Expansion of the UNSW Cowan Field Station

Consultancy Report

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The consultancy report should be read in consultation with the metadata report.

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Executive Summary

Overview

TransGlobal GIS has prepared this Site Suitability Analysis on behalf of the University of New South Wales (UNSW) as part of the Cowan Field Research Station Expansion Project. The purpose of this analysis is the identification of suitable locations for the expansion of the existing research and accommodation facilities.

The following considerations were used when selecting expansion sites:

- Minimise construction costs
- Minimise the impact to areas of high conservation value
- Minimise the potential for sediment, chemical and organic pollution to enter the waterways
- Minimise the hazard from bush fires

Four types of models were created to perform this analysis: Erosion Model, Fire Model, Building Model and Conservation Model. The Erosion Model is based on the Universal Soil Loss Equation (USLE) and the Fire Model is mostly based on the MacArthur Fire Danger Meters Mk5. The Building and Conservation Models are largely based on distance parameters as well as information derived from the 10m gridded digital elevation model (DEM). These four models were each scaled using Fuzzy Membership at various stages in their development. The Fire, Erosion and Building Models later combined using the Fuzzy Overlay tool and the difference between these combined models and the Conservation Model produced the final Suitability Models. All GIS analyses were performed using tools in ArcMap v10.0.

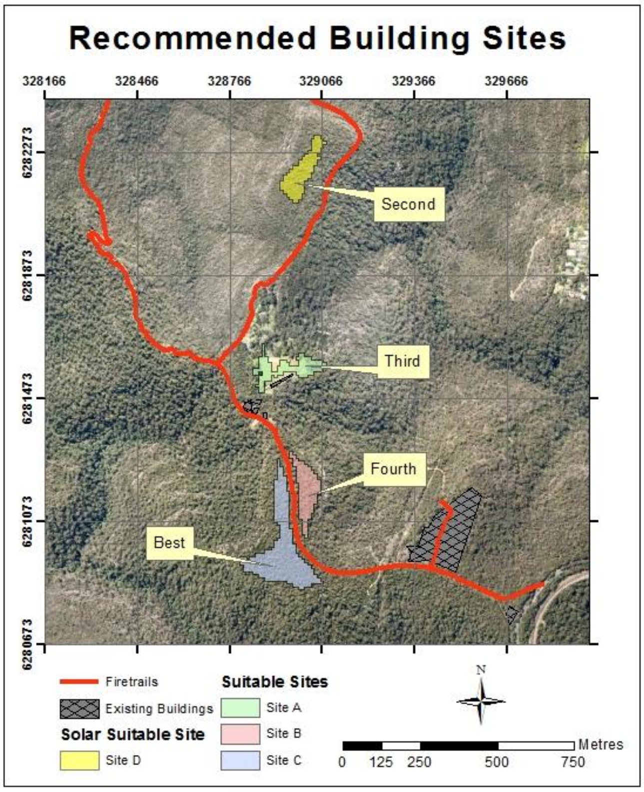

Figure 1: Map of Recommended Building Sites

Three suitable building sites were identified in the analysis with a fourth suitable site identified as an alternative solar powered option. The final four sites have been ranked in regard to their size (area), potential for solar radiation, visibility (views) and the estimated amount of vegetation to be cleared or thinned (Table 1). The site with the most favourable characteristics is Site C (Figure 1) however each has a combination of desirable attributes and meets the suitability criteria.

Table 1: Site Rankings

Site Rankings					
	View	Solar	Fuel	Total	Rank
Site A	2	4	1	8	Third
Site B	4	1	4	9	Fourth
Site C	3	2	3	8	Second
Site D	1	3	2	6	Best

Background

The UNSW Cowan Research Station is located within the Muogamarra Nature Reserve, and roughly 40 kilometres north of the Sydney CBD, New South Wales, Australia (Figure 2). The site is accessed from the Pacific Highway and internal access is provided via Glendale Road and 4WD fire trails. The existing station covers a 6-hectare area and was developed in the 1960's. The field station currently contains a laboratory, storage rooms, and a variety of wildlife pens, cages and fenced areas. The facilities also include a water tank for fire suppression (NSW National Parks and Wildlife Service 1998).

Suitable sites for expansion are based on building cost and environmental conservation, incorporating the constraints of fire hazard and erosion risk. The extension sites also must allow adequate space for a number of development and activity scenarios. These include additional laboratory space, classroom space, toilet block facilities, extension to water tank provisions and accommodation for students and faculty as well as low-impact bush camp shelters.

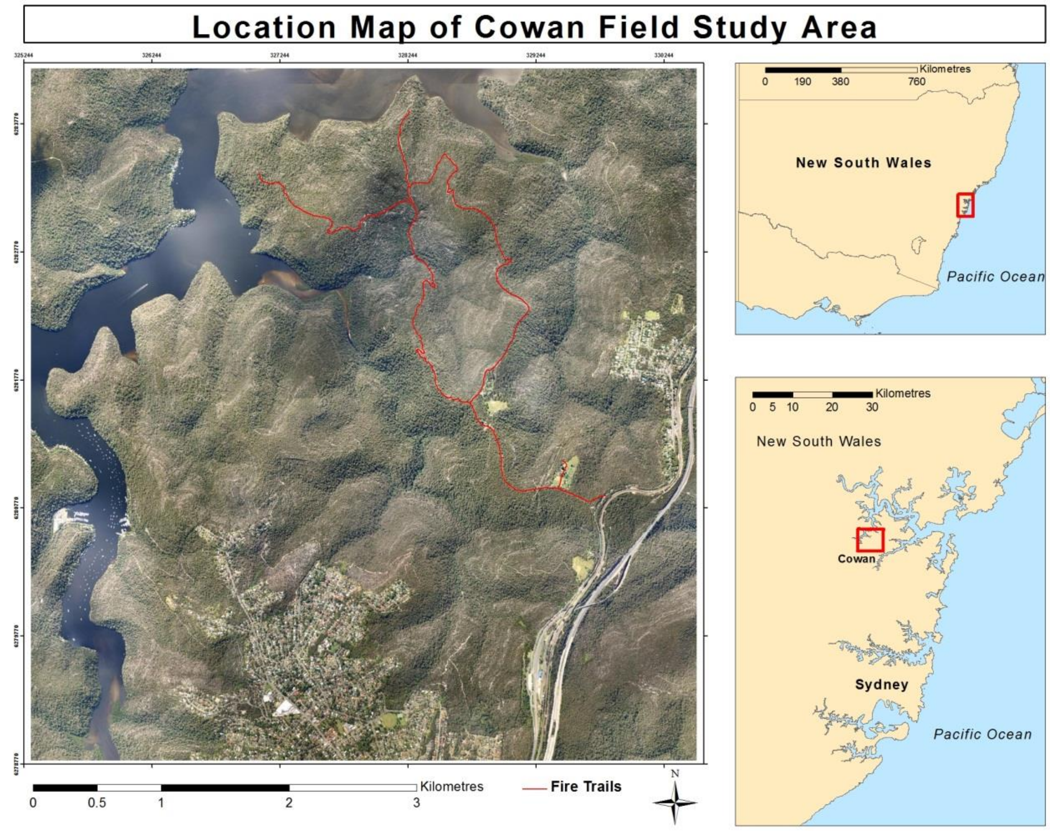

Figure 2: Location Map of Cowan Field Study Area

Data Sets

Multiple data sets were used in this site suitability analysis, requiring data preparation prior to any use. These data sets were acquired by several sources including the Hornsby Shire Council, NSW Department of Lands, Nearmap.com and UNSW. Data was reprojected from Australian Geodetic Datum 1966 (AGD66) to Geocentric Datum of Australia 1994 (GDA94) resulting in a consistent coordinate projection for all data sets. The data sets are in the coordinate system GDA94 using the Map Grid of Australia Zone 56 (MGA Zone 56) for this study area. Further details about required data sets are discussed within the analysis sections.

