Creating wildland fire simulations for evacuation routes in Twente, The Netherlands

Addressing evacuation exercises for multi-hazards in Europe

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Preface

This thesis is on the creation maps that show wildland fires in order to create more efficient and safer evacuation routes. Even though the area of research will be in The Netherlands, the greater goal is to develop a tool that can be used by people all around the world. This thesis is for every single person who might find themselves endangered by fires, or those who have great interest in this topic. The time frame used for the writing of the thesis is from February 2020 to July 2020, led by Supervisor Dr. Andreas Kamilaris and critical observer Prof. Dr. In. Alfred Stein.

I would like to thank Andreas Kamilaris and Alfred Stein for their feedback, help, and words of encouragement when I needed them the most. Next, I would like to thank Jesper Provoost for his patience and fresh outlook on the problems faced in this thesis. Also, I would like to thank Nick Schellhase from the municipality of Hollands Kroon for the time he has put into helping me gather data for this thesis.

Lastly, but surely not less important, I would like to thank my family and friends for their support and feedback. Without your kind words the journey would have been a lot more difficult.

Marjolein Kerssens
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Abstract

With climate change affecting the earth, natural disasters occur increasingly and become more devastating with passing time. Many countries and their citizens are not prepared well enough for these disasters even though they will become omnipresent. People need to be prepared for this at all times and as a large portion of the population has a mobile phone, the solution might lay there.

The research question states: “*What is the best way to model wildland fires in order to create better evacuation routes for Twente?”.* A solution was found in the software application FlamMap6, created by researchers in the United States. The choice for this solution was made based on what data could be found as useful data was difficult to obtain, output, and whether the programme was user friendly for someone with basic knowledge of the topic. The solution was supported by a set of requirements coming from literature research and user needs. The following key requirements were found: a map showing fire propagation, identification of dangerous situations, and understandable to all people. The proposed solution creates a map that shows accurate fire propagation, which helps the user evacuate to a safe location. The solution was evaluated by checking whether everything seemed logical and seeing if the overall product did what it was intended to do. The overall product and solution look promising but future work has to be done to make it available in other countries.

1 Introduction

The core of this project can be described well with a quote from Neil deGrasse Tyson:

"*Even with all our technology and the inventions that make modern life so much easier than it once was, it takes just one big natural disaster to wipe all that away and remind us that, here on Earth, we're still at mercy of nature."*

The inventions that benefit us in our daily life can have big consequences for our earth. Many people do not worry about this but they probably should as this earth supports the group that they are a part of; humanity. The planet which is considered home can easily wipe away all of the comfort within an amazingly short period of time, and when it happens, populations need to be prepared. Let's use the technology and inventions that we benefit from so greatly, to keep us safe.

1.1 Background

The earth is being affected by climate change in many different ways. The occurence of more and heavier natural disasters is an example of this, as are extreme weather and loss of biodiversity, according to Wood (2020). In Greece, for instance, the temperature is expected to rise 4.5℃ in combination with a drying of 30%-60% (Zittis, 2014). The increase in disasters is something governments must be prepared to act on quickly.

1.2 Problem Description

Many countries are not well-prepared for natural disasters yet. Countries in the south of Europe will have to deal with these hazards but their infrastructure is not in prime condition for efficient evacuation, even though there are evacuation plans in place. Next to this, the evacuation plans in regions where forest fires are not common (northern Europe, or i.e. The Netherlands) are not fully implemented with relation to forest fires. There is no proper response policy as these will come unexpected. Sometimes climate change enhances mistakes caused by human actions, deliberate or accidental (like throwing a cigarette on the ground). This renders communities in this area extremely vulnerable without a clear idea of what to do when they are struck by a disaster, which could end in a catastrophe if anything were to happen to these parts of Europe.

1.3 Constraint

As the main tool that will be used for this project is a GIS application, satellite images are needed. Next to this, specific layers will be needed to model the fires. Therefore, these images and layers must be obtained but this can be rather difficult as these are sometimes a) hard to find, or b) extremely expensive. Hopefully, the data can be gotten from Pervasive Group, this does however cause a dependency. Next to this, information might be needed from the local area and it is unclear yet whether this is possible or not.

1.4 Research questions & subquestions

With all things considered, the main research question is:

“***What is the best way to model wildland fires in order to create better evacuation routes for Twente?***“.

• How is the occurence of wildland fires changing in Europe?

• How do governments currently deal with natural disasters?

• What influences fire propagation and how can this be predicted?

• How can fire propagation be calculated?

• What protective actions in wildfires exist?

• What satellite images are needed?

1.5 Outline

The chapters will appear in the following order:

- Literature Review/State of the Art
  - This chapter will contain all relevant research, as well as literature and developments in the field. In this chapter, the sub-research questions will be discussed and answered.

- Methods and techniques
  - The main focus of this chapter will be on the methods used to create the models. The methods and techniques will be explained here.

- Ideation
  - The focus of this chapter will be on the design process. Here, problem definition and relevant information are collected. The ideas will be generated.

- Realisation
  - In this chapter, the model is used and results are generated. This is an iterative process where feedback is incorporated at different times to perfect the models.

- Evaluation
  - The evaluation chapter contains several techniques if the proposed model is the best model.

- Discussion and conclusion
  - In this chapter, the final chapter, the conclusion will be given. Next to this, all research questions will be answered. The discussion will consist of

comments on the entire process. There will also be a discussion of future work and limitations.

2 Literature review & state of the art

In this chapter literature and relevant research will be considered to answer research questions and create the foundation for the thesis. The research will be split up into three parts. First, a general approach will be used to identify how wildland fires affect Europe and in particular, The Netherlands. The second part will consist of models that can be used to model fire and to calculate fire propagation. In this part, multiple protective actions will be looked at as well. Lastly, different satellite images will be discussed to make sure the images fit well with the scope of the project.

2.1 Natural disasters - wildfires

There are multiple hazards threatening Europe. Wood (2020) states that natural disasters are in the top ten risks by impact, as can be seen in figure 2.1. One of these disasters is heat waves, where there is a significant increase in the temperature. The frequency of these heat waves has increased progressively and significantly. The heat waves in combination with the increase in severity of streamflow droughts and decrease in river floods cause the land to become drier. Interestingly enough, this does not cause an increase in the frequency of extreme disasters, such as wildfires. However, there also is a progressive increase in wildfires in all of Europe, Australasia, and the Far East (EAFE), as pointed out by Forzieri (2015).

Box 1. Top-ranked global risks

Top risks by likelihood	Top risks by impact
1. Extreme weather	1. Extreme weather
2. Biodiversity loss	2. Climate change
3. Water crises	3. Water crises
4. Climate change	4. Biodiversity loss
5. Urban planning	5. Food crises
6. Man-made disasters	6. Man-made disasters
7. Involuntary migration	7. Urban planning
8. Food crises	8. Natural disasters
9. Asset bubbles	9. Involuntary migration
10. Illicit trade	10. Interstate conflict

In Box 1, the top ten global risks are ranked by mean perceived likelihood of occurrence and impact in the next 10 years. There is a significant overlap between the two lists showing a potentially worrisome congruence that the most likely risks are also those with the greatest perceived impact.

Figure 2.1: top-ranked global risks (Source: Future Earth, Wood, 2020)

Based on numbers from the CBS (2019), The Netherlands deal with quite a few wildland fires as well. This can be seen in figure 2.2. According to the data, over 60% of these fires happened in the driest and hottest part of the year. This means that not only the south of Europe has troubles with wildfires, also the northwestern parts (which usually have lower temperatures) have to deal with this type of natural disaster. In The

Netherlands, a national park called “De Hoge Veluwe” experiences a significant amount of wildfires. In 2014, a fire destroyed 320 hectares worth of land. It is worth mentioning that most fires in The Netherlands are caused by reckless behaviour of citizens. However, when temperatures are high and the soil is dry, a cigarette can cause a huge fire. This can also happen when garbage starts burning due to sunlight hitting it a certain way and thus creating high temperatures.

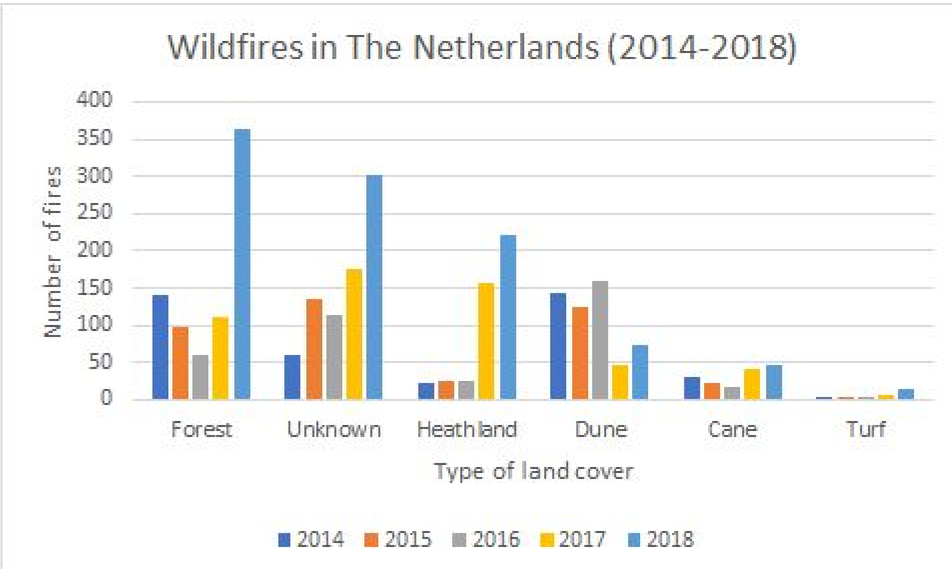

Figure 2.2: Amount of Wildfires in The Netherlands. Source: CBS, 2019

Governmental action

Governments have multiple ways of dealing with wildfires. An example of this is prescribed burning (PB), a method that is used all over Southern Europe, this can be seen in the figure below. Prescribed burning is planned use of fire in order to burn specific parts of forests. The goal is to decrease wildfire risk while keeping habitats for wildlife intact. While this system is recommended, there is poor understanding of the consequences of the method among citizens. Whether PB works well, depends on the type of land cover of the area that needs to be controlled. The method is used far more in shrublands than in forests, as can be seen in the figure below. There are two patterns in which PB is operated; either random or strategic (an example of this is straight lines). The scope of the to-be burned area is often small, less than 30 ha, but can be much larger, up to 200 ha. In figure 2.3 several charts can be seen on prescribed burning and its use.

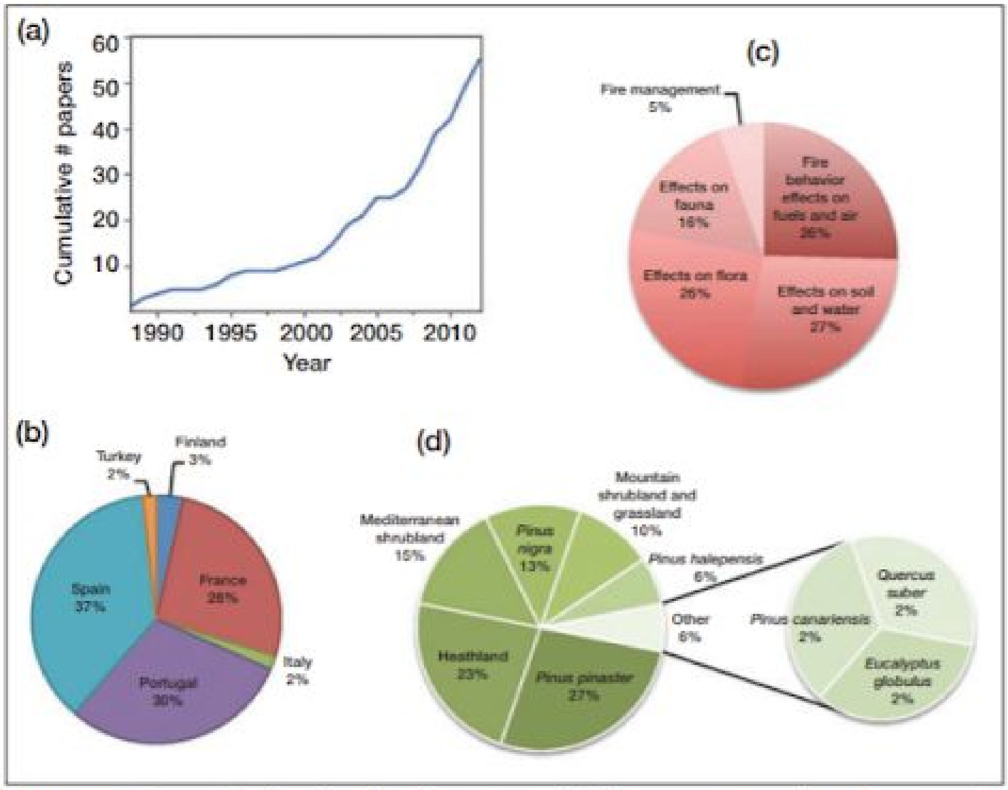

Figure 1. *Research directly related to prescribed burning in southern Europe. (a) Cumulative number of papers published (as of September 2012, data from Thomson Reuters Web of Science) and paper distribution by (b) leading author country, (c) research topic, and (d) ecosystem.*

Figure 2.3: Prescribed burning in southern Europe: research and management. Source: Fernandes, 2013

The reason that the method is only used in a few areas is due to the fact that there are large risk-related concerns. There is also a lack of experienced professionals and legislations which prohibit prescribed burning, this is the case in Greece. Lastly, the public opinion on forest fires, even controlled ones, is not positive, even if the outcome is for the greater good. PB has a positive effect on the amount of wildfires on a variety of different land covers. Before and after PB (under equivalent weather condition) heathland has a 78% decrease in the intensity of fires. (Fernandes et al. 2013)

According to a report by the Institute for Physical Safety (Instituut Fysieke Veiligheid) (2017), The Netherlands are trying to control wildfires as best as they can. In 2016, the Dutch fire department created the “Vision for Wildfire Management” (Visie Natuurbrandbeheersing). This gives insight in the preferred situation and the plans for wildfire control. Every region has vegetation maps and calculations which involve the model for the spread of wildfire (NBVM). From this, critical locations are chosen and the fire department then ensures that these regions are made more safe. Next to this, citizens are well informed on the risks and causes of wildfires. They are asked to report dangerous situations to the police or fire department, and to always check for an evacuation route. The latter might sound simple, but the opposite is often the case.

Types of fires

The IFV (2017) states that there are multiple types of wildland fires. First, a *surface fire*, where mostly vegetation such as small bushes and heathland is affected. Next, *ground fire*, here, there is a fire in the layers of deceased vegetation on the ground or even the roots that are in the ground. There is also *crown fire*, where the tops of the trees are burning. This is often in combination with surface fire. Lastly, *spotting*, which is the result of a crown fire. Here, burning needles and leaves get moved by the wind and create new fires elsewhere. It is crucial to detect what type of fire is threatening the land as this influences the safety of some of the roads, meaning that it influences the evacuation routes.

2.2 Models & Evacuation

In order to create accurate evacuation routes, multiple questions have to be answered. Questions such as: “What influences fire propagation and how can this be predicted?”, “How can fire propagation be calculated?”, and “What protective actions in wildfires exist?”. To answer these questions well, several models will be looked at and research on different types of protective actions will be done, looking at more than just evacuation.

2.2.1 Fire Propagation

The most used fire behaviour model is the one created by the United States Department of Agriculture by Rothermel (1972). This model enables the possibility to calculate the behaviour of surface fires. These fires usually affect ground vegetation only and therefore propagate at a high speed. It is important to note that the input variables are homogenous for a small area and a short period of time. The model gives different output parameters, being: the rate of fire spread ($ros\ [m\ s^{-1}]$), the effective wind speed (*efw* $[m\ s^{-1}]$), and direction of maximum spread $(sdr[°])$. In an ideal situation, the front of a fire would be a circle, unfortunately this is almost never the case due to external factors. This model takes the influence of wind and terrain into account. These two parameters cause the fire front to be a double ellipse instead of a circle and therefore create a model that is close to the real life situation.

One way to use the Rothermel model is in combination with the Monte Carlo simulation. The original model is complicated to use as it needs over 80 equations, but the Monte Carlo simulation allows the use of a black box instead of the entire model. The level of accuracy can be increased by increasing the amount of runs. The downside of the simulation is that it takes a lot of computational power as it needs to take 17 input variables into account. If the Taylor Series is applied to the Rothermel model, all of the 80 equations still have to be done but then the implementation work can be applied to any data set. The Taylor Series introduces an approximation error which can be large as long as the variation of the input uncertainty is large in comparison to the smoothness of the function. (Bachmann & Allgöwer, 2002)

Alexander & Cruz (2012) visualised Byram's research which was published in 1959. Byram defined the intensity of the fireline as the ratio of heat energy release per time and length of the fire. An illustration to make this model more clear can be found in the figure below.

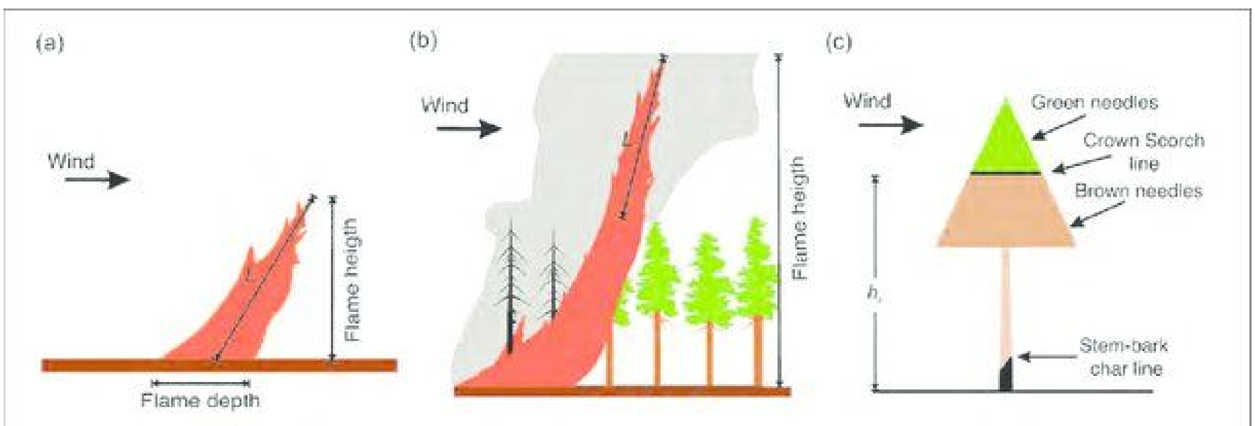

Figure 2.4: Explanation of Byram's model and the effect of wind on the flame length. Source: Alexander & Cruz, 2012, https://www.researchgate.net/publication/276201344_Graphical_aids_for_visualizing_Byram%27s_fireline_intensity_in_relation_to_flame_length_and_crown_scorch_height/figures?lo=1

In research, Byram found that the flame length is different for different types of land cover. The result of this can be seen in figure 2.5. In the figure can be seen that forest land cover types have a tendency to have a tall flame length while not being as intense as fires with lower flame lengths on other types of land cover. This is likely due to the fuel type influencing the fire.

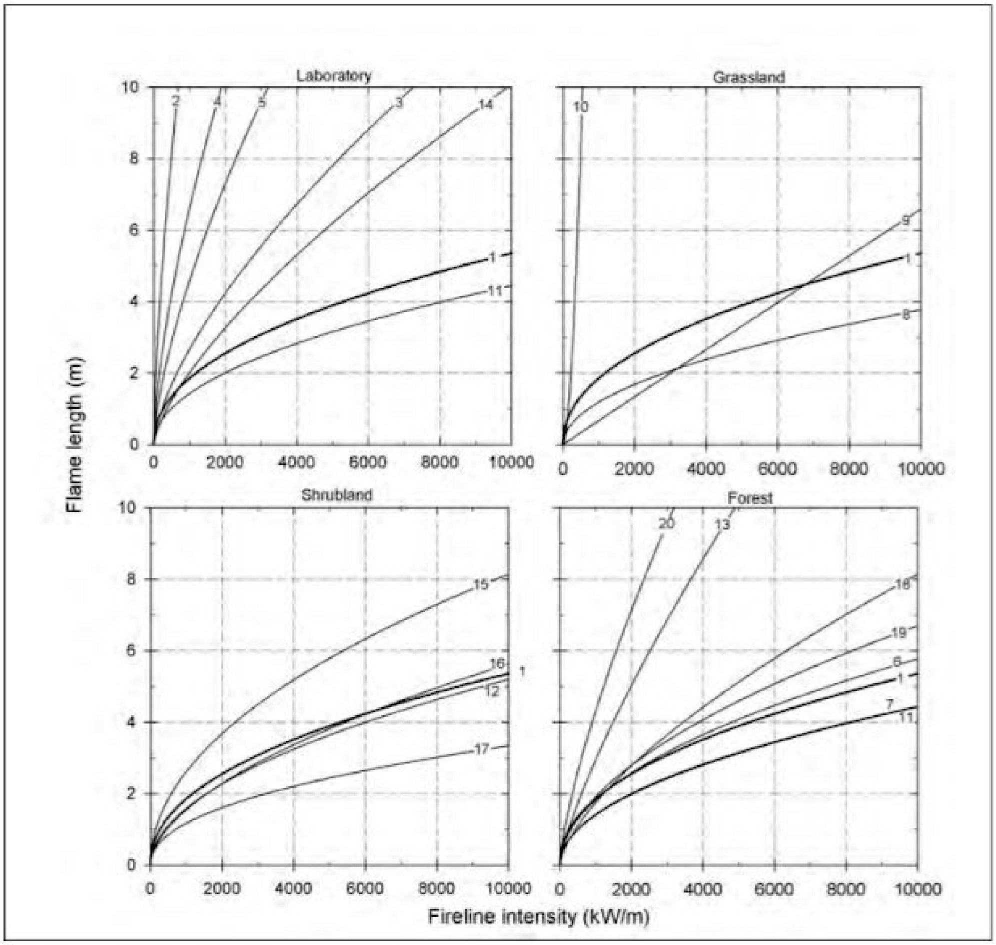

Fig. 3. Graphical representation of Byram's (1959) flame length – fireline intensity relationship for pine litter with grass understorey (represented by curve **1**) and other models (field and laboratory based) reported in the literature by four broad fuelbed types according to the listings given in Alexander and Cruz (2012b): **2** – wood cribs (Fons *et al.* 1963); **3** – wood cribs (Thomas 1963); **4** – lodgepole pine slash (Anderson *et al.* 1966); **5** – Douglas-fir slash (Anderson *et al.* 1966); **6** – general rule of thumb (Newman 1974); **7** – understory fuels (Nelson 1980); **8** – southern USA fuels (Nelson 1980); **9** – grasslands-head fire (Clark 1983); **10** – grasslands-backfire (Clark 1983); **11** – litter and shrubs (Nelson and Adkins 1986); **12** – fynbos shrublands (van Wilgen 1986); **13** – eucalypt forest (Burrows 1994); **14** – excelsior (Weise and Biging 1996); **15** – shrublands (Vega *et al.* 1998); **16** – shrublands (Catchpole *et al.* 1998); **17** – shrublands (Fernandes *et al.* 2000); **18** – 10-m tall jack pine forest-crown fire (Butler *et al.* 2004); **19** – maritime pine-head fire (Fernandes *et al.* 2009); and **20** – maritime pine-backfire (Fernandes *et al.* 2009). All of the relationships, unless otherwise specified, are for heading surface fires. The relationships represented by curves **7** and **11** are very similar but not truly identical.

Figure 2.5: Flame length and fire intensity on different land covers and fuel types. Source: Alexander & Cruz, 2012, [*https://www.researchgate.net/publication/276201344_Graphical_aids_for_visualizing_Byram%27s_fireline_intensity_in_relation_to_flame_length_and_crown_scorch_height/figures?lo=1*](https://www.researchgate.net/publication/276201344_Graphical_aids_for_visualizing_Byram%27s_fireline_intensity_in_relation_to_flame_length_and_crown_scorch_height/figures?lo=1)

In research, Coen (2013) states the different aspects of fire behaviour, being: the rate at which the front of the fire advances, the heat-release rate, and the moving of the front, transition to crown fires as opposed to surface fires, and the activities such a fire whirls. The modelling tool used in the research couples a NWP (numerical weather prediction) model with a module that describes wildland fire behaviour that includes fire propagation through surface fuels. Part of this process includes relationships that are semi empirical, meaning that some parts involve assumptions, to take a better look at physical processes of fire that cannot be resolved at atmospheric-modelling grid scales.

Clark & Miller (1994) elaborate on these aspects and mention that three environmental factors influence wildland fires: topography, weather, and characteristics of fuel. The latter includes: mass loading per unit area, fuel type (based on vegetation, for instance pine trees or indigenous trees), and physical characteristics of fuel beds.

Next to the incorporation of weather prediction, dynamic models are crucial to create a model of significance. Only with dynamic modelling can the exchange of forces between the atmosphere and the fire be represented. For this, kinematic models are mostly used in wildland fire modelling. When only looking at the atmospheric environment, Mandel (2005) showed that the impact of the fire on ambient wind velocity can be devastatingly large. This renders the models useless.

In the model used by Coen (2013), three attributes are combined. First, a coupled weather-fire modelling system (more on this will follow) is described. For this, WRF-Fire (Weather Research and Forecasting) is used. It allows treatment of fire effects on atmospheric dynamics, as well as feedback to the behaviour of fire. In this way, weather can be created by the simulated fire. In the simulation, the atmosphere applies a force of wind on the fire. In this way it directs where and how quickly the fires spread. In combination with local surface winds, the fire’s spread rate and direction are determined. The simulated fire consumes fuel composed of both live and dead vegetation and releases heat and water vapor into the air. This causes the fire to rise and changes the winds in the environment of the fire. The fire model then in its turn calculates the consumed amount of fuel and therefore the energy released as heat in the lower layers of the atmosphere.

The next attribute is the atmospheric model component. The used model (WRF) is designed to be state-of-the-art and allows for flexible use. It solves a set of equations involving: motion of fluid, mass conservation, and atmospheric thermodynamics. It also includes equations for multiple water states, in this way it computes a forecast of the temperature, water vapor, rain, and air velocity. The variables are arranged in an Arakawa-C arrangement (as seen in figure 2.6), the system used is a terrain-following hydrostatic-pressure vertical coordinate system.

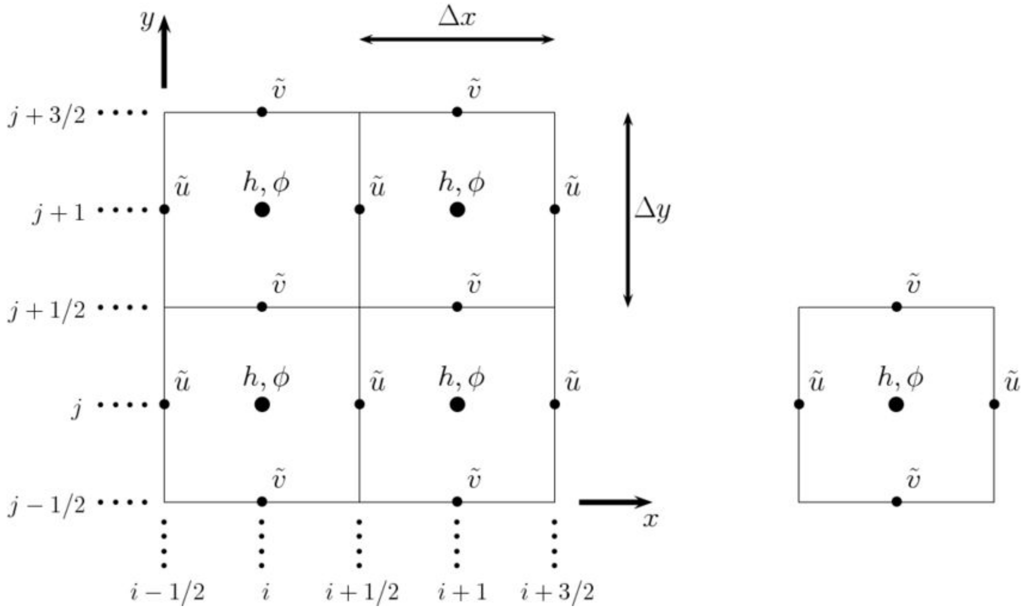

Figure 2.6: Arakawa-C arrangement. Source:
https://www.researchgate.net/figure/The-Arakawa-C-grid-layout-of-the-variables-in-our-numerical-scheme-The-domain-is-divided_fig4_267118062

The last attribute is the wildland fire-behaviour component. This component allows the user to simulate the growth, decay, as well as the propagation of wildland fires. All components of the WRF coupled weather-fire model can be found in appendix A.

The aforementioned research is in line with another paper by Patton & Coen (2004). Here it is mentioned that algorithms like BEHAVE (Andrews, 1986) and FARSITE (Finney, 1998) have created tools that are usable in the field, but other tools are needed to understand the relationship between weather and fire. The coupled models, such as WRF-Fire, have shown that the feedback between the fire and the environmental atmosphere is at the core of fire shape and behaviour, which is necessary when modelling fire in real time.

FARSITE is used all over the United States by National Parks and the U.S Forest Service. The model uses topography, fuels, weather, and wind lines as parameters, and with this, it computes wildfire growth and fire behaviour over long periods of time. The output of the programme is in the form of maps, to which coordinates can be added. For FARSITE LCP files (Landscape grid) are needed. This is beneficial to the goal of the research. Finney (1998) notes that FARSITE is developed for use on personal computers only. This means that the output files are compatible with GIS software and PC graphics. Unfortunately, FARSITE is not available anymore, it is now included in FlamMap6. FARSITE makes use of Rothermel's model as well as Byram's model.

BehavePlus5 is the new version of BEHAVE (Andrews, 1986). Andrews (2014) states that the current version of BehavePlus is organised in calculation modules, based on fire models. These modules can be used seperately but can also be combined and serve as input for one another. Every calculation in BehavePlus is based on assumptions of uniform conditions, it is a point modelling system. The programme works in such a way that comparison through graphs and tables is encouraged. Over forty fire models are included in BehavePlus5, including the Rothermel model and Byram's model. All different types of fire have their own models, in this way accurate output can be obtained for each scenario. The programme also contains a "safety zone" model, where the needed minimum distance between a person and the fire front is calculated. Most outputs are in the form of tables or graphs.

Pugnet (2013) describes PHOENIX, a wildfire modelling system used in Australia. It's designed to portray large and fast moving fires. Tolhurst (2008) mentions that PHOENIX is a part of a wildfire risk management model made of southern Australia. This model consists of three parts: a characterization model, an impact model, and a management business model. PHOENIX can be described as a scenario based model, where the risk management model will show the consequences of the scenarios created by the fire manager. It is a dynamic fire behaviour and characterization model that runs in a dynamic environment that changes based on fuel, topographic conditions, and weather. PHOENIX is supported by the CSIRO grassland fire spread model (Cheney & Sullivan, 1997) and the McArthur Mk5 forest fire behaviour model. The two models had to be adjusted to make them suitable for the dynamic environment. PHOENIX uses the same fire spread algorithm as FARSITE, which is Huygen's.

Ramírez et al. (2011) describe WildFire Analyst, a software application which allows users to get insight in real time fire propagation. The software introduces the user to new modes of simulation with automatic ROS adjustments, evacuation time calculations and an option to calculate the economic impact. The core platform of the software is based on ArcGIS to provide for GIS data and modelling without licensing needed. In the software, the fire propagation model used is Rothermel (1972) as well as the modifications made by Albini (1976). It uses Scott and Burgan (2005) fuel models but also allows the user to create custom fuel models. The software includes two ways to adapt the rate of spread, being firebreaks and rate of spread factors, such as wind speed and wind direction. The output includes rate of spread, minimum travel time (according to the function created by Finney, 2006), crown fires, and moisture content. The user can choose between static and dynamic modelling, depending on their needs.

