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ERRATA

Figure 1 requires two corrections. First, the DC standard moisture equivalent equation ($MC=800/e^{(DC/400)}$) should be replaced by the national standard equation for moisture content ($MC=400/e^{(DC/400)}$), where the DC has been assigned a maximum theoretical moisture content of 400%.

Second, there is an error in the equation for southern interior B.C. (Nelson) forests ($MC=1392.7/e^{(DC/79.1)}$). This equation should be replaced with the following: $MC=285.8/e^{(DC/304.5)}$.

The four corrected equations are plotted in a revised Figure 1 below, with corrected caption.

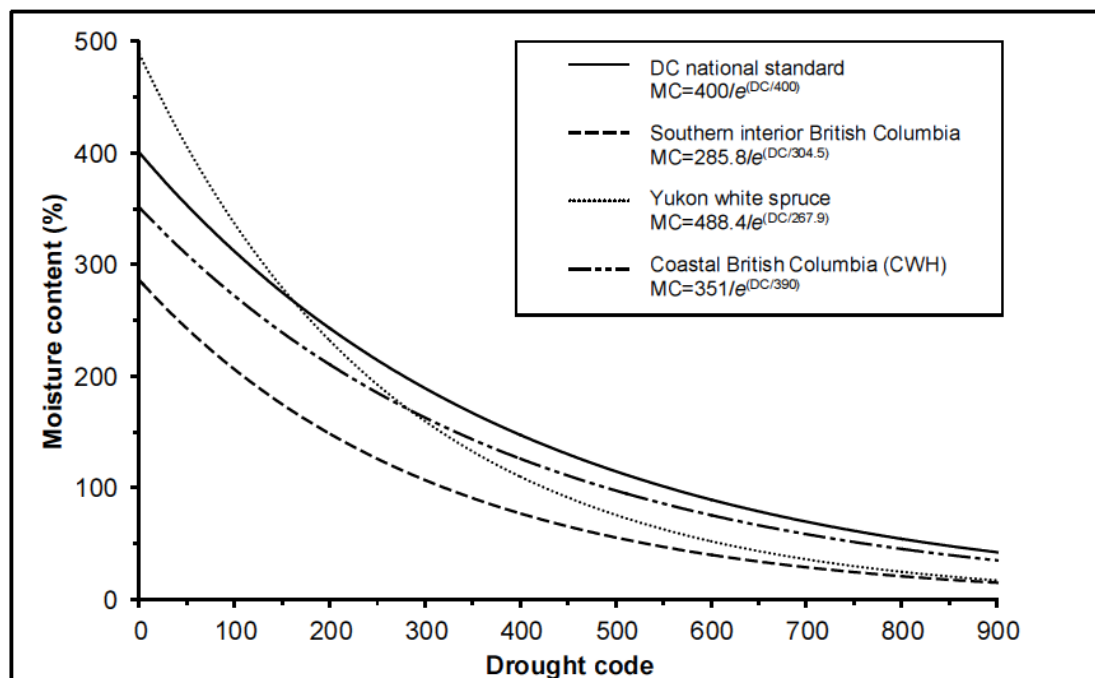


Figure 1. Calibration curves for forest floor moisture content as a function of Drought Code (DC): national standard, coastal British Columbia cedar-hemlock (CWH) forests, southern interior British Columbia forests, and southern Yukon white spruce forests.

These two corrections were incorporated and explained on p. 33-34 in Lawson and Armitage's (2008) update of the Weather Guide for the Canadian Forest Fire Danger Rating System, electronically published by Natural Resources Canada, Can. For. Serv., Nor. For. Cent., Edmonton, Alberta.

Bruce D. Lawson (retired)

O. Brad Armitage (Ember Research Services Ltd.)

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Ground-truthing the Drought Code: Field Verification of Overwinter Recharge of Forest Floor Moisture

by

Bruce D. Lawson¹ and George N. Dalrymple²

¹ CFS retired. Present address:
Ember Research Services Ltd.
4345 Northridge Cres.
Victoria, B.C. V8Z 4Z4

² Canadian Forest Service
506 W. Burnside Rd.
Victoria, B.C. V8Z 1M5

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For additional copies and/or further information about the Canada-British Columbia
Partnership Agreement on Forest Resource Development: FRDA II, contact:

Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5
(250) 363-0600

or B.C. Ministry of Forests
Research Branch
31 Bastion Square
Victoria, B.C. V8W 3E7
(250) 387-6719

EXECUTIVE SUMMARY

Users of the Canadian Forest Fire Weather Index System are required to precede computation of the Drought Code (DC) component each spring by first calculating a mathematical model of overwinter recharge of moisture in the forest floor. Practical limitations of the mathematical model, required for operational simplicity, have resulted in requests from users for a field sampling procedure that can be used to verify the model, where, and when desired.

This report describes a standard procedure for destructively sampling the forest floor by depth class, oven-drying the material, and comparing the actual moisture contents against empirically derived regression equations of forest floor moisture versus DC for representative mature coastal and interior British Columbia forests, and for white spruce forests in southern Yukon. The field verification procedures and calibration equations presented here will be applicable to DC startup, not only in early spring, but any time during the fire season that a fire weather station is started up; hence, this report is relevant to prescribed burning and project wildfire operations, as well as to fire danger rating network stations.

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The authors acknowledge the helpful reviews of the manuscript by Marty Alexander, Canadian Forest Service (CFS) Fire Research, Edmonton, Dr. Mike Curran, British Columbia Forest Service (BCFS) Research Soil Scientist, and Eric Meyer, BCFS Protection Program. Former University of Victoria Co-op student Robin Pike and former CFS fire technician Rene Dejong assisted with data analysis and form design. BCFS Protection and Research staff in Nelson (Larry Hall and Mike Curran) encouraged the study and provided field calibration data for analysis. Keith Kepke, Indian and Northern Affairs Canada, supported the calibration study near Whitehorse in 1992, as did Canada's Green Plan, Forest Fire Research initiative. Funding for data analysis was provided by the Canada-British Columbia Partnership Agreement on Forest Resource Development, FRDA II, Sub-Program 3.4, Forest Protection Research.

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1 INTRODUCTION

1.1 Drought in the Canadian Forest Fire Danger Rating System (CFFDRS)

Drought in the CFFDRS is accounted for by the Drought Code (DC) component of the Canadian Forest Fire Weather Index (FWI) System. Turner (1972) developed the DC as an index of the water stored in the soil, rather than as a moisture code to track actual moisture content of a particular slow-drying forest fuel. However, the DC loses moisture exponentially, and gains it with due regard for interception losses, and so is potentially suited to calibration as an index of the actual moisture content of certain heavy fuels. The DC fuel layer can be described as a deep, compact, organic forest floor layer, corresponding to the "duff", or F and H layers of soil science terminology. These layers are, on average, 18 cm deep, with a dry weight of 25 kg/m² and a water-holding capacity of 100 mm (Van Wagner 1987). The "standard" fuel layer of these average depth and bulk density values would have a theoretical maximum moisture content of 400% when saturated.

