Wildfire risk estimation by a Bayesian Network model

Example from a Mediterranean region

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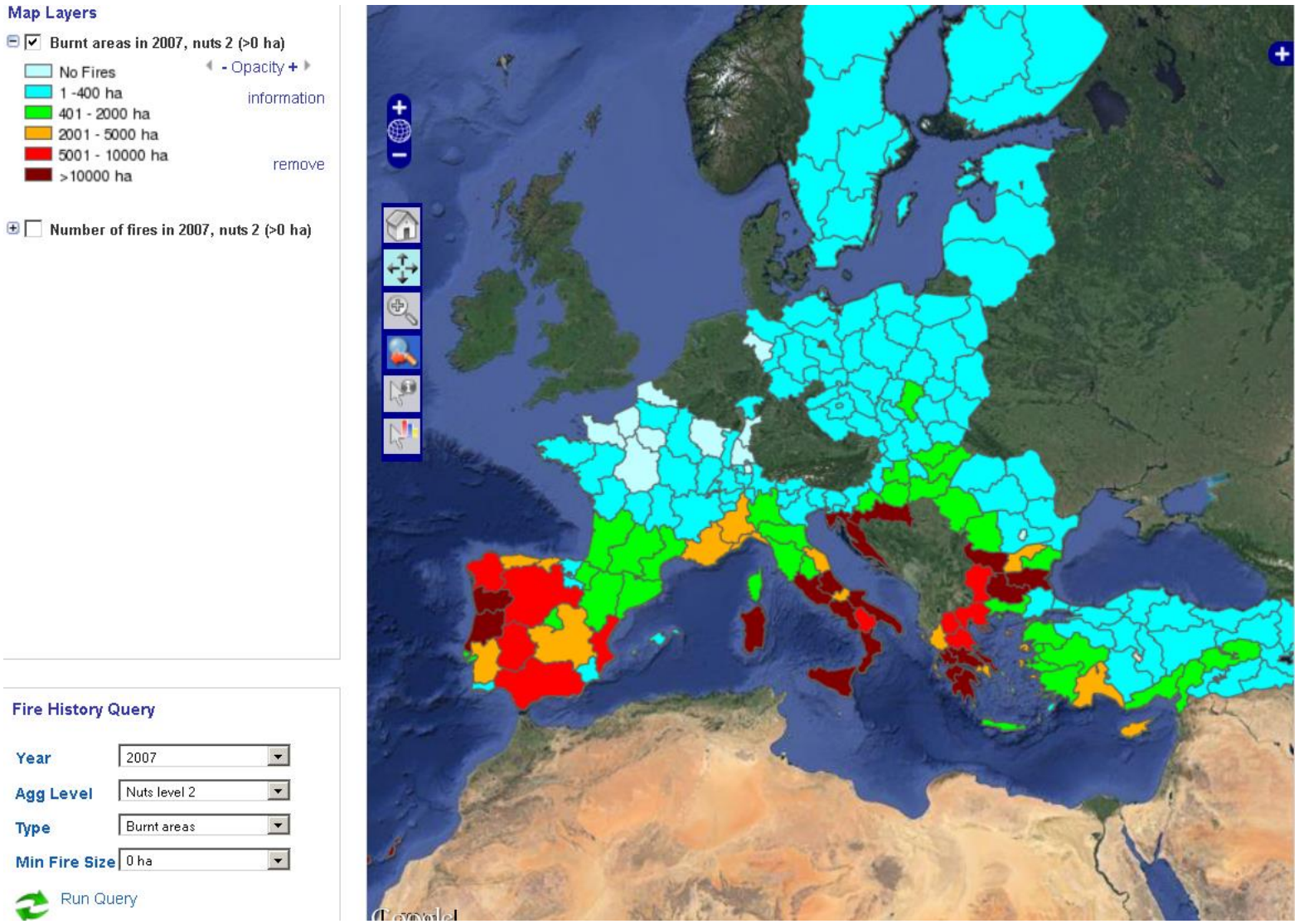
Wildfires in the Mediterranean



Source: EFFIS (European Forest Fire Information System)

Wildfires in the Mediterannean

1

Chios island, Greece, August 2013

2

Marseille, France , July 2009

3

Peloponnese Greece, August 2007

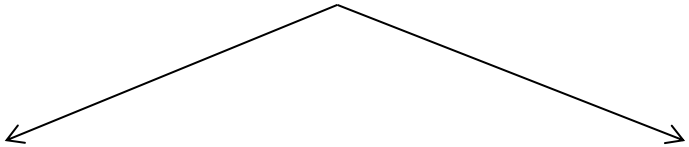
4

Genoa, Italy September 2009

1. http://www.telegraph.co.uk/news/picturegalleries/worldnews/9488070/Forest-fires-in-Greece-Spain-and-France.html?frame=2310717
2. http://www.rfi.fr/actuen/articles/115/article_4475.asp
3. http://enimerwsi.files.wordpress.com/2012/05/cf83cf84ceb7cebd-ceb7cebbceb5ceb9ceb1-2007.jpg
4. http://en.wikipedia.org/wiki/File:Bush_fire-_Genoa_2009.JPG

Quantifying Wildfire Risk (some definitions)

Risk = Pr (H) x Consequences



Vulnerability x Exposure

degree of expected damage D as a function of hazard intensity H *

items at risk (e.g. people, property)

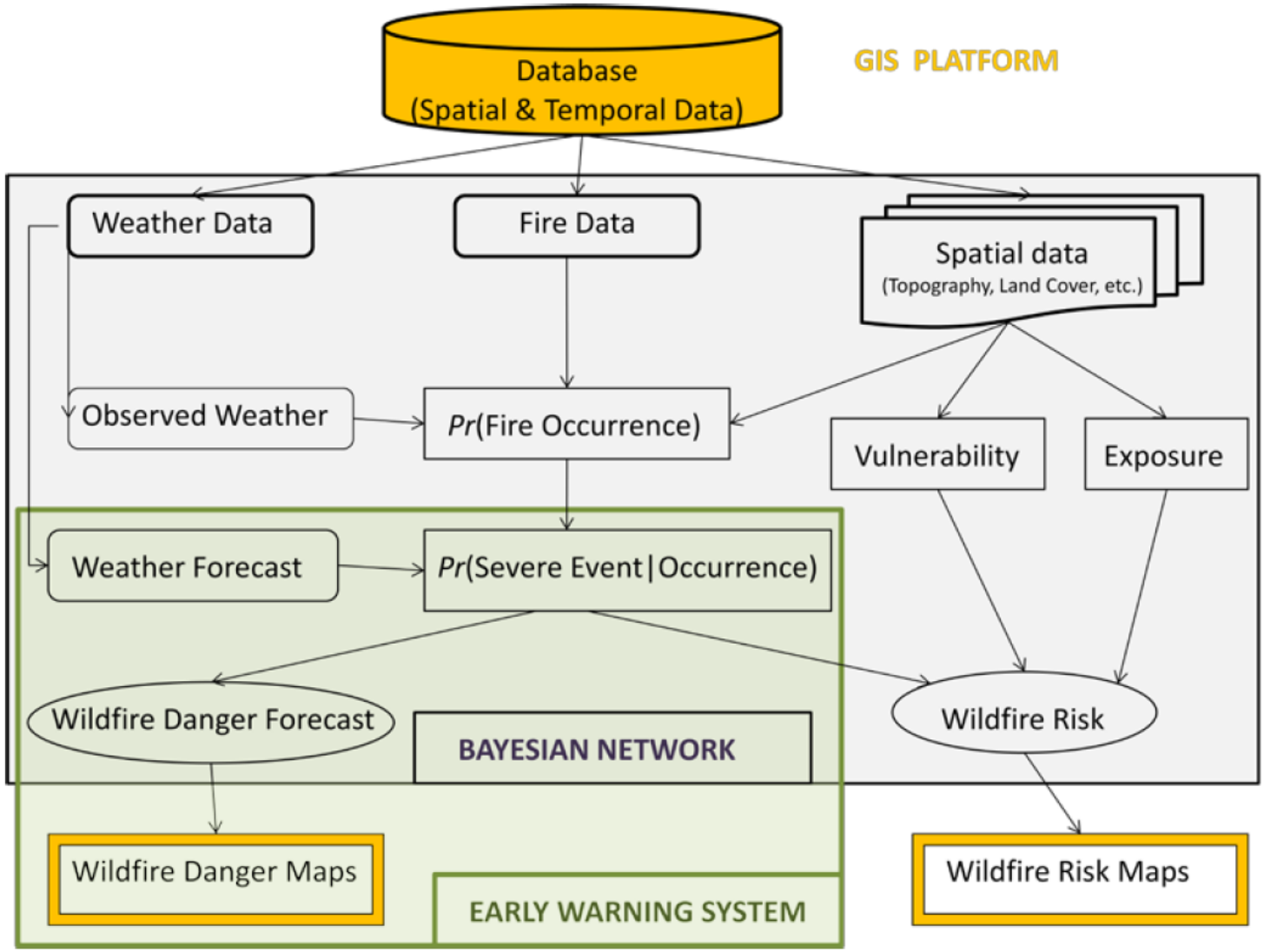
$$R = \mathrm{E}_{H,D}[C]$$

$$R = \int_H \Pr(H) \int_D \Pr(D|H) C(D,H) dD\, dH$$

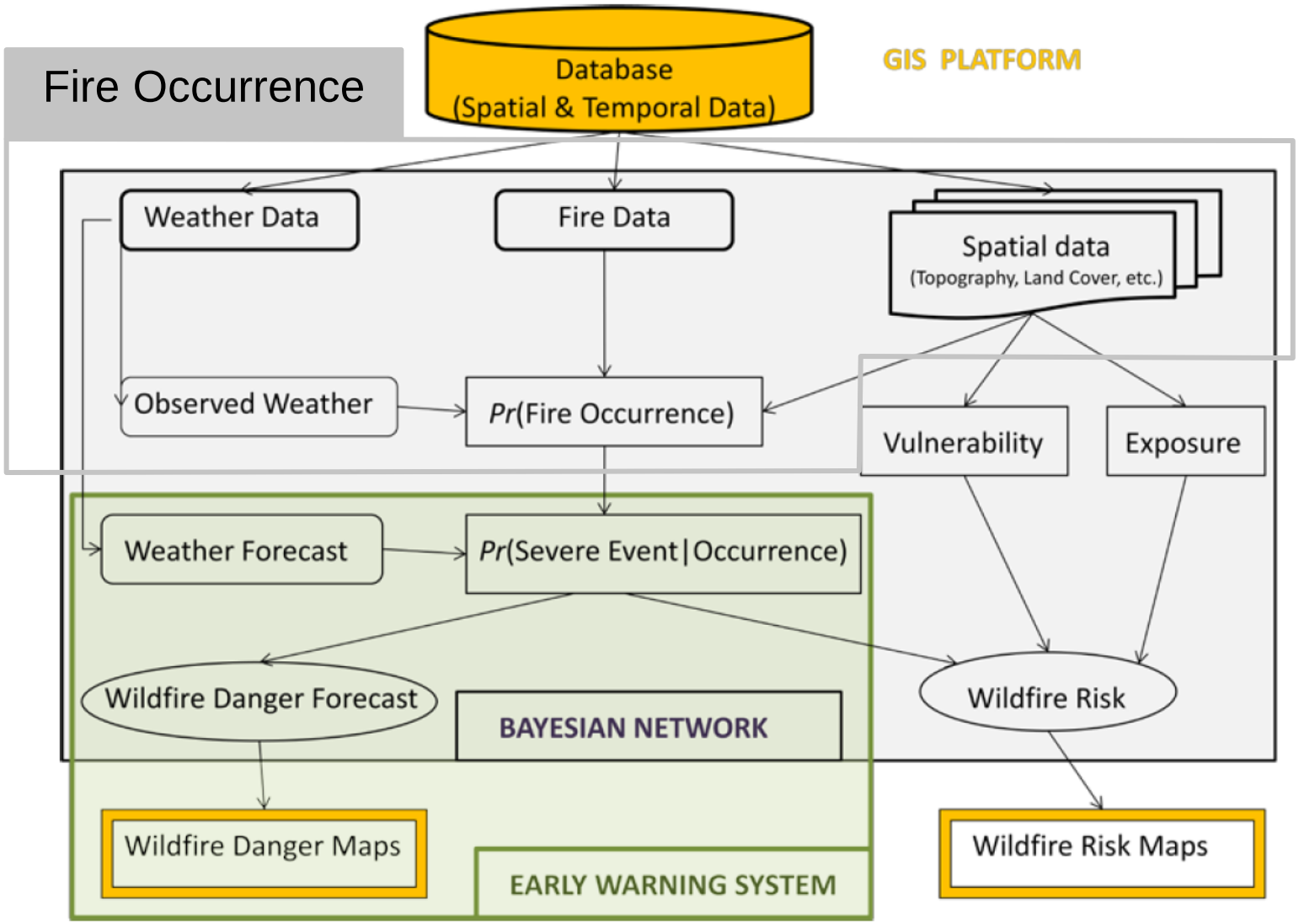
$$\mathrm{E}_D[C \mid H] = \int_D \Pr(D|H)\, C(D,H) dD$$

