



## Appendix A: Acronyms and terminology

Table below shows acronyms and terminology.

Table 1. Acronyms and terminology.									
acronym	description								
BGML	Button Grass Moorland Fire Index								
BoM	Bureau of Meteorology								
CuringRF	Curing data modelled based on satellite image								
DEM	Digital Elevation Model								
DE (DroughtEastor)	Drought Factor, which is calculated from Soil Dryness Index (SDI) and								
DF (DroughtFactor)	precipitation in the last 20 days								
FDI	Fire Danger Index								
FFDI	McArthur Forest FDI								
flammability	Likelihood of fire								
FN	False Negative								
FP	False Positive								
GFDI	Grassland Fire Danger Index								
PostGIS	An extension of the relational database management system								
RH	Dolotivo humidity								
(RelativeHumidity)	Relative humidity								
SDI	The required precipitation for saturation of soil								
(SoilDrynessIndex)	The required precipitation for saturation of som								
sensitivity	Degree of potential damage from a single fire on the ecology in the								
sensitivity	vegetation community								
TN	True Negative								
TP	True Positive								
WindDir	Inward wind direction. Used only for WindNinja's parameter								
WindDirWN	Inward wind direction generated by WindNinja								
WindMag	Wind Speed (1 knot = 1.85 km/h). Used only for WindNinja's parameter								
WindMagWN	Wind Speed generated by WindNinja								

Table 1. Acronyms and terminology.

### **Appendix B: Data structure**

Data sources for the prototype consist of both spatial and non-spatial data (Error! Reference source not found.). Spatial data are categorized into raster and vector. In this prototype, raster data consists of three types of format, ESRI ASCII, netCDF and TIFF [1,2]. DEM for the study area is distributed as ESRI ASCII format by ListMap [3] while various forecast weather data, such as wind direction and temperature, are provided by Bureau of Meteorology (BoM) and formatted as netCDF.

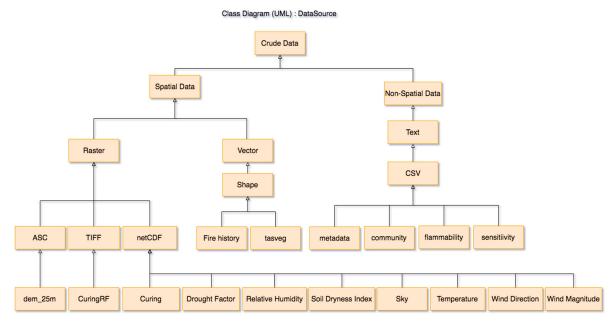


Figure 1. Category of crude data (UML class).

Although curing data is included in the initial forecast weather data provided, the ground observations which are modelled based on satellite imagery are available in TIFF format as "CuringRF" with finer resolution than the other climate data (Error! Reference source not found.). Therefore, the "CuringRF" is ingested to predict the fire behavior in this prototype.

raster type	pixel size (meter)
CuringRF	$453.78 \times 453.78$
Forecast weather	2322.70 × 2322.70
Topography	$25.00 \times 25.00$
Wind generated by WindNinja	308.68 × 308.68

Table 2. Resolution by raster type.

In terms of vector data, the fire history and vegetation type (TasVeg 3) in Tasmania are ingested to model fire behavior. With regard to non-spatial data types, additional vegetation information [4] supporting vegetation types have been converted from comma-separated value (CSV) files into the database. These data include descriptions of vegetation communities including flammability and sensitivity so that this community file allows identification of which areas include flammable vegetation. However, some data were missing in the vegetation community file against the latest vegetation vector file. The missing data were, therefore, manually supplemented with flammability data from ListMap [3].

In addition, wind magnitude and direction are refined by WindNinja, which is a diagnostic tool allowing generation of topographically sensitive files with various file types, such as ascii, shape file and pdf [5,6].

Note: When WindNinja is executed, a pdf file can be optionally generated to visualize the wind behavior along the topography. For example, the direction and strength of wind are depicted in various colors of arrows in **Error! Reference source not found.** and the directions of arrow, that is, wind directions, are changed on the ridges because the winds tend to detour due to the topography. On the other hand, the wind levels off on the plain indicated light color in the figure.

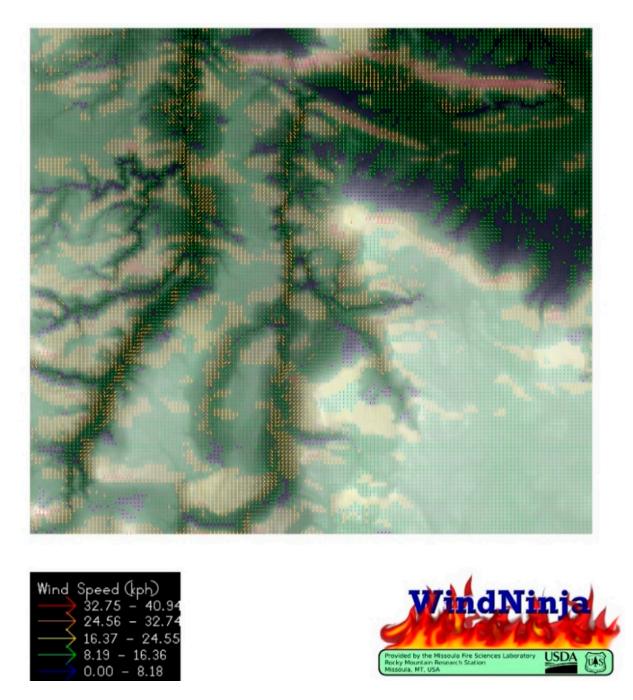


Figure 2. Visualised wind behaviour by WindNinja.

**Error! Reference source not found.** displays the relationship of TasVeg, flammability and sensitivity in the prototype's database, wildfire.

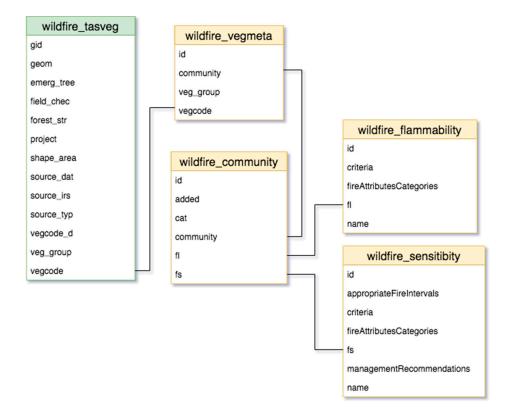


Figure 3. Table relationship for TasVeg, flammability and sensitivity.

In the wildfire database, raster data are stored in PostGIS with metadata as part of the record in wildfire\_raster with names, and wildfire\_band (Error! Reference source not found.; Error! Reference source not found.).

field name	field type	constrain
id	integer	NOT NULL
name	character varying(16)	NOT NULL
rast	raster	NOT NULL
metadata	text	NOT NULL

Table 3. Meta information of database table, wildfire\_raster.

