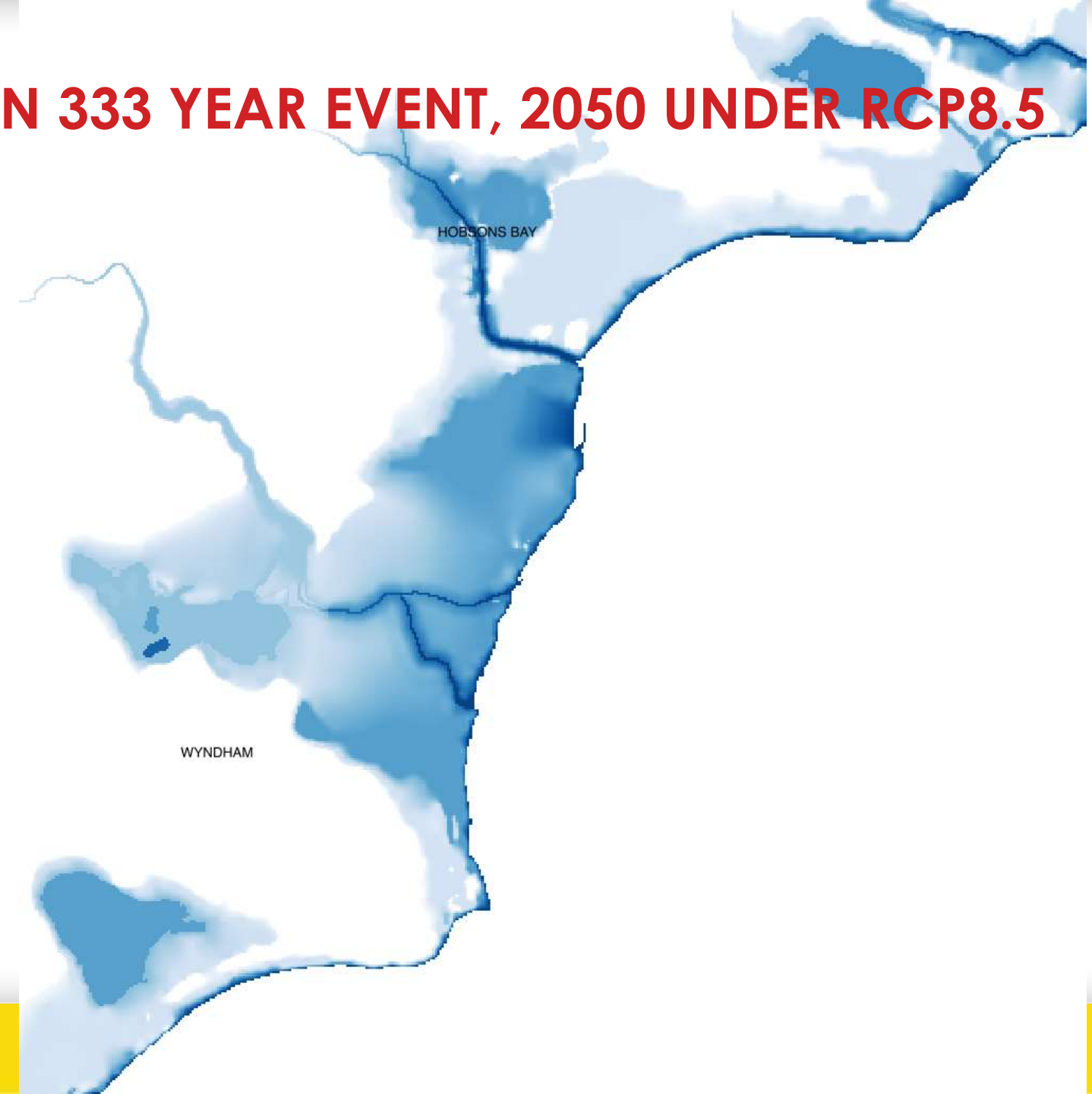
1 IN 100 YEAR EVENT, CURRENT CONDITIONS



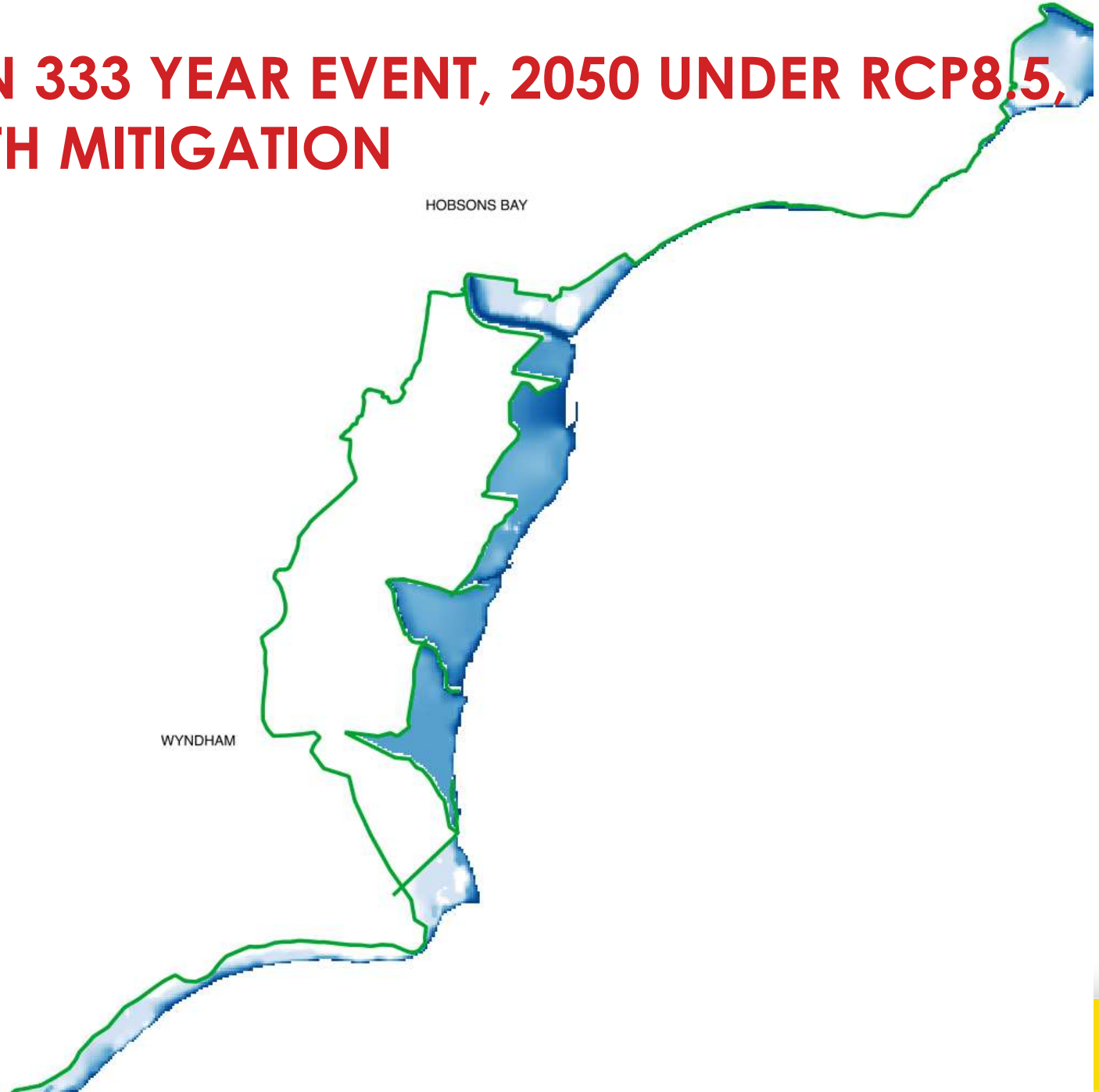
1 IN 333 YEAR EVENT, CURRENT CONDITIONS

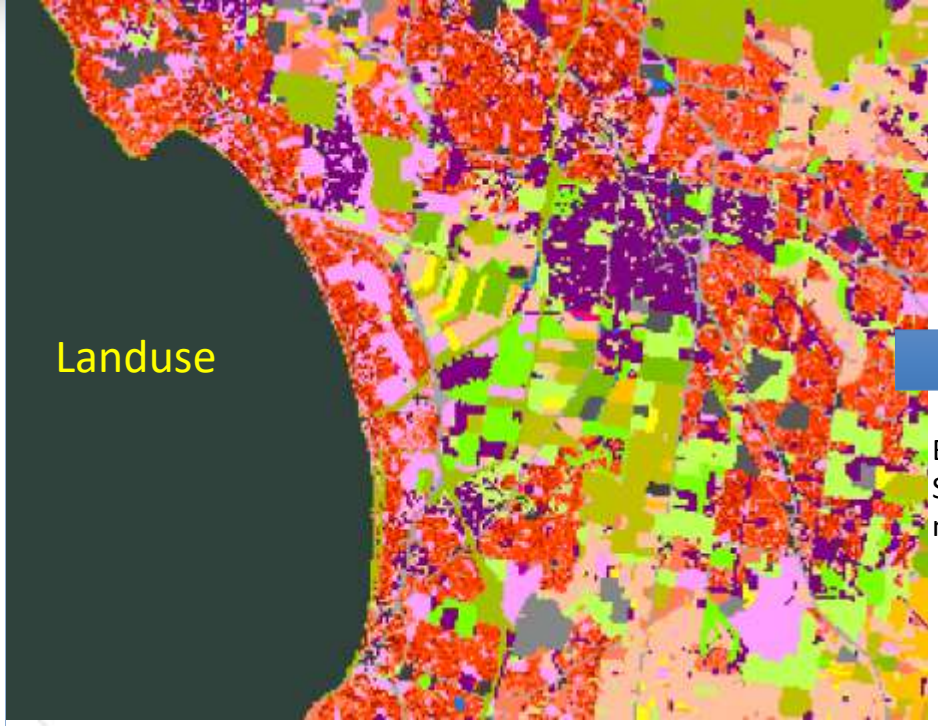


1 IN 333 YEAR EVENT, 2050 UNDER RCP8.5



1 IN 333 YEAR EVENT, 2050 UNDER RCP8.5, WITH MITIGATION

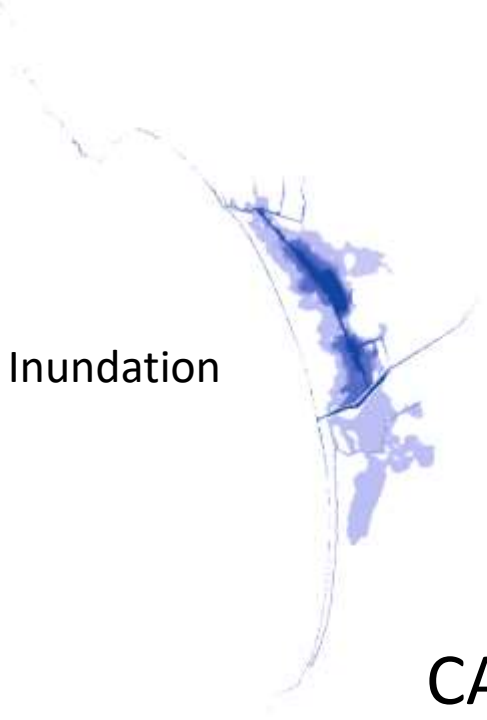


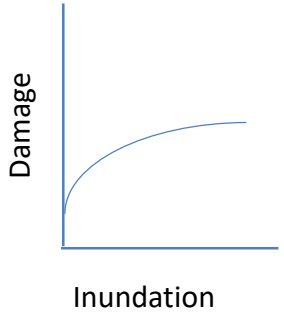


Building Stock model

Building value

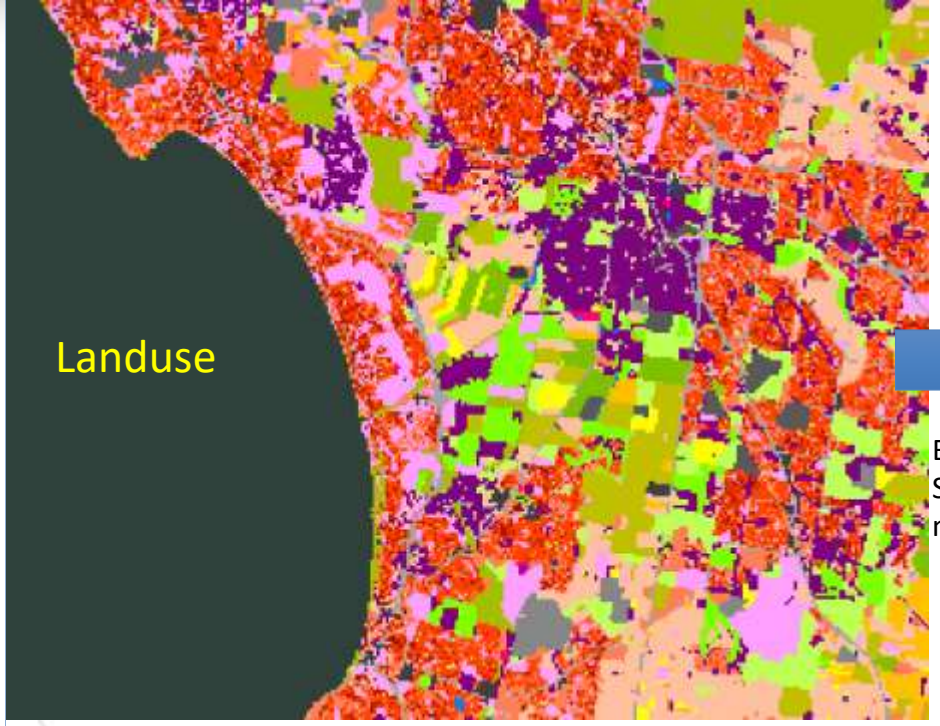
Building vulnerability curves





Loss/Risk

CALCULATION OF RISK FOR 2015



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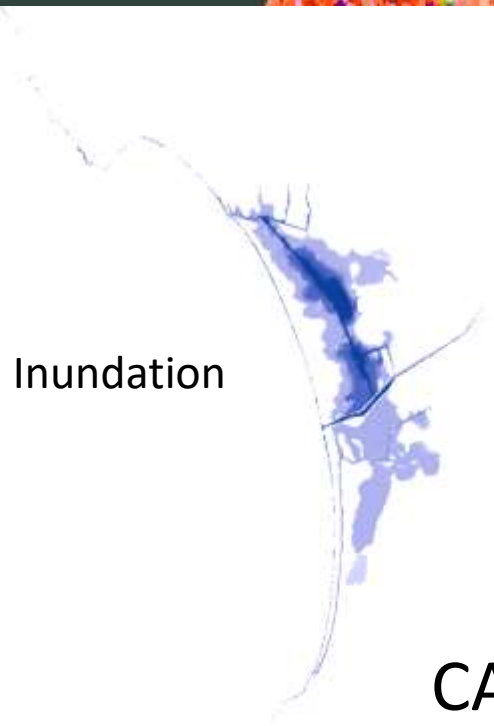
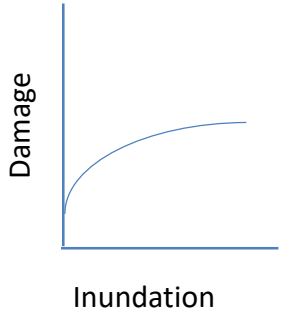
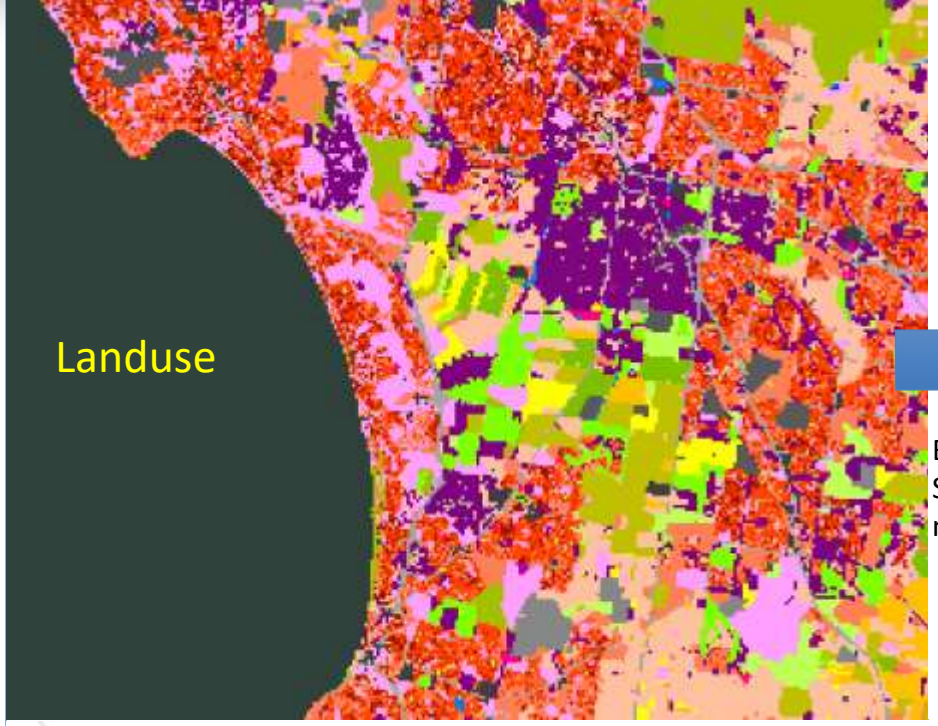




Loss/Risk

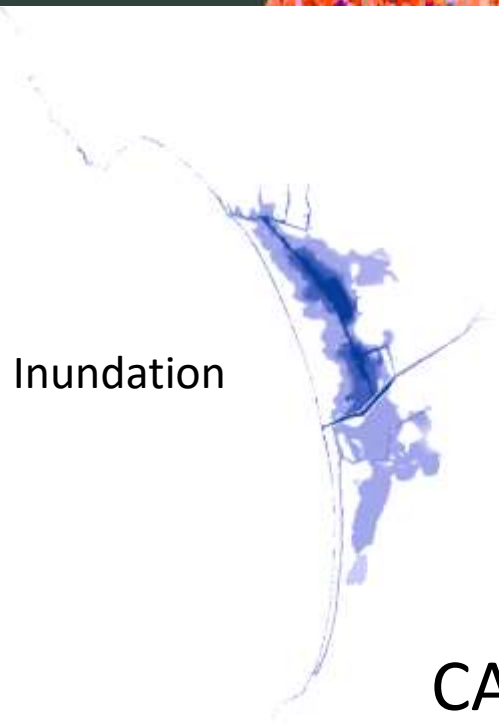
CALCULATION OF RISK FOR 2030

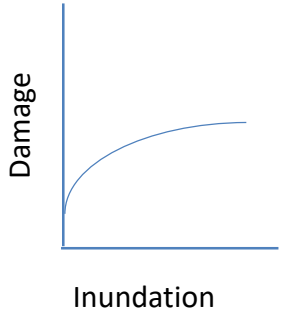


Building Stock model

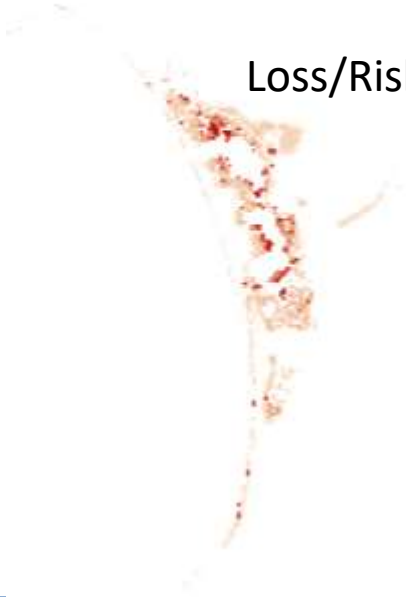
Building value

Building vulnerability curves





Loss/Risk

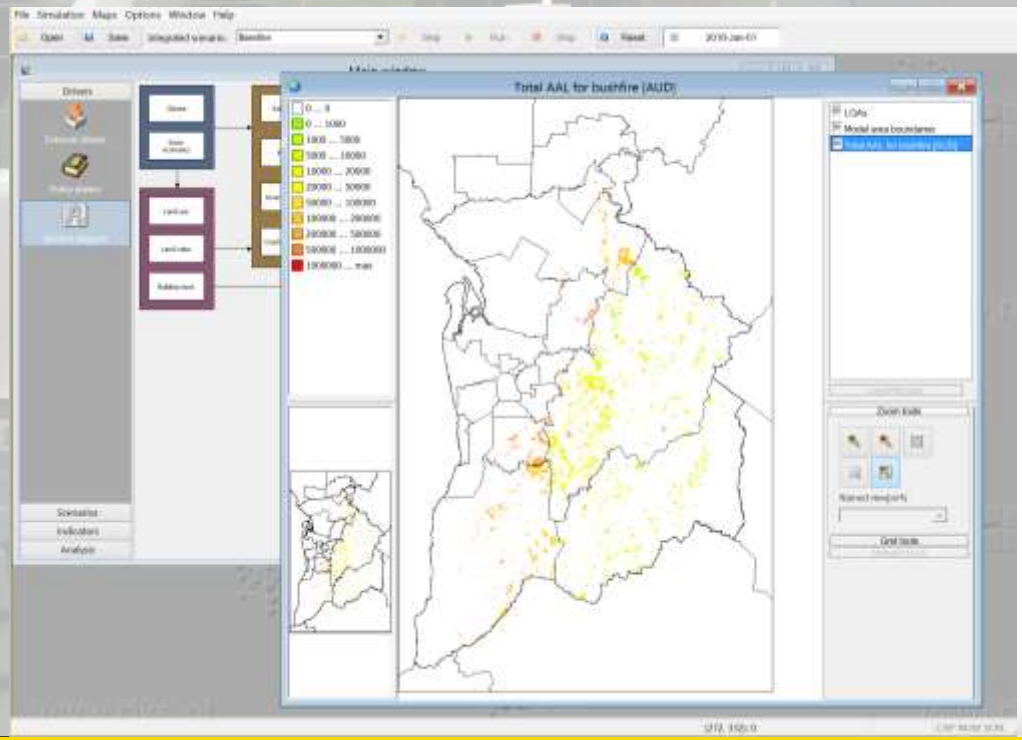


CALCULATION OF RISK FOR 2050

Framework & DSS for understanding and reducing disaster risk

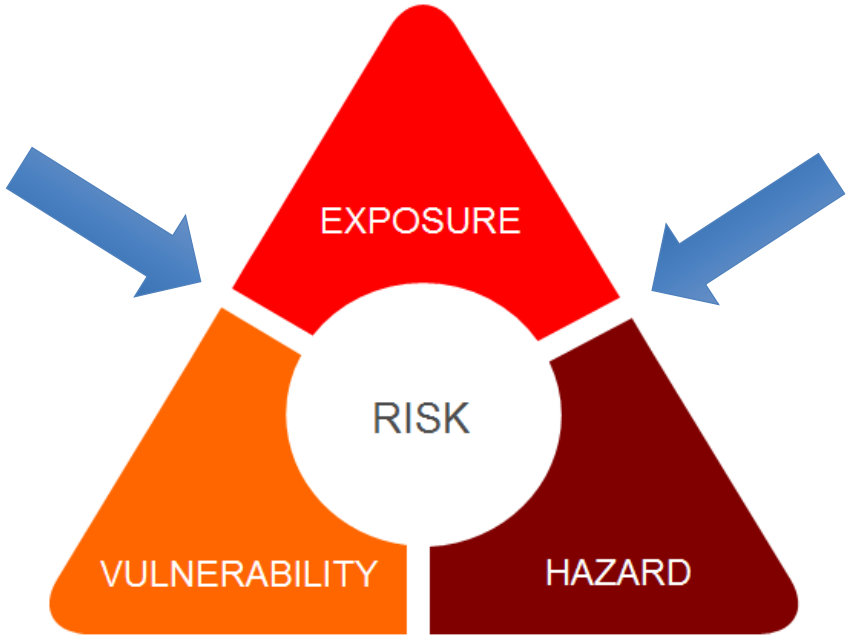
Considers:

- Long term dynamics & uncertainties
- Exposure
- Hazard intensity and likelihood
- Building vulnerability
- Multi-hazard
  - Earthquake
  - Coastal inundation
  - Riverine flooding
  - Bushfire
- Risk reduction options
  - Land Use planning
  - Structural Measures
  - Land Management
  - Education & Awareness
  - Building Codes



Things we generally **cannot** control

- Population growth
- Economic change
- Technological change
- Climate change

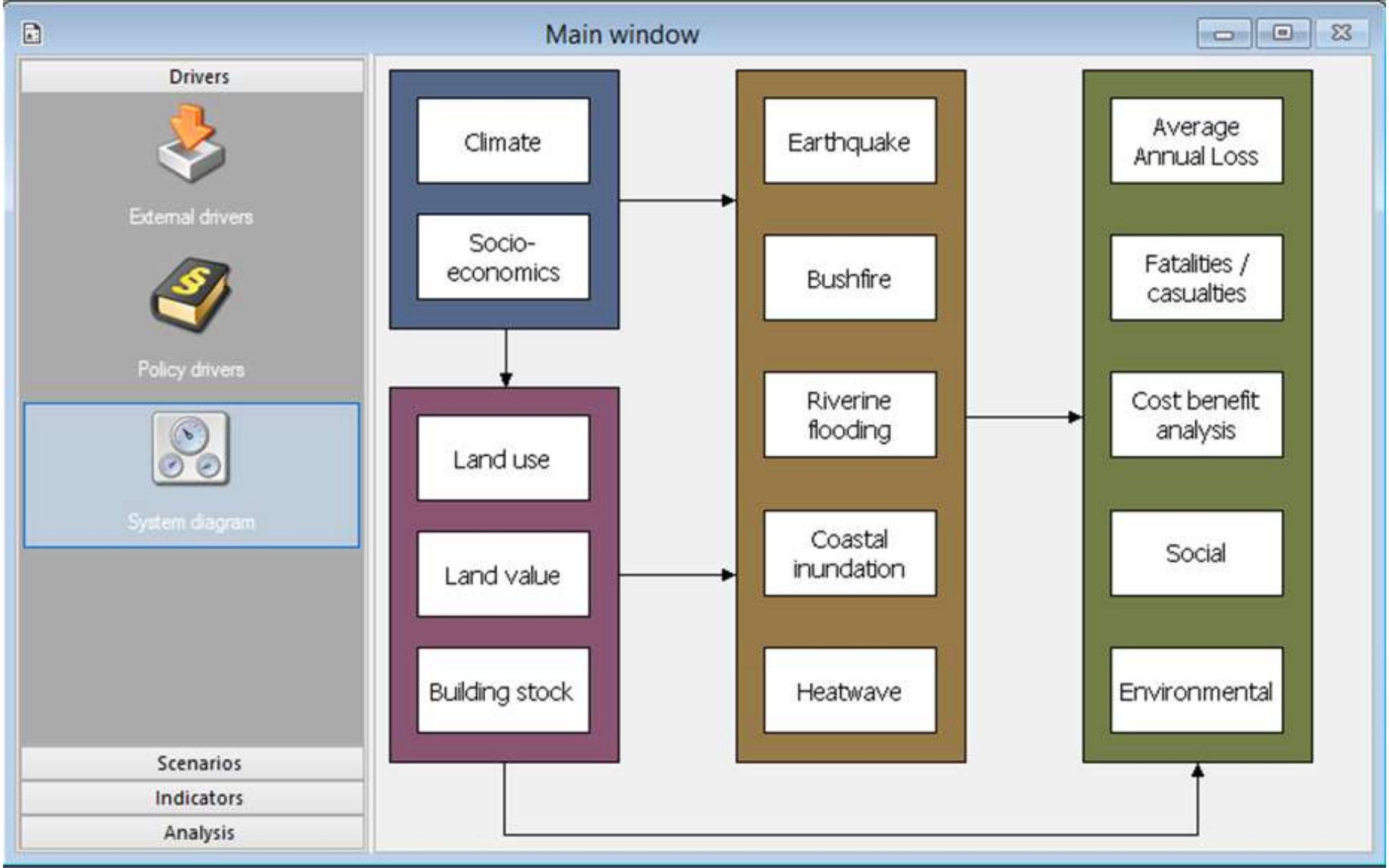


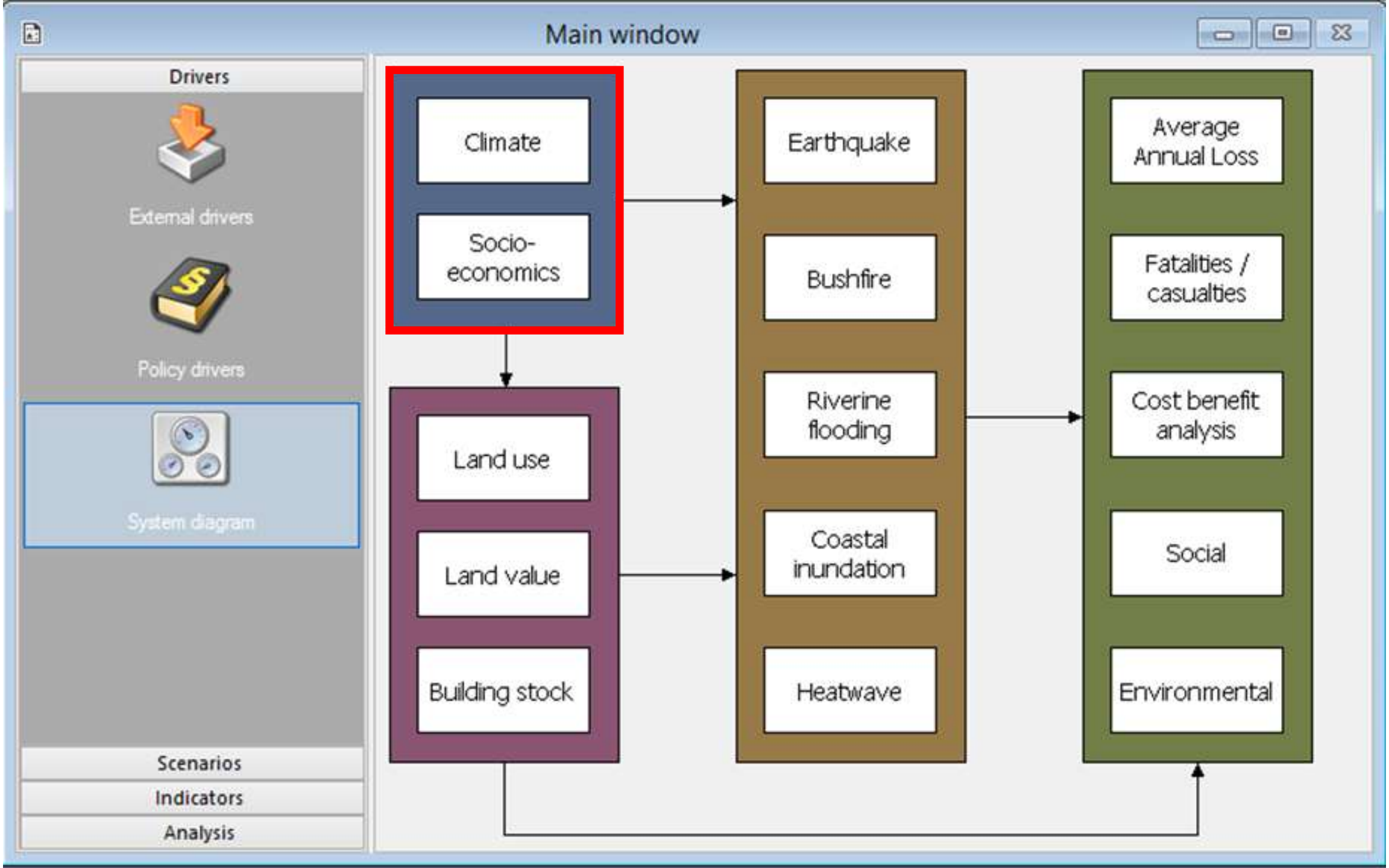
MODEL

Evolution over **time**

Things we generally **can** control

- Land use planning
- Structural measures
- Building codes
- Community education


Main window
Drivers
External drivers
Policy drivers
System diagram
Scenarios
Indicators
Analysis
Climate
Socio-economics
Land use
Land value
Building stock
Earthquake
Bushfire
Riverine flooding
Coastal inundation
Heatwave
Average Annual Loss
Fatalities / casualties
Cost benefit analysis
Social
Environmental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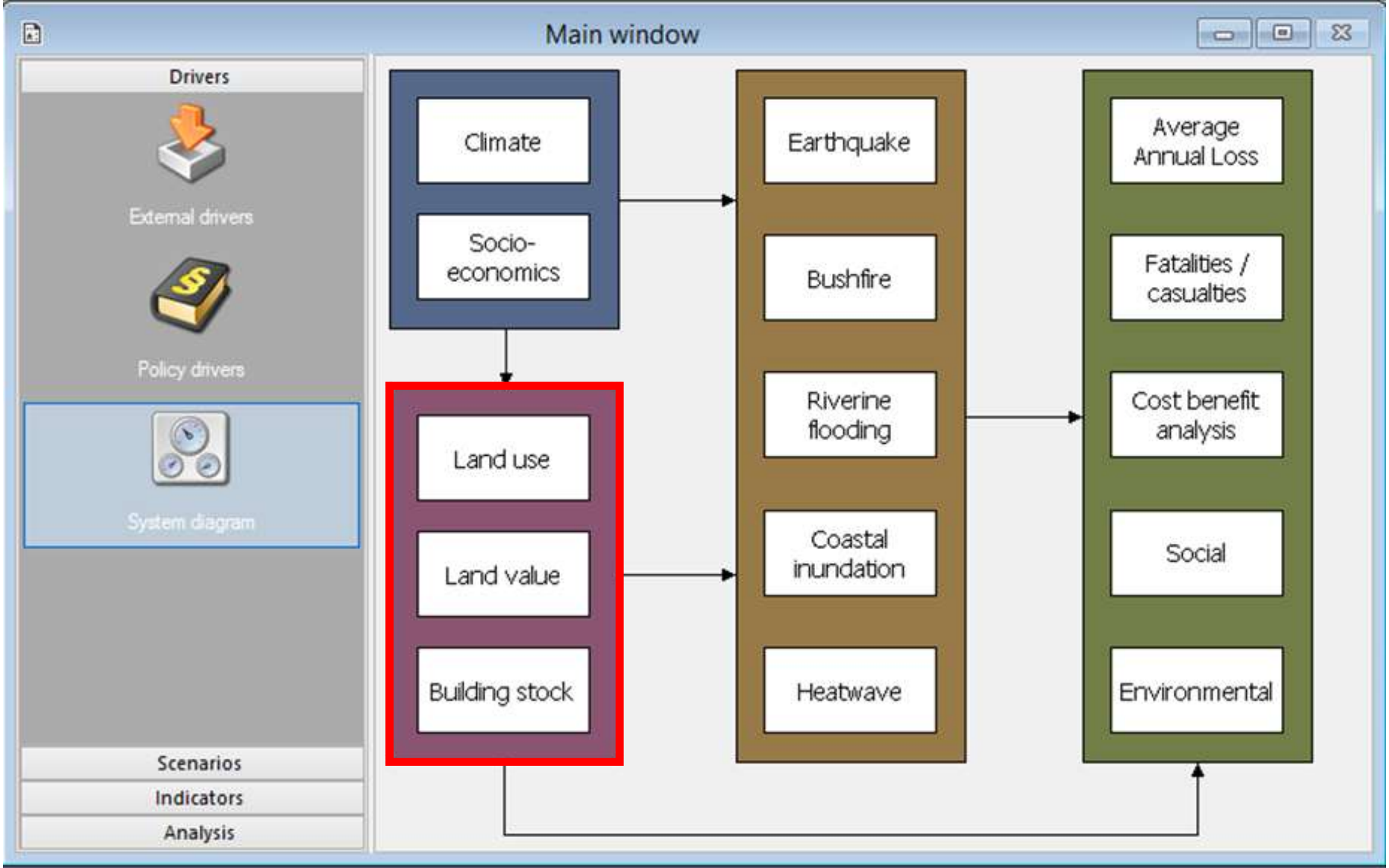
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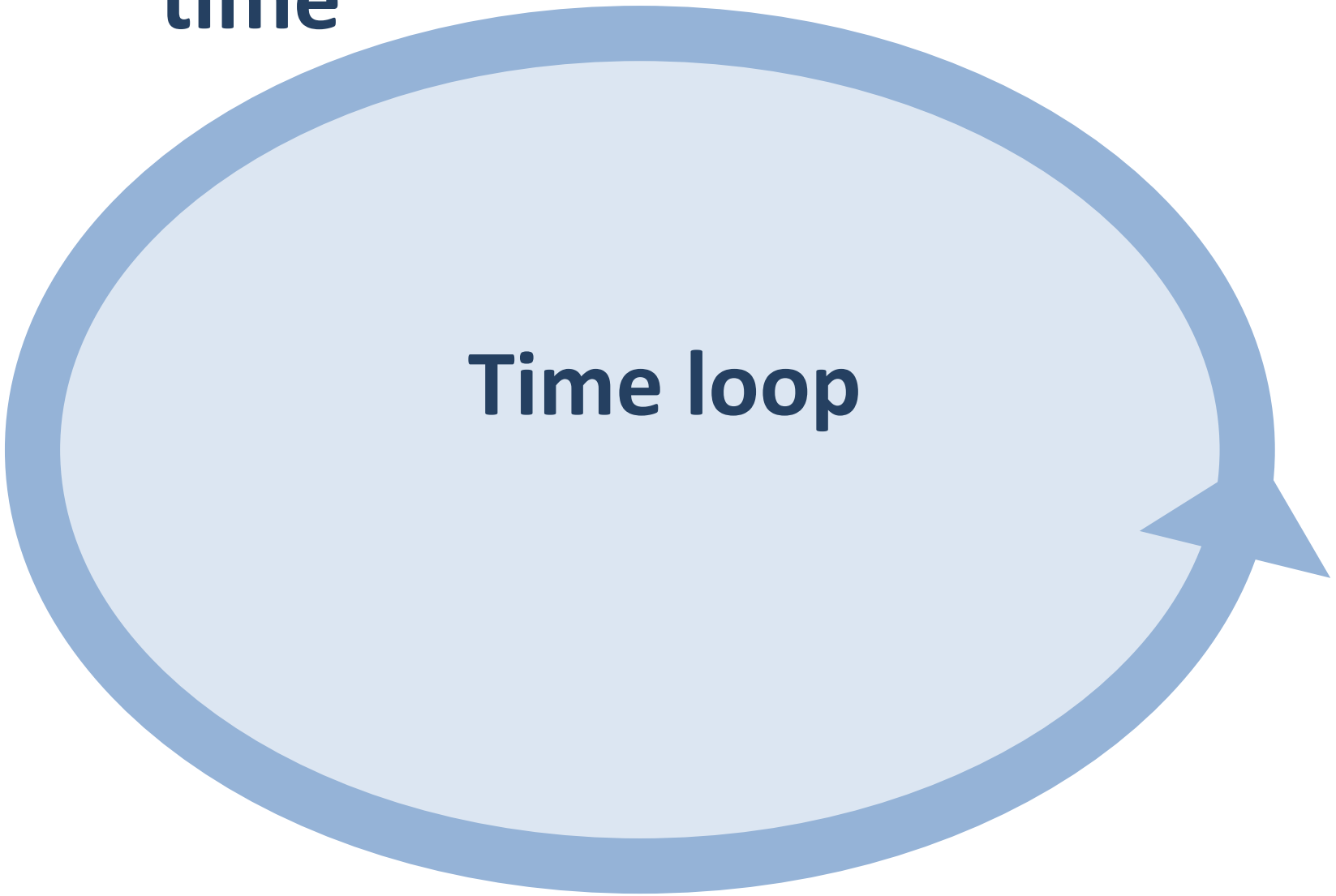
Land use change with time



Time loop

Land use at time T

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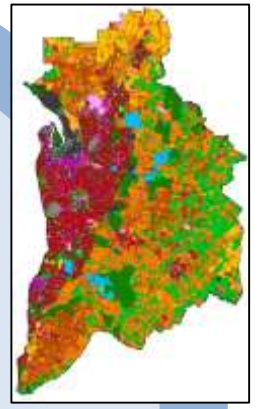

Interaction Rules

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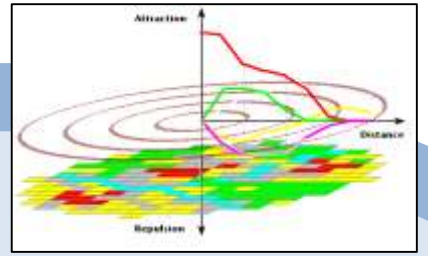

Land use at time T

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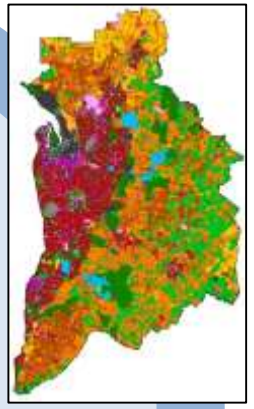

Time loop

Stochastic Perturbation

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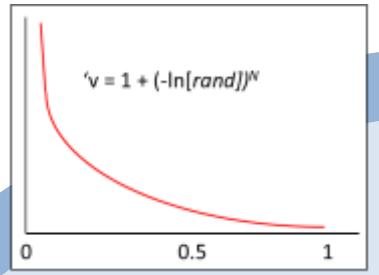

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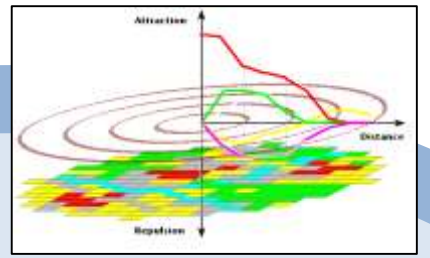
Interaction Rules



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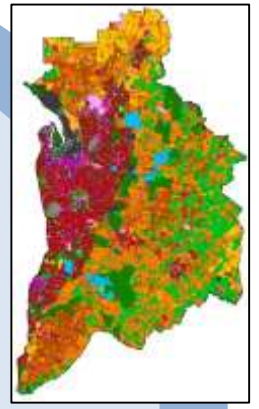
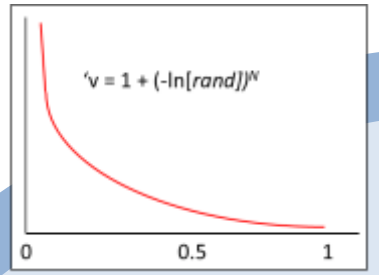
Land use at time T



Time loop

Stochastic Perturbation



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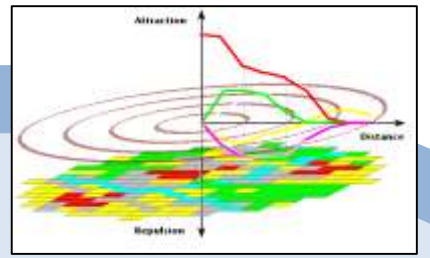
Interaction Rules



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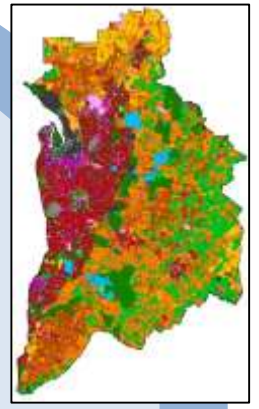
Land use at time T



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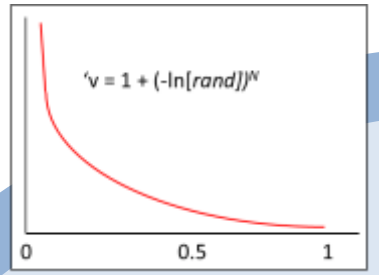
Suitability

