Canadian Fire Weather Index System (FWI system)
Why build the FWI System?

Adapted from Alexander & de Groot (1988)
Before the FWI

- In 1928 fire research effectively began in Canada
  - Day-to-Day fire susceptibility began to be tracked everywhere

- By 1957 there were 4 major danger rating systems and many regional modifications to these

- The conceptual basis of these lead to the FWI system
Scope

“It was decided early on, however, that the main goal was a new danger index based solely on weather that could be used to give uniform results throughout Canada. The question of how fire behavior varies with fuel types was judged to be a separate problem, to be tackled in other ways.”

- C. E. Van Wagner (1987)

• Not a fire behavior model

• It tracks moisture changes in different layers of forest floor alongside changes in weather

• It combines fuel moisture with current weather conditions to give relative estimates of potential fire behavior
Fuel Moisture Codes

**Fine Fuel Moisture Code (FFMC)**
- Litter layer, and other cured fine fuels
- 0 – 1.2 cm depth in the forest floor (0.25 kg/m²)
- Plays a significant role in ignition probability and spread

**Duff Moisture Code (DMC)**
- Loosely compacted, fermenting (decomposing) organic matter
- 1.2 – 7 cm depth in the forest floor (5 kg/m²)
- Contributes to lightning receptivity and overall fire intensity

**Drought Code (DC)**
- Deep layer of compact humus (decomposed) organic matter
- 7+ cm depth in the forest floor (25 kg/m²)
- Contributes to depth of burn, intensity, and suppression difficulty
Fuel Moisture Codes

- Differences in the codes can be understood in-terms of their water capacity and drying speed
- Drying occurs exponentially
  - Instantaneous drying rate is proportional to the current free moisture content
- Drying speed can be understood by the slope of these curves, but more commonly by the “Timelag constants” (the time it takes for one of these layers to lose 2/3 of its moisture)

<table>
<thead>
<tr>
<th>Code</th>
<th>Timelag days</th>
<th>Water capacity mm</th>
<th>Required parameters</th>
<th>Nominal fuel depth cm</th>
<th>Nominal fuel load kg/m²</th>
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<tr>
<td>FFMC</td>
<td>2/3</td>
<td>0.6</td>
<td>T, H, W, r</td>
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<td>0.25</td>
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<td>12</td>
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<td>T, H, r, mo</td>
<td>7</td>
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<td>T. r. mo</td>
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</table>

¹T — temperature, H — humidity; W — wind, r — rain, mo — month.
MC = 101 - FFMC
Fire Behavior Indices

Initial Spread Index (ISI)
- Combines FFMC and wind speed
- Varies greatly based on current wind conditions
- Represents ROS as a relative term (i.e. ISI = 17 > ISI = 10 => higher ROS)

Build-Up Index (BUI)
- Combines DMC and DC, with increased weight placed on the DMC
- Does not vary throughout the day
- Represents total fuel available for consumption

Fire Weather Index (FWI)
- Combines the ISI and BUI, with increased weight on the ISI
- Is more stable than the ISI, but varies with it throughout the day
- Represents potential fire intensity
Fire Behavior Indices

(ISI) and (BUI) $\Rightarrow$ (FWI)

Where:
- ISI = potential ROS
- BUI = potential fuel consumption
- FWI = potential fire intensity

$I = hwr$

Byram’s Intensity

Where:
- $r$ = spread rate (m/sec)
- $w$ = fuel consumption (kg/m$^2$)
- $h$ = low heat of combustion (kJ/kg)
- $I$ = fire intensity (kW/m)
Canadian Forest Fire Weather Index System

Fire Weather Observations:
- Temperature
- Relative Humidity
- Wind
- Rain

Fuel Moisture Codes:
- FFMC

Fire Behavior Indexes:
- ISI
- DMC
- DC
- BUI
- FWI
Data Collection

“Standard Fire Weather”

A standard fire weather station should be in a 100 m diameter clearing, not adjacent to water body

Daily weather observations collected at 12:00 local standard time (LST) of:

- Ambient temperature (°C)
- Relative Humidity (RH) (%)
- Mean wind speed, at 10 m above surface (km/h)
- Rainfall, 24 hr total (mm)
The FFMC is the only code that can be directly converted to fuel moisture.

