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Unsw Smiths Lake Field Station Site Expansion Consultation Report

Image courtey of NSW Office of Environment and Heritge. http://www.environment.nsw.gov.au/estuaries/stats/SmithsLake.htm

GEOS9016 - Principles of Geographic Information Systems
Assignment 2 - Major Report

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Executive summary

This report provides three ranked site recommendations for the future expansion of the UNSW Field Station at Smiths Lake in NSW, Australia. Potential sites are suitable for accomodation and meet strict building and environmental constraints.

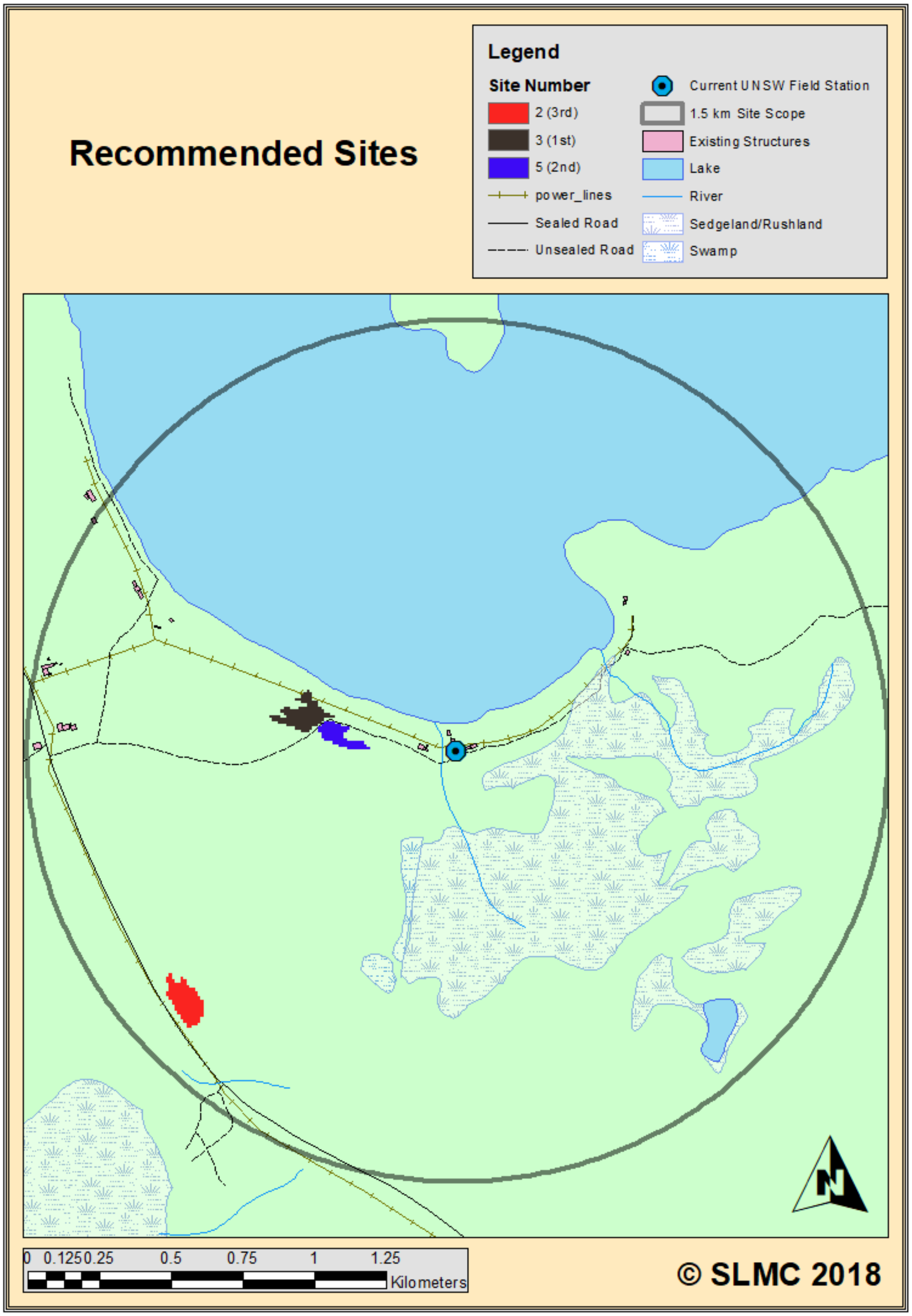
Sites are within areas that are low cost to build, minimize the impact on conservation needs, minimize fire hazard risk, minimize the risk of pollutant runoff whilst maximizing the aesthetics of the location.

Site suitability is determined by performing building cost, conservation risk, fire hazard, soil erosion, and ranking models. These models utilize fuzzy logic to determine Goldilocks zones around key resources, such as roads and powerlines and the current field station. Fuzzy logic is also used to create minimum buffer zones around areas of conservation concern, such as threatened fauna and flora, swamps, and natural drainage systems.

Models utilise a range of different datasets including the digital elevation model (DEM) generated from phase 1 of this project as well as fuel load data, powerline data, vegetation classifications, roads, rivers, lakes, as well as various satellite images and photographs. All data is projected using the GDA94/MGA zone 56 coordinate system before use in the models.

Fuzzy logic is used to combine the models to produce areas that meet all minimum requirements. The top 11 largest sites are then extracted from this and ranked based by size, view (aspect), fire hazard, soil erosion, solar radiation, proximity to the field station and conservation concern.

The top three site recommendations are shown on next page.


Recommended Sites
Legend
Site Number
2 (3rd)
3 (1st)
5 (2nd)
power_lines
Sealed Road
Unsealed Road
Current UNSW Field Station
1.5 km Site Scope
Existing Structures
Lake
River
Sedgeland/Rushland
Swamp
0 0.125 0.25 0.5 0.75 1 1.25
Kilometers
N
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I. Introduction

The University of New South Wales is seeking to expand the current field station at Smiths Lake, New South Wales, Australia. The new site will be close to the existing field station and within the range of 1500 metres. This place will be mainly used for accommodation purposes with the possibilities of future development. The geographic location of current station and the project scope is illustrated in Figure 1.

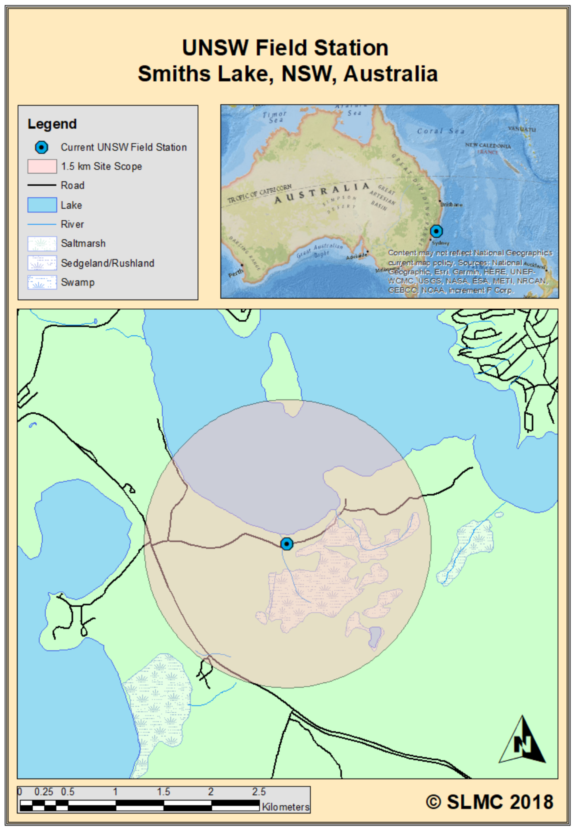


Figure 1 Project Definition

The aim of this report is to identify site that have a low construction cost, low level of fire hazard and low soil erodibility, while at the same time has minimal environmental impact on local flora and fauna. To achieve this, we utilised four key models that correspond to each requirement and then combined their results to obtain potential candidate sites. After that, we ranked all candidates and picked out the most favourable three options as our recommendations (Figure 2).

The primary software used in this project is arcGIS Desktop (version 10.6, Environmental Systems Research Institute, Inc.).

