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More than just the FWI: Exploring all components of the Canadian Fire Weather Index System for International Fire Danger Rating Systems

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Abstract

The Canadian Fire Weather Index (FWI) System has its origins in early Canadian fire research and resultant hazard rating systems dating back to the 1930s. Today the FWI System is one cornerstone of the larger Canadian Forest Fire Danger Rating System (CFFDRS), which is comprised of several sub-systems, each evaluating fire potential at different scales and resolutions. The other major sub-system in the CFFDRS is the Fire Behaviour Prediction (FBP) System, designed to give quantitative predictions of fire behaviour in specific situations under constant conditions. Whereas the FBP System requires information on fuels, weather and landscape features to calculate potential fire behaviour on variable timescales, the FWI System provides a set of six daily outputs derived from weather observations, each indicative of different aspects of potential fire activity useful in fire management planning.

The basic design of the FWI System and simple inputs has made it a popular choice for adaptation in other regions. The System outputs can be readily adapted to act as the foundation for a new fire danger rating system or as an enhancement to an existing system. Research exploring the utility of the FWI System for characterizing fire activity in a region often focus on the final indicator, the FWI (not to be confused with the System namesake). While the FWI (the indicator) is a highly useful indicator of potential fire intensity, it is not necessarily the most appropriate indicator from the System to capture specific fire management needs. In adapting the FWI System to a new jurisdiction to support fire management, each indicator from the System should be evaluated on how it informs specific fire management needs in a region; that is, which of the System's six outputs relate most closely to important aspects of fire activity. Furthermore, it is important to understand how the standard Canadian pine fuel type might differ from those in the region in question.

This paper will review examples of how each of the indicators of the FWI System are used in operational fire management planning in Canada, and present Canadian Forest Service (CFS) experience in adapting the FWI System to other jurisdictions. We will evaluate each of the six components of the FWI System and their use to describe different aspects of fire potential in the wildland fire environment. While grounding this discussion in the way the System outputs are used to inform operational fire management decision-makers in Canada, we will also discuss their potential adaptation to support fire management planning in other locations. We will touch on the question of adaptation of the System to different fuels, and how these might affect the interpretation of each component and, how these considerations can lay the foundation to building local fire behaviour predictors.

While there is no set recipe for adaptation of the FWI System to a new region, understanding what each element of the wildland fire environment the FWI System outputs are designed to track is a critical first step.

The Canadian Forest Fire Danger Rating System (CFFDRS) is the national system for fire danger rating used throughout Canada. The two main sub-systems of the CFFDRS are the Fire Weather Index (FWI) System and Fire Behaviour Prediction (FBP) System. The FWI System uses daily weather observations to create six indicators, each capturing different aspects of potential fire activity important in daily fire management planning. The simple design and use in Canadian fire management planning has made the FWI System a popular choice for adaptation to other regions. When adapting the FWI System to a new jurisdiction, each of its six indicators should be calibrated to the regional landscape and evaluated with respect to how each can inform local fire management planning. In this paper, we discuss the fire management structure in Canada, the development of the FWI System and its outputs, describe fire management decision-aid tools and provide examples of the use and adaptation of each components of the FWI System to other regions.

1. Fire management and danger rating in Canada

Wildland fire management in Canada is largely the responsibility of its ten provinces and three territories, each organizing and operating a fire management agency independent of each other, conforming to policies and regulations specific to their jurisdictions. However, they engage collectively in risk-sharing by agreeing to share suppression resources during periods of heightened activity that overload the resource capacity in a specific geographic area. To support preparedness and response planning each agency relies upon its own internal fire intelligence capacity, running their own fire weather monitoring networks and fire danger calculation activities. The CFFDRS provides a 'common language' for characterizing potential fire activity in the wildland environment across the country; however, local interpretation and decision-making tools are as unique as each region.

2. International evaluations and adaptations

When considering the FWI System for adaptation to other regions outside Canada, a variety of methods have been used to evaluate its effectiveness and to adapt the System. Such studies tend to focus on evaluating the final component of the FWI System, also known as the Fire Weather Index (FWI). While the FWI component is a good indicator of general fire danger, evaluating the association between FWI and information about different aspects of the fire environment (e.g., number of fires, ignition date, weather or total area burned) may not identify the most useful relationships between different aspects of fire activity and the FWI System as a whole. Other components of the FWI System may be better suited to inform specific fire management decision-making needs (Table 1). When adapting the FWI System to new regions, the evaluation of how each indicator best reflect the different aspects of fire potential is an important first step in generating effective FWI System based decision-aids.

Table 1, Examples of each Fire Weather Index System indicator and their fire management decision-aid associations.

