University of Alberta

Aspen Forest Duff Moisture Depletion and Ground Fire Potential

by:

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ABSTRACT

Elk Island National Park (EINP) has maintained a robust prescribed fire program, but ground fire risk may limit its use. The Fire Weather Index System is the nationally recognized means of assessing moisture. The Duff Moisture Code (DMC) and the Drought Code (DC) report moisture in the shallow and deep duff layers, but have not been evaluated for the aspen forest. This study developed and validated DMC and DC relationships and quantified duff ignition within aspen stands of EINP. The role of soil bulk density and inorganic content were also evaluated. Moisture relationships and ignition thresholds at various DMC and DC were established. The DMC, as modelled from summer moisture under leaf-on conditions, appears suitable as a conservative tool for assessing fire risk. This research may also form the basis for new moisture codes for the D-1 aspen fuel type, improving prediction of ground fire occurrence.

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encouraged me throughout the journey and covered off a lot of family business while I was going to classes, doing fieldwork and writing.

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List of Abbreviations

allcal – all calibration data
Aw – aspen poplar (*Populus tremuloides* Michx.)
bd – bulk density in kg m^{-3}, a measure of dry weight by volume in soil science
BUI – Buildup Index
CFFDRS – Canadian Forest Fire Danger Rating System
CFS – Canadian Forest Service
CIFFC – Canadian Interagency Forest Fire Centre
C1/S1/N1 – calibration site plots
CV – coefficient of variation, a relative measure of variation and in the same units as the observed values
D-1 – the nominal mid-seral stage, leafless aspen poplar fire fuel type
DMC – Duff Moisture Code
DC – Drought Code
ECP – Ecosystem Conservation Plan from Elk Island National Park.
EINP – Elk Island National Park
EIWFE – Environment Canada EINP Campbell Weather station identifier
EF – modelling efficiency, or, 1 – (the sum of squares of the observed minus predicted values, divided by the corrected sum of squares of the observed values).
EMC – equilibrium moisture content, the theoretical lowest moisture content in the DMC
fallcal – fall calibration data
FBP – Fire Behaviour Prediction System
FWI – Fire Weather Index
g - grams
GPS – global positioning system
ICFME – International Crown Fire Modelling Experiment
ISI – Initial Spread Index
inorg – inorganic content of ash in %
kW/m – fire intensity expressed as kilowatts per metre
L-F-H – the litter/fibric/humus layers of the soil
loc – plot location
MAE – mean absolute error, the sum of the difference between the observed and predicted values, divided by the number of samples
MC – moisture content in %
mn - month
nat std – national standard
PC – Parks Canada Agency
P.Ig – probability of ignition
precip – precipitation in mm and 1/10 mm
PSP – permanent sample plot
Q – moisture equivalent for DC
R^2 - coefficient of determination, the proportion of the Y variable accounted for in a regression analysis.
RH – relative humidity in %
RMSE – root mean square error, or the dependence of the variable Y on the independent

variable(s) X_i.
sumcal –summer calibration data
sprcal – spring calibration data
T – temperature in degrees Celsius
val – validation data
WD – wind direction in degrees
WS – wind speed in km/hr
YEG – Edmonton International Airport (weather station) identifier

Chapter 1. WHY ASSESS GROUND FIRE POTENTIAL IN ASPEN FORESTS

1.1. Introduction

The boreal landscape of Elk Island National Park (EINP) has evolved in conjunction with the process of fire. Parks Canada recognizes the need for adequate fire control capability as well as the use of fire through prescription (Parks Canada 1994, 2005). The potential for severe drought to produce conditions conducive to undesirable fire consequences is possible in EINP and its surroundings. If the occurrence and persistence of ground fire could be more accurately forecasted, the potential to manage fire, including prescribed fire, would be increased. More specifically, appropriate prescriptions for the successful use of fire relative to management objectives would be possible (Frandsen 1987).

The prediction of ground fire occurrence prior to ignition in trembling aspen (*Populus tremuloides* Michx.) dominated forest fuel types, and ground fire persistence after ignition, are serious concerns in the wildlands of western Canada. Upland vegetation within EINP is predominately deciduous aspen trees. Ground fire, the smouldering combustion that frequently lingers after an initial surface or crown fire sweeps an area, may persist under dry conditions for an extended period. This type of fire can produce large quantities of smoke due to long-term smouldering and low energy output, which may affect visibility in the surrounding areas should there be a prevalence of early morning atmospheric inversions and subsequent smoke accumulations (Brad Hawkes, CFS Fire Researcher, pers. comm.). Ground fire may also create sites conducive to non-native plant invasions, nutrient leaching, tree mortality, smoke pollution and erosion, as well as escaped fires (Gisborne 1928; Van Wagner and Methven 1980; Frandsen 1987; Stock et al 1996; Achtemeier 2001; Miyanishi 2001). Much of the Aspen Parkland and Lower Boreal Mixedwood ecoregions of the Prairie Provinces are in proximity to settled areas, where the natural process of burning may produce these or other unwanted social consequences.

Fire plays a key ecological role in the aspen dominated forests of the central and northern prairies (Heinselman 1978; Van Wagner 1990; Peterson and Peterson 1992). Fire in hardwood forests are most common in the early spring, prior to the green-up of forest vegetation (Wright and Beall 1938; Quintilio et al. 1991; Bourgeau-Chavez et al. 2000). At this time of year, the ground should have just thawed and fuel moisture content may be very low. Over the last few years the prairie regions have experienced prolonged drought, resulting in lower than normal spring moisture. Severe fires have been common, and include those at Elk Island National Park (2000, 2001 and 2004), Chisholm (2001), Redwater, House River and Prince Albert (2002). Spring fire behaviour during such drought years is not fully understood.

Drought conditions in forest floor fuels can be measured directly (Lawson and Dalrymple 1996a; Frandsen 1997). Duff moisture content, inorganic content and bulk density are three attributes that directly affect whether duff or fuel layers in the soil may ignite and sustain smouldering combustion. These attributes, combined with heat and oxygen, are the foundations of basic fire ecology.

Relative numerical codes have been devised to provide cost- and time-effective methods of tracking fuel moisture without extensive sampling requirements. The Canadian Forest Fire Danger Rating System (CFFDRS) is the nationally accepted means of determining forest fire behaviour in Canada (Stocks et al. 1989). Within this rating system is the Canadian Forest Fire Weather Index System (Van Wagner 1987), and the Canadian Forest Fire Behavior Prediction System (Forestry Canada Fire Danger Group 1992), which are used to calibrate individual parameters related to forecasted fire weather (FWI) or fire behaviour (FBP), respectively. The FWI system has a means of re-calibrating start-up drought code values in the spring (i.e usually April), which are calculated when over-winter precipitation is less than 200 mm (Lawson and Dalrymple 1996a), but this system is untested for aspen (D-1) dominated fuel types. In normal precipitation years it is assumed that spring rains and drying variations will correct these codes through readjustment within a few weeks of weather station start-up (personal experience, and Lavoie 2004), however this remains untested in aspen. Spring fires in aspen forests often occur prior to any potential normalization of codes for the year.

The FWI duff moisture code (DMC) and drought code (DC) are the numerical values of most assistance to fire managers in assessing forest fuel dryness. These indicate the relative dryness of the shallow and deep duff soil layers, the layers susceptible to sustaining and/or carrying ground fire. Accurate correlation of these codes with actual spring duff moisture conditions is required, as well as documenting the association between these codes and the probability of ignition. Currently there is no predictive model for aspen forest duff layers.

1.2. Objectives

The goal of this thesis is to establish the actual FWI code moisture depletion rates for aspen forest, as well as duff layer susceptibility to ground fire ignition and persistence. The schematic diagram in Figure 1.1 demonstrates the conceptual link between basic fire ecology and the actual parameters available for measurement, as well as the tools of applied fire behaviour commonly used in indirect analysis and management. Each of the proposed hypotheses is linked to components in this diagram.

Questions in relation to the specific research objectives for this project include evaluating the following:

Ho: 1). Does the national standard (DMC/DC, developed primarily for coniferous types) apply to the D-1 (aspen) fuel type in EINP? Is it possible to determine a consistent and predictable relationship between readily available weather parameters, as reflected in the DMC/DC, and measured duff moisture content within the Parks aspen dominated plant communities? Finally, determine whether this relationship (DMC/DC vs. duff moisture) is robust to variations in soil bulk density and inorganic content.

Ho: 2). Are duff moisture levels and the associated DMC/DC projected from weather data similar on different topographic positions and across different seasons?

Ho: 3). Is it possible to predict ignition probability from duff moisture content, inorganic content and organic bulk density, or alternately, from DMC/DC codes?

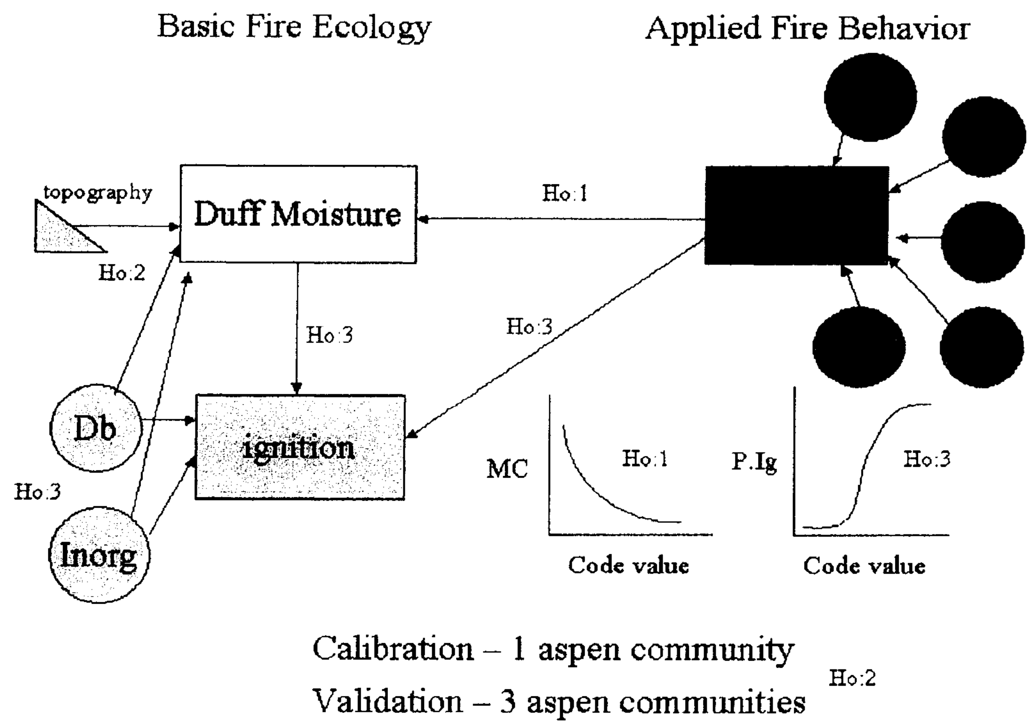

Figure 1.1. Theoretical relationship of basic fire ecology and applied fire behaviour that led to development of the hypotheses tested, where Ho: = hypothesis, Db = bulk density, Inorg = inorganic content, Mn = month, T = temperature, RH = relative humidity, day l = day length, MC = moisture content and P.Ig = probability of ignition.

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Chapter 2. LITERATURE REVIEW

2.1. Aboriginal/Cultural Use of Fire

Among the powerful forces of nature, fire has been the most common and earliest used worldwide (Bronowski 1976; Pyne 1982; Ferguson 1990; Kay 2000). For thousands of years North American Aboriginals developed a relationship with fire and had a certain knowledge of its effects (Lewis 1977, 1982; Turner 1991). Early societies also had a significant influence over the ecological landscapes within which they lived: hunting, firewood gathering and warfare are but a few reasons fire was utilized. The area in and around Elk Island National Park (EINP) also has a rich fire history (Kjorlien 1977; Thomas 1977). Fire has swept over, into or out from portions of EINP and the Beaver Hills many times in the past.

The Cooking Lake Forest Reserve, established in 1899, is situated within the Beaver Hills and was created to protect the region's timber and wildlife resources, in part because of the need to suppress the frequent fires in the area. A severe fire during 1895 nearly eliminated coniferous trees in the area (Kjorlien 1977). EINP was created in 1906 to protect remnant elk herds in the area, and therafter continued the practice of fire exclusion.

2.2. Parks Canada

Some agencies still practice full fire suppression with the intent of eliminating the deleterious effects of fire (Martell 1983). The philosophy of fire exclusion can be traced to scholarly views from the early 20th century, when fire was viewed as disorderly and destructive, something to be controlled if North America was to be successfully settled by Europeans (Pyne 1982). Fire was known to make 'idle land and costly timber' (Gisborne 1928). However, this perspective is ineffective at sustaining the ecological integrity of aspen in the long-term as the forests of the Great Plains are fire dependent, requiring this disturbance periodically to sustain and/or rejuvenate them (Heinselman 1978; Peterson and Peterson 1992). A greater understanding of the process of fire is needed so that it might be properly managed within acceptable risk parameters. Uncontrolled periodic wildfire, either large or small-scale, is often not acceptable by society at large. Therefore, the judicious introduction of prescribed burning is required to replace the historical process at appropriate temporal and spatial scales.

Since the late 1970s Parks Canada has come to understand the importance of fire within certain ecosystems (Van Wagner and Methven 1980; Lopoukhine and White 1985). Planning to manage fire rather than exclude it began to be formalized through structured plans (Fisher 1984). Staff at EINP recognized the need to re-introduce fire in the 1970s, and have been conducting prescribed burns at various scales since 1979 (Alexander and Dubé 1983). The Park Management Plan (Parks Canada 2003) and Ecosystem Conservation Plan (ECP) (Parks Canada 2004b) for EINP both have detailed rationales for the judicious use of fire to meet landscape management objectives, such as landscape diversity, plant community composition and structure. Specific target ranges are listed in the Park Management Plan for fire frequency, understory and overstory forest structure and composition as baseline indicators. The Plan also specifically identifies fire as a key process, in recognition that the effects of periodic fire on the landscape may produce ecological benefits beyond the specific targets listed above.

One recognized priority for research in the ECP is to further understand fire severity. Fire severity patterns may directly affect how and when plant species re-colonize an area. Moreover, landscape or other diversity-based ecological targets may be difficult to achieve without predictable fire severity prescriptions. Given that post-fire vegetation inventory and/or analysis of plant response has been limited to date for the Park (Johnston 1981; Bork 1993), the presence of fire, prescribed burning or otherwise, must be carefully evaluated to fully assess the impact of this disturbance on the ecological integrity of Park resources.

The Panel on the Ecological Integrity of Canada's National Parks has called for the presence of more fire in most parks (Parks Canada 2000), and this is reinforced with legislation and policy (Parks Canada 1994, 2001). Fire is viewed as one of the cornerstone natural processes required to maintain the ecological integrity of our National Parks. Directive 2.4.4 of Parks Canada (Parks Canada 2005) deals specifically with the control and use of fire within Park lands. This directive states that the capability for suppression of unwanted fires should be balanced with the knowledge and ability to light and manage prescribed burns.

Prescribed burning involves the knowledgeable use of fire on the landscape to accomplish predetermined land-use objectives [Canadian Interagency Forest Fire Centre (CIFFC) 2003]. A detailed burn plan is required to justify and explain the procedures involved along with the expected outcomes. These plans are routinely circulated among different national parks and park administrative agency levels as well as externally for scrutiny and review. The more detailed the objectives and more specific the expected results, the greater the chance of agency approval and funding.

2.2.1. Elk Island National Park and the Beaver Hills

Elk Island National Park is situated in east central Alberta, Canada. It is part of the Lower Boreal Mixedwood ecoregion (Strong and Leggat 1991), which is recognized as one of the most productive regions for wildlife in Alberta (Telfer and Scotter 1975). EINP is at the northern edge of the greater Beaver Hills moraine and was once part of the federal Cooking Lake Forest Reserve.

The climate is cool-continental, with mean summer monthly temperatures ranging from 5 °C in spring to 17 °C in midsummer (Rogeau 2004a), and summer precipitation varying from 260 to 470 mm over the last 10 years (Parks Canada 2004c). The Park is situated within an elevated dead ice (hummocky disintegration) moraine with a relief of approximately 30 m above the surrounding plains. Upland soils are predominately Orthic Gray Luvisols and Dark Gray Luvisols (Crown 1977). These soils are rated as poor to fairly good arable (Bowser et al. 1962). In general, the majority of the Park area had little modification from agricultural practices prior to establishment.

The overstory forest structure is predominantly trembling aspen poplar (*Populus tremuloides* Michx.) and balsam poplar (*Populus balsamifera* L.). The shrub layer beneath these forests contains saskatoon (*Amelanchier alnifolia* Nutt.), choke cherry (*Prunus virginiana* L.f.), beaked hazelnut (*Corylus cornuta* Marsh.), prickly rose (*Rosa acicularis* Lindl.), and low bush cranberry (*Viburnum edule* Michx.), among many others. Kentucky blue grass (*Poa pratensis* L.), marsh reed grass (*Calamagrostis canadensis* Michx.), and sedges (*Carex* spp.) are the major grass species (Budd and Best 1976; Bork et al. 1997a).

The Park is 194 km² in size, and is a crucial part of the ecological land base within the Beaver Hills moraine. The moraine is 1572 km² of hummocky 'knob and kettle' terrain (Patriquin 2004), deposited after the last glaciation more than 10,000 years ago. Vegetation across the region is within a fire-dependent ecosystem, with other jurisdictions recognizing fire as an essential ecosystem element through their vegetation management goals (e.g. Blackfoot Management Plan 1997; Miquelon Lake Management Plan, in press). These plans often work toward maintaining a diverse assemblage of vegetation, in which fire is considered one tool towards attaining this end. Practical considerations such as fire prevention are being considered with longer-term issues such as collaborating on regional fire management issues for the area (Beaver Hills Initiative 2004). The Beaver Hills Initiative is currently pursuing completion of a fire history study for the entire moraine (Rogeau 2004b), which will enrich our knowledge of the historical role of fire in these ecosystems.

The Beaver Hills is a much valued landscape to local residents (Graham and McFarlane 2001), as well as recreationalists and nature enthusiasts who travel to the Park from remote regions. The Park also contributes scientific expertise that will benefit the entire ecosystem. Fire issues are but one practical aspect in this area.

2.2.2. Science Advisory Committee

EINP consults with an external review body known as the Science Advisory Committee (SAC). The committee is comprised of individuals from various natural and social science disciplines who critique the science program at the Park and offer advice on future research needs and priorities.

Recently, the SAC compiled a list of knowledge gaps and research priorities for the Park (Science Advisory Committee 2001). Fire frequency, severity and the interaction of fire with other landscape processes were some of the areas of importance included on that list.

2.3. Aspen Ecology

The aspen forest within EINP is situated at the southern edge of the lower boreal forest ecoregion of Canada (Rowe 1972). Aspen poplar or trembling aspen is the most widespread species within this area. Aspen is one of Canada's most prevalent deciduous tree species, growing throughout forested areas (Hosie 1975). Aspen trees average 12-18 m in height and 20-25 cm in diameter (Hosie 1975) (see Plate 2.1).

In many areas aspen trees are utilized in the manufacture of composite particleboard and as pulpwood (Mullins and McKnight 1981), although aspen in the Beaver Hills and EINP are not commercially significant. In the absence of commercial harvesting, there remains larger tracts of relatively undisturbed aspen, interspersed with increasing densities of rural acreage development.

Aspen is considered a shade intolerant, early seral or pioneer species that can invade disturbed landscapes, including following fire (Peterson and Peterson 1992; Bourgeau-Chavez et al. 2000). While aspen is a disturbance dependent species, it only ignites under specific climatic conditions (Wright and Bailey 1982; Quintilio et al. 1991). Although aspen forests are reported to usually be low in flammability (Alexander and Maffey 1990; Peterson and Peterson 1992), fire is recognized as a crucial element in the natural regeneration of aspen forests. Repeated spring burning can reduce aspen cover or check the invasion of aspen into grasslands (Anderson and Bailey 1980). The fuel available for combustion in an aspen stand is generally quite low due to the high moisture content and bulk densities of the litter and duff layers (Alexander and Sando 1989; Alexander and Maffey 1990). Light to moderate surface fires induce aspen suckering, while high intensity or severe fire will impede suckering and kill larger trees (Peterson and Peterson 1992).

Cumming et al. (2000) suggested aspen forests in western Canadian boreal forests are older than previously inventoried due to various gap dynamics. The gradual senescence of older trees within stands may allow for vigorous understory tree re-growth as early as 40 years after stand establishment. The role of intense, hot fires is understood to be vastly different from cooler, less intense fires. In EINP, mean stand ages among aspen community types vary from 62 to 93 years (Best and Bork 2004). There are few remaining dominant trees approximately 100 years old within the study area, while co-dominant trees are generally 60 years or less in age. Many of the dominant trees have died over the last 10 to15 years from various effects, including stress from forest tent caterpillar infestation of the 1980s to drought conditions from the 1990s to today. Fire occurrence and/or use will introduce additional factors to aspen stands in EINP.

Within EINP, upland forests are influenced by herbivory, topography and fire (Bork et al. 1997a). More recently, six different upland aspen plant community types have been identified in the Park (Best and Bork 2004). The use of fire has been recognized as one key factor regulating plant community modification. Within different community types it is important to understand whether ground fire can be predicted with similar accuracy.

2.4. Fire Ecology

2.4.1. Fire Environment

The fire environment is determined by the interaction of fuels, weather and topography (Countryman 1966, 1972). Topographical or static elements such as slope gradient and aspect affect moisture regimes, solar radiation angles and therefore, the susceptibility to ignition. The hummocky disintegration moraine of EINP has frequent, yet shallow (<10%) slope gradients. Fuel loading, arrangement and distribution, which are relatively constant (i.e. constant over the course of any one season), are important factors affecting fire, and in turn, are affected by the amount and distribution of duff layers. Perhaps the most important fuel consideration within forests of EINP is the seasonality of foliage. In particular, the aspen forests of EINP experience drying and wetting during the growing season during periods with and without leaves. Weather is the most volatile aspect to modelling fire and is discussed to in the next section (2.5).

For combustion to occur, heat, oxygen and fuel must be present. When fuels combust, they progress through the stages of preheating, volatilization, charring, smouldering and glowing (Byram 1959; Nelson 2001). The amount of smouldering will depend on the antecedent fuel moisture conditions after passage of a fire front, plus the thermophysical characteristics of the duff, such as conductivity and diffusivity (Miyanishi 2001). The smouldering stage of fire includes ground fire.

There are currently 16 major Canadian fuel classification types, of which leafless aspen (D-1) (Forestry Canada Fire Danger Group 1992) is under discussion here. The aspen fuel type is used to represent a typical western Canadian aspen forest found in the

Aspen Parkland or the Lower Boreal ecoregions. Low to moderate surface fires typically occur here, and the duff layer seldom contributes to the combustion process (Quintilio et al. 1991; Forestry Canada Fire Danger Group 1992).

With the potential climate changes toward global warming, more potential exists for increased fire in aspen forests. Global climate change scenarios using double the CO_2 of current rates have been predicted to produce increases of between 10 and 50% in seasonal fire severity ratings (Flannigan et al. 2000). The occurrence of extreme weather/fire events may also increase. Additionally, the size of wildfires may increase under global warming (Amiro et al. 2001).

2.4.2. Fire Regime Elements

2.4.2.1. Fire Frequency

The fire regime for an area includes characteristics of fire frequency, intensity, severity and season of burn. Fire frequency is one method of influencing plant community dynamics. While infrequent fires influence stand structure, more frequent fire is usually required to change stand composition (Holling 1973). The fire cycle, or frequency of burns, has increased more than three fold in the Boreal Mixedwood regions of Alberta since the early 1900s (Peterson and Peterson 1992). Increases in fire size are most prevalent since the 1970s (Van Wagner 1988). Since 1979 EINP has burned 10,186 ha through prescribed fire, and has had wildfires affecting a total of more than 2460 ha since 1959 (Parks Canada 2004a). Given the terrestrial land base size of approximately 12,000 ha in EINP, the Park has had the equivalent burn area of over one full fire cycle since inception in 1906. Within this area, however, some portions were burned more than once while many areas received no fire at all. Regardless, this is a greater fire cycle for EINP than reported in de Groot et al. (2003).

2.4.2.2. Fire Intensity

Fire intensity, or energy release per unit time (CIFFC 2003), is the most visible and dramatic aspect of fire on the landscape and associated vegetation, and determines the amount of combustible material consumed during passage of a fire front. The preburn fuel load generally determines fuel consumption rates in instances where duff layers are too moist (Quintilio et al. 1991). The Fire Behaviour Prediction System of the CFFDRS specifically identifies intensity as one of the primary parameters used to predict fire behaviour (Stocks et al. 1989). Taylor et al. (1997) developed a field guide to assist in calculating intensity classes, and threshold fire intensities for safe direct suppression efforts (i.e. >4000 kW/m) have been recommended (Beck et al. 2002).

2.4.2.3. Fire Severity

Fire severity is concerned with the combination of the flaming and smouldering combustion phases. Severe or deep burning fires have the greatest potential to cause plant community compositional changes and/or variation in vegetation re-growth (Miyanishi 2001). Fires that persist after the flaming phase for a period of time through the smouldering phase of combustion are referred to as ground fires. Ground fire occurrence and persistence are affected by soil or duff moisture conditions and heavy woody surface fuel concentrations (Kiil 1971; Hartford 1989; Lawson et al. 1997a, 1997b). The depth of burn is influenced by the dryness of forest fuels at ignition and thereafter during ground fire. This process is considered relatively independent of frontal fire intensity (Alexander 1982a).

2.4.2.4. Depth of Burn

Aspen forests tend to be much more flammable in spring or fall when live foliage is desiccated or absent. During the normal summer climatic cycles within aspen forests, there is sufficient moisture present in soils and foliage to prevent the occurrence of fire (Quintilio et al. 1991). Should a fire start, the severity is usually very low and the final fire size quite small (Peterson and Peterson 1992; Parks Canada 2004a). Light spring burning in the Aspen Parkland has shown an increase in the soil Ah layer organic matter content and no appreciable difference in bulk densities between burned and unburned areas (Anderson and Bailey 1980).

Deeper burning ground fires can occur in (aspen) forests if the right combination of low fuel moisture conditions is reached (Lawson and Dalrymple 1996a). During drought years such as 2002, even lightning-caused summer forest fires occurred in the aspen forests of EINP, the first recorded in the Park since 1914. Only two years later, in 2004, the Park experienced the largest spring wildfire since park inception (Parks Canada 2004a).

Severe aspen fires can infrequently occur. During the Chisholm Fire of 2001 in Alberta, extreme fire intensities and higher than predicted fuel consumptions were recorded that may be attributed to downed-woody fuel accumulations and/or severe spring burning conditions (Ember 2003). During the fall of 1981 in the Cameron Hills and the summer of 1982 in the Caribou Mountains of Alberta, under severe burning conditions, the primary investigator observed crown fire runs and deep ground fire pits in pure aspen and aspen mixedwood stands. Control tactics in September 1981 included digging several miles of trenches 3 to 4+ ft deep to contain the ground fires. The aspen fires during June and July of 1982 were so intense that suppression efforts were ineffective in aspen stands and resource efforts were redirected to coniferous fuel types in an attempt to steer fire fronts away from the volatile deciduous stands.

2.4.3. Fire Regime Type

Heinselman (1978) described six different kinds or categories of fire regimes in North America. The aspen forests of EINP have historically experienced light, frequent surface fires (Kjorlien 1977), whether man-made or lightning started. The Park has also experienced the effects of periodic longer return interval crown fires, such as the fire of 1895, a fire so severe that the present day Elk Island area was described at the time as a scene of 'utter desolation' (Kjorlien 1977). EINP is wholly contained within the Lower Boreal Mixedwood Ecoregion, and this area is completely surrounded by the Aspen Parkland Ecoregion (Strong and Leggat 1991). Hence, a combination of fire regime categories for the Park is quite likely. Historically, the frequent, light surface fires (1-25 yr return interval) of the Park or surrounding Aspen Parkland were likely accompanied by periodic, long return interval crown fire (100 to 300 yr return interval) episodes. A complete fire history analysis for the Park and the entire Beaver Hills should be available by 2006 (Rogeau 2004b).

2.4.4. Duff Moisture Considerations

Ground fuel moisture content in the duff layer can vary considerably over the course of a soil profile throughout the year. In most years the lower duff layers are significantly wetter than upper layers (Samran 1991). During spring time (April to May), and before full leaf flush in aspen stands, the forest floor is normally too wet to sustain severe fires (Wright 1932; Alexander 1982c; Alexander and Sando 1989; Alexander and Maffey 1990; Quintilio et al. 1990; Forestry Canada Fire Danger Group 1992). During some years, however, the relative humidity in spring may be very low, decreasing the moisture content of the forest floor (Wright and Beall 1938) and resulting in severe burning conditions (Ember 2003). If the duff over-winter moisture conditions are also low, as witnessed during the spring periods of 2002 to 2004, extensive fires are possible in aspen stands. Additionally, threshold moisture content levels may contribute to fuel consumption and affect fire prescriptions (Ferguson et al. 2002).

2.4.4.1. Duff Moisture Sampling

Accurate sampling for fuel moisture through proper plot spatial distribution is essential for sampling (Potts et al. 1986; Nalder and Wein 1998) as well as in maintaining a sufficient experimental design (Hulbert 1984). A broader range of moisture content sampling may be obtained by the introduction of moisture exclusion areas (Van Wagner 1970) or the selection of sites that are heavily sheltered from precipitation (Alexander et al. 1991; Wotton et al. 2005), allowing the practitioner to induce dryness in certain areas and record a wider spectrum of fuel moisture conditions.

The forest floor moisture content can be expected to vary somewhat over the course of a catena topographical sequence, and fire response over the landscape may vary with topography (Bork et al. 1997a, 1997b). While fires in the aspen forest often tend to be cooler on north-facing slopes, the differences in moisture between topographic positions are noted to decline as drought severity increases (Cheney 1978).

To extract duff cores for moisture sampling, a sharpened steel coring tube can be used (Nalder and Wein 1998). Duff samples are extracted with a drill and 5 cm diameter piece of aluminium water pipe approximately 40 cm long, sharpened at the end. Each sample core is placed on a split PVC pipe tray for delineating soil horizon measurements and the demarcation of 2 cm deep layers for drying. This coring method permits a greater number of samples to be collected than the conventional blocking method, which in turn should allow for a more reliable sampling of duff variability (Nalder and Wein 1998). In Nalder and Wein (1998), a mean bulk density coefficient of variation ± standard deviation was found to be 32% ± 12% for 47 stand samples in *Populus tremuloides*.

The most used method within the fire science community to assess moisture content is that of Lawson and Dalrymple (1996a). This well-established method involves weighing moist samples at the lab, oven-drying, and subsequent reweighing in tared soil moisture tins to determine moisture content as follows:

Moisture content (%) = [(Wet Weight – Dry Weight)/ Dry Weight] X 100.

Bulk density calculations can also follow Lawson and Dalrymple (1996a) with the following formula;

Bulk density ($g \cdot cm^{-3}$) = Dry Sample Wt / Sample Volume.

These estimates of bulk density can then be converted to kg m^{-3} (i.e. 1000X greater than g cm^{-3}) to ensure comparability to other studies.

Inorganic content determinization is done as per Kalra and Maynard (1991). Oven-dried samples are ground to a 2 mm size or less and 5 g of each sample are placed in a muffle furnace to oxidize the organic matter for at least 16 hrs. Organic matter is calculated as follows:

Organic Matter (%) = [(Dry Sample Wt – Sample Wt After Ignition)/ Dry Sample Weight] X 100.

2.4.4.2. Precipitation Received

The majority of annual precipitation within EINP falls within the growing season of April to October, but peaks in June through August (Parks Canada 2004c). Growing season precipitation is primarily thunderstorm or cell-based, and the amounts received throughout the Park can be quite variable.

2.4.4.3. Seasonality and Canopy Interception of Precipitation

Seasonality has been recognized as a significant factor in fire hazard conditions from very early on (Wright and Beall 1938). Green vegetation requires more heat to ignite than dry vegetation and will further increase the atmospheric humidity within a stand of trees. The seasonal growth and loss of foliage for aspen is a further consideration. Van Wagner found that pine and aspen forests tend to dry similarly during the summer, yet aspen dried twice as fast during leafless periods due to different exposure to the sun and weather elements (Van Wagner 1970).

The leaves within a stand of trees may also serve as a precipitation interceptor. Canopy interception occurs at a higher proportion for smaller rainfall events (Wotton et al. 2005). A study by Dunne and Leopold (1978) suggested a deciduous canopy median interception rate of 13%.

2.4.4.4. Fuel and Soil Characteristics

Certain fuel characteristics may affect duff moisture content. Chemical composition, the internal structure of either live or dead fuels, and the physical properties of the duff layers all have an effect on moisture content (Nelson 2001). The chemical components of cellulose, hemicellulose, lignin and extractives each display a certain affinity for water (Nelson 2001). In aspen, the primary water attracting components of cellulose plus hemicellulose comprise 84%, much higher than jack pine (71%) or white spruce (73%) in western Canada (Mullins and McKnight 1981). Live fuels can also be expected to hold more moisture than dead fuels, and this is further shown by the physical characteristic of wood shrinkage. Aspen can be expected to shrink 8.3% between green and air-dry conditions, versus 5.7% for jack pine and 6.8% for white spruce (Mullins and McKnight 1981).

The soils of EINP are primarily Orthic Gray or Dark Gray Luvisols, which develop in well to imperfectly drained sites and sometimes occur in the forest-grassland transition zone (Soil Classification Working Group 1998). The presence of well developed Ae and Bt layers distinguishes this soil type, which will have an effect on duff moisture drainage patterns.

2.4.4.5. Overwintering the Drought Code

Adjustments to the DC are recognized as commonly required in western Canada, especially as over winter precipitation is generally less than 200 mm (Alexander 1983b, Lawson and Dalrymple 1996a). Overwintering of the DC is recognized as crucial in determining the spring start-up number for the code. The standard procedure uses the national standard equation for DC start-up calculations and incorporates the proportion of overwinter precipitation absorbed by the deep duff layers since the previous years fire indices were discontinued. The spring start-up equation utilizes two coefficients, a and b. The a coefficient relates to when fire weather readings ended the previous year, while the b coefficient corresponds to the predicted proportion (as a %) of effective carryover precipitation from the snow pack into the next spring. However, the over-wintering equation has never been altered to reflect different fuel types. The standard formulae used (Turner and Lawson 1978) are as follows:

$$SMIf = 800\exp(-1(DCf/400))$$
$$SMIs = a(SMIf) + b(3.94\,P)$$
$$DCs = 400\ln(800/SMIs),$$

where, SMIf = fall value of DC (DCf) for November 1st or freezeup, as expressed in units of SMI,
SMIs = spring starting DC (DCs) as expressed in units of Stored Moisture Index (SMI),
a = carry over fraction of fall moisture (1.00, 0.75, 0.50),
b = precipitation effectiveness fraction (0.90, 0.75, 0.50), and
P = overwinter precipitation in mm water equivalent from Nov. 1st or freeze-up until spring start-up date.

For EINP the a coefficient used is 1.0, which corresponds to measuring the FWI values through to October 31st of each year. The b coefficient historically utilized is 0.50, the lowest winter carry-over value possible.

2.4.5. Duff Inorganic Content Considerations

Duff consumption during fire is also affected by soil inorganic content (Frandsen 1987, 1991, 1997; Hartford 1989; Lawson et al. 1997b; Anderson 2000; Anderson and Otway 2003). As the percentage of duff inorganic content increases for a given area, a corresponding decrease in organic matter occurs, resulting in a reduced water holding capacity (Anderson and Otway 2003). In Frandsen (1987), an inorganic to organic ratio of 4.3 or greater was found to limit combustion in the absence of moisture.

2.4.6. Duff Organic Bulk Density Considerations

As the (organic) bulk density increases in the duff layer, combustion can be expected to decrease (Wein 1983; Frandsen 1987, 1991, 1997), especially at lower moisture levels (Frandsen 1997). As the bulk density increases, the supply of oxygen may be reduced at the combustion interface, which slows the rate of burning (Frandsen 1991; Miyanishi 2001). Bulk densities in EINP spruce stands have been recorded as high as 0.2 to 0.3 g cm^{-3} (F layer) and 0.3 to 0.6 g cm^{-3} (H layer) (Anderson and Otway 2003).

2.5. Canadian Forest Fire Danger Rating System (CFFDRS)

2.5.1. Development of the Canadian Forest Fire Danger Rating System

J.G. Wright and H.W. Beall (1938) published the original Canadian fire danger tables, which were based on a 'Tracer Index' relating to moisture contents in needle litter and shallow duff of pine stands (Wright 1933). Wright (1932) provided a thorough overview of weather factors, soil moisture considerations and combustion principles just prior to the Tracer Index. The first systematic American approach to a danger rating system was by H.T. Gisborne, who published a 'fire danger meter' in 1933 (Brown and Davis 1973). Gisborne (1936) stressed that three important principles be followed, namely measurement of daily variables, thorough sampling of the forest areas and consistency in reporting. He also stressed that the variable factors of date, fuel moisture, wind, visibility and the activity of fire-starting agencies be considered. Various constant and variable elements of fire danger are presented in Brown and Davis (1973), however they stressed that the three most important ones to measure included fuel moisture, vegetative stage and wind speed.

From these early beginnings Canadian fire scientists assumed a leadership role with the early work at the Petawawa Forest Experiment Station in Ontario (Brown and Davis 1973; Stocks et al. 1989). A fire danger working group was formed in 1965 to begin work on the CFFDRS. This group introduced a provisional version of the danger rating system in 1968, which in turn, led to the first edition of the FWI System in 1970 (Taylor and Alexander 2005). For the current CFFDRS structure now operating in Canada, see Figure 2.1.

2.5.2. Fire Weather Index System

The most variable factor in the fire environment is weather (Countryman and Schroeder 1960; Schroeder and Buck 1970). The Canadian Forest Fire Weather Index (FWI) System (Canadian Forestry Service 1984; Van Wagner 1987) is a sub-set of the CFFDRS used to produce numerical ratings of mid-afternoon fire potential and includes estimates of fuel moisture, based on four daily weather observations: dry-bulb temperature, relative humidity, 10 m open wind speed and 24 hr accumulated precipitation recorded at 1200 hr local standard time (Turner and Lawson, 1978). Additional contributing factors include barometric pressure, upper atmospheric instability, day length and solar radiation received at ground level (Schroeder and Buck 1970; Brown and Davis 1973). These components affect how easily a fire may start, grow larger, and ultimately, effect the environment (Turner and Lawson 1978).

The FWI System is a means of tracking and predicting fire danger in forest fuels on a daily basis, as represented by the mid-afternoon danger (1600 hr local standard time) each day (Van Wagner 1987). The FWI system has six components, three fuel moisture codes (FFMC, DMC & DC) and three fire behaviour indices (BUI, ISI & FWI) (see Figure 2.2). The FWI System considers fuel moisture within the three organic forest floor layers and the moisture codes, as summarized in Table 2.1.

A series of national standard relationships were developed that relate the actual forest-floor moisture content (MC, expressed as a percent oven-dry weight basis) to the dimensionless values of FFMC and DMC (Van Wagner 1987). The FFMC (i.e. litter) does not carry ground fire and was not studied in this paper.

2.5.2.1. Sampling DMC/DC Fuel Moisture Codes

All the fuel moisture codes were developed after extensive field sampling of duff moisture conditions. Various red pine and jack pine stands (*Pinus* spp.) from around the Petawawa National Forest Institute in Ontario were chosen to represent a nominal national standard fuel type from which to compare readings to. Early work in duff moisture sampling in Canada included the works of Wright (1932, 1933), Wright and Beall (1938), Van Wagner (1970) and Turner (1972). While aspen was included in earlier sampling, the results were not utilized because of uncertainty over duff drying rates under aspen as affected by seasonal canopy changes (Van Wagner 1970).

Van Wagner (1983, 1987) described in more detail the basic development of these codes. Seasonality or time of year influences the amount and angle of solar radiation received throughout the year, and a daylength factor or daylength adjustment was calculated for the DMC and DC, respectively (Van Wagner 1987). The notion of equilibrium moisture content (EMC) (the lowest probable value) was determined to be 20% for the DMC layer, but was not assigned to the DC layer. For the wetting function, it was determined that the first 1.5 mm and 2.8 mm for the DMC and DC, respectively, would not permeate the assigned duff layer and were therefore ignored in calculations. The efficiency of rain wetting will also decrease as the rainfall rate increases and the moisture content of the duff rises. For the drying phase, a negative exponential rate is assumed, with the EMC used (for DMC) as the lowest possible number. The use of a code scale was designed with the intuitive notion to increase the code with decreasing moisture contents. The codes 'hide' the actual moisture content, as a correlation with actual moisture conditions is assumed. Standardized non-linear relationships were calculated for each of the codes and remain in use today (Van Wagner 1987).

The DC was developed originally to serve as an index of water stored in the soil (Turner 1972). This code was found to also represent certain slow-drying, heavy fuels (Muraro and Lawson 1970; Van Wagner 1974), however, it was never intended to represent any one particular fuel type (Alexander 1982b). With a 53-day time lag, the

DC has a long enough period for it to be considered suitable for overwintering considerations (Turner and Lawson 1978; Lawson and Dalrymple 1996a). Tables were drafted to assist in the calculations of spring DC (Alexander 1983b), which today are generally computerized for ease of implementation.

More recent moisture sampling for boreal types, and their subsequent correlation to DMC or DC includes Norum and Miller (1984), Chrosciewicz (1989a, 1989b), Lawson and Dalrymple (1996a), Lawson et al. (1997b), Wilmore (2001), Anderson and Otway (2003), Abbott et al. (2004) and Jandt et al. (2005), among others. A great deal of recent sampling has included fuel types different than the national standard. The DMC and DC moisture content curves (logarithmic function) for different boreal types are required to enhance the accuracy of the FWI system. These curves are non-linear regression equations that quantify increasing values of DMC/DC as duff moisture declines.

The moisture relationship curves for aspen were not completed in 1970 and remain unknown as of 2005. The need for accurate moisture curves for aspen forests in EINP, and hence accurate DMC and DC values, is addressed in Chapter 3 of this thesis.

2.5.3. Fire Behavior Prediction System

In 1984, a first edition (interim) was published on the Fire Behaviour Prediction (FBP) System (Lawson et al. 1985). Eight years later, the Canadian Forest Fire Behavior Prediction System (Forestry Canada Fire Danger Group 1992) was completed. The FBP system contains quantitative estimates of fire-spread rates, fuel consumption and intensity, as well as the type of fire as the primary components (see Figure 2.3). The forest fuel types used are the same as those for the FWI system (Stocks et al. 1989). The FBP System was not designed to report on ground fires, persistence or smouldering components of a fire. The preferred route then, includes the proper calibration of FWI codes and determining ground fire thresholds from the resultant values.

2.6. Ignition and Persistence of Ground Fire

The presence or absence of smouldering combustion is an important yet neglected aspect within the fire environment (Anderson 2000). The quantity of duff moisture in the ground directly affects the probability of ignition. Under very dry conditions fire severity or depth of burn increases, the duff layer having dropped below the threshold of moisture required for combustion (Ferguson et al. 2002). The ability to forecast or predict ground fires is crucial to generate accurate and reliable fire prescriptions. A DMC of 20 and/or a DC of 300 are often considered benchmarks for the start of ground fire occurrence and persistence in the field (Wotton et al. 2005), yet a DC of 400 has also been purported (Alexander 1982b). Prior to use, these benchmarks require testing.

While there are equations correlating the probability of ignition and DMC/DC for some boreal forest types and experimental commercial peat moss fuel types (Hartford 1989; Frandsen 1987, 1991, 1997; Lawson et al. 1997b), these relationships do not exist for aspen. There is also a theoretical ignition survival curve for aspen ground fire versus moisture content and DC, but it remains untested (Anderson 2000). Anderson (2000) produced a relationship between average duff characteristics from the literature, including aspen, which showed an average duff depth of 2.4 cm, a bulk density of 0.061 g cm^{-3} and inorganic content of 59%. In a study of Saskatchewan forest fires, the quantile DMC for lightning caused fires was deemed to be approximately 45 for a probability of 50% (Anderson and Englefield 2001). Aspen forests comprised 12.5% of that study. Gray or Dark Gray Luvisolic soils are frequently found throughout EINP (Bork 1993; Best 2001), and these soil types will influence the moisture regimes, bulk densities and inorganic contents, and hence, the probability of ground fire occurrence.

Another factor that may influence the probability of ignition in duff is spring frost levels. During the spring, frost may persist at various depths for some time and either temporarily inhibit or suspend the natural drainage of moisture through duff and soil layers, or cause the snowmelt to run off prior to infiltration (Lawson and Dalrymple 1996a; Bork et al. 2001), thereby influencing combustion potential. This condition was not encountered during 2003 or 2004 sampling, but was encountered during the spring of 2005 in EINP and near Peace River, Alberta (Bob Mazurik, Forest Protection Officer, Alberta Sustainable Resource Development, pers. comm. 2005).