 Table 4. Meta information of database table, wildfire\_band.

field type	constrain
integer	NOT NULL
timestamp with time zone	
text	NOT NULL
Integer	NOT NULL
	integer timestamp with time zone text

The records in table raster consist of both topographical and climate data as below.

name	type	unit	description
Curing	Climate percentage		Flammability from the estimation of grasses (Not
			Used)
DEM	Topography	meter	Digital Elevation Model
DroughtFactor	Climate		Drought Factor calculated from SDI and
-			precipitation in the last 20 days

Table 5. Records in wildfire\_raster table.

RelativeHumidity	Climate	percentage	Relative humidity
Sky	Climate	percentage	Cloud cover
SoilDrynessIndex	Climate	mm	The required value of precipitation for saturation
			of soil
Temperature	Climate	C°	
WindDir	Climate	degree	Inward wind direction. Used only for
		-	WindNinja's parameter
WindMag	dMag Climate kn		Wind Speed (1 knot = 1.85 km/h). Used only for
			WindNinja's parameter
WindDirWN	Climate	degree	Inward and topologically sensitive wind
			direction. Generated by WindNinja
WindMagWN	Climate	Km/h	Topologically sensitive wind speed generated by
			WindNinja
CuringRF	Climate	percentage	Observed data from satellite image and ground-
-		-	base
			WindNinja Observed data from satellite image and groun

# Appendix C: Study area

Table 6. Proportion of flammability of vegetation in Lake Mackenzie Road Fire cited in [4].

flammability	criteria	lost area (km²)	%
Very High	Immediately burnable all through the year in mild weather	2.80	0.87
(VH)	after more than a week without precipitation		
High (H)	Burnable when dry, usually between the beginning of	65.02	20.23
	spring to early autumn		
Moderate (M)	Will burn in strong winds and mild conditions after at least two weeks without precipitation	204.21	63.52
Low (L)	Will burn when FFDI > 40 under drought, i.e. lack of precipitation for more than four weeks	27.71	8.62
Not Rated (N)		21.76	6.77
Total		321.50	100.0

Table 1: Proportion of sensitivity of vegetation in Lake Mackenzie Road Fire cited in [4]

sensitivity	criteria	lost area ( <i>km</i> <sup>2</sup> )	%
Extreme (E)	Non-recuperative or long term, i.e. more than semi-millennium to recover from single fire	4.61	1.43
	damage		
Very High (VH)	50 to 100 years to recover from single fire	76.90	23.92
	damage		
High (H)	At least 30 years to recover the structure from single fire damage	145.54	45.27
Moderate (M)	15 years to recover at least	30.05	9.35
Low (L)	Less than 10 years to recover	42.64	13.26
Not Rated (N)	-	21.76	6.77
Total		321.50	100.0

Appendix D: Pseudo code

```
# See prediction (figure in Appendix: Flowchart - prediction)
If reset=True Then
    clearEstimation()
    polygon = firstEstimtion()
Else
    polygon = lastEstimation()
End If
Loop until limit
    neighbors = polygon.getNeigbhours()
    neighbor = firstNeigbhour()
    # See estimateAdjacencies() in Appendix: Flowchart - prediction
    Loop until end of neighbors
         # see estimateTime() in Appendix: Flowchart - estimate time ingesting parameters and
selecting FDI
         vegetation = getVegetation()
         climate = getClimate()
         topology = getTopology()
         If any data is invalid, Then
             Skip this neighbor
         End If
         newElapse = FDI(neighbor)
         If newElapse < neighbor.elapse Then
             neighbor.elapse = newElapse # replace with new one
         End If
         neighbor = nextNeighbor()
    End Loop
    polygon = nextEstimation()
End Loop
```

Figure 4. Pseudo-code: prediction.

# Appendix E: Flowcharts, UML diagrams and supporting figures

This section displays various figures supporting the methodologies.

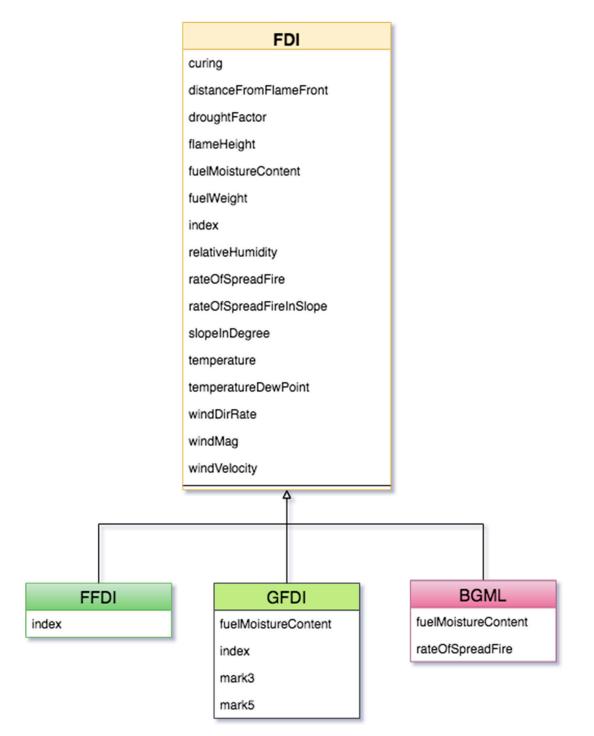


Figure 5. Class diagram: types of FDI.



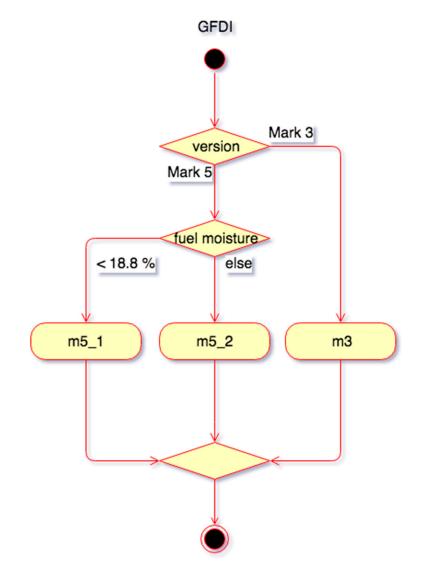


Figure 6. GFDI flowchart.

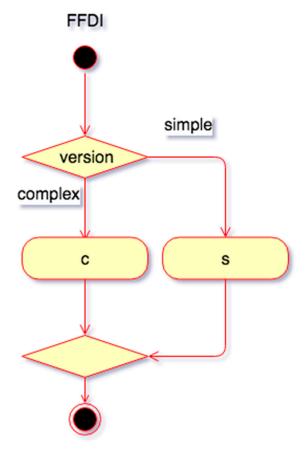


Figure 7. Decision making process of selection of FFDI.

# Moisture Content at BGML

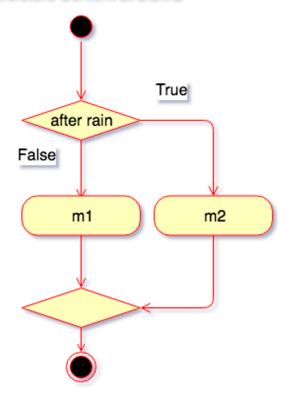


Figure 8. Dead fuel moisture content at BGML.

