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# The 2025 Update to the FWI System: Structure, Changes and Interpretation



Canadian Forest Service  
Great Lakes Forestry Centre  
Information Report  
GLC-X-42

Canada

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## **PREFACE**

The current core members of the Canadian Forest Service Fire Danger Group are Gabrielle Ayres, Jonathan Boucher, Luke Collins, Patrick Deane, Anne Cotton-Gagnon, Chelene Hanes, Natasha Jurko, Sam Lacarte, Daniel Perrakis, Mackenzie Simpson, Steve Taylor, Dan K. Thompson, Derek Van Der Kamp and Mike Wotton.

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## **1 EXECUTIVE SUMMARY**

The FWI2025 update is part of a broader initiative to modernize the Canadian Forest Fire Danger Rating System (CFFDRS). An enhanced calculation methodology allows the use of higher resolution data within a consistent and scientifically sound framework, while maintaining the simplicity of the current FWI System (FWI1987).

This document informs experienced users, particularly operational agencies, about the modifications in FWI2025. It guides users in interpreting and utilizing the outputs generated by the updated System in their operational planning.

Key updates include:

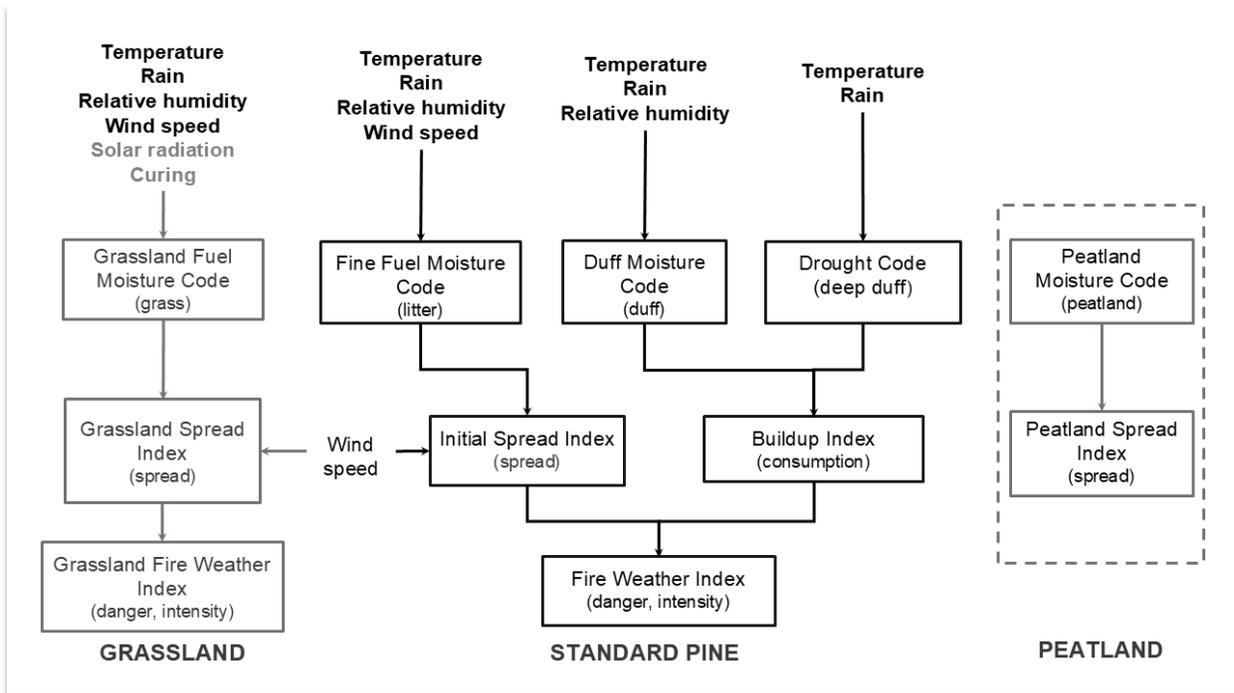
- Using hourly weather to better reflect maximum burning conditions.
- An increased data granularity for flexible fire danger monitoring throughout the day and night.
- The introduction of optional grassland components for fire danger calculation.
- Methods to estimate hourly weather inputs when observed/forecasted data is unavailable.
- Examples of daily fire danger summaries based on hourly FWI2025 outputs.

FWI2025's improvements provide a more accurate and flexible tool for daily fire danger assessment, enhancing the effectiveness of fire management strategies.

## 2 INTRODUCTION

Organized development of what would become the modern Canadian Fire Weather Index (FWI) System began in Canada in the late 1920s. To understand the linkages between ignition and fuel moisture, field ignition tests in a wide variety of fuel types and fuel sampling was used to characterize the moisture in fuels available to be consumed during fire. Direct in-forest measurement of daily evaporation was quickly replaced with tables that linked weather observed around solar noon to moisture in forest or grassland litter (Beall 1939). The first fuel moisture and fire hazard rating tables were created in the 1930s and updated regularly, adapting the system to different regions in the country. The FWI System that has been used operationally throughout Canada since 1970 evolved from these regional adaptations of the Canadian fire danger rating approach. The System has remained largely unchanged since then, apart from some minor changes documented by Van Wagner (1987). In this document, to distinguish between the systems, we will use the labels FWI1987 (current) and FWI2025 (updated). This naming convention will allow for version control for future updates. Overall, moving forward we assume that the System will still be referred to in general as the FWI System.

The updated FWI2025 (Figure 1) retains the simplicity of the original and maintains the critical elements that influence forest fire danger. FWI1987 was designed to track conditions in a generalized pine forest (similar to C-3), and this common fuel type, which provides a set of nationally consistent indicators, remains in FWI2025. The regional interpretation of these outputs to provide information for operational fire management planning remain unchanged. To better reflect diurnal weather patterns, FWI2025 use updated calculations for moisture codes and behaviour indexes. New optional codes and indexes are introduced for grassland fuels and, in a future update, codes and indexes will be introduced for peatland fuels. These new components maintain the core structure and the simple, interpretable output format that has contributed to the FWI System's widespread success over the past 50 years.



**Figure 1.** General structure of the inputs and outputs of the FWI2025 System. The grey text are new optional inputs for the grassland components. The peatland components are still in the final stages of development and will be added in a future update.

While the structure and interpretation of the System's codes and indexes remain, the FWI System calculation is now done hourly regardless of the temporal resolution of the weather input stream (see section 3.1 for details). The reliance on a single daily weather observation timed to the very early afternoon has been part of the System since the late 1930s (Beall 1939). Making this change to earlier versions would have been a challenge when the System's outputs were estimated by hand using extensive sets of lookup tables (Canadian Forestry Service 1984). Today however, weather observations and calculations are largely automated. By generating hourly outputs for each code and index, with the added option of generating daily summaries, this ensures that the latest assessment of fire behaviour is still available at a daily scale, while also having access to hourly outputs.

Users will also have the option of using the Grassland, and eventually a Peatland set of indexes. The introduction of these two new sets of codes and indexes represent potential for ignition, spread and intensity in very different fuel types compared to the standard pine fuels represented by the standard FWI System. The Grassland Fuel Moisture Code (GFMC) reacts much more quickly compared to the Fine Fuel Moisture Code (FFMC) as it tracks the moisture in the very fine cured fuels of an open grassland, while the Peatland Moisture Code (PMC) dries at a much slower rate compared to the Drought Code (DC).

The purpose of this document is to describe and provide rationale for the new or modified elements of FWI2025 and clarify the interpretation of its outputs given these changes. This document does not provide a detailed history of the development of the FWI System, nor is it meant to provide a detailed scientific rationale for the origins and derivation of the models that support the elements within the FWI2025. These descriptions will appear in other documents for those seeking to develop a greater understanding of the specific structure and mathematical models in the System. In this regard, we assume the reader has a general working knowledge of FWI1987. The FWI2025 calculation code will be freely available and open source. At the time of publication, documented source code for the FWI2025 calculations is available in an open-source code repository<sup>1</sup>; given that IT infrastructure and best practices can change, operational users should check with members of Canadian Forest Service's Fire Danger Group to ensure this repository is up to date before adopting the code.

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<sup>1</sup> Natural Resources Canada - Canadian Forest Service Fire (nr-can-cfs-fire) / CFFDRS-NG.  
<https://github.com/nr-can-cfs-fire/cffdrs-ng>

## 3 INPUTS

### 3.1 Weather inputs

The simple models in FWI1987 that relate observed open-weather conditions to in-stand fuel moisture were developed to be bookkeeping systems that track moisture in key components of the surface fuel in a pine forest. The calculations implicitly assumed a static daily weather cycle that did not change. These models relied on a single daily weather observation from approximately solar noon (standardized to be 13:00 Local Daylight Time [LDT]). The weather at ground level varies throughout the day and a 13:00 observation provided an anchor point to an anticipated diurnal structure to the weather variation over the day. This 13:00 observation provided a means of calculating the System's outputs prior to the typical burning conditions at the peak of the day (typically late afternoon), estimating fuel moisture levels and fire behaviour that could be expected later in the day.

#### **The origin of the 13:00 weather observation**

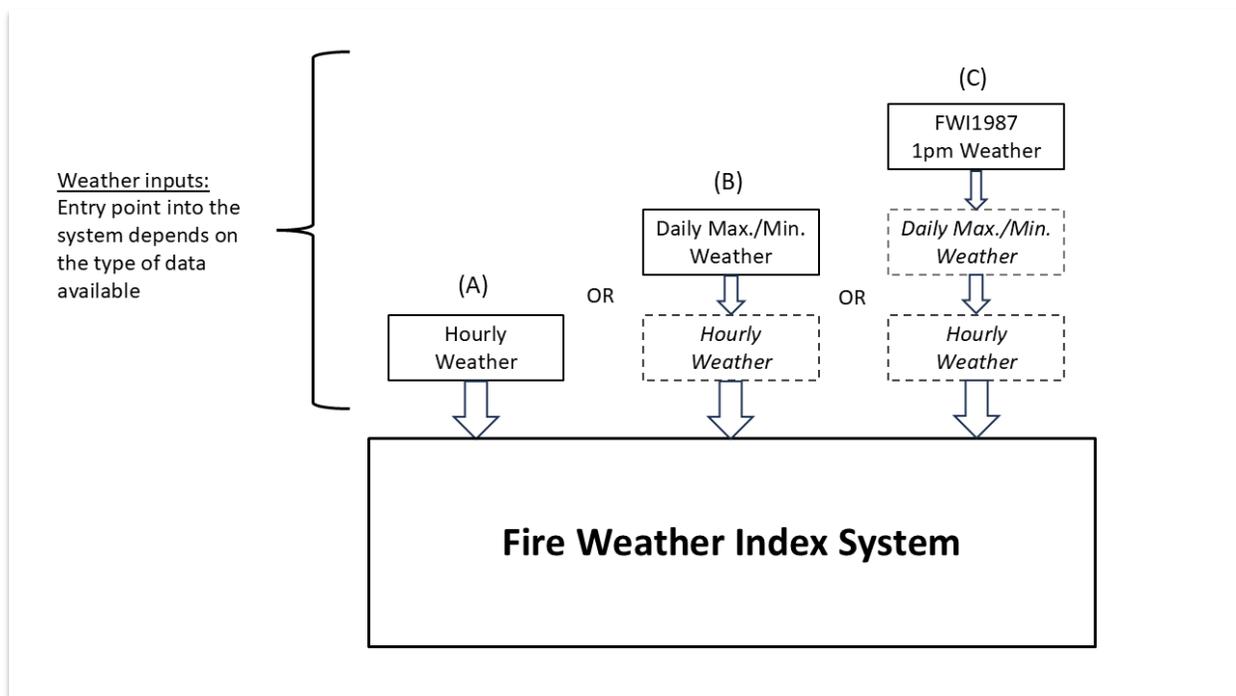
The original fuel moisture estimation methods in the very first generation of fire hazard assessment methods developed in Canada used a zinc "pan" of water placed within a forest and measured at the end of the afternoon or early evening (Wright 1933). The amount of evaporation from this pan directly integrated environmental conditions experienced within the forest over the entire day to estimate the change in moisture content of important fuels for ignition and spread of fires. This provided an excellent estimate of the practical effect of the day's conditions in terms of fuel drying; however, it provided that information only towards the end of the day. As forest fire management became more organized, planning earlier in the day became an essential part of operational success. To facilitate providing fire danger potential information earlier in the day for daily planning purposes, the 13:00 LDT observation was introduced in the late 1930s. This 13:00 observation allowed estimation of the total expected amount of fuel moisture change for the day and provided a way of estimating the potential conditions during the expected late afternoon peak of fire activity.

#### **3.1.1 The primary weather inputs in the FWI2025 System**

FWI2025 better reflects the observed daily weather cycle, accounting for changing conditions, the time of year and the location of the weather station by leveraging hourly weather data to account for diurnal weather variations, primarily influencing moisture calculations and fire behaviour outputs. The primary weather inputs remain air temperature, relative humidity (RH), 10-m open wind speed and rainfall amount (Lawson and Armitage 2008). By incorporating hourly weather inputs, the System aims to more accurately track moisture in key forest floor layers, especially the rapidly drying litter layer, and thereby improves the estimate of fire behaviour potential for the day, be it at peak burn or throughout the day. Additionally, FWI2025 now expressly uses the latitude, longitude of the weather observation location measured in decimal degrees and date (day, month and year) in its calculations. These inputs are used to estimate time of sunrise, time of sunset and daylight hours.

While ideally driven by hourly inputs of observations and forecasts, FWI2025 can accommodate different weather scenarios such as daily maximum and minimum observed or forecast data, or the standard 13:00 weather observation or forecast. A more detailed description of the process can be found in Appendix A in regard to estimating diurnal weather from daily maximum and minimum values. The goal is to use the best information available to estimate the hourly weather streams needed by the FWI System. In Figure 2, three scenarios for each input data formats are presented. These are common weather data forms that we expect users to have available. The dashed boxes represent estimated data forms based on the provided input data, but other data timing formats can also be used. Users can refer to Appendix B for a discussion of other possible input configurations. Below are descriptions of weather scenario examples and data processing pathways with their rationale:

- A) Best scenario - Direct hourly observed (or forecast) weather: Provides the most accurate representation of diurnal weather patterns.
- B) Good scenario - Daily maximum and minimum observed (or forecast): Allows for estimation of hourly weather conditions.
- C) Usable scenario - The standard 13:00 weather observation (or forecast) that is currently used: Can be used to estimate hourly weather but may be less accurate.



**Figure 2.** The basic structure of entry points into the FWI2025 System calculations based on a user's data resolution.

The weather data used as an input to the System should be judged by the user as the best data available, even if it's not in an hourly timestep. For instance, if a user has only the traditional daily 13:00 LDT weather observation, they would use the input option C in Figure 2, whereas a user with hourly weather observations could input these directly into the System as shown in Figure 2, input option A. Methods to convert these different timesteps of weather data into hourly estimates are available in the [code repository](#).

**Daily interpretation from hourly data**

The FWI2025 System calculations always use hourly weather, either observed or forecast, directly or estimated from daily information. However, this does not mean operational users of the System will have to consider hourly outputs. The data processing can go on in the background of a fire agency's information system. For users who want to use the System as they have traditionally, the primary output of the System could still be considered peak burn conditions from a single hour. Users now have the flexibility to take this from the calculations at a specific time the user selects as “peak burn,” or from the actual time at which peak fire behaviour would be expected.