The process of smouldering occurs at lower temperatures, with slower rates of propagation and with less complete oxidation than flaming combustion (Miyanishi 2001). The smouldering interface progresses both downwards and laterally in duff, and shallow duff layers can decrease the chance of ground fire survival through heat loss in the oxidation/pyrolysis zone (Miyanishi 2001). Moisture content of the duff and duff depth are purported to be key factors in determining the extinguishing point of ground fire, as well as the potential upward movement of moisture from the mineral soil below (Samran et al. 1995; Miyanishi 2001).

2.6.1. Procedures for Ignition Trials

To calculate the probability of ignition and its response to fuel moisture, ignition trials can be conducted similar to Lawson et al. (1997b). Core samples are taken in each plot as per Nalder and Wein (1998), using a cordless drill and cylindrical tube auger. Extracted core samples are separated into 2 cm increments and later oven-dried to determine the moisture content of the DMC/DC layers. Core holes from moisture sampling are then filled with smouldering peat moss. The peat used for ignition tests was commercially available bagged dry peat moss. An ignition was considered successful if smouldering was still present after a two-hr time lapse (Lawson et al. 1997b). Ignition survival rates for the D-1 fuel type are addressed in Chapter 4 of this thesis.

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Table 2.1. Comparison of fuel moisture codes in the FWI system.

	FWI Codes		
	FFMC	DMC	DC
Description	Unaltered fine surface litter, foliage and small branches	Loosely-matted decomposing duff	Deep compact organic layer
Nominal depth in soil	1.2 cm	7 cm	18 cm
Water capacity	0.6 mm	15 mm	100 mm
Nominal fuel load	0.25 kg m^{-2}	5 kg m^{-2}	25 kg m^{-2}
Drying time to lose ⅔ moisture	⅔ day	15 days	53 days

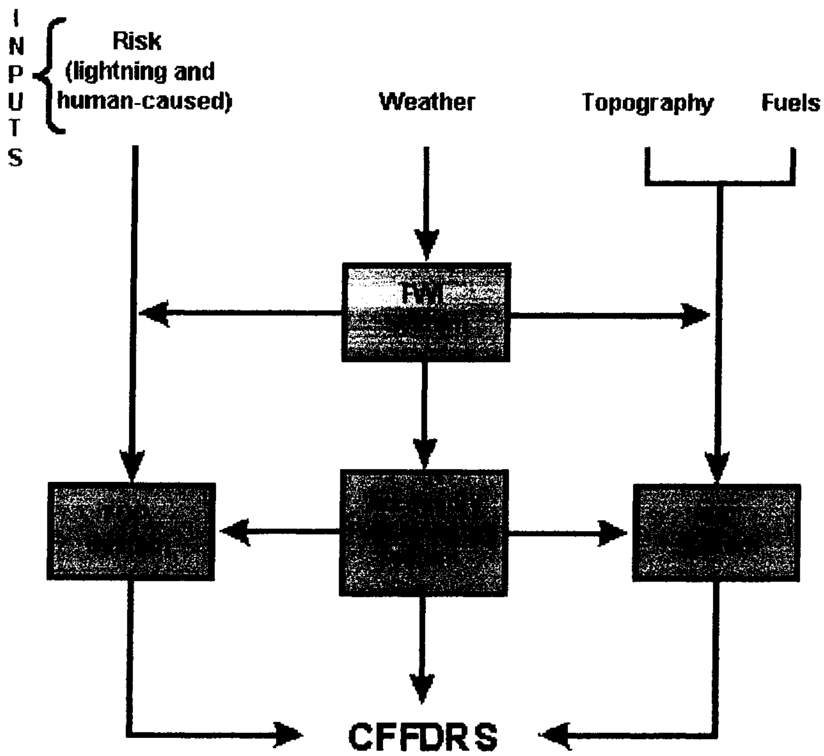

Figure 2.1. A simplified structure diagram of the CFFDRS.

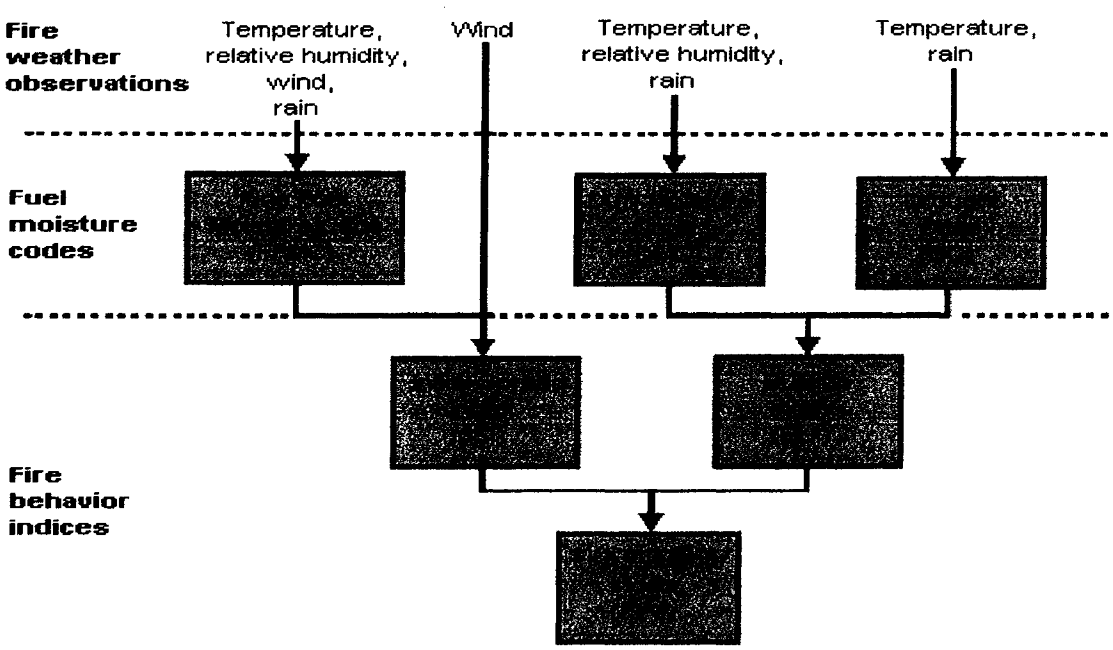

Figure 2.2. Structure of the Canadian Forest Fire Weather Index System.

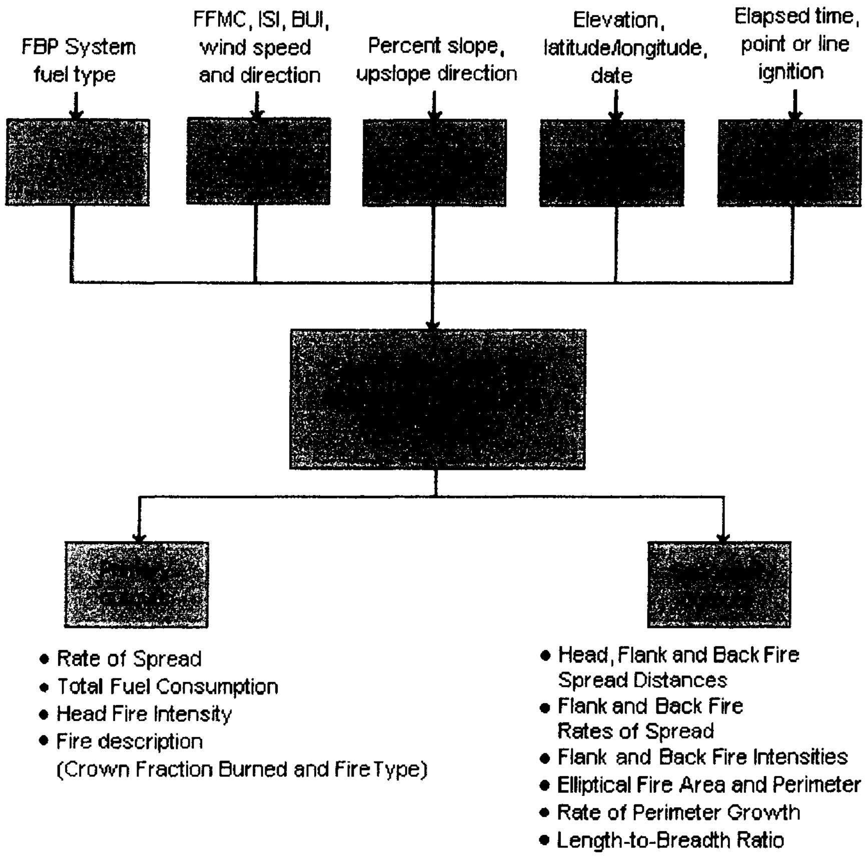

Figure 2.3. Structure of the FBP System.

Plate 2.1. Typical aspen forest vegetation structure.

Chapter 3. RELATING DUFF MOISTURE CHANGES TO FWI CODES IN ASPEN COMMUNITIES

Abstract

The rate at which aspen forest spring duff moisture increases or decreases during the growing season was investigated in Elk Island National Park, Alberta, Canada. A calibration and validation procedure was utilized incorporating one calibration site with three topographic positions, which was subsequently compared with 12 validation sites across three vegetation types throughout the Park. Duff moisture changes versus the Fire Weather Index codes from the validation sites were compared to the predicted values based on equations developed from the calibration site, and indicated reasonable predictability (mean absolute error = 20.7-54.2%). Spring, summer and fall rates of duff moisture change differed significantly ($P<0.05$), being greatest in spring. While moisture changes on the south and crest positions were similar, moisture loss was greater ($P<0.05$) compared to the north aspect. Correlation analysis of duff moisture versus inorganic content and bulk density indicated both soil duff characteristics influenced associated moisture levels, though were limited compared to weather parameters. Calibration and validation data were analysed to produce new empirical relationships between DMC/DC and moisture content for the D-1 aspen fuel type in Elk Island National Park. Using the new DC equation, a new overwintering formula was also derived.

3.1. Introduction

The Canadian Forest Fire Danger Rating System (CFFDRS) is the nationally accepted standard means of determining forest fire behaviour in Canada (Stocks et al.

1989). Within this rating system is the Canadian Forest Fire Behavior Prediction System (FBP) (Forestry Canada Fire Danger Group 1992) and the Canadian Forest Fire Weather Index System (FWI) (Van Wagner 1987), which are used to calibrate individual parameters related to forecasted fire behaviour and fire weather, respectively.

Duff moisture code (DMC) and drought code (DC) are the numerical values used in the FWI to represent soil duff (i.e. LFH) moisture dryness (Van Wagner 1987), and therefore, its potential to influence fire behaviour.

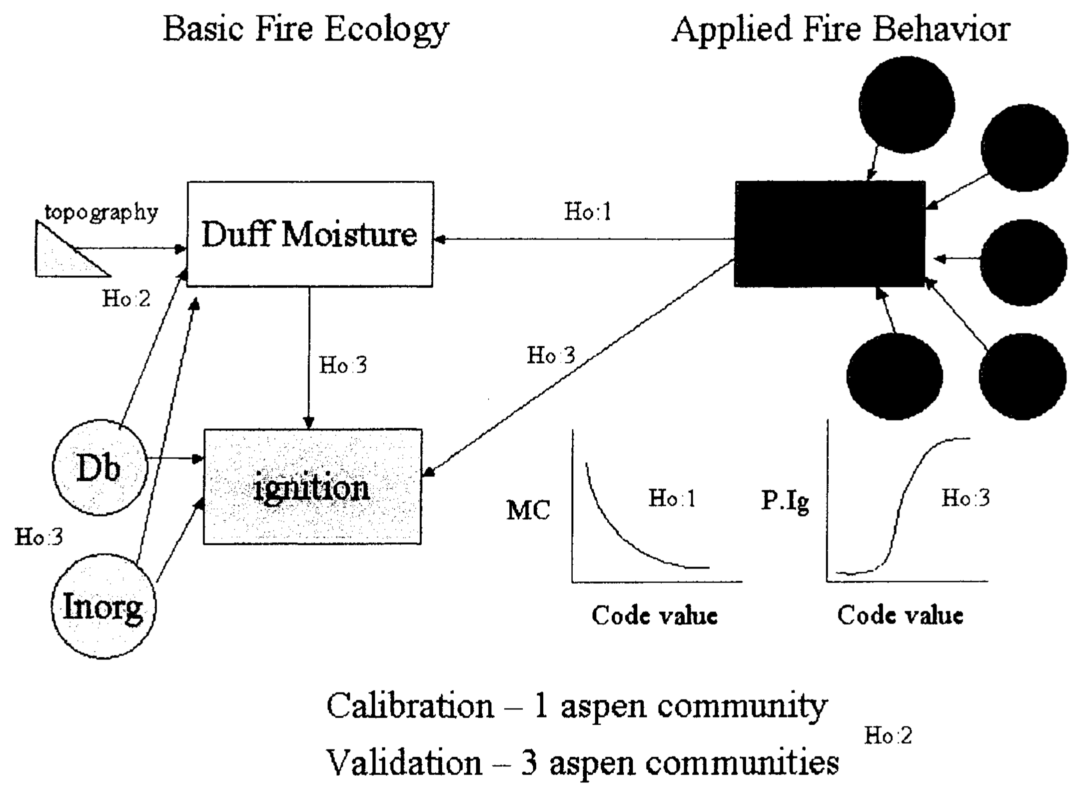

Figure 3.1. Theoretical relationship of basic fire ecology and applied fire behaviour that led to development of the hypotheses tested, where Ho: = hypothesis, Db = bulk density, Inorg = inorganic content, Mn = month, T = temperature, RH = relative humidity, day l = day length, MC = moisture content and P.Ig = probability of ignition.

Changes in the DMC track moisture in the shallow duff or fibric soil horizon (F-layer), while the DC tracks the humus or deep duff layers (H-layer), as well as coarse downed woody materials. Both indices are determined at noon (standard time) each day during April to October from standardized weather readings of temperature, wind speed, relative humidity and 24 hr precipitation (Figure 3.1). The DC also has a carry-over function, whereby moisture conditions over the winter months may influence fire risk the following spring.

Both the DMC and DC are re-calibrated annually beginning at 'start-up' three days after snow loss in spring, and are continually updated throughout the fire season until October 31st or freezing conditions return (Turner and Lawson 1978). Snow loss is often followed by a period of cool, freezing conditions where very little duff moisture loss or frost release occurs. For this reason the Park also waits until three days have passed with a recorded noon temperature of 12 °C (Turner and Lawson 1978) before calculating FWI indices. The method of calculating DMC and DC assumes forest soils dry exponentially in the absence of rainfall, loosing ⅔ of their moisture in 15 and 53 days, respectively. Conversely, the rate of moisture recharge is considered to decrease as duff layers become wetter, presumably due to soils approaching their maximum water holding capacity. The DMC and DC components of the FWI are numerical values of most assistance to fire managers in assessing forest fuel dryness and associated fire risk.

The landscape of Elk Island National Park (EINP) has evolved with fire and Parks Canada recognizes the need for adequate fire control capability as well as the use of prescribed fire (Parks Canada 1994, 2005). Fire has been used periodically since 1979 on a prescribed basis in many areas of the Park (Alexander and Dubé 1983), although more recently, several wildfires have occurred in and around the Park (e.g. 2002 and 2004). In addition, recent periods of severe drought between 2000 and 2004 have produced conditions conducive to undesirable fire consequences in EINP and the surrounding area, including the risk of persistent ground fire. Fire occurrence during drought may threaten human safety and Park infrastructure, and have negative consequences on ecosystems. As a result, forecasting the occurrence and persistence of ground fire is important to the effective management of this disturbance and conservation of the Parks resources.

EINP is dominated by trembling aspen (*Populus tremuloides* Michx.) forest. Although these communities may not burn as readily as other forest communities in the Boreal region (Peterson and Peterson 1992), ground fire may persist under dry conditions for extended periods (Lawson and Dalrymple 1996a). Ground fire is the smouldering combustion that lingers after an initial surface or crown fire. These fires can produce large quantities of smoke, and through vegetation disturbance, nutrient leaching and/or erosion, as well as create sites conducive to non-native plant invasions (Van Wagner and Methven 1980; Lawson and Dalrymple 1996a; Achtemeier 2001; Sutherland 2004).

While significant information exists within the FWI system (i.e. DMC/DC criteria) for coniferous forests of the Boreal region (Chrosciewicz 1989a, 1989b; Lawson and Dalrymple 1996a; Lawson et al.1997b; Wilmore 2001; Anderson and Otway 2003; Abbott et al. 2004; Jandt et al. 2005), and for moisture content and other factors such as inorganic content and bulk density in relation to ignition potential (Frandsen 1987, 1991, 1997; Hartford 1989), little is known of the dynamics of fire risk associated with trembling aspen communities (Van Wagner 1970). Moreover, because the DMC and DC moisture curves are fundamental to the accuracy of the FWI system for predicting fire behaviour (Figure 3.1), they are also required for the effective management of this disturbance in aspen forests.

This study was conducted to evaluate seasonal moisture content (including depletion and recharge) within the soil duff layer of forests in EINP, and develop specific DMC/DC codes for the aspen communities of the Park (Ho: 1, in Figure 3.1). Additionally, this study evaluated the impact of soil bulk density and inorganic content, as well as topographic position, on duff moisture and the associated DMC/DC (Ho: 2, in Figure 3.1).

3.2. Materials & Methods

3.2.1. Study Area

EINP is situated 35 km east of Edmonton in central Alberta (53° N and 112° W), at the north end of the Beaver Hills. The Beaver Hills were formed by the Cooking Lake dead-ice moraine southeast of Edmonton and are elevated 10 to 30 m above the surrounding plains, which is sufficient to place the area within the Lower Boreal Mixedwood ecoregion (Strong and Leggat 1991). The landscape of the Park is distinctly undulating with 5 to10 m relief, resulting in a diverse mix of plant communities. The dominant vegetation of uplands is trembling aspen forest, although open grasslands, shrublands, and white spruce forest [*Picea glauca* (Moench) Voss] are interspersed throughout the area (Polster and Watson 1979). Lowlands are dominated by either aquatic environments, or where sufficiently drained, riparian meadows, fens or bogs. Within the area used for calibration in this study, aspen trees measured were found to have a mean age of 76 years.

The climate of the area is cool-continental, with long, cold winters and short, warm summers (Bowser et al. 1962). Annual precipitation over the last 44 yrs at the Edmonton International Airport, the closest long-term weather station, indicates an average yearly precipitation of 460 mm (see Figure 3.2). Precipitation has ranged from a low of 257 mm in 2002 to a high of 630 mm in 1996. April to October (inclusive) precipitation accounts for 81% of the yearly totals (Table 3.1), and has ranged from 220 to 470 mm over the last 10 yrs in the Park (Parks Canada 2004c) (see Figure 3.3). Mean growing season temperatures during April to October vary from a low of 5 °C in spring and fall to a high of 17 °C in midsummer (Rogeau 2004a), while the frost-free period is approximately 100 days (Crown 1977).

Precipitation fluctuates throughout the year in the area, with summer receiving the most precipitation (Figure 3.4). Within the growing season alone (April to October), just over half of the precipitation (for EINP or Edmonton) occurs during the summer months of June to August (Table 3.1). (The spring and fall seasons receive ~15% or less of the yearly total). The growing season precipitation is primarily thunderstorm or cell-based, and the precipitation amounts received throughout the Park can be quite variable, with differences of up to 14% from the EINP Campbell Scientific (EIWFE) rain gauge recorded within the Park during 2004 over the summer months in total (Table 3.2).

The calculated DMC/DC codes for EINP reflect the varied precipitation received during the fire season (April to October) over the last three years, and inter-annual variation during that time. The codes demonstrate that 2002 was the driest year, with numerous peaks and troughs in the following two years coinciding with dry and rainy periods, respectively (see Figure 3.5).

Dominant soils found throughout the Park are Dark Gray or Orthic Gray Luvisols (Soil Classification Working Group 1998) under forest vegetation (Crown 1977). Low lying areas tend to be dominated by Humic Luvic Gleysols or Rego Gleysols. The calibration site soil type was on Orthic Gray Luvisol, with distinct Ae and Bt horizons (see Plate 3.1).

3.2.2. Experimental Approach

The experimental approach used in this study was to develop and test empirical relationships between DMC/DC and soil moisture from various sites throughout the Park. Initially, three plots at one location representing three different ecosites (i.e. microclimates) and associated aspen plant communities (e.g. from south to north across a catena toposequence) were used to calibrate the relationship between DMC/DC and moisture. Calibration involved intensive, repeated sampling of plant communities at the south-facing (S-1), crest (C-1) and north-facing (N-1) topographic positions, to assess detailed changes in moisture and corresponding DMC/DC from 2002 to 2004 (April – October) (see Table 3.3). The calibration site was chosen close to road access to facilitate rapid and frequent sampling prior to and after precipitation events. Sampling of the three calibration sites was performed both within *in-situ* soils as found within each plot, and within 'rainfall exclusion' treatment areas, designed to exclude rain and simulate a drought effect (Van Wagner 1970). Rainfall exclusion areas were 3 x 3 m in size, and tarped 1 m above ground to eliminate rainfall and soil moisture recharge. This was done to ensure that low moisture levels (i.e. high DMC/DC values) were represented in at least a portion of the soil moisture cores sampled (see Plate 3.2).

Following initial calibration of the DMC/DC codes to duff moisture, the resulting empirical relationships were subsequently tested in 2004 on replicated plots of each of three main aspen communities found throughout EINP (Best and Bork 2004). This validation procedure was used to test the generality of the DMC/DC empirical relationships derived from the calibration area, to reliably predict soil moisture at other independent locations.

3.2.3. Field Sampling

All plots (calibration and validation) were 20 x 20 m in size, permanently marked at the corners with metal pegs, their location recorded using a global positioning system (GPS), and photographed. The calibration area consisted of three plots, each of which was sampled periodically throughout the spring, summer and fall of 2003 and 2004. All plots in the calibration site were situated within plant communities encompassing traits similar to the two most prevalent aspen community types found across EINP. The two community types (Type D and E) account for approximately 70% of the aspen sample plots previously investigated in the Park as part of an ongoing vegetation monitoring program (Best and Bork 2004). On average, four soil cores (i.e. sub-samples) were collected within each plot on each day of sampling. Occasionally two or three samples were collected per plot, either due to loss of battery power in the drill, a rain shower occurrence or lack of room in the drying oven for more tins.

Validation plots were selected from a series of 96 Permanent Sample Plots (PSPs) already situated on forested uplands throughout the Park as part of the long-term vegetation monitoring program. Previous studies have indicated these PSPs represent six different aspen community types (Best and Bork 2004), including three common types. These communities differ primarily by seral stage and tree canopy closure, understory plant composition and overall productivity. For each of the three validation community types examined in 2004, four plots were selected using a stratified random approach (n = 12 total). Validation plot selection required a stratified random approach to ensure the plots utilized were relatively accessible to facilitate repeated sampling, and had slope gradients that were generally flat to less than 5%. Replicates were randomly selected from within a representative group of existing PSPs and known to belong to each aspen community type. Of the four PSP plots per community type, all were sampled once in June and two (randomly selected from within the initial four) were sampled repeatedly throughout the summer of 2004.

Preliminary data collected during 2002 on test sites served primarily as an opportunity to initialize sampling procedures on different locations other than the calibration or validation areas. Sampling methodologies were refined during this period, particularly the decision to demarcate the FFMC/DMC boundary from duff core samples. The FFMC layer was always included in the 0 to 2 cm sample tin, regardless of actual depth, thereby ensuring the 2 to 4 cm tin always contained only DMC layer materials. Preliminary data were not included in the final data analysis. Specific plot locations for all calibration and validation plots are provided in Appendix A.

Rainfall exclusion treatment areas were established in each of the three calibration plots in 2003 and 2004 to track moisture changes in relation to DMC/DC in the absence of precipitation. Additionally, following the successful use of tarps from June of 2003 through into 2004 at the calibration site, the blue polyethylene tarps were also used at three of the validation plots (one per community type) in 2004. Tarps were stretched over understory shrubs, and tied to trees or anchored to the ground at the corners. Air movement and transpiration by plants remained possible under the tarps. Regular inspections of the tarps were made to prevent leakage or damage (see Plate 14.6). Tarped plots in 2003 and 2004 successfully held off moisture from the covered ground until late May 2004, when moisture began to seep horizontally under the tarps through deeper soil layers from outside the tarped perimeter during heavy rainfall. The samples collected from under the calibration tarps were further compromised by heavy rainfall and subsequent moisture creep during July 3 to 14th and July 26 to 27th, 2004. After downpours on these dates, excessive moisture in untarped areas appeared to infiltrate downwards through the duff layer to mineral soil, then move laterally, confounding moisture readings under the tarped areas. However, short-term lateral movement through the duff layers was not detected (see Appendix 12). Data collected from these dates or shortly thereafter were considered confounded and excluded from analysis. New tarps were deployed after each of these precipitation events to restart the moisture exclusion process. Moisture values from successive sampling dates under a tarped area were checked to ensure mean moisture contents were less than the previous date sampled. The last set of tarps was deployed in the calibration site in September 2004. One tarp in the Beaver area had to be replaced during 2004 within the validation areas.

Sampling of the three calibration plots and 12 validation plots for soil moisture occurred throughout the growing season, including spring (April and May), summer (June through August) and fall (September and October). Moisture sampling was undertaken on a schedule frequent enough to detect relatively small increases in DMC (i.e., changes of five points) at each site and the corresponding DC values. Sampling was further modified to include more frequent sampling shortly prior to and after significant amounts (>2 mm) of forecast precipitation. Frequent sampling, particularly close to precipitation events, coupled with the sampling of open and rainfall exclusion treatments within each plot, facilitated a wide range (minimum and maximum) of observed DMC and DC values within each period, thereby increasing the robustness of empirical relationships between DMC/DC and soil moisture. Individual soil cores within a sample date and plot (and rainfall treatment) were considered sub-samples (minimum of three) and averaged for use in all subsequent moisture calculations. Coefficients of variation in moisture readings among sub-samples ranged from 5-35%.

To extract duff cores for moisture assessment, a sharpened steel coring tube was used (Nalder and Wein 1998). Duff sub-samples were extracted with a drill and 5 cm diameter piece of aluminium water pipe approximately 40 cm long, sharpened at the end. Each core was placed on a split PVC pipe tray for delineating soil horizon measurements and the demarcation of 2 cm deep layers for drying. At the time of sampling, all duff sub-samples were assessed for the depth of litter (L), fibric (F) and humic (H) soil horizons, the presence of compression and other attributes such as charcoal or large root fragments. Compression was primarily recorded within the FFMC or litter layer, however the litter (L) soil duff layer was not utilized in this study. Immediately after extraction the cores were cut into 2 cm increments and enclosed in soil sample tins. To ensure the relatively shallow soils in EINP were accurately sampled, the litter layer was always demarcated at the 2 cm depth, with materials above included in the first tin (0 to 2 cm) and subsequent tins (2 to 4 cm, 4 to 6 cm, etc., down to 10 to 12 cm) used to capture the DMC and DC layers below. This was done to ensure the shallow litter layer (i.e. ~0.5 to 1.0 cm in thickness) did not confound results from the DMC layer.

In 2002 there were 24 soil cores taken during preliminary sampling, with 144 tins measured for moisture (Table 3.3). During 2003, a total of 149 soil cores were taken, yielding 894 tins. In 2004, 497 soil cores were sampled, for a total of 2982 tins containing various soil strata.

All tins sampled between 2002 and 2004 were measured for duff moisture and bulk density. While rapid results are possible using soil moisture meters (Martech 2002), there is no known published literature on the accuracy of this instrument. Ultimately, the method chosen to assess moisture was that of Lawson and Dalrymple (1996a). This well-established method involves weighing moist samples in the lab, oven-drying, and subsequently reweighing in tared soil moisture tins to determine moisture content as follows:

Moisture content (%) = [(Wet Weight – Dry Weight)/ Dry Weight] X 100

Bulk density calculations also followed Lawson and Dalrymple (1996a) using the following formula:

Bulk density ($g \cdot cm^{-3}$) = Dry sample Wt / Sample Volume.

These estimates of bulk density were then converted to $kg \cdot m^{-3}$ to ensure comparability to other fire research studies.

A representative number of soil core samples were retained and bagged for inorganic content determination at a later date at the Canadian Forest Service lab in Edmonton. During 2003 and 2004, 380 and 360 sample tins, respectively (0 to12 cm), were assessed for inorganic content. Inorganic content determinization was done as per

Kalra and Maynard (1991). Oven-dried samples were ground to a 2 mm size or less and 5 g of each individual sub-sample were placed in a muffle furnace to oxidize organic matter for at least 16 hrs. Organic matter was calculated as follows:

Organic Matter (%) = [(Dry Sample Wt – Sample Wt After Ignition)/ Dry Sample Weight] X 100.

Weather parameters were measured at the EINP Warden Office, 800 m from the calibration site, utilizing an Environment Canada, Campbell Scientific year-round weather station. Additionally, precipitation was measured locally within the calibration area using two on-site manual rain gauges to ensure that shower-based precipitation events were accurately recorded. One gauge was placed in an area with no forest overstory while the second was situated directly within the C1 (i.e. crest position) calibration plot to evaluate the extent of precipitation interception by the forest canopy (see Table 3.4). Additional on-site manual rain gauges were placed at each of the validation sites to track localized precipitation events, which were necessary for the determination of 'local' DMC/DC values. Fire indices (i.e. FWI) were started three days after 'snow gone' was declared (>90% of ground was snow free) and three days where noon M.S.T. temperatures of 12 °C were recorded, with corrections made to the drought code for overwinter adjustments (Turner and Lawson 1978). Weather indices were tracked for all stations as per Turner and Lawson (1978), using the Campbell station for temperature, wind speed and humidity, and modified per site with precipitation readings from the portable rain gauges (Appendices 5 and 6).

Adjustments to the DC are recognized as commonly required in western Canada, especially as over winter precipitation is generally less than 200 mm (Alexander 1983b, Lawson and Dalrymple 1996a). This is crucial in determining the spring start-up number for the code. The standard procedure uses the national standard equation for DC start-up calculations and incorporates the proportion of overwinter precipitation absorbed by the deep duff layers since the previous years fire indices were discontinued. The spring start-up equation utilizes two coefficients, *a* and *b*. The *a* coefficient relates to when the fire weather readings ended the previous year, while the *b* coefficient corresponds to the predicted proportion (as a %) of effective carryover precipitation from the snow pack into the next spring. However, the over-wintering equation has never been altered to reflect different forest fuel types. The standard formulae used (Turner and Lawson 1978) are as follows:

$$SMIf = 800\exp(-1(DCf/400))$$
$$SMIs = a(SMIf) + b(3.94\,P)$$
$$DCs = 400\ln(800/SMIs),$$

where, SMIf = fall value of DC (DCf) for November 1st or freezeup, as expressed in units of SMI,
SMIs = spring starting DC (DCs) as expressed in units of Stored Moisture Index (SMI),
a = carry over fraction of fall moisture (1.00, 0.75, 0.50),
b = precipitation effectiveness fraction (0.90, 0.75, 0.50), and
P = overwinter precipitation in mm water equivalent from Nov. 1st or freeze-up until spring start-up date.

For EINP the *a* coefficient used was 1.0, which corresponds to measuring the FWI values through to October 31st of each year. The *b* coefficient historically utilized is 0.50, the lowest winter carry-over value possible.

3.2.4. Data Analyses

The variables utilized in all analyses included duff moisture (as relative moisture in %), bulk density (in kg m^{-3}), and the inorganic content (measured as ash content in g, and reported as % inorganic). All statistical analyses of sample locations were undertaken using regression analysis (PROC REG) while comparisons between sites were conducted with ANOVA (PROC GLM), using SAS (2001).

The mean soil duff depths of 3 cm (2 to 4 cm layer) and 5 cm (4 to 6 cm layer) were used as the benchmark depths for calculating DMC and DC, respectively (see Figure 3.1). The relatively shallow depths of the F and H horizons in EINP differ markedly from the national standard depths of 7 and 18 cm.

Adjustments for overwintering the drought code were performed using the formula from Turner and Lawson (1978). The standard procedure was adjusted from the national standard equation and replaced with the best-fit DC equation from the current research study and incorporating a new b coefficient. Conversion of the final calibration equation using the summer data involved a series of steps, namely changing the SMIf equation with the summer calibration figures, adjusting the *b* coefficient in the SMIs equation to reflect the summer calibration moisture relationship, and changing the DCs equation. The steps are outlined below:

1. Change the SMIf equation to SMIf = 130.56exp(-1(DCf/454.54))
2. Change the SMIs equation to SMIs = 1(SMIf) + 0.165(3.94P)
3. Change the DCs equation to DCs = 454.54ln(130.56/SMIs).

The moisture curves for aspen forest established from sampling within the calibration plots were calculated and subsequently compared to the national standard equations for the FWI system (Van Wagner 1987). Standard equations for the DMC and DC are as follows:

DMC: MC=exp[(244.7-DMC)/43.4]+20

DC: Q=800/exp(DC/400),

where DMC and DC are Duff Moisture Code and Drought Code, MC is moisture content and Q is moisture equivalent (Van Wagner 1987).

Data from the three calibration sites were initially examined with scatter plots using the DMC/DC code against the natural log (ln) of the moisture content on the y-axis. As the calibration sites were sampled continuously from June 2003 to August 2004, the spring calibration data (April and May) were generated primarily during 2004, the fall data (September and October) during 2003, and the summer data (June through August) from both years. Thus, the summer data, collected from the same sites with no change in biophysical conditions other than weather, were pooled across the two years. Data for the spring, summer and fall periods were evaluated separately to assess potential seasonal differences in moisture loss, with linear regression used to compare rates of moisture content loss to the associated modeled values of DMC/DC. Non-linear or exponential relationships, similar to those evident within the national standard equations (Van Wagner 1987) were also evaluated. All relationships generated were assessed for similarity using a Tukey test (SAS 2001). Relationships determined to be similar ($P>0.05$) based on the Tukey tests were combined and graphed as negative exponential curves, and compared to the national standard curves.

All validation plot data obtained from sampling during the period May to August, 2004 were also assessed through regression to determine the initial relationship between DMC/DC and moisture, and through exponential equations for comparison to the national standards. Additionally, observed moisture content results from sampling of the validation plots were compared to the predicted moisture values calculated using the previously established calibration equations. Calibration equations used for comparison included those found with the greatest goodness-of-fit (R^2) values and associated statistical significance. Comparisons were made considering different seasons of sampling, topographic positions and the interaction of season by position. All validation equations used for comparison to the best-fit calibration equations through regression analysis were assessed for accuracy through the calculation of mean absolute error (MAE) and modelling efficiency (EF) (Mayer and Butler 1993). The leading models were considered those with a representative sample size, the greatest R^2 value, the lowest MAE, and the greatest EF.

To evaluate whether bulk density or inorganic content were associated with soil moisture, a correlation analysis was performed with PROC CORR (SAS 2001), and was followed by a stepwise regression using PROC STEPWISE (SAS 2001). Only the sampling periods for which there were direct inorganic data available (and associated moisture content and bulk density) were used in this analysis.

3.3. Results

The generally thin DMC and DC layers, ranging in thickness from 2 to 4 and 4 to 6 cm, respectively, are 3 to 14 cm less than that associated with the national standards (Table 3.5). Soil inorganic content averaged 37% and 55% in the DMC and DC layers, respectively (Table 3.5). The inorganic content comparisons by depth reveal similar mean values, with an associated CV of 17 to 49% at the 2 to 4 or 4 to 6 cm depths (Table 3.6a). In contrast, bulk density values in the calibration sites were considerably greater (285 to 445 kg m^{-3}) than that associated with the national standard (71 to 139 kg m^{-3}) (Table 3.5). Bulk densities by soil depth from the various topographic positions displayed minimal variation, with an associated CV among sub-samples of 30 to 34% at the 2 to 4 and 4 to 6 cm depths during 2004 (Table 3.7a). Within the calibration area, both bulk densities and inorganic contents among topographic positions increased with depth (Tables 3.6a and 3.7a).

3.3.1. Calibration Results

In general there was less effect of topographic position than season of sampling on the resulting empirical relationships between soil duff moisture content and DMC/DC. That is, relatively few differences existed in the association between moisture and DMC/DC at the crest, south and north-facing topographic positions, results supported by the Tukey tests on season by position interactions for both DMC (Table 3.8a) and DC (Table 3.8b).

There were, however, more differences apparent among those calibration moisture models developed for the spring, summer and fall time periods. Spring sampling yielded the wettest moisture regime, followed in descending magnitude, by the summer and fall seasons. There were also significant differences ($P<0.05$) between many of the leaf-off periods of spring and fall versus summer leaf-on periods at the calibration site in both DMC (Table 3.8a) and DC (Table 3.8b) values. However, the spring and fall leaf-off periods were also dissimilar ($P<0.05$) to each other for both indices.

Based on the Tukey test results, the calibration site DMC data were not significantly different ($P>0.05$) between the C1 and either S1 or N1 topographic positions during spring, between C1 and S1 during summer, and no differences ($P>0.05$) were found among any topographic positions during fall (Table 3.8a, Figure 3.6 - A,B,C).

Pooled across positions, seasonal comparisons indicated that the summer and fall data resulted in similar models ($P>0.05$), but both were different ($P<0.05$) than the spring (Table 3.8a, Figure 3.7-A). The resulting best-fit equations by season for the DMC data included the combined C1/N1 model in spring (Table 3.9a). While the summer and fall models were all generally strong (Table 3.9a), the all summer and all fall data models were preferred because of the larger sample sizes associated with their development and the resulting greater likelihood that they applied to a broader range of landscape conditions.

For the DC data, the Tukey test results indicated the C1 and S1 positions resulted in similar models during both spring and summer ($P>0.05$), and once again little difference was apparent among any models developed from the fall data (Table 3.8b, Figure 3.6 – D,E,F). When pooled across positions, data from the three seasons indicated a trend similar to the DMC, with the summer and fall resulting in similar models ($P>0.05$), each of which was different ($P<0.05$) from the spring (Table 3.8b, Figure 3.7 - B). Overall, the best-fit equations by season for the DC data indicated that none of the spring models were strong (i.e. all had $P>0.05$; Table 3.9b), with the combined C1/S1 model having the greatest significance ($P = 0.16$). In the summer, the S1 and N1 locations resulted in the greatest R^2, although the all summer data led to the most significant model ($P<0.0001$), and was therefore preferred (Table 3.9b). In the fall data, the S1 model led to the greatest R^2 and the greatest significance ($P=0.02$), however the difference between the fall models was minor (Figures 3.6 - F, 3.7 - B).

When models for all the calibration data were combined (i.e. Allcal) for the analysis of either DMC or DC, the results were very similar ($P \leq 0.0001$) to the all summer data (Table 3.9a,b).

Results of the non-linear regression analysis using the calibration data indicated that the DMC and DC moisture relationships established for EINP were different from the national standard equations. Models developed from the DMC spring and fall data tended to have a relatively flat or linear moisture loss rate, compared to the summer data (Figure 3.7A). In contrast, the DC model curves were all very similar (Figure 3.7B). All the models tested demonstrated moisture relationships that when compared to the national standards, had a lower moisture content or moisture equivalent at lower code values.

Calibration models developed from each season that were subsequently used for comparison with the validation data for DMC/DC included C1/N1 and C1/S1 for spring, and the all summer, all fall and all calibration data combined. Given the increased sample sizes used to establish the summer calibration curves, the overall favourable goodness of fit, and the fact that the validation data were collected during the same time frame, the all summer data were considered the most representative group for comparison among all the data.

3.3.2. Validation Results

Comparison of observed validation site moisture contents to predicted moisture content values for the validation sites using the top calibration models in each season and across all seasons, yielded R^2 values ranging from 0.61 to 0.78 for the DMC, and 0.02 to 0.38 for the DC (Table 3.10). Moreover, within each unique validation data set (i.e.

aspen community type), R^2 values were similar for the leading model from each season, as well as the final calibration model based on all the calibration data (Allcal) (Table 3.10). Although this suggests models from each season were similar in predicting duff moisture content, closer examination of the validation results indicated the seasonal models differed in MAE and EF (i.e. model accuracy).

Among the DMC models, the summer data resulted in a lower MAE than the spring data and lower EF, although the latter was due only to the Tawayik site, where EF was particularly low (Table 3.10). Compared to the summer data, the fall model resulted in greater MAE and lower EF. Models developed using all the calibration data resulted in a MAE greater than that for the summer models, but lower than the fall models. A similar pattern was evident within the DC data (Table 3.10), with considerable variation in R^2, MAE and EF among validation sites and seasonal calibration data sets. Graphs of observed moisture content for all validation plots combined compared to the predicted values of moisture from DMC or DC using either the all summer or all calibration data models are presented in Figures 3.8a and 3.8b. There was a consistent tendency in the calibrated relationships to over-estimate soil moisture at low actual moisture and under-estimate at high actual moisture using the modelled equations (Figure 3.8a,b).

Using the lowest average mean absolute error (MAE) as the primary measure of accuracy, the best-fit DMC and DC models were the summer calibration equations (MAE = 32.2 and 30.6, respectively) (Table 3.10). Using the highest average modelling efficiency (EF) method, the best-fit DMC model was the C1N1 spring calibration data (EF= 0.38) and the DC best-fit was the all calibration data set (EF= 0.52). However, the summer calibration data were relatively close in both instances (EF= 0.36 and 0.45 for

DMC and DC, respectively) (Table 3.10). Therefore, the summer calibration data sets were considered the most suitable models for further testing, with the lowest average MAE in both indices and the next to best EF in both, as well.

The validation procedure also facilitated comparison of the leading moisture models developed from the calibration data sets among various validation sites. Notably, only the Beaver DC model was non-significant (R^2= 0.02), while the other sites were more similar (DMC: R^2= 0.56 to 0.78, $P<0.0001$; and DC: R^2= 0.13 to 0.38, $P<0.01$). These results indicate that the original calibration equations resulted in a reasonable predictability of moisture across the various validation sites. As a result, the relationship between predicted moisture using the calibration model developed from the summer calibration data was plotted in comparison to the national standard equations for both DMC (Figure 3.9a) and DC (Figure 3.9b). Both of these relationships differed markedly from that of the national standard as they begin at a much lower moisture content with low DMC/DC, and lose moisture at a slower rate relative to the national standard. Moisture decline was particularly limited for the DC (Figure 3.9b). Final moisture equations calculated from the validation data are presented in Table 3.11.

3.3.3. Bulk Density and Inorganic Content

Soil bulk density, inorganic content and moisture content data were compared through a correlation analysis in each of 2003 and 2004. During 2003, inorganic content was significantly correlated with both bulk density and moisture content ($P<0.01$) in the DMC and DC layers. However, moisture content was not associated with bulk density ($P>0.49$) in either layer (Table 3.12). One year later in 2004, all correlations among the three variables were significant ($P<0.0001$). The 2004 correlation results demonstrated negative relationships between moisture content and bulk density ($r = -0.67$ and -0.80 for the DMC and DC layers, respectively) and moisture content and inorganic content ($r = -0.62$ and -0.79 for the DMC and DC layers, respectively). In other words, as bulk density and inorganic content levels declined, moisture increased. In contrast, a positive relationship was observed between inorganic content and bulk density ($r = 0.87$ and 0.84 for DMC and DC, respectively).

A stepwise regression utilizing those samples that had actual inorganic content data available indicated that only inorganic content during 2003 was significant at the entry level of $P=0.05$, while the remaining comparisons for both years were not significant ($P\geq0.05$).

3.3.4. Overwintering the DC

Overwintering the drought code yielded interesting results. April 12th was the start-up date for the DC during 2004 and moisture sampling on that date indicated a mean average moisture content of 117.7%. Overwinter precipitation was 98 mm, less than the 200 mm necessary to avoid adjusting for overwinter precipitation. The standard overwinter adjustment equation, then, utilizing the 98 mm received, yielded a DC of 206, considered overly high by the author. However, utilizing the summer calibration model, this moisture content equated roughly to a DC of 50. By adjusting the standard overwintering equation with the summer calibration model equation, and changing the b coefficient to 0.165 for EINP, a DC of 52.5 was found, which is a close representation of the observed average moisture content. In comparison, if the national standard equation were utilized with a moisture content of 117.7%, the corresponding DC would have been much greater, at approximately 800.

For the year 2005, the starting DC moisture content was 212% on April 11th. This value was likely confounded (i.e. higher than normal) due to the presence of frozen ground beneath the 6 cm depth and the lack of drainage for the duff moisture present (i.e. suspended moisture versus actual duff moisture). Utilizing 1 and 0.165 for the codes in the spring of 2005 yielded a conservative start-up DC of 26. This value is much lower than the value of 145 obtained using the national standard.

3.4. Discussion

In determining whether different seasons influenced moisture relationships, it became apparent that the summer moisture relationships were generally dryer than those of the spring, and experienced greater drying, yet were moister than that observed during the fall. Despite this, an attempt to develop a separate model for moisture regimes under leafless (spring and fall) aspen would likely yield DMC and DC models very close to the leafed (summer) model. Among the data sets, the models developed from all the summer data appeared to be the most robust as determined by MAE and EF criteria. The summer sampling periods also received the most precipitation, allowing sampling of the widest quantitative range of soil moisture contents, particularly when augmented with rainfall-excluded values. In contrast, fall sampling during 2003 and the spring sampling of 2004 occurred during drought, with an associated reduced opportunity to sample a broad range of moisture distributions. This, in turn, may have limited the ability to compare moisture loss during these periods with that occurring in the summer.