* (UNDRO 1991)

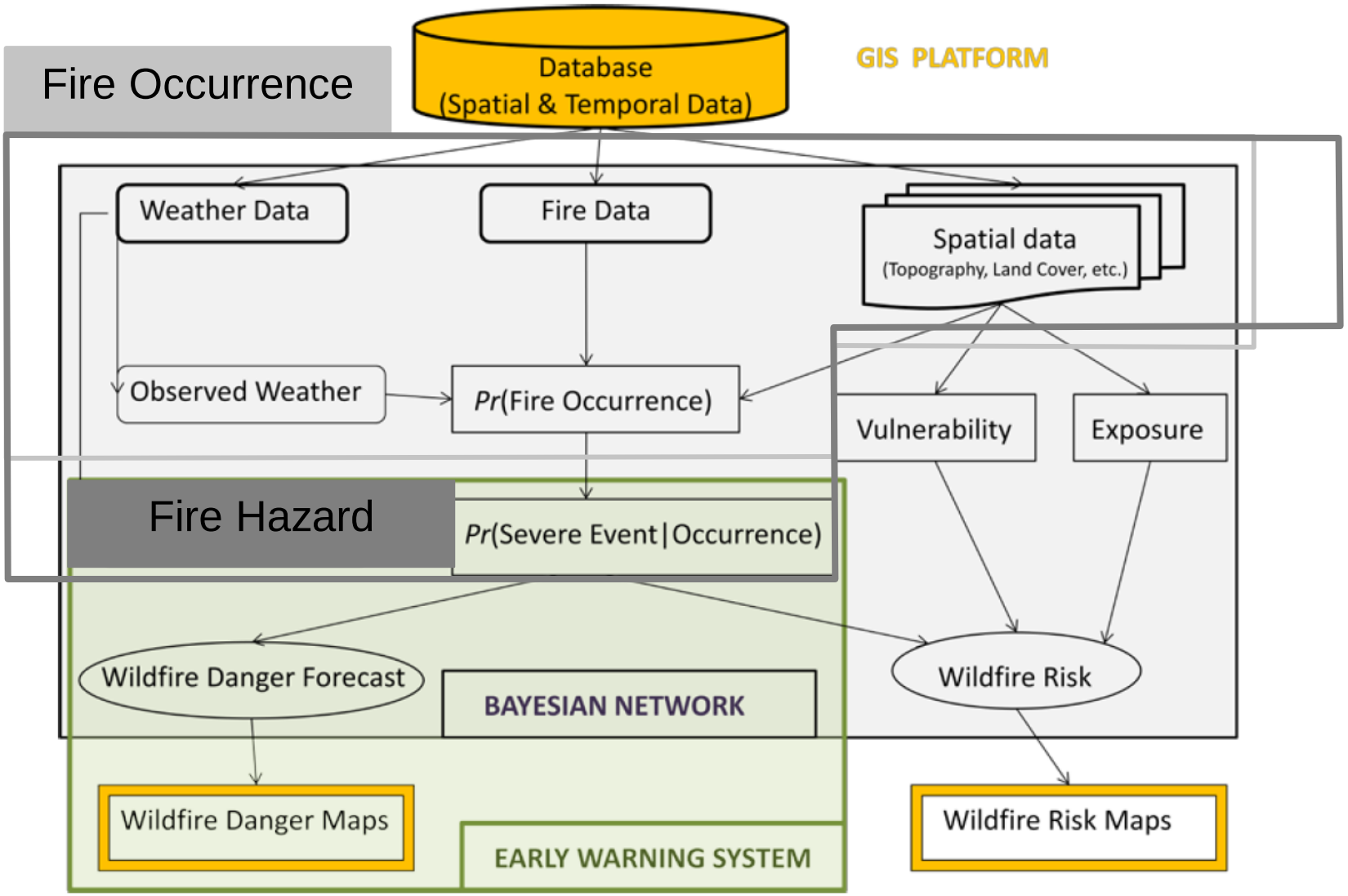
Quantifying Wildfire Risk - **Conceptual model**



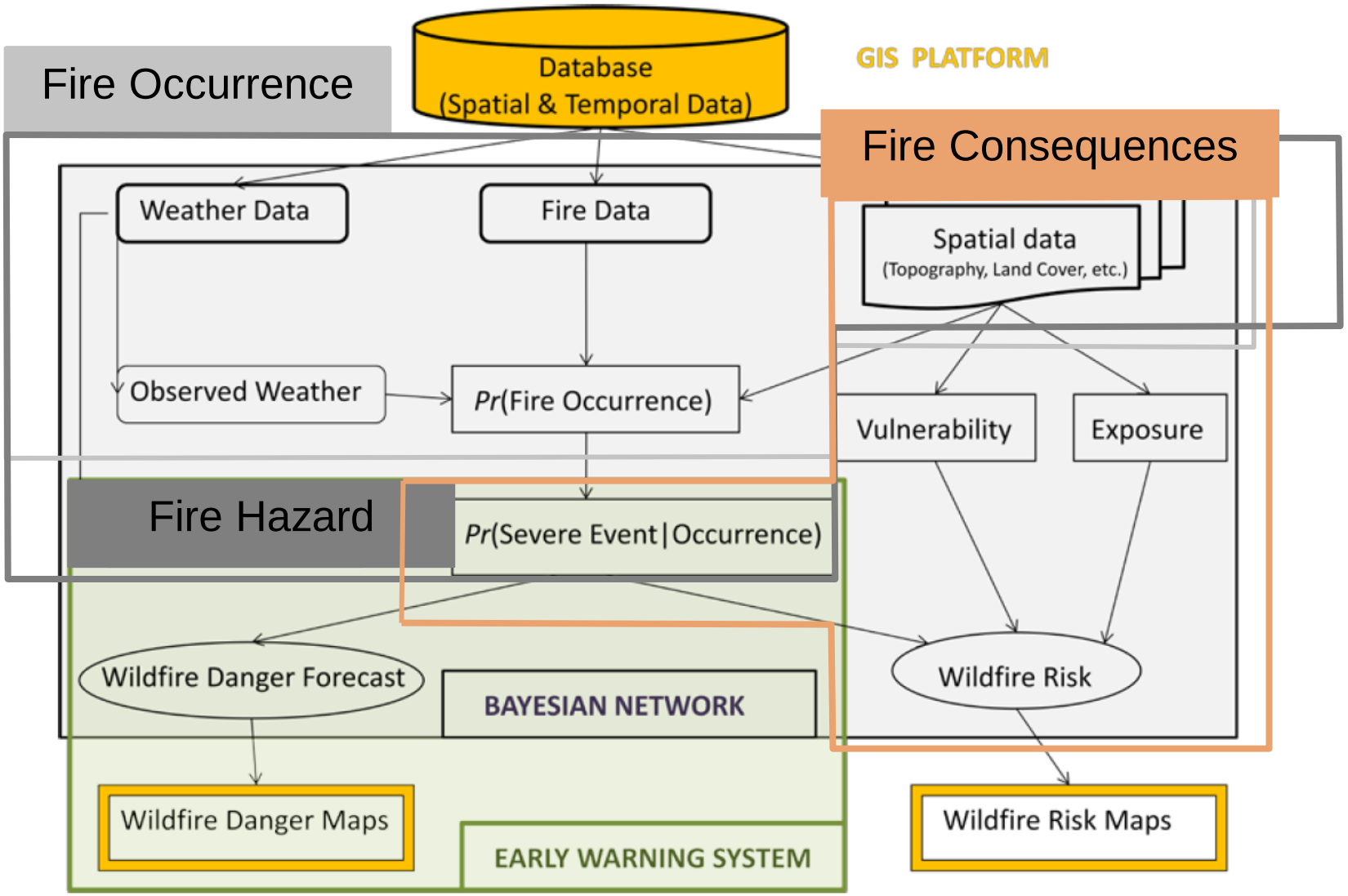
Quantifying Wildfire Risk - **Conceptual model**



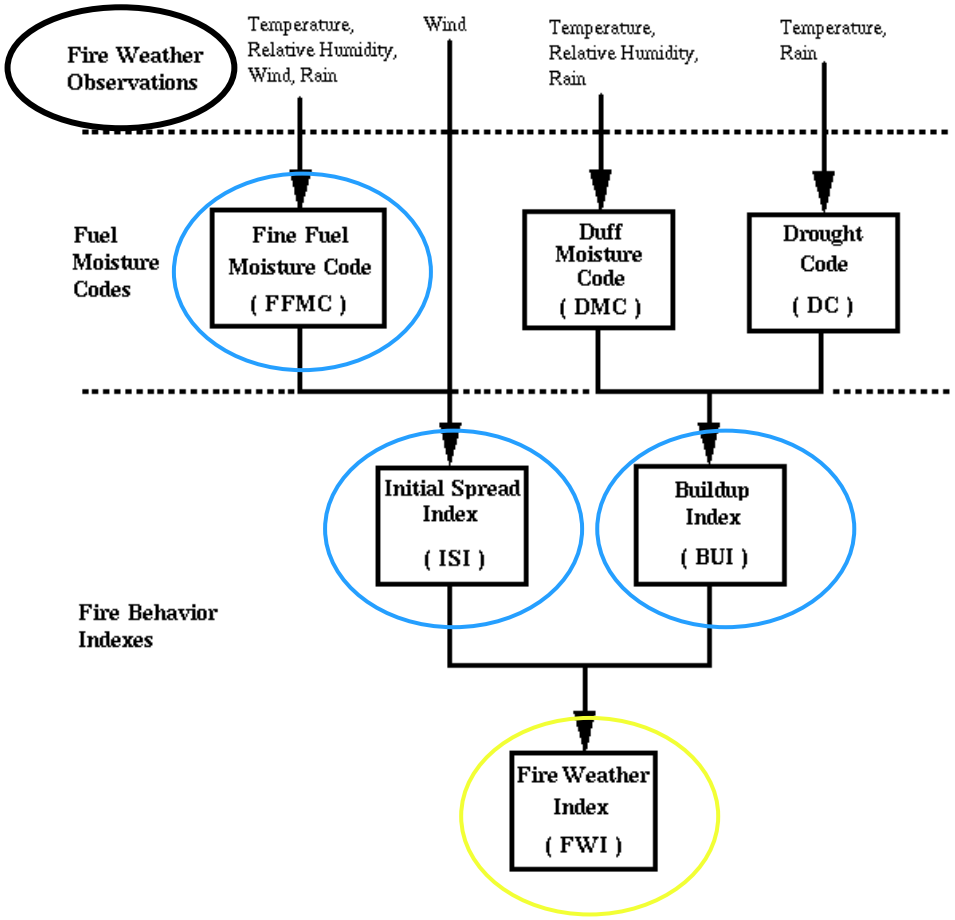
Quantifying Wildfire Risk - **Conceptual model**