The internal calculations of the code are performed on moisture – not the FFMC

\[
FFMC = \frac{59.5 (250 - m)}{147.2 + m}
\]

\[
m = \frac{147.2(101 - FFMC)}{59.5 + FFMC}
\]

INPUTS:
- Temp (°C)
- RH (%)
- WS (km/h)
- Precip (mm)

INITIAL CONDITION:
- Previous FFMC

OUTPUT RANGE:
0 - 101
FFMC

Drying:

\[ k_0 = 0.424 \left( 1 - \left( \frac{RH}{100} \right)^{1.7} \right) + 0.0694 \sqrt{\text{Wind Speed}} \left( 1 - \left( \frac{RH}{100} \right)^8 \right) \]

Wetting:

\[ k_0 = 0.424 \left( 1 - \left( \frac{100 - RH}{100} \right)^{1.7} \right) + 0.0694 \sqrt{\text{Wind Speed}} \left( 1 - \left( \frac{100 - RH}{100} \right)^8 \right) \]

Now you get \( k \), which is change in \( \log(\text{m/day}) \):

\[ k = k_0 \left( 0.581 e^{0.0365T} \right) \]
FFMC

\[ E_d = 0.942 \, RH^{0.679} + 11 \, e^{\frac{RH-100}{10}} + 0.18 \, (21.1 - T)(1 - e^{-0.115 \, RH}) \]

\[ E_w = 0.618 \, RH^{0.753} + 10 \, e^{\frac{RH-100}{10}} + 0.18 \, (21.1 - T)(1 - e^{-0.115 \, RH}) \]

\[ m = E_d + (m_0 - E_d) \times 10^{-k_d} \]

\[ m = E_w - (E_w - m_0) \times 10^{-k_w} \]
FFMC - rainfall

\[ \frac{\Delta m}{r_f} = 42.5 e^{\left(\frac{-100}{251-m_0}\right)}\left(1 - e^{\left(\frac{-6.93}{r_f}\right)}\right) \]

\(\Delta m = \text{increase in } m \text{ due to rainfall}\)

\(r_f = \text{the forest canopy corrected rain: } r_f = r_0 - 0.5\)

IF \(m_0 > 150\) then a correction is added to the above:

\[ 0.0015 (m_0 - 150)^2 r_f^{0.5} \]
DMC

Duff ≈ F-layer (also H)

DMC = duff up to 7 cm
DMC

The internal calculations of the code are performed on moisture

**INPUTS:**
- Temp (°C)
- RH (%)
- WS (km/h)
- Precip (mm)

**INITIAL CONDITION:**
- Previous DMC

**MOISTURE RANGE:**
- MAX = 300 %
- EQ = 20 %

Duff is not exposed to wind
DMC

Rainfall phase, only if: \( r_0 > 1.5 \text{ mm} \)

\[ r_e = 0.92 r_0 - 1.27 \]

\[ M_r = M_o + 1000 \frac{r_e}{(48.77 + b r_e)} \]

\[ b = \frac{100}{0.5 + 0.3 P_o} \quad , \quad P_o \leq 33 \]

\[ b = 14 - 1.3 \ln P_o \quad , \quad 33 < P_o \leq 65 \]

\[ b = 6.2 \ln P_o - 17.2 \quad , \quad P_o > 65 \]

\( r_0 = \text{wx rainfall} \)

\( r_e = \text{effective rainfall} \)

\( P_0 = \text{previous DMC} \)
DMC

\[ DMC = 244.72 - 43.43 \ln(m - 20) \]

*Figure 5. Graph of scale linking DMC to duff moisture content.*
DC

• Represents the DEEP organic layer (min 7 cm, typically 18 cm)
• Also correlates well with coarse woody debris
• 54 day time lag
• primary long-term memory in the system
DC

Provides a warning about deep fuels
The internal calculations of the code are performed on moisture.

