

**Fighting Fire with Fire: A Matrix-Based Approach for HRB vs.
Logging Allocation and Fire Spread Minimization**

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Problem 2: Bushfire Prevention

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The 2019-20 Black Summer Fires have proven to be one of the most devastating natural disasters in NSW's history. With our increasing population and the inevitable effects of climate change, how can NSW better prevent future bushfires?

Our team has developed a model for understanding the areas of NSW that can better respond to either logging or hazard response burning (HRB), which are two popular fire management techniques that involve the cutting of trees or planned burning forested areas, respectively. We based our model off of five key environmental factors extracted from current NSW geographical data: wind speed, humidity, temperature, rainfall, and foliage projection cover (the density of vertical foliage in a given area). With this data, we mathematically mimicked the effects of logging and HRB in terms of immediate changes in temperature and tree density to understand large-scale forest changes over time as a result of our prevention techniques. Finally, using established criteria known to start bushfires, we sought to optimize an ideal combination of HRB to logging that would minimize the fire spread in high-risk bushfire areas, both in terms of the intensity of the given areas and the number of areas susceptible to fire.

Our results have produced a grid-representation of NSW that delineates the area regions that are most suitable for HRB, logging, or preventative action. Although, due to time constraints, we were unable to simulate multiple HRB/logging combinations, our current version finds that the average velocity in areas with high fire-potential would be 0.1875 km/hr and the overall fire velocity across all NSW regions is a mere 0.01148 km/hr. We are excited to continue improving this model and build upon its current drawbacks in hopes of creating a safer and healthier NSW.

1. Introduction

The 2019-20 “Black Summer Fires” of New South Wales (NSW) was the most catastrophic fire season in Australia’s history. By March 2020, the fires destroyed over 3,000 houses, killed 33 people and over 1 billion animals, and burnt almost 19 million hectares (Filikov et al 2020). The damage from the fires, along with increasing medical, environmental, and insurance costs, have resulted in an estimated 110 billion dollar loss in the NSW economy (Deb et al. 2020). Although bushfires have long been a part of NSW’s natural landscape, its growing urbanized population, combined with more frequent and severe drought due to climate change, pose an immediate threat to NSW’s citizens and forests.

The Australian Capital Territory (ACT) Government has implemented numerous collaborative policies within NSW fire and emergency services agencies to mitigate the risks and impacts of bushfires. Namely, the ACT Government seeks to utilize hazard response burning (HRB), using a dynamic evidence-based approach to determine location, timing, and intensity of fuel-reduction activities (Amundson et al. 2016). HRB is a planned or “prescribed” burning of a certain forest region to reduce fuel buildup and reduce the severity of future fires. NSW fire management protocols further involve logging or thinning. However, despite the approximate 18 billion dollars spent in fire prevention techniques such as hazard response burning (HRB) and logging, bushfires continue on the rise (Ashe, de Oliveira, & McAneney 2012).

In this report, we propose a model for the selective use of HRB and logging in an array model of NSW. Drawing upon principles in image processing, linear transformations, ecological data, and existing research in bushfire management, our model intends to minimize average fire spread at potential bushfire hotspots following forest recovery from bushfire management techniques.

2. Methods

2.1 General Approach

In solving this problem, we decided to take a reverse approach in first understanding where logging and HRB can be used and translating this information into an optimization model for fire spread. Much of our model utilizes principles in linear algebra, in that we described large-scale geographical changes with simple linear transformations from matrix representations of New South Wales. Figure 1 outlines our overall plan for the methodology.