The single most important measure of a drought index is its timelag, the property that governs the length of weather history covered by the index (Van Wagner 1985). The DC has a 52-day timelag in standard, moderate weather. This is long enough that the amount of winter precipitation may affect the spring start-up values. It can not be assumed that melting snow will saturate the deep organic layer (Van Wagner 1987). As a result, the DC is the only moisture code of the three in the FWI System that requires overwintering. A study of seasonal trends in DC across Canada (McAlpine 1989) did not apply the over-wintering model to any stations because of insufficient data, but overwintering is a recommended operational procedure.

1.2 Overwinter Model for the DC

Turner and Lawson (1978) developed a mathematical procedure for overwintering the DC, which is summarized in Van Wagner (1987) using the following equations:

$$Q_s = a Q_f + b(3.94 P) \quad (1)$$

where Q_s - starting spring moisture equivalent of DC value
 Q_f - final fall moisture equivalent of DC value
 P - winter precipitation (mm)
 a, b - are user-selected values (Table 1)

Q_f is calculated from the equation

$$Q_f = 800 \exp(-DC_f / 400) \quad (2)$$

where DC_f = final fall DC value

The spring DC value can then be calculated from the conversion equation

$$DC_s = 400 \ln (800/Q_s) \quad (3)$$

The values for a and b are set by regional fire weather authorities using guidelines from Table 1 (adapted from Turner and Lawson 1978), and account for carryover fraction and wetting-efficiency fraction, respectively. Computer applications are generally used by regional weather authorities to calculate spring DC starting values, but look up tables are also available (Alexander 1983a).

Experience to date with overwintering the DC has shown that adjustments to spring starting values are only occasionally required in eastern Canada (Stocks 1979), but are commonly required in drier parts of western and northern Canada (Alexander 1983b; Alexander and Kreibom 1984¹; Ricketts 1991). In areas where normal winter precipitation

¹ Alexander, M.E. and C.H. Kreibom. 1984. Analysis of spring Drought Code starting values for Fort Smith and Yellowknife NWT: 1953-1980. Can. For. Serv., North. For. Res. Cent., Edmonton Alta. Unpubl. Rep.

exceeds 200 mm, the DC overwintering exercise tends to be unnecessary. While this mathematical procedure has been carried out in British Columbia and Yukon for a number of years, there has been limited rigorous field

testing of overwinter adjustment procedures against deep organic-layer moisture contents in dry locations. The available studies pertinent to British Columbia and Yukon are described below.

TABLE 1. User-selected values and criteria for (a) carryover fraction of last fall's moisture, and (b) effectiveness of winter precipitation in recharging moisture reserves in spring

Value	(a) Criteria	Value	(b) Criteria
1.0	Daily DC calculated up to Nov. 1, continuous snow cover, or freeze up, whichever comes first.	0.9	Poorly drained, boggy sites with deep organic layers.
0.75	Daily DC calculations stopped before any of the above conditions met or the area is subject to occasional winter "chinook" conditions, leaving the ground bare and subject to moisture depletion.	0.75	Deep ground frost does not occur until late fall, if at all. Moderately drained sites that allow infiltration of most of the melting snowpack.
0.5	Forested areas subject to long periods in fall or winter that favour soil moisture depletion.	0.5	Chinook-prone areas and areas subject to early and deep ground frost. Well-drained soils favouring rapid percolation or topography favouring rapid runoff prior to melting of ground frost.

Note: One combination of a and b values may be chosen to apply to all the stations in a region, for convenience.

2 FIELD STUDIES OF FOREST FLOOR MOISTURE RELATIONSHIPS TO DC

Rivard *et. al.* (1989) found good correlations between DC and the moisture contents of drained and undrained peat soils in boreal forests in Alberta. In a limited-sampling study, Muraro and Lawson (1970) found that the DC follows the moisture variations in deep, compact duff layers with properties similar to the standard DC properties in mature and over-mature cedar-hemlock (CWH) forests on southern Vancouver Island. They noted some important findings relative to moisture

reversals with depth, and between forest floors and cutovers (Section 4).

Russell (1975)² explored the DC as a predictor of organic-layer moisture in more detail. Calibration curves for moisture content at specific depths for mature coastal cedar-hemlock (CWH) forests were produced (Lawson

² Russell, R.N. 1975. Organic layer moisture regimes in coastal forests. In Improved fire danger assessment. Proj. PC-17. Can. For. Serv., Pac. For. Res. Cent., Victoria, B.C. Proj. Progress Rep., pp. 20-39.

1977). A general calibration curve for 9–10-cm depth in both coastal and interior mature forests, based on 168 observations from eight sites over two seasons (1969–1970), was developed (Figure 1).

Two additional field studies are reported here that include comparisons to the extensive study of Russell (1975). In the first study, done in June 1988, forest floor moisture samples were collected from 11 sites in the Nelson Forest Region of southeastern British Columbia, under the supervision of British Columbia Forest Service (BCFS), Regional Research. A wide range of ecosystems, from

dry interior Douglas-fir (IDF) to wet interior cedar-hemlock (ICH), were examined; however, only one site produced forest floor samples deeper than 6 cm (Appendix 1). Each site was sampled once between June 2 and July 1, with at least three replications.

The second study was conducted in a single mature white spruce stand with a feathermoss forest floor, near Whitehorse, Yukon, between May and August 1992. The same site was sampled weekly.

Descriptive data for the three study sites are given in Table 2 and Appendix 1.

TABLE 2. Site, stand, forest floor characteristics and regression equation statistics, Drought Code calibration studies, B.C. and Yukon

Feature	Coastal B.C.	South Interior B.C.	Southern Yukon
Biogeoclimatic Zone(s)	CWH	IDF, MS, ICH	BWBS
Geographic Reference	Mission, B.C.	Nelson Forest Region	Whitehorse
Lat. / Long.	49°1' / 122°2'	49°–51° / 115°–118°	60°50' / 135°10'
Site Characteristics:			
slope(%) / aspect	10% / SE	Appendix 1	flat
elevation (m)	470	Appendix 1	670
moisture regime	mesic	Appendix 1	mesic
Forest stand			
species ^a	Fd/Hw/Cw	Appendix 1	Sw
age/height(m)/DBH(cm)	110/–/53	Appendix 1	124/12.7/11.3
stocking (m ² /ha) (sph)	NA	NA	18.4(5650)
Forest floor			
reference depth (cm);(avg)	9–10	0–10 (5.0)	6–10 (7.2)
bulk density (g/cm ³)	0.090	-	0.061
ash (%)	-	-	18.5
Regression equation statistics			
DC range; sample size (n)	21–563 (168) ^b	69–480 (17)	144–606 (43)
R ² ; C.V.	0.93 ^b ; 11.2	0.56; 36.3	0.74; 56.9

^a Fd=Douglas-fir, Hw=western hemlock, Cw=western redcedar, Sw=white spruce

^b regression based on 9 class mid-point values

3 DC CALIBRATION EQUATIONS: COASTAL AND INTERIOR BRITISH COLUMBIA AND SOUTHERN YUKON

Best-fit non-linear regression equations of the form $Y=a/\exp(x/b)$, the equivalent form used for the DC national standard moisture equivalent equation ($MC=800*\exp(-DC/400)$), were calculated using SAS software for the coastal British Columbia Data, and Jandel's TableCurve software for the Nelson and Whitehorse data.