&

Time loop

Stochastic Perturbation



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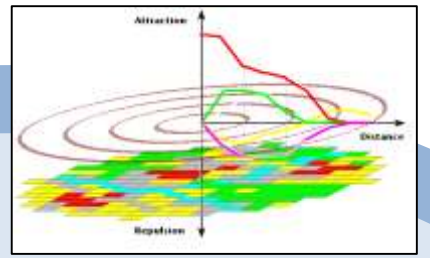
Interaction Rules



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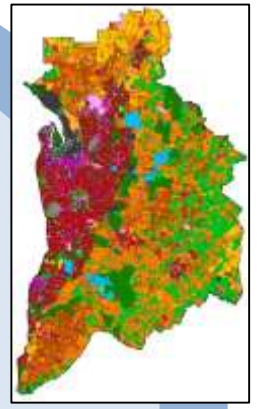
Land use at time T



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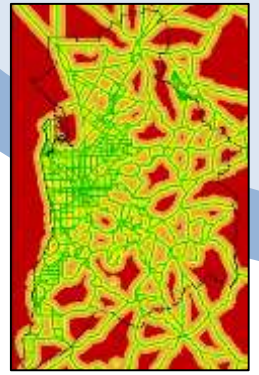
Accessibility



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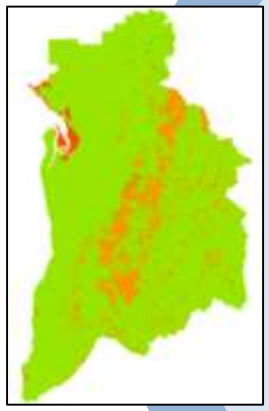
Suitability



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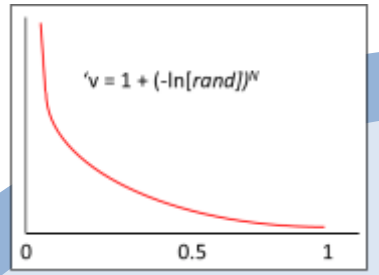
Time loop

Stochastic Perturbation



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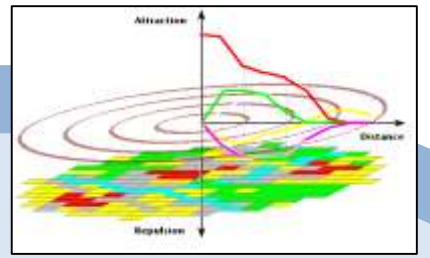
Interaction Rules



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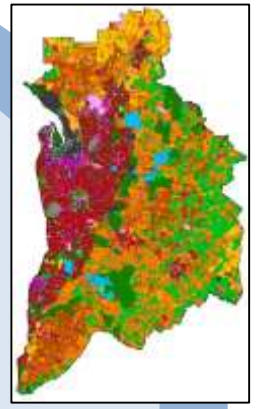
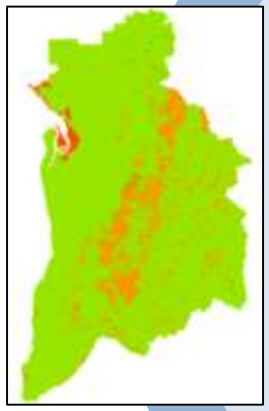
Land use at time T



Suitability



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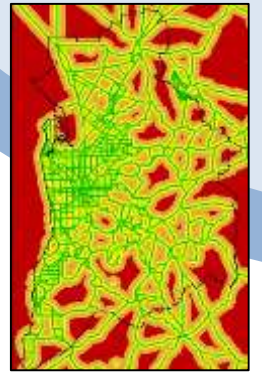
Accessibility



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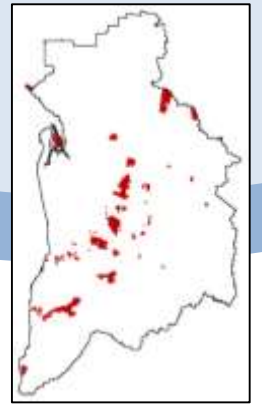
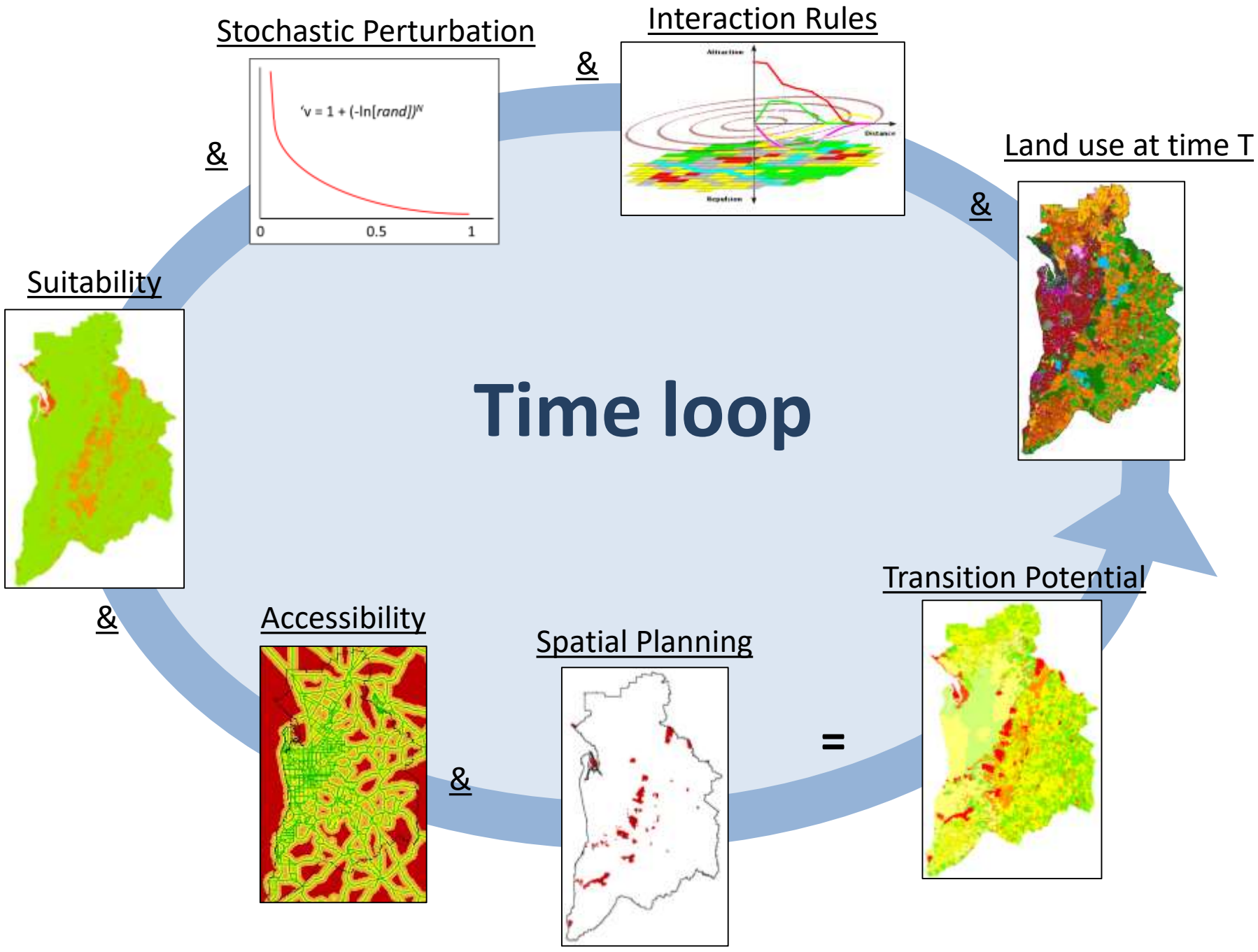
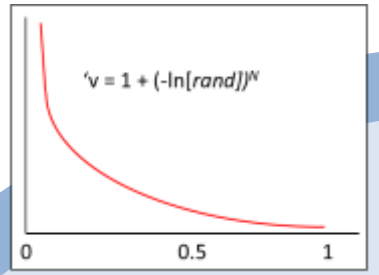
Spatial Planning



Time loop


Stochastic Perturbation
'v = 1 + (-ln[rand])^N
0
0.5
1
&
Interaction Rules
Attraction
Distance
Repulsion
&
Land use at time T
&
Transition Potential
=
Spatial Planning
&
Accessibility
&
Suitability
Time loop

Stochastic Perturbation



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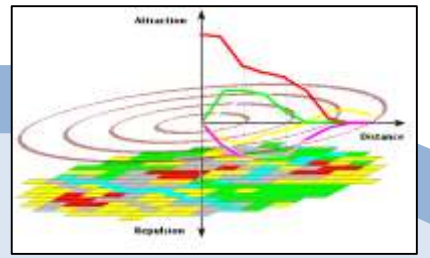
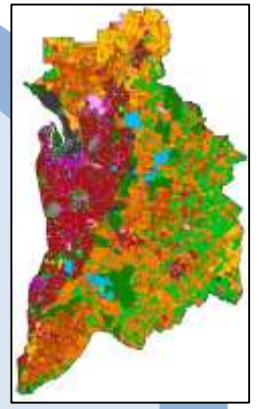
Interaction Rules



&

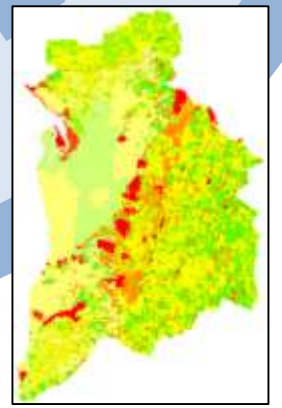
Land use at time T



Transition Rule

Change cells to the land use for which they have the highest transition potential *until regional demands are met*

Transition Potential



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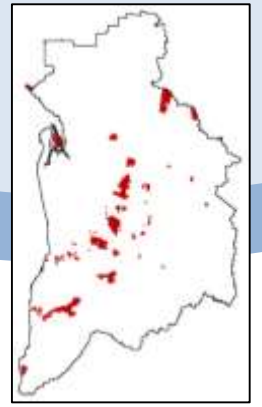
Spatial Planning



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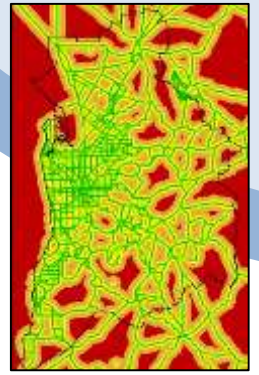
Accessibility



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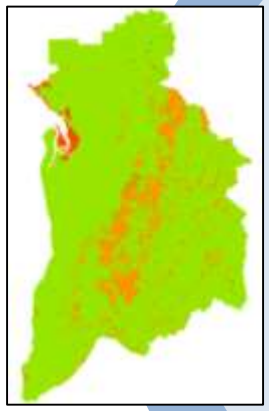
Suitability



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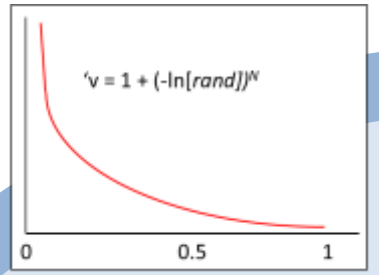
Stochastic Perturbation



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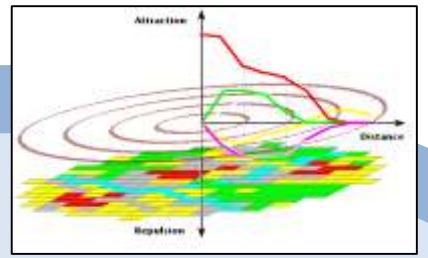
Interaction Rules



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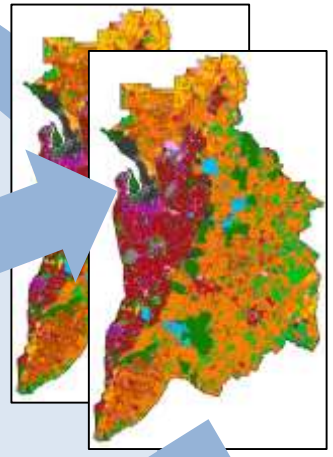
Land use at time T

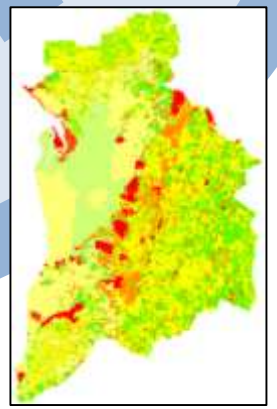


Land use at time T+1

Transition Rule

Change cells to the land use for which they have the highest transition potential *until regional demands are met*

Transition Potential



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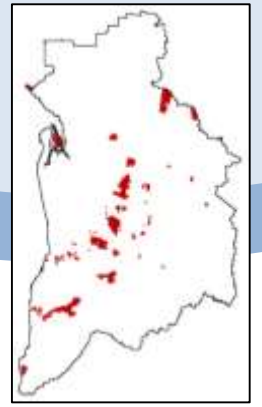
Spatial Planning



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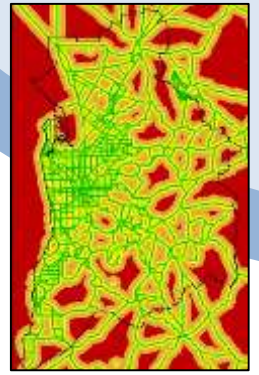
Accessibility



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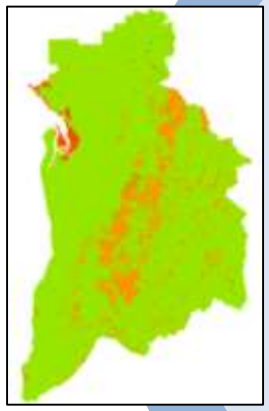
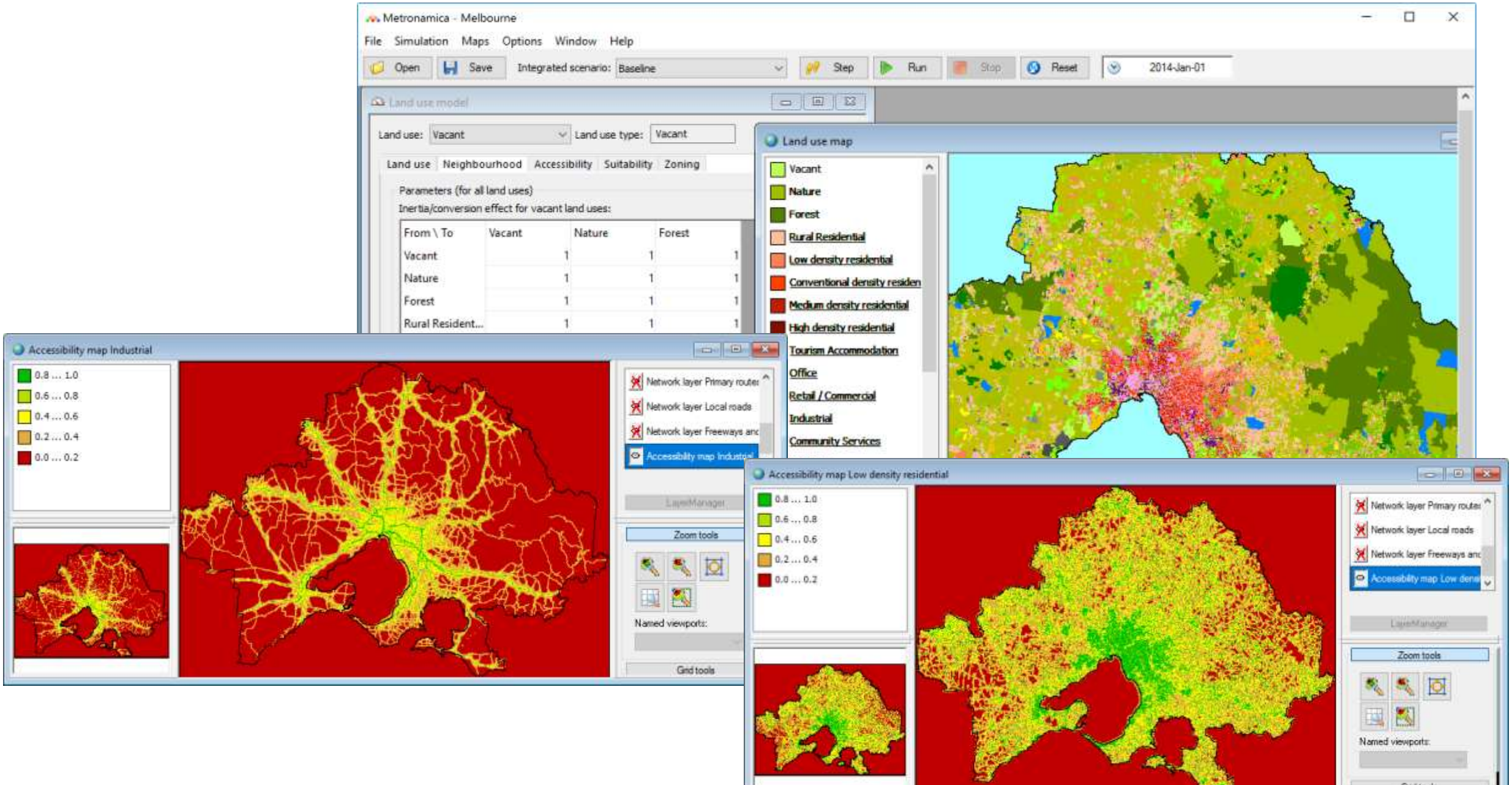
Suitability

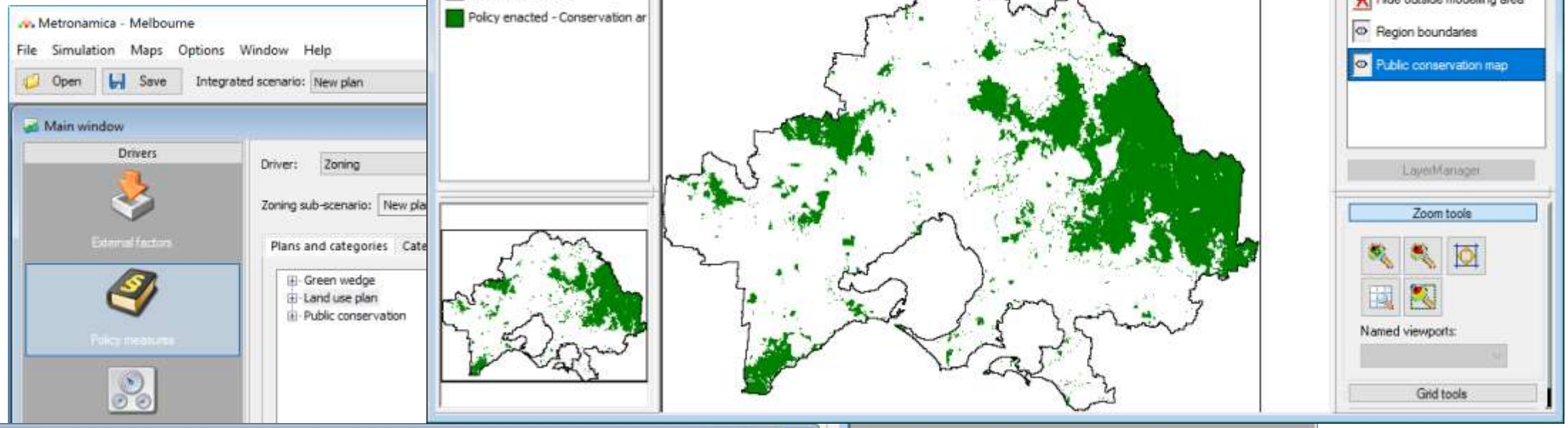


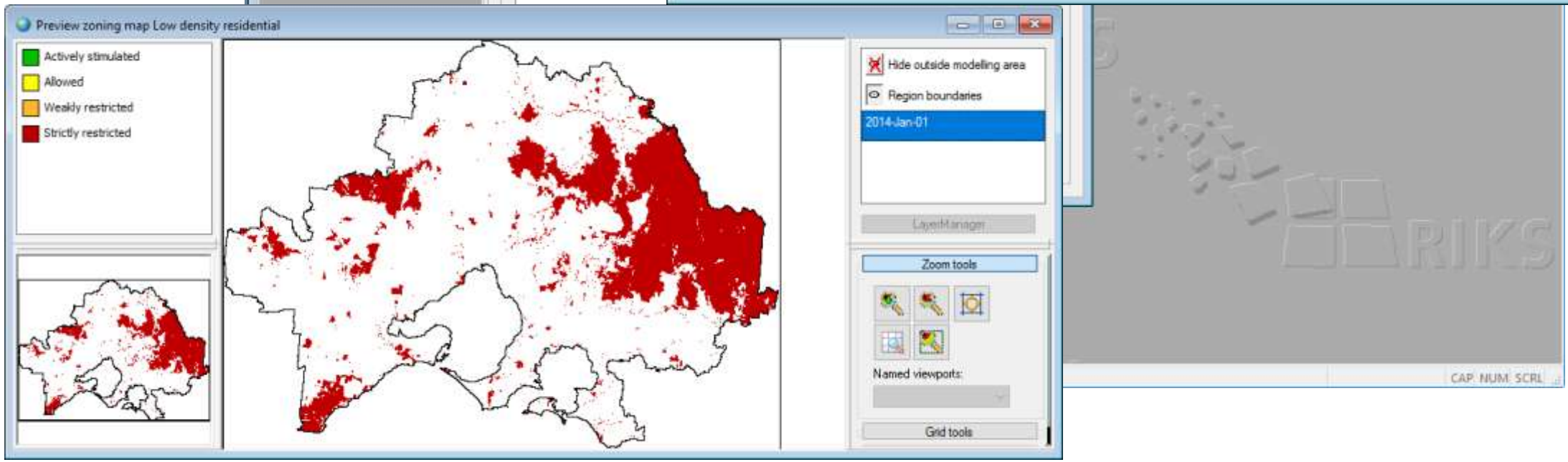
&

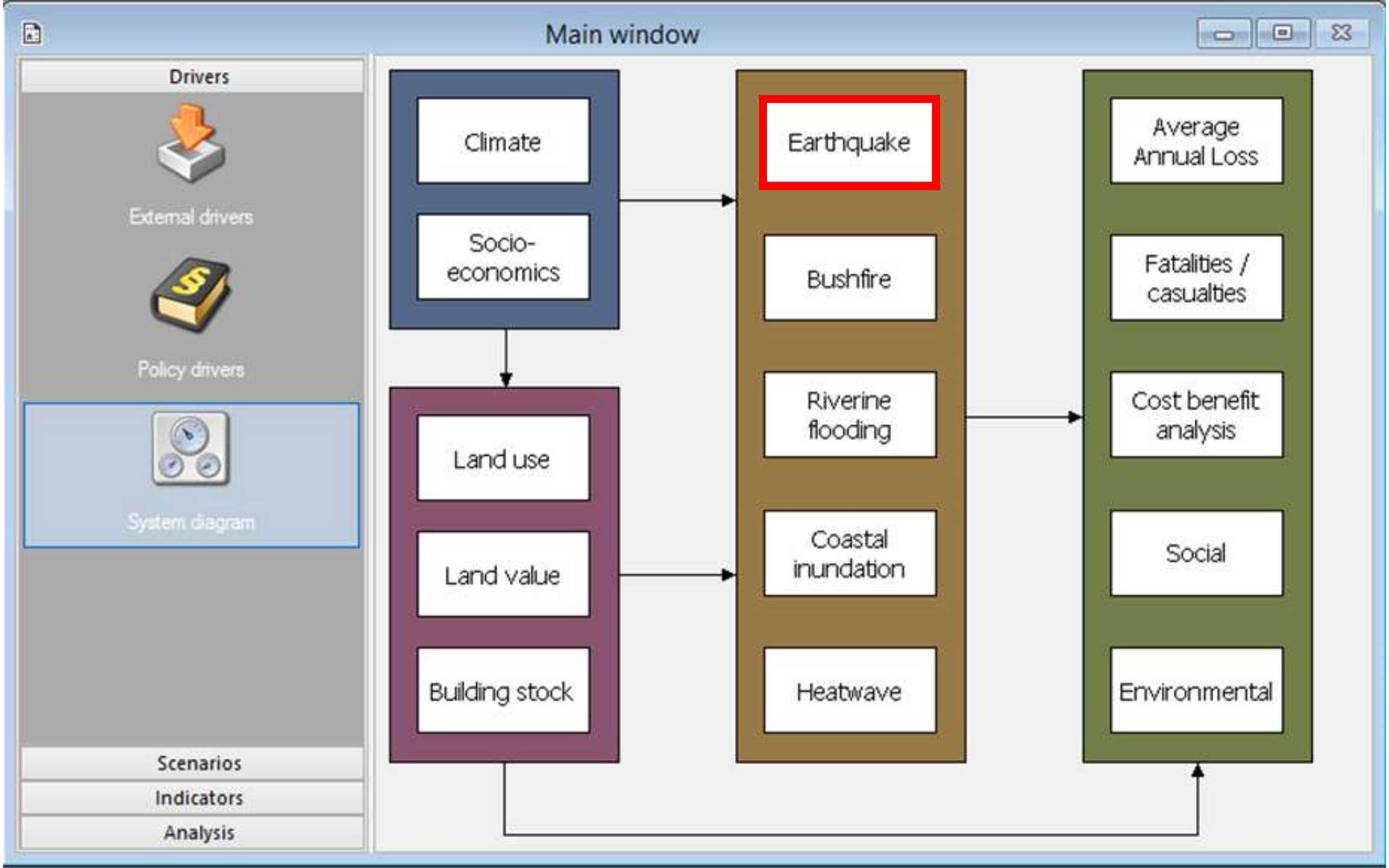
MODELLER INTERFACE LAND USE

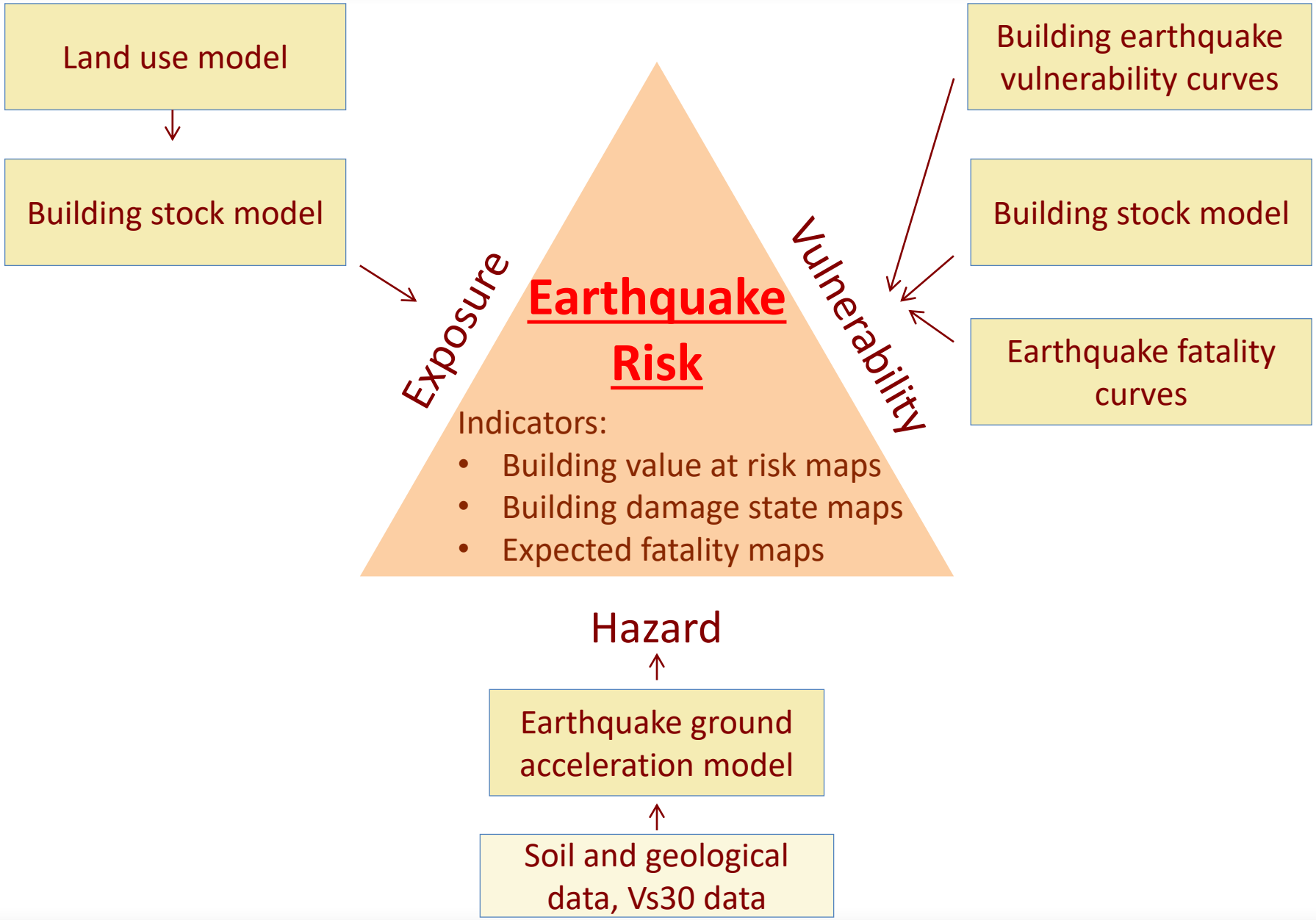


POLICY INTERFACE





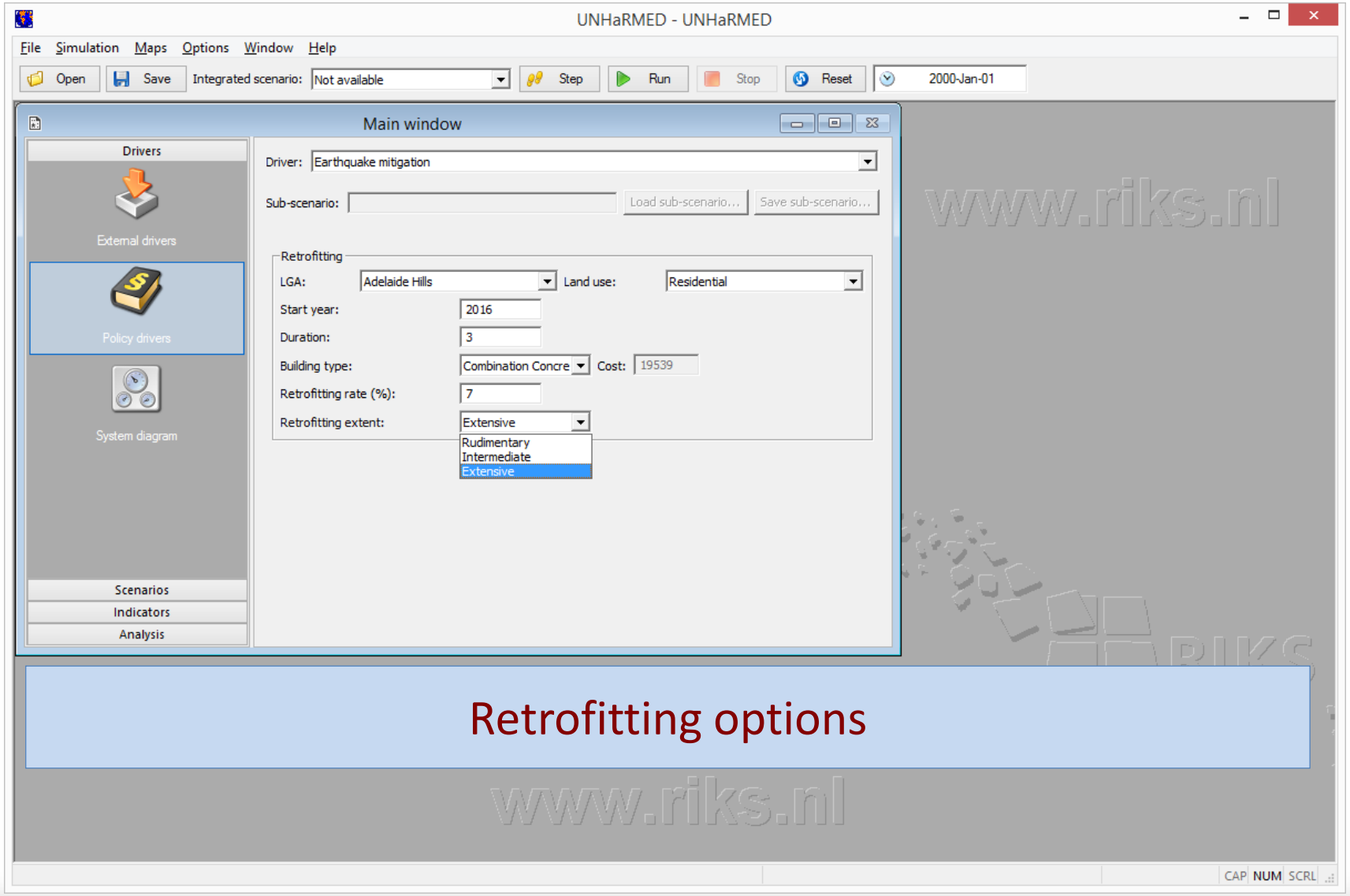

Main window
Drivers
External drivers
Policy drivers
System diagram
Scenarios
Indicators
Analysis
Climate
Socio-economics
Land use
Land value
Building stock
Earthquake
Bushfire
Riverine flooding
Coastal inundation
Heatwave
Average Annual Loss
Fatalities / casualties
Cost benefit analysis
Social
Environmental


Land use model
Building stock model
Exposure
Earthquake Risk
Indicators:
• Building value at risk maps
• Building damage state maps
• Expected fatality maps
Vulnerability
Building earthquake vulnerability curves
Building stock model
Earthquake fatality curves
Hazard
Earthquake ground acceleration model
Soil and geological data, Vs30 data

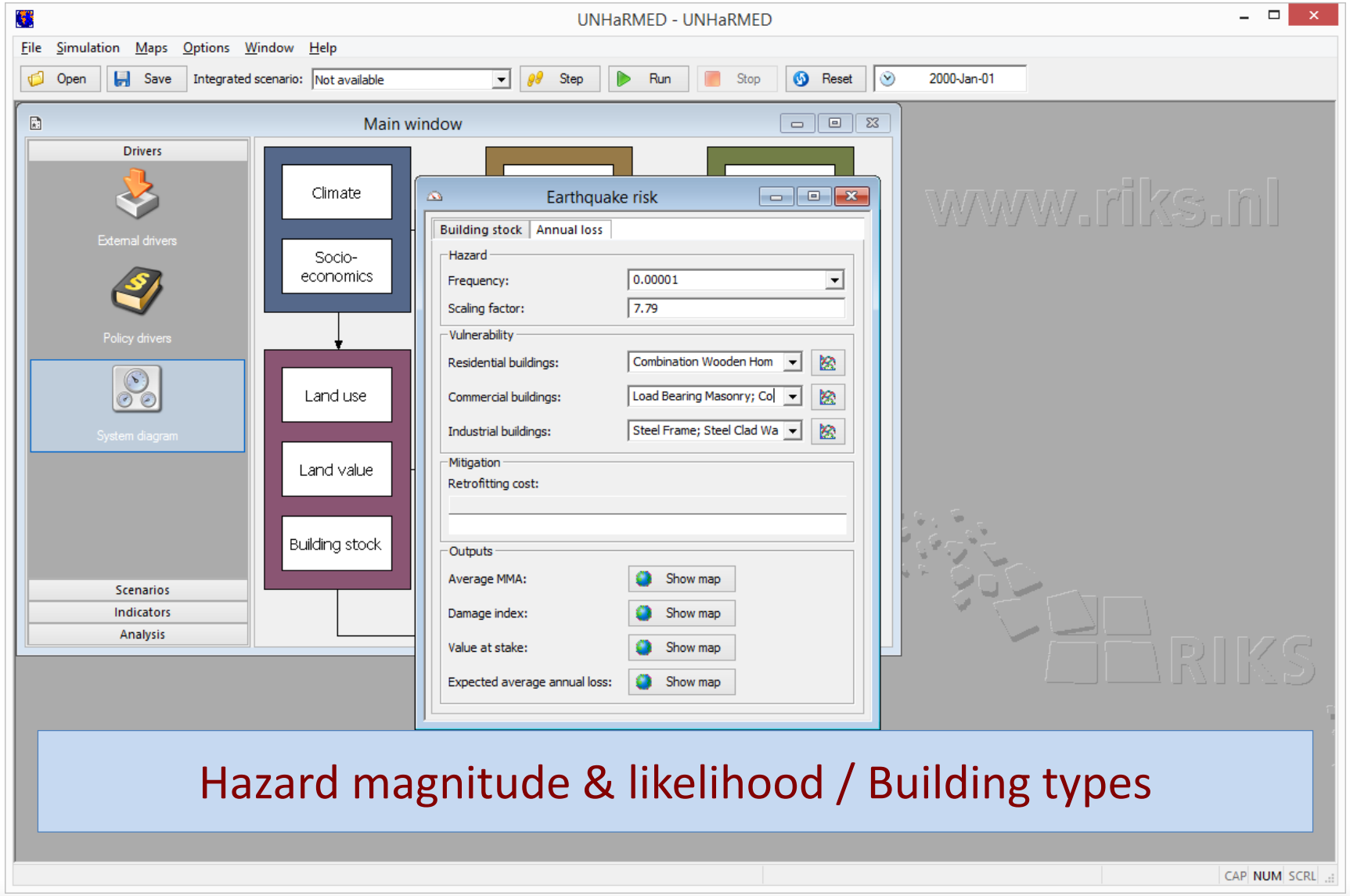
MITIGATION OPTIONS EARTHQUAKE

- Hazard
  - -
- Vulnerability
  - Retrofitting building types
  - Changes to the building stock mix
- Exposure
  - Land use planning

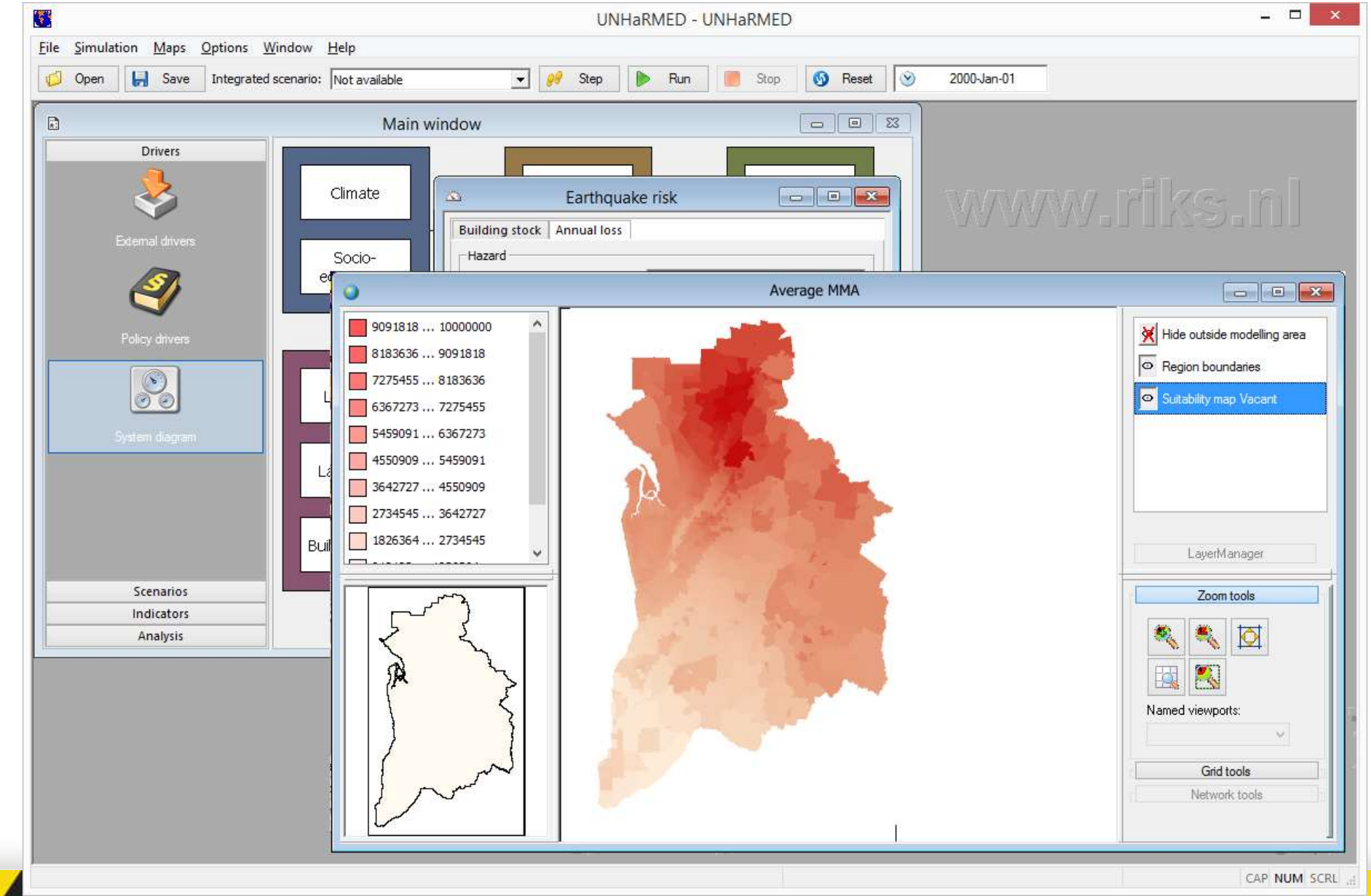
POLICY INTERFACE EARTHQUAKE



MODELLER INTERFACE EARTHQUAKE



Hazard magnitude & likelihood / Building types


UNHaRMED - UNHaRMED
File Simulation Maps Options Window Help
Open Save Integrated scenario: Not available Step Run Stop Reset 2000-Jan-01
Main window
Drivers
External drivers
Policy drivers
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Scenarios
Indicators
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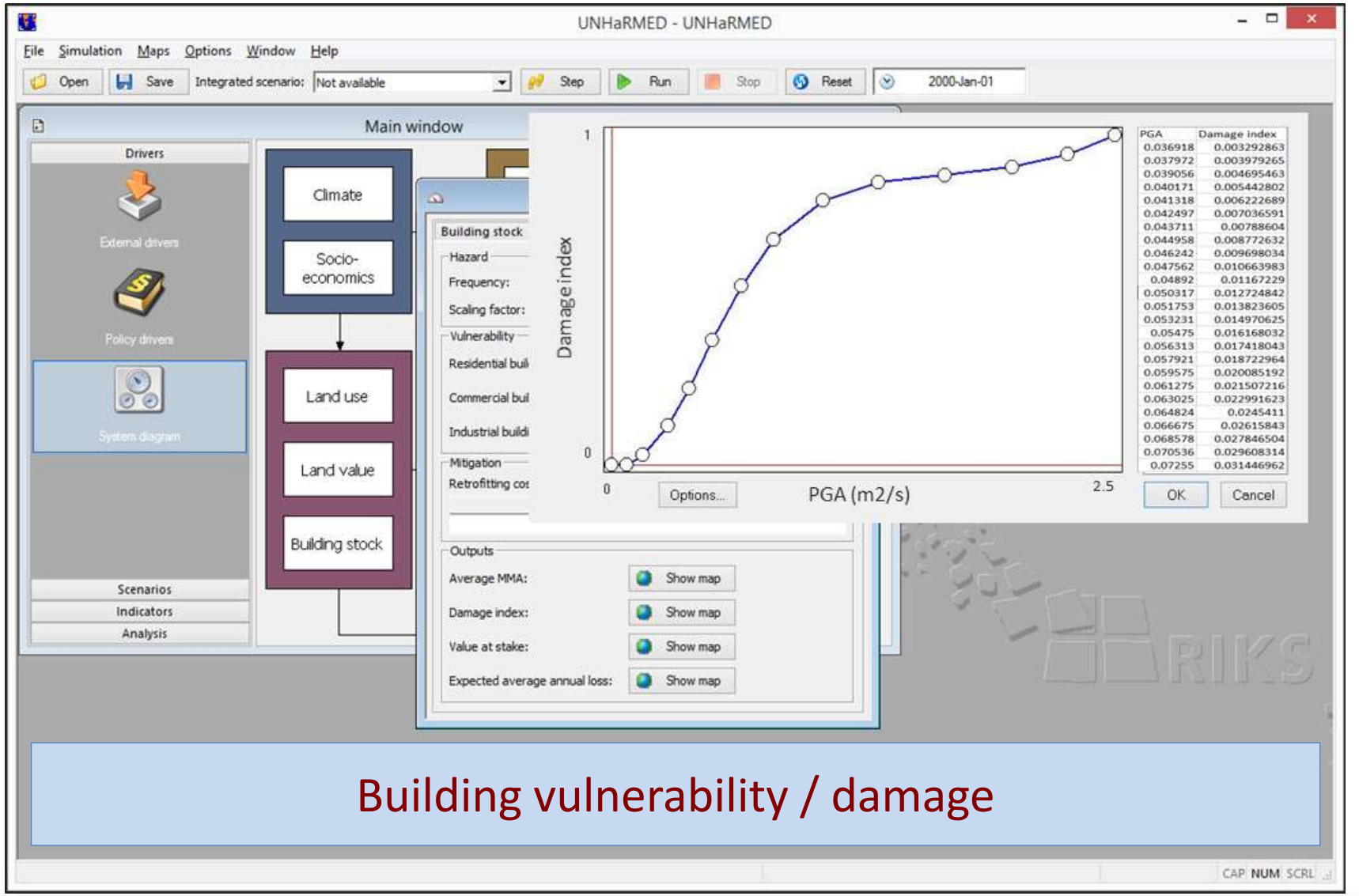
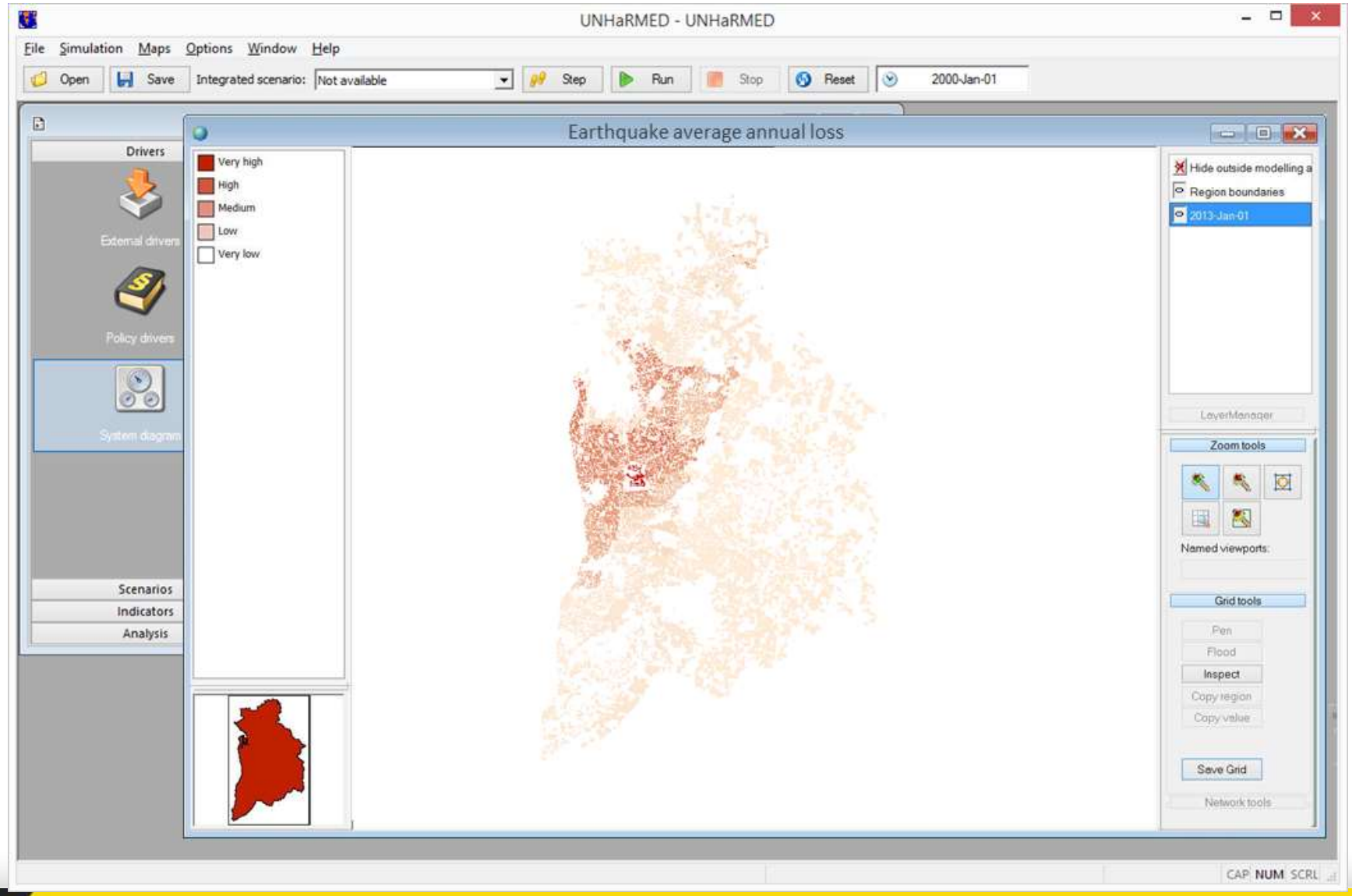
Climate
Socio-
Earthquake risk
Building stock
Annual loss
Hazard
www.riks.nl
Average MMA
9091818 ... 10000000
8183636 ... 9091818
7275455 ... 8183636
6367273 ... 7275455
5459091 ... 6367273
4550909 ... 5459091
3642727 ... 4550909
2734545 ... 3642727
1826364 ... 2734545
Hide outside modelling area
Region boundaries
Suitability map Vacant
LayerManager
Zoom tools
Named viewports:
Grid tools
Network tools
CAP NUM SCRL