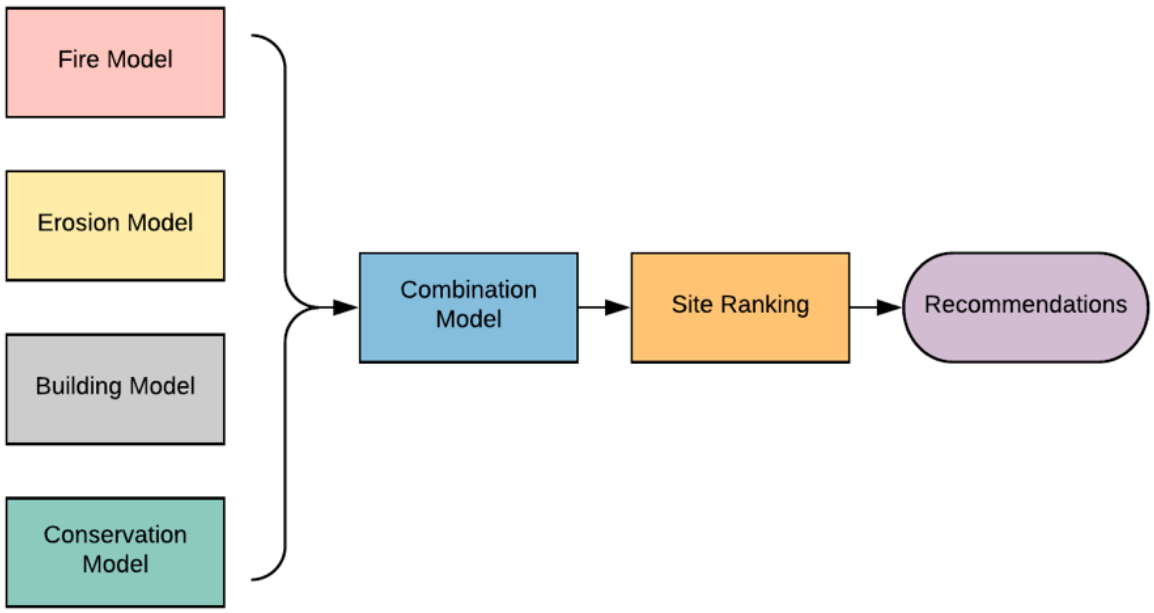


Figure 2 Report Methodology

II. Key datasets

The primary data source is from the digital elevation model (DEM) generated from phase 1. This model was developed using the Australian National University Digital Elevation Model (ANUDEM) algorithm with the input of contour data, river, coastline, water bodies and point elevation data (Hutchinson, 1988). Please see phase 1 consultancy for more details. Some additional data was also used in the development of key models, such as fuel load data in the fire model and the powerline data in the building model. The source of these data and their processing (if any) are described in their respective sections.

All datasets are projected using the Geocentric Datum of Australia 1994 / Map Grid of Australia 1994 Zone 56 coordinate system (GDA94/MGA zone 56). This coordinate system is used because it is the official map projection used by the NSW Government and recommended by the Surveyor General.

III. Analysis

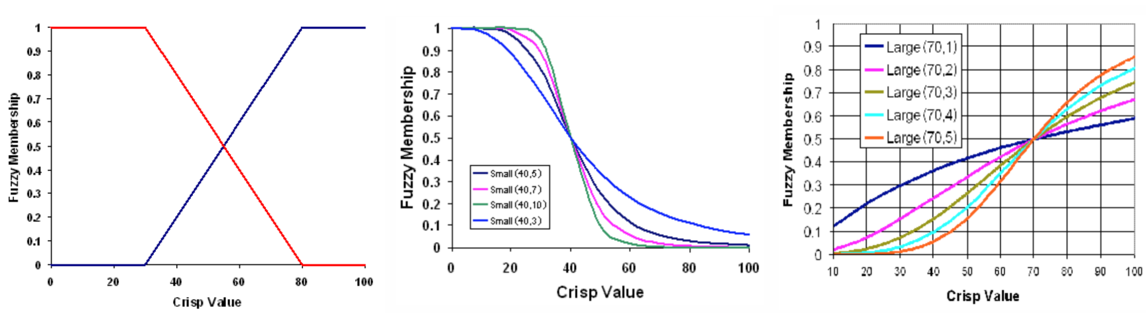
Fuzzy logic

In this project, we used the fuzzy logic to explain and categorise the outcomes of each model. Fuzziness is a type of imprecision that represents classes without a sharply defined boundary (Burrough & McDonnell, 1998). So those fuzzy sets cannot be predicted completely and only have some possibilities of becoming one certain member of a specific set. For example, we may confidently say the fire intensity is safe at one very low level and unsafe at another very high level, but we can only claim some possibilities for any value in between. This is a logical way to categorise those classes that are not binary or clearly defined. In the fuzzy logic, 0 is assigned to represent the locations that are not in the member set, and 1 is assigned to those locations that are definitely in the set. Any value between 0 and 1 represents a possibility of a membership and the value of the fuzzy membership indicates how likely it represents the class from the maximum value.

We employed three types of fuzzy membership functions in this report, which affects how we explain the values and their relationship between 0 and 1. In the linear fuzzy membership function, which is used in fire model and the erosion model, the data keeps a linear function between the minimum and maximum values. On the other hand, in the large and small fuzzy membership, the functions are not linear. In the fuzzy large function, the larger values are more likely to be member of the set when they past the midpoint and in the fuzzy small function, smaller values past the midpoint are more likely in the membership. They have been used in our conservation model and building model. The basic concept of these fuzzy membership functions are shown in Figure 3.

Fuzzy small and large functions are useful in situations where the rate of change rapidly increases as you approach the boundary threshold. For example, we might want to apply a fuzzy proximity for access to a particular resource. Being at 40 metres is probably ok, and being at 60 is probably not ok. But being at 20 is still a little better than being at 40 and being at 80 is a little worse than being at 60. This is where linear models cannot be used.

The fuzzy overlay function is the algorithm that combines the fuzzy membership functions from each model. In this project we used the "AND" fuzzy overlay that gets the minimum value from all input models. In this way, an input can only have a high value only if all of the outputs are high values.



(a) (b) (c)

Figure 3 Fuzzy membership functions: (a) linear, (b) small (c) large (Source: ESRI)

<u>Fire Model</u>

The aim of the fire model is to calculate fire intensity and then determine fire the hazard level within the project region. Fire intensity is a function of the heat yield, fuel load and the rate of fire spread (Perry, 1998):

$$FI = HWR$$

Where H is the heat yield of fuel (J/g), W is fuel load (g/m2), and R is the rate of fire spread.

In this project, the H value represents eucalyptus fire, which is equivalent to 18,600 J/g (Fernandes, Barros, Anita, & Santos João, 2016). So the equation above can written as:

$$FI = 18600WR$$

The calculation of fire spread rate (R) is based on McArthur Mk 5 Forest Fire Danger Meter and Mk 5 Grassland Fire Danger Meter. These two models are empirical fire behaviour models that derived from test fires and expressed as simple mathematical equations (Noble, Gill, & Bary, 1980). Roads and water bodies were firstly eliminated from the model by manually giving them a zero value of fire spread rate. These areas were identified if they have not specified a vegetation type and clearly look like roads or water bodies on the ESRI "World Imagery 2018" basemap. After that, we defined the forest areas to be those that have distinguishable tree types from the attribute table and then assumed the rest of grids to be grassland as they have no specific tree types prescribed and do not within any waterbody or road.

The Mk 5 Forest Fire Danger Meter calculates the rate of fire spread R (km/h) on level ground by means of:

$$R = 0.0012FW$$

Where F is Forest Fire Danger Index and W is the fuel weight (t/ha).

The forest danger index (F) is a function of drought factor(D) ranged from 0 to 10 (Sirakoff, 1985), relative humidity (RH, %), temperature (T, °C) and the average 10-metre open wind speed (U10, km/h). It can be calculated by:

$$F = 2.0 \times e^{-0.450+0.987ln(D)-0.0345RH+0.0338T+0.0234U_{10}}$$

Where:

D: drought factor

RH: relative humidity, %

T: temperature, °C

U10: average 10-metre open wind speed, km/h

Similarly, McArthur Mk 5 Grassland Fire Danger Meter algorithms can be determined by the following equations (Noble, Gill, & Bary, 1980):

$$R = 0.13F$$

Where F is the grassland fire danger index.