Results of the three detailed studies are plotted in Figure 1 as non-linear regression equations that predict forest floor moisture content (%) at specified depths from calculated DC values to which the standard overwinter model (Turner and Lawson 1978) has been applied. Appendix 2 includes graphs of the Mission, Nelson, and Whitehorse study data. Nelson data are plotted as site means (most sample locations consisted of two or three sites; Kikomun 1 and 2 and Goldstream 3 sites were excluded from analysis as apparent outliers). Whitehorse data are plotted as means of the weekly samples, usually two per week. Statistics for these equations are included in Table 2.

While both R^2 (coefficient of determination) and C.V. (coefficient of variation) values are included for each regression equation in Table 2, the C.V. (calculated as the percentage value the standard deviation, or root mean square error, is of the mean value of the dependent variable (Y), or moisture content) is the more meaningful statistic in non-linear regression. It should be noted that, while the coastal British Columbia regression equation has the lowest C.V., the equation was derived from 9 class mid-point values, rather than the original 168 sample data points, which were no longer available for analysis.

The "standard" curve of DC moisture equivalent (Figure 1) would not be expected to relate closely to sampled forest floor moisture on well-drained sites because DC is a representation of a 200-mm (8 inch) moisture

"reservoir", not a forest floor. Vanderlinden³ examined moisture contents sampled every few days throughout the 1993 fire season from the 6-7-in (15-18-cm) depth in a boreal (black) spruce forest floor on the Tetlin National Wildlife Refuge, near Tok, Alaska (lat./long. 63° 18' / 142° 40'). These data (taken by 1-in depths from the surface down to 8-in or ice) for the 6-7-in layer correlated strongly with the standard DC calibration equation, possibly because the underlying ice layer restricted moisture drainage.

The equation for the 9-10-cm depth in coastal cedar-hemlock forests near Mission, British Columbia, derived from Russell's (1975) sampling, is probably the most representative of deep, compact forest floors that generally exhibit DC properties of depth and bulk density. The CWH equation shows a saturated value of 350% at zero DC, similar to the theoretical saturation value of 400% for a forest floor of "standard" DC properties.

The equation for the southern interior of British Columbia, developed from the 1988 Nelson Region "one-shot" sampling, lies below the CWH curve because of shallower-than-standard depths and lower bulk densities, and because the Nelson equation is based on analysis of the entire organic layer, rather than a particular depth stratum. *Because most of the forest floors sampled in the Nelson study were less than 10 cm, (average depth of LFH 5.0 cm) they did not meet the standard DC properties for depth and bulk density. Caution is advised when applying this equation as a moisture content predictor.* The equation is, however, a useful relative indicator, suggesting that the DC does correlate generally with forest floor moisture content, at least for the range of June DC values sampled (69-480) over a wide range of ecosystems and moisture regimes in the Nelson study.

³ Vanderlinden, L., Regional Fire Management Officer, USDI Fish and Wildlife Service, Anchorage, Alaska, pers. comm. June 1996.

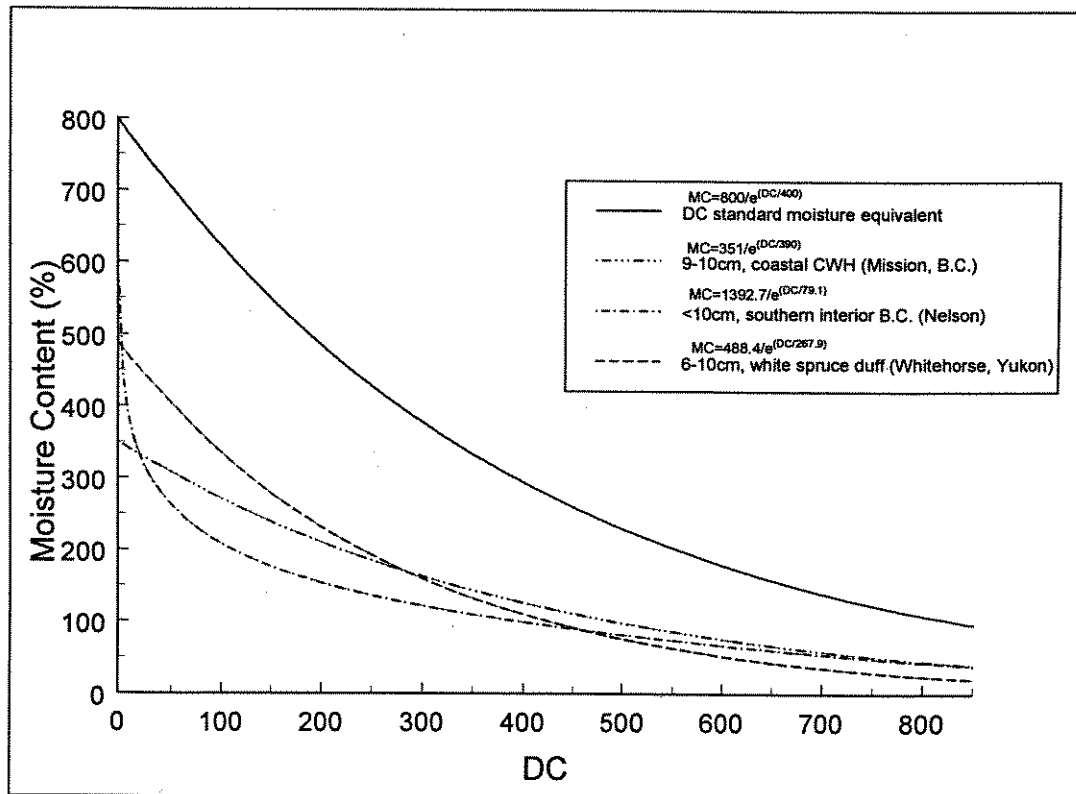


FIGURE 1. Calibration curves for forest floor moisture content vs. Drought Code: national standard moisture equivalent, coastal British Columbia cedar-hemlock (CWH) forests, southern Interior British Columbia forests and southern Yukon white spruce forests.

The Whitehorse regression equation is based on 43 observations, each the average of at least two samples taken weekly throughout the summer. The best correlation of sampled moisture content with DC was obtained from the 6–10-cm depth. The equation for northern white spruce duff crosses the CWH curve, which suggests some other factor may be causing a higher saturated moisture content at low DC values in spring. Restricted drainage due to frozen ground that persists well into June north of 60 degrees latitude, even on non-permafrost sites, may account for the higher saturated moisture contents at low DCs in the Whitehorse data, compared to the CWH saturation values, where restricted site drainage due to ice or permafrost is not a factor. An ice layer below the duff was noted on the

Whitehorse sites from May to mid-June. This phenomenon was noted by Van Cleve *et al.* (1981) as a factor accounting for considerably higher spring duff moisture contents at 10-cm depths in permafrost-dominated black spruce muskeg than at the same depth in a well-drained black spruce forest on a north-facing slope in interior Alaska. Duff moistures in muskeg increased from mid-May values of 200% to mid-June maximums of 350%, while on the well-drained slope without permafrost, they ranged from 110 to 180% over the same time. The cross-over at approximately DC 300 may suggest that the longer northern summer day lengths tend to produce slightly lower forest floor moistures than in southern British Columbia forest floors, such as those found in CWH ecosystems.