**3.1.1.1 Weather input option with hourly weather (Figure 2, option A)**

Since remote automatic weather stations are now commonplace, many fire agencies have hourly data readily available. Hourly weather observations provide an ideal data source from which to estimate the variation of environmental conditions throughout the day and provide information on the timing of rainfall. Given the uncertainty in the process of modelling fuel moisture, observations more frequent than one-hour intervals are unnecessary, though this FWI2025 formulation of the FWI System calculations can be adapted to use sub-hourly data inputs.

Many numerical weather models now provide forecasts of hourly weather a few days into the future and can flow directly into the FWI2025 calculations. In the medium-term weather outlook, the output frequency from many numerical models drops to three-hour or even six-hour intervals. This data format lies somewhere in between the “A” and “B” options shown in Figure 2. These less frequent outputs can be used to estimate hourly weather as well and is discussed further in Appendix B.

### **3.1.1.2 Weather input option with daily maximum and minimums (Figure 2, option B)**

#### **Regarding temperature, relative humidity and wind**

When hourly data is not available, estimates of the daily maximum and minimum environmental conditions can be used to estimate the expected diurnal variation in conditions throughout the day. This relies upon a modification of a model for diurnal variation developed by Beck and Trevitt (1989), which has been used by Canadian fire management agencies over the past several decades. This method is enabled within Prometheus, the Canadian Wildland Fire Growth model (Tymstra et al. 2010), for producing the hourly weather required by Prometheus when the user only provides daily maximum and minimum values (often from agency meteorologist forecasts). The calculation relies on the timing of sunrise and sunset based upon latitude, longitude and date of the weather observation and based on an analysis of historical hourly data from across the country. The daily maximum/minimum method will generate estimated hourly weather, which then flows into the FWI2025 (Figure 2, option B) allowing data to be used consistently within the same calculation process that is used for direct hourly observations (or forecast) inputs. Compared to FWI1987, this new method allows for better incorporation of the variation daylength, both as latitude varies and throughout the fire season.

#### **Regarding rainfall**

Within the daily maximum and minimum approach, several options exist depending on the data available to the user. If the end of a period of continuous rainfall is known, then rain can be placed at the end of that period. When the exact timing of rainfall recorded over a period is unknown, we try to associate the timing of rainfall with the estimated start of drying. In the case of once-per-day observations of rainfall, because drying is assumed not to occur overnight, this assumption means the daily rainfall is associated with the top of the hour after sunrise and the drying of the fuel layers happens over the full period of potential drying for the day. This can bias the fuel moisture calculations to the drier side; however, for operational decision making, this potential bias is considered acceptable. This same approach was used in the fuel moisture calculations of the FWI1987 as well as in the hourly FFMC calculation method (Van Wagner 1977).

Two scenarios are described below that offer more specific examples of rainfall timing and use in the FWI2025 and are expanded upon in Appendix B. These examples describe the principles that will allow FWI System users to appropriately and accurately use the information that is available for assessing fuel moisture and are not meant to describe a specific standard procedure that users must follow.

#### **Rainfall scenario 1: If the timing of the rainfall is known**

If the time and accumulation of a relatively continuous period of rainfall is known, more specifically, if the end of that period of rainfall is known, then the rainfall amount observed over the day can be placed at the end of the period of rain. The hourly calculation within the FWI System will assume the rainfall wetted fuels at the beginning of the previous hour (this is the way the hourly FFMC calculations treat each hourly observation). Although imperfect, it

provides a good estimate of the point where the drying of the fuel begins again after a rain, because the primary concern is determining the return to dryness after rain.

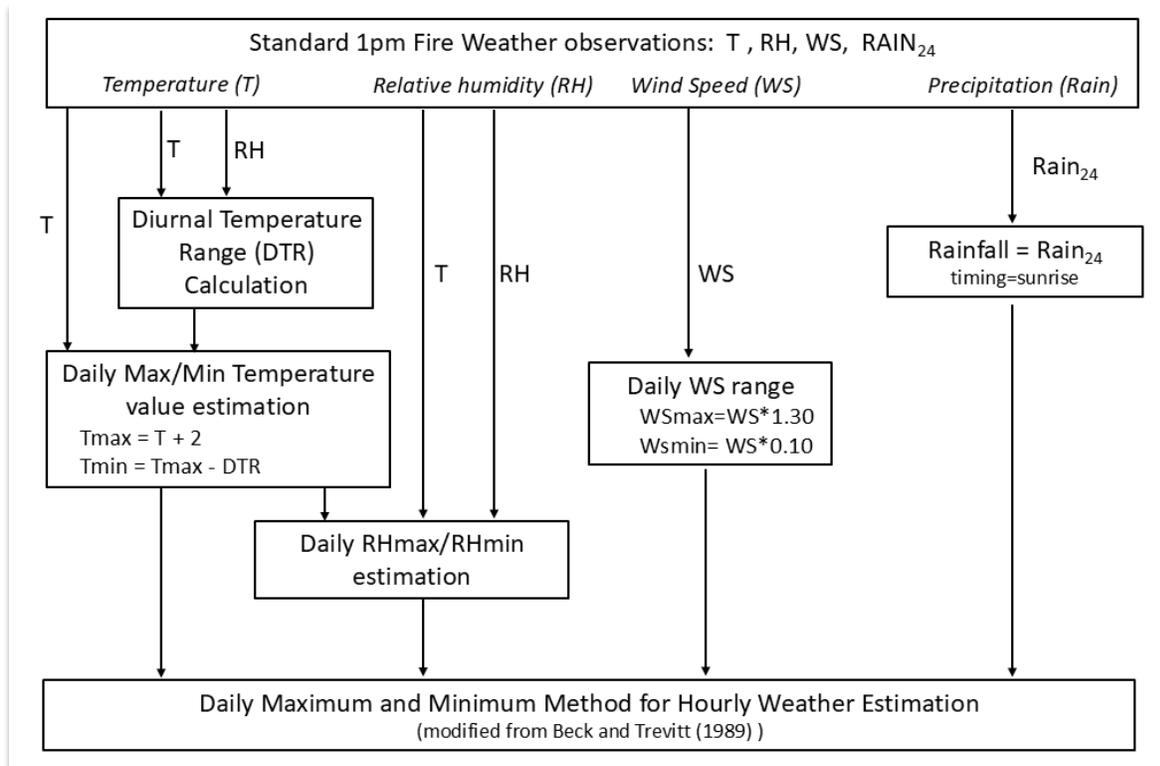
For example, for weather stations that regularly report rainfall at six-hour intervals, the observed rain should be associated with the first hour after the start of the observing interval. This approach associates the rainfall with the start of the period and, given that no information about the timing of the end of the rainfall period is known, errs on the side of assuming fuels have dried over the full period (given the other weather conditions). Appendix B provides a more detailed description.

### **Rainfall scenario 2: If the timing of daily rainfall is unknown**

When accumulated rainfall is available only once per day (e.g., the standard 13:00 observation), that rainfall amount is associated with the top of the hour after sunrise, which is assumed to be the start of the drying day. While observing practices vary between Canadian fire management agencies, many fire weather stations have a morning rainfall observation between 06:00 and 08:00. Depending on the timing of the weather observation, the morning observation often includes overnight rainfall and, in many cases, accumulated rainfall from the previous day at the standard 13:00 observation. Since the timing of the rainfall is unknown, this morning observation of rainfall should be associated with the closest hour after sunrise, with the time of sunrise calculated within FWI2025. This approach associates the rainfall with the start of the drying period for the current day and, given that no information about the timing is known, assumes the fuels will have dried over a full drying period; this is consistent with the method used in FWI1987.

#### **3.1.1.3 Weather input option with 13:00 weather observation (Figure 2, option C)**

While not ideal, the traditional 13:00 fire weather observation can be used with no additional data requirement apart from station latitude, longitude and date. This single observation may be the only daily observation available for historical analysis or, if a region only has access to weather observations from the standard 13:00 fire weather observations. To maintain the capability to use the FWI1987 fire weather observation, the 13:00 observation is used to estimate daily maximum and minimum values, based on Canadian historical averages (Figure 3), from which, as described in section 3.1.1.2, an hourly weather stream is estimated.



**Figure 3.** Conversion of the traditional 13:00 fire weather observation into inputs for the daily maximum/minimum method for estimating hourly weather.

To use the traditional fire weather observation, historical hourly weather from across Canada was analyzed to assess the average difference between the air temperature at 13:00 LDT and the maximum and minimum air temperatures for the day. While the averages are fairly consistent across space and time, there was some variation from location to location and period of the fire season. Regionally specific estimates could be used, but with the widespread availability of fine-scale numerical weather models, reanalysis datasets and common reporting of daily max/min values in weather station observations, the need for locally and temporally specific constants for adapting the traditional 13:00 fire weather observation will become less important. We expect in the transition to FWI2025 that these general methods for using the 13:00 weather observation should be adequate for most purposes. The following adjustments were developed for each input:

**Temperature:** A simple model that predicts the diurnal temperature range for a day based on the temperature and RH at 13:00 was developed using data from central Canada. On average, daily maximum temperature was found to be about 2 °C above the 13:00 observation.

**Relative humidity (RH):** The RH model is based on a standard RH adjustment technique. RH observed at 13:00 is used along with the 13:00 temperature to estimate the amount of water vapour in the air on the day, and then standard methods are used to estimate RH at the time of maximum and minimum temperature, assuming the amount of water vapour in the air mass stays constant.

Wind speed: The daily minimum wind speed is assumed to occur overnight and be 10% of the 13:00 observation. The daily maximum value reaches 30% higher than the 13:00 wind speed observation. This latter value was found to be a general average over multiple fire seasons in central Canada.

Rainfall: Rainfall from the traditional 1:00 PM observation, which represented accumulated rainfall over the previous 24 hours, should be associated with the first hour after sunrise. This is the way the 13:00 rainfall was treated in the FWI1987 System; even if it fell in the late morning, rain was assumed to have fallen by sunrise and was then followed by a standard full day of fuel drying. More details on this method are presented in Appendix B.

To reiterate, however, the use of this single mid-day observation is less than ideal; using observed daily maximum and minimum values would be superior.

### **3.2 Implications of the change in weather observation timing**

Rooted in the 1930s, the FWI1987 System relied on a single daily weather observation at 13:00 to assess potential for peak fire activity later in the afternoon. As forecast weather became available, users could assess afternoon fire danger over several days. While this approach provided a useful early indication of afternoon fire danger, it was inherently limited as it relies on several assumptions. With FWI2025, the characterization of the hourly weather variation for the day should allow more accurate assessment of drying throughout the fire season and over a range of latitudes; the longer periods of daylight in the far north will be better reflected in the moisture codes estimated by the FWI System overall. In addition, in some provinces or territories that span a wide range of longitudes, issues around the timing of the 13:00 LDT fire weather observation, time zone boundaries and the range in the timing of solar noon across a jurisdiction should be eliminated.

#### **Use of observed and forecast weather**

In operational settings today, the System calculations often involve a mix of observed weather stations and forecasted data for planning over several days. This approach maintains consistency in the FWI calculations, regardless of the data source. However, it is crucial to recognize the distinction between planning and the accurate assessment of the fuel moisture. The System's moisture codes function as a bookkeeping system, tracking changes in fuel moisture over time. To ensure the most accurate starting point for future forecasts, it is essential to update these moisture codes with observed hourly weather data whenever available.

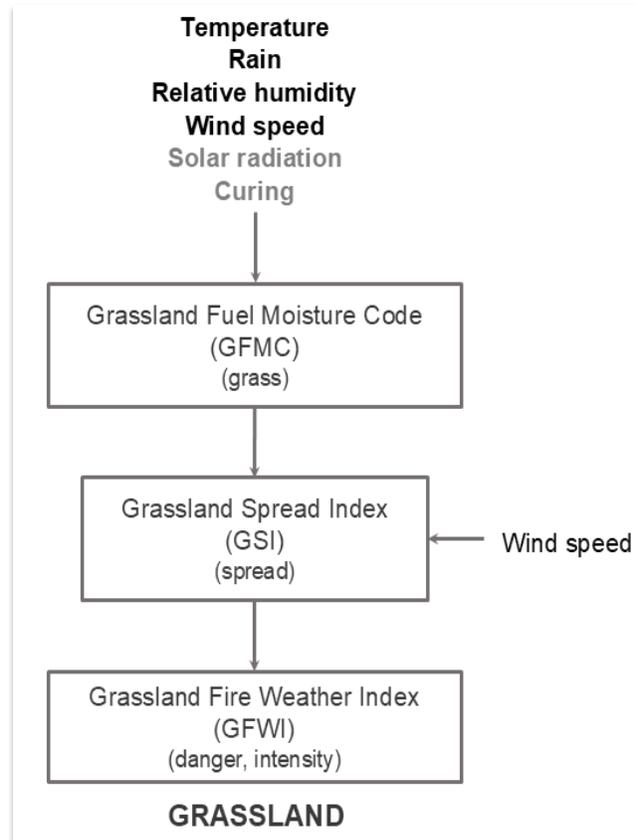
Jurisdictions with access to near real-time hourly weather data can leverage automated processes to update FWI calculations either hourly or several times a day. Agencies may decide to monitor the changes to the real-time weather or can update the forecasted outlook as the day progresses. This approach provides a continuous assessment of fire danger, allowing fire intelligence specialists to quickly identify significant changes in weather conditions. In the regular day-to-day operations, from the perspective of daily response planning, there would be little need to examine updated calculations on an hourly basis. However, on days with significant weather changes, they offer valuable insights for in-depth analysis and decision making.

For jurisdictions with limited capacity for real-time updates, a strategic approach to updating the System is essential. The best time for an update of moisture with observed data is just after sunrise, but prior to the initial morning planning cycle (an automated calculation at 07:00 for example). The observed weather conditions over the previous evening and overnight provide the most accurate assessment of the state of moisture content in forest fuels at the start of the new period of diurnal warming for the day (i.e., just after sunrise). A second update around noon (or the traditional 13:00 LDT observation) can validate the morning forecast and provide additional insights into evolving fire conditions.

### 3.3 New optional inputs

FWI2025 includes the capability to directly estimate fire potential in grasslands. Grassland fuels are more exposed to wind and the direct heating of solar radiation. They tend to gain and lose moisture much more quickly than the litter layer sitting on top of a moist organic layer in a closed canopy forest. This capability drives some of the need for new optional inputs: solar radiation and curing. The addition of these inputs to the System allows users to calculate new output streams and will, in future, provide enhanced accuracy in some elements at the core of the FWI System. These inputs, such as solar radiation, will eventually be incorporated into other aspects of fuel moisture estimation and thus become a more widely used input (Canadian Forest Service Fire Danger Group 2021). Where users do not have these inputs available on an hourly or daily basis, we provide methods for estimating these values.

The focus of the new grassland components is estimating moisture content in the dried, cured, exposed fine fuels of the grassland itself as the grassland fuel complex in the FWI System has no appreciable organic layer. A new grassland moisture model, tracking moisture content in cured grass, is used in FWI2025 along with an estimate of the curing state of the fuel complex (i.e., the opposite of the amount of green annual vegetation in the fuel complex) to create a GFMC. New guidance for starting stations in early spring is provided in Appendix C; these new grassland components may provide significant added value in understanding early spring fire potential in some areas. In addition, a new Grassland Spread Index (GSI) and Grassland Fire Weather Index (GFWI) have been created (Figure 4). These are described in further detail in the Output section (section 4.2).