To obtain the grassland fire danger index (F), the moisture content(MC, %) should be calculated first and the equation is written as:

$$MC = \frac{97.7 + 4.06 \times RH}{T + 6.0} - 0.00854 \times RH + \frac{3000}{C} - 30$$

Where:

RH: Relative humidity, %.

T: temperature, celsius.

U10: average 10-m open wind speed, m/s

C: Grass curing, %

Then, for MC less than 18.8%, Grassland Fire Danger Index is written as:

$$F = 3.35We^{-0.0897MC+0.0403U_{10}}$$

or for MC between 18.8% and 30%, the equation is:

$$F = 0.299W(30 - MC)e^{-1.686+0.0403U_{10}}$$

Where:

U10: average 10-m open wind speed. km/h

MC: moisture content, %.

W: Fuel weight, t/ha.

It is noticeable that in both forest and grassland algorithms, the fuel weight W is considered when calculating the rate of fire spread R. The difference is that the forest incorporates fuel weight into the fire danger index (F) while the latter does not. With this consideration, the rate of fire spread R is a function of fuel weight W in Mk 5 Fire Danger Meter, and this is clearly different from Mk 4 Fire Danger Meter where the standard fuel weight of 4.5 t/ha is applied.

To obtain the Fire Danger Index F, we incorporated the climate data (Bureau of Meteorology, Australia) of "Forster - Tuncurry Marine Rescue" station (32.18° S, 152.51° E), which is the closest station from project scope. We mimicked a "likely worst scenario" from past monthly climate statistics that combines historical record of minimum mean 3pm relative humidity, maximum 3pm 10-m wind speed and highest temperature between 1999 and 2010. The drought factor is set to the maximum value of 10 and grass curing value is selected to be 80% arbitrarily.

Based on the aforementioned methods, the rate of forward spread (R, km/h) over level ground is:

$$R = 0.0138 \times W \text{(forest)}$$

$$R = 0.301 \times W \text{ (grassland)}$$

In addition, it is noticeable that fire will travel much faster upslope with prevailing wind than on the ground. For instance, a 5-degree slope would increase the rate of spread by 1/3, and a 10-degree slope double the rate (Yeo, Kepert, & Hicks, 2014). To justify this, R_θ is used to replace R in the fire intensity calculation and it can be described as:

$$R_\theta = R \times e^{0.069 \times \theta}$$

where θ is the slope angle in degrees.
So finally, the fire intensity (FI, kW/m) in both cases is calculated by:

$$FI = 18600 W R_\theta$$

The fire intensity indicates the amount of energy (kW/m) released from headfire edge. Multiple studies in Australia, Canada, and the United States have shown that fire intensity less than 2000 kW/m is the likely upper limit for direct attack by machines and air tankers while the fire intensity over 3500-4000 kW/m is hard to get effectively controlled (Hirsch & Martell, 1996). Therefore by using fuzzy logic, we selected the fire intensity value of 2000 kW/m as the safe threshold, 2000 - 3500 kW/m as the acceptable range, and any value over 3500 kW/m as the unacceptable range.

The fire intensity model outcome is shown in Figure 4. The grid with red colour indicates a higher risk because of the higher fire intensity, and that with green color indicates a lower risk. It can be read from the map that majority of this area has a high level of fire hazard, with some scattered low hazard areas in the northeast, south and west side of current field station.

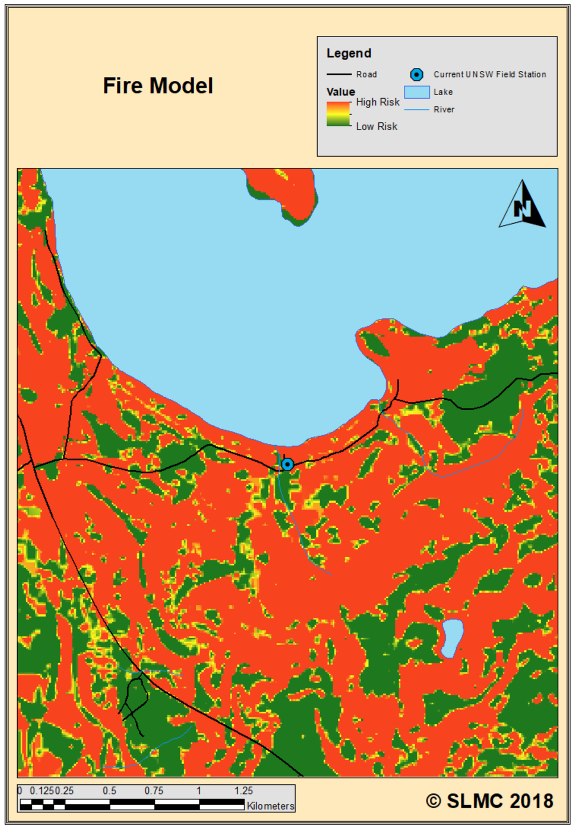


Figure 4 The output of fire model

Erosion Model

As the new site is primarily for accommodation, domestic chemical and organic pollutants may be easily discharged into the water bodies if location is chosen at somewhere with a high level of soil loss. Therefore, we employed a soil erosion model that can predict the annual soil loss by water in our project area. This model uses the Revised Universal Soil Loss Equation (RUSLE) and it calculates annual soil loss by water with six parameters (Rosewell, 1993):

$$A = R \times K \times S \times L \times C \times P$$

Where:

A: annual soil loss amount, tonne ha^{-1} $year^{-1}$

R: rainfall factor, MJ mm ha^{-1} h^{-1} $year^{-1}$

K: average soil erodibility factor, ton ha h ha^{-1} MJ^{-1} mm^{-1},

S: slope gradient

L: slope length

C: cover management factor

P: support practice factor.

The R value is determined by interpolating the rainfall factor map for Australia, and it is approximately 3500 MJ mm ha^{-1} h^{-1} $year^{-1}$. The K value is an indication of soil erodibility. A value of less than 0.02 indicates low soil erodibility and greater than 0.04 high soil erodibility (Rosewell, 1993). In our project, the K values are raster data derived from the soil texture data table (Rosewell, 1993) based on previous field survey. They fall between 0.014 and 0.054, indicating a highly variable pattern of erodibility in the project area.

Two topographic factors, slope gradient (S factor) and slope length (L factor) are represented in this model to quantify the effect of slope. The S factor is calculated from the slope derived from DEM and proportional to the sine of the slope with the power of 1.35 (Moore & Burch, 1986).

$$S = (\sin(slope/57.296)/0.0896)^{1.35}$$

The L factor is defined as

$$L = (\lambda/22.13)^m$$

Where:

λ: flow accumulation times cell size (10m)

m: exponent, 0.4.

The C factor represents the surface vegetative resistance to erosion. This factor is estimated from other existing similar studies. In this project, we firstly categorised different landscapes based on their respective vegetation types in attribute table and then gave each category a unique C value. The value of C factor is 0.004 for all forest type areas and 0.042 for grassland based on the tables from Rosewell(1993). The wetlands and water bodies are given the values of 0.05 and 0.01, respectively (Dawen, Shinjiro, Taikan, Toshio, & Katumi, 2003). The support practice factor P is set to 1, which is the default value that means no specific practice will be taken to change soil erodibility. Now that all factors have been decided, the annual soil loss can be then calculated. Following the scales of soil erosion map in Australia (Viscarra Rossel et al., 2016), the maximum soil loss level in this map is 25t ha^{-1} yr^{-1}.

However, it can be difficult to decide a certain soil loss tolerance solely from the erosion data. There are some previous studies trying to define a soil loss tolerance but very often, they vary case by case. A previous survey using Caesium-137 indicated a possible threshold of 0.5 t ha^{-1} yr^{-1} net soil loss and the average soil loss by water in Australia is 1.86 t ha^{-1} yr^{-1}.(Loughran, Elliott, McFarlane, & Campbell, 2004). While these cutoffs are meaningful, it was too strict to apply on this project. In fact, there are existing residential areas adjacent to the project scope that have a soil loss of more than 5 t ha^{-1} yr^{-1} on our model. Another factor to consider is that we did not incorporate any support practice, so the actual level of soil loss might be lower than the model prediction.