The software also allows for postfire analysis. In this part the economic impact of the fire is determined, which can result in better prepared agencies for upcoming fires. Next to this, there is a function called “reverse time mode”, which models the fire backwards, so from the largest area to the location where the fire started.

In 2017, The Dutch government created a model for the spread of wildfires. The “Natuurbrandverspreidingsmodel” (NBVM). This model simulates the development of the fire up to 6 hours into the future, this helps the fire brigade to act on it in the most efficient and safe way. The model uses the amount of burnable vegetation and the type of fuel, next to vegetation maps. The government is working on a new model, a version 2.0, which incorporates satellite data.

Artès et al. (2015) point out multiple terrain characteristics which influence wildland fire spread. These include: alignment toward the sun (which in turn influences the received amount of energy), and the steepness of the mountain slopes, which influences the wind behaviour. The problem, according to the paper, with wildfire behavior models is that they do not only have data errors, but also errors due to computational abstraction. Because of this, the models will never accurately simulate the situation. The use of DDDAS (Dynamic Data Driven Application Simulation) could aid in this, as real time data is collected and being turned into a model. However, the use of DDDAS can be complicated and requires a lot of processing power.

It is likely that FlamMap6 will be used for the research as the output fits well with the scope of the project, because it outputs maps. Next to this, many parameters are taken into account in FARSITE, this will likely give accurate data. BehavePlus might be used for additional information regarding certain calculations, but this will not be the main model for this research as the programme outputs mostly graphs rather than maps. The reason why WRF-Fire is not used is because the programme is too complicated to use for a wildland fire novice.

2.2.2 Evacuation Routes

McCaffrey et al. (2015) describe how wildfire evacuation takes place in several communities over the United States. There, firefighters and law enforcement personnel collaborate to determine if evacuation is needed. The regions that are most susceptible to wildfires are often difficult to get away from, as there are limited access points and high chances of fast spreading fire. Here, people may not have enough time to get to safety. McCaffrey (2015) notes that postponing evacuation can be extremely dangerous. It is therefore important to inform citizens accordingly and early on. An approach that is often used is the Stay or Go. Here, people have two choices: they either are prepared, stay where they are, and defend, or they leave as early as possible. Well-informed citizens are an important first step to successful evacuation.

Sorensen et al. (2004) establish that there are two options in protective action: evacuate or shelter-in-place. The latter strategy should only be recommended when there is more risk in moving people than there is in them staying where they are. This also means that the choice for evacuation should be considered only when there is reasonable assurance that evacuation truly is the safest option. It is important to consider each public building is considered individually to ensure the safety of the people within that building. These choices are part of the protective action decision process. It includes only two questions:

1. Will shelter-in-time provide adequate protection?
2. Is there enough time to evacuate?[1]

If the answer to one question is “yes”, the choice is obvious. If the answer to both questions is “yes” then considerations such as disruption and costs come into play. Even though shelter-in-place may not be the first option people think of in the case of fire, it can be important to consider as it can save citizens who are surrounded by the fire already or those who have to take dangerous roads to get to safety. For this, the citizens must be prepared well and informed ahead of time. Sorensen (2004) claims that shelter-in-place is mostly sufficient to use for chemical emergencies.

Cova (2009) elaborates that the shelter-in-place strategy is used increasingly in the case of wildfires, whereas it was first only used for chemical emergencies. As many communities that are located in fire-prone areas do not have many exits, a shelter can be of great help. The following chart mentions the options that exist in the case of a wildfire threat. In the image can be seen that shelters can have different options. The shelter can either be in or near the house, or a refuge may be needed. These refuges have three options, being: structure, safe area, or water body. In the area of research, there are not many water bodies available for shelter, so this would not be an option.

[1] Sorensen, 2004 https://www.sciencedirect.com/science/article/pii/S0304389404001463, page 2

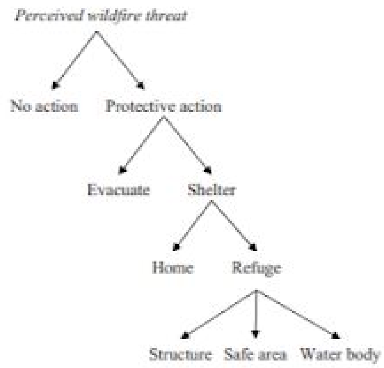

Fig. 1. Wildfire protective-action decision space

Figure 2.7: Wildfire protective-action decision space. Source: Cova (2009)

The most dangerous part of evacuation is the fact that people tend to wait until the last moment to evacuate. This creates hazardous situations as the roads are not made to transport that many people in a short amount of time and congestions occur.

2.3 Data acquisition

After deciding to work with FARSITE, the next question is “What satellite images are needed?”. Next to the satellite images, other data will be necessary to create accurate maps.

According to Keane et al. (2000), several data layers are needed. This includes: satellite imagery, biophysical simulation, and terrain modelling. Furthermore, FARSITE needs fire behaviour models and vegetation characteristics. It might be necessary to prepare data in a GIS software, such as QGIS or Capaware, before it can be put into Flammap6.

There are several types of satellite images to choose from. The final choice will depend on the amount of accuracy needed versus the frequency of images of the same area needed. MeteoSat images are often used to create vegetation maps. These pictures have a short resolution in time but the spatial resolution is not that great (about 1 to 5 kilometers). Modis satellite images have a much more detailed spatial resolution (250 meters) but are not available as often as the MeteoSat images. Landsat images have an incredible spatial resolution (30 meters) but are only made every 2 weeks. Sentinel-2 images have a spatial resolution of about 10 meters. As the goal is not to follow a forest fire closely, but rather to plan ahead of one, there is no need for a data source where new data is often available. It is much more important to have a medium resolution so less mistakes are made. LandSat images or Sentinel-2 images could be a great option for this as their spatial resolution is high. The choice for medium resolution is made as there is a need to clearly differentiate between roads, houses, and forest, but there is no need to see all cars individually. There are many sources with free satellite images, according to the EOS. Sentinel-2 images can be taken from the ESA Copernicus Open Hub.

The data such as wind speeds, vegetation characteristics, and fuel types cannot come from satellite images and must therefore come from elsewhere. The wind speed obviously depends on the day, so for this, an average will be taken and a couple of different speeds will be used to create different models. The data on vegetation characteristics and fuel types is integrated in Flammap6 and will be used accordingly.

2.4 Related work - State of the art

FARSITE

A paper by Castrillón et al. (2011) describes the method of using FARSITE for visualisation of wildfires in real-time. In this research, Capaware is used. It offers all usual features for a GIS software, and on top of that it offers visualisations of dynamic objects. It allows the user to put objects in the selected area. These objects could include: vehicles, humans, or houses. If these objects have a GPS device attached, the programme allows the user to to track their data and real-time position. The GPS devices give updates periodically. This could be useful for real-time wildfire mapping and evacuation routes, but that is not within the scope of this project. FARSITE provides information on the fire, its perimeters, flame intensity, and speed of propagation. These parameters were used to create a graphic representation. This representation is based on two particle systems, one to model the fire and one to model the smoke. In research, a Level of Detail strategy is used to reduce the amount of data per perimeter. The closer the user is to the fire, the more details get shown in the visualisation. This way of simulating would work well for cases where real-time simulation is needed.

Jahdi et al. (2015) describes a research on evaluation of fire modelling systems. The simulators used are FARSITE and FlamMap (it is important to note that anno 2020, these two simulators are integrated). The fires used in the research were chosen from the GNP database records. From this, models on the environment and fuel characteristics were made. FARSITE created the two dimensional simulations. FlamMap made calculations on fire behaviour independently for every location of the landscape. In this case, weather and fuel data were constant. After modelling, accuracy assessment was done by calculating the Sorensen coefficient and Cohen's *k* coefficient.

Based on the calculations, the conclusion was that FlamMap was slightly more accurate than FARSITE. Both models were not accurate in estimating the burned area.

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Hao (2018) researched how accurate FARSITE is by comparing maps from actual fires to the output of the simulated fires. For this, multiple statistical methods were used. These include: Sørensen's Q statistic, Hamming distance, and Jaccard similarity coefficient. First, Sørensen's Q statistic, which is also known as the Sorensen-Dice coefficient, measures the similarity between two samples. The value is between 0 and 1. The closer the value is to 1, the more similar the samples are. (Sørensen, 1948; Dice, 1945). Jaccard similarity coefficient is rather similar to Sørensen's Q statistic. It also has a value between 0 and 1 and it compares the similarity between two samples by seeing what the overlap is between the two sets. The Hamming distance calculates the difference between two strings. It does not only measure the value, but also the position. Based on the calculations, Hao (2018) notes the same findings as Jahdi (2015). FARSITE appears to be quite accurate in both the Sørensen-Dice coefficient and the Jaccard similarity coefficient. The Hamming distance is not as accurate but this is in line with other research that has been done, where it is often seen that the Hamming distance becomes less accurate when the Sørensen-Dice coefficient and the Jaccard similarity coefficient are accurate. From this research is concluded that the FARSITE simulation model is a good option to map and predict wildfires.

WildFire Analyst

Cardil et al. (2019) describe a way to assess wildland fire simulations using Wildfire Analyst. WFA provides a scope of outputs which are available as charts, GIS maps, and reports. The programme allows for input of many variables, making it accurate and adaptable to the user's needs. Using the VIIRS (Visible Infrared Imager Radiometer Suite) and MODIS (Moderate Resolution Imaging Spectroradiometer), both sources for satellite active fire data, the comparison was made between those data sources and WFA. Fire growth simulations were performed with WFA and the output was compared to the data from VIIRS. Spatial discrepancies were analysed with the Sørensen's coefficient. Which gives the following calculation: $SC = \frac{2A}{2A + B + C}$ with: A = the burned area in both outputs, B = the area burned only in WFA's output, and C = the burned area only in VIIRS. The results were compared at every satellite overpass, the moment a satellite crosses a certain point on earth's surface. The results were fairly accurate, ranging from SC = 0.74 to SC = 0.86 in different fires. It must be noted that the SC value increased with the fire duration.

Comparing WildFire Analyst to other software
According to the user manual provided by WildFire Analyst (2019), the programme uses the same models as FARSITE and FlamMap, and the output is similar as well. However, when comparing WFA to FARSITE and FlamMap, WFA is more up to date and state of the art. Both FlamMap and WFA have a minimum travel time function, but the one used by WFA is claimed to be more optimized with the use of variable density. Next to this, WFA allows the user to view the fire propagation during a time interval of seven days where FlamMap supports up to three days. FlamMap allows for daily constant weather input, where WFA, like FARSITE, allows for an hourly variable weather input. Next to this, a mobile version of WFA is available which allows for flexibility and use in the field. Lastly, where FlamMap needs landscape files containing ASCII grid data, WFA uses LANDFIRE and editable data sources to allow for easy use.

2.5 Conclusion of the literature research

When looking at the data presented in the first paragraph of the literature review, the importance of the research becomes clear. Countries where wildfires are more common are more likely to have detailed evacuation plans ready, or they are likely to be better prepared for this disaster than countries in the Northwestern parts of Europe. As The Netherlands will have to deal with wildfires increasingly due to climate change, an evacuation plan for parts of the country is needed. De Hoge Veluwe would be a good area to map, as it often deals with wildfires and it has many people that visit during the warmer periods of the year. In areas like this, clear evacuation plans are crucial to ensure that all visitors stay safe.

After researching multiple models, the decision was made to use FARSITE (and therefore Flammap6) for the research as it is accurate enough for the intended goal of the research. This is due to the fact that real-time modelling is not necessary. Next to this, FARSITE is user friendly and can be adapted to the needs of this project. The reason that the NBVM is not used is because this model simulates 6 hours into the future, this information is not necessary to create evacuation routes, that has to be done beforehand. Rothermel’s model is incorporated in FARSITE, so that is used as well, just not separately. After trying out BehavePlus, the conclusion is that even though this programme works well and is extremely user friendly, it does not directly give the data that is needed, it mostly outputs data in graphs and tables. FARSITE creates maps with coordinate systems, this is more efficient and in line with the needed data. After looking at related work for FARSITE, the conclusion can be drawn that FARSITE is accurate for the scope of this project. This is because multiple researches have shown that maps generated in FARSITE show substantial similarity with the maps created after a fire happens. As accuracy is crucial in this project, a programme is needed that allows high accuracy. Therefore, the preferred programme is Flammap6 with the use of FARSITE. However, if FlamMap6 ends up not working, the next step would be to try BehavePlus. As mentioned before, this software is not ideal for users with little knowledge in wildland fire modelling. In the case that the output of this programme is not understandable enough, WildFire Analyst will be the next option.

3 Methods and techniques

In this thesis, multiple methods of design have been implemented. First, the design process will be presented and after that a method for requirements and ideas is explained.

3.1 Design process of Creative Technology

The study for which this thesis is made, Creative Technology, has its own design process proposed by Eggink & Mader (2014). Creative Technology design makes use of switches between divergence and convergence, in order to generate a lot of ideas but end up with a specific one. The ideation phase is broad but diverges quickly into specific requirements and a small design space. The latter is influenced by the knowledge of the designer and the requirements the product has. Next to this, spiral models are used to evaluate the product at each step. These models are related to problem solving where each design problem creates a series of questions specific to the original problem. The process can be seen in Appendix B.

The Creative Technology design process consists of four parts which will all be elaborated on below. As this thesis is not a standard Creative Technology design, not all phases will be the exact same as described below but they will be altered to fit the needs of the project.

Ideation
This is the starting point of every design process. Here, the tinkering starts and the goal is to identify applications for new or existing products. This is all on a conceptual level. The problem is defined and ideas are generated.

Specification
Here, the first prototypes made and product requirements are defined. As this thesis does not make use of prototypes, that part will not be used. The product requirements will be defined by the MoSCow method, which is explained later.

Realisation
With all requirements defined and a clear plan written down, the product can be realised. The components are integrated to work together as a whole. A small

evaluation will be done to see if the product fits the requirements stated in the specification phase.

Evaluation

The last phase of the process, the evaluation. This is where the product is tested to see if it works well and if all the requirements are implemented as they should be. This is the analysis part of the design process.

3.2 MoSCoW method

Waters (2009) describes the MoSCow method, a design method for agile planning. In this method, designers look at what the product requirements are. These requirements all fit into four categories: Must have, Should have, Could have, and Won’t have (but would like to have in the future). The requirements that fall in the category “must have” have to be in the product as otherwise the product is not functioning like it should. Without these features, the product can not fulfill its purpose. This is the minimum scope of the project. “Should have” requirements are not critical for the product to work, but they do add to the experience of the user. “Could have” are requirements that would be nice to have but are not critical to the product or experience of the user. These are the first to be removed from the product when time is running out. “Won’t have” are the requirements that would be good to have, but can not be implemented in the time scale provided. These features will be added to the product in the future.

4 Ideation

4.1 Area of research

In this thesis, it is important to conduct the research in a representative area as this influences the results significantly. The first plan is to conduct the research on De Hoge Veluwe, a national park in The Netherlands. The reason for this can be read in the literature review. In short, this area of The Netherlands deals with many wildland fires of which the occurrence is starting to become more prevalent as time progresses. In case this plan does not work out, the research will be moved to the area in which the University of Twente is. In case FlamMap is the only working option, the area of research will be moved to the United States to see if the programme works well.

4.2 Plan A - FlamMap6

The ideation phase for this project was not necessarily a creative process, it was an iterative process of trial and error to find an accurate and efficient way of researching. The first part consisted of finding different models and programmes that simulate and show fire in different ways. Most of these were downloaded to see how they worked and how user friendly they were for someone who does not have a ton of experience with the modelling of wildland fires. Next to this, state of the art was reviewed to see what kind of research used what model. Here, the focus layed not only on the research itself, but also the wanted output, the used parameters, and the needed input. For instance, BehavePlus needs clear input that is easily obtained, but the output is not what is needed for this specific research.

After a model and a programme were chosen, in this case FARSITE which is incorporated into FlamMap6, the next phase of ideation begins: figuring out how to get the desired file type and how to prepare the images for the programme. FlamMap needs Landscape (.lcp) files for the rasters. These .lcp files consist of multiple ASCII files that contain data on the elevation, fuel model, slope, aspect, and canopy cover. ArcMap has a function to create ASCII files from raster files, which is exactly what is needed. As ArcMap is also the programme used to do the multi spectral classification, the classified images can be turned into ASCII files straight away.

4.2.1 Data acquisition

It is important that the data is in the right format for FlamMap6, which is a landscape file (.lcp) and it must include a raster file to shape the map correctly. So far, FlamMap is mostly used in the United States and much data is available for that area. The Netherlands could be a different case as data with the right parameters in the correct format can be harder to find.

4.2.2 Data preparation

The landscape files will be put through ERDAS first. In this programme, the different types of land cover will be classified through multi-spectral classification. In this process, all covers will be classified by hand, by looking at what the cover looks like on the satellite image. This will be saved in a table. In this process, the artificial intelligence agent is getting trained, so that after training is done, the programme can classify the images more accurately and a lot faster than a human can. An accuracy report will give information on the accuracy of the classification, as well as the areas that cause error. Here, the decision can be made to either to re-do the classification and continue the training, or the result is accurate enough and the next step of the process is started. Next to this, ArcMap will be used to create ASCII files from raster files. This can be done by taking the elevation file and using the “Spatial Analyst” tool, creating a slope file. This is a raster file, but can be transformed into an ASCII file. This slope file (in raster format) can then be used to create the aspect file using the same “Spatial Analyst” tool. Once again, the output is a raster file. The ASCII files are needed to create the Landscape (.lcp) file that FlamMap needs in order to model the data.

4.2.3 Use of FlamMap

The first step in FlamMap is to create the Landscape file. This file consists of a satellite image with layers of ASCII files with data on the elevation, slope, canopy cover, aspect, and fuel model. As mentioned in the previous paragraph, some transforming of the files will be needed before they can be put into FlamMap. FlamMap then provides the option to model a fire in the area built from the ASCII Raster files. After creating the landscape file, FlamMap has the option to start a fire at a selected location and will simulate the spread of the fire with the result of the calculations made. The result is a map with the fire propagation on which the evacuation route will be added.

4.2.4 Analysis

The plan for the analysis is the following. The software application will create a map of a fire that is not real, it is a simulation of a potential fire and its propagation. The first option is to use the “Risico Index Nederland (RIN)” which is used by municipalities and the agencies responsible for the safety of their region. The RIN shows the expected spread of the fire as well as the possibility of the fire happening in that location. This information is based on an indexing system that goes from 0 points (which stands for non-burnable material) to 100 points (for extremely burnable material). This software unfortunately is not available to the public and can therefore not be used for this research. In this type of analysis the two applications are compared to one another rather than checking if one of them is correct.

To test if the method is accurate, a past fire which is well documented will be recreated to see if the application comes up with the same spread as the real life situation.
For this it is likely that a fire that happened in the United States will be recreated as these are often well documented with all needed parameters. The two maps (the one created with the application and the documented one) will be stacked on top of eachother in a software application such as ArcMap. It will then become clear where the differences in the two maps are and possibly what caused them. The latter will be done by checking the parameters of the area. For instance, is there a slope difference compared to the rest of the area that could have caused problems with the simulation? It is also possible that the type of land cover suddenly changed and that this became a liability in the accuracy of the simulation. These are all things that are considered when looking at the accuracy of the maps and the reason why some parts might not be accurate.

In the case where the previously mentioned method of testing will not work correctly, the created maps will be put into the mobile application to see if it integrates well, as the greater goal is to create a well-working mobile application for people to use.

4.3 Plan B - BehavePlus

In case that the data conversion does not work, FlamMap does not accept data, or data cannot be found, a plan B needs to be in place. In this case, the second option is BehavePlus. BehavePlus is fairly user friendly and has a clear interface with distinct features and needs. BehavePlus is a point model, meaning that it only requires basic information, and not all the layers that Flammap needs although it is the same information. The only thing that is crucial in this programme is to find the right fuel model for the area. Like Flammap, BehavePlus runs on Rothermel’s model and Byram’s flame length model. The downside to using BehavePlus is that the output is not in an ideal format, it produces graphs and tables rather than maps (which FlamMap6) does.

4.3.1 Data acquisition

The data acquisition for BehavePlus is different from FlamMap. Where the latter needs ASCII files, BehavePlus only needs parameters that can be filled in in the programme’s interface. Now, only data on the area is needed rather than point clouds or DSMs. This data can be found on government websites such as ahn.nl and on the website of the national park.

4.3.2 Use of BehavePlus

Once all parameters have been found, they can be entered in the software. The interface of the programme can be seen in figure 4.1. With all parameters filled in, the programme will calculate the Surface Fire Rate of Spread and the Surface Fire Flame Length. It also has the option to add these outputs for Crown fires.

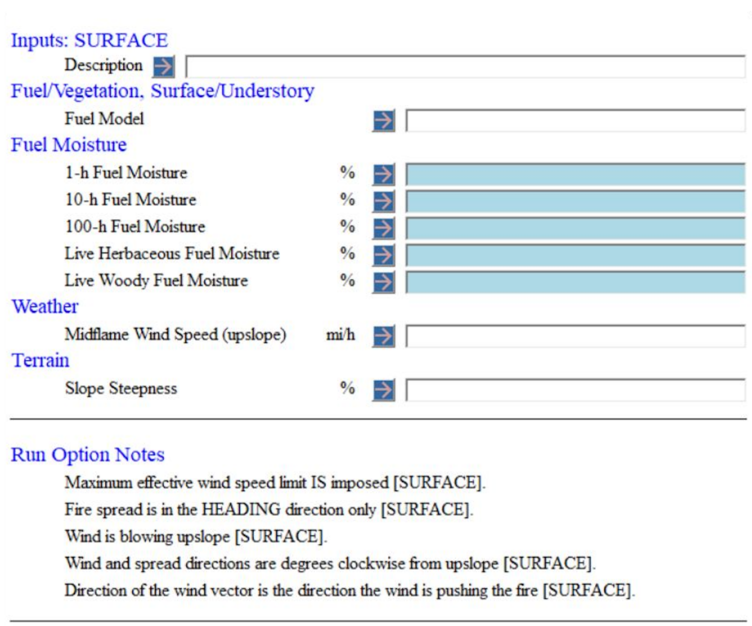


Figure 4.1: Interface of BehavePlus

4.3.3 Analysis

As mentioned above, this programme does not output a map, it outputs values and these can be used to create a graph. This is not ideal for the scope of this project. This makes it difficult to analyse the data as overlap with maps from past fires is not possible. The way to test this method is more or less the same as for FlamMap. A well-documented past fire will be researched and the circumstances (slope, fuel, vegetation) will be put in BehavePlus to see if the application gives the same result as what actually happened. This is more difficult than comparing two maps as this data is often not publically available.

4.4 Plan C - Wildfire Analyst

The third plan is to use software by Wildfire Analyst. This company has made an application for mobile phones that can be used to model a fire in a location of choice. The app will then predict the fire spread based on wind speed, wind direction, temperature, type of land cover, slope, and aspect. The application can only be used to model fire in the app itself, but the company also has software available for computers. In this software, much more can be done than in the application. Additional features include evacuation time simulations, fire spread simulations including different routes the fire could take to spread, risk assessment, and the option to add safe spaces onto the map, as mentioned in the literature research.

4.4.1 Data acquisition

WildFire Analyst has its own database from which a certain area can be selected and worked with. The mobile application has an intuitive, 3D map that allows for easy use and no need to upload new data from other sources. For the software application, data on elevation (a Digital Elevation Model) and a fuel layer based on Anderson (1982) or Scott & Burgan (2005) is needed. A DEM can be created from the DSM available on PDOK (a service from the Dutch government that allows users to obtain geodata) by using ArcMap. The fuel layer will have to be created manually.

4.4.2 Use of WildFire Analyst

The use of WFA will be split into two parts. First, a basic analysis with the mobile application will be performed as the software application needs a demo. For this demo, the company must grant access to the user. With the data from the mobile application, the first maps will be created. These are expected to not be as accurate as the software application as the mobile version can not take too much storage space on one's cell phone. Then, once the demo has been received, the process will be repeated on a computer to get a more accurate result. This will be the part that is going to be analysed in the end.

4.4.2.1 The mobile application - WFA pocket

The mobile application allows for easy use in the field with an intuitive map and interface present. On the interface, the user can add parameters such as land cover, information on wind, slope, and temperature. The application then shows a large, yellow circle on the map, which indicates the spread of the fire. The user can change the amount of time taken to see what the propagation is. The “results” section shows information on fire behaviour and characteristics in the form of a chart. Next to this it shows the outcomes of the calculations, including the rate of spread, residence time (the time the front of the fire occupies one place), intensity of the fire, and flame length. It also shows the distance a person should keep to stay safe. It allows the user to plot multiple parameters against one another in the “Charts” section of the application. Lastly, it enables the user to pick between two fuel models: Scott & Burgan (2005) and Anderson (1982).

4.4.2.2 The software application

For the software application, WildFire Analyst has to receive data so they can create and optimize the programme for the user. Then, the user can easily create different scenarios and obtain several outputs from the application, including a fire simulation, safe routes, and economic damage.

4.4.3 Analysis

The analysis of the results for WFA will be the same as for FlamMap6. As the output is similar, the analysis can be done in the same way. The method here will be to compare two maps, one made by an external company/agency and the other one coming from the used software. The differences will be noted and an analysis of the reason for error will be done.

5 Specification

5.1 Requirement details

For the determination of the requirements, the MoSCoW method is used, as explained in chapter 3. Below, a table can be found with information on the requirements and what category they fall into.

Table 5.1: Requirements according to MoSCoW method

Requirement	*Must have*	*Should have*	*Could have*	*Won't have*
A map that shows fire propagation	X			
Clear evacuation route shown on map		X		
Open source to use in further development of project			X	
Helps in identifying dangerous situations	X			
Understandable for all people	X			
Available to entire population		X		
Helps citizens prepare for evacuation			X	
Shows alternate route when the original one is blocked		X		

	Must have	*Should have*	*Could have*	*Won't have*
Incorporates fire paths to create safer routes			X	
Easy to incorporate into the application that is being made			X	

6 Realisation

6.1 FlamMap6 - What went wrong?

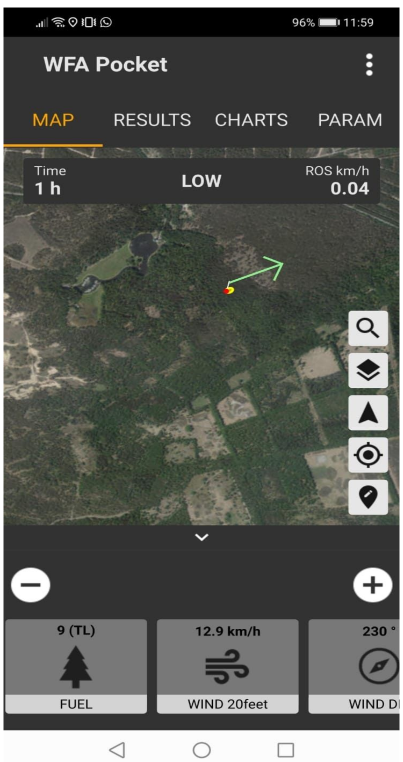
Although some scepticism existed when starting to work with FlamMap, the programme seemed easy to understand and user friendly. The only question was: “Why is no one in Europe using this?” The first task, as mentioned in the ideation, is to create the landscape file. This created many problems. First, it was difficult to find a satellite image of the area that was free for download and where a certain area could be clipped out. After more research, it turns out that the satellite image is not necessarily needed and this was removed from the plan. Then, the landscape file needed ASCII format files from the elevation, slope, and aspect of the area. After searching for a long time, someone from the municipality of Hollands Kroon got involved to help out with the elevation map. It was a known fact that the slope and aspect could be created from the elevation in ArcMap, so it seemed as if the problem was fixed. This was not the case as The Netherlands only has the “AHN” (Algemene Hoogtekaart Nederland ~ Elevation map of The Netherlands). The data from this could only be downloaded in point clouds or in Digital Surface Models or Digital Terrain Models. Unfortunately, some data was missing in the files and ArcMap could not open them properly. The ASCII files that were made based on the point cloud from the AHN were missing a lot of data and this could not be added by hand as the files were obtained in an ASCII format but FlamMap needed an ASCII raster. This was extremely difficult to transform and therefore not possible to use. After this, people from Arcadis were contacted as they have the experience needed in the right programme. However, this also did not grant access to the needed data and the decision was made to move on to the next plan. FlamMap works well in the United States as there is a website that allows the user to download specific, clipped out areas and then instantly downloads the correct ASCII files, while in Europe ASCII files are often not used anymore. This programme does not work well in Europe as it does not contain data from this area. FlamMap is not ready yet for comprehensive use outside of the United States of America.

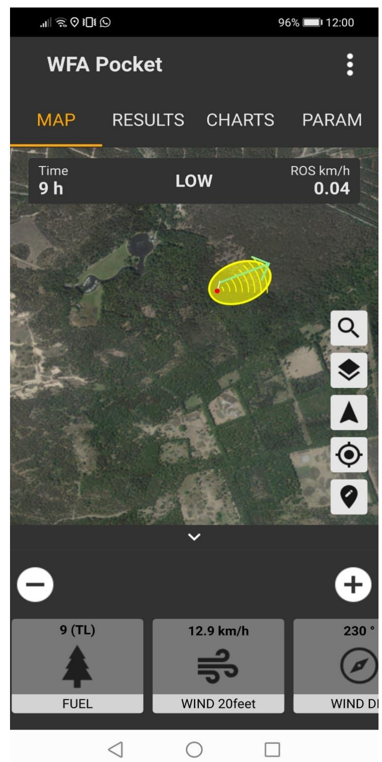
6.2 BehavePlus - What went wrong?

Even though the programme was not extremely difficult to use, there were a few problems with it. First, it was once again hard to find the right data from the area of research. Information on vegetation height and fuel moisture was impossible to find, and these are the most important parameters to get an accurate result. Next to this, like mentioned before, the output of the application is not necessarily what works well for the wanted result of this project. The projected output gives accurate results but with just numbers, it is hard to make a nice, visually appealing explanation of what is actually going on. Personal lack of knowledge on the subject rendered this plan not workable as it was difficult to analyse, or even get, the results and to make sense of them.

6.3 Wildfire Analyst Pocket edition

Here, the process for the mobile application is described. Please note that this fire propagation is not perfectly accurate as in the application it is not possible to add more than one vegetation type or information on the topography of the area. The function of this part is to show what the application does and how it works. In the figures below, the propagation of the fire can be seen as a yellow circle. The green arrow is the direction in which the wind blows and the red dot is the starting point of the fire.