A digital elevation model (DEM) was interpolated using the ANUDEM algorithm, with 10 m elevation contours, spot heights, creeks and rivers as input data. The DEM has a 10 m cell size. Further information for the DEM can be accessed in the previously submitted metadata.

Analysis

Overview of Fuzzy Logic

The four models described in the following sections, as well as some of their components, were scaled using fuzzy memberships and subject to fuzzy overlay before they were combined to identify suitable building sites. The use of fuzzy logic allows for analyses which more closely represent real-world phenomena, providing for a range of solutions along a scale of degrees of truth. This is in contrast to analyses which simplify answers into 'true or false' categories. Fuzzy logic helps in tackling the common problem that there are inaccuracies in data set attribute values, particularly in the class definition and measurement of natural occurrences, that in reality boundaries between classes are not often well defined (Verstraete et al. 2005). Fuzzy logic manages this problem by assigning a degree of membership to a set for each cell, reflecting the possibility of membership (Burrough and McDonnell 1998, p. 268) and has been used in a variety of disciplines as a method to solve spatially related problems (Charabi and Gastli 2011; Soltani and Marandi 2011; Ocalir et al 2010; Ilanloo 2000).

In this analysis fuzzy logic has been used to address data and model uncertainties as well as the often indistinct boundaries inherent in the natural environment. The four models created for this analysis were each 'fuzzified' in their final stages and subject to fuzzy overlays before they were combined to produce the final models.

Erosion Model

Background
The erosion model was developed to assess the risk of local water pollution based on the erosion potential of the landscape. The erosion model is based on the Universal Soil Loss Equation (USLE). It was originally developed in the USA to predict long term average annual erosion under a variety of crop management systems. More complex models have since been developed, including the Water Erosion Prediction Project (WEPP) however these models are more process based and are beyond the scope of this analysis. The USLE allows for the calculation of potential annual soil erosion using seven variables: Rainfall Erosivity Factor (R), Soil Erodiblity Factor (K), Slope Gradient (S), Slope Length (L), Cropping Factor (C) and Control Practices (P) (Equation 1). USLE model tends to over-predict the lower-end values and under-predict upper end values, however this does not significantly impacts its usefulness (Nearing 1998).

The USLE Erosion Model states

$$A = R * K * S * L * C * P \qquad \text{Equation 1}$$

Where A = Soil Erosion (tonnes/ha/yr)

Table 2: Erosion Model Data Sets

Erosion Model	Data Type	Description
Soil Erodibility Factor	Raster	Susceptibility to erosion by rainfall and runoff
Flow Accumulation	Raster	Water accumulation along flow paths derived using D∞ algorithm
Vegetation	Polygon	Observed vegetation

		including vegetative resistance factor
Slope	Raster	Terrain slope in degrees
Slope Gradient	Raster	
Flow Length	Polyline	Distance along a flow path clipped to 150m
Slope Length	Polygon	Derived from flow accumulation and flow length

Methods

Rainfall Erosivity Factor (R)

The Rainfall Erosivity Factor values were derived from the NSW map in the SOILOSS handbook (Rosewell 1993). The values in the region of the study site are shown to be between 3000 and 4000. An R-value of 4000 has been used as it represents the worst case scenario for erosion and minimises the risk for pollution at the chosen site for the extension of the UNSW Field Station. It is important to note that this range of values has been derived for a large area, ignoring local variations, age of the data and fluctuations in rainfall and storm events since data collection; these factors can result in slight error and some uncertainty in the final model

Soil Erodibility Factor (K)

Soil Erodibility is a measure of the susceptibility of the soil to erosion (Rosewell 1993). The K-factor reflects the ease with which the soil is detached by splash during rainfall and/or by surface flow (Angima et al. 1993). The K-factor in this model has been derived using Table 2 of Rosewell (1993). The K-factor raster was generated based on the digital elevation model (DEM), flow accumulation, slope, Normalized Difference Vegetation Index (NDVI) and greenness indices, correlated with the soil survey data from the site; and was developed using a decision tree (Laffan 2012).

Slope Gradient of the Landscape (S)

The Slope Gradient is calculated based on the DEM using an equation derived from unit stream power theory (Moore and Burch 1986a). The initial derivation of the USLE effectively required the LS factor to be constrained to plane slopes as the methods failed to fully account for the hydrological processes, which significantly affect erosion and runoff. This modified equation is designed to reduce inconsistencies and account for more complex slope geometry (Moore and Burch 1986a).

$$S = (\sin(\text{slope}/57.296)/0.0896)^{1.35} \qquad \text{Equation 2}$$

Where slope is in degrees and converted to radians. There is a range of exponent values in the literature ranging from 1.3 to 2. This analysis has used a value of 1.35 (Selby 1993).

Slope Length (L)

Slope Length is defined as the distance, measured parallel to the ground surface, from the origin of overland flow to the point where either the slope gradient decreases enough so that sediment deposition begins or where run-off becomes concentrated in a defined channel (Rosewell 1993). The slope length is defined as flow length raised to a power.

$L = \text{flow\_length}^{m}$
$\text{flow\_length} = (\text{flow\_accumulation} * \text{cell size}/22.13)$ Equation 3

Where the exponent *m* varies with slope gradient (Kinnell 2010).

The exponent m-value in the literature ranges from 0.1, for areas of low slope gradient, to 0.6 with experiments elsewhere indicating a higher value is more representative of the actual phenomena (Selby 1993). An m-value of 0.4, which lies within the range cited in the literature, has been used in this analysis.

The flow length is calculated by generating a flow accumulation surface using a D-infinity algorithm multiplied by cell size over 22.13 (Moore and Burch 1986b). The D-infinity (D∞) algorithm (Tarboten 1997) models flow dispersal and convergence, with flow allocated on a weighted basis to two downslope neighbours (Wang and Laffan 2009). The Slope length was limited to a maximum of 150m, as erosivity does not increase significantly beyond this distance (Rosewell 1993).