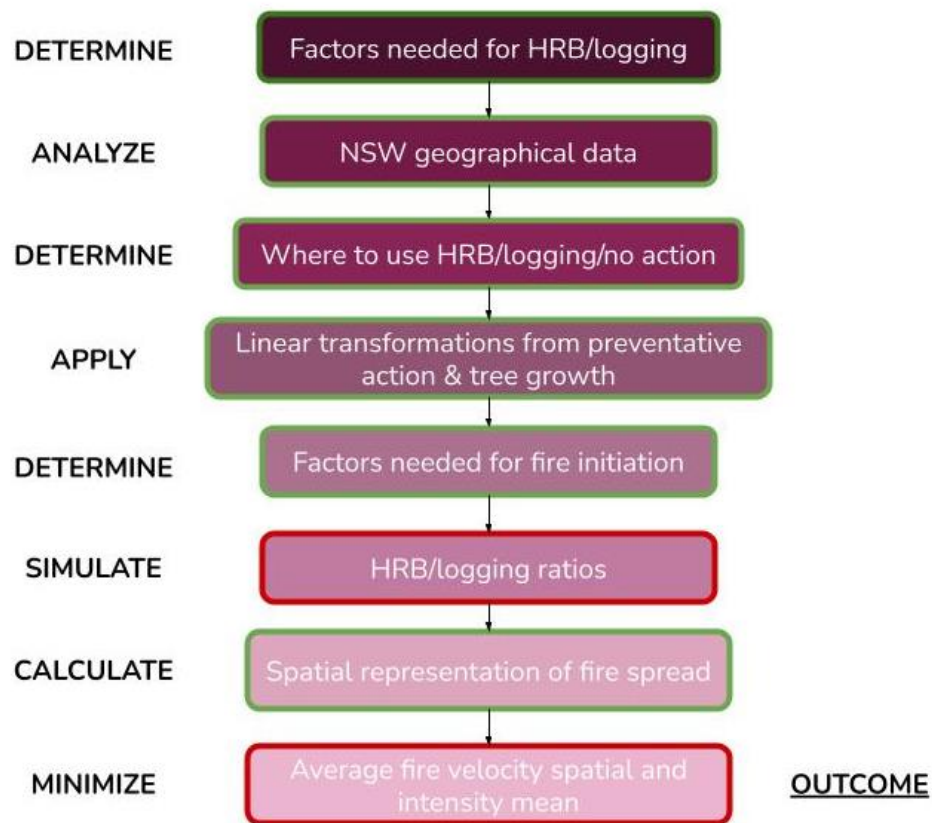


Figure 1. General reasoning process. Boxed outlines in green are completed or mostly completed steps; boxed in red are incomplete steps.

2.2 Variables and Assumptions

We classify criterion variables, input variables, constants, and output variables. Criterion variables are designated as factors contributing to bushfires and specific designations for HRB. Input variables are used to determine the optimum ratio for reducing bushfire severity. Output variables are being measured from manipulating input variables into pre-existing equations.

Criterion Variables:

- Humidity ($\text{g} * \text{kg}^{-1}$, %)
- Wind velocity (km/hr)
- Temperature ($^{\circ}\text{C}$)
- Tree density (FPC, %)
- Rainfall ($\text{mm} * \text{month}^{-1}$)

Input Variables

- HRB (FPC, %)
- Logging (FPC, %)

Output Variables

- Fire velocity (km/hr)
- Fire velocity intensity mean (km/hr, the sum of fire velocity entries divided by nonzero entries)
- Fire velocity spatial mean (km/hr, the sum of fire velocity entries divided by all entries)

Constants

- Climate change ($^{\circ}\text{C}/\text{year}$)
- Average forest density change ($\%/ \text{year}$)
- The decision for logging only depends on the FPC of trees in a given area, and is independent of temperature, wind speed, and humidity.

Assumptions and Definitions

- We will consider all vegetation to function as a single group such that individual differences among plant species don't affect its ability to generate, sustain, or spread fire. In this manner, the forest growth rate can be generalized to all areas of non-negligible FPC (see 2.4).
- We will assume to have “unlimited” funding and labor available for HRB and logging
- All trees are cut “instantaneously” or in a negligible time period, and all cut/burned trees are removed from the forested area (i.e. no fallen stalks).
- All fires are the result of natural and not human causes (i.e. dropped cigarette, stove fire, arson, etc.).
- Since bushfires and forest fires occur in the same manner and spread the same way, we can use them interchangeably for this context.
- All HRB happens only once to each region.
- Since logging is a more selective process, we will assume that a logged region will reduce the FPC to the threshold level 0.45.
- Fire severity will be measured as the rate of fire spread, because the faster a fire moves, the more area it covers, the harder it is to extinguish, and the more dangerous it becomes.

2.3 Criteria

2.3.1 When to use HRB vs. Logging

Figure 1 provides a visual representation of our HRB vs. logging decision model. HRB is a dangerous process that requires very specific weather conditions so as to prevent larger and more severe fires. Previous research and practice have determined optimal ranges for humidity (30-55%), wind speed (8-16kph), temperature (<15 C), and foliage projection cover (45%)

(Prescribed-Fire 2020, Auburn University n.d., Coppin, Ayote & Steggel 2003, Song & Lee 2016). Foliage projection cover (FPC) is the percentage of ground area occupied by the vertical projection of foliage, such as trees and upright bushes. However, we modified a few of our optimal ranges of ease of model creation, which can be found in Figure 2.

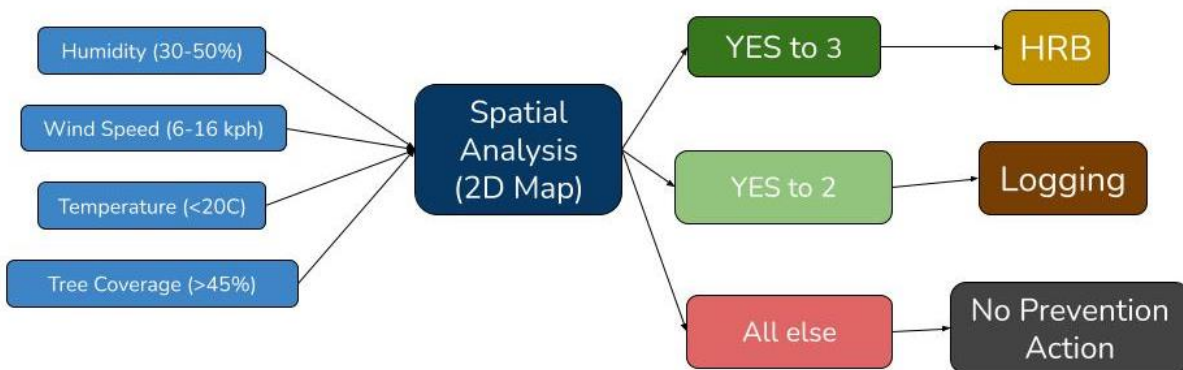


Figure 2. Schematic diagram of HRB vs. logging use selection criteria

2.3.2 What starts a fire and how does it spread?

Although a fire ignition can be a rather spontaneous, erratic process, especially in the case of natural bushfire, we found that regions with rainfall values that exceed $150 \text{ mm} \cdot \text{month}^{-1}$, temperatures ranging from 30 to 32.5 C, and humidity content from 20-45% have been shown to have the highest likelihood in fire initiation (Clark 2020). These served as our fire ignition conditions, from which we were able to calculate fire spread (see 2.4.2).