Quantifying Wildfire Risk - **Conceptual model**

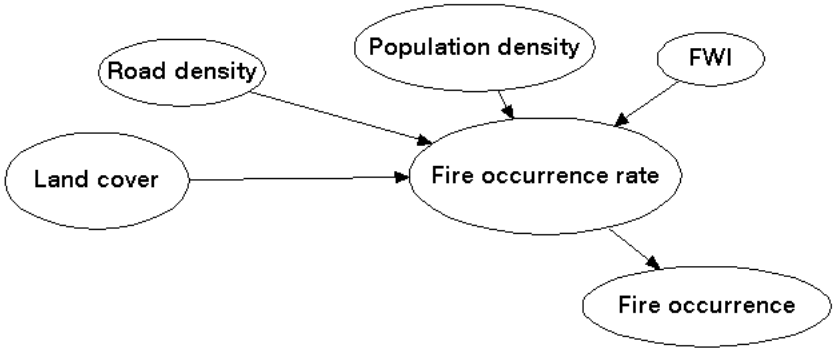


Canadian Forest Fire Weather Index System



Source: Natural Resources Canada, Canadian Forest Service

Fire occurrence model

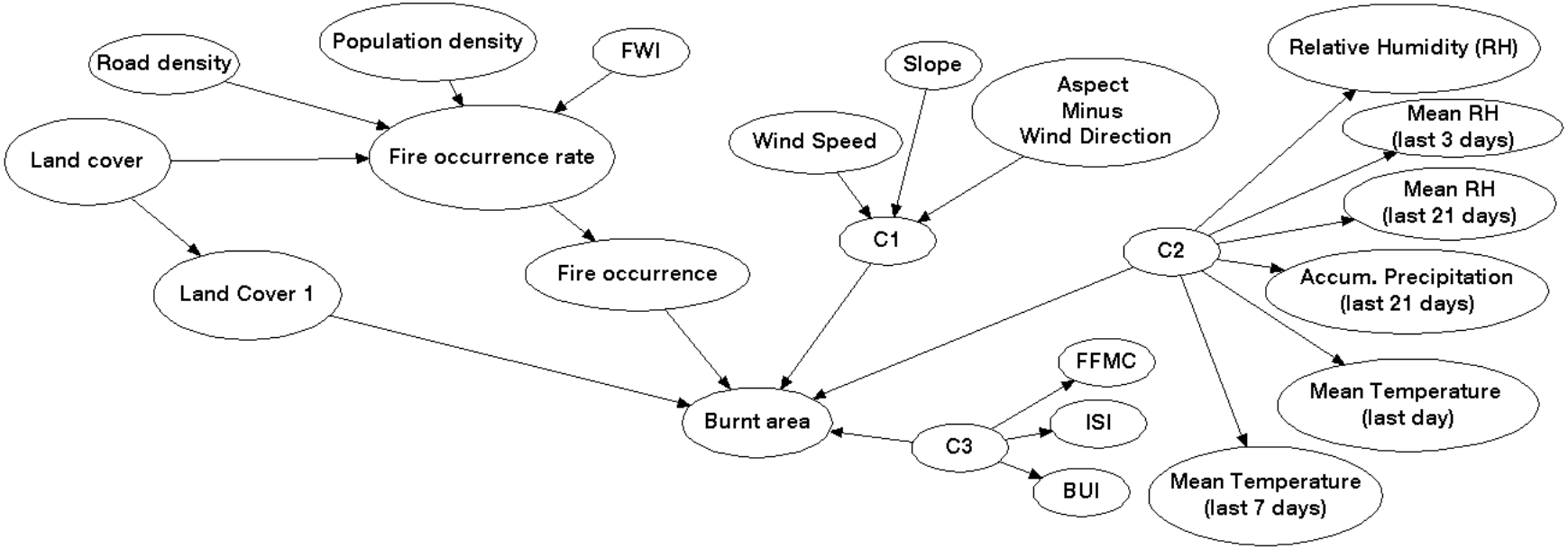


$$\lambda \left[\frac{\text{Nr.Fires}}{\text{day}\cdot\text{km}^2}\right]$$

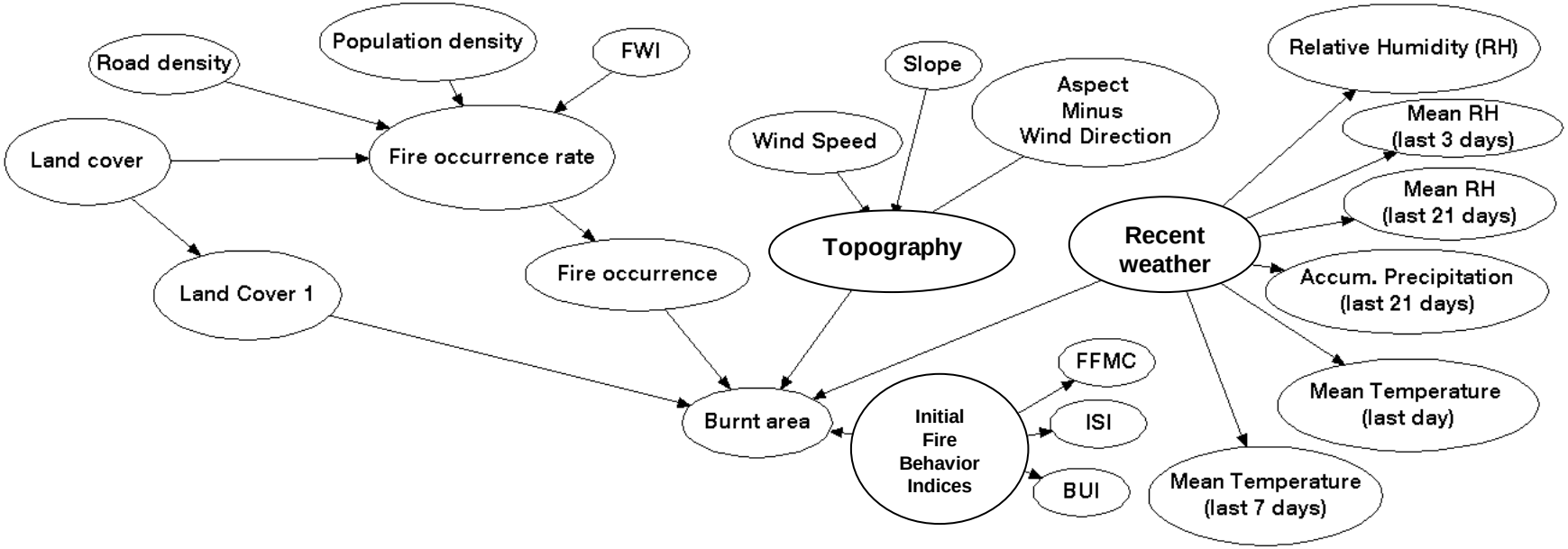
$$\log(\lambda) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k = \mathbf{x}^T \boldsymbol{\beta}.$$

$$\Pr(N = n|\,\lambda) = \frac{(\lambda\alpha)^n}{n!}\exp(-\lambda\alpha)\,, \qquad n = 0,1,2,\ldots$$

Fire hazard model



Fire hazard model

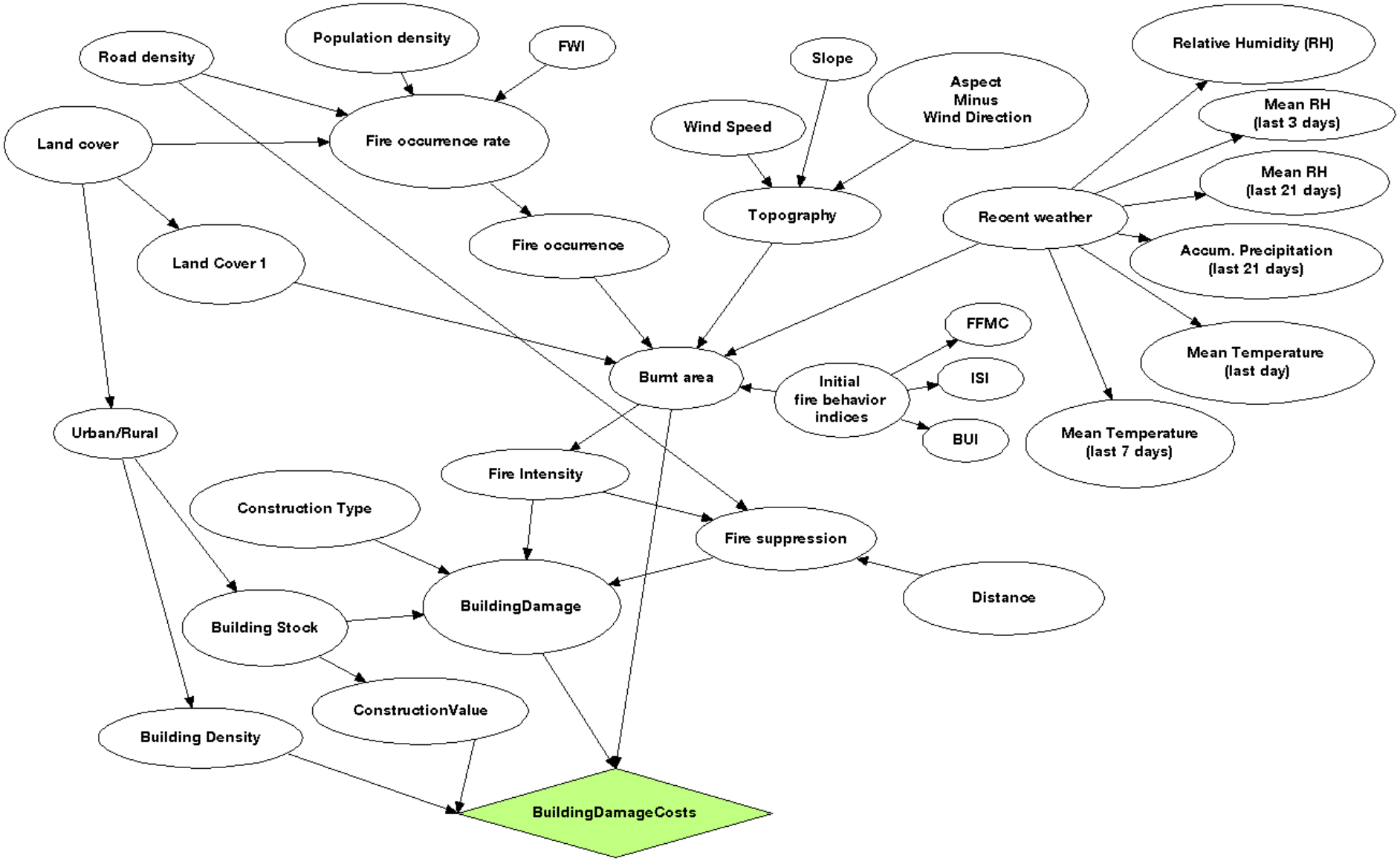


- Hidden variable can reduce the number of parameters required to specify a Bayesian Network
- Causalities of the model easier to understand and to communicate
- Parameter learning with Expectation-Maximation algorithm