Cropping Factor (C)

The Cropping Factor indicates the vegetative resistance to erosion. The USLE was originally devised for agricultural landscapes but it can be adapted to other landscapes by using unique C-factor values, which take into account the different vegetation cover. In this model a C-factor of 0.004 was assigned for forests and a value of 0.042 for cleared land (Rosewell 1993). The tarred roads and rail line in the study area were added to the vegetation shapefile and these features were assigned a C-factor of 0, as the erodibility of roads and rail lines are negligible.

It is important to note that no differentiation in the C-values has been made for different vegetation communities within the forest or cleared groupings. This is a limitation in the model as there may be different erosion resistance in different the vegetative communities.

Reduction in Erosion due to Control Practices (P)

The P-Value in the equation has been assigned a value of 1 as there are no control practices for erosion reduction in the study area (Rosewell 1993).

Figure 3 displays all of the erosion factors used in this model.

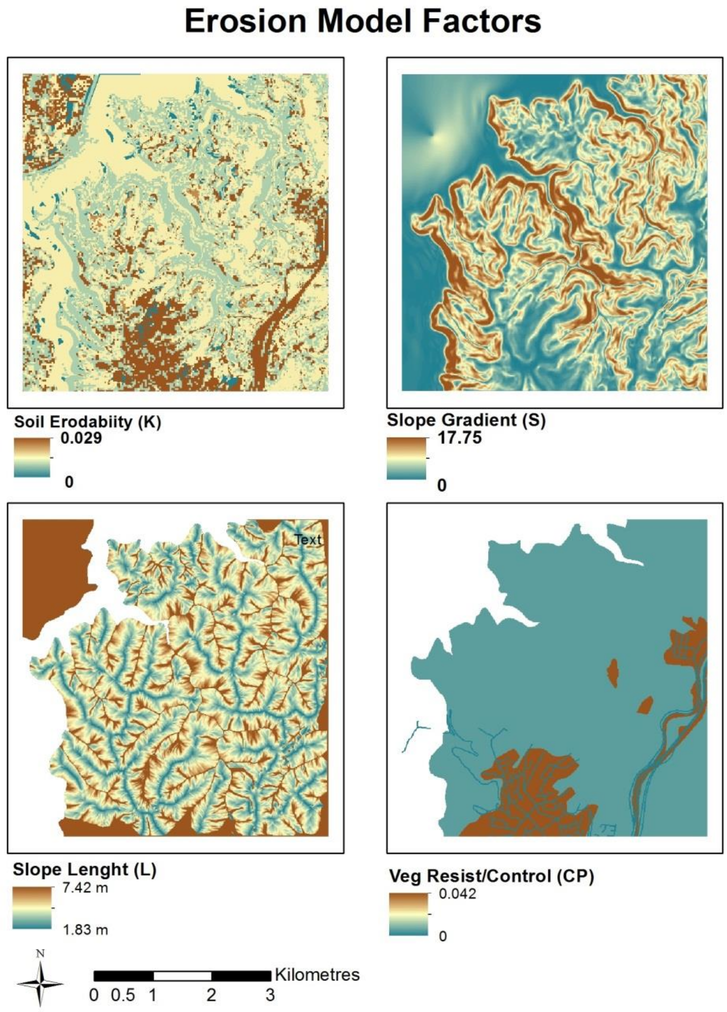

Figure 3: Erosion Model Factors

Fuzzy Membership of the Erosion Model

The resulting erosion model was scaled using fuzzy logic, using the fuzzy membership tool, to identify areas where the amount of soil loss in t/ha/yr would not be inhibitive for building. It has been assumed that an erosion rate of 0-10 t/ha/yr is optimal, 10-20 t/ha/yr is acceptable and a rate of over 20 t/ha/yr to be too high. Using these parameters, the minimum fuzzy membership value of 10 t/ha/yr and the maximum value of 20 t/ha/yr were used when scaling the model.

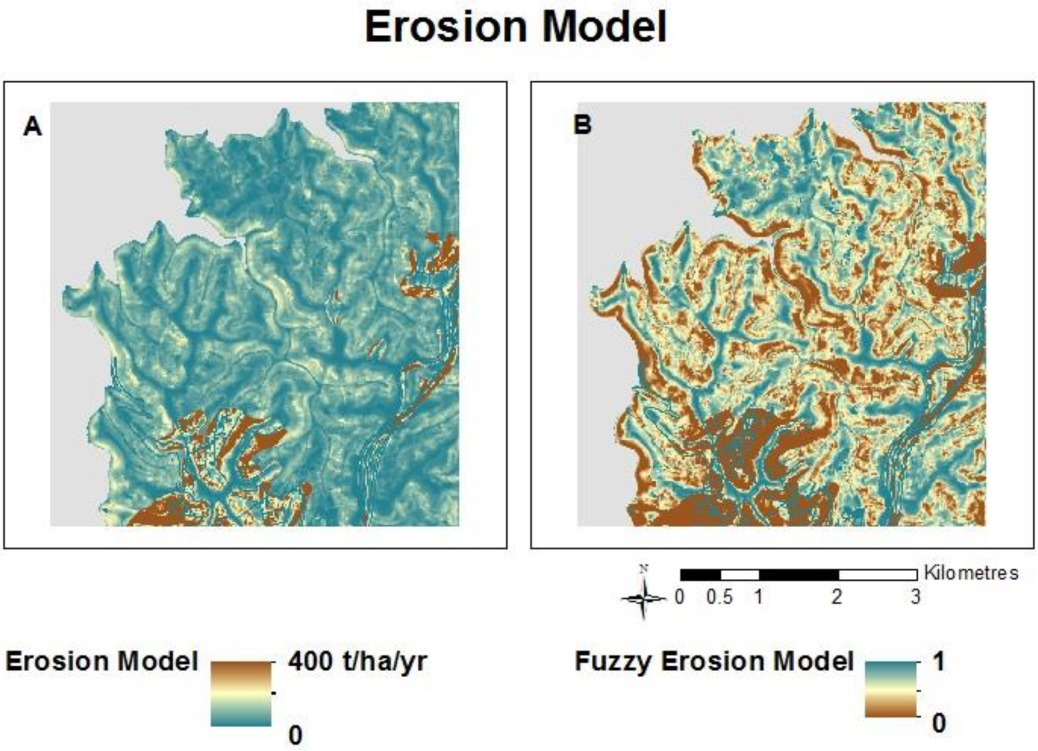

Figure 4a: Erosion Model
Figure 4b: Fuzzy Erosion Model

Fire Model

Background
The Fire Model was developed to measure the fire intensity potential across the study area. This model is based on the MacArthur Forest Fire Danger Meter Mk5 and the Grassland Fire Danger Meter Mk5. The parameters used are based on the works of Noble et al. (1980) and Sirakoff (1985). For the purposes of this study, three different scenarios were examined to determine various fire hazard models: high, moderate, and low fire conditions (Figure 5).