MODELLER INTERFACE EARTHQUAKE

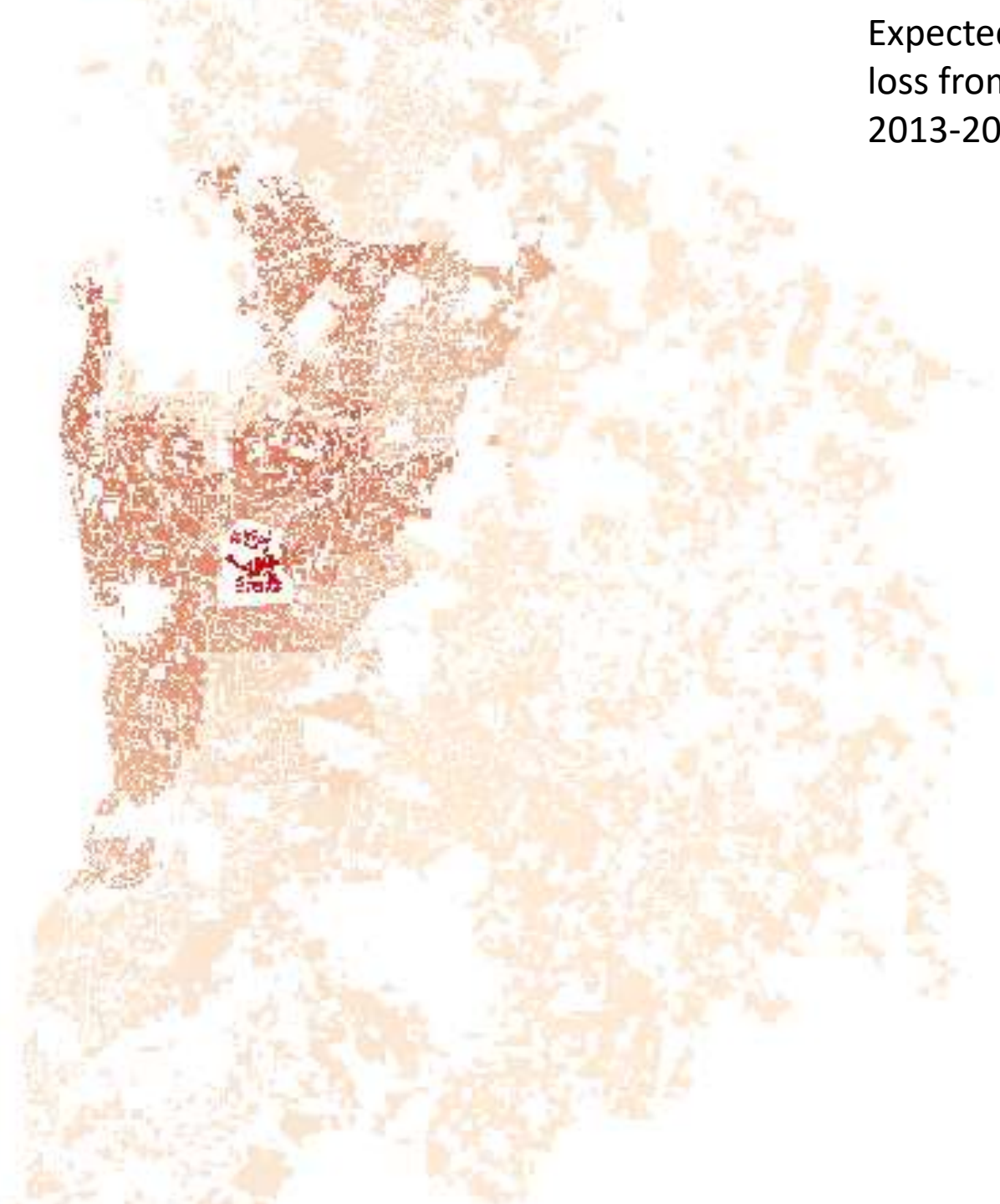


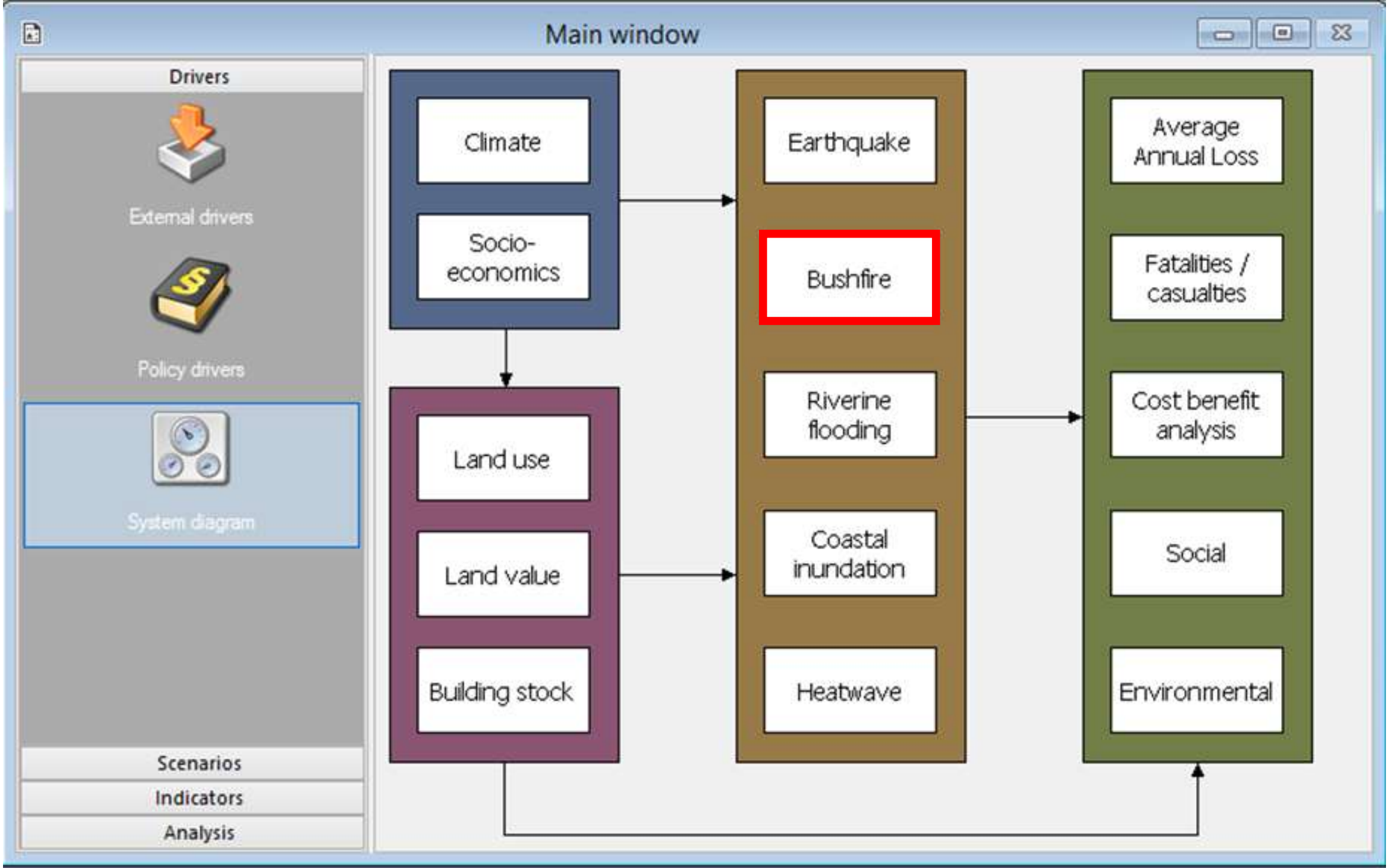
Building vulnerability / damage

MODELLER INTERFACE EARTHQUAKE



Expected average annual loss from earthquakes 2013-2050

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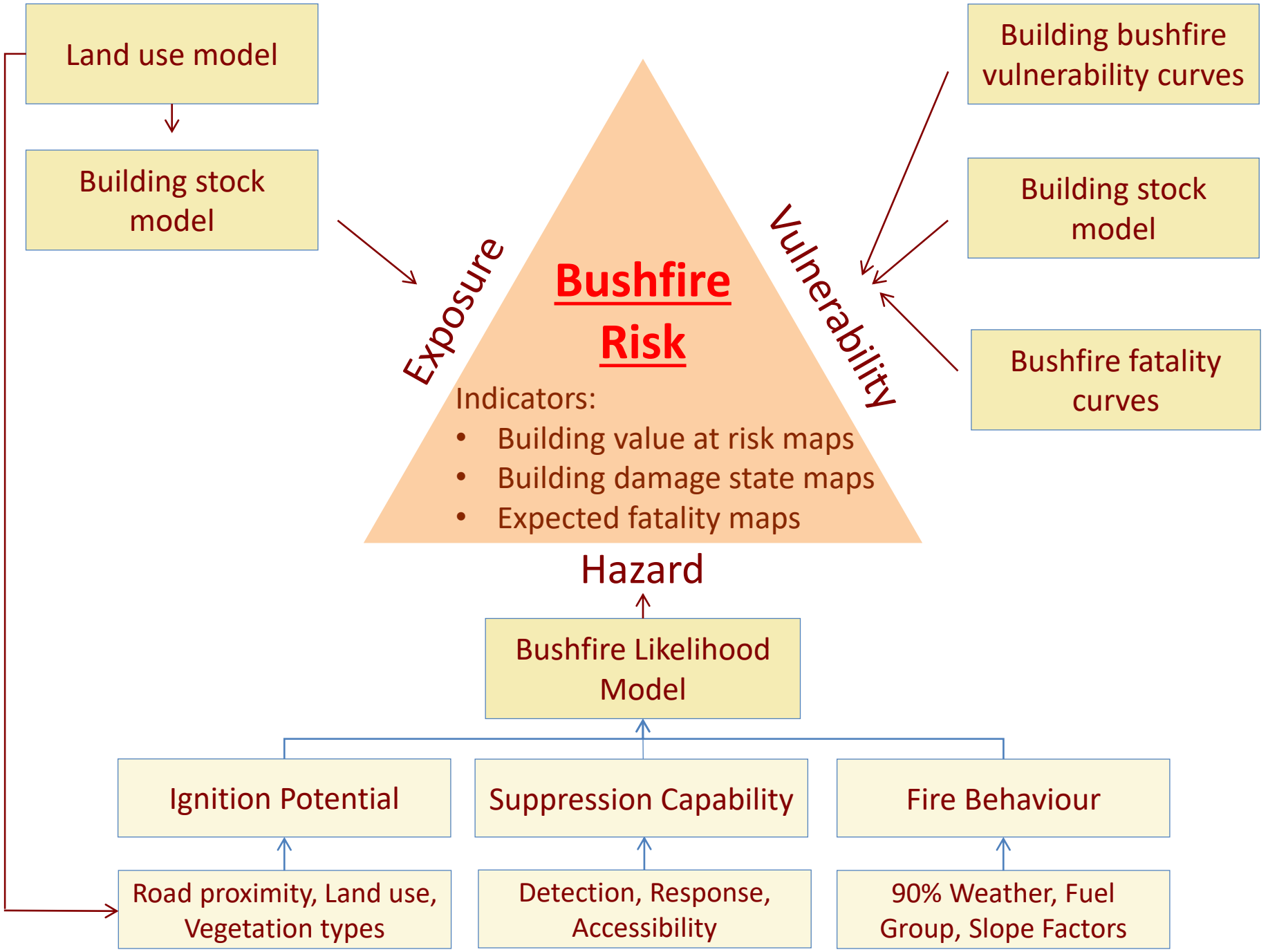
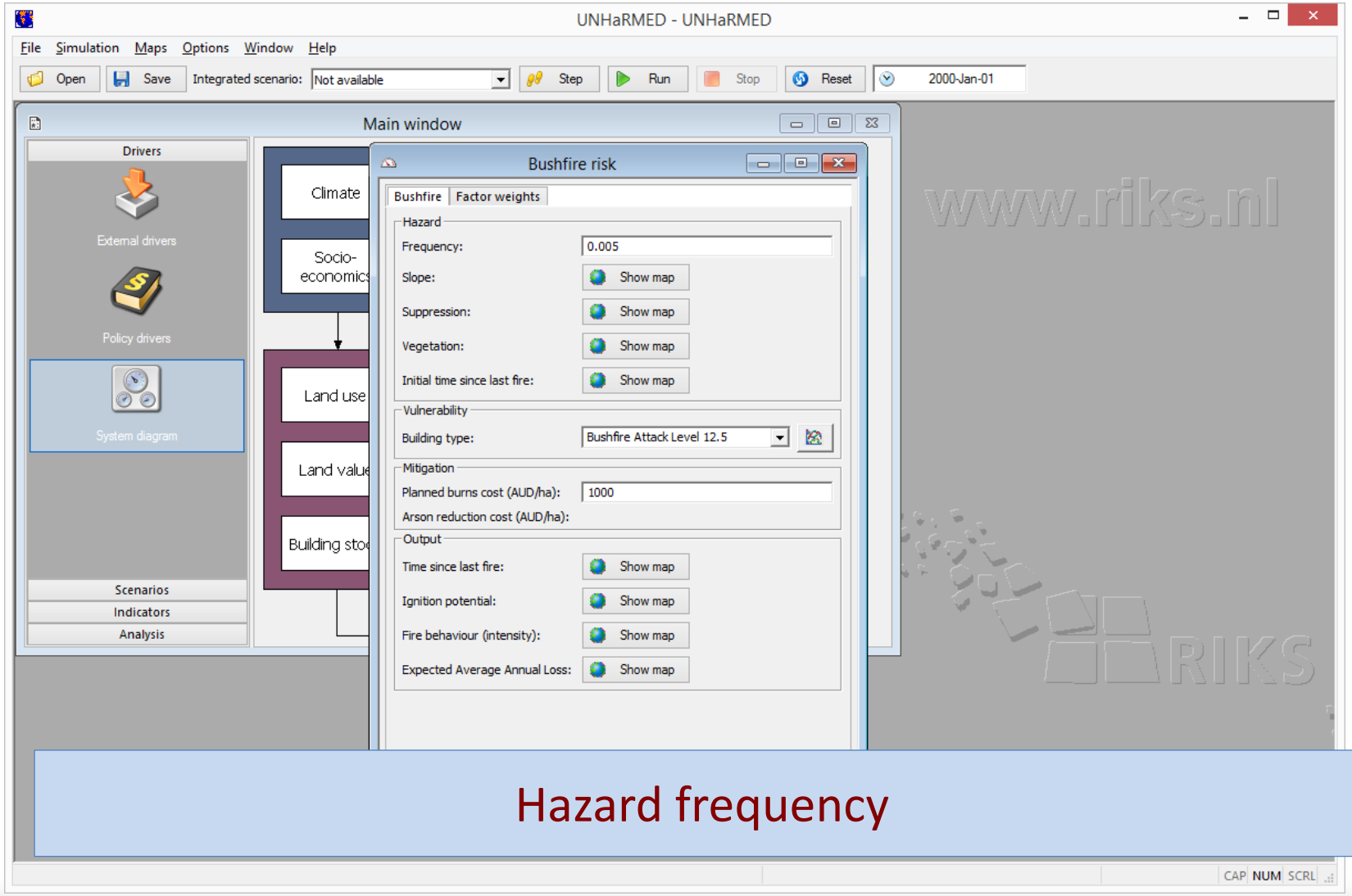

Land use model
Building stock model
Building bushfire vulnerability curves
Building stock model
Bushfire fatality curves
Exposure
Vulnerability
Bushfire Risk
Indicators:
• Building value at risk maps
• Building damage state maps
• Expected fatality maps
Hazard
Bushfire Likelihood Model
Ignition Potential
Suppression Capability
Fire Behaviour
Road proximity, Land use, Vegetation types
Detection, Response, Accessibility
90% Weather, Fuel Group, Slope Factors

MITIGATION OPTIONS BUSHFIRE

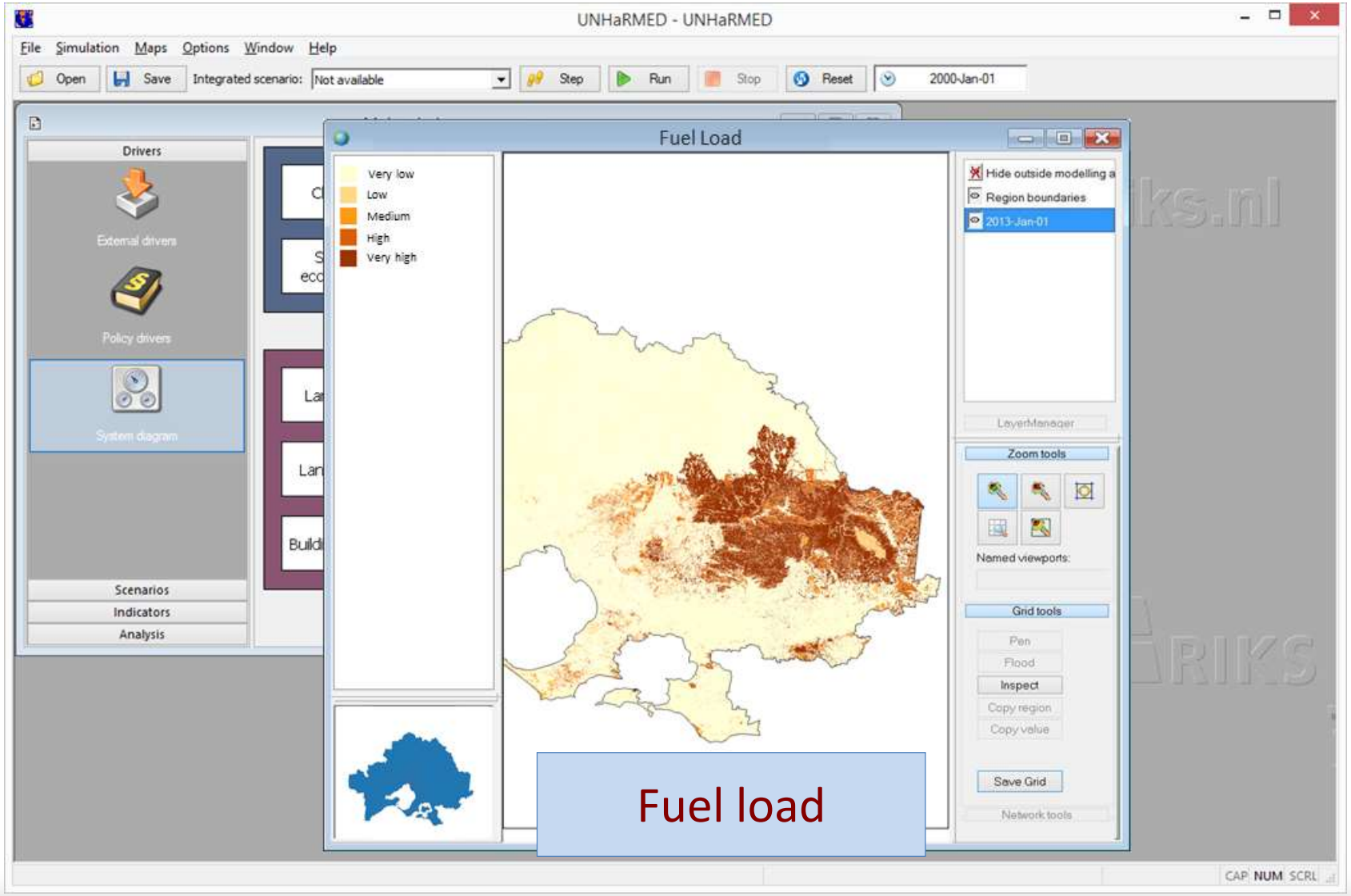
- Hazard
  - Planned burns
  - Education and awareness to reduce arson
- Vulnerability
  - Changes to the building stock mix
  - Education and awareness to manage your property and have a kit ready
- Exposure
  - Land use planning