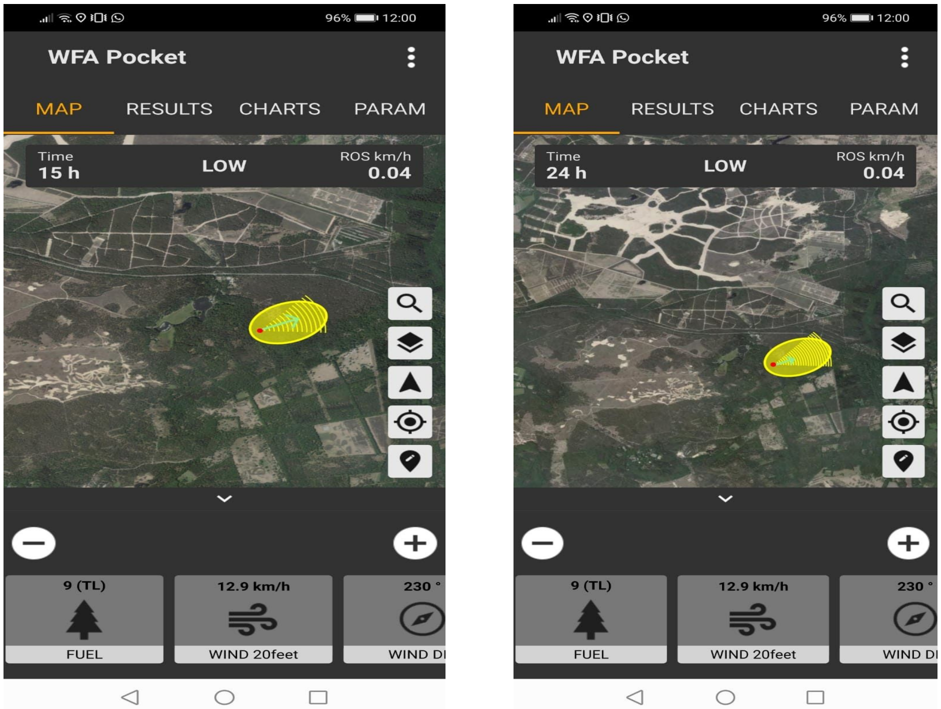


Figure 6.1a-e: Screenshots of the application Source: Wildfire Analyst Pocket edition

The screenshots were taken at the one hour mark, three hour mark, nine hour mark, 15 hour mark, and after 24 hours. As can be seen in the images, the yellow circle expands in the direction of the wind, this is the way the fire will propagate. As mentioned earlier, this is not very accurate and that is why the software application is needed.

6.4 Wildfire Analyst software application - What went wrong?

Unfortunately, the company never emailed back so the software application could not be used as the user has to get the demo from the company. This is unfortunate as it seemed a fantastic solution. The next step will be to revisit FlamMap 6 to see if there is another option to use that programme rather than finding a complete new solution.

6.5 FlamMap revisited

6.5.1 The new plan

After trying out several other methods which all did not work up to the standard where significant research could be conducted, FlamMap was revisited. As mentioned in the ideation chapter, an area of the United States of America was selected to test out the software. This area is somewhat similar to the initial area of research, the forest around the University of Twente. The selected area is near the Rockhouse 1 weather station in Oregon (specific location: latitude in decimal degrees: 44.9250, longitude in decimal degrees: -123.4694). The obtained data will be put into the mobile application to see if it works as it should. The reason for the change of location is the fact that the United States has the required data available in the right format, making it much easier to conduct research. Whether to move on with future work on this topic will be assessed based on the results after combining the data with the mobile application.

6.5.2 Execution

Fire behaviour options

FlamMap6 requires several steps to produce a fire propagation map. As mentioned in previous chapters, FlamMap works with landscape files. These files contain ASCII grid layers on elevation, slope, aspect, fuel model, and canopy cover. As the research has been moved from The Netherlands to a location in the United States, the landscape file can be downloaded as a whole without having to put it together yourself. This data can be found on https://iftdss.firenet.gov/. This is the website of the American government that contains all of the data needed to model fires. Next, this landscape file is placed into FlamMap. This can be seen in figure 6.2.

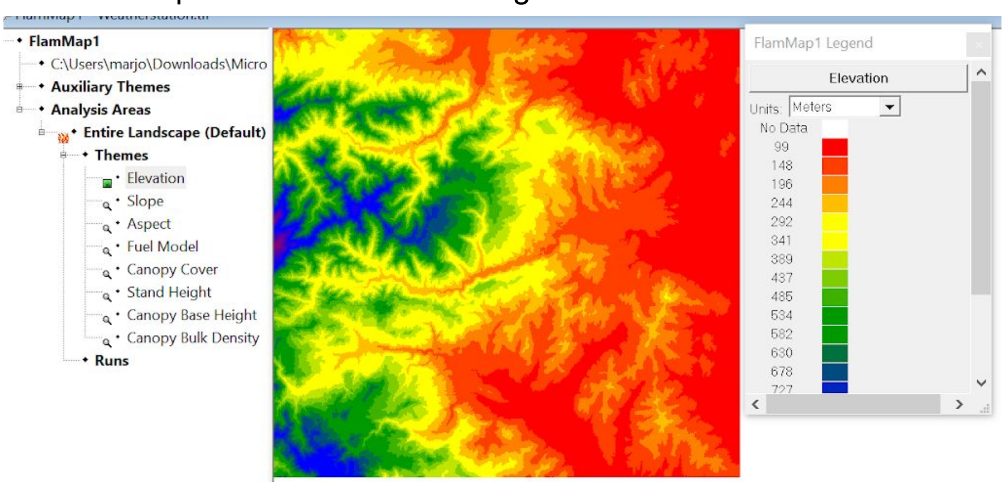


Figure 6.2: FlamMap after uploading a landscape file

After this, a “FlamMap run” has to be done. This can be found in: *Analysis area → New FlamMap/MTT/TOM Run.* After that, inputs can be selected. These inputs include a fuel moisture file (format .fms). This file contains information about the amount of moisture left in the fuel after 0 hrs, 1hr, 10hrs, 100hrs of burning, herbaceous fuel moisture, and live woody fuel moisture. FlamMap can create this file based on the fuel layer added in the landscape file. Next, the wind direction is set to a speed (20 MPH) and an azimuth is put. This is an angular measurement, and it is set to 30 degrees. Then, the canopy characteristics are added. This contains foliar moisture content (set to 100%) and a crown fire calculation method is added. In the case of this research that method is Finney (2004). Lastly, fuel moisture settings are added, in this case in the form of a weather stream (format is .wxs). This file has to be created with data from weather stations and the use of Fire Family Plus. In Fire Family Plus, a FW13 file is created. In the programme, the weather station is selected (in the case of this research that weather station is Rockhouse 1), a time frame is set, and an analysis period length is set, this has to be set to 1. Then, the programme allows for a FlamMap export. The step-to-step guide can be found on https://iftdss.firenet.gov/firenetHelp/help/pageHelp/content/20-models/classifiedwthr/aboutwxslfb.htm. Then, this file is imported into FlamMap with a selected time frame. In the case of this research that time frame is July 1st to July 31st. Then, the “Relative spread direction from maximum” was chosen, as this creates a more accurate output. Lasty, outputs are selected. For this research the following ones were chosen: fireline intensity, rate of spread, flame length, crown fire activity, spread factors, horizontal movement rate, and lastly all of the fuel moisture outputs (1hr, 10hr, 100hr, 1000hr). These results can be found in appendix 9.3.

Minimum Travel Time (MTT)

To create the maps needed for the mobile application, a more accurate map of the fire propagation, including all fire paths and the major fire paths, is needed to make the final product more accurate. This can also be done in FlamMap by using the “Minimum Travel Time” function. This function needs all of the inputs mentioned above, plus a file that contains information on locations of the ignitions of the fire. These ignitions can be simulated in FlamMap itself and then be saved as a shape file (.shp) to serve as input for the MTT function. The parameters on spotting and calculations are set to their standard number, this can be seen in figure 6.3. Like the results from the FlamMap run, all results can be found in appendix 9.3 and all results will be discussed in the next chapter.

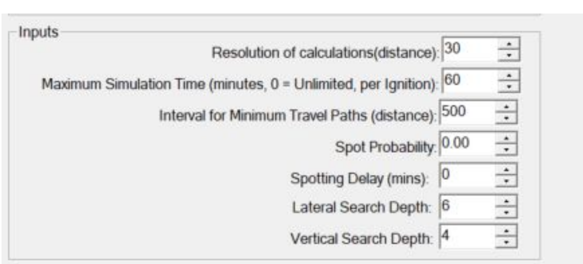


Figure 6.3: FlamMap’s MTT inputs, set to standard

7 Evaluation

7.1 Analysis of the results

As can be seen in appendix 9.3, several maps were produced. These maps contain all kinds of information on fuel type, topographic parameters, Minimum Travel Time functions, flow paths, and fire information such as fireline intensity and rate of spread. In this paragraph, some of the maps will be discussed and an analysis will be done to see if the maps are considered accurate. It is crucial to note that the initial idea was to put the maps into the mobile application to see if they worked together. Unfortunately, this was not possible due to time constraints.

The first thing that has to be discussed is the fact that the “100hr fuel moisture map”, figure 9.3.8 shows a completely different site than the “1000 hr fuel moisture map”, figure 9.3.9. The 100 hrs map shows a much more diverse amount of moisture left in the vegetation than the 1000 hrs map. It is likely that this is due to the fact that during the burning, water continuously is condensed and evaporated. It is important to note however that the difference in fraction is rather small. Therefore the difference could also be caused by a mistake in the data.

For figure 9.3.10 it is important to note that the “0” connected to the colour grey means that there is no data available, and the “0” connected to the colour green means that the rate of spread is less than a meter per minute.

When comparing the fireline intensity map to the MTT fireline intensity map, which runs on a different model, one can see that the latter one shows a more mild view of the simulation. This might be due to differences in calculations between the different models.

A factor that shows that the programme works rather accurately is figure 9.3.21, where the major flow paths are put onto the map with the canopy cover. In this map, it is shown very clearly that the fire path follows the vegetation, especially the places where the canopy cover has a high percentage. This means that the trees cover a large part of the ground as seen from above.

Figure 9.3.24 shows something rather interesting. When looking at the map, one can see that the major fire path follows the places where node intensity is high. These nodes are used for spotting to see the maximum spotting distance and azimuth, based on canopy cover. When looking at figure 9.3.15, it seems that this node intensity is linked to the slope.

The maps containing data on arrival time, figure 9.3.11 and 9.3.41, show a complete red map. This is because all the data falls into one category. It is not understood why the information is spreaded in smaller fractions to make this map clear. It is not a feature that can be adjusted by the user.

The integration into the application
When integrating this information into the application, it would be best to use the maps on rate of spread and the flame paths. When overlaying the flame path on the map showing the fuel model (where the roads are clear) it becomes clear where the fire will cross a road. These roads should not be available for evacuation as that puts people in great danger. Next to this, the rate of spread and the arrival time (if there is a way to make this more accurate) can be used to calculate how much time people have to get out of the area. This is important in the case of evacuation as time is a crucial factor for authorities to ensure the process is safe.

7.2 Requirement review

A part of the evaluation is looking back at the MoSCow that was created at the start of the specification phase. A very important requirement was the map that showed fire propagation. This goal has been accomplished as the maps showing rate of spread and the maps that show the flow paths give a clear view on the expected propagation. The next goal was “helps in identifying dangerous situations”, which it does. The flow paths in combination with the map showing fuel types give away the location of roads and where the fire will cross the roads. Next, “understandable for all people”, it is a little difficult to say whether this goal has been achieved, but overall the maps give a clear view of the area. Improvements on this can be found in the “future work” section of the thesis, in chapter 8. Many of the “should have” requirements will become clear once the maps are integrated into the mobile application. Only then information on evacuation routes and availability to citizens will become available.

7.3 Ethical considerations & possible misuse of the result

This part of the report was taken from an essay written for Reflection. The full version can be found in appendix 9.4.

7.3.1 Ethical considerations

The first ethical consideration to take into account would be the people who live in remote areas, far away from cities, with poor roads leading to the villages. If these people live in or near a forest, they are likely to be the first ones affected by these disasters. The roads here are sometimes not properly documented or are just not made to transport many people in a short amount of time, so the evacuation plans have to take this into account as these people must also have the chance to get to safety.

Next, the difference between wealthy and poor people should not affect the plans and jeopardize the safety of a part of the population. There must not be a way for the more prosperous citizens to get to safety earlier on because they already knew the evacuation routes beforehand or because they have the ability to receive the news earlier. The plans of evacuation and the fact that evacuation is necessary should be received by all citizens accordingly.

The plans also must act on the fact that not all citizens are able to get away themselves, for instance elderly people who do not have a car. These people also have to have the chance to get to safety and the government/local authorities must be aware of this and have an extended plan ready for these citizens.

7.3.3 Possible misuse of the result

This part of the chapter comes from a paper writing for "*Reflection".* The whole paper can be found in Appendix 9.4. This section is on the malicious things people could do with the result of this thesis. Even though designers try to help people with their projects, there are always people who see an opportunity to use it with malicious intent.

Unfortunately, not everyone has good intentions. In every great invention that is meant to help people, there is a way to abuse the good of some and apply it in a terrible way. It is worth mentioning that for this chapter, the final goal (making the maps available for more locations) is taken into account rather than just de Veluwe.

First of all, hacking. The database with these maps can be hacked and people can put in wrong information which can lead to catastrophically dangerous situations. Different data creates different fires, and it is crucial for the evacuation routes that the right fire propagation is used. If not, all the people in the area can go in the wrong direction and walk straight into the furnace. This is obviously not the reason that these maps are being made. The hackers can manipulate the data in such a way that the maps show certain routes that are completely unsafe, even though the people using them think they are headed in the right direction. So, shortly: creating a situation where the maps are based on the wrong data.

Next, the correct maps can be used for the wrong reasons. If these maps are available to everyone, and they should be as every person should be able to get to safety, then people with malicious intentions can get to them as well. They could check the maps beforehand, block the designated evacuation route so that in the case of a fire, people cannot get out via that route. As de Veluwe is a rather big area, it could take a long time for people to travel to another exit to get to safety. During the event of a fire, time is of the essence as fire spread is not linear. What you want is for people to follow a clear, streamlined evacuation route and if this is blocked, there will be massive amounts of panic which will cause more people to get injured.

Thirdly, the maps could show secret military bases. If it happens to be that the evacuation route goes straight through a military training location, this will create many problems (example: citizens getting shot for entering a classified site). Now, this can obviously be avoided by blocking out that area on the options of exits. Problem solved! Well… no. If people with bad intentions think ahead (and they probably do as they have a clear goal envisioned) and check these maps, they could wonder why a specific area of the map is blocked out. It becomes clear that the public can not enter that area, and they could wonder why that is the case. If they manage to put 1 and 1 together, they will come to the conclusion that the specific area on the map must contain something that is not meant for the public, and could mistreat this information. This jeopardizes national security and the safety of the citizens.

The last case that was thought of is not necessarily malicious or evil, but it is a reality that has to be taken into account. If the maps show where the fire is going to go, and it happens to be that the fires cross the same piece of land every time, this plot of land could lose its value. This often happens when a piece of land is located in an area that is prone to disasters or other things that cause dissatisfaction, such as a railroad 10 meters from the backyard. This is not that much of a problem when it’s owned by the national park, but when it happens to a piece of land that belongs to a different owner, let’s say a homeowner, it could be terrible for them. The price of their house will decrease. This might not be as terrible for the public as the other mentioned cases, however it could be upsetting for the people living in the area around the national park, or maybe even in the park.

8 Discussion and conclusion

8.1 Conclusion

Based on the analysis of the results, the following conclusion is drawn. After many tries with FlamMap and several other programmes, FlamMap seems to be the best option. It is a well working programme to map fires as long as the user is mapping the United States. It is crucial to note that outside of that area, the programme becomes a lot less user friendly and more difficult to understand. Next to this, it is unfortunate that several other programmes have to be downloaded to perform tasks in FlamMap, such as FireFamilyPlus. FlamMap requires quite a lot of processing power and this was a problem during the Minimum Travel Time modelling phase. Especially afterwards it often took a long time for the maps to load. It is difficult to find a programme that is open source and uses commonly available data for this purpose. It would be a great opportunity to develop a programme like this. The next step would be to integrate the maps into the mobile application, more about this can be read in paragraph 8.3.

8.2 Limitations

A crucial limitation, which can also be read about in chapter 6, is that several of the application options only work in the region in which they were created. For instance, FlamMap works perfectly in the United States as the data is freely available there in the right format, but it is difficult to get the programme to work on other areas. An advice would be to have governments/companies who work in this field discuss this topic and come up with a solution together.

Next, it is important to note that the way of analysing the accuracy of the results is not the best way to go. The method used is very inaccurate and unprofessional, but due to time constraints no other way was possible. In the future, this should be done more accurately, with user testing and expert reviews.

8.3 Recommendations & possible future work

One extremely important future work would be to get the programme, FlamMap, to work in different areas than just the United States. The idea is to make the mobile application available for large numbers of people in different countries and that is not possible as of right now. However, this requirement is crucial to the final product. As of right now, it is difficult to get FlamMap to work in The Netherlands. In a future attempt, someone with a lot of experience should look into this.

In the future, a better analysis of the product should be done. Here the results should be integrated into the mobile application to see if it works well for the user and if any problems occur. Then, extensive user testing can be done and a more accurate analysis of the results can be performed.

One of the “must have” requirements was that the product is understandable for all people. While the maps are clear, it is unsure whether all information is understood by people of all ages. Something that could help in this is adding landmarks and names of roads and cities, to give a more clear view of the user’s location and where they should be headed to get to safety.

9 Appendices

9.1 Appendix A - WRF model components

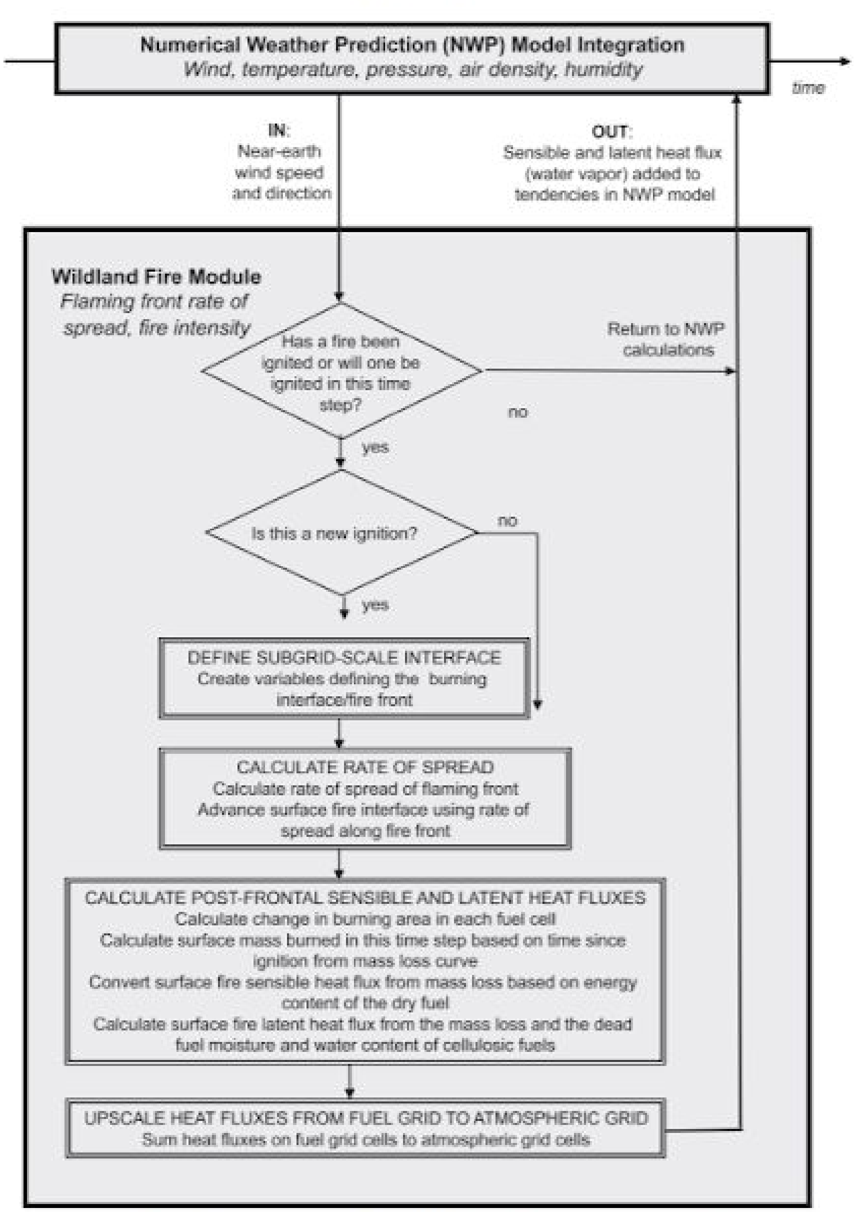


FIG. 1. The components of the WRF coupled weather–fire model.

Source: Coen et. al. (2013) WRF-Fire: Coupled Weather–Wildland Fire Modeling with the Weather Research and Forecasting Model, Journal of applied meteorology and climatology volume 52, page 6, link: https://journals.ametsoc.org/doi/full/10.1175/JAMC-D-12-023.1

9.2 Creative Technology design process

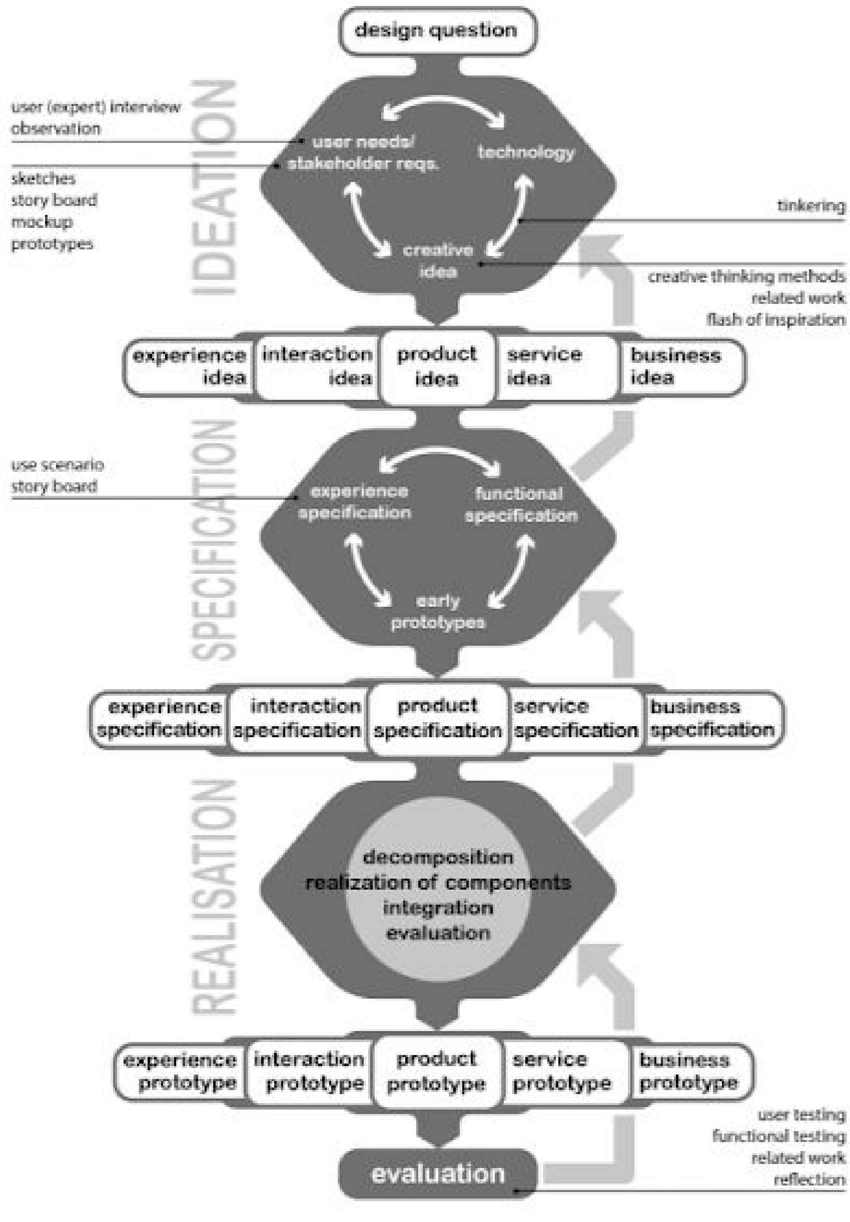


Figure 1. A Creative Technology Design Process

Source: Mader, A., & Eggink, W. (2014). A design process for Creative Technology. INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION, 1–6. Accessed from https://www.designsociety.org/download-publication/35942/a_design_process_for_creative_technology , page 3

9.3 FlamMap run outputs

Flow paths showing on multiple base maps

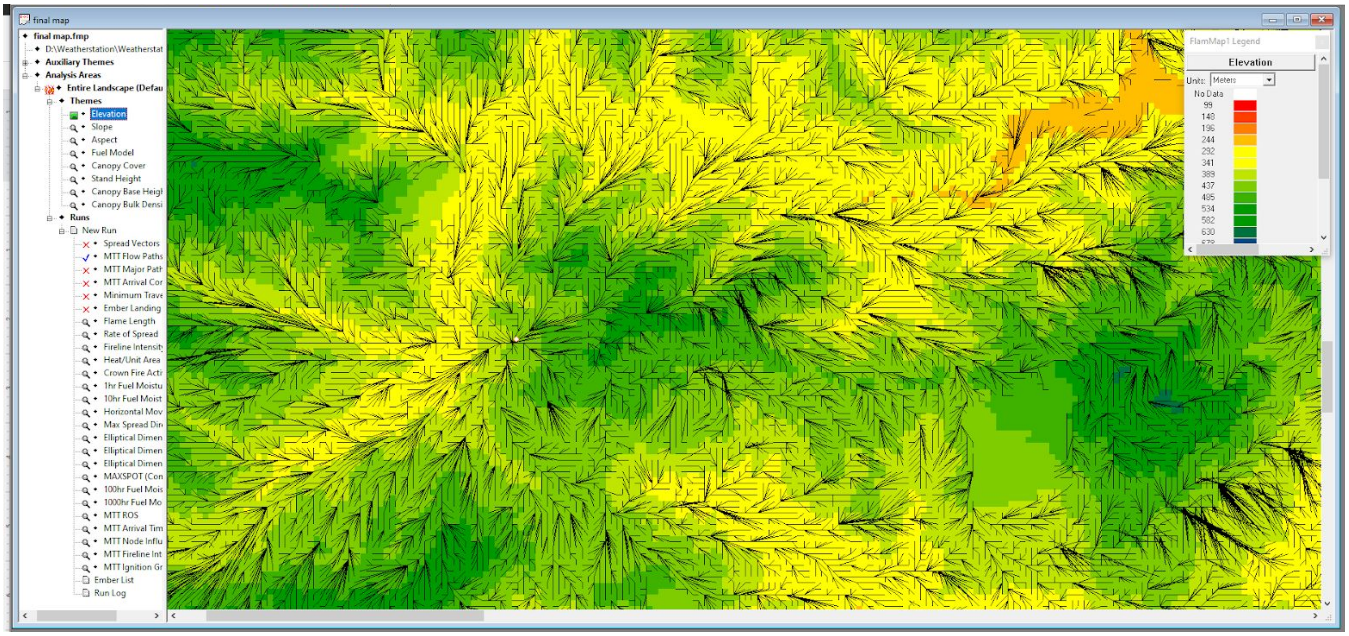


Figure 9.3.1 Elevation

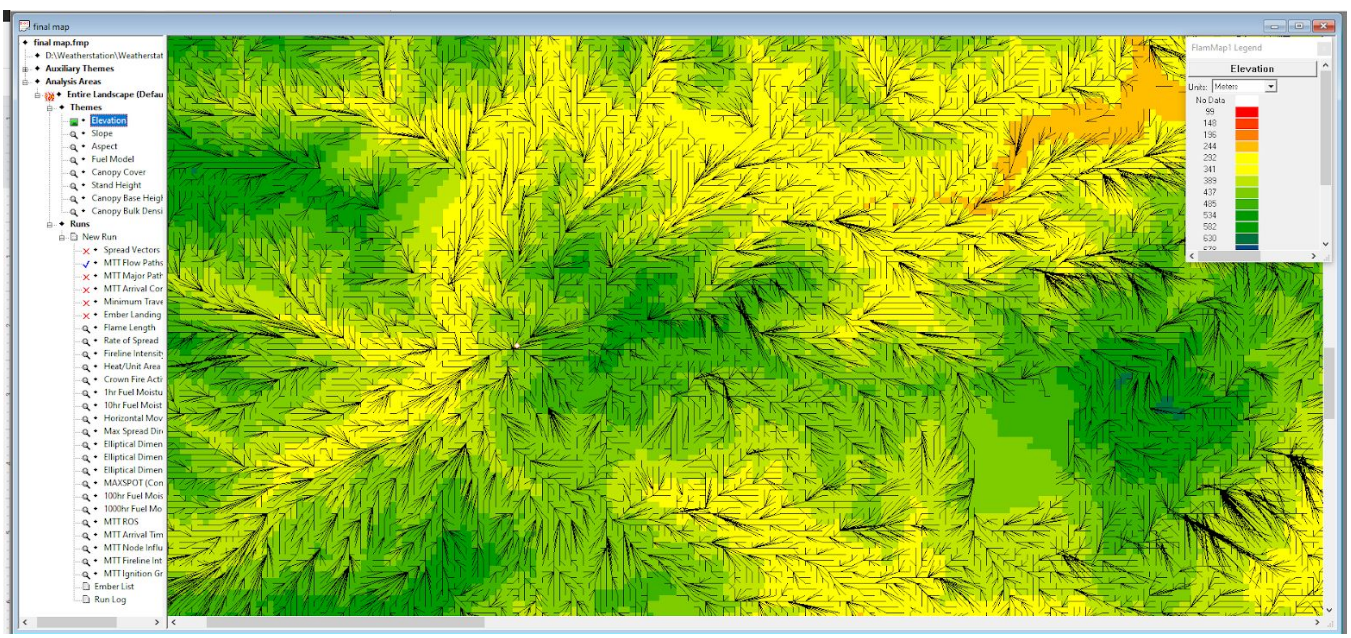


Figure 9.3.2 Fuel model

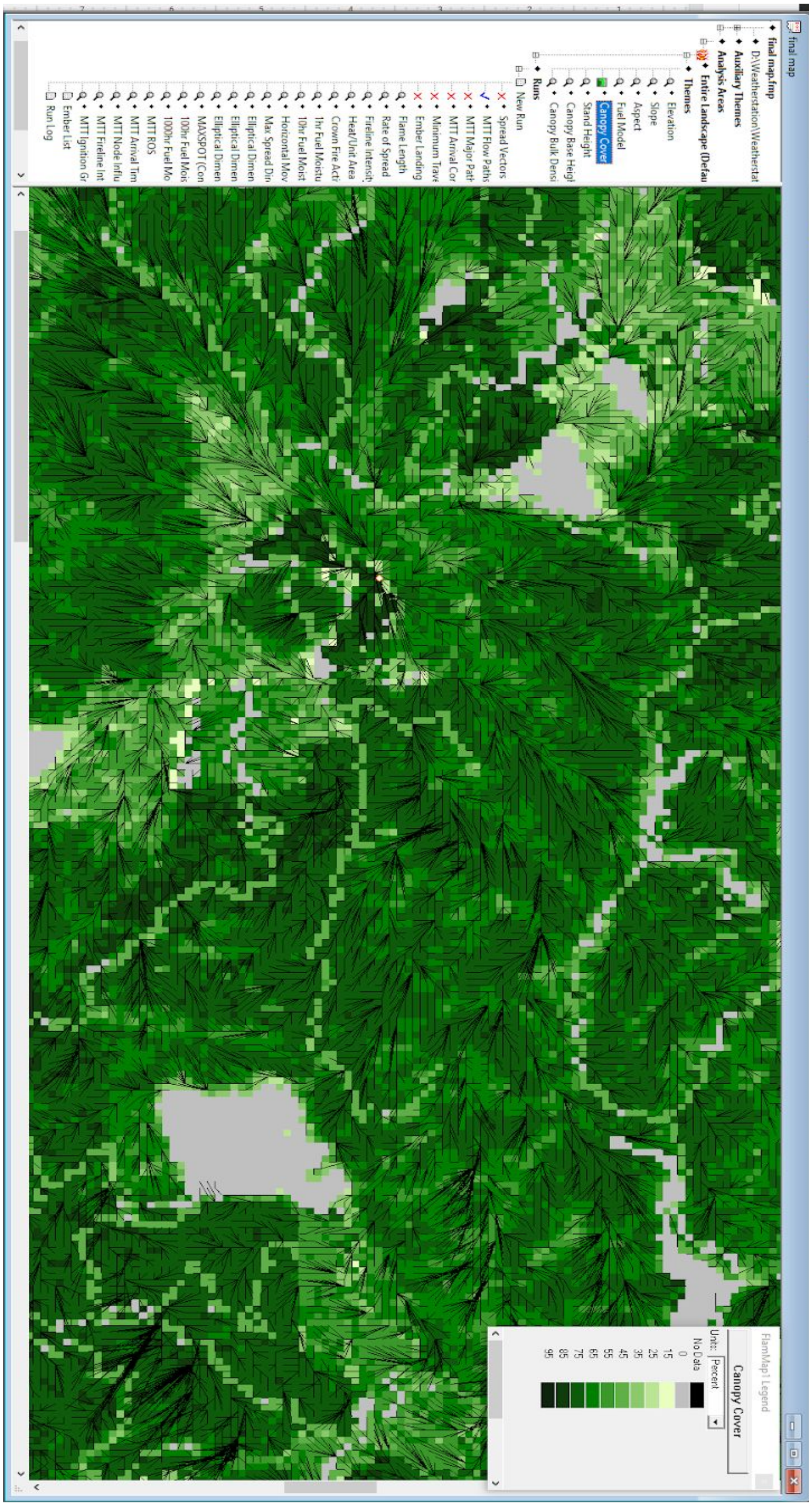


Figure 9.3.3 Canopy cover, this one has been rotated as it was difficult to see otherwise