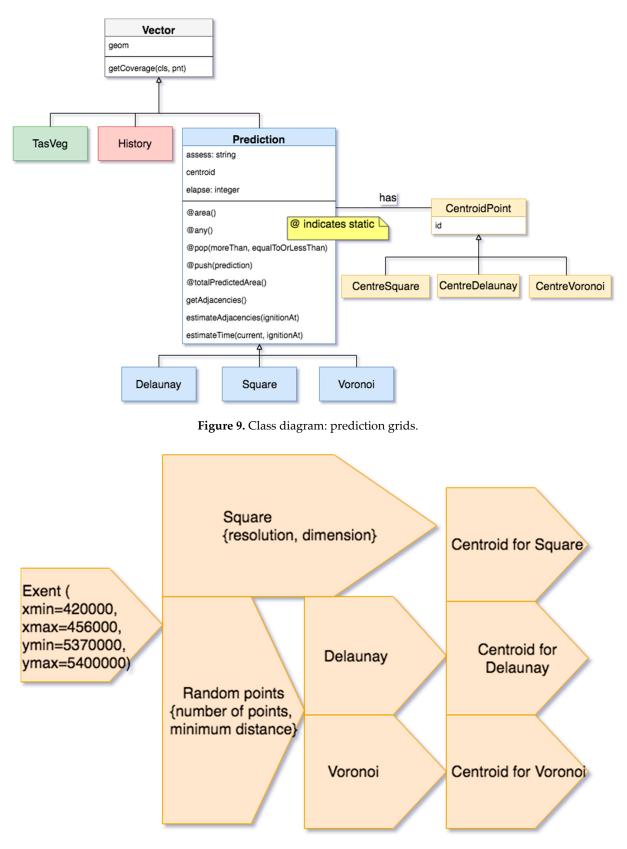


Figure 10. Overall prediction flow.



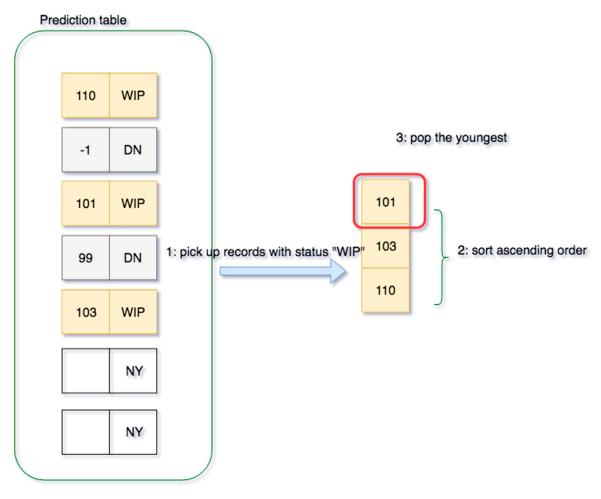
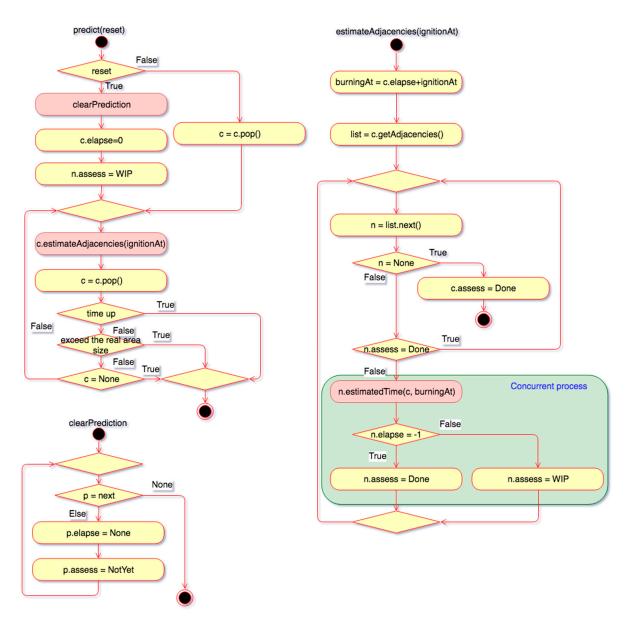


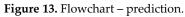
Figure 11. Cursor movement on prediction grid (example).

NY	NY		WIP:101	WIP:101	WIP:110	
WIP:100	NY		DN:99	WIP:100	WIP:101	
NY	NY	V	DN:-1	WIP:101	WIP:103	
has   109	been update by the left g	ed from 110 to		7		
ht is re-est	imated		2: top cer	ttre now na	is cursor	
WIP:101	WIP:109		WIP:101	WIP:101	WIP:110	
DN:100	WIP:101		DN:99	DN:100	WIP:101	
WIP:101	WIP:103	N	DN:-1	WIP:101	WIP:103	
	WIP:100 NY After has 109 ht is re-est WIP:101 DN:100 WIP:101	WIP:100NYNYNYNYNYAfter re-estimation has been update 109 by the left grht is re-estimatedWIP:101WIP:109DN:100WIP:101WIP:101WIP:103	WIP:100       NY         NY       NY         NY       NY         After re-estimation, the elapse has been updated from 110 to 109 by the left grid         ht is re-estimated         WIP:101         WIP:101         WIP:101         WIP:101         WIP:101	WIP:100       NY       DN:99         NY       NY       DN:-1         After re-estimation, the elapse has been updated from 110 to 109 by the left grid       J         Int is re-estimated       2: top cent         WIP:101       WIP:109         DN:100       WIP:101         WIP:101       WIP:103	WIP:100       NY         NY       NY         NY       NY         After re-estimation, the elapse has been updated from 110 to 109 by the left grid       DN:-1         MIP:101       WIP:101         DN:100       WIP:101         WIP:101       WIP:103	

Figure 12. Estimation of immediate neighbors (example).



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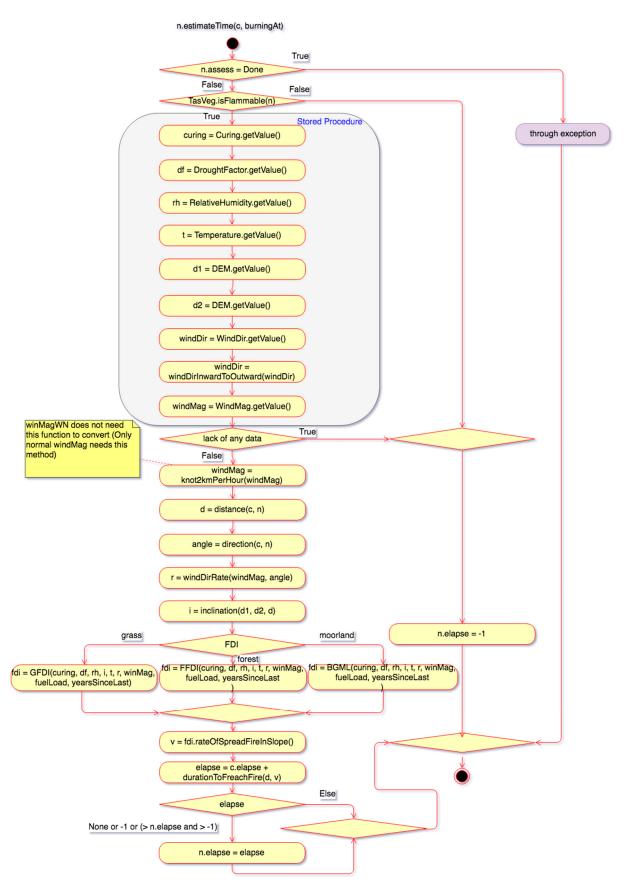


Figure 14. Flowchart - estimate time ingesting parameters and selecting FDI.