**Figure 4.** New Grassland inputs and components in the FWI System.

### 3.3.1 Solar radiation

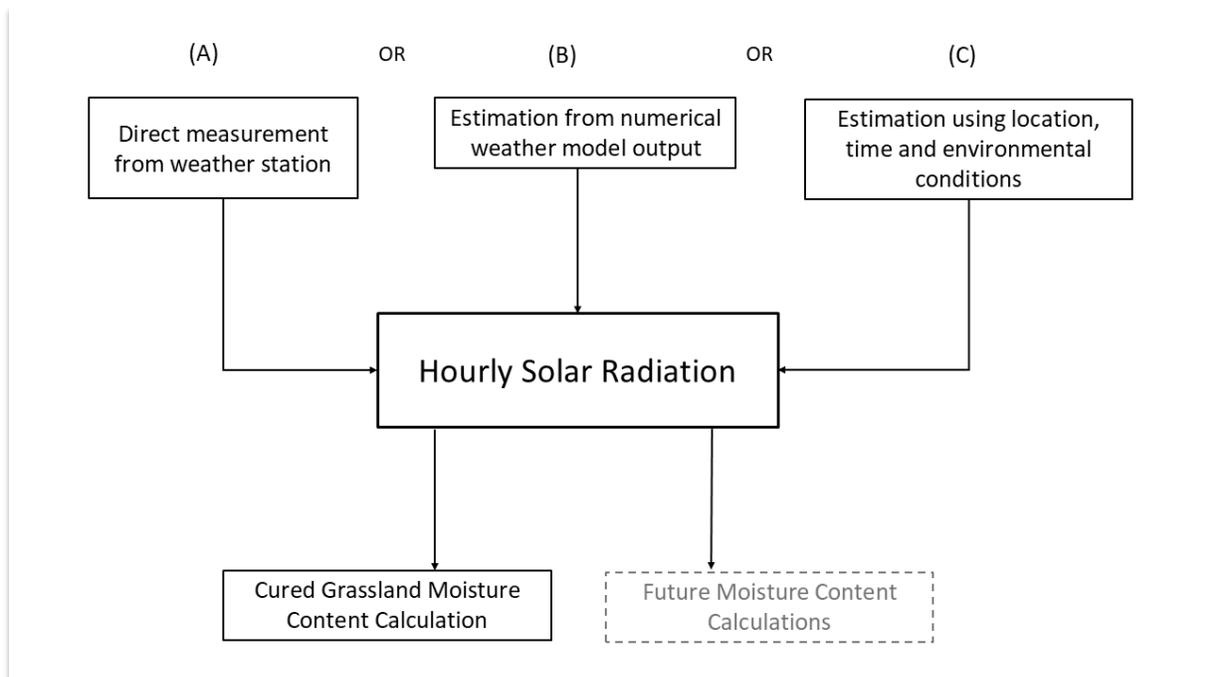
Grasslands are significantly influenced by solar radiation, due to their exposed nature. Direct solar radiation can heat fuels to more than 20 to 30 °C above ambient air temperatures, particularly in the spring where the previous season's growth has become matted by winter snowfall. The flattened surface is a good receptor and holder of heat from solar radiation. To accurately assess fire danger in these conditions, FWI2025 incorporates solar radiation, measured at ground level in kW/m<sup>2</sup>, as an input for the GFMC calculation.

With this new requirement in mind, we have identified three potential sources for collecting observed and forecast solar radiation data. These, as described below, go from most ideal (Option A, Figure 5) to least ideal (Option C, Figure 5):

A) Direct measurement: A direct measurement of incident solar radiation (kW/m<sup>2</sup>) at a specific weather station equipped with a pyranometer would be the superior choice. Ideally, this would be at least a 10-minute average, like wind measurements, and not an instantaneous value at the hour.

B) Numerical weather model: Solar radiation data from numerical weather models can provide a reliable estimate. Such outputs are now part of forecasted conditions provided by numerical weather models.

C) Estimation: If no source for solar radiation is available for either observed or forecast, a simple estimation method can be used that relies on the geographic location of a station, air temperature and relative humidity. This estimate is included as part of the input data configuration of the FWI System structure if other sources of solar radiation are not available.



**Figure 5.** Three potential sources for estimating solar radiation incident on the grassland fuel complex.

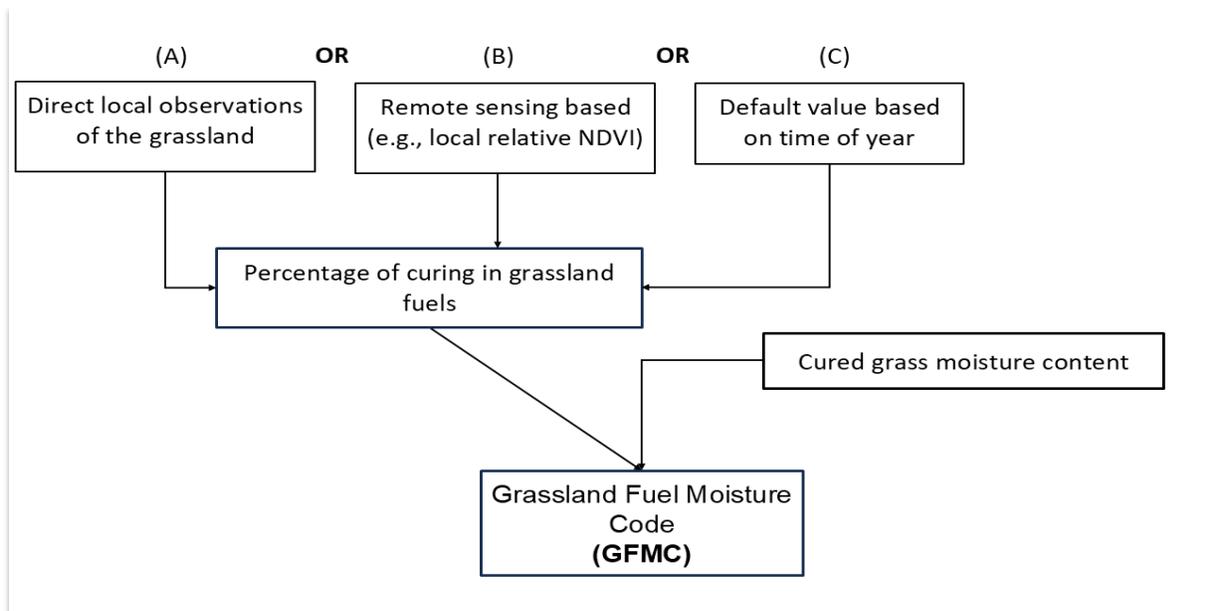
### 3.3.2 Grassland curing/greenness

To accurately estimate fire potential in grasslands throughout the fire season, it is important to assess the current state of curing in the fuel complex, now included as an additional input in FWI2025. Three general options are shown in Figure 6 for estimating the state of grassland curing (or greenness) for use in the FWI System. The default option built into the input processing uses one set of regional assessments based on historical analysis of satellite ‘greenness’ metrics. We chose the Boreal Plains region as it was a good general representative for the country. This analysis was done for multiple regions across the country, and an agency could choose to replace the Boreal Plains default with another set of data. This ‘default’ is essentially a type of ‘climatological average’ provided for situations when no other information is available. It does not account for weather or local species differences which might influence the timing of the emergence or senescence of annual growth; therefore, users should use the best available information for their assessment.

Lush, annual green vegetation can inhibit fire spread if it is a significant component of the fuel complex. The Canadian Forest Fire Behaviour Prediction (FBP) System provides a mechanism to account for this effect by considering the percentage cured, which represents the proportion of the fuel complex composed of fully cured grasses. In the new Grassland components (Figure 4), we consider the entire fuel complex to consist of grasses, both fully cured and live (or senescing). Fully cured fuels readily exchange moisture with the atmosphere, while green and senescing grasses retain higher moisture levels and are less affected by daily weather fluctuations. The percentage of cured fuel within a grassland directly correlates to the proportion of fine fuels in the fuel bed that are fully cured.

#### **Curing and greenness**

In fire behaviour modelling, and within the CFFDRS’s FBP System, we characterize the live state of grasslands by the percentage of the fuel complex that comprises fully cured grasses. A value of 100% means the grassland has lost all of its live moisture and is fully cured (the post winter condition often observed). This state of curing, particularly in the spring season, is most commonly observed by noting the amount of new live (green) growth that has emerged in the grassland overall. The concept of the “greenness” of the grassland may be a more easily understood characteristic for users who are not as familiar with the FBP System and its specific use of the term “curing”. Remotely sensed observations of vegetative state (i.e., Normalised Difference Vegetation Index) are often referred to as greenness indexes. For the purposes of the FWI System, greenness and curing can be thought of as opposite sides of the same coin (the percentage greenness is equal to 100 minus the percentage curing). To remain consistent with the FBP System overall, here we will continue to use the word curing.



**Figure 6.** Three different sources for estimating grassland curing and their place in the flow of calculations in the grassland components.

Like the new solar radiation input, we present potential sources to estimate the state of curing in grasslands. Figure 6 presents three options and how they are incorporated into the calculation of Grassland Fuel Moisture Content (GFMC).

A) Direct local observation: The best approach is for users at field locations to visually estimate the percentage of curing in the grasslands in the region. This percentage represents the proportion of fully cured to total biomass of the entire grassland.

B) Remote sensing-based observation: Remote sensing products, such as the NDVI, can provide estimates of grassland greenness, instead of curing. Users can calibrate these estimates with local fuel conditions. The Canadian Wildland Fire Information System (CWFIS) offers a provisional, national NDVI dataset, providing spatially detailed information on relative greenness (Canadian Forest Service 2020).

C) Default value based on the time of year: When field observations or remote sensing data are unavailable, we include here a method of estimating grassland greenness based on regional historical analysis. This method uses a time series of data for the seasonal variation of the curing fraction to estimate greenness for grassland and open woodland sites based on data from central Canada. This default provides a very coarse estimate of the state of fuels, as the timing of growth and curing in grasslands varies year to year and will not account for uncharacteristic drought. Similar curves exist for other regions in Canada and could be substituted; however, any such curve will have the disadvantage of not reflecting seasonal anomalies.

### **3.3.3 Standard grassland parameters**

To maintain consistency with the FBP System, a default value of 0.35 kg/m<sup>2</sup> for surface fuel load is set in FWI2025. However, like in the FBP System, users can specify a different value. This influences the estimate of head fire intensity that is used to calculate GFWI.

In the spring, the grassland will be assumed to be fully matted. From the middle of the growing season until snowfall, the grassland will be assumed to be standing. In areas without snow where grasslands remain mostly standing in the spring, users can modify FWI2025 to assume grass is standing throughout the year.

## **4 OUTPUTS OF FWI2025**

### **4.1 Updates to the standard pine components**

FWI1987, designed for closed-canopy mature pine forests, tracks fuel moisture content and fire behavior. The core components of this System remain largely unchanged in FWI2025 (Figure 1). Any adjustments that have been made are to ensure compatibility with a wider range of input data while maintaining the consistency of output values. This means that an FFMC of 91 in FWI1987 should correspond to an FFMC of approximately 91 in FWI2025. Any deviations between the two systems should reflect meaningful differences in fuel moisture content, as FWI2025 more accurately models diurnal drying and wetting processes.

#### **4.1.1 Moisture: Fine fuels**

FWI2025 utilizes an hourly FFMC calculation offering a refined approximation of real-world conditions, and so values may deviate from the daily FFMC estimate from FWI1987. This hourly calculation has been modified from the original version from Van Wagner (1977) and provides a better approximation of the diurnal change in moisture associated with the actual day while still relying on the concept of exponential drying and wetting towards an equilibrium moisture content. Additional details on modifications of the FFMC in FWI2025 are explained below.

#### **Canopy interception of rainfall**

In the daily FWI1987, the first 0.5 mm of rainfall was assumed to be intercepted by the canopy, thus not reaching the forest floor. And while the canopy interception was not included in the hourly Van Wagner (1977) version of FFMC due to the potential hourly accumulation, the FFMC in FWI2025 maintains this simplified canopy interception like the daily version. In the hourly FWI2025, the canopy interception is cumulative throughout a day. The first 0.5 mm of rain at the start of a rain event is intercepted, saturating the canopy, and any subsequent rain within that event reaches the forest floor. In the daily version (FWI1987), the FFMC canopy interception threshold is reset at the end of each day, meanwhile in this new hourly version (FWI2025), a six-hour time constant is introduced to account for canopy drying. After six hours without rain, the canopy is assumed to dry, and the 0.5 mm interception threshold is reapplied at the start of the next rain event.

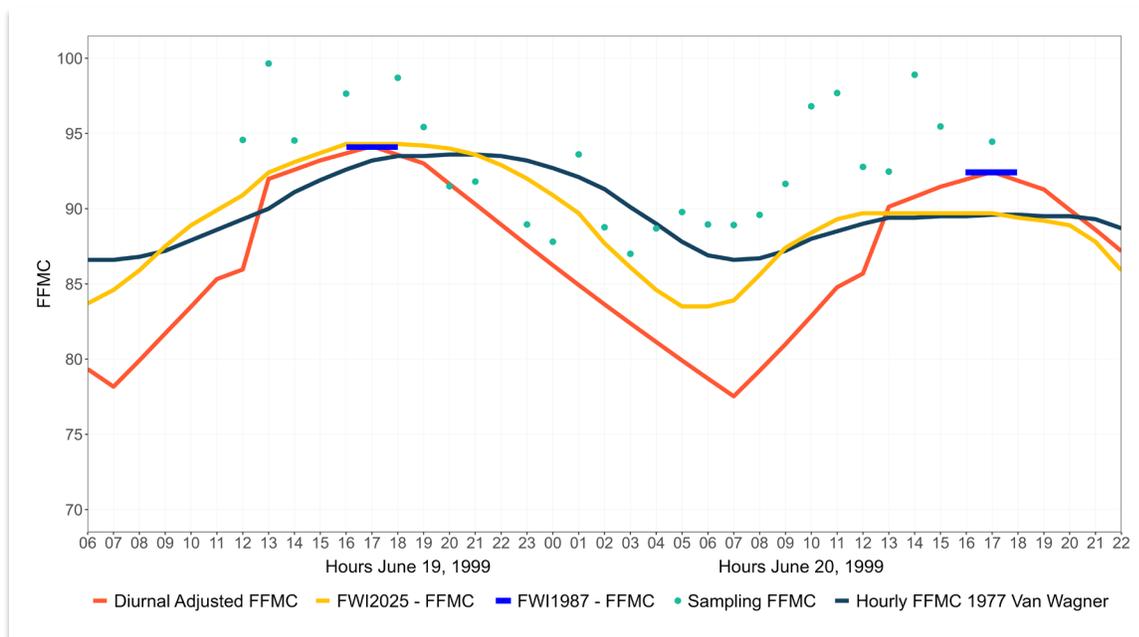
Physically, a canopy interception of rainfall is a reasonable assumption and many models of precipitation interception and throughfall exist. For the sake of simplicity, we have kept the simple canopy interception model from the original daily FFMC and included it in the hourly calculation. This rainfall time constant is also used for the moisture codes of the heavier fuels, the duff moisture code (DMC) and the drought code (DC) and is illustrated in section 4.1.2 below. Resetting the canopy interception threshold after six hours is a simple approximation of drying; evaporation would depend on atmospheric conditions and begin immediately after rainfall has ended in many conditions. Weather-based models of evaporation exist; however, we have not investigated their impact on the fuel moisture calculations used in the FWI System. Therefore, for the FWI2025 update we introduce this simple approximation to introduce the concept and will refine it and test its impacts in future development of the moisture models. The FWI2025 also retains the original effective rainfall absorption fraction of approximately 5%, which represents the amount of rainfall that is absorbed by the litter layer. Future

improvements in fuel moisture modelling may allow for a more refined representation of this process.