Table 3: Fire Model Data Sets

Fire Model Data Sets	Data Type	Description	Source
Slope	Raster	Terrain slope, in per cent	D
Vegetation	Polygon	Vegetation type	NSW Department of Lands
Rate of Spread	Raster	Fire spreading rate per type of vegetation	N
Rate of Spread on a slope	Raster	Fire spreading rate on a slope per type of vegetation	N
Surface Fuel	Raster	Fuel load on surface	M
Bark Fuel	Raster	Fuel load of bark	M
Elevation Fuel	Raster	Elevated fuel load	M

Fuel Load	Raster	Weight of fuel load for surface, bark and elevated vegetation	N
Fire Intensity	Raster	Amount of energy a fire will burn at a location	N

N – Newly created, D – Derived from DEM, M – Measured in situ

The fire intensity raster was calculated with regard to three factors: the rate of spread across flat ground (based on vegetation), the modified rate of spread on a slope, and the fuel load at each cell. This model quantifies the amount of energy a fire will burn with at a location. The parameters used in the model are based on the weather conditions of the area.

Wind is a very influential force on fire behaviour, but can be one of hardest elements to predict because of its variability. Fire spreads most rapidly in the direction of winds and in the direction of upslope terrain. Due to the frequent changes in wind direction and the complex effect of topography on fire behaviour (Pyne et al. 1996), neither the direction of the wind nor the effect of ridge tops are accounted for in this model. Absence of these factors in the fire model can result in slight error in the final rasters.

Methods
Factors incorporated in the fire model include wind speed, air temperature and humidity. The rates of spread are determined by these factors using a method derived from Noble et al. (1980). The value assigned to each factor differs between the low, moderate and high fire models are shown below.

Environmental Conditions	Moderate Fire	High Fire	Low Fire
McArthur Drought Index (D)	10	10	8
Air Temperature (T)	37.2°C	40°C	32°C
Relative Humidity (H)	15%	10%	40%
Wind Speed at 10 m height (V)	40 km/hr	60 km/hr	25 km/hr
Degree of Curing (C)	80%	80%	80%

Where Moderate Fire is set by the moderate fire model lab conditions, High Fire is set by extreme fire conditions, and Low Fire is set by more typical, low fire conditions.

Vegetation types in the study area were classed into four categories: grasslands, forests, scrublands, or non-vegetation. The grasslands consisted of cleared areas, while the forests consisted of Sheltered Hawkesbury Forest, Rough-barked Apple open forest, Low-woodland Hawkesbury, Exposed Hawkesbury woodland, and Plateau Low Open Forest. Scrublands consisted of Low woodland-shrubland, Banksia-Hakea scrub heath, Reedland, open scrub, and shrubland areas (NSW National Parks and Wildlife Service, 1998). All other areas were either unclassifiable or non-vegetated; therefore no fire spreading rates were assigned for these classes. Note that some vegetation, such as mangroves, is not represented in these models. They were not included in the vegetation data set due to their extremely low fire spreading rates and their location relative to other vegetation types. The mangrove forests are adjacent to vegetation with high fire danger, so they would not reduce any fire danger in those areas.

The rate of spread of fire was calculated using the Fire Danger Meter Mk5 for both grasslands and forests (Noble et al. 1980), while the rate of spread for scrublands was derived from McCaw et al. (2007).

For grasslands, the Grassland Fire Danger Meter Mk5 equations were used to calculate the per cent of fuel moisture content (M), the fire danger index (F), and the rate of spread (R).

$$M = \frac{97.7 + 4.06 \times H}{T + 60} - 0.00854 \times H + \frac{3000}{C} - 30 \qquad \text{Equation 4}$$

$$F = 3.35 \times W \times \exp^{(-0.0897 \times M + 0.0403 \times V)} \qquad \text{Equation 5}$$

$$R = 0.13 \times F \qquad \text{Equation 6}$$

For forests, the Forest Fire Danger Meter Mk5 equations were used to calculate the fire danger index (F) and the rate of spread (R).

$$F = 1.25 \times D \times e^{([TH/30]+0.0234 \times V)} \qquad \text{Equation 7}$$

$$R = 0.0012 \times F \times W \qquad \text{Equation 8}$$

The fuel load (W), in tonnes per hectare, was estimated by several consultancy groups for the majority of the study area using the Overall Fuel Hazard Guide by McCarthy et al. (1999). The fuel survey identified three fuel components: bark fuel, surface fuel, and elevated fuel. Some error is inherent in this method due the subjectivity of the individual sampler. Rates of spread for fire were calculated based on the fuel load survey and are shown below.

Rates of Spread (R)	Moderate Fire	High Fire	Low Fire
Grasslands	0.801 m/s	1.920 m/s	0.3397 m/s
Forests	0.0802 m/s	0.166 m/s	0.0165 m/s
Scrublands	0.534 m/s	1.107 m/s	0.1111 m/s

The rates of spread were then multiplied by $e^{(0.069*slope)}$ to give the rate of spreading on a slope.

The fire intensity is a combination of the parameters calculated above and is computed using the following formula:

Fire intensity = (energy that the forest fire will burn)*(fuel load)
(rate of spread on a slope)(0.27777)*(0.1) Equation 9

A value of 18600J was used for the energy with which the forest fire will burn, as suggested by Perry (1998). The fire intensity maps are shown below.