Fire spread was modeled by the equation:

$$R = (2.518 \times U) / (60 - T + H)$$

where R is the rate of fire spread in (km/hr), U is the wind speed (km/hr), T is the temperature (C), and H is humidity (%) (Indigenous Knowledge Institute n.d.).

3. Results

3.1 Image Processing and Factor Matrices

We acquired geographic distribution maps for humidity (%), wind velocity (km/hr), temperature (C), and foliage projective cover (%), from which we developed a series of cropped, linear grids with the origin set at the top left corner of NSW bordering Queensland and South Australia (Australian Government Bureau of Meteorology 2016, Fisher et al. 2016). By implementing Matplotlib, PIL, numpy, and Image packages on Python, we converted each overlaid image into an array, and determined the range of indices where the black vertical and horizontal grid lines start and end. Then, iterating through the entire numpy array, we averaged the RGB values of all the pixels within the boundaries of the grid lines, or in each cell, by their corresponding red, green, and blue components. Each averaged RGB value became an element of a 14 by 14 matrix, with each element corresponding to a cell in the image, and subsequently compared to the RGB value associated with the colorized levels in the meteorological dataset (Figure 3).

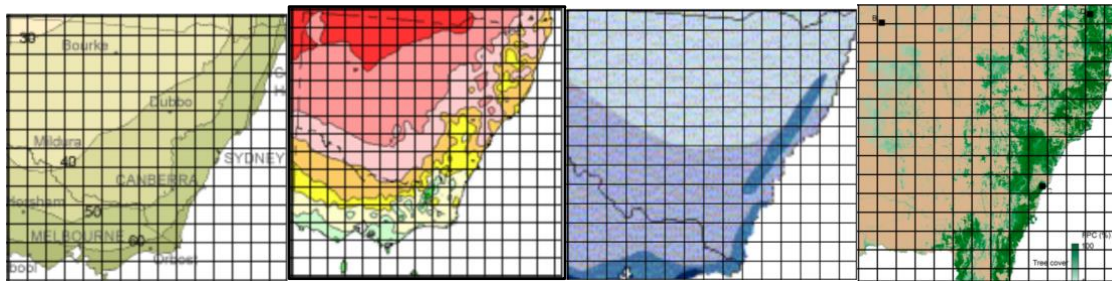


Figure 3. Grid representations of geographical data for humidity, temperature, wind speed, and FPC (from left to right)

The error between the two was calculated by their red, green, and blue components, and then averaged across the three. Based on the distribution of the errors for each comparison, we chose different thresholds to decide whether or not the conditions to apply fire prevention methods are met. Our error thresholds for humidity, temperature, wind speeds, and forest density, are 0.05, 0.05, 0.3, and 0.7, respectively. We adjusted the error while considering the

algorithm’s difficulty in differentiating between certain colors (i.e. light colors and white backgrounds), the large range that an RGB component value can cover (0-255), and ability to visually match the geographic maps. Each condition would then produce a 14 by 14 matrix with values 0 or 1: 1 if the condition is met, 0 if it is not.

3.2 Transformations

3.2.1 Fire Prevention Transformation

The four matrices for humidity, temperature, wind speed, and forest density were added to produce our factor matrix for fire prevention. Entries ranged from 0 to 3, where either no conditions were met or at least 3 conditions were satisfied (Figure 4). As HRB is the more effective and environmentally-wary fire prevention method, as well as the method with the greater number of requirements, for our first mix we decided to assign any entry with the value 3 to HRB, and any entry with the value 2 to logging. Recognizing that both HRB and logging are ultimately detrimental for forest health, we did not oversaturate our matrix and selected sparingly. We then created a fire prevention matrix, which consisted of “N/A,” “LOG,” and “HRB” according to the aforementioned procedure (Figure 5). The preventative action matrix is likewise a 14 by 14 array that corresponds to the cells of the modified NSW maps.

```
[1, 2, 1, 1, 1, 1, 1, 1, 2, 1, 0, 0, 0, 0]
[2, 2, 1, 1, 1, 1, 1, 1, 1, 2, 0, 0, 0, 0]
[1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 0, 1, 0, 1]
[1, 1, 1, 1, 1, 1, 1, 1, 0, 2, 1, 1, 0, 1]
[1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 1, 1]
[1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 1]
[1, 1, 1, 1, 1, 1, 1, 2, 1, 1, 1, 1, 1, 1]
[1, 1, 1, 2, 1, 1, 1, 1, 2, 0, 1, 1, 1, 1]
[2, 1, 1, 1, 1, 2, 3, 2, 3, 1, 3, 1, 1, 2]
[1, 1, 1, 1, 1, 1, 2, 1, 1, 2, 1, 2, 1, 1]
[1, 1, 1, 1, 1, 1, 1, 1, 2, 1, 1, 0, 1, 1]
[1, 1, 1, 2, 2, 2, 2, 1, 1, 1, 0, 0, 0, 0]
[2, 2, 3, 3, 2, 2, 2, 0, 1, 0, 0, 0, 0, 0]
[2, 2, 2, 2, 2, 1, 0, 0, 1, 0, 0, 0, 0, 0]
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Figure 4. Matrix representing number of satisfied criteria

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['N/A', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A']
['LOG', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A']
['N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A']
['N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A']
['N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A']
['N/A', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'LOG', 'N/A', 'N/A']
['N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A']
['N/A', 'N/A', 'N/A', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A']
['LOG', 'N/A', 'N/A', 'N/A', 'N/A', 'LOG', 'HRB', 'LOG', 'HRB', 'N/A', 'HRB', 'N/A', 'N/A', 'LOG']
['N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'LOG', 'N/A', 'N/A', 'LOG', 'N/A', 'LOG', 'N/A', 'N/A']
['N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A']
['N/A', 'N/A', 'N/A', 'LOG', 'LOG', 'LOG', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A']
['LOG', 'LOG', 'HRB', 'HRB', 'LOG', 'LOG', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A']
['LOG', 'LOG', 'LOG', 'LOG', 'LOG', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A', 'N/A']