Seasonality has been recognized as a significant factor in fire hazard conditions (Wright and Beall 1938). Green vegetation requires more heat to ignite than dry vegetation and will further increase the atmospheric humidity within a stand of trees. Leaves may also intercept precipitation, reducing duff moisture recharge. During low rainfall events, a greater proportion of rainfall tends to be subject to canopy interception (Wotton et al. 2005). Data obtained by the two manual rain gauges installed at the calibration site provided further insight into the role of canopy interception on moisture dynamics. During 2003, the in-stand gauge had 28.8% less rainfall overall than the gauge positioned in the open, while during 2004 this difference was 11.8%. These differences increased further when rainfall events declined in intensity. For example, when precipitation events were less than 10 mm, the difference in rainfall received between closed and open areas was 31.4% and 24.2% during 2003 and 2004, respectively. When rainfall events less than 6 mm were considered, these numbers increased further to 38.5% and 25.0%, respectively (Table 3.4). Thus, the pattern and intensity of precipitation may influence actual changes in soil moisture, which in turn, may not be reflected in accurate seasonal changes within the calculated values of DMC and DC. A study by Dunne and Leopold (1978) suggested an overall deciduous canopy median interception rate of 13%. This may be a conservative value relative to the aspen stands investigated here. Although it could be argued that the canopy interception rate would also be less without leaf cover, this remains to be determined.

Analysis across topographic positions revealed that moisture models developed for the crest and south-facing slopes were generally similar, while that of the north-facing slope was often different (see Figure 3.6 A to F, and Table 3.9a,b). Of the three positions, the north aspect would receive the least direct solar radiation, affecting soil temperatures and evaporation. Furthermore, post fire vegetation data from EINP indicate differential burning impacts on north-facing aspects (Bork et al. 1997a), presumably due, at least in part, to these microclimatic conditions.

Samran et al. (1995) also considered differential flammability among different slope positions in EINP. That study concluded that the ground fuel moisture contents were significantly different (P= 0.096) between three different slope positions. Deeper soil horizons were also found to have greater soil moisture. The study by Samran et al. (1995) was carried out during a year with near normal April to October precipitation (312.5 mm, versus the 11 yr Park average of 353.5 mm). However, the Edmonton weather data indicate that of the antecedent April to October weather for the preceeding 10 years prior to the Samran study, only 1992 was 5% less than the 44 yr average, with all the remaining years having above average precipitation. Soil moisture conditions were therefore clearly very different in the study by Samran et al. (1995) from those of the current investigation, where there was a marked moisture inversion profile in the duff and soil layers (i.e. the deeper the sampling, the dryer the soil moisture content).

During 2002, the Park received 38% less moisture than the preceding 10 yr average, while the Edmonton station showed that 2003 and 2004 were 23% under and 2% over the long-term average, respectively (Parks Canada 2005). Additionally, five of the 10 years previous to the current study had precipitation levels below average. The differing results between the current study and that of Samran et al. (1995) could therefore be caused by a residual forest soil moisture deficit initiated during 2002 and 2003 in the Park.

During the validation procedure, there was a consistent tendency for the calibrated models to over-estimate soil moisture at low actual moisture and under-estimate when moisture was high (Figure 3.8). This may be attributed to the potential inherent error associated with sampling such a shallow portion of the soil layer (0 to 6 cm), where minor variation in soil conditions may lead to a higher proportional error than might be found if testing deeper soil profiles. Recurrent drought conditions faced over the last few years may also have influenced results, where deeper and drier soil horizons may have affected moisture draw-down rates from overlying horizons in undetermined ways. Finally, variation in ecosite conditions from the calibration to validation locations, such as subtle differences in understory vegetation, inorganic content (see Table 3.6b) or bulk density (see Table 3.7b) may have influenced the results.

Despite the variation among models relating moisture to DMC/DC, the relationships developed among the calibration sites were all more representative of soil moisture conditions in EINP than the national standard equation models. All the new models indicate moisture retention levels well below that expected under the national standards. Notably, in Anderson and Otway (2003), the maximum moisture content measured under white spruce stands in EINP was found to be 140%, similar to the current study within aspen forests. The reasons for these lower values may be site-based, and include the shallow duff depth in addition to the relatively high soil inorganic contents and bulk densities. Lawson et al. (1997a) suggested shallow duff layers could account for this difference (see Table 3.5). The D-1 fuel type sampled in the Park also had a very high bulk density (see Table 3.7a,b), suggesting less potential for water holding capacity and air movement compared to fuel types with a lower bulk density, as are commonly found in conifer vegetation types (see Table 3.5). However, because these bulk density values are consistent with those found in Anderson and Otway (2003) for white spruce stands within the park, the unique soil moisture properties in EINP may be linked as much to the nature of the parent material or other soil forming processes, rather than the dominant type of vegetation residing on it. Finally, the relatively high inorganic content for the D-1 fuel type found in the Park, particularly within the DMC layer, could also account for the reduced water holding capacity. Inorganic particles generally contain less air space (i.e. porosity) to facilitate water retention compared to organic fuel types.

A comparison of the final summer calibration curves to those generated by Chrosciewitz (1989a) in jack pine cutovers, Lawson et al. (1997a) in interior cedar hemlock forests of British Columbia, Anderson and Otway (2003) for white spruce in EINP, and Abbott et al. (2004) in jack pine at the International Crown Fire Modelling Experiment (ICFME), are presented for comparison in Figure 3.10. Results indicate these coniferous types (except for Anderson and Otway 2003) possess duff layers that retain more moisture at lower DMC/DC code values, and experience greater moisture loss relative to modelled increases in DMC/DC, when compared to the deciduous forests of EINP (Figure 3.10). Van Wagner (1970) reported that aspen appeared to dry at approximately twice the rate of pine types during leafless periods. From the models created in the current study, it appears that aspen forests in EINP do not dry twice as fast as other fuel types, but rather that the moisture content relationship is simply half of the other types at lower code values to start with. In other words, moisture values within the soils associated with D-1 fuel types are inherently lower, possibly due to greater moisture use from the productive understory typically associated with these deciduous aspen stands (Best and Bork 2004). Another possible reason may be linked to the intense grazing pressures of the high ungulate populations in the Park, and their subsequent biomass consumption and loss of (moisture retaining) organic material.

Moisture sampling during the drought period of the last three years has also revealed the degree to which free moisture loss in the duff layer may occur in the Park. During the two sampling dates of Oct 17th and 19th, 2003, the open area moisture content had dropped to within approximately 20% of the tarped areas, the latter of which had rainfall excluded for four consecutive months. Results from 2003 also indicated a steady decrease in the soil moisture profile in the upper 7 cm compared to 2002. The 9 cm+ soil depths did not decrease substantially in moisture content from 2002 onwards, potentially indicative these depths were quite possibly already near the minimum threshold of free moisture availability. Drought conditions subsequently persisted through the spring of 2004 until the rains of late May. Extremely low moisture values were measured on May 31st, 2004 from samples taken under the tarps installed 11 months before in 2003. Notably, the DMC free moisture limit had dropped below the minimum theoretical equilibrium level of 20%, particularly under the N-1 tarp (i.e. DMC MC = 10.6%). The equilibrium level was proposed in Van Wagner (1970), when it was observed during field development of the DMC that sheltered (i.e. moisture excluded) samples rarely fell below this moisture content. As a result, should a drought cycle return to the Park area, the 20% 'limit' must be viewed with caution, at least for the D-1 fuel type.

Conversely, during wetter periods the measurements of the DC layer revealed a maximum moisture level far less than the theoretical maximum of 400%. The theoretical code is based on a deep duff layer of 18 cm thickness, while in the Park, a depth of 2 to 3 cm was more typical of the deep humus layer within the aspen communities sampled. The effects of high herbivory cannot be excluded as one possible reason why the duff layers are so shallow (i.e. due to trampling and compaction), nor the residual effects of ground fire duff consumption from the severe fire season of 1895 or thereafter.

The shallow duff layers in the Park may also influence the utility of the DC as an indicator of dryness for practical purposes. Overwintering of the DC in this shallow depth revealed a *b* coefficient of 0.165, an indication that only 16.5% of the overwinter precipitation permeated into the H-horizon. This is remarkably similar to a personal rule of thumb observed that ~70% of snow sublimates, and of what is left, about half of that runs off before frost leaves the ground. During the spring of 2004 the aspen forest floor was absent of the usual frozen, black and wet (matted) litter layer commonly found. Snow pack from the previous winter rapidly receded from 25 cm at the start of April to snow gone (>90% snow free) one week later. During the spring of 2005, a 75% loss of the settled snow pack occurred during the week of March 6-12th. It is not uncommon for the snow pack to recede this quickly in the Park, often while the ground is still frozen, potentially minimizing infiltration. Surface runoff has been hypothesized as responsible for the greater dependence of upland grassland production on summer (4 mn) precipitation rather than the September to August (12 mn) water year period (Bork et al. 2001). Forest vegetation in EINP often occurs on steeply sloped topography (e.g. 5 to 15%), where snowfall is additionally redistributed to lower lying areas due to drifting. This redistribution may further limit snow pack depths during eventual snow melt (Bork et al. 2001). Finally, during the spring of 2005, it was also observed that the frost layer was very slow to release. Frost tends to suspend the residual overwinter moisture in the surface duff layers, in effect temporarily trapping the moisture from naturally infiltrating the soil and increasing soil moisture (Lawson et al. 1996a).

The summer calibration model indicated that when the DC values were 50 and 450, moisture contents were approximately 118% and 50%, respectively. Thus, unlike many conifer forests, a large change in the DC values observed (i.e. 9 fold increase) within these aspen stands failed to correspond to a very large change in actual soil moisture content within the DC layer. In contrast, the DMC lost a correspondingly greater amount of moisture as the DMC value increased. It could therefore be argued that the DMC layer is more sensitive to moisture change than the DC layer within the aspen forests of EINP, and may indeed be a better indicator of soil dryness and associated ground fire potential.

3.5. Conclusions & Management Considerations

The empirical relationships between soil moisture and DMC/DC developed for the D-1 fuel type in EINP support the notion of utilizing the all summer calibration model to assess soil moisture in these aspen forests. Moreover, the combined moisture draw-down curves differed markedly from that of the national standard curves (i.e. the moisture regime for any given DMC or DC value was lower than forecasted previously), and from conifer types from other regions. Precipitation may vary across the Park, which will affect on-site FWI codes, and the addition of portable rain gauges can be used to record differences in rainfall. Therefore, prescribed burn planning or wildfire management preparations need to incorporate these considerations. This study found soil duff depths in aspen stands (comprising the D-1 fuel type) were substantially less than the national standard depths in both the F (DMC) and H (DC) soil horizons. Additionally, soil bulk densities within EINP appear to be much greater than in many other fuel types documented across Canada, possibly as a result of the higher levels of inorganic content.

Inorganic content and bulk density sampling yielded significant correlations with changes in moisture content, although the empirical relationships between moisture and the DMC/DC codes are likely robust to variation in these soil characteristics.

The results found here also suggest the summer calibration equation conversion for overwintering of the Drought Code should be utilized to more accurately reflect spring DC start-up values. The *b* coefficient of 0.165 achieves this for EINP. The new formula, which includes the adjusted coefficients, is likely more accurate for the Park than the national standard equation, and is recommended for implementation in modelling soil moisture values within the DC layer throughout the region. While the drought code is a necessary component of the FWI System, the results of the current study also suggest that the DC code has limited use as a sensitive indicator of changing duff moisture conditions in the Park, particularly in comparison to the DMC.

The duff moisture sampling and analysis completed in this investigation will contribute to the national FWI system and may be accepted by the Canadian Forest Service as the newest or interim standard for the D-1 fuel type in western Canada. Further research is needed on the applicability of the moisture models developed here to areas outside of the Beaver Hills, including those that may have different parent materials or soils.

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Table 3.1. Precipitation summary for Edmonton International Airport (YEG), for 1961 to 2004 and Elk Island National Park (EIWFE), for 1994 to 2004.

Season[1]	YEG		EIWFE	
	Mean Precip.mm	Percentage	Mean Precip. mm	Percentage
Spring	69.2± 30.2[2]	15.1± 6.4	69.0± 27.2	15.3± 4.9
Summer	240.1± 62.6	51.8± 8.7	222.5± 47.3	50.4± 7.4
Fall	64.0± 31.1	13.9± 6.2	61.9± 32.1	13.5± 5.5
Growing Season	373.3± 73.0	80.8± 19.0	353.5± 81.2	79.2± 5.8
Winter	87.7± 25.6	19.2± 5.5	93.6± 33.7	20.8± 5.8
Yearly Total	461.0± 79.6	100± 17.0	447.1± 101.1	100± 16.1

[1] Spring (April to May), summer (June to August), fall (September to October), growing season (April to October) and winter (November to March).

[2] Standard Deviation

Table 3.2. Precipitation amounts (mm) for all calibration and validation site rain gauges for May to September 2004, with distances and percent differences from the main Elk Island National Park rain gauge.

Site	Gauge[1]	Precipitation (sd)[2]	Approx. Distance from EIWFE (m)	Difference from EIWFE (%)
Calibration	EIWFE	369.3	--	--
	Home	345.9	1000	-23.4 (6.4)
	Post	368.0	800	-0.3 (<1)
	Bush[3]	338.6	800	-30.7 (8.4)
Validation	Beaver	372.2	3000	+2.9 (<1)
	Goose	318.9	8000	-50.4 (13.7)
	Tawayik	353.7	6000	-15.6 (4.3)
Mean Total		352.4 (19.5)		

[1] EIWFE= Elk Island National Park Campbell Scientific station, Home= residence gauge, Post and Bush= Calibration site gauges in open area and within forest stand, respectively.

[2] Standard deviation.

[3] The bush gauge was situated within stand for comparison sakes and was not to standard (Turner and Lawson 1978).

Table 3.3. Soil core sampling summary by year, season and topographic position.

Year	Season[1]	Location	Number of Cores	Cores Analysed	Not Used or Confounded[2]
2002	Spring to Fall	Test Sites	24	0	24
2003	Spring	Calibration	17	17	0
		Test Sites	2	0	2
	Summer	Calibration	54	54	0
		Test Site	6	0	6
	Fall	Calibration	70	70	0
2004	Spring	Calibration	176	162	14
	Summer	Calibration	164	160	4
		Beaver	53	53	0
		Goose	53	53	0
		Tawayik	51	51	0
Site Totals		Test Sites	32	0	32
		Calibration	481	463	18
		Validation[3]	157	157	0
Grand Total			670	620	50

[1] Spring, summer and fall represent April to May, June through August and September to October periods, respectively.

[2] Moisture samples confounded from under tarps after rainstorms or from test sites.

[3] Validation includes Beaver, Goose and Tawayik combined.

Table 3.4. Precipitation comparisons between the post and bush rain gauge from the calibration site for the years 2003 and 2004, for light rain events.

	2003	2004	2003		2004	
Dates	Jun 3 – Oct 28	Apr 2 – Oct 31	Less than 6mm event	Less than 10mm event	Less than 6mm event	Less than 10mm event
Post gauge[1] (mm)	291.8	392.4	47.5	87.7	100.1	116.9
Bush gauge[2] (mm)	207.8	346.3	29.2	59.8	75.1	88.6
Difference (mm)	84.0	46.3	18.3	27.9	25.0	28.3
Difference (%)	28.8	11.8	38.5	31.8	25.0	24.2

[1] Post gauge to standard as per Turner and Lawson (1978).

[2] Bush gauge within 1m of ground and within the aspen stand of the C-1 calibration plot area.

Table 3.5. Comparison of mean (±SE where available) duff depth, inorganic content and bulk density for selected vegetation types.

Sample Type	N	Mean Depth cm	Bulk Density $Kg\ m^{-3}$	Inorganic Content %	Source
Nat Std DMC	-	7	71.43	not determined	Van Wagner 1987
Nat Std DC	-	18	138.9	not determined	Van Wagner 1987
Calibration Site DMC[1]	116	2-4	285.2±13.3	37.2±1.6	Otway 2005
Calibration Site DC[1]	116	4-6	444.6±19.8	55.0±1.7	Otway 2005
D-1 Fuel Type Average	-	2.4	61	59	Anderson 2000
D-1 Fuel Type	-	2.37±0.36	108±25	59±14	Quintilio et al. 1991
EINP Aspen Sites	510	6.5±0.07	140±2	not determined	Samran et al. 1995
White Spruce Duff	-	0-5	122	35.9	Lawson et al. 1997b
EINP Spruce Stands	46	2-4	200-300	not determined	Anderson and Otway 2003
EINP Spruce Stands	46	4-6	300-600	not determined	Anderson and Otway 2003
ICFME Jack Pine	38	2-4	91.5±2.8	13.7±21.8	ICFME 2004

[1] Sample size used for bulk density and inorganic content analysis in ignition trials of Chapter 4.

Table 3.6a. Comparisons of duff inorganic content for the years 2003 and 2004 at different topographic positions and soil depths across the calibration site, showing the location, depth (cm), number of samples (N), mean inorganic (%), standard deviation (SD), standard error (SE), and coefficient of variation (CV) of sub-samples.

		2003					2004				
Location	Depth	N[1]	Mean	SD	SE	CV	N	Mean	SD	SE	CV
C-1	0-2	22	30.1	11.5	2.4	38.0	8	15.4	7.1	2.5	46.0
	2-4	22	45.6	12.6	2.7	27.6	8	45.1	8.1	2.8	17.9
	4-6	22	61.3	14.0	3.0	22.9	8	54.1	9.9	3.5	18.2
	6-8	22	74.9	14.6	3.1	19.5	8	78.0	10.1	3.6	12.9
	8-10	22	84.9	7.6	1.6	9.0	8	88.7	4.0	1.4	4.5
	10-12	22	89.3	4.7	1.0	5.3	8	90.1	2.8	1.0	3.1
N-1	0-2	17	26.9	13.4	3.2	49.8	8	13.3	3.6	1.3	27.0
	2-4	17	48.7	13.4	3.3	27.6	8	33.0	16.2	5.7	49.2
	4-6	17	65.1	11.4	2.8	17.5	8	45.9	19.2	6.8	41.8
	6-8	17	76.7	12.8	3.1	16.6	8	63.4	14.6	5.2	23.1
	8-10	17	82.1	10.4	2.5	12.7	8	78.8	11.2	4.0	14.2
	10-12	17	88.0	7.2	1.7	8.2	8	85.6	5.6	2.0	6.5
S-1	0-2	17	25.6	10.9	2.6	42.7	8	12.0	2.5	0.9	20.7
	2-4	17	42.1	12.1	2.9	28.8	8	24.4	8.3	2.9	33.8
	4-6	17	58.2	13.5	3.3	23.2	8	38.0	12.5	4.4	32.8
	6-8	17	76.0	17.5	4.2	23.0	8	62.4	17.6	6.2	28.2
	8-10	17	87.4	8.9	2.2	10.2	8	87.6	7.6	2.7	8.6
	10-12	17	89.7	6.3	1.6	7.0	8	92.7	2.9	1.0	3.2

[1] Number of subsamples collected for inorganic content analysis varied over the two years.

Table 3.6b. Comparisons of duff inorganic content for the year 2004 at different validation site locations and soil depths, showing the location, depth (cm), number of samples (N), mean inorganic (%), standard deviation (SD), standard error (SE), and coefficient of variation (CV) of sub-samples.

		2004				
Location	Depth	N	Mean	SD	SE	CV
Beaver	0-2	12	10.5	1.3	0.4	12.6
	2-4	12	29.4	21.5	6.2	73.1
	4-6	12	49.6	28.0	8.1	56.3
	6-8	12	80.4	14.4	4.1	17.9
	8-10	12	91.0	7.2	2.1	7.9
	10-12	12	94.8	4.0	1.2	4.2
Goose	0-2	12	10.9	2.6	0.8	24.0
	2-4	12	30.1	20.0	5.8	66.5
	4-6	12	47.1	24.9	7.2	53.0
	6-8	12	79.2	13.0	3.8	16.4
	8-10	12	90.1	7.4	2.1	8.1
	10-12	12	95.7	1.7	0.5	1.7
Tawayik	0-2	12	13.7	7.3	2.1	53.6
	2-4	12	19.8	5.5	1.6	27.7
	4-6	12	52.0	17.5	5.0	33.7
	6-8	12	81.8	10.1	2.9	12.3
	8-10	12	89.2	8.0	2.3	9.0
	10-12	12	95.7	1.4	0.4	1.4

Table 3.7a. **Comparison of bulk densities for the years 2003 and 2004 at different topographic positions and soil depths across the calibration site, showing the location, depth (cm), number of samples (N), mean bulk density (kg m^{-3}), standard deviation (SD), standard error (SE), and coefficient of variation (CV) of sub-samples.**

		2003					2004				
Location	Depth	N	Mean	SD	SE	CV	N	Mean	SD	SE	CV
C-1	0-2	56	119.4	0.06	0.01	48.5	162	29.9	0.02	0.00	64.5
	2-4	56	272.9	0.10	0.01	38.7	162	233.5	0.07	0.00	30.2
	4-6	56	394.0	0.19	0.02	47.5	162	319.6	0.11	0.01	34.0
	6-8	56	568.6	0.27	0.04	47.7	162	524.4	0.28	0.02	54.3
	8-10	56	757.2	0.26	0.04	34.6	162	785.1	0.30	0.02	37.8
	10-12	54	995.3	0.27	0.04	27.6	162	1049.8	0.27	0.02	26.2
N-1	0-2	44	125.4	0.06	0.01	48.3	88	37.4	0.02	0.00	53.1
	2-4	44	321.5	0.13	0.02	39.6	88	287.5	0.10	0.01	33.2
	4-6	44	440.5	0.17	0.03	39.5	88	499.1	0.15	0.02	29.8
	6-8	44	571.6	0.24	0.04	41.7	88	669.2	0.19	0.02	28.2
	8-10	44	670.7	0.33	0.05	49.8	88	879.2	0.23	0.02	26.6
	10-12	44	844.7	0.36	0.05	42.1	88	1121.1	0.26	0.03	23.6
S-1	0-2	41	112.1	0.05	0.01	42.4	87	33.1	0.02	0.00	47.9
	2-4	41	257.8	0.10	0.02	40.3	87	237.7	0.07	0.01	29.1
	4-6	41	360.7	0.18	0.03	51.1	87	335.9	0.11	0.01	33.5
	6-8	41	538.4	0.30	0.05	55.0	87	487.8	0.20	0.02	41.9
	8-10	41	782.0	0.36	0.06	45.8	87	778.0	0.26	0.03	33.5
	10-12	39	981.7	0.29	0.05	29.5	87	1047.7	0.29	0.03	27.7

Table 3.7b. **Comparisons of duff bulk densities for the year 2004 at different validation site locations and soil depths, showing the location, depth (cm), number of samples (N), mean bulk density (kg m^{-3}), standard deviation (SD), standard error (SE), and coefficient of variation (CV) of sub-samples.**

		2004				
Location	Depth	N	Mean	SD	SE	CV
Beaver	0-2	53	29	0.01	0.00	46.4
	2-4	53	325	0.17	0.02	53.8
	4-6	53	533	0.25	0.03	46.7
	6-8	53	722	0.27	0.04	38.0
	8-10	53	916	0.22	0.03	24.5
	10-12	53	1206	0.23	0.03	18.9
Goose	0-2	53	33	0.02	0.00	70.4
	2-4	53	257	0.10	0.01	38.4
	4-6	53	450	0.19	0.03	42.9
	6-8	53	749	0.26	0.04	34.8
	8-10	53	1028	0.34	0.05	32.6
	10-12	53	1274	0.32	0.04	25.2
Tawayik	0-2	51	26	0.01	0.00	47.9
	2-4	51	194	0.06	0.01	31.9
	4-6	51	347	0.13	0.02	38.5
	6-8	51	694	0.28	0.04	40.7
	8-10	51	1000	0.34	0.05	33.7
	10-12	51	1281	0.23	0.03	18.0

Table 3.8a. Results of the calibration site Tukey tests on season X topographic position interactions for DMC. Comparisons are based on the natural log (ln) of moisture loss from the non-linear moisture loss equation versus DMC.

		Spring				Summer				Fall			
Season[1]		C-1	S-1	N-1	Sprall	C-1	S-1	N-1	Summ-all	C-1	S-1	N-1	Fallall
Spring	C-1		ns[2]	ns	ns	*[3]	*	*	*	*	*	*	*
	S-1			*	ns	*	*	*	*	*	*	*	*
	N-1				ns	ns	ns	*	*	ns	*	*	*
	Sprall					*	*	*	*	*	*	*	*
Summer	C-1						ns	*	ns	ns	*	*	ns
	S-1							*	ns	ns	*	*	ns
	N-1								*	ns	*	ns	ns
	Summall									ns	*	*	ns
Fall	C-1										ns	ns	ns
	S-1											ns	ns
	N-1												ns
	Fallall												

[1] Seasons include spring (April and May), summer (June through August) and fall (September and October).
[2] Not significant, P>0.05
[3] Significant, P<0.05

Table 3.8b. Results of the calibration site Tukey tests on season X topographic position interactions for DC. Comparisons are based on the natural log (ln) of moisture loss from the non-linear moisture loss equation versus DC.

		Spring				Summer				Fall			
Season[1]		C-1	S-1	N-1	Sprall	C-1	S-1	N-1	Summ-all	C-1	S-1	N-1	Fallall
Spring	C-1		ns[2]	*[3]	ns	*	*	*	*	*	*	*	*
	S-1			*	ns	*	*	*	*	*	*	*	*
	N-1				*	ns	ns	*	ns	ns	*	*	ns
	Sprall					*	*	*	*	*	*	*	*
Summer	C-1						ns	*	ns	ns	*	*	ns
	S-1							*	ns	ns	*	*	ns
	N-1								*	ns	ns	ns	ns
	Summall									ns	ns	ns	ns
Fall	C-1										ns	ns	ns
	S-1											ns	ns
	N-1												ns
	Fallall												

[1] Seasons include spring (April and May), summer (June through August) and fall (September and October).
[2] Not significant, P>0.05
[3] Significant, P<0.05

Table 3.9a. Calibration site model equations between moisture content and DMC developed from different seasons and topographic positions.

Site	Linear Analysis Equation[2]	N	R^2	RMSE	P>t	Transformed Non-linear Moisture Equation[1]
DMC Nat std						**MC=exp((244.7-DMC)/43.4)+20**
Spring						
C-1	y=-0.0117x+5.0304	62	0.59	0.26	0.0008	MC=exp((429.9-DMC)/85.47)+20
S-1	y=0.0004x+4.6647	57	0.00	0.37	0.9221	MC=exp((11.662-DMC)/2500)+20
N-1	y=-0.0072x+4.5018	57	0.37	0.25	0.0163	MC=exp((625.25-DMC)/138.89)+20
C-1/N-1	y=-0.0096x+4.7718	119	0.38	0.32	0.0003	MC=exp((497.06-DMC)/104.17)+20
Allspr	y=-0.0062x+4.7323	176	0.16	0.37	0.0072	MC=exp((763.27-DMC)/161.29)+20
Summer						
C-1	y=-0.0136x+4.7033	106[3]	0.67	0.31	<.0001	MC=exp((345.83-DMC)/73.53)+20
S-1	y=-0.0141x+4.8499	45	0.77	0.26	<.0001	MC=exp((343.96-DMC)/70.92)+20
N-1	y=-0.0226x+4.7464	44	0.87	0.30	<.0001	MC=exp((210.02-DMC)/44.25)+20
C-1/S-1	y=-0.0138x+4.7495	151	0.69	0.29	<.0001	MC=exp((344.17-DMC)/72.46)+20
Allsumm	y=-0.0157x+4.7461	195	0.65	0.37	<.0001	MC=exp((302.3-DMC)/63.69)+20
Fall						
C-1	y=-0.0036x+4.0699	31	0.46	0.32	0.0636	MC=exp((1130-DMC)/277.78)+20
S-1	y=-0.0092x+4.1093	31	0.92	0.31	0.0105	MC=exp((446.66-DMC)/108.69)+20
N-1	y=-0.0039x+3.7324	30	0.80	0.22	0.0411	MC=exp((957.02-DMC)/256.41)+20
Allfall	y=-0.0057x+4.1321	92	0.68	0.32	0.0116	MC=exp((724.93-DMC)/175.44)+20
All Season						
All C-1	y=-0.0095x+4.6021	199	0.47	0.41	<.0001	MC=exp((484.43-DMC)/105.26)+20
All S-1	y=-0.011x+4.8004	133	0.53	0.48	<.0001	MC=exp((436.4-DMC)/90.91)+20
All N-1	y=-0.0097x+4.3339	131	0.46	0.49	<.0001	MC=exp((446.79-DMC)/103.1)+20
Allcal	y=-0.01x+4.5831	463	0.45	0.47	<.0001	MC=exp((458.31-DMC)/100)+20

[1] Standard non-linear transformation as per Van Wagner (1987).
[2] x = DMC and y = moisture content (%).
[3] Number includes calibration site samples from ignition trials.

Table 3.9b. Calibration site model equations between moisture content and DC developed from different seasons and topographic positions.

Site	Linear Analysis Equation[3]	N	R^2	RMSE	P>t	Transformed Non-linear Moisture Equation[1]
DC Nat std						**Q=800/exp(DC/400)[2]**
Spring						
C-1	y=0.0007x+4.6462	62	0.03	0.28	0.5759	Q=104.19/exp(DC/1428.6)
S-1	y=0.0028x+4.1362	57	0.15	0.35	0.1744	Q=62.56/exp(DC/357.14)
N-1	y=-0.0017x+4.7798	57	0.14	0.24	0.1784	Q=119.08/exp(DC/588.2)
C-1/S-1	y=0.0016x+4.4369	119	0.07	0.30	0.1579	Q=84.5/exp(DC/625)
Allspr	y=8.02X10-6x+4.7465	176	0.00	0.17	0.9937	not significant
Summer						
C-1	y=-0.0021x+4.9365	106	0.24	0.32	0.0040	Q=139.28/exp(DC/476.19)
S-1	y=-0.0021x+4.9538	45	0.35	0.15	0.0343	Q=141.71/exp(DC/476.19)
N-1	y=-0.0025x+4.6429	44	0.33	0.19	0.0409	Q=103.84/exp(DC/400)
Allsumm	y=-0.0022x+4.8718	195	0.23	0.27	0.0001	Q=130.56/exp(DC/454.54)
Fall						
C-1	y=-0.0007x+4.3375	31	0.16	0.33	0.3276	Q=76.52/exp(DC/1428.57)
S-1	y=-0.0016x+4.6649	31	0.89	0.15	0.0165	Q=106.15/exp(DC/625)
N-1	y=-0.0008x+4.265	30	0.53	0.19	0.1633	Q=71.16/exp(DC/1250)
Allfall	y=-0.0012x+4.5602	92	0.41	0.27	0.0894	Q=95.6/exp(DC/833.33)
All Season						
All C-1	y=0.0005x+4.5369	199	0.01	0.36	0.0064	Q=93.4/exp(DC/2000)
All S-1	y=-0.0022x+5.1317	133	0.37	0.38	0.0002	Q=169.3/exp(DC/454.54)
All N-1	y=-0.0015x+4.5673	131	0.28	0.31	0.0014	Q=96.28/exp(DC/666.67)
Allcal	y=-0.0018x+4.8996	463	0.26	0.38	<.0001	Q=134.2/exp(DC/555.55)

[1] Standard non-linear transformation as per Van Wagner (1987).

[2] Q is moisture equivalent as per Van Wagner (1987), and is a logarithmic conversion of the soil moisture index from Turner (1966).

[3] x = DMC and y = moisture content (%).

Table 3.10. Validation goodness of fit (R^2), significance (Pr>t), mean absolute error (MAE) and modelling efficiency (EF) arising from the application of the four best-fit calibration models between DMC or DC and soil moisture, to the independent validation sites, either individually or collectively. Results indicate the relationship between actual and predicted soil moisture.

		Calibration Data Source															
		C1N1-Sprcal				Summcal				Fallcal				Allcal			
Validation Data	n	R^2	Pr>t	MAE	EF	R^2	Pr>t	MAE	EF	R^2	Pr>t	MAE	EF	R^2	Pr>t	MAE	EF
DMC																	
Beaver	53	0.606	<.0001	36.5	0.10	0.605	<.0001	32.3	0.37	0.605	<.0001	40.9	-0.02	0.606	<.0001	35.7	0.26
Goose	53	0.716	<.0001	35.8	0.43	0.735	<.0001	30.2	0.48	0.702	<.0001	44.8	-0.09	0.718	<.0001	34.9	0.35
Tawayik	51	0.779	<.0001	29.3	0.36	0.772	<.0001	34.1	-0.03	0.781	<.0001	54.2	-1.39	0.779	<.0001	37.3	-0.17
Allval[1]	157	0.556	<.0001	33.9	0.64	0.568	<.0001	32.2	0.62	0.546	<.0001	46.6	1.28	0.557	<.0001	35.9	0.74
Ave. Err.	157			33.9	0.38			32.2	0.36			46.6	-0.05			35.9	0.30
		C1S1-Sprcal				Summcal				Fallcal				Allcal			
DC																	
Beaver	53	0.024	0.4607	30.8	0.82	0.022	0.4771	35.5	0.78	0.025	0.4497	31.4	0.82	0.023	0.4661	39.4	0.72
Goose	53	0.339	0.0023	34.8	0.21	0.337	0.0023	31.3	0.22	0.340	0.0022	34.0	0.08	0.338	0.0023	32.9	0.24
Tawayik	51	0.378	0.0014	41.3	-1.56	0.378	0.0014	25.0	-0.07	0.378	0.0014	29.8	-0.55	0.378	0.0014	20.7	0.23
Allval	157	0.132	0.0015	35.6	1.29	0.127	0.0018	30.6	0.88	0.134	0.0013	31.8	0.97	0.130	0.0016	31.0	0.90
Ave. Err.	157			35.6	0.19			30.6	0.45			31.8	0.33			31.0	0.52

[1] All validation data (Allval) includes Beaver, Goose and Tawayik combined.

Table 3.11. Validation site model equations between predicted moisture content and DMC/DC, as derived from various calibration models developed from different seasons and topographic positions.

Site	Linear Analysis Equation[2]	N	R^2	RMSE	P>t	Transformed Non-linear Moisture Equation[1]
DMC Nat Std						**MC=exp((244.7-DMC)/43.4)+20**
Beaver	y=-0.0871x+6.0576	53	0.74	0.68	<.0001	MC=exp((69.55-DMC)/11.48)+20
Goose	y=-0.0364x+5.3656	53	0.87	0.35	<.0001	MC=exp((147.41-DMC)/27.47)+20
Tawayik	y=-0.0219x+5.2827	51	0.86	0.20	<.0001	MC=exp((241.22-DMC)/45.66)+20
All Val	y=-0.0337x+5.2126	157	0.47	0.74	<.0001	MC=exp((154.68-DMC)/29.67)+20
DC Nat Std						**Q=800/exp(DC/400)[3]**
Beaver	y=-0.0024x+4.5587	53	0.07	0.57	0.1912	Q=95.46/exp(DC/416.67)
Goose	y=-0.0046x+5.5151	53	0.45	0.43	0.0002	Q=248.41/exp(DC/217.39)
Tawayik	y=-0.0025x+5.1144	51	0.36	0.27	0.0019	Q=166.4/exp(DC/400)
All Val	y=-0.0026x+4.9045	157	0.16	0.50	0.0005	Q=134.9/exp(DC/384.62)

[1] Standard non-linear transformation as per Van Wagner (1987).
[2] x = DMC and y = moisture content (%).
[3] Q is moisture equivalent as per Van Wagner (1987) and is a logarithmic conversion of the soil moisture index from Turner (1966).

Table 3.12. Correlation coefficients among calibration site duff layer (F and H horizon) characteristics, including moisture content (mc), bulk density (bd) and inorganic content (inorg) for each of 2003 and 2004.

		2003 (n=56)		2004 (n=60)	
Duff Layer	Comparison	r	Pr>r	r	Pr>r
F-horizon	mc vs. bd	-0.076	0.5796	-0.673	<.0001
	mc vs. inorg	-0.343	0.0097	-0.617	<.0001
	inorg vs. bd	0.790	<.0001	0.870	<.0001
H-horizon	mc vs. bd	0.934	0.4936	-0.803	<.0001
	mc vs. inorg	-0.404	0.0020	-0.791	<.0001
	inorg vs. bd	0.338	0.0107	0.838	<.0001

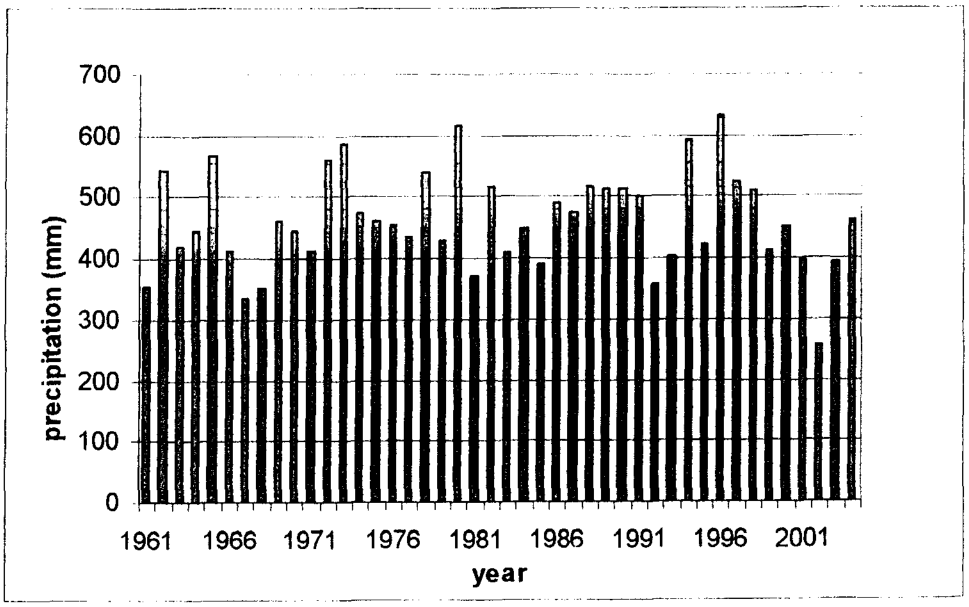


Figure 3.2. Edmonton International Airport (YEG) yearly precipitation (Jan-Dec) from 1961 to 2004. The 44 year average precipitation amount for the station is 461.0mm. The 44 year average for April to October is 373.3mm.

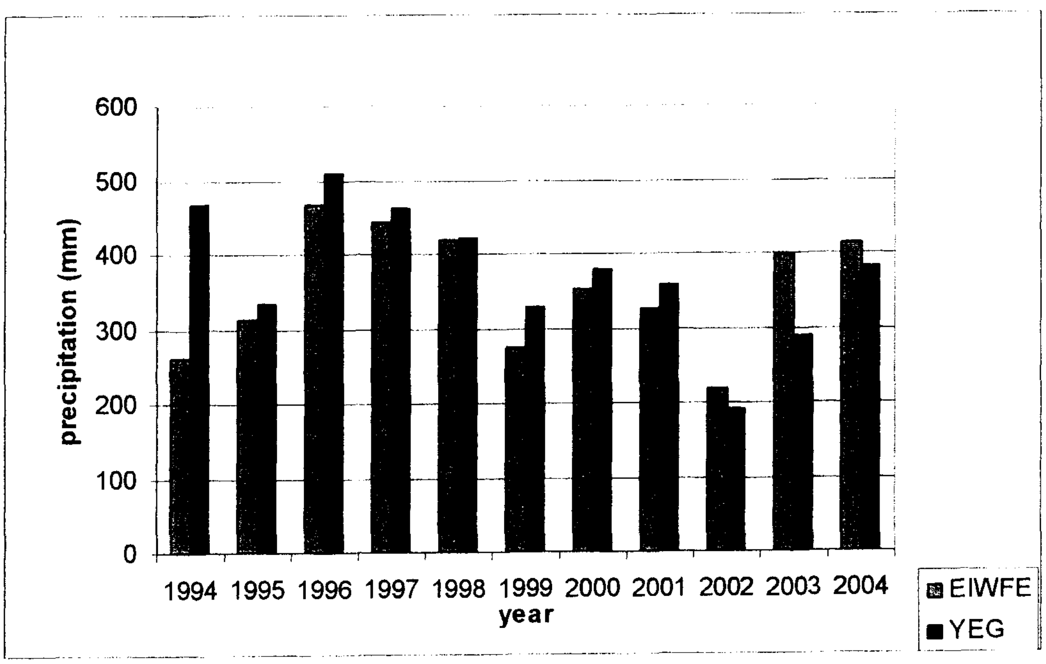


Figure 3.3. Comparison of April to October fire season precipitation between Edmonton International Airport (YEG; 11 year ave. = 374.2mm), and the Park station (EIWFE; 11yr ave. = 353.5mm) between 1994 and 2004.

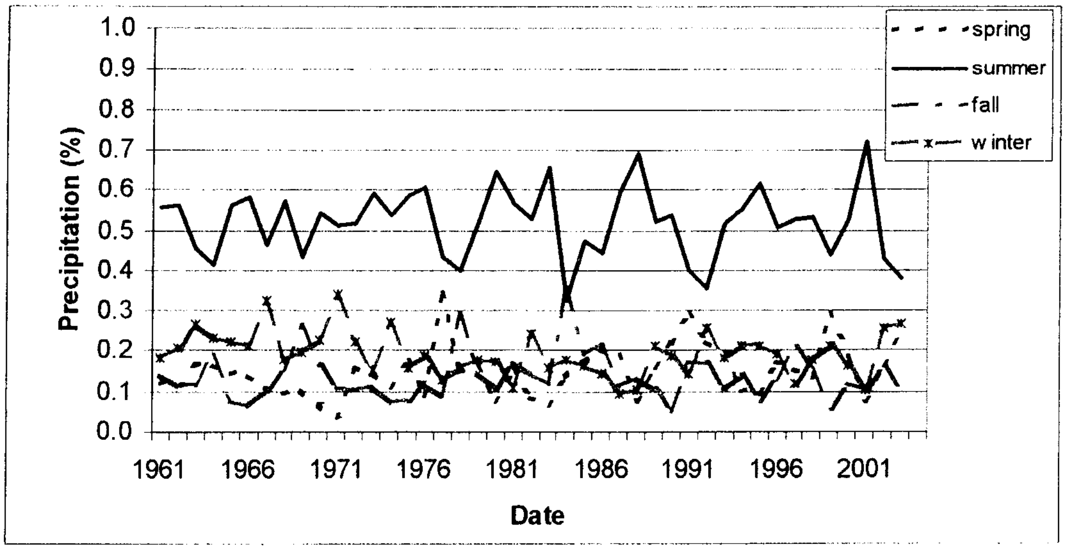
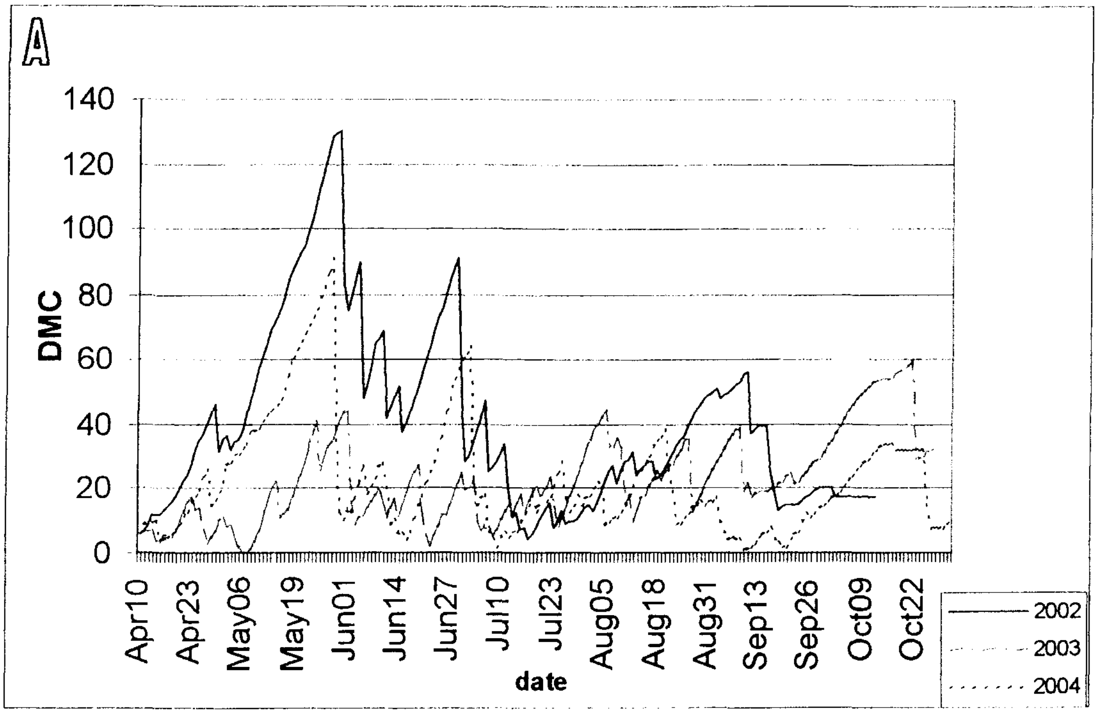


Figure 3.4. Yearly precipitation amounts expressed as a percent of yearly totals for Edmonton International Airport (YEG), from 1961 to 2004. Spring= April and May, summer= June through August, fall= September and October and winter= November through March.