In view of these, we employed a linear fuzzy membership with the maximum value of 10 t ha^{-1} $year^{-1}$ and the minimum value of 0.5 t ha^{-1} $year^{-1}$**.** We intentionally made this criteria flexible as this was still a rough estimation, but still, only half of the areas represent a low level of soil loss (Figure 5).

Building Model

The purpose of the building model is to find a possible location that can minimise any construction costs. The building model helps achieve this by scoring $10m^2$ cells based on their relative building costs. In practice, the building costs are influenced by several factors, including local slope (gradient), proximity to roads (for vehicle access), proximity to low voltage powerlines and proximity to existing UNSW field station. Therefore, we specified the following constraints following these restrictions: 1) Minimum 30m from sealed roads 2) Minimum 10m from unsealed roads 3) maximum of 1500m from current field station 4) Not too close to existing structures 5) Not too close to high voltage powerlines. For the latter two restrictions, we arbitrarily defined a minimum buffer size of the existing structures to 10m (as we employed a 10m cell size) . We also assumed that it is OK to build right next to low voltage powerlines and the building sites should be roughly within 100m of road access and low voltage powerlines.

In addition to key data sets described above, the source data consists of roads, existing structures, slopes, powerlines and field station location. All source data was initially in or reprojected to GDA 1994 MGA Zone 56 Coordinate System. The data type and data source and our additional processing is summarised in Table 2.

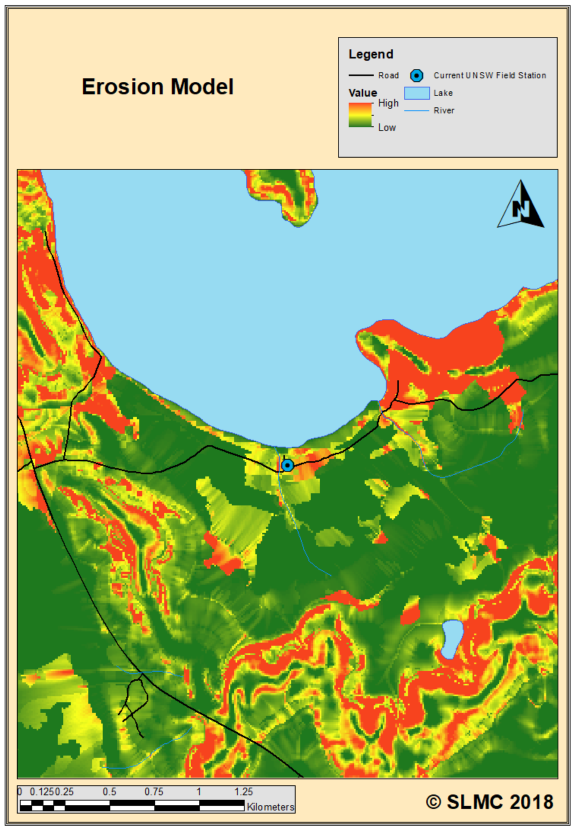


Figure 5 The output of erosion model

Table 2 Data in building model

Data	Data type	Source	Processing
Roads	Polyline	Forests NSW Data Integration Program 1996 GURAS Roads Update Program 2010-2013 NPWS Data Integration Program 2010-2013 RTA Classified Roads Integration Program 2001-2013	Manually corrected with the aid of a dataset of GPS points created by 2015 UNSW Field Trip students. The dataset were further split into two groups, sealed and unsealed. The roads data were verified by ESRI "World Imagery 2018" data and Google Streetview from 2008. It is assumed that the road surfaces have not changed since this data was captured.
Existing Structures	Polygon	Created by manually tracing the outline of structures visible on the ESRI "World Imagery 2018" basemap.	Only visually identifiable structures were selected. So structures that are completely under the canopy of a tree cannot be seen from a satellite and would therefore be missing from this dataset.
Slope	Raster	Created using the Digital Elevation Model from phase 1 of the project.	
Powerlines	Polyline	Created by manually observing Esri "World Imagery 2018" and Google StreetView 2008 images.	The high voltage constraint of this project has been ignored as there are none within range of the current site. Low voltage data cannot be directly seen in the Esri imagery, however powerlines also can only be installed in cleared land. So we define the powerline by observing straight cleared tracks. The routes of the powerlines can be verified within StreetView by observing the powerlines leaving the road side and heading into these clearing.
Field Station	Point	Created based on the position suggested by Google Maps 2018 data.	

The building model is a combination of models incorporating these parameters and using small or large fuzzy membership. The models are summarised in Table 3 and shown in Appendix I. They are then combined into a single raster by running a fuzzy 'AND' overlay. This approach heavily penalised any area with at least 1 poor score and ensures that only those areas that meet all requirements are presented as acceptable (values closer to 1).

Table 3 Fuzzy membership functions in building model

Data	**Restriction**	**Fuzzy membership**
Unsealed roads	≥ 10m	Large, midpoint: 10m
Sealed roads	≥ 30m	Large, midpoint: 30m
Existing structures	≥ 10m	Large, midpoint: 10m
Slope rating	≥ 5° and ≤ 20°	Linear, min: 5°, max: 20°. Inverted to ensure flat slopes receive a high mark (1) and steep slopes receive a low mark (0).
Low voltage powerline	≤ 100 m	small, midpoint: 100m
All roads (Sealed and unsealed)	≤ 100 m	small, midpoint: 100m
Proximity to current field station	≤ 1500 m	Small, midpoint: 1500m A maximum cut off of 1500m was also applied so that any area outside this range was marked "No Data" and was ignored in all further models. The midpoint was assigned to the maximum distance as we did not want to heavily penalise an area unless it was almost on the threshold.

The results of the building model is shown in Figure 6. This Model produces two distinct areas that are relatively low cost. The first area is a along the southern banks of Smiths Lake on either side of the current field station. The second area is along the western road at the limit of the acceptable 1500m building range. This regions is hillier and is often interrupted by unacceptably steep slopes. This model clearly excludes a number of smaller roads as they do not have access to powerlines.

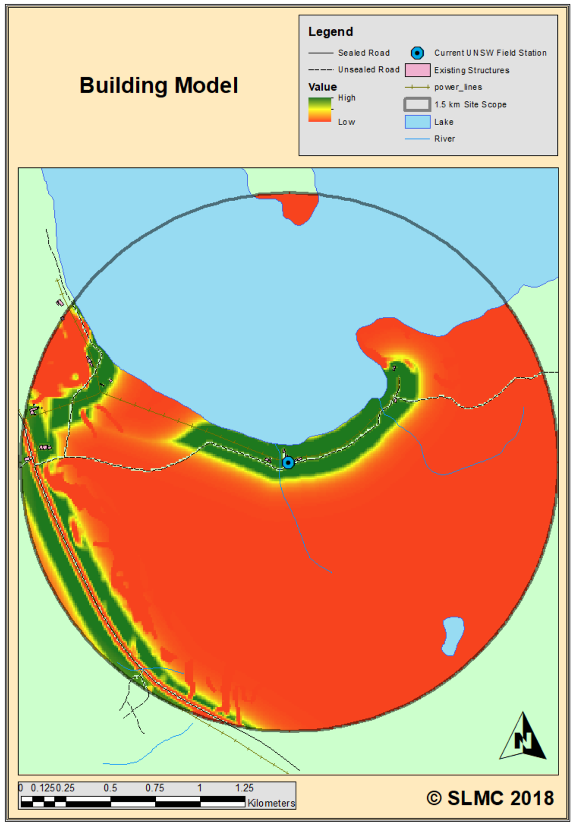


Figure 6 The output of building model

Conservation model

The aim of the conservation model is to minimise any conservation issues at the site. This model helps achieve this by scoring all cells (10m x 10m) based on their level of conservation concern. Generally speaking, conservation concerns are influenced by several factors. The new facility should not be too close to known locations of threatened flora or fauna, or to drainage lines (rivers, streams and lakes). Besides, it is not suitable to build at places too close to mangroves, wetlands and swamps.