```

Figure 5. Preventative Action Matrix

The purpose of creating a fire prevention matrix is to record the action applied to the forest, and to shift the temperature and FPC values according to type of prevention. If the forest is burned, we reduce the parallel cell in the foliage projection cover matrix by 5% (Lorber, Thomas-Van Gundy, & Croy, 2018) and thus increase the corresponding temperature cell by 0.35 degrees celsius (Rogan, Ziemer, Martin, Ratick, Cuba, & DeLauer, 2013). If the forest is logged, we reduce the cell to 45% (Song & Lee 2017), and increase the temperature based on how much the logging decreased the FPC value (Rogan, Ziemer, Martin, Ratick, Cuba, & DeLauer, 2013). The transformed FPC matrix allows us to appropriately simulate the effect of fire prevention methods on surrounding area temperatures, as reducing tree coverage would increase exposed land surface area and reduce transpiration (National Wildlife Federation, 2021). Therefore, cells that had prevention methods applied would also have a greater fire intensity in later computations, demonstrating the phenomenon that regenerated forests experience more severe fires when we calculate fire ignition (Figure 6).

3.2.2 Forest Growth Transformation

Before applying our modified factor matrices to determine the criteria for fire ignition, we first considered forest regeneration over the span of five years. We assumed that forest

growth is linear and at a rate of 2% per year (Hanscom, Wackernagel, Lin, & Kirsch-Posner, 2020). The transformation consists of a 10% addition to each cell of the FPC matrix.

3.3 Fire Velocity

With the temperature matrix adjusted for the effect of logging and HRB, a rainfall matrix, and a humidity matrix, we created another 14 by 14 matrix that consisted of 0 and 1 entries: 1 if the conditions to start a bushfire from section 4.3.2 are satisfied, 0 if they are not. We chose to use an additional rainfall matrix rather than our original FPC matrix after applying natural forest growth because pre-bushfire rainfall is tightly linked to fire intensity, and is directly related to plant growth and thus fuel necessary for fire ignition. Then, with the modified temperature matrix, the humidity matrix, and the wind speed matrix, we calculated the rate of fire spread for any cell that satisfied all fire ignition conditions with the equation mentioned in section 2.3.2 (Figure 7).