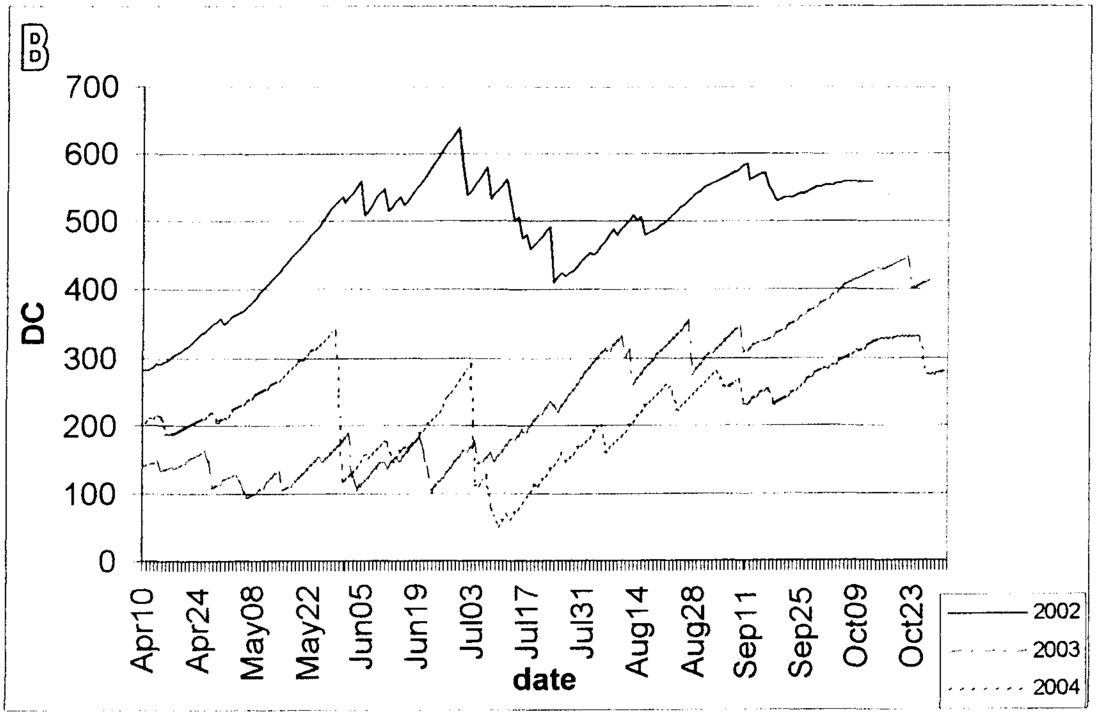


Figure 3.5. Comparisons of DMC (A) and DC (B) values over the fire season of April to October for the Elk Island National Park station (EIWFE) in each of the years 2002, 2003 and 2004.

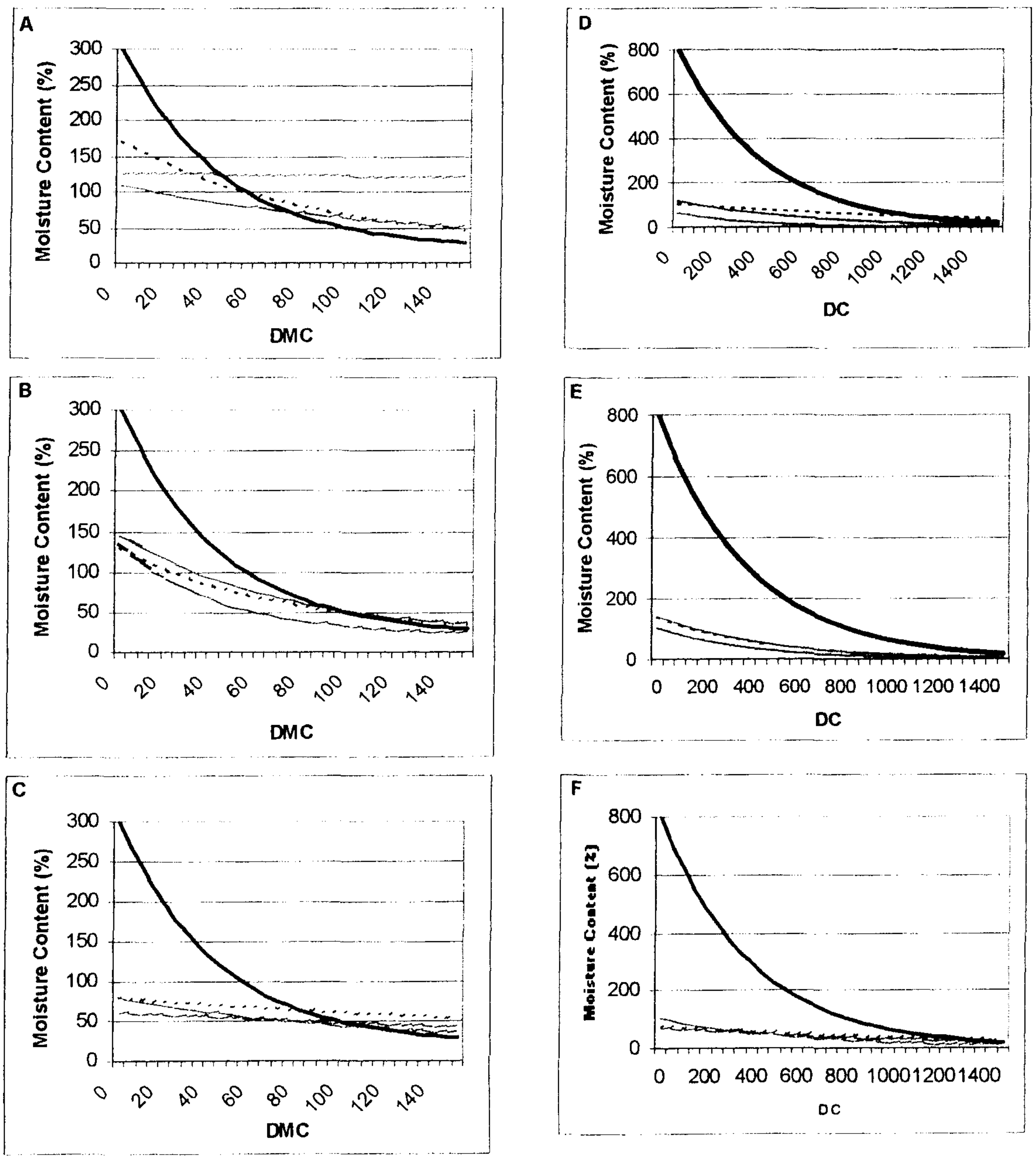


Figure 3.6. Comparisons of moisture relationship models by season and topographic position versus the national standard equation (nat std) and DMC spring, summer and fall (A, B and C), or DC spring, summer and fall (D, E, and F). C1 = blue dot line, S1 = red dot-dash line, N1 = blue double dot-dash line and national standard = solid black line.

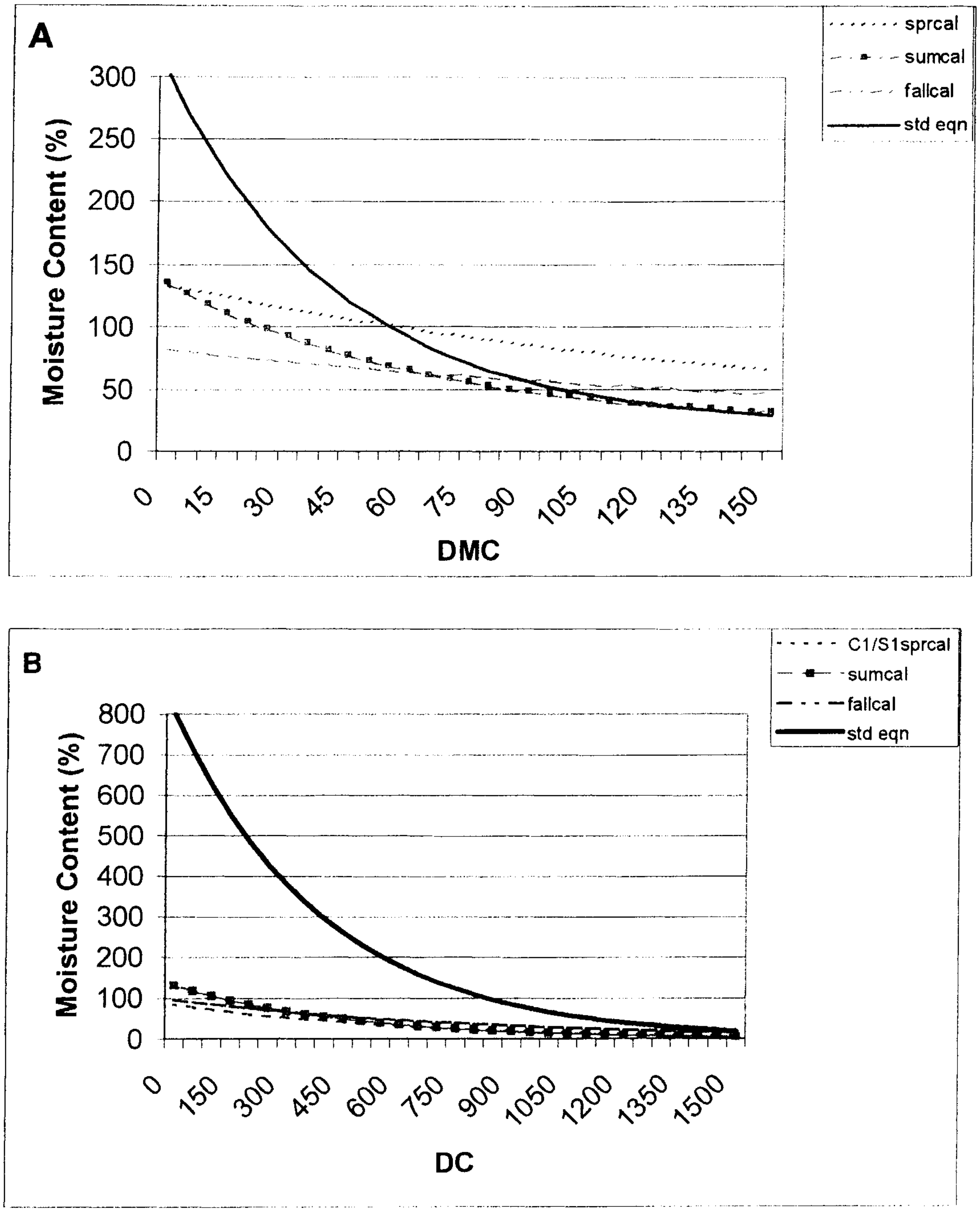


Figure 3.7. Comparisons of modelled relationships between predicted moisture and DMC (A) or DC (B) using the best-fit equations (by season of sampling) obtained from the calibration site.

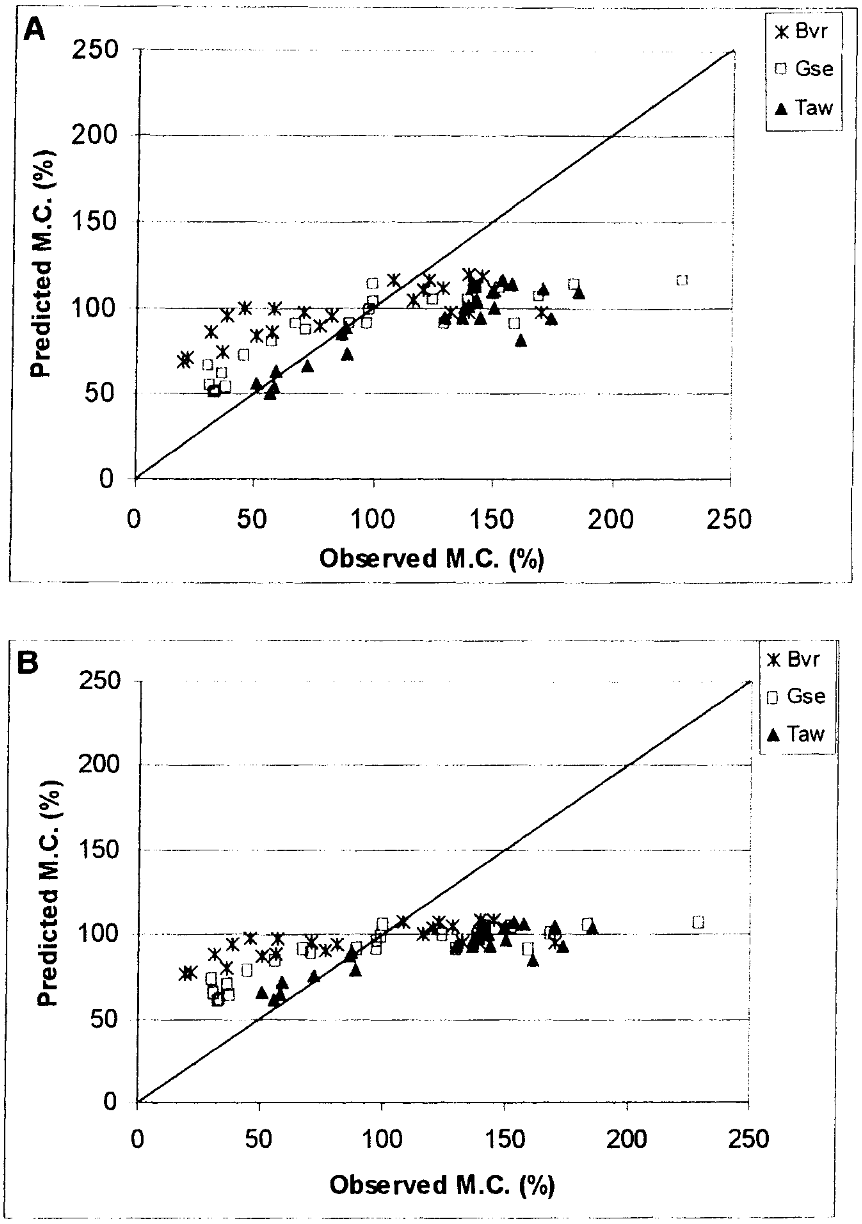
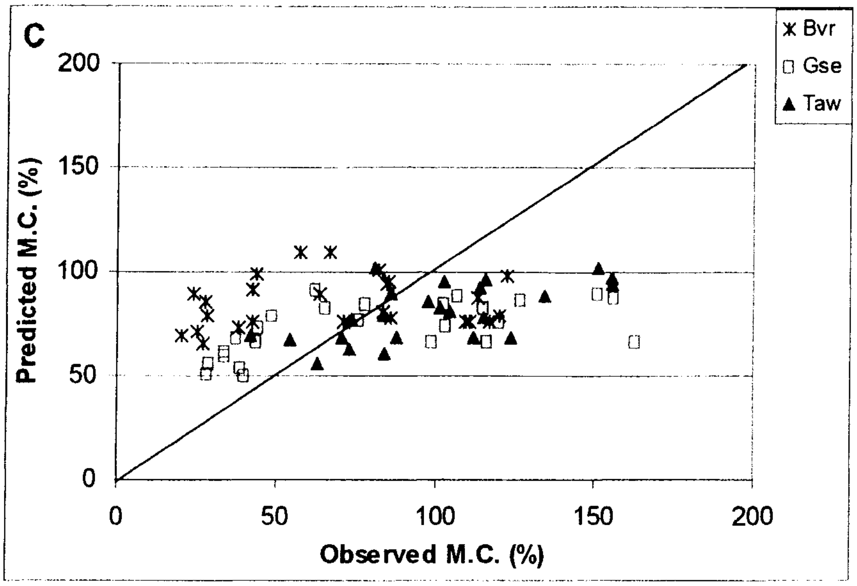


Figure 3.8a. Comparisons of observed moisture content for all validation plots versus model predictions. Predicted values are based on DMC data using the summer calibration equation (A), or the all calibration equation (B).



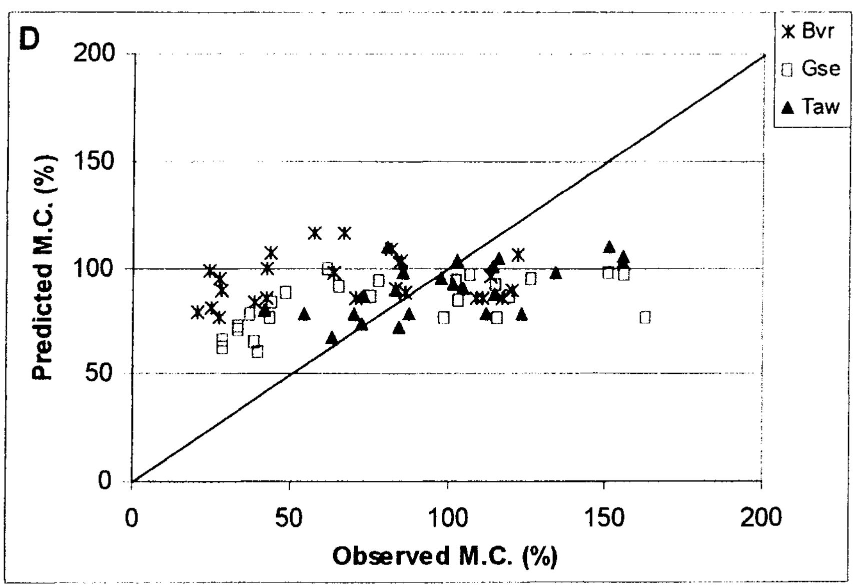


Figure 3.8b. Comparisons of observed moisture content for all validation plots versus model predictions. Predicted values are based on DC data using the summer calibration equation (C) or the all calibration equation (D).

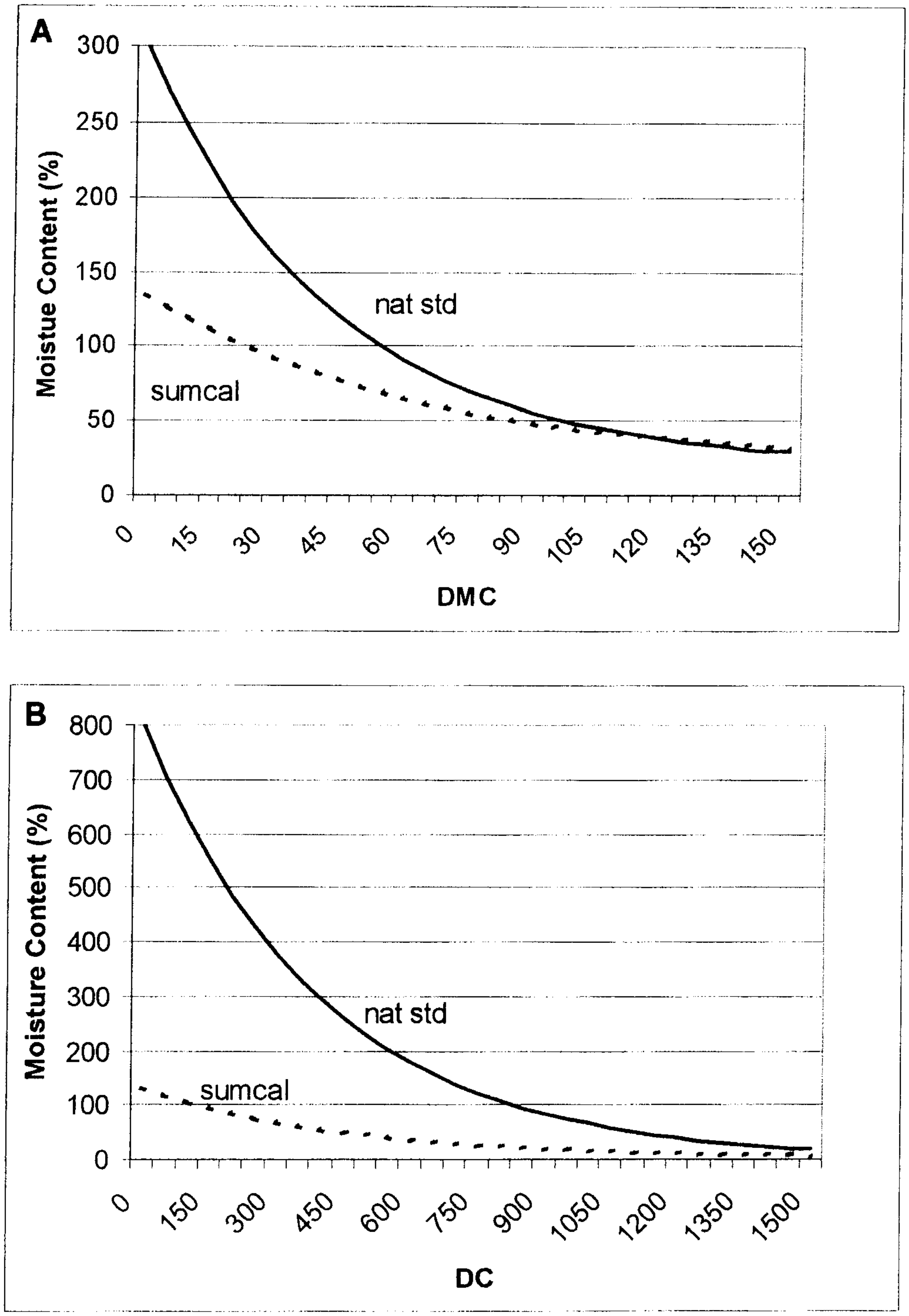


Figure 3.9. Summer calibration (sumcal) moisture relationship plotted in comparison to the national standard (nat std) equation for each of DMC (A) and DC (B).

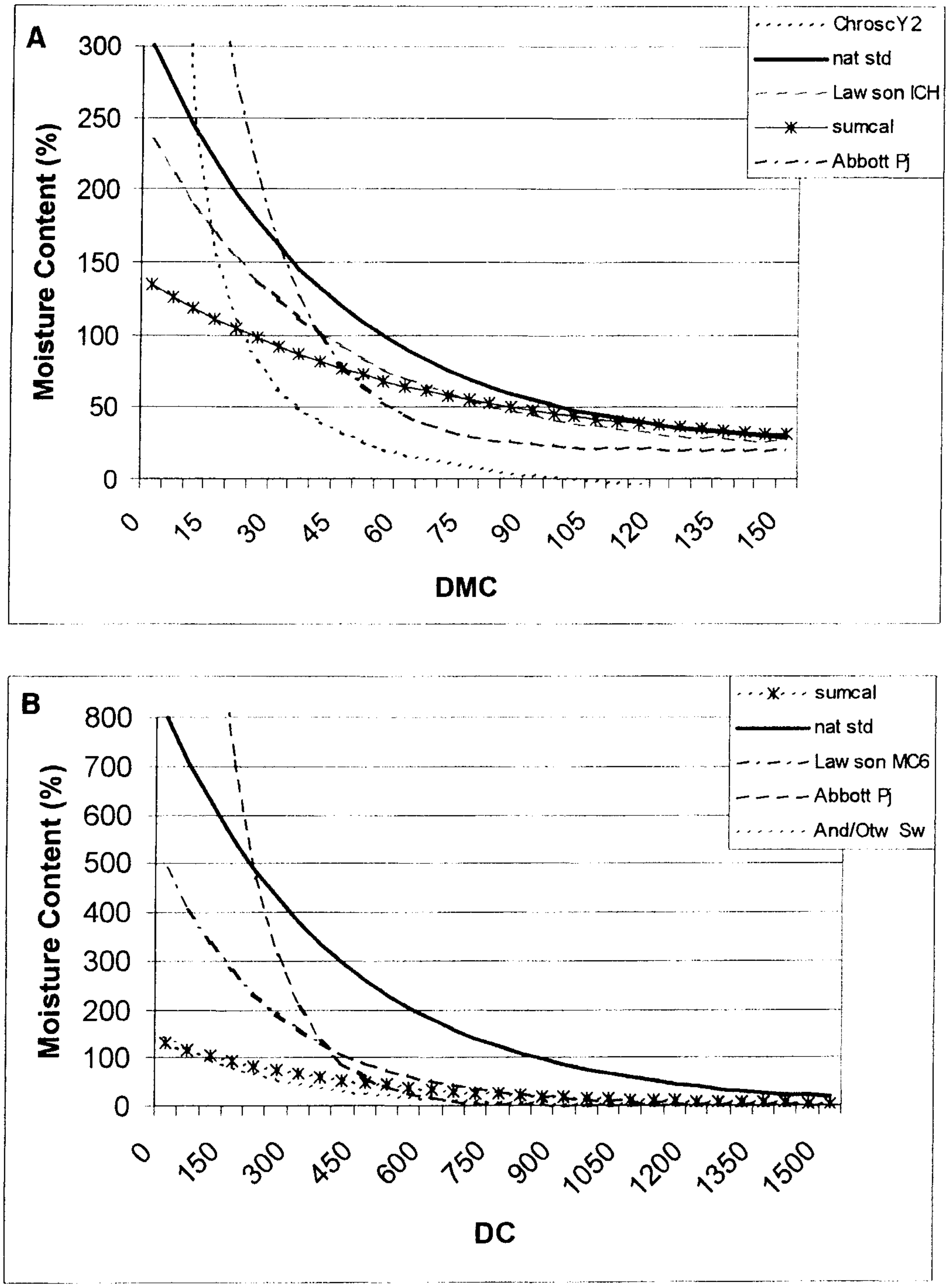


Figure 3.10. Comparison of moisture relationships in the DMC (A) and DC (B) layers in EINP with that modelled using the all summer (sumcal) and the national standard (nat std) equation, as well as those from other studies. [Lawson = Lawson et al. (1997b), MC-6 equation; ChroscY2 = Chrosciewicz (1989); Lawson ICH = Lawson et al. (1997a); And/Otw SW = Anderson and Otway 2003; Abbott Pj = Abbott et al. (2004)].

Plate 3.1. Luvisolic soil profile from the C1 calibration site.

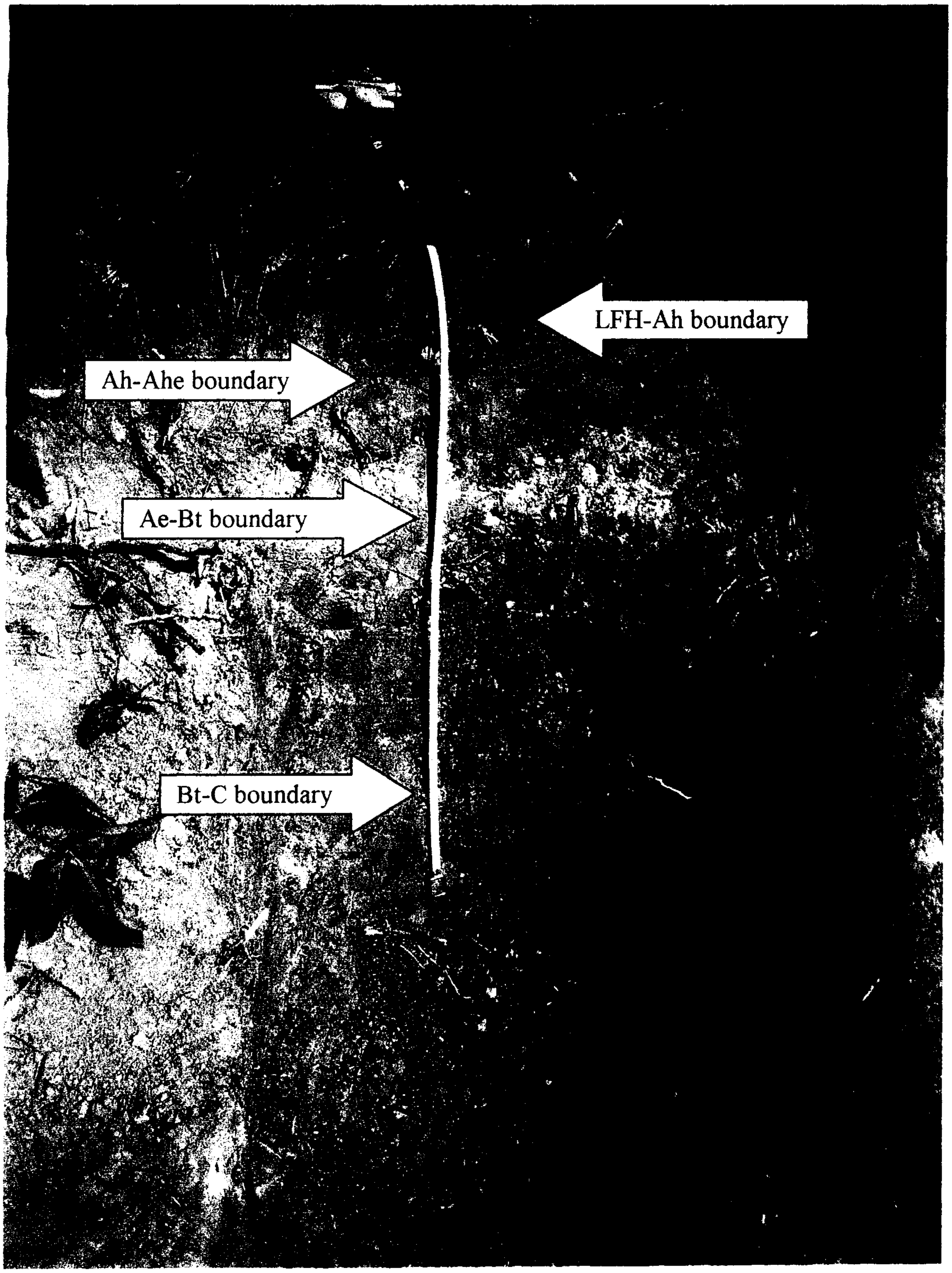
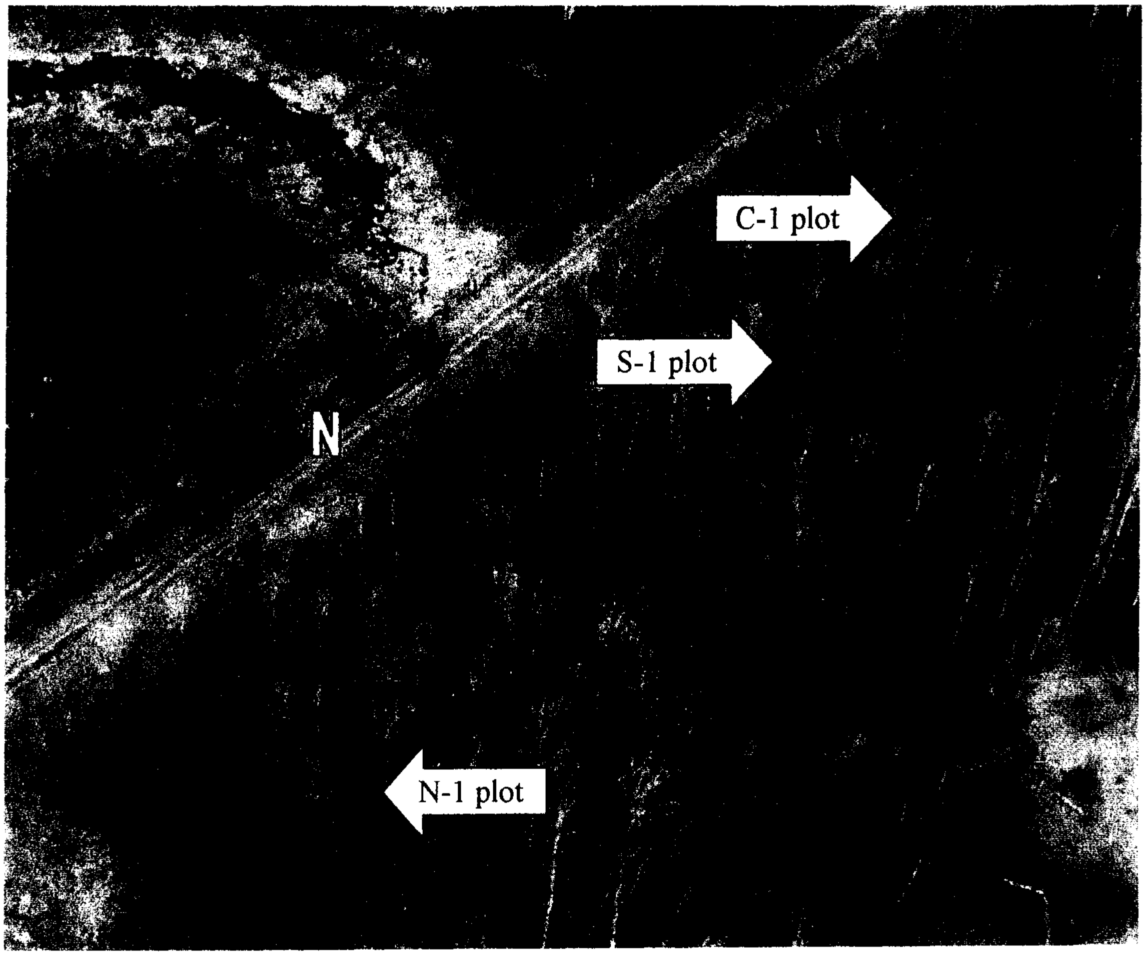


Plate 3.2. Aerial view of calibration plot area, May 2nd, 2004.



Note: moisture exclusion tarps are blue.

Chapter 4. PREDICTING GROUND FIRE POTENTIAL IN ASPEN COMMUNITIES

Abstract

The process of fire, in conjunction with herbivory and flooding, are some of the key drivers in the ecosystem in Elk Island National Park. The use or non-use of fire is one of the tools at the disposal of Park staff. Clearly understanding the role of fire in aspen within the Park would directly contribute towards improving park management.

Duff moisture conditions, under which ground fire may start, persist or expand in aspen (*Populus tremuloides* Michx.) forests are presented. Ground fire is the smouldering phase of combustion that persists long after the flaming fire front has passed over an area. Smoke generation and plant community re-growth may be affected by severe, deep burning ground fires. Different topographic positions, plant communities and seasons were factored into the design for this research. The Duff Moisture Code and Drought Code indices of the Canadian Forest Fire Weather Index System were calculated and factors including duff moisture content, bulk density and inorganic content were measured. New probability of ignition non-linear equations were derived for the aspen forest (D-1) fuel type.

Fire research activities continue to include refinement of the FWI/FBP system components, including those applicable to aspen dominated forest types. This research will contribute to the national Fire Weather Index System and to the understanding of ground fire effects under certain soil moisture conditions in Elk Island National Park. With increased knowledge on aspen ground fire potential, fire management capability will be enhanced.

4.1. Introduction

The Canadian Forest Fire Danger Rating System (CFFDRS) is the nationally accepted standard means of determining forest fire behaviour in Canada (Stocks et al. 1989). Within this rating system is the Canadian Forest Fire Behavior Prediction System (FBP) (Forestry Canada Fire Danger Group 1992), which is used to provide quantitative estimates of fire activity and growth, and the Canadian Forest Fire Weather Index System (FWI) (Van Wagner 1987), used to calibrate individual parameters related to forecasted fire weather. The link between fire weather and growth of an actual fire is the persistence of a fire start after ignition. A high probability of survival, or ignition as it is commonly referred to, may result in persistent ground fire.

The duff moisture code (DMC) and drought code (DC) are the numerical values used in the FWI system to represent soil duff (i.e. LFH) moisture dryness (Van Wagner 1987), and therefore, its potential to influence fire behaviour. Changes in the DMC track moisture in the shallow duff or fibric soil horizon (F-layer), while the DC tracks the humus or deep duff soil layers (H-layer) as well as heavy downed woody materials. Both indices are determined at noon (standard time) each day during April to October from the standardized weather readings of temperature, wind speed, relative humidity and 24 hr precipitation (Figure 4.1). The DC also has a carry-over function, whereby precipitation received over the winter months influences the spring starting DC and hence, fire hazard conditions the following spring.

Both DMC and DC are re-calibrated annually beginning at 'start-up', three days after snow loss in spring, and are continually updated throughout the fire season until

October 31st or freezing conditions return (Turner and Lawson 1978). Snow loss is often followed by a period of cool, freezing conditions where very little duff moisture loss or frost release occurs. For this reason, the Park also waits until three days have elapsed with a recorded noon temperature of 12 °C (Turner and Lawson 1978) before calculating FWI indices. The method of calculating DMC and DC assumes forest soils dry exponentially in the absence of rainfall, loosing ⅔ of their moisture in 15 and 53 days, respectively. Conversely, the rate of moisture recharge is considered to decrease as duff layers become wetter, presumably due to soils approaching their maximum water holding capacity (Van Wagner 1970, 1987). The DMC and DC components of the FWI are the numerical values of most assistance to fire managers in assessing forest fuel dryness and associated fire risk.

The landscape of Elk Island National Park (EINP, or the Park) has evolved with fire and Parks Canada recognizes the need for adequate fire control capability, as well as the use of prescribed fire (Parks Canada 1994, 2005). Fire has been used periodically since 1979 on a prescribed basis in many areas of the Park (Alexander and Dubé 1983), although more recently, several wildfires have occurred in and around the Park (e.g. 2002 and 2004). In addition, recent periods of severe drought between 2000 and 2004 have produced conditions conducive to undesirable fire consequences in EINP and the surrounding area, including the risk of persistent ground fire. Fire occurrence under drought may threaten human safety, Park infrastructure, and have negative consequences on the areas ecosystems. As a result, forecasting the occurrence and persistence of ground fire is important to the effective management of this disturbance, be it wildfire or prescribed fire, and the conservation of Park resources.

EINP is dominated by trembling aspen (*Populus tremuloides* Michx.) forest. Although these communities may not burn as readily as other forest communities in the Boreal region (Peterson and Peterson 1992), ground fire may persist in this vegetation type under dry conditions for extended periods (Lawson and Dalrymple 1996a). These fires can produce large quantities of smoke, and through vegetation disturbance, nutrient leaching or erosion, create sites conducive to non-native plant invasions (Van Wagner and Methven 1980; Lawson and Dalrymple 1996a; Achtemeier 2001). Severe or deep burning fires have the greatest potential to cause plant community compositional changes and/or variation in vegetation re-growth.

There are currently modelled equations correlating the probability of ignition and DMC/DC for some boreal forest types using experimental commercial peat moss fuel types (Frandsen 1987, 1991, 1997; Hartford 1989; Lawson et al. 1997b). In Frandsen (1987), peat moss was utilized with increasing amounts of inorganic clay as the burn substrate sampled. Hartford (1989) extended this study with the addition of variable organic bulk densities within the samples, while Sphagnum moss was utilized as the sample material in Frandsen (1991). In Lawson et al. (1997b) and Frandsen (1997), efforts were extended to include representative fuel types collected from various field sites in Alaska and the continental USA. In these studies, samples were placed in an open-ended box and ignited by exposure to a heated coil under controlled laboratory conditions. A limited number of field trials conducted by Lawson et al. (1997b) involved removing a core of forest floor duff with a cordless drill and filling the space with pre-ignited, smouldering peat moss.

In this study, the probability of sustained combustion (i.e. ignition) was examined for the forest duff (DMC/DC) layers in aspen forests of Elk Island National Park, with ignition tests conducted *in-situ*, as per the Lawson et al. (1997b) field trials. Combustion may or may not persist depending upon characteristics of the duff, including duff moisture content, inorganic composition, organic bulk density and interactions among them (see Ho: 3 in Figure 4.1). This study also determined whether the indices of modeled DMC/DC predict ignition in D-1 aspen forest equal to that of duff moisture, with or without soil bulk density and inorganic content considerations. To date, these relationships are not known for aspen. While there is also a theoretical ignition survival curve for aspen ground fire versus moisture content and DC, it remains untested (Anderson 2000). Empirical data on the probability of ignition will contribute directly to the FWI and FBP systems for predicting fire occurrence and behaviour, and therefore, to the effective management of this important ecological process.

4.2. Materials & Methods

4.2.1. Study Area

EINP is situated 35 km east of Edmonton in central Alberta (Latitude 53° and Longitude 112° approximately), at the north end of the Beaver Hills. The Beaver Hills were formed by the Cooking Lake dead-ice moraine southeast of Edmonton and are elevated 10 to 30 m above the surrounding plains, which is sufficient to place the area within the Lower Boreal Mixedwood ecoregion (Strong and Leggat 1991). The landscape of the Park is distinctly undulating with 5 to 10 m relief, resulting in a diverse mix of plant communities. The dominant vegetation of uplands is trembling aspen forest, although open grasslands, shrublands, and white spruce forest [*Picea glauca* (Moench) Voss] are interspersed throughout the area (Polster and Watson 1979). Six different aspen plant communities have been identified within the Park (Best and Bork 2004). Lowlands are dominated by either aquatic environments, or where sufficiently drained, riparian meadows, fens or bogs.

The climate of the area is cool-continental, with long, cold winters and short, warm summers (Bowser et al. 1962). Annual precipitation rates over the last 44 yrs at the Edmonton International Airport, the closest long-term weather station, indicates an average yearly rainfall of 460 mm (Figure 4.2). Precipitation has ranged from a low of 257 mm in 2002 to a high of 630 mm in 1996. April to October (inclusive) precipitation has accounted for 81% of the yearly totals (Parks Canada 2004c), and has ranged from 220 to 470 mm over the last 10 yrs (see Figure 4.3). Mean growing season temperatures vary between a low of 5 °C in April to a high of 17 °C in midsummer (Rogeau 2004a), while the frost-free period is approximately 100 days (Crown 1977).

The calculated DMC/DC codes for EINP reflect the varied precipitation received during the fire season (April to October) over the last three years, and interannual variation during that time. The codes demonstrate that 2002 was the driest year, particularly May to June (see Figure 4.4). Both DMC and DC in the Park have fluctuated considerably over the 2002 to 2004 seasons, remaining unseasonably dry from 2002 to 2003 and continuing dry until late May of 2004, when conditions ameliorated.

Dominant soils found throughout the Park are Dark Gray or Orthic Gray Luvisols (Soil Classification Working Group 1998) under forest vegetation (Crown 1977). Low lying areas are dominated by Humic Luvic Gleysols or Rego Gleysols.

4.2.2. Experimental Approach

The experimental approach used in this study was to develop and test empirical relationships between DMC/DC and experimental ignition trials from various sites throughout the Park. A main calibration site was utilized, involving intensive, repeated sampling and testing within one plant community to establish a detailed profile of burning success under various DMC/DC levels. The calibration site was chosen close to road access to ensure frequent and rapid sampling prior to and after precipitation events (i.e. at many DMC/DC levels), and to facilitate ease of extinguishing experimental fires. Sampling of the site was performed both within *in-situ* soils as found within each plot, as well as within 'rainfall exclusion' treatment areas, designed to exclude rain and simulate a drought effect (Van Wagner 1970). Rainfall exclusion areas were 3 x 3 m in size, and tarped 1 m above ground to eliminate rainfall and soil moisture recharge. This was done to ensure that low moisture levels (i.e. high DMC/DC values) were represented in at least a portion of the plots where test burns were conducted.

Following initial calibration of the DMC/DC codes to the primary ignition plots, the relationships between ignition and DMC/DC were subsequently tested on independent replicated plots within each of three main aspen plant community types found throughout EINP (Best and Bork 2004). This 'validation' procedure was used to test the ability of the DMC/DC relationships derived from the calibration area, to reliably predict the probability of ignition elsewhere in the Park.

4.2.3. Field Sampling

All plots (calibration and validation) were 20 x 20 m in size, permanently marked with metal pegs at the corners, their location recorded using GPS, and photographed. Plots at the calibration site were sampled every 2 to 5 days throughout the summer of 2004. The calibration area was situated within a plant community type encompassing traits similar to the two most prevalent community types previously documented (Types D and E; see Best and Bork 2004): these two types account for approximately 70% of all aspen communities previously investigated within the Park. On average, there were two ignition tests conducted within each plot on each day of sampling.

Validation plots were randomly selected from a series of 96 Permanent Sample Plots (PSPs) already situated on forested uplands throughout the Park as part of the long-term vegetation monitoring program. Previous studies have indicated these PSPs represent six different aspen community types (Best and Bork 2004), including three relatively common types. Community types differ primarily by overstory successional stage, understory plant (herb and shrub) composition, canopy closure and overall productivity. For each of the three aspen community types where the calibrated relationships between DMC/DC and ignition were subsequently tested, four plots (i.e. PSPs) were selected using a stratified random approach (n = 12 total). Validation plot selection required a stratified random approach to ensure the plots utilized were relatively accessible to facilitate repeated duff moisture sampling and test burning, and had topographic aspects that were generally flat to less than 5% in slope gradient. Replicates were randomly selected from a representative group of existing PSPs already in place and known to belong to each aspen community type (Best and Bork 2004). Within each community type, two of the four were intensively sampled throughout the summer of 2004 while another two were sampled only once in mid-summer. See Appendix 1 and 2 for specific plot locations.