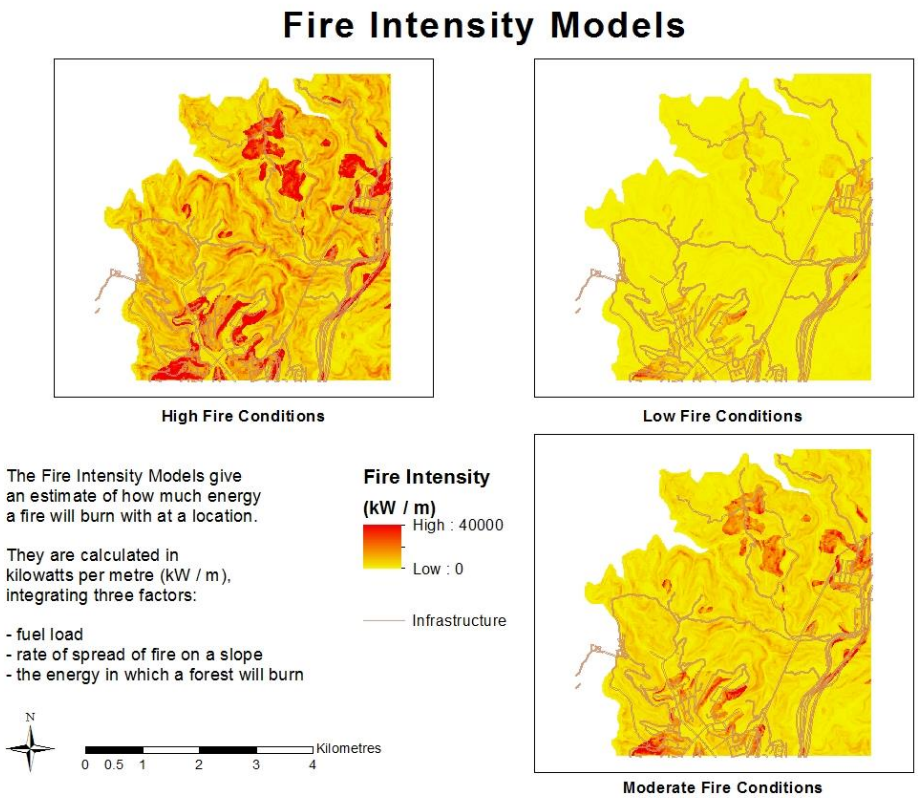

Figure 5: Fire Intensity Models

A bush fire is assumed to be easily controllable below 3000 kW/m and uncontrollable above 4000 kW/m (Gill, 1998). The final fire models were scaled using fuzzy logic, assigning full membership to any value that was below 3000 kW/m and non-membership to any value that was above 4000 kW/m, values between 3000-4000 kW/m were scaled between 1 and 0, respectively (Figure 6).

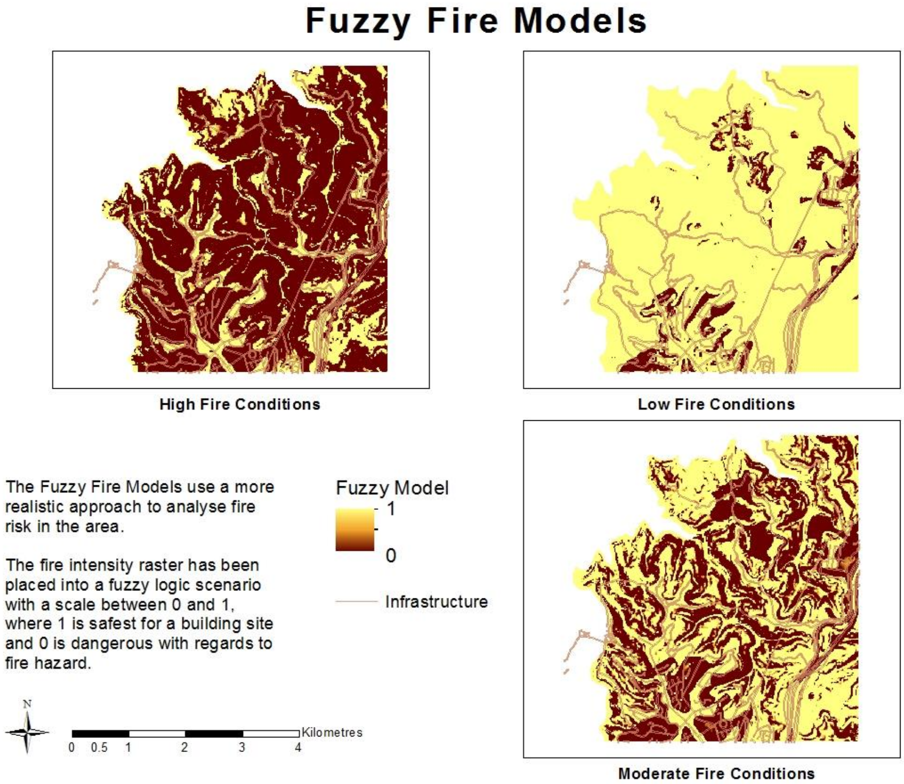

Figure 6: Fuzzy Fire Models

Building Model

Background
The Building Model was developed with the aim to minimise construction cost constraints and maximise occupant safety. This was done by identifying sites which minimise the need to grade the land, minimise the distance to the access roads and the electricity source while incorporating adequate setbacks from high voltage power lines and the F1 and Pacific Highway and rail lines.

Site selections in respect to building site attributes were dictated by six criteria: (1) proximity to the access roads, (2) proximity to low voltage power lines along Glendale Road (3) distance from high-voltage power lines, (4) slope, (5) distance from existing structures and private property and (6) distance to the highways and rail line (Figure 8a).

Method
The spatial data used to create the building model was first either extracted from existing data sets or created using ortho-photo imagery. Some data was adjusted in order to reflect current conditions at the study site, and distance rasters were derived for all vector data. Finally all rasters were assigned fuzzy membership and fuzzy overlayed to create the final building model.

The road access was narrowed down to include only Glendale Road and the 4WD fire trail. These roads were realigned using GPS centreline data obtained during a field visit as well as ortho-photo imagery. The realignment was necessary after assessing the root mean square (RMSE) of the existing fire trail data set against more current GPS data for the roads centreline. The RMSE was calculated at 88.5m in some areas, particularly in the south parts of the trail. The access roads were then compared to an ortho-photo image of the field site and minor adjustments were made.

Existing structures were identified using ortho-photo imagery and a polygon shapefile was created for all major buildings, excluding small animal pens, as well as the private property located along Glendale Road. The 132kV high-voltage powerlines, and the highways and rail lines were each extracted from the infrastructure shapefile. The low-voltage powerlines are assumed to follow Glendale Road and terminate at the NPWS building; these were also derived from the infrastructure shapefile (Figure X). Finally a slope raster was generated from the 10m gridded digital elevation model (DEM) developed prior to this suitability analysis.

In order to assign fuzzy membership, it was first necessary to convert each vector shapefile to a 10m gridded raster file using ArcMap 10.0 distance tools. The distance tools assign an increasing numeric value as the distance from the input feature increases. The path distance tool was used for the low-voltage power lines and access roads, and allowed the DEM to be input as the surface raster. The path distance tool was used because it integrates the surface over which the powerline and connection to the access roads must be constructed, which affects building costs. The Euclidean distance tool was used for the highways and rail lines, and existing buildings. This is a straightforward assignment of distances. The slope raster was of course not subject to a distance analysis.

All resulting distance rasters and the slope raster were assigned fuzzy membership values using the monotonic linear function (Table 4) resulting in positive and negative slopes dependant upon whether higher or lower values, such as distance and proximity, were desired. The access road was assigned fuzzy membership using the trapezoid function, where two fuzzy memberships were assigned using the monotonic linear function and were then combined using fuzzy overlay (Figure 8a). The optimal and acceptable input values for each variable were chosen based on local planning regulations, state fire policy and reasonable assumptions. The fuzzified data sets were then overlayed using the fuzzy overlay tool resulting in a layer with a resulting fuzzy membership value range of 1 to 0. This resulting layer was used in the Site Suitability Model.

