Burn-P3

Version 4.7

User's manual, 2017

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Contents

Burn-P3 user's manual

The Burn-P3 user's manual is divided into four sections. The first section (The Burn-P3 fire simulation model) presents a brief introduction to the concepts driving Burn-P3. The second section (Burn-P3 components) describes Burn-P3 inputs and settings, as well as its outputs. The third section (File menu items) explains how to import and export a Burn-P3 project, as well as how to use the run batch function. Finally, the fourth section (Troubleshooting) provides solutions to resolve common problems.

The official Burn-P3 technical documentation is Parisien et al. (2005) (see below). However, many changes in Burn-P3 have occurred since this document's publication. The Burn-P3 user's manual should therefore be considered to hold the most up-to-date information. Several studies using Burn-P3 can be found in the Resources section at the end of the document.

To create Burn-P3 inputs, the user must have some knowledge of raster-based geographic information systems (GIS) applications. Also, because Burn-P3 is largely based on the Canadian Forest Fire Danger Rating System (CFFDRS), the user is expected to be familiar with its two main sub-systems: the Canadian Fire Weather Index (FWI) System (Van Wagner 1987) and the Canadian Fire Behavior Prediction (FBP) System (FCFDG 1992). Familiarity with the Prometheus fire growth model is also highly recommended.

The Burn-P3 software and test files can be downloaded from the Alberta Agriculture and Forestry FireGrowthModel.ca website (1) as well as from the University of Alberta website (2):

1) http://www.firegrowthmodel.ca/burnp3/software_e.php

2) https://www.ualberta.ca/~wcwfs/burn-p3-en.html

The official Burn-P3 citation is:

Parisien, M.-A., Kafka, V.G., Hirsch, K.G., Todd, B.M., Lavoie, S.G., and Maczek, P.D. 2005. Mapping fire susceptibility with the Burn-P3 simulation model. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta, Information Report NOR-X-405.

Section 1: The Burn-P3 fire simulation model

What is Burn-P3?

Burn-P3 (Probability, Prediction, and Planning) is a simulation model that evaluates the fire likelihood or burn probability (BP) of a large fire-prone landscape. The model is packaged as a Windows-based software application that is available free of charge.

Burn-P3 general design

This section provides a model description of the Burn-P3 fire simulation model according to the Overview, Design concepts, Details (ODD) protocol for describing models (Grimm et al. 2006; Grimm et al. 2010). Note that other fairly detailed descriptions of Burn-P3 can be found in previously published studies (Beverly et al. 2009; Braun et al. 2010; Parisien et al. 2005, 2011, 2013).

Here, the elements and the conceptual framework of the modeling approach are described, rather than the structure of the Burn-P3 software, which is subject to change.

Purpose

The purpose of this model is to evaluate the relative likelihood of burning or burn probability (BP) at every given point (i.e., grid cell) on a rasterized landscape. This is achieved by modeling the ignition and spread of individual wildfires greater or equal to a specified size (e.g., ≥ 200 ha).

Entities, state variables, and scales

Entities

The modeled entities used in this model are individual grid cells.

State variables

The state variables used in the simulation of each fire in Burn-P3 are found in table below. They can be partitioned into those that are intrinsically spatial (*spatial units*) and those that are aspatial and affect the entire fire indiscriminately of space. Note that many of the state variables used in Burn-P3 are optional.

State variables used in burn probability modeling with Burn-P3

Class	Name	Data type	Description[A]
Spatial units	Fuels	Raster grid (nominal)	Canadian Forest Fire Behavior Prediction System fuel types and non-fuel features
	Topography[B]	Raster grid (numeric)	Elevation (m)
	Ignition locations	Raster grid (numeric)	Relative probability of ignition (unitless); ignitions can be spatially structured or completely random
	Fire zones[B]	Raster grid (nominal)	Geographic zones with distinct fire regimes
	Weather zones[B]	Raster grid (nominal)	Geographic zones with distinct fire weather
	Wind grids[B]	Raster grid (numeric)	Influence of topography on wind direction (degrees) and wind speed (km/h) for the cardinal and intercardinal directions
	Firebreaks[B]	Vector shapefiles (nominal)	Linear features of a specified width that interrupt fire spread (can be breached if specified)
Environment	Seasons[B]	Setting (nominal)	Start and stop dates of periods for which fire weather, grass curing, and green-up change
	Causes[B]	Setting (nominal)	The cause of fire ignition; the spatial patterns by cause may vary by season
	Fire duration	Frequency distribution (numeric)	Number of spread-event days per fire; a single (i.e. constant) value can be specified for all fires
	Number of hours per day of burning	Frequency distribution (numeric)	Number of hours of burning per day; separate distributions can be specified for each season, or a single (i.e. constant) value can be specified for each season, or a single value can be specified for all seasons
	Daily fire weather conditions	List of burning conditions (numeric)	Daily fire station weather at noon local standard time and associated Fire Weather Index System components (Van Wagner 1987); list is partitioned by season and weather zone; daily weather conditions for fires spreading for >1 day may be sampled sequentially or randomly from the fire weather list

[A]Units included in parenthesis for numeric variables

[B]Denotes optional state variables

The spatial units consist of fuels, topography, ignition location, fire zones, weather zones, wind grids, and firebreaks. The fuels variable consists of a classification of fuel types based on vegetation attributes. Each fuel type has a characteristic fire behavior that varies according to weather and topography. Pixels that do not burn (e.g., open water, exposed rock) are considered "non-fuel". Topography influences fire spread in accordance with the interaction of slope and aspect with wind. The ignition location variable represents a spatially weighted probability of experiencing an ignition at any given point on the landscape; these probabilities may vary by season and cause. The fire zones stratify the landscape in areas of distinct fire regimes, as modeled in Burn-P3. The weather zones represent areas of distinct fire weather conditions with which fire growth is simulated. The wind grids modify the input wind direction and wind speed as a function of the underlying topography. The firebreaks consist of linear features of a specified width that will interrupt fire spread: these features can be breached (if specified).

The environment comprises the following variables: season, cause, fire duration, number of hours per day of burning, and daily fire weather conditions. Season consists of time periods when the daily fire weather conditions differ, as well as the state of the fuels whose phenology greatly affects fire behavior (i.e., deciduous and grass). Cause is the type of fire ignition; causes and seasons can have distinct spatial ignition patterns. Fire duration refers to the number of spread-event days for each fire, which may vary by fire zone. This number may vary by season and also from a day to the next. The number of hours per day of burning can be constant, or vary from a day to the other, and depending on the season. The daily fire weather conditions variable represents the weather under which fire spread is simulated; that is, the weather attached to each spread-event day of a fire.

Scales

Each iteration represents one year and the simulation of this same year is repeated a very large number of times. Individual fires are modeled using a daily time step. The spatial extent is that of a study landscape (e.g., an ecoregion or land management unit), whereas the spatial resolution (i.e., pixel size) typically varies from 25 to 500 m. A buffer surrounding the study area should be added in order to avoid edge effect by letting fires ignite outside the study area and burn within its boundary. This buffer area is ultimately removed by the user.

Process overview and scheduling

The process overview of the Burn-P3 model is shown in the following figure. The ellipses represent specific model processes and the inputs (i.e., state variables and modeling parameters) from which the information is drawn (specified in parentheses). The product resulting from these events is the area burned by the simulated fire(s) in one iteration. Burn probability is obtained by simulating a very large number of iterations and, ultimately, calculating how many times each pixel burned relative to the total number of iterations.

During a given iteration, the number of ignitions is determined either from a probability distribution or a constant value. Then, for each ignition, the location, the season, the cause, and the duration of burning are determined from their respective state variables. For each new iteration, a new draw of the number of ignitions is made and the state variables are updated.

Daily fire weather conditions for each fire are then drawn and attached to each day of burning. Unlike the previously described processes, for which a single value is drawn for a given fire, the process of adding fire weather to a fire occurs at a daily time step (fires can burn for more than one day). If the number of hours per day of burning is specified in a distribution, the number of hours of burning is also drawn for each day.

Once the information pertaining to the ignition location, season, cause, duration of burning, daily fire weather conditions, and the number of hours per day of burning is determined, fire spread is carried out using the fire growth submodel Prometheus (described in Submodels subsection) for all ignitions of a given iteration. The areas burned by each simulated fire in an iteration are recorded on the rasterized landscape. The burned areas from each iteration are compiled into a cumulative grid of burned areas where BP is calculated as follows:

$$BP_i = \frac{b_i}{N} \qquad (1)$$

where b_i is the number of iterations in which pixel i experienced a fire and N is the number of iterations simulated.

This process is repeated for the specified number of iterations.

Draw number of ignitions per iteration (from probability distribution)

For each ignition in iteration

Draw ignition location (from spatial probability grid)

Draw fire duration (spread-event days; from probability distribution)

Draw season of burning (from probability distribution)

For each fire day of burning

Repeat for *n* iterations

Draw fire weather conditions by season and weather zone (from fire weather list)

Draw number of burning hours (from probability distribution)

Simulate the fire perimeter spread of each fire (using a fire growth model)

Process overview of the Burn-P3 fire simulation model

Design concepts

Basic principles

The Burn-P3 model estimates the BP of the current landscape; therefore, it does not account for vegetation succession from one year to the next. Rather, Burn-P3 is based on the idea that capturing most of the natural variability in the processes driving fire ignition and spread generates more realistic fire patterns (Lertzman et al. 1998).

Although the variables driving fire growth are probabilisitic (ignition location, duration of burning, daily fire weather), Burn-P3 also takes advantage of the fact that deterministic fire growth algorithms produce robust fire perimeter estimates (Finney 2003).

Modeling fire spread is computationally intensive. As such, we build inputs to consider only fires larger than a specified size (e.g., 200 ha). This is a sensible shortcut in most fire regimes. In the boreal forest of Canada, for example, fires of 200 hectares and larger account for ~97% of the area burned (Stocks et al. 2002).

Similarly, even though fires in the study area may burn for several weeks, significant fire growth is usually confined to a few days of high to extreme burning potential, termed spread-event days (Podur and Wotton 2011). In Burn-P3, only the spread-event days and their associated weather conditions are modeled. The use of spread-event days is a common shortcut in burn probability modeling (Finney 2005).

Emergence

The interaction of inputs can produce complex patterns that are difficult to relate to any specific state variable. The resulting BP patterns can have a high degree of emergence. Parisien et al. (2010) documented that complex and unanticipated BP patterns can emerge in Burn-P3 from highly simplistic artificial inputs.

Prediction

At each pixel, the likelihood of being burned (i.e., BP) in one year is computed. Collectively, the pixels represent a grid or map of burn probabilities of the study area. Although the model is parameterized using real data, it is preferable to interpret these probabilities as relative to one another. That is, a pixel with a value of 0.3 is three times as likely to experience a fire as a pixel with a value of 0.1.

Interaction

In the study areas, two (or more) fires burning during a given year may merge. Clearly, a given pixel cannot be burned twice in a single year. This interaction is modeled in Burn-P3 as follows: within a given iteration, pixels that have been burned by a previous fire are not allowed to re-burn.