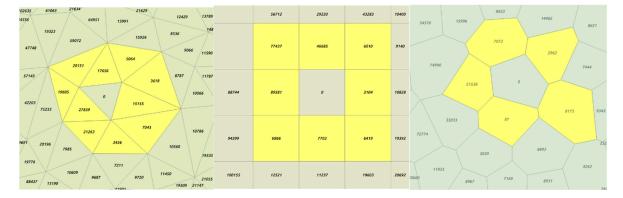


Figure 15. Adjacent grids (Delaunay in the left, Square in the middle, Voronoi in the right).

### **Appendix F: Fire Danger Indices**

#### F.1. Common attributes and methods in FDI

Some class attributes, such as refined curing (curingRF), drought factor (DF), relative humidity (RH), temperature, wind direction and velocity, can be retrieved from the database tables, wildfire\_raster and wildfire\_band (Error! Reference source not found., Error! Reference source not found.).

#### F.2. Grassland Fire Danger Index (GFDI)

Two versions of GFDI, Mark 3 and Mark 5 are currently available and selectable in configuration (Error! Reference source not found.). The equation for Mark 3 is described below [7].

$$M3 = 2.0 \times \exp\left[-23.6 + 5.01 \times \ln(C) + 0.0281 \times T - 0.226 \times \sqrt{H} + 0.633 \times \sqrt{V}\right]$$
(1)

where C indicates the degree of grass curing in percent, T represents temperature in Celsius, H is the relative humidity and V is the wind velocity (in kmh<sup>-1</sup>) which is calculated as the multiplication of wind magnitude with the rate of alignment of the directions of the head of fire and wind.

With regard to Mark 5 GFDI, it is essential to calculate fuel moisture content in advance because the index is chosen by the value of fuel moisture. The equation of fuel moisture is as follows:

$$M = \frac{97.7 + 4.06 \times H}{T + 6.0} - 0.00854 \times H + \frac{3000.0}{c} - 30.0$$
 (2)

where M is fuel moisture.

Fuel moisture has an impact on the decision as to which equation for FDI is employed, as mentioned above. If the moisture is less than 18.8 %, then equation is:

$$m5_{1} = 3.35 \times W \times exp(-0.0897 \times M + 0.0403 \times V)$$
(3)

where W indicates the fuel load (tones per hectare).

On the other hand, when the fuel moisture is at least 18.8 %, the equation becomes

$$m5_2 = 0.299 \times W \times exp(-1.686 + 0.0403 \times V) \times (30.0 - M)$$
(4)

The decision which version, Mark 3 or Mark 5, is used can be made by "WILDFIRE\_GFDI\_MARK5" in the configuration file (**Error! Reference source not found.**). Although Mark 5 is employed to predict the fire propagation in this prototype, Mark 3 can be used in future, if required.

Table 8. FDI Configuration.

	description	default
configuration key	I	value

WILDFIRE_FUELLOAD_WITH_FL	Whether or not fuel load is	True
	multiplied with	
	flammability	
WILDFIRE_MISSING_CURING	Missing value -1 for curing	None
WILDFIRE_MISSING_DF	Missing value -1 for	50
	drought factor	
WILDFIRE_GFDI_MARK5	True: Mark 5, False: Mark 3	True
WILDFIRE_FFDI_COMPLEX	FFDI version	True
WILDFIRE_BGML_DF_THRESHOLD	Threshold of precipitation	6
WILDFIRE_BGML_HOURS_SINCE_LAST_RAIN	Hours since last	(20*24)
	precipitation	
WILDFIRE_BGML_MAX_YEARS_SINCE_LAST_FIRE	Max years since last fire	5
WILDFIRE_BGML_PRECIPITATION_MM	Amount of precipitation	10
	(mm)	
WILDFIRE_WIND_VECTOR_RANGE		'min':-1,
		'max':1

#### F.3. Forest Fire Danger Index (FFDI)

Two versions of the equation for FFDI [7] may be used. The simple version of FFDI is denoted as "s" (Error! Reference source not found.). The accuracy is lower than the complex version and the equation is expressed:

$$s = 1.25 \times D \times \exp\left[\frac{(T-H)}{30.0} + 0.0234 \times V\right]$$
 (5)

where D is drought factor, T indicates temperature in Celsius, H is the relative humidity and V is the wind velocity which is calculated as the multiplication of wind magnitude with the rate of alignment of the directions of the head of fire and wind. On the other hand, the complex version identified as "c" (Error! Reference source not found.) is:

$$c = 2.0 \times \exp\left[-0.450 + 0.987 \times \ln(D) - 0.0345 \times H + 0.0338 \times T + 0.0234 \times V\right]$$
(6)

#### F.4. Button Grass Moorland Fire Index (BGML)

Button grass moorland fire index (BGML) computes the fire rate of spread. The equation is as follows:

$$R = 0.678 \times V^{1.312} \times \exp(-0.0243 \times M) \times [1 - \exp(-0.116 \times Age)]$$
(7)

where R indicates the rate of spread of fire, V means the wind velocity, M is the fuel moisture content of dried vegetation and Age indicates the number of years since the last fire [8]. Dead fuel moisture content (M) is as follows:

$$m1 = \exp(1.66 + 0.0214 \times H - 0.0292 \text{ Td})$$
(8)

where H represents the relative humidity in percent and Td is the dew point temperature [9]. Moreover, an extra equation is appended after rain as follows:

$$m2 = \exp((1.66 + 0.0214 \times H - 0.0292 \text{ Td}) + 67.128 \times [1 - \exp((-3.132 \times P)] \times \exp((-0.0858 \times t))$$
(9)

where P is amount of precipitation in millimeters and t represents hours since last rain. In this prototype, the precipitation is configurable and the default value is 10 [10]. The decision as to whether or not it is after rain is made by drought factor (DF) which indicates the moisture content of fine fuel and is calculated using Soil Dryness Index (SDI) and recent precipitation and ranges from 0 (wet) to 10 (dry)[7]. The threshold of this index is configurable as "WILDFIRE\_BGML\_DF\_THRESHOLD", with a default value of 6 (**Error! Reference source not found.**). That is, if DF is equal to or more than the threshold, m1 is selected because the buttongrass fuel is considered to be dry. Otherwise, m2 is chosen (**Error! Reference source not found.**).