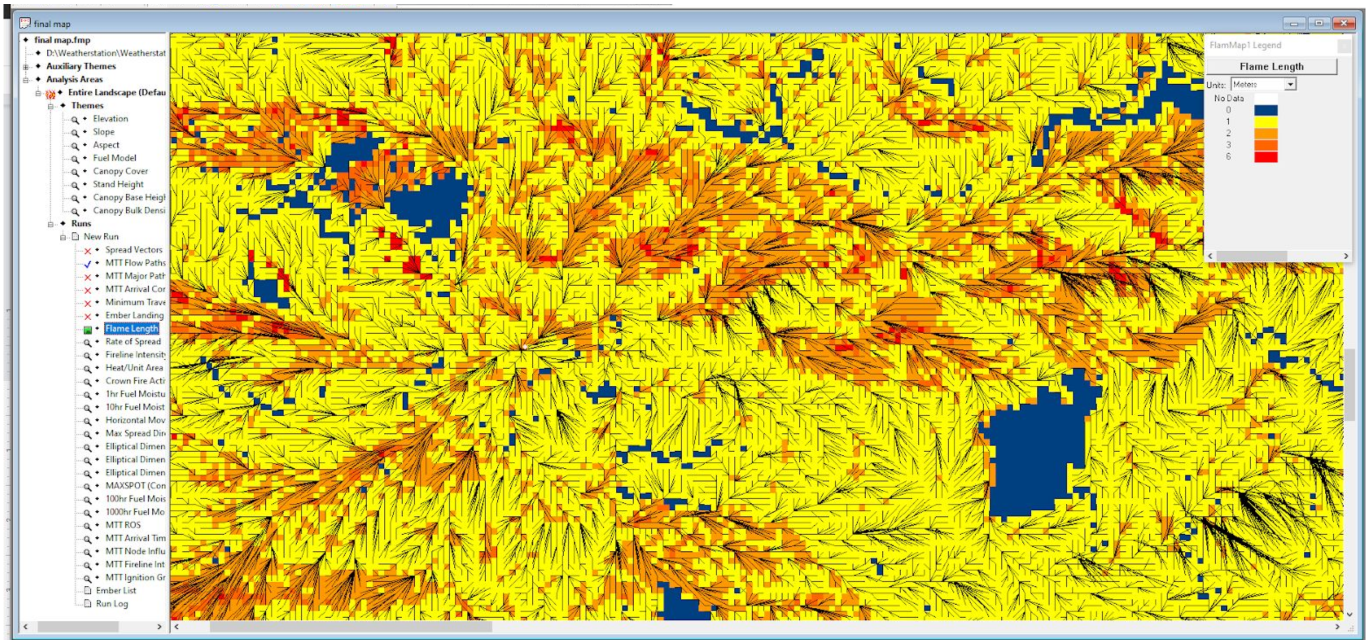


Figure 9.3.4 Flame length

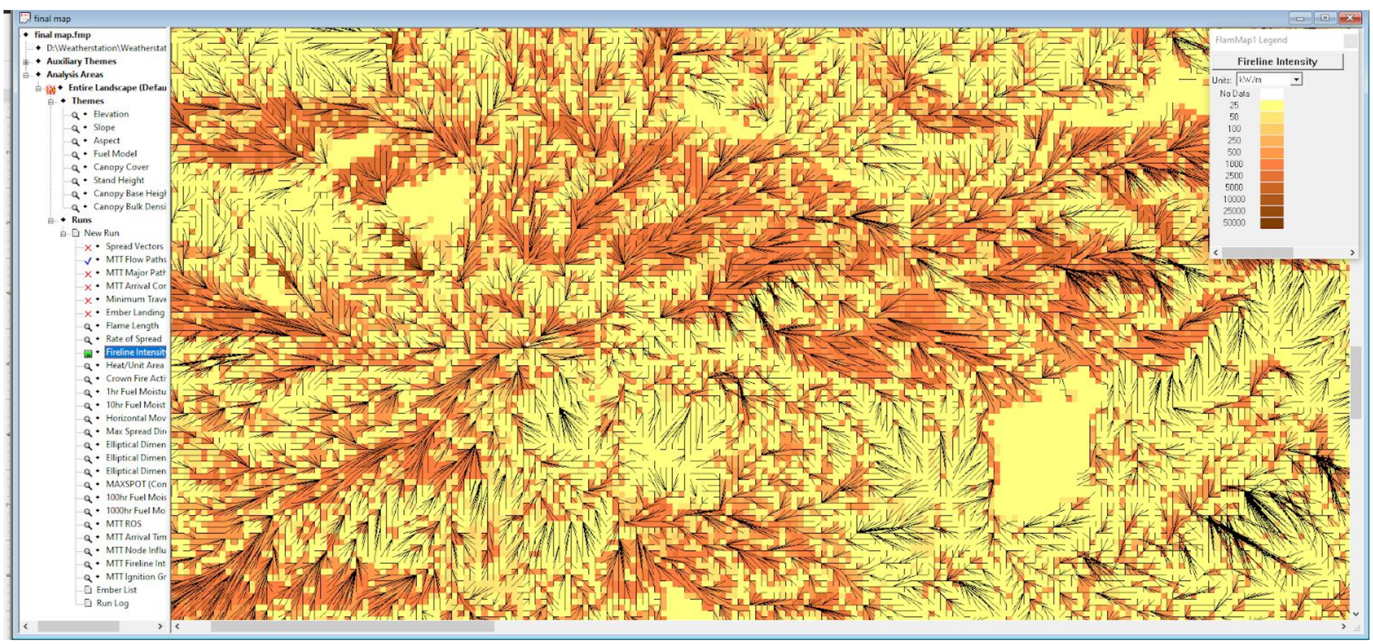


Figure 9.3.5 Fire line intensity

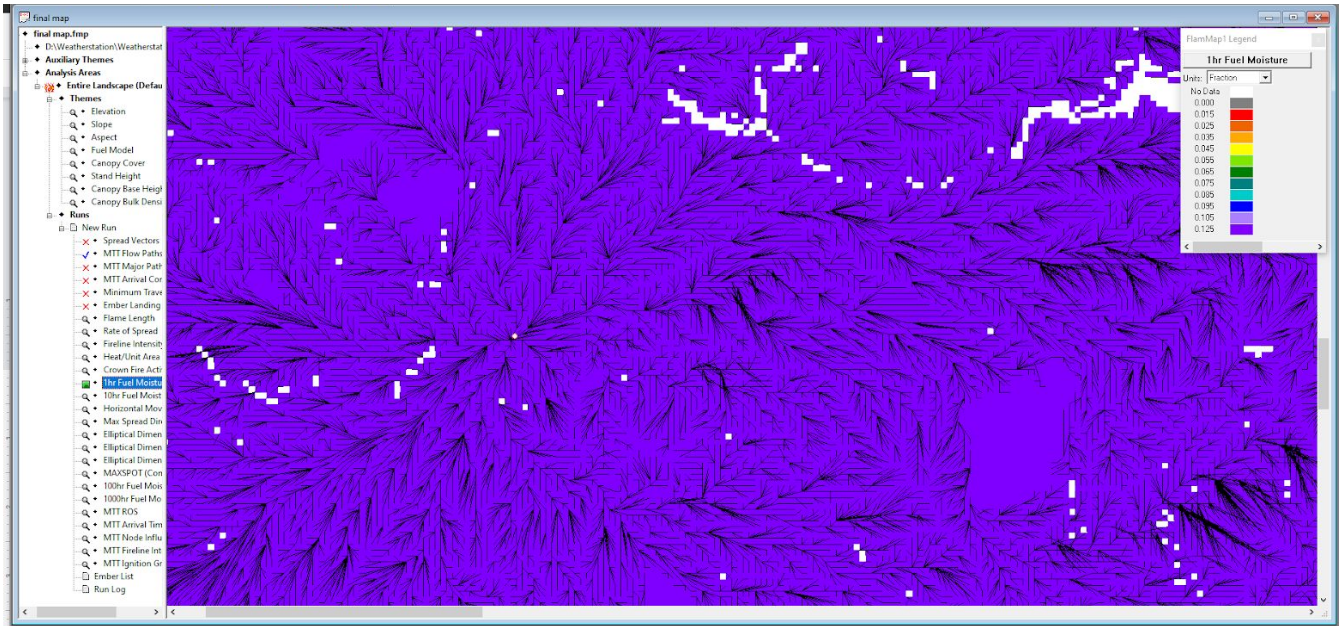


Figure 9.3.6 Fuel moisture 1hr

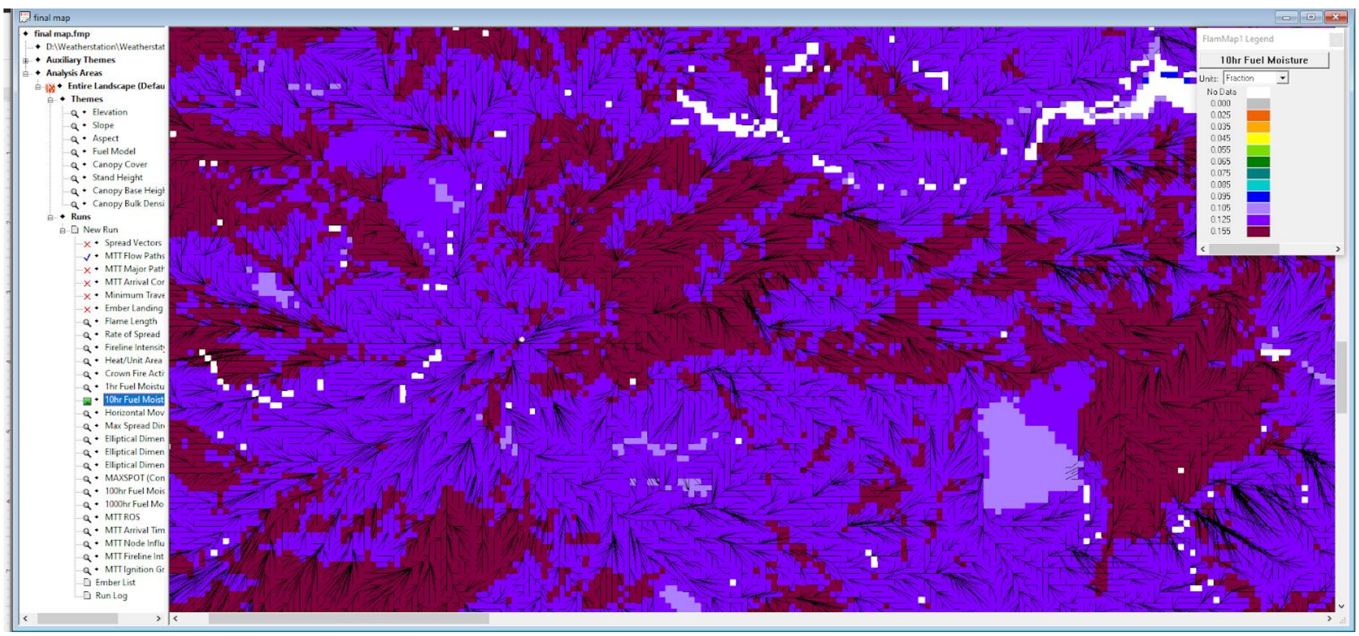


Figure 9.3.7 Fuel moisture 10 hr

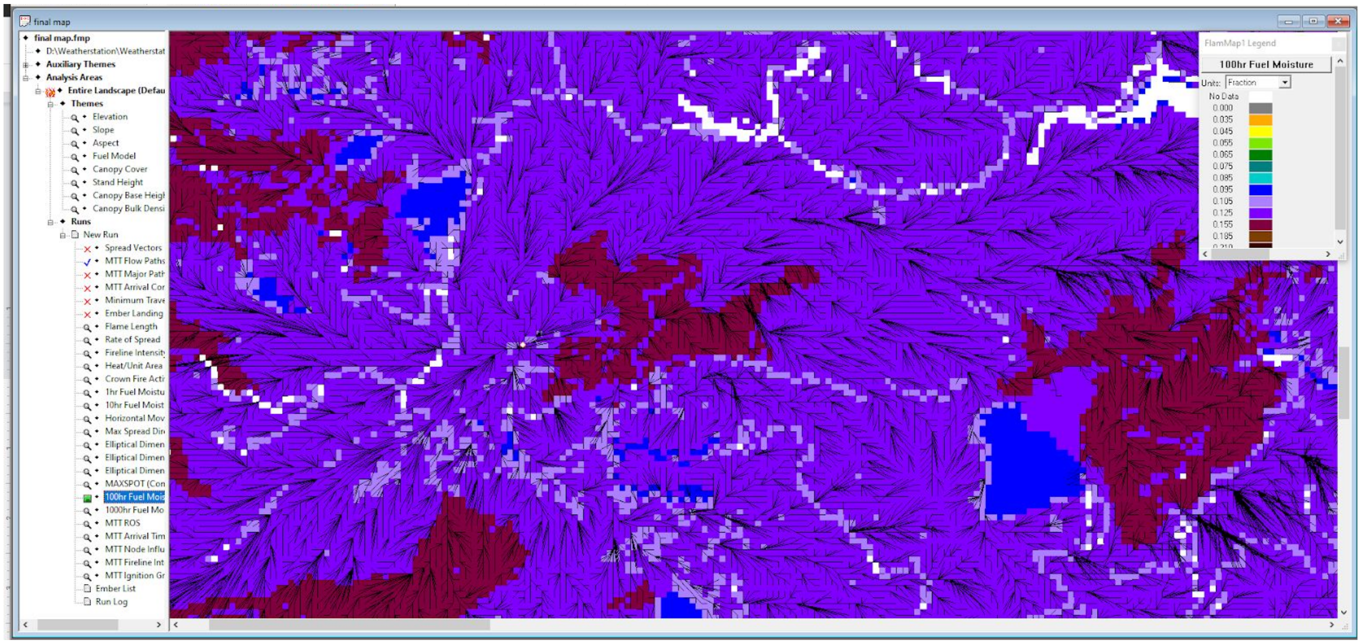


Figure 9.3.8 Fuel moisture 100 hr

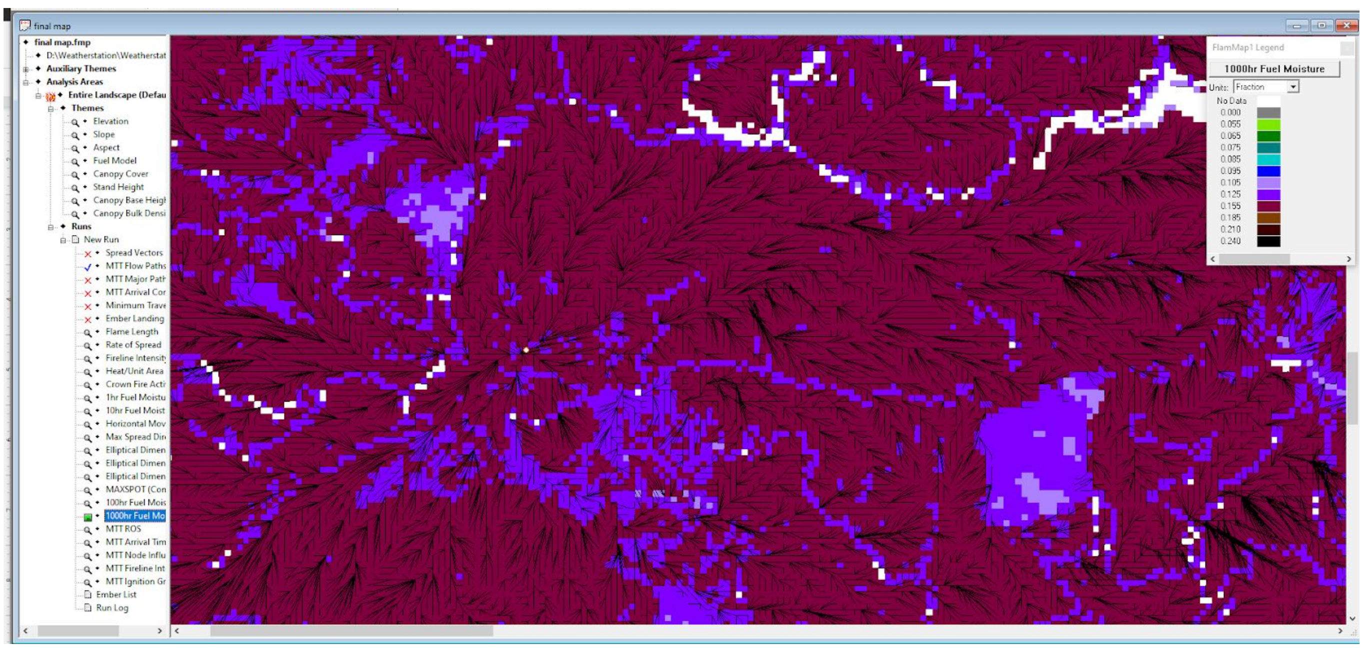


Figure 9.3.9 Fuel moisture 1000hr

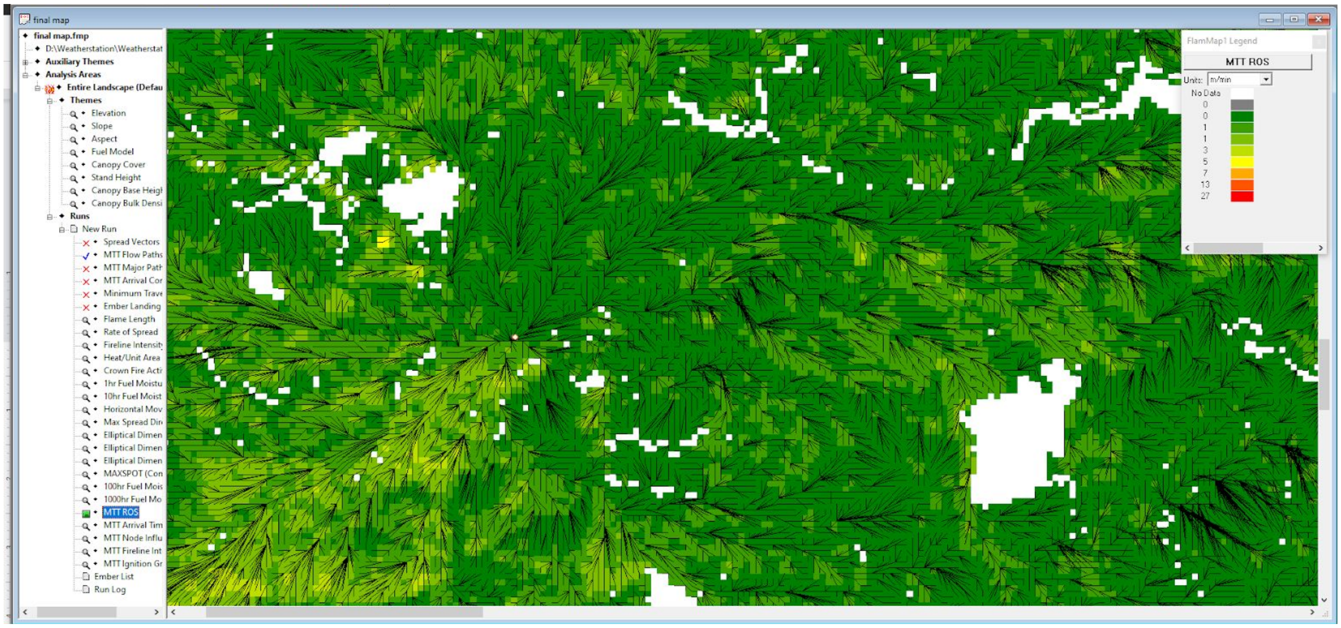


Figure 9.3.10 MTT ROS

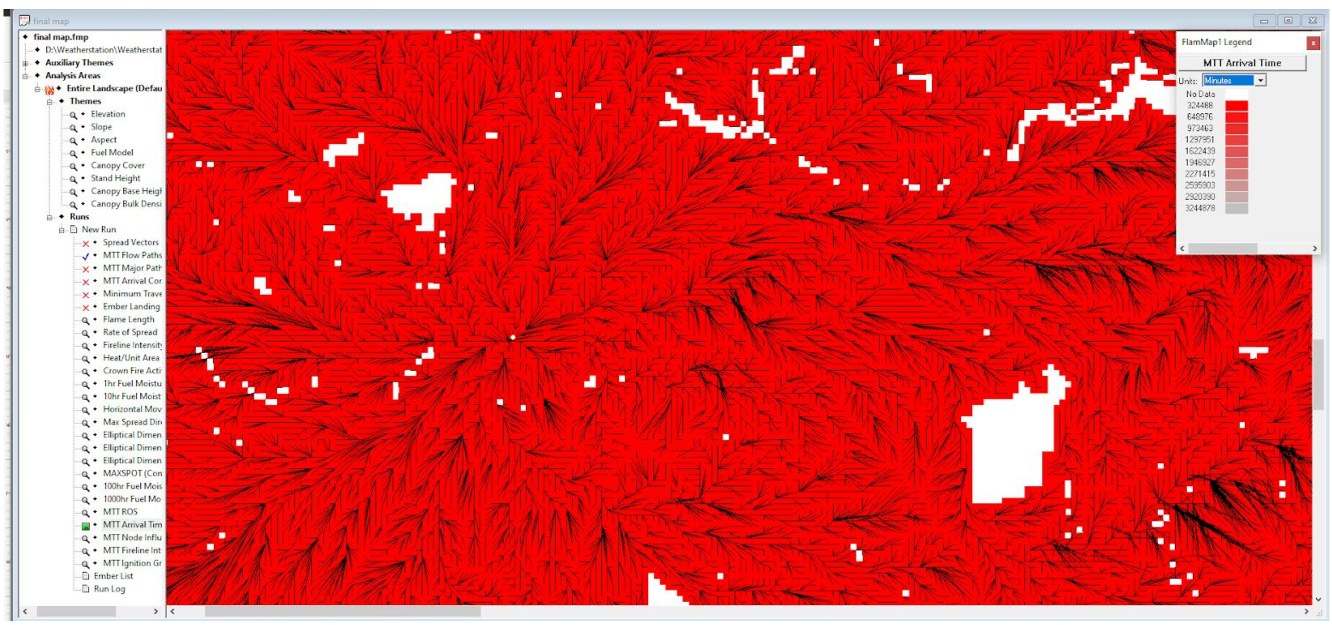


Figure 9.3.11 MTT arrival time

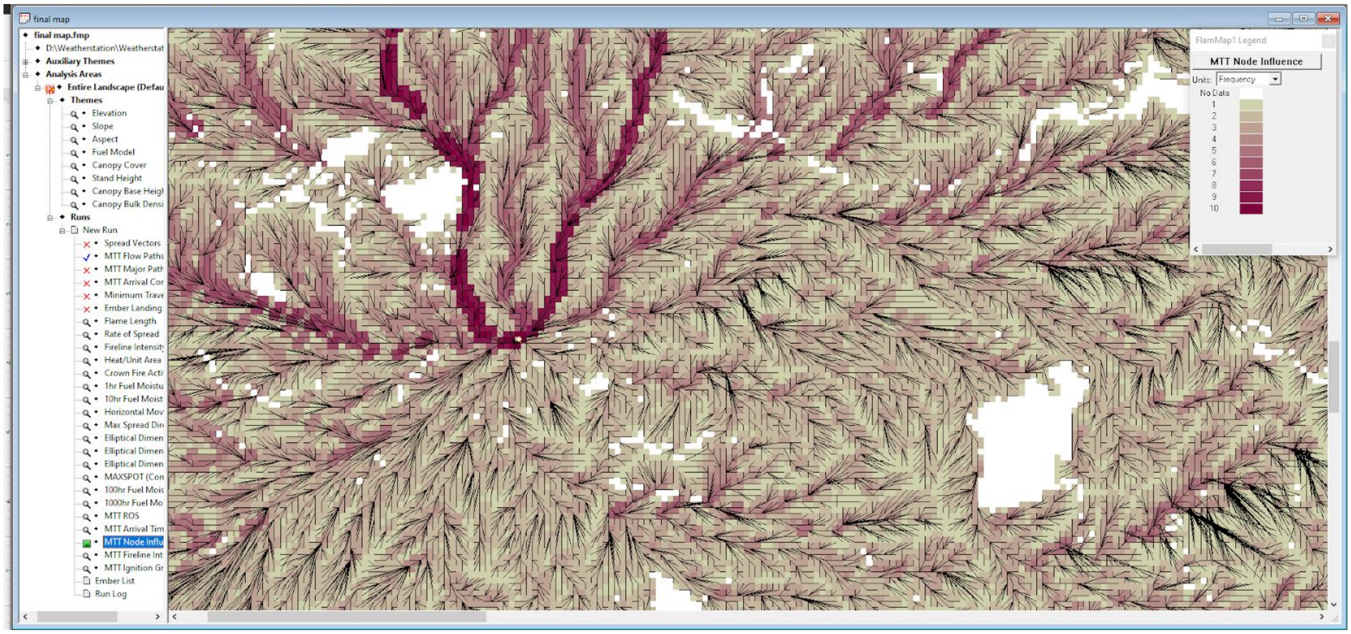


Figure 9.3.12 MTT node influence

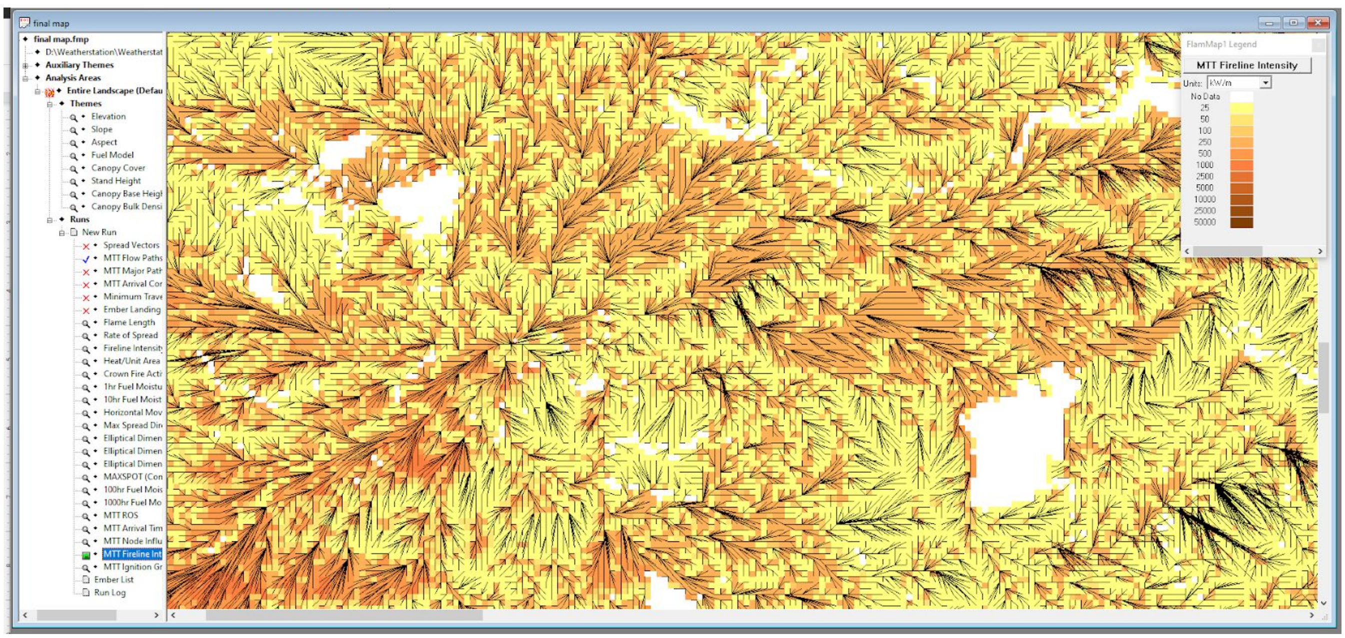


Figure 9.3.13 MTT fireline intensity

All themes (basemap) without run overlays (note: different zoom than with flow paths)