MODELLER INTERFACE BUSHFIRE

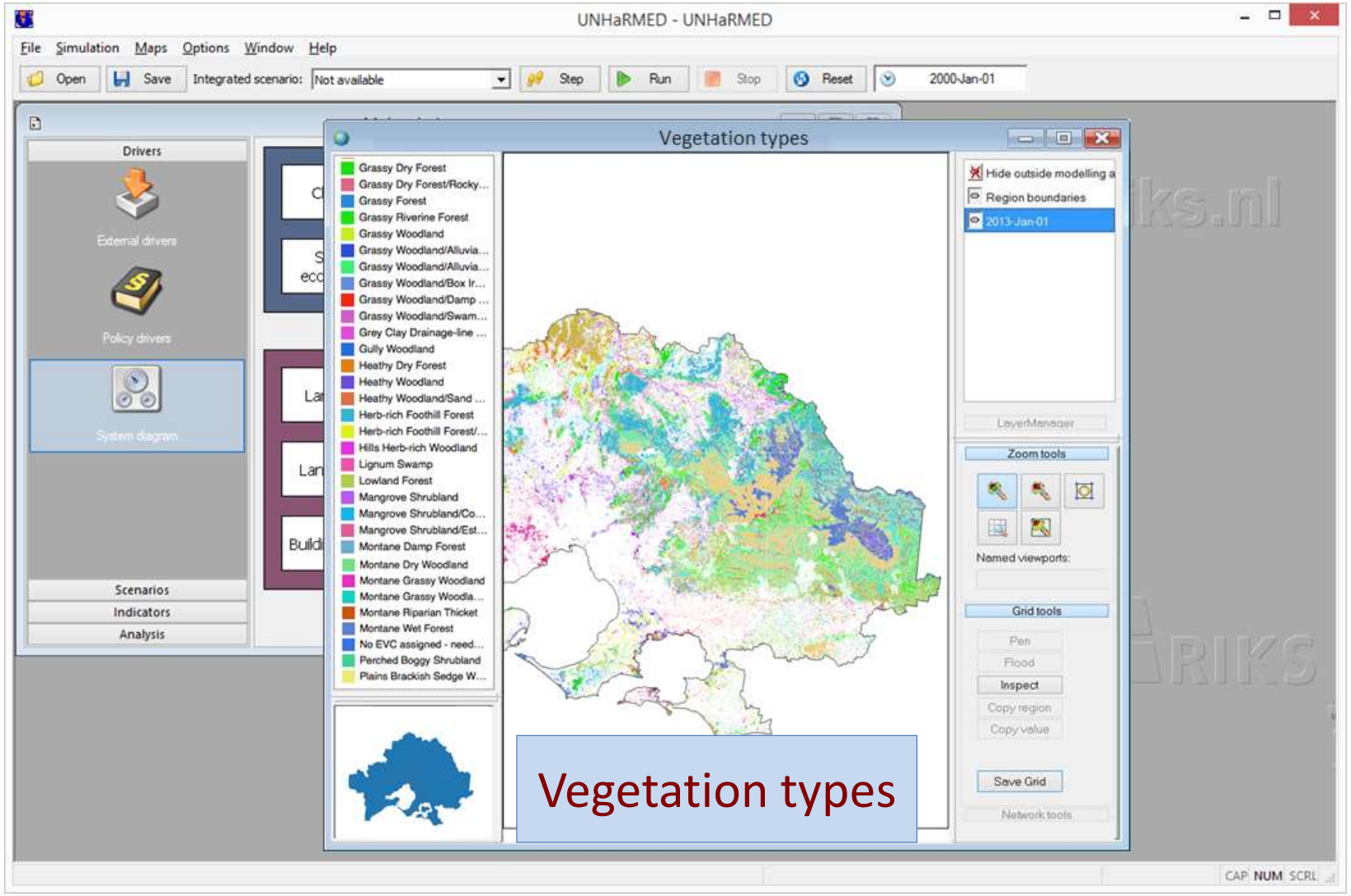


Hazard frequency

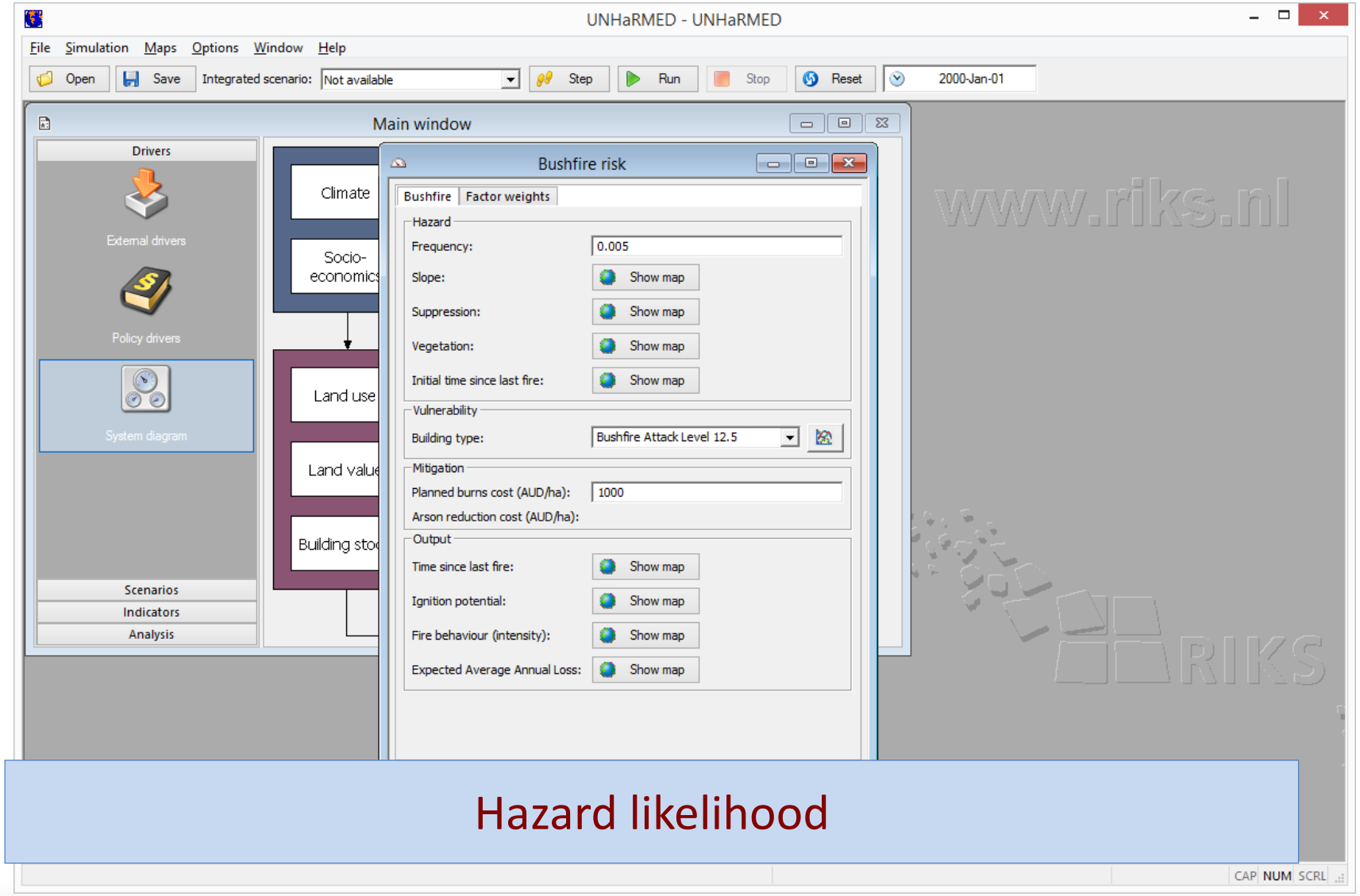
MODELLER INTERFACE BUSHFIRE



MODELLER INTERFACE BUSHFIRE

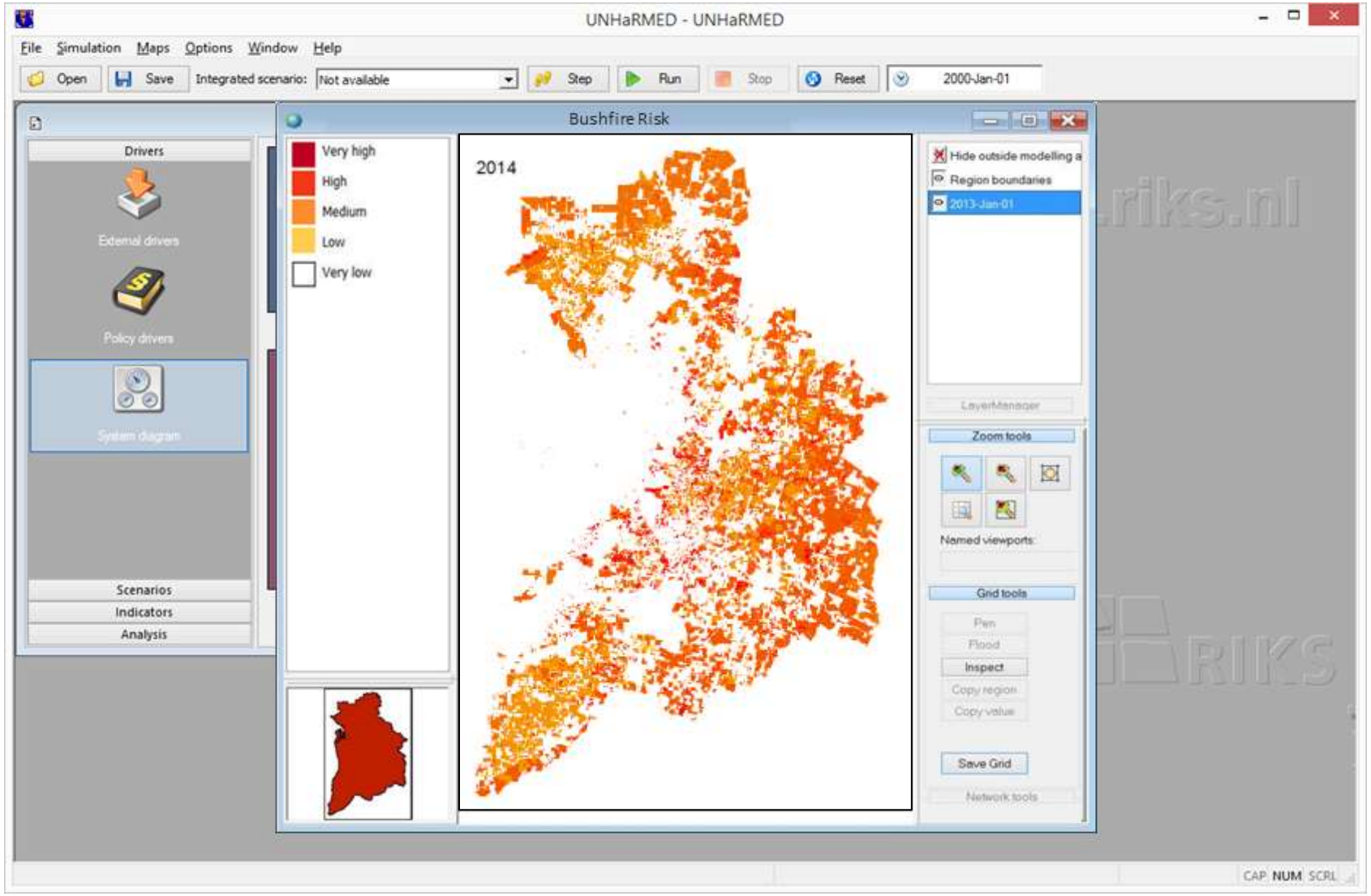


MODELLER INTERFACE BUSHFIRE

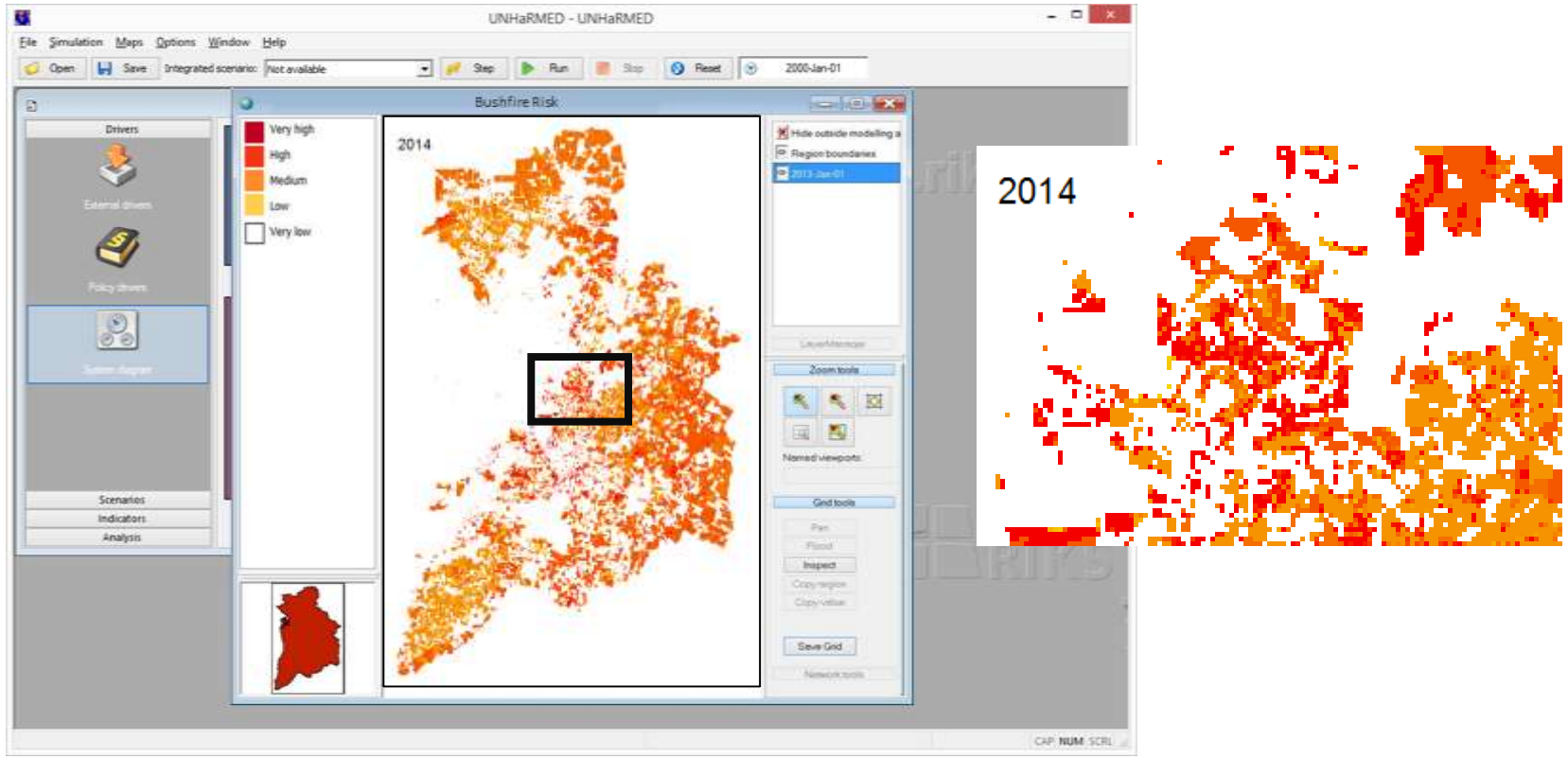


Hazard likelihood

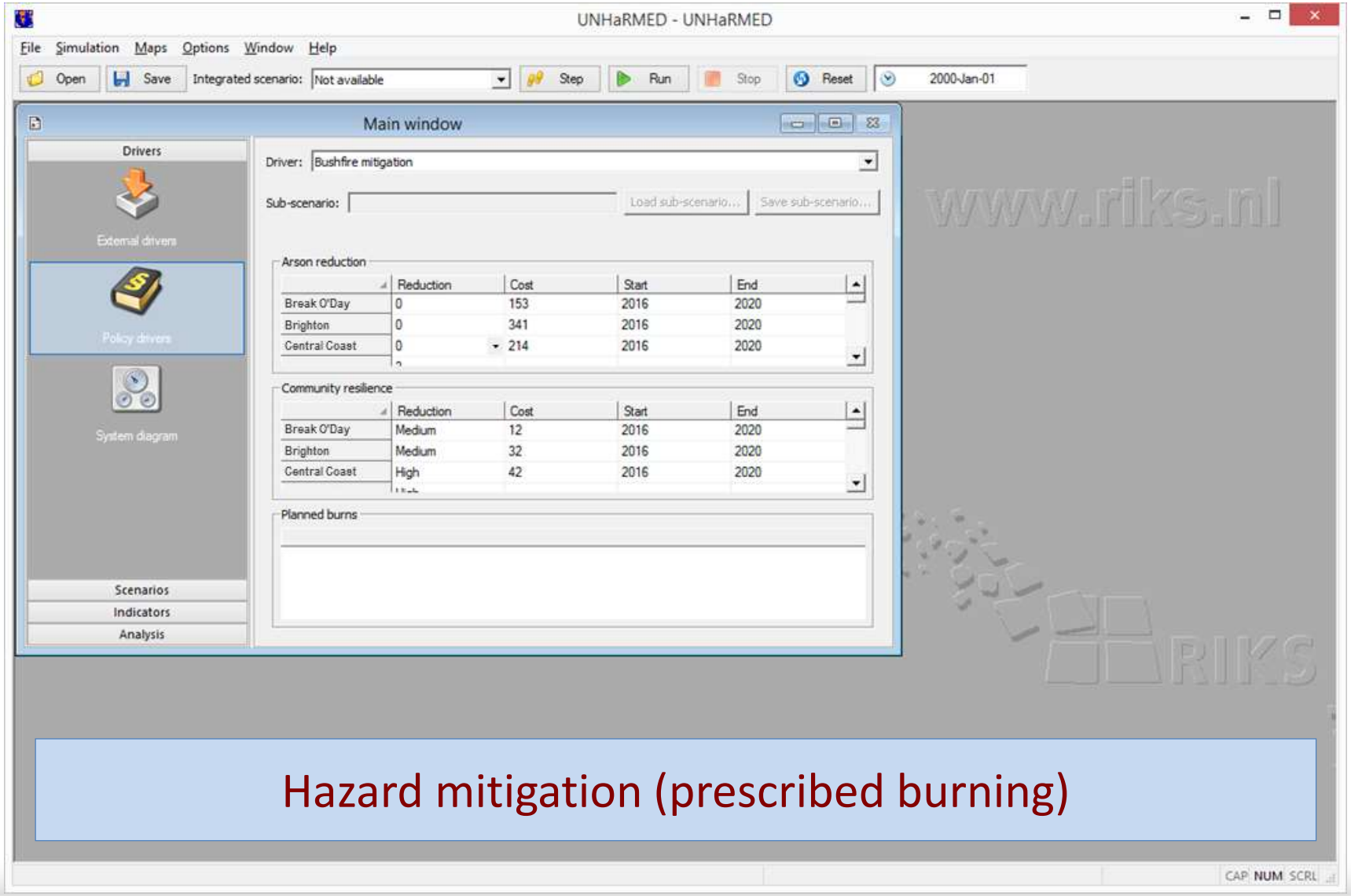
DYNAMIC WILDFIRE RISK MODELLING



DYNAMIC WILDFIRE RISK MODELLING

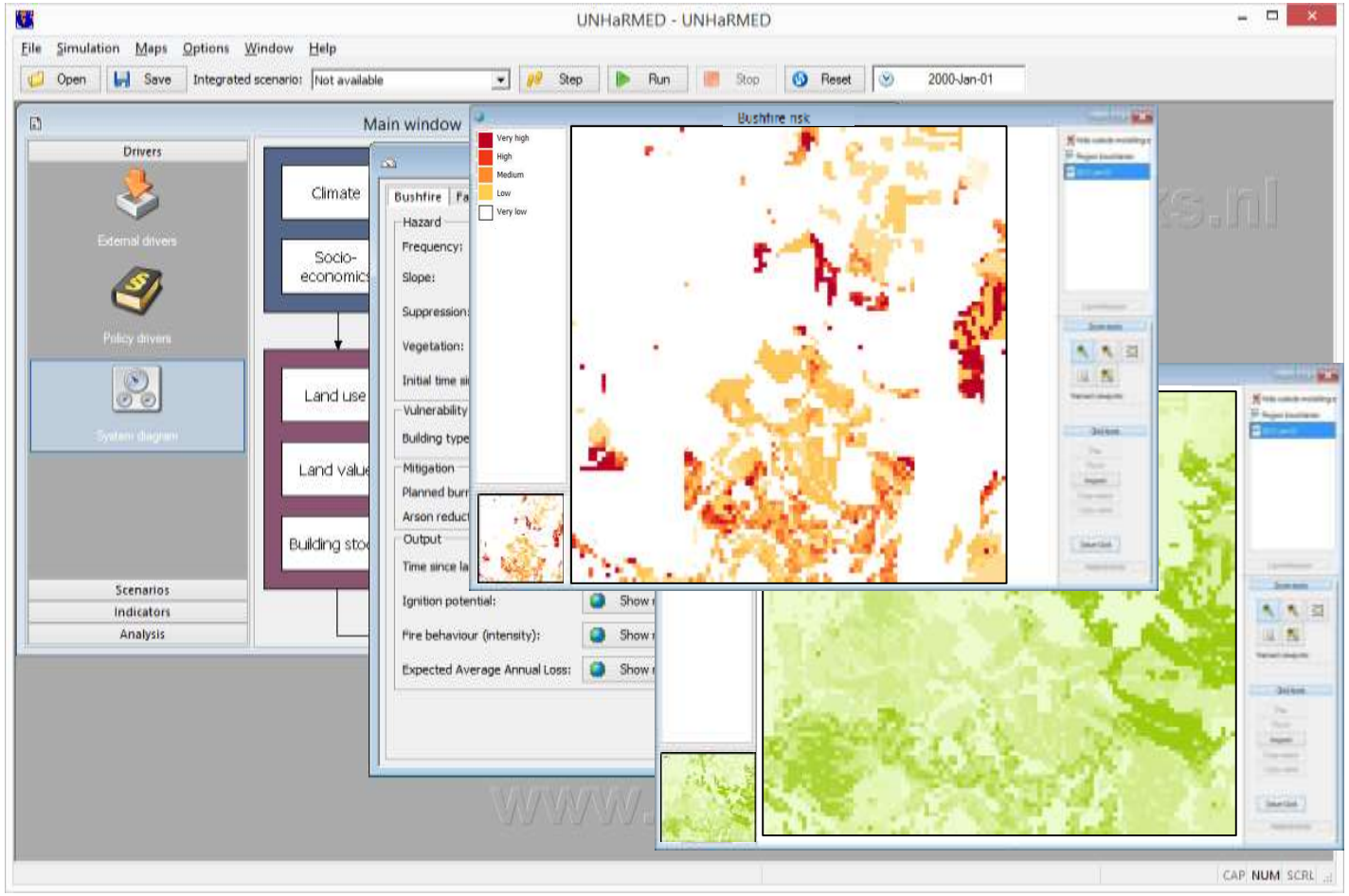


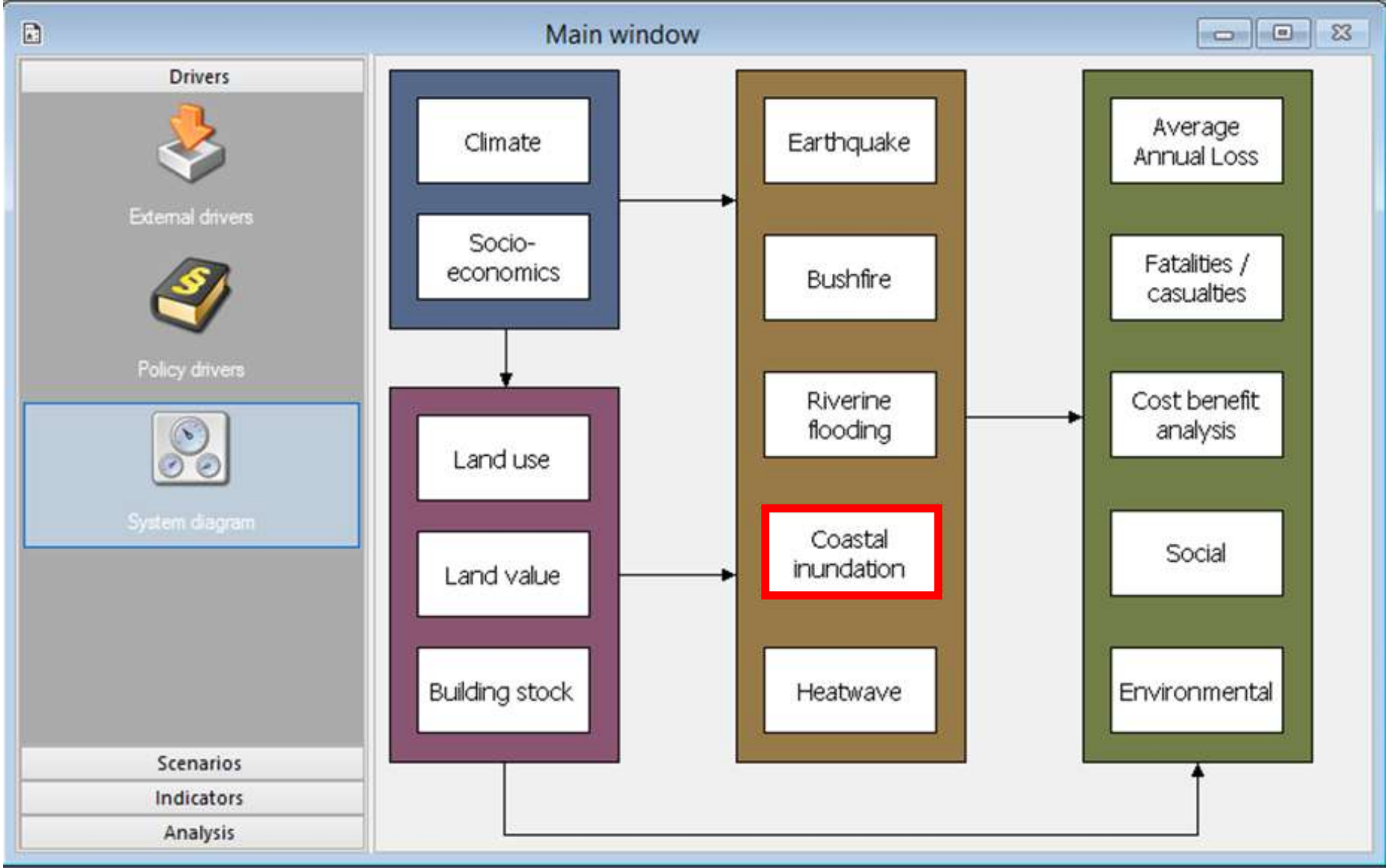
POLICY INTERFACE BUSHFIRE – RISK REDUCTION



Hazard mitigation (prescribed burning)

PLANNED BURNS

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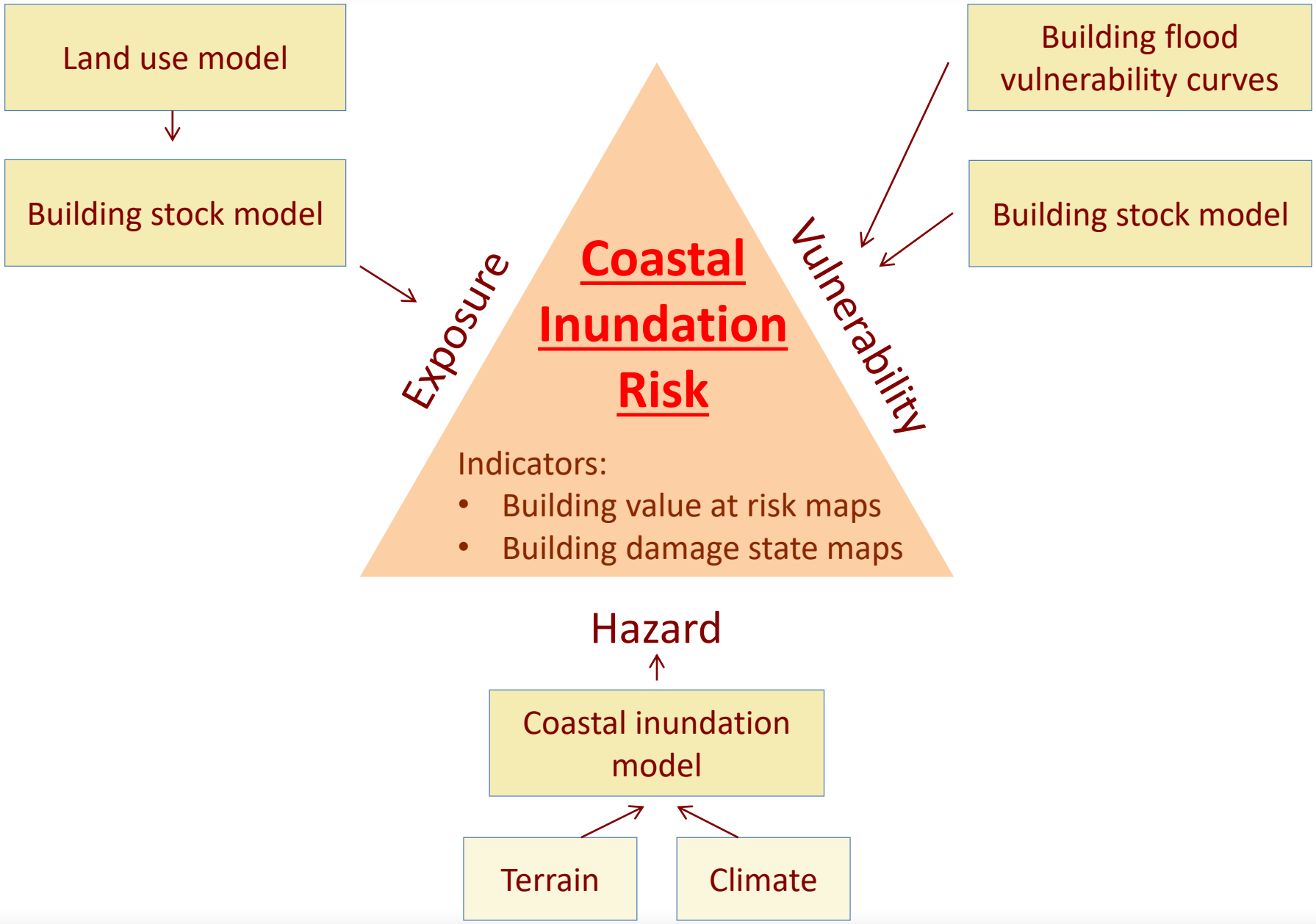
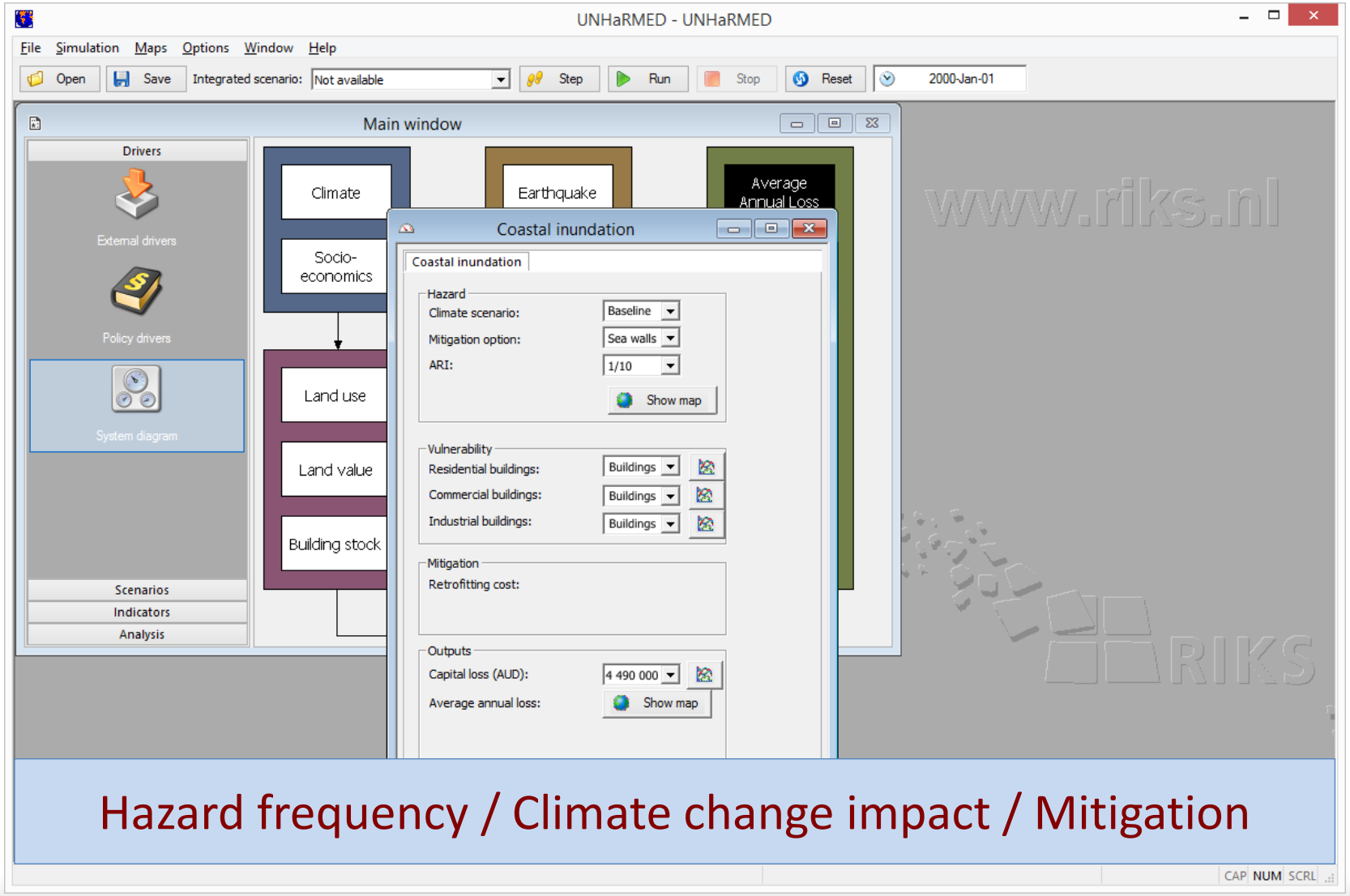
Social
Environmental


Land use model
Building stock model
Building flood vulnerability curves
Building stock model
Exposure
Vulnerability
Coastal Inundation Risk
Indicators:
• Building value at risk maps
• Building damage state maps
Hazard
Coastal inundation model
Terrain
Climate

MITIGATION OPTIONS COASTAL INUNDATION

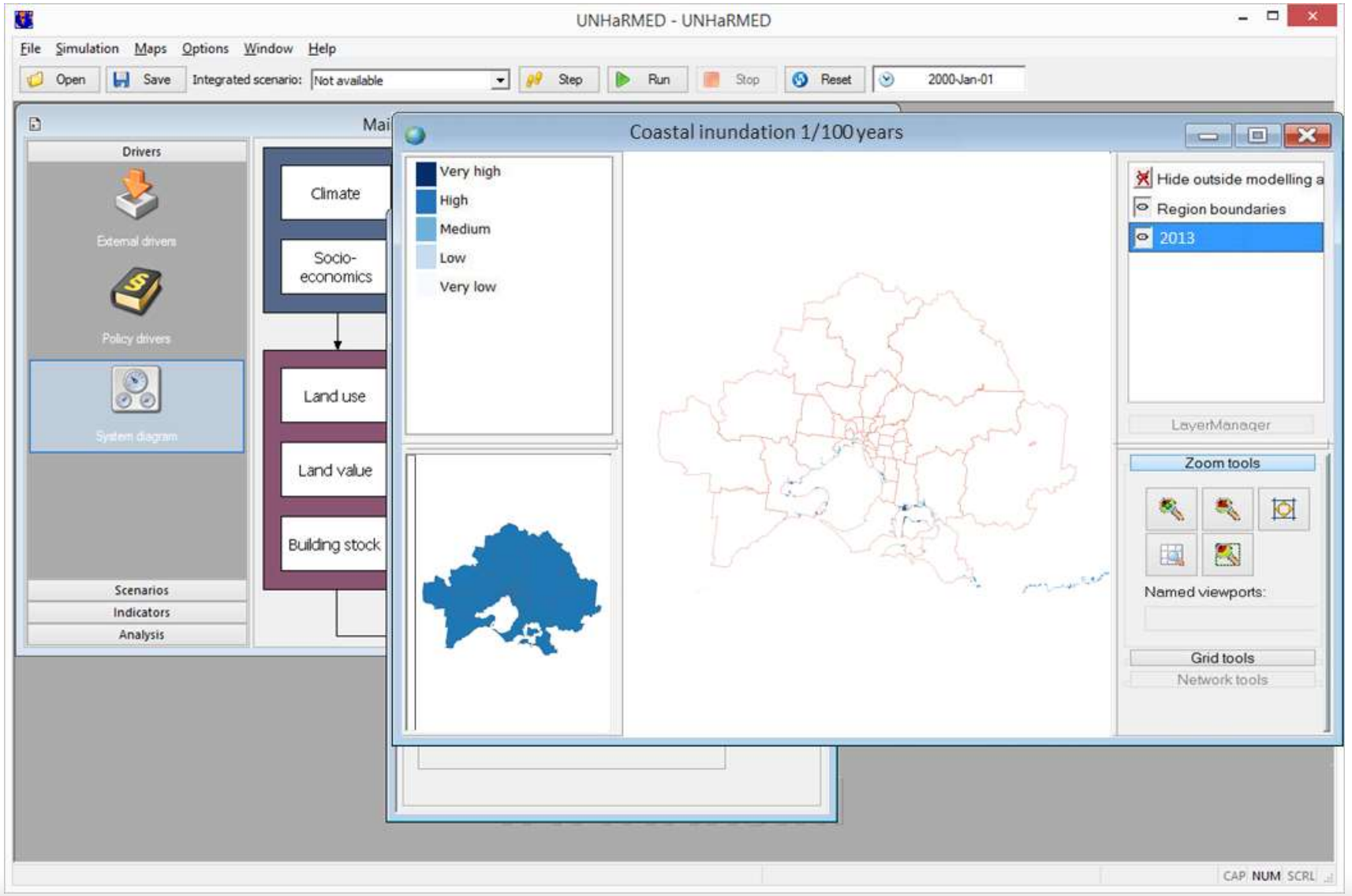
- Hazard
  - Structural measures
- Vulnerability
  - Retrofitting building types
  - Changes to the building stock mix
  - Education and awareness to manage your property
- Exposure
  - Land use planning

