Appendix 3: Sub-contracted Report:

Fuel Load and Fire Behaviour Assessments for Vegetation within LCDB2

H. Grant Pearce - Fire Scientist, Scion, Forest Research Limited, Christchurch

Background

The release of the updated version of the Landcover Database (LCDB2) has resulted in improved description of the vegetation cover of New Zealand. This provides an opportunity to improve definitions of fuel types, fuel loads and potential fire behaviour for use in determining the "Hazard" component of the New Zealand Wildfire Threat Analysis System (NZWTAS).

Updated equations or values for calculating fuel load, rate of fire spread, and head-fire intensity (as well as degree of curing and slope correction factor) are presented for 32 of the 43 cover classes contained in LCDB2, where the presence of vegetation implies fire spread. These are assigned on the basis of the current state of knowledge on fire behaviour in New Zealand vegetation types (Pearce and Anderson 2004), including a mix of observations obtained from fuel sampling, experimental burning trials, wildfire documentation, and expert opinion.

Results

Generalised equations

In the previous version of the NZWTAS hazard layer (Leathwick and Briggs 2001), assignment of values or equations for fuel load and rate of fire spread, in particular, were made for individual vegetation or cover classes. This resulted in at least 3 equation forms for fuel load and a further 4 equations for rate of spread, based on available models for grass, scrub or forest fuel types or assumed constant values (Borger and Pearce 2000).

In the process of updating fuel model assignments from LCDB1 to LCDB2, a decision was made to streamline the process by developing a single, generic equation for all fuel types for each of fuel load and rate of spread. The intention was to simplify the programming requirements for producing algorithms within GIS, and to remove confusion and potential sources of error associated with re-entering the various equation forms.

As a result, a single algorithm for each of fuel load and rate of fire spread can now be programmed for all vegetation types, and the various fuel load and rate of spread parameters described in table form.

Fuel Load

Fuel load (in tonnes per hectare, t/ha) was described for each vegetated cover type as either a constant value or an equation. Fuel loads for grass and scrubland vegetation types were assigned a constant value (FL_0). In the absence of information on vegetation structure within the Land Cover class description (Thompson *et al*. 2003), this was typically arrived at by combining an estimate of average vegetation height and ground cover with models for available fuel load (Fogarty and Pearce 2000). In the case of forested fuel types (both indigenous and exotic), equations for available fuel load were defined based on the Buildup Index (BUI) component of the FWI System for standing pine or mixedwood (FL_1), or logging slash (FL_2) fuel types (after Forestry Canada Fire Danger Group 1992, Borger and Pearce 2000).

The three equation options updated for each fuel load model are as follows:

$$FL_0 = p1_1$$

$$FL_1 = p1_1 * [1 - EXP(p2_1 * BUI)]^{p3_1}$$

$$FL_2 = p1_1 * [1 - EXP(p2_1 * BUI)] + p1_2 [1 - EXP(p2_2 * BUI)]$$

and the generalised fuel load equation for all fuel types is:

$$FL_g = p1_1 * [1 - EXP(p2_1 * BUI)]^{p3_1} + p1_2 * [1 - EXP(p2_2 * BUI)]^{p3_2}$$

Values associated with each of the parameters contained within the various fuel load equations are specified in Table 1. Default values for non-critical parameters required within the generalised rate of spread equation are shown in shaded cells (in red font).

Table 1. Fuel load equation parameters for LCDB2 land cover types.