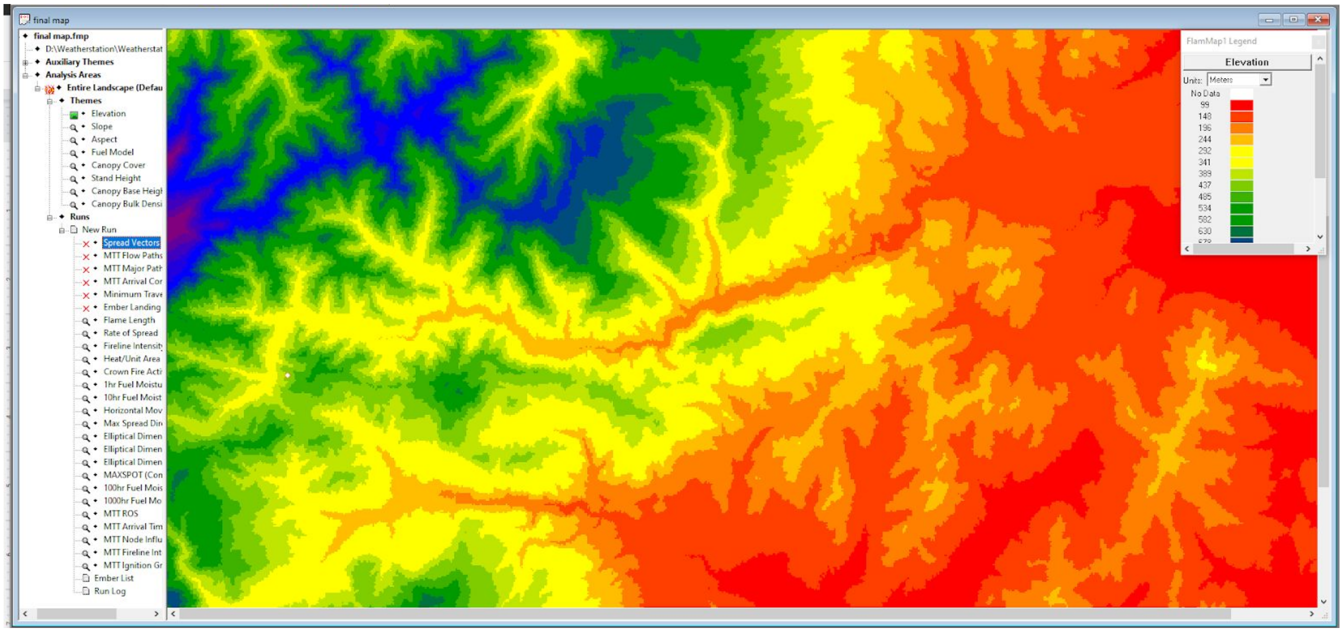


Figure 9.3.14 Elevation

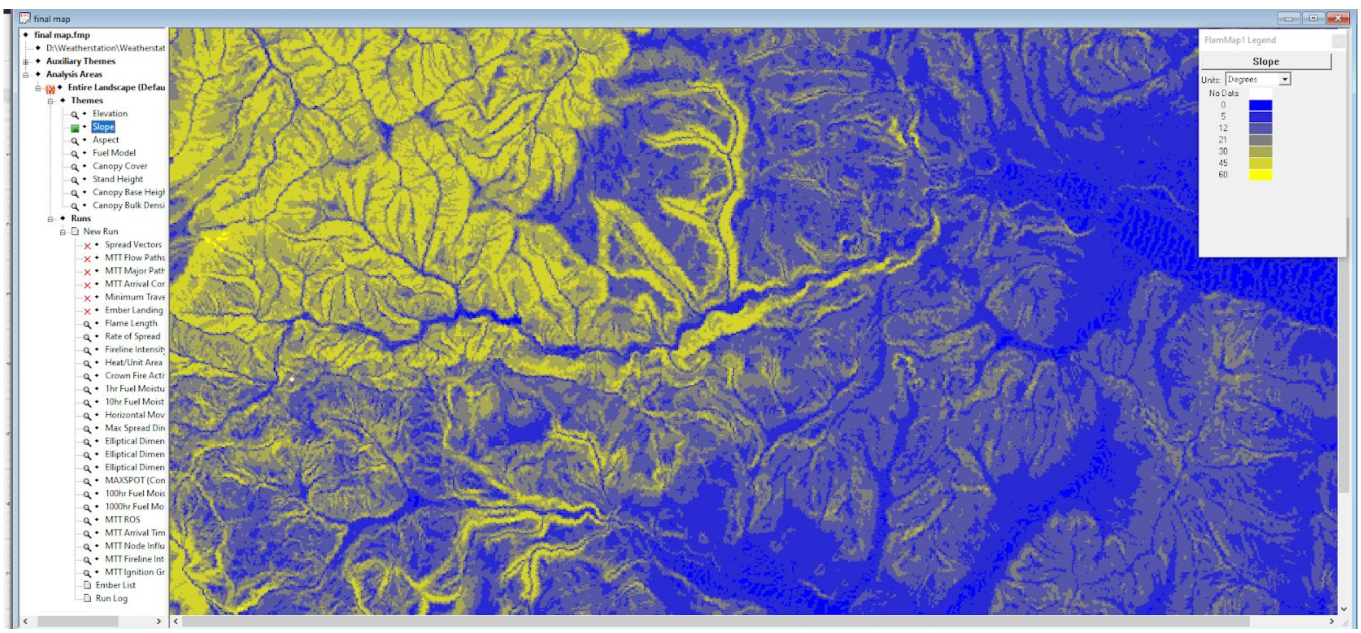


Figure 9.3.15 Slope

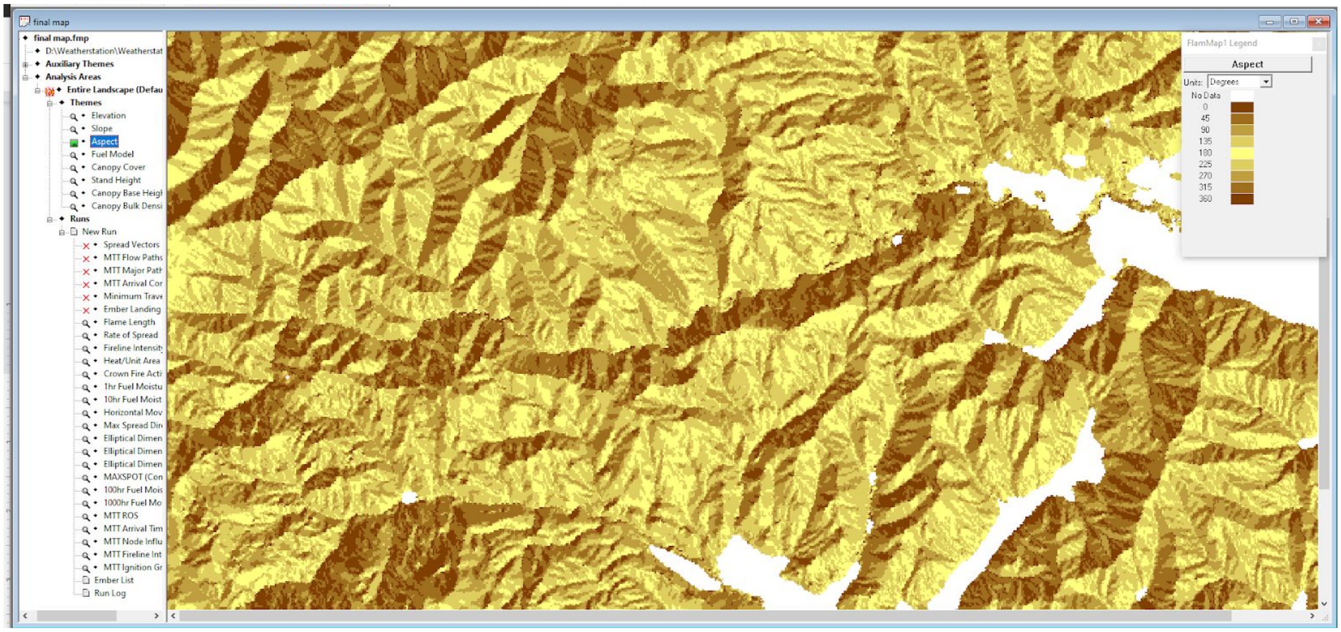


Figure 9.3.16 Aspect

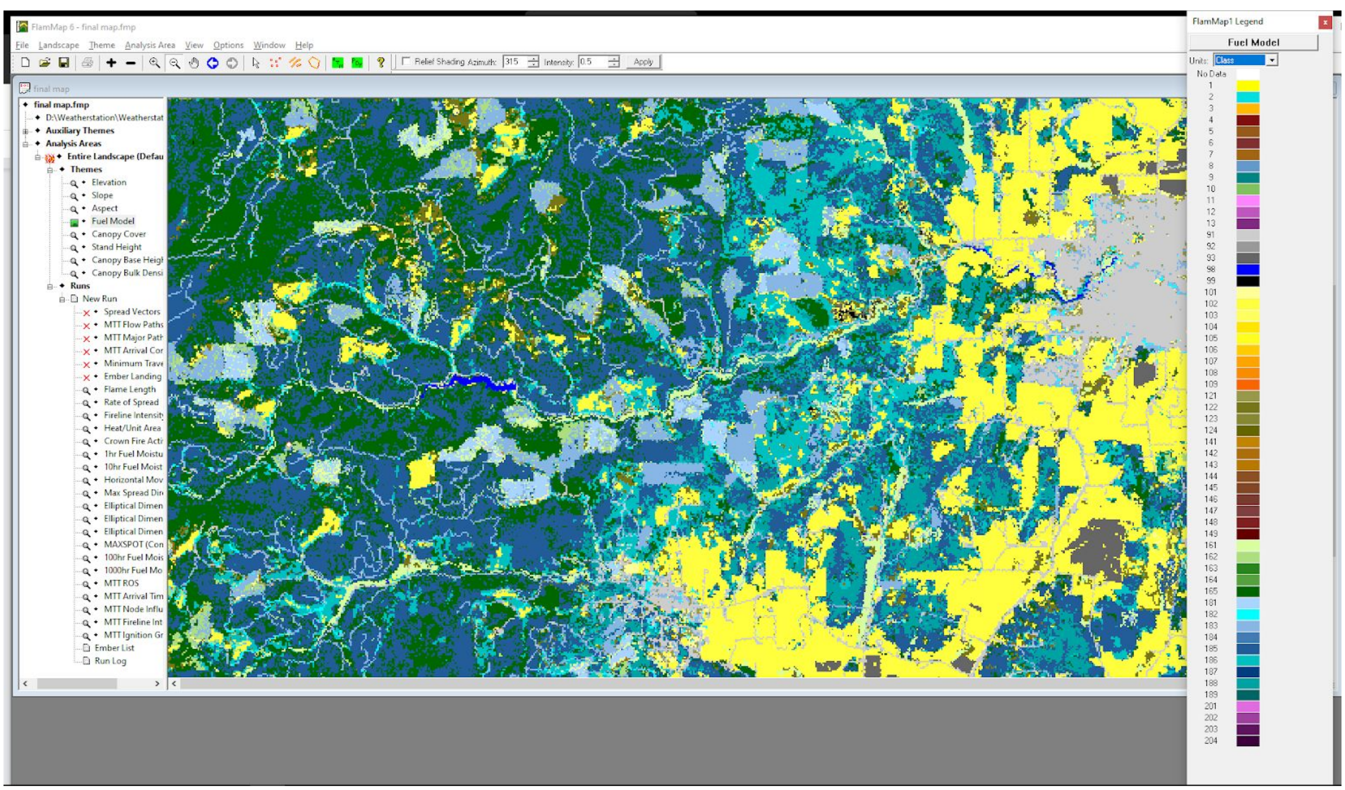


Figure 9.3.17 Fuel model

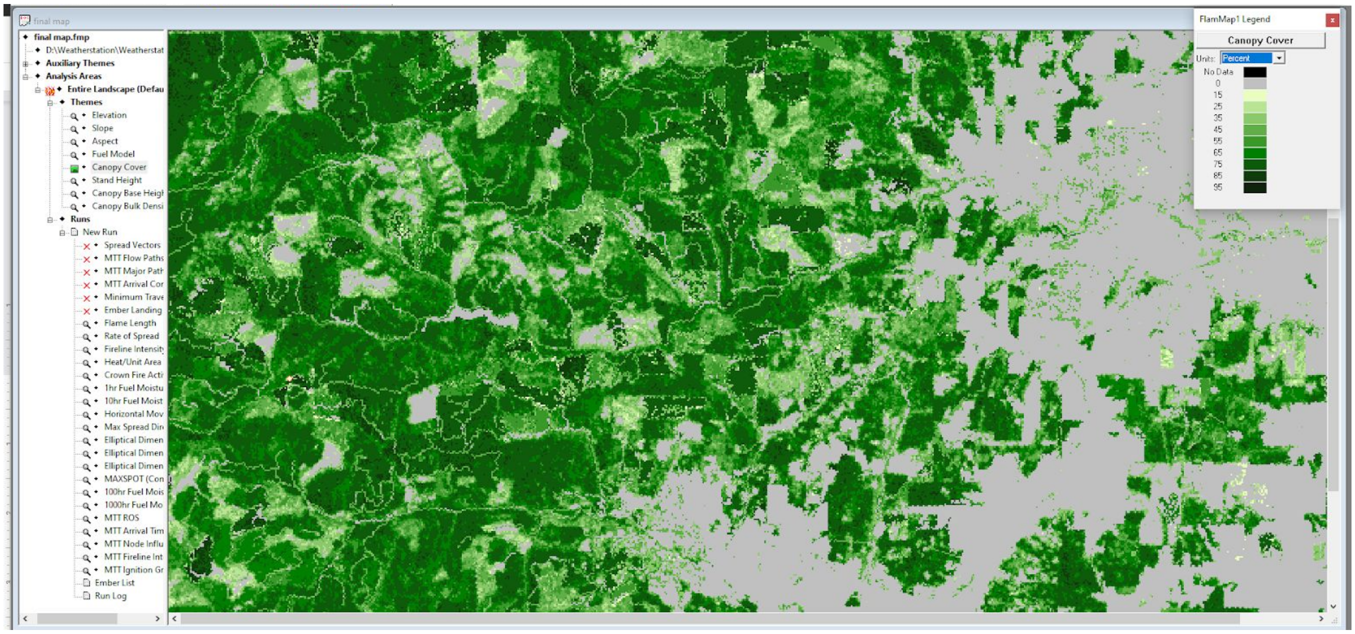


Figure 9.3.18 Canopy cover

MTT major flow paths showing on multiple base maps

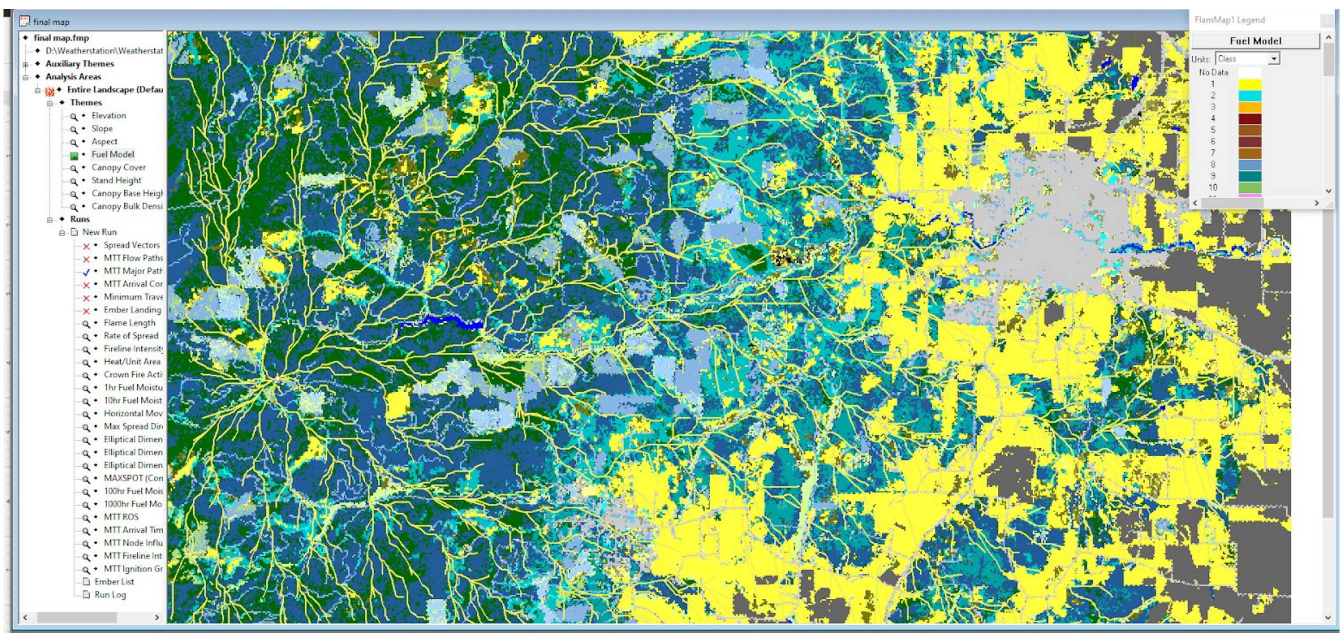


Figure 9.3.19 Fuel model zoomed out

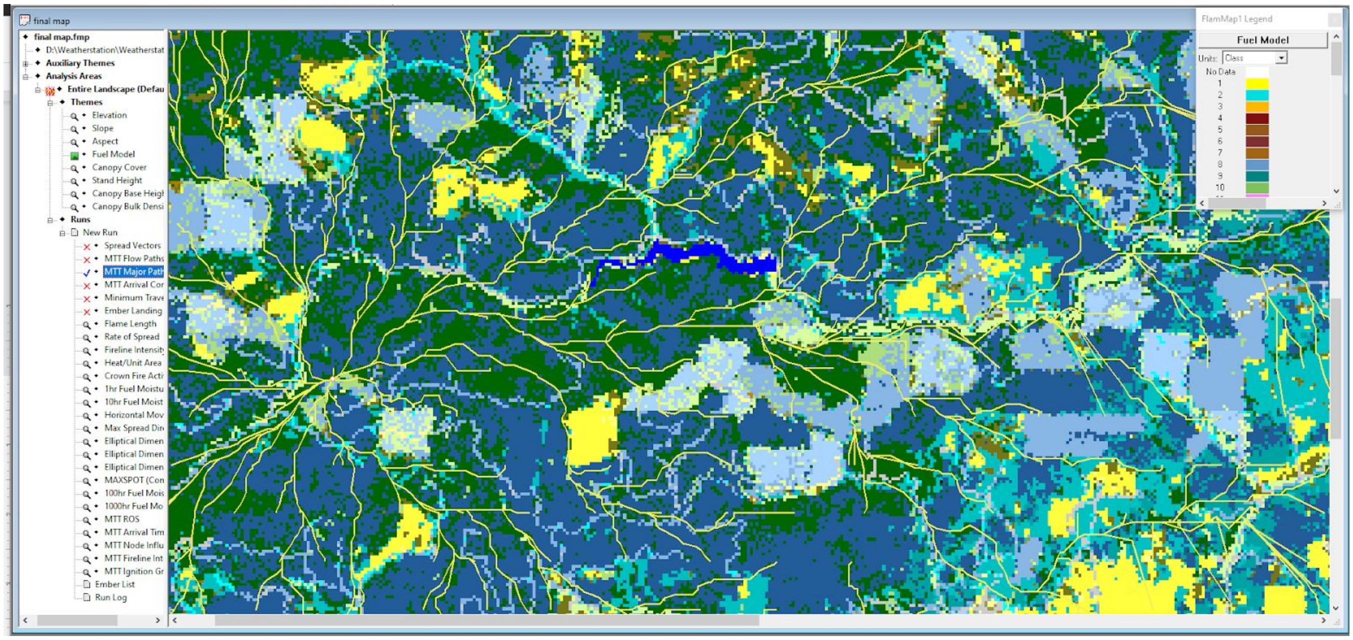


Figure 9.3.20 Fuel model normal

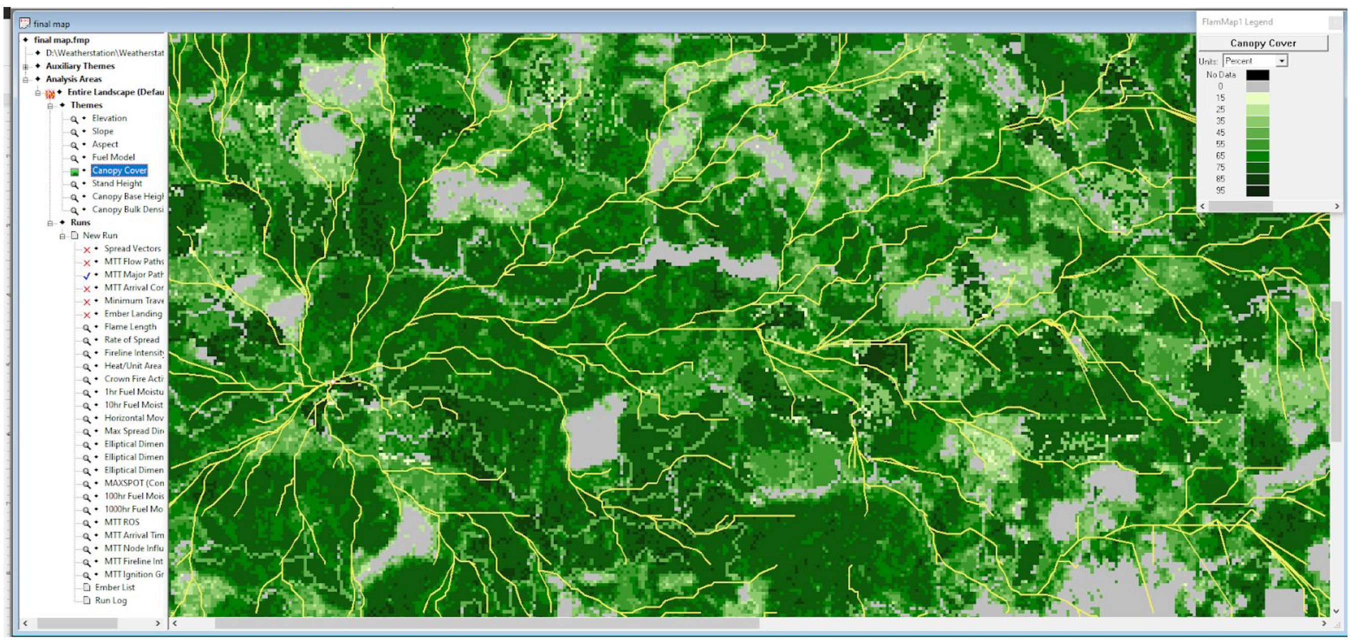


Figure 9.3.21 Canopy cover

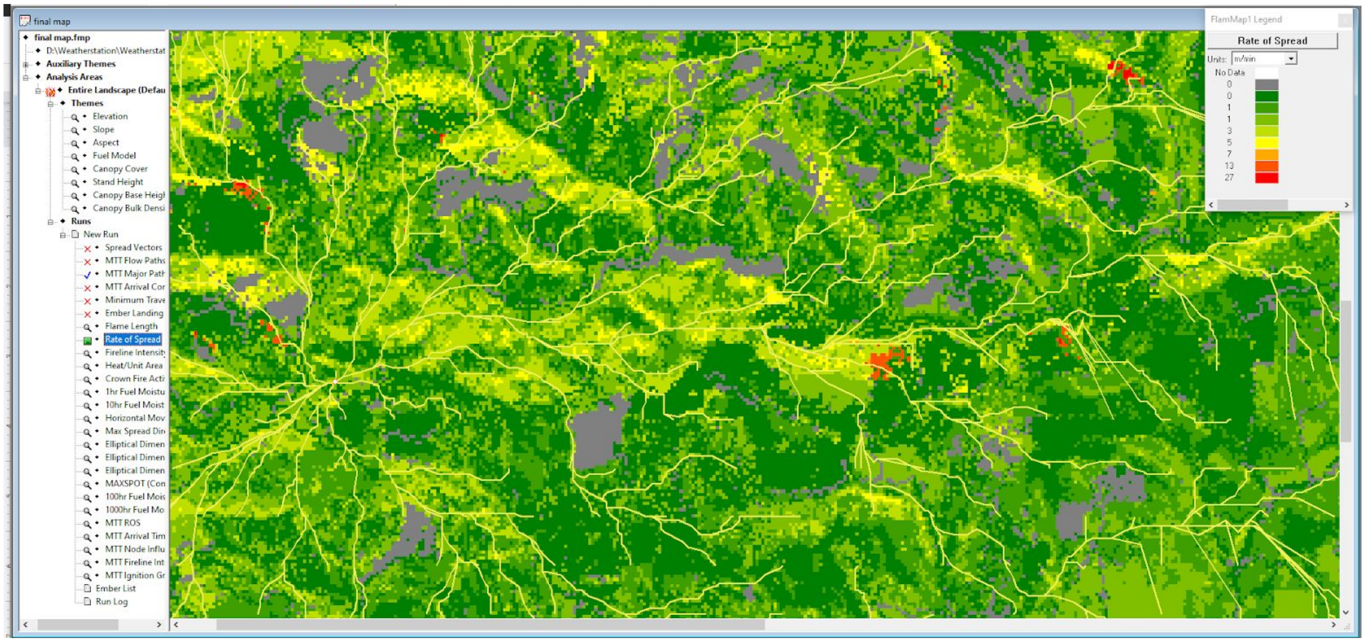


Figure 9.3.22 Rate of spread

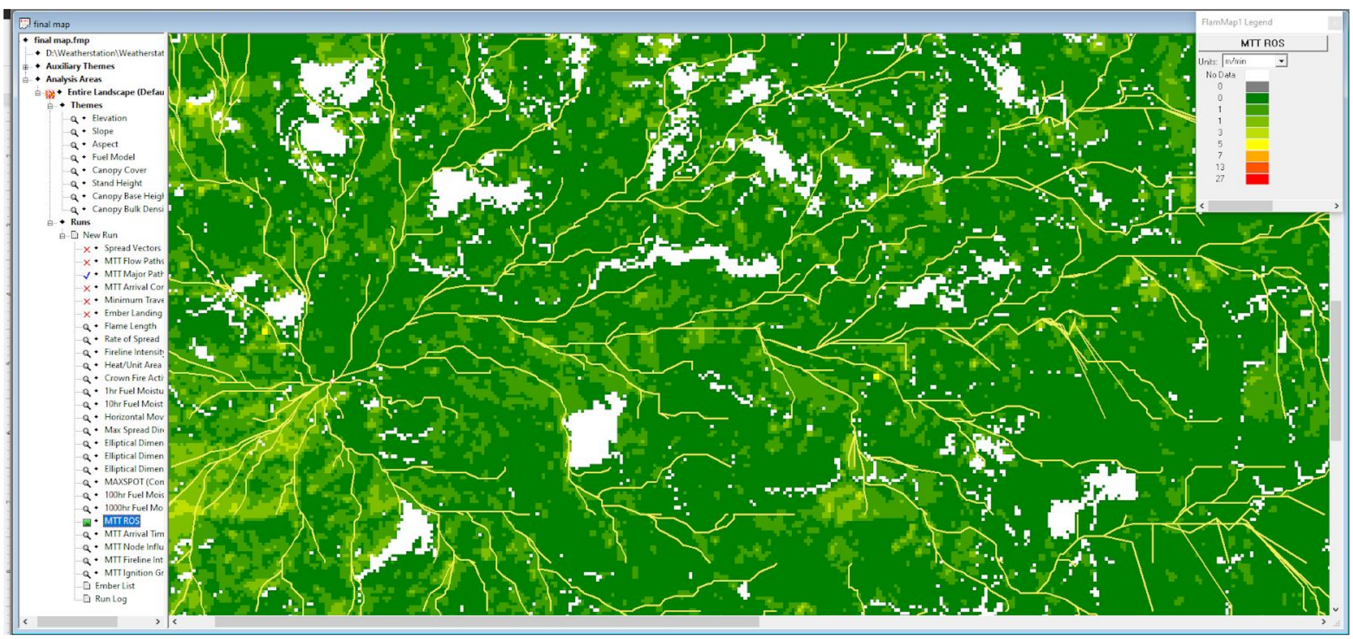


Figure 9.3.23 MTT ROS

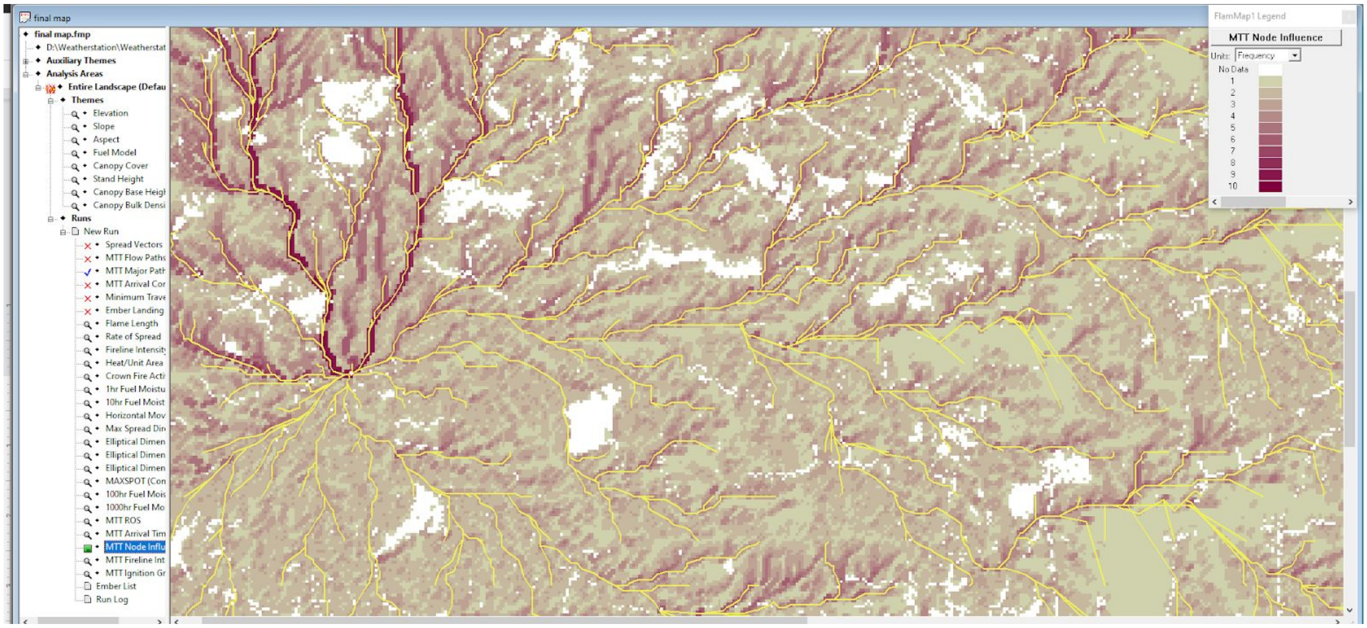


Figure 9.3.24 MTT Note influence

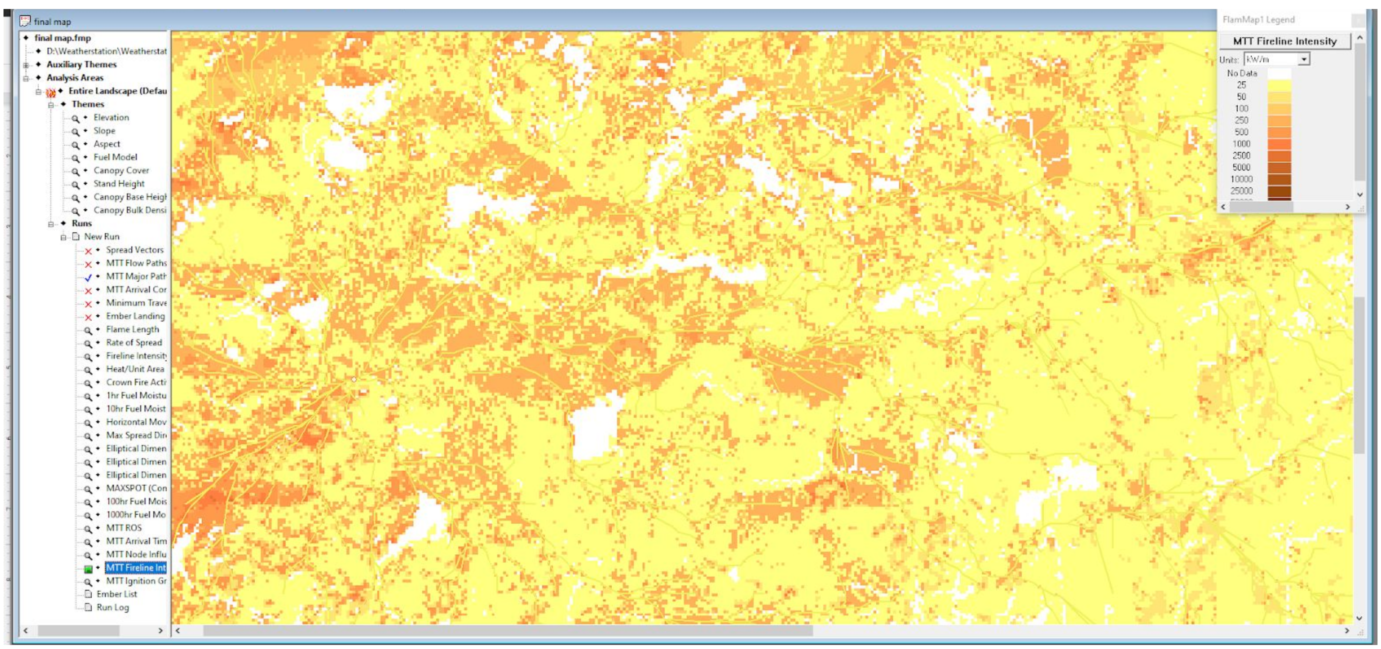


Figure 9.3.25 MTT fireline intensity

Spread factors showing on multiple base maps (note: all of these have been rotated to make the image more readable)

