

# The Application of a Wildfire Evacuation Tool to Swedish locations

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# **The Application of a Wildfire Evacuation Tool to Swedish locations**

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### **Abstract**

WUI-NITY is a computer modelling program for wildfire evacuation simulations. This thesis examines the applicability of WUI-NITY to locations in Sweden. The program was tested at example locations representing the Swedish landscape. The objective of this work was both to examine the application of the model, but also to produce a process by which the model might be applied – highlighting challenges during this process. The refinement of this process required the practical application of the model – identification of issues and necessary user steps. The process was clearly documented from start to finish, which was the basis for the result presented. From the documented process an application protocol was created containing detailed guidance on how the program can be configured for new locations. It includes not only Sweden, but also other countries where WUI-NITY is desired as a wildfire evacuation tool. The application protocol has been used successfully generating output data at new locations as well as influencing the development of future versions of the program. During the process, gaps and errors in the program were discovered as well as problems encountered during the application. Some gaps/problems have been addressed during the course of the process (as part of this project); for example, errors in the WUI-NITY code. Others have been discussed together with relevant literature resulting in suggestions of improvements for further development considering WUI-NITY's applicability to new locations, but also for general development of the program. Some of the suggested improvements are listed below:

- Change the wildfire modelling tool from FARSITE to Prometheus, which will better represent a fire in the Swedish landscape. If WUI-NITY is to be applied in other countries, it is important that a suitable wildfire modelling tool is used.
- Create a map for Sweden containing all the necessary data needed to create a .lcp file (or similar if Prometheus is used). Integrate that map into WUI-NITY to eliminate the time-consuming steps required to collect and modify data for the .lcp file.
- Integrate live weather and FWI updates into WUI-NITY enabling real-time wildfire simulations with more reliable output data.

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Supervisor for this thesis and was fully committed throughout the entire process. Contact was made with regularly meetings consisting of good discussions about problems encountered and how to move forward in the processes. It is easy to see that Steve has many years of experience in the field as he shows prominent level of knowledge. A special thanks to Steve for being a guide to solve an unexplored problem.

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Jonathan is the founder and creator of WUINITY. He provided with the latest updates of the program. He showed a phenomenal problem-solving ability when gaps were identified that was needed to be solved in order to move forward in the process. Long meetings even after office-hours have been crucial to understand the problems encountered, but also to receive a deep knowledge about the program. Thank you, Jonathan!

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Vai has provided with important input regarding the structure and content of the thesis. He has also used the *Application Protocol (4.1)* to a new location (Marsden Moor, UK) with success, which confirms the applicability of this thesis. Additionally, during Via's application, constructive questions was received enhancing the content of this work. Thank you!

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Peter is currently working with the new GUI for WUI-NITY. In that process, the content of this thesis has been used. Peter have provided with constructive question enhancing the content of this work. Thank you!

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## Summary

WUI-NITY is a computer modelling tool enabling the user to simulate evacuations of WUI-communities (WUI - Wildland Urban Interface). The tool was developed with the purpose of running simulations in the US landscape, with respect to the local topography and vegetation presented there. Recent statistics has proven that the likelihood and severity of wildfires has increased during the last years and will continue to increase in the future. More people threatened by wildfires in need of evacuation is a possible outcome of the growing threat. It is then of interest to examine WUI-NITY's applicability to other locations, that might benefit from the tool in the future. This thesis has examined the applicability of WUI-NITY to the Swedish landscape.

The methodology of this approach can be summarised accordingly:

**1:** Literature review about WUI-NITY and wildfire computer modelling. **2:** Identification of countries with similar landscape and vegetation. **3:** Literature review about past wildfire evacuations (occurred in Sweden and other countries). **4:** Learning the program. WUI-NITY was installed, assessed and tested. **5:** The process of applying WUI-NITY to a Swedish location. **6:** Discuss the outcome of the application – generating conclusions and suggestions of improvements.

The result received during the process is presented in four main sections:

*4.1 application protocol* – A guidance created from knowledge and result received during the application process, without all the missteps and errors. The application protocol can be used to apply WUI-NITY to new locations in Sweden as well as other countries. The application protocol has been used to apply WUI-NITY to a location in the UK, Marsden Moor. *4.2 Important findings and gaps discovered* – During the process of applying and using WUI-NITY, errors, gaps and important findings was discovered. For example: FARSITE is included as the fire modelling tool in WUI-NITY. To run simulations in the Swedish landscape, Prometheus is a more suitable option due to the program being based on the same wildfire prediction tool used in Sweden (CFFDRS). Errors in the code was also discovered during the process that when addressed, generated new versions of WUI-NITY. *4.3 Knowledge required to set up WUI-NITY to a new location* - This section provides a recommendation of knowledge needed for the application process. For example, knowledge about GIS is essential. *4.4 Simulated data* – The application process generated output data for two Swedish locations, Dorotea and Bottnaryd.