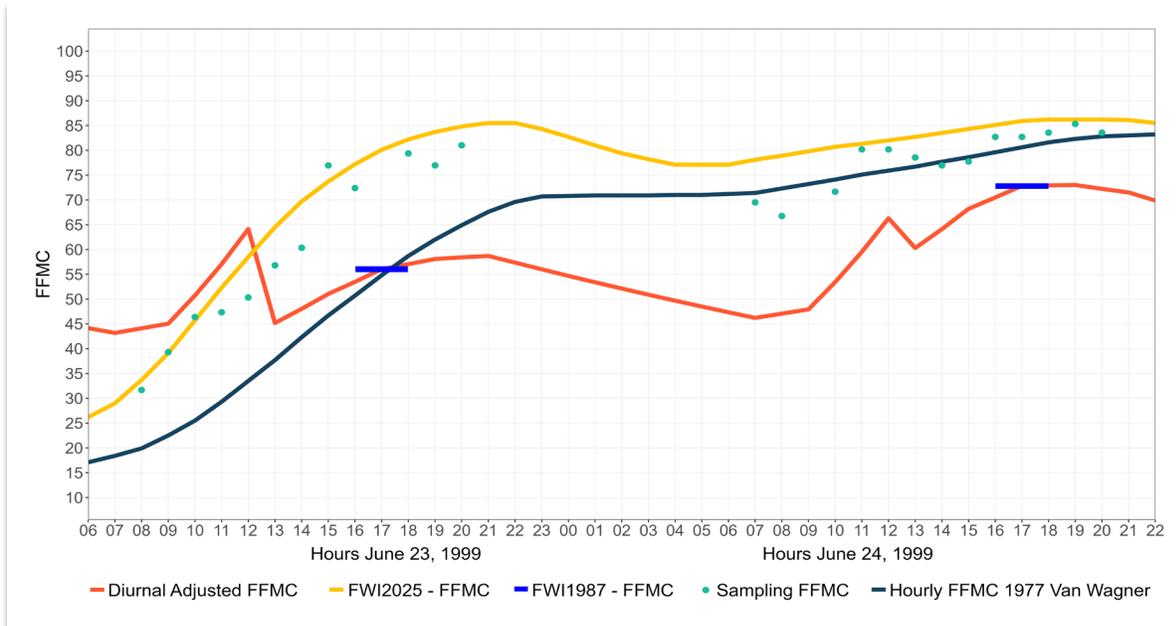
### Drying

Observations of litter moisture from the field have suggested that the drying rate in the FFM model itself is too slow (e.g., Beck and Armitage 2004, Wotton 2007). Work by Anderson (1990) on moisture diffusivity and observations on rate of drying by Nelson (2001) and Van Wagner (1979) also suggest the time lag drying and wetting constants should be shorter than the drying rate function in the hourly FFM (Van Wagner 1977).

Therefore, to better match field observations of litter moisture content variation throughout the day, the time lag function used in the FWI2025 for the FFM has been cut in half. Time lag still varies with temperature and relative humidity following a similar function form to the original FFM. This faster drying rate tracks observations from our in-situ sampling of fuel moisture and brings the daily range of the FFM closer to that found in the diurnal adjustment to the FFM (Figures 7 and 8). Under the right temperature and relative humidity conditions, the FFM will also continue to dry overnight. Developing and adopting a more process-based yet operational methodology of calculating litter-layer drying and wetting is an ongoing applied research activity to improve future generations of the System.



**Figure 7.** The different versions of FFMC compared to field sampling of fine fuels (green points) collected during the International Crown Fire Modelling Experiments (ICFME) in the Northwest Territories over a two-day period.



**Figure 8.** A second example of the different versions of FFMC compared to field sampling of fine fuels (green points) during the ICFME in the Northwest Territories over a two-day period.

#### 4.1.2 Moisture: Heavier fuels

To maintain consistency in hourly outputs, FWI2025 includes hourly calculations for DMC and DC, despite the slower drying rates of these heavy fuel layers. While this hourly resolution may be more granular than necessary, it ensures consistency across all System components. In developing these hourly methods, we prioritized keeping the time lag in the fuel layer consistent with the original daily version and retaining the original effective rainfall model. Enhancing our models of organic layer moisture is a continuing area of applied research. Our focus on these current updates was to modify the original methods such that they provided reasonable and consistent outputs in an hourly calculation; as a result, several significant assumptions and approximations have been made to make this work.

#### Drying

The DMC and DC follow the same exponential drying towards a very dry equilibrium state that has been used in their original formulation. Drying only occurs between sunrise and sunset and the drying rate for each hour is calculated from the hourly environmental conditions and the previous hour's moisture content using a modification of the original drying rate functions in the DMC and DC, respectively.

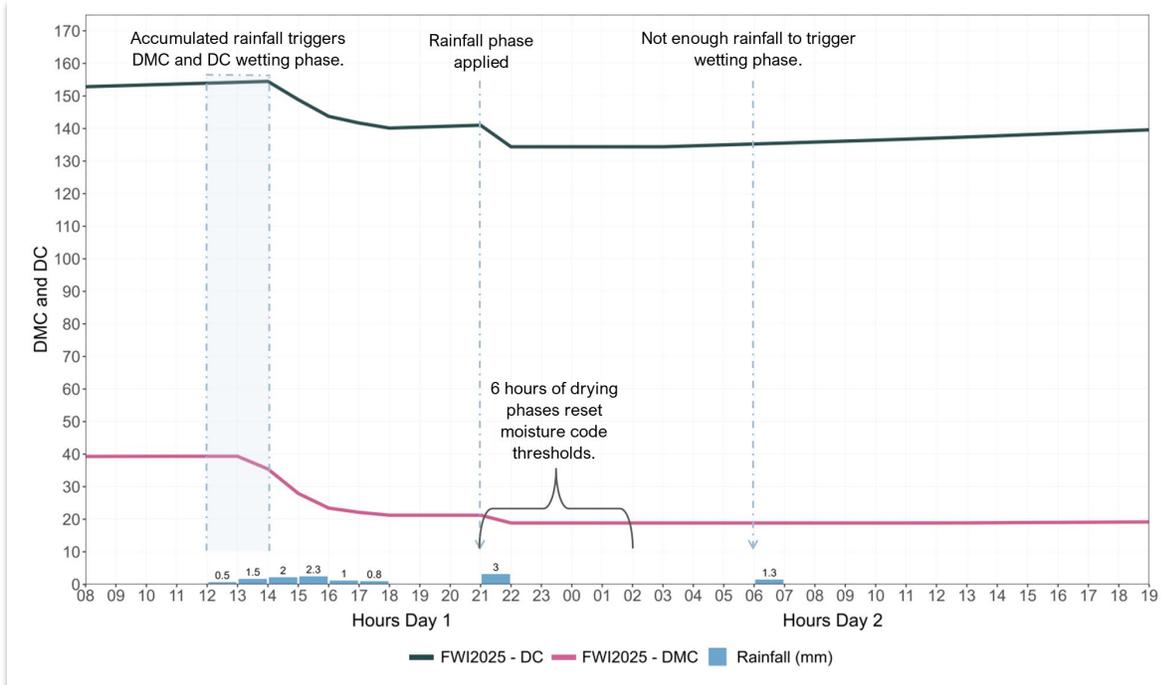
#### Rainfall

In the DMC and DC models, a calculation of effective rainfall, the quantity that is assumed to have the potential to be absorbed into the organic layer, is carried out to reduce the rainfall amount observed in the open. In the daily FWI1987 System only rains >1.5 mm and rains >2.8 mm influence the fuel layers tracked by the DMC and DC, respectively. These effective rainfall thresholds are maintained in FWI2025.

The FWI2025 models for estimating effective rainfall in the hourly DMC and DC, like within the new hourly FFMC, treat rainfall as cumulative throughout the day. In the DMC, rain does not affect the moisture content until the amount of accumulated rainfall passes the rain threshold (1.5 mm); after this point, accumulating rainfall begins to affect moisture content in the duff. Once cumulative rainfall has surpassed the rain threshold, Van Wagner's (1970, 1987) effective rainfall function from the daily DMC is used to estimate the wetting in the organic layer that has occurred over the hour. The 1.5 mm holding capacity in the DMC function is reset 6 hours after rainfall ends. Once six hours of no rainfall has passed, the canopy holding capacity is reset and any new rainfall will again need to surpass the rainfall threshold of 1.5 mm before it begins to wet the upper organic layer tracked by the DMC. This process of cumulative rainfall and resetting of the rain threshold is the same for the DC, except with a threshold of 2.8 mm. Figure 9 graphically illustrates the rainfall process for these two moisture codes over a two-day period. In this example, rainfall occurring between 12:00 and 14:00 accumulates and eventually reaches the precipitation thresholds for the DMC and DC. Once these thresholds are met, subsequent rainfall is directly applied to the moisture codes. If there is a brief interruption in precipitation of less than six hours, the rainfall continues to wet the fuels, and the moisture codes continue to decrease. For instance, the 21:00 rainfall on June 7 in Figure 9. However, if a six-hour rain-free period occurs, the thresholds for all moisture codes are reset. The precipitation on June 8 in Figure 9 exemplifies this, as rainfall must accumulate towards reaching the thresholds again before initiating a new wetting phase.

From a procedural perspective, this is a significant change to how rainfall was treated in the past. On days with one main rain event, there should be little to no difference in the rainfall's effect on wetting the duff. On days where two rainfall events are spaced apart by more than six hours, the canopy holding capacity threshold is reapplied to the second event, and this change will potentially reduce the amount of effective rainfall reaching the organic layer. All other things being equal, this will err to the dry side of fuel moisture.

These rainfall thresholds and effective rainfall absorption models are parts of the FWI2025 that will be examined and then improved in subsequent revisions of the System.



**Figure 9.** An example of the hourly calculation of DMC and DC over two days with intermittent rainfall.

#### 4.1.3 The standard fire behaviour outputs

The core of FWI2025 retains the three primary fire behaviour index outputs, which are indicators of fire behaviour in closed-canopy mature pine stands. However, it incorporates a modified Initial Spread Index (ISI) from the FBP System which was introduced in 1992 (Forestry Canada Fire Danger Group 1992). The original ISI formula in the FWI System can lead to excessively high values at extreme wind speeds, and to address this, FWI2025 will adopt the modified ISI function from the FBP System. This modification limits the impact of high wind speeds on the ISI at wind speeds over 40km/h, ensuring a more realistic representation of fire behaviour. It is important to note that this change is primarily relevant for extreme fire conditions and should not significantly impact fire agency classification thresholds. The calculation for the Build-Up Index (BUI), Fire Weather Index (FWI), Daily Severity Rating (DSR) and other FWI transformations will remain unchanged.

#### 4.2 The new grassland components

Early fire hazard rating systems recognized differences in drying rates between exposed and shaded fuels (Wright 1933) and developed specific tables for grasslands (Wright and Beall 1938). Regional Forest Fire Danger tables (1956–1962) included adjustments for fast and slow-drying fuels (Forestry Branch 1957).

Many operational users of the System, particularly those involved in springtime prescribed burning in grasslands, have recognized that there are situations where the FWI System does not work well in grasslands, particularly in the hours and first day or two immediately after rain. Grassland fuels can recover and be ready to burn just hours after a significant rainfall (Cheney and Sullivan 2008); having a time lag of well under an hour because exposed grassland fuels have a very quick drying rate (see figure 10a). Furthermore, the impact of the curing of the

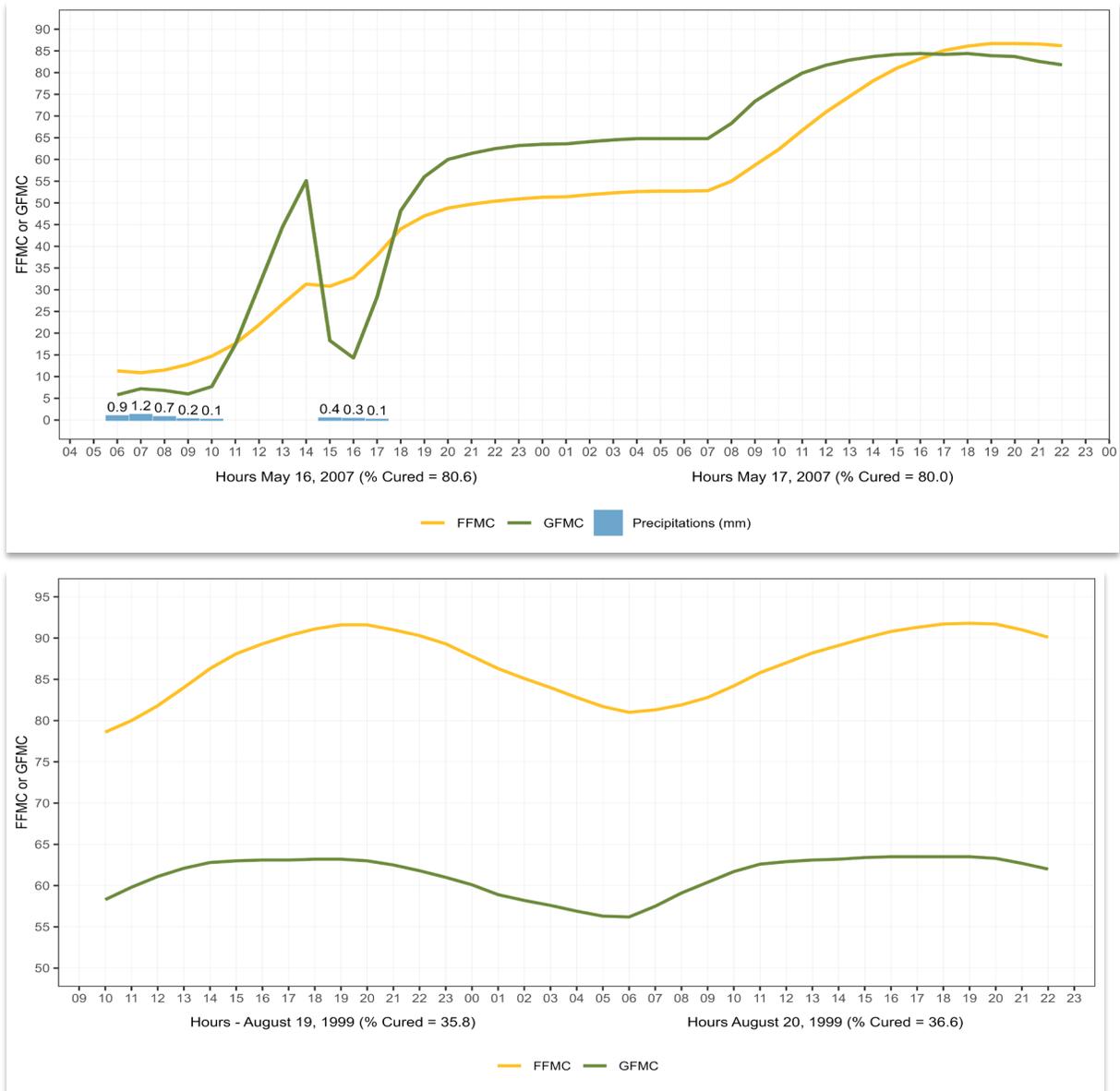
annual growth in the fuel complex in open grasslands is not explicitly addressed in the current FWI System, unlike in FBP. This has been recognized as a limitation in adaptations of the FWI System internationally (e.g., in their adaptation of the FWI System, New Zealand developed a separate element for grassland danger based on the FBP System).