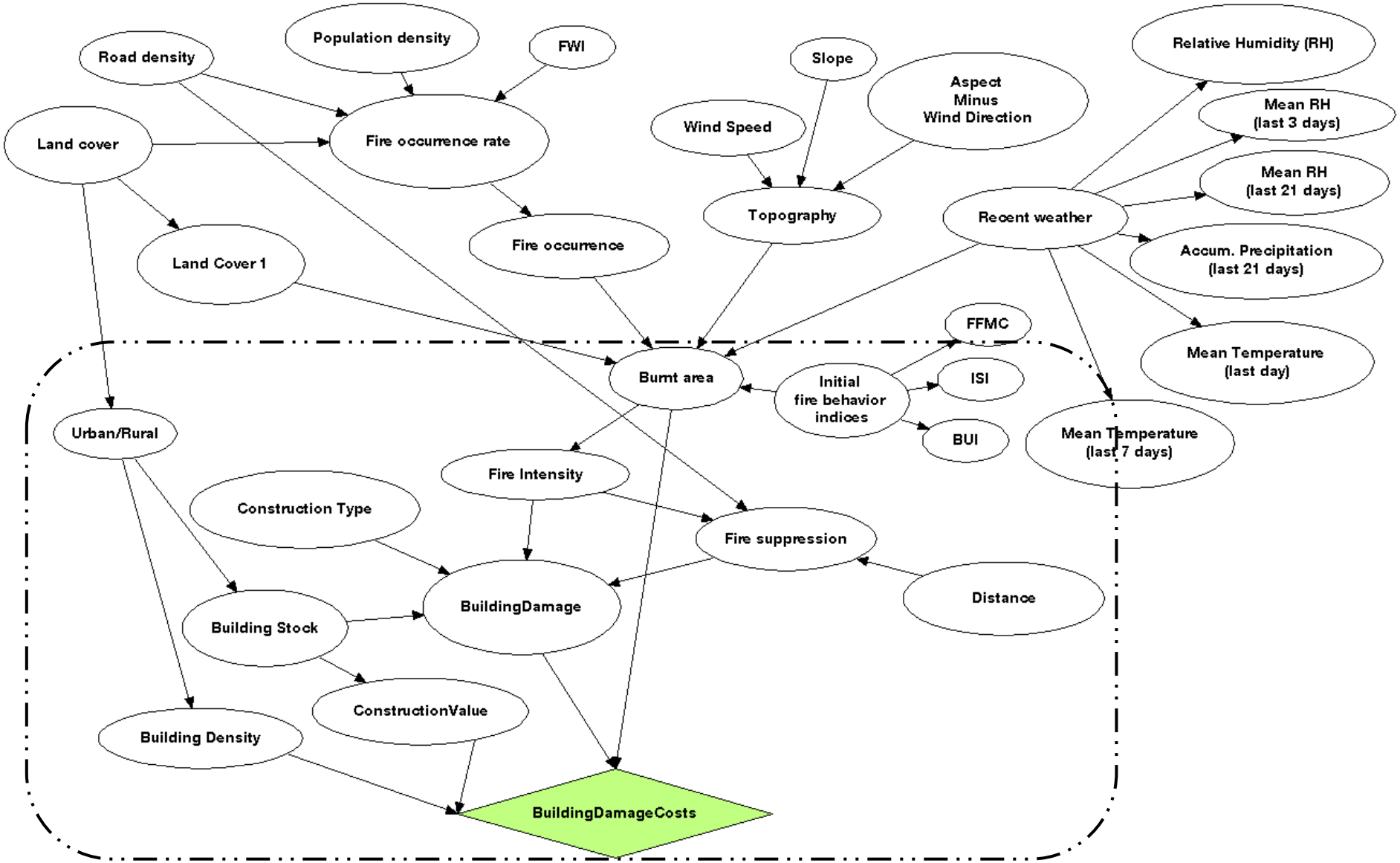
Two steps repeated iteratively until stopping criterion fullfilled

1. E-step : computation of the expected values of hidden variables (expectation step)
2. M-step: maximization of the parameter likelihood, using the expected values as if they were observed values
   (maximization step)