The result was discussed together with relevant literature generating conclusions and suggestions of improvements. The most important outcomes of this thesis is summarised:

- WUI-NITY is applicable to the Swedish landscape. Future work is required to eliminate and mitigate potential gaps and uncertainties – resulting in reliable output data. Example: replace FARSITE with Prometheus, examine more suitable input variable affecting the output data and include live update of those and other input variables.
- The *application protocol* can be used to apply WUI-NITY to new locations, in Sweden as well as in other countries. The protocol eliminates many time-consuming steps making the process of application efficient.
- It is recommended to create a map for Sweden containing all the necessary data needed to create a .lcp file (or similar if Prometheus is used). Eliminating the time-consuming steps of collecting and modifying data for the .lcp file.

- This work has developed WUI-NITY in general, both regarding addressing errors in the main code of the program as well as influencing future development (for example the new GUI-design).

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## List of Abbreviations

ASET	Available Safe Egress Time
BUI	Built Up Index
CBD	Crown Base Density
CBH	Crown Base Height
CFFDRS	Canadian Forest Fire Danger Rating System
DC	Drought Code
DMC	Duff Moisture Code
EFFIS	European Forest Fire Information System
EGPU	External Graphic Processor Unit
FARSITE	Fire Area Simulator
FBP	Fire Behaviour Prediction
FFMC	Fine Fuel Moisture Code
FOP	Fire Occurrence Prediction
FVS	Fire Vegetation Simulator
FWI	Fire Weather Index
GPW	General Population of the World
GIS	Geographical Information System
GUI	Graphical User Interface
HRR	Heat Release Rate
IGPU	Integrated Graphic processor Unit
ISI	Initial Spread Index
OSM	Open Street Map
PERIL	Population Evacuation trigger algorithm
RAM	Random Access Memory
RSET	Required Safe Egress Time
SMHI	Swedish Metrology and Hydrology Institute
UTM	Universal Transverse Mercator (Coordinate system)
WUI	Wildland Urban Interface
$\Delta H^{\circ}_c$	Heat of Combustion (J/kg)

# 1. Introduction

The purpose of this chapter is to provide background information regarding why this thesis was necessary as well as the purpose, goals and limitations of this work.

## 1.1 Background

Due to an increase in extreme weather conditions, more frequent and extensive wildfires across the globe can be expected in the future. The number of wildfires will increase by 50 percent to the year of 2100 (UNEP & Grid-Arendal, 2022). It is reasonable to infer that the increase in wildfires, will also increase the need to evacuate people trapped by them. Recent statistics shows that the needs of evacuation initiated by wildfire are elevated. For example, in Canada, 20 evacuations were carried out each year between 1980-2007, one year as high as 53 evacuations (Beverly & Bothwell, 2011). In the US, over one million people were evacuated from wildfires in California alone between 2017-2019 (Wong et al., 2020). Wildland fires do not only affect the rural areas, but also the suburban and urban areas. The increasing threat of WUI (Wildland Urban Interface) fires is, and will be, a serious challenge in the future. Large WUI-fires can result in severe consequences such as property loss, loss of life and mass evacuations. Due to the increase of the global temperature, these consequences are predicted to become even worse (Wahlqvist et al., 2021).

According to Gwynne et al., 2019 one way of assessing the threats and impacts from a WUI-fire to a given community, is by using computer modelling tools – to generate evidence of evacuation performance for community planning. A couple of computer modelling tools exist today with the purpose of predicting the spread and behaviour of wildfires, for example Prometheus and FARSITE (Finney, 2004; Tymstra et al., 2010). But only the spread and understanding of the fire behaviour might not be enough as a predictor of how populated areas are affected. In addition to the fire behaviour, according to Wahlqvist et al., 2021 and Kuligowski, 2020, other factors such as the density of the population, the capacity and the arrangement of the road network, the geographical terrain surrounding the area and a community's ability to manage a wildfire are also important. Those factors can play a crucial roles for the prediction on; if, when and how to evacuate a community threatened by a wildfire.