4 PRACTICAL APPLICATIONS

4.1 Verifying Spring DC Starting Values for Key Fire Weather Network Stations

Methods for destructively sampling forest floor moisture, either for ground-truthing the DC, or for direct use in fire prescriptions, are provided in Appendix 3, while forms for sampling and DC verification computations are provided in Appendix 4. These methods and forms are variations on earlier versions presented by Lawson (1988).⁴

A completed example of Form 1 (Appendix 4) is included to illustrate the calculations required to verify the starting DC for a key weather station, assuming the ground-truth moisture content of the forest floor was sampled as soon as start-up conditions for FWI System calculations were met. In the example, the starting DC is 296 on May 1, corresponding to an expected forest floor moisture content of 162% from the most representative calibration equation for the site of interest. In this example, the actual forest floor moisture content sampled in the field was within 22% of the expected value, suggesting that the DC starting value was verified by the ground-truth sampling.

Taking into account the rather high C.V. values (Table 2) for the regression equations presented, a difference of 50 or more points between the sampled moisture content and the moisture content predicted by the DC calibration equation of choice would be required to justify adjusting the DC starting value, assuming that the ground-truth sampling was not affected by a large rainfall event (>20 mm) within 2 days before sampling, which could confound the calibration exercise. Drought Code responds to rain like a reservoir, irrespective of how much moisture the reservoir contains at the time, but the calibration

equations presented here are confined to specific depths in the case of the CWH and Whitehorse spruce equations, so sufficient time must be allowed for significant rainfalls to pass through the forest floor before sampling can produce usable results.

4.2 Verifying DC Values for Late-starting Fire Weather Network Stations

Fire weather stations may be established later in the season for some special purpose such as servicing a project wildfire, or for a prescribed burn. Normally, the fuel moisture codes from the nearest representative weather station will be applied as starting values for the late-starting station. However, in critical situations, the procedures described here could be used to ground-truth the DC from the network station at the time of starting the late station. If the predicted forest floor moisture differed greatly from the sampled moisture on the site of interest, then the late-starting DC could be adjusted up or down, as appropriate. Keep in mind the cautions regarding the use of the Nelson equation, since it was based on "one-shot" sampling in spring, rather than season-long trends of rather shallow forest floors. This equation should be used with caution outside the May-June period and for forest floors deeper than 6 cm. For such conditions, the CWH equation would be a better choice for latitudes south of 60 degrees.

4.3 Verifying Forest Floor Moisture Reversal with Depth

The forest floor sampling procedures and forms provided can be used in the field to verify the presence of a phenomenon that can produce negative, or even disastrous, results from prescribed burns (or wildfires) under certain

⁴ Lawson, B.D. 1988. Drought in the Canadian Forest Fire Danger Rating System: field verification of spring Drought Code starting values. Can. For. Serv., Victoria, B.C., Rep. prep. for Pacific Region Fire Weather Committee.

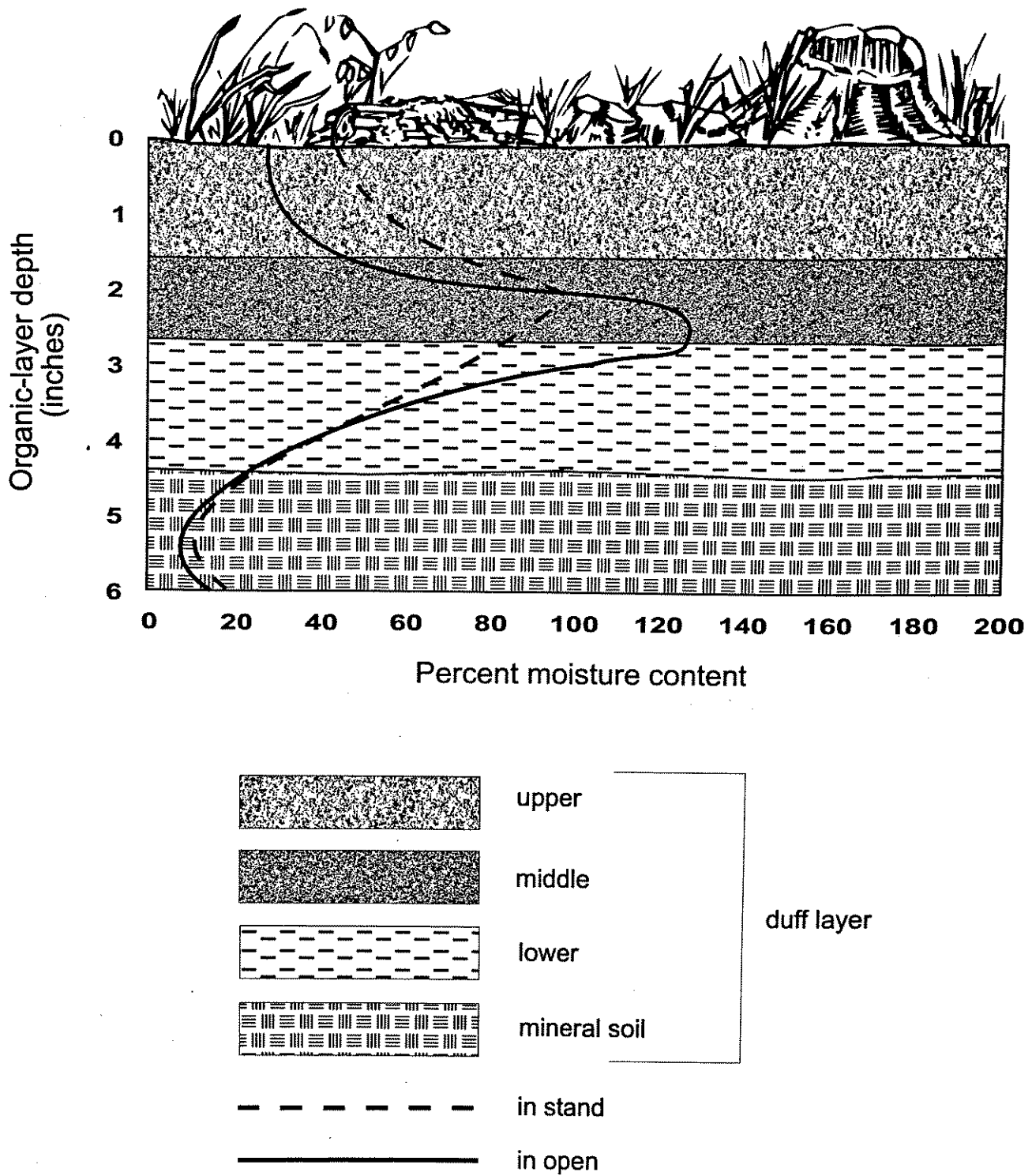


FIGURE 2. Forest floor moisture profiles with depth: stand vs. clearcut (from Henderson and Muraro 1968). Profile of actual organic layer moisture reversal (decrease) with depth below 2 inches, in cutover and adjacent mature forest, September 28, 1967, north of Sooke, British Columbia, following severe summer drought, DC=700.