LCDB2 Class No.	LCDB2 Class	FL model	FL_p1_1	FL_p1_2	FL_p2_1	FL_p2_2	FL_p3_1	FL_p3_2
1	Built-up Area							
2	Urban Parkland / Open Space	FL	2	0	1	1	0	0
3	Surface Mine							
4	Dump	FL	10	0	1	1	0	0
5	Transport Infrastructure							
10	Coastal Sand and Gravel							
11	River / Lakeshore Gravel and Rock							
12	Landslide							
13	Alpine Gravel and Rock							
14	Permanent Snow and ice							
15	Alpine Grass / Herbfield	FL	2	0	1	1	0	0
20	Lake and Pond							
21	River							
22	Estuarine Open Water							
30	Short-rotation Cropland – Grain	FL	8	0	1	1	0	0
31	Vineyard	FL	2	0	1	1	0	0
32	Orchard and Other Perennial Crops	FL	2	0	1	1	0	0
40	High Producing Exotic Grassland	FL	4	0	1	1	0	0
41	Low Producing Grassland	FL	3	0	1	1	0	0
43	Tall Tussock Grassland	FL	20	0	1	1	0	0
44	Depleted Tussock Grassland	FL	2	0	1	1	0	0
45	Freshwater Sedgeland / Rushland	FL	8	0	1	1	0	0
46	Saltmarsh	FL	8	0	1	1	0	0
47	Flaxland	FL	10	0	1	1	0	0
50	Bracken Fern	FL	10	0	1	1	0	0
51	Gorse and Broom – Gorse	FL	30	0	1	1	0	0
52	Manuka and/or Kanuka	FL	25	0	1	1	0	0
53	Matagouri	FL	8	0	1	1	0	0
54	Broadleaved Indigenous Hardwoods	FL1	50	0	-0.0149	1	2.48	1
55	Sub Alpine Shrubland	FL	15	0	1	1	0	0
56	Mixed Exotic Shrubland	FL	10	0	1	1	0	0
57	Grey Scrub	FL	10	0	1	1	0	0
60	Minor Shelterbelts	FL1	40	0	-0.0149	1	2.48	1
61	Major Shelterbelts	FL1	50	0	-0.0149	1	2.48	1
62	Afforestation (not imaged)	FL	3.5	0	1	1	0	0
63	Afforestation (imaged, post LCDB 1)	FL2	30	25	-0.025	-0.034	1	1
64	Forest – Harvested	FL2	45	30	-0.025	-0.034	1	1
65	Pine Forest - Open Canopy	FL2	20	20	-0.015	-0.035	1	1
66	Pine Forest - Closed Canopy	FL2	15	12	-0.025	-0.034	1	1
67	Other Exotic Forest	FL1	50	0	-0.0115	1	1	0
68	Deciduous Hardwoods	FL1	15	0	-0.0183	1	1	0
69	Indigenous Forest	FL1	60	0	-0.0149	1	2.48	0
70	Mangrove	FL	5	0	1	1	0	0

Rate of Spread

Rate of fire spread (in metres per hour, m/h), uncorrected for the effect of slope, was described for each vegetation cover type using an equation or, in a few cases (e.g., dumps, mangroves), an assumed constant value (ROS_0). Rate of spread in shrub/scrub vegetation types (ROS_1) was based on variations of the New Zealand scrubland fire danger model (Pearce 2001, Pearce and Anderson 2004), which uses the Initial Spread Index (ISI) component from the FWI System. Rate of spread in grassland vegetation types (ROS_2) was based on the open grass fuel models from the Canadian FBP System (Forestry Canada Fire Danger Group 1992, Borger and Pearce 2000), which utilise the ISI component and an estimate of the degree of grass curing (DoC%). Depending on the predominant fuels expected to carry a fire, forest fuel types were based on either grass models (ROS_2), logging slash or standing pine models (ROS_3) or, in the case of indigenous forest, mixedwood fuel types (ROS_4) from the Canadian FBP System (Forestry Canada Fire Danger Group 1992, Borger and Pearce 2000). As well as the ISI component, these latter equations also include a BUI effect on rate of spread. The mixedwood fuel type also includes a vegetation mix component (pp%).

The four updated rate of fire spread equation options for different fuel types are:

$$ROS_0 = p1_1$$

$$ROS_1 = p1_1 * \left[1 - EXP\left(p2_1 * ISI\right)\right]^{p3_1}$$

$$ROS_2 = p1_1 * \left[1 - EXP\left(p2_1 * ISI\right)\right]^{p3_1} * \left[0.02 * DoC\% - 1\right]$$

$$ROS_3 = p1_1 * \left[1 - EXP\left(p2_1 * ISI\right)\right]^{p3_1} * EXP\left(50 * LN\left(p4\right) * \left(\frac{1}{BUI} - \frac{1}{p5}\right)\right)$$

$$ROS_4 = \left[\frac{pp\%}{100} * p1_1 * \left(1 - EXP\left(p2_1 * ISI\right)\right)^{p3_1} + 0.2 * \left(1 - \frac{pp\%}{100}\right) * p1_2 * \left(1 - EXP\left(p2_2 * ISI\right)\right)^{p3_2}\right]$$
$$* EXP\left(50 * LN\left(p4\right) * \left(\frac{1}{BUI} - \frac{1}{p5}\right)\right)$$

and the single generalised equation for rate of spread in all fuel types is:

$$ROS_g = \left[\frac{pp\%}{100} * p1_1 * \left(1 - EXP\left(p2_1 * ISI\right)\right)^{p3_1} + 0.2 * \left(1 - \frac{pp\%}{100}\right) * p1_2 * \left(1 - EXP\left(p2_2 * ISI\right)\right)^{p3_2}\right]$$
$$* EXP\left(50 * LN\left(p4\right) * \left(\frac{1}{BUI} - \frac{1}{p5}\right)\right) * \left[0.02 * DoC\% - 1\right]$$

Values associated with each of the parameters contained within the various rate of spread equations are specified in Table 2. Again, default values for non-critical parameters required within the generalised rate of spread equation are shown in shaded cells (in red font).