MODELLER INTERFACE COASTAL INUNDATION

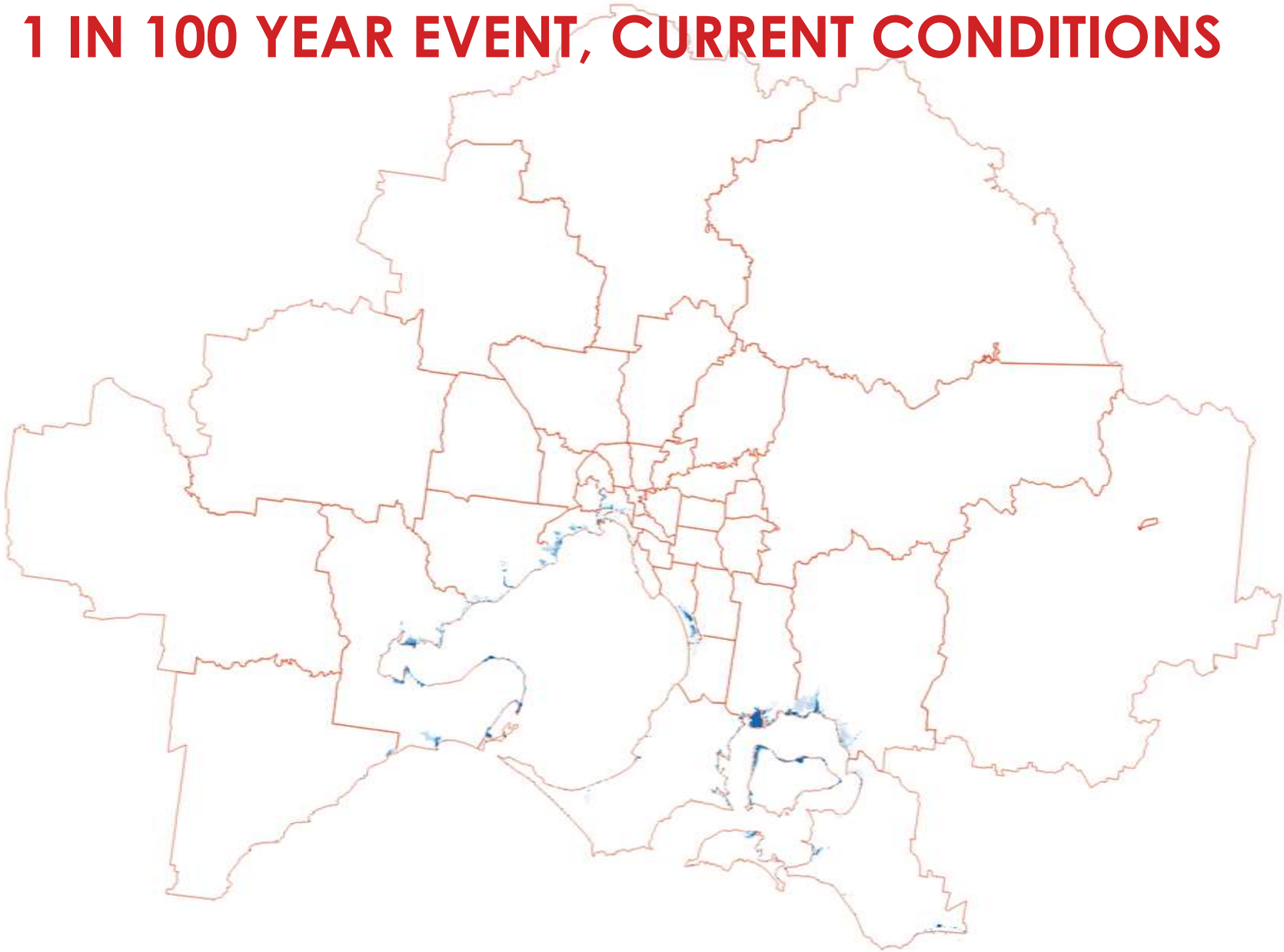


Hazard frequency / Climate change impact / Mitigation

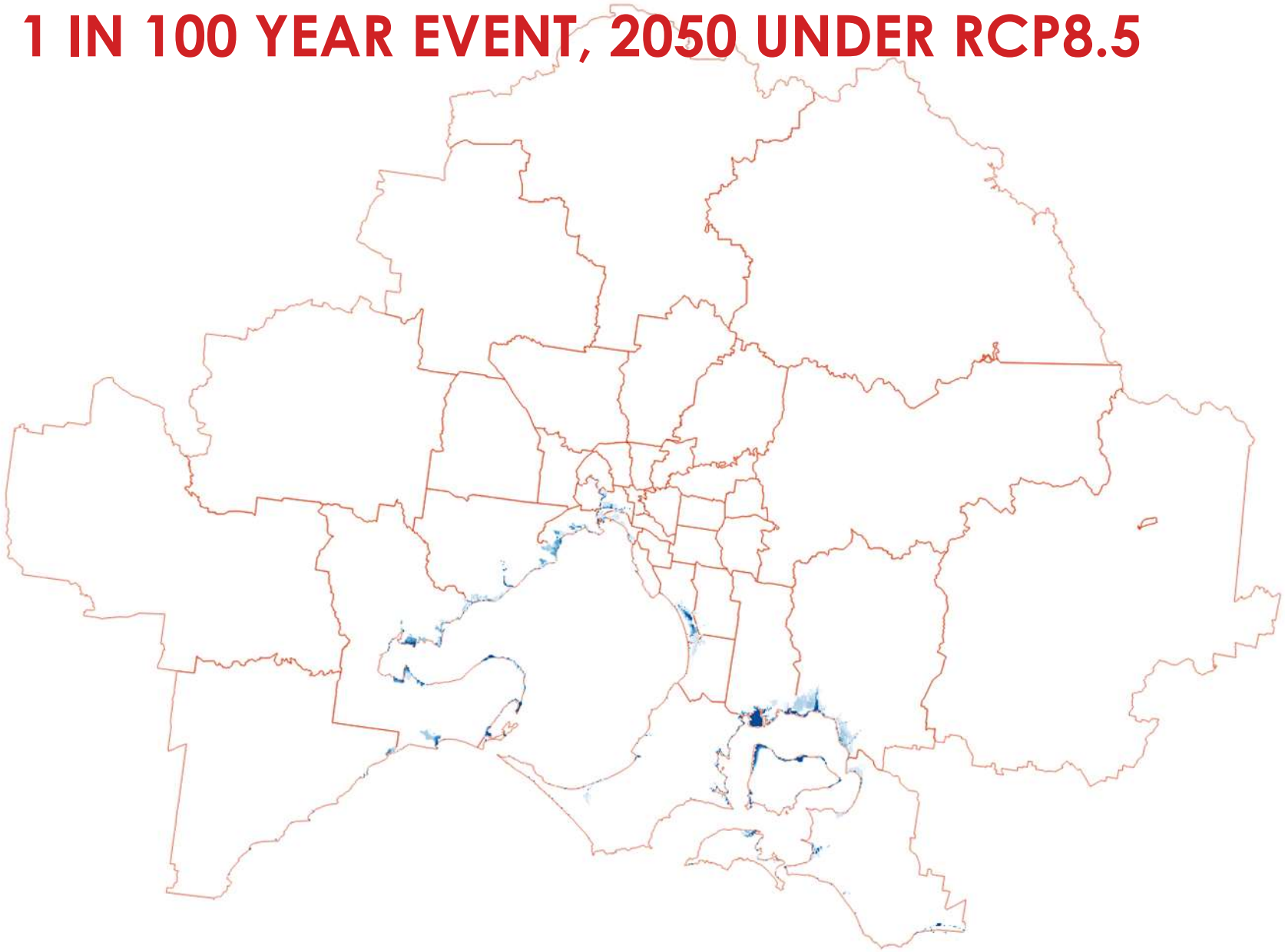
MODELLER INTERFACE COASTAL INUNDATION



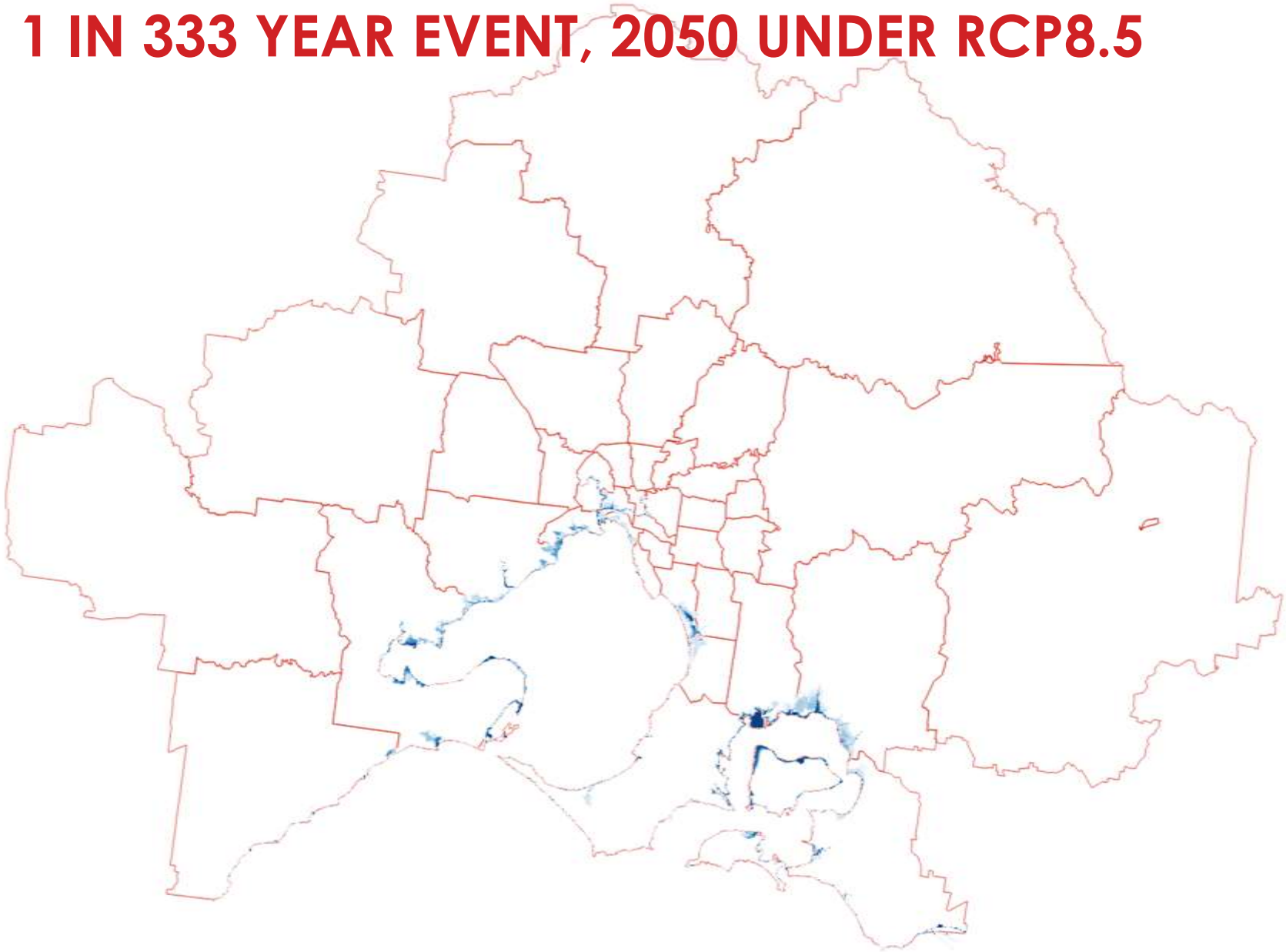
1 IN 100 YEAR EVENT, CURRENT CONDITIONS



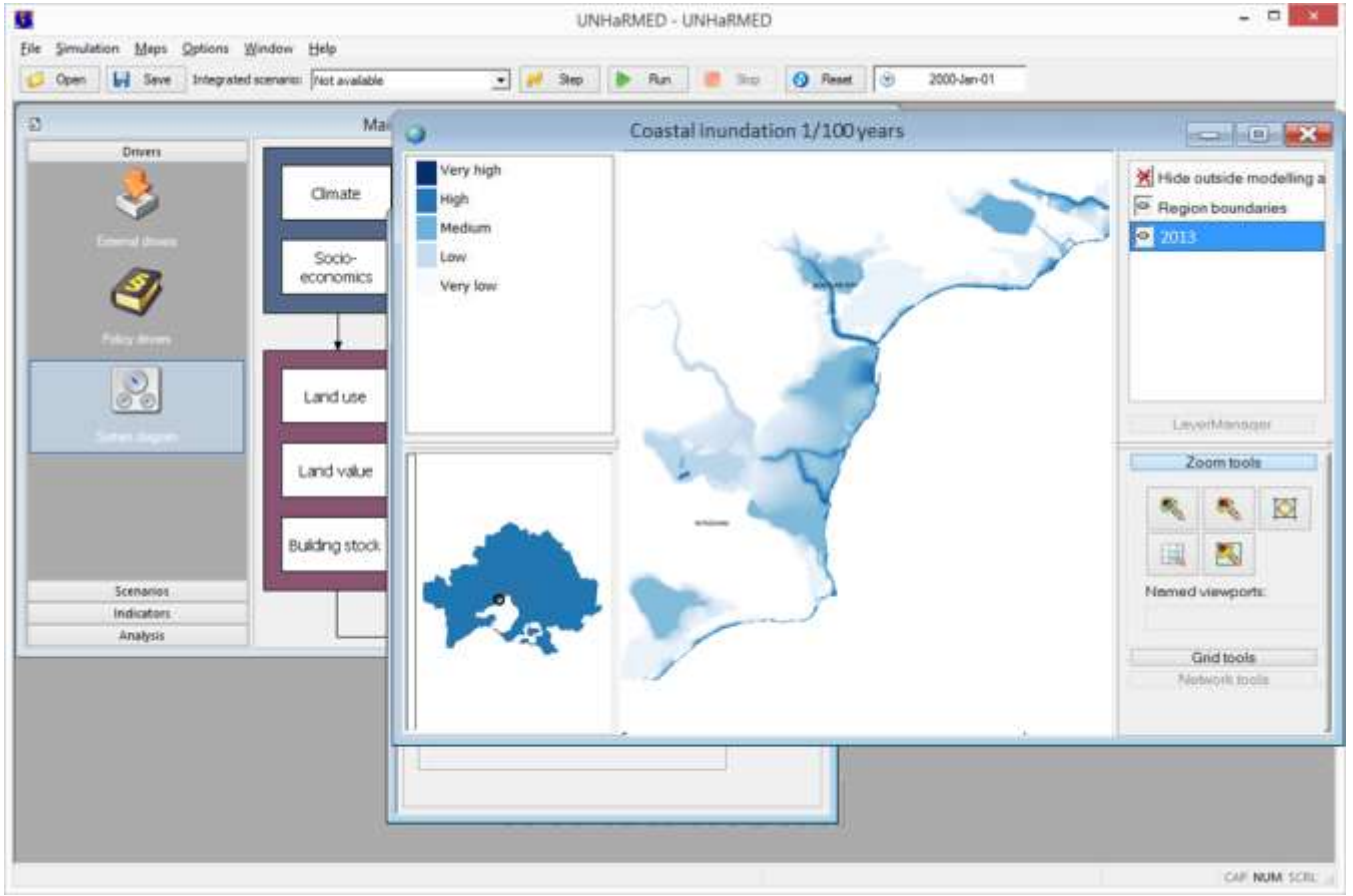
1 IN 100 YEAR EVENT, 2050 UNDER RCP8.5



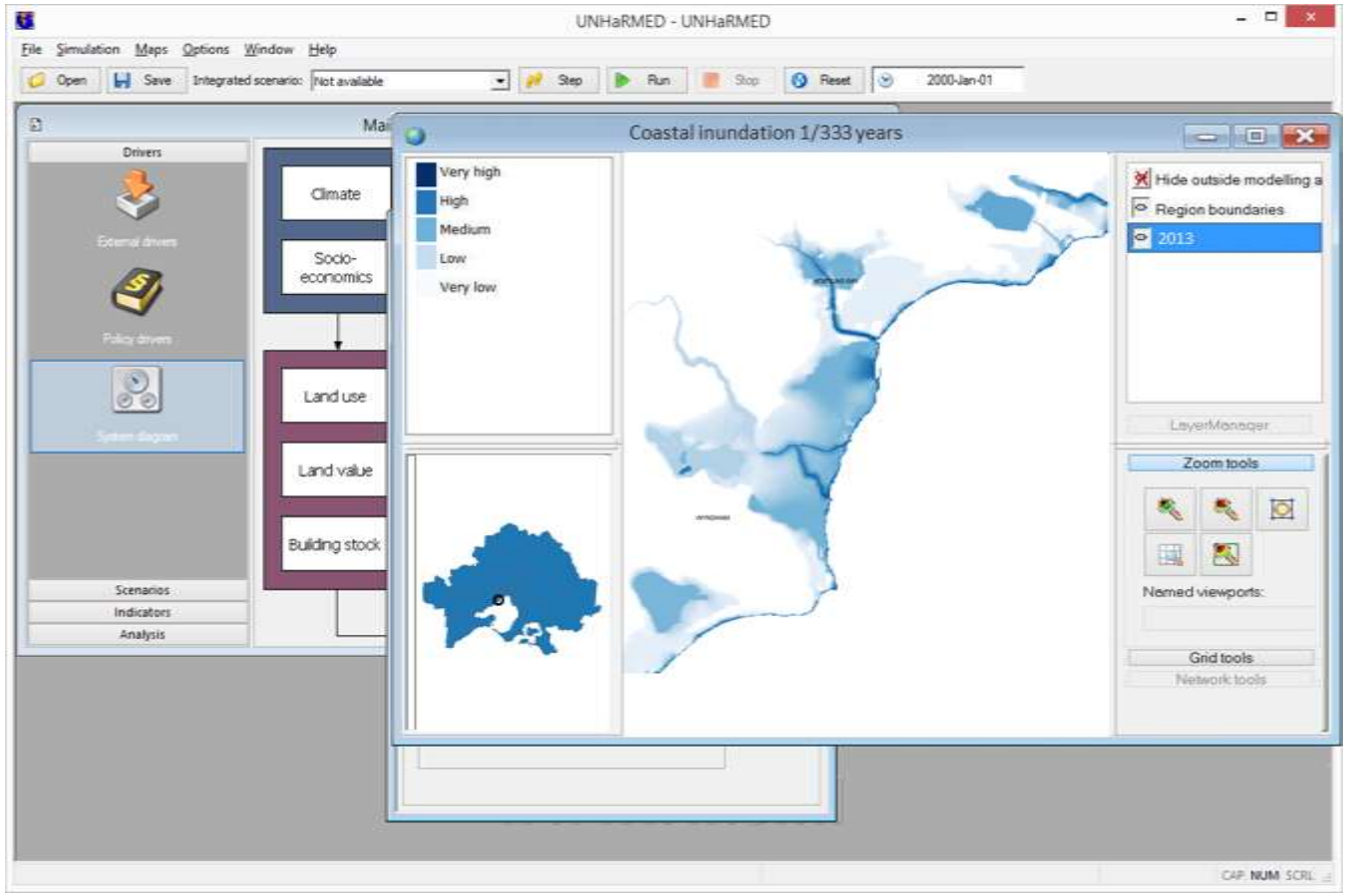
1 IN 333 YEAR EVENT, 2050 UNDER RCP8.5



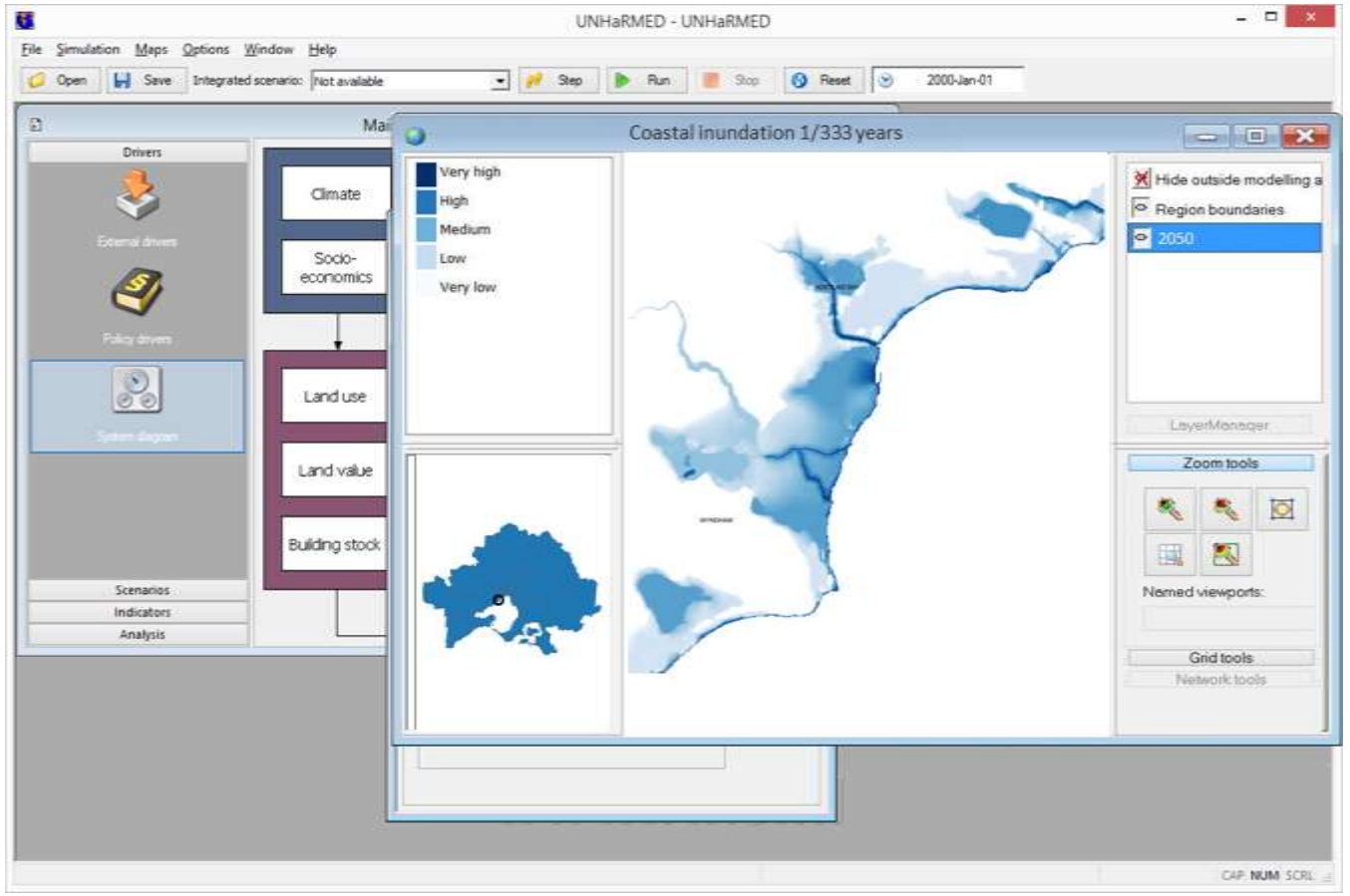
MODELLER INTERFACE COASTAL INUNDATION



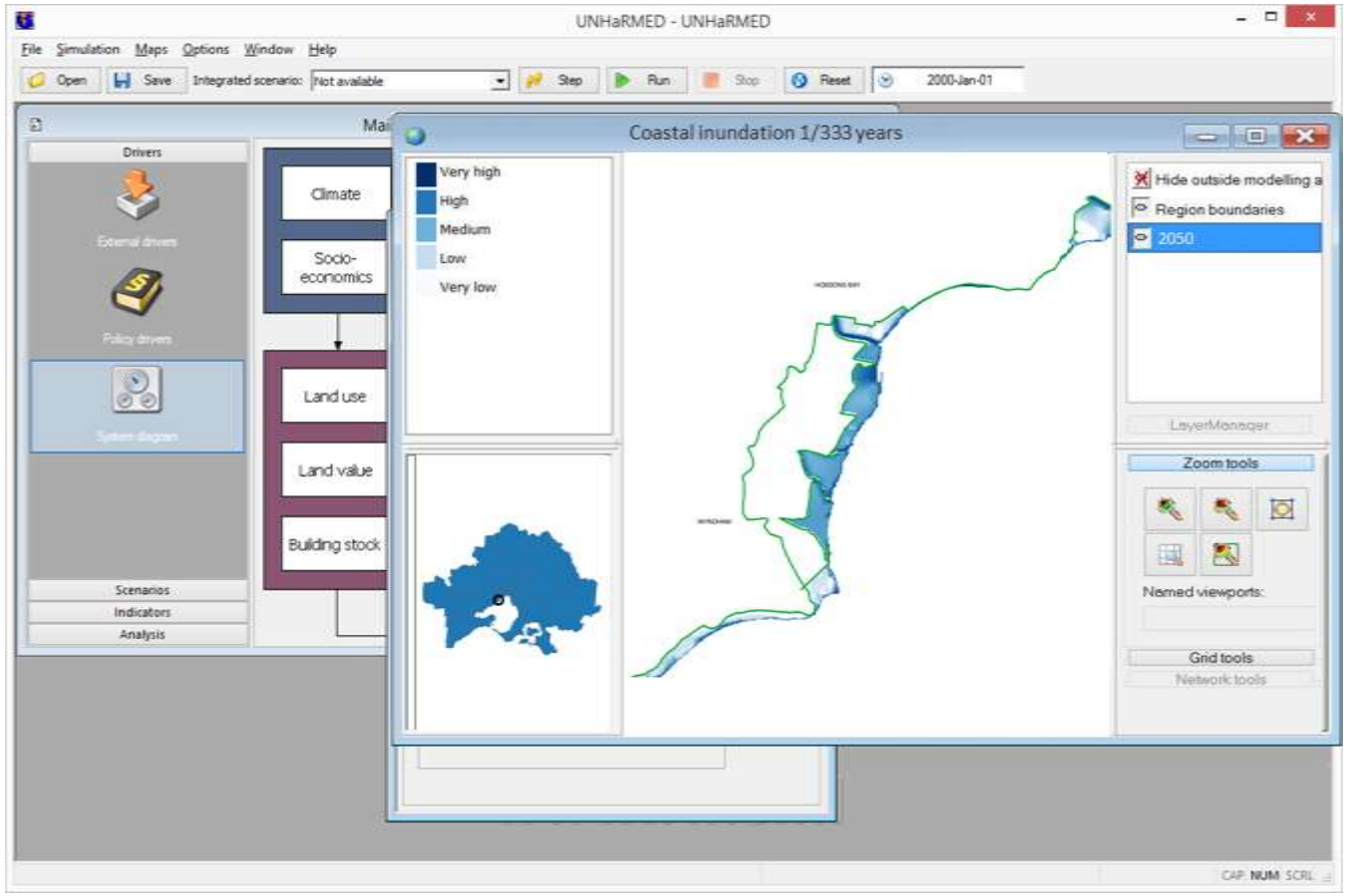
MODELLER INTERFACE COASTAL INUNDATION



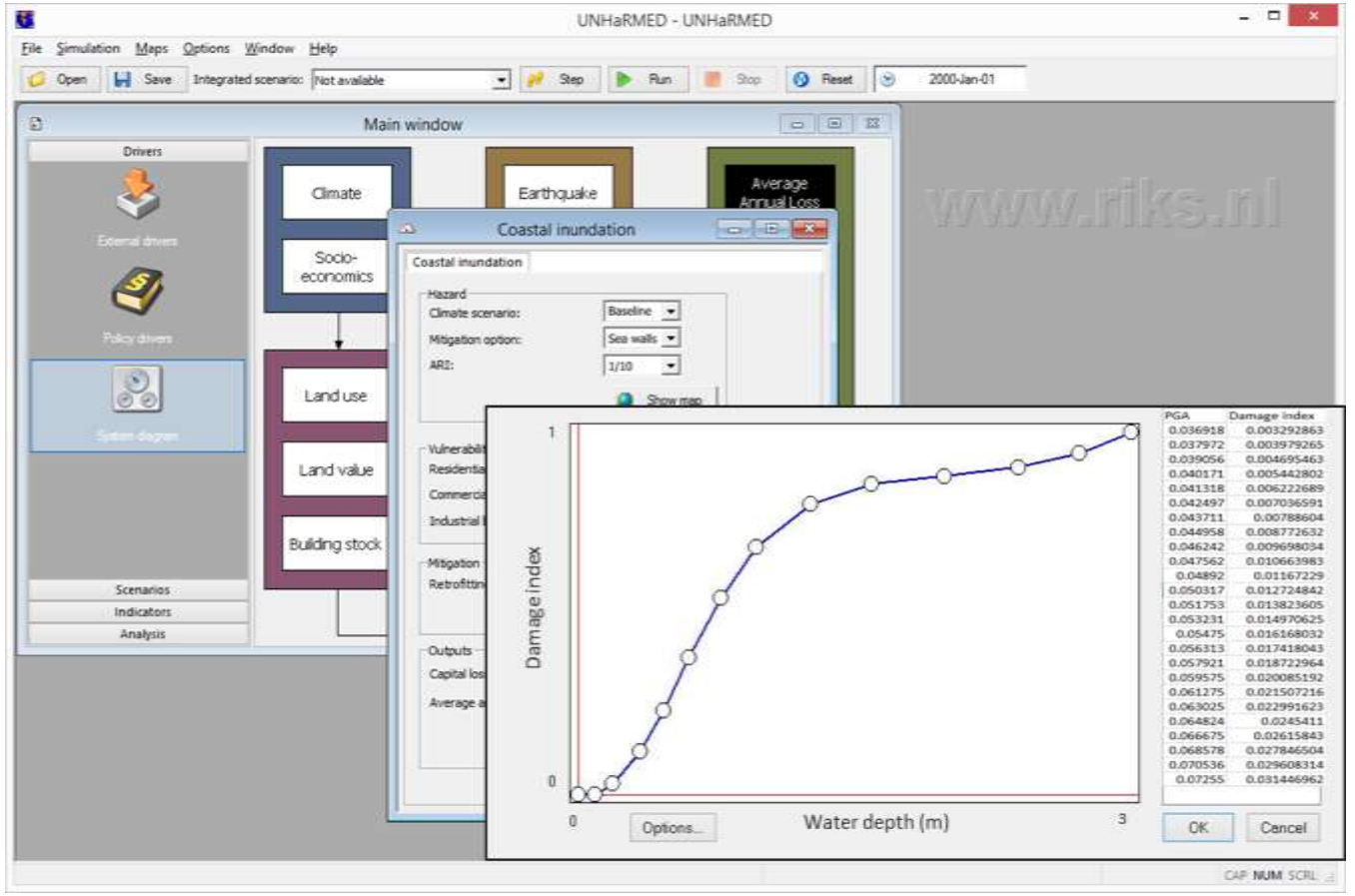
MODELLER INTERFACE COASTAL INUNDATION

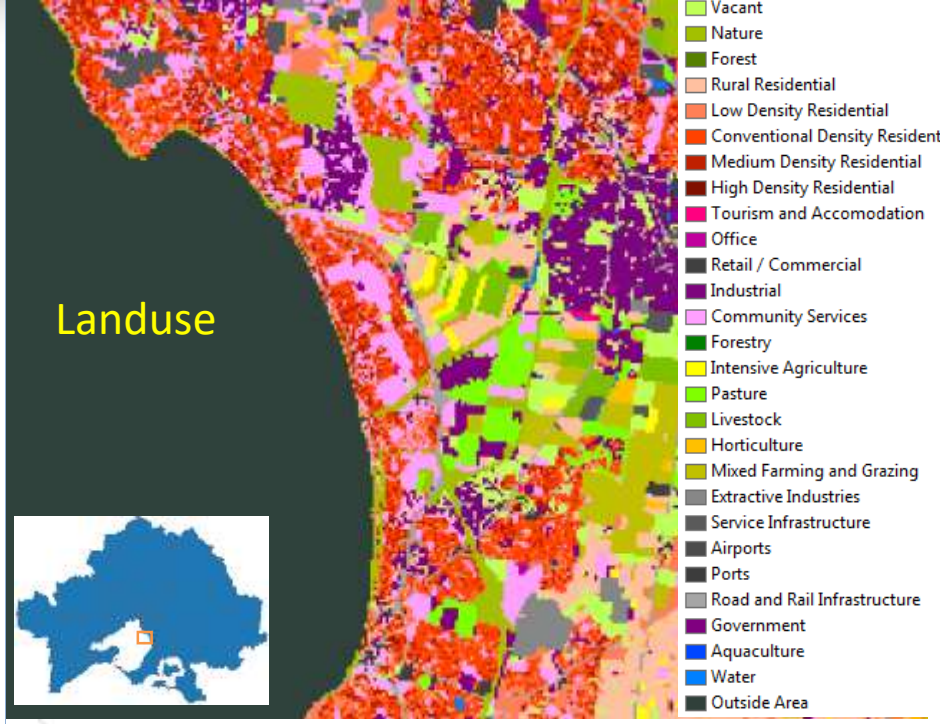


MODELLER INTERFACE COASTAL INUNDATION



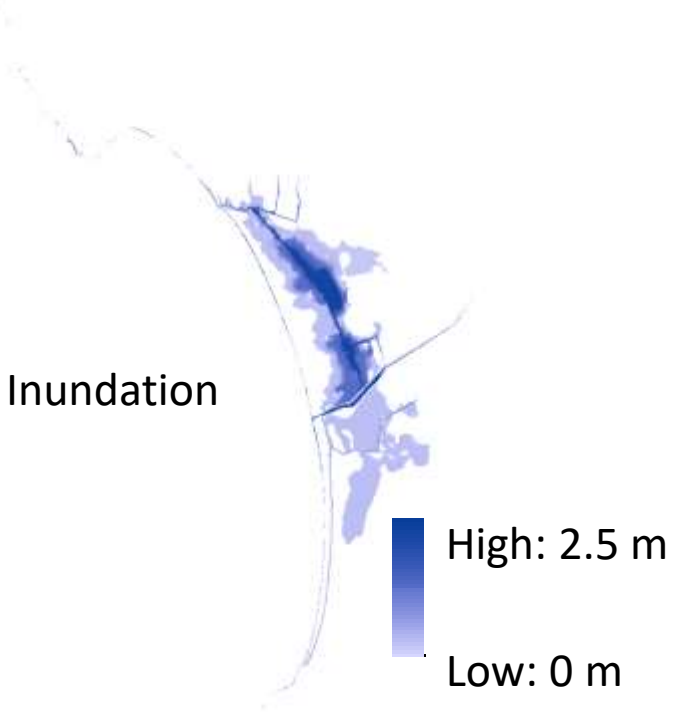
MODELLER INTERFACE COASTAL INUNDATION

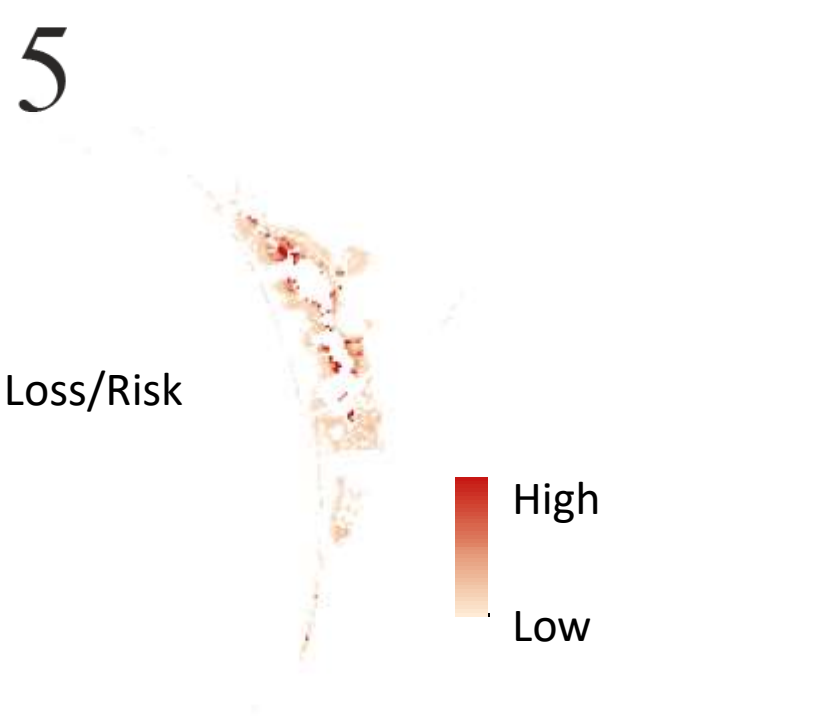


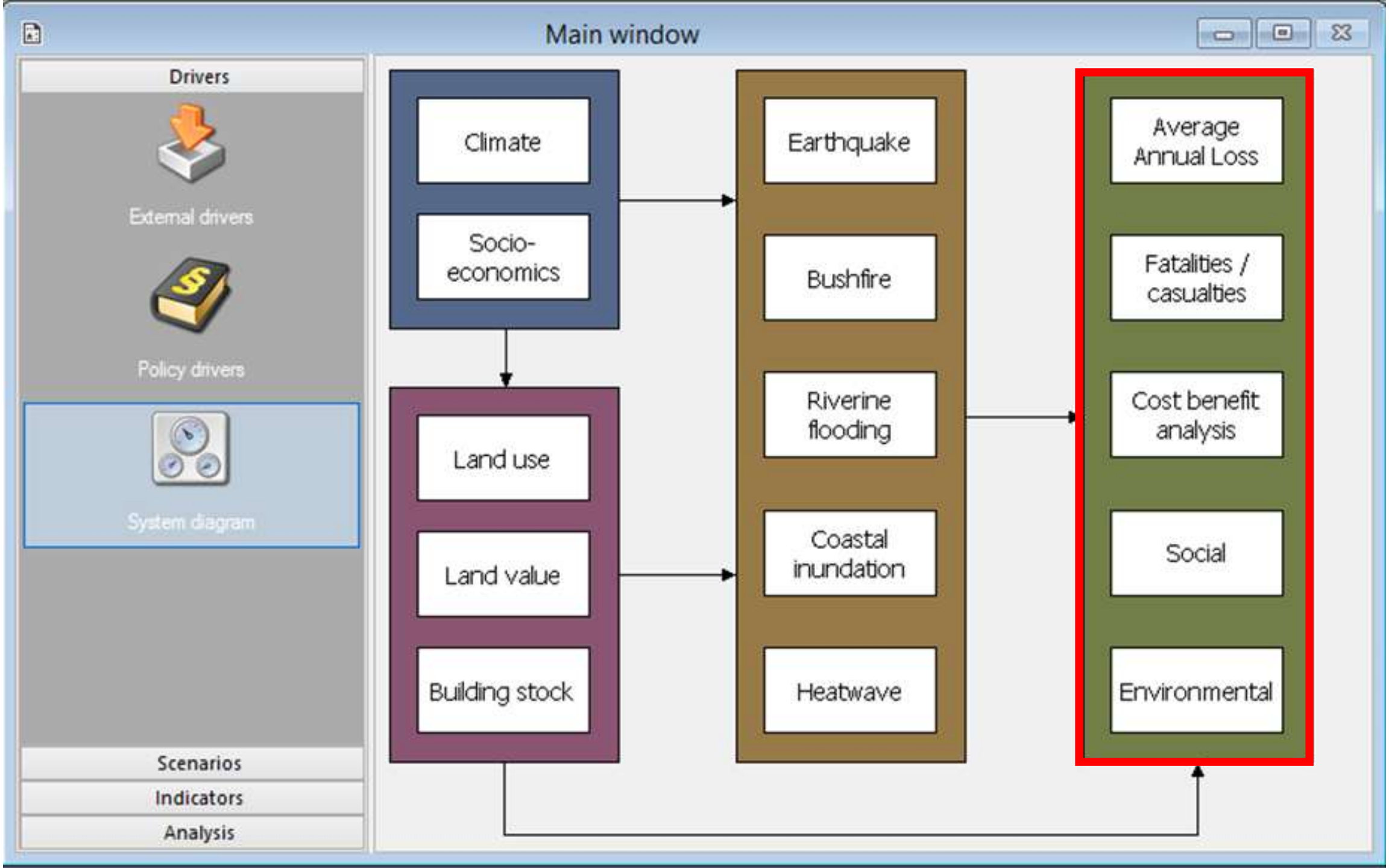

Landuse
Vacant
Nature
Forest
Rural Residential
Low Density Residential
Conventional Density Residential
Medium Density Residential
High Density Residential
Tourism and Accomodation
Office
Retail / Commercial
Industrial
Community Services
Forestry
Intensive Agriculture
Pasture
Livestock
Horticulture
Mixed Farming and Grazing
Extractive Industries
Service Infrastructure
Airports
Ports
Road and Rail Infrastructure
Government
Aquaculture
Water
Outside Area

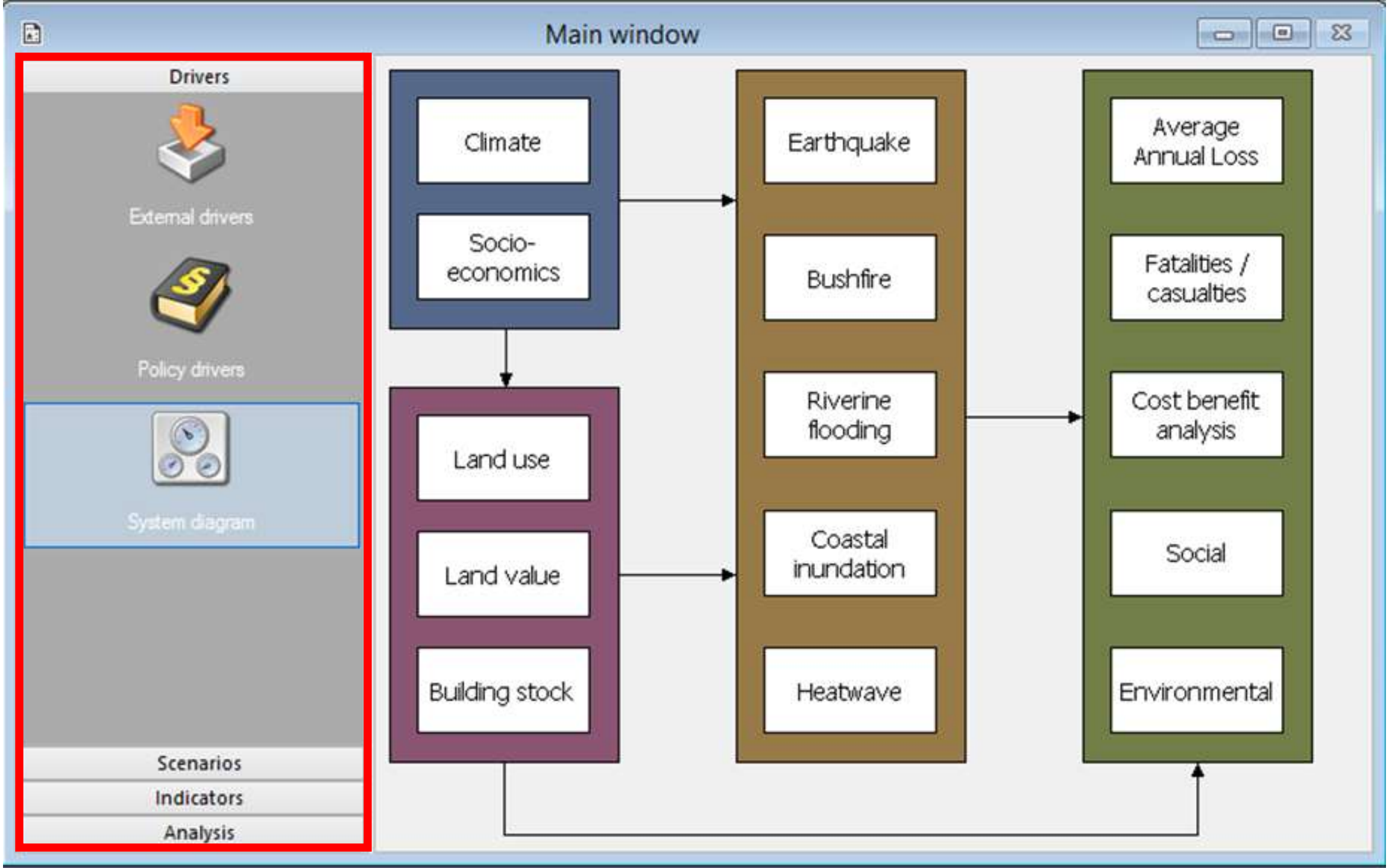

Building value
High
Low

2015


Inundation
High: 2.5 m
Low: 0 m


Loss/Risk
High
Low


Main window
Drivers
External drivers
Policy drivers
System diagram
Scenarios
Indicators
Analysis
Climate
Socio-economics
Land use
Land value
Building stock
Earthquake
Bushfire
Riverine flooding
Coastal inundation
Heatwave
Average Annual Loss
Fatalities / casualties
Cost benefit analysis
Social
Environmental


Main window
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Average Annual Loss
Fatalities / casualties
Cost benefit analysis
Social
Environmental

Collaborative approach

Collaborative approach

Development Process

Use Process

BENEFITS OF PROPOSED APPROACH

End users involved in:

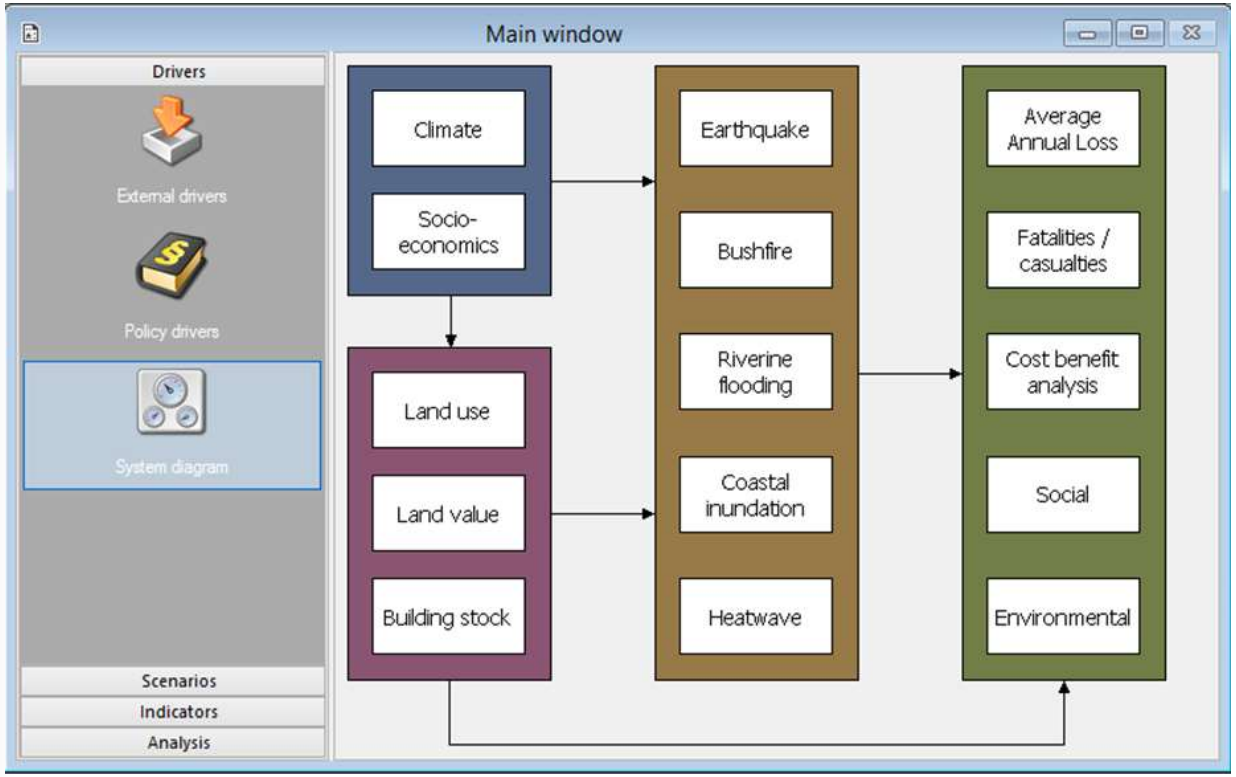
- Model development & selection
- User interface design
- Scenario development
- Policy assessment & planning

Social learning occurs when stakeholders, modellers and facilitators explore and evaluate policy options through group interaction with the DSS

Builds strategic capacity by exploring future risk profiles

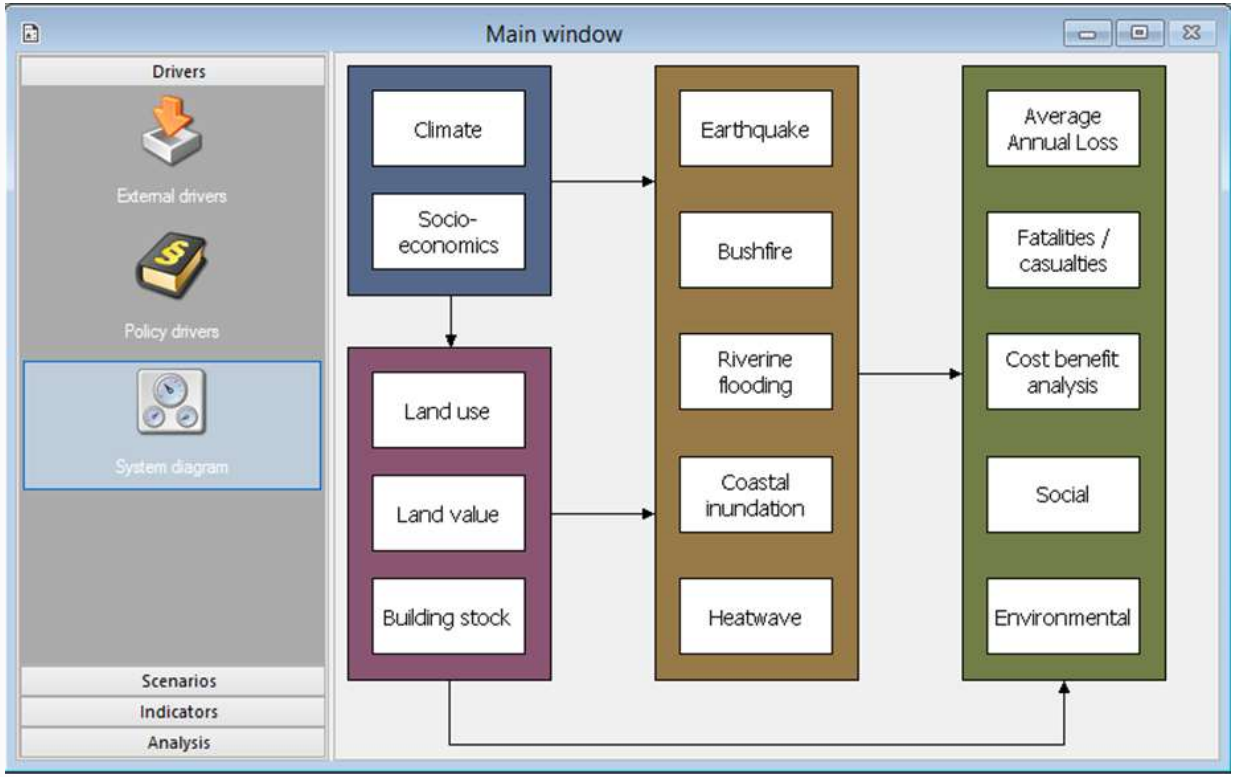
Looks towards integration of system within organisations

BENEFITS OF PROPOSED APPROACH



- Flexibility / Customisation
  - Policy / risk-reduction options
  - Hazards (e.g. single- or multi-hazard)
  - Spatial extent
  - Temporal scale (e.g. short- or long-term)
  - Outputs / indicators

EXPECTED OUTCOMES

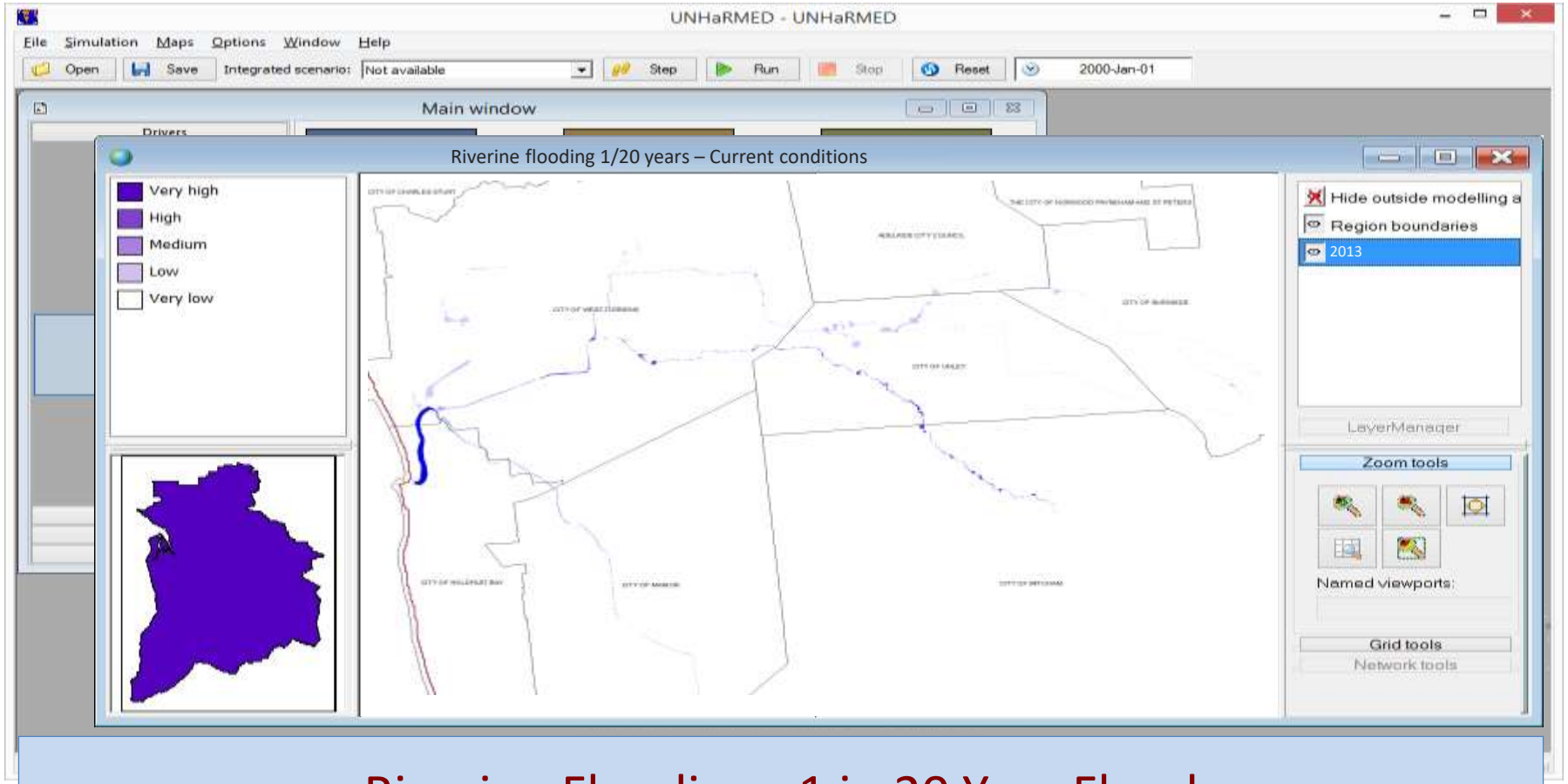


- Best-practice approach to identification of outcomes that represent value of money
  - Evidence-based decision-making
  - Increased transparency, efficiency and effectiveness in decision-making processes
- Development of shared understanding of risks, how they interact and what can be done about them
- Understanding of relative importance of different factors in specific decision contexts
- Development of flexible, adaptable pathways to reducing disaster risk

EXAMPLE APPLICATIONS

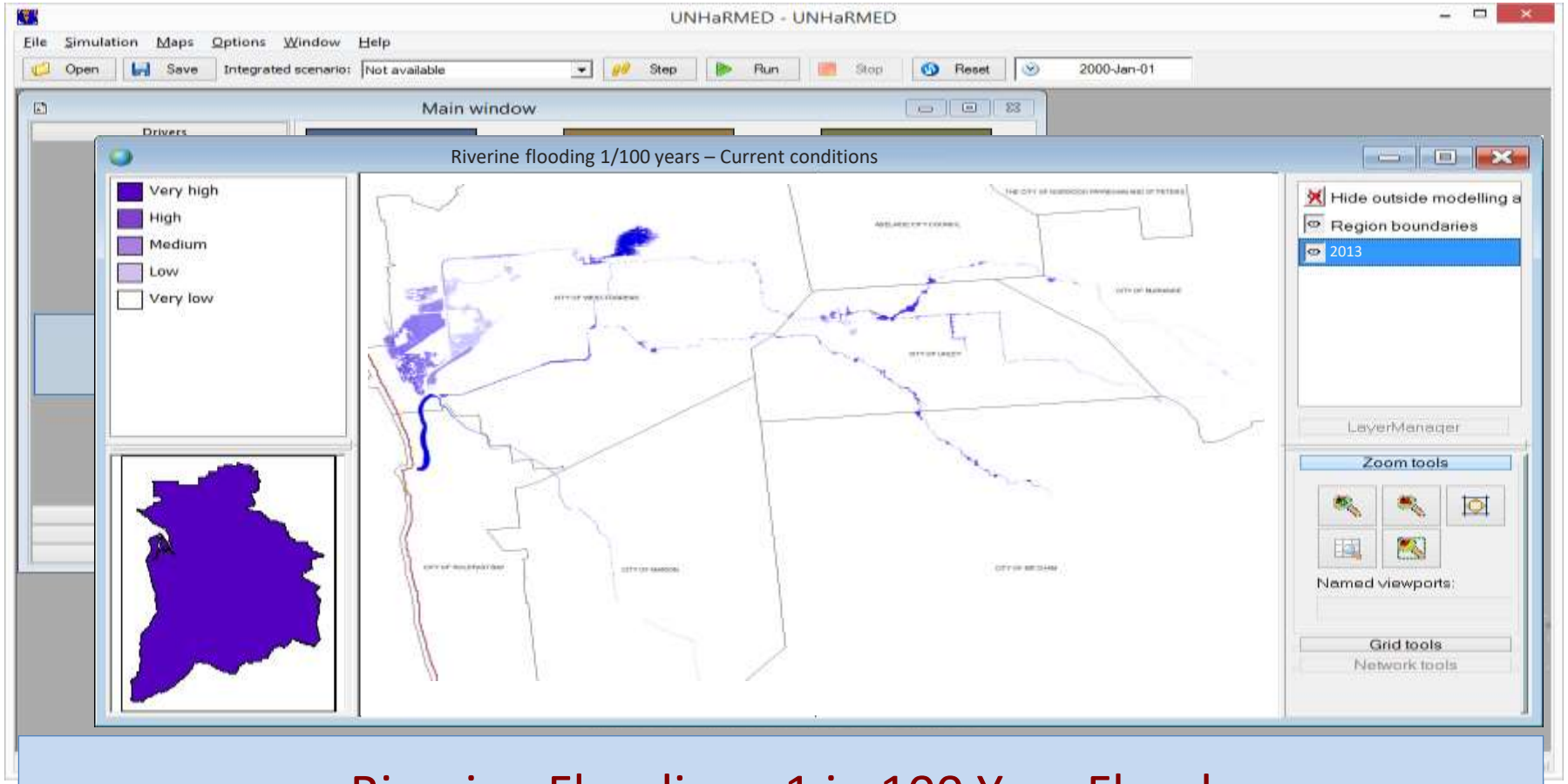
HAZARD

What is the likely magnitude and extent of a hazard?



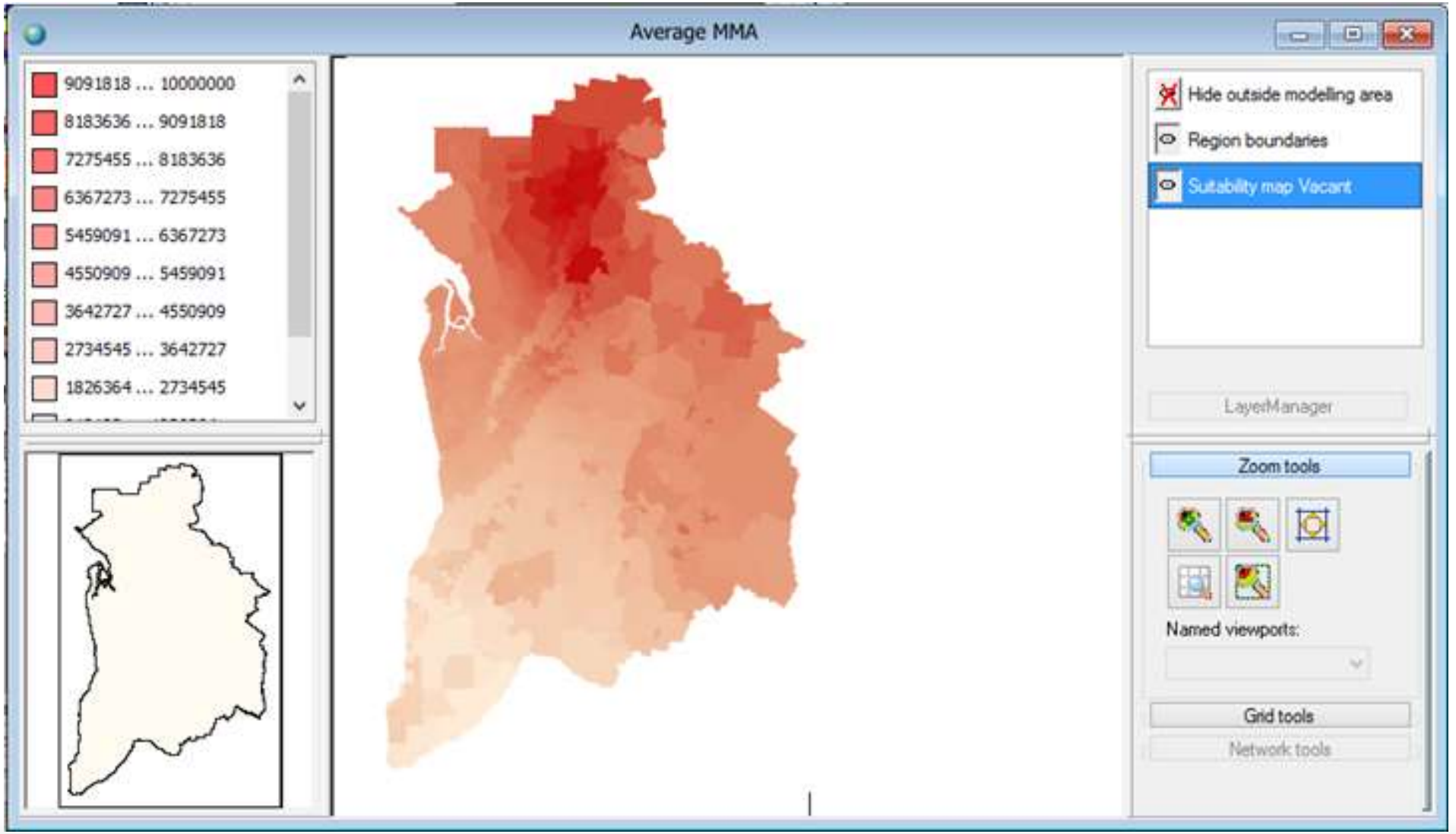
Riverine Flooding - 1 in 20 Year Flood

What is the likely magnitude and extent of a hazard?

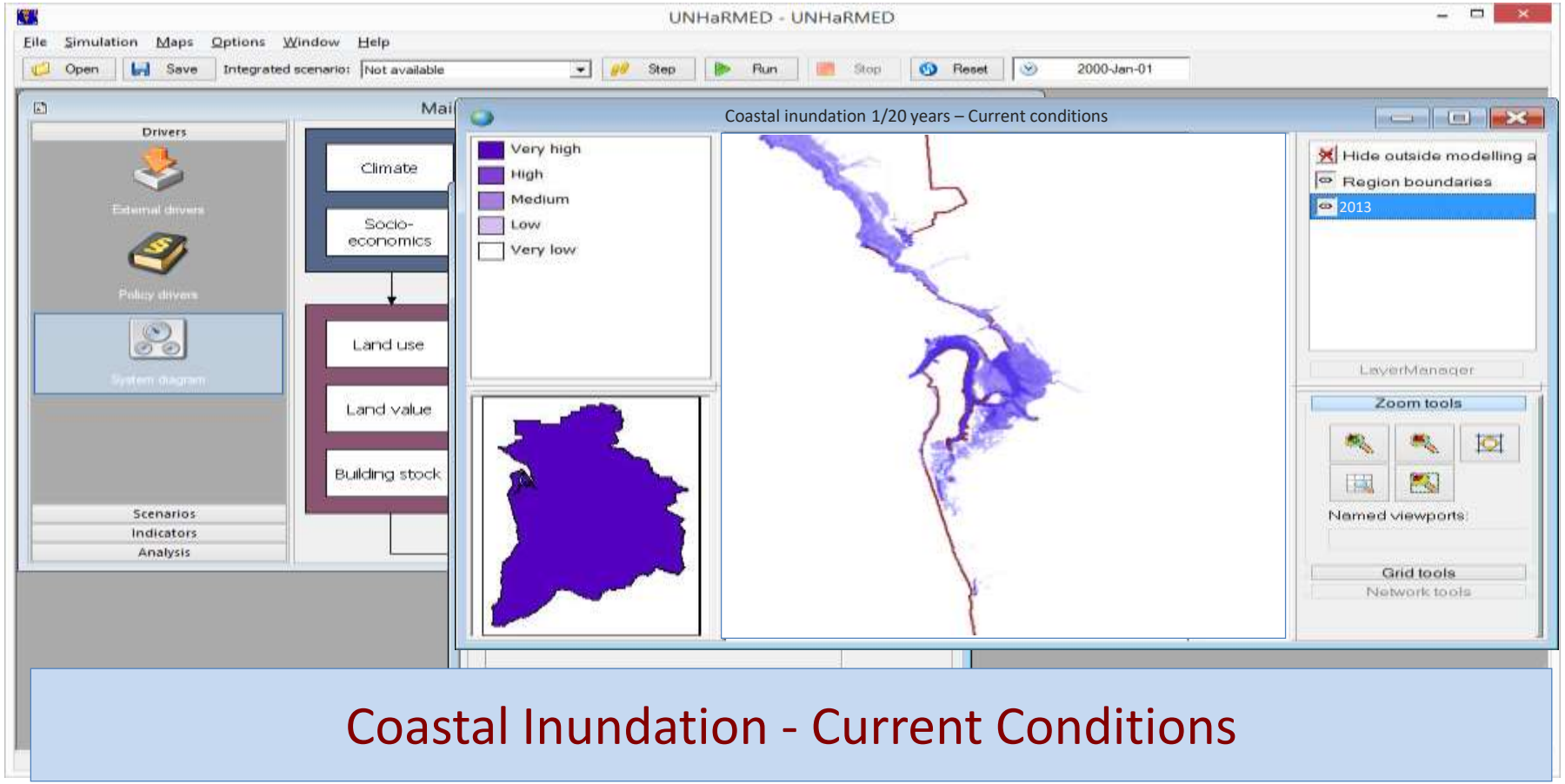


Riverine Flooding - 1 in 100 Year Flood

What is the likely magnitude and extent of a hazard?