FWI indicator	Physical association	Primary association in fire management	Examples of fire management associations
FFMC	Forest litter moisture	Flaming ignition sustainability	- Human-caused fire occurrence - Spot fire ignition - Vigor of surface spread
DMC	- Duff moisture (F-layer) - Medium woody debris	Lightning fire ignition	- Depth of burn
DC	- Deep duff moisture (H-layer) - Logs, large woody debris	Sustained smouldering	- Depth of burn - Lightning fire holdover - Fuel consumption - Live moisture deficit - Suppression difficulty
ISI	Fire Spread	Fire spread rate	- Crown fire potential
BUI	Surface fuel moisture levels	Surface fuel consumption	- Depth of burn - Sustained smouldering - Fire intensity
FWI	Fire intensity	Suppression resource effectiveness	- Public facing assessment of fire danger - Flame size

Understandably, methods of evaluation and adaptation are dependent on a number of factors; analysis is constrained by data availability, such as historical weather data and accurate area burned datasets. While field campaigns can add invaluable information in the adaptation of the System, these are often limited due to resource or timeliness constraints. Evaluation may start as a data driven exercise and be re-evaluated as more historical data and statistical methods for classification become available (e.g., de Jong et al., 2016, Dentoni, 2015). Strategies of calibrating the FWI System components over very different landscapes while maintaining a consistent calibration have been developed by the European Forest Fire Information (EFFIS) System by introducing additional layers to provide context (Camia and Amatulli, 2010). Others may have additional information from field data to examine the relationship between the different FWI System indicators and regional fuel composition (e.g., de Groot et al., 2007, Dimitrakopoulos et al., 2011, Fogarty et al., 1998) allowing local adaptations to be tailored to the specific effects of weather on forest floor fuel types. Re-evaluating each FWI System component after initial adaptation as data is collected can lead to better understanding and evaluation of each indicators use as a decision-aid. Fire management agencies in Canada have been developing the expert knowledge to use the FWI System over several decades and research continues to provide FWI System indicators and classification methods to reflect the changing demands in wildland fire management (Hanes et al., 2021).

3. The outputs of the FWI System and their use

The FWI System contains six indicators, calculated daily based on solar noon observations of temperature, relative humidity, wind speed and 24hr accumulated precipitation (Figure 1). The first three indicators of the FWI System are the moisture codes; they act as a bookkeeping system to track moisture in dead fuels in different layers of the forest floor. The three moisture codes are then used to calculate three fire behaviour indexes, which are general indicators of potential fire spread, fuel availability and fire intensity. The outputs of all indicators are on an increasing numerical scale, where higher numbers signify higher danger during the peak burning period of the day, generally late afternoon.

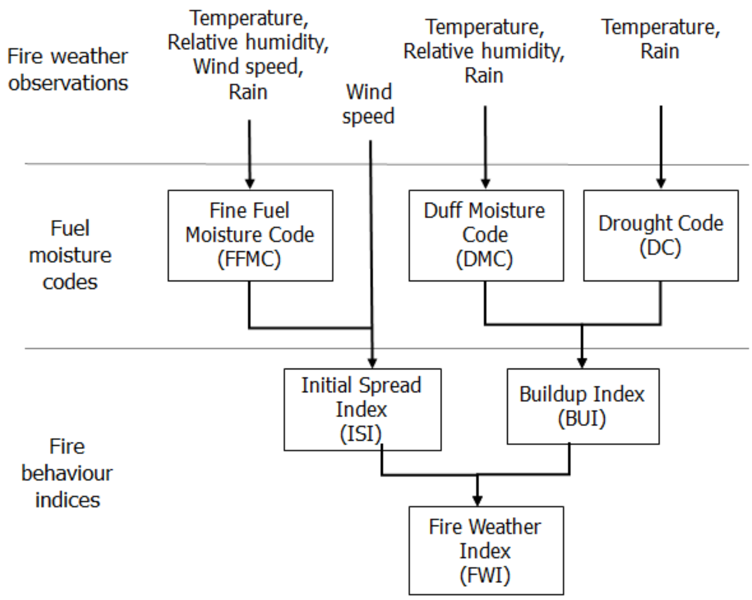

Figure 1: Structure of the Canadian Fire Weather Index (FWI) System.

The first of the three moisture codes in the FWI System is the Fine Fuel Moisture Code (FFMC), which tracks the moisture content of the fine dead fuels on the forest floor. Moisture content in fine fuels is a primary factor controlling the sustainability of a flaming ignition in fuel beds. The FFMC therefore plays a role as an indicator of the readiness of forest floor fine fuels to sustain flaming ignition; its utility in this regard has been demonstrated in many fuel types (e.g. Beverly and Wotton 2007). From the perspective of fire management agencies, this makes the FFMC well suited as an indicator of the day-to-day changes in the number of human-caused fires expected in regions with human activity in the wildland (this has been demonstrated throughout different fuel types in Canada). When the FWI System has been adapted to other regions, the relationship between FFMC and sustainable flaming ignition has been calibrated to other fuel types. For example, de Groot et al. (2005) calibrated dead grass fuel with FFMC using fuel moisture measurements and small-scale ignition field experiments in three grassland sites of Indonesia. In this case, dead grass was chosen as the fuel type as it was a common fuel source and a fuel of concern for fire managers in Indonesia.