Stochasticity

To capture inter-annual variability, the number of iterations to be simulated in each iteration is drawn from a probability distribution. For example, two fires may be simulated across the landscape during the first iteration, whereas 20 fires may be simulated during the following iteration. It is also possible to specify a constant number of ignitions per iteration.
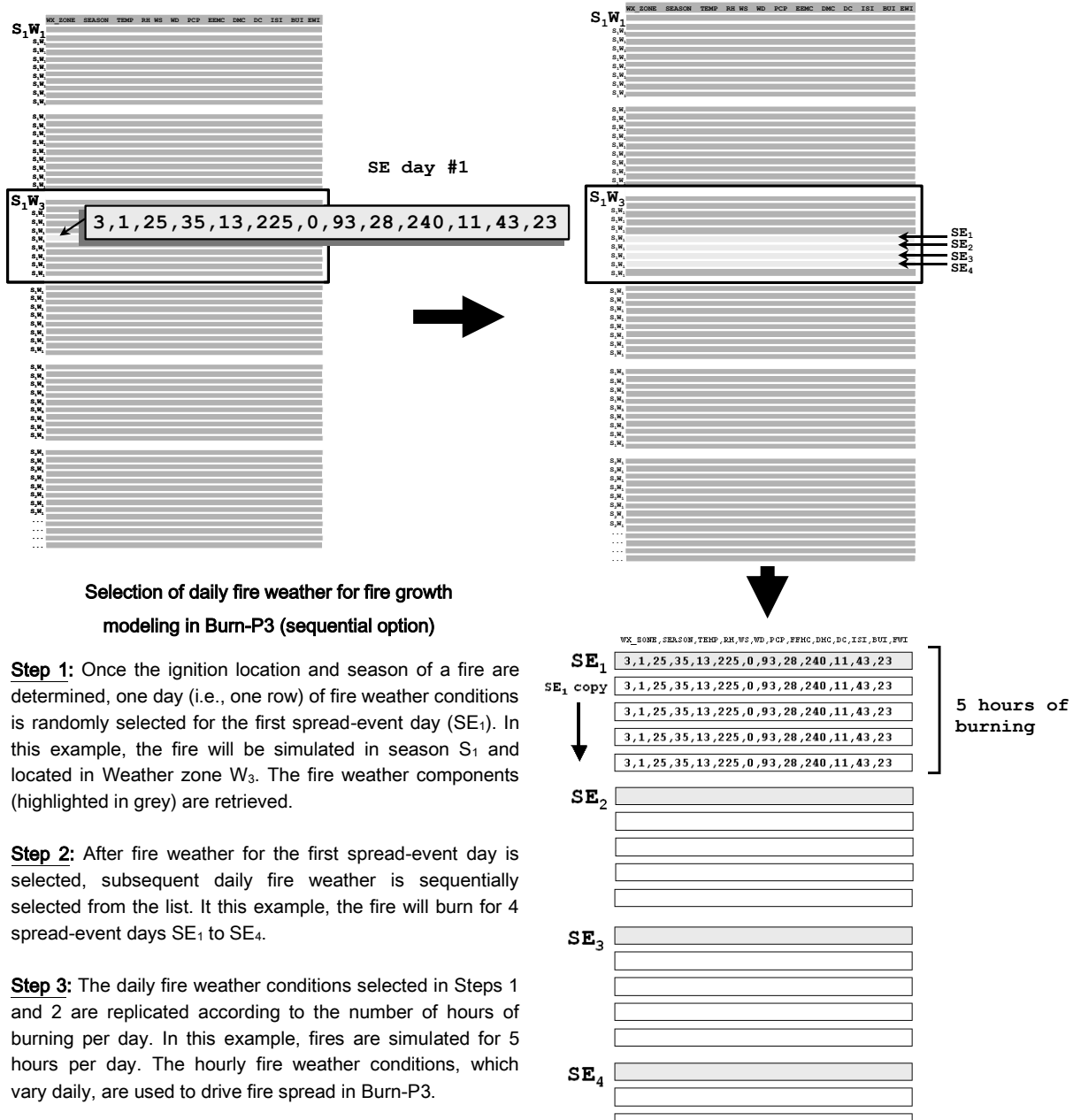
Because some combinations of season and cause experience more fires than others, fires simulated in Burn-P3 are probabilistically apportioned by season and cause, if these are specified. This stratification allows the model to account for differences in fire weather patterns among seasons and causes, as well as the state of the vegetation (pre- vs. post-leaf flush and grass curing) that can affect fire spread.

After the number of ignitions has been determined for the iteration and the season of ignition has been chosen, the next step consists of selecting its ignition location. The ignition location of each ignition is drawn from a probability density grid. Spatial patterns of ignitions may vary by season and cause. If a given fire ignition does not achieve the minimum size threshold (e.g., 200 ha), then another ignition is drawn until the total number of ignitions selected for the iteration are simulated.

The duration of burning is usually highly variable among wildfires. This variability is modeled in Burn-P3 by drawing the duration of burning of each fire from a frequency distribution of spread-event days. It is also possible to use a constant number of spread-event days for all fires. Similarly the number of hours of burning for each day can be constant, specified by season, or drawn from a distribution.

Daily fire weather conditions are then attached to each spread-event day in a partly random process that is described in the figure below. Fire weather is drawn from a list of historical fire-conducive weather conditions that is categorized by season and by weather zone, if these variables are specified. The daily fire weather conditions of this "fire weather list" are ordered by date; however, they only contain days on which the fire danger is conducive to fire spread. For each simulated fire, the fire weather conditions of the first spread-event day are randomly selected for the appropriate season and weather zone, and weather conditions of subsequent days are

selected sequentially from the fire weather database for each additional spread-event day, thereby retaining the observed temporal variability in burning conditions. Alternatively, weather conditions can be selected randomly for a given combination of season and weather zone.

Selection of daily fire weather for fire growth modeling in Burn-P3 (sequential option)

Step 1: Once the ignition location and season of a fire are determined, one day (i.e., one row) of fire weather conditions is randomly selected for the first spread-event day (SE_1). In this example, the fire will be simulated in season S_1 and located in Weather zone W_3. The fire weather components (highlighted in grey) are retrieved.

Step 2: After fire weather for the first spread-event day is selected, subsequent daily fire weather is sequentially selected from the list. It this example, the fire will burn for 4 spread-event days SE_1 to SE_4.

Step 3: The daily fire weather conditions selected in Steps 1 and 2 are replicated according to the number of hours of burning per day. In this example, fires are simulated for 5 hours per day. The hourly fire weather conditions, which vary daily, are used to drive fire spread in Burn-P3.

Process by which daily fire weather conditions are attached to the spread-event days of each simulated fire using the Sequential option (see Daily fire weather selection method).

Observation

In addition to the BP map, Burn-P3 produces a table describing the size of each simulated fire, as well the ignition location, season, number of spread-event days, and the area burned in each fuel type. For calibration purposes, simulated fire sizes can be compiled into a frequency distribution that can be compared to the observed fire size distribution derived from a fire history of the study area. Modifying the Burn-P3 state variables may affect both the mean of the distribution (i.e., mean fire size) and the shape of the distribution (i.e., how skewed it is). All state variables, as well as some of the Burn-P3 settings, notably the fire duration and number of hours per day of burning, can affect simulated fire sizes. Calibration is performed heuristically by carefully adjusting the model inputs.

Burn-P3 can also produce a set of optional outputs in tabular or gridded format. One of these outputs consists of the record of iterations in which fires have burned for each pixel (Specialized outputs; Burn iterations). This output allows the user to explore the distribution of fire intervals modeled in their Burn-P3 run. Another set of outputs, which can be in gridded or tabular (i.e., "raw") format, is derived from the FBP System primary outputs. These outputs are produced by recording an FBP System output of interest (e.g., fire intensity) at each pixel every time it is burned. From this information, selected summary statistics (i.e., mean, maximum, minimum, or median) or user-specified percentile values are computed and gridded to produce FBP System outputs.

Initialization

The state at the beginning of each iteration is the intact study landscape (i.e., without any simulated burnt areas). In other words, each iteration starts with a "clean slate", whereby the area burned by the previously simulated fires is removed from the landscape. Iterations are computed independently of one another.

Burn-P3 uses a number of user-specified constant settings. The number of daily hours of burning represents the number of hours of the day in which appreciable burning occurs, which is typically late morning to early evening. The Number of hours per day of burning can also be specified as a distribution. The minimum fire size sets a threshold on the simulated fire size so that very small fires are not simulated. The final setting is the length of the simulation (in iterations). The number of iterations must be large enough to yield a stable estimate of BP.

Some settings related to the season state variable are also constant across each simulation run. First, the leaves for the deciduous and mixedwood fuel types are usually off in the spring and on in the summer and fall seasons. Second, the percent curing of the grass fuel type also usually varies by season, whereby most of the aboveground biomass is either cured or dead in the spring and late fall.

Input data

Input data for Burn-P3 is usually based on observed historical databases. In each iteration, the number of ignitions is usually sampled from a probability distribution, whereby the values may decrease from the lowest (zero) to a large number of ignitions. The season of burning is drawn from a categorical probability distribution. These distributions can be obtained from a data set such as the Canadian National Fire Database (http://cwfis.cfs.nrcan.gc.ca/ha/nfdb), which represents an atlas of mapped fire perimeters.

The fire duration is drawn from a frequency distribution of spread-event days with values usually decreasing across its range (e.g., 1 to 12 days). This distribution can be obtained from a data set of daily fire progressions derived from satellite fire detection data (https://fsapps.nwcg.gov/afm/).

The daily fire weather conditions usually consist of real observations from weather stations located in and around the study landscape. Usually, only days corresponding to high and extreme fire weather danger are used. Weather stations that are unrepresentative of the surroundings (e.g., those on top of the highest mountain ridge) are usually not used for Burn-P3 modeling.

Submodels

The Prometheus fire growth model

Fire spread in Burn-P3 is based on the Prometheus fire growth model (Tymstra et al. 2010), which was designed to calculate the spread of fire through complex terrain and fuels according to the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992). The spread mechanism of Prometheus belongs to a family of modern fire-growth algorithms that produce realistic burn patterns, including unburned islands. Unlike the other Burn-P3 inputs used in this study, fire growth is deterministic; therefore, a given set of inputs will always result in the same fire perimeter. However, obtaining two identical fires is highly unlikely because of the modeled variability in the ignition location (hence the fuels that burn), season of burning (affecting the phenological state of the vegetation), and weather (including duration of burning and the daily fire weather conditions).

The Prometheus fire growth model can be downloaded from:
http://firegrowthmodel.ca/prometheus/overview_e.php

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Section 2: Burn-P3 components

This section lists and describes the inputs and outputs to the Burn-P3 modules.

The exclamation mark icon ⚠ provides supplementary information and useful tips.

Mandatory inputs	File format	File extension
Dictionary	Binary text	*.dic
FBP System fuel lookup table	Prometheus	*.lut
FBP System fuels	Grid ASCII	*.asc
Projection file	Projection	*.prj
Number of ignitions per iteration (single value or distribution)	Comma-delimited text	*.csv or *.txt
Ignition locations (random, Ignition grids, or List of ignition locations)	Comma-delimited text or Grid ASCII	*.csv or *.asc
Fire weather list	Comma-delimited text	*.csv or *.txt
Fire duration (single value or distribution)	Comma-delimited text	*.csv or *.txt
Number of hours per day of burning (single value or distribution)	Comma-delimited text	*.csv or *.txt

Optional inputs	File format	File extension
Elevation	Grid ASCII	*.asc
Fire zones	Grid ASCII	*.asc
Weather zones	Grid ASCII	*.asc
Firebreaks	Shapefile	*.shp
Distribution of ignitions by season, cause, and Fire zone	Comma-delimited text	*.csv or *.txt
Wind grids	Grid ASCII	*.asc

Outputs	File format	File extension
Burn probability map	Grid ASCII	*.asc
Statistics table	Comma-delimited text	*.csv or *.txt
Burn-P3 log file	Comma-delimited text	*.csv or *.txt

Specialized outputs	File format	File extension
FBP System outputs	Grid ASCII	*.asc
Fire perimeters	Shapefile	*.shp
Burn iterations	Comma-delimited text	*.csv or *.txt

Dictionary

The Dictionary is a catalogue of Burn-P3 attribute information. It specifies numeric codes for the inputs such as cause and season that are used throughout the Burn-P3 project. Therefore, it is crucial that the user ensures a perfect match between the Dictionary entries and those of the other inputs (e.g., fire weather, ignition locations, fire zones, weather zones, etc.).

The numeric code required for each of the user-specified features is either entered interactively by the user or imported from a previously created dictionary file that can be opened and modified only within Burn-P3.

The season and cause are mandatory fields in the Dictionary, even if there is only a single season or only a single cause. Optional elements such as Fire zones and Weather zones must be included in the Dictionary if they are used.