The source data include rivers, lakes (water bodies), vegetations and threatened mammals and flora data (Table 3). The wetlands and swampy areas are defined by their vegetation type in the ecological zone dataset and verified by Google StreetView and Esri "World Imagery". Despite this verification, the actual topography may vary. In addition, the areas with Swamp Mahogany and Swamp Oak vegetation types were excluded from the swamp category because those plants live in a versatile environment and we were unable to decide if those areas are actually swamps. The vegetation dataset used in phase 1 was not useful in extracting swamp data as the descriptions appeared to be too vague to be useful. The area definitions from vegetation dataset also did not align with the observations of the satellite imagery from Esri.

The threatened mammals and flora datasets contain sightings of endangered animals and plants but they are incomplete. Many sightings are only found immediately next to walking trails and not further inland. This could create the illusion of endangered plants and animals not being in an area simply because there is no path there. However, we reply on a building model that require the site close to roads, so this was not be a great concern. And for some reasons, some sightings of land animals are in lakes. They were later clipped out by the lake buffer in the combination model.

Table 4 Data in conservation model

Data	Data type	Source	Processing
Rivers	Polyline	From phase 1	
Lakes	Polygon	From phase 1	
Mangroves	Polygon	Extracted from vegetation dataset of phase 1	

Data	Data type	Source	Processing
Wetlands and swamps	Polygon	Extracted from the ecological zone dataset of phase 1	Swamp, Saltmarsh Sedgeland and Rushland polygons were extracted from the ecological zone dataset. These data were verified by overlaying Esri "World Imagery". Swampy land was clearly visible from satellite images.
Threatened fauna and and flora	Point	Extracted from the 2015 Atlas of Living Australia data.	

Similar to the building model, we employed fuzzy membership functions that build four different buffer zones in respect of each restriction (Table 5). After that, the obtained four buffer zone rasters are then combined into a single raster by running a fuzzy 'AND' overlay. This is to ensure that only those areas that meet all requirements are presented as acceptable (values close to 1) and any area with at least 1 poor score (close to 0) will not be prioritised.

The results predicted by the conservation model is shown in Figure 7. It can be seen from the map that this conservation model primarily restricts potential site selection from the lake in the north and south west, as well as the large swamp complex south east of the current field station. Due to the possible inaccuracy of source swamp data and threatened species data, the model outcome can become drastically different if these datasets are later refined or altered.

Table 5 Fuzzy membership functions in conservation model

Data	Restriction	Fuzzy membership
Rivers	≥ 10m	Large, midpoint: 10m
Mangroves, wetlands and swamps	≥ 50m	Large, midpoint: 50m
Lakes	≥ 10m	Large, midpoint: 10m

Data	Restriction	Fuzzy membership
Threatened fauna and and flora	≥ 50m	Large, midpoint: 50m

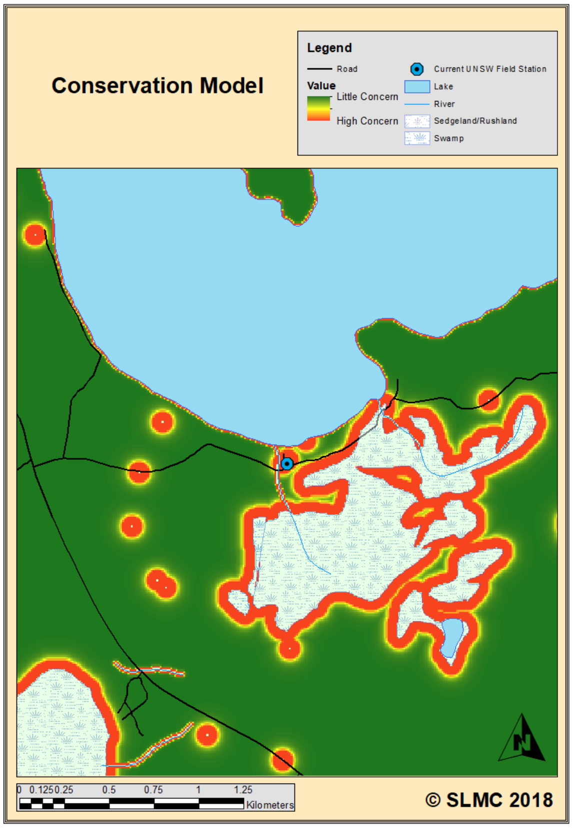


Figure 7 The output of conservation model

Combination and site rankings

Potential site recommendations are based on scores from the fire hazard model, soil erosion model, building cost model and conservation model. In addition to the above models, sites are further ranked by their aesthetic properties using solar radiation outcomes and aspect raster The top three candidates are then formally recommended. We arbitrarily specified the site size around 10000 m^2, which is equivalent to 100 cells on the raster data by definition.

The ranking system can be split into three sections:

1) Combination Model: merging the previous four models into a single raster containing a score.
2) Site Ranking Model: extracting distinct sites that meet a minimum score threshold then allocating a mean score for each criteria for each site.
3) Site Tabulation Rankings: ranking the sites by their relative scores in each criteria.

The combination model aims to integrate the fuzzy outcome of previous four models. The fire model and erosion model output rasters were inverted to ensure that low fire hazard or soil erosion level is close to 1 and high level is close to 0. This transformation unifies the logic of all models that a grid with higher value equals to better selection. After that, these two models were combined with building and conservation model by running a fuzzy 'AND' overlay. This is to ensure that only those areas that meet all requirements are presented as acceptable by selecting the minimum value.

The site ranking model is built upon the outcome of combination model (Figure 8). Those grids that have a score of less than 0.3 are reclassified as "NoData" so that they are ignored in future analysis. After that, distinct sites were then extracted based on size. Two cells are considered to be part of the same cite if they share a N/S/E/W border. We then extracted the largest 11 sites that met the minimum scoring threshold. Ideal sites would be close to 10000m^2 however the smallest candidate site is 4600m^2 (Figure 9). Each candidate site was assigned a score based on the mean value of each model output of their respective areas.

The site ranking table is then populated based on how each of the 11 candidate sites scored relative to each other and assigned 0 to 11 by their rankings (Table 6). Sites were primarily differentiated by their size, building score, view/aspect, erosion and proximity to the current field station. As all sites had good view/aspect, solar radiation and very good conservation scores (except site 11), the outcome only relies on the total ranking score of size, building cost, erosion and fire hazards.

Our final site selection is the top 3 sites (which has the lowest sum of ranking) from Table 7 and their locations are shown in Figure 10. These sites are site 2, 3 and 5.[1]

Table 6 Site ranking score criteria

Score	Criteria
Building cost	mean of the Building Cost Model output raster cells
Conservation	mean of the Conservation Model output raster cells
Erosion	mean of the Erosion Model output raster cells
Fire	mean of the Fire Hazard Model output raster cells
Solar	mean of the Solar Radiation raster cells
Aspect	mean of the aspect raster cells

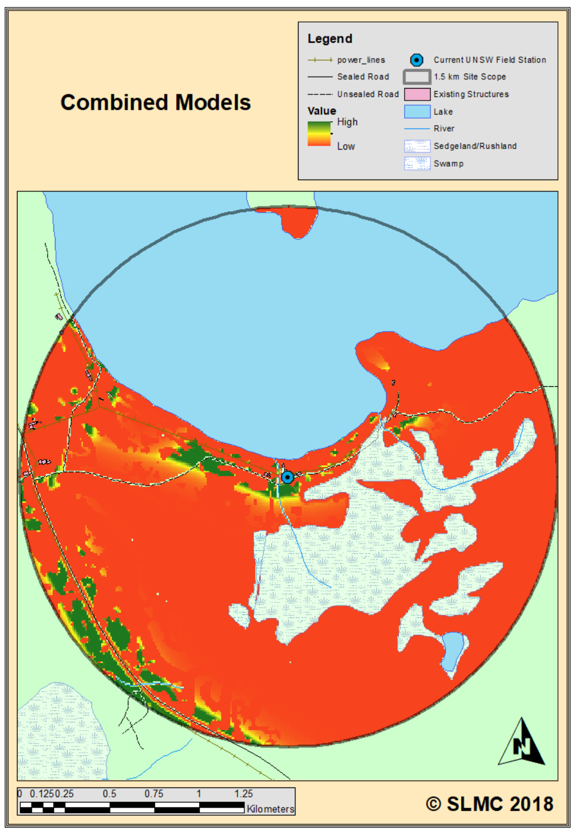


Figure 8 The output of combination model

[1] As mentioned previously, Mahogany Swamp and Oak Swamp ecological zones are not included as part of proper swamps. If they are, the top 3 sites would change to sites 2, the central third of site 1 (as it is too large) and site 6.