The Duff Moisture Code (DMC) tracks the moisture content in the loosely packed layer of decaying dead organic fuel directly beneath the fine litter (FFMC) layer. Moisture content in organic layers has been shown in both lab and field-based studies to indicate the sustainability of smouldering combustion; tracking moisture in this layer is of value for users looking to estimate the potential for consumption in this layer (i.e., depth of burning) or to estimate the ability of ignitions to 'holdover'. In day-to-day fire management planning in Canada, the DMC is used to indicate the potential for ignitions from lightning, (a significant cause of wildfires throughout most of the country).

The Drought Code (DC), tracks the compact decaying organic material deep (typically >10cm deep) in the forest floor, often associated with the humus layer of the organic horizon. While such deep layers are not always present throughout mature upland pine forests in Canada, tracking the impacts of drought is considered an important part of understanding conditions in the wildland fire environment. Operationally the DC is considered in lightning fire ignition and when examining the potential for deep burning and requirements for extended periods of suppression resource utilization for mop-up and the mitigation of the risk of restarts. In Canada, the DC has been studied in fen and bog peatlands to explore a relationship with the water table and volumetric moisture content (Waddington 2012). In South East Asia fire danger rating system applications, the DC has been calibrated to track drought in peatlands where fire activity has caused major haze disasters affecting health and industry (Field et al. 2004). In other more arid regions without deep organic layers the DC might have most utility as an indicator of drought effects on live fuel moisture.

The three moisture codes: FFMC, DMC, and DC are inputs used to calculate the three remaining FWI System indicators, which reflect different aspects of fire behaviour. The Initial Spread Index (ISI) provides an indication of the potential rate of spread of a fire by capturing the interaction between the dryness of fine dead surface fuels (which carry flaming) and the wind. The FBP System provides explicit characterization of the relationships between spread rate and ISI over a wide range of fuel types found in Canada; ISI is a good indicator of spread in all these types. In other regions, where grass fuel type is the main concern for wildland fire activity, the ISI has been adapted as an indicator for general fire intensity. For example, fire management guidelines in Indonesia indicate difficulty of wildfire control (and suppression resource effectiveness) as associated with the ISI (de Groot et al., 2007).

The Build-Up Index (BUI) is a weighted average of the DMC and DC and is a general indicator of the potential heavier fuel available for consumption by a passing fire. The FBP System uses the BUI as the primary variable influencing surface fuel consumption across a broad range of forest types. Because of this association with surface fuel consumption, as a daily planning aid the BUI is used to inform fire managers about the potential for increased fire intensity due to the long-term dryness of surface fuels. Because it provides a weighted indication of moisture content throughout the forest floor, it can also be used as a general indicator of potential below surface smoldering.

The final primary fire behaviour output of the FWI System is the Fire Weather Index (FWI). In the scaled, unitless world of the FWI System the FWI is an expression of Byram's fireline intensity concept, capturing the interaction between spread rate (ISI) and fuel consumption (BUI) in a relative way (Van Wagner 1987). In Canada, many agencies use the FWI when communicating 'fire danger levels' to the public, because it combines information from other parts of the system on ignition potential, spread potential, and the difficulty of suppression of a fire, into a single number. However, in operational fire management planning, the different elements of the FWI System that more directly influence each of those separate aspects of fire activity are used directly.

The FWI System remains an important tool for daily planning at the regional scale, providing fire management personnel an overview of potential fire activity over large landscapes. Increased fire activity, which increases demands for resources along with changing priorities in managing fire in Canadian forests has made decision-making in wildland fire planning increasingly challenging across the country. To support these complex demands and new technologies, updates to the CFFDRS are underway to incorporate new data sources and new modular, process-based approaches. Updates to the FWI System include a modification to the fire danger calculations to better reflect peaks in daily fire weather, and new fire danger indicators specific to grasslands and peatlands (Canadian Forest Service Fire Danger Group, 2021). The addition of the grassland and peatland moisture codes and intensity indexes will widen the adaptability of the FWI System in other regions outside Canada. As the threat from wildland fire increases in many parts of the world, the FWI System indicators can be a foundation for local decision-support tools. Evaluation of the adaptability of the System to any new region must start with an evaluation of the information needs specific to fire management decision-making and then an evaluation of how the different indicators within the FWI System structure can inform those fire management decision-making needs.

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