There are no limits to the number of features in a category. For example, one project may require four seasons, whereas another only has two. If only a single feature is used in a given category (e.g., a single season), it must still be entered in the Dictionary and given a numeric code.

⚠️ The median date of each season must be included because Burn-P3 uses this value to calculate the seasonal foliar moisture content, which is a component of the FBP System.

All the required information for the Dictionary is entered directly in Burn-P3 to produce a binary text file (*.dic).

The following information is required to create the Dictionary:

Input	Information	Format	Description
Seasons	name	string	The name of each season
	numeric code	integer	A numeric value corresponding to each season
	median date	date (mm/dd)	A date that lies in the middle of the season
Causes	name	string	The name of each cause of ignition
	numeric code	integer	A numeric value corresponding to each cause of ignition
Fire zones	name	string	The name of each Fire zone
	numeric code	integer	A numeric value corresponding to each Fire zone
Weather zones	name	string	The name of each Weather zone
	numeric code	integer	A numeric value corresponding to each Weather zone

Landscape

The only mandatory landscape input required to run Burn-P3 is the FBP System fuel grid, for which the attribute data are provided by the FBP System fuel lookup table. Burn-P3 can also integrate optional landscape components such as Elevation, Fire zones, Weather zones, and Vectorized firebreaks.

FBP System fuel lookup table

The Fire Behavior Prediction (FBP) System fuel lookup table contains the attribute data for the FBP System fuel grid. These attributes give meaning to the values used in the FBP System fuel grid. All values in the grid must have a corresponding value in the FBP System fuel lookup table, but there can be values in the table that are not represented in the grid.

Burn-P3 provides a standard default FBP System fuel lookup table. This table is identical to the Prometheus fuel lookup table. Some fire management agencies have custom FBP System fuel lookup tables for Prometheus that can be readily incorporated into Burn-P3.

FBP System fuel values can be modified with other software. Alternatively, any of the attributes can be modified and saved directly in the FBP System fuel lookup table.

⚠ The user must ensure that re-classified fuels' numerical codes in the FBP System fuel lookup table match values in the FBP System fuel grid.

The FBP System fuel lookup table (*.lut) is a comma or tab-delimited text file that can be read and modified in any word processing or spreadsheet application. The numeric codes of the FBP System fuel lookup table must be integers.

The FBP System fuel lookup table holds the following information:

Column	Name	Type	Description
1	grid_value	integer	Numeric code used in the FBP System fuel grid
2	export_value	integer	Value used when the fuel grid is exported
3	descriptive_name	string	Agency fuel type name
4	fuel_type	string	FBP System fuel type name
5	r	integer	Display colour red
6	g	integer	Display colour green
7	b	integer	Display colour blue
8	h	integer	Display hue
9	s	integer	Display saturation
10	l	integer	Display luminosity

Mapped inputs

The study area is represented by the Mapped inputs: <u>FBP System fuels</u>, <u>Elevation</u>, <u>Fire zones</u>, <u>Weather zones</u>, and <u>Vectorized firebreaks</u>.

⚠️ All raster grids must have the same projection, resolution, and extents.

⚠️ In order to allow fires to burn in from outside the study area, and thereby avoid edge effects, a buffer should be added around the study area.

The standard format for all Burn-P3 grids is the grid ASCII file (*asc). This format is supported by most, if not all, raster geographic information system (GIS) applications. The file contains header data followed by space-delimited values for every cell in the grid by row from top left to bottom right.

The grid ASCII file header contains the following information:

Header info	Description
ncols	number of columns in the data set
nrows	number of rows in the data set
xllcorner	x coordinate of lower left corner
yllcorner	y coordinate of lower left corner
cellsize	cell size, in m, for the dataset; resolution
NODATA value	value assigned to cells having an unknown value, the default 'no data' value is –9999

The grid data are found directly beneath the header information and are sequentially arranged with the first value (row 1, column 1) being the value at the top-left corner of the grid.
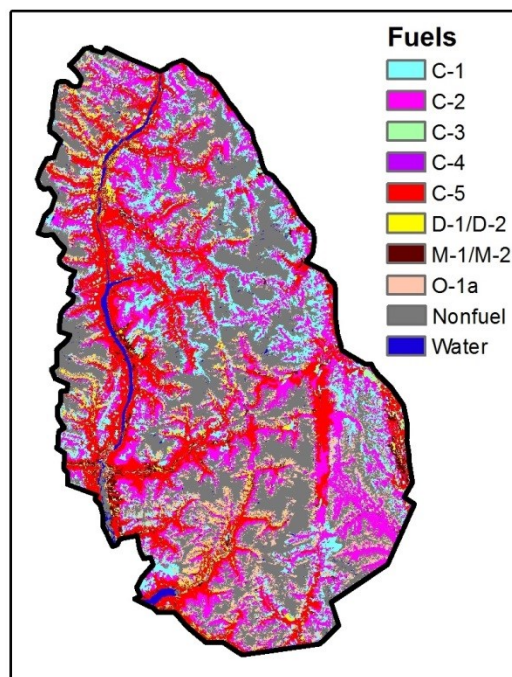
FBP System fuels

The grid of Fire Behavior Prediction (FBP) System fuels is the only mandatory Mapped input to run Burn-P3. It is incomplete without the Projection file and the FBP System fuel lookup table, which provide, respectively, the geo-referencing and attribute data for the grid. The FBP System fuel grid consists of integers corresponding to those in the FBP System fuel lookup table.

⚠ The FBP System fuel grid data cannot be modified directly in Burn-P3, but the data can be assigned different attributes in Burn-P3 through the FBP System fuel lookup table.


This is an example of a FBP System fuel grid:

Projection file

The projection information of the mapped inputs is specified in the projection file (*.prj), typically associated with the FBP System fuel grid. The projection file is a mandatory input imported at the same time as the FBP System fuel grid and other Mapped inputs. It contains the coordinate reference system and projection parameters for all the grids and shapefiles used in the Burn-P3 project. Most GIS applications write out a projection file when a grid ASCII file is produced. It cannot be changed directly in Burn-P3, but it is a simple text file which can be modified in a word processing or spreadsheet application.

Elevation

The Elevation grid represents the altitude, in meters. This input is used to compute the foliar moisture content in the FBP System, and modify the wind direction and wind speed as prescribed by the FBP System. A default elevation can be specified by the user for the analysis. However, elevation grid is strongly recommended topography is known to affect fire spread.

All Mapped inputs must have the same projection, resolution, and extents. Unlike the FBP System fuel grid, the data in the Elevation grid are real values. This is an example of an Elevation grid:
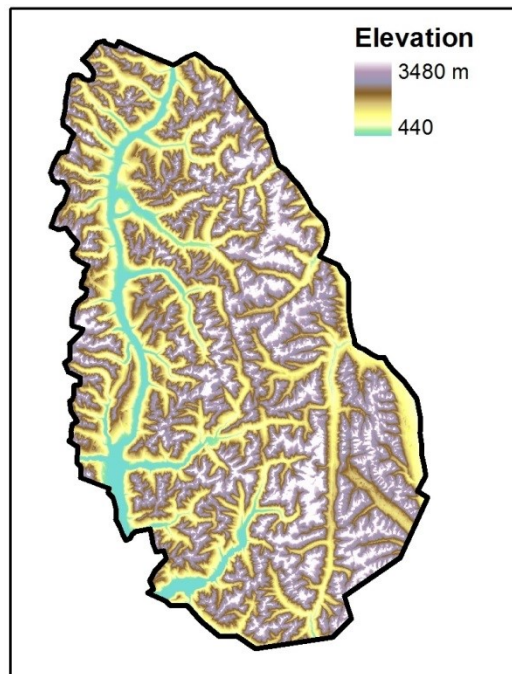
Fire zones

Fire zones are geographical regions in which the fire regimes vary. Fire zones information can be used in conjunction with the Distribution of ignitions by season, cause, and Fire zone to provide an adjustment to the Ignition locations. It may also be used in the Ignition restrictions, Different spread-event days by Fire zone, and the Green-up rules to specify different geographical constraints on ignition and spread.

⚠️ The Fire zones grid is optional; however, it is particularly useful when the study area is large, or when it encompasses significantly different ecological units or administrative areas of different fire suppression strategies.

All Mapped inputs must have the same projection, resolution, and extents. The Fire zones grid must include integer values only. This is an example of Fire zones:
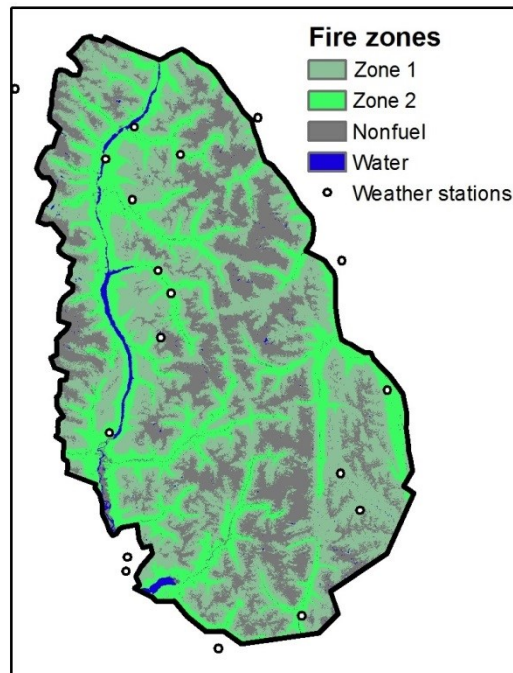
Weather zones

Weather zones are geographical areas experiencing distinct fire weather, which in Burn-P3 consists of weather observations and their associated FWI System codes and indices (Van Wagner 1987). Burn-P3 models spatio-temporal variation in fire weather as a function of Weather zones and seasons.

Weather zones are given a numeric value in the Dictionary. This information links each ignition location to the Burning conditions module.

All Mapped inputs must have the same projection, resolution, and extents. The Weather zones grid must have integer values. This is an example of Weather zone grid:
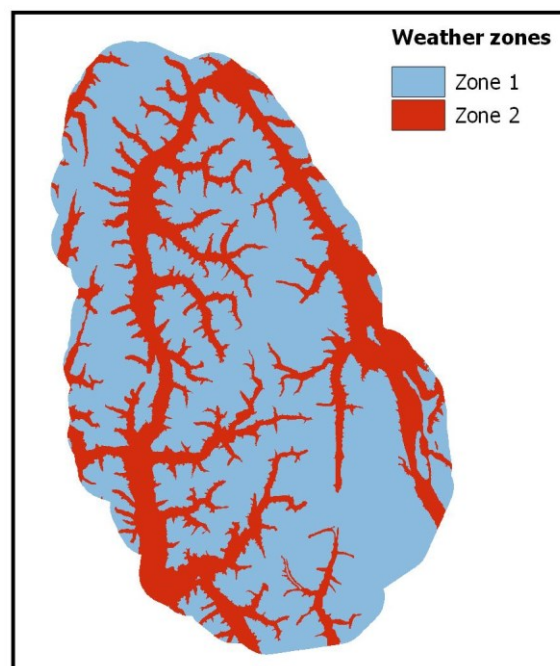
Vectorized firebreaks

Vectorized firebreaks are imported from shapefiles (*.shp), they are vector lines representing features of the landscape that affect fire spread. When a Vectorized firebreak is imported, the user must specify the width of the linear feature. All firebreaks of the shapefile have the same width; however, more than one Vectorized firebreaks shapefile can be imported.