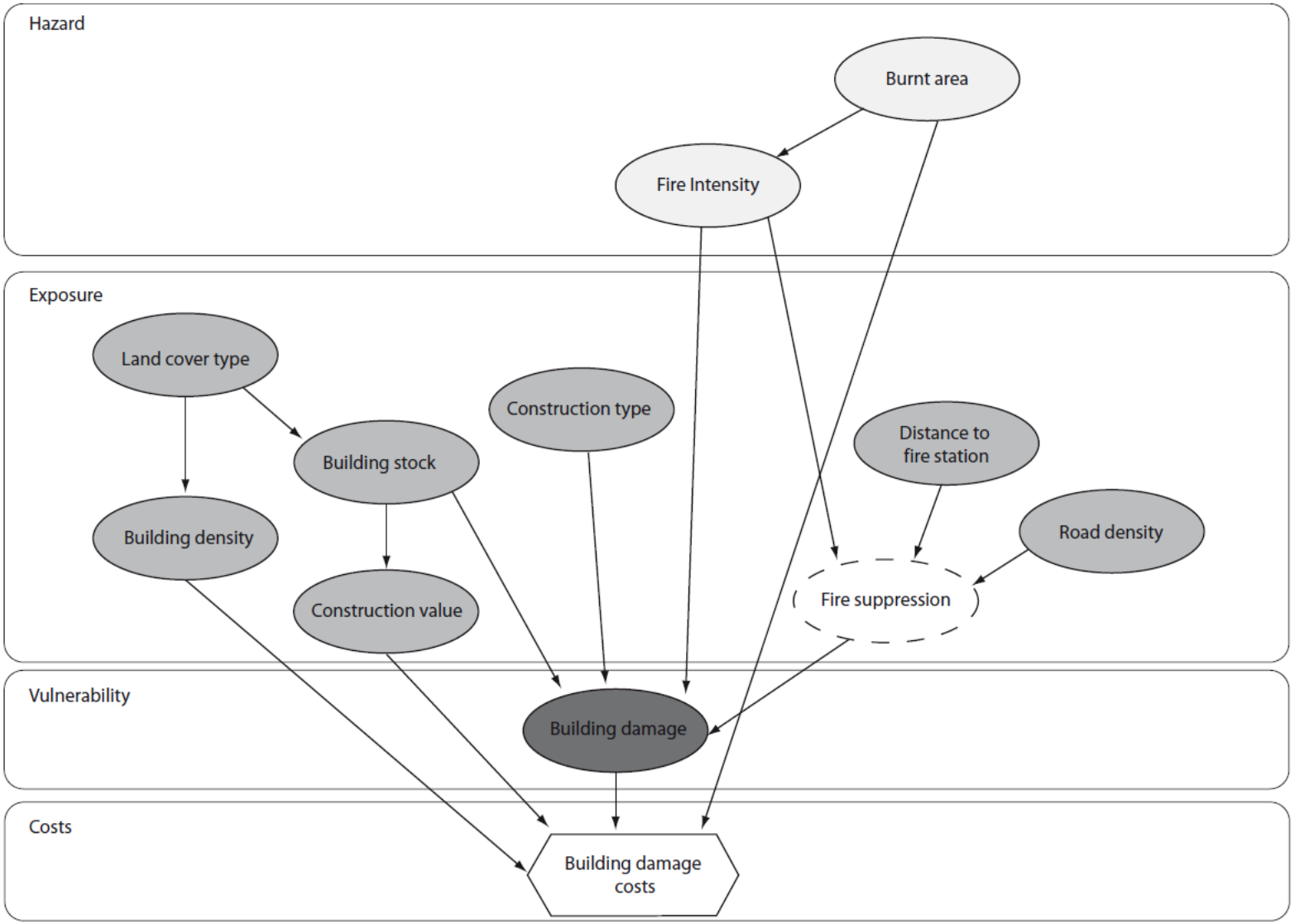
Fire risk model



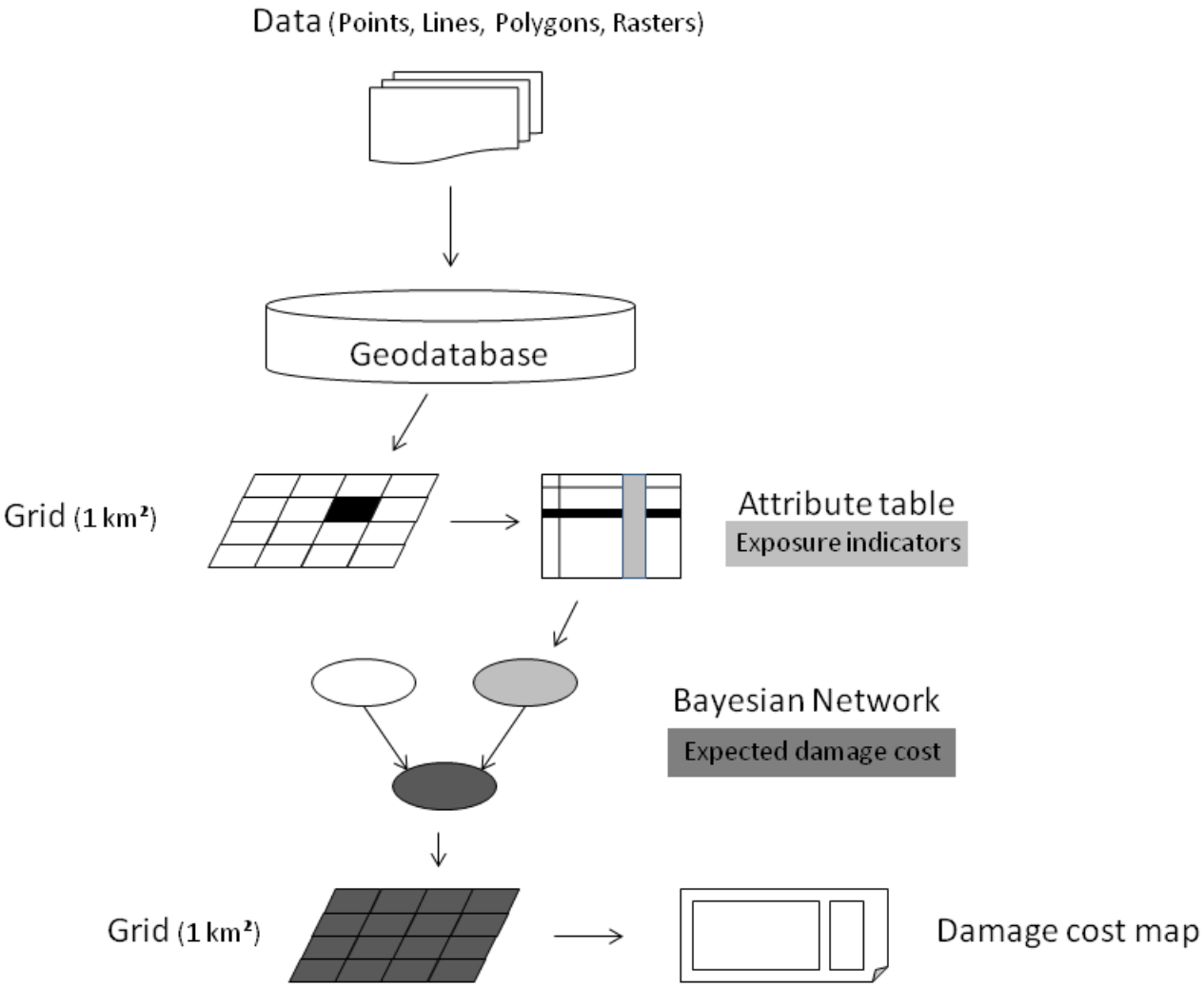
Fire risk model



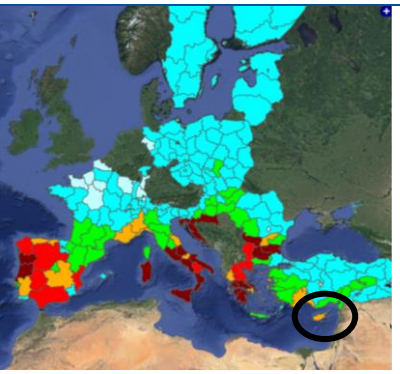
Building damage costs model

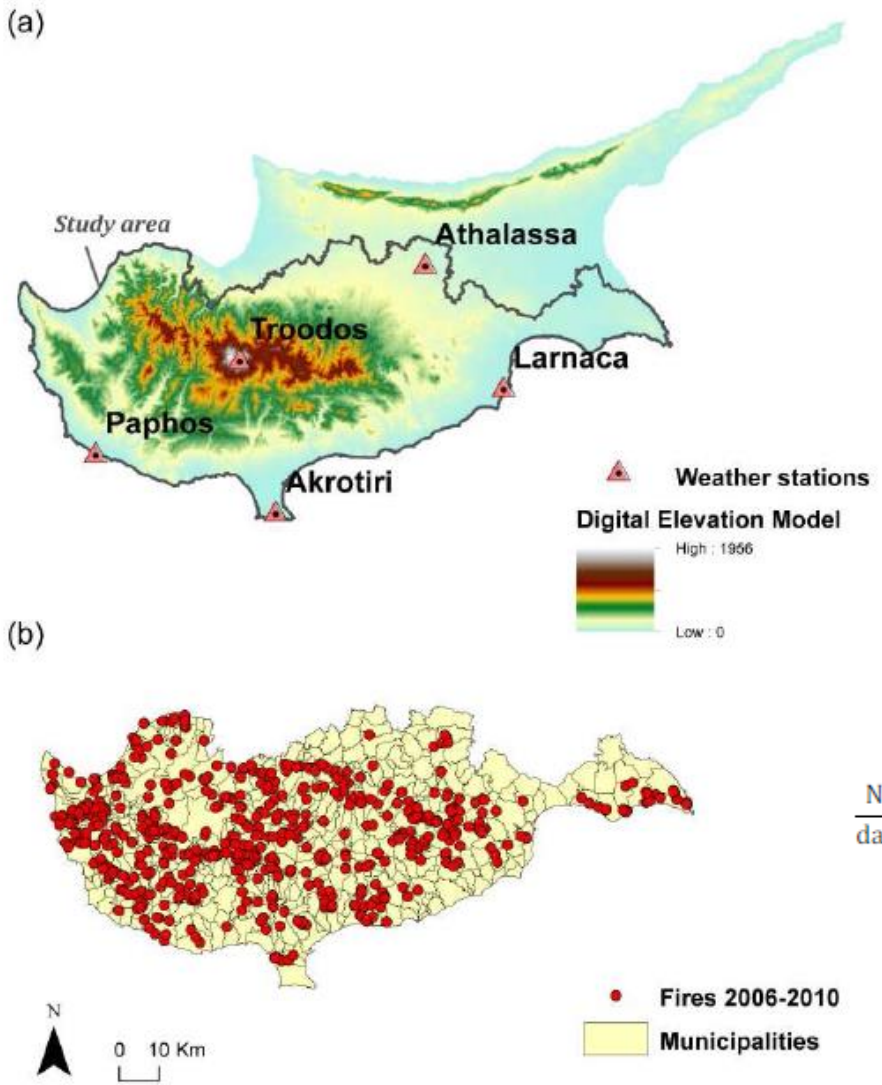


Linking BN to GIS



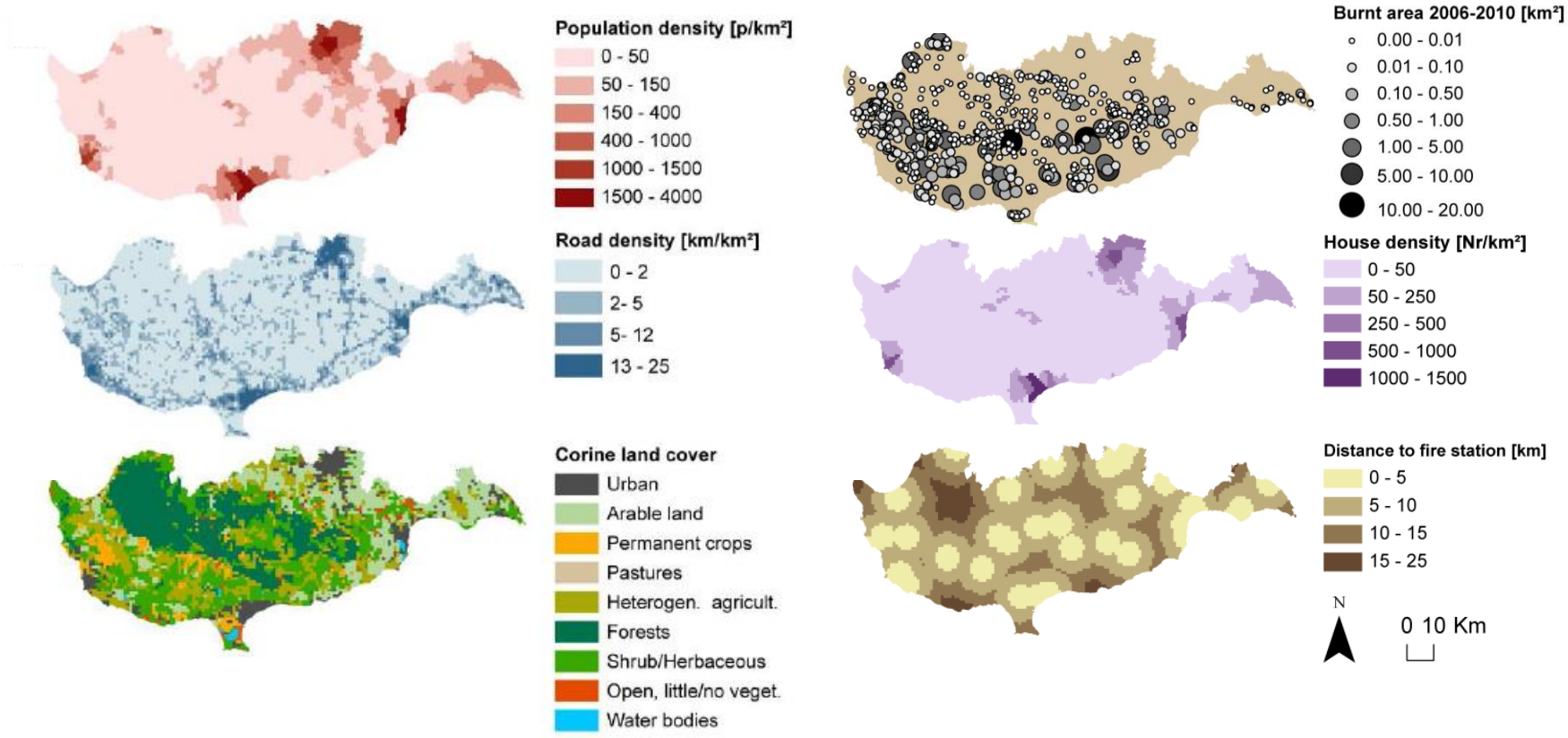
Test-bed area: Cyprus



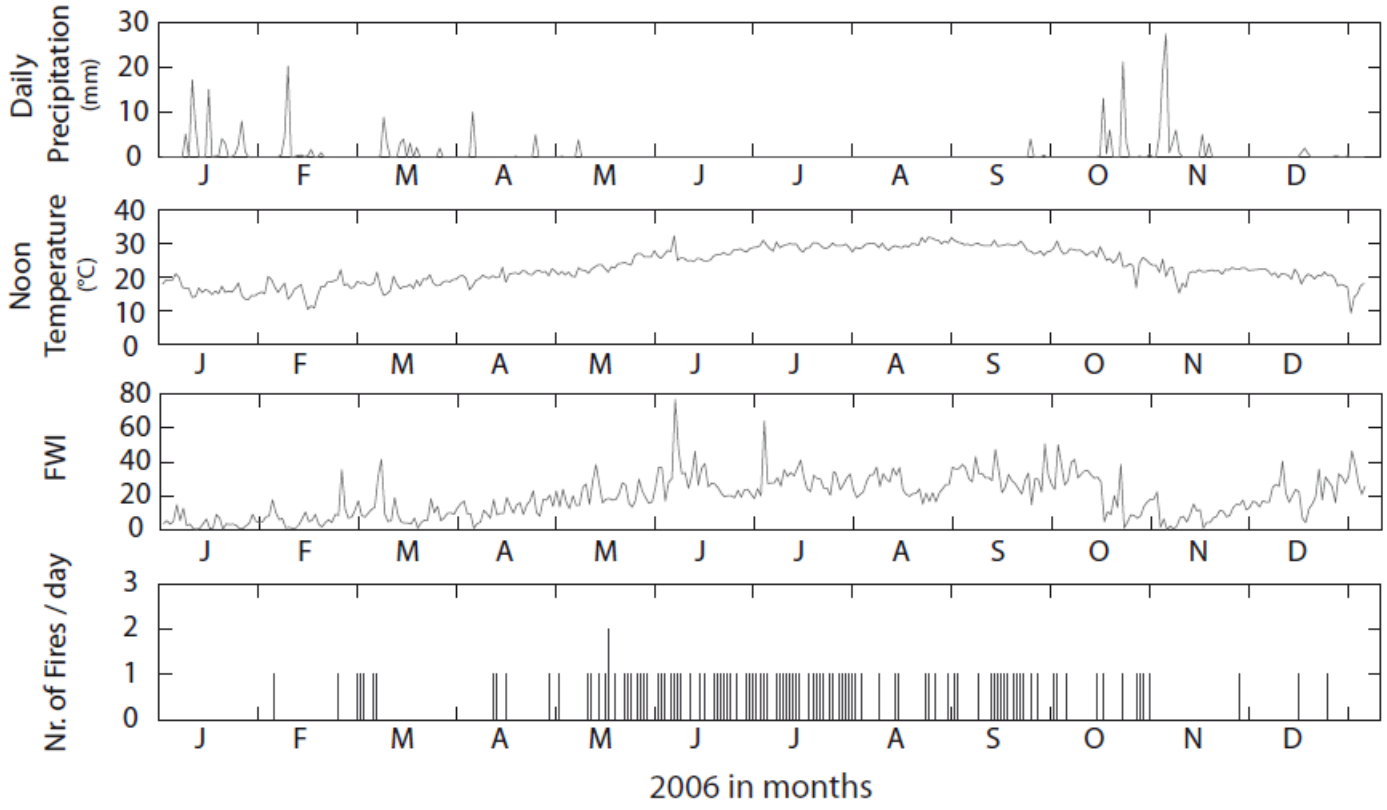


$$\frac{\text{Nr. Fires}}{\text{day} \cdot \text{km}^2} = \frac{616}{[(365 \cdot 5) + 2] \cdot 6078} = 5.5 \times 10^{-5}.$$