The FWI2025 code and indexes calibrated for open grasslands address some of these differences in fuels and fire behaviour in an open grassland setting compared to the standard pine fuel type (see Figure 10a and 10b).

### **GFMC: Grassland Fuel Moisture Code**

A grass moisture model, based on the FFMC, has been available for some time (Wotton 2009) and is already incorporated into prescribed burning guides (Kidnie et al 2010). These grass fuel moisture models represent moisture content in fully cured grasses in open, exposed grassland. There are versions of this model for both standing and matted grasses, corresponding to fall and spring conditions in much of Canada. These models have been modified for their inclusion in FWI2025. The applicability of the GFMC to other open fuels such as lichens in C-1 and fine woody debris in slash fuels is currently being evaluated.

The conversion of grass moisture content to the GFMC is more complex than the FFMC conversion between conifer litter moisture and the FFMC using the FF-scale (Van Wagner 1987). The conversion to GFMC incorporates the estimated amount of live vegetation in the grassland, using the FBP System's curing function for grassland. This function assumes that green annual growth acts as an energy sink, inhibiting sustained combustion, this will be most pronounced when there is higher proportion of green growth versus cured grass (Figure 10b). Therefore, the GFMC is not an average moisture content but rather an "effective moisture content" that considers the impact of live vegetation on ignition probability. It is designed to directly indicate the likelihood of sustained ignition in a grassland.



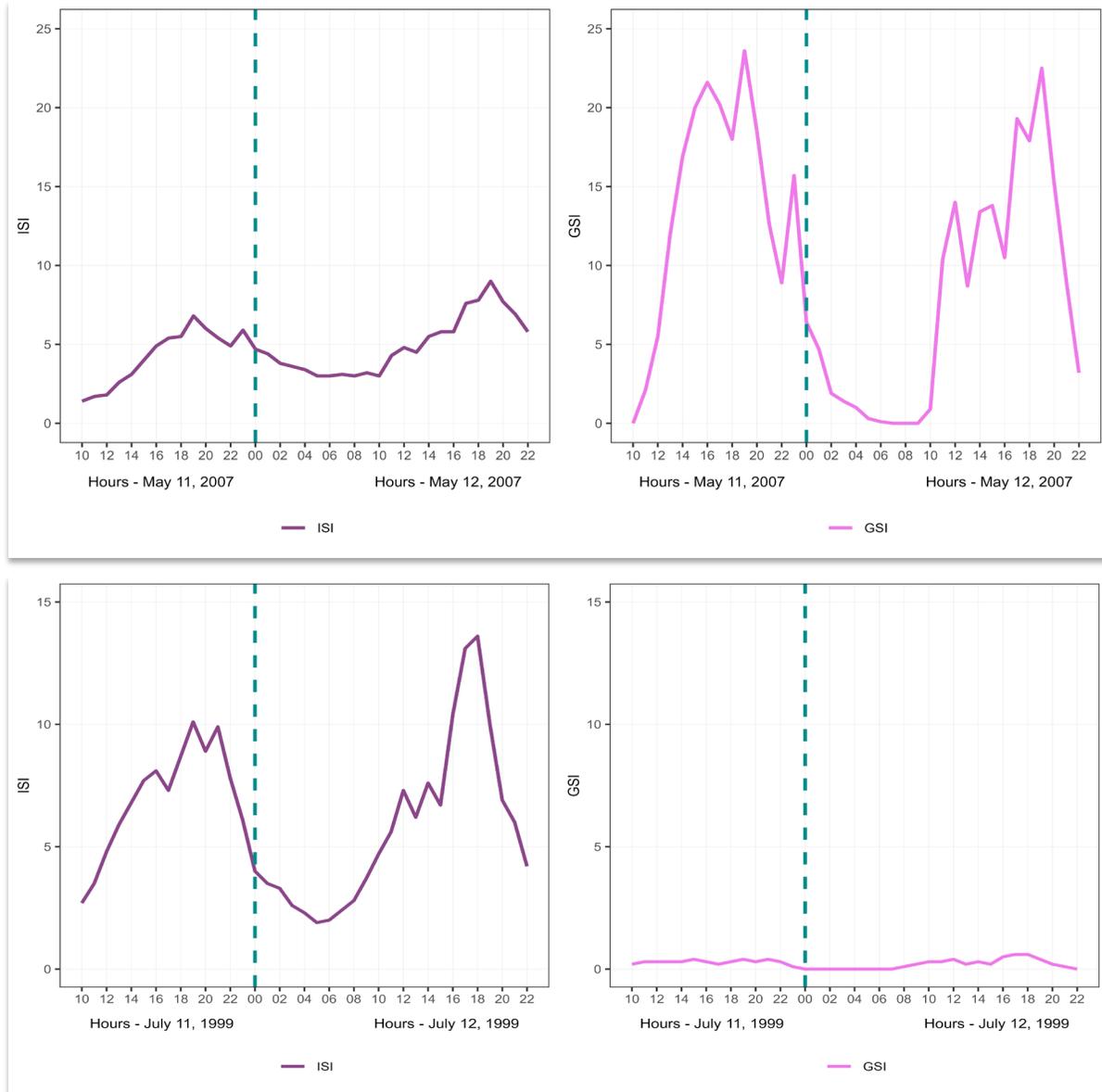
**Figure 10.**

- a) A springtime example of the effect and recovery of precipitation on the GFMC (green) and FFMC (yellow). In May, the grassland is considered matted, and there is a larger proportion of cured grass compared to green.
- b) Comparison of GFMC and FFMC Models in the summertime. Both models are based on the FF-scale but the GFMC incorporates the impact of live vegetation, often resulting in lower values during summer months.

### **GSI: Grassland Spread Index**

The GSI provides an indication of potential fire spread rate in grasslands. It considers the curing stage of the fuel complex from the FBP System. The GSI calculation incorporates moisture content of cured grass, percent curing, and open wind speed. Similar to the ISI, the GSI is a relative (unitless) indicator of fire spread. However, it is specifically designed for grassland fuels and uses the FBP System's grassland spread models. The GSI, while unitless, increases linearly with the expected rate of spread in grasslands. The scaling for the GSI was chosen so that the

expected rate of spread in fully cured grasslands for a GSI value of 10 corresponded to the expected rate of spread in a conifer forest (an average of C-2 and C-3) for an ISI value of 10. GSI changes with the curing state of the grassland throughout the season consistent with the way grassland spread rate changes with curing in the FBP System; in the spring when grasslands are fully cured the GSI shows much more variability compared to ISI (Figure 11a), and when grasslands are fully green (in early summer) the change in GSI throughout the day can be much more muted than the change in ISI (Figure 11b).



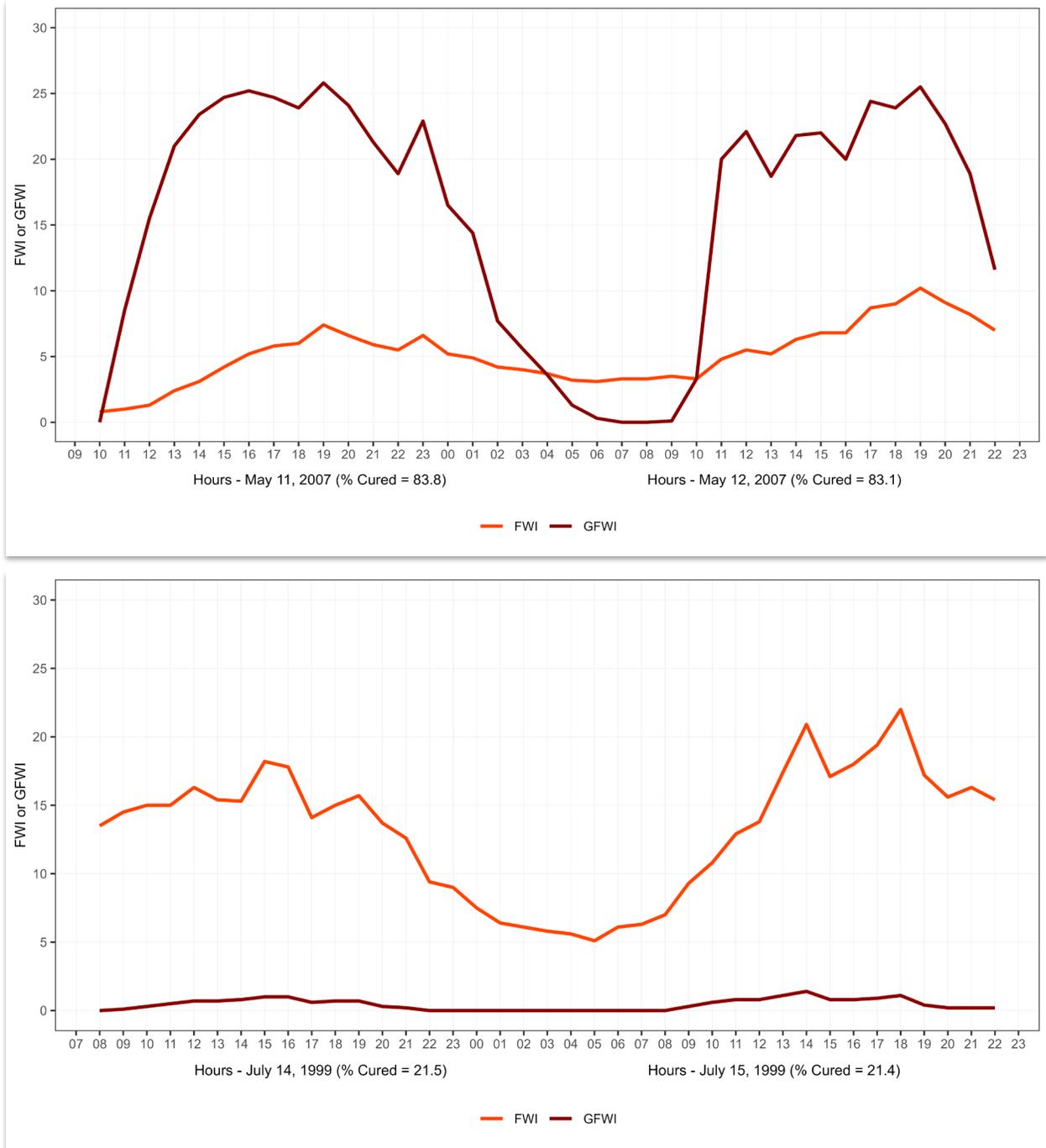
**Figure 11.** Examples of the GSI and ISI from data collected at the International Crown Fire Modelling Experiment (ICFME) field side in Northwest Territories.

- a) GSI and ISI in Spring, where there is a larger proportion of the fuel complex that is matted and cured. Note the scales of GSI and ISI are different.
- b) ISI and GSI in summer. At this stage of the season, the curing factor influences the expected spread rate in the GSI.

### **GFWI: Grassland Fire Weather Index**

The GFWI is designed to be similar to the FWI and consistent with the FBP System grass fire behaviour models (Figures 12a and 12b). It is a scaled, unitless indicator of predicted grassland fire intensity. The GFWI estimates grassland fire intensity using a simple transformation designed to match the scaling relationship between FWI and Head Fire Intensity (HFI) in the mature Jack Pine fuel type (C-3) of the FBP System. The grassland fireline intensity is calculated from the GFMC, GSI and grassland fuel load. Because GSI is influenced by curing, the change in GFWI throughout a day can also be very muted during the summer when grasslands have a considerable live, green component (Figure 12b). The scaling of the GFWI was chosen so that similar FWI and GFWI values correspond to roughly the same overall fireline intensity.

Agricultural areas with a mixture of pasture, natural grasslands and crop residues should also be well-represented by the GFWI. Public Fire Danger maps for large continuous areas or administrative regions of non-forest (i.e., grasslands and agriculture) may choose to represent Fire Danger maps using only GFWI.



**Figure 12.** Examples of the GFWI and FWI from data collected at the International Crown Fire Modelling Experiment (ICFME) field side in Northwest Territories.

- a) GFWI and FWI (FWI1987) in the spring. The high curing factor in the Springtime grasslands, combined with the finer fuels results in a more dynamic GFWI.
- b) GFWI and FWI in the summer. A higher percentage of live vegetation in the grassland reduces the potential fire intensity in the GFWI.

### **4.3 The new peatland components**

The Peatland component is associated with a fuel complex that changes its moisture more slowly than the organic moisture models in the rest of the updated FWI System. These peatland-specific indicators are envisioned as optional for users with significant peatland fuels on their landscapes. The indicators will identify when these areas could act as fuel breaks or propagate fire and sustain extended deep smouldering and therefore lead to significant smoke and particulate production. Such widespread sustained smouldering in deeper organic layers can take considerable time or resources to extinguish and produce emissions that can significantly influence the health of both fire responders and the public. Because fuel availability in terms of deep sustained smouldering fire in peatlands is linked to water tables, peatland indicators of fuel moisture (i.e., ability to sustain smouldering) change slowly, like the DC element of the current FWI System.