If the Fire can breach firebreaks function is toggled on, the Prometheus method for breaching is applied according to a set of rules based on the width of the firebreak and the calculated flame length (Tymstra et al. 2010). If Vectorized firebreaks are specified but the breaching function is not toggled on, the linear features will stop fire spread.
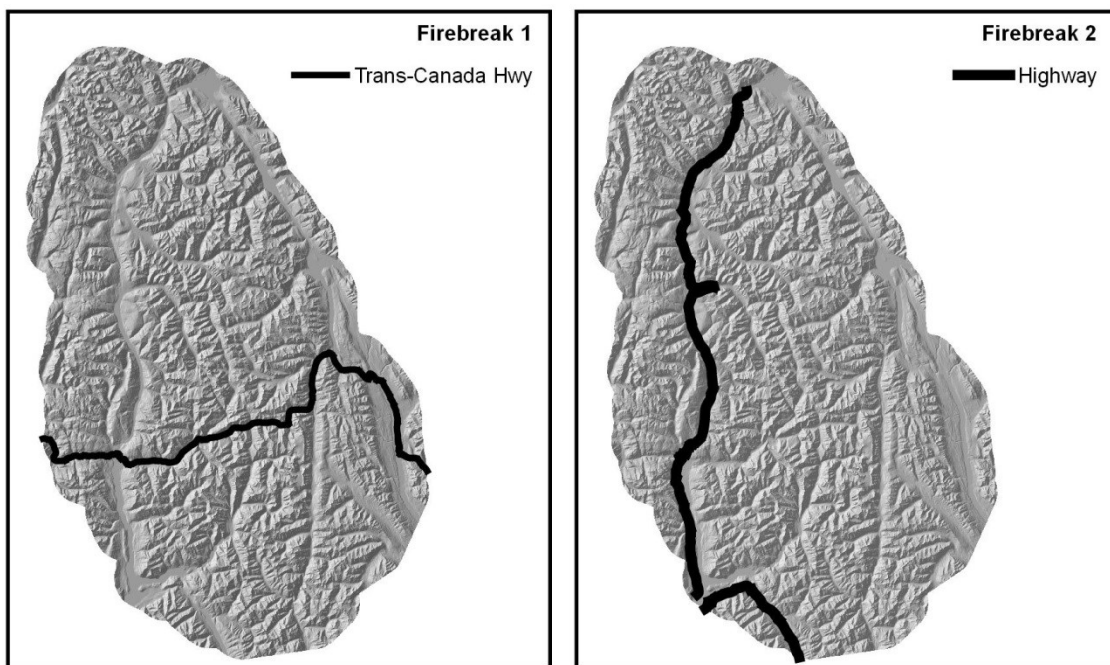
⚠ FBP System nonfuels can also act as firebreaks. However, the Vectorized firebreaks will better represent linear features such as roads and rivers because a width finer than the pixel can be specified.

⚠ The projection of this input must be the same as the other Mapped inputs.

This is an example of two Vectorized firebreak shapefiles with different width:

The shapefile is the native ESRI file format for storing vector data. A shapefile actually consists of a group of 3 to 5 files (including the main *.shp file) that should be used as a unit. The attribute information that is attached to the different features of the shapefile is stored in the *.dbf file. Shapefiles cannot be manipulated in Burn-P3.

Landscape properties

The basic properties of the modeled landscape are listed in the Landscape properties: the grid information (cell size, the number of columns and rows, and the grid size), the location of the lower left corner, the default elevation, and the time zone.

Grid information

Cell size

This represents the spatial resolution of the mapped inputs, in meters. Burn-P3 retrieves this information from the mapped input grids.

Columns and rows

This represents the spatial extent of the mapped inputs, in terms of the number of columns and rows of data. Burn-P3 retrieves this information from the mapped input grids.

Grid size

This is another measure of the spatial extent of the mapped inputs, in meters. These values are obtained by multiplying the number of columns and rows by the cell size.

Location of lower left corner:

These represent the latitude and longitude, in degrees, of the lower left corner of the simulated landscape. Burn-P3 retrieves this information from the Projection file.

Default elevation

The average elevation, in meters, calculated from the Elevation grid, if specified. If an elevation grid is not used, the user can manually enter a value. The elevation affects the foliar moisture content component of the FBP System.

Time zone

Burn-P3 requires that a time zone be selected in order to calculate some of its fire-behavior parameters.

Ignitions module

This module is used to determine the location, number, and the timing (i.e., season) of ignitions for each iteration.

Number of ignitions per iteration

The Number of ignitions per iteration includes only ignitions that result in fires larger than the Minimum fire size. This Minimum fire size is specified in the Simulation window, and represents the size of a fire that would escape initial attack. The number of ignitions per iteration can be either a constant value or a distribution. If a distribution is specified, Burn-P3 draws from this distribution to determine the number of fires to simulate in each iteration.
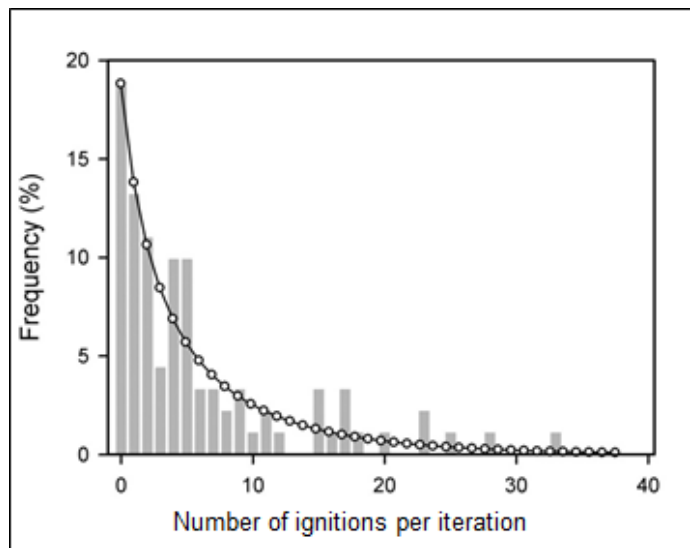
Distribution of the number of ignitions per iteration (points), smoothed from the raw data (bars).

It is a simple table saved as a comma-delimited text (*.csv) file that holds the following information:

Column	Name	Type	Description
1	ign_per_it	Integer	The number of ignitions per iteration
2	pct	Real	The percent likelihood of having n ignitions per iteration

Ignition locations

The ignition location settings give the user control over the pattern of ignitions on the landscape. They can be random or non-random. If they are non-random, ignition locations can be drawn from one or more probability density grids (Ignition grids), or specified from a List of ignition locations (x-y coordinates).

Spatially random ignitions

Once the Number of ignitions per iteration is determined, a location is determined randomly for each ignition. When an ignition does not lead to a fire of the minimum size, a new ignition location is drawn until a fire simulated meets that threshold. The spatially random ignition is the default setting in Burn-P3.

Ignition grids

The Ignition grids represent the spatial patterns of fire ignitions by season and cause, as specified in the Dictionary. Values of these grids need not to be true probabilities (between 0 and 1). They can simply be relative weights. For example, a pixel with a value of 3 would experience three times the number of ignitions as a pixel with a value of 1.

The user can also specify combinations of season, cause, and Fire zone in which no ignitions are allowed by using Ignition restrictions.

The maximum number of Ignition grids is the product of the number of seasons and causes of fires used in a Burn-P3 simulation. If there are two causes (e.g., human and lightning) and two seasons (e.g., spring and summer), up to four Ignition grids can be specified.

⚠ If an Ignition grid is not specified for a given season-cause combination, Burn-P3 will assume the ignition locations to be random for that combination.

⚠ The Ignition grids must have the same resolution, projection, and extent as the other Mapped inputs.

The figure below contains two sample ignition grids, along with ignition locations that could be produced using these grids:
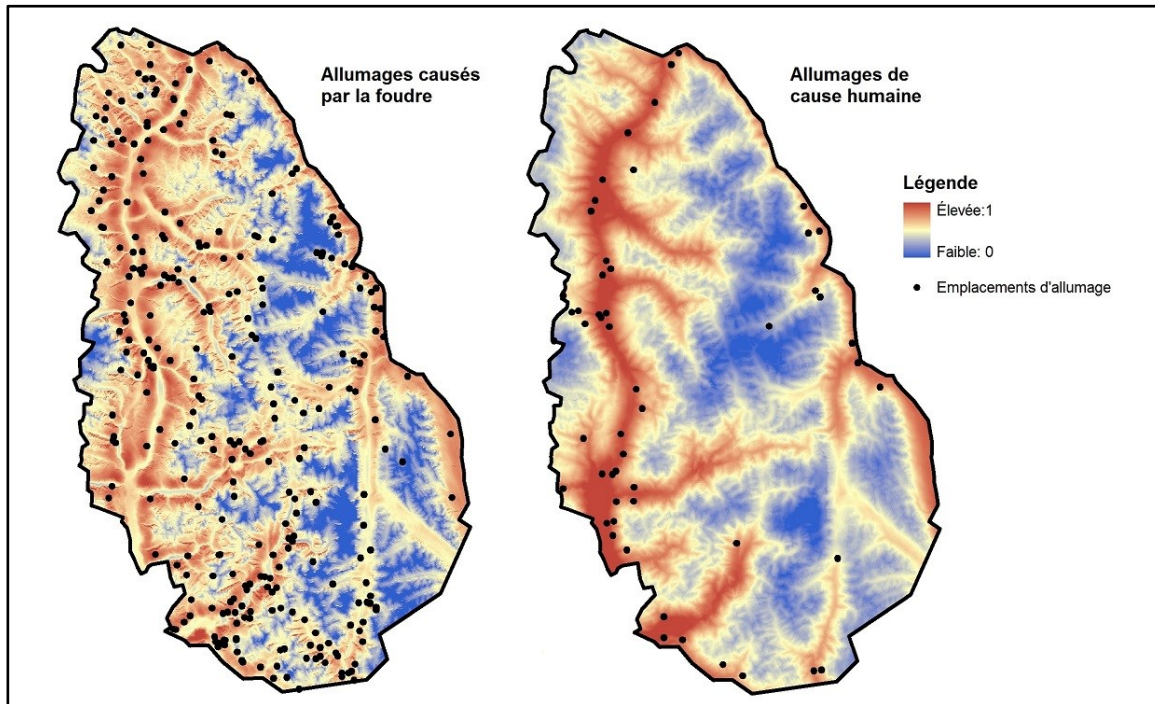

Ignition location list

It is also possible to specify a list of ignition locations as x-y coordinates. If this input is used, it will set the length of the Burn-P3 run by modeling every ignition in the list. In that case, the Ignition grids input is disabled, because the spatial pattern of ignitions will already be included, as well as the Number of ignitions per iteration.

If one ignition location does not produce a fire large enough to meet the minimum size threshold (see Simulation window), this location will be skipped and Burn-P3 will move on to the next ignition location on the list until the list is processed in its entirety.

⚠ When an Ignition locations list is used, Burn-P3 always assigns the first season listed in the Dictionary. In other words, this input does not vary by season. The user will therefore have to do separate runs in order to use more than one season.

⚠ The user must make sure that the ignition locations coordinates are consistent with the projection file and that they are all located inside the study area.

The Ignition locations list (x-y coordinates) must be presented in a comma delimited text file (*.csv).

Column	Name	Type	Description
1	x_coor	Real	X coordinate (northing) of the ignition location
2	y_coor	Real	Y coordinate (easting) of the ignition location

Ignition restrictions

The Ignition restrictions represent one or more combinations of fuel type, cause, season, and Fire zone (but not necessary all of them) for which ignitions are not permitted. It is an optional input that overrides the values of the Ignition grids. If an ignition is not permitted, another fire location is drawn until the ignition conditions are met.

Distribution of ignitions by season, cause, and Fire zone

This option specifies the proportion of ignitions to be simulated for each combination of cause, season, and Fire zone, if specified. The Distribution of ignitions by season, cause, and Fire zone is used to better reflect known spatial and temporal (i.e., seasonal) patterns of fire ignitions.

It is imported as a comma-delimited text (*.csv) file and holds the following information:

Column	Name	Type	Description
1	season	integer	The season's numeric code
2	cause	integer	The cause's numeric code
3	zone	integer	The Fire zone's numeric code
4	esc_fires	real	The percentage of ignitions by season, cause, and fire zone

Burning conditions module

This module determines the conditions under which fire ignition and spread are simulated.