#### F.5. Forward spread rate with slope (GFDI and FFDI only)

FDI can account for slope in computing the forward rate of spread of fire [7]. Firstly, the rate of spread of fire can be expressed in the equation without slope:

$$R = 0.0012 \times F \times W \tag{10}$$

where R is the rate of spread of fire, F represents either FFDI or GFDI, and W indicates fuel load [7]. Then the degree of slope is considered as:

$$R_{\theta} = \mathbf{R} \times \exp\left(0.069 \times \theta\right) \tag{11}$$

where  $R_{\theta}$  is the forward rate of spread of fire, and  $\theta$  denotes the slope [7]. As noted in Section F.4, the rate of spread of fire in BGML is calculated differently.

#### Appendix G: Extent of spatial grids

This section shows the extent of various input data to predict fire evolution. Prediction grid must be large enough to enclose actual fire area and included in prediction parameters, such as DEM, TasVeg and weather data.

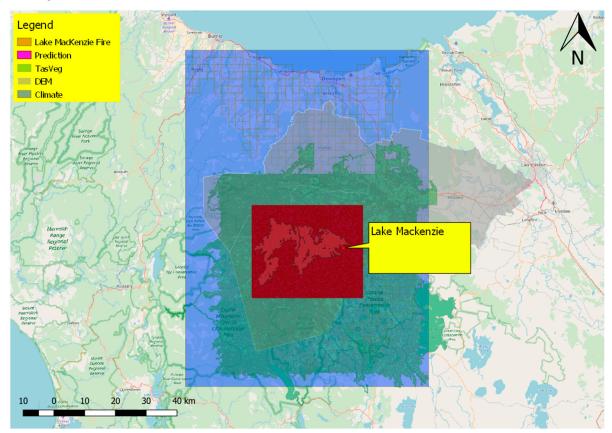


Figure 16. Extent of prediction.

### **Appendix H: Prediction grids**

This section shows prediction grids by different shapes, such as Delaunay, Square and Voronoi, and sizes, such as fine, medium and coarse, with their centroids as well as random points. Irregular grids, namely, Delaunay and Square, are generated based on random points by QGIS (Error! Reference source not found.).



Figure 17. Square and centroid around Lake Mackenzie - fine.

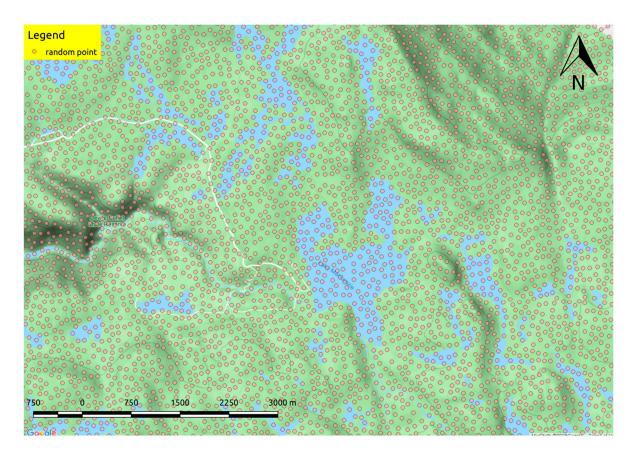


Figure 18. Random point around Lake Mackenzie - fine.

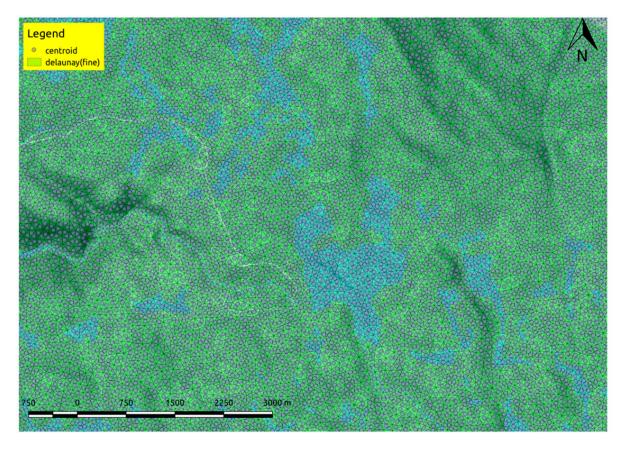


Figure 19. Delaunay and Centroid around Lake Mackenzie - fine.

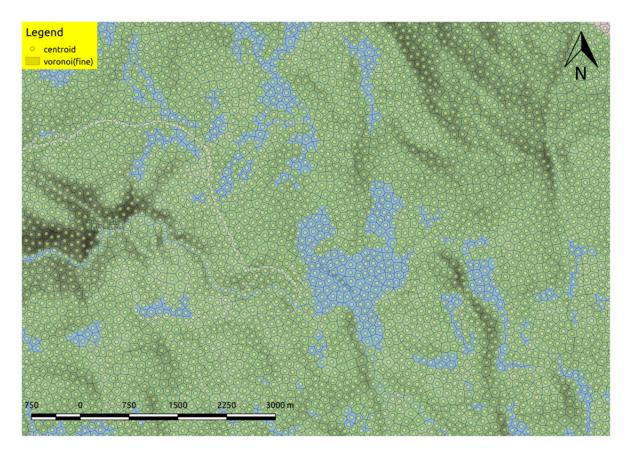


Figure 20. Voronoi and Centroid around Lake Mackenzie – fine.

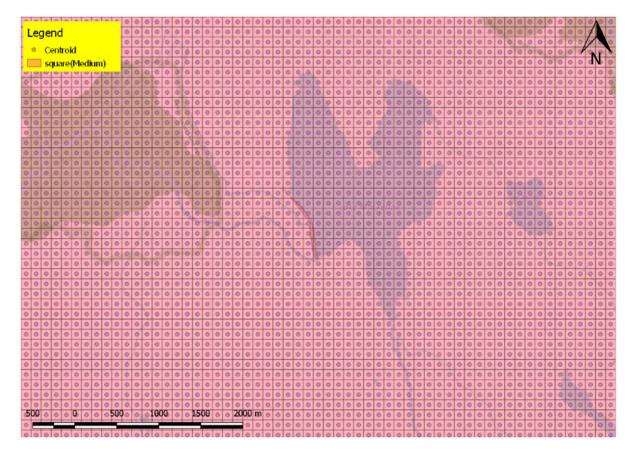


Figure 21. Square and Centroid around Lake Mackenzie - medium.

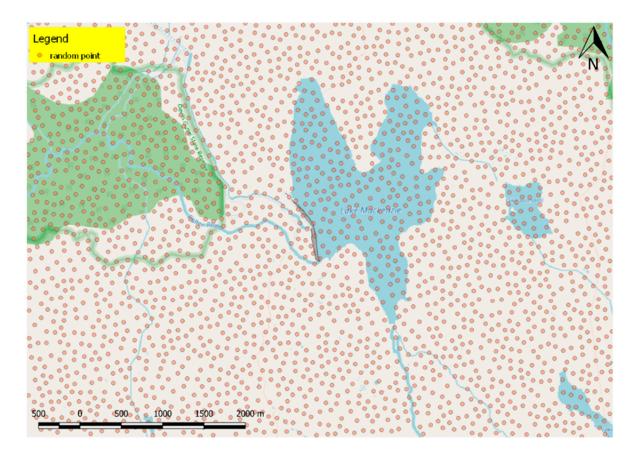


Figure 22. Random point around Lake Mackenzie - medium.