If a computer model accounts for fire weather, traffic flow, and emergency evacuation etc., practitioners might be able to determine when to evacuate a location or if a wildfire poses a threat at all. That is an effective way to assess a community's vulnerabilities and plan accordingly (Ronchi et al., 2019). Historically, few opportunities exist to model community evacuation in response to wildfire threats. Given this, there have been limited means to employ an evidence-based approach to establishing when communities should respond to an incident. Such models are now just beginning to appear allowing specific applications to be conducted. One of these models is named WUI-NITY (Ronchi et al., 2020).

WUI-NITY is a software tool developed to simulate wildfire spread affecting communities and human behaviour of those evacuating. WUI-NITY is developed using a game engine called UNITY 3D. WUI-NITY focuses on three layers that are present during a wildfire evacuation; the fire, pedestrian movement, and traffic flow. With these factors considered, evacuation behaviour can be predicted over time (Ronchi et al., 2020). The current version of WUI-NITY includes FARSITE (Ronchi et al., 2020) as the fire modelling tool, a pedestrian model developed to represent resident delays on leaving their home (before entering the traffic system), and the Lighthill-Whitham-Richards model for modelling the traffic flow during the evacuation (Ronchi et al., 2020; Initi et al.,

2019). WUI-NITY can be used for education purposes, forensic analysis and during an event to predict if and when a community should evacuate (Ronchi et al., 2020).

In 2019 a community evacuation drill was conducted in Roxborough Park (USA). The evacuation drill was also set up in WUI-NITY to test the program's reliability and its application to a real-life scenario. Ronchi et al., 2020 compares the results of the real-life drill with the same case simulated by WUI-NITY. The evacuation simulation was complete in 2 hours, while the drill was completed in 2,5 hours. The difference in the evacuation time could be explained by the spatial resolution, the speed of the cars in the simulations and time-steps used in configuring the simulations. Ronchi et al., 2020 concluded that future validation and work is needed to improve the accuracy of the WUI-NITY model prediction.

So far, the program has only been tested against datasets from the United States. Since wildfires are also becoming increasingly commonplace across the globe, the next step is to test WUI-NITY in environments and landscapes in other countries. That was examined in this study, if WUI-NITY is applicable to be used in the Swedish landscape. And with that application, the tool might also be applicable to countries with similar landscape.

The Swedish landscape is similar to that in Canada in terms of the vegetation types presented. Therefore, the same wildfire prediction tools can be used for simulating the fire behaviour (MSB, 2022). Tymstra et al., 2010 states that the simulation of fire behaviour in Canada is done by a computer modelling program called Prometheus. Prometheus includes the sub-models of CFFDRS (Canadian Forest Fire Danger Rating System) which consists of FWI (Fire Weather Index) and FBP (Fire Behaviour Prediction). Both the computer modelling program and the sub-models are created in Canada with respect to the environment presented there (Tymstra et al., 2010). And due to the similarities between the Canadian and the Swedish landscape, it is suggested that the modelling program and the sub-models are also applicable to the latter. FWI and FBP are used in Sweden as the main tools for wildfire risk analysis (MSB, 2022). Eriksson et al., 2022 has tested the applicability of the FWI model to the Swedish landscape – indicating that the tool is a good choice. FWI specifies the probability of ignition and intensity of the fire. FBP can be used for calculating the behaviour and spread of a wildfire in a given landscape (MSB, 2022).

During the summer of 2014, a large wildfire started in Sala municipality by a harvester (*Appendix C.1*). Over one thousand people were evacuated and approximately 6000 people were planned for evacuation as 20 busses stood on standby. The fire was closing in on a town called Norberg and decision-makers were just hours away from blowing the horn to give the evacuation order (Ou, T., 2017; Ronchi et al., 2021: *Appendix C.1*). Since 2014, Sweden has further experienced a few large and fierce wildfires (Kelly et al., 2021). 69 percent of Sweden's surface is covered by forest (SCB, 2019), which means that a large part of the country's area is at risk of being affected by forest fires in the future. And given the trend of global warming and the expectations of larger and more frequent wildfires in the future, there is an increasing need for a reliable wildfire evacuation tool to address the public safety issue.

## 1.2 Problem statement

This thesis aims to explore and identify the challenges of applying WUI-NITY to the Swedish landscape. The tool will be applied to example communities in Sweden to identify challenges with the application and identify practical workarounds or gaps that needs to be filled.

## 1.3 Goals of the study

The goal is to apply WUI-NITY to example locations in Sweden - identifying model limitations and omissions that will be documented. The documented findings will be addressed if possible, otherwise they will be presented as future suggestions of improvements. The goal is also to provide a step by step guide making the process of applications to new locations much more efficient in the future.