Table 7 Site ranking outcome

Candidate	Size		Build		Fire		Erosion		Conservation	Solar
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Value
1	366	1	0.536	7	0.203	10	0.040	7	0.983	1381524
2	**142**	**2**	**0.610**	**3**	**0.137**	**7**	**0.049**	**8**	**1.000**	**1362374**
3	**139**	**3**	**0.643**	**2**	**0.134**	**6**	**0.005**	**5**	**0.998**	**1393871**
4	96	4	0.531	8	0.129	5	0.004	3	1.000	1378442
5	**85**	**5**	**0.578**	**5**	**0.085**	**4**	**0.003**	**1**	**1.000**	**1391699**
6	71	6	0.491	10	0.000	1	0.037	6	1.000	1397960
7	53	7	0.568	6	0.147	8	0.050	9	0.913	1349335
8	51	8	0.660	1	0.261	11	0.004	2	1.000	1377355
9	50	9	0.492	9	0.183	9	0.136	10	0.918	1429244
10	48	10	0.468	11	0.038	2	0.005	4	0.998	1392157
11	46	11	0.610	4	0.051	3	0.311	11	0.757	1389762

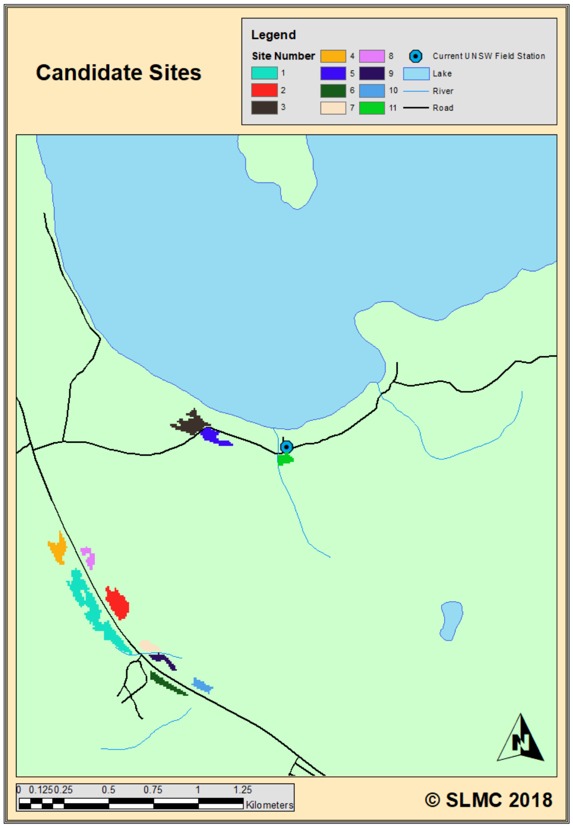


Figure 9 The Candidate Sites

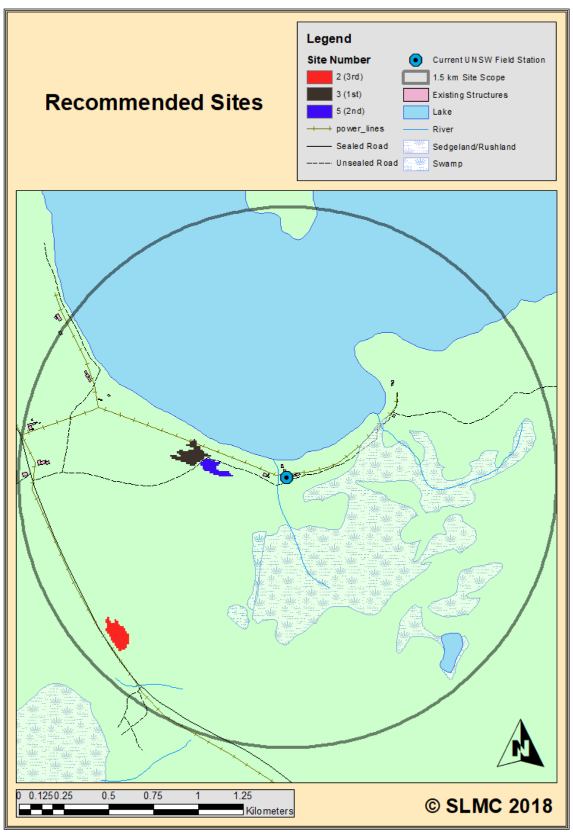


Figure 10 Recommended site locations

IV. Recommendations

Our top recommendation is site 3 (dark grey), because it is fairly close to current station, with comparatively low fire hazard and soil erosion problem. Site 2 is the second choice as it has a slightly higher fire hazard and soil loss than site 3. Both locations have a large size for possible construction and a good view looking towards the lake. Site 5 ranks the third as it has a smaller size and higher building cost. But this is also a good choice as it is close to the road and has a much lower level of fire hazard and soil erosion. The view at site 5 might not be so satisfactory. Even though it is facing the lake on the west, one needs to travel through a marsh to access the west lake or climb some hills to reach lake to the north.

V. References

Burrough, P. A., & McDonnell, R. (1998). Principles of geographical information systems ([Rev. ed.] ed.) Oxford ; New York : Oxford University Press.

Dawen, Y., Shinjiro, K., Taikan, O., Toshio, K., & Katumi, M. (2003). Global potential soil erosion with reference to land use and climate changes. Hydrological Processes, 17(14), 2913-2928. 10.1002/hyp.1441

Fernandes, P. M., Barros, A. M., Anita, P., & Santos João, A. (2016). Characteristics and controls of extremely large wildfires in the western mediterranean basin. Journal of Geophysical Research: Biogeosciences, 121(8), 2141-2157. 10.1002/2016JG003389

Hirsch, K., & Martell, D. (1996). A review of initial attack fire crew productivity and effectiveness10.1071/WF9960199

Hutchinson, M. F. (1988). Calculation of hydrologically sound digital elevation models. Proceedings of the Third International Symposium on Spatial Data Handling, August 17-19, Sydney. International Geographical Union, Columbus, Ohio, pp 117-133.

Moore, I. D., & Burch, G. J. (1986). Physical basis of the length-slope factor in the universal soil loss Equation1. Soil Science Society of America Journal, 50(5), 1294-1298. 10.2136/sssaj1986.03615995005000050042x

Noble, I. R., Gill, A. M., & Bary, G. A. V. (1980). McArthur's fire-danger meters expressed as equations. Australian Journal of Ecology, 5(2), 201-203. 10.1111/j.1442-9993.1980.tb01243.x

Perry, G. L. W. (1998). Current approaches to modelling the spread of wildland fire: A review. Progress in Physical Geography: Earth and Environment, 22(2), 222-245. 10.1177/030913339802200204