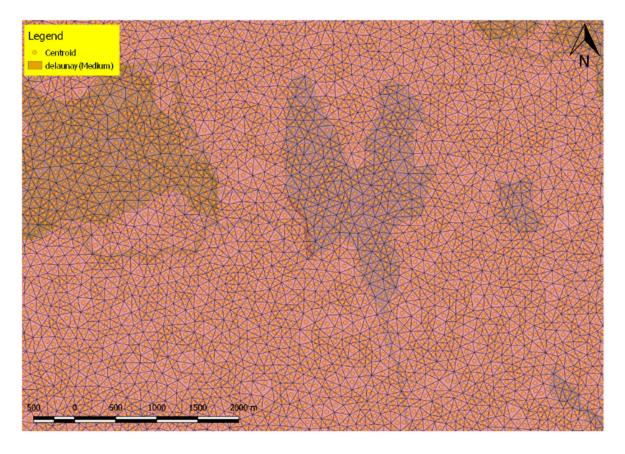


Figure 23. Delaunay and Centroid around Lake Mackenzie - medium.

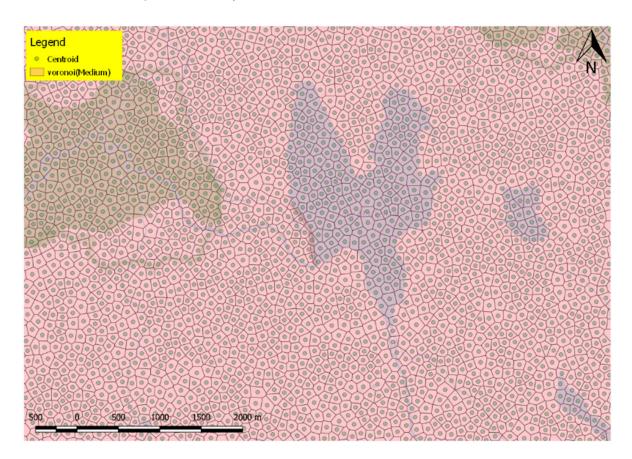


Figure 24. Voronoi and Centroid around Lake Mackenzie - medium.

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-	•	•	•	0		0	•	0	•			•	•	•		•	•	•	20	•	•	•	100

Figure 25. Square and Centroid around Lake Mackenzie - coarse.

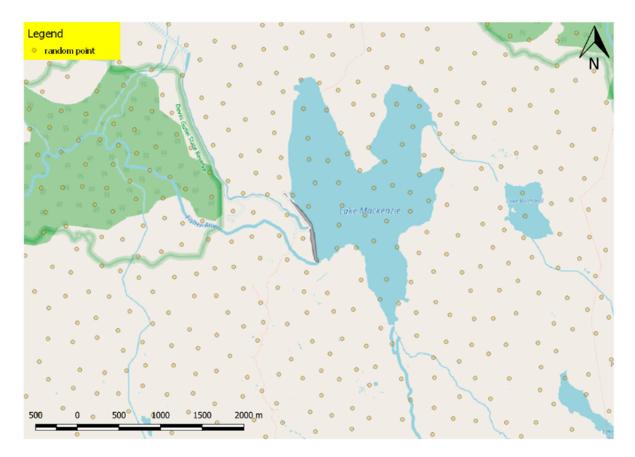


Figure 26. Random point around Lake Mackenzie - coarse.

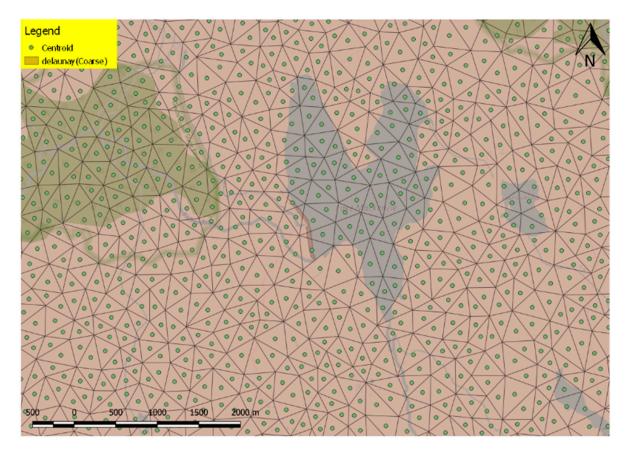


Figure 27. Delaunay and Centroid around Lake Mackenzie - coarse.

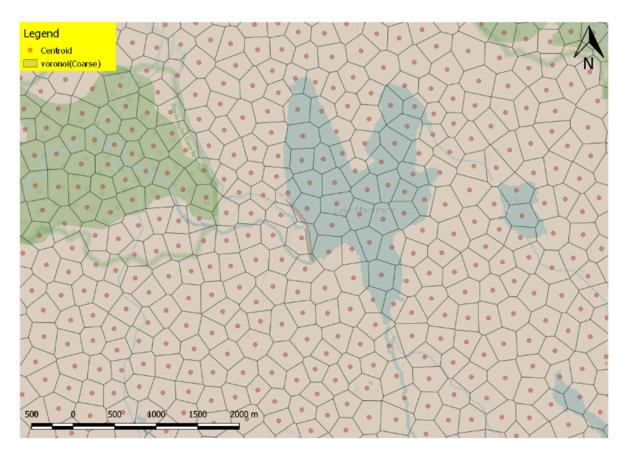


Figure 28. Voronoi and Centroid around Lake Mackenzie – coarse.

#### **Appendix I: Confusion matrix**

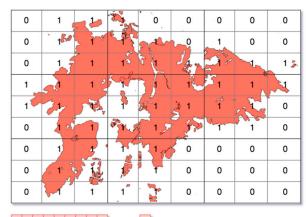
In this prototype, a binary confusion matrix is employed, in which there are four categories, true positive (TP), true negative (TN), false positive (FP) and false negative (FN). The observed event falls into the fire record or history data as true class while the predicted result is the inferred class, with the various shapes of grid, such as Delaunay Triangulation, Square and Voronoi. The status in each case is represented in two dimensions and contains the number of TN, FN, FP and TP (Error! Reference source not found.) occurrences. TP indicates the number of counts predicted as true and also observed as true. For instance, 47 grids are TP in the example because 47 grids represent the burnt area in both observed and predicted model (Error! Reference source not found.). In the same manner, FN indicates the observed result is true but the prediction is false. In the example, there are 5 TNs. FN displays that actual result is false while the prediction true. There are 14 FPs in the example. Both prediction and observation show false in the TN case. There are 15 TNs in the example (Error! Reference source not found.).

		Inferred class		
		Predicted No	Predicted Yes	
True class	Actual No	TN	FP	
	Actual Yes	FN	TP	

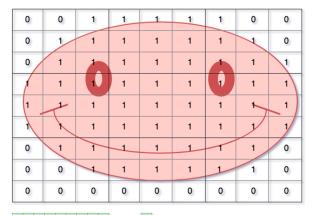
Several common summary indicators are described in Error! Reference source not found. [11,12].