Rainfall exclusion treatment areas were established in the calibration and validation plots (one per community) in 2004. Tarps were stretched over understory shrubs, and tied to trees or anchored to the ground at the corners. Air movement and transpiration by plants remained possible under the tarps. Regular inspections of tarps were made to prevent leakage or damage (see Plate 12.1). The calibration and Beaver tarps were compromised by heavy rainfall and subsequent moisture creep during July 26 to 27th, 2004. After downpours on these dates, moisture appeared to infiltrate downwards through the duff layer to mineral soil, then move laterally under the tarps through the deeper soil layers, confounding moisture readings taken under the tarps. Data collected from these dates or shortly thereafter were considered confounded and thus excluded from analysis. New tarps were deployed after these precipitation events.

Ignition tests occurred throughout the months of May to August, and occurred on a schedule frequent enough to coincide with relatively small increases in DMC (i.e., changes of five points) and the corresponding DC values. Sampling was further modified to include frequent enough sampling to record a series of ignitions ranging from 0 to 100% success at each site once or more over the course of the summer.

Weather parameters were measured at the Parks Canada Warden Office, 800 m from the calibration site, utilizing an Environment Canada, Campbell Scientific year-round weather station. Precipitation was also measured locally within the calibration area using two on-site manual rain gauges to ensure that shower-based precipitation events were accurately recorded. One gauge was placed in an area with no forest overstory while the second was situated directly within the forest understory of the calibration plot. Additionally, one on-site manual rain gauge was placed at each of the validation sites to track local precipitation. Fire indices were started three days after 'snow gone' was declared (i.e. >90% of ground was snow free) and after three days where noon M.S.T. temperatures of 12 °C were recorded, with corrections made to the drought code for overwinter adjustments (Turner and Lawson 1978). Fire weather indices (DMC/DC) were tracked for all locations using the Campbell station for temperature, wind speed and humidity, and modified at each site using precipitation readings from the portable rain gauges (Appendices 5 and 6).

4.2.4. Ignition Testing and Analysis

A few ignition trials occurred in the fall of 2003, while the majority of the field testing occurred during 2004. To calculate the probability of ignition and its response to fuel moisture, ignition trials were conducted similar to Lawson et al. (1997b). Core samples were taken in each plot as per Nalder and Wein (1998), using a cordless drill and cylindrical tube auger, 5 cm in diameter. Extracted core samples were separated into 2 cm increments and later oven-dried to determine the moisture content and bulk density of the DMC/DC layers (Figure 4.5). Core holes from the moisture sampling were then filled with smouldering peat moss. The peat used for ignition tests was commercially available bagged dry peat moss. The peat was placed into a frying pan, then set upon a small camp stove and heated until approximately ⅔ black in colour and actively smouldering, producing greyish-black smoke. The 5 cm diameter and 12 to15 cm deep hole generally required two cups of peat moss. The hot peat moss was then transported the final distance to the hole and placed carefully into the hole with a garden trowel. The hole was slightly overfilled to compensate for the eventual collapse of the mass as the last of the peat moss blackened. Test holes usually smoked for upwards of 2 to 5 min until a greyish ash covering formed.

It was not possible to check the burning success at repeated intervals within the first 2 hrs without influencing the oxygen supply and potentially confounding the ignition results. Thus, after the requisite 2 hr period, the peat was carefully scooped out using the garden trowel, making sure not to scrape the sides of the hole at the combustion interface. Bare fingers were promptly used to test the perimeter of the hole throughout the DMC (2 to 4 cm) and DC (4 to 6 cm) depths for evidence of persistent ignition after 2 hrs. The proportion of the cylindrical core still found smouldering corresponded to the reported percentage of success or probability of ignition after 2 hrs. A successful ignition after two hours was considered to be continuous or free ranging, and had a smouldering rate of $\geq$50% of the core, while a smouldering rate of $<$50% after two hours was declared unsuccessful. Where applicable the horizontal distance burned outwards from the core for the DMC layer was also measured to the nearest mm. These methods were consistently repeated and proved to be reliable for measuring smouldering combustion.

All extracted soil core samples were measured for duff moisture and bulk density. While rapid results are available using soil moisture meters (Martech 2002), there is no known published literature on the accuracy of this instrument. Ultimately, the proven method chosen here to assess moisture was that of Lawson and Dalrymple (1996a), which involves weighing moist samples at the lab, oven-drying, and subsequently reweighing to determine moisture content as follows:

Moisture content (%) = [(Wet Weight – Dry Weight)/ Dry Weight] X 100.

Bulk density calculations also followed Lawson and Dalrymple (1996a) using the following formula:

Bulk Density ($g{\cdot}cm^{-3}$) = Dry Sample Wt / Sample Volume.

These estimates of bulk density were then converted to $kg\ m^{-3}$ to ensure comparability to other studies.

A representative number of soil core samples were retained and bagged for inorganic content determination at a later date at the Canadian Forest Service lab in Edmonton. During 2003 and 2004, 380 and 360 samples, respectively (0 to12 cm), were assessed for inorganic content for both the DMC and DC layers (see Table 3.3). Inorganic content was determined using the methods of Kalra and Maynard (1991). Oven-dried samples were ground to a 2 mm size or less and 5 g of each sample was placed in a muffle furnace to oxidize organic matter for a minimum of 16 hrs. Soil organic matter was then calculated as follows:

Organic Matter (%) = [(Dry Sample Wt – Sample Wt After Ignition)/Dry Sample Wt] X 100.

The use of an elongated aluminum culvert-like cylinder protective sleeve above Ground (50 cm wide X 100 cm high) allowed the trials to be conducted safely in the forest floor area during periods of low soil moisture. The cylinder was dug in with a shovel to reach below the duff layers and extended significantly (~1m) above the ground foliage. This safety feature was not considered to influence data collection results, given that all the weather inputs (besides wind) were relatively unaffected by this sleeve. Wind is further not a required input in relation to DMC/DC moisture calculations. A total of 117 ignitions were carried out over the two years. In most areas the 'burning window', ranging from 0% to 100% success, was duplicated at least twice. In other words, ignition trials were timed to coincide with a wide range of indices in DMC/DC, including wet enough conditions to ensure an unsuccessful ignition, right through the drying phases of partial successes of ignition, and finally into very dry conditions where there was complete success in smouldering combustion around the core perimeter after 2 hrs.

4.2.5. Data Analysis

The variables utilized in all analyses included DMC/DC, duff moisture (as relative moisture in %), bulk density (in kg m^{-3}), and the inorganic content (measured as ash content in g, and reported as % inorganic). To arrive at one model comparing the probability of ignition success versus the corresponding observed DMC/DC, a non-linear procedure, PROC NLIN (SAS 2001) was used and fitted to a logistic model.

The first analysis involved comparing the probability of ignition versus the DMC or DC only on the calibration plots. Coefficients derived from initialization were run on SAS to check for convergence and derive the a and b values of the estimates. The a and b parameters from SAS were then inserted into a simple non-linear regression equation and run within Excel to generate the graphs. The standard formula used was:

P=exp(a+b*DMC/DC)/(1+exp(a+b*DMC/DC)),

where DMC/DC are Duff Moisture Code and Drought Code, respectively, and *a* is the intercept and *b* designates the slope of the regression coefficients. A total of 64 of the 117 ignition tests were done on the calibration plot. To confirm the relative accuracy of the calibration equations generated, a linear regression analysis was used to determine the goodness of fit (R^2) and other statistical parameters of the equations in relation to the actual probabilities observed.

The second analysis included development of a multiple non-linear regression model, which included DMC/DC, bulk density and inorganic content values, using the following formula (Lawson et al 1997b):

P=exp(a+b*DMC/DC+c*inorg+d*bd)/(1 +exp(a+b*DMC/DC+c*inorg+d*bd)),

where DMC/DC were Duff Moisture Code and Drought Code, respectively, *a* was the intercept and *b*,*c* and *d* designate the slopes as regression coefficients. For the multiple non-linear regression analysis (i.e. multiple equations), the simple equation coefficients *a* and *b* were utilized as a starting point, and when combined with the average inorganic content and actual bulk density measurements (as per Lawson et al. 1997b), used to initialize the approximate *c* and *d* coefficients. Only the DMC or DC value was changed at any one time to form the new multiple equation models that were checked against the results of the field trial ignition probabilities. Next, these approximate coefficient values were then inserted into SAS (SAS 2001) along with the actual data set of varying bulk density values and the different average inorganic values (i.e. values from the 2003 and 2004 inorganic content were averaged). Finally, the coefficients derived from above were run once more with the average bulk density and inorganic values in the multiple non-linear regression equation run with SAS. The multiple equations were also assessed for goodness of fit (R^2) and other statistical parameters through linear regression with the actual ignition probabilities measured.

The 53 validation site burns were subsequently tested against the calibration models by comparing actual validation ignition success rates (i.e. probability values) against the predicted results expected from the simple non-linear calibration models. Testing involved the evaluation of goodness-of-fit (R^2) and other statistical parameters obtained through the use of linear regression with PROC REG (SAS 2001). The 53 validation burns included 20 for Beaver, 14 for Goose and 19 in Tawayik.

Both the calculated moisture content and the corresponding DMC/DC codes were compared against observed ignition trial results through linear regression with PROC REG (SAS 2001) to determine any differences between predictive capabilities.

Burn charts were developed following the method of Frandsen (1987) in order to compare those results with the current study. Burn charts plotted the inorganic ratio and moisture ratio of the samples tested for ignition, including the fate of ignition test plots (e.g. burned vs. not burned). The equations presented in Anderson (2000) are;

$$R_\iota = f_\iota/(1-f_\iota) \text{ and}$$

$$R_m = mc/(1-f_\iota)$$

where R_ι is the inorganic ratio, Rm the moisture ratio, f_ι the ratio of inorganic mass over total dry mass, and mc is the moisture content. The variables of moisture ratio and inorganic ratio were analysed using both PROC CORR (SAS 2001) and PROC REG (SAS 2001).

Modelled ignition probabilities from Lawson et al. (1997b) were also considered, utilizing the results modelled at the 50% probability level for comparison. Finally, a correlation analysis using PROC CORR (SAS 2001) was conducted on ignition day DMC/DC values.

4.3. Results

The generally thin DMC and DC layers, ranging in thickness from 2 to 4 and 4 to 6 cm, respectively, are 3 to 14 cm less than that associated with the national standards (Table 4.1). Soil inorganic content averaged 37% and 55% in the DMC and DC layers, respectively (Table 4.1). In contrast, bulk density values in the calibration sites were considerably greater (285 to 445 kg m^{-3}) than that associated with the national standard (71 to 139 kg m^{-3}) (Table 4.1).

4.3.1. Calibration Results

Results of the ignition probability analysis generated from the calibration site data are provided in Table 4.2, and indicate that both the simple and multiple models for both the DMC and DC layers were highly significant ($P<0.0001$). However, overall R^2 values were greater, and RMSE and CV values less, for the models generated for the DMC layer when compared to results for the DC layer (Table 4.2). While the simple and multiple models resulted in similar R^2, RMSE and CV within the DMC data, the simple model resulted in a greater R^2 and lower CV than that of the multiple model in the DC data (Table 4.2). The multiple models utilized the average inorganic content values of 37%

and 55% and average bulk density values of 285 and 445 kg m^{-3}, for each of the DMC and DC, respectively.

Final coefficients for both the simple and multiple models in the DMC and DC are shown in Table 4.3. Simple and multiple non-linear models were additionally compared graphically within each of the DMC and DC (Figure 4.6). These results indicate that the simple model predicted a slightly greater probability of ignition than the multiple model at a given FWI moisture code (i.e. DMC/DC), although this difference was more apparent within the DC data (Figure 4.6). Described another way, this result indicates the addition of soil bulk density and inorganic content to the model tended to reduce the probability of ignition. For example, the simple model indicated a 50% probability of ignition at DMC and DC values of 27 and 300, respectively (Figure 4.6). In contrast, the DMC and DC codes resulting in the same probability, but using the multiple model were 29 and 336. Given that the results from either model type were quite similar, and because the size of the data set with inorganic content was limited, the simple models were chosen for subsequent comparison to the validation data.

4.3.2. Validation of Ignition Prediction Models

Ignition probability values observed at the validation site field trials, including Beaver, Goose and Tawayik, were compared directly to the values predicted using the simple model developed from the calibration site for both DMC and DC layers (i.e. utilizing the calibration non-linear equation coefficients, with actual validation DMC/DC code values). For the DMC data, a particularly strong relationship ($P \leq 0.001$) was observed between the observed and predicted ignition, but only at the Beaver and

Tawayik validation sites (Table 4.4), with no relationship (P = 0.52) evident at Goose. Goodness-of-fit comparisons for the former two sites were relatively strong (R^2 = 0.46 – 0.49), with a positive relationship generally evident between predicted and observed ignitions (Table 4.4), at the Beaver and Tawayik locations. Despite these apparently favourable results, more detailed examination of the relationship between predicted and observed ignitions indicated there was a tendency for models to under-estimate ignition likelihood at high actual ignition, and a tendency to over-estimate ignition when ignition was rare (Figure 4.7, 4.8).

Results of the DC analysis were similar to DMC, although results for the DC indicated a significant relationship ($P \leq 0.01$) between actual and observed ignition at all three validation sites (Table 4.4). Goodness-of-fit values for the three sites were similar (R^2 = 0.33-0.54) to those observed previously with the DMC. Also similar to the DMC, predictive ignition models using the DC tended to under-estimate the likelihood of ignition when the risk of ignition was actually much greater (Figure 4.8).

4.3.3. Comparison Between MC and FWI Codes on Ignition Success

Regression results indicated that the goodness-of-fit for the F-layer varied between 0.44 and 0.62 for the calibration trials, and 0.20 and 0.27 for the combined burn trials. The CV varied between 22 and 34%, and all comparisons with observed ignition success were significant ($P < .0001$) (Table 4.5). For the H-layer, the goodness-of-fit varied between 0.09 and 0.53, with the CV ranging from 70 to 92%. All comparisons were also significant ($P \leq 0.0008$). In all comparisons except the calibration F-layer, the DMC/DC was a better predictor of ignition probability, with a lower RMSE and CV.

4.3.4. Comparison of Results to Other Models

The current ignition results were compared with the burn charts of Frandsen (1987). Correlation results of moisture ratio and inorganic ratio (DMC: $P = 1.0$; DC: $P = 0.15$) and regression analysis (DMC: $P = 0.00$; DC: $P = 0.37$) produced generally poor results (see Figure 4.9). Results from the current study generally exceeded the parameters of moisture ratio or inorganic ratio utilized by Frandsen (1987).

An analysis comparing the DMC and corresponding DC values on burn day trials (Figure 4.10) was undertaken to determine if any trends were discernable. Results of the burn chart analysis indicate that as the DMC increased in value, it appeared that a corresponding increase in the DC value was required to achieve simultaneous ignition in both layers (see Figure 4.10). The correlation analysis revealed that the relationship between corresponding ignition day values of DMC and DC from this study were not significant ($P = 0.90$, $P = 0.43$ and $P = 0.06$ for no burn, DMC burn and all burn tests, respectively).

Comparison of the modeled ignition values derived here to Lawson et al. (1997b) indicate that the ignition probabilities from EINP predict lower DMC/DC values for similar probabilities of ignition in boreal forest duff types. At the 50% probability of ignition, Lawson et al. (1997b) calculated DMC values of between 39 and 58 in upper feather moss and upper sphagnum moss vegetation types. For Lawson's fuel types, the reported inorganic contents and bulk densities were 12 to 26% and 21 to 56 kg m^{-3}, respectively. Using the lower feather moss fuel type, the Lawson et al. (1997b) DC value at 50% ignition was 482, while inorganic content and bulk density were 19% and 39 kg

m^{-3}, respectively. As mentioned in Lawson et al. (1997b), the equations generated by that study are only applicable to boreal forest fuel types. In Anderson (2000), the 50% probability of ignition survival for DC in D-1 was calculated to be near 79, however the logistic regression utilized was from Hartford (1990), which was determined from commercial peat moss experiments.

4.4. Discussion

Using the simple ignition models, code values of 27 and 300 for DMC and DC, respectively, were determined to approximate the 50% probability of ignition in EINP. After combining inorganic content and bulk density into the multivariate predictive model, a DMC value of 29 and DC value of 336 was associated with a 50% probability of ignition. These results indicate the addition of specific soils data only marginally altered the fit of the predictive models, with a slight tendency to reduce fire risk at a given code. Given the sampling effort required to obtain the additional data required for development of the multiple non-linear models (i.e. sampling for inorganic content and bulk density), the use of multiple models incorporating soils data do not appear warranted for the D-1 vegetation type at this location. Based on personal field experience obtained from working with fire in aspen forests of EINP and elsewhere, either set of probability values are within the lower end of expected ground fire occurrence. Both Frandsen (1987) and Lawson et al. (1997b) modelled multiple equation coefficients for certain fuel types tested; however, neither study provided definitive assessments of the accuracy or predictability between the simple or multiple equation models they observed. Within both Frandsen (1987) and Lawson et al. (1997b), ignition tests were recorded as either successful (i.e. 1) or not (i.e. 0), whereas in the current study a range of probabilities were recorded to a finer resolution (i.e. 0.0 to 1.0).

Interestingly, the DMC/DC values corresponding with the simple equation probabilities of ignition success were less than those from the multiple equation probabilities in the current study, allowing for a more conservative application of results during use in the field. That is, implementation of the simple model will tend to increase the probability of predicting ground fire occurrence at a given DMC/DC. In doing so, this will tend to overestimate ground fire risk, in turn causing resource managers to take greater precautions at earlier stages of the FWI codes in order to prevent undesirable ground fire. Finally, while there is no other reason than current accepted convention (M.E. Alexander, CFS Fire Researcher, personal communication) to choose the 50% level of ignition probability as a management target, in doing so, fire managers should at a minimum, be able to avoid the zone of 'underestimation' apparent within the higher levels of ground fire probability identified within the model structures of this study.

Model goodness-of-fit values based on comparison of the validation data to the calibration data indicated that the risk of ground fire occurrence could be predicted to some degree from the calibrated ignition models. These results were particularly encouraging as they suggest the actual risk of ground fire in various aspen plant community types (but all belonging to the D-1 class) may be predicted using a model developed from other regions of EINP. Variation in model accuracy may be explained by the shallow nature of the surface (i.e. L-F-H) duff profile and the substantial inorganic content and bulk density values found in duff layers of the Park. Shallow duff layers (e.g. <5 cm) may not sustain smouldering in a consistent manner due to heat loss between the oxidation and pyrolysis zones (Miyanishi 2001). The duff layers sampled in EINP were approximately 2 cm for each of the DMC and DC layers, which is significantly shallower than many other conifer types (Table 4.1). This shallow duff layer may inherently add variation in ground fire occurrence or spread, including disruption of ground fire altogether through fuel discontinuity.

Within the validation data sets for DMC and DC, the observed results from Goose DMC were not significant, with a particularly poor fit between actual and predicted ignition. Moreover, the inorganic content and bulk density means derived from the calibration site averages were not substantially different from those at the Goose site (see Tables 3.3b, 3.4b and 4.1). One possible alternative explanation for the divergence within the Goose DMC data is the aspen community type at that location (i.e type B, Best and Bork 2004). The Goose unit is characterized as quite different from the majority of Park PSPs (i.e. 14/95 PSPs were within type B). High herbaceous productivity, yet low species diversity and richness were noted in this unit. It is possible these vegetation conditions influenced the soil moisture and subsequent ignition in the DMC layer.

The validation ignition models for the DC layers, while significant, were observed to have a lower R^2 and higher CV than the validation DMC layers. The relatively shallow depth of the DC layer, coupled with the higher inorganic content than in the DMC may explain these observations. Inorganic material within the duff layer often absorbs heat from organic (i.e. combustible) sources, yet does not by itself produce heat for further transfer (Frandsen 1987), and thus, poses a barrier to ground fire occurrence and persistence. The CV of inorganic contents among soil cores sampled in this study typically varied from 17 to 49%, which may have been sufficient to influence ignition success. Moreover, the soil inorganic values found in this study were relatively high compared to many conifer types sampled elsewhere (Table 4.1), possibly due in part, to their shallow nature and greater potential for mineral soil admixing with disturbances from soil fauna, large ungulates or wind damage to vegetation.

Soil bulk densities were also high within the Park, with a CV of 29 to 48% among duff sub-samples. This variation in duff density likely had a substantial influence on ignition success. Increases in bulk density correspond to a decreasing probability of sustained smouldering (Hartford 1989). In Nelson (2001) the particle surface-to-volume ratio is observed to influence the exchange of heat between duff particles and the surrounding moisture content. As the surface-to-volume ratio decreases, the exchange of heat is observed to decrease due to a reduced surface area per unit of duff volume. The H-layer has been observed to contain smaller particles, and contain a higher bulk density than the F-layer (Miyanishi 2001). Miyanishi (2001) observed that sustained combustion may not be possible in duff depths less than 5 cm. Within EINP, the observed bulk densities, in duff observed to be less than 5 cm, would indicate a reduced surface-to-volume ratio and increased difficulty of sustaining ignition.

Despite a relatively strong relationship between predicted and observed ignition probabilities, the resulting model accuracies often varied considerably from that expected. Validation site ignition results were consistently under-estimated by the calibration models at actual ignition levels over 50% (Figures 4.7 and 4.8). Ignition successes in the field often increased from less than 20% to over 50% and above, over a very short time interval (i.e. days). Ignition responses appeared to change rapidly with moisture depletion and changing FWI codes. As a result, effectively modelling changes in ignition remains difficult under rapid changes in environmental conditions, in turn affecting the accuracy of ignition models.

Comparisons between the observed ignition probabilities and either DMC/DC or moisture content suggest the DMC/DC are a better predictor of actual results than moisture content alone. The DMC/DC codes are designed to gradually increase with drying days and lack of precipitation (or vice versa), as per the published calculations, whereas the natural variability of results obtained from moisture content sampling may demonstrate a wider variety, due to micro site conditions.

Results from the comparison with Frandsen (1987) were not significant, likely because sampling methodologies differed between the studies. In Frandsen (1987), commercial peat moss was used with increasing fine clay added to cover a range of inorganic ratios to over 4.0 (i.e. approximately 80% inorganic content). The moisture ratios used in Frandsen (1987) also did not exceed 1.0 (i.e. approximately 110% moisture content). Similarly, the type of inorganic material in his study was fixed using a common soil medium with a bulk density of 110 kg m^{-3}. By comparison, in the current study the range of inorganic ratios was from the bulked soil core averages at each site as obtained by direct sampling, which in each case was less than 1.0, while the moisture ratio reflected field conditions that often exceeded 1.0 (or 110% moisture).

While there was no significant relationship demonstrated between the burn day DMC and corresponding DC value (Figure 4.10), under natural fire conditions, ignition persistence would be primarily generated downwards and laterally (Miyanishi 2001). As the ignition success rate in the DMC layer increased, there would be a correspondingly greater opportunity for ground fire in the DMC layer to persist and overcome the large heat of vaporization (Frandsen 1987) within the DC layer, enabling a heightened probability of ignition in the latter. As the probability of ignition increased for the DMC layer, the ignition probability for the DC layer might therefore be expected to follow.

Results from the boreal fuel ignition trials of Lawson et al. (1997b) demonstrated the impact of different fuel type conditions. The 32 test fires conducted in Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) – subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) utilized the ignition procedures followed in the current study. However, bulk density and inorganic content values were less than those encountered in EINP in the D-1 fuel type, particularly the bulk density values. Notably, the smouldering threshold (i.e. the 50% probability of ignition) for the DMC or DC was much higher than observed in the current study. It was also observed in Lawson et al. (1997b) that a narrow range of moisture contents separated successful from unsuccessful ignitions, particularly in white spruce duff, somewhat similar to related observations within the current study (i.e. where the observed pattern of ignition success increased from 20 to 50% and greater over the period of a few days). The different soil properties of the D-1 fuel type in EINP (i.e. bulk density and organic content), compared to Lawson et al. (1997b) may account for these differences.

During the spring of 2004 the aspen forest floor was devoid of the usual frozen, black and wet litter layer. Snow pack from the previous winter also receded quickly from a depth of 25 cm at the start of April, to snow gone (>90% snow pack loss) one week later. In contrast, during the spring of 2005, a 75% loss of the settled snow pack occurred during the week of March 6 to 12th, but a late winter snowstorm occurred on March 20th, and official snow gone was not declared until April 2nd. It is not uncommon for the snow pack to recede very quickly in the Park while the ground is usually still frozen, potentially minimizing infiltration and reducing plant growth (Bork et al. 2001). When FWI indices began for the 2005 fire season, the soil horizons were completely frozen below the duff layers (6 cm) until April 11th, whereas during 2004, the frost layers during the start-up of indices were intermittent at 10 cm and below. While the residual snowpack may be minimal post-runoff, the presence of shallow, frozen soil horizons may prohibit effective infiltration (i.e. suspend moisture) of the remaining moisture in the duff layers, until the frost layers recede (Lawson and Dalrymple 1996a). This suspension of moisture might compromise initial moisture content readings and associated FWI code representations.

Within the FWI system the starting DMC is set at 6 (Van Wagner 1987). Under the frequent warm and dry periods possible during the spring in EINP, it may only take a few weeks or less to progress from a settled snow pack, to snow gone, and through to the 50% range of ground fire probability. In 2003 and 2004, the DMC climbed from the base value of 6 to a DMC of over 27, within six and three weeks, respectively.

On April 28th, 2004, there was 7.8 mm of precipitation recorded in the Park. On April 30th the largest wildfire in the Park's history started, covering 2422 ha. Of particular interest was the near total lack of ground fire found subsequently in the D-1 fuel type, even though the spring of 2004 was still fully engaged in a drought period. In contrast, other fuel types within the burn (e.g. white spruce, white birch) appeared to experience extensive amounts of ground fire. One explanation for this difference is that the precipitation received two days prior to ignition may have insulated the DMC layer during passage of the fire front (i.e. a DMC of only 18.9 was recorded on the day of ignition). With the duff layer in EINP being shallow and holding less moisture than other fuel types, it is possible that relatively little precipitation is necessary to restore soil moisture and reduce the risk of ground fire compared with other fuel types.

Fire managers responsible for managing prescribed fire or wildfire in aspen forests will benefit from information on the relationship between DMC/DC and ground fire ignition. However, the use of specific DMC/DC ignition models should also be done cautiously. The ignition tests in this study were induced under artificial conditions, (i.e. a fire source was applied directly to the duff layers in question using commercially available peat moss). In most forest fire situations, duff ignition would likely occur on the surface as a result of lightning or human-caused ignition. Many of the days during the study when ignition was successful were on days that may have had moist fine fuels in the litter layer, where a surface laden firebrand might not have survived to reach the lower duff layers. Regardless, the calibration ignition model developed in the current study more closely matches the subsequent validation data than other predicted models from either (Frandsen 1987) or Lawson et al. (1997b). If further sampling of D-1 within the greater Beaver Hills area were to determine that the basic soil properties, such as average L-F-H depth, inorganic content and bulk density were found to be similar to those within EINP, ignition probabilities might also be similar.

4.5. Conclusions & Management Implications

This research established and tested calibrated non-linear models relating DMC and DC to the probability of duff ignition, or ground fire. Overall, simple rather than complex multivariate models appeared more effective in relating DMC and DC to ignition. When average inorganic content and bulk density data were included in a multivariate non-linear model, modelled results for the 50% probability of ignition were within two points of the simple DMC equation and 36 points for the simple DC equation. Simple models also resulted in more conservative (i.e. sensitive to fire risk) threshold values for burning. Thus, the simpler models should suffice for practical use in EINP. Additionally, during the validation procedure, models developed for the independent calibration site were relatively effective at detecting a change in ignition, although the accuracy of those models remained quite low. In particular, the probability of ground fire was typically underestimated at high actual ignition, suggesting conservative FWI codes should be used to avoid ground fire when prescribed burning.

Results of this study indicate that the aspen forest and D-1 fuel type of EINP is quite unique in its properties, not only with respect to the characteristics of the duff layer (i.e. bulk density and inorganic content), but also its apparent wetting and drying characteristics and associated ground fire risk. Thus, the results of this study are not directly comparable to either that of Frandsen (1987) or Lawson et al. (1997b) in conifer vegetation types. Similarities between other areas of the Lower Boreal Mixedwood or Aspen Parkland ecoregions are to be determined.

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Table 4.1. Comparison of mean (±SE where available) duff depth, inorganic content and bulk density for select vegetation types.

Sample Type	N	Mean Depth cm	Bulk Density Kg m⁻³	Inorganic Content %	Source
Nat Std DMC	-	7	71.43	not determined	Van Wagner 1987
Nat Std DC	-	18	138.9	not determined	Van Wagner 1987
Calibration Site DMC[1]	117	2-4	285.2±13.3	37.2±1.6	Otway 2005
Calibration Site DC[1]	117	4-6	444.6±19.8	55.0±1.7	Otway 2005
D-1 Fuel Type Average	-	2.4	61	59	Anderson 2000
D-1 Fuel Type	-	2.37±0.36	108±25	59±14	Quintilio et al. 1991
EINP Aspen Sites	510	6.5±0.07	140±2	not determined	Samran et al. 1995
White Spruce Duff	-	0-5	122	35.9	Lawson et al. 1997b
EINP Spruce Stands	46	2-4	200-300	not determined	Anderson and Otway 2003
EINP Spruce Stands	46	4-6	300-600	not determined	Anderson and Otway 2003
ICFME Jack Pine	38	2-4	91.5±2.8	13.7±21.8	ICFME 2004

[1] Sample size used for bulk density and inorganic content analysis in ignition trials.

Table 4.2. Linear analysis of calibration site DMC and DC values, and observed probability of ignitions using simple or multiple regression modelled equations, showing goodness of fit (R^2), root mean square error (RMSE), coefficient of variation (CV) and probability (Pr>F).

		Linear Analysis			
Code	Model Type	R^2	RMSE	CV	Pr>F
DMC	Simple Equation	0.74	0.14	16.69	<.0001
	Multiple Equation	0.74	0.15	18.72	<.0001
DC	Simple Equation	0.54	0.23	50.42	<.0001
	Multiple Equation	0.43	0.24	80.93	<.0001

Table 4.3. Coefficient parameters and standard errors for simple and multiple non-linear models comparing DMC and DC values to the probability of ignition in the D-1 fuel type.

Code	Model Type	a	SE[3]	b	SE	c	SE	d	SE	F	Pr>F
DMC	Simple[1]	-3.11	0.63	0.12	0.02	-	-	-	-	1008.31	<.0001
	Multiple[2]	2.92	1.38	0.12	0.02	-0.16	0.05	-0.002	0.001	485.68	<.0001
DC	Simple	-8.96	2.22	0.03	0.01	-	-	-	-	147.14	<.0001
	Multiple	7.98	3.03	0.04	0.01	-0.36	0.08	0.0002	0.001	127.55	<.0001

[1] Simple non-linear equation is P=exp(a+b*DMC/DC)/(1+exp(a+b*DMC/DC)).
[2] Multiple equation is P=exp(a+b*DMC/DC+c*inorg+d*bd)/(1 +exp(a+b*DMC/DC+c*inorg+d*bd)).
[3] Standard error.

Table 4.4. Comparison of the validation observed field burning data to the calibration site modelled results using simple linear regression, showing goodness of fit (R^2), root mean square error (RMSE), coefficient of variation (CV) and probability (Pr>F).

		Linear analysis			
Code	Validation Site	R^2	RMSE	CV	Pr>F
DMC	Beaver	0.49	0.20	31.12	0.0006
	Goose	0.04	0.26	34.67	0.5216
	Tawayik	0.46	0.23	33.85	0.0013
DC	Beaver	0.50	0.11	78.05	0.0004
	Goose	0.54	0.22	49.84	0.0029
	Tawayik	0.33	0.23	80.79	0.0102

Table 4.5. Comparison of observed ignition success versus either moisture content (MC) or the FWI codes of DMC/DC, showing goodness of fit (R^2), root mean square error (RMSE), coefficient of variation (CV) and probability (Pr>F).

		Linear Analysis			
Soil Layer	Parameter	R^2	RMSE	CV	Pr>F
F-layer	Allcal MC	0.62	18.94	22.42	<.0001
	Allcal DMC	0.44	23.02	27.26	<.0001
	Allburn MC	0.20	28.66	33.99	<.0001
	Allburn DMC	0.27	27.33	32.40	<.0001
H-layer	Allcal MC	0.25	40.32	74.47	<.0001
	Allcal DC	0.53	31.98	59.07	<.0001
	Allburn MC	0.09	44.10	92.38	0.0008
	Allburn DC	0.48	33.42	70.01	<.0001

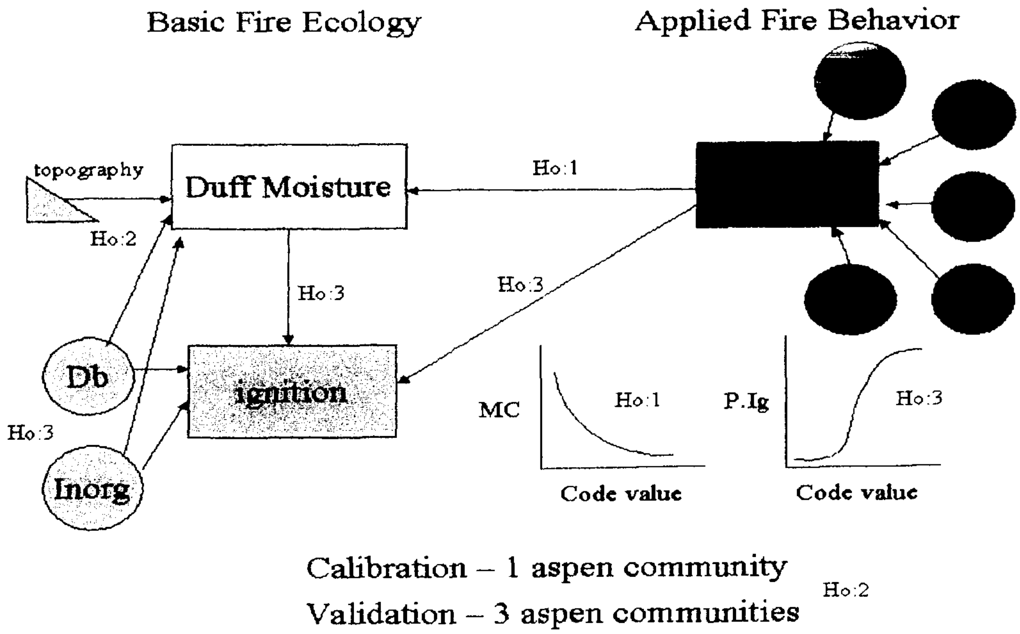

Figure 4.1. Theoretical relationship of basic fire ecology and applied fire behaviour that led to development of the hypotheses tested, where Ho: = hypothesis, Db = bulk density, Inorg = inorganic content, Mn = month, T = temperature, RH = relative humidity, day l = day length, MC = moisture content and P.Ig = probability of ignition.

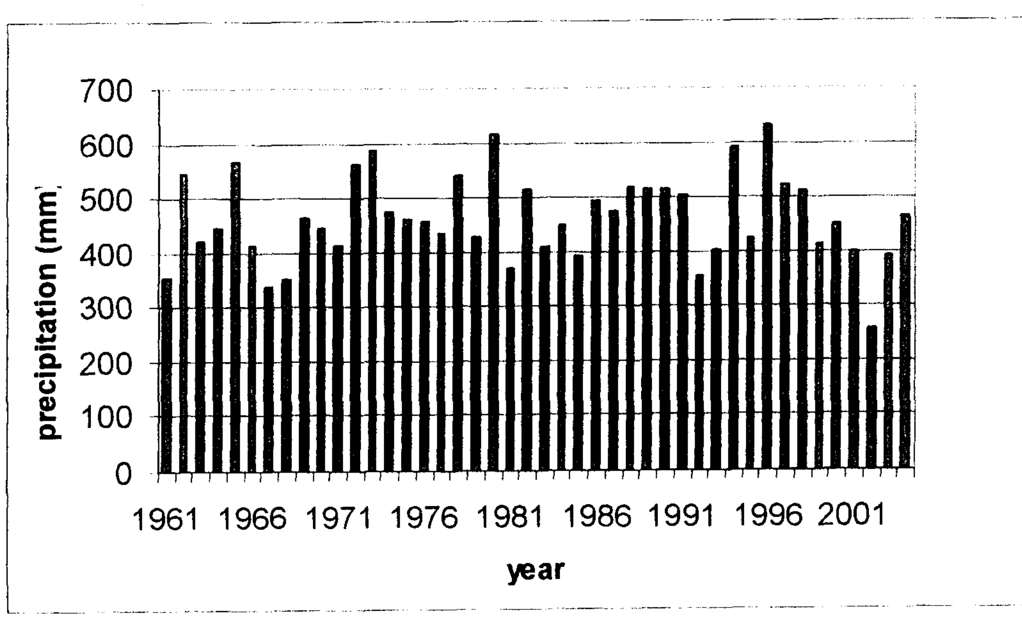

Figure 4.2. Edmonton International Airport (YEG) yearly precipitation (Jan-Dec) from 1961 to 2004. The 44 yr average precipitation amount =461.0 mm. The 44 yr average for April to October = 373.3 mm average.

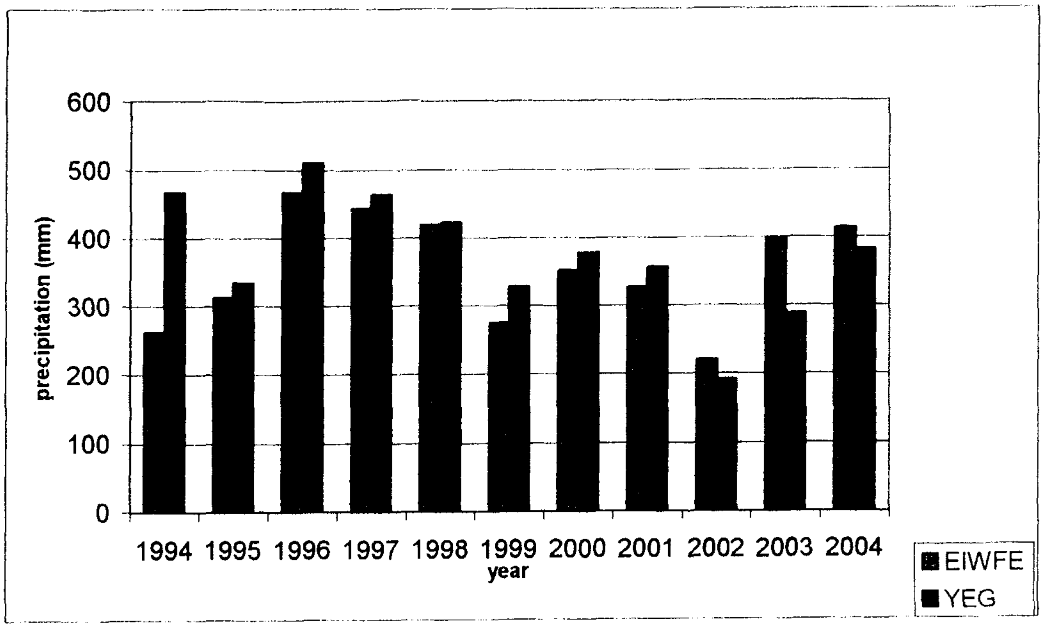

Figure 4.3. Comparison of April to October fire season precipitation between Edmonton International Airport (YEG; 11 yr ave. = 374.2 mm), and the Park station (EIWFE; 11yr ave. = 353.5 mm) between 1994 and 2004.

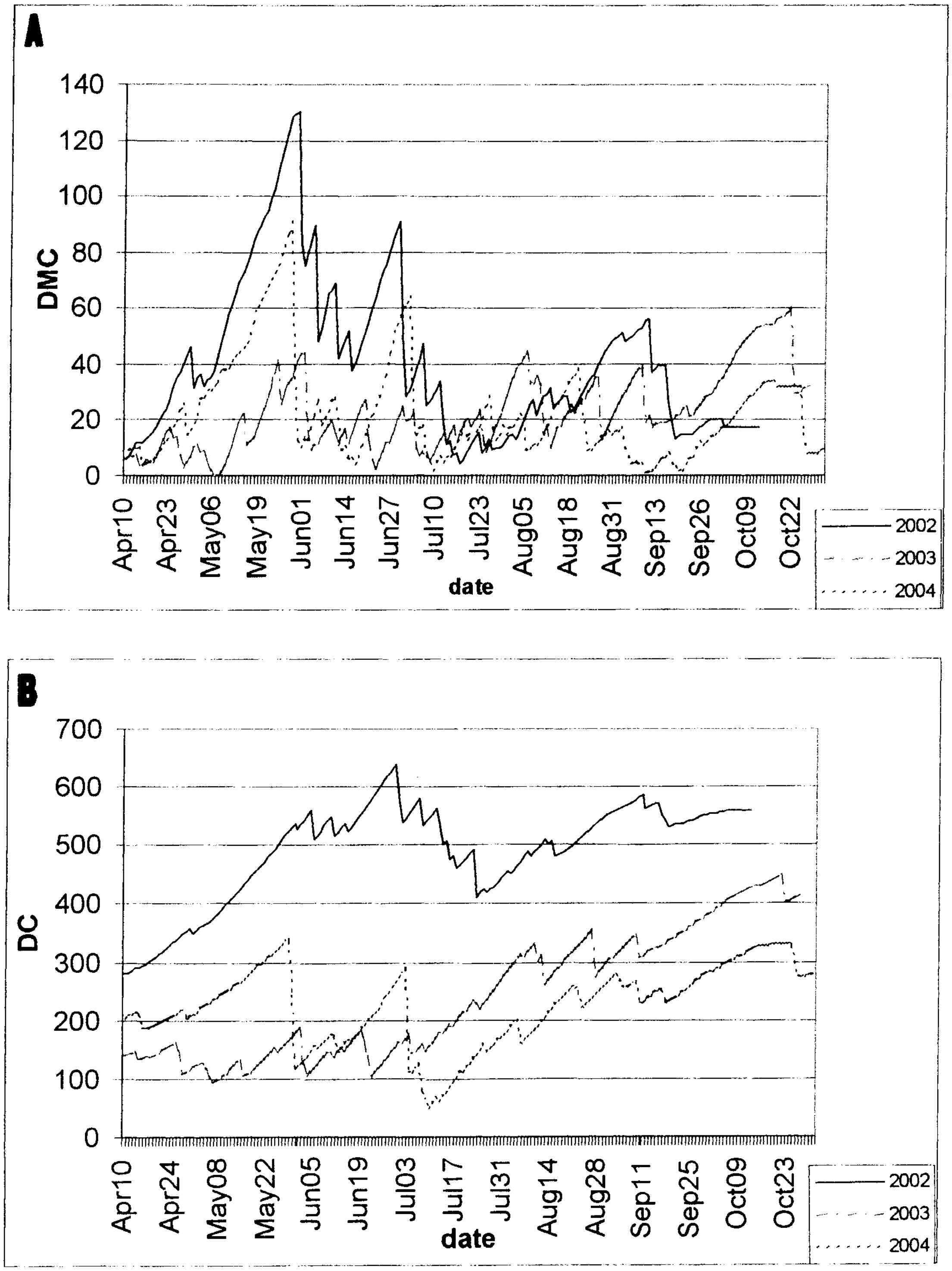

Figure 4.4. Comparison of DMC (A) and DC (B) values over the fire season of April to October for the main Park weather station (EIWFE) in each of the years 2002, 2003 and 2004.

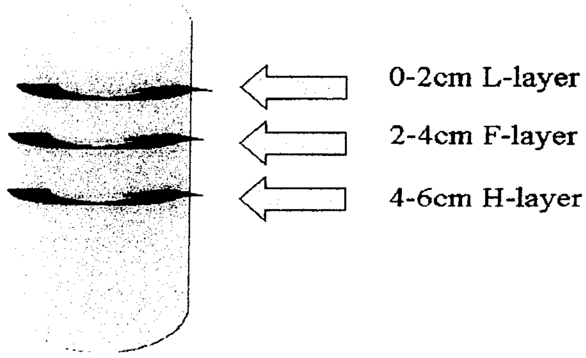

Fig. 4.5. Diagram of a soil core showing the stratification into 2 cm layers for further analysis.