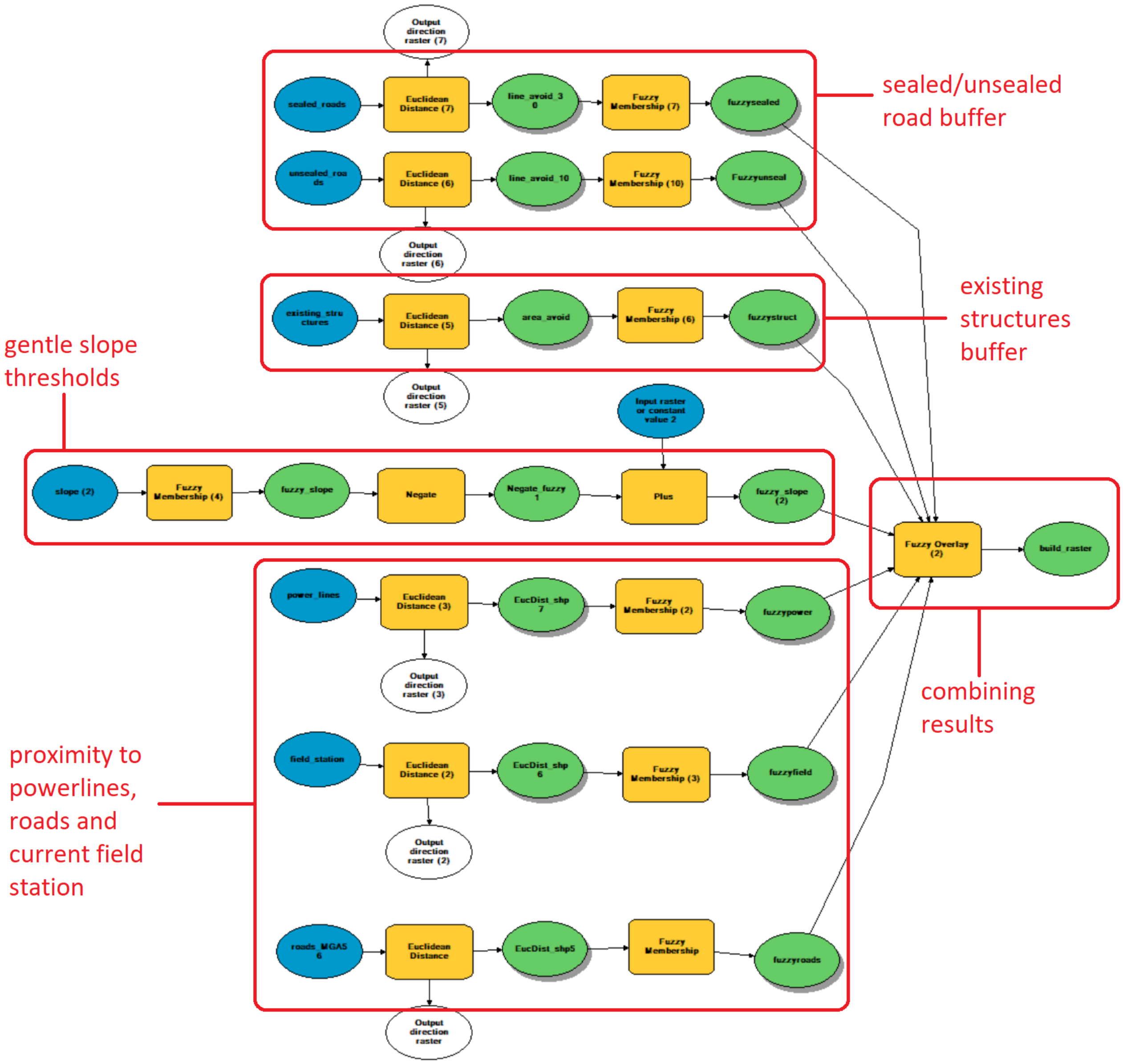
Rosewell, C. J. (1993). SOILOSS: A program to assist in the selection of management practices to reduce erosion

Sirakoff, C. (1985). A correction to the equations describing the McArthur forest fire danger meter. Australian Journal of Ecology, 10(4), 481. 10.1111/j.1442-9993.1985.tb00909.x

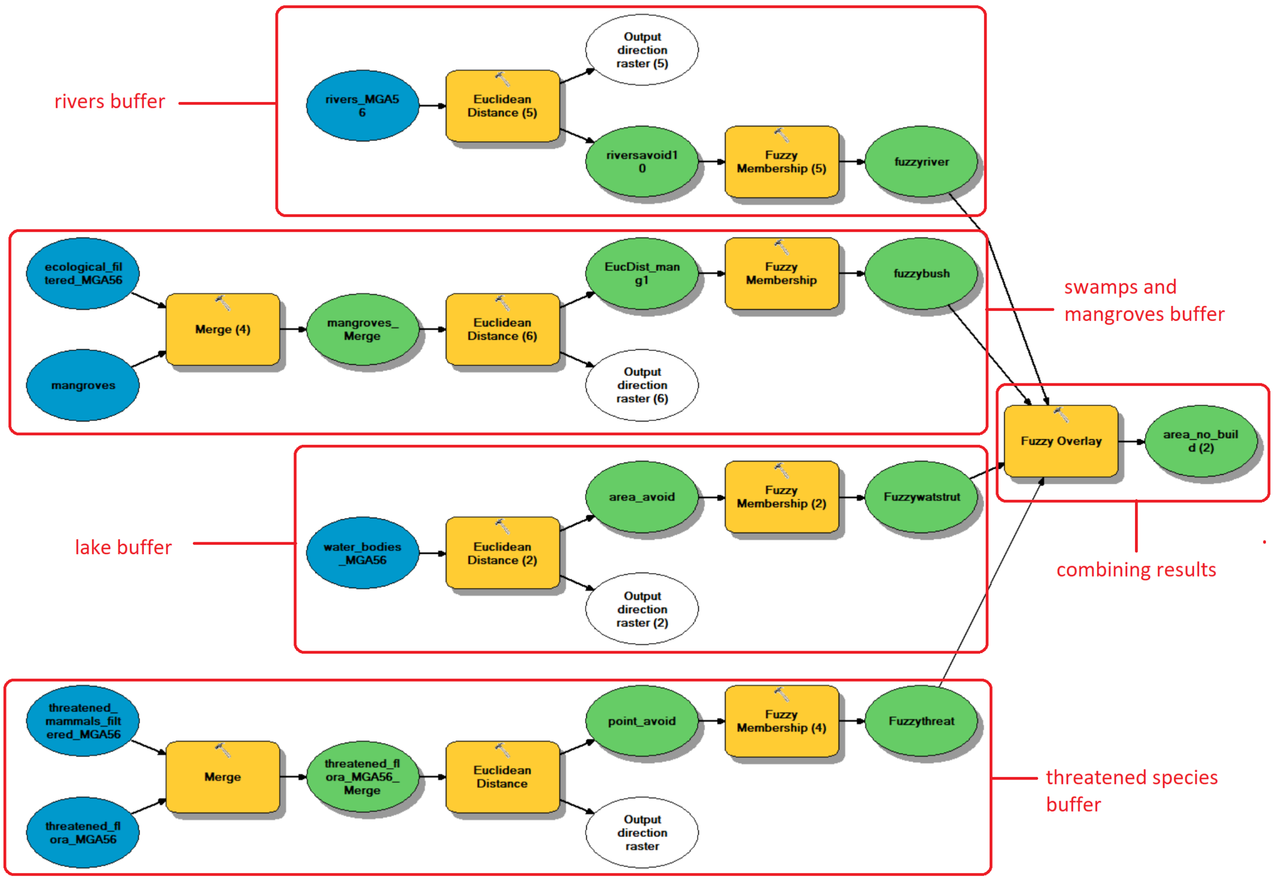
Viscarra Rossel, R., Teng, H., Zhou, S., Behrens, T., Chappell, A. & Bui, E. (2016). Maps of australian soil loss by water erosion derived using the RUSLE. Commonwealth Scientific and Industrial Research Organisation (CSIRO).