Table 2. Rate of spread equation parameters for LCDB2 land cover types.

LCDB2 Class No.	LCDB2 Class	ROS model	ROS_pp %	ROS_p1$_1$	ROS_p1$_2$	ROS_p2$_1$	ROS_p2$_2$	ROS_p3$_1$	ROS_p3$_2$	ROS_p4	ROS_p5	DOC%
1	Built-up Area											
2	Urban Parkland/Open Space	ROS2	100	11400	0	-0.0310	1	1.4	0	1	1	60
3	Surface Mine											
4	Dump	ROS	100	20	0	1	1	0	0	1	1	100
5	Transport Infrastructure											
10	Coastal Sand and Gravel											
11	River and Lakeshore Gravel and Rock											
12	Landslide											
13	Alpine Gravel and Rock											
14	Permanent Snow and ice											
15	Alpine Grass / Herbfield	ROS2	100	15000	0	-0.0350	1	1.7	0	1	1	100
20	Lake and Pond											
21	River											
22	Estuarine Open Water											
30	Short-rotation Cropland – Grain	ROS2	100	15000	0	-0.0350	1	1.7	0	1	1	100
31	Vineyard	ROS2	100	11400	0	-0.0310	1	1.4	0	1	1	80
32	Orchard and Other Perennial Crops	ROS2	100	11400	0	-0.0310	1	1.4	0	1	1	60
40	High Producing Exotic Grassland	ROS2	100	15000	0	-0.0350	1	1.7	0	1	1	60
41	Low Producing Grassland	ROS2	100	11400	0	-0.0310	1	1.4	0	1	1	80
43	Tall Tussock Grassland	ROS2	100	15000	0	-0.0350	1	1.7	0	1	1	100
44	Depleted Tussock Grassland	ROS2	100	15000	0	-0.0350	1	1.7	0	1	1	100
45	Freshwater Sedgeland / Rushland	ROS1	100	4920	0	-0.1000	1	1.5	0	1	1	100
46	Saltmarsh	ROS2	100	15000	0	-0.0350	1	1.7	0	1	1	100
47	Flaxland	ROS1	100	4920	0	-0.1000	1	1.5	0	1	1	100
50	Bracken Fern	ROS2	100	15000	0	-0.0350	1	1.7	0	1	1	100
51	Gorse and Broom – Gorse	ROS1	100	4920	0	-0.1000	1	1.5	0	1	1	100
52	Manuka and or Kanuka	ROS1	100	4920	0	-0.1000	1	1.5	0	1	1	100
53	Matagouri	ROS2	100	15000	0	-0.0350	1	1.7	0	1	1	80
54	Broadleaved Indigenous Hardwoods	ROS4	50	1800	1800	-0.0697	-0.0232	4.0	1.6	0.80	50	100
55	Sub Alpine Shrubland	ROS1	100	4920	0	-0.1000	1	1.5	0	1	1	100
56	Mixed Exotic Shrubland	ROS1	100	4428	0	-0.1000	1	1.5	0	1	1	100
57	Grey Scrub	ROS1	100	2460	0	-0.1000	1	1.5	0	1	1	100
60	Minor Shelterbelts	ROS3	100	1800	0	-0.0800	1	3.0	0	0.80	62	100
61	Major Shelterbelts	ROS3	100	1800	0	-0.0800	1	3.0	0	0.80	62	100

(cont. over)

Table 2 (cont.). Rate of spread equation parameters for LCDB2 land cover types.													
LCDB2 Class No.	**LCDB2 Class**	**ROS model**	**ROS_pp %**	**ROS_p1_1**	**ROS_p1_2**	**ROS_p2_1**	**ROS_p2_2**	**ROS_p3_1**	**ROS_p3_2**	**ROS_p4**	**ROS_p5**	**DOC%**
62	Afforestation (not imaged)	ROS2	100	15000	0	-0.0350	1	1.7	0	1	1	70
63	Afforestation (imaged, post LCDB 1)	ROS2	100	15000	0	-0.0350	1	1.7	0	1	1	70
64	Forest – Harvested	ROS3	100	4500	0	-0.0297	1	1.3	0	0.75	38	100
65	Pine Forest - Open Canopy	ROS2	100	15000	0	-0.0350	1	1.7	0	1	1	70
66	Pine Forest - Closed Canopy	ROS3	100	1800	0	-0.0800	1	3.0	0	0.80	62	100
67	Other Exotic Forest	ROS3	100	1800	0	-0.0800	1	3.0	0	1	62	100
68	Deciduous Hardwoods	ROS3	100	1800	0	-0.0232	1	1.6	0	0.90	32	100
69	Indigenous Forest	ROS4	60	1800	1800	-0.0697	-0.0232	4.0	1.6	0.80	50	100
70	Mangrove	ROS	100	5	0	1	1	0	0	1	1	100