### 1.3.1 Questions to be answered during the study

*How is WUI-NITY applicable to the Swedish landscape?*

*What improvements can be made to the program as well as for the process of application?*

## 1.4 Limitations

The Swedish landscape varies geographically – within Sweden and with other areas historically vulnerable to wildfire events (for example California). There are a variety of trees and vegetation types scattered across the country. This thesis will carry out simulations only in several locations, which means that certain tree and vegetation types will be missed.

PERIL is a computer simulation tool used for the trigger buffer function in a wildfire scenario, in other words – it contains a function that indicates when the community should be evacuated, enabling everyone to be evacuated in time before the fire reaches the community. PERIL was before integrated in WUI-NITY, but when this thesis is written, it is not. That will hence be a limitation of the study, to not use PERIL as a part of the evacuation assessment. If PERIL is to be integrated in WUI-NITY once more, its application to the Swedish environment has to be tested.

All models are limited. There are inevitably elements not included in the model itself, or uncertainties of certain parameters. This was clearly documented in this thesis. However, the goal here is primarily to demonstrate the potential of this approach.

This work tested a new approach to an unexplored problem. It is therefore hard to specify all the possible limitations of this study, there is no benchmark for comparison. There will inevitably be ‘unknown-unknowns’ that might be discovered as limitations in the future.

## 2. Methodology

The methodology of this thesis can be summarised accordingly:

1. Literature review regarding WUI-NITY and wildfire computer modelling.
2. Literature review about past wildfire evacuations (occurred in Sweden and other countries).
3. Identification of countries with similar landscape and vegetation.
4. Learning the program. WUI-NITY was installed, assessed and tested.
5. The process of applying WUI-NITY to a Swedish location.
6. Discuss the outcome of the application – generating conclusions and suggestions of improvements.

### 2.1 Literature review

The first part of this project focused on understanding the requirements of applying WUI-NITY to a Swedish location. A literature review was conducted, and it was discovered that WUI-NITY uses traffic flow, decision-making behaviour, and fire weather factors to generate output data. It was then crucial to understand these factors for the purpose of maximizing the result, and to establish relevant information from recent wildfire incidents. It was also necessary to establish an understanding of factors influencing community evacuations. To be able to run simulations and understand the methodology behind the program, scientific articles, books and other literature was studied. The second step of the study focused on research about past wildfire evacuations that had occurred in Sweden. And to broaden the perspective, the third step was to identify countries with similar landscape and climate as Sweden, and by that discover past evacuations in other countries that could be applicable to this thesis even though the focus lays at Sweden.

*To retrieve articles about past evacuations in Sweden and in countries with similar landscape following keywords was used:*

- Wildfire OR Forest Fire
- AND Sweden OR Norway OR Finland OR Canada OR United Kingdoms
- AND Evacuation OR Evacuation time OR mass evacuation OR evacuation Simulation

*To broaden the search for Swedish literature, Swedish keywords was used:*

- Skogsbrand OR Skogsbränder
- AND Sverige
- AND Evakuering

To retrieve articles about the program, WUI-NITY, the only keyword used was *WUI-NITY*. As the program is relatively new, there is a limited amount of literature.

Two search engines - Google scholar and LUBsearch - were used to find the literature. A snowball approach was used when cited references for relevant articles was studied. 72 articles were found which were then sifted down to 15. For the past evacuation data study, articles containing data regarding countries with landscapes that is not similar to the Swedish were excluded. Articles containing no valuable evacuation data was also excluded. For the WUI-NITY study, most of the articles found was used. Some articles were excluded due to containing similar information. The literature review was carried out between 2022-01-29 – 2022-03-01.

For the purpose of learning WUI-NITY as well as describing the program in the thesis, sufficient articles was found. But for articles regarding wildfire evacuation data for Swedish evacuations, only a small number of articles was found. It was also doubtful if the existing data could be used. The amount of data from other countries with similar landscape was more extensive, especially from Canada.

During the first stages of this thesis work, the main focus was on applying WUI-NITY to Swedish locations, assuming that the process would have been trivial, and then take the output data generated from those simulations and compare it with the evacuation data from the literature. But the process of application was not as smooth as the author had hoped for with a lot of errors and problems encountered. Due to that fact, as well as the fact that there was only a small amount of data available for Swedish evacuations, the focus shifted. Instead of focusing on a comparison of the output data with the literature, the main focus shifted to the methodology of applying WUI-NITY to Swedish locations and identify errors, gaps, etc. that could develop the program. But also to make the process of application more efficient for future applications.