Table 4: Building Model Variables

Building Model Variable	Minimum	Maximum
Slope Steepness	20%[1]	10%
Proximity to Low Voltage Powerlines	850m	200m[2]
Distance to High Voltage Powerlines	200m	300m
Distance to Highway and Rail Line	450m	600m
Distance to Existing Structures	5m	25m
Proximity to Access Road	16m[3], 500m	22m, 350m

1 Hornsby Shire 2006, pp. 30

2 Powercor 2011

3 NSW Fire Brigades 2010

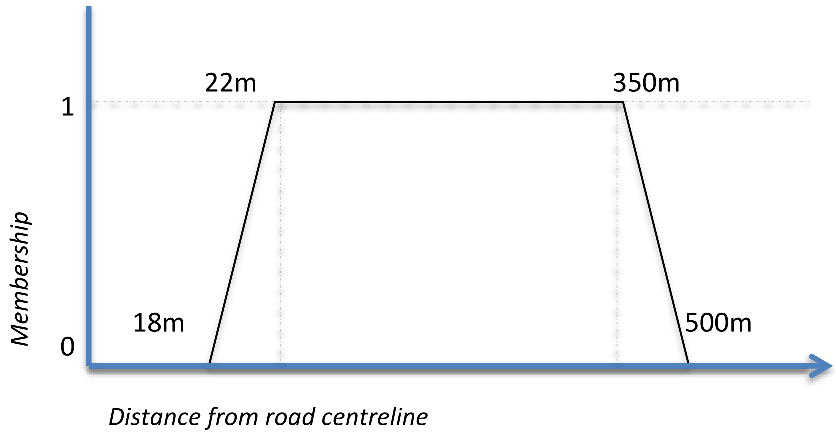

Figure 7: Fuzzy Membership Trapezoid Function for Access Roads

Alternative - Solar Building Model

The UNSW advocates incorporating environmental factors in new buildings (UNSW 2012), so a Solar Building Model was developed. The Solar Building Model was developed with the same aims as the original Building Model however it is based on the ability to self-sustain in regard to electricity through passive solar.

The Solar Building Model uses the same constraints as the original Building Model with the exception of proximity to low voltage power lines, which are not a limiting factor. Additional constraints in this model are (1) annual estimated solar radiation and (2) proximity to Glendale Road (Figure 8b). The final criteria are included as a safety measure; the quality of the access road, in terms of grade and width, deteriorates as the distance from Glendale Road increases. The ability to evacuate occupants of the future Research Station or allow for emergency vehicle access is significantly impacted by the road quality and distance.

Method

A solar radiation raster was created using the solar radiation tool and is based on the DEM. The Glendale Road shapefile, created in the original Building Model, was used to create a distance raster using the Euclidean distance tool. Both rasters were rescaled using fuzzy membership (Table x) and overlayed with the five fuzzy data sets created in the Building Model. The fuzzy overlay included potential solar radiation, proximity to Glendale Road as well as the slope, distance to high voltage power lines, distance to the highways and rail line, proximity to the access road, and distance to existing structures. The resulting raster has a fuzzy membership scale of 0.89 to 0, and was used in the Alternative Solar Suitability Model.

Table 5: Solar Building Model Variable

Solar Building Model Variable	Minimum	Maximum
Proximity to Glendale Road	2000m	500m
Potential Annual Solar Radiation	682kW	1,501kW

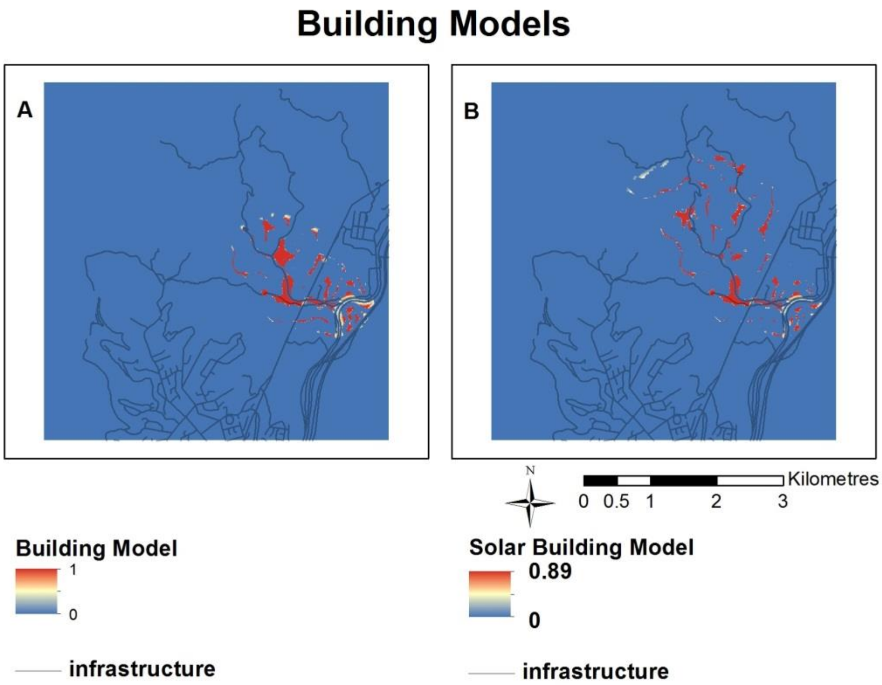

Figure 8a: Building Model
Figure 8b: Solar Building Model

Conservation Model

Background
The Conservation Model was generated to identify areas of high conservation value in the field study area, taking into account threatened flora and fauna, creeks and rivers, and mangrove forests. The Muogamarra Nature Reserve is home to vegetation that is relatively absent in the remainder of the region and protects a fairly undisturbed Hawkesbury Sandstone ecosystem, for which it has been listed on the Register of the National Estate (NSW National Parks and Wildlife Service 1998). Within the boundaries of the field study area six threatened flora species and 17 threatened fauna species have been observed, as well as four stands of mangrove forest. Of particular concern are the Regent Honeyeater and the Spotted-tailed Quoll, both of which are endangered, and five additional species which are listed as vulnerable by the Commonwealth of Australian (EPBC Act 1999).

Method
The feature data sets for threatened flora, threatened fauna, mangroves and creeks were used to created distance rasters using the Euclidean distance tool. These rasters were then assigned fuzzy membership values with locations of high conservation assigned full membership and areas of low conservation assigned non-membership (Table 6). Each of the four fuzzy layers was then overlayed using the fuzzy overlay OR function, which uses the highest value of each corresponding cell. The resultant Conservation Model indicates areas to be preserved due to their high conservation value (Figure 9).