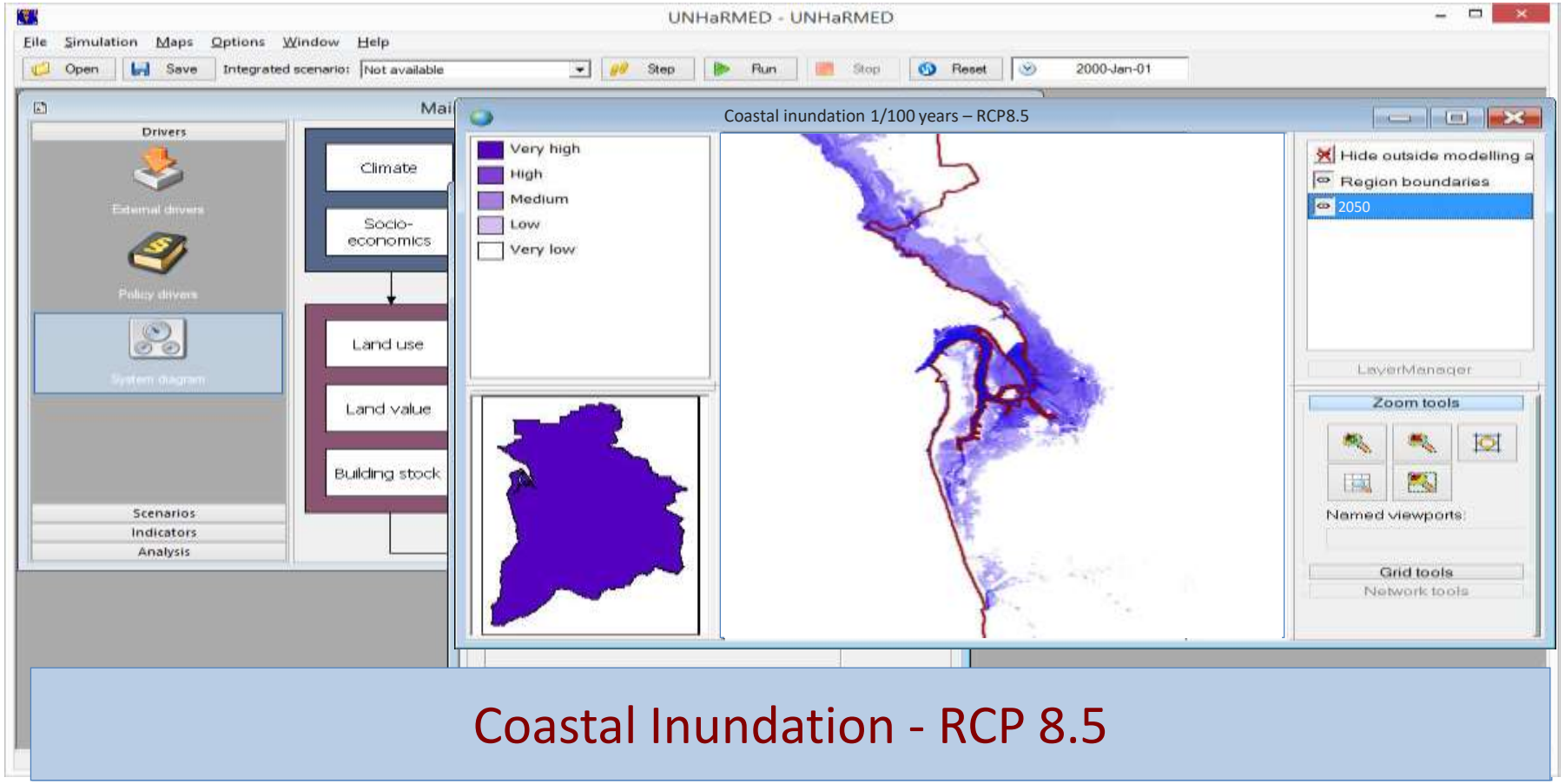


What is the impact of climate change on a hazard?



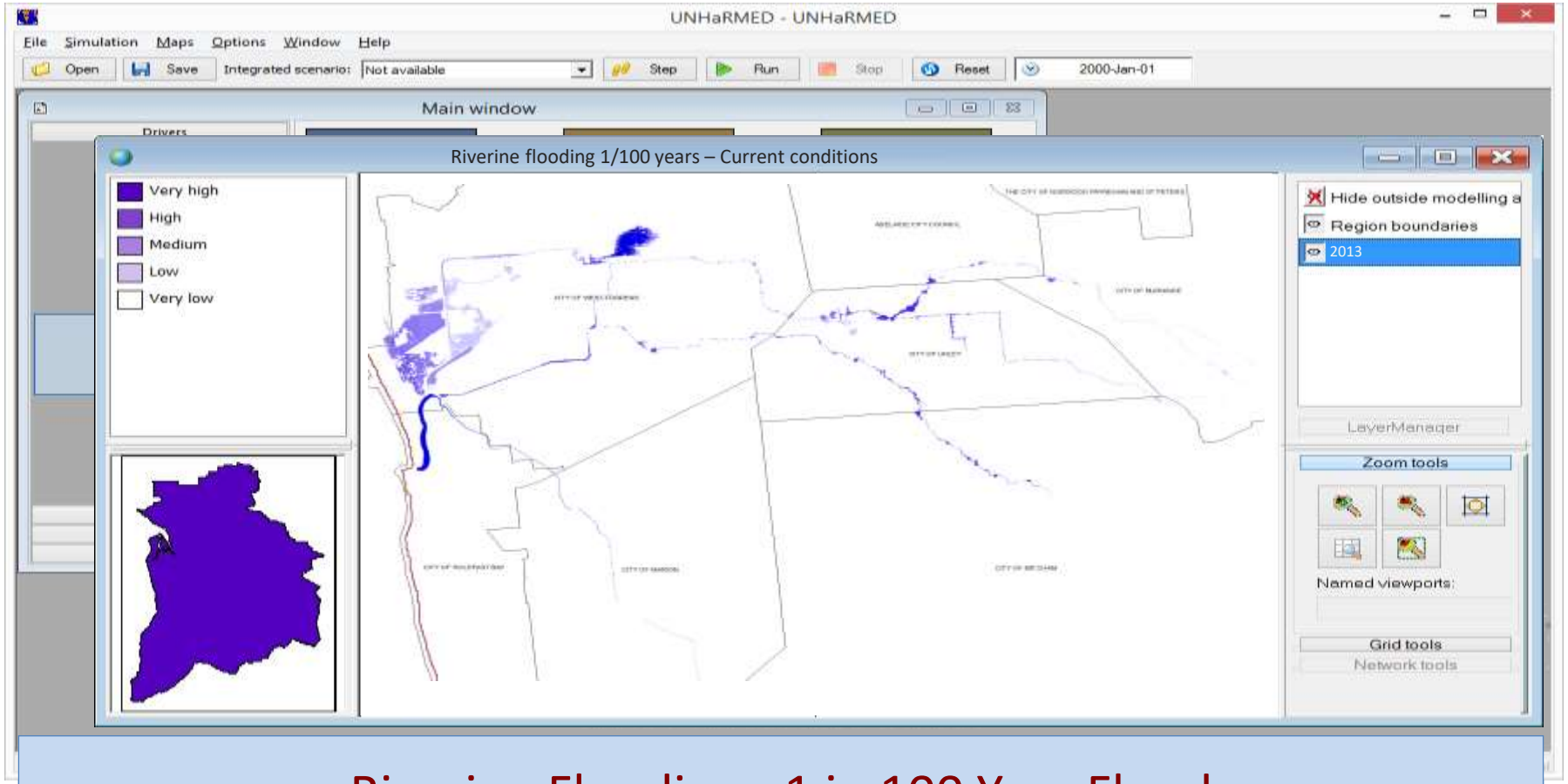
Coastal Inundation - Current Conditions

What is the impact of climate change on a hazard?



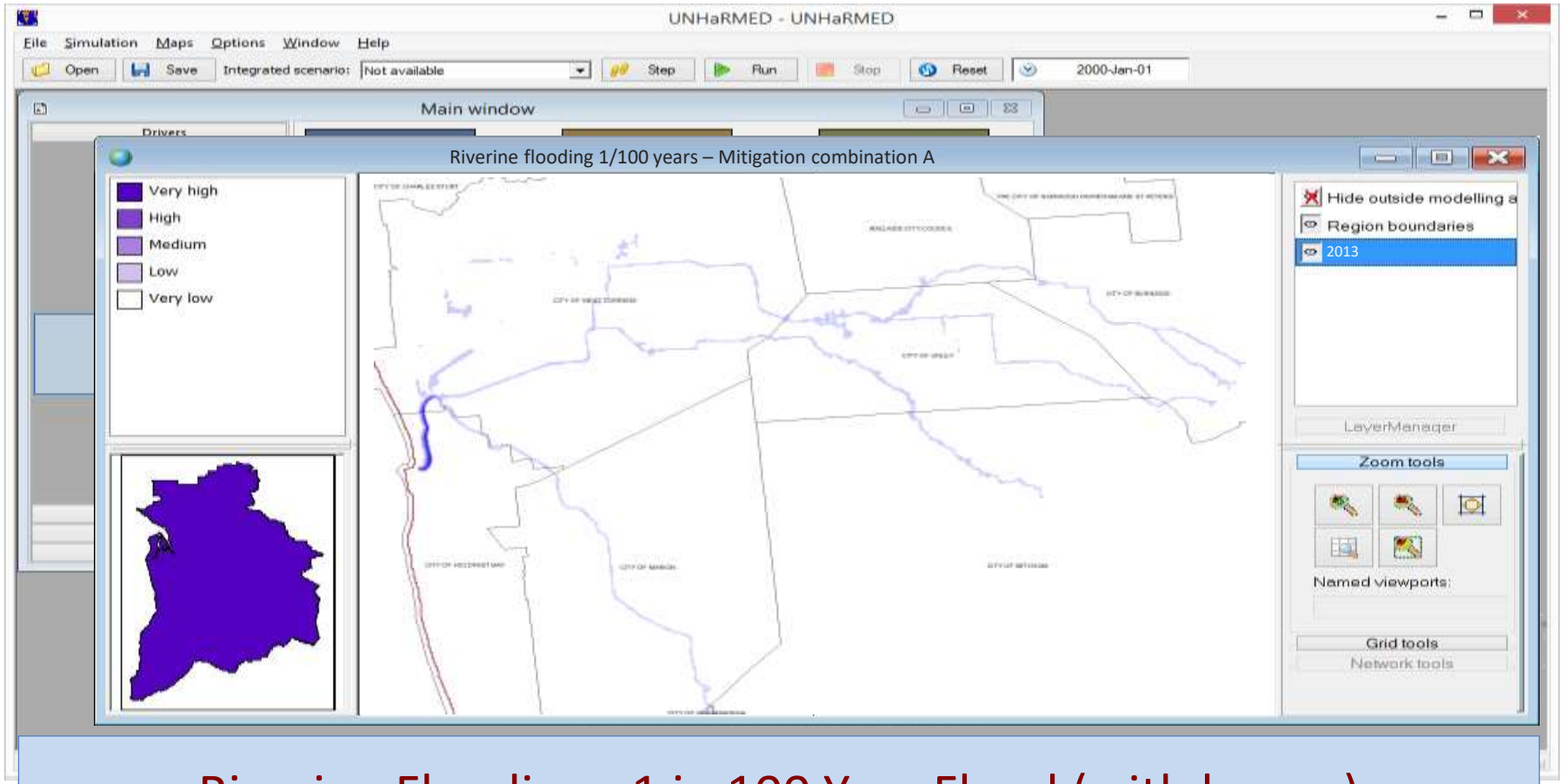
Coastal Inundation - RCP 8.5

What is the impact of mitigation on a hazard?



Riverine Flooding - 1 in 100 Year Flood

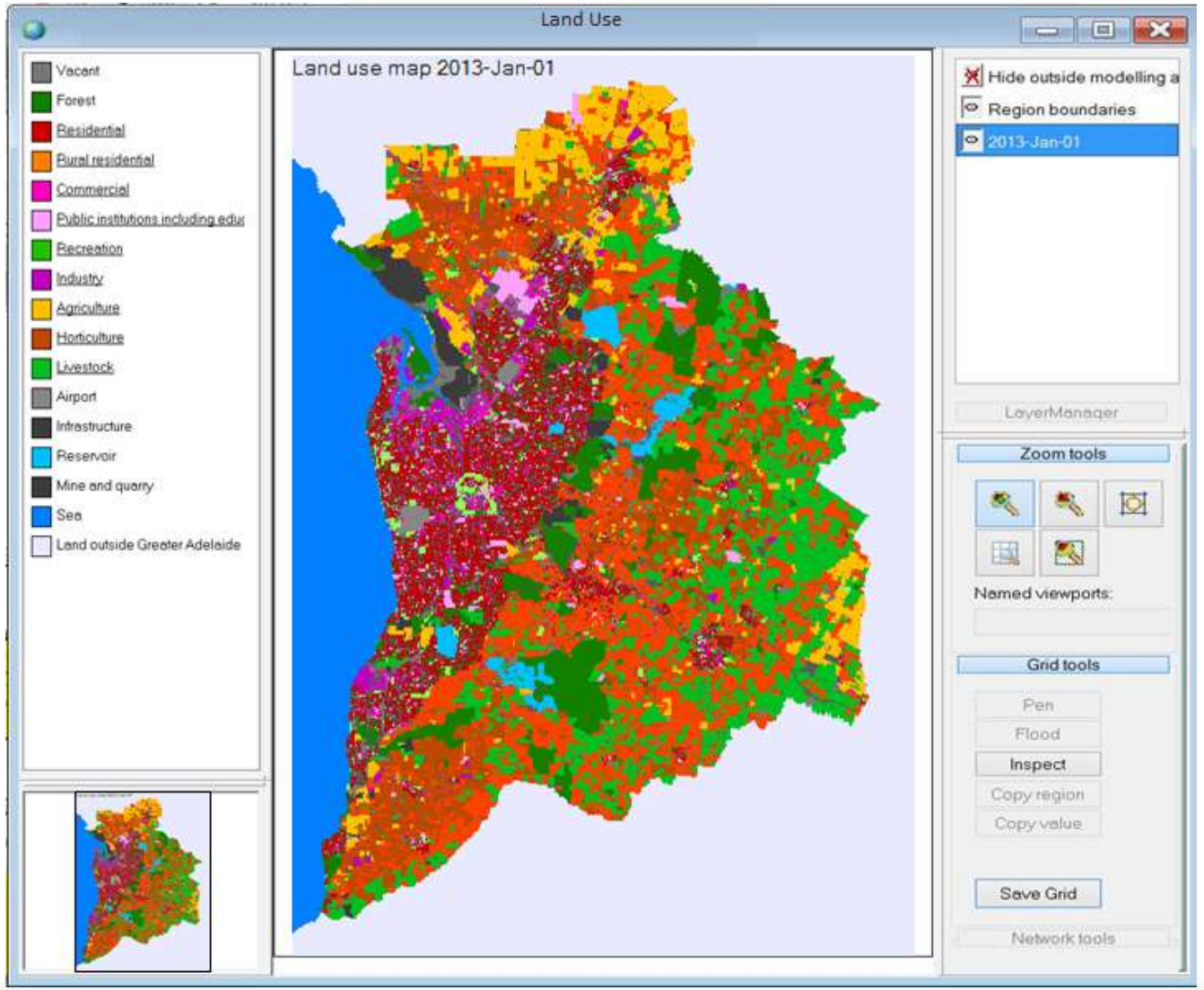
What is the impact of mitigation on a hazard?



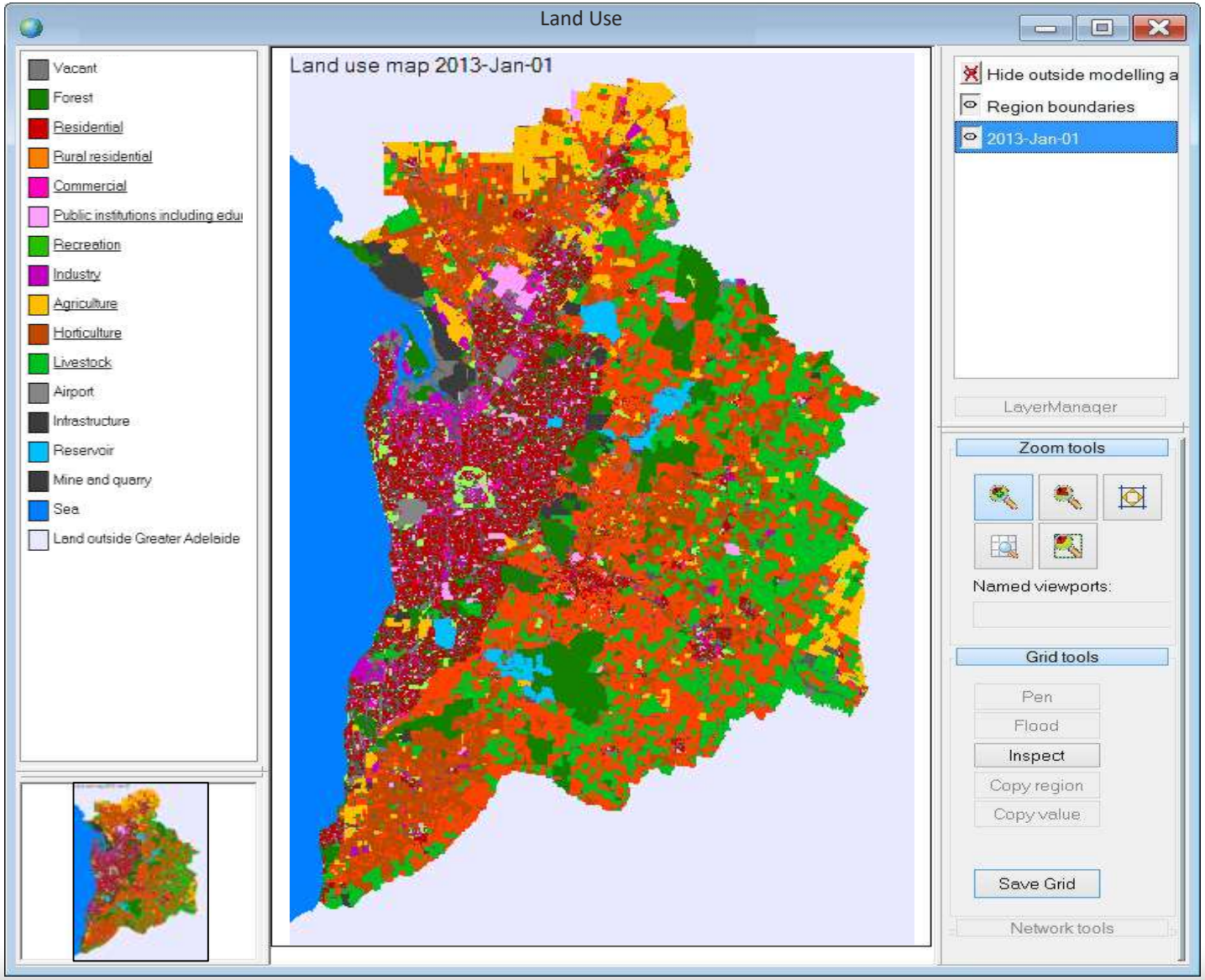
Riverine Flooding - 1 in 100 Year Flood (with levees)

EXPOSURE AND VULNERABILITY

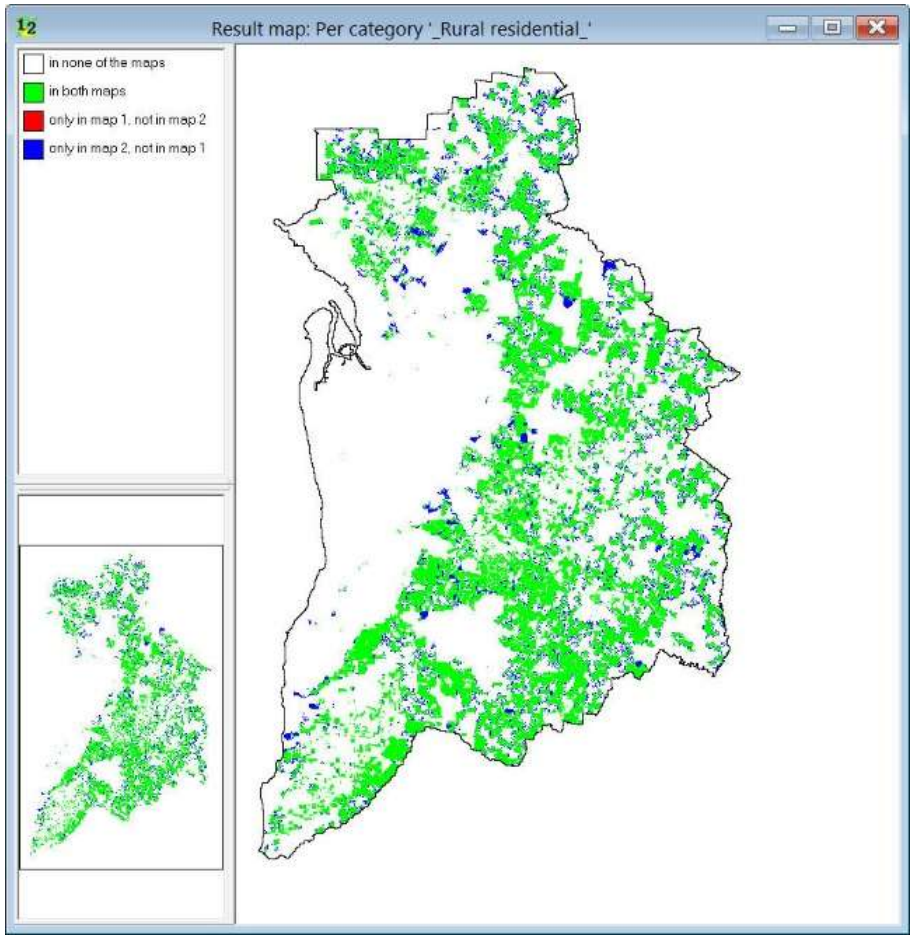
What is the current land-use?



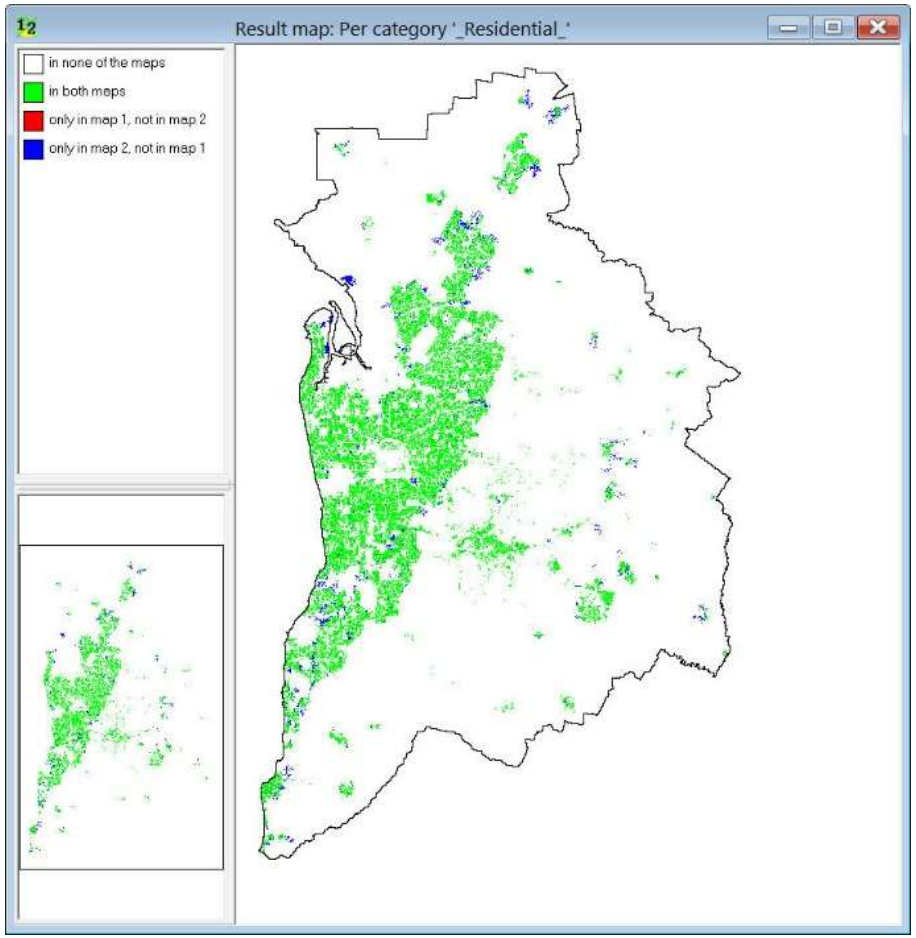
What is the future land-use?



What is the future land-use?

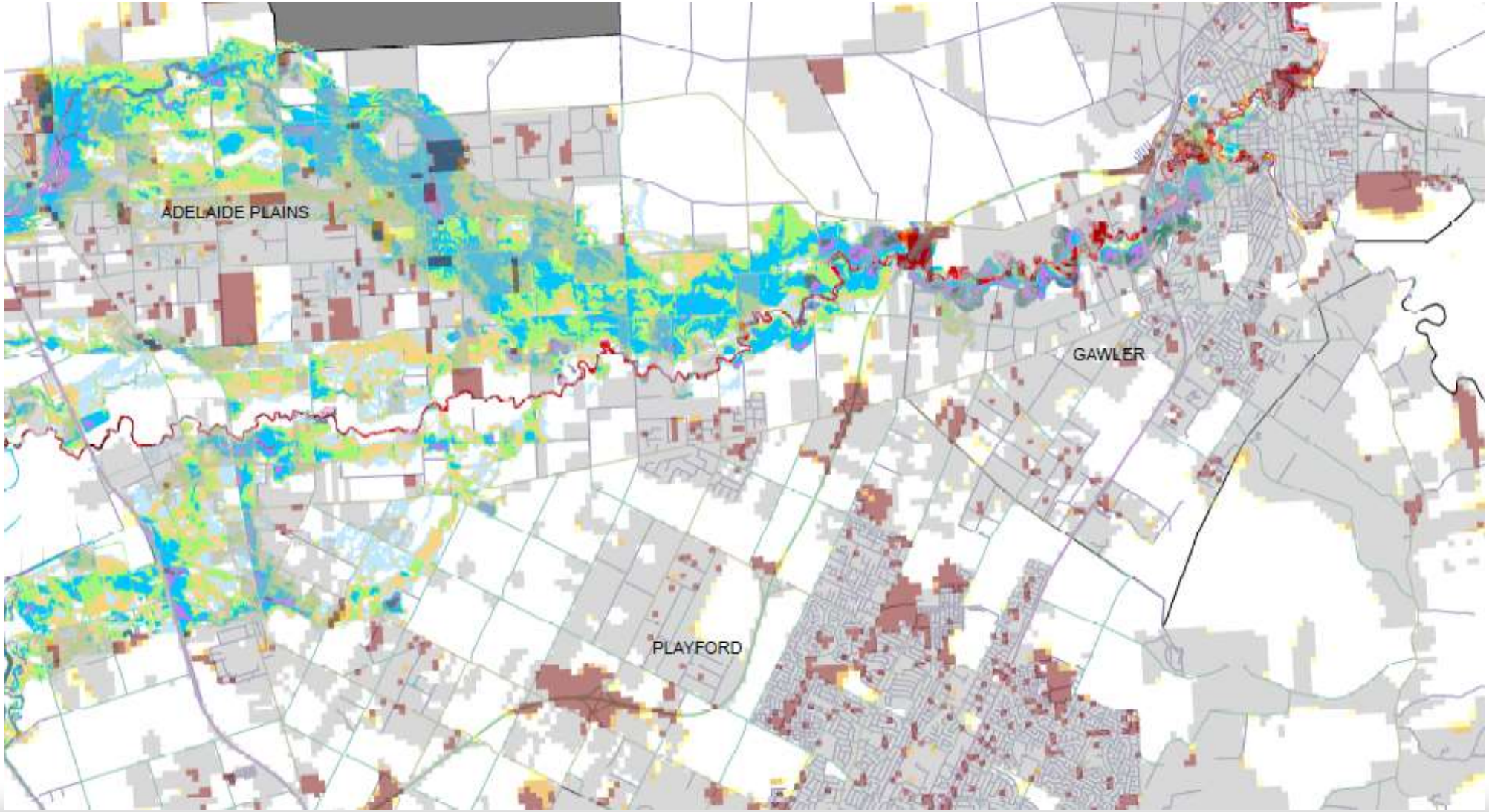


Change Map – Rural Residential



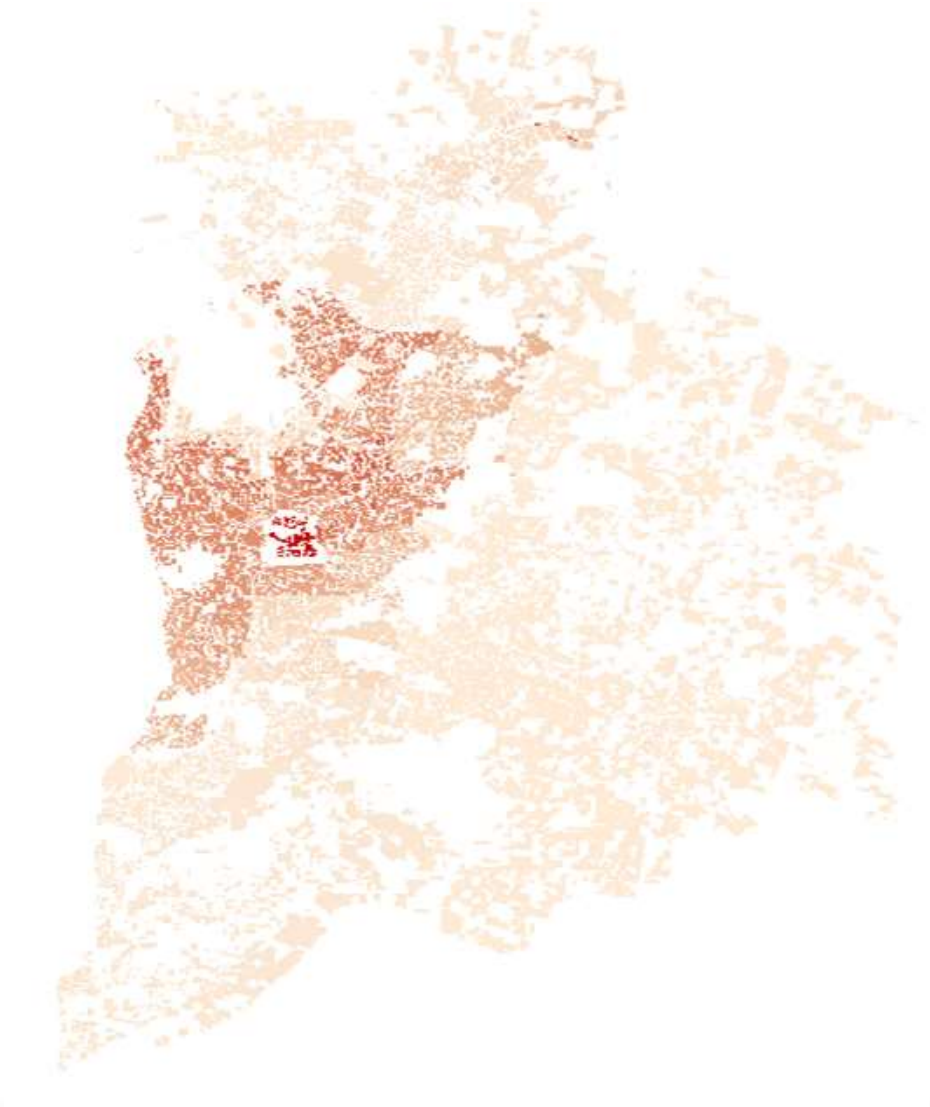
Change Map – Residential

What is the probability of urbanisation in the future?

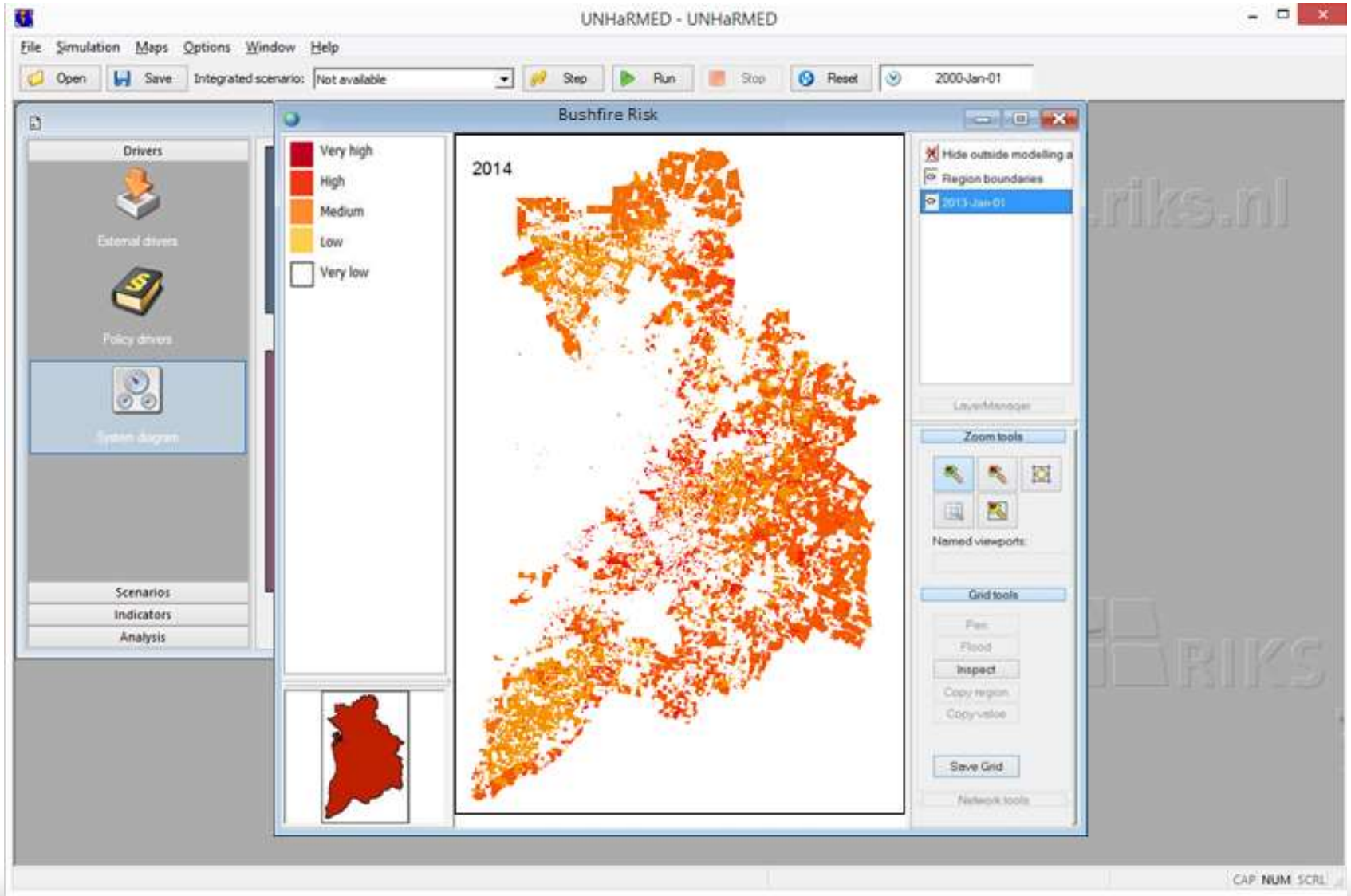


RISK

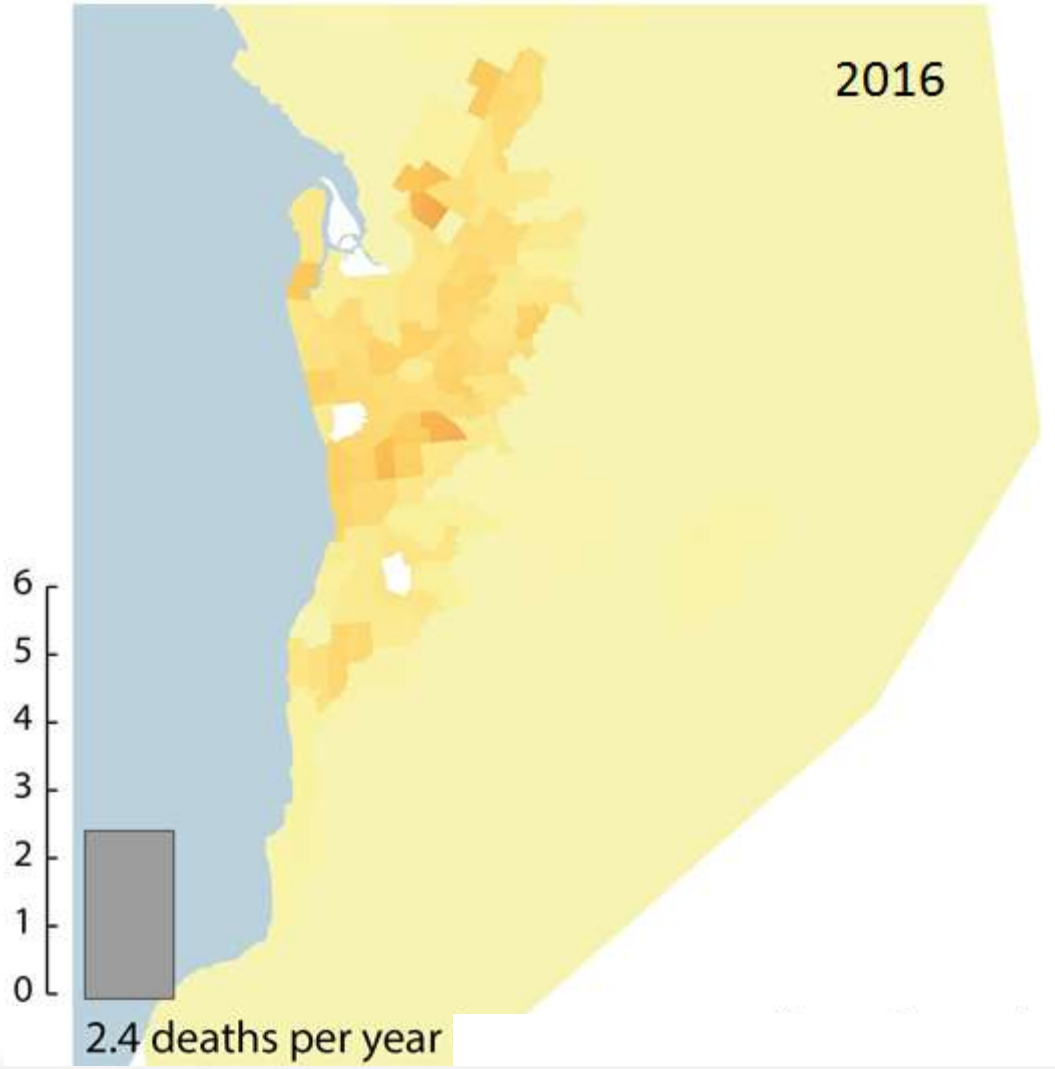
What is the current expected average annual loss from earthquake?

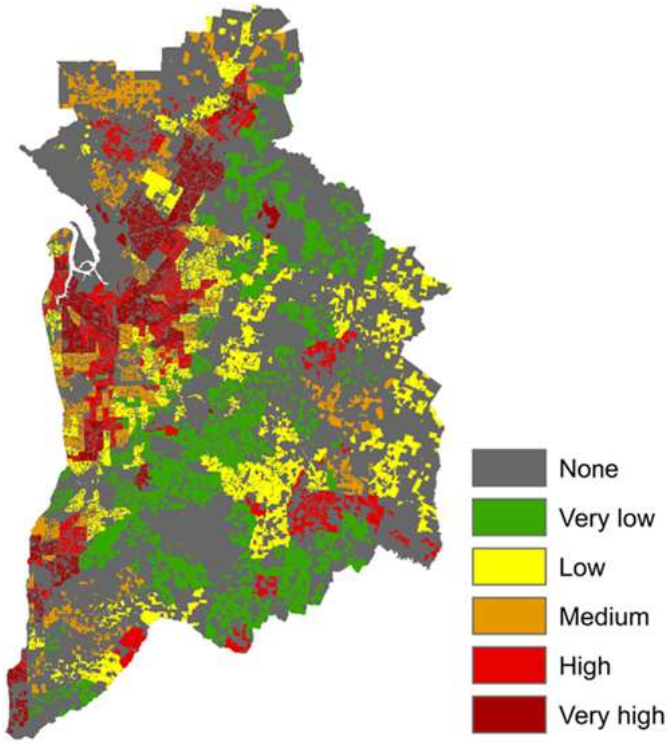


What is the current bushfire risk?



What is the current expected average annual deaths from heatwave?