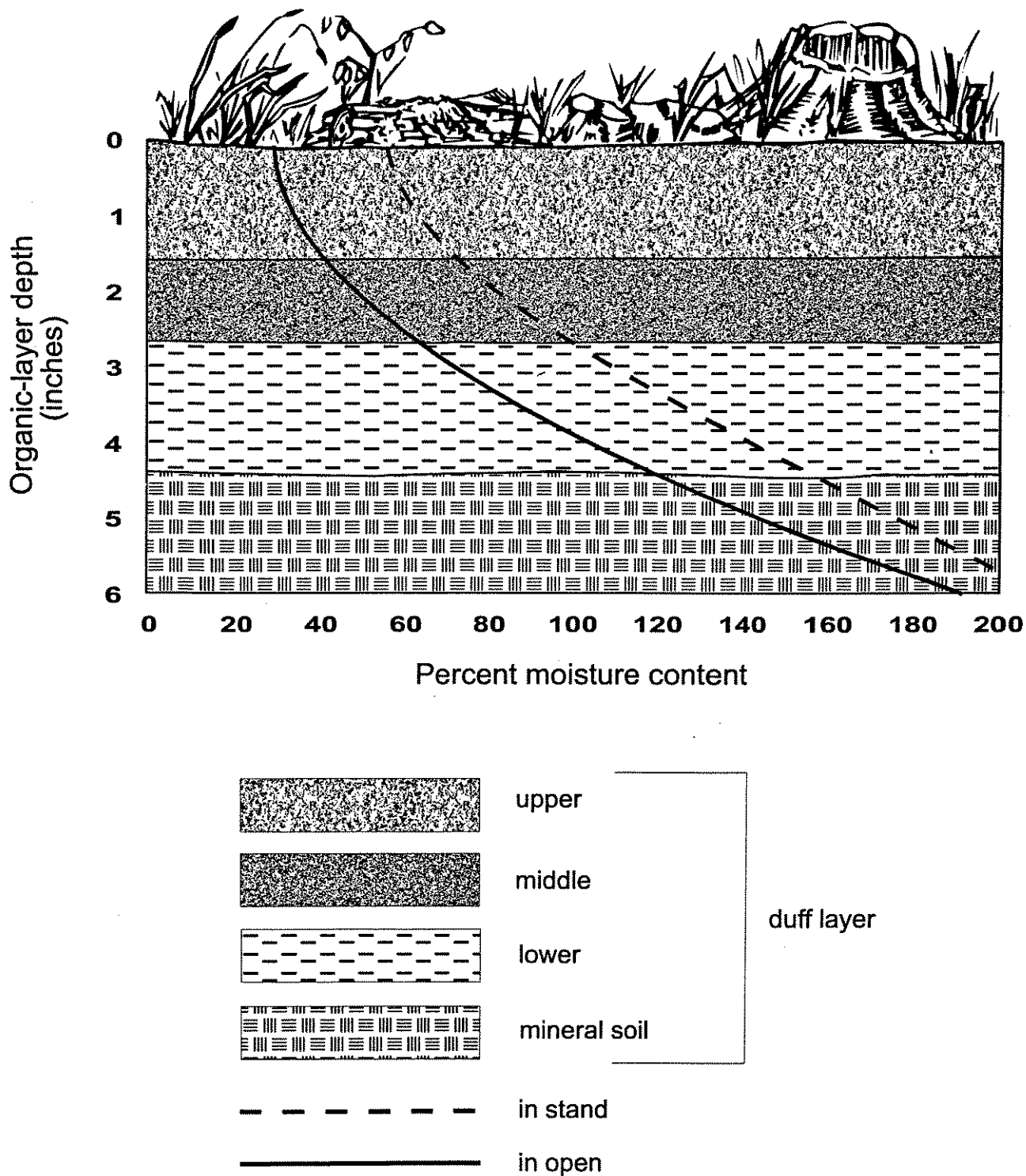


FIGURE 3. Forest floor moisture profiles with depth: stand vs. clearcut (from Henderson and Muraro 1968). Profile of theoretical organic-layer moisture content increasing with depth, under "normal" drought conditions, with cutover drier than mature forest.

conditions (Henderson and Muraro 1968) (Figures 2 and 3). Muraro and Lawson (1970) documented that on sites with mature forest cover and deep, compact forest floors, reversals in the normal trend of increasing moisture content with depth can occur at DC values greater than 300. As DC increased above this threshold, forest floors deeper than 12 cm were found to be drier at depth than near the surface, and drier beneath the forest canopy than in cutovers, creating the potential for deep burning and persistent smoldering (adding to mop-up difficulty), and for escaped fires days or weeks later. This phenomenon can also contribute to excessive consumption of the forest floor, potentially resulting in excessive nutrient losses and erosion on sensitive sites. A

guideline (Canadian Forest Service 1971) warned of the dangers of prescribed burning under moisture-reversal conditions, which can be expected at DCs greater than 500. While the trends in Figures 2 and 3 pertain to coastal British Columbia forests in the CWH zone, Kiil (1970)⁵ reported similar findings for deep feathermoss-dominated forest floors in white spruce-subalpine fir stands and clearcuts in Alberta after the dry summer of 1967. The top 10 cm in the stand became increasingly drier than in the clearcut, reaching 50% moisture, while the clearcut did not fall below 100%. Kiil also found a tendency for decreased moisture with depth below 10 cm in the stand after a prolonged dry spell, although this was not as pronounced a reversal as shown in Figure 2.

5 CONCLUSIONS AND RECOMMENDATIONS

The results of these wide-ranging empirical field studies generally support the theoretical need (based on timelag) to overwinter the DC. A consistent model is essential, particularly if users want to infer actual forest floor moisture contents from one of the regression equations in Figure 1. The simple overwinter model of Turner and Lawson (1978) and one of the regression equations from Figure 1 are adequate for broad area-based DC calibration and forest floor moisture inferences for fire danger rating purposes. However, such site-specific requirements as late-season fire weather station and fuel moisture code startup for prescribed burning or project wildfire management may require forest floor moisture to be destructively sampled on-site. Detailed sampling procedures and guides to data interpretation are provided in the Appendices to this report.