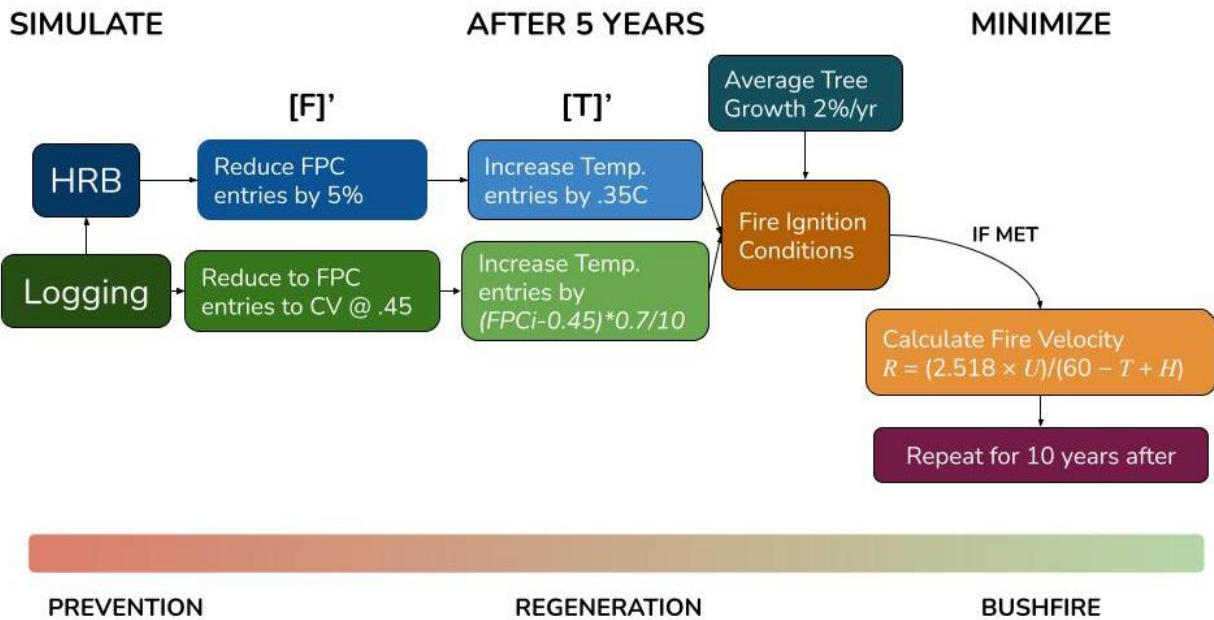


Figure 6. Optimization Algorithm for fire spread

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[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.1481176, 0.0]
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.1736552, 0.0, 0.0]
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.1736552, 0.1481176, 0.0, 0.0]
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.1481176, 0.0, 0.0, 0.0, 0.0, 0.0]
[0.0, 0.2560678, 0.2560678, 0.0, 0.0, 0.0, 0.145971, 0.145971, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
[0.0, 0.0, 0.0, 0.0, 0.2189565, 0.2189565, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.2169131, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]
[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]

```

Figure 7. Fire Velocity Matrix (km/hr)

3.4 Resulting Averages

The resulting matrix was then averaged in two ways: 1) the fire velocity values were added and divided by the number of cells with fire existence, giving the fire velocity intensity mean 2) the fire velocity values were added and divided by the total number of cells (i.e. 14^2), giving the fire velocity spatial mean. This allows differentiation between the average magnitude of the fire velocity values and the overall severity of the fire in the context of the NSW map. The

final fire velocity intensity that we obtained by the specific combination of HRB and logging methods derived in section 2.4.1 is **0.1875 km/hr**, and the final fire velocity spatial mean is **.01148 km/hr**.

4. Discussion

We've developed a decision algorithm that utilizes the conditions for fire prevention and topological data to determine the more efficient prevention method, HRB or logging, in a given area. Our model found that coastal regions were the prime fire prevention regions and given additional time, we would aim to find the optimal mix of logging and HRB that would best minimize fire spread both in terms of intensity and spatial area.

4.1 Strengths & Weaknesses

In appreciating its strengths, our current model is built off of relevant and previously recorded geographic data which are significant in causing bushfires. The locations for where fire prevention conditions are met based on our decision criteria are lined up to previous data for where fires began along the east coast. Additionally, although perhaps too over-generalized, our model simulates the effects of HRB and logging as linear functions, which may mathematically demonstrate why logging and HRB in general are considered to be ineffective in the long run. As the reduction in tree density has an inversely proportional relationship with the temperature of that area, logging and HRB in unideal proportions may have minimal or even adverse effects, and lead to more fires (Foley, 2020).

Our biggest challenge with this model was the grid representation of the geographic data. We ran into numerous errors in the computer program which attributed values to areas without color (i.e. the ocean represented as the white image background) and areas with color were often

not assigned a value. As a result, when manipulating the matrices, the compilation of values would differ from the expected value, producing a high error value. Error can also be attributed to the words on graphs being of different color which would provide a value when analyzed by the algorithm. Since the graphs were also of different scales as they came from multiple sources, they were not uniformly lined up when overlaid.

Our decision algorithm for HRB over logging use attributed binary values to the regions that met the criteria. However, in applying our linear transformations, we needed to calculate the exact quantity of each grid cell. Due to the faultiness of our algorithm for even binary detection, we manually created our datasets for wind speed, humidity, FPC, temperature, and rainfall using the images as a guide. This led our datasets to be highly susceptible to human error, and broke out the connection of the fire spread model with the HRB/logging decision model. Furthermore, the lack of time prevented our ability to account for other important variables, such as elevation, which has an immense influence on fire speed, and limited us in analyzing fire spread only spatially rather than temporally as well (Hayes 1942).

The equation for fire spread is an oversimplified model and only one example of the numerous models that factor in additional atmospheric and biophysical conditions we were unable to find with current data. The rate of fire spread is extremely variable and reliant on a multitude of factors. Recent studies say that one may estimate a 2.5 km/h wildfire spread rate for a wind speed of 25 km/h, while also stating that rates of fire spread and corresponding wind speeds ranged from 0.8-8.0 km/h and 30-100 km/h, respectively (Cruz, Alexander, 2021). Taking into account that our wind speed map was averaged over a long period of time and over a large area, and thus presented a very low range of wind speeds (0-10 km/h), our resulting means for fire velocity is appropriately small. In reality, the application of fire prevention methods prior to

fire ignition should indeed reduce the severity of future fires, even with the implied condition of weak, regenerated forests. Furthermore, a fire will not stretch across the entirety of NSW (as determined by our own defined criteria), and will appear in more local areas, thus driving our spatial mean down to very low levels.

4.2 Future Improvements

Many of the weaknesses described above can be drastically improved with more precise datasets, still using a similar colorimetric scale for representing different quantities. This would ensure a more accurate reading of the spatial differences in geographic data among NSW's multiple regions. We would also hope to factor additional variables such as elevation, individual terrain differences, and proximity to water sources, as well as factor in more concisely the temporal component of fire management. It is also important to consider that HRB and logging are not recommended practices, so it would be helpful to consider other methods of fire management to use in conjunction with HRB and logging.

Our current solution is a guide to fire prevention, however, further action needs to be taken to account for other fire prevention strategies and climate change action to approach the issue of bushfires in a more holistic and sustainable manner.

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5. Appendix

Code for grid production (applied to humidity, rainfall, temperature, foliage coverage, and wind speed):