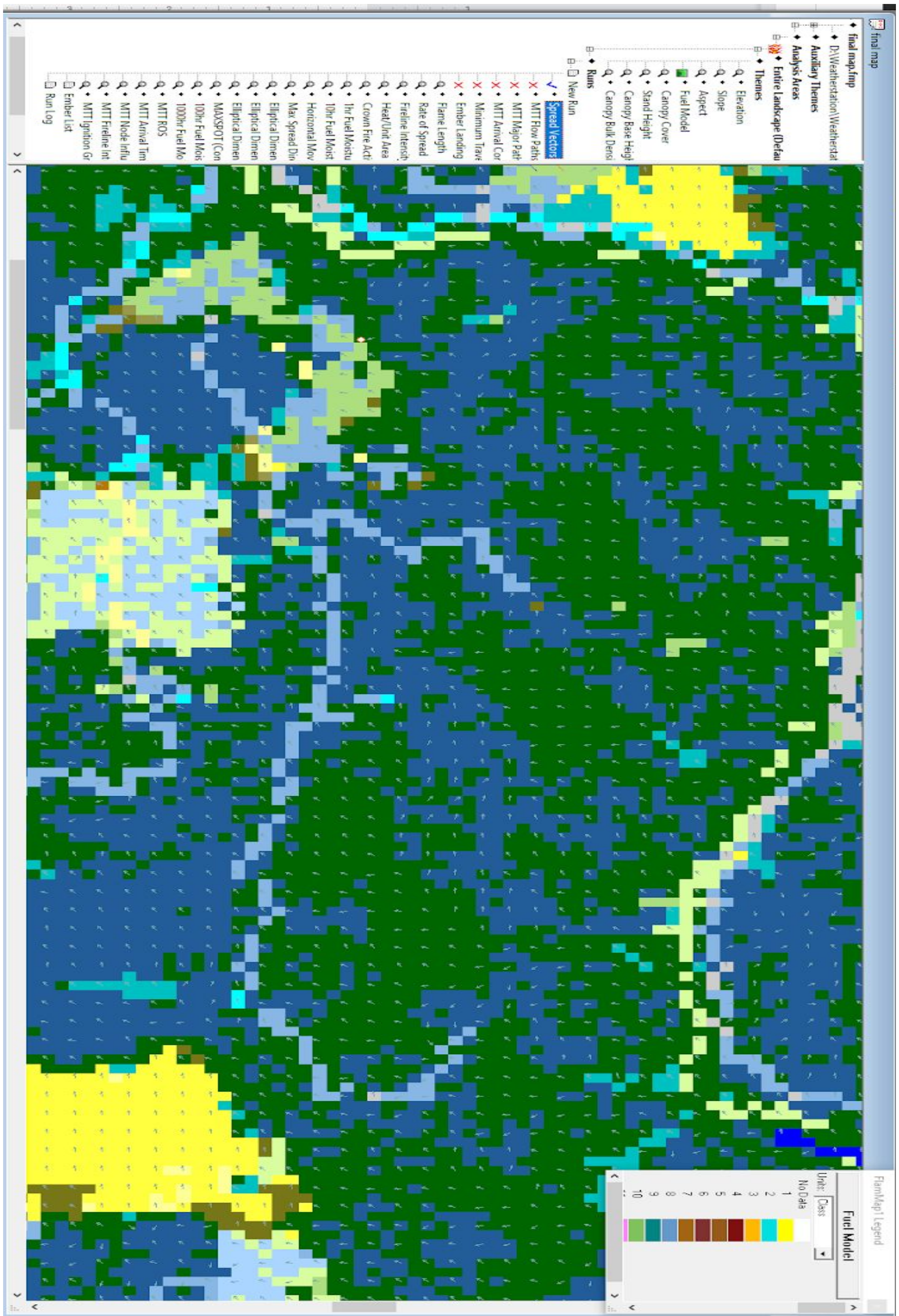


Figure 9.3.26 Fuel model

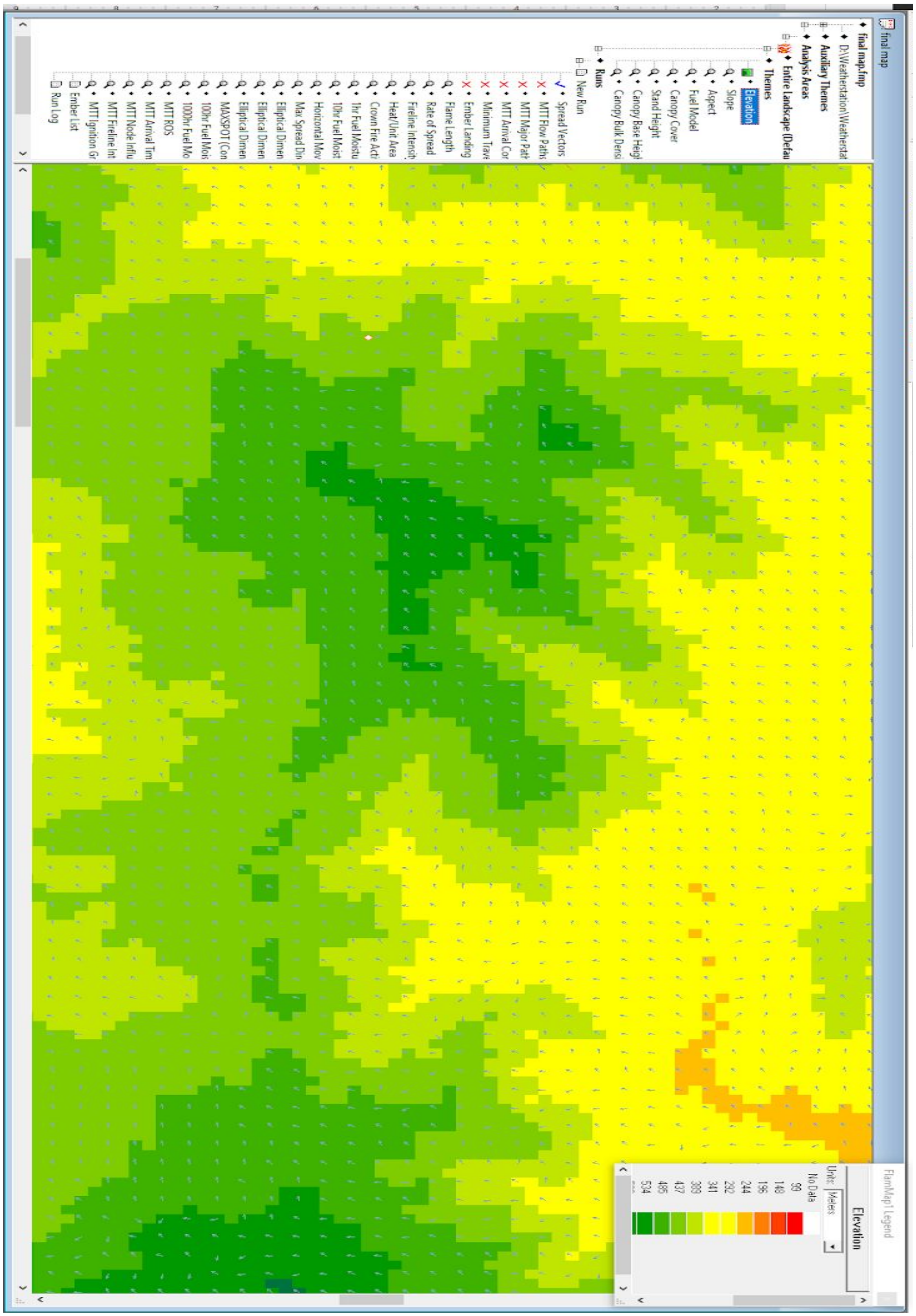


Figure 9.3.27 Elevation

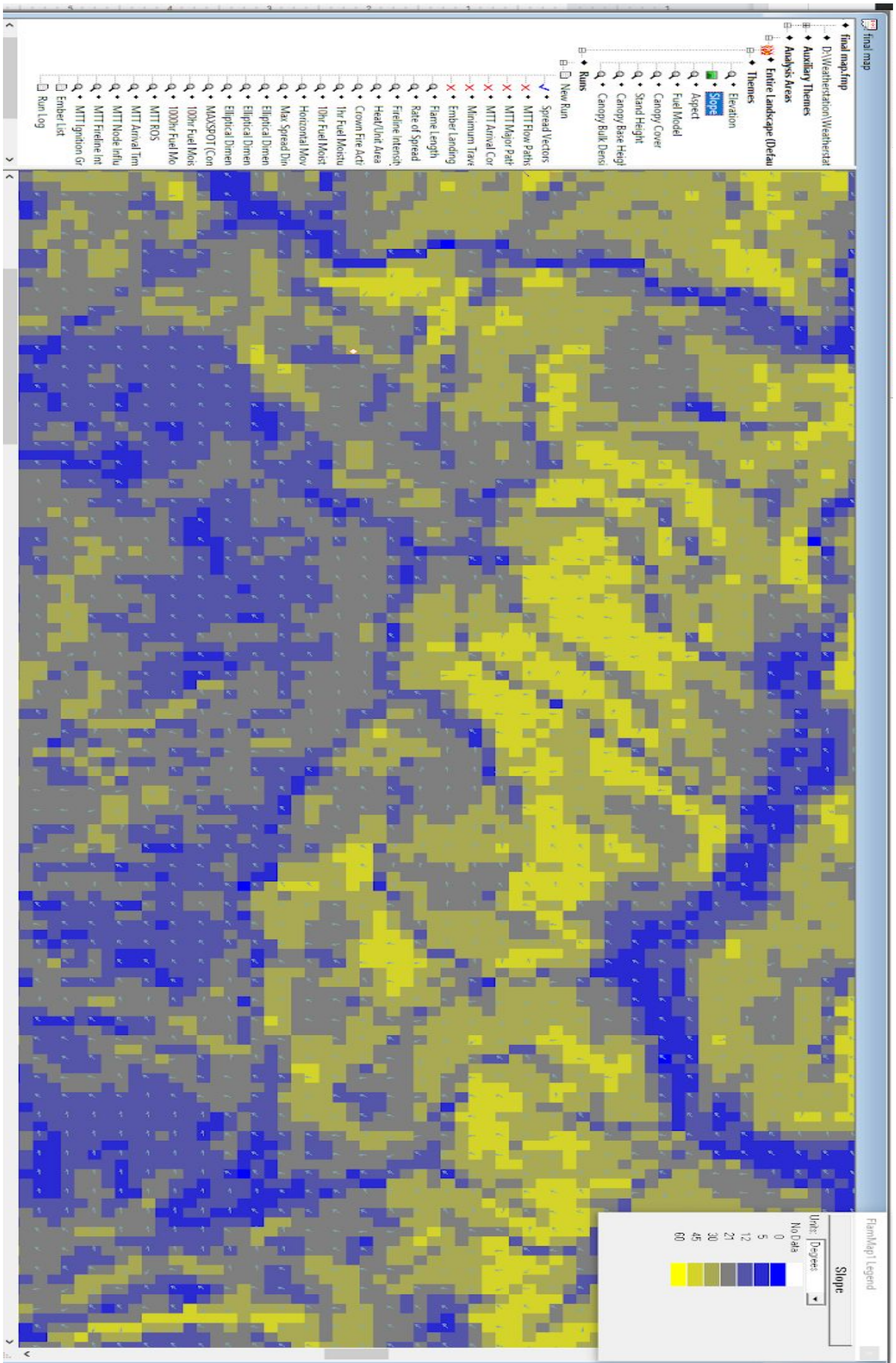


Figure 9.3.28 Slope

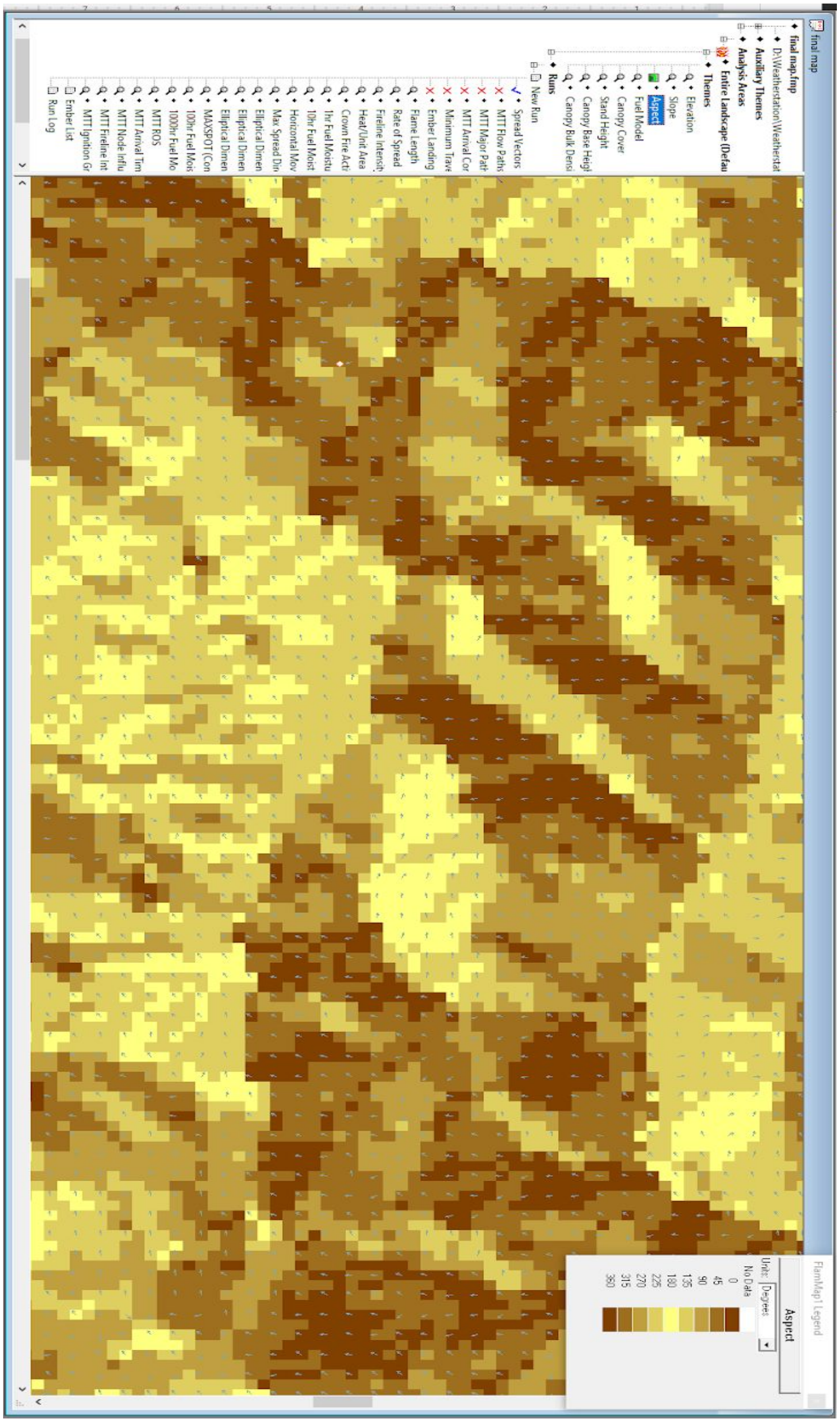


Figure 9.3.29 Aspect

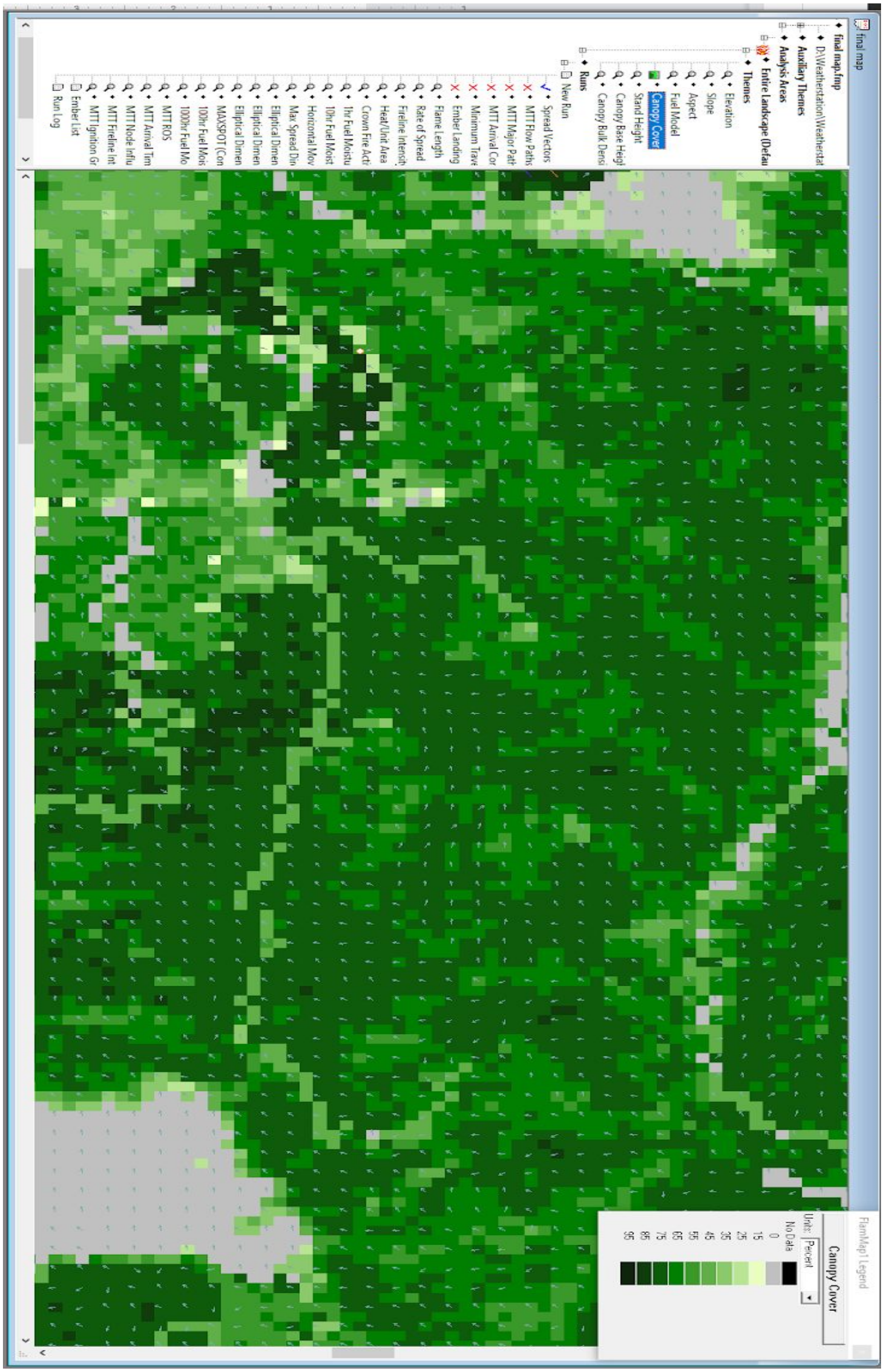


Figure 9.3.30 Canopy cover

Runs without overlay

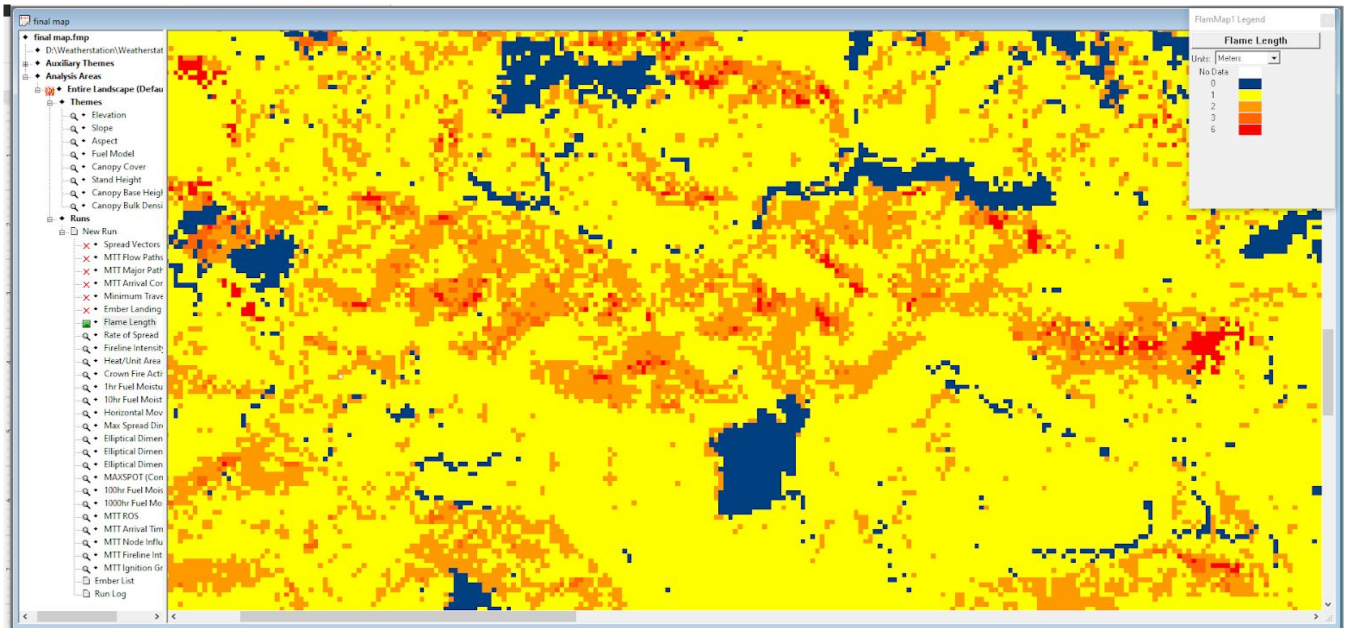


Figure 9.3.31 Flame lengths

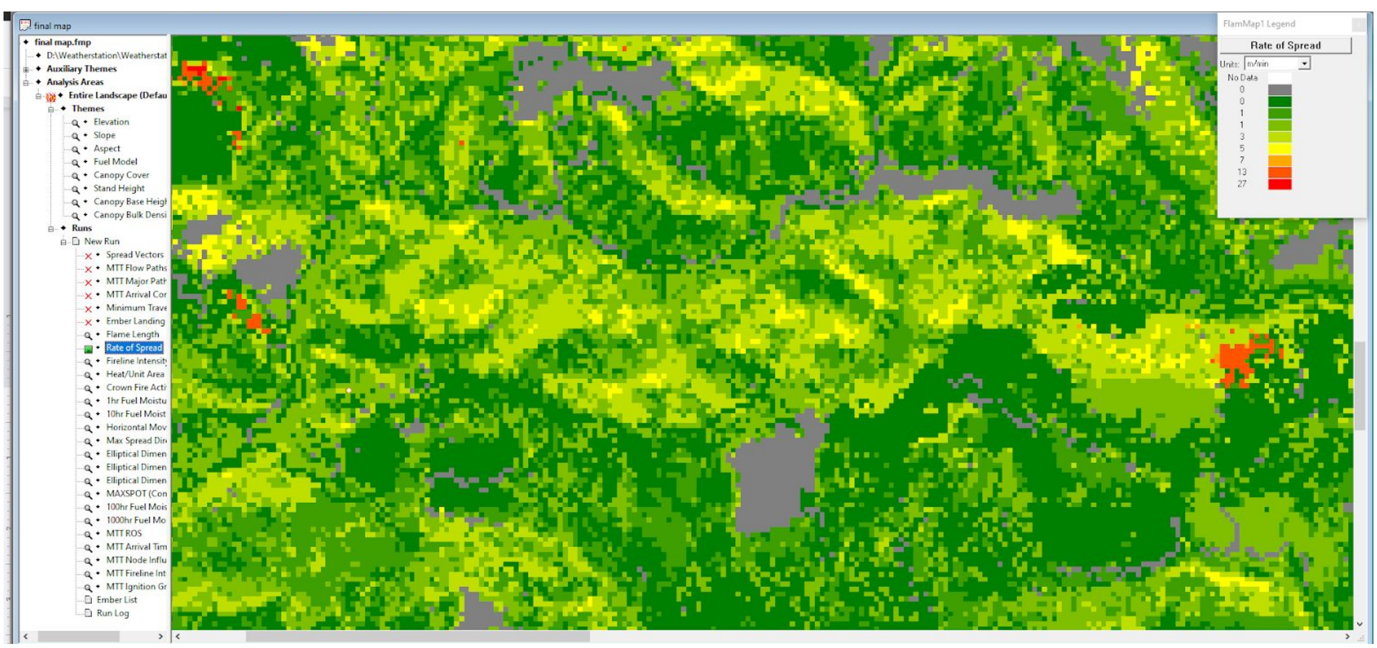


Figure 9.3.32 Rate of spread

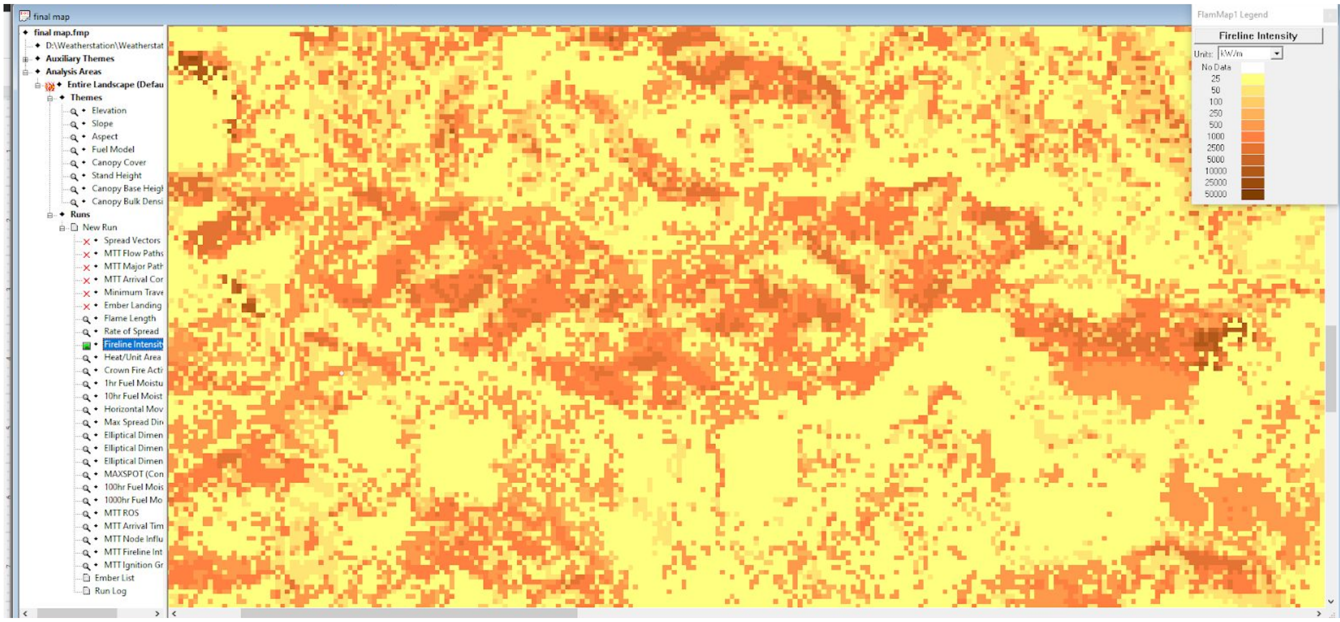


Figure 9.3.33 Fireline intensity

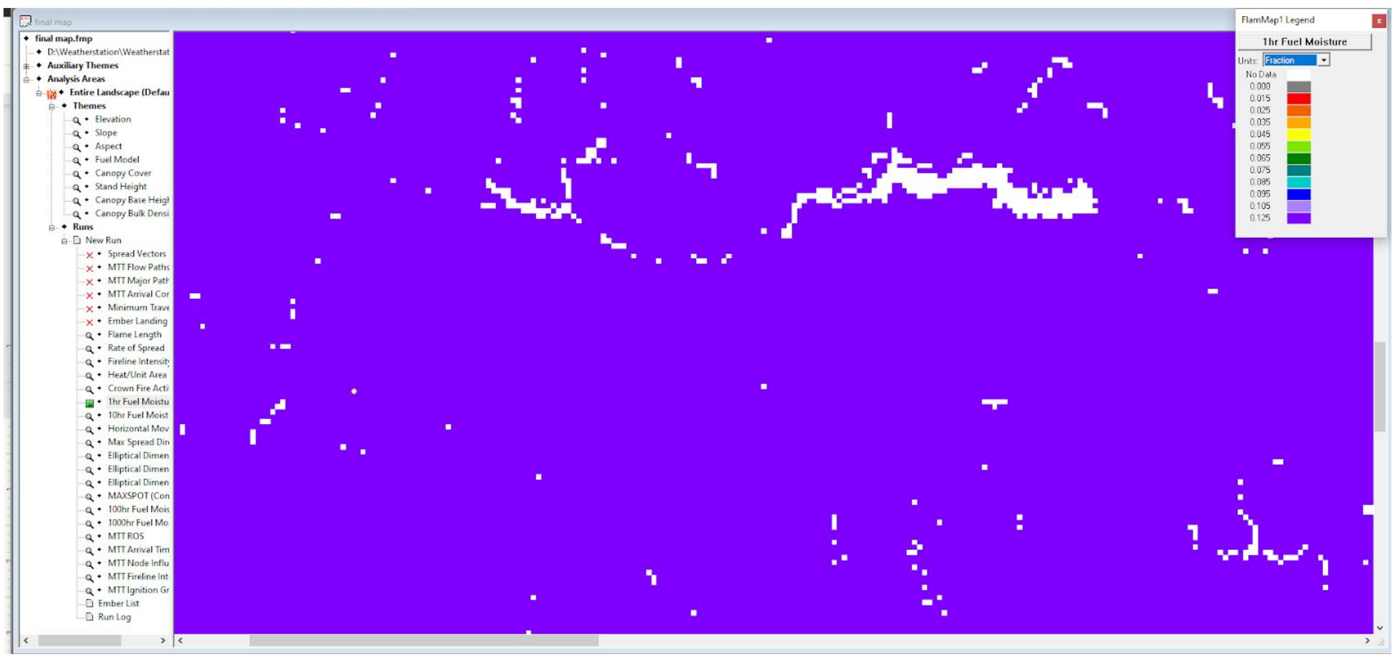


Figure 9.3.34 Fuel moisture 1 hr

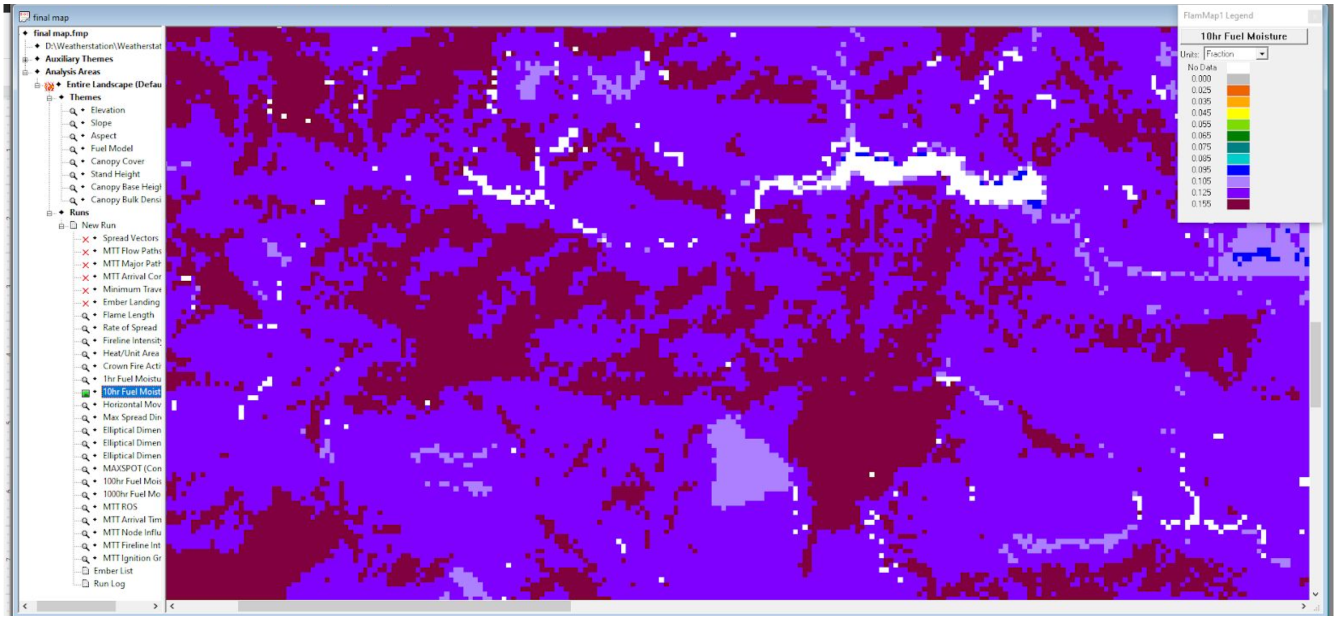


Figure 9.3.35 Fuel moisture 10 hr

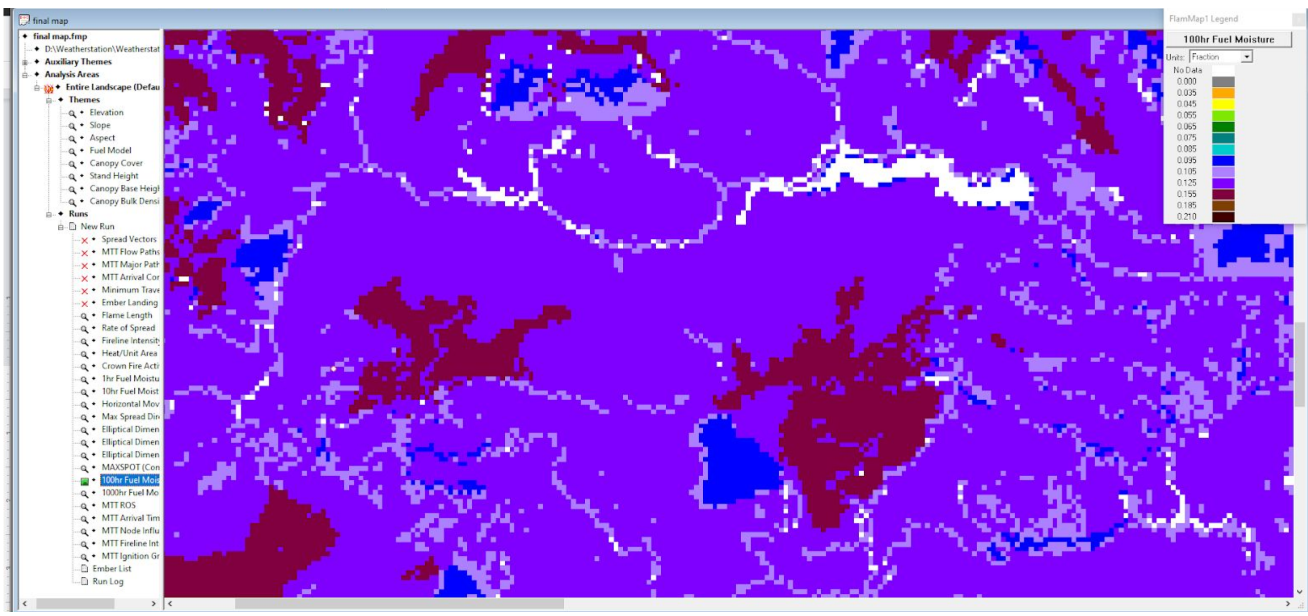


Figure 9.3.36 Fuel moisture 100 hr

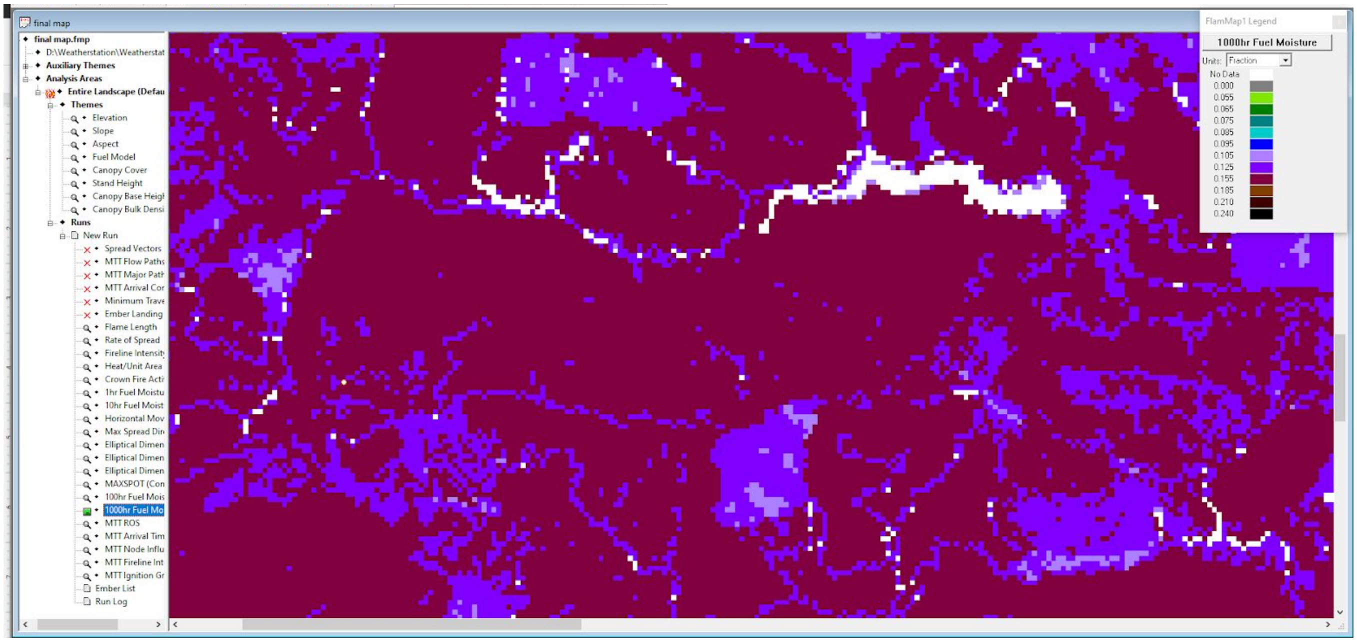


Figure 9.3.37 Fuel moisture 1000hr

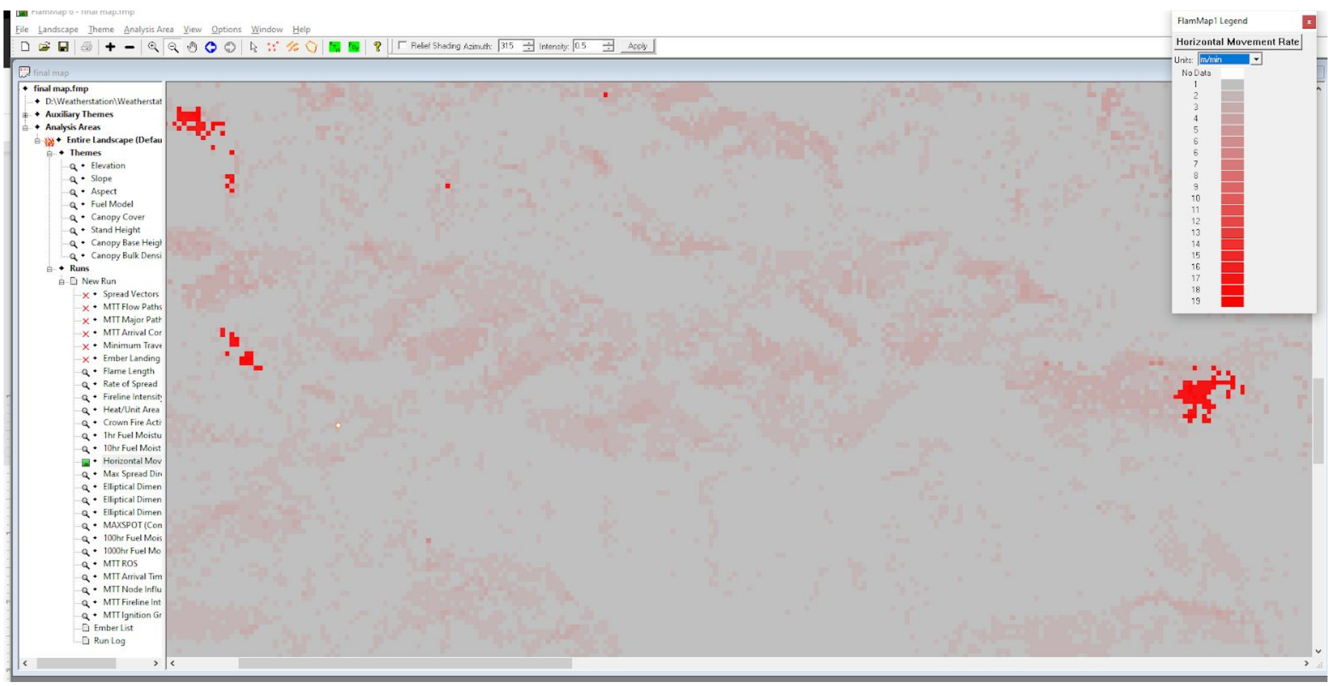


Figure 9.3.38 Horizontal movement rate

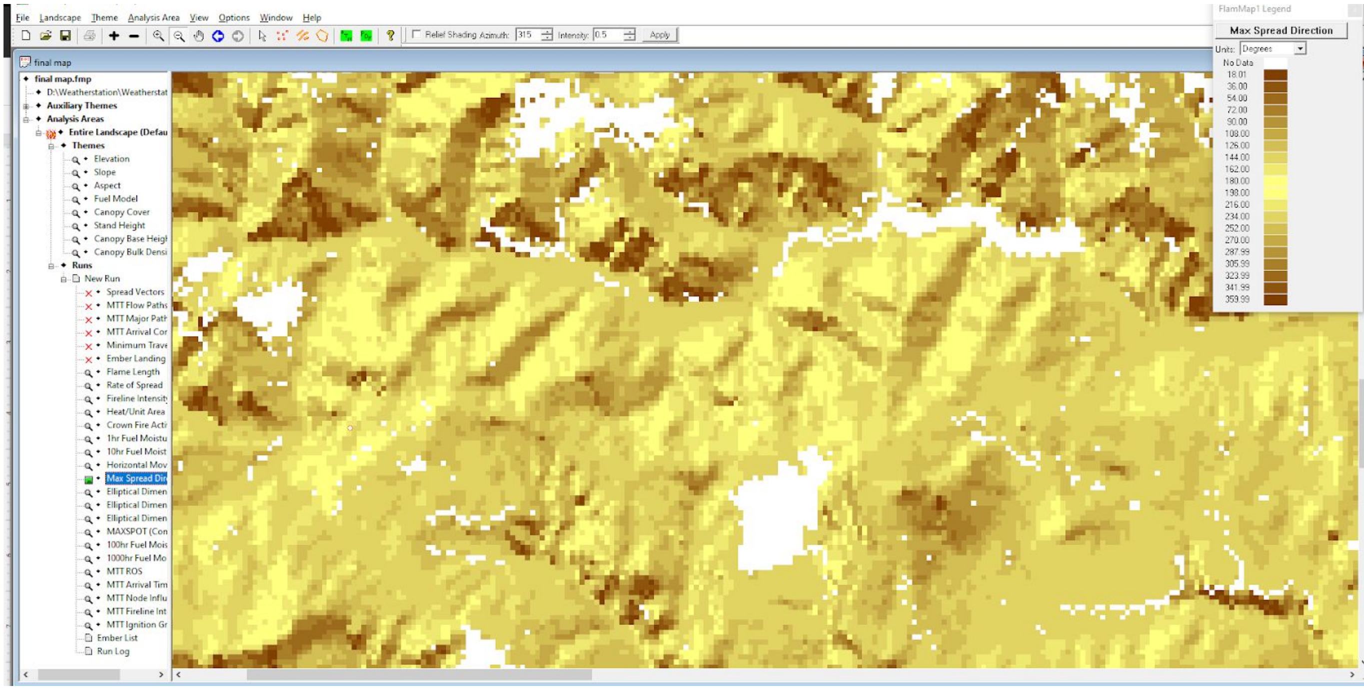


Figure 9.3.39 Max spread direction

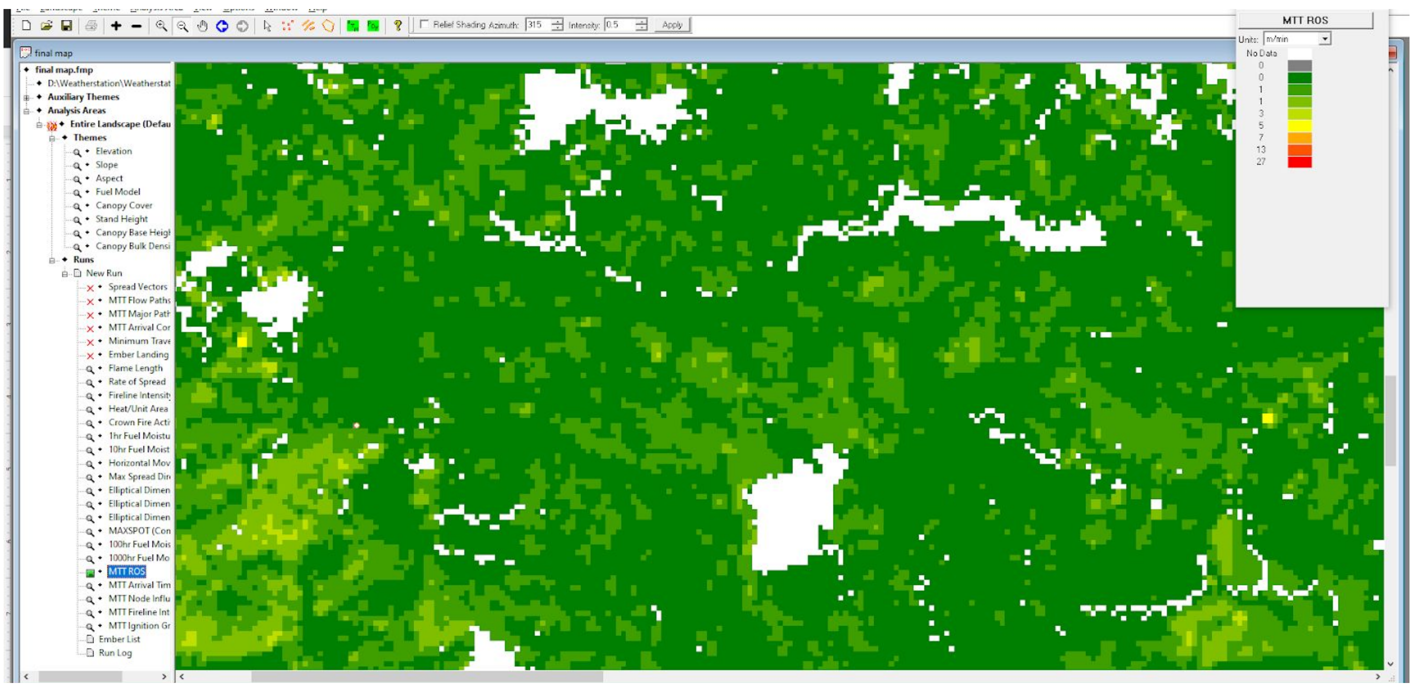


Figure 9.3.40 MTT ROS

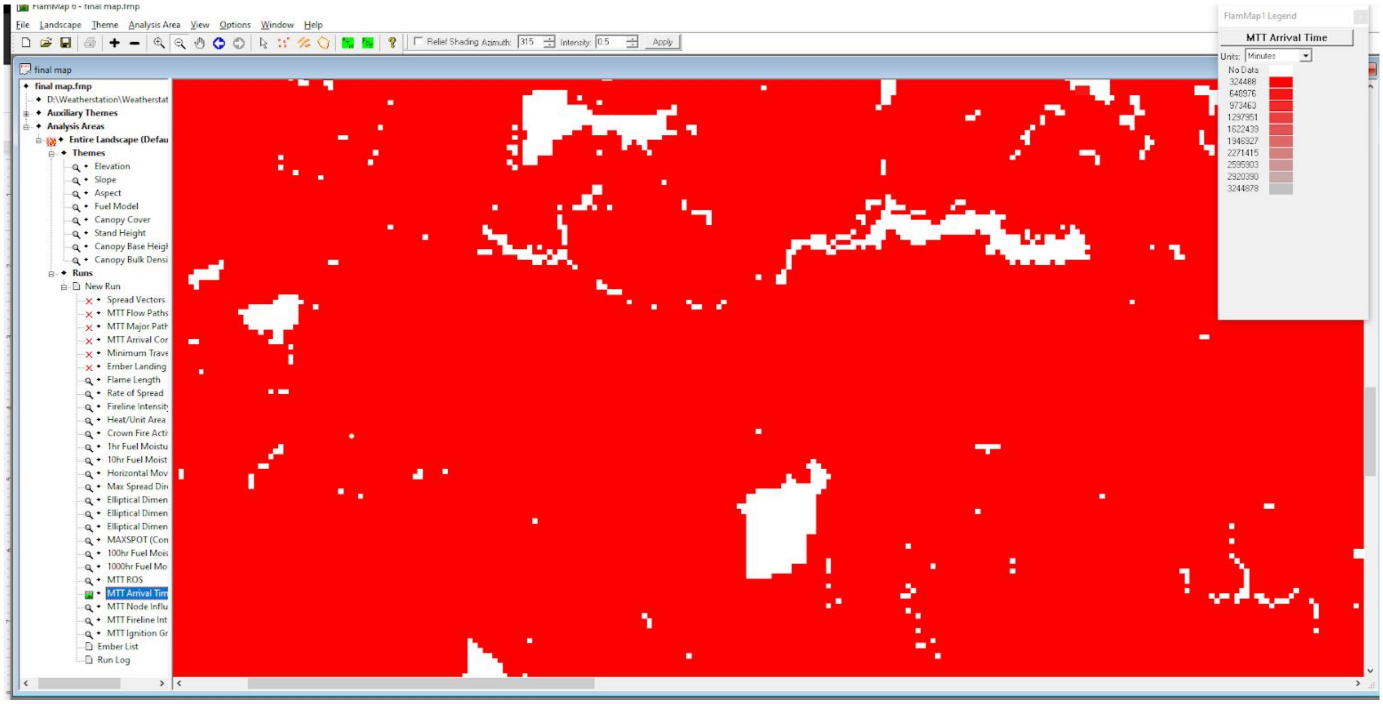


Figure 9.3.41 MTT arrival time

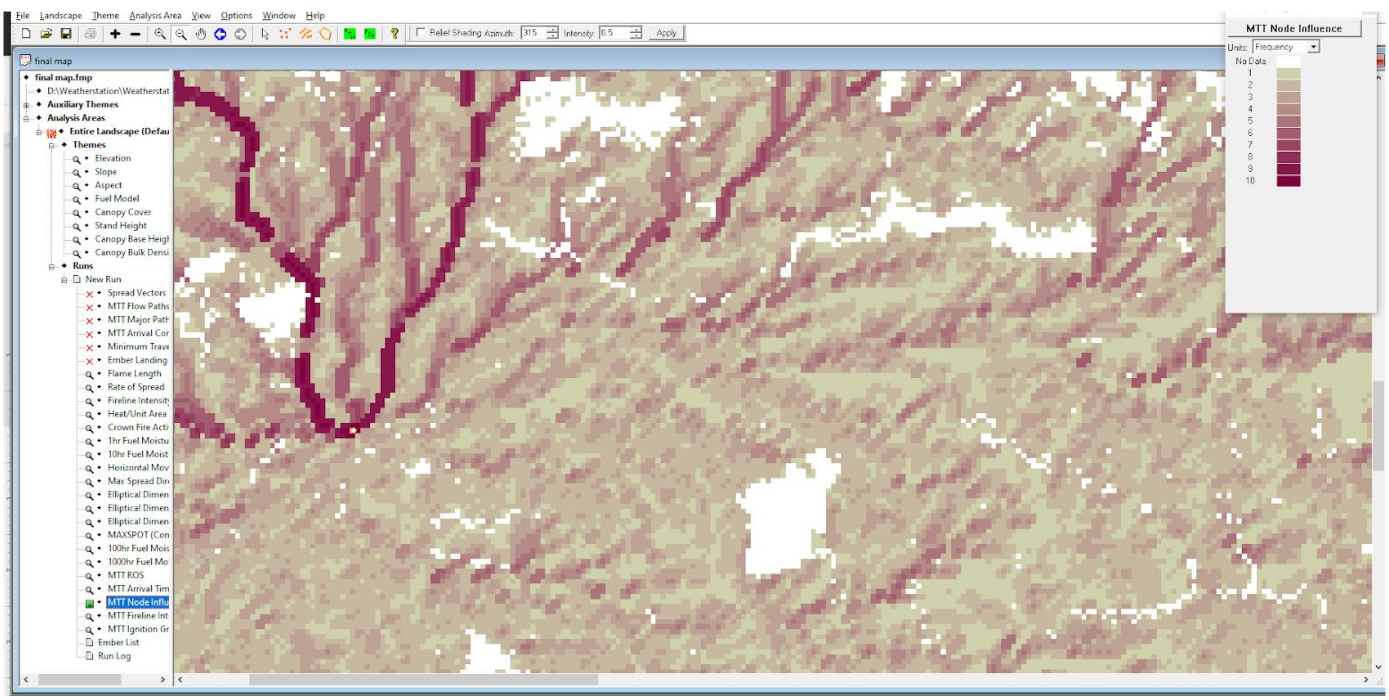


Figure 9.3.42 MTT node influence

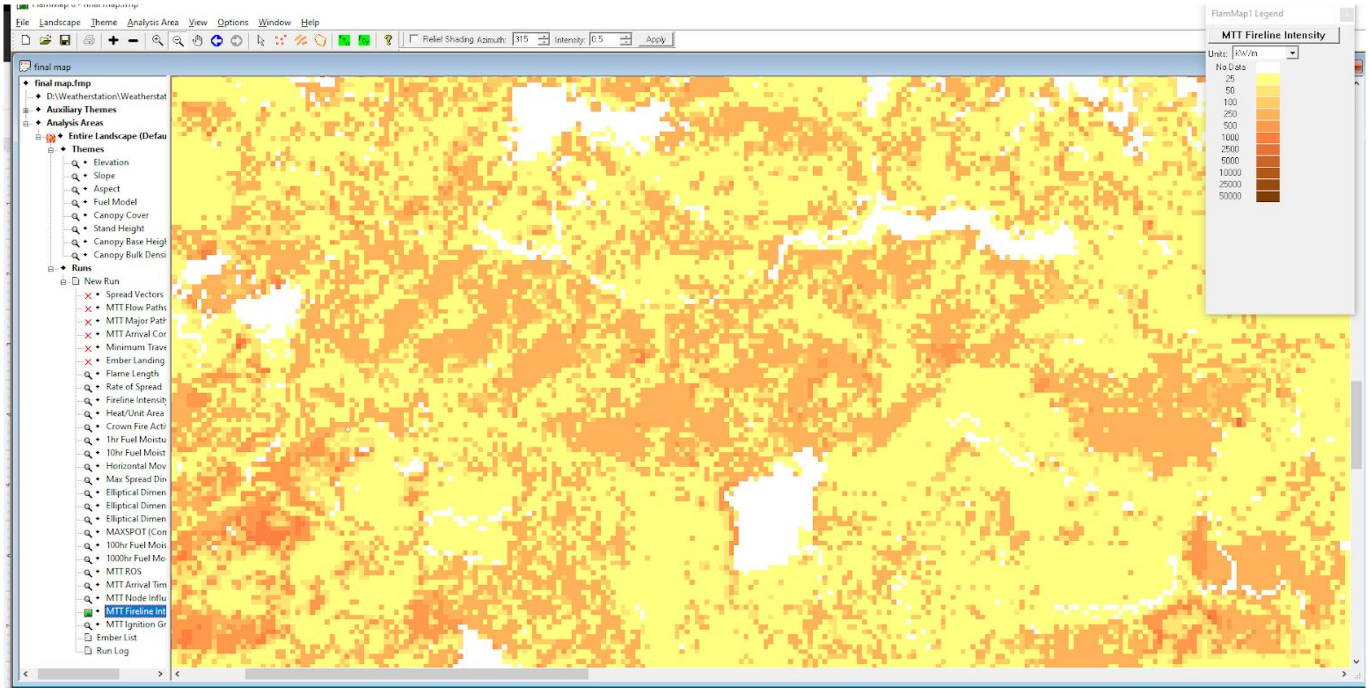


Figure 9.3.43 MTT fireline intensity

Fully zoomed out MTT maps

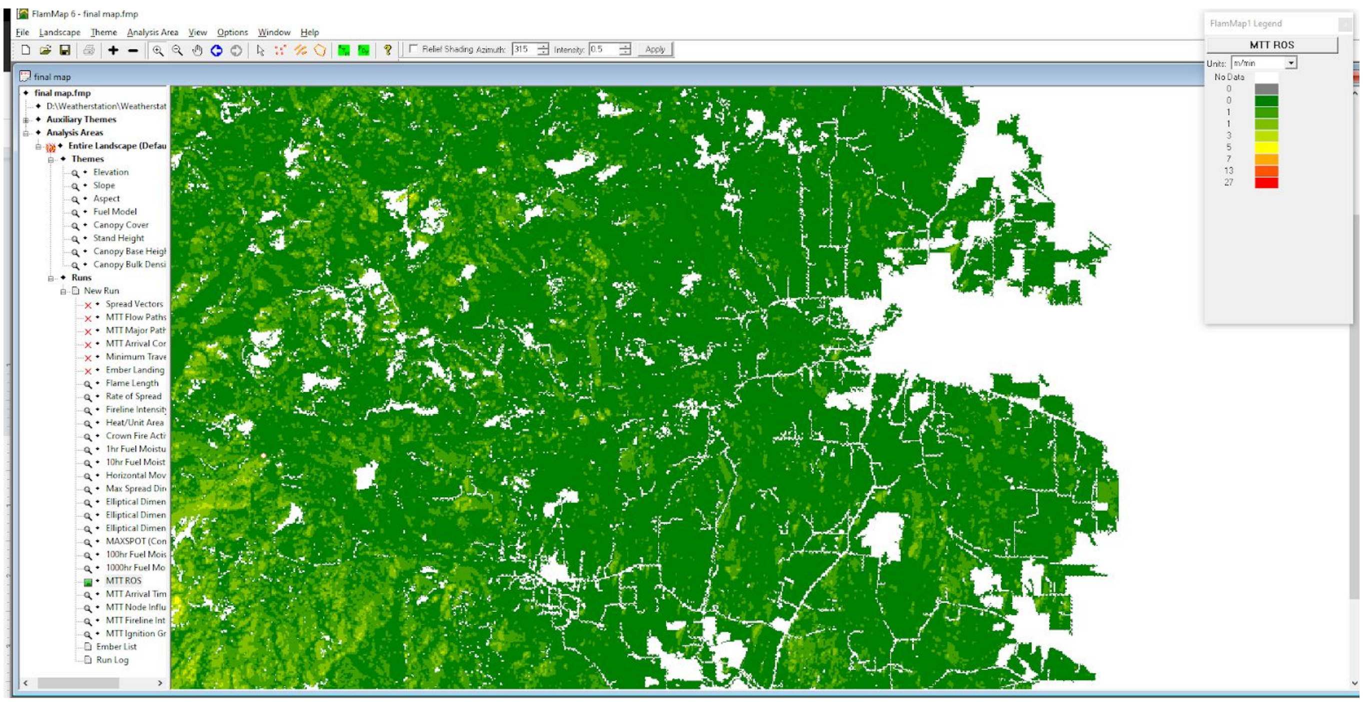


Figure 9.3.44MTT ROS

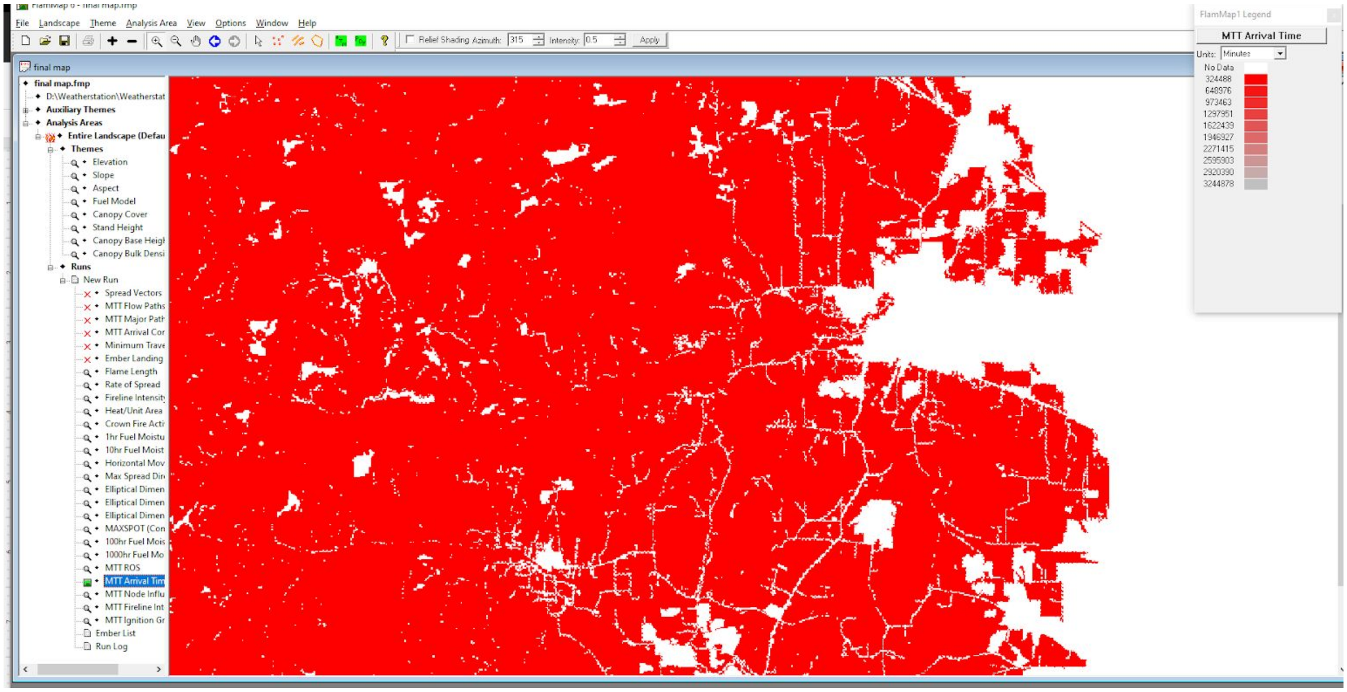


Figure 9.3.45 MTT arrival time

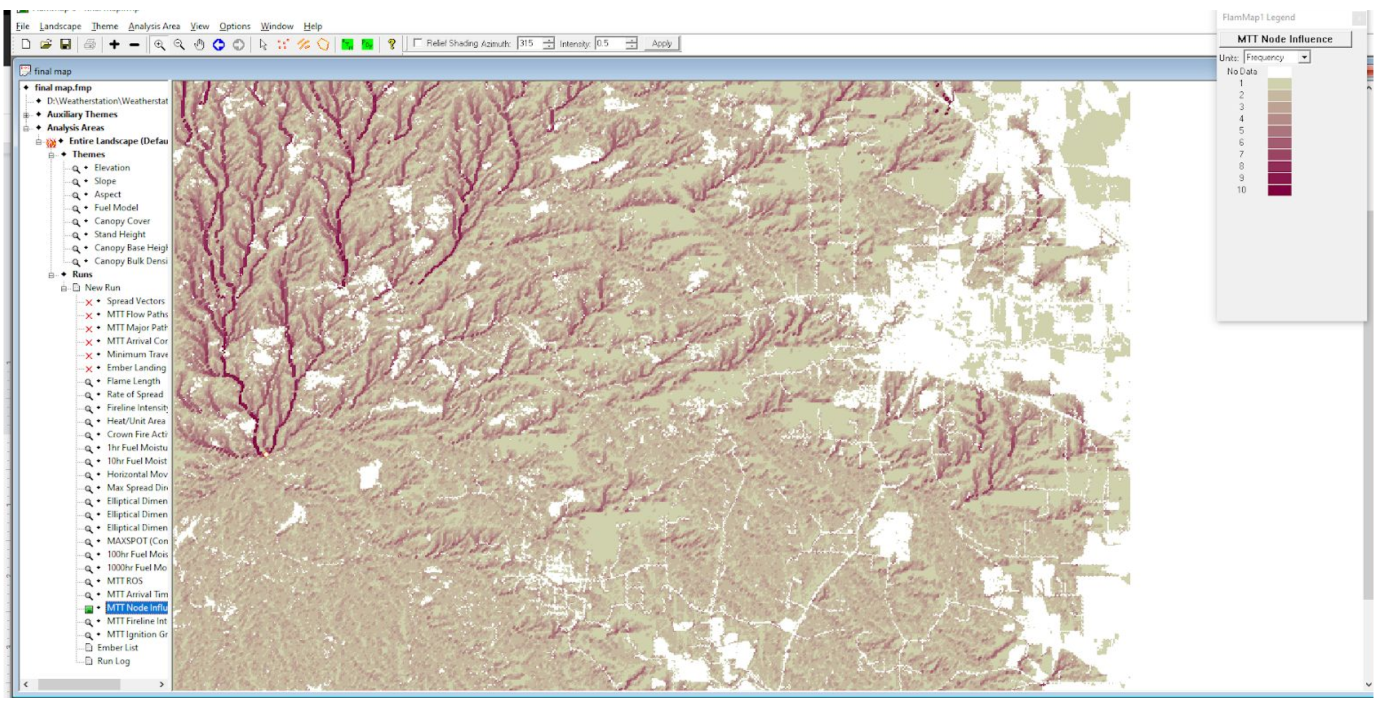


Figure 9.3.46 MTT node influence

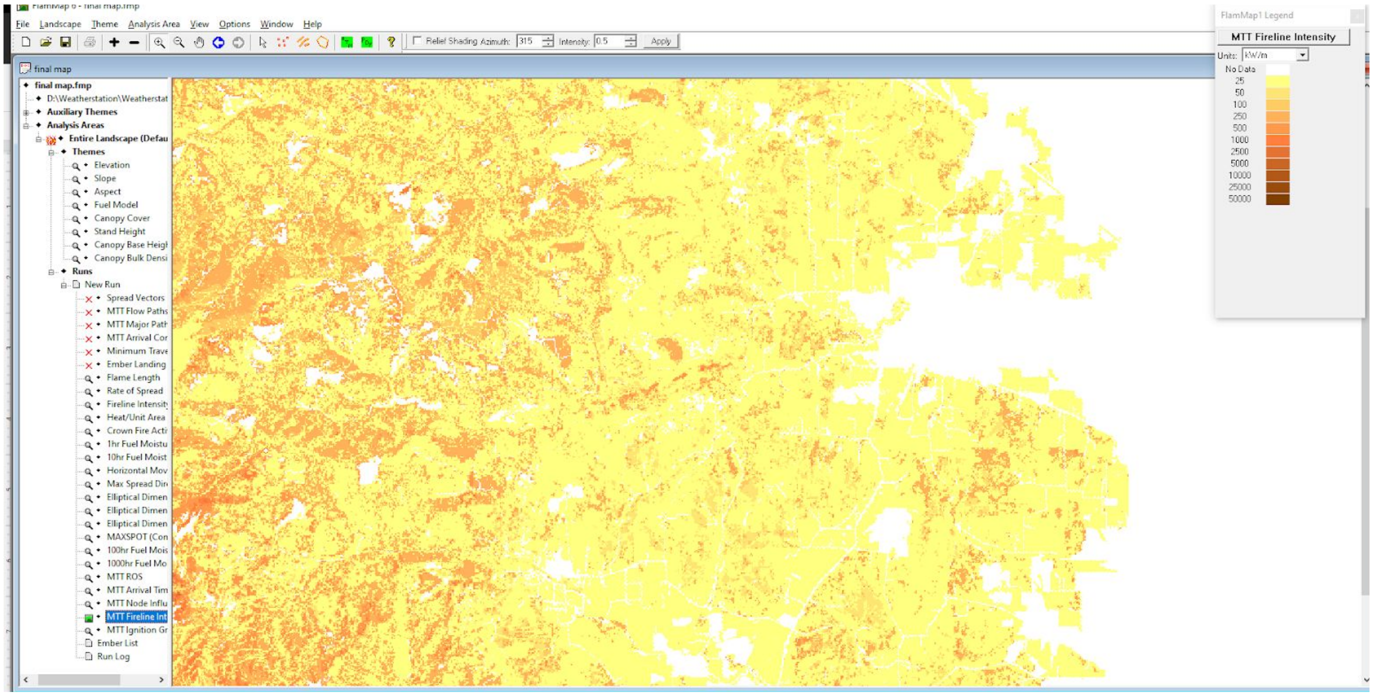


Figure 9.3.47 MTT fireline intensity

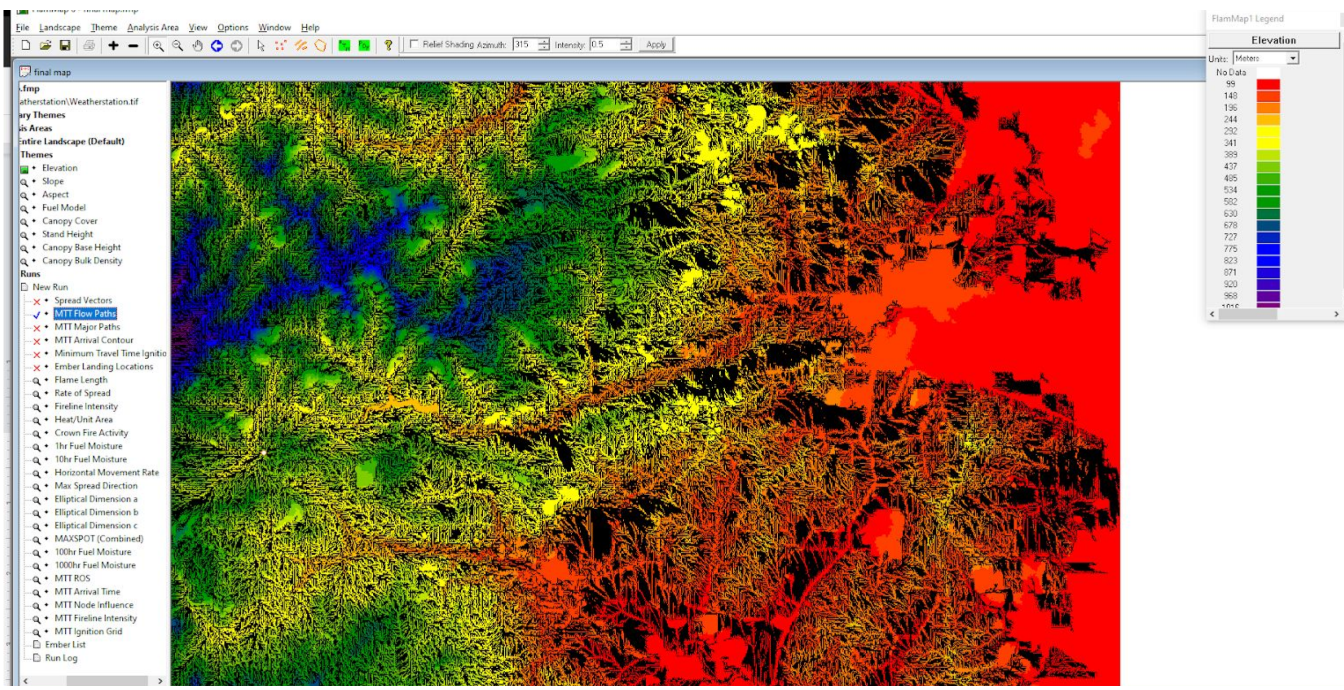


Figure 9.3.48 Elevation + MTT flow paths

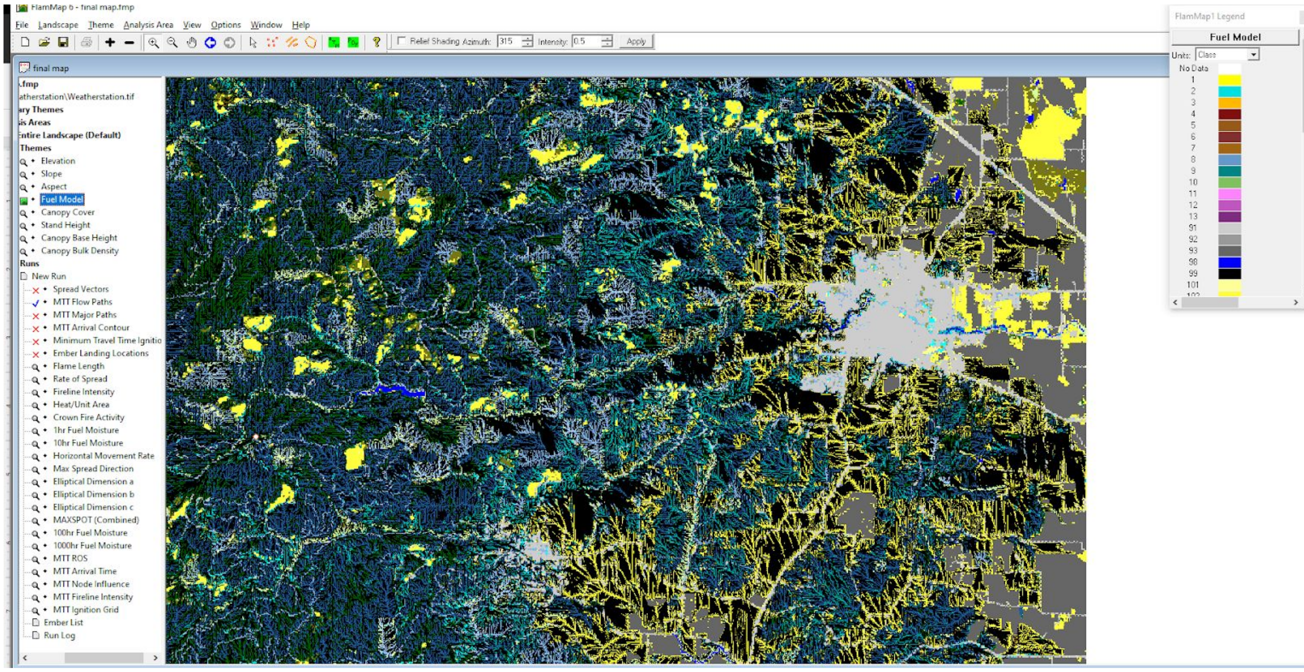


Figure 9.3.49 Fuel model + MTT flow paths

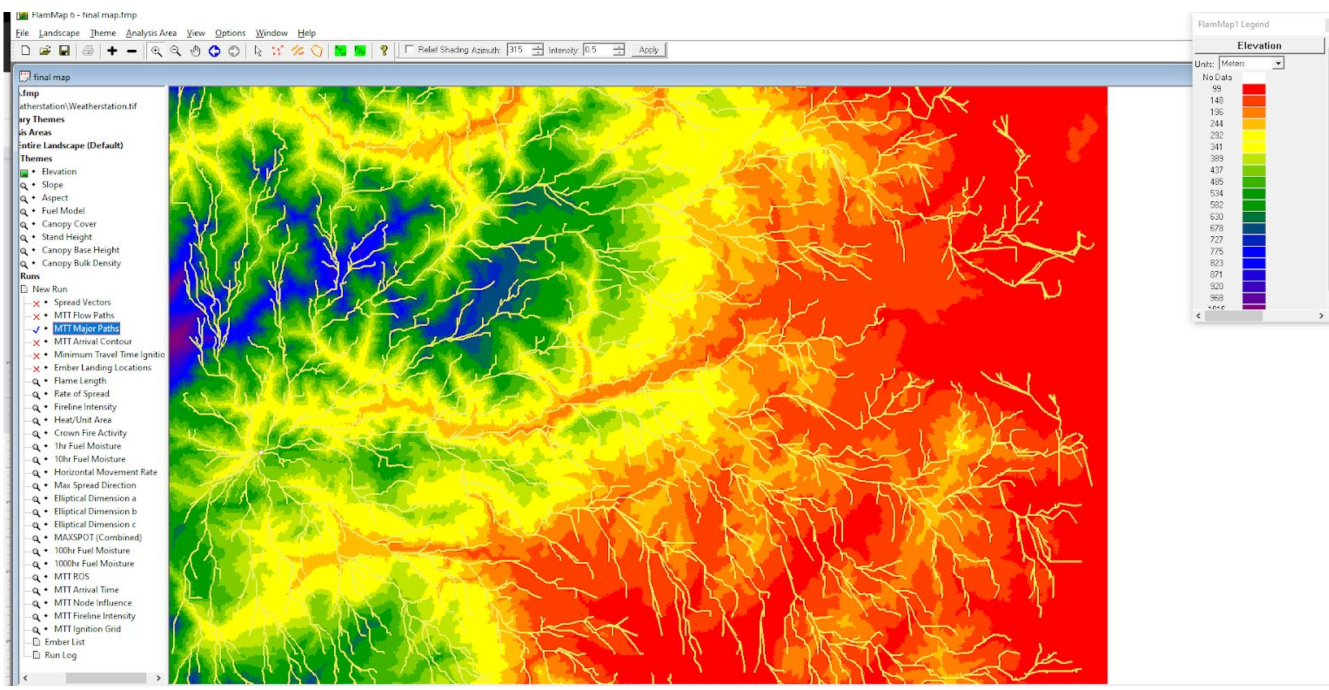


Figure 9.3.50 Elevation + MTT major paths

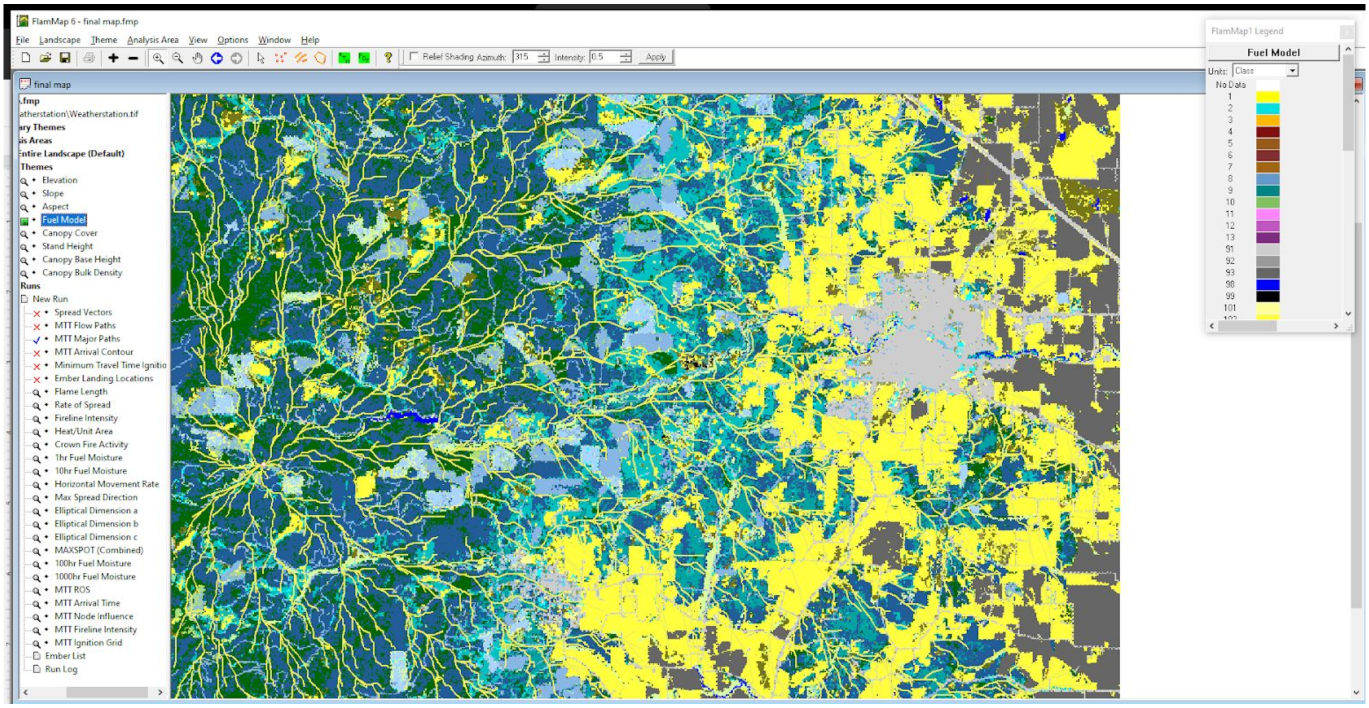


Figure 9.3.51 Fuel model + MTT major paths

9.4 Ethical review

For the ethical review, the applied ethics framework was used to ethically test the thesis. The results and process of the test can be found below.

Introduction of the project

The goal of the graduation project is to develop maps that show the spread and propagation of wildland fires on De Hoge Veluwe so that evacuation routes can be made. These evacuation routes are based on the newest information and technology and will hopefully ensure the safety of the many visitors of the national park. The goal is to create maps that can be accessed in real time and that can be accessed from an app (but that is someone else's thesis). The focus of the graduation project is on a specific area in The Netherlands, but the final goal is to make it available at more locations and in different countries.

1 Ethical risk-sweeping

A crucial first step is to define what ethical risks exactly are. According to Vallor (2018), an ethical risk can be best described as a decision that could cause damage to people (or different individuals who have a moral status), or are expected to provoke moral controversy. So, if these risks are foreseeable, why are they not always noticed straight away? This is due to many reasons, some of which are: there is a disparity between the perspective of the stakeholder and the designer; moral harm is not taken into account, only economic or material harm; risk assessment goes wrong and ethical risks end up being classified as different kinds of risks; and sometimes the risks are too subtle to notice.

It is crucial to identify stakeholders and search well for possible risks, even if they are not at the surface. Designers must therefore take their time to identify risks with different types of search. In the following list, some ethical risks of the graduation project can be found.

- The maps are not correct and end up creating dangerous situations rather than safety.
- Municipalities and provinces not updating the changes to infrastructure, rendering the satellite images and maps with other information outdated and therefore not useful.
- Technological risks
    - The use of technology and databases creates an opportunity for hackers to put in false information.
    - People may rely on the technology too much and this could be a burden in them thinking for themselves and using common sense.
- The information not being available to people who do not have a computer or cellphone.
- Not taking into account the opinion and/or advice of the stakeholders.
- Sudden changes in weather create dangerous situations and make the fire more unpredictable

2 Ethical pre-mortems and post-mortems

The previous chapter focussed on individual risks. In this chapter, the focus lays on the cascade effect, where multiple failures that by themselves would not create a huge problem, add up and do create a disaster. These two tools should always be combined with each other as reflection on the ethical risk sweeping can offer insight in the pre- and post-mortems of the project (Vallor, Green & Raicu, 2018). Looking at these aspects will not only help avoiding a disaster, it can also increase the chances of success of the project. As the graduation project is not finished yet, a post-mortem view is not possible. Therefore, only the pre-mortem will be discussed.

One is likely to assume that a pre-mortem is the opposite of a post-mortem. In medicine, a post-mortem is often used to determine what caused a patient to die. In a pre-mortem, the project team takes a look at the possible problems at the start of a project, rather than at the end. (Klein, 2007)

In the case of this thesis, a big risk that could occur is the maps failing when they are truly needed. The maps can fail because of many things: wrong input, power failure at the database that keeps the data, malfunction of the way the maps are presented. All of these things are not that big a deal on their own (as they can be solved individually), but when combined it would be catastrophic. Especially if the teams leading the evacuation and extinguishing the fire also rely on the data and maps.

To avoid these risks, it is important to remember that design is a continuous process. As long as the product is not finished, new risks and problems can come up and it is therefore important for the design team to frequently meet to see if any new risks have arisen and how the team should act on them.

3 Expanding the ethical circle

This chapter will revolve around the people who need to be involved in the project and its design process. It will also contain the way in which they shall be included as well as the phenomena that happen when they do not get included.

According to Vallor, Green & Raicu (2018), there are a couple of risks that come with designing with only the design team. These will be discussed in this part of the chapter.
Groupthink is what happens when a team consisting of the same people works together a lot. When this goes on for too long, the group members and thus the group as a whole will start to struggle with adopting new perspectives as they have developed their way of designing a product. This can also happen when the group does not work together for an exceptionally long time, but when they are socially speaking "too close".