Degree of Curing

The degree of curing of grass fuels is used to describe the seasonal die-off of grasslands, and is typically expressed as the proportion (%) of dead material within the total grass complex. It is a key variable in determining the rate of fire spread in grassland vegetation types and, at values below 50% curing, rate of spread is normally assumed to be zero. In the previous version of the NZWTAS hazard layer, this degree of curing (DoC%) was treated as a constant that only varied slightly as a result of seasonal dryness, described using the Drought Code (DC) component of the FWI System; i.e. if DC ≤300, DoC% = 70%; if DC >300, DoC% = 80%.

Due to the larger number of vegetation cover types within LCDB2, and wider variability in curing values expected within these cover types (e.g., from irrigated grasses within urban parklands, orchards and other perennial crops with low to moderate DoC% values through to depleted tussock and alpine grasslands, and short-rotation grain crops with high DoC% values) under the extreme dry (20% worst fire season) fire weather scenario used in the NZWTAS, it was felt that a wider range of assumed constant values of DoC% would be more appropriate for this version of the hazard layer calculations. The constant values of DoC% assigned to the various grass-dominated cover types within LCDB2 are depicted in Table 2, and range from 60% to 100%.

Slope Correction Factor

Fires generally travel faster upslope, with spread rate increasing exponentially with increasing slope steepness. The Slope Correction Factor (SCF) is therefore used to adjust rate of spread estimates derived from the above equations (determined for flat ground) for the effect of slope of slope steepness. In all cases, slope is assumed to be positive so that fires always travel upslope.

In the previous version of the NZWTAS hazard layer, two different SCF relationships were included that distinguished between the slope effect in scrub fuels compared with other vegetation type. This was based on limited observations available at that time from fires in scrub fuels. However, there has been no further evidence to support the need for a separate relationship for scrub fuels since this previous analysis, so that it is now recommended that the single SCF relationship be used in producing the updated hazard layer. This relationship is as follows, where slope angle is expressed in degrees (º):

$$SCF = EXP\left(TAN\left(\frac{Slope}{57.29578}\right)^{1.2} * 3.533\right)$$

- applies to slopes up to 35º; above this, assume slope = 35º (i.e. SCF ~10).

- email to Craig Briggs sent 24/08/05:
The issue with very high values more than likely results from applying the SCF relationship beyond the range over which it was developed. It was really only intended to be used for vegetated slopes (i.e., slopes on which you would normally expect to find vegetation growing), so that it probably only applies for slopes up to 35 degrees (70%). Above this, we'd expect patchy vegetation interspersed with rock screes or outcrops with little or no vegetation, and certainly not continuous vegetation required for continuous fire spread. You could probably verify this by overlaying slope steepness over your vegetation types. I'd recommend that you put in an upper limit at 35 degrees (SCF ~ 10), above which the SCF doesn't change (i.e. remains constant at 10). This would then give you a much more useful range of SCF values from 1-10.
- this may be as simple as putting in a statement that IF SCF >10, THEN SCF = 10

Head Fire Intensity

The head fire intensity represents the potential energy output (in kilowatts per metre, kW/m) of the spreading fire front (assumed to be at the head where the rate of spread is the greatest). It is determined from the amount of fuel consumed (assumed to be equivalent to the available fuel load, FL) and the slope-corrected rate of fire spread (ROS * SCF):

$$HFI = \frac{FL * ROS * SCF}{2}$$

Summary

Fuel models and associated equations for fuel load and rate of spread have been assigned to the 32 vegetated land cover classes contained within the updated Landcover Database (LCDB2). In addition, a single generalised equation for use with all vegetation types has been derived for both fuel load (FL) and rate of spread (ROS), and required parameters provided in tabular format. Relationships for determining degree of curing (DoC%) and slope correction factor (SCF) have been simplified, with DoC% values being assigned to each cover class (in tabular format) and a single SCF equation replacing the multiple equations used previously. The final equation for determining head fire intensity (HFI) that combines these intermediate components is also re-iterated.

In addition to the equations and values outlined in this document, all equations and tables are also contained in a separate Excel spreadsheet, a copy of which is supplied with this report (LCDB2_eqn.xls). Equations and tables have also been loaded into a GIS format (ESRI ArcGIS), and these algorithms and associated data tables are available on request.

References

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