Fire weather list

Fire weather refers to daily records of noon Local Standard Time (LST) weather observations of temperature, relative humidity, wind speed, wind direction, and 24-hour precipitation, as well as their associated Fire Weather Index (FWI) System (Van Wagner 1987) fuel moisture codes and fire behavior indexes. This information is similar to the standard fire weather format used by most Canadian fire management agencies.

One record in the Fire weather list (i.e., row) represents one day of fire weather observations. To capture sufficient variability in day-to-day burning conditions, as many records as possible should be included in the Fire weather list. However, it is important to include only fire weather conditions that can potentially lead to fire spread; that is, there is no use in including days that will never yield any spread in Burn-P3. In other words, only days of high and extreme fire weather should be included in the Fire weather list.

The daily fire weather records of the Fire weather list must be stratified by season and by Weather zone. Each season and Weather zone requires a numeric code, which has to be entered in the Dictionary. Even if only one season is used in a Burn-P3 project, this season's numeric code must appear in the Fire weather list. Given that the Weather zones are optional, the 'wx_zone' column can be omitted from the Fire weather list. If no Weather zone is specified in the Dictionary, Burn-P3 will ignore the field.

⚠ If the Fire weather list contains erroneous or missing values, Burn-P3 will halt simulation when this record is encountered.

The Fire weather list used in Burn-P3 is a comma-delimited text (*.csv) file. It is imported in the Burning conditions module and contains the following information:

Column	Name	Type	Description
1	wx_zone	integer	Weather zone (numeric code) (optional)
2	season	integer	Season (numeric code)
3	temp	real	Temperature (in °C)
4	rh	real	Relative humidity (in %) (> 0 and < 100)
5	ws	real	Wind speed (in km/h)
6	wd	real	Wind direction (in cardinal degrees) (from 0 to 360)
7	prec	real	Precipitation (in mm)
8	ffmc	real	Fine Fuel Moisture Code (FFMC)
9	dmc	real	Duff Moisture Code (DMC)
10	dc	real	Drought Code (DC)
11	isi	real	Initial Spread Index (ISI)
12	bui	real	Buildup index (BUI)
13	fwi	real	Fire Weather Index (FWI)

Daily fire weather selection method

The Daily fire weather conditions can be selected from the Fire weather list in two ways: random or sequential.

Random

The random selection of fire weather records draws conditions for each spread-event day randomly for each combination of season and Weather zone. By default, random selection is used.

Sequential

The sequential selection of fire weather records draws the first spread-event day of a given fire at random (also for a given combination of season and Weather zone) and selects the conditions for the following spread-event days sequentially in the order in which they appear in the Fire weather list. This method will therefore be more representative of real sequences of burning conditions; however, the order of days must be preserved in the Fire weather list.

See also the Process by which daily fire weather conditions are attached to the spread-event days

Fire duration

The days over which fires have burned a significant proportion of their final size are called spread-event days. The user can specify a constant number of spread-event days for all fires or specify a frequency distribution of spread-event days, for the entire study area or by fire zone.

Use a constant number of spread-event day(s) per fire

The default fire duration in Burn-P3 is a constant of one spread-event day per fire.

⚠ Using a constant number of spread-event days per fire may yield spatially inaccurate results in the Burn probablility map.

Distribution of spread-event day(s)

If fires have variable duration of burning in a study area, as is usually the case, it is crucial that the variability in spread-event days be reflected in the distribution of spread-event days.

There are many ways to produce the distribution of spread-event days. For example, Parisien et al. (2005) defined a spread-event day as a day when a fire has achieved ≥4% of its final size, from a database of daily fire progression for 130 large fires. The example provided below represents a distribution of spread-event days derived from MODIS daily fire detections (https://fsapps.nwcg.gov/afm/).
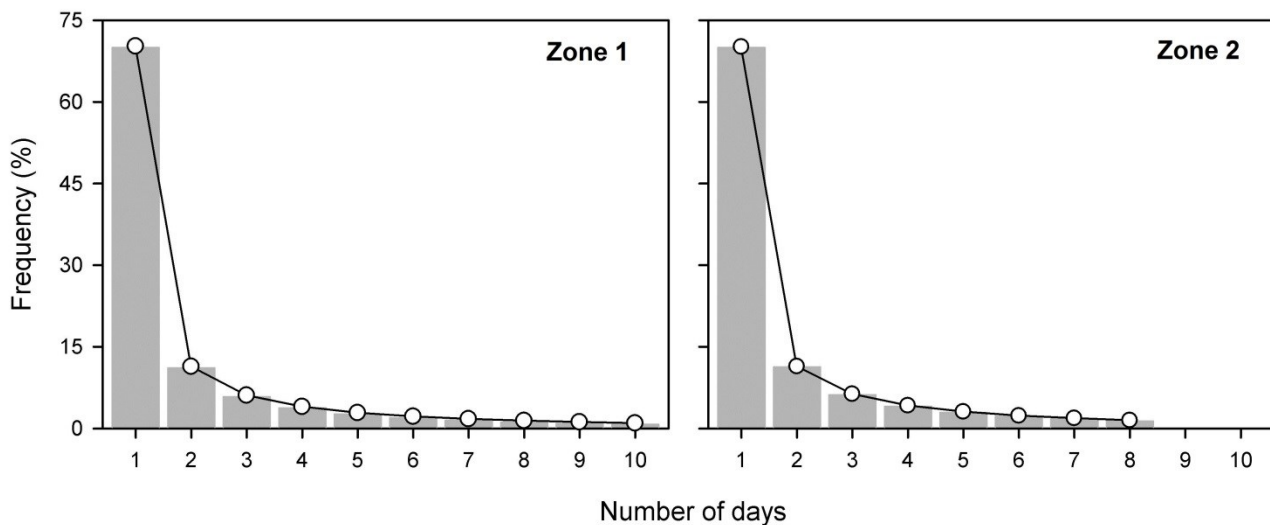
Distribution of spread-event days (points), smoothed from the raw data (bars).

This distribution imported as a *.csv file contains the following information:

Column	Name	Type	Description
1	sp_ev_days	Integer	The number of spread-event days
2	pct	Real	The percent likelihood of having n spread-event days per fire

Different spread-event day(s) by fire zone

For each Fire zone, the user can interactively enter a constant number of spread-event days or import a distribution of spread-event days. This feature is used if the duration of burning varies among Fire zones.

Specialized fire weather

Wind grids

General wind direction and wind speed patterns are highly affected by rugged topography. To account for this effect, Burn-P3 allows the user to import Wind direction and Wind speed grids. Both types of grids can be created using the WindNinja software (Forthofer and Butler 2007), which is available from the USDS Forest Service website (www.firelab.org/project/windninja). See below for additional information about WindNinja.

Because winds can blow from any direction in Burn-P3, Wind grids need to be built for 8 wind directions (N, N-E, E, S-E, S, S-W, W, N-W). The entire set of Wind grids will thus consist of 8 Wind direction grids and 8 Wind speed grids. The use of Wind direction grids in Burn-P3 is fairly straightforward. A given grid is enabled on the condition that the input Wind direction (from the Fire weather list) falls between ±22.5° of a given direction. For example, if the wind direction falls between 337.5° and 22.5°, Burn-P3 will use the "North" wind direction grid and the fire will generally be south-burning, depending on the contents of the wind direction grid.

The use of Wind speed grids in Burn-P3 is similar to the Wind direction grids but involves an additional step, which is carried out automatically by Burn-P3. Basically, Burn-P3 "transforms" Wind speed grids in order to obtain multipliers. For example, a 10 km/h wind may yield an 18 km/h wind at a particular location because it is going up a steep slope. This implies that the 10 km/h value is multiplied by a 1.8 scalar at this particular location. The value of 1.8 is what Burn-P3 will compute and use. The reason for using this approach is that the scalar can be applied to any wind speed obtained from the Fire weather list.

From the users' standpoint, Wind speed grids are specified in the same way as the Wind direction grids.

The Bulk import button allows the user to import the content of all Wind speed and Wind direction grid files from a folder at once. The list of imported files can be modified using the Edit file spec. button.

⚠️ In Burn-P3, the user has the flexibility to specify only one type of Wind grids; however, if there is fairly variable topography, we recommend using both types of grids.
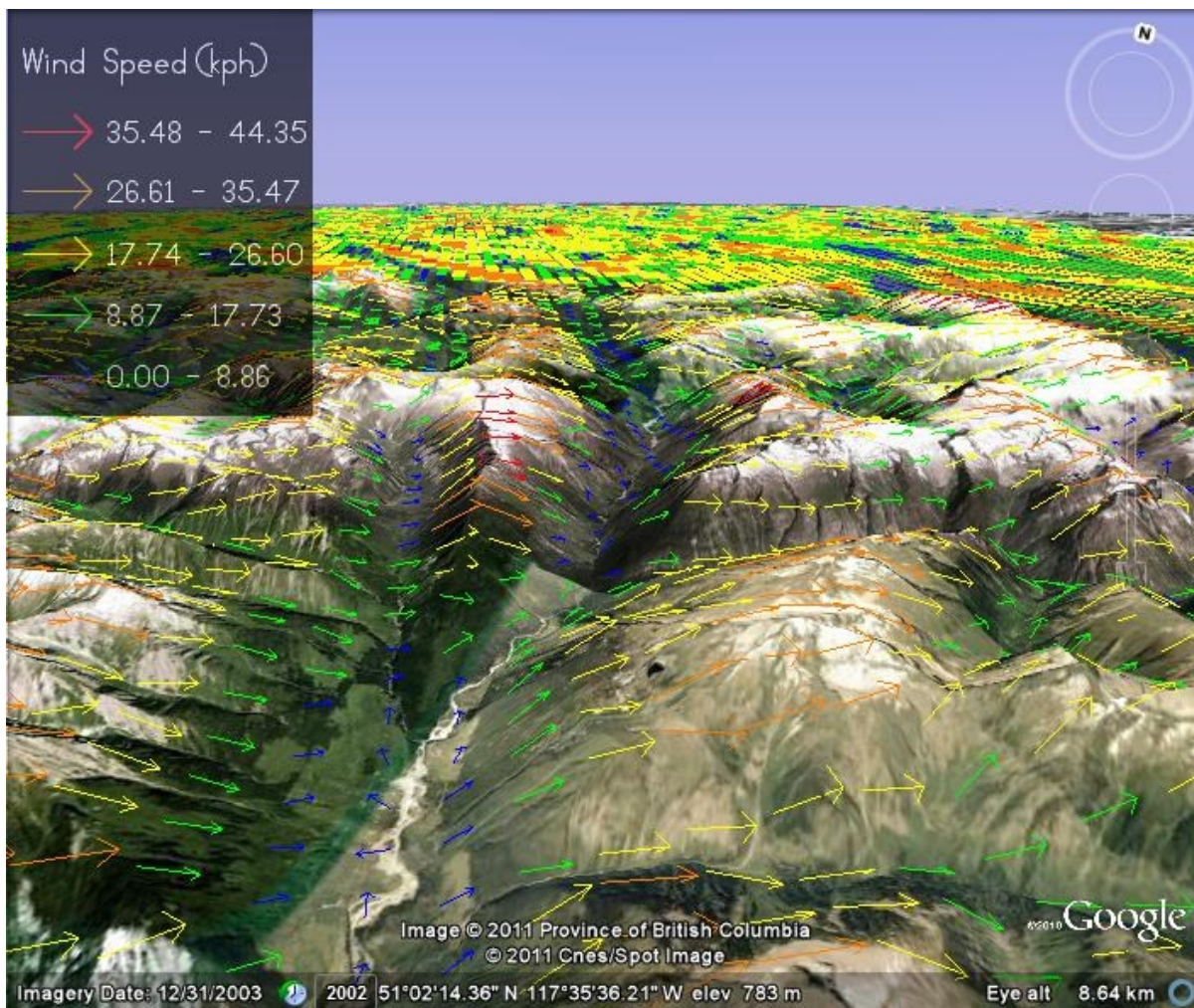
⚠️ The Wind grids cannot be used without the Elevation grid.

⚠️ The projection, extent and resolution of the wind grids must be the same as the other Mapped inputs.