## 2.2 The process of application

The fourth part was to learn the program. WUI-NITY was installed and assessed by using an example case (the Roxborough case) provided by the founder of the program, Jonathan Wahlqvist. In order to run WUI-NITY with respect to the Swedish landscape, a range of input data was required, including the population of the area studied, the road network map, terrain (aspect, slope, elevation), characteristics of the fire, fuel types and fuel density. During this step the sub-models within WUI-NITY were also studied, mainly FARSITE (*Section 3.4*) and PERIL (*Section 3.2*). It was discovered that PERIL was not available through WUI-NITY anymore.

The fifth step was to examine WUI-NITY's applicability to the Swedish landscape. The locations of Bottnaryd and Dorotea was used for the application. Dorotea was the primary choice due to:

- It is a small town in northern Sweden with a population of approximately 1850 people.
- It is surrounded by a lot of woods, which is typical for a small town/society in Sweden, i.e. a WUI-community.
- The main vegetation is pine and that is a fire-friendly fuel. Pine is a very common fuel type in Sweden.

The most time-consuming part of this thesis involved data collection, learning new programs, using GIS to modify data etcetera. A lot of research had to be done in order to identify gaps in the program (WUI-NITY) and the process of applying the program. A detailed documentation of that process is described in *Appendix A – Documentation of the process*. *Appendix A* can be studied from several perspectives, one of these perspectives is to study *Appendix A* as a detailed methodology. It is then recommended to read through *Appendix A* before studying *Section 4* and forward in this thesis.

The sixth step was to analyse the process and the generated data. The process of applying the model was summarised as an *application protocol* (*Section 4.1*) for further research, containing detailed guidance on how the program can be configured for new locations – without all the gaps as missteps that have been experienced during this work. Gaps discovered were also documented along the way and are presented in *Section 4.2* and discussed at *Section 5.2*. Output data generated by WUI-NITY was analysed and is presented in *Section 4.4 Simulated data* and discuss in *Section 5.2*.

During this work, several people were crucial for the process to progress in the right direction. During some steps (as presented in *Appendix A*) it was necessary to contact certain key persons in order to move forward. Those persons are mentioned under *acknowledgement*.

It is also worth mentioning that such a time-consuming and detailed process as this has been, would not have been possible if this work had not been started early. The project time plan was constructed during the late months of 2021, and the work was initiated in January 2022. This means that this thesis project has been carried out over a period of time that extends for more than a year.

During the late stage of this work, professionals have studied the content of this thesis – mainly the *Application protocol* (*Section 4.1*). Those professionals have since used the content, both to apply WUI-NITY to new locations in other countries and to develop a new GUI for future versions of the programs. The use of the content of this thesis has generated questions, which have been answered in *Appendix G*.



### 3. Theory

In the following chapter, necessary theory is described with the purpose of deepening the knowledge of the reader to better understand the content of this thesis.

#### 3.1 WUI-NITY

WUI-NITY is a computer simulation tool that can simulate evacuations of a community afflicted by a wildfire. WUI-NITY is developed by using the game engine named UNITY 3D. By using UNITY, sub-models can be developed and integrated into the program for simulation purposes (Ronchi et al., 2020). FARSITE (wildfire behaviour), a traffic flow equation and a pedestrian/traffic evacuation model are integrated in WUI-NITY and developed by the use of the game engine UNITY 3D (Ronchi et al., 2020: Ronchi et al., 2017). PERIL (a tool to calculate when a evacuation is needed, *Section 3.2*) was integrated into WUI-NITY before, but when this thesis is written (2022), PERIL is not included in WUI-NITY due development of the program. The goal is to include PERIL in WUI-NITY once the PERIL is enhanced.

As a summary, WUI-NITY is a tool that can be used to help WUI communities across the globe for the purpose of planning, training, preparedness, and emergency situations (a live wildfire threatening a community). To be able to run simulations with WUI-NITY, input data is needed (Wahlqvist et al., 2021). Some of the input data is described in more detail below, but here is the full list of necessary files:

*Table 1: Overview of the full list of necessary input files and a short description to each file. Note that the .rcp, .gif and .egs is files created when running a case in WUI-NITY (output files).*