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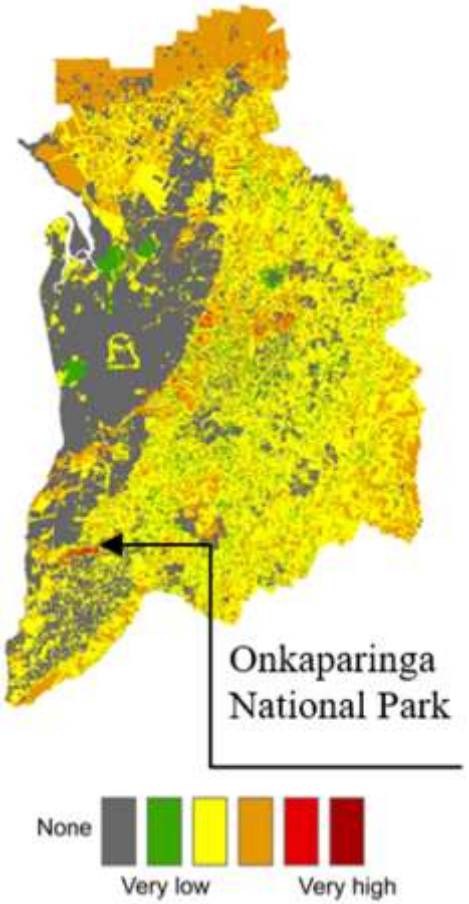

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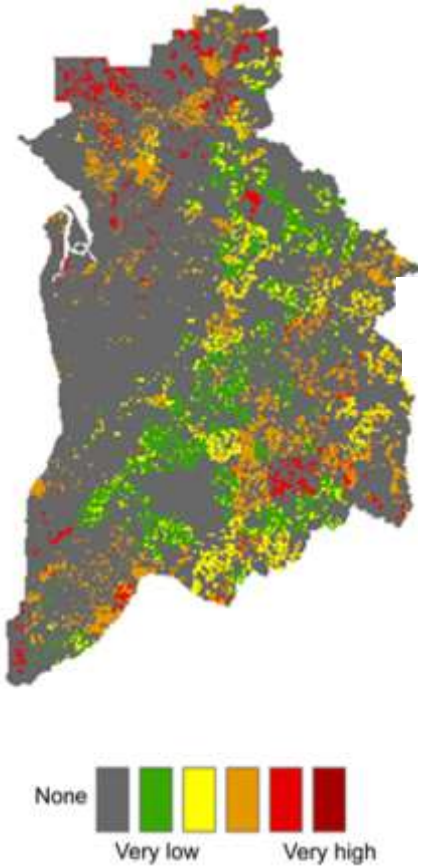
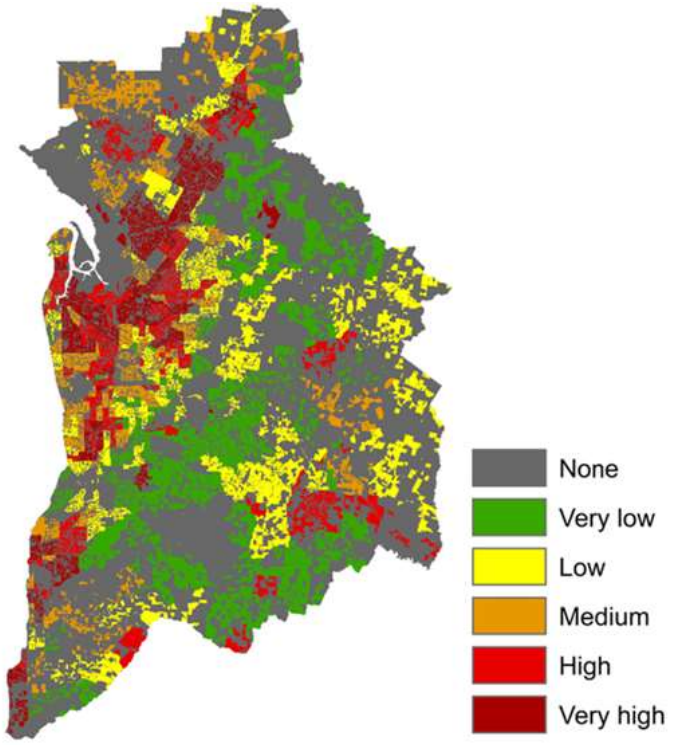


CURRENT SOCIAL VULNERABILTY

CURRENT BUSHFIRE HAZARD

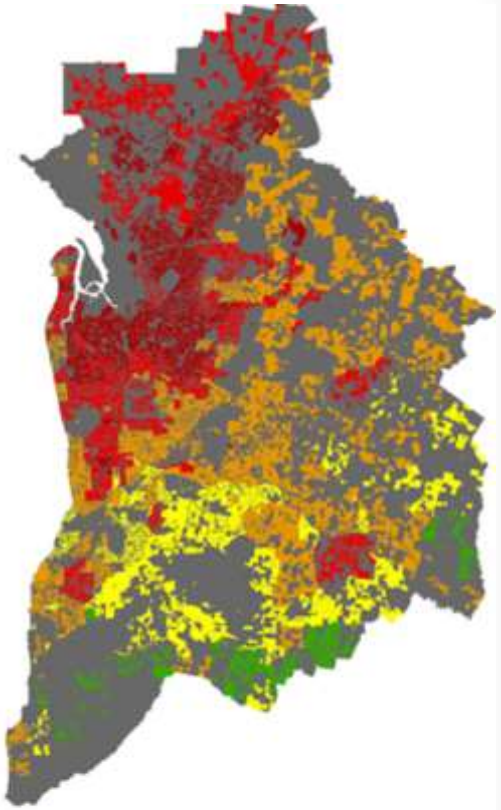
CURRENT BUSHFIRE RISK



+

None
Very low
Low
Medium
High
Very high

=



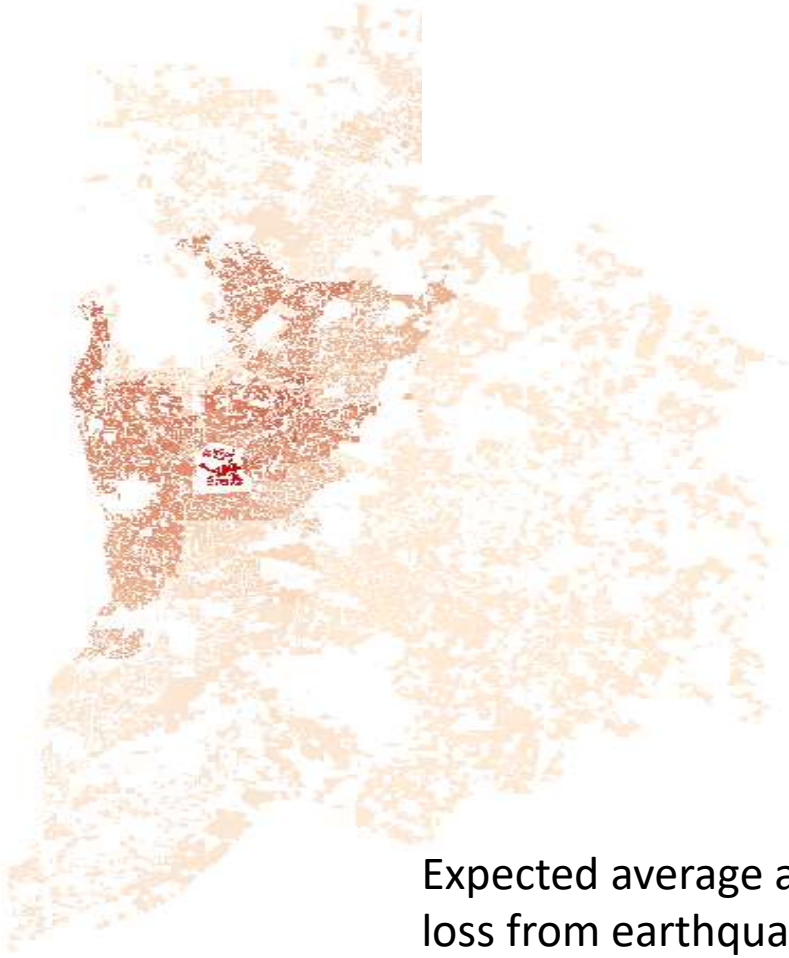
None
Very low
Very high

CURRENT SOCIAL VULNERABILTY

CURRENT EARTHQUAKE HAZARD

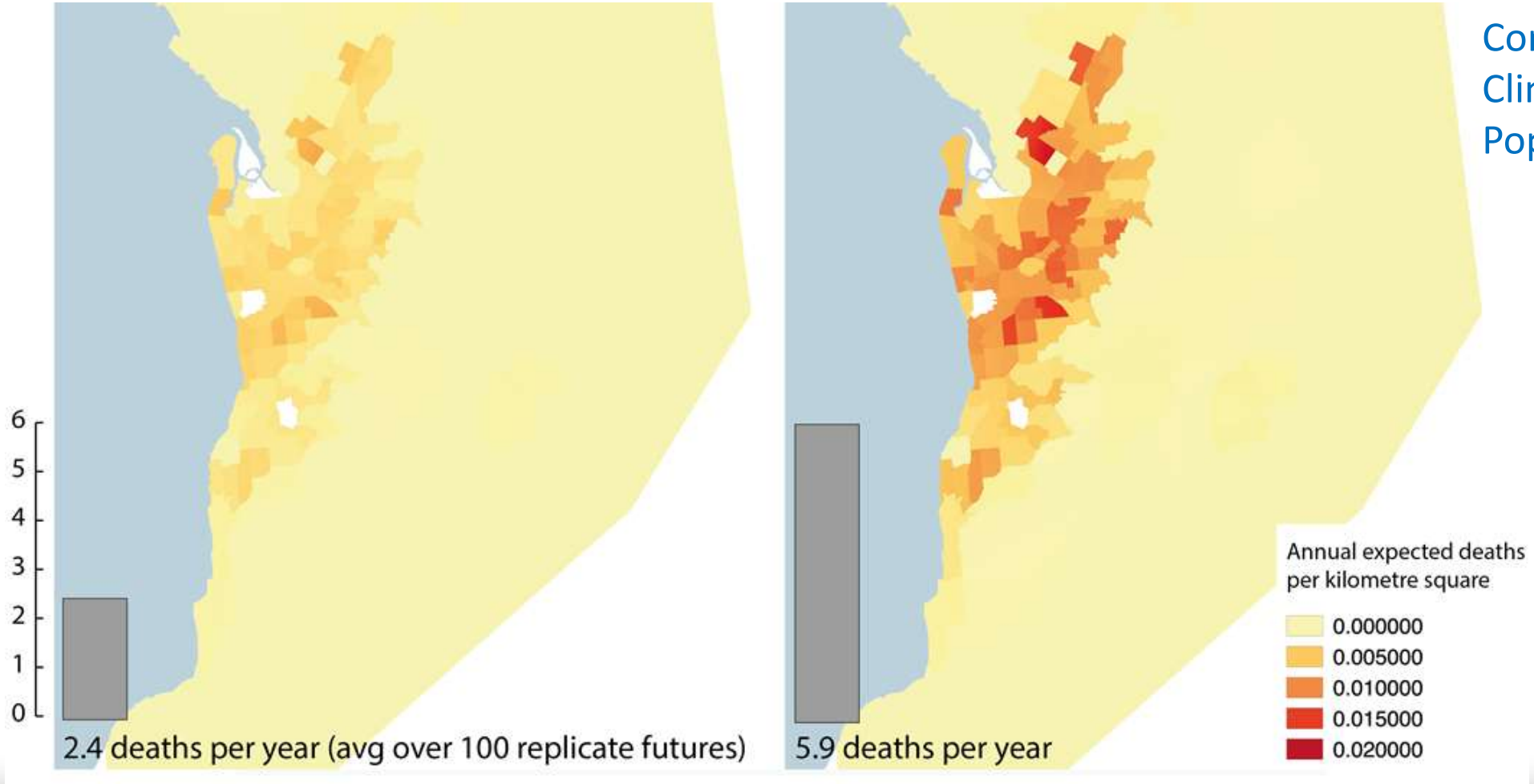
CURRENT EARTHQUAKE RISK

What is the future expected average annual loss from earthquake?



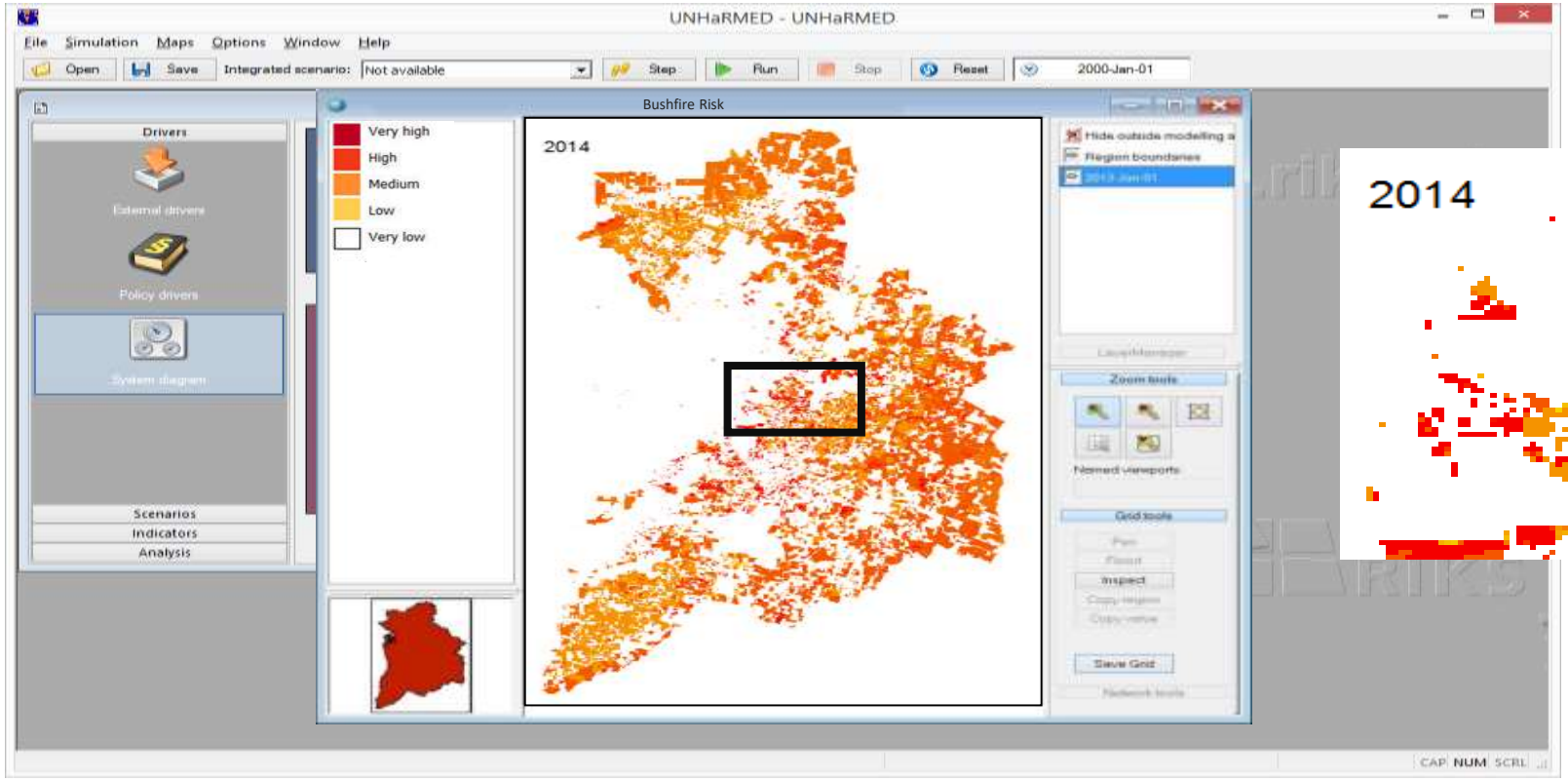
Expected average annual loss from earthquakes 2013-2050

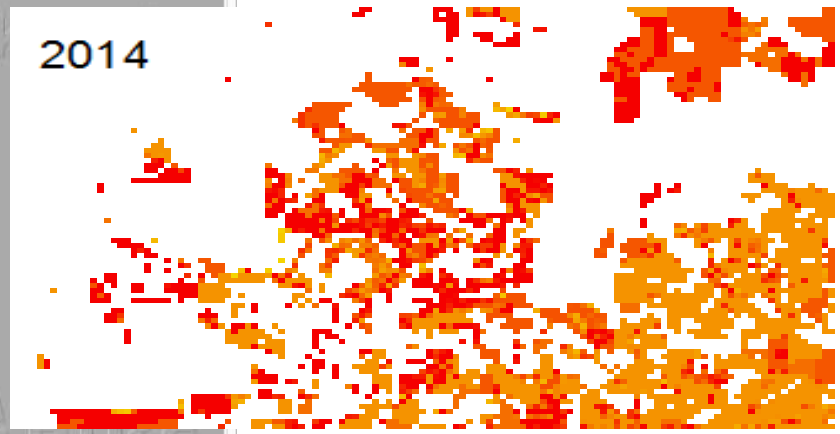
What are the future expected average annual deaths from heatwave?



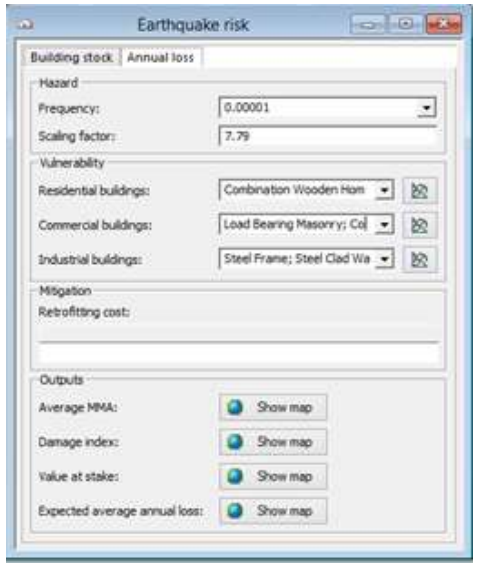
Combined Impact of Climate Change and Population Growth

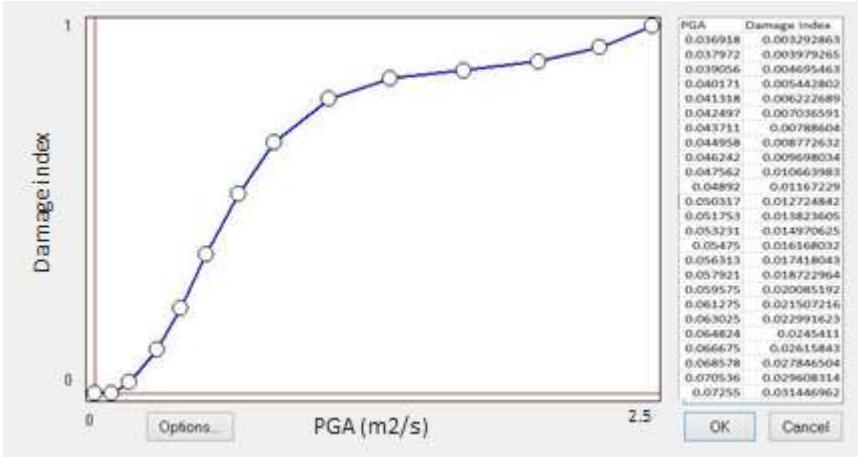
What is the future bushfire risk?

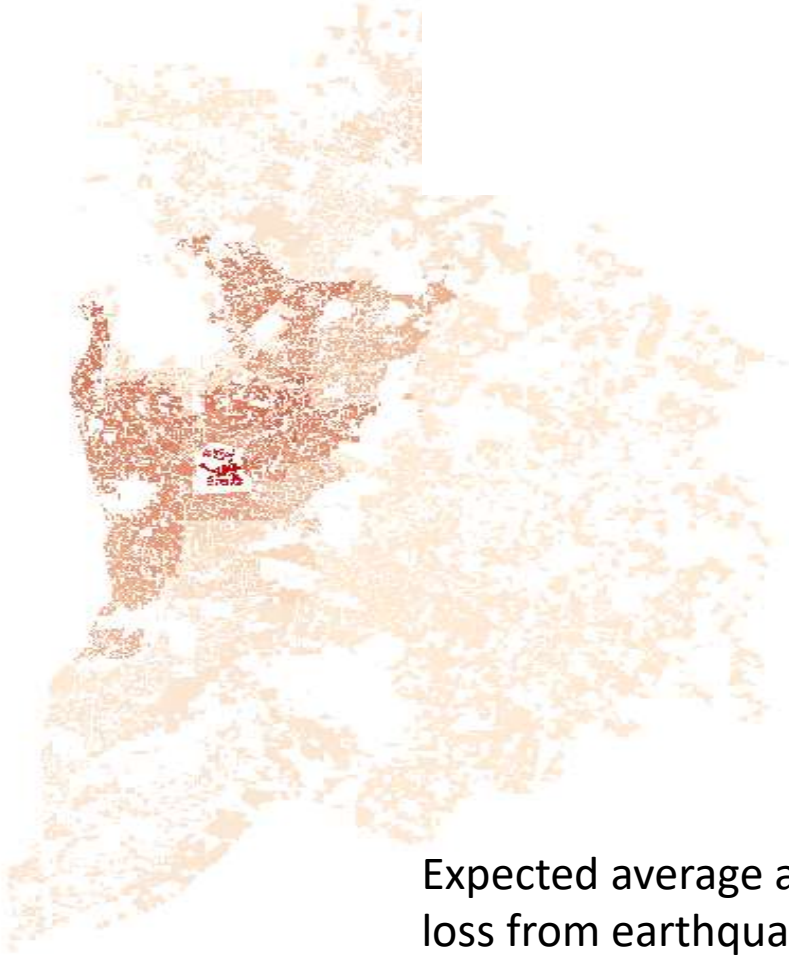




What is the future expected average annual loss from earthquake under building retrofit?

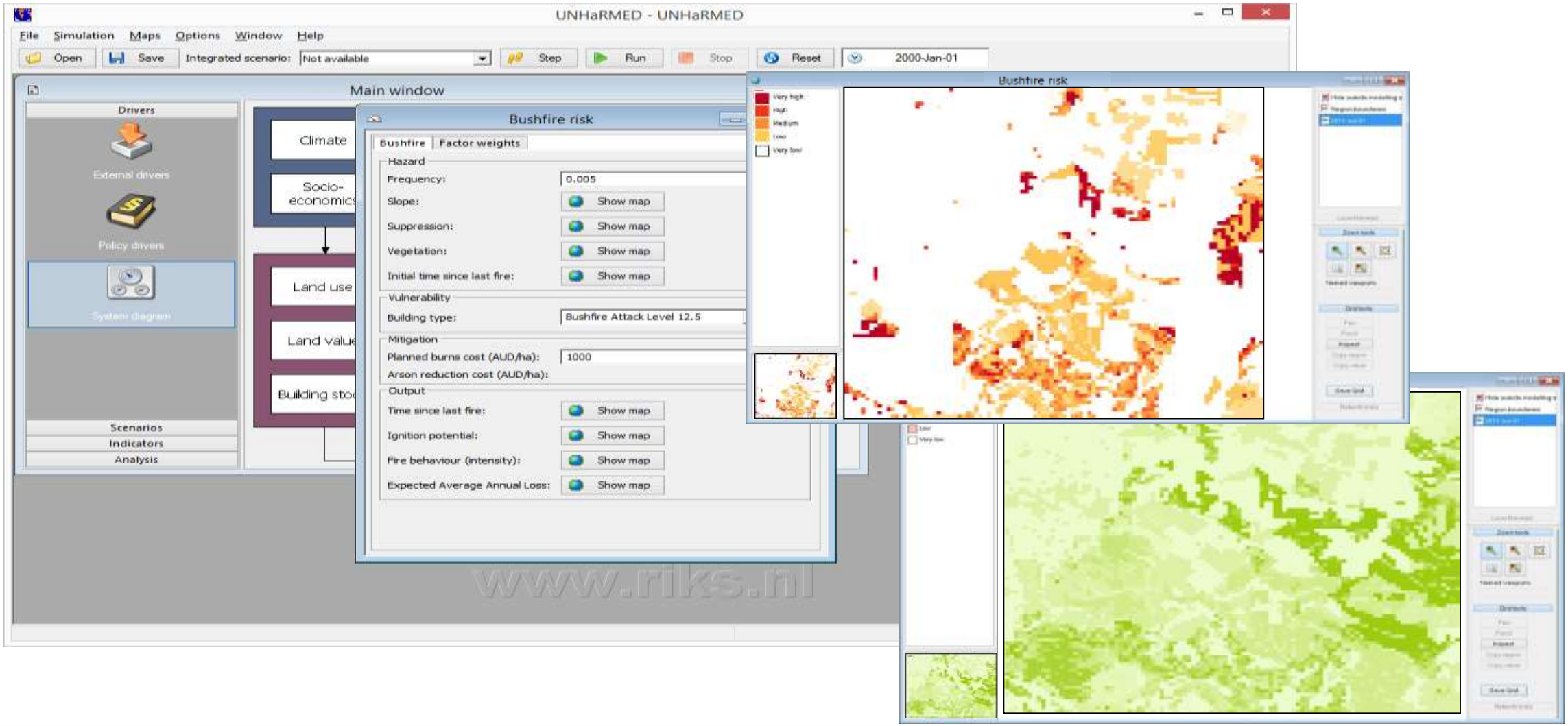




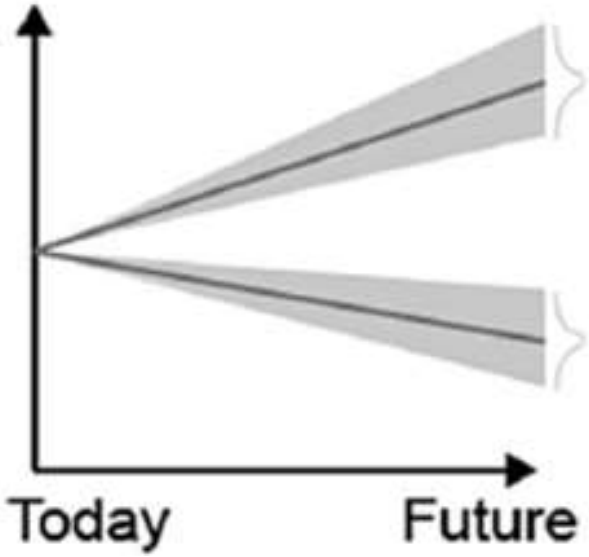


Expected average annual loss from earthquakes 2013-2050

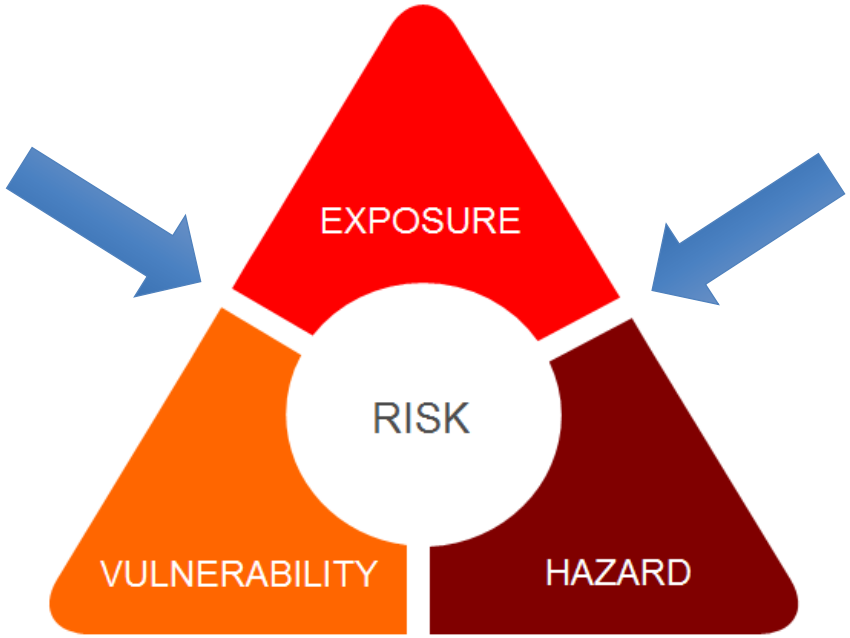
What is the future bushfire risk under prescribed burning?



INTEGRATED SCENARIOS



Things we generally **cannot** control



MODEL

Evolution over **time**

Things we generally **can** control

What is the impact of… (different climate change scenarios, different population projections, different mitigation strategies, different hazards)

What is the relative importance of… (different long-term drivers, different mitigation strategies, different hazards)

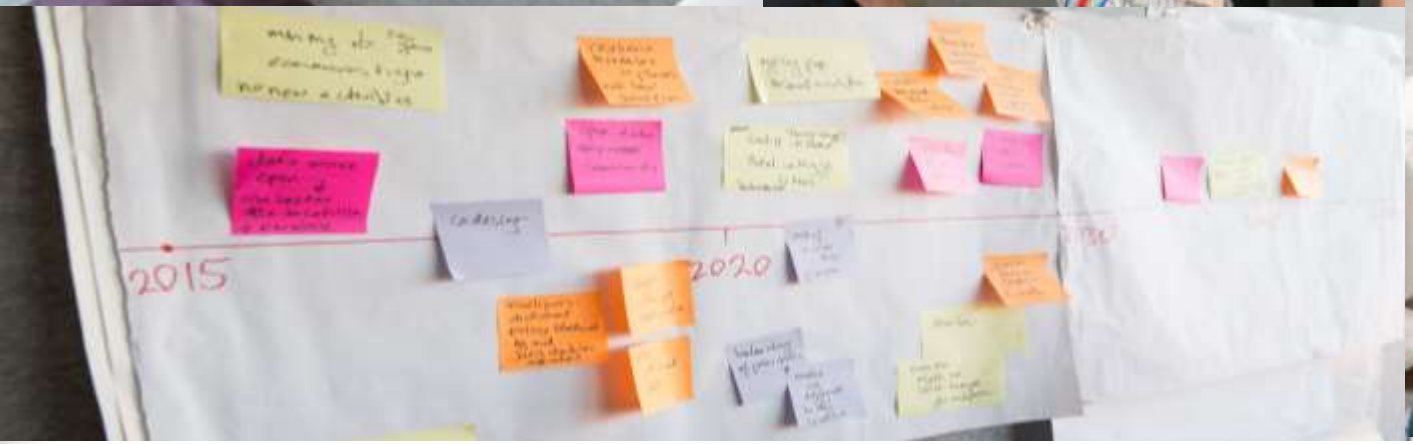
What is the relative benefit cost ratio of different mitigation strategies?

What is best portfolio of mitigation strategies for a given budget?

What are trade-offs between cost and risk of different mitigation strategies?

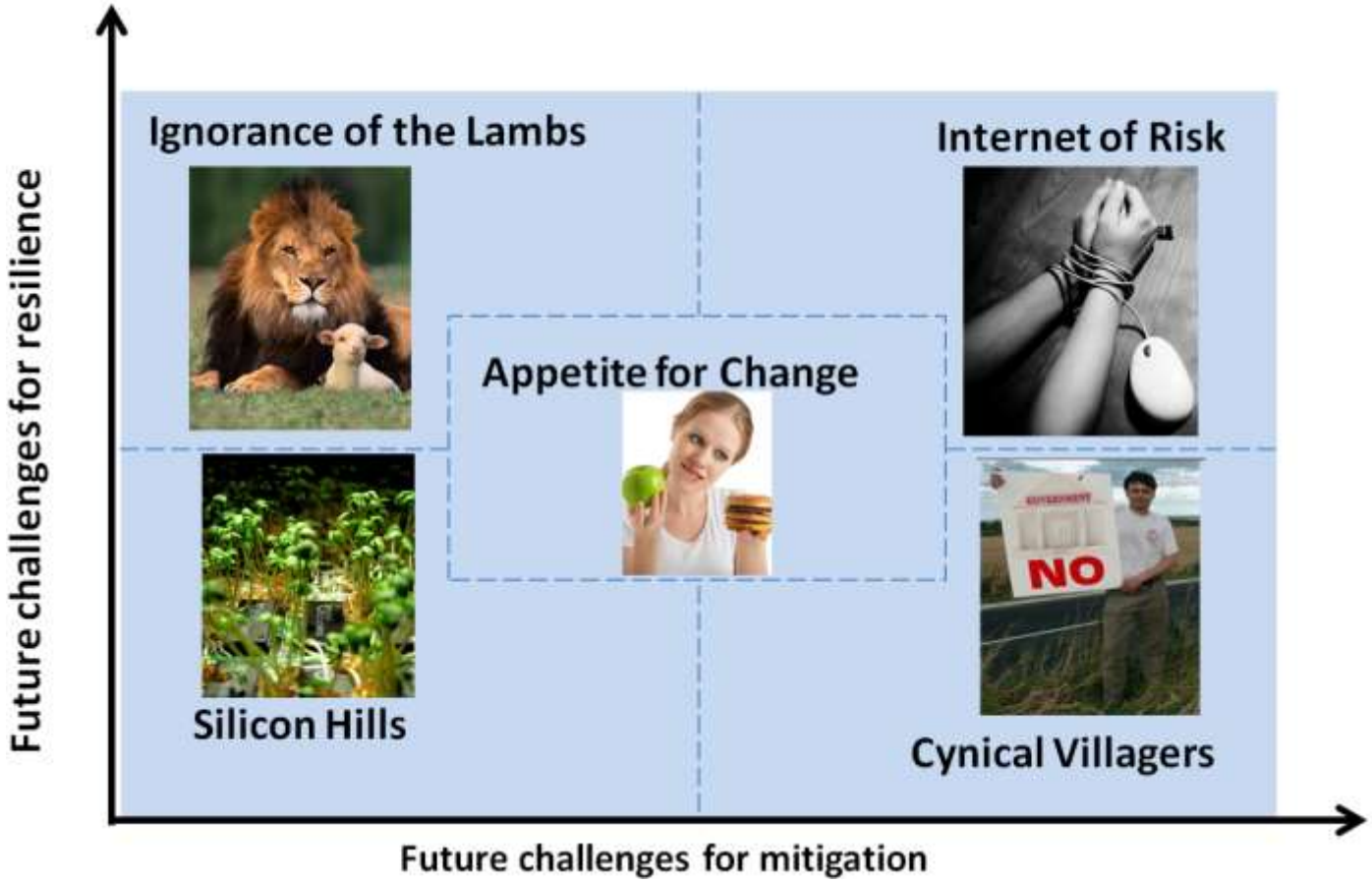
When are important future tipping points ?

What are plausible future developments and what are their impacts?


2015
2020

An exploration of disaster risk and the future

Graeme A. Riddell, Hedwig van Delden, Graeme C. Dandy, Holger R. Maier, Aaron C. Zecchin, Jeffrey P. Newman, and Charles Newland
School of Civil, Environmental & Mining Engineering, The University of Adelaide, SA
Research Institute for Knowledge Systems, Maastricht, the Netherlands



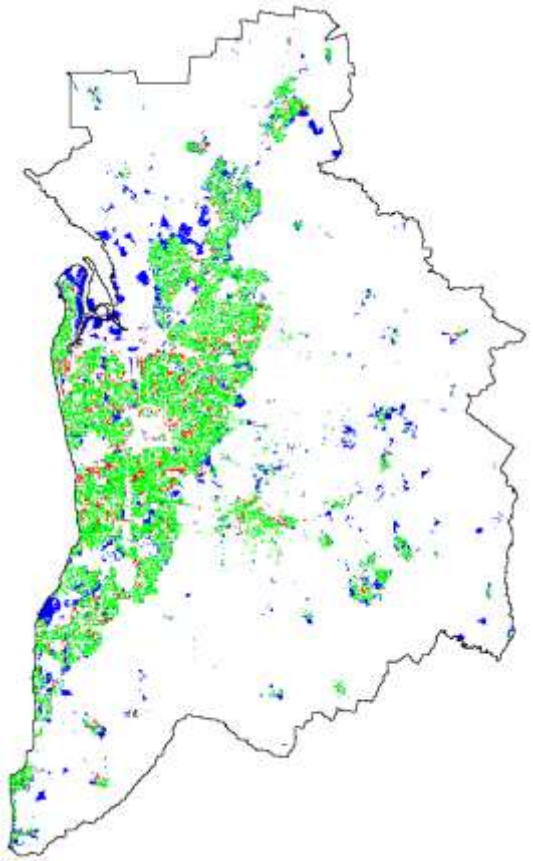
Riddell G.A., van Delden H., Dandy G.C., Zecchin A.C. and Maier H.R. (2018) **Enhancing the policy relevance of exploratory scenarios: Generic approach and application to disaster risk reduction**, *Futures*, **99**, 1-15.

Main scenario drivers and outcomes

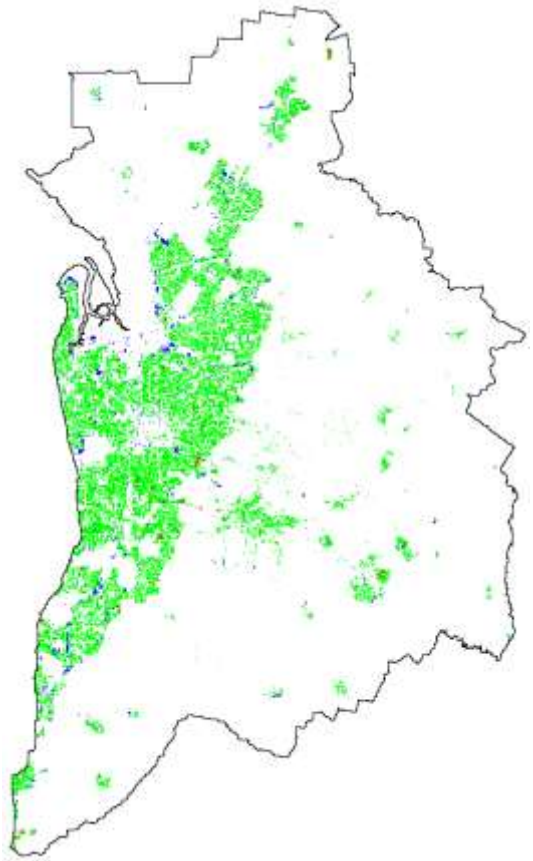
	Silicon Hills	Cynical Villagers	Ignorance of the Lambs	Appetite for Change	Internet of Risk
Population in 2050	1.9 M	1.5 M	2.5 M	1.8 M	1.5 M
Economy					
Community resilience					
Building stock resilience					
Residential land use developments	*Gradual growth urban and rural areas*	*Large increase in rural residential, mixed with other land uses*	*Residential commuter communities in the hills*	*Infill, some sprawl on the fringe and rural residential development*	*Large increase in rural residential*
Land use planning					
Education & awareness					
Structural mitigation					

Scenarios

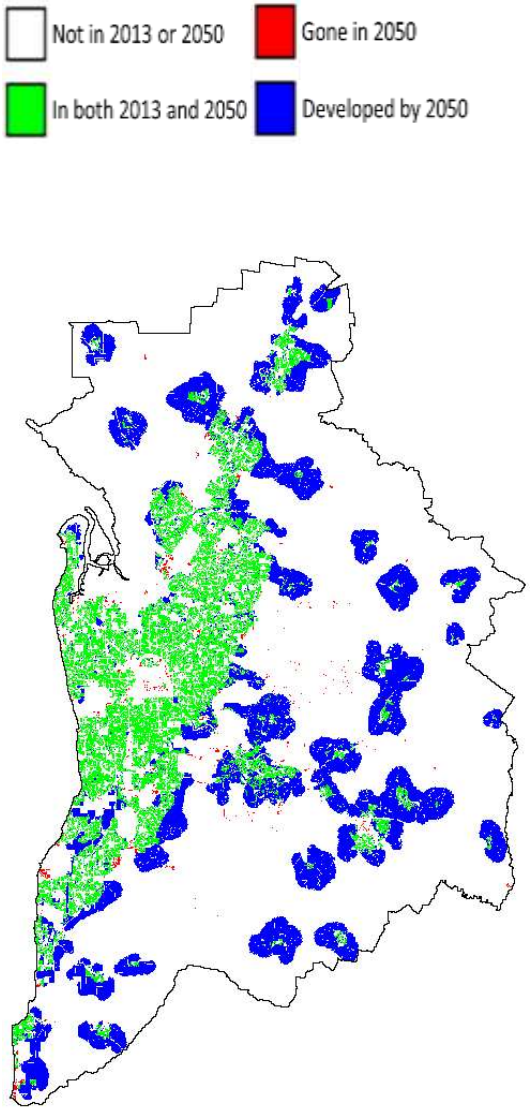
RESIDENTIAL LAND USE CHANGES 2013 - 2050



Silicon Hills
Low challenges



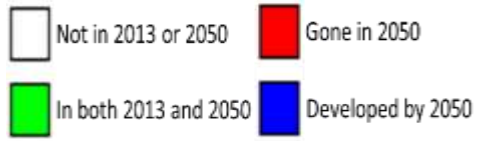
Cynical Villagers
High challenges mitigation

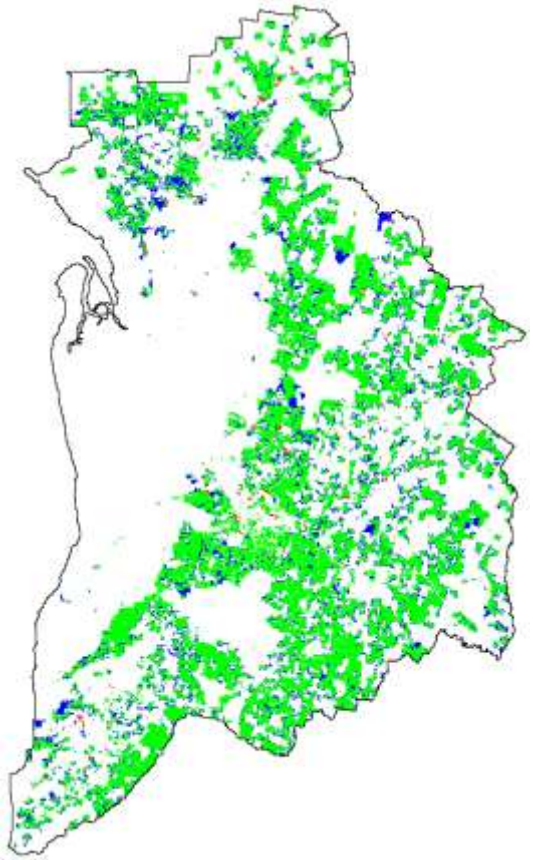


Ignorance of the Lambs
High challenges resilience

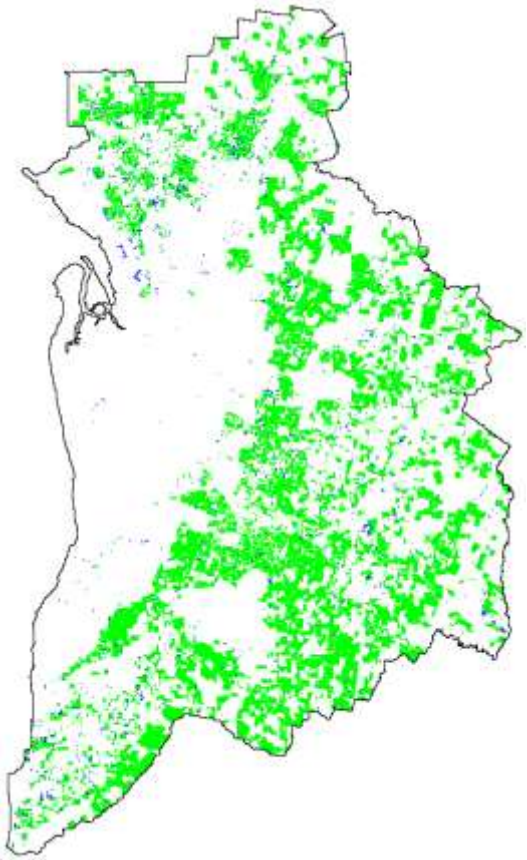
Scenarios

RURAL RESIDENTIAL LAND USE CHANGES 2013 - 2050

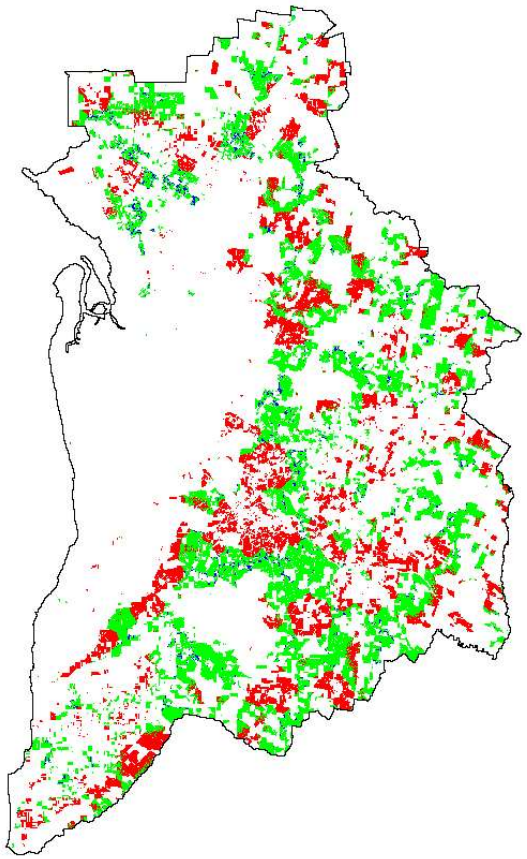




Silicon Hills
Low challenges



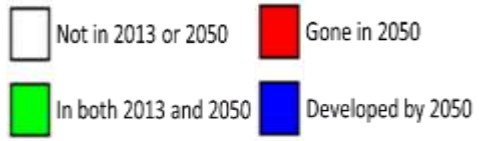
Cynical Villagers
High challenges mitigation