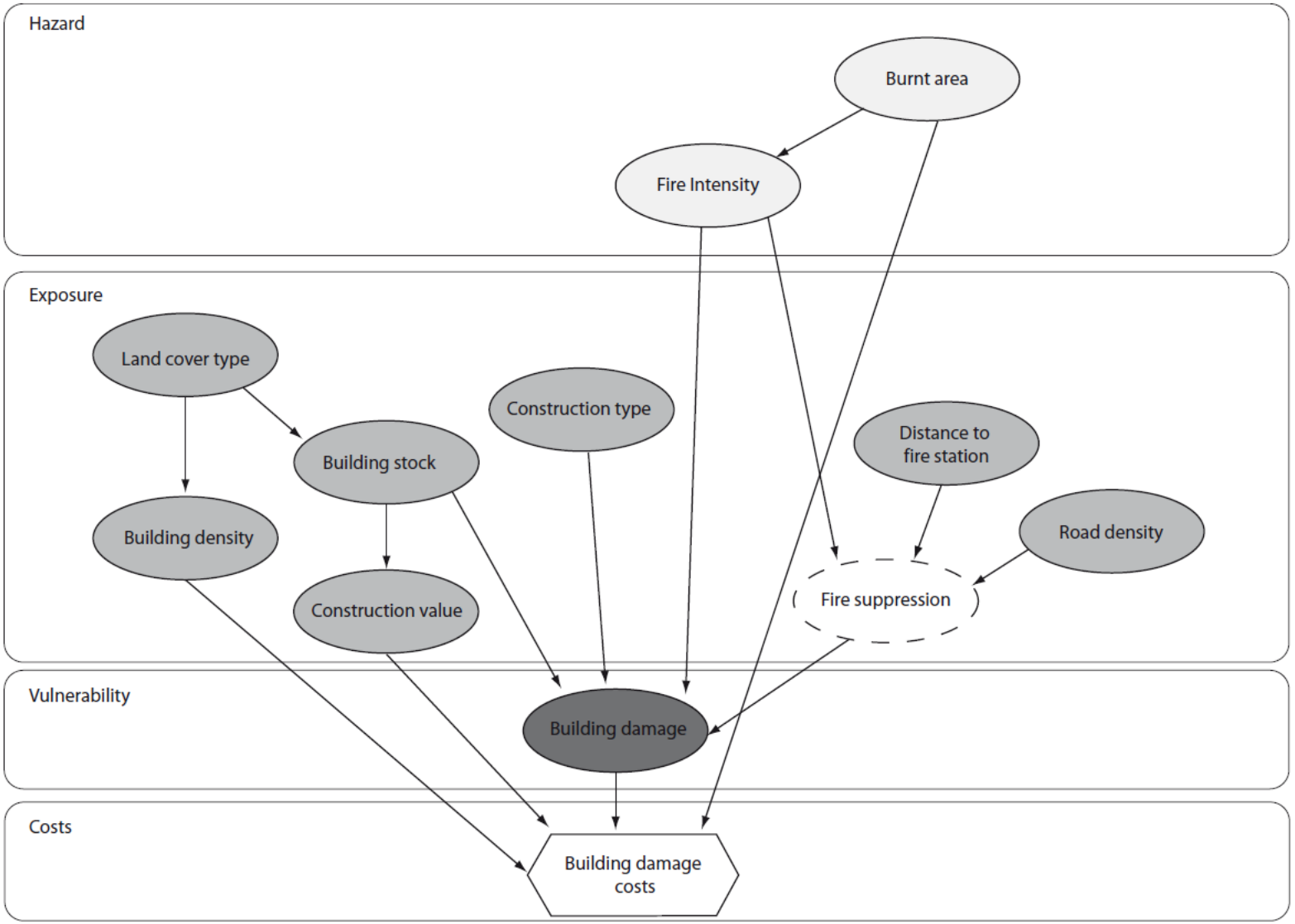
Test-bed area: Cyprus



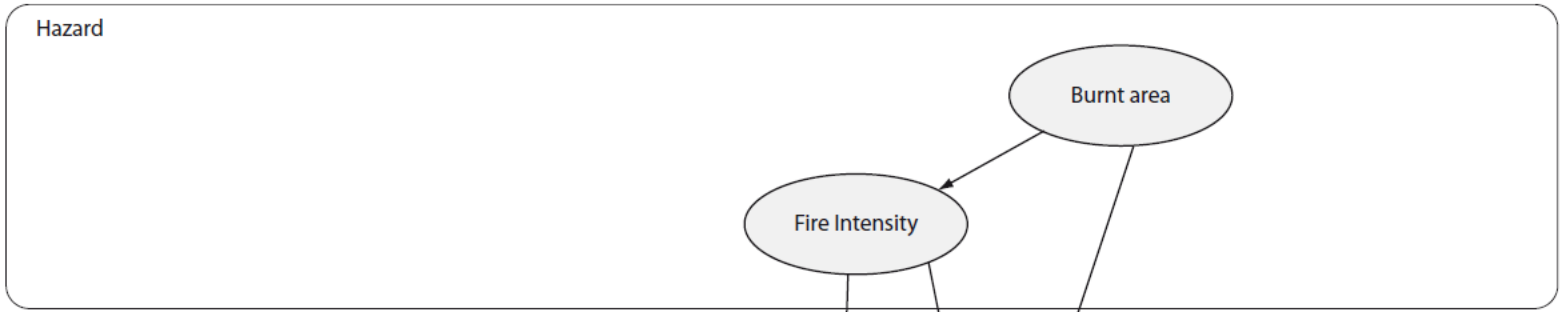
Test-bed area: Cyprus – preliminary data analysis



BN for building damage costs

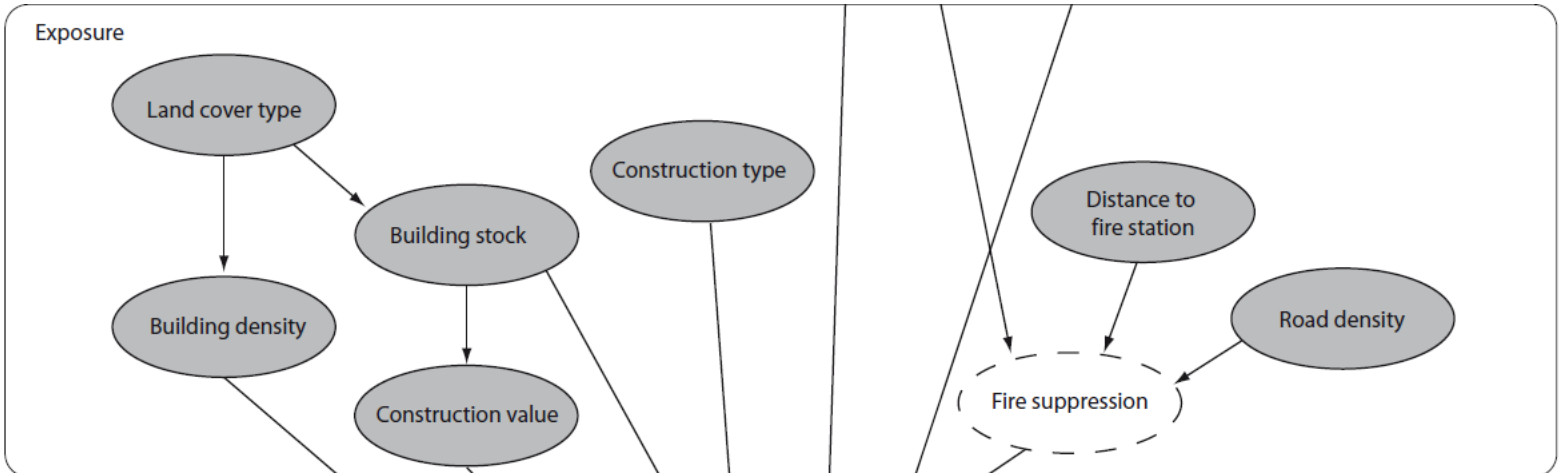


BN variables, data sources and CPTs (Hazard)



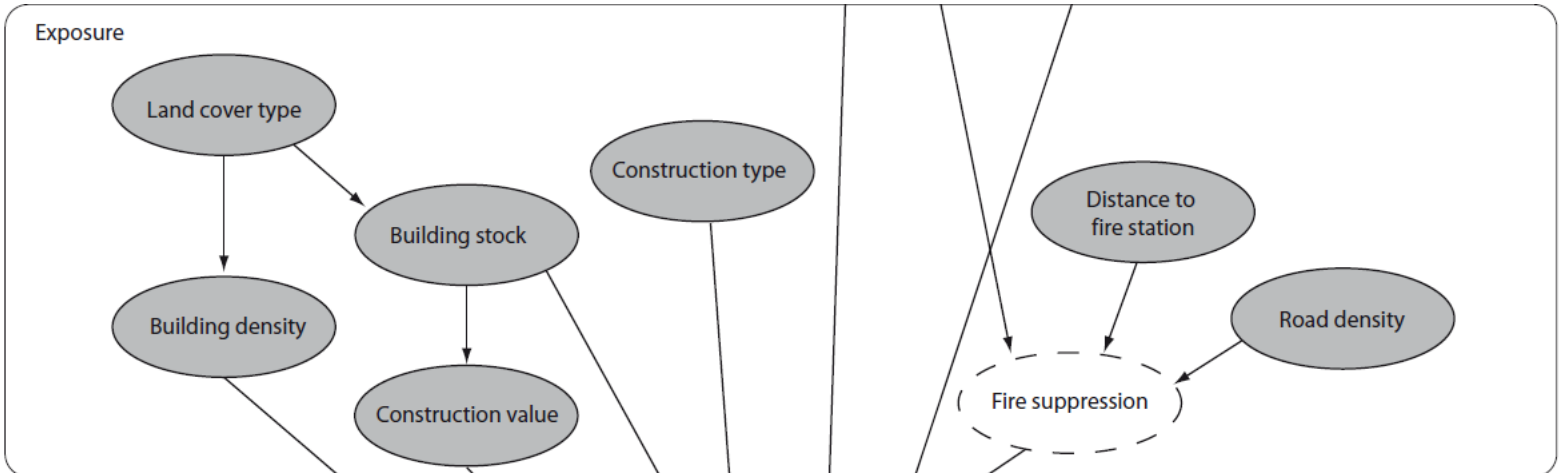
Variable	#states	States	Source of probability distribution
Fire intensity [kW/m]	4	0-346 346-1730 1730-4000 >4000	Classification based on (Sugihara et al. 2006), p.63 (Box 4.1, 4.2 'Heinselman's fire regimes') and p.68, (Ryan et al. 2012), p.56, Table A-1 ('Representative ranges for fire behavior characteristics') (Ryan 2002)
Burnt area [km²]	**7**	**0-0.01** **0.01-0.1** **0.1-1** **1-3** **3-6** **6-10** **10-15**	Historical fire events (2006-2010) Data source: Department of Forest, Ministry of Agriculture Cyprus