Table 6: Conservation Model Variable

Conservation Model Variable	Minimum	Maximum
Proximity to Threatened Flora Habitat	100m	50m
Proximity to Threatened Fauna Habitat	100m	60m
Proximity to Mangrove Forests	100m	50m
Proximity to Creeks	100m	40m[1]
Proximity to Rivers	100m	40m[1]

1 Hornsby Shire 2006, pp. 30

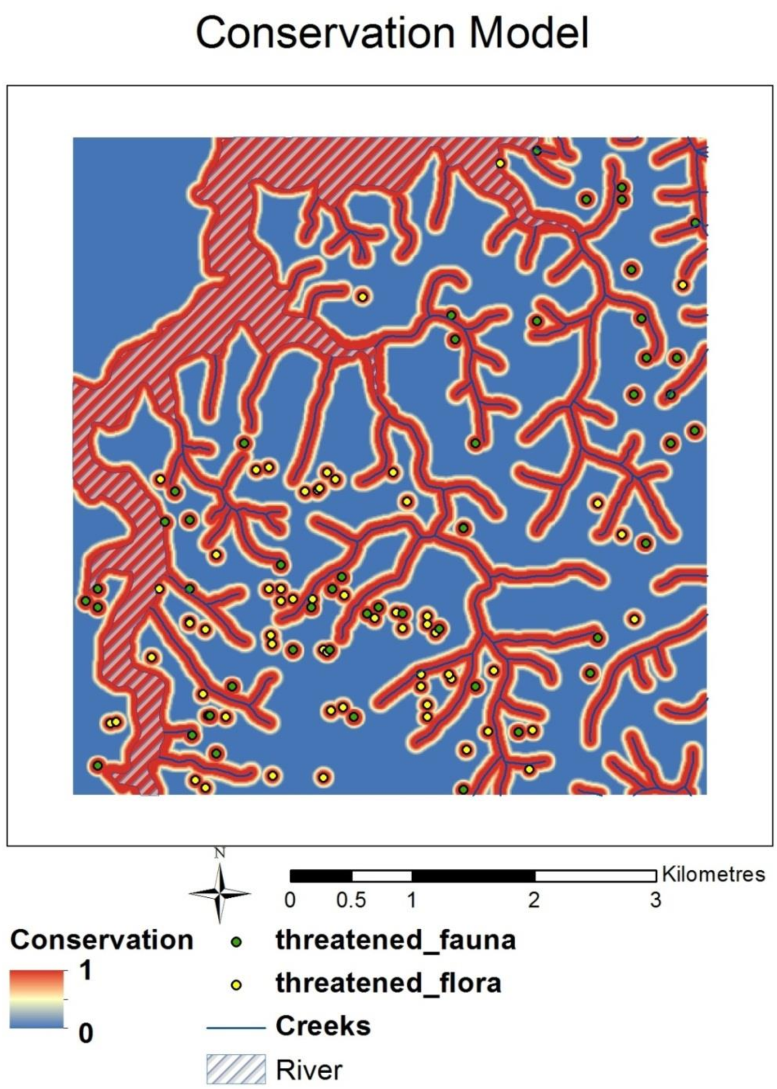

Figure 9: Conservation Model

Building Site Identification

Suitability Model

After development of the building, conservation, fire and erosion models, the final step in selecting suitable building sites was to combine the models and identify areas of acceptable levels of membership, where building costs are minimised and high conservation areas are avoided. The Moderate Fire Conditions Model (M), Erosion Model (E) and Building Model (B) were combined using the fuzzy overlay tool, taking the minimum membership value in corresponding cells. The Conservation Model (C) was then subtracted from the combined model (Equation 10). The resulting Suitability Model (S) has a range of membership from -1 to 0.99 where locations with a membership closer to 1 are more suitable for building and of lower conservation value, while areas with a value closer to -1 are less suitable for building and of higher conservation value.

Fuzzy Overly [M AND E AND B] MINUS [C] = [S] Equation 10

Endeavouring to find sites with high building suitability and of low conservation value, areas with a membership of greater than 0.9, 0.8 and 0.7 were identified and examined for size and shape. The membership value of 0.7 produced several sites, and lowering the membership value to areas with a membership of more than 0.65 provided the most appropriate fit, identifying three sites (Sites A through C) of adequate size and shape for the intended purposes (Figure 10).

Alternative - Solar Suitability Model

To provide an alternative option, the fuzzy overlay tool was used to combine the Solar Building Model (R), the High Fire Conditions Model (L) and the Erosion Model (E). As in the previous model, the Conservation Model was subtracted from the combined model, producing the Solar Suitability Model (A) (Equation 11). The resulting Solar Suitability Model (S) has a range of membership from -1 to 0.92.

Fuzzy Overlay [R AND L AND E] MINUS [C] = [A] Equation 11

The High Fire Conditions Model was used in the Solar Suitability Model because the parameters in the Solar Building Model allow sites to be located much farther from the point of egress onto the Pacific Highway thus increasing the distance for evacuation and the distance for fire and rescue to travel to reach the site.

The same threshold evaluation for membership was conducted, where 0.65 membership was again chosen as the best fit. One additional suitable site (Site D) was identified from the Solar Suitability Model.

Site Ranking

The four sites identified in the analysis have been ranked according to their size (area), potential for solar radiation, visibility (view) and the estimated amount of vegetation to be cleared or thinned (Table 1). Values for the ranking criteria were obtained using the solar radiation raster, the observer points tool, the fuel load raster and area was calculated using the geometry tool. Values in the first three raster were extracted using for each polygon and summarised to rank the sites.

Table 1: Site Rankings

Site Rankings					
	View	Solar	Fuel	Total	Rank
Site A	2	4	1	8	Third
Site B	4	1	4	9	Fourth
Site C	3	2	3	8	Second
Site D	1	3	2	6	Best

Recommendations

On the basis of this analysis Site C is the most suitable site for expansion of the Cowan Field Station. The site is an area where building costs will be lowest and impact on sensitive environmental features will be minimised. Site C is large offers adequate space with 3.3ht available for building, high solar potential and high visibility (views).

As an alternative 'green' site, Site D is recommended as it offers high solar suitability and is farthest away from the highways and rail lines. This site has the highest visibility and the lowest fuel load, and is not constrained by the need to connect to the lower voltage power lines, thus lowering costs for construction. However, it would be the furthest from which to evacuate in the event of a fire.

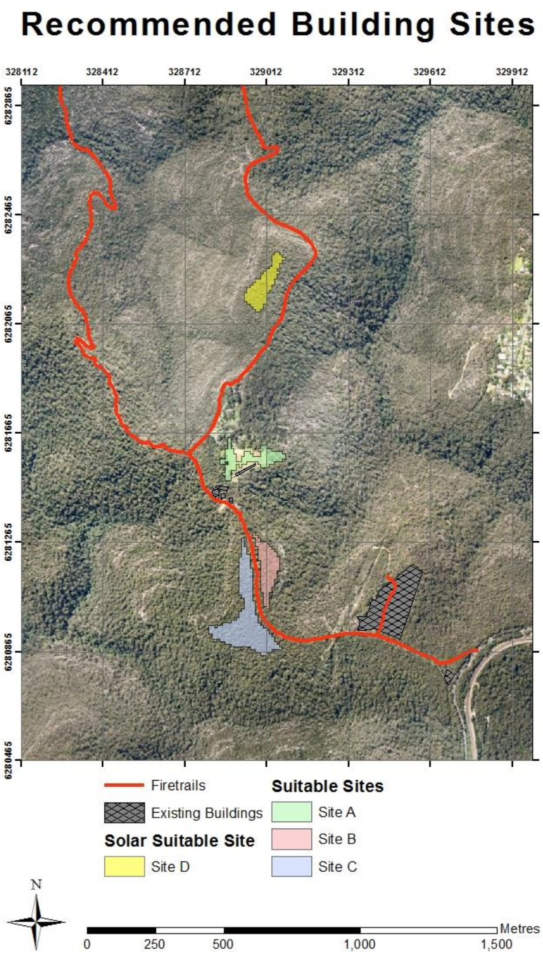

Figure 10: Recommended Building Sites

Due to the shape and low aesthetics of Site A, this location is ranked lower. Site B has the highest fuel load and least desirable views compared to the other sites. These locations are suitable, but could be too costly for construction or operation.