# **Confusion Matrix**

# **Observation (Actual)**



### Prediction



# 0 1 1 1 0 0 0 0 0 .... 0

	Predicted: No	Predicted: Yes
Actual: No	TN = 15	FP = 14
Actual: Yes	FN = 5	TP = 47

## Legend

v

Observation: v can be either 0 or 1

0 0 1 1 1 1 1 0 0 .... 0

- v Prediction: v can be either 0 or 1
- TN: true negative
- FP: false positive
- FN: false negative

## TP: true positive

Figure 29. Example of confusion matrix.

indicator	equation	description
Accuracy	TP + TN	Frequency of correct classifier
	TP + TN + FP + FN	
Misclassification Rate (aka, Error	FP + FN	Frequency of incorrect classifier
Rate)	TP + TN + FP + FN	= (1-accuracy)
True Positive Rate (aka,		Rate of observed true over both
Sensitivity or Recall)	TP + FN	classifiers indicating true
False Positive Rate	FP	Rate of observed false over both
	TN + FP	classifiers representing true
Specificity	TN	Rate of observed false over both
	TN + FP	classifiers representing no
		= (1- False Positive Rate)
Precision	ТР	Rate of correct prediction yes
	TP + FP	
Prevalence	FN + TP	Rate of "Actual Yes"
	TP + TN + FP + FN	

### **Appendix J: Results**

The figures below show the prediction overlaid with the Lake Mackenzie Road Fire. The mesh in red indicates the observed fire area and the red polygon is the prediction, but the fine grain polygons appear to be in dark red because they are too dense and small for their polygons to be displayed individually.

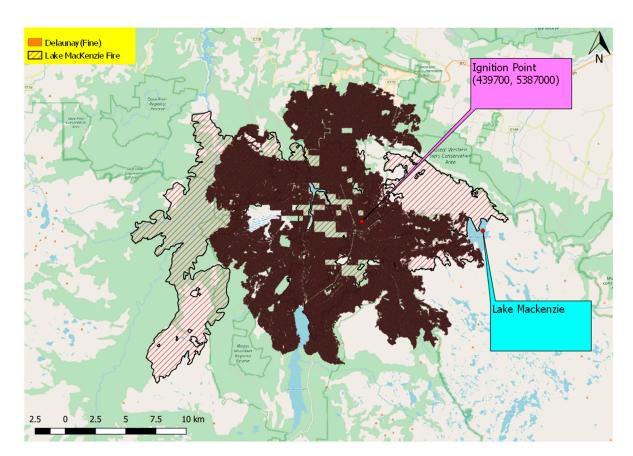


Figure 30. Delaunay (fine) overlapped with fire history.

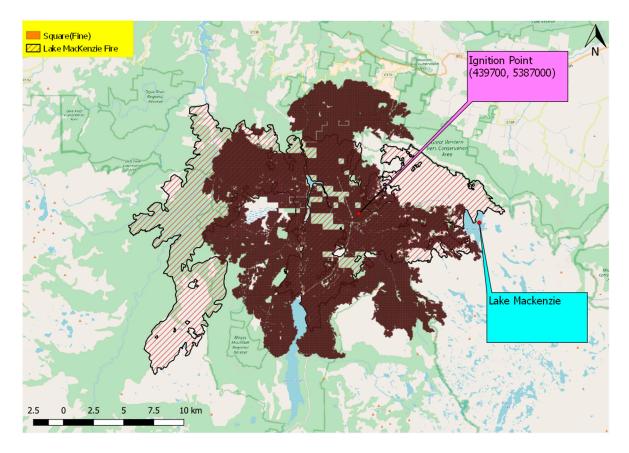


Figure 31. Square (fine) overlapped with fire history.

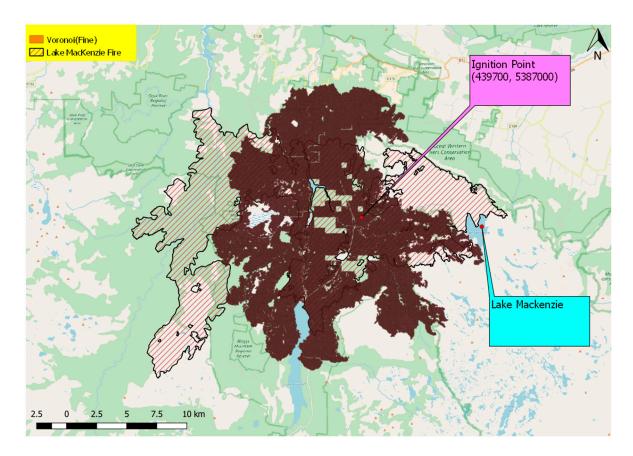


Figure 32. Voronoi (fine) overlapped with fire history.

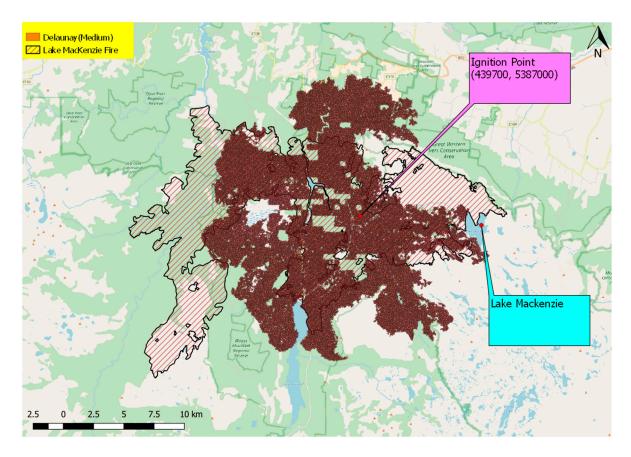


Figure 33. Delaunay (medium) overlapped with fire history.

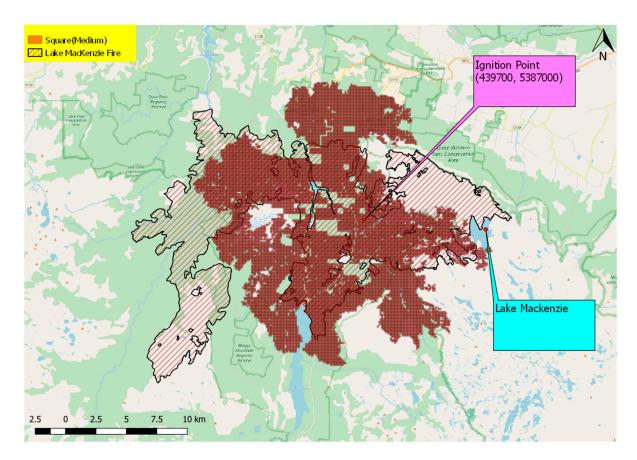


Figure 34. Square (medium) overlapped with fire history.