<b>Filename</b>	<b>File extention</b>	<b>Description</b>
WUI file	.wui	Main input file
Landscape file	.lcp	File used to map the conditions in the area
General population file	.gpw	The database for the .pop file
Population file	.pop	Mapping of the location and number of people in the area
Road network file	.osm	Mapping of the road network for the area
Router database	.routerdb	Pathways to routing of the inputdata
Ignition file	.ign	Specifies the coordinates for the ignition points
Fuel moisture file	.fmc	Specifies the moisture content in the shallow soil
Weather file	.wtr	Specifies temperature, date of the year and time of the day
Wind file	.wind	Specifies the speed and direction of the wind
Fuel file	.fuel	File that specifies the attributes of the fuel types in the area
Evacs goals	.ed	File that specifies the coordinates of the safe areas
Evac groups	.eg	Distribution of evacuating people to each safe area
Response curve	.rc	A curve over the evacuating population
Reported average	.rcp	File created by WUI-NITY
	.gif	File created by WUI-NITY
	.egs	File created by WUI-NITY

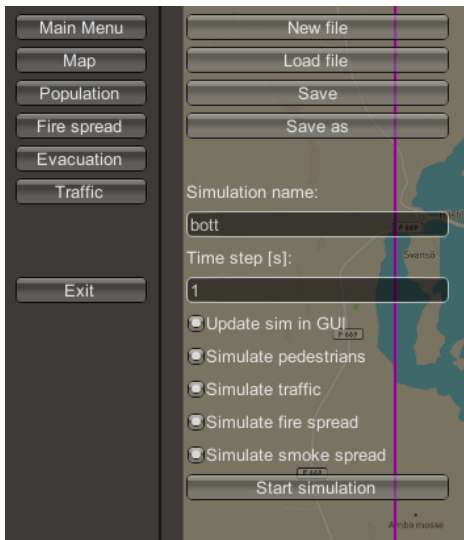


Figure 1: The interface of WUI-NITY (version 0.15).

### 3.1.2 Files needed by WUI-NITY

In order for WUI-NITY to successfully execute simulations, a number of files needs to be modified and included. Some of the files are described below, regarding its function and necessity.

#### 3.1.2.1 WUI-file (.wui)

The .wui file can be described as the main file. All the other code files are linked and connected to the .wui file. When starting WUI-NITY, the first thing is to load the .wui file. That can be described as opening the specific case in the program. An example of codelines presented in the .wui file can be seen in *Appendix B.1*.

#### 3.1.2.2 Landscape file (.lcp)

A landscape file is needed by WUI-NITY to simulate a fire in a given area (using FARSITE, *Section 3.4*). The landscape file can be described as a mapping of the conditions in the area where the fire will spread - a mapping of the local topography and vegetation presented there (tree types, lakes, elevation, slope etc) (Finney 2004). To run simulations in the Swedish landscape and vegetation, an .lcp file created with raster data from the Swedish landscape of a given location is needed. The file can be created in several different ways. One way is by using FlamMap (*Section 3.3*), another is by installing the Arcfuel (*Section 3.6.2*) toolbar and integrate it into ArcGIS (*Section 3.6.1*). The outcome is the same - the raster data is merged into one .lcp file that can be used in WUI-NITY. Regardless of which method is used, following raster data is needed to be able to create the file:

- Topographic (elevation, slope, aspect)
- Fire Behavior Fuel Model
- Forest Canopy Cover
- Forest Canopy Height
- Forest Canopy Base Height
- Forest Canopy Bulk Density

### **3.1.2.3 Population file (.pop), GPW - database**

The .pop file is generated by either using the GPW-database or manually (by WUI-NITY) populating the area. The GWP-database can be described as a mapping of where the world's population are located (number and location of people) (SEDAC, 2022). If an area is to be examined, for example Sweden, the GPW database will provide the number of people living in the area and the location of those living there. An example of codes used in the .gpw file can be seen in *Appendix B.3*

### **3.1.2.4 Road network file (.osm)**

To be able to study and take the road network into account, an .osm file is needed. People evacuating from a community will use the road network to escape the threat of a wildfire. OSM is an abbreviation for Open Street Map. By simple words, the file can be described as a mapping of the local road network (Open Street Map, 2022). The .osm can be filtered down by the help of WUI-NITY to only include data of the road network for the studied area. The filtering process is described in *Section 4.1*, and *Appendix A*.