Example of the topography-modified wind speed and wind direction on a landscape. The Wind grids were produced using the WindNinja software (Forthofer and Butler 2007).

Producing grids with WindNinja

In WindNinja, Wind direction and Wind speed grids are produced from an input elevation grid and constant wind speed and direction values. Several grids can be produced at once.

The computation of Wind grids in WindNinja is highly intensive. For this reason, a mesh size that is coarser than the input Elevation grid is specified. For example, using the Burn-P3 test data, a 1000-m mesh size is appropriate; WindNinja will not compute Wind grids at the original 100-m resolution on most computers. Although the calculation is made at a coarser resolution, the grids output by WindNinja can (and should) be output in the original resolution (e.g., 100 m) in order to be used with the other gridded inputs in Burn-P3. +

It is important to note that WindNinja recommends some default resolutions that are typically non-integers (e.g., 971.45 m). If the user specifies a non-integer mesh size, the output grids from WindNinja will not have the same extent as the specified Elevation grid. This is a problem because all grids must have exactly the same resolution and extent in Burn-P3. One way to ensure that the grids produced by WindNinja have the same spatial extent as those of the Elevation grid is to make the mesh size an integer factor of the desired resolution. For example, a 1000-m mesh size will work, because 1000 m divided by 100 m (the desired pixel size) equals 10.

Fire growth module

This module encompasses many of the functions and settings necessary for fire growth modeling with Prometheus.

Prometheus settings

Hours per day of burning under maximum conditions

This represents the number of hours per day for which fires are simulated. The number of hours per day of burning can be specified as a constant for all fires, different constants depending on the season, or drawn from a distribution. The default is a constant of 6 hours of burning per day.

Distribution of hours per day of burning

The number of hours per day of burning can be drawn from a distribution. The distribution is designed to reflect the variability in the daily duration of burning.

This distribution imported as a *.csv file contains the following information:

Column	Name	Type	Description
1	hours	Integer > 0	The number of burning hours per day
2	pct	Real >=0.0	The percent likelihood of having n hours of burning per day
3	cum_pct	Real	Cumulative percentage from the percentage column (optional)

Different hours per day of burning hours per season

The number of hours per day of burning can be specified for each season. These numbers should reflect seasonal differences in day length, weather conditions, or fuel conditions not fully accounted for in the Fire weather list and the FBP System fuel parameters.

Fires stop growing when encountering plot edge

This feature interrupts fire growth when the simulated fire perimeter touches the grid boundary. If the study area buffer is not very wide compared to the size of simulated fires, this setting is not recommended (i.e., let fires grow). The default is "off".

Seasonal vegetation states

Grass parameters

Fire behavior in the O-1 fuel type (Grass) can vary significantly throughout the fire season as a function of the percent curing (i.e., proportion of dead grass) and grass fuel load.

Fuel load

The fuel load is the amount of cured grass available to burn, in tonnes per hectare. The default value is 3.5 t/ha.

Percent curing of the O-1 fuel type

Because Burn-P3 runs usually take into account more than one season, the Percent curing of the O-1 fuel type must be set for each season. In Burn-P3, these settings cannot be saved to a separate file, but they are saved in the Burn-P3 project. The default curing value is 60%.

Green-up rules

Green-up refers to the transition in deciduous trees from leafless to leafed-out. Green-up affects the D-1/2, M-1/2, and M-3/4 fuel types. This setting must be specified by season in the Green-up rules. These rules also allow the user to specify the season of green-up by Fire zone, as very large areas may have deciduous trees greening-up in the south much earlier than in the north (or green-up may occur earlier at lower elevations than higher elevations). These settings are saved in the Burn-P3 project file. The default is ''on'' (i.e., green).

Simulation

Length of run

This sets the length of a Burn-P3 run as the number of iterations. To obtain a stable BP map, that is, one that produces very similar results in two independent runs, a large-enough number of iterations should be specified. There is no steadfast rule regarding the number of iterations because this will vary as a function of the size of the study area, the landscape configuration, and the characteristics of the fire regime (especially with respect to fire size).

Minimum fire size

This represents the minimum size (in hectares) a simulated fire must achieve to be recorded in the Burn-P3 outputs. The minimum fire size defines the threshold at which the fires are assumed to have escaped initial attack.

Auto-save Burn-P3 outputs

This feature automatically saves the Burn-P3 outputs at specified iteration increments. These files are saved using the specified file names; therefore, files are overwritten as the run progresses if the auto-save function is used.

Randomization control

Burn-P3 is a fundamentally stochastic model, whereby most of its inputs are drawn using a Monte Carlo process. As such, no two Burn probability maps are exactly the same, even though they use the same inputs. However, it can be useful to replicate a Burn-P3 map exactly, or force one component of Burn-P3 (such as the order of ignition locations) to be replicated while other inputs are stochastically modeled. Burn-P3 has this capability.

Do a new run

The default randomization control method is to do a new run, and therefore obtain different probability grids.

Redo the last run

This option allows the user to redo a Burn-P3 run in its entirety. If all inputs and parameters remain the same, Burn-P3 will produce exactly the same probability grids as the last run.

⚠ The behavior of this function has not been fully assessed and it should therefore be used with caution.

Although Burn-P3 may be forced to draw exactly the same inputs in the same order, changes to other inputs can lead to unanticipated results. For example, if the Ignition locations are repeated but the FBP System fuels have changed, it is possible that some ignitions will no longer meet the Minimum fire size threshold, which will nullify the attempt to replicate the same fires in the same sequence as a previous run. There are, however, ways around this. For example, in the replicated run, the user can set the 'Minimum fire size' at a very small size (say, 1). In brief, this can be an extremely useful function, but the outputs should be examined carefully.

Control random streams

This option constrains the stochastic variability of one or more specific components. The user can choose to use new or the same numbers in the number of fires per iteration, the Ignition locations, the Fire weather, and the Number of spread-event days as a previous run.

Outputs

In Burn-P3, the outcome of a run consists basically of 3 output types: a Burn probability map (*.asc), a Fire statistics table (*.csv), a map statistic file (*.csv), and a log file (*.log). The user can also produce advanced outputs such as Burn iterations, FBP System outputs, and Fire perimeters.

Burn probability map

The Burn probability map is the main Burn-P3 output and represents a quantitative evaluation of fire likelihood for one year (e.g., the upcoming fire season). The pixel-wise output can either be expressed as a percent for each grid cell (i.e., burn probability), or as the number of times burned. Once the Burn-P3 simulation is completed, the Burn probability map is displayed on the screen and automatically exported as a grid ASCII file to a user-specified path.

⚠️ To obtain a reliable Burn probability map, the user must be sure to properly model the variability in the Burn-P3 inputs and specify a large-enough number of iterations.

Percentage

This setting will write the Burn probability map with percentage (real numbers). This is the default.

Integer

Instead of a percentage, the integer option will record the number of times each cell has burned in the Burn probability map. This integer grid does not represent a true burn probability: for this, it must be divided by the number of iterations (and multiplied by 100 to obtain a percentage, if desired).

The figure below is an example of a Burn probability map:
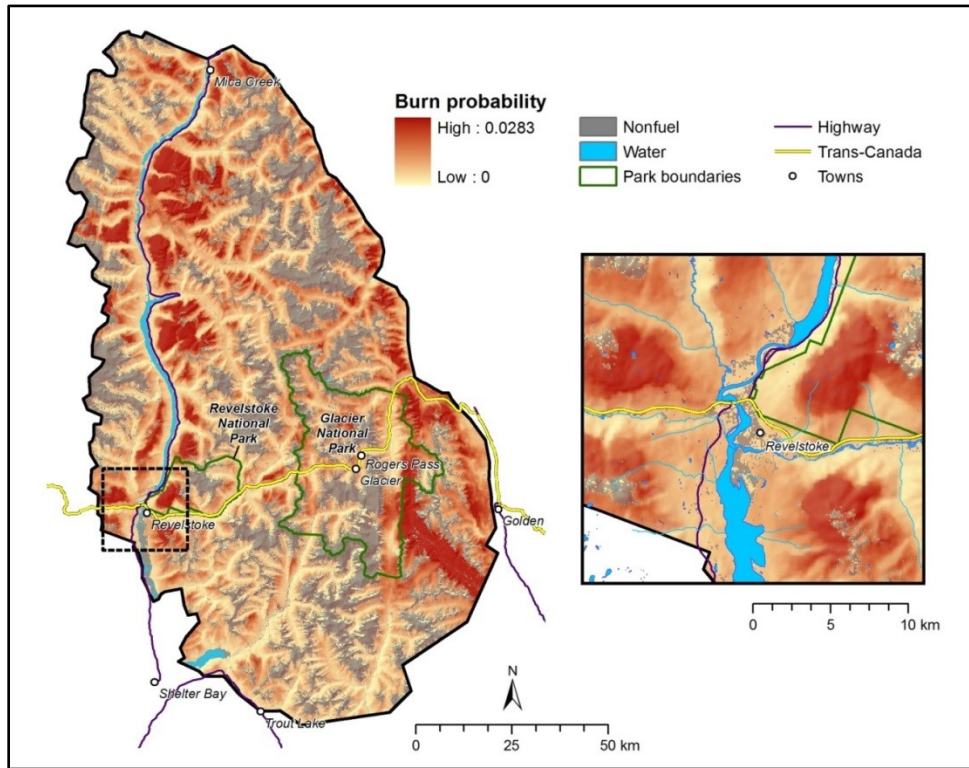
Burn probability map produced by Burn-P3

Statistics table

The other main output of Burn-P3 is the Statistics table. Each line in this table represents information pertaining to one simulated fire. This information is essential for the calibration of Burn-P3. The comparison between these statistics to historical (i.e., observed) distributions will help to modify inputs in order to obtain more realistic fire size distributions and burn probability patterns.

This output consists of information and statistics pertaining to every simulated fire. Each line represents a fire and contains the following information:

Column	Name	Type	Description
1	fire	integer	Fire number (an identification number for each fire)
2	iteration	integer	Iteration of the simulated fire
3	x_coord	integer	X coordinate (easting)
4	y_coord	integer	Y coordinate (northing)
5	cause	integer	Cause
6	season	integer	Season
7	zone	integer	Fire zone
8	wx_zone	integer	Weather zone*
9	sp_event	integer	Number of Spread-event days
10	hrs_burning	integer	Total number of hours of burning
11	ign_fuel	integer	Fuels in which the fire ignited
12	tot_ab	real	Total area burned (ha)
13	D-1/D-2	real	Area burned in D-1/D-2 fuel type (ha)
14	M-1/M-2	real	Area burned in M-1/M-2 fuel type (ha)
15	O-1a	real	Area burned in O-1a fuel type (ha)
16	FBP System fuel type n	real	...

*The Weather zones information is not used to determine ignitions; this input is used to link the ignition locations information to the Burning conditions module of Burn-P3.

From column 13 onwards, the number of columns in the Statistics table depends on the number of fuel types found in the FBP System fuels: only the fuel types present in this grid will be included in the output.

Burn-P3 log file

The list of inputs, outputs, and characteristics of the Burn-P3 run are written in a Burn-P3 log file as soon as Burn-P3 initiates simulation. This file is useful for replicating a Burn-P3 project, or verifying that all of the desired inputs have been properly included in a model run. Note that the Burn-P3 log file automatically takes the name and location of the Burn probability map output.

Specialized outputs

FBP System outputs

The Burn probability map only uses the burned/unburned information. However, it may be useful to some users to complement this information with fire behavior information, as computed by the Canadian Forest Fire Behavior Prediction (FBP) System.

Burn-P3 allows the user to record the FBP System components each time a pixel experiences a fire. This yields a distribution of values at any given pixel. From this distribution, summary statistics (mean, median, minimum, and maximum) can be calculated as well as user-specified percentile values, and the results are gridded to produce FBP System outputs. The percentile calculation method used is described here:
http://en.wikipedia.org/wiki/Percentile

It is also possible for the user to extract the raw data with which the FBP System outputs are produced. Each line of the raw data consists of a unique x and y location, followed value of the selected FBP System output. It is saved as a comma-delimited file (*.csv).