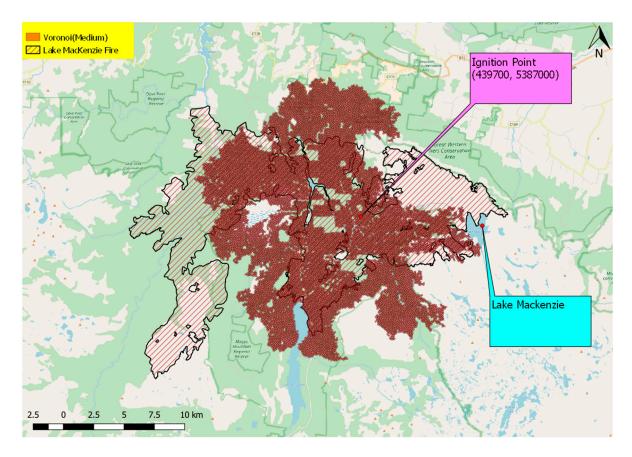


Figure 35. Voronoi (medium) overlapped with fire history.

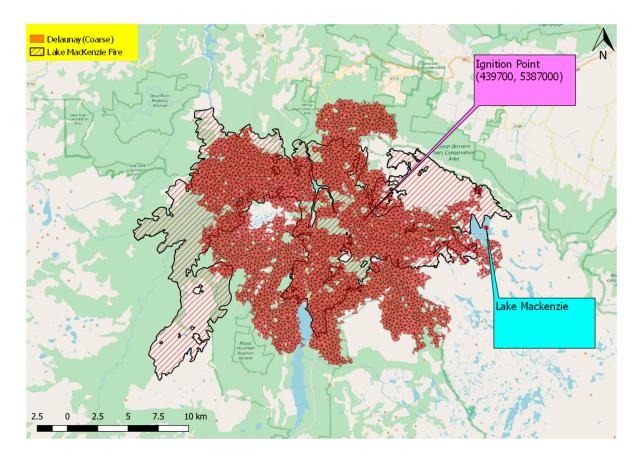


Figure 36. Delaunay (coarse) overlapped with fire history.

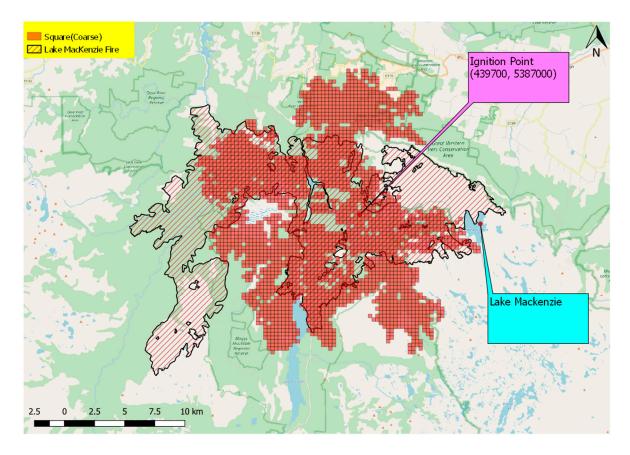


Figure 37. Square (coarse) overlapped with fire history.

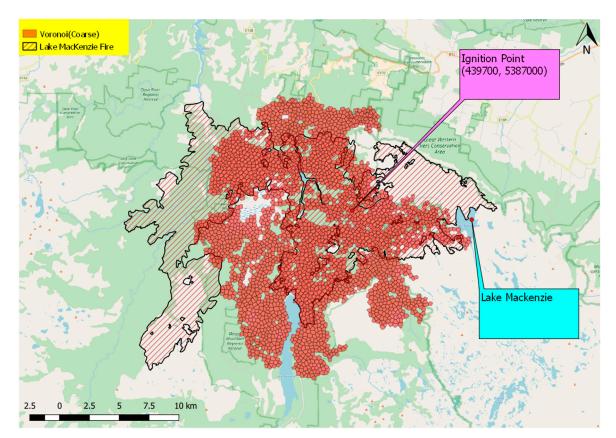
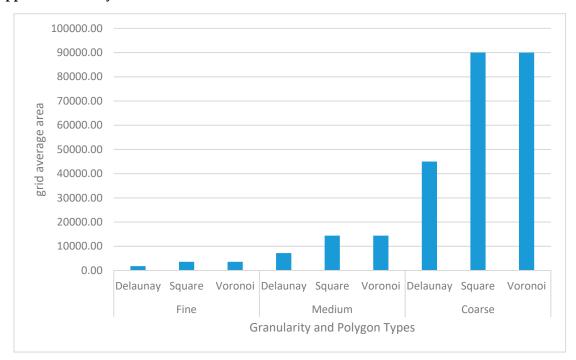


Figure 38. Voronoi (coarse) overlapped with fire history.



# **Appendix K: Analysis**

Figure 39. Comparison of average area size in square meters between the three polygon types.



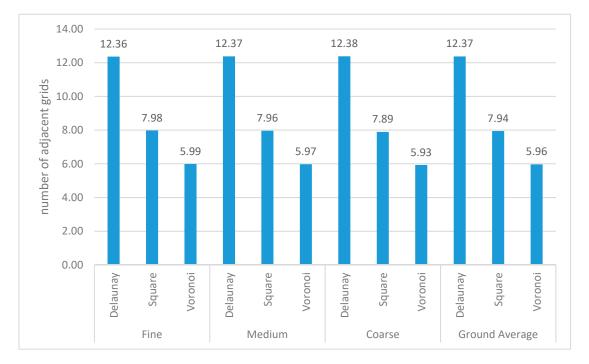


Figure 40. Comparison of number of immediate neighbors

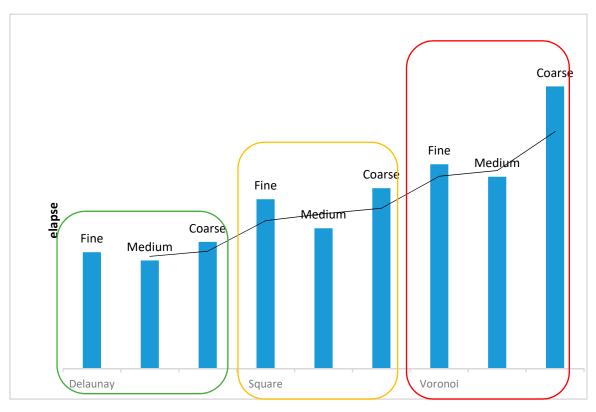


Figure 41. Elapse—actual.

**Appendix L: Miscellaneous** 

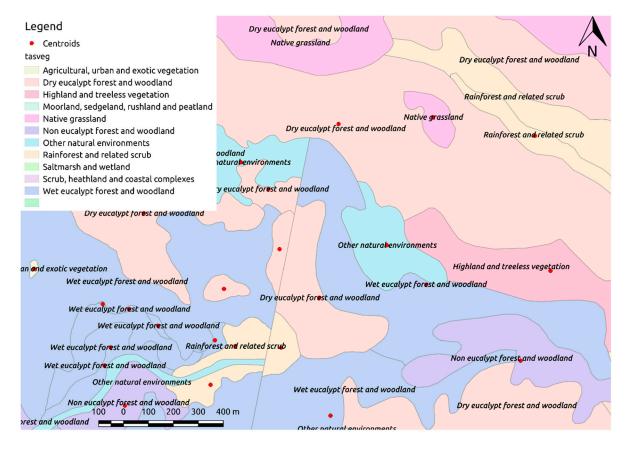


Figure 42. Centroid in red contained in TasVeg.

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