The "bubble"mentality is similar to the groupthink. The difference is that in this case, the group does not necessarily work together too much, they are too similar. Their demographic, experiences, educational level, and identities are identical. The way one views the world and how they have lived in society influences their opinions and if too many people in a group share the same opinion, the room for discussion becomes very small. The people in these groups have a shared blindspot and therefore easily fall into making an unethical decision, purely because their view of the world is not focussed on that specific problem.

The "Friedman fallacy" is a phenomenon that occurs when the only goal of a company is to maximise the profit of the shareholders and they are not held accountable for the impact the product can have on public interest. The problem here is that it is easy for the company to hide behind their goal, rather than coming clean about what went wrong and the fact that they did not bother to think about it, or even worse: did think about it but did not do anything about it.

The phenomenon most likely to happen for this thesis is the "*Groupthink*" as the only people working on this project are from the university and user testing is not necessary. The way this problem is avoided is through frequent and close contact with municipalities, instances in The Netherlands who are responsible for the physical safety, the people who work at the national park, and the Dutch fire department. Although some of these stakeholders were not identified right at the start of the project, they became important stakeholders along the way.

4 Case based analysis

1. *Identify similar or “paradigm” cases that mirror the present case*

For this, three cases will be used. The first one is on Strava, an app that shows routes people use for showing their jogging routes. The second one is a case on an app that helps people assert whether a flood is going to happen and if they should evacuate. The last one is a case on a mistake made by a United States agency with regards to floods which led to opposition and residents losing a lot of money and belongings.

Strava is an excellent example of what can go wrong with showing routes and tracking of user’s locations. According to The Guardian (2018), Strava gave away the location of multiple secret US army bases. This happened because of app use by personnel on active service who used the app to track their route. These bases are not visible on Google maps, but because a lot of users tracked the same route, suspicion rose as the heat map showed specific laps used by all of the users in that area. This means that through Strava, secret information was shared due to the fact that app makers did not take this way of using the app into account.

BWDB Flood App is an app that shows the likelihood of a flood happening near the user (only in the country of Bangladesh). It provides flood warning information as well as the current water level and its forecast. Users can access historical and forecast water level information for all stations. Lastly, it has a function to help get alerts to users in a flood situation.

FEMA (the Federal Emergency Management Agency) is responsible for the management of local flood maps. Citizens can use these maps to know whether their house is in the area considered dangerous in the case of a flood, and thus to know if they need additional insurance for this. FEMA should update these maps every five years to make sure that they are up to date, but they did not do this. The maps were last updated in 1983. Then, hurricane Harvey arrived on the mainland of Texas, causing billions of dollars of damage and most people were not insured. When this was research, more problems were found. For instance maps often failed to pass verification checks and were often not published for the residents to see.

2. *Identify relevant parallels between/differences among all the cases*

Below, a table can be found in which these cases are compared on requirements from the thesis.

Table 1: Requirements and cases

Requirements	*Strava*	*BWDB Flood App*	*FEMA’s flood maps*
Uses maps	Yes	Yes	Yes
Helps users identify dangerous situations	No	Yes	Yes
Helps people with evacuation	No	Yes	Partially

Helps people with safety of their belongings	No	Yes	Yes
Is focussed on fire	No	No	No
Easy to use	Yes	Yes	No
Takes the user's environment into account	Partially	Yes	Yes

3. *Evaluate choices made and outcomes of the paradigm cases*

To fix the problem, Strava gained a stakeholder: the US military. The Central Command has begun to change the privacy policies for its troops. Unfortunately for Strava, the US military never deemed the app to be secure enough and the troops are now only allowed to use fitness trackers as long as their commanders take responsibility to tighten security. The preferred use for a fitness tracker is now FitBit, and the use of Strava is not considered safe anymore, according to Wired (2018).

In the BWDB app, there were no real problems to learn from for the thesis. However, it is a great example of how use of technologically advanced maps can save lives.

FEMA has tried to update the maps but ran into opposition from residents. As expected, the local citizens were angry to find out that their house had been in a risky area and they had not been informed on this. It must be noted that FEMA had already encountered this opposition when trying to update the maps earlier. The opposition comes from the fact that people might not be able to afford the insurance needed and they will be asked to leave their homes. People were suspicious that FEMA altered the maps to be able to collect more insurance money. FEMA has now delayed the maps until new procedures for the evaluation of risk are developed, the new maps were expected in 2019. They are also rolling out a campaign to help communities understand the risk and need for insurance.

4. *Use analogical reasoning to identify parallel risks, opportunities, solutions, risk mitigation strategies*

When comparing the Strava case to the thesis, an important lesson can be learned. It is very important to take into account that the data can be used for the wrong things. It was never Strava's intention to reveal military bases (I hope) but it is an unfortunate unforeseen use of the app. It teaches the lesson to always think about what people with wrong intentions can do with your data. This is definitely a risk that comes with the data of the thesis as well, so it is good to look out for it. They should have had the military as a stakeholder to avoid this problem from happening.

BWDB is an excellent example of what the thesis hopes to achieve. It enabled a way to help residents get to safety and it helped them prepare for it. This is exactly what the goal of the thesis is. It appears that they had the right stakeholders for the project, and that is an aspiration for this thesis.