⚠ Note that the creation of FBP System outputs may be computationally intensive on some computers and more selected grids will require more processing time. Therefore, only the grids that will be useful to a given project should be selected.

This is an example of Fire intensity map produced with Burn-P3:
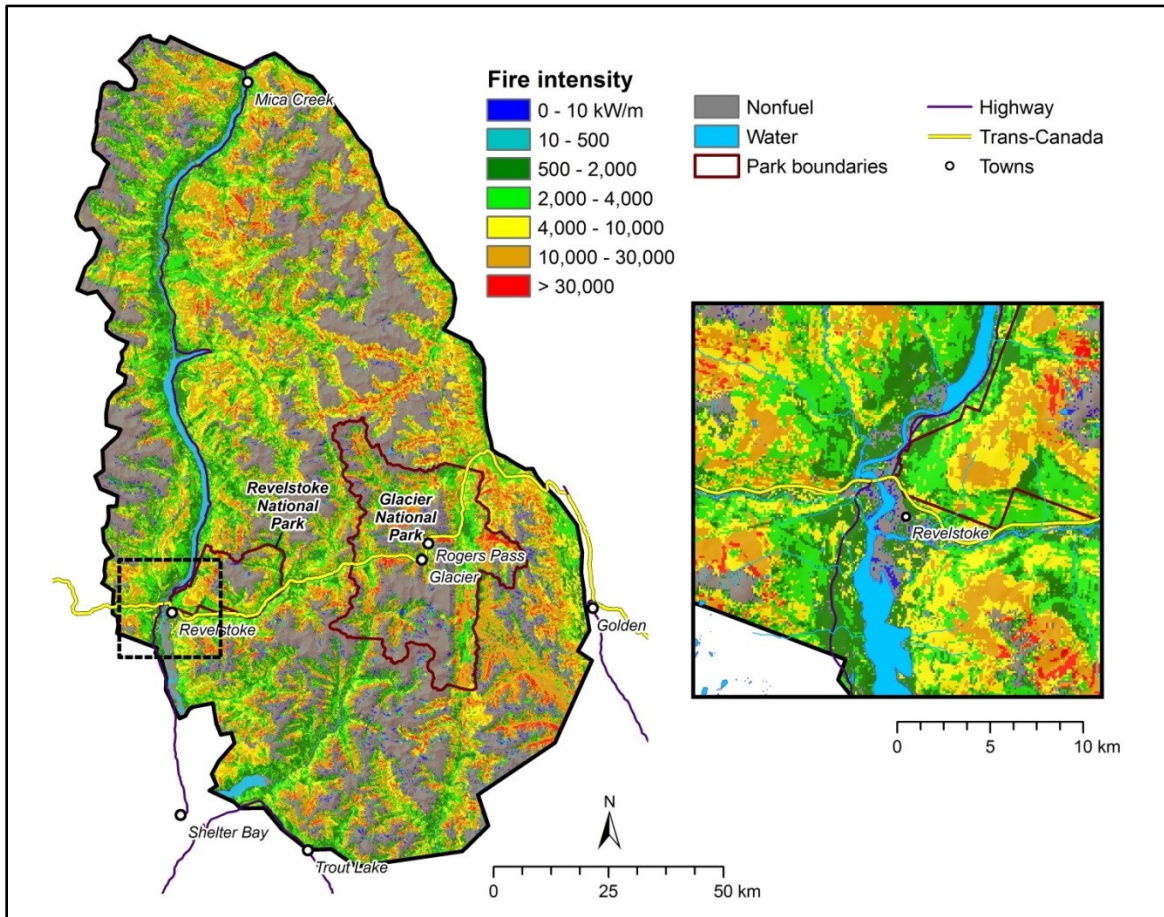
Fire perimeters

This output contains the Fire perimeter of each simulated fire in Burn-P3 compiled in a shapefile, which can be readily imported into GIS software. The attributes from the Fire statistics table will be attached to each perimeter. Lakes and other non-fuels are not included in the fire perimeters and therefore appear as holes.

This is an example of fire perimeters produced with Burn-P3:
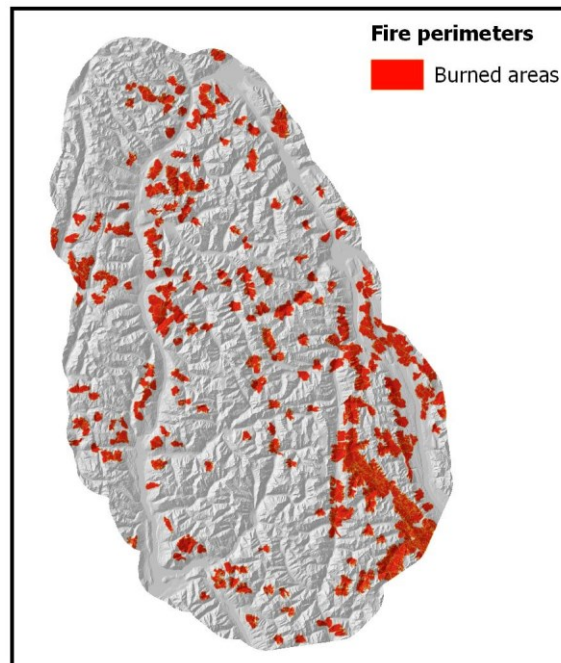
Burn iterations

The Burn iterations output is a raw data table (*.csv) listing the iterations in which each pixel burned. These data can be used to calculate fire frequency metrics.

The Burn iterations are presented as comma-delimited text file of raw data with the following information:

Column	Name	Type	Description
1	column	real	column number
2	row	real	row number
3	Iterations burned	integer	number of times this pixel burned

Replay ignition list

The purpose of the Replay ignition list is to re-run exactly the same ignitions as in the original run, while varying one or more of the other inputs and parameters. To use this feature, Burn-P3 has to be run twice. The ignitions simulated in the first run are used for a second run (or any number of subsequent runs).

If this option is selected, Burn-P3 will export a list (in CSV format) of ignition locations used in the run. This list can then be used as the Ignition location list in the Ignitions module to replay the run using exactly the same ignition locations.

The file contains the following information:

Column	Name	Type	Description
1	x_coor	real	Ignition X coordinate in map units (typically meters)
2	y_coord	real	Ignition Y coordinate in map units
3	wseed	integer	weather random number seed
4	sseed	integer	duration random number seed (duration and hours per day of burning)
5	season	integer	season identifier as defined in the dictionary

Only the ignition locations are saved directly. The fire weather, duration (number of days of burning), hours per day of burning, and season are saved by reference to the fire weather list, distribution of spread-event days, distribution of hours per day of burning, and the dictionary, respectively. When the Replay ignition list is used, it binds the location to the weather, burning days and hours, and season. Wseed and sseed are used to find the way back to the original weather and spread information. The season is stored as 1st, or 2nd, or 3rd, etc. entry in the dictionary. If a stored ignition location falls on an invalid fuel cell, all of its information is discarded and Burn-P3 moves on to the next location in the list. If it is valid, it burns with the same weather, burning days and hours, and season as in the first run.

⚠ Note that an Ignition location list that is not associated with the replay option does not have to contain all these fields. As explained under Ignition location list section, only x_coord and y_coord are required.

1. The replay ignition list includes "unsuccessful" ignitions, namely those that did not end up burning the minimum fire size, and so do not appear in the original run. The number of ignitions in the list may therefore exceed the number originally specified. However, if a different fuels map is used for subsequent runs, or different

weather is used, these fires may achieve the minimum size and therefore be included. Similarly, ignitions that "succeeded" in the original run, may not succeed in the replay.

2. If an ignition in the original run falls in non-fuel, it is not included in the replay list. Therefore even if there is fuel at that location in the subsequent run, no fire will ever start there.

3. If a different weather list is used for subsequent runs, it must have the same season identifiers as the original. If there are seasons that appear in the list that are then not found in the dictionary or the weather list, an error message will be displayed and processing will stop. If there are additional seasons in the weather list that are not found in the replay ignition list, no fires will burn in that season.

4. If a distribution of ignitions by season, cause, and fire zone was specified in the original run, it will be ignored in the replay, as is always the case when an ignition location list is used. The same is true of any ignition restrictions. Because some successful ignitions in the original run may be unsuccessful in the replay, and vice versa, the distribution of ignitions may not follow the originally specified distribution, and may violate the ignition restrictions originally specified.

5. The concept of an iteration is not present in the replay run, as is always the case with ignition location lists. This means that ignitions that originated from the same iteration can now burn over each other. In that case, the overlap area will appear as twice-burned in the replay run, and only once-burned in the original.

The replay option behaves differently from the redo option. Both will produce outputs identical to the original if all the inputs are identical, except when fires within one iteration burn the same area (see item 5 above). However, if for example the fuels map is different in the subsequent run, redo will attempt ignitions that fell in non-fuel in the original run, whereas replay will not. Redo will always deliver the number of fires requested. For example, if there are 30 one-fire iterations, redo will stop after 30 fires. If additional fires are successful, an equivalent number will be dropped at the end. If fewer fires are successful, additional ignitions at new locations will be attempted at the end, until there are 30 successful fires. In contrast, replay will run through the list of ignitions provided and then stop, regardless of how many are successful. (Here "successful" indicates ignitions that result in fires greater than the minimum fire size.)

Both replay and redo are unrelated to the replication function in the tools menu. Replication uses a new set of

random ignition locations, weather, duration, and hours per day of burning for each replicate, if the user has selected random ignitions and distributions for these inputs.

Section 3: Menu items

File menu

Import/export BP3T

There are two ways of saving project in Burn-P3. The first way is to save the project in a *.BP3 file. This file type does not save the external inputs that have been imported in Burn-P3, but rather uses pointers (directory paths) to locate them. The advantage of saving a project as a *.BP3 file is that it produces a very small file. However, the project can only be transferred and used on a different computer if the file architecture is identical to that of the saved project file.

As an alternative to the *.BP3 file, the user can export a Burn-P3 project in a *.BP3T file (the 'T' is for 'transport'). This file type saves all of the files used in a Burn-P3 project. Therefore, it has the convenience of being fully "transportable" from one computer to the next. However, the user should be cautious when exporting a project as a *.BP3T file, because the file can be very large.
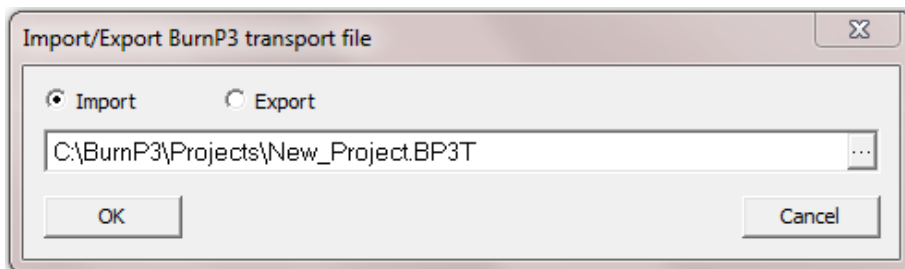
The Batch run function

Many applications of Burn-P3 require the production of several Burn probability maps. Therefore, a batch process is included in Burn-P3 whereby the user can provide the software with a list of Burn-P3 projects that should be run in a sequence.

Each run of the batch consists of a saved Burn-P3 project (*.bp3).The batch runs are included in a text file that simply lists the projects, including their directory, as follows:

```
C:\BurnP3\Projects\Project_1.bp3
C:\BurnP3\Projects\Project_2.bp3
C:\BurnP3\Projects\Project_3.bp3
C:\BurnP3\Projects\Project_4.bp3
C:\BurnP3\Projects\Project_5.bp3
```
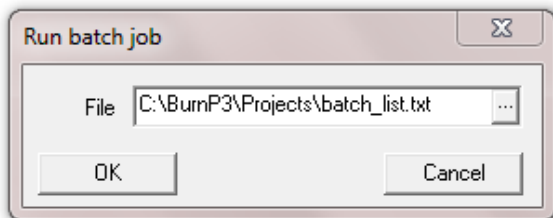

The batch file is imported through the File menu / Batch run…

If a project in the list crashes, the batch run is not interrupted but simply moves on to the next item on the list. We thus strongly recommend using the Auto-save option so that at least part of the run that crashed will have been created. Note that Burn-P3 does not alert the user if one or more runs of the batch were not completed. It is up to the user to determine if all runs were completed; this is easily done by looking at the log file for each run, or by looking at the Statistics table, which lists all of the simulated fires.