**INPUTS:**
- Temp (°C)
- RH (%)
- WS (km/h)
- Precip (mm)

**INITIAL CONDITION:**
- Previous DC

**MOISTURE RANGE:**
MAX = 400%

Deep / coarse layer only responds to temp and significant precip.
\[ D = 400 \ln \left( \frac{800}{Q} \right) \]

**Where:**
- \( D \) = current DC
- \( Q \) = m equivalent

**Rainfall Phase (if \( r_0 > 2.8 \) mm):**

\[ r_d = 0.83 \ r_0 - 1.27 \]

\[ Q_r = Q_0 + 3.937 \ r_d \]
Drying Phase

\[ V = 0.36 \times (T + 2.8) + L_f \]

\[ D = D_o \text{ (or } D_r) + 0.5 \times V \]

- \( V \) = potential evapotranspiration
- \( T \) = noon temp
- \( L_f \) = day length adjustment by month
- \( D_0 \) = initial DC
- \( D_r \) = DC after rain calculation
DC
OVERWINTERING
The DC time lag is long enough that you cannot assume snow melt will saturate the DC

\[ Q_s = a \cdot Q_f + b \cdot (3.94 \cdot r_w) \]

- \( Q_s \) = final fall moisture equivalent
- \( r_w \) = winter precip in mm
- \( Q_s \) = starting spring moisture equivalent
- \( a \) and \( b \) are constants

• Topic of great concern
• Depends very much on the nature of the melt (e.g. Ontario 2012)
• Most managers don't trust spring DCs until a heavy rain resets them
ISI

• The wind function of the fire behavior based indexes
• Describes the potential rate at which a fire will spread
• Depends solely on wind and the fine fuel moisture code

INPUTS:
- WS (km/h)
- FFM
FFMC = 93.7, WS = 8 km/h → ISI = 10.8

FFMC = 91.8, WS = 2.6 km/h → ISI = 6.2

FI = 3854 kW/m

FI = 676 kW/m
ISI

Wind Function \[ f(W) = e^{0.05039W} \]

FFM Function \[ f(F) = (91.9 e^{-0.1386m}) \left(1 + \frac{m^{5.31}}{4.93 \times 10^7}\right) \]

\[ ISI = 0.208 f(W)f(F) \]
BUI

• Represents the available fuel for combustion
• Combines the DMC and DC in a harmonic mean
• If the DMC \sim 0 then no value of DC can raise the BUI
• Due to the trend of increasing DC over the summer there is a slight seasonal BUI trend

\[
BUI = \frac{0.8 (DMC) (DC)}{(DMC + 0.4DC)}
\]

INPUTS:
- DMC
- DC
FWI

• Represents potential fire intensity
• Combines the ISI and BUI as theoretical FI scale
• Provides a general scale for potential fire intensity

Is not used anywhere in the CFFBPS, and often not in response either

INPUTS:
- ISI
- BUI
FWI

BUI < 80

\[ f(D) = 0.626 BUI^{0.809} + 2 \]

BUI > 80

\[ f(D) = \frac{1000}{25 + 108.64 e^{-0.023 BUI}} \]

\[ \ln(FWI) = 2.72 \left( 0.434 \ln(0.1 \text{ ISI } f(D)) \right)^{0.647} \]

* IF \((0.1 \text{ ISI } f(D)) < 1\) then \(FWI = (0.1 \text{ ISI } f(D))\)
## Applications

### Weather Forecast Report (Official)

Report Produced: 2012/07/04 11:32  
All times on this report are Eastern Time  
Total Number Of Records: 39

### Report Selection Criteria

- Time: 13:00  
- Start Date: 2012/07/05  
- End Date:  
- Fire Area: CHA

**Forecast for 2012/07/05 saved on 2012/07/03 at 14:38 by corbettma**  
Resp. Sector: E04

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Calibration

Global Fire Danger Forecast

September 26, 2013

FWI - Fire Weather Index

Base Layer
- FWI
- FFMC
- DMC
- DC
- ISI
- BUI
- USR
- World Outline

Overlays
- 24hr Hotspots
- Country Labels

-80.85938, 5.62500
Exportation

It works pretty much everywhere.


Common Misconceptions

- FWI is the name of the system so the FWI must be the most important index
- Forecasts fire behavior
- Calibrations are exportable
- Predicts fire occurrence
- Predicts fuel moisture (beyond the FFM)
- Describes foliar moisture