BN variables, data sources and CPTs (Exposure)



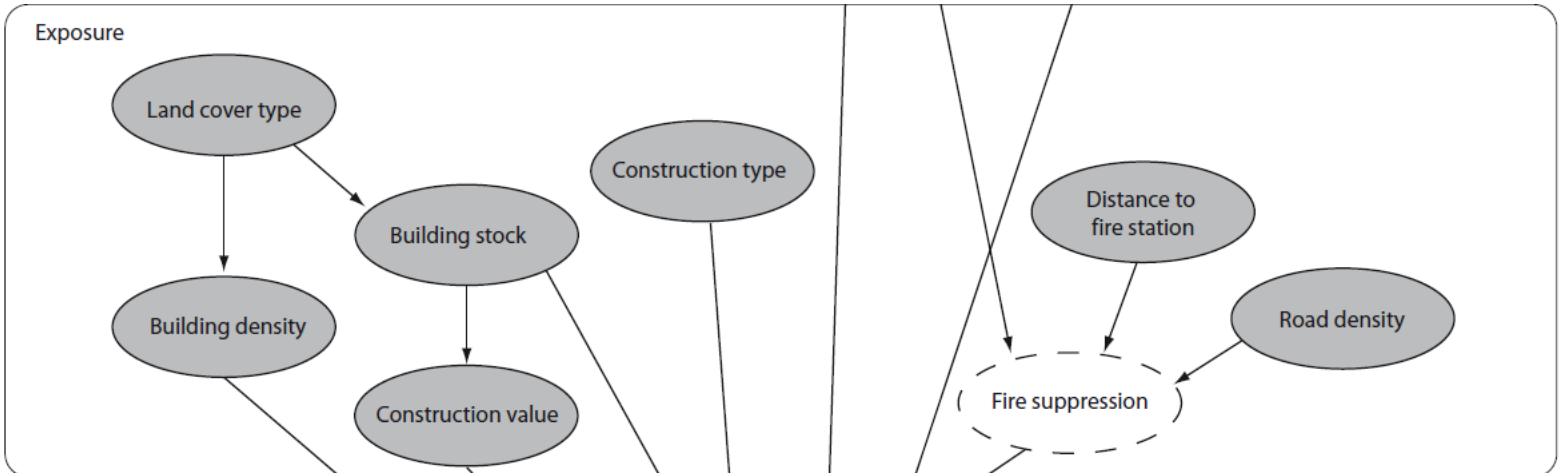
Variable	#states	States	Source of probability distribution
Road density [km/km²]	3	0-2 2-5 5-15	Edited from road map Data source: Open Street Map
Distance to next fire station [km]	3	0-5 5-10 10-30	Edited from fire station locations Data source: Cyprus Fire Service
Fire suppression	**2**	**poor** **successful**	Conditional on fire intensity based on: (Smith 2011) p.18, Table 4 ('Fire intensity limits for various suppression options') Conditional on road density and distance to fire station based on fire response times: (ECONorthwest 2007), Appendix C, page C-5

BN variables, data sources and CPTs (Exposure)



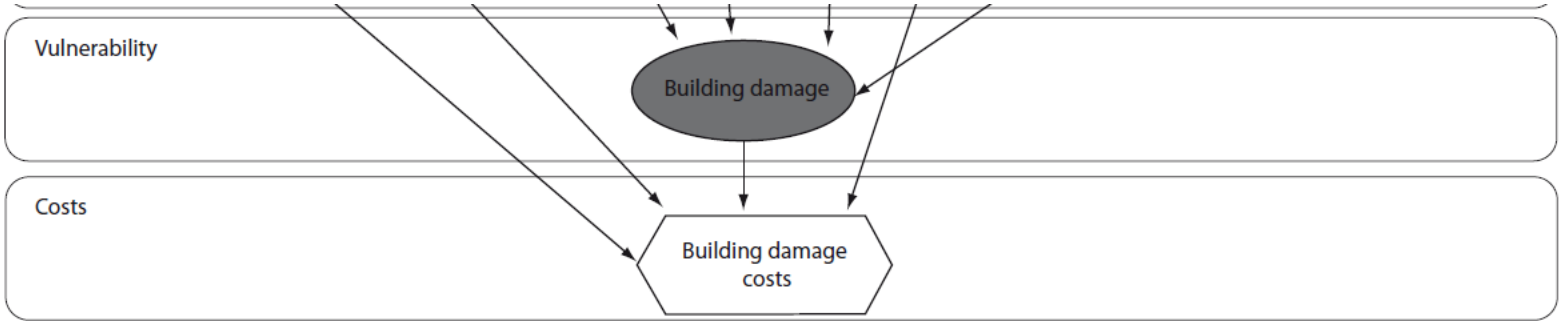
Variable	#states	States	Source of probability distribution
Land cover	2	Urban/Rural	Edited from Corine Land Cover map (version 13) Data source: European Environmental Agency
Building Stock	2	40s_25r_35a 70s_20r_10a	s: single houses r: row houses a: apartments (% percentage) Edited from data from (Cyprus Statistical Service 2010)

BN variables, data sources and CPTs (Exposure)



Variable	#states	States	Source of probability distribution
Construction Type	2	5t_15s_80i 10t_25s_65i	t: traditional house, stone/mud wall s: single brick wall/flat roof house i: insulated brick/inclined roof (% percentage) Edited from (Statistical Service Cyprus 2012) (Florides et al. 2001), p. 228 (Nemry, Uihlein 2008), p.A147 (Cyprus Statistical Service 2010)
Building density [Nr.dwelings/km²]	**4**	**0-1.8** **1.8-17.3** **17.3-152** **152-1318**	Based on Nr.dwellings (houses) statistics and municipality borders Data source: Statistical Service Cyprus

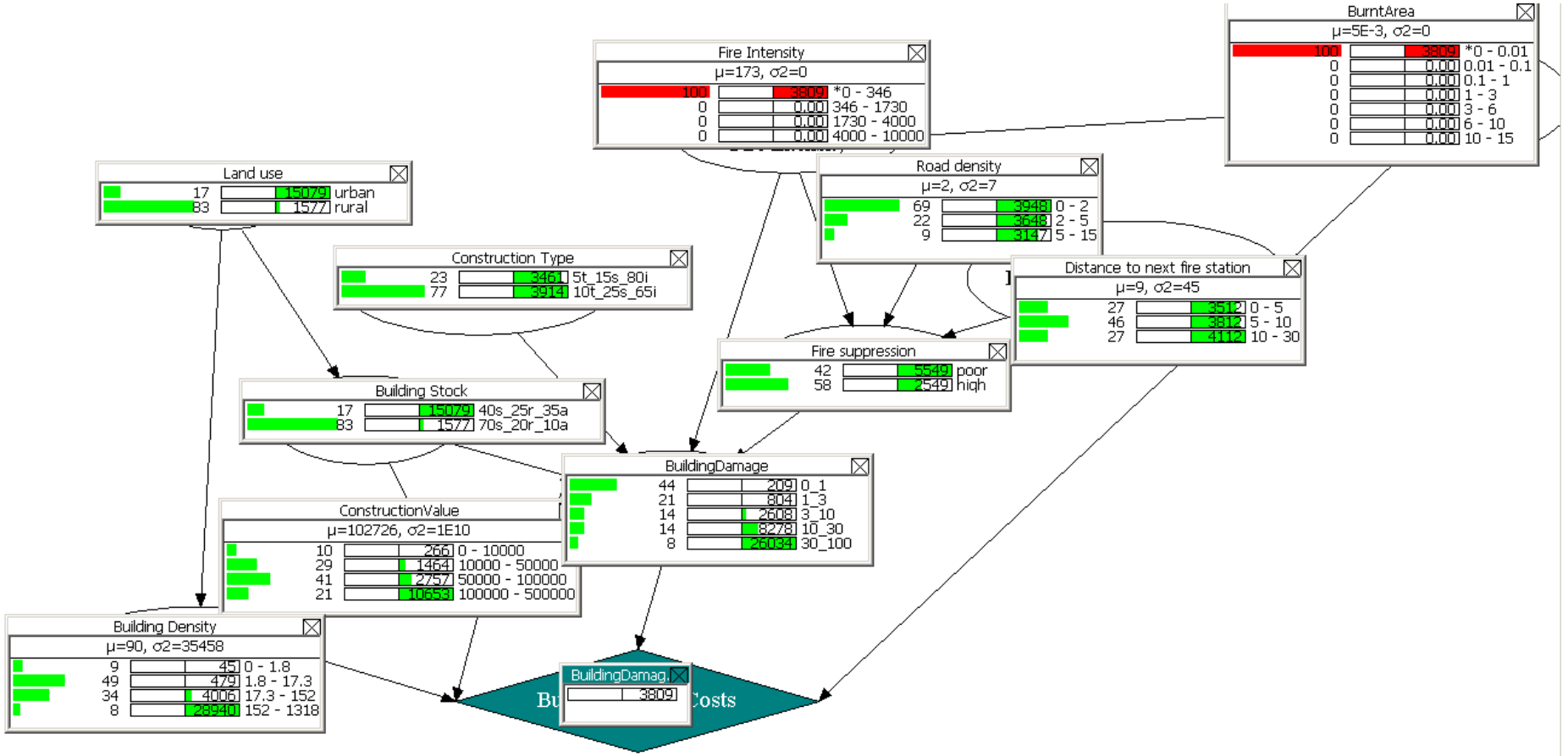
BN variables, data sources and CPTs (Vuln & Cost)



Variable	#states	States	Source of probability distribution
Building damage	**5**	**0-1** **1-3** **3-10** **10-30** **30-100**	Conditional on fire intensity based on fire severity evaluation of different fire intensities: (Sugihara et al. 2006), p.68 assumed minor for fire intensities<346 kW/m Conditional on construction type based on scoring from: (Oregon Department of Forestry 2004), p.11-12 (ECONorthwest 2007), Appendix C, page C-8 Conditional on building stock (defensible space) based on scores from: (Long, Randall 2004), p.6-7 (Oregon Department of Forestry 2004), p.11-12
Construction value [x 10^3 €]	4	**0-10** **10-50** **50-100** **100-500**	Customized to Building Stock based on mean value and range for each building type, data from: (Cyprus Statistical Service 2010), p. 160 (Table 14: Building permits authorized by type of project 2010)