Of the three DC calibration equations presented here, only the coastal British Columbia CWH equation is regarded as "final,"

in the sense that it is based on sufficient sampling from several "benchmark" sites with typical DC forest floor characteristics over more than one season. The Whitehorse equation for upland white spruce extended over one complete season and one site, and is only sufficient to serve as a "preliminary" equation, pending further calibration tests on additional white spruce benchmark sites. Additional testing of the Yukon equation on new benchmark sites has been initiated by Indian and Northern Affairs Canada, Fire Management Program during 1996.⁶

The southern interior British Columbia equation is the least robust since it is based on one-shot sampling of a wide range of sites, reflecting the purpose of that particular sampling project. A sub-set of three or four benchmark sites in the ICH and ESSF zones, chosen to represent DC fuels, should be sampled periodically over an entire season or two in order to further test and refine the preliminary equation presented here.

⁵ Kiil, A.D. 1970. Distribution of moisture in spruce-fir duff and its relevance to fire danger rating. Can. For. Serv., For. Res. Lab., Edmonton, Alta. Int. Rep. A-34. 14 p.

⁶ Ember Research Services. 1996. Drought Code verification Yukon, 1996. Rep. submitted to Lou Foley, Head, Fire Management, Northern Affairs Program, INAC, Whitehorse, Yukon.

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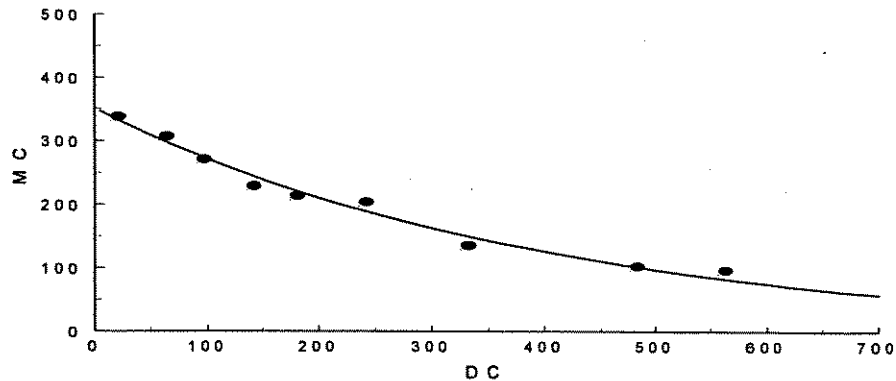
APPENDIX 1. Drought Code calibration study site characteristics, Nelson Forest Region, 1988

Weather Station			Site Characteristics					Stand characteristics		Forest floor depth		
Name	No.	BCFS	Site	Biogeoclimatic class ^a	slope (%)	aspect (°)	elevation (m)	moisture regime	species ^b	DBH (cm)	F+H (cm)	L
Cranbrook	2701		1	IDFdm2	12	340	950	subhygric	Lw/Pl	25	2.2	2.2
Kikomun	2708		1	IDFdm2	15	96	850	submesic	Fd	35	2.1	1.6
			2		0	98	820	mesic	Lw	30	1.6	2.0
Toby	2709		1	IDFdm2	8	100	1080	mesic	Lw	23	2.5	1.6
Beaverdell	2502		1	IDFdm1	34	287	960	mesic	Fd	42	3.1	0.8
Flathead	2710		1	MSdk	0	-	1340	mesic	Pl/Lw	25	2.2	1.7
			2		15	92	1340	subhygric	Lw	30	3.3	2.6
Quinn	2712		1	ESSFdk/MSdk	0	-	1450	mesic	Se	35	3.2	0.8
			2		27	130	1550	mesic	Se	25	4.0	0.6
Castlegar	2601		1	ICHdw	18	318	880	mesic	Pl/Lw/Fd	35	3.5	1.7
Pend D'Oreille	2613		1	ICHdw	10	244	860	mesic	Bg/BI	NA	5.4	0.7
			2		16	266	965	mesic -	Bg	NA	3.3	1.0
								submesic				
Dewar Cr.	2713		1	ICHmw1	28	260	1370	submesic	Hw	44	4.0	1.2
			2		27	267	1330	mesic	Se	25	4.6	1.0
			3		18	313	1420	subhygric	Cw/Se	55	3.9	1.2
Trout Lk.	2411		1	ICHmw1	18	250	960	submesic	Hw	55	2.9	1.3
			2		50	255	1180	subxeric	Hw	40	2.5	1.2
Goldstream	2217		1	ICHwk1	35	236	800	mesic -	Hw	NA	5.3	0.5
								submesic				
			2		10	216	640	subhygric	Hw/Cw	NA	9.5	0.5
			3		55	270	570	subxeric	Hw	50	5.8	0.6

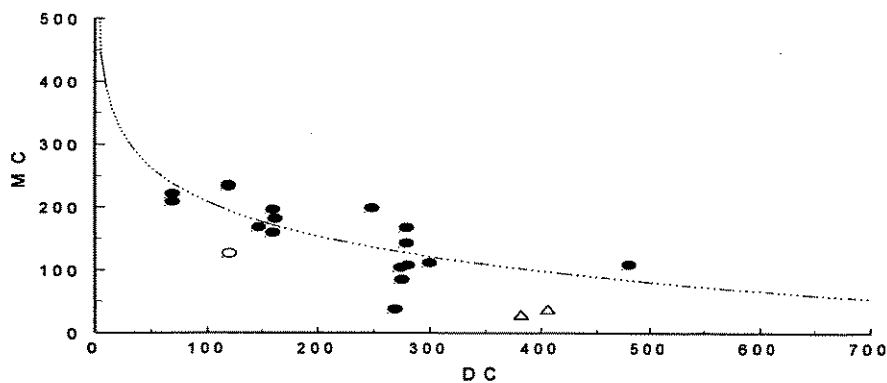
^a Braumandl and Curran (1992). A field guide for site identification and interpretation for the Nelson Forest Region. B.C. Min. For. Land Manage. Handb. no. 20, B.C. Min. For., Res. Br., Victoria, B.C.

^b Cw=western redcedar, Hw=western hemlock, Lw=western larch, Pl=lodgepole pine, Fd=Douglas-fir, Se=Engelmann spruce, Bl=subalpine fir, Bg=grand fir

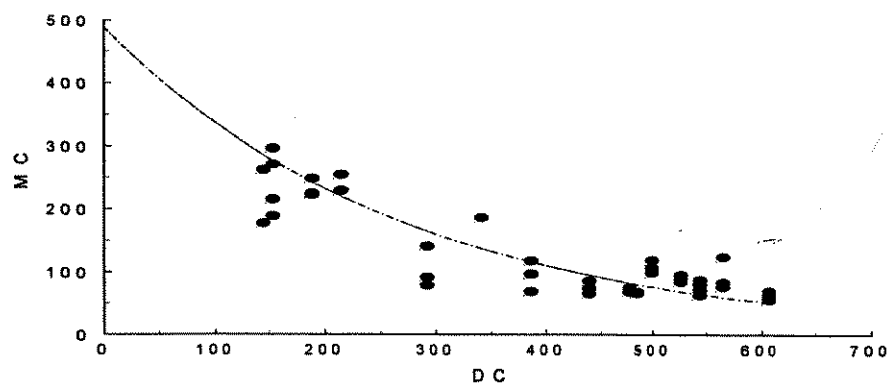
APPENDIX 2. Graphs of organic-layer moisture content vs. Drought Code: coastal British Columbia, 1969–1970; Nelson Region, 1988; and Whitehorse, 1992.