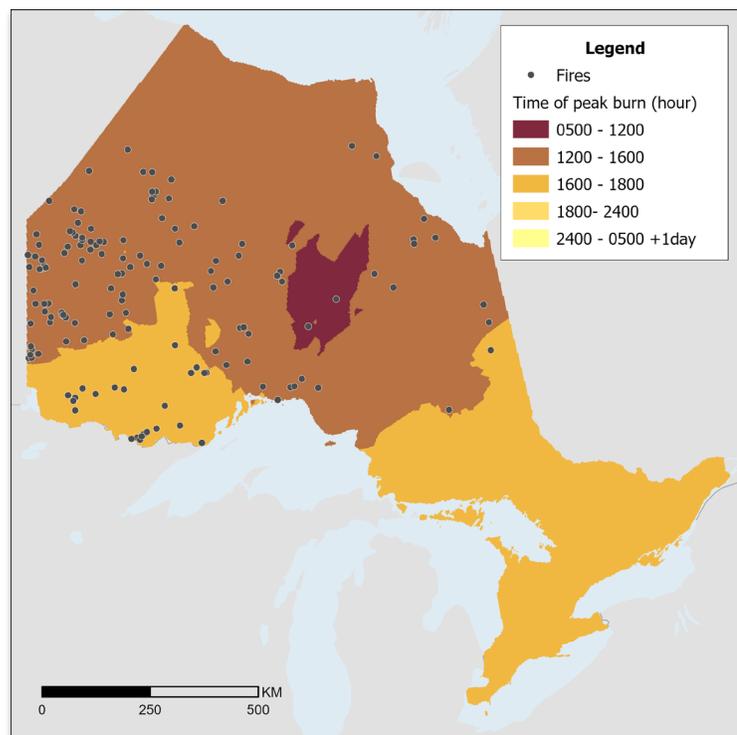
The PMC will integrate several factors related to water table depth and moisture in the upper half metre of organic material in a peatland; it will indicate the receptivity of peatlands to deep smouldering. The Peatland Spread Index (PSI) will combine wind and peatland surface moisture levels and provide an indication of the ability of surface fire to spread easily and rapidly across peatland areas. These indicators have been in development and testing for some time in a range of different Canadian peatland types (e.g., Waddington et al. 2012, Thompson et al. 2019, Bona et al. 2020), though their final form for inclusion into the FWI System has not yet been determined. They will be formally included in the System in following updates of the FWI System calculation methodology.

#### 4.4 New daily summaries of hourly outputs

By calculating outputs hourly, FWI2025 can summarize the components of the System in a number of ways to supplement traditional daily planning briefings. In addition to standard FWI System outputs, FWI2025 now includes sunrise, sunset and sunlight hours. The Fire Danger Group has developed additional methods for summarizing FWI2025 components as examples and starting points, available on the CFFDRS2025 FWI GitHub page and described below.

##### Time of peak burn

FWI1987 lacks a precise definition for the time to which its outputs are correlated to the peak burning conditions of the day. However, training material often suggests 16:00 or 17:00 as general approximations. The FWI2025 daily summary defines the “peak burn” as the hour corresponding to a maximum, smoothed ISI during the day. Whereas “peak burning conditions” are defined in terms of spread potential in the ISI and captures the interaction between the daily FFMC and the daily wind. Hourly wind speeds can be quite variable in the afternoon. In addition, variation in RH throughout the daily cycle can also lead to variability in hourly FFMC, particularly in conditions where the fuels are getting close to equilibrium values. To reduce the impact of this variability, the wind speed is smoothed over the day (in the daily summaries process). A smoother ISI is calculated from these values and the hour the maximum smoothed ISI occurs is taken as the “time of peak burn.” This estimate of peak burn represents a mathematical maximum and does not provide an indication of how sharp or flat that “peak” is. A further estimate of the width of the burning window on a particular day may also be a useful addition. Figure 13 demonstrates a method for visualizing the hour of peak burn. In this example, the daily weather summary is interpolated across the province and classified based on the hour of peak burn. The classes are designed to highlight areas experiencing early morning, mid-afternoon, traditional peak burn time and evening peak burn periods. While incorporating active fire locations can inform regional planning regarding the potential activity of current fires, this visualization does not directly convey the peak ISI values across the province.



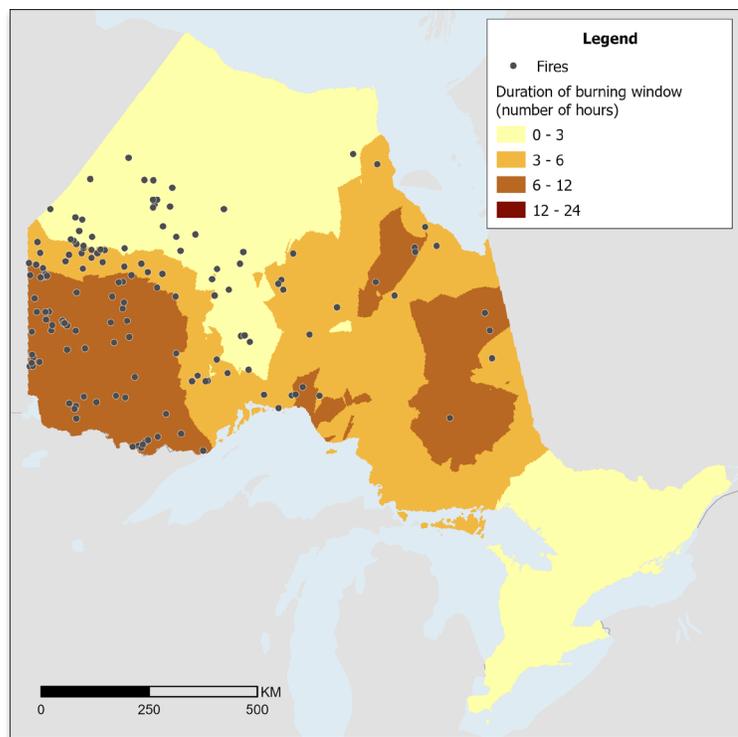
**Figure 13.** Map representing the time of peak burn. This example is a result of a daily summary from Ontario weather station observations on July 17, 2021, interpolated across the province.

### Duration of the burning window

The smoothed hourly ISI values can also be used to estimate the length of the active burning period during the day, which might be useful for understanding the impacts of non-standard conditions (i.e., very dry air masses). This requires the definition of a threshold for active burning. We have defined the threshold for active burning as ISI equal to or greater than five, which corresponds to spreading surface fires and the transition from the Moderate class to the High class in the physically based classifications we suggest in Table 1 (section 5.3). An agency could modify these values based on local data.

The hour of the day when hourly ISI reaches this active burning threshold is estimated to be the start of the burning window and the point when the ISI falls below this value is considered the end of the burning day. The difference between these two times is the burning window. However, if the ISI cycles several times above and below this active burning threshold, the calculation will use the first time in a 24-hour day that it goes above the thresholds and the last time in the day that it drops below the thresholds as the start and the end of the burning period respectively.

Figure 14 is an example of mapping the burning window, using a basic interpolation on the daily weather station summary that estimates the number of hours of active burning based on ISI values of five or higher. The smoothing applied to the hourly wind and the FFMC should result in a smooth hourly structure which defines the overall characteristics of the burning day.



**Figure 14.** Map representing the number of hours where  $ISI \geq 5$  on July 17, 2021.

## 5 USE AND INTERPRETATION

The FWI System was designed to provide a systematic and standard way of assessing fire potential for use in informing prevention, preparedness and planning activities. The interpretation of the core outputs of the FWI2025 has not changed. The move from the once per day weather observation to hourly weather will allow agencies to better account for changes throughout the daily weather cycle.

Effective fire management planning requires accurate weather forecasts. While hourly forecasts are ideal, other forecast intervals can be used to estimate daily weather variations. Operational planners should strive to leverage the best available information to make the most accurate weather estimates for a given forecast period. To support this, we have developed methods to convert longer-interval weather data into estimated hourly information. However, any weather estimate, including those derived from our methods, involves inherent assumptions. Users must recognize the potential impacts of these assumptions on the uncertainty of their fire potential assessments. This is comparable to the uncertainties associated with using 13:00 fire weather observations to estimate late afternoon peak burn conditions in the current FWI1987.

### 5.1 Daily planning with hourly FWI2025

While FWI2025 calculates hourly outputs, peak burn period data will likely remain the primary focus for daily operational planning, aligning with the original FWI System. The hourly resolution offers several additional advantages. It enables users to estimate the expected timing of peak fire activity and duration as well as track overnight fire spread potential and overnight RH recovery. The increased resolution in the FWI System's outputs can provide not only an indication of variation in the expected timing of the peak of fire activity in a day but also the duration that burning potential might be expected to be above a critical threshold.

While hourly outputs may be an overwhelming amount of data from the daily regional planning perspective, this real-time monitoring can highlight discrepancies and potential shifts in fire behaviour, enabling timely adjustments to operational plans. This functionality could provide an early indication of unexpected activity and trigger an assessment of impacts on plans made earlier in the day.

Fire management decision making and its information needs vary region to region as well as across the continuum of low to extreme fire activity. As such, each agency should assess its specific information requirements and evaluate how to best leverage the capabilities of FWI2025 to support its operational needs.

We provide some initial recommendations below on options for using the new System in daily planning activity to help begin implementation discussions:

#### 1) Status quo

A conventional approach is to summarize the FWI System outputs once daily at a standardized time (e.g., 17:00), aligning with traditional FWI1987 practice. This provides a consistent evaluation time, but it may compromise the accuracy of predicting peak burn times and the full range of fire behavior potential throughout the day. A standardized output time may not fully capture the impact of atypical diurnal or nocturnal weather

patterns (like overnight humidity recovery). Agencies should weigh the benefits of standardized reporting against the potential loss of valuable information from hourly outputs.

## 2) Daily planning supported with peak burn indicators

Daily mapped and tabular summaries based on estimated time of peak burn can provide valuable insights. For clarity, the specific time represented by these summaries should be clearly communicated and interpretable by the user. While peak burn can be defined in various ways (e.g., ignition potential, spread rate or intensity), section 4.4 outlines a standard method for estimating peak burn, which we have included in FWI2025 calculation post processing as an optional output. Users can evaluate what best fits their operational requirements and summarize their data accordingly.

While losing the standardized time (e.g., 17:00) associated with system outputs, we gain a more consistent indication of the maximum expected fire potential on a given day. This should provide a clearer picture of the most challenging conditions anticipated by fire suppression resources. Additionally, directly displaying the time of peak burn activity on output maps and tables offers valuable information for planning purposes.

We note that peak burn time varies as weather systems move across a region. Furthermore, like any spread metric associated with wind (e.g., ISI), there can be significant local variation in the value itself. To address this, mapping smoothed variables, such as wind speed and max ISI, like those suggested in section 4.4 and displaying individual station values may provide a clearer picture (as is done currently in many jurisdictions for noisy fields like ISI). When weather indicates parts of a region should experience peak burn at noon, while in other parts it is expected to occur later in the evening, a choice would need to be made about the time chosen for the daily summary presented to planners and decision makers.

Planning based on variable time of peak burn across a region can also pose challenges. Users may find value in anchoring their planning with reference to and comparison with FWI System outputs from a specific time. Referencing the time and value of peak burn with a standard time (e.g., 17:00) provides an indication of a day with potential burning that deviates from standard or expected values.

Another challenge is that peak burn time may not be overly meaningful on a day with no burn potential at all, for example, on a day of extended rain where peak burn actually happens at midnight and fire potential decreases throughout the day. In such a case, knowing the peak burn time, and having output from that very atypical time, might be more of a distraction than an aid. A simple flag to indicate atypical fire behaviour could address this potential issue.

Other optional outputs, which could be summarized daily in tabular form or mapped to provide extra daily planning information, are:

- the estimated start of the active burning window for the day,
- the duration of the active burning period for the day,
- the extension of the active burning window after sunset.

## 5.2 Fire potential in other fuel types

The FWI System has been used for planning for fire activity occurring in a range of the forest types across Canada. Its success has hinged on outputs being interpreted locally by fire managers who, through their training and experience, understand what the outputs of the System mean for their region. The simplicity of this approach is powerful and remains a cornerstone of the System. With time however we have developed better understanding and ability to predict fire occurrence and spread in vegetation types that vary considerably from the conifer forest that defines the FWI System fuel type. One example is the rapid recovery of grasslands from rainfall. Prescribed burners and other fire management personnel often observe how grasslands can support ignition and flaming spread in just a few hours after even a significant rainfall. In the hours and day(s) following a rain event, the moisture and spread potential in grasslands is not well predicted by the slower drying FFMC. Furthermore, fire management personnel observe that as the grassland greens up with new vegetative growth in the spring, the spread potential diminishes greatly. The same is true for deciduous forests as they develop new annual growth in the spring each year. Fire managers interpret the System's output, again based on training and experience, in the context of these seasonal differences.

We anticipate fire managers will continue to use the System in this way; there is significant power in users predicting potential fire activity using both the outputs of a simple standardized System (adjusted by their experience) and knowledge of local conditions. The FBP does provide methods for assessing specific elements of fire potential in specific fuel types. Probability of ignition, spread rate and fire intensity can be estimated for a range of different forest types. Fuel moisture can be estimated from weather for different surface cover types and canopy closure situations. These methods exist in the FBP System and will have further refinement in the Fuel Moisture System.

## 5.3 Adjective rating classes

In Canada each wildfire management agency developed adjective rating classifications (e.g., Low, Moderate, High) for each of the numeric outputs of the FWI System. This was done sometimes in cooperation with CFS fire researchers responsible for the FWI System implementation (e.g., Stocks 1971, Kiil et al 1977) and sometimes within an agency by knowledgeable fire behaviour experts. In most jurisdictions these classifications have not changed in 40 years or more. Because of this history of independent development, the thresholds between adjective rating levels vary across jurisdictions. This is not in itself a problem as each jurisdiction defines these adjective levels according to their own processes and procedures. However, it does introduce inconsistencies in adjective classifications across borders and between jurisdictions.

The development of FWI2025 provides an opportune time for agencies to revisit the adjective ratings by which they classify the System's outputs. To introduce greater national consistency into this process and to the interpretation of adjective ratings for each FWI System output, we suggest a simple starting framework for this approach. First, the classification of each of the thresholds for a particular output of the System should be tied to one specific physical process (Table 1). Second, the threshold levels should be determined from data and models of the

physical process consistent with a general fuel type (i.e., the C-3 fuel type in the FBP System or pine needle litter). The former criteria will bring consistency in the interpretation of how outputs are being classified from region to region. The latter will bring consistency between the FWI System classifications and the FBP System’s outputs.

This simple approach was explored in Ontario (Hanes et al 2021). We have broadened this work to explore weather and fire data from across Canada and create a proposed national set of classes for a generic conifer fuel type for Canada. Table 1 shows a physically based set of thresholds for the classification for each of the FWI2025 System outputs based on models in the FBP2025; a more detailed description of each FWI System output’s classification will be described in an upcoming information report. Note the grassland classifications have not been previously tested and the validation is underway, therefore these threshold suggestions may change in forthcoming publications. No such classification will be perfect as it depends on a choice of fuel type and on more subjective choices about how different classes should be distinguished from one another. They are not meant to be definitive but used as initial guidance and to provide a nationally consistent set of classifications. We recognize that agencies may need to modify these for their specific jurisdictions to better fit with their operational information and decision-making needs.

**Table 1.** Physically based national classifications of the FWI System and the primary physical process the classification has been based on. (Integer values are rounded.)

Code / Index	Low	Moderate	High	Very High	Extreme	Primary basis of the classification
FFMC	0–75	76–84	85–89	90–92	93+	Sustainable flaming ignition
DMC	0–10	11–25	26–45	46–60	61+	Lightning ignition probability
DC	0–70	71–190	191–300	301–500	501+	Deep organic consumption
ISI	0–2	3–5	6–10	11–15	16+	Spread (transition to crowning)
BUI	0–20	21–40	41–60	61–90	90+	Surface fuel consumption
FWI	0–5	6–15	16–22	23–29	30+	Intensity and suppression difficulty
GFMC	0–75	76–81	82–87	88–92	93+	Sustainable flaming ignition in grassland or fine open fuels
GSI	0–4	5–20	20–50	51–75	76+	Spread (breaching a fuel break)
GFWI	0–5	6–15	16–23	24–31	32+	Intensity and suppression difficulty

### **5.3.1 Public communication of fire danger**

Fire danger ratings have been, and are still, communicated to the public via roadside fire danger signs and are supplemented with prevention messaging through radio, TV and now social media messaging by wildfire management agencies to raise awareness of elevated fire potential as well as to announce forest use restrictions (e.g., campfire bans, full forest closures).