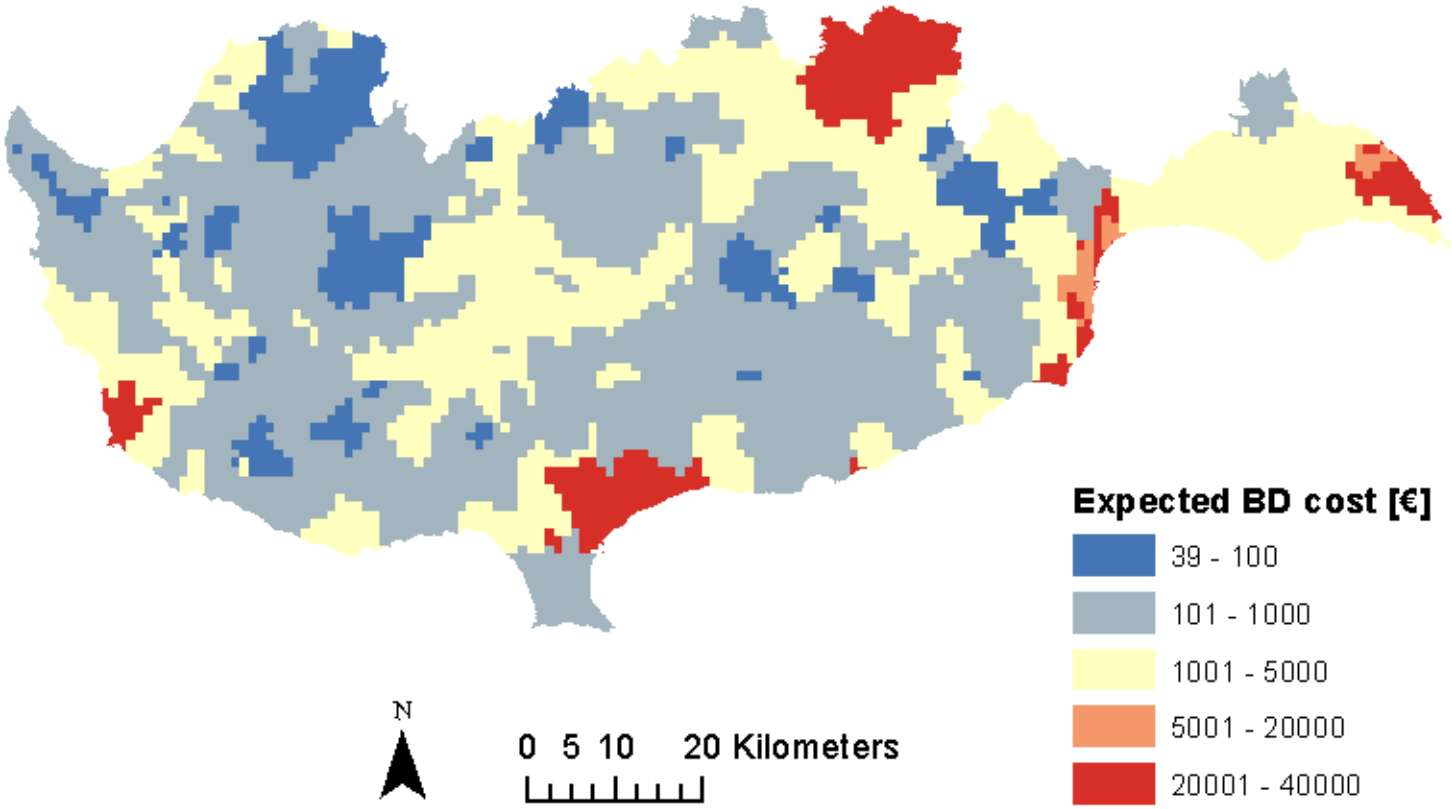
Results

BN model estimating building damage cost [€] with evidence given on burnt area [km²] and fire intensity [kW/m]



Results

Expected building damage cost [€] conditional on burnt area = 0-0.01 km² and fire intensity= 0-346 kW/m

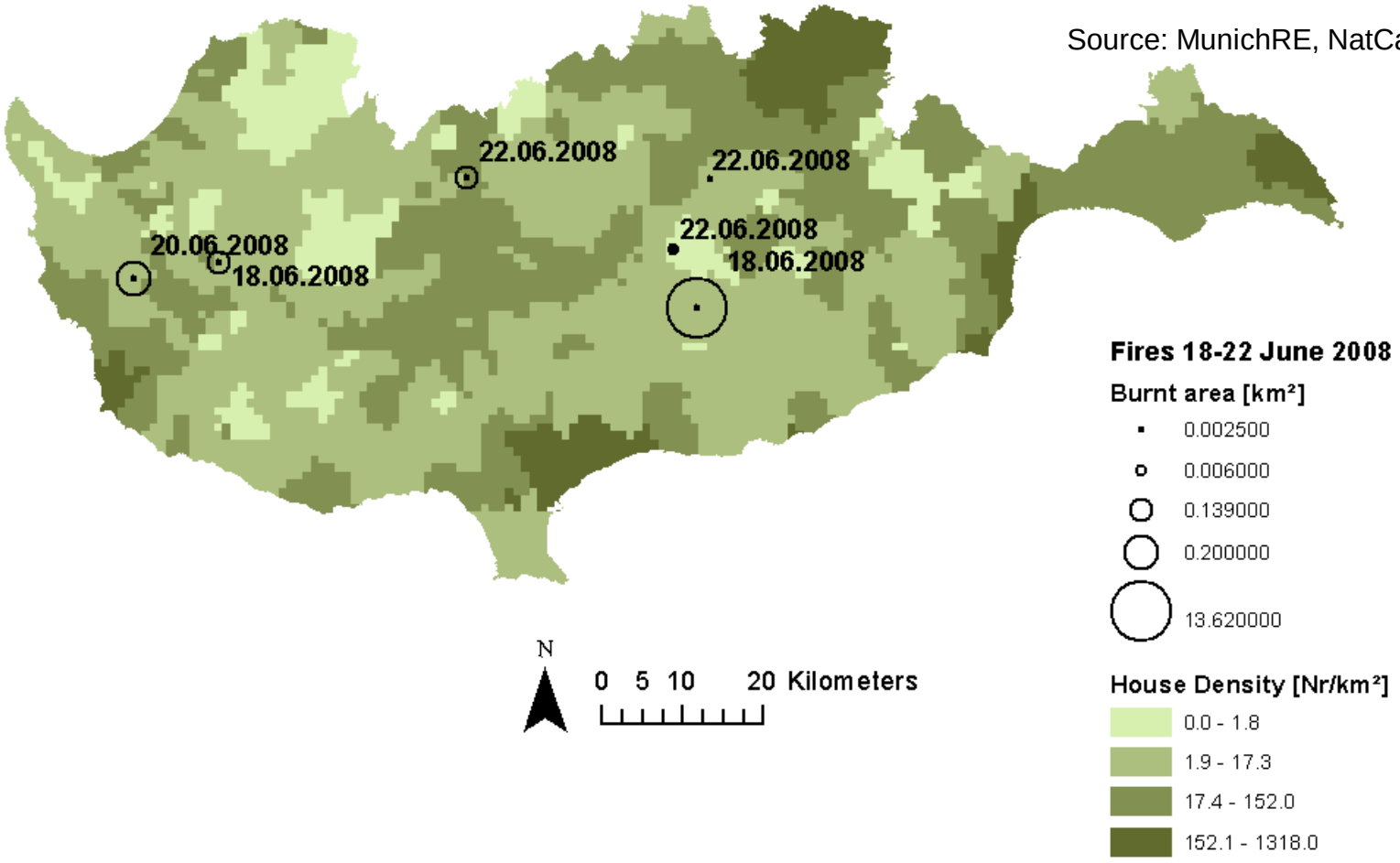


Results

Fire period: 18-22 June 2008

18-22.06.2008
Forest fires. 5 houses destroyed. Farmland affected. Injured: 5 firefighters.

Source: MunichRE, NatCat Service



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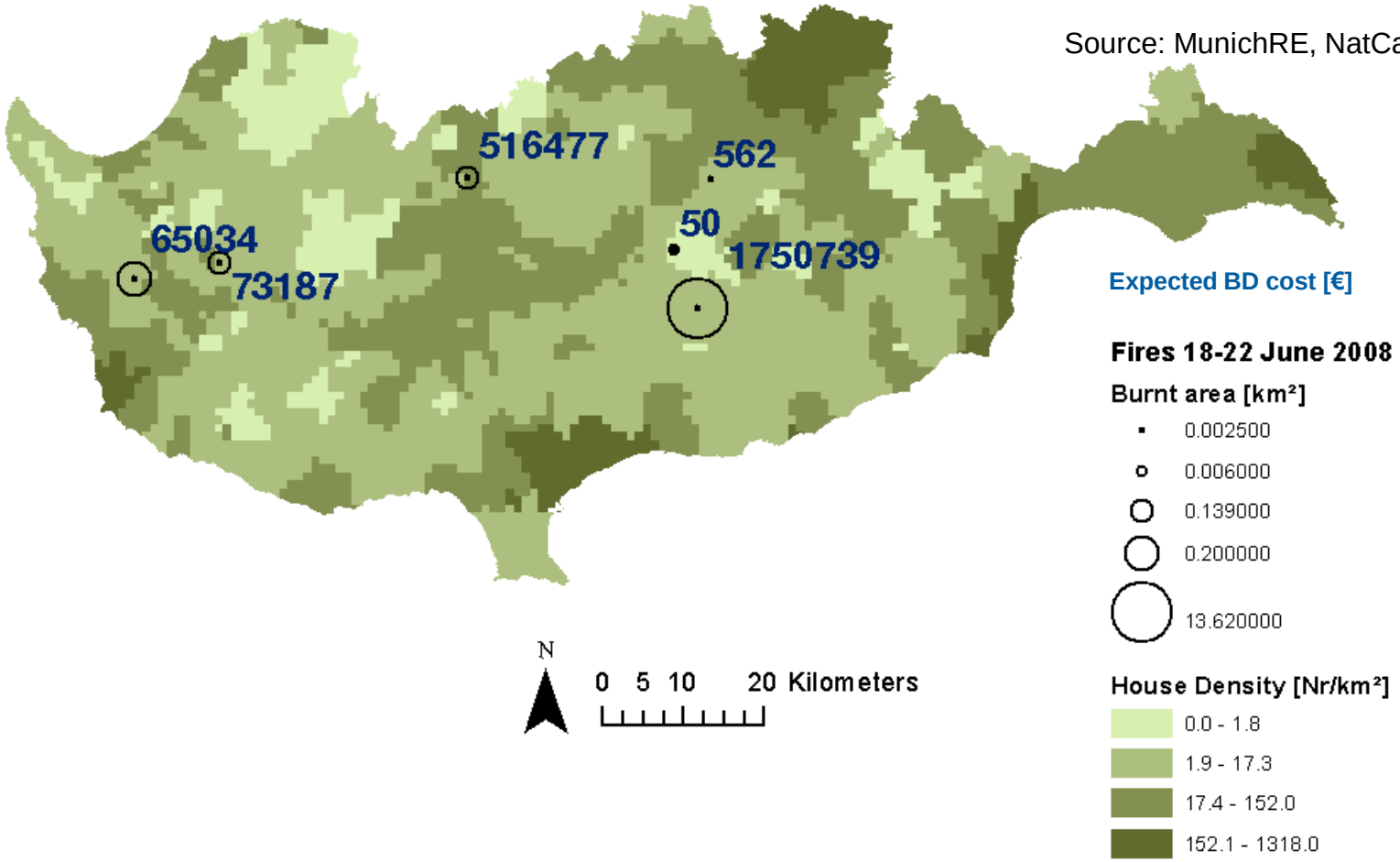

Conclusions

- **BN models** to predict **Wildfire risk** in the meso scale (1km²)
- BN model for **building damage cost due to wildfires** in the meso scale (1km²)
- **BN and GIS coupling** provided building damage cost maps with respect to different hazard characteristics
- **Uncertainties due to building portfolios** in the meso scale rather than individual buildings
- **Airborne fire suppression** here neglected, expected to reduce resulting damages
- **Sensitivity analysis** and additional **model validation** with published data as next steps
- Model can be **expanded** to estimate other consequences (life safety, agriculture damages, etc.)

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