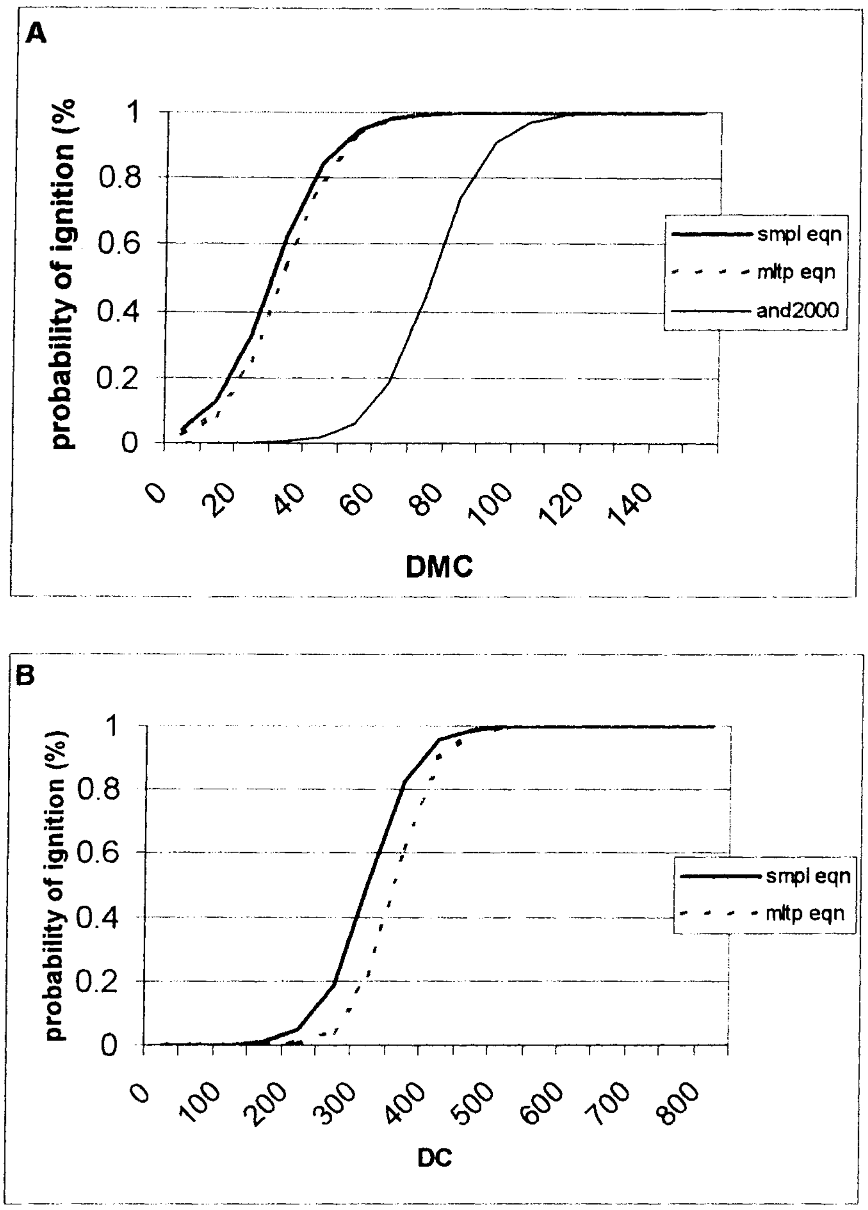

Figure 4.6. Results of the non-linear analysis fitted to a logistic model showing the probability of sustained ignition against the DMC (A) and DC (B). Model predictions at the 50% probability for either the simple/multiple equations for DMC are 27/29, and for DC are 300/336. For DMC (A), and2000 (Anderson 2000) shown for comparison.

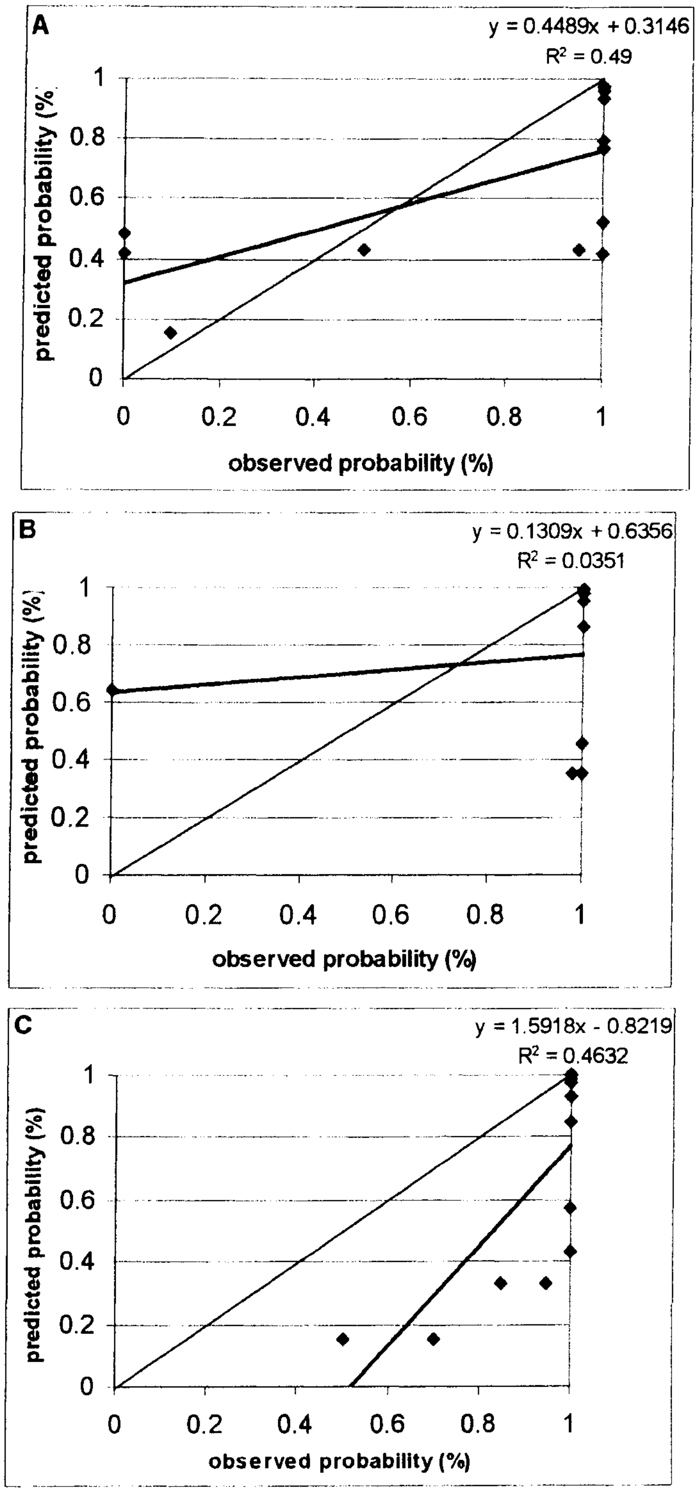

Figure 4.7. Comparison of modelled relationships between observed ignition probabilities in the DMC layer for the Beaver (A), Goose (B) and Tawayik (C) validation sites, and the predicted probability of ignition obtained using the simple non-linear regression model from the calibration site.

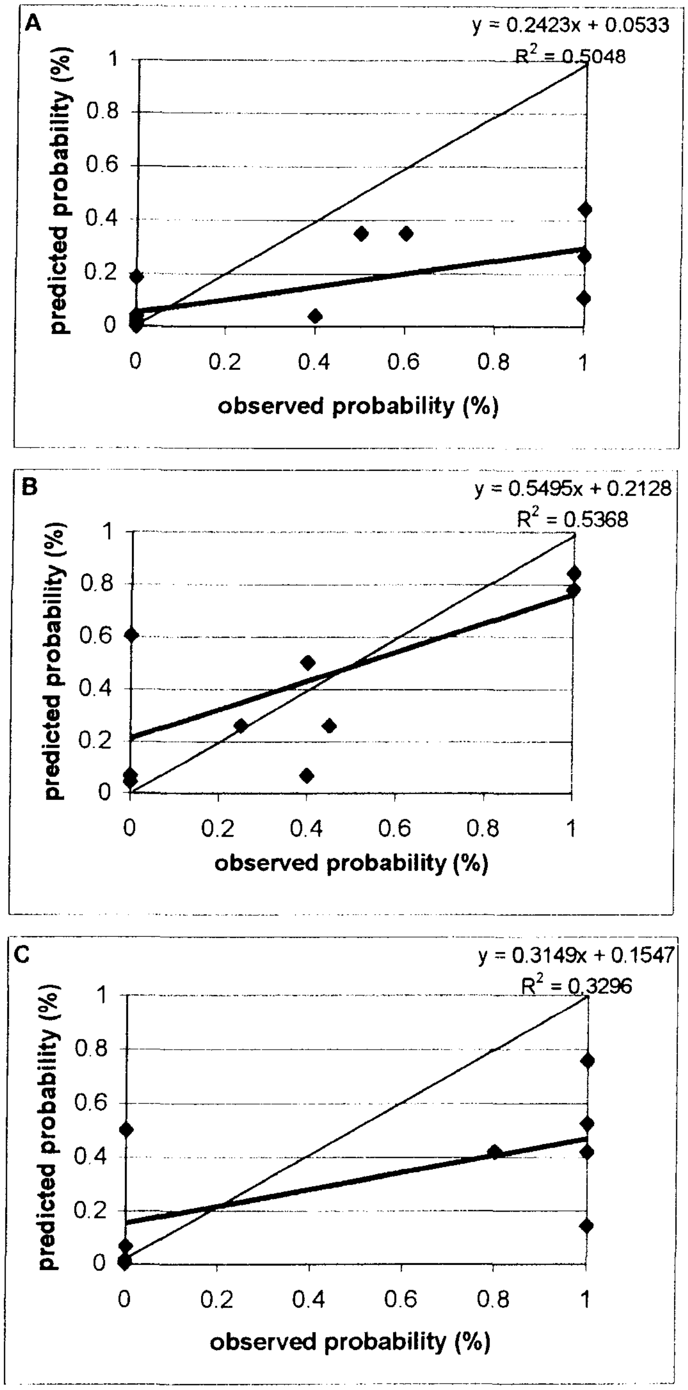

Figure 4.8. Comparison of modelled relationships between observed ignition probabilities in the DC layer for the Beaver (A), Goose (B) and Tawayik (C) validation sites, and the predicted probability of ignition obtained using the simple non-linear regression model from the calibration site.

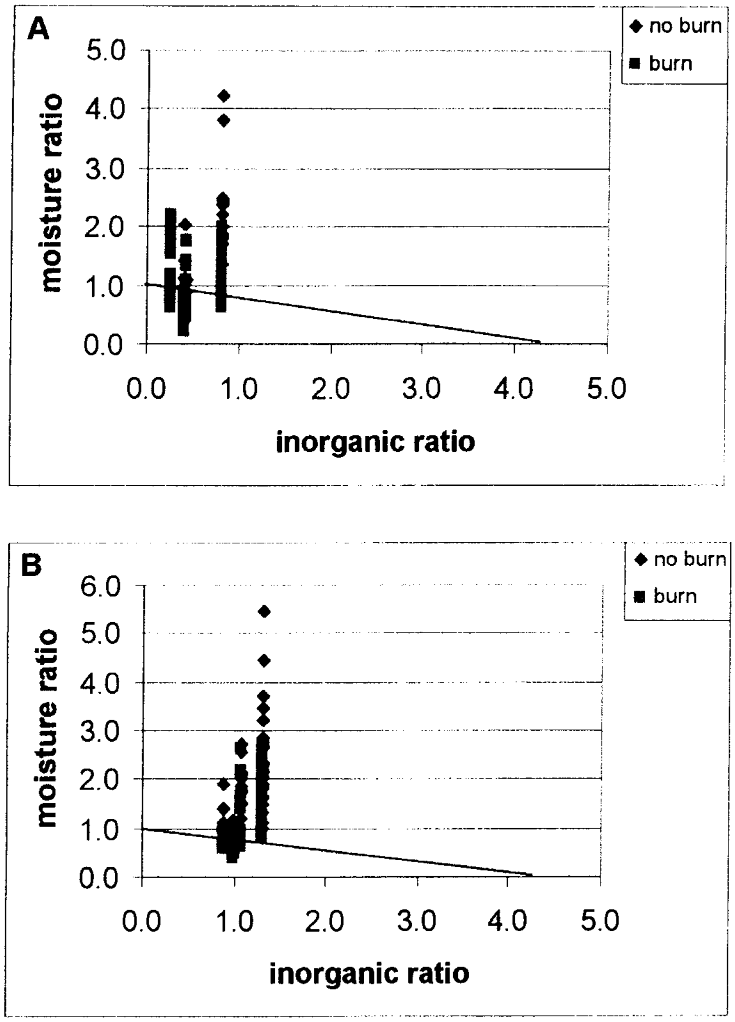

Figure 4.9. Comparison of the inorganic ratio to moisture ratio from burning trials conducted in the DMC (A) and DC (B) layers based on Frandsen (1987). Frandsen's 'burn-no burn' threshold line has been added.

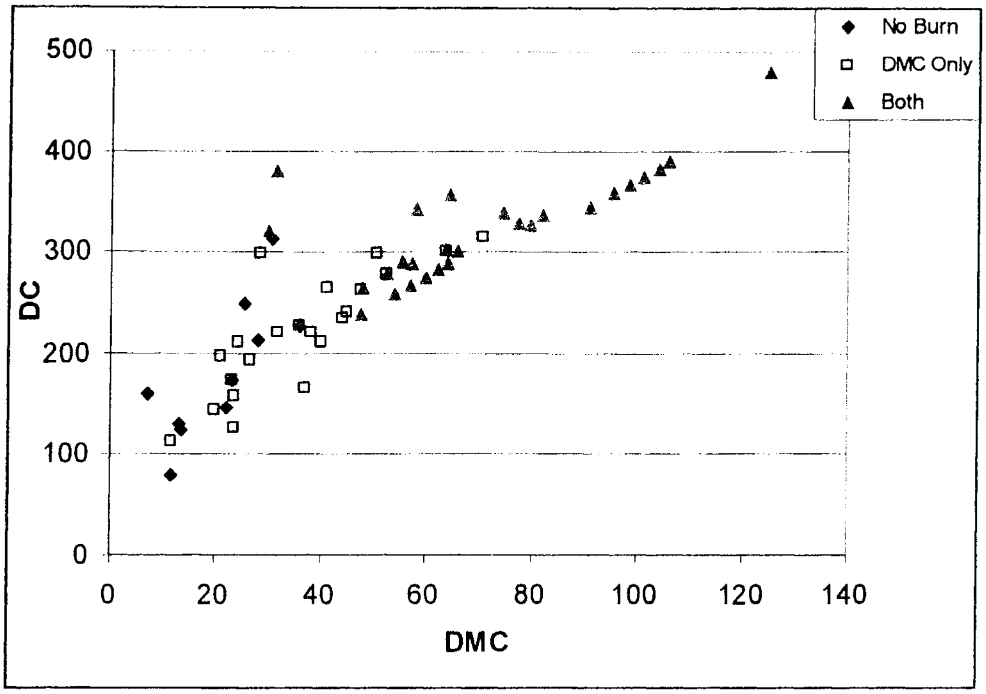

Figure 4.10. Ignition day FWI indices of Duff Moisture Code (DMC) and Drought Code (DC) recorded as either <50% burning success in either layer (No Burn), DMC layer ignition ≥ 50% and DC <50% (DMC Only), and ignition success ≥50% for both DMC and DC (Both).

Chapter 5. SYNTHESIS

The objectives of this study included evaluating whether the national standard DMC/DC (i.e. duff moisture) of the FWI System apply to the D-1 (aspen) fuel type in Elk Island National Park, and whether there are similar codes among different locations in the Park, including various aspen community types, soil bulk densities and inorganic values. Additionally, this study determined whether the ignition probability of the D-1 type could be predicted from the associated DMC/DC and how ignition varied relative to site conditions among locations.

Moisture depletion curves in the DMC and DC layer in EINP revealed far less water holding capacity at lower code values than the national standard curves, possibly as a result of the shallow duff layers (6 to 7 cm vs. the 25 cm standard for the F and H layer horizons in most conifer stands). Although moisture loss among the upland topographic positions examined varied somewhat, they were more similar to one another than the differences noted between seasons (spring vs. summer vs. fall). Overall, soil moisture samples taken during the spring displayed more variation between aspects than in the summer, which in turn, were more variable than the fall. Additionally, soil moisture decreased throughout the growing season. While north-facing slopes generally burn with less intensity than crest or south-facing slopes during large-scale fires in spring, this may occur, in part, because of lower on-site FFMC conditions (i.e. lower code value) inhibiting ignition success, rather than the actual DMC/DC moisture in duff layers at that time.

The calibration site moisture models were validated at several independent locations throughout the Park. There was a tendency, however, for soil moisture overestimation at low actual levels and underestimation at high levels. Compared to other boreal forest types, the shallow F and H horizons of aspen stands contained relatively high bulk densities and inorganic contents. These properties may have contributed not only to the reduced water holding capacity of the duff, but also the potential for greater inherent site-based variation in the validation data. One potential strategy to manage this variability would be to plan around the ground fire risk associated with the driest possible conditions in the landscape, thus recognizing these areas as the most problematic for supporting ground fire.

Spring and fall sampling during this study were preceded by recent drought conditions that had dried the soil horizons beneath the duff layers to conditions drier than those above, (i.e. creating an inverted soil moisture profile). During the summer of 2004, however, extensive and timely precipitation allowed for a full range of moisture conditions to be sampled, and for the gradual, partial moisture recharge of deeper soil horizons. From 2002 to 2004, the soil moisture loss within both the duff and soil layers was substantial. While the duff layers in Elk Island are quite shallow, and can dry out rapidly, there are indications that a short-term reversal of this dryness, or moisture recharge, in these shallow layers can also occur quickly. Consequently, trends in DMC/DC values should be closely tracked during the fire season.

Over-wintering of the DC poses another unique challenge. The national standard equation indicates potential moisture equivalent maximums of nearly 800 for the DC, values never realized in data from the aspen (D-1 fuel type) calibration sites studied here. This suggests the national standard is not as suitable as the locally modelled calibration equations for the D-1 fuel type. Given that conditions in the Park can revert from a settled snow pack, to snow free within a very short time frame, an accurate and meaningful spring DC should be sought for this fuel type. Using the new formula derived in this investigation, much lower DC starting values tend to be calculated. However, Park managers must also be aware that even at low DC values, modelled moisture values within the duff layers were considerably lower than those predicted by the national standard equation. Another key consideration of the D-1 fuel type models derived here is that the new DC model was a relatively insensitive measure of fuel dryness. An increase in DC from 50 to 450 only represented a corresponding decrease of moisture content from 118% to 50%. In contrast, the modelled DMC layer was a far more sensitive indicator of moisture loss, and therefore should be relied upon more than the DC for prescribed burn planning and ground fire risk assessment in EINP.

The mean monthly DMC is reported to have the strongest relationship to area burned in west-central Canada, with the fire cycle for EINP forecasted to decrease from 135 to 57 yrs over the next 100 yrs (de Groot et al. 2003), attributable in part to modelled climate change scenarios (Flannigan et al. 2000; Amiro et al. 2001; de Groot et al. 2003). While the role of fire is recognized as essential within EINP, the size and management complexities of a small, fenced park require that Park managers be cautious with the use of fire (Alexander and Dubé 1983; Science Advisory Committee 2001; Parks Canada 2003; Parks Canada 2004b; Parks Canada 2005). In essence, prescribed burn prescriptions for EINP need to avoid DMC prescriptions that might be expected to incur extensive ground fire occurrence.

Precipitation amounts may also vary throughout the park, but the placement of portable rain gauges within or next to potential prescribed burn areas should assist in the accurate determination of on-site FWI codes.

The overwintering formula b coefficient of 0.165 is a substantial departure from the minimum national standard value of 0.5, indicating soil moisture recharge is limited in EINP, likely due to rapid sublimation and high run-off of the snow pack. Further testing for spring moisture contents will assist in further refining this coefficient through time.

The issue of seasonality in the D-1 fuel type is an important factor to consider in fire management and burn planning. While the data presented in this study did not support the use of separate moisture models for different seasons from spring to fall, the D-1 fuel type appears to be potentially impacted by canopy interception of rainfall during leaf-on conditions, in turn possibly affecting duff moisture levels.

Based on the test fire data, the ignition potential at the 50% probability was noted to occur from 27 to 29 for the DMC and 300 to 336 for the DC, depending on whether the simple or multivariate non-linear model was used. For practical purposes, the simple non-linear model appeared sufficient for application in the Park. The addition of environmental (i.e. site) data in multiple models had little or even a negative impact on the quality of the models. When applied to the validation sites, calibrated models had reasonably similar goodness-of -fit, but high coefficients of variation were again attributed to the shallow duff profile and inherent variability of the soil inorganic and bulk density values. As with duff moisture, the ignition models under-estimated the probability of ignition at high actual risk levels. The 50% ignition probability should therefore be used cautiously for practical purposes, and DMC/DC data perhaps supplemented with information on actual ground duff moisture conditions.

Theoretically, the more easily the DMC layer ignites, the greater the potential for spread deep into the DC layer. Unless there is a penetrating ignition source (e.g. lightning) that directly exposes deep layers to an ignition source, most ignitions spread from the surface downwards through the horizons. The ease of ignition in the DMC/DC layers during burning trials was predicated primarily on the changing moisture content of F and H soil layers, regardless of seasonality. However, one practical difference, untested in this investigation, was the condition of the fine fuel layer (FFMC). During leaf-on periods, much of the L-layer was generally moist due to the high relative humidity found under green vegetation. Under these conditions, the fine fuel layer might not have ignited, thereby providing no opportunity for the DMC/DC layers to become exposed to live firebrands, regardless of how wet or dry those layers might have been at the time. As a result, the Park could conceivably experience drought in the F and H-layers of the soil profile during the summer months, yet not experience significant fire hazard conditions until the fall or following spring when the FFMC dried out sufficiently to present an ignition concern. More research is needed on the role of the FFMC in fire occurrence and severity within the aspen (D-1) fuel type, including that of EINP.

Smoke generation is an important management concern for the Park, particularly when using prescribed fire. Smoke presence affects air quality and may reduce visibility in the surrounding travel corridors, posing a safety risk to the public. The surest method of reducing ground fire potential is to plan prescribed burns when the likelihood or probability of ground fire occurrence is reduced in aspen forests. Most previous concerns with smoke in the Park have been in fuel types other than the D-1 type. This may be because many of those areas (i.e. spruce stands, dried out wetland meadows, etc.) have considerably deeper duff layers (>10 cm) than those found in the aspen forest. While aspen forests in the Park have shallow duff layers, they do account for the largest upland plant community in the area. Even small lingering amounts of smoke in these areas could accumulate and create smoke concerns. Limiting prescribed burn prescriptions to a DMC of no more than approximately 30 should be considered as a management guideline, although this will admittedly not eliminate the risk of ground fire altogether. Planning to burn with DC values less than 300 will also assist the Park with minimizing ground fire within aspen forests.

Further sampling should be undertaken in other aspen forests of the lower Boreal or Parkland ecoregions, to compare modelled moisture and ignition results with those from this study, particularly in those areas with differing soil duff depths, inorganic contents and bulk densities from that sampled in EINP. For national parks in western Canada, both Riding Mountain and Prince Albert have substantial areas in the D-1 fuel type. Additionally, in some eastern national parks, such as La Maurice, the D-1 fuel type indices are referenced for the predominately maple hardwood forest during prescribed burn planning. Whether these eastern hardwood stands have properties similar to the D-1 aspen forest type in western Canada requires further investigation.

To manage vegetation with fire, the fire regime components of intensity and depth of burn require knowledge of the relevant FWI codes for the fuel type considered (Van Wagner and Methven 1980). With the potential for continued drought in aspen forests and the increasing concern associated with smoke originating from ground fires, more precise fire prescriptions can now be developed utilizing the moisture and ignition models developed in this thesis. The use of more accurate fire severity prescriptions should increase our predictive capability of ground fire occurrence, smoke management, and help influence vegetative structure and composition within aspen forest ecosystems.

5.1. Literature Cited

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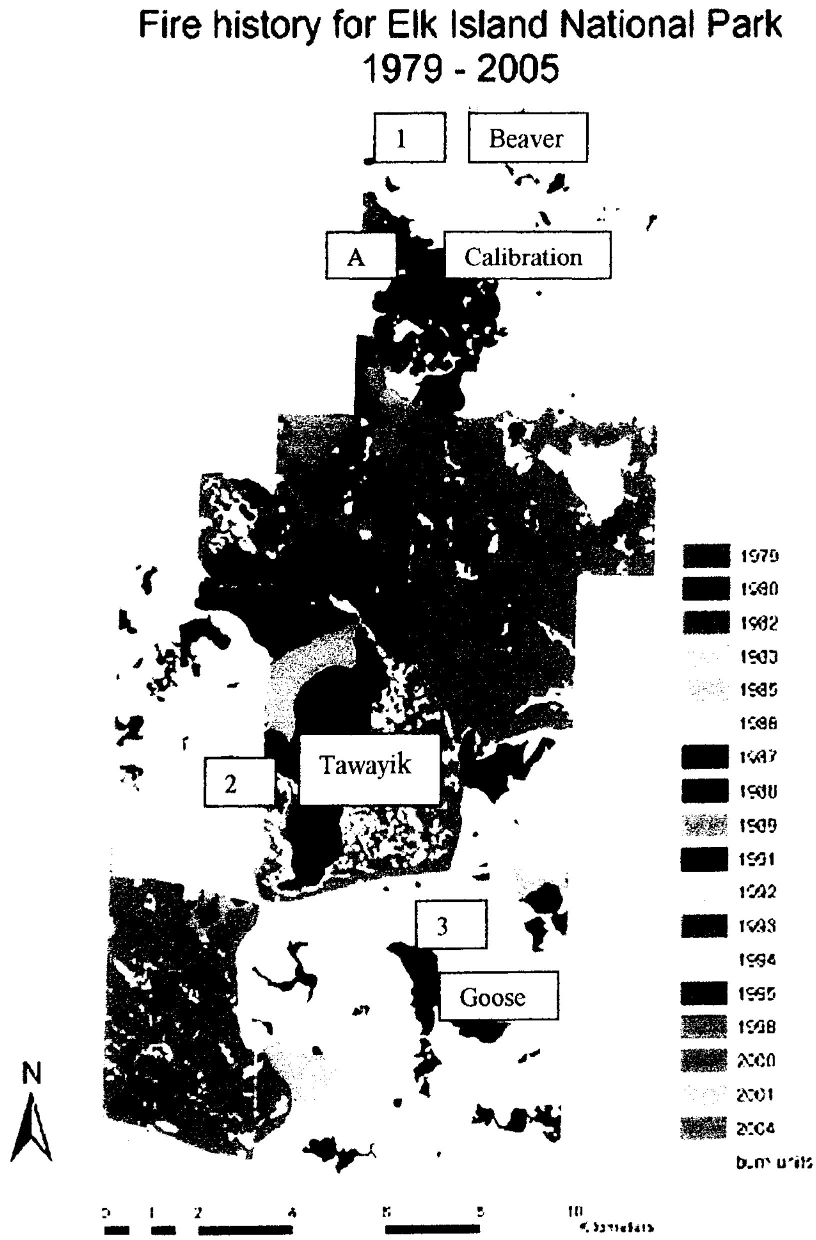
APPENDIX 1. Plot Locations of calibration and validation areas in EINP.



APPENDIX 2. Calibration plot locations.

Plot #	corner	GPS N 53deg 40min	GPS W 112deg 52min
S-1	SW	0.737	0.596
	SE	0.740	0.574
	NE	0.747	0.577
	NW	0.747	0.593
C-1	SW	0.747	0.593
	NW	0.760	0.596
	NE	0.760	0.598
	SE	0.747	0.577
N-1	NW	0.698	0.591
	SW	0.689	0.590
	SE	0.692	0.577
	NE	0.700	0.580

APPENDIX 3. Calibration site rain gauges and DMC/DC codes during 2002, from April 29th to Oct 31st.

Month	Day	EIWFE	DMC	DC	Month	Day	EIWFE	DMC	DC
Apr	29	3.0	6.0	280.0	Jun	13	0.0	113.7	501.5
Apr	30	0.2	6.9	281.8	Jun	14	0.0	118.5	509.1
May	1	0.0	8.6	284.3	Jun	15	0.0	123.6	517.3
May	2	0.0	11.6	289.3	Jun	16	0.0	128.2	525.2
May	3	0.0	11.6	291.4	Jun	17	0.0	129.5	531.4
May	4	0.0	11.9	294.1	Jun	18	0.2	130.2	536.7
May	5	0.0	12.6	297.1	Jun	19	4.0	83.1	528.3
May	6	0.0	13.9	300.6	Jun	20	2.2	74.7	535.4
May	7	0.0	15.6	304.4	Jun	21	0.0	79.9	543.3
May	8	0.0	17.4	308.4	Jun	22	0.0	85.0	551.5
May	9	0.0	19.4	312.5	Jun	23	0.0	89.9	559.9
May	10	0.0	21.8	317.0	Jun	24	11.0	47.6	508.5
May	11	0.0	23.9	321.5	Jun	25	0.0	52.2	516.6
May	12	0.2	27.2	326.7	Jun	26	0.0	58.0	525.6
May	13	0.0	32.1	332.9	Jun	27	0.0	65.0	534.8
May	14	0.0	34.9	338.1	Jun	28	0.6	66.4	541.4
May	15	0.0	37.0	342.4	Jun	29	0.2	68.6	548.5
May	16	0.0	40.0	347.5	Jun	30	8.0	41.9	515.8
May	17	0.0	42.9	352.5	Jul	1	0.0	45.6	522.5
May	18	0.2	46.0	357.8	Jul	2	0.0	48.8	529.4
May	19	4.6	31.6	349.6	Jul	3	0.0	51.6	536.4
May	20	0.0	35.0	355.2	Jul	4	4.6	37.5	524.9
May	21	0.0	36.1	359.1	Jul	5	0.0	40.1	531.5
May	22	2.4	32.0	362.7	Jul	6	0.0	43.5	538.8
May	23	0.0	34.2	366.8	Jul	7	0.0	48.0	547.0
May	24	0.0	35.1	370.5	Jul	8	0.0	51.4	554.6
May	25	0.0	37.7	375.3	Jul	9	0.0	55.6	562.6
May	26	0.0	42.4	381.5	Jul	10	0.0	59.9	571.2
May	27	0.0	47.2	388.0	Jul	11	0.0	64.0	580.1
May	28	0.0	52.0	394.7	Jul	12	0.0	69.0	589.3
May	29	0.0	56.8	401.3	Jul	13	0.0	73.0	598.1
May	30	0.0	61.0	407.3	Jul	14	0.6	75.6	605.9
May	31	0.4	64.4	412.7	Jul	15	0.4	79.6	613.7
Jun	1	0.0	68.5	418.5	Jul	16	0.0	83.9	621.9
Jun	2	0.0	72.4	425.5	Jul	17	0.0	88.0	630.5
Jun	3	0.0	75.5	432.3	Jul	18	0.0	90.6	638.5
Jun	4	0.0	79.5	439.7	Jul	19	10.4	48.3	580.3
Jun	5	0.0	84.2	447.4	Jul	20	9.0	28.0	538.5
Jun	6	1.2	86.9	453.4	Jul	21	1.4	30.0	545.4
Jun	7	0.0	89.9	459.4	Jul	22	0.0	33.8	553.2
Jun	8	0.0	92.7	465.6	Jul	23	0.0	38.3	561.7
Jun	9	0.6	94.8	471.9	Jul	24	0.2	42.0	570.0
Jun	10	0.0	98.6	478.9	Jul	25	0.0	47.2	579.1
Jun	11	0.0	102.6	485.7	Jul	26	9.4	24.9	533.8
Jun	12	0.0	108.1	493.4	Jul	27	1.2	26.1	540.4

Month	Day	EIWFE	DMC	DC
Jul	28	0.6	28.3	547.3
Jul	29	0.2	30.9	554.1
Jul	30	0.4	33.8	561.0
Jul	31	6.6	19.4	533.6
Aug	1	8.0	11.2	500.6
Aug	2	0.0	12.0	505.5
Aug	3	8.0	7.1	474.5
Aug	4	0.0	8.1	479.6
Aug	5	6.4	4.4	459.0
Aug	6	0.2	5.3	464.7
Aug	7	0.0	7.7	471.3
Aug	8	0.0	10.3	478.2
Aug	9	0.0	13.3	485.4
Aug	10	0.0	15.1	491.5
Aug	11	18.8	7.7	410.9
Aug	12	0.0	10.1	417.4
Aug	13	0.0	13.1	424.5
Aug	14	3.8	9.2	419.2
Aug	15	0.4	9.6	424.4
Aug	16	1.4	10.0	428.7
Aug	17	2.0	10.4	434.8
Aug	18	1.4	12.2	441.0
Aug	19	1.0	14.1	447.3
Aug	20	0.8	14.7	452.8
Aug	21	3.4	13.2	450.4
Aug	22	0.0	15.3	457.3
Aug	23	0.0	18.3	464.8
Aug	24	0.0	21.9	472.8
Aug	25	0.0	25.2	480.8
Aug	26	0.0	27.3	487.9
Aug	27	4.2	21.6	480.8
Aug	28	0.0	25.0	488.4
Aug	29	0.0	28.5	496.1
Aug	30	0.0	29.1	501.9
Aug	31	0.0	31.4	508.7
Sep	1	3.8	24.1	501.7
Sep	2	0.0	25.8	506.3
Sep	3	0.4	27.0	480.0
Sep	4	0.0	28.0	484.0
Sep	5	0.0	28.0	487.0
Sep	6	2.6	23.0	490.0
Sep	7	0.0	24.0	494.0
Sep	8	0.2	26.0	499.0
Sep	9	0.0	28.0	504.0
Sep	10	0.0	31.0	510.0
Sep	11	0.0	33.0	515.0

Month	Day	EIWFE	DMC	DC
Sep	12	0.0	35.0	520.0
Sep	13	0.4	36.0	524.0
Sep	14	0.0	39.0	530.0
Sep	15	0.0	42.0	536.0
Sep	16	0.0	44.0	541.0
Sep	17	0.0	46.0	545.0
Sep	18	0.0	48.0	550.0
Sep	19	0.0	49.0	554.0
Sep	20	0.2	50.0	557.0
Sep	21	0.2	51.0	560.0
Sep	22	1.8	48.0	563.0
Sep	23	0.0	49.0	566.0
Sep	24	0.4	50.0	569.0
Sep	25	0.0	51.0	572.0
Sep	26	0.0	52.0	575.0
Sep	27	0.0	53.0	578.0
Sep	28	0.2	55.0	583.0
Sep	29	1.0	56.0	586.0
Sep	30	5.2	37.0	563.0
Oct	1	0.0	38.0	566.0
Oct	2	0.0	39.0	569.0
Oct	3	0.0	39.0	571.0
Oct	4	0.2	39.0	572.0
Oct	5	5.1	25.0	550.0
Oct	6	3.1	19.0	541.0
Oct	7	3.8	13.0	529.0
Oct	8	0.2	14.0	532.0
Oct	9	1.6	15.0	535.0
Oct	10	0.0	15.0	537.0
Oct	11	0.7	15.0	537.0
Oct	12	0.0	15.0	538.0
Oct	13	0.0	16.0	541.0
Oct	14	0.0	17.0	543.0
Oct	15	0.0	18.0	545.0
Oct	16	0.0	19.0	548.0
Oct	17	0.2	20.0	551.0
Oct	18	0.0	20.0	552.0
Oct	19	0.0	20.0	553.0
Oct	20	0.9	20.0	554.0
Oct	21	2.4	17.0	555.0
Oct	22	0.0	17.0	556.0
Oct	23	0.0	17.0	557.0
Oct	24	0.0	17.0	558.0
Oct	25	0.0	17.0	558.0
Oct	26	0.2	17.0	558.0
Oct	27	0.0	17.0	558.0

Month	Day	EIWFE	DMC	DC
Oct	28	0.0	17.0	558.0
Oct	29	0.0	17.0	558.0
Oct	30	0.0	17.0	558.0
Oct	31	0.0	17.0	559.0

APPENDIX 4. Calibration site rain gauges and DMC/DC codes during 2003, from April 11th to Oct 28th.

month	date	post gauge	bush gauge	wx stn gauge	EIWFE DMC	codes DC
April	11	0.0	0.0	0.0	6.0	139.7
April	12	0.0	0.0	0.0	6.7	142.2
April	13	0.0	0.0	0.0	6.9	143.6
April	14	4.0	0.0	0.0	7.1	145.0
April	15	0.0	0.0	7.0	3.4	133.6
April	16	0.0	0.0	0.0	3.8	135.8
April	17	0.0	0.0	0.2	5.4	138.8
April	18	4.8	0.0	0.4	5.7	140.7
April	19	0.0	0.0	4.6	4.7	136.8
April	20	0.0	0.0	0.0	6.8	140.2
April	21	0.0	0.0	0.0	10.4	144.5
April	22	0.0	0.0	0.0	12.7	148.2
April	23	0.0	0.0	0.0	16.1	152.6
April	24	0.0	0.0	0.2	17.2	155.9
April	25	4.0	0.0	2.8	13.3	158.2
April	26	0.0	0.0	0.0	13.6	159.8
April	27	4.2	0.0	7.8	7.1	145.9
April	28	18.4	0.0	18.8	3.3	109.0
April	29	0.0	0.0	0.0	4.9	111.6
April	30	0.0	0.0	0.0	6.7	114.7
May	1	0.0	0.0	0.0	10.2	118.8
May	2	0.0	0.0	0.0	11.0	122.3
May	3	0.0	0.0	2.2	8.9	124.6
May	4	0.0	0.0	0.4	8.9	126.9
May	5	10.0	0.0	6.8	4.6	117.8
May	6	6.0	0.0	10.0	1.8	102.3
May	7	5.8	0.0	7.4	0.3	92.9
May	8	1.6	0.0	1.8	0.1	95.8
May	9	0.0	0.0	0.0	1.4	99.7
May	10	0.0	0.0	0.0	3.7	104.4
May	11	0.0	0.0	0.0	6.8	109.8
May	12	0.0	0.0	0.0	11.2	115.9
May	13	0.0	0.0	0.0	15.3	121.8
May	14	0.0	0.0	0.0	19.5	127.8
May	**15**	0.0	0.0	0.0	22.4	132.5
May	16	14.0	0.0	0.0	11.3	104.9
May	17	0.0	0.0	0.0	12.0	108.2
May	18	0.0	0.0	0.0	13.8	112.1
May	19	0.0	0.0	0.0	17.0	117.0
May	**20**	0.0	0.0	0.0	20.7	122.3
May	21	0.0	0.0	0.0	23.8	127.5
May	22	0.0	0.0	0.0	27.9	133.5
May	23	0.0	0.0	0.0	31.8	139.5
May	24	0.0	0.0	0.0	36.6	146.3
May	25	0.0	0.0	0.0	41.2	153.5
May	26	0.0	0.0	6.2	25.9	147.5
May	27	5.0	0.0	0.0	29.8	153.7
May	**28**	0.0	0.0	0.0	32.9	159.6
May	29	trc	0.0	1.6	34.5	165.0
May	30	0.0	0.0	0.0	38.0	170.8
May	31	0.0	0.0	0.0	41.8	177.0
June	1	0.0	0.0	0.6	43.8	182.7
June	2	0.0	0.0	1.0	43.7	188.6
June	3	28.0	17.0	30.0	16.2	124.9
June	4	17.0	7.0	12.8	9.4	106.9
June	5	0.0	0.0	0.0	10.9	112.4
June	6	trc	0.0	0.0	11.6	117.5
June	7	0.0	0.0	0.0	13.9	123.9
June	8	0.0	0.0	0.0	16.2	130.6
June	**9**	0.0	0.0	0.0	17.6	136.3
June	10	0.0	0.0	0.0	19.5	142.6
June	11	10.5	12.5	3.6	15.1	144.0
June	12	8.6	6.2	7.2	11.2	138.0
June	13	0.0	0.0	0.0	14.3	145.8
June	14	0.0	0.0	0.0	16.5	152.5
June	15	8.0	5.6	6.2	11.8	147.8
June	16	trc	0.0	0.4	15.2	155.0
June	17	0.0	0.0	0.0	19.2	162.5
June	18	0.0	0.0	0.0	22.8	170.4
June	19	0.0	0.0	0.2	25.3	176.9
June	**20**	0.3	0.0	0.0	26.9	182.9
June	21	13.0	10.0	12.6	12.3	160.6
June	22	15.0	10.0	13.6	5.8	136.9
June	23	18.0	12.5	19.0	2.6	103.4
June	24	trc	0.0	0.2	5.4	110.0
June	25	0.0	0.0	0.0	8.9	117.2
June	26	0.0	0.0	0.0	11.6	124.0
June	27	1.8	1.8	2.2	11.6	130.4
June	28	0.0	0.0	0.0	14.9	137.3
June	29	0.0	0.0	0.0	19.1	145.3
June	30	trc	trc	0.4	21.4	152.7
July	1	0.0	0.0	0.0	24.4	159.9
July	2	3.8	2.0	3.8	19.6	161.2
July	3	1.4	0.9	1.6	20.3	167.9
July	**4**	0.5	0.3	0.6	22.2	174.7
July	5	17.6	13.5	16.6	9.8	143.9
July	6	3.0	1.5	3.0	7.1	146.2
July	7	0.0	0.0	0.2	8.8	153.0
July	8	3.0	2.5	2.0	7.9	159.4
July	9	9.0	7.8	9.8	5.4	147.1
July	10	1.3	0.5	0.6	7.6	154.4
July	11	0.0	0.0	0.0	10.4	162.4

month	date	post gauge	bush gauge	wx stn gauge	EIWFE DMC	codes DC	month	date	post gauge	bush gauge	wx stn gauge	EIWFE DMC	codes DC
July	12	0.7	0.5	0.6	12.9	170.3	August	29	0.0	0.0	0.2	15.3	283.3
July	13	0.0	0.0	0.0	15.0	178.0	August	30	0.0	0.0	0.0	17.8	290.3
July	14	n/a	n/a	4.4	12.2	178.1	August	31	0.0	0.0	0.0	21.3	297.6
July	15	0.0	0.0	0.0	15.2	185.7	Septbr	1	1.0	0.4	1.2	23.3	303.6
July	16	0.0	0.0	0.0	17.7	193.5	Septbr	2	0.0	0.0	0.0	25.7	308.7
July	17	7.6	5.4	5.0	12.8	191.2	Septbr	3	0.0	0.0	0.0	28.0	314.5
July	18	0.0	0.0	0.0	16.2	198.8	Septbr	**4**	0.0	0.0	0.0	30.1	320.1
July	19	0.0	0.6	0.0	18.9	206.7	Septbr	5	0.0	0.0	0.0	32.5	325.9
July	20	0.0	0.0	0.0	20.3	214.2	Septbr	6	0.0	0.0	0.0	34.7	331.9
July	21	3.3	2.0	3.0	17.7	218.0	Septbr	7	0.0	0.0	0.0	37.1	337.8
July	22	0.0	0.0	0.0	20.4	226.2	Septbr	**8**	0.0	0.0	1.4	38.2	342.1
July	**23**	0.0	0.0	0.0	23.4	234.4	Septbr	9	0.0	0.0	0.0	38.8	345.7
July	24	6.0	4.0	5.8	14.4	227.9	Septbr	10	15.0	9.8	13.6	19.1	306.3
July	25	7.0	5.6	6.0	8.5	221.0	Septbr	11	0.0	0.0	0.0	21.4	311.1
July	26	0.6	0.5	0.2	11.2	228.7	Septbr	12	2.0	0.7	2.6	17.4	314.2
July	27	0.0	0.0	0.0	14.9	237.2	Septbr	**13**	1.0	0.3	0.2	18.5	318.4
July	28	0.0	0.0	0.0	17.9	244.9	Septbr	14	0.0	0.0	0.0	18.9	322.0
July	29	0.0	0.0	0.0	20.9	252.6	Septbr	15	0.0	0.0	0.0	19.2	324.6
July	30	0.0	0.0	0.0	24.3	260.9	Septbr	16	trc	trc	0.0	19.3	326.5
July	31	0.0	0.0	0.0	28.4	269.7	Septbr	17	0.0	0.0	0.0	19.4	328.4
August	1	0.0	0.0	0.0	32.3	278.4	Septbr	18	0.0	0.0	0.0	20.0	331.6
August	2	0.0	0.0	0.0	35.0	285.5	Septbr	19	0.0	0.0	0.0	21.2	336.0
August	3	0.0	0.0	0.0	38.4	293.0	Septbr	20	0.0	0.0	0.2	22.3	339.9
August	4	0.0	0.0	0.0	40.2	299.5	Septbr	21	0.0	0.0	0.0	23.7	343.8
August	5	0.0	0.0	0.0	42.2	306.3	Septbr	22	0.2	0.1	0.0	24.8	348.0
August	6	0.0	0.0	0.0	44.4	313.5	Septbr	23	3.0	2.0	2.6	21.2	351.2
August	7	0.0	0.0	4.0	33.4	311.6	Septbr	24	0.0	0.0	0.0	22.3	354.7
August	8	5.6	3.6	1.6	33.1	318.0	Septbr	25	0.0	0.0	0.0	23.9	358.8
August	9	0.0	0.0	0.0	35.8	325.6	Septbr	26	0.0	0.0	0.2	25.4	363.2
August	10	2.7	0.6	2.2	32.5	332.4	Septbr	27	0.0	0.0	0.0	27.2	367.6
August	11	14.5	10.0	11.4	15.4	302.9	Septbr	**28**	0.0	0.0	0.0	28.3	371.5
August	12	0.0	0.0	0.0	17.0	309.8	Septbr	29	0.0	0.0	0.0	29.4	374.8
August	13	18.5	17.5	18.4	9.8	261.3	Septbr	**30**	0.0	0.0	0.0	31.4	379.3
August	14	0.0	0.0	0.0	13.3	268.7	Octbr	1	0.0	0.0	0.0	33.6	384.3
August	15	0.0	0.0	0.0	17.0	276.5	Octbr	2	0.0	0.0	0.0	35.0	387.9
August	16	0.9	0.9	0.2	17.8	282.7	Octbr	3	0.0	0.0	0.2	37.2	392.3
August	17	0.0	0.0	1.0	20.6	289.7	Octbr	4	0.0	0.0	0.0	39.2	396.5
August	18	0.0	0.0	0.0	22.8	297.0	Octbr	5	0.0	0.0	0.0	41.6	401.1
August	19	2.3	2.0	0.0	25.3	303.6	Octbr	6	0.0	0.0	0.0	44.3	406.0
August	20	0.0	0.0	2.6	22.7	310.0	Octbr	**7**	0.0	0.0	0.0	46.2	410.3
August	21	0.0	0.0	0.0	24.9	316.9	Octbr	8	0.0	0.0	0.2	47.7	413.9
August	22	0.0	0.0	0.0	26.8	323.5	Octbr	9	0.0	0.0	0.0	49.3	417.1
August	23	trc	trc	0.0	27.5	328.9	Octbr	10	0.0	0.0	0.0	50.5	419.9
August	24	0.0	0.0	0.0	29.8	335.0	Octbr	11	0.0	0.0	0.0	51.8	422.8
August	25	0.0	0.0	0.0	32.2	341.1	Octbr	12	0.0	0.0	0.0	52.8	425.3
August	**26**	0.0	0.0	0.0	34.9	347.9	Octbr	13	0.0	0.0	0.0	53.7	427.7
August	27	0.6	0.2	0.6	35.2	353.0	Octbr	14	0.6	0.3	0.2	53.9	429.4
August	28	25.0	20.0	24.6	13.2	276.7	Octbr	15	0.2	trc	0.6	54.0	430.3

month	date	post gauge	bush gauge	wx stn gauge	EIWFE DMC	codes DC
Octbr	16	0.0	0.0	0.0	54.2	431.8
Octbr	**17**	0.0	0.0	0.0	54.9	434.4
Octbr	18	0.0	0.0	1.0	56.1	437.7
Octbr	**19**	0.0	0.0	0.2	56.5	439.7
Octbr	20	0.0	0.0	0.0	56.9	441.8
Octbr	21	0.5	0.4	0.8	58.6	445.7
Octbr	22	0.0	0.0	0.0	60.0	448.8
Octbr	23	12.0	8.2	11.6	29.6	403.1
Octbr	24	0.0	0.0	0.4	29.7	404.1
Octbr	25	0.0	0.0	0.0	30.3	406.1
Octbr	26	1.2	0.6	1.0	31.3	409.4
Octbr	27	trc	trc	0.2	32.0	411.7
Octbr	**28**	0.0	0.0	0.0	32.1	412.8
Octbr	29	snow	snow	snow		
Octbr	30					
Octbr	31					

APPENDIX 5. DMC/DC codes for all calibration sites in 2004 for the dates April 10th to Oct 31st, 2004.