Coastal B.C., 9–10-cm depth.



Nelson Region , entire forest floor, various ecosystems.



Whitehorse, white spruce forest floor, 6–10 cm.

APPENDIX 3. Fuel moisture sampling methodology

a) Site-selection criteria (Form 1)

1. Continuity of year-round weather data is required. Fire weather network stations are preferred, especially those that can be readily instrumented for winter precipitation. Historically, Atmospheric Environment Service airport weather stations have been the source of overwinter precipitation data. However, this is not ideal because the stations tend to be located at elevations, or in topographic situations, that are not very representative of the forests to which they are to be applied. Consequently, the use of these stations has required normalizing the actual precipitation to the elevation of the station of interest before entering the equations. Currently, some fire management agencies operate some of their key fire weather network stations year-round, providing a source of more directly applicable winter precipitation data to spring startup of Drought Code calculations. In addition, Environment Canada now has access to many stations that collect winter precipitation at mid and high elevations, operated by such agencies as B.C. Ministries of Environment, Transportation and Highways, and B.C. Hydro. The DC is not intended to be calculated on a daily basis through the winter months in snow-prone regions. The advantages to the fire management agency of more-representative, year-round weather data include greater accuracy in determining final fall DC values, and a better indication of when spring starting-threshold conditions are reached, in terms of noon temperatures and snow departure. Total winter precipitation is required from the closing date of daily fire weather observations and FWI System calculations in the fall until the starting date in the spring. This can be accomplished using a simple storage gauge (Finklin and Fischer 1990), supplemented by snow-depth readings on a weekly, or at least monthly, basis. However, due to the costs of obtaining this data from fire weather network stations, it may be satisfactory to use precipitation data from other agencies.
2. Sites must be representative of the forested areas of concern. They should have deep, compact organic layers that are typical of the DC model. Mid-elevation and mid-slope benches covered by mature or overmature forests on mesic to sub hygric sites, in terms of drainage and moisture retention, offer the best calibration opportunities.
3. Opening size criteria for primary fire weather stations should be met (i.e., five to ten times tree height [Turner and Lawson 1978]), to ensure normal exposure of precipitation gauges to wind, rain, and snowfall patterns.

The following documentation should be recorded on Form 1 (Appendix 4) for each site:

1. Date and fall closing DC value for the station.
2. Date of organic layer freeze up.
3. Date of significant and persistent snow cover.
4. Total monthly precipitation (rain and snow).
5. Date of snow departure from sampling area.
6. Date of spring thaw within the organic layer.
7. Note evidence of low water levels (lakes and swamps).
8. Keep notes on any significant meteorological events through the winter that could affect the recharge of the DC; e.g., prolonged thaws, significant rains falling on snowpacks.

Site Requirements

It is assumed that field personnel will have a basic knowledge of macro- and micro-scale sample site selection criteria (Potts *et. al.* 1986), and will be familiar with forest and vegetation inventory destructive sampling techniques and equipment for gravimetric moisture determination on an oven-dry basis (Countryman and Dean 1979; Norum and Miller 1984).

Select a sampling site close enough to the reference fire weather station so that the overwinter precipitation measured at the station will be representative of the forested site. Ensure that the area will not be cut for several years to allow repeat sampling to establish a calibration history for the site.

Minimum site requirements are as follows:

- mature to over-mature closed-canopy coniferous stand (without large openings from blowdown, root rot, or beetle kill);
- mesic site, moderately drained, fine-textured loam soil type;
- moderate slope (preferably < 35 %); aspect other than north.
- organic layer average depth at least 10 cm from top of litter to mineral soil.

Permanently mark sampling sites in the field and prepare maps and location details for future reference. Photograph the stand from outside and within, including closeups of the forest floor and cross-section characteristics.

Complete sample site description and stand and vegetation inventory to user's desired standards and methods and record summarized data on Form 1. Include a simple, large, down woody fuel tally as indicated on Form 1.

Determine the date to commence fuel moisture sampling. Samples should be collected when the entire organic layer has thawed. This differs from the FWI system startup criteria; i.e., the third day after snow leaves the area (Turner and Lawson 1978). Also, allow at least 2 days for a significant rain (greater than 20 mm) to runoff and percolate into the organic layer before sampling.

b) Organic-layer destructive sampling methods (Form 2)

Select destructive sample points in locations typical of the stands; avoid large openings, tree bases, squirrel caches, etc.

It is desirable to sample a fixed plot size, preferably 0.1 m² (31.6 x 31.6 cm) in area to allow the calculation of bulk density and load of each stratified depth horizon in addition to the moisture content.

For each sample, collect all litter separately, recording its depth. Then collect and label the remaining organic layer, including moss, by 2-cm horizons down to mineral soil (Form 2, Appendix 4; Appendix 5). Record the depth at which ice or permafrost is encountered, if present.

Remove all live plant stems, roots, rhizomes greater than 3-mm diameter, other parts of living plants, and animal droppings (Norum and Miller 1984).

Numbered, standard laboratory-type tins with tight lids are preferred for holding the samples. Each sample should be recorded as it is collected. If wet weights are not taken immediately in the field, the lids should be taped securely to prevent spillage and moisture loss.

When ready to weigh the samples, remove tape completely.

Obtain wet weight.

Place samples in oven for a minimum of 2 days at 100 degrees C to ensure oven dry weight is achieved (Ponto 1972)¹.

For deep organic layers it may be impractical to use sample tins for an entire 0.1 m² sample. Collect one tin of each depth stratum for moisture content determination, and bag the remainder for bulk density and fuel load calculations, with appropriate labelling.

After drying, obtain oven dry weight.

Compute moisture content (% oven-dry weight basis) (Form 2).

$$\text{Moisture Content (\%)} = \frac{\text{Net Wet Weight} - \text{Net Dry Weight}}{\text{Net Dry Weight}} * 100$$

Compute bulk density (g/cm³, dry weight basis) (Form 2).

¹ Ponto, R.L. 1972. Procedures for oven-drying forest slash components and organic matter; study carried out in Alberta, 1967-1971. Can. For. Serv., North. For. Res. Cent., Edmonton, Alta. Misc. Rep. NOR-Y-9. 9p.

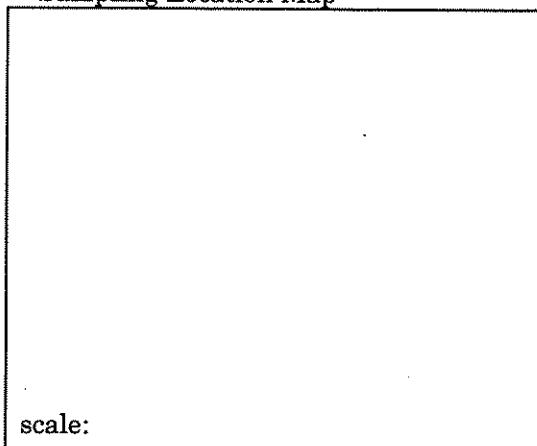
APPENDIX 4. Forms

Form 1. Drought Code reference data and sample site description.