The fire danger level used on these signs and on online maps throughout most of Canada uses a simple classification of the FWI itself; for the most part, this approach has not changed in decades. This does not need to be the case. The FWI, as a scaled indicator of fire intensity, is a useful final indicator for the FWI System. However, it is not necessarily the best indicator on which to base public communication, it is simply an indication of weather-based environmental conditions for the day. Internationally, other agencies have begun exploring more action-oriented public communications to enhance situational understanding and preparedness (Metrix 2019).

## **6 FUTURE DEVELOPMENT**

Applied science will continue to improve fuel moisture and fire behaviour models and to assess how these may be incorporated into the CFFDRS and specifically into the FWI System. New science does not by default get incorporated into the CFFDRS. Considerable time is spent assessing new or updated models in terms of their impact on the outputs within the context of the operational decision making.

There are numerous enhancements that were intended for this generation of the FWI System but have been left out subject to our own extended testing and validation. We include a partial list here to provide users with some advance notice of updating improvements to sub-components of the system. To allow more seamless updates in the future, users should build applications that can update code for models that are an official part of the CFFDRS. While the CFS Fire Danger Group's primary goal is to provide a usable, scientifically sound framework for fuel moisture and fire behaviour prediction to support operational fire management, we will also try to provide regular updates of code for calculation.

Future developments or updates to the FWI System are listed below; some of these are currently under development and testing and will be documented more fully in the Fuel Moisture System.

- Revising the effective rainfall functions in the three fuel types in the FWI System; exploring the implications of rainfall intensity.
- Including environmental conditions in the duration of canopy saturation (it is a constant currently).
- Revising the organic layer rainfall absorption functions in DMC and DC.
- Introducing simple yet more physically based drying functions for FPMC, DMC and DC that will include solar radiation.
- Incorporating the peatland moisture and spread components.

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The concepts and changes present in the Next Generation CFFDRS, including the Fire Weather Index System, has been a work in progress for well over a decade. These improvements would not have been possible without a dedicated team of fire scientists (current and retired) and would not have been possible or meaningful without the contributions and collaborations with fire managers.

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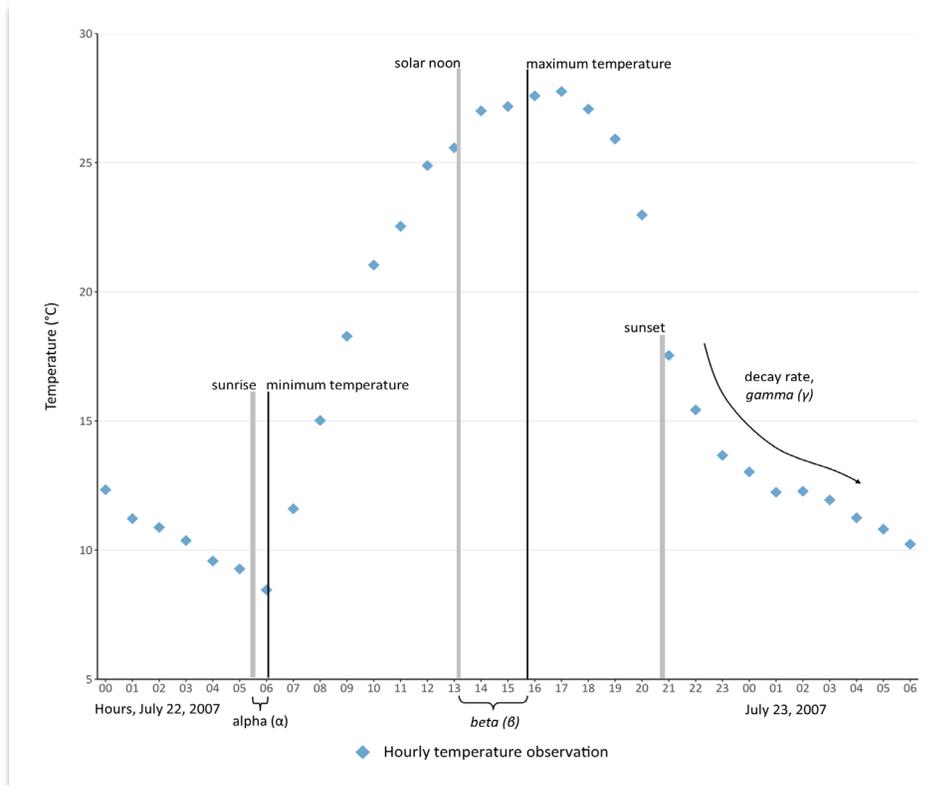
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## APPENDICES

### Appendix A: Estimating diurnal weather from daily maximum and minimum values

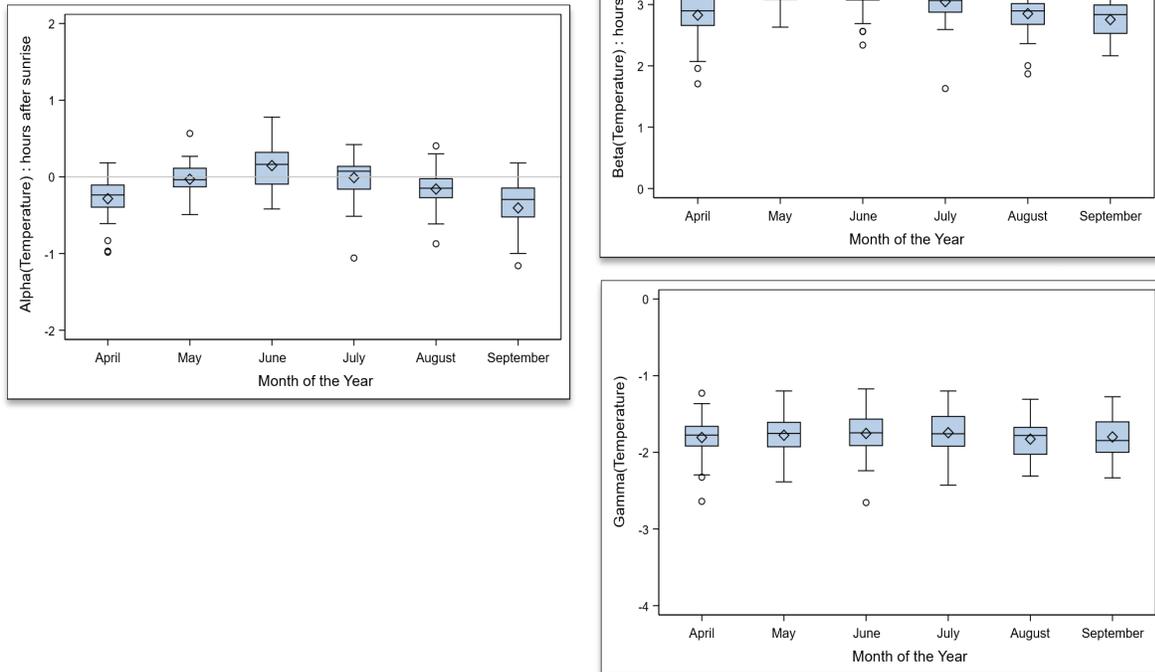
Dead fuel moisture varies throughout the day, driven by the changing conditions in the physical environment. For large fuels that tend to have significant mass (the organic layer, downed and dead branchwood), these changes throughout the day can be small (in the absence of a wetting rain). For the fine dead fuels in which surface fires ignite and spread, the variation in fuel moisture through the day can be important. Originally, because of the manual observation of weather, the fire danger rating system in Canada was developed to use only a single observation of weather to estimate this daily variation. The timing (13:00 Local Daylight Time) was chosen as it would give a good early estimate of the amount of heating throughout the day. This single observation does not allow the System to capture actual diurnal structure of the day explicitly, but implicitly embeds a single standard diurnal curve anchored to the 13:00 observations; in general, this has been quite successful. The ubiquity of automatic weather stations reporting throughout the day and the desire to better capture potential variations in the diurnal structure of the day have led to a revision of the FWI System to now rely on hourly calculations. Making this change has also allowed us to eliminate the differences that arise in the values of the daily FFMC, the hourly FFMC and the diurnally adjusted FFMC. For users who have hourly weather in their information systems, the FWI System can now use that hourly weather (Figure 2, option A) to calculate FWI2025 outputs and capture the effects of their diurnal variation.

For users without hourly data (observed or forecast), we have developed methods and tools to estimate hourly weather from the observed (or forecasted) maximum and minimum weather conditions for the day (Figure 2, option B). We have adapted the method originally published by Beck and Trevitt (1989), which has already been used in Canada in applications like Prometheus. This method anchors on an estimate of the sunrise and sunset timing for a station, which depends on the day of the year and the station's latitude and longitude. The method uses a simple model of sinusoidal variation to create estimated hourly weather over the diurnal cycle. While more complex models exist and could be adapted, this straightforward model with its understandable coefficients seemed the proper level of complexity for this process in the CFFDRS. We modified the method slightly to calculate offsets for the relative humidity (RH) as well as temperature and wind speed. In this method the variation through the day relies on an offset for the time when maximum temperature, minimum RH and maximum wind speed occur relative to the day's timing of solar noon. Similarly, a separate offset for the timing of minimum temperature, RH and wind speed is used to adjust the timing of the peaks and valleys of the diurnal curve (Figure A-1).



**Figure A-1.** An example of diurnal variation in temperature and the interpretation of the alpha, beta and gamma coefficients used in the Beck and Trevitt (1989) method. Alpha, beta and gamma, are interpreted similarly for RH and for wind speed.

We analyzed diurnal weather across Canada and estimated these coefficients for locations across the country; however, in that extensive analysis, we found that, while there is some variation in these offsets in different geographic locations and for different times of year, the variation is fairly small (Figure A-2). We have created a single default set of these coefficients that can be used to produce satisfactory results over the Canadian fire season (Table A-1). The important aspects of the latitudinal or seasonal changes in the diurnal structure of a typical day are captured by the calculation of the daily timing of sunrise and sunset. However, for users who observe that these standard national coefficients (Table A-1) do not capture average conditions at their location, these offsets can be a dynamic input into the system calculations. Such users could compile historical data and make their own local estimates of the alpha, beta and gamma coefficients; members of the CFS Fire Danger Group can provide assistance with that estimation process. However, it is our recommendation that users who want to estimate locally specific coefficients consider the perceived increase in precision with respect to the diurnal curve, along with the other uncertainties in the wildland fire environment.



**Figure A-2.** Diagram illustrating the variation in alpha, beta, and gamma estimates based on hourly temperature data collected over 10 years at 39 weather stations in Saskatchewan.

**Table A-1.** Offset and decay parameters for maximum/minimum estimation of diurnal variation in temperature, relative humidity (RH) and wind speed using the weather estimation method from Beck and Trevitt (1989).

Coefficient	Temperature	RH	Wind speed
Alpha	0	0.25	1.0
Beta	2.75	2.75	1.5
Gamma	-1.9	-2.0	-1.3

In the initial transition to using FWI2025, we anticipate there will be some users, even those collecting hourly weather observations, who will not be operationally forecasting hourly weather. This maximum/minimum method allows these data to be used consistently within the same calculation process that is used for direct hourly observations (or forecast) inputs. That is, the daily maximum/minimum method simply creates estimated hourly weather, which then flows into FWI2025 (Figure 2, option B). In this way the same calculation method is used for each “type” of weather data, be it hourly or daily, regardless of the System used (FWI1987 or FWI2025). This flexibility and consistency are a critically important part of what we were trying to achieve with these changes to the FWI System.

## Appendix B: Examples of the use of daily data and some common variants

The move to using hourly weather within the FWI System is intended to improve the accuracy of estimating the fuel moisture and fire behaviour outputs. It is also to improve the consistency between the estimated daily outputs used for planning and the hourly calculations, which are used by many for fire behaviour predictions. Hourly weather data, if available, is the best way to capture the diurnal weather variation over the day, be it observed, forecast or modelled hourly weather. However, we recognize that hourly weather is not always available and that diurnal weather patterns can be estimated based upon daily weather information (see section 3.1.1 for a longer discussion). Further to Appendix A, there are many potential input weather formats and timesteps. Below are some guidelines and examples on using different daily weather formats to create the estimated hourly weather stream needed for the FWI2025 calculations. This guidance is meant to help users achieve consistency in using different weather formats and observation timings. Furthermore, it serves to emphasize that the goal is achieving the best estimate of the fuel moisture and fire behaviour potential on the landscape for the purpose of assisting operational wildfire management planning.

These examples are not meant to address all potential weather data formats but to provide users with examples of how we suggest certain formats be transformed into hourly timesteps. This will ideally help users adapt new weather formats to use in their FWI System calculations.

General guideposts when transforming non-hourly weather sources:

- o When in doubt, err on the side of having slightly drier (and hence more volatile) conditions. This is because the System is designed first and foremost as a tool to help fire managers plan for the expected conditions in the wildland fire environment. This has always been the philosophy in the models that underlie the CFFDRS.
- o All inputs, even hourly observations, provide an estimate of the conditions in the wildland environment throughout the day.
- o Throughout this document, hourly data is referenced as the finest and most desirable temporal scale for weather. Given current weather stations and weather model outputs, this seems a reasonable assumption for the purposes of this discussion. If finer weather observations (or predictions) are available they can be used, if users feel strongly that this is important, though many programmed algorithms for the FWI System calculation default to the hourly time step. The standardization of the FWI System to a finer time scale does not translate into interpretation of the FWI System outputs over a finer landscape or spatial scale. The System outputs are still meant to be used in landscape level planning.
- o The FWI System models have been designed to estimate fuel moisture and fire behaviour potential in a consistent and understandable way. They are models and as such simplifications of reality that produce estimates of the important elements of the wildland fire environment we want to track; this has always been the case in the CFFDRS and continues to be so. The value in the System is that these estimates are produced in

a consistent framework, day to day and region to region, and therefore provide a common set of values from which to do daily planning.

### **B.1 Using the traditional 13:00 observation**

If one only has the standard 13:00 weather observations, the diurnal structure of the day can be estimated. As shown in Figure 2, when only the standard 13:00 observation is known, these values are used to estimate maximum and minimum temperature, RH and wind speed values for the day. These in turn are used to estimate hourly weather via the standard diurnal weather method (Appendix A).

Figure 3 in section 3.1.1.3 presents the default central Canadian values for adjusting the daily 13:00 values. These were developed based on an analysis of hourly data provided to the FDG by Canadian fire management agencies. If users know these values differ for their region, they can use values appropriate for the region. The goal is to estimate the actual diurnal structure of the day using the information available. Such adjustments, however, should be evidence-based (i.e., based on analysis of a reasonable sample of local data) rather than anecdotal or opinion-based.

#### **A comment on rainfall in the FWI1987 System**

The FWI System has always assumed that the accumulated rainfall observed over the 24-hour period ending at 13:00 has all fallen by sunrise on the day of observation (prior to the start of any drying for the day). That is, all days, regardless of whether rainfall was recorded, are subject to a full day of drying influenced only by the temperature, RH and wind speed as measured at 13:00.