Any final decision will require an on the ground examination of each site and should incorporate considerations in regard to wildfire risk such as onsite emergency vehicle access, extension of the on-site water supply, incorporation of Asset Protection Zone (APZ) standards and AS 3959 building standards.

References

Angima, SD, Stott, DE, O'Neill, MK, Ong, CK & Weesies, GA 2003. Soil erosion prediction using RUSLE for central Kenyan highland conditions. *Agriculture, Ecosystems & Environment*, 15, 295-308.

Burrough, PA and McDonnell, RA 1998. *Spatial Information Systems and Geostatistics*. Oxford University Press, New York.

Charabi, Y & Gastli, A 2011. PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation, *Renewable Energy*, vol. 36, pp. 2554-2561.

Gill, M 1998. Research Letter #2: A Richter-type scale for fires? Division of Plant Industry, CSIRO.

Hornsby Shire 2006. *Berowra Cowan Development Control Plan*, Hornsby, NSW.

Ilanloo, M 2000. A comparative study of fuzzy logic approach for landslide susceptibility mapping using GIS: An experience of Karaj dam basin in Iran, *Procedia Social and Behavioral Sciences*, vol. 19, pp. 668–676.

Kinnell, PIA 1999. AGNPS-UM: applying the USLE-M within the agricultural non point source pollution model. *Environmental Modelling & Software*, 15, issue 3, 331-341.

Kinnell, PIA 2010. Event soil loss, runoff and the Universal Soil Loss Equation family of models: A review. *Journal of Hydrology*, 385, 384-397.
Kordi, M & Brandt, SA 2012. Effects of increasing fuzziness on analytic hierarchy process for spatial multicriteria decision analysis, *Computers, Environment and Urban Systems*, vol. 36, pp. 43–53

Laffan, SW 2012. *GEOS9016 Principles of GIS: course notes*, University of New South Wales, Sydney.

Malczewski, J 2006. Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis, *International Journal of Applied Earth Observation and Geoinformation*, vol. 8, iss. 4, pp. 270-277.

McCarthy, G J, Tolhurst, KG & Chatto, K 1999. *Overall Fuel Hazard Guide, 3rd edition*. Victorian Department of Natural Resources and Environment, Fire Management Research Report 47.

McCaw, WL, Gould, JS & Cheney, NP. 2008. Existing fire behaviour models under-predict the rate of spreads of summer fires in open jarrah (*Eucalyptus marginate*) forest. *Australian Forestry*, vol. 71, no. 1, pp. 16-26.

Moore, ID & Burch, G 1986a. Physical basis of the Length-Slope Factor in the Universal Soil Loss Equation. *Soil Science Society of America Journal*, 50, 1294-1298.

Moore, ID & Burch, G 1986b. Modeling Erosion and deposition: topographic effects. *Transactions of ASAE*, 29, 1624-1630.

Nearing, MA 1998. Why soil erosion models over-predict small soil losses and under-predict large soil losses. *Catena*, 32 (1), 15-22.

NSW Fire Brigades 2010. Guidelines for Emergency Vehicle Access, Policy no. 4, v. 2. State Government of NSW: Greenacre, NSW.

NSW National Parks and Wildlife Service 1998. *Marramarra National Park, Muogamarra Nature Reserve and Maroota Historic Site Plan of Management*, Hornsby, NSW.

Noble, IR, Bary, GAV, & Gill, A.M 1980. McArthur's fire-danger meters expressed as equations. *Australian Journal of Ecology*, vol. 5, no. 2, pp. 201-203.

Ocalir, EV, Ercoskun, OY, & Tur, R 2010. An integrated model of GIS and fuzzy logic (FMOTS) for location decisions of taxicab stands, *Expert Systems with Applications*, vol. 37, pp. 4892–4901.

Perry, GLW. 1998. Current approaches to modelling the spread of wildland fire: a review. *Progress in Physical Geography*, vol. 22, no. 2, pp. 222-245.

Powercor 2011. Customer's Selection Guide – Indicative Powerline Construction Costs, viewed 16 May 2012, <http://www.powercor.com.au/docs/pdf/Electricity%20Networks/Powercor%20Network/INDICATIVE%20COST%20GUIDE_ic001_110811.pdf>.

Pyne, SJ, Andrews, PL & Laven, RD. 1996. *Introduction to Wildland Fire, 2nd edition*. New York, John Wiley and Sons, pp. 52.

Rosewell, CJ 1993. SOILOSS : a program to assist in the selection of management practices to reduce erosion, Technical handbook No 11, Soil Conservation Service, Gunnedah
Selby, M. J. & Hodder, A. P. W. (1993) Hillslope materials and processes, 2nd edn. Oxford University Press, Oxford.

Sirakoff, C 1985. A correction to the equations describing the McArthur forest fire danger meter. *Australian Journal of Ecology*, vol. 10, no. 4, pp. 481.

Soltani, A & Marandi, EZ 2011. Hospital Site Selection Using Two-Stage Fuzzy Multi-Criteria Decision Making Process, *Journal of Urban and Environmental Engineering (JUEE)*, vol.5, no.1, pp.32-43.

Tarboton, DG 1997. A New Method for the Determination of Flow Directions and Contributing Areas in Grid Digital Elevation Models. Water Resources Research, 33(2): 309-319

UNSW 2012. *Environmental Policy, v. 3.0*, viewed 8 May 2012, <http://www.gs.unsw.edu.au/policy/documents/environmentpolicy.pdf>.

Verstraete, J, De Tre, G, De Caluwe, R, and Hallez, A Petry, FE, 2005. 'Chapter 3: Field Based Methods for the Modeling of Fuzzy Spatial Data,' pp. 41-69. In: Robinson, VB, and Cobb, MA (eds) 2005. *Fuzzy Modeling with Spatial Information for Geographic Problems*, Springer: New York, NY.

Wang, D & Laffan, SW 2009. Characterisation of valleys from DEMs: *proceedings of the 18th World IMACS / MODSIM Congress*, Cairns.