```
from matplotlib import pyplot as plt
import matplotlib.ticker as plticker
try:
    from PIL import Image
except ImportError:
    import Image

# Open image file
image = Image.open('wind.png')

# Size of the image in pixels (size of original image)
width, height = image.size

left = 33*width/50
top = 11*height/20
right = 16.7*width/20
bottom = 8*height/10

image = image.crop((left, top, right, bottom))

my_dpi=80.

# Set up figure
fig=plt.figure(figsize=(float(image.size[0])/my_dpi,float(image.size[1])/my_dpi),dpi=my_dpi)
ax=fig.add_subplot(111)

# Remove whitespace from around the image
fig.subplots_adjust(left=0,right=1,bottom=0,top=1)

# Set the gridding interval: here we use the major tick interval
myInterval=17.
loc = plticker.MultipleLocator(base=myInterval)
ax.xaxis.set_major_locator(loc)
ax.yaxis.set_major_locator(loc)

# Add the grid
ax.grid(color="black",which='major', axis='both', linestyle='-')

# Add the image
ax.imshow(image)

plt.savefig('windgrid.png')
```

Code for image processing and matrix building (applied to humidity, temperature, foliage coverage, and wind speed):

```
import numpy as np
from PIL import Image
from matplotlib import pyplot as plt
import math
```

```

# # Open image and make greyscale and Numpy versions
pimRGB = Image.open('/Users/julietjiang/Downloads/humiditygrid.png')
pixRGB = pimRGB.load()
pimgrey = pimRGB.convert('L')
nimRGB = np.array(pimRGB)
nimgrey = np.array(pimgrey)

# Work out where the horizontal lines are
rowmeans = np.mean(nimgrey,axis=1)
rowthresh = np.where(rowmeans>128,255,0)
# Difference each element with its neighbour...
diffs = rowthresh[:-1] - rowthresh[1:]
rowStarts, rowEnds = [], []
for i,v in enumerate(diffs):
    if v>0:
        rowStarts.append(i)
    if v<0:
        rowEnds.append(i)

# Work out where the vertical lines are
colmeans = np.mean(nimgrey,axis=0)
colthresh = np.where(colmeans>128,255,0)
# Difference each element with its neighbour...
diffs = colthresh[:-1] - colthresh[1:]
colStarts, colEnds = [], []
for i,v in enumerate(diffs):
    if v>0:
        colStarts.append(i)
    if v<0:
        colEnds.append(i)

width = 14
height = 14
grid = []
def average_tuple(nums):
    temp1 = 0;
    temp2 = 0;
    temp3 = 0;
    for i in nums:
        temp1 += i[0]
        temp2 += i[1]
        temp3 += i[2]
    return (int(temp1/len(nums)), int(temp2/len(nums)), int(temp3/len(nums)))

h, w, _ = nimRGB.shape
for r in range(height):
    grid.append([])
    for c in range(width):
        tempcolors = []
        for j in range(colEnds[c], colStarts[c+1]):
            for k in range(rowEnds[r], rowStarts[r+1]):
                if (j < h and k < w):
                    tempcolors.append(pixRGB[k,j])
        grid[r].append(average_tuple(tempcolors))

humid1 = (238,232,180)
humid2 = (221,220,159)
humid3 = (199,209,141)

```

```

def subtract(nums1, nums2):
    return (nums1[0]-nums2[0], nums1[1]-nums2[1], nums1[2]-nums2[2])

def divide(nums1, nums2):
    return (nums1[0]/nums2[0], nums1[1]/nums2[1], nums1[2]/nums2[2])

def error(nums1, nums2):
    terr = divide(subtract(nums1,nums2),nums1)
    err = (terr[0] + terr[1] + terr[2])/3
    return abs(err)

test = []
for i in range(height):
    test.append([])
    for j in range(width):
        print(error(humid1, grid[i][j]))
        if (error(humid1, grid[i][j]) < 0.05 or error(humid2, grid[i][j]) < 0.05 or error(humid3,
grid[i][j]) < 0.05):
            test[i].append(1)
        else:
            test[i].append(0)

for i in range(len(test)):
    print(test[i])

```

Code for matrix transformations, matrix modifications, and calculations (applied to fire prevention, forest regeneration, temperature increase, fire velocity, etc):

```

hum = [[1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0],
[1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0],
[1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0],
[1, 1, 1, 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 0],
[1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0],
[1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0],
[1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 1, 0, 0, 0],
[1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 1, 0, 0, 0],
[1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 1, 0, 0, 0],
[1, 1, 1, 1, 1, 0, 1, 0, 0, 0, 0, 0, 0, 0],
[1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1],
[1, 1, 1, 1, 1, 1, 0, 0, 0, 1, 0, 0, 0, 0],
[1, 1, 1, 1, 1, 0, 0, 0, 1, 0, 0, 0, 0, 0],
[1, 1, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0]]

temp = [[0, 1, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0],
[1, 1, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 1, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0],
[0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 0, 0],
[0, 0, 0, 0, 0, 0, 1, 0, 1, 0, 1, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 1, 0, 0, 0],
[1, 0, 0, 0, 0, 0, 1, 0, 1, 0, 1, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 1, 1, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]]

```