### **B.2 Transforming the 13:00 observation**

This traditional 13:00 observation must be transformed into estimates of the daily maximum and minimum conditions expected given the observations. This is shown earlier in Figure 3. The diurnal temperature range (DTR) is estimated based on a dataset of multiple weather stations from Ontario. While the relationship did show some variability from month to month in the fire season, it was felt a simple general estimate of DTR was sufficiently accurate overall for generating the maximum and minimum values to allow the old 13:00 observations to be used to generate hourly data. The offset of two degrees between maximum daily temperature and temperature at 13:00, while it varied from day to day, overall was consistent.

Daily RH maximum and minimum is estimated from maximum and minimum temperatures and a calculation of absolute humidity in the local air mass given the 13:00 RH and temperature observation. That is, the calculation assumes the air mass does not change throughout the day.

Wind speed is assumed to reach 10% of the 13:00 observation at its overnight minimum. In many cases this is a reasonable assumption, however, it would tend to underpredict wind speeds in the overnight hours on days when sustained winds last through the night. However, predicted fire activity should not be sensitive to errors in this value. On average, in the dataset the maximum hourly wind speed observed was 25% higher than the observation at 13:00.

The 24-hour rainfall observed in the 13:00 observation should be associated with the top of the hour after sunrise, keeping in mind that time of sunrise is calculated by the FWI2025. For example, if 7mm of rain was recorded in the 24-hour observation at 13:00 on a day where sunrise happened at 05:30, that 7 mm of rain should be associated with the 06:00 weather observation in the estimated stream of hourly weather used within the System.

Many operational fire management agencies make a morning observation of the weather to assess whether rain had been observed overnight and examine the extent of overnight recovery of humidity. The timing of these observations from fire weather networks seems to have varied between 06:00 and 08:00 in different jurisdictions across the country; however, the ubiquity of real-time reporting from hourly weather stations may be diminishing the operational importance of the specific timing of this observation. However, several agencies have these morning observations recorded in their historical weather archives, so we provide some interpretation of how to use the added information about the timing of rainfall from this observation.

These observations could be used to adjust minimum temperature and maximum RH values used later in the day if the user is confident in how the morning observation reflects minimum overnight temperatures and humidity levels. The main value of this observation is whether it gives enhanced resolution of the timing of rainfall that can be used to improve the FWI System calculations. However, this added information has relatively little impact in forest floor moisture estimations because the daily calculation method in the System assumes rainfall measured at 13:00 has fallen around the time of sunrise (before the start of drying for the day).

### **B.3 Maximum and minimum input data: Rain observations of different frequencies**

The maximum/minimum approach estimates diurnal weather from daily maximum and minimum temperatures, RH and wind speed values, a local estimate of sunrise, solar noon and sunset, and some offsets developed from an analysis of historical weather data. This is described in detail in Appendix A.

Some weather stations and many operational weather forecasting models output weather “observations” at intervals throughout the day, for example at six-hour intervals or at three-hour intervals.

**Table B-1:** Examples of time and rainfall accumulation interval for the FWI System.

<b>Rainfall observation time</b>	<b>Associated period of accumulation</b>	<b>Hour at which to place total rainfall for the period</b>
00:00	18:01–00:00 <sup>A</sup>	19:00 <sup>A</sup>
06:00	00:01–06:00 <sup>B</sup>	01:00
12:00	06:01–12:00	07:00
18:00	12:01–18:00	13:00

<sup>A</sup>. This time is associated with the previous day.

<sup>B</sup>. Describing this period as ending exactly on the hour and starting at xx01 is meant to clearly distinguish that the next period of rain accumulation begins after the observation of the rain from the previous period. Whether the observation takes place exactly on the hour or at some point after is not critically important; that the rainfall accumulation resets at this point and is uniquely accumulated from period to period is the important point.

For consistency when using this weather input data format, the DAILY maximum and minimum values should be used for temperature, RH and wind speed. The interval format however provides extra information about the timing of rainfall and therefore this should be used. Given that the timing of rainfall even if the period is unknown, for consistency (and to err on the side of a slight over-prediction), we place the rainfall at the start of the interval over which it has been recorded. Table B-1 shows an example of this for standard six-hour rainfall observations.

If rainfall is observed at 6-hour intervals on a 24-hour day, then the observation at 06:00 represents the rain that fell between 00:01 and 06:00. This rainfall amount should be put into the estimated hourly weather stream at the first hour of the interval during which it was recorded; that is, in this example rain should be placed in the hourly weather record at 01:00.

## **Appendix C: Added discussion and clarification on weather inputs**

The Weather Guide to the CFFDRS, originally published as Turner and Lawson (1978) and updated and republished as Lawson and Armitage (2008), lays out operational guidelines for weather station location, instrumentation and overall weather observation practice, including startup and shutdown of station calculations. This section is not meant to replace that but merely seeks to augment some of the information and offer clarifications that may be useful to operational users with access to varied new sources of information.

### **C-1. Numerical weather models as a source of fire weather in FWI2025**

The field-based models that underlie the System are based upon relationships linking observed moisture in forest fuels (and aspects of fire behaviour such as ignition) to point observations of weather. These relationships are then related to aspects of fire behaviour including ignition potential consumption, rate of spread and intensity. Today, the outputs of numerical weather models are increasingly available and provide consistent forecasts of weather conditions into the future. Such modelled weather outputs have great potential for use in fire management. In addition, numerical weather models are increasingly integrated with ground observations of weather to provide near real-time re-analyses of weather across landscapes. Observed weather is used to refine these model predictions to recreate spatially detailed weather surfaces across the landscape. Such re-analyses have the potential to provide more accurate, physically realistic spatial detail of the variation of weather across the landscape compared to naïve interpolation methods that have been used to date. Although, there is a significant caveat in such applications: numerical weather model outputs are not strictly the same as point observations of weather from a weather station. At the grid cell scale, outputs from numerical models typically represent what can be thought of as average conditions across that cell. This is of course a simplification.

Studies of the differences in model output versus point observation have been used to understand the ability of such models to accurately reproduce traditional fire weather and hence fire danger. From the operational fire management perspective, these comparisons are critically important because the decisions that rely on fire danger or behaviour often depend on indexes surpassing a specific absolute threshold. The thresholds used by fire management agencies to classify each of the outputs of the FWI System into rating classes (e.g., “Low,” “Moderate,” “Extreme”) are a common example of how the outputs are interpreted operationally at some scales within the decision-making process. The potential bias introduced by numerical model assumptions must be evaluated and considered when such weather data informs outputs that are linked to the interpretation of fire activity using previously developed physical thresholds or operational heuristics (i.e., “rules of thumb”). Such evaluations should focus on the more important dry periods when fire danger is highest; it is at these times when even small bias in weather values will have the most potential impact.

### **C-2. Season start and early season calculation**

As stated many times throughout this document, the moisture codes in the FWI System can be thought of as bookkeeping systems; therefore, their starting points are important, more so for those models tracking fuel layers with larger water holding capacity and slower response times

(i.e., the DMC, DC and eventually the PMC, which is to be added in the next update). This section will outline the important aspects of when weather-based fuel moisture calculations should be started given the seasonal changes in weather experienced in Canada. In particular, we will try to provide some clarity to procedures during the early and late seasons that occur around the cold winter months.

The important principle to follow in assessing whether moisture exchange should be estimated is determining if water in fuels is frozen (i.e., fuel temperature is below 0 °C), then those fuels can be assumed to not exchange moisture with the atmosphere. If ground fuels are not frozen, then they could in fact exchange water with the local environment (e.g., humidity from the air or water from rain or snow melt). This section is not meant to replace the information provided in the Weather Guide to the CFFDRS, but to simply clarify the thinking behind the start-up and calculation of the FWI System components.

### **C-2.1. Pre-thaw (early season)**

In the early spring, the situation can arise that snow cover has disappeared from open areas (e.g., grasslands), but forested areas may still be snow covered. In this situation, the FWI System should be calculated so that the grassland fire hazard can be estimated. The day-to-day change in DMC and DC should not be calculated in this situation. If snow cover is still present throughout the forest, it should be noted that the hazard only corresponds to open areas where fuels are exposed. If the snow has gone from the forest and it is known that the ground is still frozen beneath the surface litter, then DMC and DC should still not be calculated, as these ground layers cannot exchange moisture with the atmosphere in their frozen state. However, in the absence of freeze/thaw data or soil temperatures that directly relate to the organic layers, once snow has gone from within stands one might assume that the organic layer in the forest floor of moderately closed stands will be thawed as well. The early season calculation of FFMC and ISI at open fire weather stations (sometimes called “spring stations”) has been going on in many jurisdictions for some time; we seek simply to formalize and clarify this process here. The addition of the optional grassland set of outputs within the FWI2025 also provides clarity on start-up of these fine fuel moisture indicators. Both the FFMC and the GFMC are useful indicators of moisture levels in early spring in post-snowpack matted fuel beds and should be calculated to assist in assessing hazard. This early season calculation is more about providing information to fire managers about fire potential in open, exposed fuels and less about the need to get the bookkeeping system for moisture functioning when moisture exchange starts. The small water holding capacity of these fine fuels (e.g., ~0.6 mm in the FFMC layer) and their quick response times mean that inaccuracy introduced from errors in the Code calculation start-up should disappear relatively quickly.

The new GFMC should be initiated as soon as a significant portion of the grassland fuels in a region are snow free or earlier if the requirement for hazard estimation in a specific area exists. The very rapid response times in the exposed grassland fuel complex mean that any error introduced by inaccurate starting moisture levels in this grassland fuel moisture indicator should disappear very rapidly (i.e., in just a few hours). The GSI and the GFWI are also directly derived from grassland fire behaviour models and can be calculated at this time.

As has been the informal practice in many jurisdictions, the FFMC should also be calculated at this time to provide an additional fine fuel moisture indicator for exposed areas. The FFMC may be used as an indicator of the moisture within thick matted layers of cured grass (which may be present after several years of accumulation). The ISI can also be calculated at this time. Since the organic layer is frozen, little more than surface litter will be consumed in the passage of a flaming front; therefore, fuel consumption contributing to fireline intensity will be mainly influenced by litter only. A notional value of BUI of six (corresponding to a DMC of six, the typical start-up value) can be used to calculate an FWI in this situation if desired; however, in the FWI2025 the GFWI is probably a more useful indicator for open grasslands.

### **C-2.3. Ground thaw: When to start full calculation?**

Currently the criteria most often used across Canada for the start of the daily FWI System calculations at individual weather stations is to start calculation three days after the disappearance of snow cover. When this cannot be observed or snow cover was not a significant factor through the winter, FWI System calculations start after three days of temperatures  $>12\text{ }^{\circ}\text{C}$  (Lawson and Armitage 2008). Over time, some of these criteria have, in some regions, been considered the mandatory rules for start-up. However, both of these criteria are simply surrogates for the harder to observe state where the organic layer in the forest has thawed (i.e., is no longer frozen) and can begin exchanging moisture with its environment.

The FWI System calculations (of DMC and DC) should begin when the organic layer is no longer frozen. This is not a new approach in the FWI System calculation; this has always been the way the calculation methods for organic moisture codes in the system should be carried out and simply follows basic physical logic. The challenge for operational users, however, is observing or estimating when this ground thaw has occurred across enough of their forested region that they want to start up the System. Many options exist for estimating the date the organic layer has thawed in a weather region. It can be directly observed: personnel in the forest could report on the depth of the frozen layer through simple observation or, given the ease of automated measurement and data communications, the soil temperature within the organic layer could be monitored as part of an in-stand observing station (which could be linked to a local open weather station, or treated as a secondary stand-alone station). In the absence of actual in situ ground thaw observations, this transitional state could be estimated through various weather-based methods ranging from the traditional three days past snow gone or above  $12\text{ }^{\circ}\text{C}$  rule.

#### **Standards; A means to an end**

Establishing standard methods is a means to an end: they ensure that the same process is used widely and consistently. However, the goal or guiding principle behind the standard methods should never be forgotten. The goal is not that there be consistency in applying the defined rule, but that there is consistency in estimating the physical state of the environment. The goal is to estimate the physical state in a consistent and accurate way (i.e., ground thaw), not to consistently implement some set criteria (e.g., use the same overwinter coefficients for all regions for all years). This perhaps subtle distinction should be understood when interpreting guidelines and standards.

#### **C-2.4. Seasonal start-up values**

The standard starting values of the FWI System (i.e., at sunrise the day calculations begin GFMC=85, FFMC=85, DMC=6, DC=15) are simply estimates of moisture content in these fuel layers after three days of drying from a fully saturated starting point (i.e., GFMC=0, FFMC=0, DMC=0, DC=0). These standard starting values are estimates of the state given no other information. When other information is available, then this information should be used, and a less biased estimate of starting conditions can and should be made. Operationally this is the practice when overwintering of the DC is considered but could be the case in other situations as well. For instance, if ground thaw were known to occur on a specific day and occur coincidentally with a significant ground recharge of water, one could start organic layer moisture content calculations from this point onward using full saturation as the starting point (i.e., GFMC=0, FFMC=0, DMC=0 and DC=0).

#### **C-2.5. Season end**

While many modern automatic stations record weather year-round, often the day-to-day calculation of the FWI System outputs end at some period in mid-autumn when no further fire activity is expected and daily planning and preparedness briefings are halted for the year. The moisture contents tracked by the moisture codes in the organic layer of the forest will continue to change until ground freeze or snow accumulates. If these data are not available, or the region does not receive snowpack, calculations should continue until the occurrence of three consecutive days of a maximum daily temperature below 5 °C (Wotton and Flannigan, 1993). Measuring fire weather until these conditions are met eliminates the need to estimate the carry-over fraction of the fall moisture deficit ( $\alpha$ ) from the DC overwintering procedure;  $\alpha$  is always 1 in this situation, removing a potential source of error on the front end of the overwinter calculation. If, for some reason, the agency weather station network does not calculate the FWI System up to this date, it is recommended instead to calculate until these conditions are met using an alternate weather stream, i.e., a nearby Environment and Climate Change Canada (ECCC) station, or reanalysis data from fine-scale numerical models. Therefore, calculations should continue until the first of these season-ending weather events happen, even if they are not being operationally used for current decision support. The accuracy of the end of season calculation of DC has been shown to influence the accuracy of spring starting values (Hanes et al 2023).

#### **C-2.6. The 10-minute average wind observation**

The 10-minute average for wind speed estimation was introduced as a minimum sampling time; it is not necessary to use, and only use, a 10-minute average of wind for FWI System calculations. The 10-minute average wind was suggested originally because it was a standard observing practice developed to provide a long enough period to estimate a reasonable average over a number of gusts and lulls which might occur. It was also short enough such that an observer at a weather station could complete the observation (during the era of manual observing) in a reasonable amount of time. A shorter period than 10 minutes is not recommended for FWI2025 calculations, though could be useful in the context of fire behaviour if very fine temporal scale predictions are desired. A longer sampling period (up to an hour for the standard hourly observation) can be used in the FWI System calculations without

introducing bias. This longer period likely provides a significantly better estimate of the average wind over the period. It is important to recognize however that, from the fire behaviour prediction point of view, a sense of the finer scale temporal variation in wind may be more informative for some decision-making needs.



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