	EINP		EI summer		EI		EI summer		EI fall	
	open		oldtarp Jun03		spring		nwtarp May04		tarp Sep4/04	
date	DMC	DC	DMC	DC	DMC	DC	DMC	DC	DMC	DC
Apr10	6.0	206.0	256.0	891.0	6.0	206.0				
Apr11	9.0	209.8	259.0	895.0	9.0	210.0				
Apr12	9.6	211.6	260.0	897.0	9.6	212.0				
Apr13	9.7	212.6	260.0	898.0	9.7	213.0				
Apr14	9.7	213.3	260.0	898.0	9.7	213.0				
Apr15	4.5	186.1	260.0	899.0	4.5	186.0				
Apr16	4.6	187.0	260.0	900.0	4.6	187.0				
Apr17	5.0	188.6	260.0	902.0	5.0	189.0				
Apr18	6.2	191.0	262.0	904.0	6.2	191.0				
Apr19	8.0	194.0	263.0	907.0	8.0	194.0				
Apr20	9.3	196.7	265.0	910.0	9.3	197.0				
Apr21	11.5	200.0	267.0	913.0	11.5	200.0				
Apr22	13.0	202.5	268.0	916.0	13.0	203.0				
Apr23	16.0	206.2	271.0	919.0	16.0	206.0				
Apr24	17.7	208.7	273.0	922.0	17.7	209.0				
Apr25	19.7	211.7	275.0	925.0	19.7	212.0				
Apr26	23.8	216.5	279.0	930.0	23.8	217.0				
Apr27	25.7	219.9	281.0	933.0	25.7	220.0				
Apr28	14.7	204.5	282.0	935.0	14.7	204.0				
Apr29	16.6	207.4	284.0	938.0	16.6	207.0				
Apr30	18.9	210.5	286.0	941.0	18.9	210.0				
May01	22.3	214.6	290.0	947.0	22.5	216.0				
May02	27.7	221.3	295.0	953.0	27.9	223.0				
May03	28.5	224.9	296.0	957.0	28.7	226.0				
May04	30.4	229.7	298.0	962.0	30.6	231.0				
May05	30.9	232.5	298.0	965.0	31.1	234.0				
May06	32.6	236.4	300.0	968.0	32.8	238.0				
May07	34.0	240.4	301.0	972.0	34.2	242.0				
May08	37.8	246.2	305.0	978.0	38.0	248.0				
May09	38.2	248.8	306.0	981.0	38.4	250.0				
May10	38.7	251.9	306.0	984.0	38.9	253.0				
May11	41.0	256.1	308.0	988.0	41.2	258.0				
May12	42.9	260.1	310.0	992.0	43.1	262.0				
May13	44.0	263.5	312.0	996.0	44.2	265.0				
May14	45.9	267.8	313.0	1000.0	46.1	269.0				
May15	47.8	272.0	315.0	1004.0	48.0	274.0				
May16	51.2	277.4	319.0	1009.0	51.4	279.0				
May17	55.5	283.3	323.0	1015.0	55.7	285.0				
May18	60.8	290.0	328.0	1022.0	61.0	292.0				
May19	63.5	295.3	331.0	1027.0	63.7	297.0				
May20	65.6	299.9	333.0	1032.0	**65.8**	**301.0**				
May21	68.1	304.7	336.0	1037.0	68.3	306.0				
May22	70.6	309.3	338.0	1041.0	70.8	311.0				
May23	72.9	313.8	340.0	1046.0	73.1	315.0				
May24	75.6	318.7	343.0	1051.0	75.8	320.0				

date	EINP open DMC	DC	EI sum old tarp DMC	03 DC	EI DMC	spring DC	EI nwtrp DMC	sum May04 DC	Elfall Sep04 DMC	DC
May25	79.4	324.5	347.0	1057.0	**79.6**	**326.0**				
May26	82.4	330.1	350.0	1062.0	82.6	332.0				
May27	87.4	336.6	355.0	1069.0	87.6	338.0	87.6	338.0		
May28	90.8	342.7	358.0	1075.0	**91.0**	**344.0**	91.0	344.0		
May29	38.9	244.6	358.0	1079.0			40.8	274.0		
May30	12.3	117.9	359.0	1083.0			13.9	169.0		
May31	10.4	119.5	**360.0**	**1087.0**			15.5	174.0		
Jun01	**13.3**	**125.1**	tarp fini				18.4	181.0		
Jun02	**13.2**	**131.3**					20.3	187.0		
Jun03	17.2	138.5					24.3	194.0		
Jun04	**22.2**	**146.2**					29.3	202.0		
Jun05	27.0	154.0					34.1	210.0		
Jun06	18.3	151.4					35.7	216.0		
Jun07	20.9	157.3					**38.3**	**222.0**		
Jun08	23.6	163.6					41.0	228.0		
Jun09	26.9	170.3					**44.3**	**235.0**		
Jun10	27.6	176.2					**45.0**	**241.0**		
Jun11	20.3	176.3					45.3	246.0		
Jun12	9.1	147.6					45.5	251.0		
Jun13	10.3	153.2					46.8	257.0		
Jun14	**7.0**	**161.0**					**47.4**	**262.0**		
Jun15	6.0	167.0					49.2	268.0		
Jun16	4.0	166.0					49.7	273.0		
Jun17	7.0	172.0					**52.4**	**279.0**		
Jun18	11.0	179.0					56.6	286.0		
Jun19	15.0	187.0					61.0	294.0		
Jun20	18.0	193.0					**63.5**	**300.0**		
Jun21	22.0	201.0					67.5	308.0		
Jun22	25.0	207.0					**70.6**	**314.0**		
Jun23	**28.0**	**214.0**					73.6	321.0		
Jun24	**32.0**	**221.0**					**77.4**	**328.0**		
Jun25	**36.0**	**228.0**					**81.8**	**335.0**		
Jun26	44.0	242.0					85.7	342.0		
Jun27	48.0	250.0					90.2	350.0		
Jun28	**54.0**	**258.0**					**95.3**	**358.0**		
Jun29	**57.0**	**266.0**					**98.4**	**366.0**		
Jun30	**60.0**	**274.0**					**101.0**	**374.0**		
Jul01	**62.0**	**282.0**					**104.0**	**381.0**		
Jul02	**64.0**	**289.0**					**106.0**	**389.0**		
Jul03	22.0	112.0					106.0	394.0		
Jul04	15.0	112.0					107.0	400.0		
Jul05	17.0	118.0					108.0	407.0		
Jul06	18.0	126.0					110.0	414.0		
Jul07	7.0	76.0					110.0	420.0		
Jul08	4.0	67.0					110.0	426.0		
Jul09	2.0	51.0					112.0	432.0		
Jul10	5.0	59.0					114.0	440.0		

date	EINP open DMC	DC	EI sum old tarp 03 DMC	DC	EI spring DMC	DC	EI nwtrp sum May04 DMC	DC	EIfall Sep04 DMC	DC
Jul11	7.0	66.0					116.0	448.0		
Jul12	5.0	61.0					118.0	455.0		
Jul13	7.0	69.0					120.0	463.0		
Jul14	7.0	76.0					**123.0**	**470.0**		
Jul15	10.0	85.0					***125.0***	***479.0***		
Jul16	12.0	93.0					127.0	487.0		
Jul17	15.0	102.0					130.0	496.0		
Jul18	18.0	110.0					133.0	504.0		
Jul19	13.0	112.0					134.0	511.0		
Jul20	15.0	120.0					136.0	519.0		
Jul21	16.0	127.0					**137.0**	**526.0**		
Jul22	18.0	134.0					139.0	533.0		
Jul23	21.0	142.0					143.0	541.0		
Jul24	25.0	150.0					146.0	549.0		
Jul25	28.0	158.0					149.0	557.0		
Jul26	16.0	147.0					**151.0**	**565.0**		
Jul27	13.0	153.0					151.0	570.0		
Jul28	15.0	159.0					153.0	577.0		
Jul29	18.0	167.0					*156.0*	*585.0*		
Jul30	15.0	170.0					*158.0*	*592.0*		
Jul31	17.0	177.0					*160.0*	*599.0*		
Aug01	18.0	183.0					*161.0*	*605.0*		
Aug02	20.0	190.0					*164.0*	*612.0*		
Aug03	22.0	197.0					*166.0*	*619.0*		
Aug04	20.0	203.0					*166.0*	*626.0*		
Aug05	9.0	161.0					*167.0*	*632.0*		
Aug06	10.0	168.0					*168.0*	*638.0*		
Aug07	11.0	173.0					*168.0*	*644.0*		
Aug08	11.0	178.0					*169.0*	*649.0*		
Aug09	13.0	184.0					*171.0*	*655.0*		
Aug10	15.0	191.0					*173.0*	*661.0*		
Aug11	18.0	198.0					*176.0*	*668.0*		
Aug12	21.0	205.0					*179.0*	*676.0*		
Aug13	25.0	213.0								
Aug14	26.0	220.0								
Aug15	28.0	227.0								
Aug16	30.0	234.0								
Aug17	33.0	240.0								
Aug18	35.0	247.0								
Aug19	36.0	253.0								
Aug20	38.0	259.0								
Aug21	26.0	255.0								
Aug22	19.0	253.0								
Aug23	9.0	224.0								
Aug24	9.0	229.0								
Aug25	11.0	235.0								
Aug26	12.0	240.0								

date	EINP open DMC	DC	EI sum old tarp DMC	03 DC	EI DMC	spring DC	EI nwtrp DMC	sum May04 DC	EIfall Sep04 DMC	DC
Aug27	14.0	247.0								
Aug28	15.0	253.0								
Aug29	16.0	258.0								
Aug30	15.0	264.0								
Aug31	16.0	270.0								
Sep01	16.0	274.0								
Sep02	17.0	278.0								
Sep03	10.0	269.0								
Sep04	7.0	262.0							7.0	262.0
Sep05	4.0	257.0							7.2	265.0
Sep06	5.0	261.0							8.1	269.0
Sep07	5.0	265.0							9.4	274.0
Sep08	4.0	268.0							9.6	277.0
Sep09	1.0	230.0							9.7	279.0
Sep10	1.0	232.0							9.8	281.0
Sep11	2.0	235.0							10.0	285.0
Sep12	3.0	239.0							11.4	289.0
Sep13	5.0	244.0							13.1	293.0
Sep14	6.0	249.0							14.6	298.0
Sep15	7.0	252.0							15.3	302.0
Sep16	8.0	256.0							16.0	306.0
Sep17	4.0	230.0							16.3	309.0
Sep18	3.0	234.0							16.6	313.0
Sep19	2.0	237.0							17.0	316.0
Sep20	2.0	240.0							17.7	319.0
Sep21	4.0	244.0							19.4	324.0
Sep22	6.0	249.0							21.4	328.0
Sep23	7.0	253.0							22.6	333.0
Sep24	10.0	258.0							24.9	338.0
Sep25	12.0	263.0							27.0	343.0
Sep26	11.0	268.0							28.7	347.0
Sep27	12.0	272.0							30.5	352.0
Sep28	14.0	277.0							32.6	357.0
Sep29	15.0	281.0							33.3	360.0
Sep30	16.0	283.0							33.6	362.0
Oct01	17.0	285.0							34.7	365.0
Oct02	18.0	289.0							36.2	368.0
Oct03	19.0	290.0							36.7	370.0
Oct04	21.0	295.0							39.1	374.0
Oct05	23.0	299.0							41.4	379.0
Oct06	24.0	303.0							42.6	382.0
Oct07	26.0	306.0							44.3	385.0
Oct08	27.0	309.0							45.2	388.0
Oct09	28.0	311.0							45.7	390.0
Oct10	29.0	314.0							47.5	394.0
Oct11	31.0	318.0							49.3	398.0
Oct12	32.0	321.0							50.1	400.0

date	EINP open DMC	DC	EI sum old tarp DMC	03 DC	EI DMC	spring DC	EI nwtrp DMC	sum May04 DC	Elfall Sep04 DMC	DC
Oct13	33.0	324.0							51.2	404.0
Oct14	34.0	327.0							52.4	407.0
Oct15	34.0	328.0							52.7	408.0
Oct16	34.0	329.0							\	\
Oct17	32.0	329.0							\	\
Oct18	32.0	330.0							\	\
Oct19	32.0	330.0								
Oct20	32.0	330.0								
Oct21	32.0	330.0								
Oct22	32.0	331.0								
Oct23	32.0	331.0								
Oct24	32.0	332.0								
Oct25	15.0	298.0								
Oct26	8.0	274.0								
Oct27	8.0	275.0								
Oct28	8.0	276.0								
Oct29	8.0	277.0								
Oct30	9.0	279.0								
Oct31	9.0	281.0								

APPENDIX 6. Validation DMC/DC codes for the period of May 28th to September 8th, 2004.

	Beaver		Beaver tarp1		Beaver retarped		Goose		Goose tarp1		Tawayik		Tawayik tarp1	
date	DMC	DC	DMC	DC	DMC	DC	DMC	DC	DMC	DC	DMC	DC	DMC	DC
May28	90.8	343.0					90.8	343.0			90.8	343.0		
May29	41.2	279.0					43.6	298.0			42.6	292.0		
May30	14.0	169.0					16.1	215.0			15.2	198.0		
May31	15.6	174.0					17.7	219.0			16.8	203.0		
Jun01	18.5	180.0					20.6	226.0			19.7	210.0		
Jun02	20.4	186.0					21.5	232.0			21.6	216.0		
Jun03	24.4	194.0					25.5	239.0			25.6	223.0		
Jun04	29.4	201.0					30.5	247.0			30.6	231.0		
Jun05	34.2	209.0					35.3	255.0			35.4	239.0		
Jun06	35.8	216.0					36.9	261.0			37.0	245.0		
Jun07	25.0	211.0					39.5	267.0			39.6	251.0		
Jun08	27.7	217.0					42.2	274.0			42.3	257.0		
Jun09	31.0	224.0					45.5	280.0			45.6	264.0		
Jun10	31.7	230.0					46.2	286.0			46.3	270.0		
Jun11	20.9	226.0					36.0	286.0			34.7	269.0		
Jun12	10.4	206.0					18.7	267.0			18.9	254.0		
Jun13	11.7	211.0					20.0	273.0			20.2	260.0		
Jun14	8.2	210.0					20.6	278.0			17.8	265.0		
Jun15	8.0	217.0					17.1	279.0			14.3	265.0		
Jun16	4.5	208.0					12.9	278.0			10.6	265.0		
Jun17	7.2	214.0					15.6	284.0			13.3	271.0		
Jun18	11.4	221.0					19.8	291.0			17.5	278.0		
Jun19	15.8	229.0					24.2	299.0			21.9	285.0		
Jun20	18.3	235.0					26.7	305.0			24.4	292.0		
Jun21	22.3	242.0					**30.7**	**313.0**			**28.4**	**299.0**		
Jun22	**25.4**	**249.0**					33.8	319.0			31.5	305.0		
Jun23	28.4	256.0					36.8	326.0			34.5	312.0		
Jun24	32.2	263.0					40.6	333.0			38.3	319.0		
Jun25	36.6	270.0					45.0	340.0			42.7	327.0		
Jun26	40.5	277.0					48.9	347.0			46.6	334.0		
Jun27	45.0	285.0					53.4	355.0			51.1	341.0		
Jun28	50.1	293.0					58.5	363.0			56.2	350.0		
Jun29	53.2	301.0					61.6	371.0			59.3	357.0		
Jun30	56.2	309.0					64.6	379.0			62.3	365.0		
Jul01	58.4	316.0					66.8	387.0			64.5	373.0		
Jul02	32.2	295.0					68.9	394.0			66.6	381.0		
Jul03	9.1	95.2					25.0	194.0			23.0	133.0		
Jul04	5.6	92.0					16.6	191.0			14.3	129.0		
Jul05	7.2	98.5					18.2	197.0			15.9	135.0		
Jul06	8.9	106.0					19.9	204.0			17.6	142.0		
Jul07	3.9	69.7					7.7	131.0			7.1	83.1		
Jul08	1.5	57.5					4.5	130.0			3.5	77.3		
Jul09	1.4	43.0					3.1	122.0			2.6	70.9		
Jul10	3.8	50.5					5.5	130.0			5.0	78.4		
Jul11	5.8	58.1					7.5	137.0			7.0	86.0		
Jul12	4.2	56.1					5.7	138.0			5.4	87.7		

Jul13	6.8	64.0					8.3	146.0			8.0	95.6		
Jul14	9.0	71.6					7.6	150.0			6.7	96.9		
Jul15	**11.6**	**79.8**	11.6	79.8			10.2	158.0			9.3	105.0		
Jul16	14.0	88.1	14.0	88.1			12.6	166.0	12.6	166.0	**11.7**	**113.0**	11.7	113.0
Jul17	16.7	96.8	16.7	96.8			15.3	175.0	15.3	175.0	14.4	122.0	14.4	122.0
Jul18	19.9	105.0	19.9	105.0			18.5	183.0	18.5	183.0	17.6	131.0	17.6	131.0
Jul19	20.3	113.0	20.3	113.0			9.5	169.0	18.9	191.0	11.1	130.0	18.0	138.0
Jul20	22.3	120.0	22.3	120.0			11.5	176.0	**20.9**	**198.0**	13.1	137.0	**20.0**	**146.0**
Jul21	14.6	118.0	**23.5**	**127.0**			10.9	183.0	22.1	205.0	11.4	144.0	21.2	152.0
Jul22	17.0	125.0	25.9	134.0			13.3	191.0	**24.5**	**212.0**	13.8	151.0	**23.6**	**159.0**
Jul23	20.2	133.0	29.1	142.0			16.5	198.0	27.7	220.0	17.0	159.0	26.8	167.0
Jul24	23.6	142.0	32.5	150.0			19.9	207.0	31.1	229.0	20.4	167.0	30.2	176.0
Jul25	26.3	150.0	35.2	159.0			22.6	215.0	33.8	237.0	23.1	176.0	32.9	184.0
Jul26	14.0	132.0	**37.2**	**166.0**			10.7	160.0	35.8	244.0	10.7	121.0	34.9	191.0
Jul27	12.9	138.0	37.5	172.0			9.7	166.0	36.1	250.0	11.0	126.0	35.2	197.0
Jul28	15.2	145.0	*39.8*	*178.0*	13.0	138.0	12.0	173.0	38.4	257.0	13.3	133.0	37.5	204.0
Jul29	17.9	152.0			15.7	146.0	14.7	180.0	**41.1**	**264.0**	16.0	141.0	**40.2**	**211.0**
Jul30	14.6	155.0			18.0	153.0	12.6	183.0	43.4	272.0	15.7	149.0	42.5	219.0
Jul31	16.0	161.0			19.4	160.0	14.0	190.0	44.8	279.0	17.1	155.0	43.9	226.0
Aug01	17.7	167.0			21.1	166.0	15.7	196.0	46.5	285.0	18.8	161.0	45.6	232.0
Aug02	19.8	174.0			**23.2**	**173.0**	17.8	203.0	48.6	292.0	20.9	168.0	**47.7**	**239.0**
Aug03	21.9	181.0			25.3	180.0	19.9	210.0	**50.7**	**299.0**	23.0	176.0	49.8	246.0
Aug04	21.0	188.0			25.8	186.0	16.7	216.0	51.2	305.0	23.5	182.0	50.3	252.0
Aug05	9.5	150.0			**26.7**	**193.0**	7.5	153.0	52.1	312.0	10.7	150.0	51.2	258.0
Aug06	8.4	156.0			27.9	199.0	8.7	160.0	53.3	318.0	11.1	157.0	52.4	265.0
Aug07	7.5	161.0			28.1	204.0	8.9	165.0	53.5	323.0	11.3	162.0	52.6	270.0
Aug08	8.1	166.0			28.7	209.0	9.5	170.0	54.1	328.0	11.9	167.0	53.2	275.0
Aug09	9.8	172.0			30.4	215.0	11.2	176.0	55.8	334.0	13.6	173.0	54.9	281.0
Aug10	12.2	179.0			32.8	222.0	13.6	183.0	**58.2**	**341.0**	16.0	179.0	**57.3**	**288.0**
Aug11	15.3	186.0			**35.9**	**229.0**	16.7	190.0	61.3	348.0	19.1	187.0	60.4	295.0
Aug12	18.5	193.0			39.1	237.0	19.9	197.0	**64.5**	**355.0**	22.3	194.0	**63.6**	**302.0**
Aug13	21.6	201.0			42.2	244.0	23.0	205.0	67.6	363.0	25.4	202.0	66.7	310.0
Aug14	23.3	208.0			43.9	251.0	24.7	212.0	69.3	370.0	27.1	209.0	68.4	317.0
Aug15	25.2	215.0			45.8	258.0	26.6	219.0	71.2	377.0	29.0	215.0	70.3	324.0
Aug16	27.2	222.0			**47.8**	**265.0**	28.6	226.0	73.2	384.0	31.0	222.0	72.3	331.0
Aug17	29.5	229.0			50.1	272.0	30.9	232.0	75.5	390.0	33.3	229.0	**74.6**	**337.0**
Aug18	31.7	235.0			**52.3**	**278.0**	33.1	239.0	77.7	397.0	35.5	235.0	76.8	344.0
Aug19	33.1	241.0			53.7	284.0	34.5	245.0	79.1	403.0	36.9	242.0	78.2	350.0
Aug20	34.9	248.0			**55.5**	**291.0**	36.3	251.0	80.9	410.0	38.7	248.0	80.0	356.0
Aug21	24.7	245.0			55.7	296.0	28.7	252.0	81.1	414.0	27.6	246.0	80.2	361.0
Aug22	19.3	245.0			56.0	300.0	25.9	256.0	81.4	419.0	21.7	246.0	80.5	366.0
Aug23	9.1	218.0			56.1	304.0	13.9	241.0	81.5	423.0	9.3	206.0	80.6	370.0
Aug24	8.2	223.0			56.9	310.0	14.7	246.0	82.3	428.0	9.1	211.0	81.4	375.0
Aug25	10.0	229.0			58.7	315.0	16.5	252.0	84.1	434.0	10.9	217.0	83.2	381.0
Aug26	11.7	235.0			60.4	321.0	18.2	258.0	85.8	440.0	12.6	223.0	84.9	387.0
Aug27	13.5	241.0			62.2	328.0	20.0	265.0	87.6	447.0	14.4	229.0	86.7	394.0
Aug28	14.2	247.0			62.9	334.0	20.7	270.0	88.3	452.0	15.1	235.0	87.4	399.0
Aug29	15.5	253.0			64.2	339.0	22.0	276.0	89.6	458.0	16.4	241.0	88.7	405.0
Aug30	9.0	242.0			64.8	345.0	16.0	274.0	90.2	464.0	13.9	246.0	89.3	411.0
Aug31	9.7	247.0			65.5	351.0	16.7	280.0	90.9	469.0	14.6	252.0	90.0	416.0

Sep01	10.2	252.0			66.0	355.0	17.2	284.0	91.4	474.0	15.1	256.0	90.5	421.0
Sep02	8.1	256.0			66.6	359.0	17.8	288.0	92.0	478.0	14.9	261.0	91.1	425.0
Sep03	4.6	248.0			66.9	363.0	14.8	292.0	92.3	482.0	10.9	259.0	91.4	429.0
Sep04	3.1	245.0			67.7	367.0	10.9	290.0	93.1	486.0	7.2	254.0	92.2	433.0
Sep05	1.7	243.0			67.9	371.0	8.4	293.0	93.3	489.0	4.7	251.0	92.4	436.0
Sep06	2.6	247.0			68.8	375.0	9.3	297.0	94.2	493.0			93.3	440.0
Sep07	3.9	241.0			70.1	379.0	9.9	301.0	95.5	498.0			94.6	445.0
Sep08	4.1	254.0			70.3	382.0	8.9	304.0	95.7	501.0			94.8	448.0

APPENDIX 7. Precipitation amounts (mm) for 2004 at both calibration and validation plot areas, in comparison to the Elk Island National Park (EIWFE) gauge readings.

2004		Calibration Plots			Validation Plots			EINP
Month	Date	Home Gauge	Post Gauge	Bush Gauge	Beaver Gauge	Tawayik Gauge	Goose Gauge	EIWFE Gauge
Apr	1	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	2	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	3	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	4	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	5	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	6	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	7	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	8	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	9	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	10	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	11	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	12	0.0	trc	0.0	n/a	n/a	n/a	0.0
Apr	13	s	s	n/a	n/a	n/a	n/a	3.0
Apr	14	s	s	n/a	n/a	n/a	n/a	2.0
Apr	15	15.0	12.0	n/a	n/a	n/a	n/a	4.0
Apr	16	1.0	1.0	n/a	n/a	n/a	n/a	1.0
Apr	17	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	18	\	1.4	1.0	n/a	n/a	n/a	1.4
Apr	19	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	20	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	21	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	22	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	23	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	24	\	0.2	0.0	n/a	n/a	n/a	0.2
Apr	25	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	26	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	27	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	28	6.8	7.8	5.0	n/a	n/a	n/a	7.8
Apr	29	0.0	0.0	0.0	n/a	n/a	n/a	0.0
Apr	30	0.0	0.0	0.0	n/a	n/a	n/a	0.0
May	1	0.0	0.0	0.0	n/a	n/a	n/a	0.0
May	2	0.0	0.0	0.0	n/a	n/a	n/a	0.0
May	3	0.0	0.0	0.0	n/a	n/a	n/a	0.0
May	4	0.7	0.8	0.4	n/a	n/a	n/a	0.8
May	5	0.4	0.7	0.1	0.6	2.1	2.6	0.7
May	6	0.0	0.0	0.0	\	\	\	0.0
May	7	0.0	0.0	0.0	\	\	\	0.0
May	8	0.0	0.0	0.0	\	\	\	0.0
May	9	0.5	0.0	0.0	\	\	\	0.2
May	10	0.0	0.0	0.0	\	\	\	0.0
May	11	0.0	0.0	0.0	\	\	\	0.0
May	12	0.0	0.0	0.0	\	\	\	0.0
May	13	0.0	0.0	0.0	0.0	\	0.2	0.0

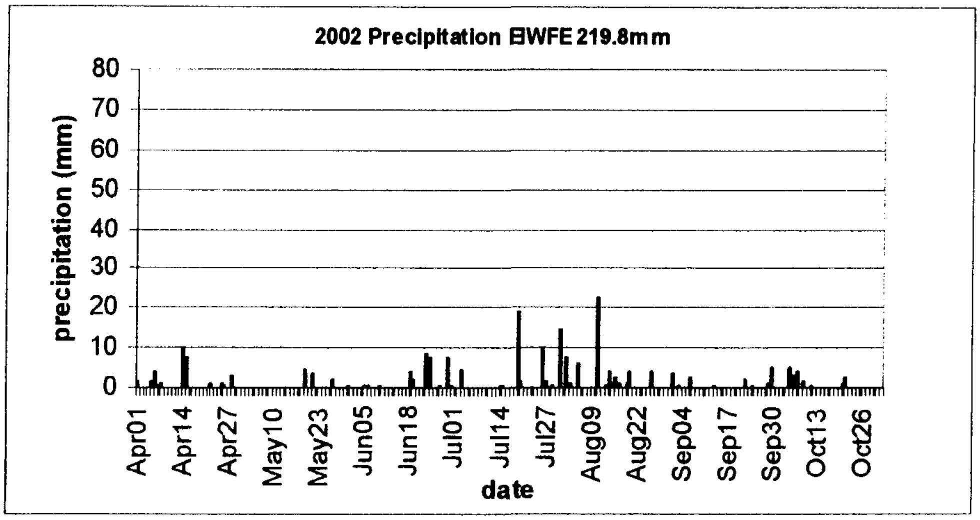
2004 Month	Date	Calibration Plots Home Gauge	Post Gauge	Bush Gauge	Validation Plots Beaver Gauge	Tawayik Gauge	Goose Gauge	EINP EIWFE Gauge
May	14	0.0	0.0	0.0	\	\	\	0.0
May	15	0.3	trc	0.0	trc	\	0.0	0.4
May	16	0.0	0.0	0.0	\	\	\	0.0
May	17	0.0	0.0	0.0	\	\	\	0.0
May	18	0.0	0.0	0.0	\	\	\	0.0
May	19	0.0	0.0	0.0	\	\	\	0.0
May	20	0.0	0.0	0.0	\	\	\	0.0
May	21	0.0	0.0	0.0	\	\	\	0.0
May	22	0.0	0.0	0.0	\	\	\	0.0
May	23	0.0	0.0	0.0	\	\	\	0.0
May	24	0.0	0.0	0.0	\	\	\	0.0
May	25	0.0	0.0	0.0	\	\	\	0.0
May	26	0.0	trc	0.0	0.0	trc	0.2	0.2
May	27	0.0	0.0	0.0	\	\	\	0.0
May	28	2.0	0.3	0.0	\	\	\	0.4
May	29	\	19.7	12.8	20.8	17.0	15.0	22.5
May	30	56.0	39.3	25.7	41.7	34.0	30.0	40.2
May	31	0.0	0.0	0.0	\	\	\	0.2
Jun	1	0.0	0.0	0.0	\	\	\	0.0
Jun	2	1.8	1.4	0.7	trc	1.5	1.6	1.5
Jun	3	0.0	0.0	0.0	\	\	\	0.0
Jun	4	0.0	0.0	0.0	\	\	\	0.0
Jun	5	0.0	0.0	0.0	\	\	\	0.0
Jun	6	4.6	4.6	4.6	\	\	\	4.6
Jun	7	trc	trc	trc	5.4	0.5	0.7	0.2
Jun	8	0.0	0.0	0.0	\	\	\	0.0
Jun	9	0.0	0.0	0.0	\	\	\	0.0
Jun	10	0.5	0.9	0.8	\	\	\	0.8
Jun	11	3.6	4.0	3.6	4.8	3.6	3.2	3.6
Jun	12	10.0	11.5	9.0	10.5	7.7	8.8	10.5
Jun	13	1.0	1.0	0.5	0.8	0.5	0.5	1.0
Jun	14	5.4	5.0	5.0	3.8	2.2	1.4	5.2
Jun	15	1.6	2.2	1.8	2.3	3.6	3.2	2.8
Jun	16	4.6	3.0	2.0	6.4	3.2	3.2	4.0
Jun	17	0.8	1.4	0.6	0.9	trc	0.3	1.0
Jun	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	20	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	21	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	22	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	23	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	25	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	26	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	27	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	28	0.0	0.0	0.0	0.0	0.0	0.0	0.0

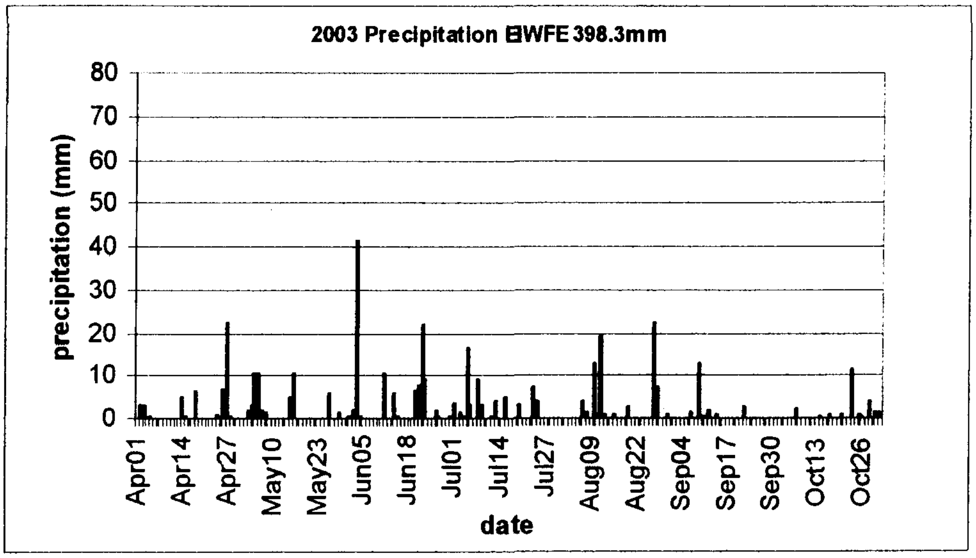
2004 Month	Date	Calibration Plots Home Gauge	Calibration Plots Post Gauge	Calibration Plots Bush Gauge	Validation Plots Beaver Gauge	Validation Plots Tawayik Gauge	Validation Plots Goose Gauge	EINP EIWFE Gauge
Jun	29	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	30	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	2	0.2	0.0	0.0	9.9	0.0	0.0	0.2
Jul	3	66.0	69.0	75.0	80.0	85.0	63.0	70.2
Jul	4	5.0	5.0	6.0	6.0	6.0	5.0	4.4
Jul	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	7	27.0	24.5	25.5	22.3	31.9	33.9	28.4
Jul	8	7.8	10.5	10.4	11.0	7.4	4.3	8.8
Jul	9	13.0	14.0	12.0	13.0	8.2	8.2	13.6
Jul	10	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Jul	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	12	6.5	15.5	24.5	6.5	4.3	4.3	8.2
Jul	13	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	14	2.6	1.5	0.8	0.4	4.6	3.2	2.4
Jul	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	16	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	17	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	18	0.0	0.0	0.0	0.0	0.0	0.0	1.4
Jul	19	2.8	4.6	4.2	1.3	5.2	10.2	4.0
Jul	20	0.9	1.4	1.3	1.2	0.5	trc	1.1
Jul	21	5.2	4.4	3.1	5.6	2.5	2.0	0.0
Jul	22	trc	trc	0.3	0.2	0.0	trc	0.2
Jul	23	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	25	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	26	8.0	9.0	8.5	12.4	28.0	25.5	9.4
Jul	27	1.5	2.8	1.4	1.8	1.3	1.8	2.4
Jul	28	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	29	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	30	2.6	4.1	4.2	3.8	2.2	3.4	3.4
Jul	31	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	4	1.5	2.1	2.1	1.7	0.8	2.5	2.0
Aug	5	19.5	19.0	23.0	19.5	17.0	28.5	20.4
Aug	6	0.6	1.4	1.3	2.4	1.6	1.0	1.4
Aug	7	0.0	1.2	0.1	1.8	1.2	0.2	1.2
Aug	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	10	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Aug	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	13	0.0	0.0	0.0	0.0	0.0	0.0	0.0

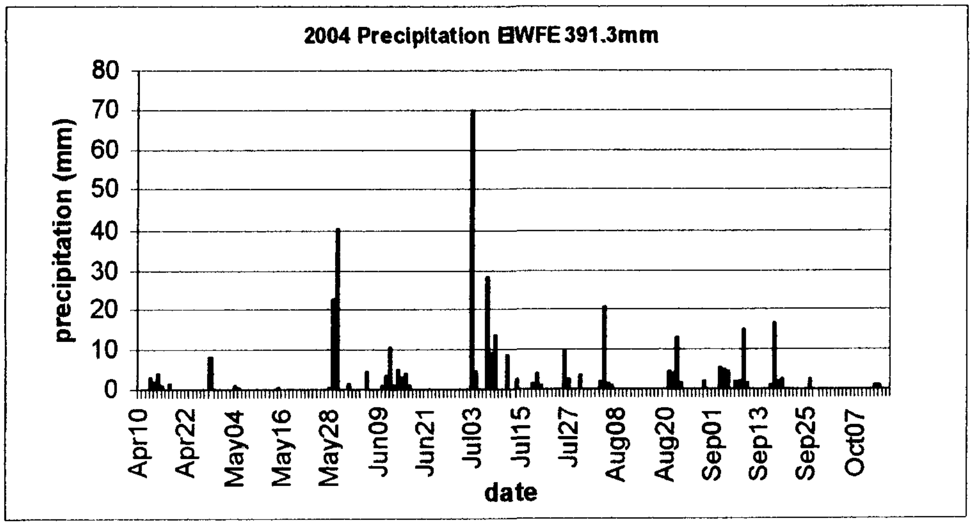
2004 Month	Date	Calibration Plots Home Gauge	Calibration Plots Post Gauge	Calibration Plots Bush Gauge	Validation Plots Beaver Gauge	Validation Plots Tawayik Gauge	Validation Plots Goose Gauge	EINP EIWFE Gauge
Aug	14	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	16	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	17	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	20	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	21	4.0	4.6	2.8	4.0	4.0	3.0	4.4
Aug	22	3.0	3.4	2.0	3.0	3.0	2.0	3.8
Aug	23	12.0	13.0	9.6	12.5	17.0	8.0	13.0
Aug	24	1.9	2.6	1.6	2.0	1.7	1.1	1.6
Aug	25	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	26	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	27	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	28	0.1	0.3	0.3	0.3	1.0	1.4	0.2
Aug	29	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	30	1.2	1.8	1.2	7.0	2.4	3.8	1.8
Aug	31	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sep	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sep	2	2.4	2.0	1.0	2.6	1.6	1.2	0.0
Sep	3	5.0	4.0	2.4	5.4	3.2	2.4	5.6
Sep	4	5.6	5.4	4.2	4.0	4.8	3.6	5.0
Sep	5	3.8	5.0	3.2	3.3	3.4	2.6	4.4
Sep	6	0.0	0.0	0.0	0.0	\	0.0	0.2
Sep	7	2.2	2.0	1.0	0.4	\	1.6	2.0
Sep	8	1.6	2.8	2.0	0.4	\	1.8	2.2
Sep	9	11.0	16.0	18.0	\	\	\	15.0
Sep	10	0.2	0.5	0.3	\	\	\	1.4
Sep	11	0.0	0.0	0.0	\	\	\	0.0
Sep	12	0.0	0.0	0.0	\	\	\	0.0
Sep	13	0.0	0.0	0.0	\	\	\	0.2
Sep	14	trc	trc	0.0	\	\	\	0.0
Sep	15	trc	trc	0.0	\	\	\	0.0
Sep	16	0.8	1.2	0.6	\	\	\	1.2
Sep	17	21.3	11.5	12.0	\	\	\	16.6
Sep	18	2.0	2.2	1.4	\	\	\	2.2
Sep	19	2.0	2.2	1.6	\	\	\	2.4
Sep	20	0.0	0.0	0.0	\	\	\	0.0
Sep	21	0.0	0.0	0.0	\	\	\	0.0
Sep	22	0.0	0.0	0.0	\	\	\	0.0
Sep	23	0.0	0.0	0.0	\	\	\	0.0
Sep	24	0.0	0.0	0.0	\	\	\	0.0
Sep	25	0.0	0.0	0.0	\	\	\	0.0
Sep	26	2.0	2.5	2.6	\	\	\	2.6
Sep	27	0.0	0.0	0.0	\	\	\	0.0
Sep	28	0.0	0.0	0.0	\	\	\	0.0

2004 Month	Date	Calibration Plots Home Gauge	Calibration Plots Post Gauge	Calibration Plots Bush Gauge	Validation Plots Beaver Gauge	Validation Plots Tawayik Gauge	Validation Plots Goose Gauge	EINP EIWFE Gauge
Sep	29	0.0	0.0	0.0	28.5	28.0	18.5	0.0
Sep	30	0.0	0.0	0.0	\	\	\	0.0
Oct	1	trc	trc	trc	\	\	\	0.2
Oct	2	0.0	0.0	0.0	\	\	\	0.0
Oct	3	0.0	0.0	0.0	\	\	\	0.0
Oct	4	0.0	0.0	0.0	\	\	\	0.0
Oct	5	0.0	0.0	0.0	\	\	\	0.0
Oct	6	0.0	0.0	0.0	\	\	\	0.0
Oct	7	0.0	0.0	0.0	\	\	\	0.0
Oct	8	0.0	0.0	0.0	\	\	\	0.0
Oct	9	0.0	0.0	0.0	\	\	\	0.0
Oct	10	0.0	0.0	0.0	\	\	\	0.0
Oct	11	0.0	0.0	0.0	\	\	\	0.0
Oct	12	0.6	0.6	0.5	\	\	\	0.8
Oct	13	0.7	0.6	0.6	\	\	\	0.8
Oct	14	0.0	0.0	0.0	\	\	\	0.0
Oct	15	0.0	0.0	0.0	\	\	\	0.0
Oct	16	\	\	\	\	\	\	0.0
Oct	17	\	\	\	\	\	\	1.8
Oct	18	\	\	\	\	\	\	0.0
Oct	19	\	\	\	\	\	\	0.0
Oct	20	\	\	\	\	\	\	0.0
Oct	21	\	\	\	\	\	\	0.0
Oct	22	\	\	\	\	\	\	0.0
Oct	23	\	\	\	\	\	\	0.0
Oct	24	\	\	\	\	\	\	0.2
Oct	25	\	\	\	\	\	\	11.4
Oct	26	\	\	\	\	\	\	9.0
Oct	27	\	\	\	\	\	\	0.0
Oct	28	\	\	\	\	\	\	0.0
Oct	29	\	\	\	\	\	\	0.2
Oct	30	\	\	\	\	\	\	0.0
Oct	31	\	\	\	\	\	\	0.0
Totals		**370.7**	**392.4**	**346.1**	**372.2**	**353.7**	**318.9**	**413.9**

APPENDIX 8. Precipitation graphs for 2002, 2003 and 2004 for Elk Island National Park (EIWFE).







APPENDIX 9a. Major plant species and other characteristics of calibration and validation sites, by percentage.