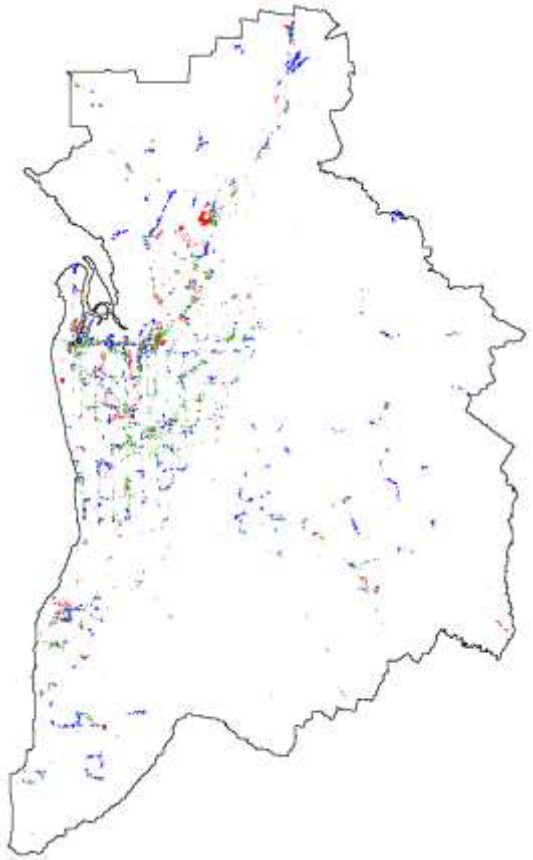


Ignorance of the Lambs
High challenges resilience

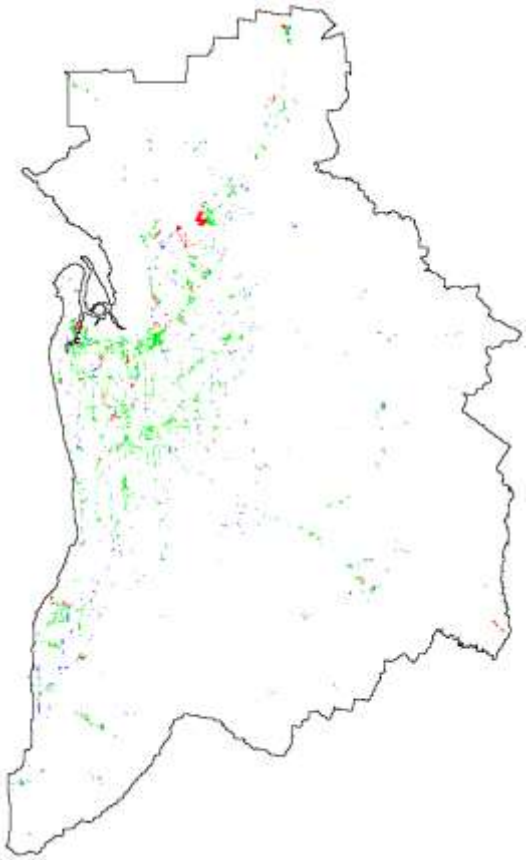
Scenarios

COMMERCIAL LAND USE CHANGES 2013 - 2050

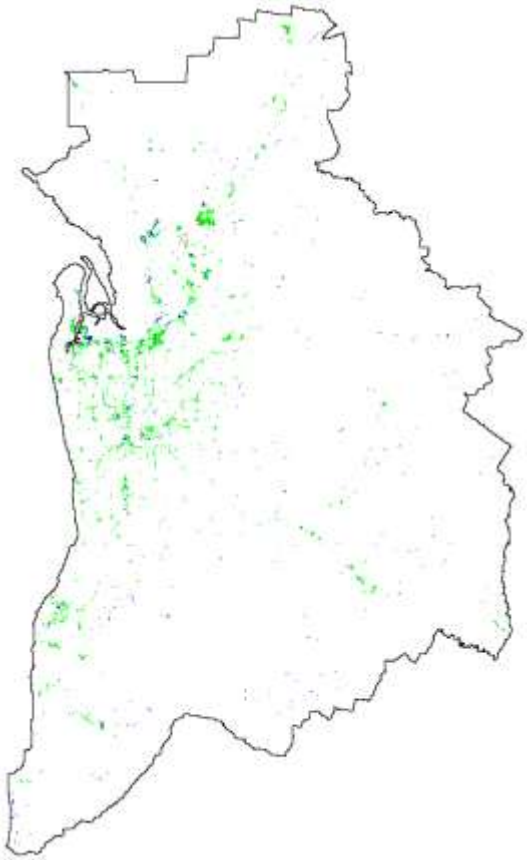




Silicon Hills
Low challenges



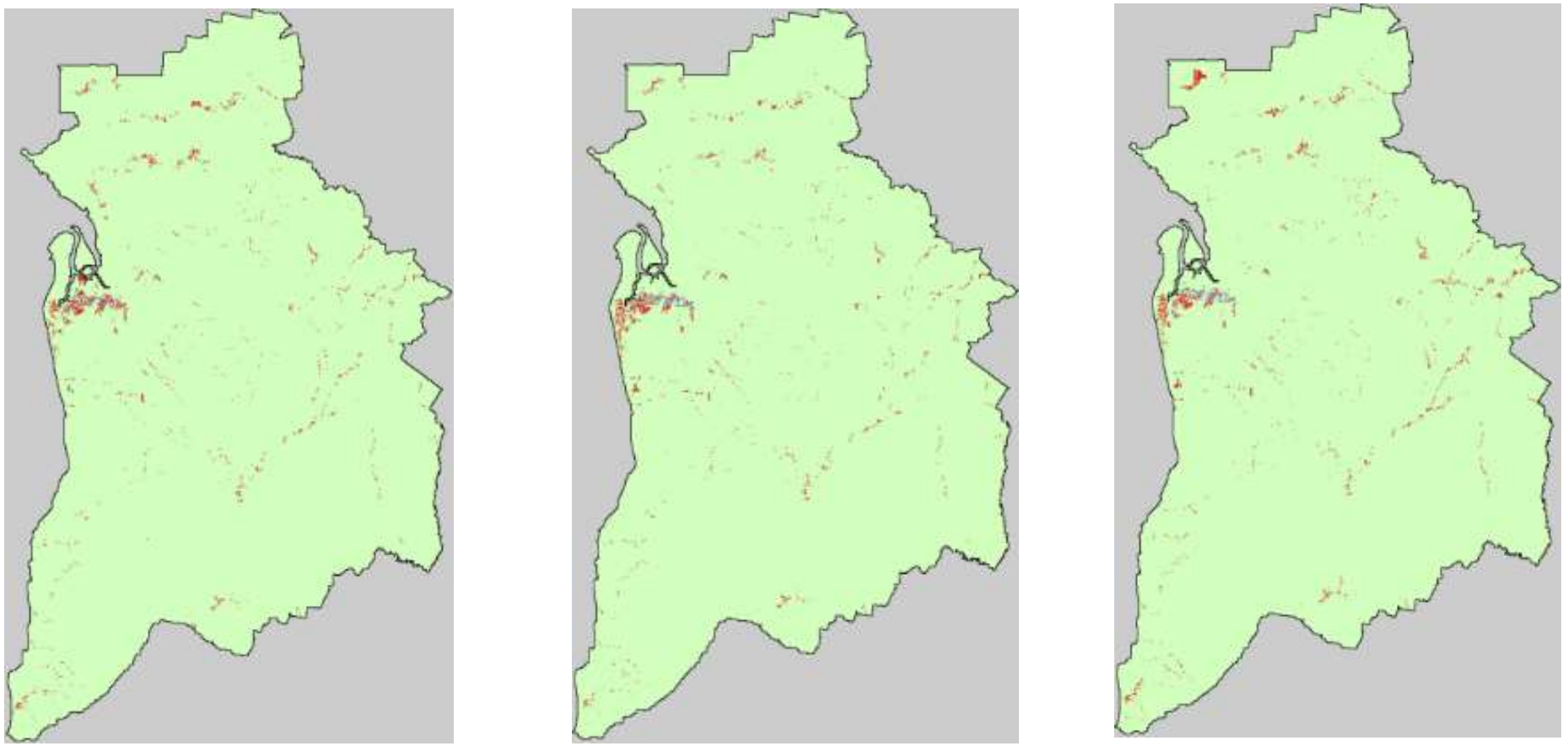
Cynical Villagers
High challenges mitigation



Ignorance of the Lambs
High challenges resilience

Scenarios

CAPITAL DAMAGE 1/500 EVENT RIVERINE FLOOD 2050



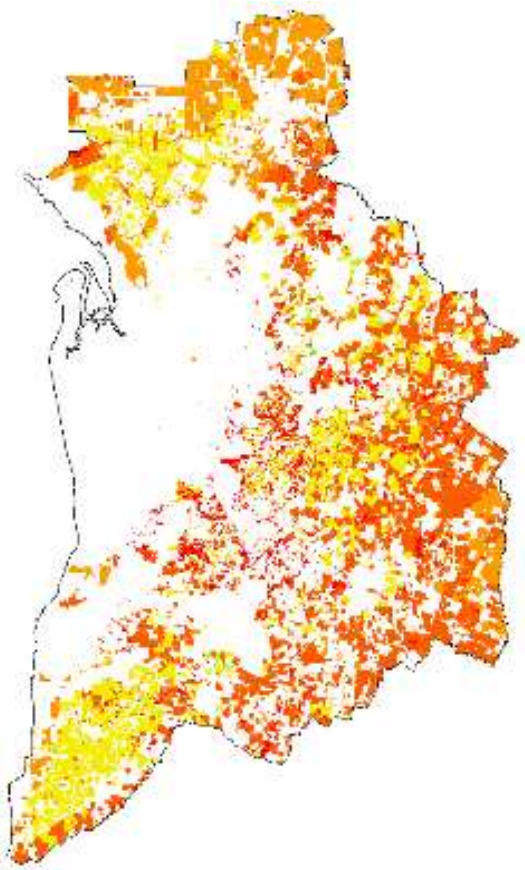
Silicon Hills
Low challenges

Cynical Villagers
High challenges mitigation

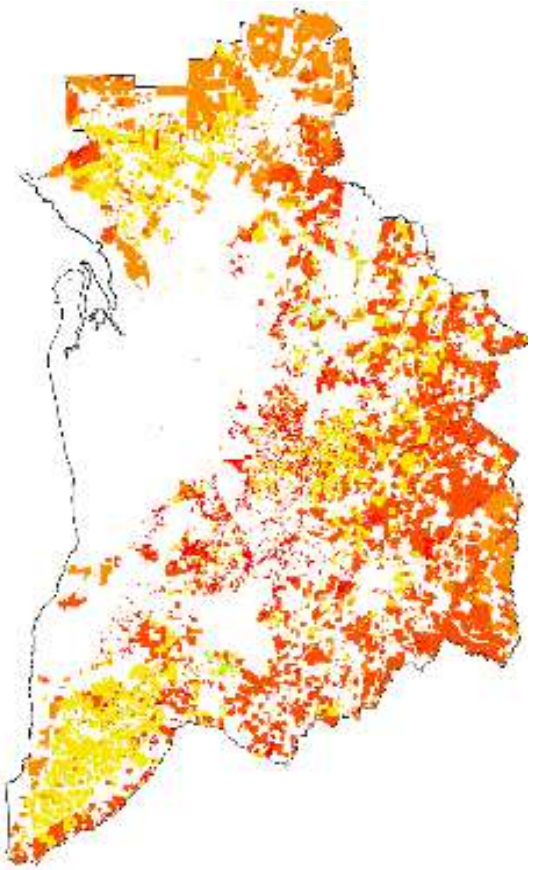
Ignorance of the Lambs
High challenges resilience

Scenarios

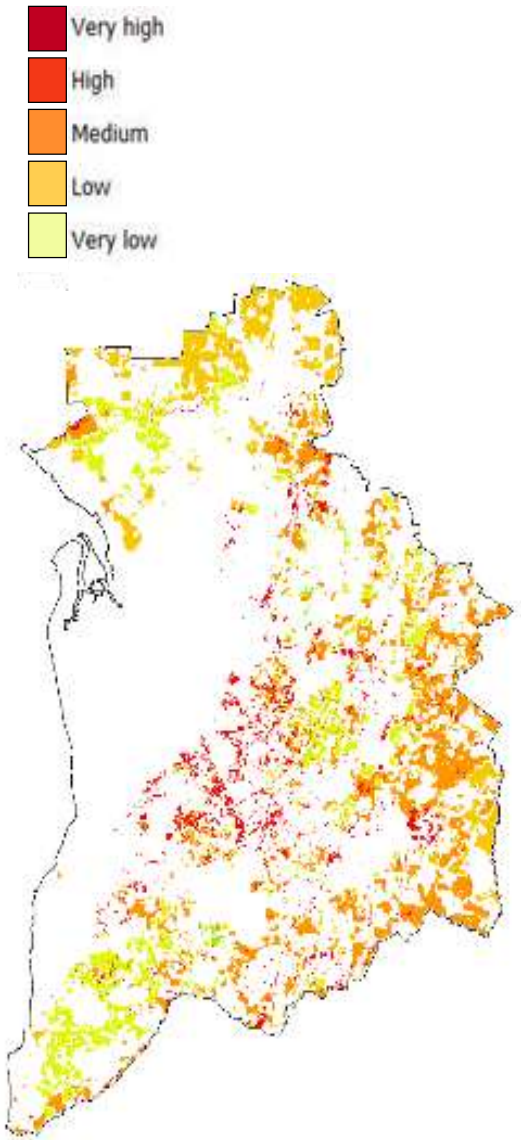
ANNUAL AVERAGE DAMAGE BUSHFIRE 2050



Silicon Hills
Low challenges

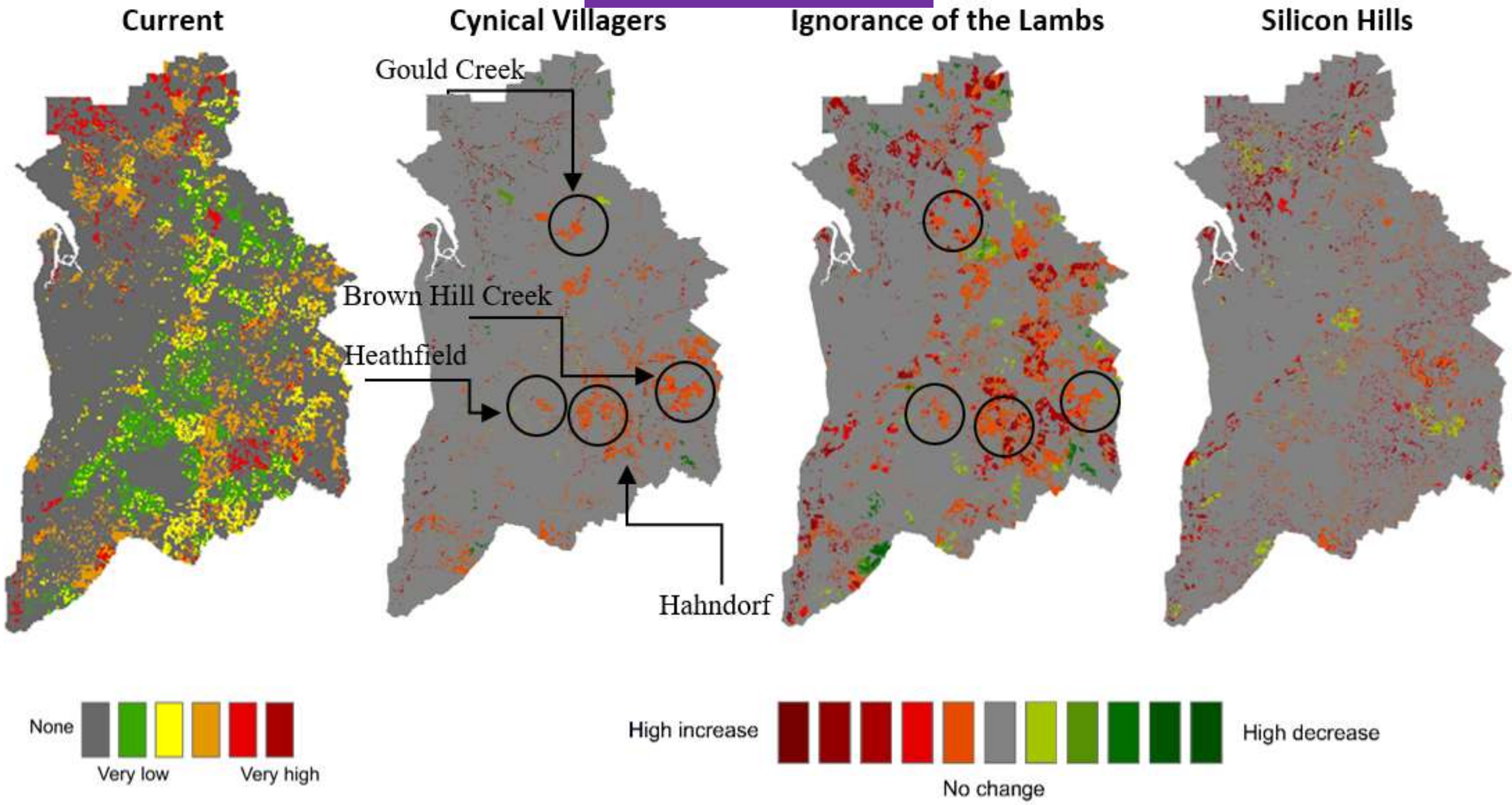


Cynical Villagers
High challenges mitigation

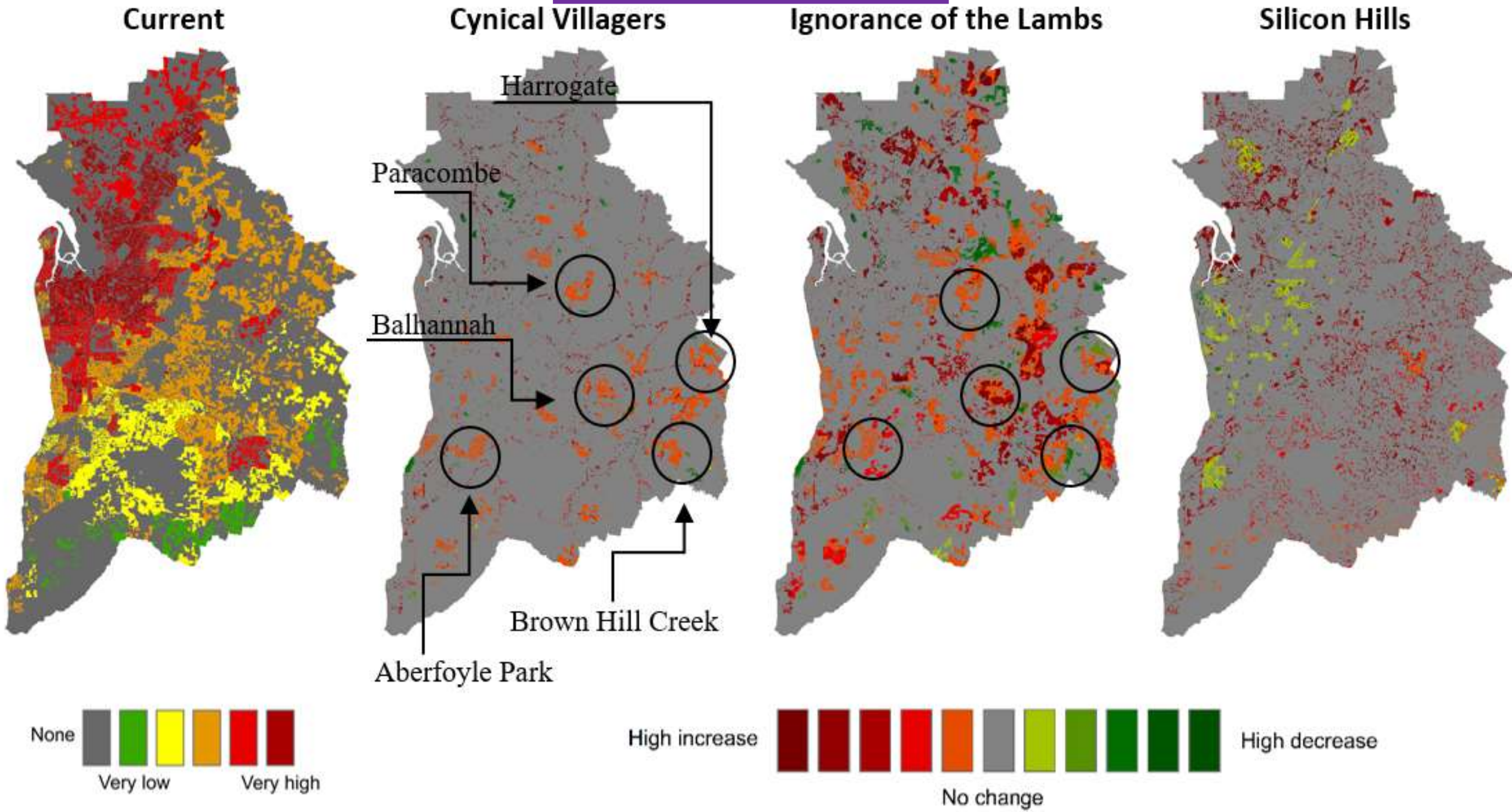


Ignorance of the Lambs
High challenges resilience

BUSHFIRE HAZARD RISK

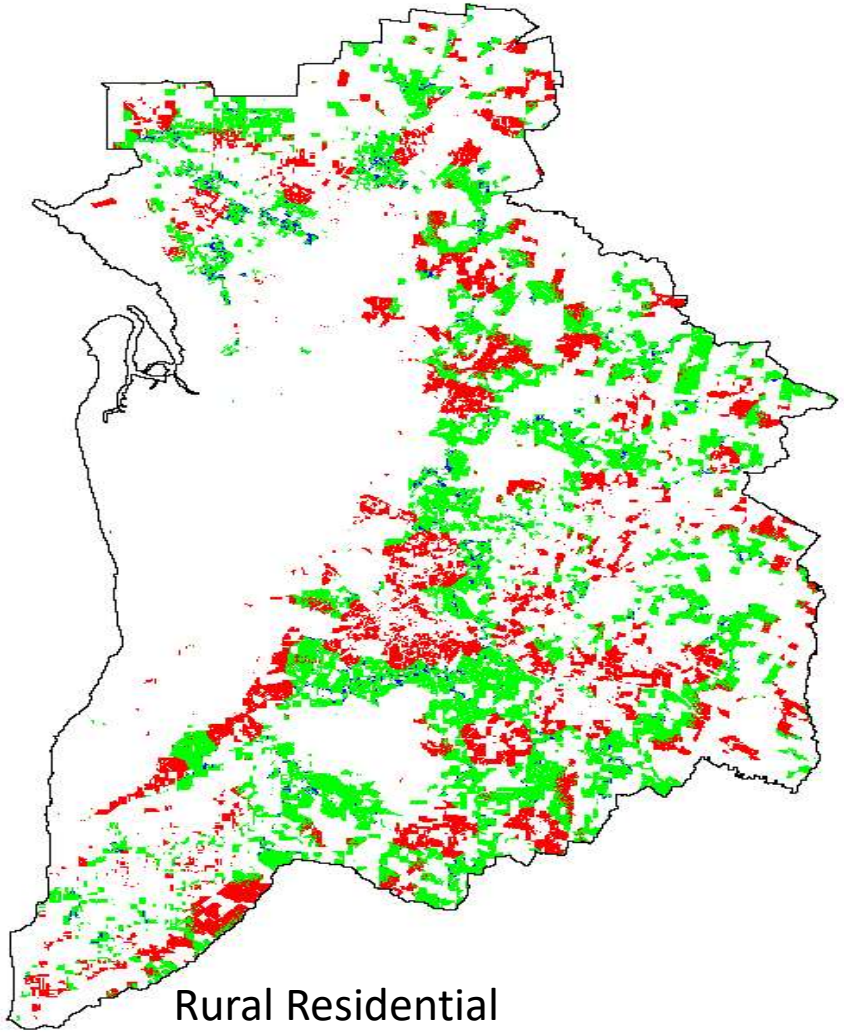


EARTHQUAKE HAZARD RISK

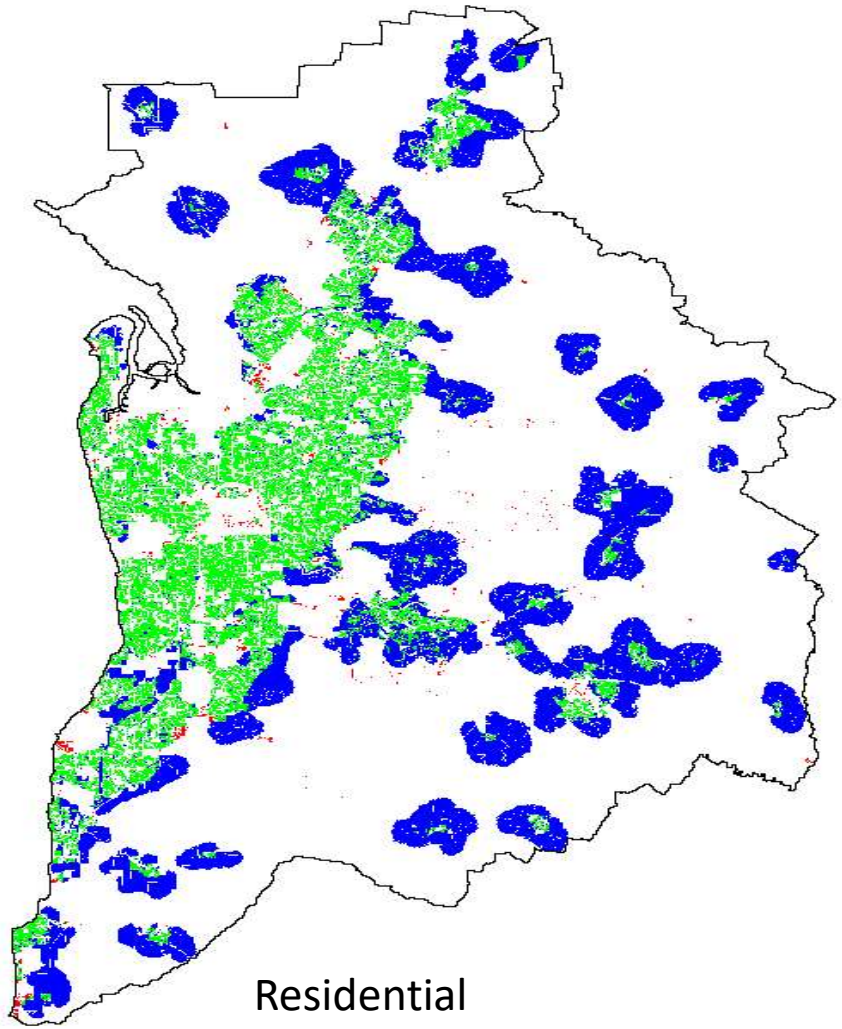


POTENTIAL UTILISATION FOR BROADER PLANNING

IMPLICATIONS FOR WATER SUPPLY?

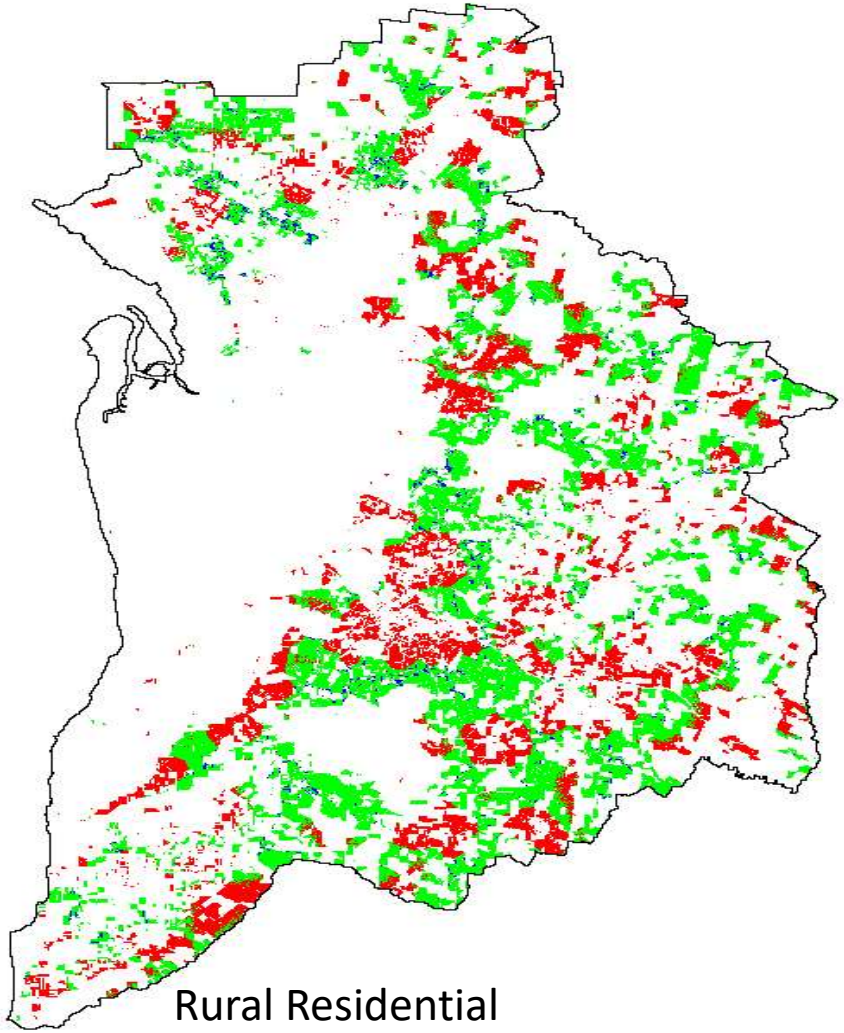


Rural Residential

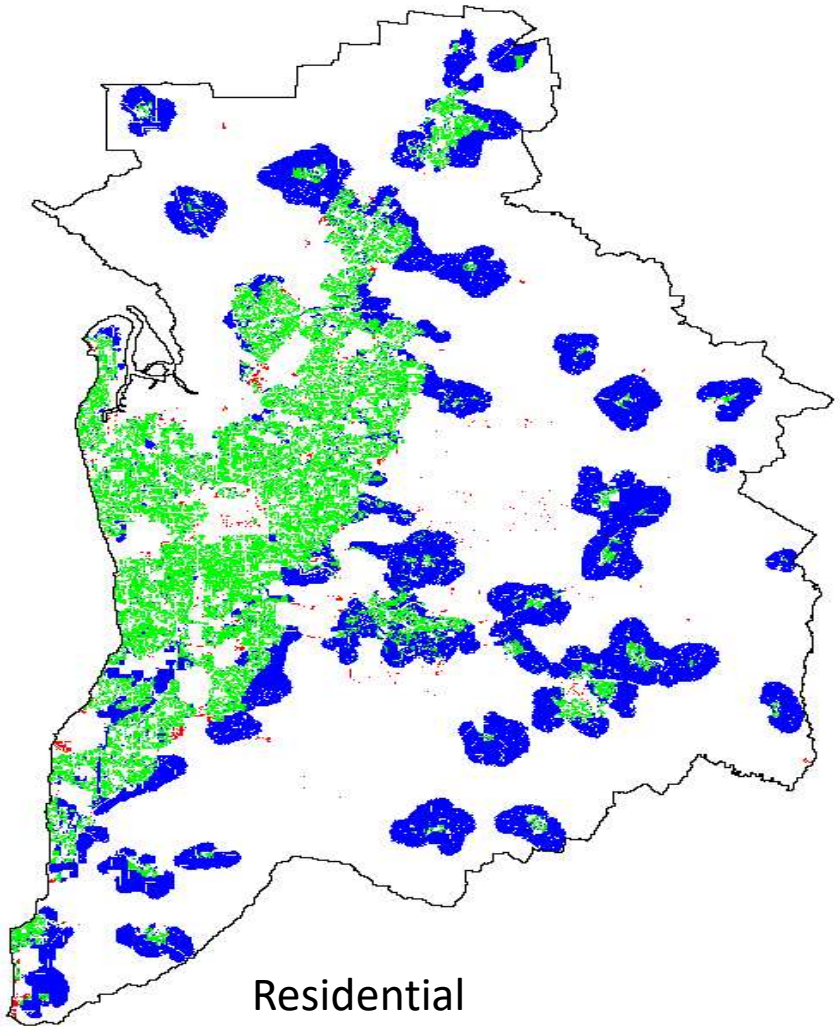


Residential

IMPLICATIONS FOR TRANSPORT?

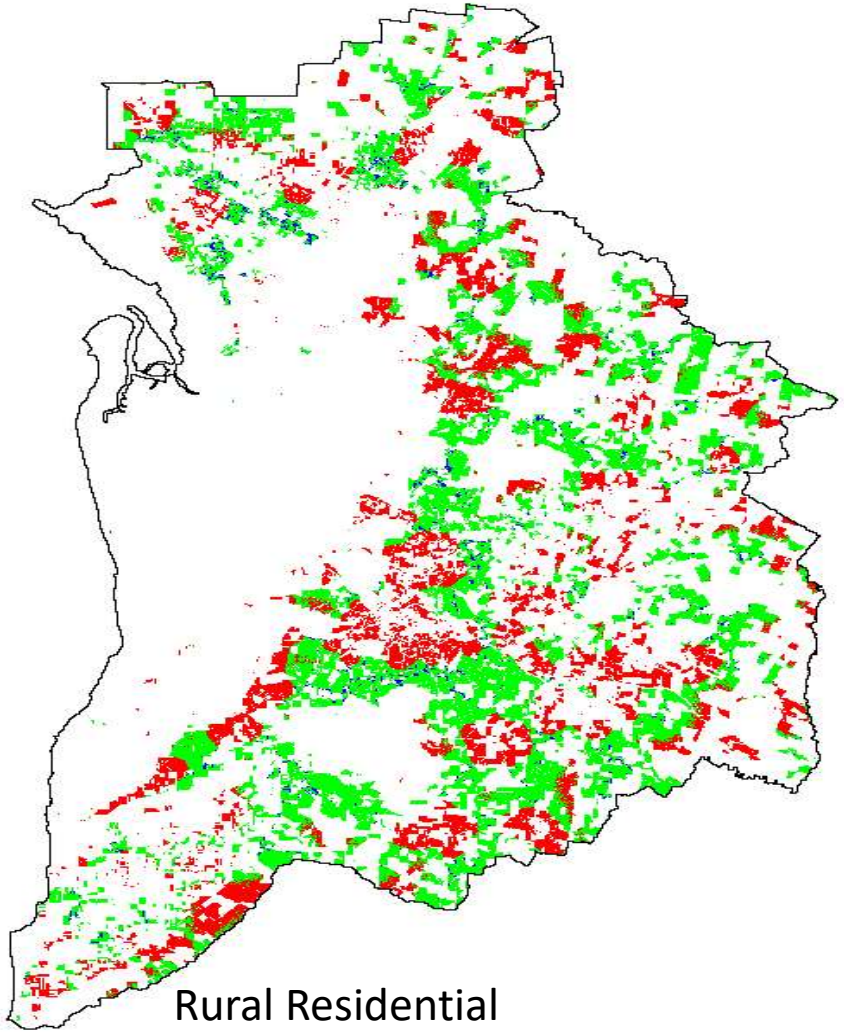


Rural Residential



Residential

IMPLICATIONS FOR BIODIVERSITY?



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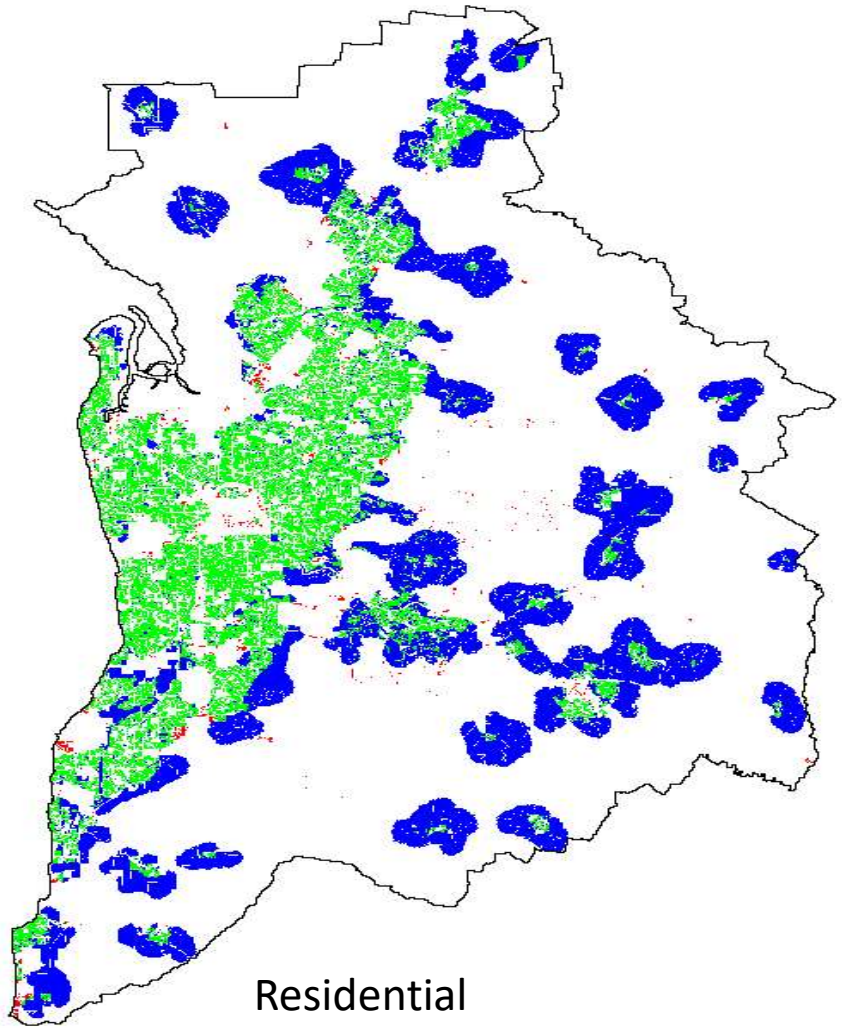
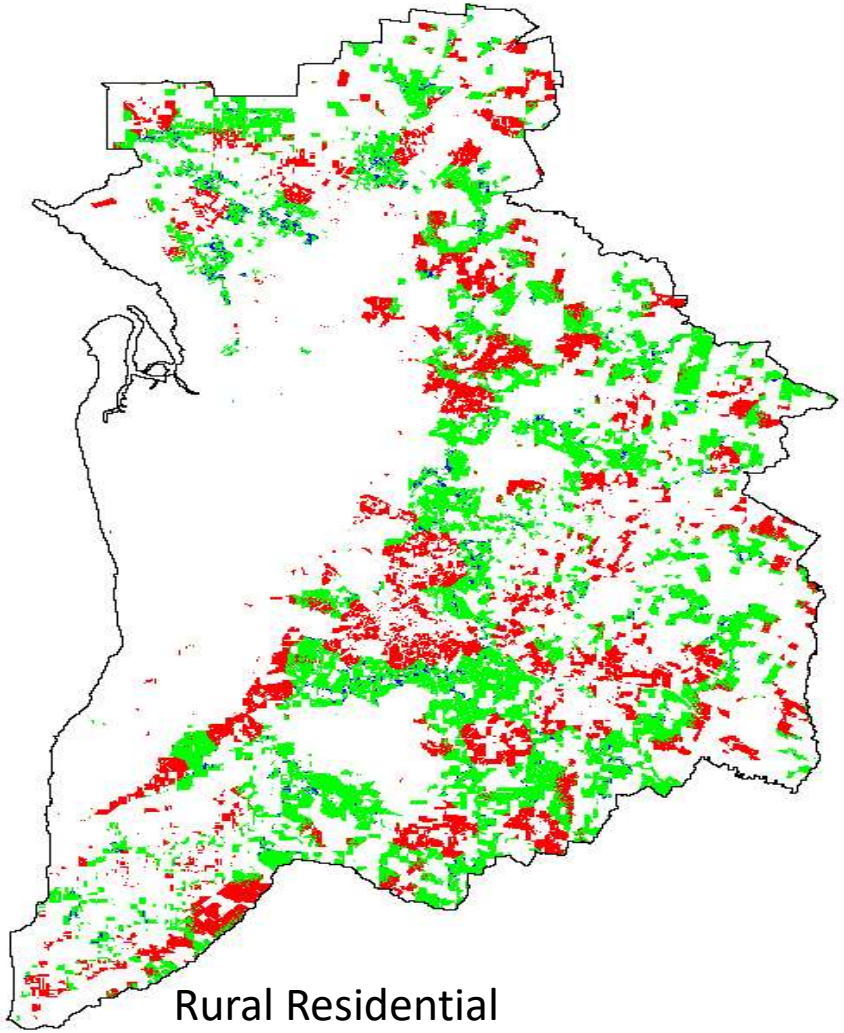
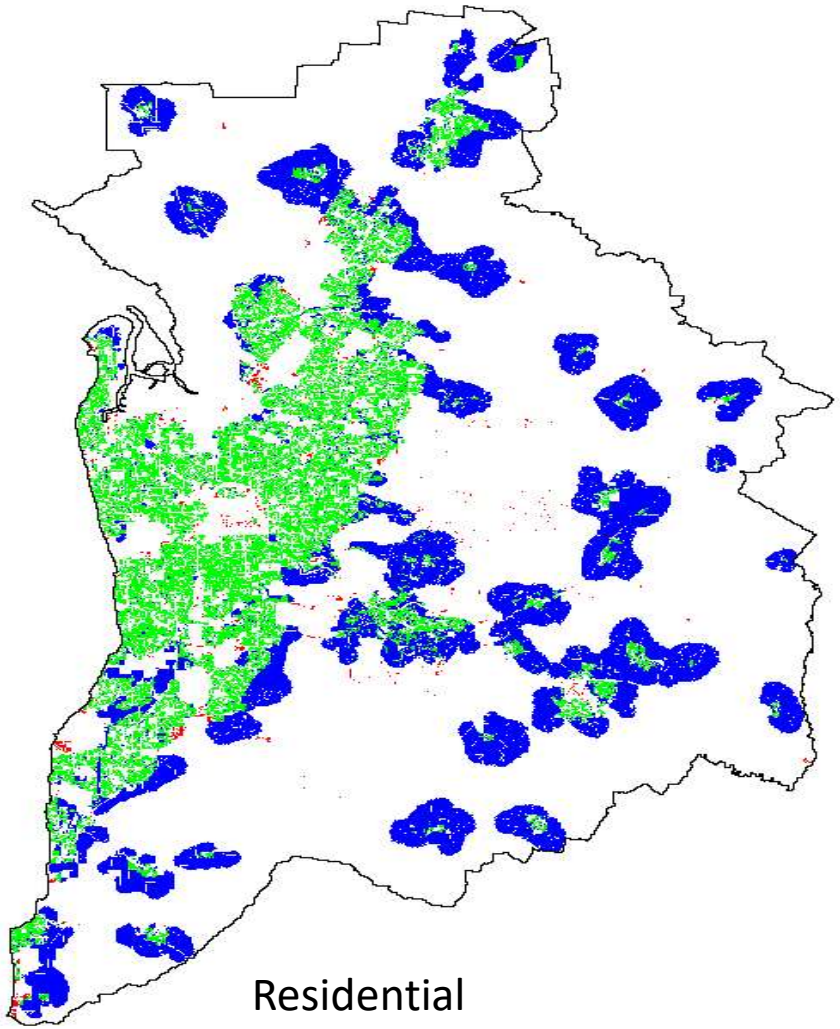


Residential

IMPLICATIONS FOR ENERGY?



Rural Residential



Residential

Summary of Uses

Strategic risk analysis

- SWOT analysis of organisation
- TCFD Physical Risk Assessment

Modelling to inform long-term resource needs and vulnerabilities

Modelling to inform future 'hotspots' or areas of concern

- Test opportunities to reduce these
- Identify areas/factors that agencies have limited control over

Assessment of climate resilience of systems

- Can consider individual systems or regions
- Can assess the resilience of supply chains

THANK YOU

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Acknowledgements: Molly O'Callaghan, Evangeline Moore, Philippa Radford, Yasmin Zhar