The FEMA flood maps give insight into how dangerous it can be to have maps that are not up to date or wrong. This is something to be avoided at all costs as in the case it cost many people a lot of money, but when mistakes like this are made in the maps from the thesis, people might get seriously injured or lose their lives. This has identified a new stakeholder for the thesis: municipalities. If these instances make sure that their maps are up to date in regards to roads, the maps are going to be much more realistic and therefore safer.

5 Remembering the ethical benefits of creative work

In the next chapter, the focus will be on how terrible people can use this project for their plans. However, this project came out of a hunger to help people when they are vulnerable. This project is made with a good heart and hope behind it. As technology advances, humankind has gained the possibility to prosper more and more. However, with this prosperity comes a price, the price of the climate changing, threatening human life as we know it. All parts of society must come together to ensure that the change that is seen in the climate does not exceed its limits, limits humankind hopefully does not cross as then the planet is damaged to an extent that cannot be fixed. In the meantime, new protocols and plans must be created as the old tools are not accurate anymore.

Especially in combination with an application, this graduation project can save the lives of many people, hopefully not just in The Netherlands, but all over the world. This project can help people get themselves and their loved ones to safety as they can predict what the best route to go is. Not all governments have the funds to develop evacuation routes to ensure the maximum safety of their citizens, but the result of this project can do it for them. Because of this progress, all citizens have the same opportunities to get to safety, loss of life based on a class system will be minimized. Maybe, as the development of the scope of this project progresses, it can be used for other disasters too. Events like floods, tsunamis, or maybe even tornados. Natural disasters are not likely to stop happening, so humankind needs to find ways to deal with them.

The loss of nature that is seen in wildland fires can not be controlled with this project, but the loss of human lives, the hurt among families who have lost loved ones in these disasters, can be minimized in the future.

6 Think about the terrible people

Unfortunately, not everyone has good intentions. In every great invention that is meant to help people, there is a way to abuse the good of some and apply it in a terrible way. That is no different for this graduation project. In this chapter, some ways of wrongdoing will be discussed. It is worth mentioning that for this chapter, the final goal (making the maps available for more locations) is taken into account rather than just de Veluwe.

First of all, hacking. The database with these maps can be hacked and people can put in wrong information which can lead to catastrophically dangerous situations. Different data creates different fires, and it is crucial for the evacuation routes that the right fire propagation is used. If not, all the people in the area can go in the wrong direction and walk straight into the furnace. This is obviously not the reason that these maps are being made. The hackers can manipulate the data in such a way that the maps show certain routes that are completely unsafe, even though the people using them think they are headed in the right direction. So, shortly: creating a situation where the maps are based on the wrong data.

Next, the correct maps can be used for the wrong reasons. If these maps are available to everyone, and they should be as every person should be able to get to safety, then people with malicious intentions can get to them as well. They could check the maps beforehand, block the designated evacuation route so that in the case of a fire, people cannot get out via that route. As de Veluwe is a rather big area, it could take a long time for people to travel to another exit to get to safety. During the event of a fire, time is of the essence as fire spread is not linear. What you want is for people to follow a clear, streamlined evacuation route and if this is blocked, there will be massive amounts of panic which will cause more people to get injured.

Thirdly, the maps could show secret military bases. If it happens to be that the evacuation route goes straight through a military training location, this will create many problems (example: citizens getting shot for entering a classified site). Now, this can obviously be avoided by blocking out that area on the options of exits. Problem solved! Well… no. If people with bad intentions think ahead (and they probably do as they have a clear goal envisioned) and check these maps, they could wonder why a specific area of the map is blocked out. It becomes clear that the public can not enter that area, and they could wonder why that is the case. If they manage to put 1 and 1 together, they will come to the conclusion that the specific area on the map must contain something that is not meant for the public, and could mistreat this information. This jeopardizes national security and the safety of the citizens.
The last case that was thought of is not necessarily malicious or evil, but it is a reality that has to be taken into account. If the maps show where the fire is going to go, and it happens to be that the fires cross the same piece of land every time, this plot of land could lose its value. This often happens when a piece of land is located in an area that is prone to disasters or other things that cause dissatisfaction, such as a railroad 10 meters from the backyard. This is not that much of a problem when it's owned by the national park, but when it happens to a piece of land that belongs to a different owner, let's say a homeowner, it could be terrible for them. The price of their house will decrease. This might not be as terrible for the public as the other mentioned cases, however it could be upsetting for the people living in the area around the national park, or maybe even in the park.

7 Ethical feedback and iteration

Looking at the project from an ethical point of view is a continuous process. Every time a feature is added or something is removed, the project has to be looked over again. Maybe, new stakeholders arise and need to be taken into account. This process is never done, not even when the product is on the market.

The following arguments should enable continuous use in an ethical way:

- The maps should always adhere to the newest technology and ways of simulating fire. In this way, the safest option is always available to the users
- Users must have a way to contact the creators of the maps; user support is needed
- Stakeholders must continuously be involved in design of updates
- If any working of the maps is compromised, the whole thesis should be reconsidered and perhaps be changed

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