Species	Calibration Area C1	S1	N1	Validation Area Site B Goose	Site D Tawayik	Site E Beaver
Grasses						
Calamagrostis canadensis	2.4	<1	<1	4.5	4.9	2.3
Oryzopsis asperifolia	<1	<1	-	-	-	<1
Poa pratensis	1.1	<1	-	-	<1	<1
Forbs						
Aralia nudicaulis	16.7	20.3	11.4	3.6	13.0	15.9
Aster ciliolatus	1.7	3.4	3.7	<1	1.8	2.2
Cornus canadensis	5.1	5.8	5.4	3.0	4.2	4.0
Equisetum arvense	-	-	-	-	<1	<1
Fragaria virginiana	1.3	1.6	-	<1	1.6	<1
Galium boreale	1.7	1.4	1.1	<1	1.4	1.1
Maianthemum canadense	<1	1.6	1.8	<1	1.3	3.8
Sanicula marialandica	1.0	2.3	-	-	1.0	<1
Solidago canadensis	-	-	-	<1	1.2	<1
Taraxacum officinale	<1	-	-	-	<1	<1
Trifolium repens	-	-	-	-	<1	-
Shrub/Tree						
Amelanchier alnifolia	19.3	11.4	3.4	<1	1.7	3.6
Corylus cornuta	1.4	25.7	11.7	20.5	15.3	37.6
Prunus virginiana	3.6	3.1	<1	-	<1	1.0
Ribes lacustre	-	-	-	<1	-	-
Ribes triste	-	-	2.4	<1	1.1	1.7
Rosa woodsii	17.8	9.1	12.5	6.1	6.3	5.4
Rubus idaeus	9.1	4.8	10.8	11.9	9.8	6.3
Symphoricarpos albus	7.7	6.3	5.6	1.5	3.8	4.4
Populus tremuloides	-	-	1.0	-	2.4	1.5
Betula papyrifera	-	-	-	-	<1	<1

APPENDIX 9b. Mean environmental and overstory characteristics of calibration and validation plot areas.

	Calibration Area			Validation Area		
				Site B	Site D	Site E
	C1	S1	N1	Goose	Tawayik	Beaver
Environment						
Slope	2.0	4.0	8.0	2.3	5.7	8.0
Aspect	Ely	S	N	NE	Var.	Var.
Last burn yr.	1895	1895	1895	1895	1982-95	1895
Add. to park	1906	1906	1906	1947	1922	1906
Understory						
LFH depth (cm)	5.0[1]	5.5	4.5	3.8	3.9	4.8
Ah depth (cm)	4.0	5.0	8.0	1.4	1.6	0.8
Ahe depth (cm)	2.0	4.0	1.0	3.2	1.8	2.0
Ae depth (cm)	17.5	9.0	20.0	9.3	0.3	3.4
Bt depth (cm)	40.0	-	-	-	-	-
Shannon Diversity	-	-	-	1.1	1.1	1.5
Spp. Rich. (#/psp)	40.0	33.0	32.0	24.2	36.0	36.2
Shrub CAG ($g{\cdot}m^{-2}$)	60.1	29.4	53.7	80.0	105.6	142.6
Forb ANPP ($g{\cdot}m^{-2}$)	21.9	29.4	9.3	70.6	23.8	37.0
Grass ANP ($g{\cdot}m^{-2}$)	8.0	3.1	0.2	167.4	82.0	9.2
Herb ANPP ($g{\cdot}m^{-2}$)	-	-	-	238.0	105.8	46.0
Total ANPP ($g{\cdot}m^{-2}$)	90.0	61.9	63.2	317.8	211.2	188.6
Downed wood (m)	-	-	-	0.01	0.01	0.01
Shrub height (m)	1.2	1.3	1.1	0.7	0.9	1.2
Overstory						
Regen height (m)	1.1	1.0	1.8	0.1	0.8	1.0
Regen density ($\#/m^2$)	-	-	-	0.02	0.40	0.32
Sappling height (m)	4.1	4.7	4.2	-	1.4	1.5
Sappling density ($\#/m^2$)	-	-	-	-	0.04	0.03
Canopy cover (%)	50.0	50.0	70.0	39.1	67.2	54.7
Tree age (yrs)	76	76	76	64	62	93
DBH (cm)	13.9	17.9	19.8	23.0	22.2	26.6
Tree height (m)	14.2	15.9	18.1	20.3	18.5	21.0
Crown class	C	C	C	C	D	C
Tree density ($\#/1000m^2$)	-	-	-	60	100	70

[1] L-layer often 0.5-1.0cm only.

Appendix 10. Comparison of moisture content across spring (April and May), summer (June through August) and fall (September and October) seasons for the calibration site.

The MEANS Procedure

Analysis Variable : mc

date	mean depth	N Obs	Mean	Std Dev	Std Error	Coeff of Variation
Apr10	1	12	89.9416667	35.7306708	10.3145562	39.7264939
	3	12	121.4666667	43.2381215	12.4817705	35.5966972
	5	12	101.5833333	49.8441906	14.3887784	49.0672918
	7	12	68.7416667	32.3265851	9.3318813	47.0261876
	9	12	43.8500000	14.4012941	4.1572955	32.8421759
	11	12	32.4750000	8.1000701	2.3382888	24.9424793
Apr12	1	12	63.1083333	15.4305163	4.4544064	24.4508379
	3	12	117.1000000	37.2794118	10.7616392	31.8355353
	5	12	117.6750000	52.6979752	15.2125951	44.7826430
	7	12	120.4833333	75.4177798	21.7712377	62.5960270
	9	12	60.3583333	39.2789432	11.3388542	65.0762555
	11	12	44.2083333	27.9082737	8.0564247	63.1289886
Apr20	1	12	86.6333333	23.1143141	6.6725277	26.6806242
	3	12	148.4166667	24.4770703	7.0659216	16.4921305
	5	12	126.8000000	35.6478738	10.2906548	28.1134652
	7	12	83.4666667	36.3789233	10.5016906	43.5849720
	9	12	48.1666667	21.7033024	6.2652037	45.0587592
	11	12	38.1416667	12.1504552	3.5075343	31.8561201
Apr24	1	12	45.1916667	26.5780312	7.6724167	58.8117969
	3	12	126.1666667	29.9448382	8.6443302	23.7343499
	5	12	120.3000000	34.8620659	10.0638116	28.9792734
	7	12	86.6166667	37.0099454	10.6838510	42.7284342
	9	12	41.7250000	14.7559618	4.2596793	35.3647976
	11	12	32.5750000	8.6906559	2.5087763	26.6789130
Apr27	1	12	38.3416667	26.0743154	7.5270065	68.0051695
	3	12	109.9250000	27.9378897	8.0649741	25.4154102
	5	12	101.7916667	37.1722883	10.7307153	36.5180073
	7	12	91.2916667	54.1478524	15.6311386	59.3130287
	9	12	74.1083333	66.7056146	19.2562523	90.0109496
	11	12	40.8916667	21.8189017	6.2985744	53.3578194
Apr30	1	12	23.1500000	9.0134748	2.6019660	38.9350962
	3	12	100.0583333	20.1952046	5.8298534	20.1834309
	5	12	86.3666667	25.0242549	7.2238802	28.9744364
	7	12	73.8750000	26.9279890	7.7734408	36.4507465
	9	12	60.6166667	33.2040751	9.5851909	54.7771380
	11	12	40.5416667	11.7058228	3.3791800	28.8735609
May5	1	12	43.4750000	31.0631359	8.9671549	71.4505713
	3	12	113.2833333	16.6175610	4.7970767	14.6690254
	5	12	118.5916667	24.5588147	7.0895191	20.7087187
	7	12	105.5916667	43.1041963	12.4431097	40.8215892
	9	12	67.5666667	39.9568707	11.5345550	59.1369571

	11	12	41.4750000	26.8935993	7.7635134	64.8429157
May9	1	12	102.8666667	116.5491729	33.6448482	113.3012050
	3	12	164.3583333	57.8457425	16.6986275	35.1948948
	5	12	140.7083333	32.0431657	9.2500652	22.7727562
	7	12	103.1083333	46.6613030	13.4699579	45.2546380
	9	12	58.8583333	40.0870974	11.5721482	68.1077685
	11	12	39.1250000	20.3016401	5.8605787	51.8891760
May13	1	12	34.9416667	8.5369207	2.4643967	24.4319219
	3	12	129.4500000	42.4137735	12.2438018	32.7645991
	5	12	141.6083333	62.5869353	18.0672920	44.1972120
	7	12	100.6500000	71.4292848	20.6198584	70.9679928
	9	12	44.2250000	14.6268822	4.2224172	33.0737867
	11	12	29.5500000	9.9376694	2.8687580	33.6300148
May17	1	12	20.3666667	9.6742708	2.7927214	47.5005112
	3	12	124.9833333	47.6793997	13.7638571	38.1486062
	5	12	147.8333333	72.0689737	20.8045207	48.7501513
	7	12	126.6083333	77.4008158	22.3436909	61.1340611
	9	12	64.8916667	49.2471957	14.2164409	75.8914022
	11	12	35.8583333	14.4154247	4.1613747	40.2010450
May20	1	14	24.5428571	8.1515184	2.1785849	33.2134046
	3	14	110.3214286	23.3220325	6.2330754	21.1400747
	5	14	116.8857143	27.4529488	7.3371092	23.4870009
	7	14	87.4142857	40.7661597	10.8952145	46.6355807
	9	14	44.6857143	13.2152509	3.5319244	29.5737713
	11	14	31.7928571	10.2636374	2.7430725	32.2828406
May25	1	14	15.7071429	10.1146097	2.7032432	64.3949686
	3	14	77.0642857	23.9438962	6.3992754	31.0700294
	5	14	96.5785714	28.0975274	7.5093801	29.0929209
	7	14	80.9785714	39.8944604	10.6622430	49.2654534
	9	14	39.9500000	10.7031807	2.8605454	26.7914410
	11	14	29.0785714	5.5155973	1.4741054	18.9679100
May28	1	14	32.8857143	19.6687123	5.2566845	59.8092901
	3	14	78.6000000	39.4500073	10.5434579	50.1908490
	5	14	101.9357143	43.0105999	11.4950663	42.1938476
	7	14	79.0357143	39.7432647	10.6218343	50.2851971
	9	14	40.0571429	20.4425542	5.4635024	51.0334805
	11	14	24.1428571	7.3185449	1.9559634	30.3134994
Jun01	1	2	105.5555556	7.8567420	5.5555556	7.4432293
	3	2	106.5241129	5.1858786	3.6669700	4.8682674
	5	2	87.8625761	14.7947191	10.4614462	16.8384764
	7	2	38.9739229	3.8081148	2.6927438	9.7709301
	9	2	28.9569161	4.5857719	3.2426304	15.8365340
	11	2	22.6984127	3.8161318	2.6984127	16.8123291
Jun02	1	2	117.6470588	24.9567099	17.6470588	21.2132034
	3	2	135.4736945	1.6404438	1.1599689	1.2108947
	5	2	136.5384616	19.0374902	13.4615385	13.9429506
	7	2	104.2818792	27.8856339	19.7181208	26.7406323
	9	2	44.1965429	12.7070982	8.9852753	28.7513397
	11	2	27.0461439	3.9397004	2.7857889	14.5665882

Jun04	1	14	35.1190476	23.8480915	6.3736705	67.9064300
	3	14	119.1706479	15.6306373	4.1774635	13.1161805
	5	14	113.6228595	30.6684348	8.1964840	26.9914302
	7	14	74.6064034	29.2614633	7.8204550	39.2211151
	9	14	40.8386514	11.3436156	3.0317088	27.7766656
	11	14	29.0823367	6.5349386	1.7465358	22.4704730
Jun07	1	14	23.0555556	11.0149225	2.9438619	47.7755674
	3	14	108.0195205	21.4714297	5.7384810	19.8773607
	5	14	108.9542027	25.5997042	6.8418087	23.4958391
	7	14	75.7555722	35.5367134	9.4975862	46.9097023
	9	14	37.4502816	7.1006410	1.8977261	18.9601805
	11	14	29.1263463	5.5560218	1.4849093	19.0755879
Jun09	1	14	28.2153380	8.1213784	2.1705297	28.7835587
	3	14	75.5008385	18.9478190	5.0640176	25.0961703
	5	14	92.3264359	43.8171142	11.7106164	47.4589036
	7	14	62.7529549	30.7073063	8.2068728	48.9336421
	9	14	42.2273048	19.1934527	5.1296660	45.4527061
	11	14	27.0176291	6.9152437	1.8481766	25.5953017
Jun10	1	2	62.5000000	53.0330086	37.5000000	84.8528137
	3	2	82.4163732	14.9077530	10.5413732	18.0883390
	5	2	102.7190923	15.7964778	11.1697966	15.3783269
	7	2	112.0529203	5.1612558	3.6495590	4.6060877
	9	2	116.8248945	12.0088810	8.4915612	10.2793853
	11	2	63.1851576	21.8365840	15.4407967	34.5596733
Jun14	1	4	129.6691176	90.3150623	45.1575312	69.6504025
	3	4	151.2757230	81.7955101	40.8977550	54.0704803
	5	4	133.0625161	74.3214208	37.1607104	55.8545133
	7	4	82.2574280	82.7633409	41.3816704	100.6150361
	9	4	43.2869969	27.1198582	13.5599291	62.6512812
	11	4	28.5864882	7.9848759	3.9924379	27.9323428
Jun17	1	14	32.0738816	15.3143996	4.0929454	47.7472598
	3	14	75.4357323	22.7273483	6.0741393	30.1280939
	5	14	74.9822253	25.7544563	6.8831680	34.3474153
	7	14	43.5324435	18.4742403	4.9374484	42.4378667
	9	14	30.3343620	10.0302754	2.6807039	33.0657208
	11	14	23.1720309	6.5622788	1.7538428	28.3198257
Jun20	1	2	26.7857143	2.5253814	1.7857143	9.4280904
	3	2	61.0536398	3.0614202	2.1647510	5.0143123
	5	2	72.7718360	12.7934649	9.0463458	17.5802421
	7	2	64.8178383	36.6335211	25.9038112	56.5176532
	9	2	32.0425932	5.8710181	4.1514367	18.3225435
	11	2	23.0480687	0.7660439	0.5416749	3.3236795
Jun22	1	2	33.7301587	7.2955462	5.1587302	21.6291486
	3	2	61.8611379	4.0230762	2.8447445	6.5033983
	5	2	79.3034128	12.5421371	8.8686302	15.8153813
	7	2	64.7576502	13.6082913	9.6225151	21.0141833
	9	2	27.3000377	2.1763525	1.5389136	7.9719761
	11	2	25.3094671	6.5220598	4.6117927	25.7692498

Jun23	1	2	43.7500000	8.8388348	6.2500000	20.2030509
	3	2	83.5716905	13.4316580	9.4976164	16.0720190
	5	2	49.1685745	10.3352274	7.3081094	21.0199859
	7	2	19.9330144	2.4765654	1.7511962	12.4244399
	9	2	16.5670603	2.1401249	1.5132969	12.9179522
	11	2	16.5240093	3.0038028	2.1240093	18.1784138
Jun24	1	4	24.9175824	9.0365825	4.5182913	36.2658880
	3	4	80.6390720	19.0536490	9.5268245	23.6283088
	5	4	76.3293145	14.8280789	7.4140395	19.4264537
	7	4	38.3995424	7.7488269	3.8744134	20.1794771
	9	4	24.9957913	4.3964736	2.1982368	17.5888555
	11	4	19.4145926	2.6369466	1.3184733	13.5822916
Jun25	1	16	31.6872756	30.7864681	7.6966170	97.1571949
	3	16	68.3241340	23.5756119	5.8939030	34.5055407
	5	16	81.0285500	28.2827934	7.0706983	34.9047260
	7	16	57.6166610	26.7529566	6.6882392	46.4326745
	9	16	34.6591870	25.2633661	6.3158415	72.8908214
	11	16	22.4381170	8.5464359	2.1366090	38.0889176
Jun28	1	16	33.2299298	30.2560935	7.5640234	91.0507294
	3	16	50.1547396	9.9557448	2.4889362	19.8500578
	5	16	68.4354406	22.3820328	5.5955082	32.7053243
	7	16	50.8528018	21.9442534	5.4860634	43.1524963
	9	16	34.6151494	21.1205741	5.2801435	61.0154064
	11	16	25.4626612	11.5491655	2.8872914	45.3572604
Jun29	1	4	2.7777778	5.5555556	2.7777778	200.0000000
	3	4	52.8466803	25.5579331	12.7789666	48.3624194
	5	4	61.0795578	14.8778456	7.4389228	24.3581422
	7	4	41.4325042	30.1667970	15.0833985	72.8094948
	9	4	22.1274251	4.1099913	2.0549957	18.5741961
	11	4	17.9777838	3.3135147	1.6567574	18.4311635
Jun30	1	16	21.9985039	15.4931159	3.8732790	70.4280434
	3	16	47.0900703	13.2713443	3.3178361	28.1828934
	5	16	61.2460637	23.1717580	5.7929395	37.8338730
	7	16	49.1761377	25.6611275	6.4152819	52.1820719
	9	16	31.8479914	21.3173182	5.3293296	66.9345767
	11	16	19.9988029	6.8336989	1.7084247	34.1705398
Jul01	1	4	29.4117647	47.7884612	23.8942306	162.4807681
	3	4	53.3503243	6.8322636	3.4161318	12.8064143
	5	4	62.6386634	4.7288290	2.3644145	7.5493773
	7	4	37.5023723	7.1304668	3.5652334	19.0133754
	9	4	22.9925039	4.3662997	2.1831499	18.9901010
	11	4	18.8013942	3.7781114	1.8890557	20.0948473
Jul02	1	16	35.4327877	35.9289070	8.9822268	101.4001702
	3	16	44.1221624	12.2485376	3.0621344	27.7605105
	5	16	58.1638414	16.2180206	4.0545051	27.8833381
	7	16	40.3897002	19.0693971	4.7673493	47.2135148
	9	16	29.0594355	18.2111596	4.5527899	62.6686628
	11	16	22.7310087	8.4972848	2.1243212	37.3819082
Jul14	1	2	25.7575758	10.7137391	7.5757576	41.5945165

	3	2	38.4790100	2.6472199	1.8718672	6.8796467
	5	2	46.2142857	0.3030458	0.2142857	0.6557404
	7	2	28.7336563	1.8490785	1.3074960	6.4352357
	9	2	24.2764726	4.3336473	3.0643514	17.8512231
	11	2	19.8028787	2.7770668	1.9636828	14.0235510
Jul15	1	2	26.5151515	13.9278608	9.8484848	52.5279323
	3	2	45.1693405	8.9743321	6.3458111	19.8681937
	5	2	59.6398305	4.0448905	2.8601695	6.7821965
	7	2	53.8780664	22.0141830	15.5663781	40.8592670
	9	2	31.8571429	5.4548237	3.8571429	17.1227651
	11	2	22.1778695	1.1577405	0.8186462	5.2202514
Jul21	1	2	83.7301587	63.4151320	44.8412699	75.7375036
	3	2	41.4855073	0.2561981	0.1811594	0.6175605
	5	2	48.4042026	13.0431730	9.2229160	26.9463647
	7	2	33.8497729	8.4162991	5.9512222	24.8636796
	9	2	22.4543888	2.5962586	1.8358321	11.5623659
	11	2	15.6404267	4.7231103	3.3397433	30.1980909
Jul26	1	1	10.0000000	.	.	.
	3	1	38.2978723	.	.	.
	5	1	36.9318182	.	.	.
	7	1	25.7510730	.	.	.
	9	1	20.6185567	.	.	.
	11	1	17.5531915	.	.	.
Jul28	1	2	16.6666667	4.7140452	3.3333333	28.2842713
	3	2	29.9696970	3.8140911	2.6969697	12.7264921
	5	2	30.8886236	1.1578075	0.8186935	3.7483297
	7	2	25.4067151	5.9721030	4.2229145	23.5060020
	9	2	18.5409064	2.9535344	2.0884642	15.9298277
	11	2	21.2943092	2.7996725	1.9796674	13.1475151
Aug04	1	2	22.5000000	3.5355339	2.5000000	15.7134840
	3	2	38.1578947	1.8608073	1.3157895	4.8765985
	5	2	51.4029181	4.1267736	2.9180696	8.0282866
	7	2	42.3206751	6.1461602	4.3459916	14.5228312
	9	2	28.9815448	5.7999189	4.1011620	20.0124561
	11	2	20.0858627	1.1218365	0.7932582	5.5852044
Aug11	1	2	16.2500000	5.3033009	3.7500000	32.6356976
	3	2	30.5446689	0.9024476	0.6381268	2.9545176
	5	2	39.5044262	13.3595420	9.4466227	33.8178358
	7	2	30.3416598	15.1303918	10.6988026	49.8667242
	9	2	23.8235431	8.5127013	6.0193888	35.7323059
	11	2	18.7857391	2.9421336	2.0804027	15.6615272
Sep-04	1	3	55.9666667	8.3362662	4.8129455	14.8950557
	3	3	85.0666667	8.4913682	4.9024937	9.9820159
	5	3	70.4666667	26.4840203	15.2905563	37.5837564
	7	3	59.1666667	33.9876939	19.6228042	57.4439896
	9	3	26.5000000	4.6936127	2.7098585	17.7117460
	11	3	18.6666667	4.2852460	2.4740879	22.9566750
Sep-13	1	12	96.5833333	29.1131284	8.4042362	30.1430147
	3	12	80.6750000	27.6218663	7.9737460	34.2384460

	5	12	66.4916667	18.1594182	5.2421725	27.3108182
	7	12	49.6083333	15.6061444	4.5051058	31.4587154
	9	12	29.9750000	13.6063571	3.9278170	45.3923507
	11	12	21.5416667	11.7105592	3.3805473	54.3623638
Sep-28	1	12	53.3500000	15.3852054	4.4413262	28.8382482
	3	12	58.7500000	9.7013120	2.8005275	16.5128715
	5	12	46.5000000	10.5232211	3.0377923	22.6305830
	7	12	35.3166667	9.6642578	2.7898309	27.3645808
	9	12	27.0333333	12.4372851	3.5903349	46.0072198
	11	12	21.0250000	11.7372852	3.3882624	55.8253755
Sep-30	1	3	45.5666667	2.8676355	1.6556301	6.2932747
	3	3	81.5666667	5.3984566	3.1168004	6.6184592
	5	3	65.0333333	12.0034717	6.9302076	18.4574142
	7	3	44.1666667	14.7038544	8.4892743	33.2917457
	9	3	24.2333333	3.5004762	2.0210009	14.4448810
	11	3	19.7000000	2.0420578	1.1789826	10.3657756
Oct-07	1	12	32.8750000	11.7438669	3.3901623	35.7227890
	3	12	52.9916667	9.2133755	2.6596724	17.3864611
	5	12	51.2750000	6.8197741	1.9686992	13.3003882
	7	12	39.3083333	14.0538871	4.0570077	35.7529458
	9	12	26.8166667	10.0602578	2.9041463	37.5149453
	11	12	19.6833333	7.1915144	2.0760114	36.5360594
Oct-17	1	12	45.5416667	8.4031875	2.4257913	18.4516469
	3	12	54.1416667	11.1282979	3.2124629	20.5540365
	5	12	46.6583333	13.7369745	3.9655230	29.4416315
	7	12	40.9833333	21.5802870	6.2296923	52.6562514
	9	12	27.0666667	10.9978786	3.1748141	40.6325563
	11	12	18.3166667	6.2105238	1.7928238	33.9064085
Oct-19	1	12	26.0833333	6.1908779	1.7871525	23.7349953
	3	12	36.0416667	8.5864013	2.4786806	23.8235413
	5	12	34.9416667	8.7044877	2.5127692	24.9114840
	7	12	23.9083333	7.0623790	2.0387332	29.5394032
	9	12	19.6416667	7.3050989	2.1088004	37.1918484
	11	12	13.1000000	2.8032449	0.8092271	21.3988158
Oct-28	1	4	86.5750000	30.0557676	15.0278838	34.7164512
	3	4	102.5250000	28.1599450	14.0799725	27.4664179
	5	4	100.6000000	32.0575524	16.0287762	31.8663543
	7	4	80.3750000	20.3824066	10.1912033	25.3591373
	9	4	47.2500000	17.1224025	8.5612012	36.2378888
	11	4	34.2750000	27.9697903	13.9848951	81.6040562

APPENDIX 11. Comparison of moisture content from the summer (June through August) season for the validation sites of Beaver, Goose and Tawayik.

The MEANS Procedure
Beaver
Analysis Variable : mc

date	mean depth	N Obs	Mean	Std Dev	Std Error	Coeff of Variation
Jun22	1	12	43.7758116	25.2307237	7.2834826	57.6362214
	3	12	127.8189251	39.4110825	11.3769995	30.8335268
	5	12	95.1091059	44.6538182	12.8904470	46.9500978
	7	12	47.7574463	28.9377107	8.3535975	60.5930863
	9	12	29.3016037	14.0404602	4.0531317	47.9170365
	11	12	22.5487167	10.1256056	2.9230106	44.9054631
Jul15	1	4	193.7500000	31.4576435	15.7288217	16.2362031
	3	4	115.2031704	19.7840126	9.8920063	17.1731494
	5	4	62.2948245	5.6615805	2.8307902	9.0883641
	7	4	38.6301201	5.4559304	2.7279652	14.1235139
	9	4	29.7198561	6.5699320	3.2849660	22.1062039
	11	4	23.0091288	3.2625081	1.6312541	14.1791901
Jul21	1	4	141.8128655	55.6293754	27.8146877	39.2273121
	3	4	92.8253378	46.1758283	23.0879141	49.7448534
	5	4	63.0717093	26.5314823	13.2657411	42.0655831
	7	4	49.4959212	18.9084935	9.4542468	38.2021247
	9	4	41.1870095	20.3872395	10.1936198	49.4991984
	11	4	29.0474410	8.5126748	4.2563374	29.3061093
Jul26	1	4	91.6000666	60.6717308	30.3358654	66.2354659
	3	4	96.0195912	53.8564522	26.9282261	56.0890247
	5	4	82.5123126	49.0853811	24.5426905	59.4885533
	7	4	53.8288417	29.3622392	14.6811196	54.5474105
	9	4	36.7756772	8.3036415	4.1518208	22.5791669
	11	4	25.9960819	5.5602282	2.7801141	21.3887164
Jul28	1	3	95.2380952	92.9486728	53.6639413	97.5961065
	3	3	121.6759863	28.7790041	16.6155658	23.6521642
	5	3	80.9605560	25.4520975	14.6947753	31.4376515
	7	3	52.8408361	7.9662927	4.5993412	15.0760157
	9	3	33.5367186	6.9671201	4.0224687	20.7746029
	11	3	24.5913102	8.9419633	5.1626449	36.3622889
Aug02	1	4	61.3888889	38.0099078	19.0049539	61.9165918
	3	4	80.9520185	41.5597904	20.7798952	51.3387945
	5	4	44.1468998	23.7928818	11.8964409	53.8947964
	7	4	28.7852154	14.0041062	7.0020531	48.6503438
	9	4	19.5055574	3.3035216	1.6517608	16.9363096
	11	4	17.8620935	2.1831014	1.0915507	12.2219794
Aug05	1	4	125.9619218	101.0019894	50.5009947	80.1845414
	3	4	88.7749001	58.2259532	29.1129766	65.5883061

	5	4	56.2089375	33.1708532	16.5854266	59.0134856
	7	4	42.4294270	21.0985976	10.5492988	49.7263316
	9	4	29.2881084	9.2079742	4.6039871	31.4392930
	11	4	23.2862129	2.7856823	1.3928411	11.9627966
Aug11	1	4	71.7532468	61.9429695	30.9714847	86.3277584
	3	4	90.3274109	69.0588834	34.5294417	76.4539610
	5	4	70.7890979	51.4070551	25.7035276	72.6200173
	7	4	51.7517512	42.3169535	21.1584768	81.7691239
	9	4	26.9746646	9.8202404	4.9101202	36.4054217
	11	4	20.7637053	3.3599945	1.6799972	16.1820563
Aug16	1	5	6.2745098	61.0133432	27.2859966	972.4001572
	3	5	63.6240183	31.9726699	14.2986127	50.2525159
	5	5	61.0492974	26.4835807	13.2417903	43.3806477
	7	5	44.3864178	10.3655336	4.6356075	23.3529402
	9	5	24.1485842	11.8640132	5.3057480	49.1292287
	11	5	14.5613726	4.1911733	1.8743497	28.7828176
Aug18	1	4	21.0416667	16.4622886	8.2311443	78.2366189
	3	4	49.3494208	31.7908365	15.8954183	64.4198777
	5	4	55.8213356	37.2637784	18.6318892	66.7554404
	7	4	44.2374877	26.6244557	13.3122278	60.1852796
	9	4	19.9355649	3.3041160	1.6520580	16.5739774
	11	4	12.5595490	2.5685052	1.2842526	20.4506168
Aug20	1	4	34.5032051	10.0238559	5.0119280	29.0519558
	3	4	38.2263855	22.1578002	11.0789001	57.9646753
	5	4	45.8381615	29.1189148	14.5594574	63.5254858
	7	4	29.6094532	13.0299244	6.5149622	44.0059607
	9	4	21.9275096	8.4423812	4.2211906	38.5013226
	11	4	14.6383503	2.2993521	1.1496761	15.7077270
Aug25	1	4	109.5833333	95.0475027	47.5237514	86.7353637
	3	4	87.3968173	69.9416698	34.9708349	80.0277081
	5	4	73.7855062	54.2875450	27.1437725	73.5748087
	7	4	60.4402077	53.7734605	26.8867302	88.9696817
	9	4	30.5224269	22.1118946	11.0559473	72.4447461
	11	4	17.5505463	6.4126177	3.2063089	36.5379949
Sep01	1	3	25.3271138	5.6670617	3.2718796	22.3754739
	3	3	30.5102647	3.4154490	1.9719104	11.1944260
	5	3	23.5530836	0.6151104	0.3551341	2.6115917
	7	3	17.2610859	2.4811469	1.4324908	14.3742224
	9	3	15.5109005	2.8782869	1.6617797	18.5565429
	11	3	11.7915382	0.3711119	0.2142615	3.1472729

The MEANS Procedure
Goose
Analysis Variable : mc

date	mean depth	N Obs	Mean	Std Dev	Std Error	Coeff of Variation
Jun21	1	12	41.9766160	27.7746207	8.0178424	66.1668885
	3	12	111.5118094	37.9231211	10.9474621	34.0081658
	5	12	105.5870609	50.0718422	14.4544958	47.4223279
	7	12	48.9838675	19.7506697	5.7015272	40.3207641
	9	12	28.2859715	10.1289702	2.9239818	35.8091650
	11	12	18.8552804	2.8320891	0.8175537	15.0201378
Jul16	1	2	80.0699301	15.3288883	10.8391608	19.1443757
	3	2	99.6401260	7.9521680	5.6230319	7.9808892
	5	2	62.2705912	18.9787694	13.4200165	30.4779013
	7	2	43.1504907	21.5176384	15.2152680	49.8664976
	9	2	27.6834327	13.0989835	9.2623801	47.3170494
	11	2	20.4877900	5.2588369	3.7185592	25.6681510
Jul20	1	4	122.8890362	59.0735007	29.5367504	48.0706030
	3	4	164.2748438	85.6551431	42.8275715	52.1413633
	5	4	114.5541265	56.9230073	28.4615037	49.6909270
	7	4	69.1071587	24.0418116	12.0209058	34.7891767
	9	4	45.2486836	20.1233149	10.0616574	44.4727079
	11	4	27.2476751	5.3904433	2.6952217	19.7831313
Jul22	1	4	63.6363636	14.8968497	7.4484248	23.4093352
	3	4	140.5408122	49.9519846	24.9759923	35.5426895
	5	4	96.2635281	40.4738440	20.2369220	42.0448375
	7	4	62.9559252	25.6239869	12.8119935	40.7014699
	9	4	45.5790044	28.7027869	14.3513934	62.9737030
	11	4	33.7557906	16.7973995	8.3986998	49.7615349
Jul29	1	4	85.7793522	59.6994131	29.8497066	69.5964840
	3	4	99.1157384	50.5921827	25.2960914	51.0435412
	5	4	75.9093580	36.8708534	18.4354267	48.5722108
	7	4	46.4905857	13.8725476	6.9362738	29.8394768
	9	4	31.6838078	7.7094947	3.8547474	24.3326015
	11	4	22.8001157	4.6014542	2.3007271	20.1817143
Aug03	1	4	55.0378788	27.1640300	13.5820150	49.3551543
	3	4	91.9457191	58.4320091	29.2160046	63.5505488
	5	4	76.4035560	49.6312315	24.8156157	64.9593213
	7	4	34.8459952	10.3725342	5.1862671	29.7667899
	9	4	22.1438850	4.0513862	2.0256931	18.2957338
	11	4	17.3901836	2.2178676	1.1089338	12.7535609
Aug10	1	4	38.9354797	25.9928713	12.9964357	66.7588315
	3	4	86.4515608	64.8664808	32.4332404	75.0321686
	5	4	94.9731309	70.7479632	35.3739816	74.4926092
	7	4	48.7713180	33.6714447	16.8357223	69.0394397
	9	4	23.2905900	4.3668338	2.1834169	18.7493481
	11	4	18.4565011	2.2118023	1.1059012	11.9838659

Aug12	1	4	37.1464646	11.4993024	5.7496512	30.9566536
	3	4	80.2905920	55.2373998	27.6186999	68.7968521
	5	4	68.5149836	52.5472558	26.2736279	76.6945463
	7	4	40.3722633	18.3463852	9.1731926	45.4430436
	9	4	22.3518389	2.9224594	1.4612297	13.0748052
	11	4	17.5832140	2.1574666	1.0787333	12.2700356
Aug17	1	4	30.4212454	8.0278300	4.0139150	26.3888933
	3	4	64.3931838	37.9783501	18.9891751	58.9788357
	5	4	38.9393141	11.7701214	5.8850607	30.2268328
	7	4	20.6648940	3.5266812	1.7633406	17.0660505
	9	4	16.6503792	3.4247000	1.7123500	20.5683006
	11	4	13.8192730	0.8397726	0.4198863	6.0768217
Aug19	1	4	36.9444444	20.5555556	10.2777778	55.6390977
	3	4	54.4323450	19.5348540	9.7674270	35.8883198
	5	4	57.4364827	30.6817567	15.3408783	53.4185855
	7	4	29.5296415	5.9850165	2.9925082	20.2678264
	9	4	20.8915248	4.7412185	2.3706092	22.6944587
	11	4	16.9172519	3.9289563	1.9644782	23.2245539
Aug24	1	4	120.2272727	103.9823438	51.9911719	86.4881499
	3	4	93.1133239	69.0388055	34.5194028	74.1449264
	5	4	74.3000137	55.5047344	27.7523672	74.7035318
	7	4	28.7038676	5.8212634	2.9106317	20.2804148
	9	4	20.3387987	4.7814047	2.3907024	23.5087863
	11	4	18.6552919	4.6022483	2.3011242	24.6699347
Aug26	1	3	107.1428571	78.2591196	45.1829237	73.0418449
	3	3	123.2446695	83.9466252	48.4666066	68.1137980
	5	3	82.2322269	36.5114852	21.0799158	44.4004578
	7	3	31.4368269	5.3089954	3.0651499	16.8878221
	9	3	22.4480826	6.6949456	3.8653286	29.8241310
	11	3	19.4039348	4.7452612	2.7396778	24.4551492

The MEANS Procedure
Tawayik
Analysis Variable : mc

date	mean depth	N Obs	Mean	Std Dev	Std Error	Coeff of Variation
Jun21	1	12	46.6226366	9.0620989	2.6160026	19.4371223
	3	12	145.7535626	25.4661471	7.3514434	17.4720581
	5	12	98.4959546	31.5346275	9.1032628	32.0161652
	7	12	45.7645209	19.1679828	5.5333200	41.8839364
	9	12	32.9422188	20.8233826	6.0111928	63.2118398
	11	12	19.9015757	4.5238737	1.3059299	22.7312339
Jul16	1	4	134.2470760	41.9446075	20.9723038	31.2443360
	3	4	161.8659664	23.2440391	11.6220196	14.3600533
	5	4	116.0420373	47.0388704	23.5194352	40.5360604
	7	4	40.7292803	13.1628687	6.5814343	32.3179506
	9	4	22.3122697	3.8579233	1.9289616	17.2905908
	11	4	20.3644721	2.0523944	1.0261972	10.0783087
Jul20	1	4	68.1547619	45.5230686	22.7615343	66.7936727
	3	4	149.7425678	14.5151708	7.2575854	9.6934165
	5	4	129.3291299	35.9150142	17.9575071	27.7702434
	7	4	72.4432690	48.1178899	24.0589450	66.4214779
	9	4	42.6690802	30.0327120	15.0163560	70.3851872
	11	4	23.2998773	8.7887461	4.3943731	37.7201391
Jul22	1	3	46.5151515	18.8312062	10.8722019	40.4840263
	3	3	146.9332910	26.5892352	15.3513021	18.0961272
	5	3	127.8249015	28.9563014	16.7179284	22.6530989
	7	3	46.0823487	12.5010090	7.2174609	27.1275431
	9	3	27.1404350	8.0750167	4.6621131	29.7527165
	11	3	22.6777605	7.8593795	4.5376149	34.6567709
Jul29	1	4	105.6372549	63.0869212	31.5434606	59.7203338
	3	4	173.4020189	15.5003914	7.7501957	8.9389913
	5	4	108.6586696	25.2153645	12.6076822	23.2060309
	7	4	48.1456320	27.2462254	13.6231127	56.5912717
	9	4	31.0427003	10.3423898	5.1711949	33.3166562
	11	4	28.4866798	9.7174312	4.8587156	34.1121930
Aug02	1	2	26.7361111	6.3836029	4.5138889	23.8763329
	3	2	88.7374462	9.0290536	6.3845050	10.1750208
	5	2	115.0182097	14.8686245	10.5137052	12.9271917
	7	2	50.3716871	10.0329631	7.0943762	19.9178619
	9	2	35.3465859	0.2367857	0.1674328	0.6698971
	11	2	23.5771300	5.3416685	3.7771300	22.6561440
Aug03	1	2	111.5384616	16.3178488	11.5384616	14.6297955
	3	2	137.3238784	21.9905752	15.5496849	16.0136573

	5	2	85.8616312	16.8978548	11.9485878	19.6803329
	7	2	49.8337213	11.1697945	7.8982374	22.4141289
	9	2	33.7007643	2.8475493	2.0135215	8.4495097
	11	2	25.5100575	1.6356924	1.1566092	6.4119511
Aug10	1	4	164.2857143	115.6231269	57.8115635	70.3792947
	3	4	110.5789446	45.3404279	22.6702140	41.0027678
	5	4	88.3459717	62.6310574	31.3155287	70.8929408
	7	4	47.9469648	38.9822945	19.4911473	81.3029453
	9	4	32.2429108	22.6923026	11.3461513	70.3791997
	11	4	23.0107449	8.0132608	4.0066304	34.8239955
Aug12	1	4	45.4861111	38.6463169	19.3231584	84.9628951
	3	4	98.8186383	46.2341560	23.1170780	46.7868783
	5	4	76.2445681	31.0580000	15.5290000	40.7347051
	7	4	49.3000467	26.3075255	13.1537628	53.3620703
	9	4	33.9228054	24.8031371	12.4015685	73.1164087
	11	4	27.7880194	18.7360911	9.3680456	67.4250685
Aug17	1	4	28.7698413	9.4823835	4.7411917	32.9594570
	3	4	69.1277212	21.5570662	10.7785331	31.1844016
	5	4	78.2560121	9.5267117	4.7633558	12.1737760
	7	4	51.9031305	15.8414839	7.9207420	30.5212494
	9	4	29.0816516	10.2979590	5.1489795	35.4105026
	11	4	18.7143650	7.2929238	3.6464619	38.9696566
Aug19	1	4	29.0966387	9.1998259	4.5999129	31.6181741
	3	4	72.2476474	18.3161537	9.1580768	25.3519033
	5	4	79.0080499	6.4488170	3.2244085	8.1622278
	7	4	45.8186671	7.0704760	3.5352380	15.4314310
	9	4	30.6265676	7.5302264	3.7651132	24.5872358
	11	4	20.9148982	10.4621681	5.2310840	50.0225627
Aug26	1	4	117.5438596	95.2229245	47.6114623	81.0105477
	3	4	106.4779615	58.7524380	29.3762190	55.1780266
	5	4	84.1309316	26.0622708	13.0311354	30.9782268
	7	4	48.6560046	19.1314565	9.5657283	39.3198264
	9	4	24.8936671	13.4098907	6.7049453	53.8686832
	11	4	20.8164592	15.5323508	7.7661754	74.6157196

APPENDIX 12. Horizontal movement of water event.

On May 31st/04 core sampling occurred under the old 2003 tarps (i.e. tarped since June 16th/03). Sampling was preceded by 59.0mm of precipitation received the previous two days. Horizontal water movement was apparent through the soil horizons under the edges of the tarps, and was rapidly about to confound moisture data throughout the tarped areas. Samples were retrieved from under the centre of the tarps where no moisture had reached yet and within 1 metre of the edge, where it was wet. Recorded DMC and DC values were 360.0 and 1087.0, respectively, for under the centre of the tarp.

Table 12.1. Average moisture content readings under tarps after rain event.

Location	Depth (cm)	Ave. M.C. (%)	Location	Depth (cm)	Ave. M.C. (%)
C1 Dry	1	12.5	C1 Wet	1	21.3
	3	16.0		3	51.0
	5	25.7		5	126.9
	7	37.8		7	101.7
	9	31.8		9	49.0
	11	21.2		11	28.7
N1 Dry	1	10.3	S1 Dry	1	5.9
	3	10.6		3	15.8
	5	9.0		5	19.2
	7	10.1		7	33.3
	9	9.4		9	40.8
	11	8.2		11	34.9

Core samples in affected areas were noted to have dry to very dry L-F-H horizons, with saturated soil directly beneath it. This revealed how rapidly moisture may move laterally through mineral soil versus the upper organic portion of the soil profile.

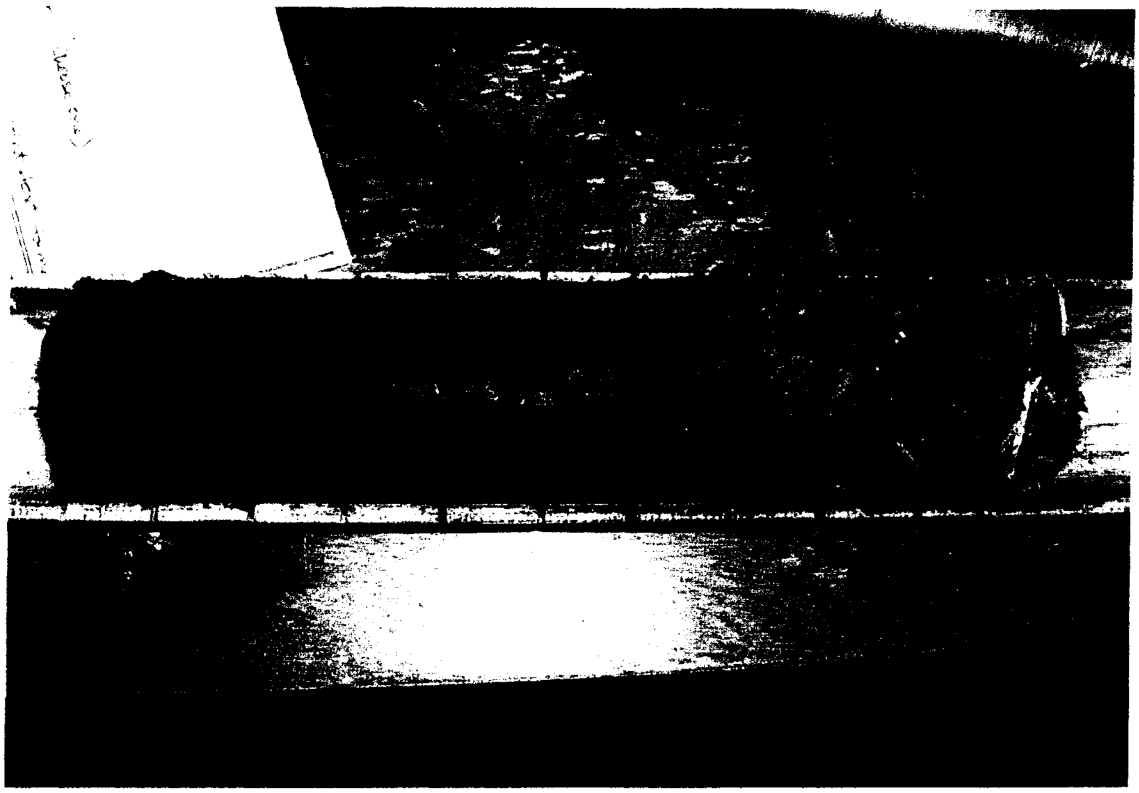


Plate 12.1. Soil core extracted from under tarp edge showing saturated Ah and Ae horizons, with very dry L-F-H horizon above.

APPENDIX 13. Moisture sampling techniques demonstrated.

Samples are recovered by drill (1), removed onto split PVC pipe tray (2), delineated by 2 cm horizons (3), put in tins and transported (4), weighed on scale (5) and oven-dried (6).

APPENDIX 14. Ignition trials techniques demonstrated.

Duff samples are removed (1), an above ground protective sleeve inserted (2), peat moss heated on camp stove (3), smouldering peat moss placed into hole drilled (4) and ignition determined over a 2 hr period *in-situ* (5). To exclude moisture in certain areas, and induce drying, tarps were used (6).