1. Reference location _____	2. Site _____
3. Observer(s) _____	4. Date _____
5. Ref. Weather Stn. name _____ no. _____	lat./long. _____
elevation (m) _____	
5.1 Fall closing DC (DCf) _____ Date _____	
5.2 Forest floor freeze up date _____	
5.3 Persistent snow cover from _____ to _____	
5.4 Monthly winter precipitation (water equivalent, mm) Oct _____ Nov _____	
Dec _____ Jan _____ Feb _____ Mar _____	Apr _____ Total (P) _____
5.5 Forest floor completely thawed date _____	
5.6 Evidence of low water levels, lakes _____ swamps _____	
5.7 Meteorological events related to forest floor recharge, e.g., prolonged Jan. thaw, early (Nov.) freeze, snowpack discontinuous (date) _____	
5.8 Spring DC starting value computation:	
i) $Q_f = 800 \exp(-DC_f/400)$	= _____
ii) User-selected constants (Table 1)	_____
a) carryover fraction of fall moisture, (a=1.0, 0.75, or 0.5)	_____
b) effectiveness of winter precipitation, (b=0.5, 0.75, or 0.9)	_____
iii) $Q_s = a Q_f + b(3.94P)$	= _____
iv) $DC_s = 400 \ln(800/Q_s)$	= _____
v) DC startup date: _____	
6.0 Verification of DCs computation:	
6.1) User-selected calibration equation from the four presented in Fig.1 _____	
6.2) Moisture content of forest floor depth range predicted from selected calibration equation, Fig. 1	_____ %
6.3) Average moisture content (%) for corresponding depths all plots sampled at site of interest for selected date (form(s) 2)	_____ %
6.4) Sampled moisture content is (higher, lower, or similar) to value predicted by selected equation (Fig. 1)	_____
6.5) Possible explanation _____	
6.6) Adjustment to DC of +/- _____ for this station for this date of sampling is warranted	

7. Forest floor sampling location
description

Sampling Location Map



scale: _____

Sample Site Description:

Biogeoclimatic classification: _____

Slope (%): _____ Aspect: _____ Elevation (m): _____

Landform: _____ Slope Position: Top / Mid / Lower

Moisture Regime: _____ Slope configuration (convex, concave, flat) _____

Soil Type (texture, rooting depth (cm)) _____

Overstory Characteristics:

Species Comp: _____ Age (yr): _____ Height (m): _____

DBH (cm): _____ Canopy Closure (%): _____

Vegetation Characteristics:

Tree Species Comp: _____ Height (m) _____ Cover (%) _____

Shrub Species Comp: _____ Height (cm) _____ Cover (%) _____

Herbaceous Species Comp: _____ Height (cm) _____ Cover (%) _____

Moss & Lichen Species Comp: _____

Dead and Down Woody Fuels:

no. of pieces > 10 cm dia / 30 m transect: _____

Form 1. Page 1 with sample data.

1. Reference location SOMEWHERE, B.C. 2. Site OLD SKI HILL
 3. Observer(s) SMITH & JONES 4. Date MAY 1, 1996
 5. Ref. Weather Stn. name PUNY LAKE no. 6001 lat./long. 60° 51.3' x 135° 11.0'
 elevation (m) 670

5.1 Fall closing DC (DCf) 591 Date OCT. 25/95
 5.2 Forest floor freeze up date NOV. 30/95
 5.3 Persistent snow cover from DEC. 20/95 to APR 15/96
 5.4 Monthly winter precipitation (water equivalent, mm) Oct 0.4 Nov 22.0
 Dec 17.5 Jan 14.9 Feb 16.9 Mar 9.1 Apr 2.0 Total (P) 82.8
 5.5 Forest floor completely thawed date MAY 1/96
 5.6 Evidence of low water levels, lakes — swamps —
 5.7 Meteorological events related to forest floor recharge, e.g., prolonged Jan. thaw, early
 (Nov.) freeze, snowpack discontinuous (date) NONE

5.8 Spring DC starting value computation:

i) $Q_f = 800 \exp(-DC_f/400)$ = 183
 ii) User-selected constants (Table 1)
 a) carryover fraction of fall moisture, (a=1.0, 0.75, or 0.5) 0.75
 b) effectiveness of winter precipitation, (b=0.5, 0.75, or 0.9) 0.75
 iii) $Q_s = a Q_f + b(3.94P)$ = 382
 iv) $DC_s = 400 \ln(800/Q_s)$ = 296
 v) DC startup date: MAY 1/96

6.0 Verification of DCs computation:

6.1) User-selected calibration equation from the four presented in Fig.1 WHITEHORSE
 6.2) Moisture content of forest floor depth range predicted from selected
 calibration equation, Fig. 1 162 %
 6.3) Average moisture content (%) for corresponding depths all plots
 sampled at site of interest for selected date (form(s) 2) 140 %
 6.4) Sampled moisture content is (higher, lower, or similar) to value
 predicted by selected equation (Fig. 1) SIMILAR
 6.5) Possible explanation SIMILAR SITE TO CALIB. EQUATION
 6.6) Adjustment to DC of +/- NIL for this station for this date of sampling is
 warranted

Form 2. Forest floor moisture content calculations

1. Reference location _____ 2. Site _____
 3. Plot no. _____ 4. Sample Date _____
 5. Forest floor component depths:
 Litter: _____ Moss: _____ F: _____ H: _____ Ah: _____ ¹

Sample #	Soil Profile	Depth at 2 cm increments	Tin #	Wet weight (grams)	Dry weight (grams)	Tin weight (grams)	Moisture ² content (%)	Bulk ³ density (g/cm ³)
	Litter							
	moss or duff	0 - 2						
	moss or duff	2 - 4						
	moss or duff	4 - 6						
	Duff	6 - 8						
	Duff	8 - 10						
	Duff	10 - 12						
	Duff	12 - 14						
	Duff	14 - 16						
	Duff	16 - 18						
	Duff	18 - 20						

Ice / Permafrost depth _____ cm

¹ Ah horizon, if present below duff layer, will give unreliable measure of moisture content because of mixing with mineral soil. Designate Ah horizons with asterisks on appropriate depth strata.

² Moisture Content (%) = (Net Wet Weight - Net Oven-dry Weight) / Net Oven-dry Weight x 100

³ Sample bulk density (g/cm³, dry weight basis) can only be determined for each 2-cm depth increment if forest floor material is collected and dried from a measured-area basis, such as the 31.6 x 31.6 cm (1000 cm²) illustrated in Appendix 5. Add sample dry weights of all tins and bags comprising a 2-cm depth increment, then divide by 2000 (2 cm x 1000 cm²) in this example. Specify sample area _____ cm².

APPENDIX 5. Forest floor cross-section

Excavated cross-section of forest floor before destructive sampling, from top of litter layer to mineral soil interface, in 2-cm strata for bulk density, load, and moisture content determination.