### **3.1.2.5 Fuel moisture (.fmc), weather (.wtr) and wind files (.wnd)**

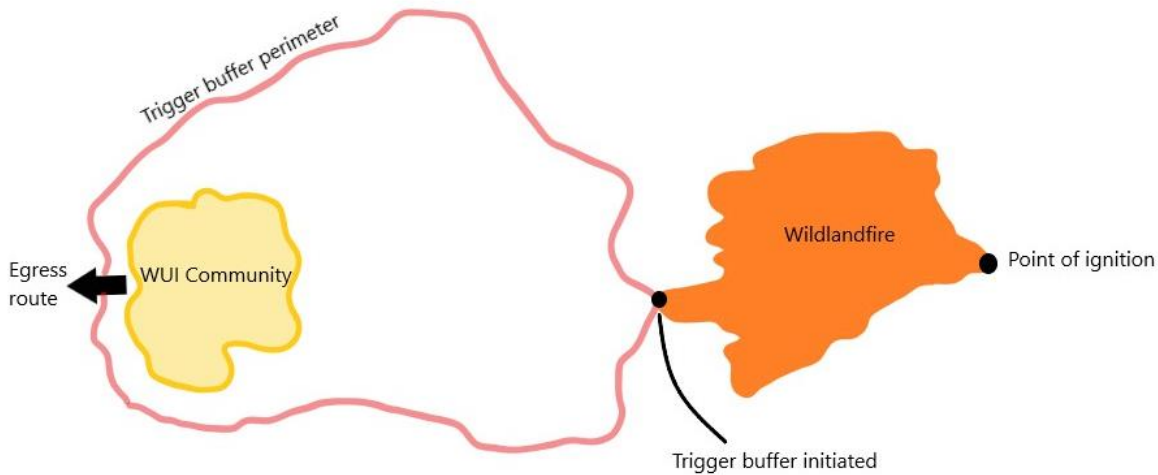
These types of files enable the user to change the weather conditions that directly influence the behaviour of a wildfire. If the fuel moisture is high, a wildfire will have a tough time spreading and the probability of ignition will lower (Taylor & Alexander, 2016). The weather-file contains information about the date of the year and time of the day. It also contains temperature information. The wind file contains data about wind speed and wind direction, which highly affects wildfires spread rate (Taylor & Alexander, 2016). Example of code used in the .fmc, .wtr and .wnd files can be seen in *Appendix B.4*, *B.7* and *B.8*

### **3.1.2.6 Fuel file (.fuel)**

The fuel file specifies what kind of fuel is present with respect to the fuel map used in order to create an .lcp file, it contains information of the vegetation types that is present in the landscape. The vegetation type in every cell is classed as a fuel class which is represented as a class colour in the map layer. Each colour/number represent a different type of vegetation (tree type, bush etc). The attributes of the vegetation types presented in the fuel map is then specified in the .fuel file. And the attributes are specified to the burn characteristics of the specific vegetation type (HRR,  $\Delta H^{\circ}$ , fuel load, fuel moisture etc) (Source: *Appendix A*). Example of code used in the .fuel file can be seen in *Appendix B.2*.

### 3.2 PERIL

PERIL is a tool used to determine the appropriate and safe time of when to evacuate a community afflicted by a wildfire (Wahlqvist et al., 2021). PERIL uses ASET and RSET to calculate when to evacuate. ASET is the Available Safe Egress Time. It answers the question about how long time it will take before the fire reaches the community. RSET is the Required Safe Egress Time. RSET answers the question about how long time it will take to evacuate the community (Wahlqvist et al., 2021). If RSET and ASET is compared, a time of when to evacuate safely can be calculated. The calculations are done by PERIL and is displayed as a zone around the community on a map. When the fire reaches that zone, it is time to evacuate the community. The zone is called a *trigger buffer perimeter* (Mitchel, 2019). An illustration of the function of PERIL is shown in *figure 2*.



*Figure 2: Illustration of a trigger buffer perimeter calculated by using RSET and ASET. When the wildland fire reaches the trigger buffer perimeter, the community is to be evacuated in order to safely escape the fire. The figure is created with inspiration from Wahlqvist et al., 2021.*

### 3.3 FlamMap

FlamMap is an analysis tool that can simulate fire behaviour in a given constant environment (weather and fuel moisture). FlamMap can, for example, simulate spread rate, flame length, fire growth and burn probabilities. FARSITE (*Section 3.4*) is included in FlamMap which also makes it possible to simulate wildfire behaviour and growth for a longer time duration with respect to terrain, fuel moistures and weather conditions. FlamMap can be used to create .lcp files (*Section 3.1.2.2*), (Finney, 2006; USDA, 2020). An .lcp file can then be included in WUI-NITY for fire behaviour simulations by the use of FARSITE (due to FARSITE being integrated into WUI-NITY as the fire modelling tool). The wildfire simulations done by WUI-NITY is based on the same calculation methods as in FlamMap and FARSITE (Wahlqvist et al., 2021). To this date, the latest version of FlamMap is FlamMap 6.