```

vel = [[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 1, 1, 1],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0]]

tree = [[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1],
[0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1],
[0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1],
[0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0],
[0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0],
[0, 0, 0, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0],
[1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0],
[1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]]

def add(m1,m2):
    result = []
    for i in range(14):
        result.append([])
        for j in range(14):
            result[i].append(m1[i][j] + m2[i][j])
    return result

one = add(tree,vel)
two = add(one,hum)
final = add(two,temp)
for i in range(len(final)):
    print(final[i])

prev_act = []
for i in range(len(final)):
    prev_act.append([])
    for j in range(len(final[0])):
        if (final[i][j] == 2):
            prev_act[i].append("LOG")
        elif (final[i][j] == 3):
            prev_act[i].append("HRB")
        else:
            prev_act[i].append("N/A")

for i in range(len(prev_act)):
    print(prev_act[i])

tree_den_initial = [[0, 0, 0, 0, 0, 10, 10, 0, 0, 30, 30, 30, 90, 70],
[0, 0, 0, 0, 0, 10, 0, 0, 20, 30, 30, 30, 90, 60],

```

```

[0, 10, 10, 30, 10, 10, 10, 50, 40, 20, 20, 50, 90, 60],
[20, 30, 30, 10, 0, 10, 0, 40, 50, 30, 20, 70, 80, 90],
[30, 30, 30, 20, 0, 0, 10, 30, 30, 30, 30, 70, 60, 70],
[20, 20, 20, 10, 10, 10, 40, 30, 40, 70, 60, 20, 40, 40],
[0, 20, 10, 0, 0, 0, 40, 30, 30, 50, 70, 100, 80, 10],
[0, 0, 10, 0, 0, 0, 30, 20, 30, 70, 60, 40, 0, 0],
[0, 0, 10, 0, 0, 10, 20, 30, 40, 80, 90, 20, 0, 0],
[0, 0, 10, 10, 10, 10, 10, 20, 30, 70, 60, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 30, 10, 20, 100, 20, 0, 0, 0],
[0, 0, 0, 0, 0, 10, 40, 90, 60, 60, 60, 0, 0, 0],
[0, 0, 0, 0, 0, 20, 20, 30, 50, 30, 90, 10, 0, 0],
[0, 0, 0, 0, 0, 10, 60, 10, 80, 0, 0, 0, 0, 0]
]

```

```

tree_den_final = []
for i in range(14):
    tree_den_final.append([])
    for j in range(14):
        if (prev_act[i][j] == "LOG" and tree_den_initial[i][j] > 45):
            tree_den_final[i].append(45)
        elif (prev_act[i][j] == "HRB" and tree_den_initial[i][j] > 0):
            tree_den_final[i].append(.95 * float(tree_den_initial[i][j]))
        else:
            tree_den_final[i].append(tree_den_initial[i][j])

```

```

tree_den_growth = []
for i in range(14):
    tree_den_growth.append([])
    for j in range(14):
        if (tree_den_final[i][j] > 0 and tree_den_final[i][j] + 10 < 100):
            tree_den_growth[i].append(tree_den_final[i][j] + 10)
        elif (tree_den_final[i][j] > 0 and tree_den_final[i][j] + 10 < 100):
            tree_den_growth[i].append(100)
        else:
            tree_den_growth[i].append(tree_den_final[i][j])

```

```

temp_val=[[36, 34, 36, 36, 36, 36, 36, 36, 36, 36, 34, 33, 32, 30],
[36, 34, 36, 36, 36, 36, 36, 36, 34, 34, 33, 32, 28, 27],
[34, 33, 33, 34, 36, 34, 33, 33, 33, 33, 32, 32, 38, 39],
[33, 33, 33, 33, 33, 33, 33, 33, 33, 34, 34, 30, 28, 28],
[33, 33, 33, 33, 33, 33, 33, 33, 33, 30, 30, 30, 28, 27],
[33, 33, 33, 33, 33, 33, 33, 33, 32, 29, 29, 29, 29, 0],
[30, 31, 31, 33, 33, 33, 31, 31, 28, 26, 28, 28, 0, 0],
[28, 30, 30, 30, 31, 31, 30, 30, 28, 26, 28, 0, 0, 0],
[27, 27, 28, 30, 30, 30, 30, 28, 27, 24, 24, 0, 0, 0],
[24, 27, 27, 27, 30, 30, 30, 24, 24, 21, 0, 0, 0, 0],
[22, 24, 27, 27, 27, 27, 21, 18, 21, 21, 0, 0, 0, 0],
[18, 18, 21, 21, 21, 18, 18, 18, 19, 19, 0, 0, 0, 0],
[0, 15, 15, 21, 15, 15, 24, 24, 24, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 12, 0, 0, 0, 0, 0, 0, 0, 0, 0]]

```