Tools menu

Process control

This tool gives the user the flexibility to control process threading in Burn-P3.

Use fewer processes

This option allows Burn-P3to use a single thread and no Prometheus multithreading.

Use the normal number of processes

This option (default setting) means that Burn-P3 will use one thread for every two GB of memory. If there are more processors than threads, those excess processors are used for multithreading the Prometheus fire growth model processes.

Use lots of processes

This option allows Burn-P3 to use one thread for every GB of memory. As with use the normal number of processes, if there are more processors than threads, those excess processors are used for multithreading the Prometheus fire growth model processes. Although most computers will be able to handle this level of use, the user is advised to initially monitor CPU temperatures when using this option because excessive CPU temperatures can cause damage to the computer.

⚠ CPU temperatures can be monitored with tools such as this one: www.alcpu.com/CoreTemp/

Replication

The replication tool allows the user to run the currently specified run multiple times. The results will not be identical because each run has a different random number seed. The purpose of this tool is to provide a measure of the variation in burn probability values and patterns given the same inputs. Separate output files are generated for each replication based on the output file names specified. For example, if the burn probability map is bp.asc, the replication tool will save bp_1.asc, bp_2.asc, and so on. The tool will also produce separate log files, statistics tables, and FBP System outputs.

The replication function differs from the Redo the last run function, which re-uses the random numbers from the previous run. For example, Redo the last run will use the same ignition locations and the same weather as the previous run.

Section 4: Troubleshooting

Problem	Error location	Solution
Error message saying that the grids do not have the same resolution or extent	• Landscape/ Mapped inputs • Ignitions module	It is essential that all grids imported in Burn-P3 overlap perfectly, they must have the same spatial extent, the same projection, and the same resolution (i.e., pixel size). This and the following error are the most common problems when building a Burn-P3 project.
Error message saying that a value found in the FBP System fuel grid is not found in FBP System fuel lookup table	• Landscape/ Mapped inputs	Every numeric value of an FBP System fuel grid must have a corresponding value in the FBP System fuel lookup table. However, the FBP System fuel lookup table may have values that are not found in the FBP System fuel grid.
Error message saying values of the Fire zones or Weather zones are invalid	• Landscape/ Mapped inputs	This occurs if a value of the Fire zones or Weather zones grid does not match those specified in the Dictionary.
Non-random Ignition grids were not specified for each combination of cause and season	• Ignitions module	When specifying non-random Ignition grids in the Ignitions module, if a grid is not specified for a given combination of cause and season, Burn-P3 will assume its ignitions are random. No warning is provided.
Error message saying that values in the Distribution of ignitions by season, cause, and fire zone are invalid	• Ignitions module	Ensure that the numeric codes of the Distribution of ignitions by season, cause, and fire zone match those defined for the causes, seasons, and Fire zones (optional) specified in the Dictionary.
Error message saying that values in the Fire weather list are invalid	• Burning conditions module	Ensure that the numeric codes of the Fire weather list match those defined for the seasons and Weather zones (optional) specified in the Dictionary. Remove all daily fire weather records that have missing values or unrealistic values (e.g., -9999) for any of the Fire weather list components.
Burn-P3 tries to simulate fires, but after a few minutes produces an error message saying that Burn-P3 has exceeded the number of trials for simulation	• Burning conditions module	In the Fire weather list, only use daily fire weather conditions that are conducive to fire spread. If no spread is possible for most of the daily records provided, Burn-P3 will exceed the number of trials for simulating a fire. This error often occurs when a user uses a database of daily fire weather for all days to build a Fire weather list, rather than one that contains only days of high or extreme fire danger.
The simulated distribution of fire sizes is substantially different from the distribution of observed fire sizes	• Burn-P3 outputs	Almost all of the inputs can contribute to this problem. However, two of them are particularly influential: (1) the Number of hours per day of burning and (2) the Distribution of spread-event days. As a first step, these inputs can be adjusted to fix (at least partly) the problem.

Problem	Error location	Solution
The shapes of simulated fires are substantially different than those of the observed fires	• Burn-P3 outputs	Many inputs can cause this problem. However, the most likely reason for this problem is that the simulated fire weather is not representative of realistic burning conditions. One way to fix this is to ensure that the temporal patterns in fire weather conditions are modeled by using the "Sequential" selection method in the Burning conditions module.
Burn-P3 runs using the same inputs produce substantially different burn probability patterns	• Burn-P3 outputs	This is likely due to an insufficient number of iteration in the Burn-P3 simulation window. If this is the case, more iteration must be simulated to obtain a stable Burn probability map (i.e., one that produces consistent outputs for a given set of inputs).
There appears to be an edge effect around the study area	• Burn-P3 outputs	To remove the edge effect, a buffer must be incorporated around the study area for which the user wants to produce a Burn probability map. This is a major problem that may require re-doing the run after modifying all grids imported to Burn-P3.
The simulated burn probability patterns do not match what is expected in the study area	• Burn-P3 outputs	The only way to fix this problem is to ensure that the inputs are properly capturing patterns of fire ignition and spread. A common error is to set a fairly large minimum fire size (e.g., 200 ha) but to use smaller fires to determine seasonal and spatial patterns of ignitions. In most of Canada, areas of high fire occurrence (e.g., where there are a lot of people) rarely, if ever, correspond to the highest rates of area burned.
The burn probability seems over-estimated in the grass (O-1) fuel type	• Burn-P3 outputs	Agricultural lands are often mistakenly classified as the O-1 fuel type, even though they burn either marginally or not at all. If it is impossible to fix the FBP System fuel grid, a quick fix is to reduce the grass curing. Even if these curing values are artificially low, this will lead to more realistic fire spread.
It is difficult to combine Burn probability maps that use the same inputs (i.e., "partial" maps) but have different numbers of iterations	• Burn-P3 outputs	Unless the user is confident that Burn-P3 will not crash, it is strongly recommended to toggle the "Integer" option in the "Format of the burn probability map" section of the Burn-P3 simulation window. It is much easier to add integer grids and divide them by the total number of iterations (to obtain a probability) than to re-weight "Percentage" grids that used different numbers of iterations.

Resources

The Canadian Forest Fire Weather Index (FWI) System:

Van Wagner, C.E. 1987. Development and structure of the Canadian Forest Fire Weather Index System. Forestry Technical Report 35. Canadian Forest Service, Ottawa, ON. 48

The Canadian Forest Fire Behaviour (FBP) System:

http://cwfis.cfs.nrcan.gc.ca/background/summary/fbp

Forestry Canada Fire Danger Group. 1992. Development and structure of the Canadian Forest Fire Behaviour Prediction System. Forestry Canada, Fire Danger Group and Science and Sustainable Development Directorate, Ottawa 64 p.

Hirsch, K.G. 1996. Canadian Forest Fire Behavior Prediction (FBP SYSTEM) System: user's guide. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. Spec. Rep. 7.

FWI System and FBP System calculators:

REDapp: The Universal Fire Behaviour Calculator: http://redapp.org/

The fwi.fbp R package: Fire Weather Index System and Fire Behaviour Prediction System Calculations:
https://cran.r-project.org/web/packages/fwi.fbp/index.html

The Canadian Forest Service National Fire Database (NFDB)

Download: http://cwfis.cfs.nrcan.gc.ca/ha/nfdb

Parisien, M.A., Peters, V.S, Wang, Y., Little, J.M., Bosch, E.M., Stocks, B.J. 2006. Spatial patterns of forest fires in Canada 1980-1999. Int. J. Wildland Fire 15: 361-374.

Stocks, B.J., Mason, J.A., Todd, J.B., Bosch, E.M., Wotton, B.M., Amiro, B.D., Flannigan, M.D.,Hirsch, K.G., Logan, K.A., Martell, D.L., Skinner, W.R. 2002. Large forest fires in Canada, 1959–1997. Journal of Geophysical Research 107: 8149 <doi:10.1029/2001 JD000484>

The Prometheus fire growth model

Download: http://firegrowthmodel.ca/prometheus/overview_e.php

Tymstra, C., Bryce, R.W., Wotton, B.M., Taylor, S.W., Armitage, O.B. 2010. Development and structure of Prometheus: the Canadian Wildland Fire Growth Simulation Model. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. Information Report NOR-X-417. 102 p.

Burn-P3: software, user documentation, and test database

Download: http://firegrowthmodel.ca/burnp3/software_e.php
https://www.ualberta.ca/~wcwfs/burn-p3-en.html

Burn-P3: Peer-reviewed scientific journals

Beverly, J.L., Herd, E.P.K., Conner, J.C.R. 2009. Modeling fire susceptibility in west central Alberta, Canada. Forest Ecology and Management 258: 1465–1478.

Braun, W.J., Jones, B.L., Lee, J.S.W., Woolford, D.G., and Wotton, B.M. 2010. Forest Fire Risk Assessment: An Illustrative Example from Ontario, Canada. Journal of Probability and Statistics, Article ID 823018, 26 pages <doi:10.1155/2010/823018>

Parisien, M.-A., Junor, D.R., Kafka, V.G. 2007. Comparing landscape-based decision rules for placement of fuel treatments in the boreal mixedwood of western Canada. International Journal of Wildland Fire 16: 664-672.

Parisien, M.-A., Miller, C., Ager, A.A., Finney, M.A. 2010. Use of artificial landscapes to isolate factors controlling spatial patterns in burn probability. Landscape Ecology 25: 79-94.

Parisien, M.-A., Parks, S.A., Miller, C., Krawchuk, M.A., Heathcott, M., Moritz, M.A. 2011. Contributions of Ignitions, Fuels, and weather to the burn probability of a boreal landscape. Ecosystems 14: 1141–1155.

Parisien, M.-A., Walker, G.R., Little, J.M., Simpson, B.N., Wang, X., Perrakis, D.D.B. 2013. Simulation modeling of burn probability in ecologically complex landscapes: a case study from the interior rainforest of British Columbia, Canada. Natural Hazards (Online First)

Parks, S.A., Parisien, M.-A., Miller, C. 2012. Spatial bottom-up controls on fire likelihood vary across western North America. Ecosphere 3:art12.

Wang, X., Parisien, M.A., Taylor, S.W., Perrakis, D.D., Little, J., Flannigan, M.D., 2016. Future burn probability in south-central British Columbia. International Journal of Wildland Fire. International Journal of Wildland Fire 25(2): 200-212

Whitman, E., Rapaport, E. and Sherren, K., 2013. Modeling fire susceptibility to delineate wildland–urban interface for municipal-scale fire risk management. Environmental management, 52(6), pp.1427-1439.

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Parisien, M.A., Hirsch, K.G., Lavoie, S.G., Todd, B.M., Kafka, V.G. 2004. Saskatchewan fire regime analysis. Canadian Forest Service Information Report NOR-X-394.

Parisien, M.-A., Kafka, V.G., Hirsch, K.G., Todd, B.M., Lavoie, S.G., and Maczek, P.D. 2005. Mapping fire susceptibility with the Burn-P3 simulation model. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta, Information Report NOR-X-405.

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Burn-P3: Conference Proceedings

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Parisien, M.-A., Junor, D.R., Kafka, V. 2006. Using landscape-based decision rules to prioritize locations of fuel treatments in the boreal mixedwood of western Canada. 2006. Pages 221-236 in P.L. Andrews and B.W. Butler, compilers. Proceedings RMRS-P-41: Fuels Management-How to Measure Success, March 28-30, 2006, Portland, Oregon, USA. USDA Forest Service, Fort Collins, Colourado, USA.

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