Yeo, C., J.D Kepert, & Hicks, R. (2014). Fire danger indices: Current limitations and a pathway to better indices.(007)

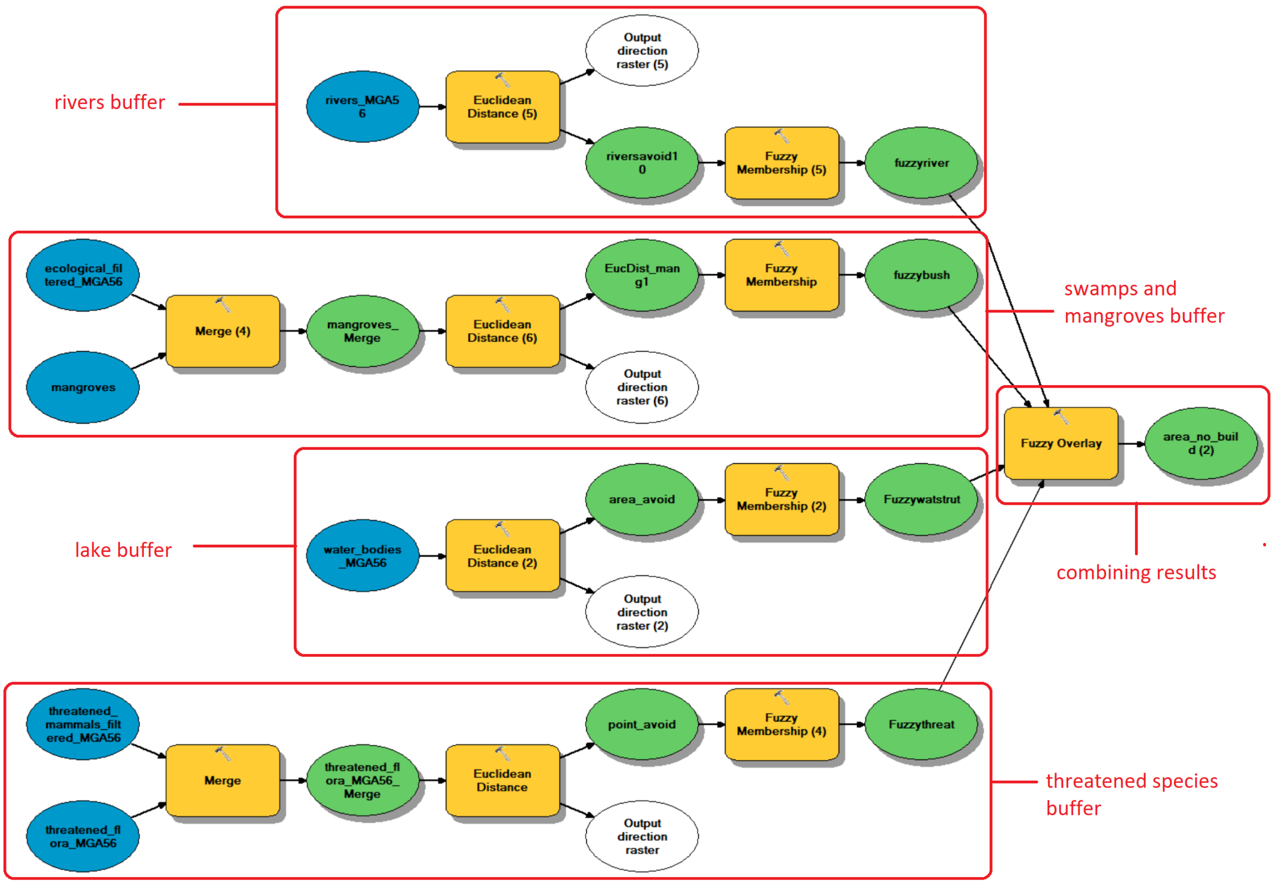
Appendix I Building model



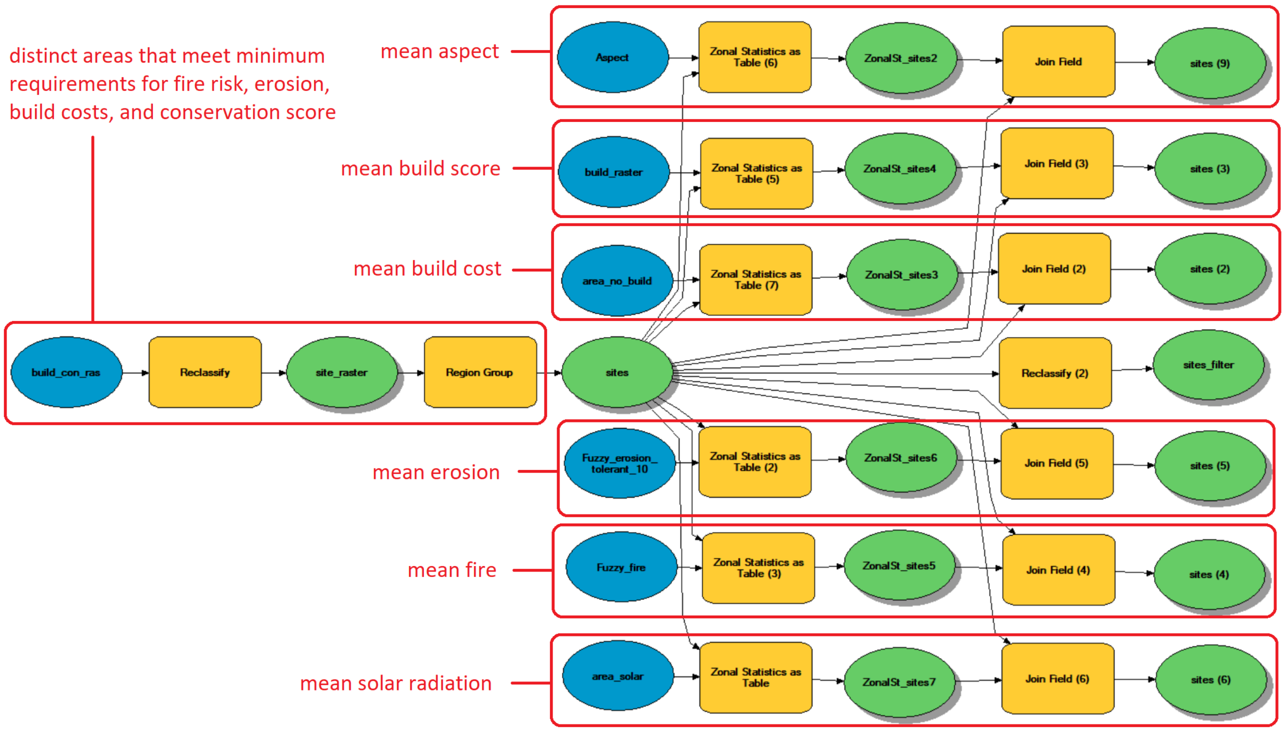
Appendix II Conservation Model



Appendix III Combined Model

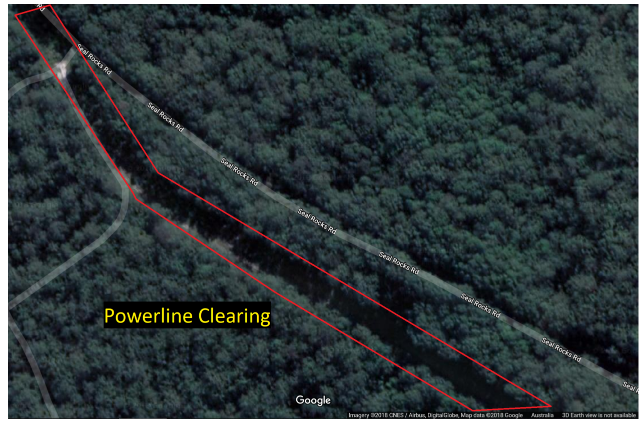


Appendix IV Ranking Model

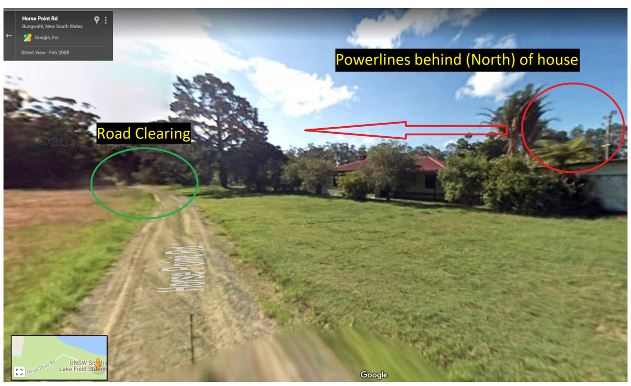


Appendix V Powerline Clearing

(a)



(b)



(c)

(d)

(a)(b): shows the powerline clearing from satellite images. This clearing is the criteria to decide low voltage powerlines.

(c)(d): Google Street View for (a) and (b)

Source: Google Maps