```

temp_val_pa = []
for i in range(14):
    temp_val_pa.append([])
    for j in range(14):
        if (prev_act[i][j] == "HRB" and temp_val[i][j] > 0):
            temp_val_pa[i].append(float(temp_val[i][j])+0.35)
        elif (prev_act[i][j] == "LOG"):
            temp_val_pa[i].append(float(temp_val[i][j])+(tree_den_final[i][j] -
tree_den_initial[i][j])*0.7/10)

```



```

else:
    temp_val_pa[i].append(temp_val[i][j])

rain = [[50, 100, 200, 200, 300, 300, 400, 400, 400, 400, 500, 600, 600, 1000],
[50, 100, 200, 200, 300, 300, 400, 400, 400, 400, 600, 600, 700, 900],
[200, 200, 200, 200, 300, 300, 350, 400, 400, 600, 600, 600, 900, 1200],
[200, 200, 200, 200, 300, 300, 400, 400, 400, 600, 600, 600, 900, 800],
[200, 200, 200, 250, 300, 400, 400, 400, 400, 600, 600, 600, 900, 0],
[200, 200, 200, 300, 300, 400, 400, 600, 600, 600, 800, 900, 0, 0],
[300, 300, 300, 300, 300, 400, 400, 400, 600, 600, 900, 500, 0, 0],
[300, 300, 300, 300, 300, 400, 400, 600, 600, 600, 900, 0, 0, 0],
[300, 300, 300, 300, 350, 400, 400, 600, 600, 700, 0, 0, 0, 0],
[350, 350, 400, 400, 400, 500, 600, 900, 600, 300, 0, 0, 0, 0],
[500, 500, 500, 500, 900, 900, 600, 600, 200, 0, 0, 0, 0, 0],
[600, 600, 600, 600, 900, 700, 600, 600, 600, 0, 0, 0, 0, 0],
[0, 400, 400, 0, 900, 600, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]]

hum_val = [[20, 20, 20, 30, 30, 30, 30, 30, 30, 30, 30, 40, 40, 40, 50],
[30, 30, 30, 30, 30, 30, 30, 30, 30, 30, 30, 30, 40, 50],
[30, 30, 30, 30, 30, 30, 30, 30, 30, 30, 30, 30, 40, 50, 50],
[30, 30, 30, 30, 30, 30, 30, 30, 40, 40, 40, 40, 40, 50, 50],
[30, 30, 30, 30, 30, 30, 30, 40, 40, 40, 40, 40, 50, 50, 0],
[30, 30, 30, 30, 30, 30, 30, 40, 40, 40, 40, 40, 50, 0, 0],
[30, 30, 30, 30, 30, 40, 40, 40, 40, 40, 50, 50, 50, 0, 0],
[30, 30, 30, 30, 40, 40, 40, 40, 40, 40, 50, 50, 0, 0, 0],
[40, 40, 40, 40, 40, 40, 40, 40, 40, 40, 50, 50, 0, 0, 0],
[40, 40, 40, 40, 40, 40, 40, 40, 40, 50, 50, 0, 0, 0, 0],
[40, 40, 40, 30, 40, 40, 40, 40, 40, 40, 50, 0, 0, 0, 0],
[40, 40, 40, 40, 40, 40, 40, 50, 40, 0, 0, 0, 0, 0],
[40, 40, 40, 40, 40, 40, 40, 40, 40, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 40, 0, 0, 0, 0, 0, 0, 0, 0, 0]]

wind_val = [[4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4],
[4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4],
[4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4],
[4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 5, 6],
[6, 5, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 8, 6],
[6, 6, 5, 4, 4, 4, 4, 4, 4, 4, 4, 7, 6, 6],
[6, 6, 6, 5, 5, 4, 4, 4, 4, 4, 5, 8, 6, 0],
[6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 8, 6, 0, 0],
[6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 8, 7, 0, 0, 0],
[6, 6, 6, 6, 6, 6, 6, 6, 6, 7, 6, 0, 0, 0, 0],
[6, 6, 6, 6, 6, 6, 6, 6, 6, 7, 0, 0, 0, 0, 0],
[6, 6, 6, 6, 6, 6, 6, 6, 7, 8, 0, 0, 0, 0, 0],
[6, 6, 6, 7, 7, 6, 6, 7, 0, 0, 0, 0, 0, 0, 0],
[7, 8, 8, 8, 8, 8, 10, 8, 8, 0, 0, 0, 0, 0, 0]]

fire = []
for i in range(14):
    fire.append([])
    for j in range(14):
        if (rain[i][j] > 150 and hum_val[i][j] < 45 and hum_val[i][j] > 20 and temp_val_pa[i][j]
< 32.5 and temp_val_pa[i][j] > 30):
            fire[i].append(1)
        else:
            fire[i].append(0)

fire_vel = []
for i in range(14):
    fire_vel.append([])

```

```
for j in range(14):
    if (fire[i][j] == 1):
        vel = round(2.518*float(wind_val[i][j])/(60-temp_val_pa[i][j]+hum_val[i][j]),7)
        fire_vel[i].append(vel)
    else:
        fire_vel[i].append(0.0)

sum = 0.0
numfire = 0
for i in range(14):
    for j in range(14):
        if (fire[i][j] == 1):
            numfire += 1
            sum += fire_vel[i][j]

avg = sum/196

print(avg)

for i in range(len(fire_vel)):
    print(fire_vel[i])
```