### 3.4 FARSITE

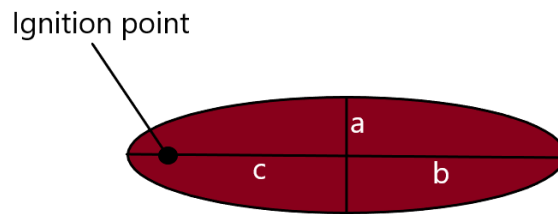
FARSITE is a wildfire modelling program that simulates the fire behaviour for each cell in the landscape file (.lcp file). By that, FARSITE can model flame length, crown fire activity, crown fire initiation, crown fire spread and fire growth. To be able to run simulations with FARSITE, the following data needs to be included for each cell of the .lcp file: dead fuel moisture, slope, aspect, shading, elevation, fuel model, canopy cover, canopy density and weather conditions (wind, humidity, temperature) (Finney, 2004). FARSITE is included in WUI-NITY as the wildfire simulation tool (as of WUI-NITY version 0.15). To be able to run wildfire simulations in FARSITE, and in WUI-NITY, an .lcp file is required. The program is developed by the United States government and is fitted to the landscape presented there (Finney, 2004; Finney, 1995).

Huygen's Principle is used for modelling the surface fire growth. The spread in X and Y direction is calculated according to the trigonometric equations [1] and [2]. *Figure 3* visualise how the fire is spreading according to equation [1] and [2] (Finney, 2004).

$$X_t = \frac{a^2 \cos \theta (x_s \sin \theta + y_s \cos \theta) - b^2 \sin \theta (x_s \cos \theta - y_s \sin \theta)}{(b^2 (x_s \cos \theta + y_s \sin \theta)^2 - a^2 (x_s \sin \theta - y_s \cos \theta)^2)^{1/2}} + c \sin \theta \quad [1]$$

$$Y_t = \frac{-a^2 \sin \theta (x_s \sin \theta + y_s \cos \theta) - b^2 \cos \theta (x_s \cos \theta - y_s \sin \theta)}{(b^2 (x_s \cos \theta + y_s \sin \theta)^2 - a^2 (x_s \sin \theta - y_s \cos \theta)^2)^{1/2}} + c \cos \theta \quad [2]$$

*Equation 1 and 2: Shows how the spread in X and Y direction is calculated by the Huygen's Principle (Finney, 2004).*



*Figure 3: The fire growth is computed by combining equation [1] and [2]. 'a' corresponds to 1/2 minor axis in the lateral direction from the centre of the ellipsis. 'b' corresponds to 1/2 of the major axis in the horizontal direction from the centre. 'c' is the distance from the ignition point to the centre of the ellipsis. The figure is created with inspiration from Finney, 2004.*

### 3.5 Prometheus

The simulation of fire behaviour in Canada are mainly done by a computer modelling program called Prometheus. Prometheus includes the sub-models of CFFDRS (Canadian Forest Fire Danger Rating System) which consists of FWI (Fire Weather Index) and FBP (Fire Behaviour Prediction). Both the computer modelling program and the sub-models are created in Canada with respect to the environment and landscape presented there. Prometheus computes spread outputs and fire behaviour given weather, fuel and topography inputs (Tymstra et al., 2010). The CFFDRS is also used in Sweden as the main wildfire prediction tool (MSB, 2022; Eriksson, 2022). In 2014 simulations were carried out in Prometheus, comparing the program with a real world fire in Lieksa, Finland. The data from the simulation and the real world fire matched well (Kolstela, 2019). Finland and Sweden have similar landscape.

According to Tymstra et al, 2010, Prometheus can for example be used for:

- Prediction of wildfire growth for decision making during wildfires
- Planning prescribed burns
- Forensic support during wildfire investigations

#### 3.5.1 CFFDRS

The Canadian Forest Fire Danger Rating System consists of three main input properties: The FOP, FWI and the FBP systems (*Figure 4*). FOP (Fire Occurrence prediction) is not fully included in the CFFDRS system as of today but will probably be in the near future. FOP is a prediction about what can and will cause a wildfire (by human, lightning strikes etc). The FWI system and the FBP systems are as of today the key ingredients in the CFFDRS (Nat Resources Canada, 2022). FWI and FBP is described below (*Section 3.5.1.1, 3.5.1.2,*).

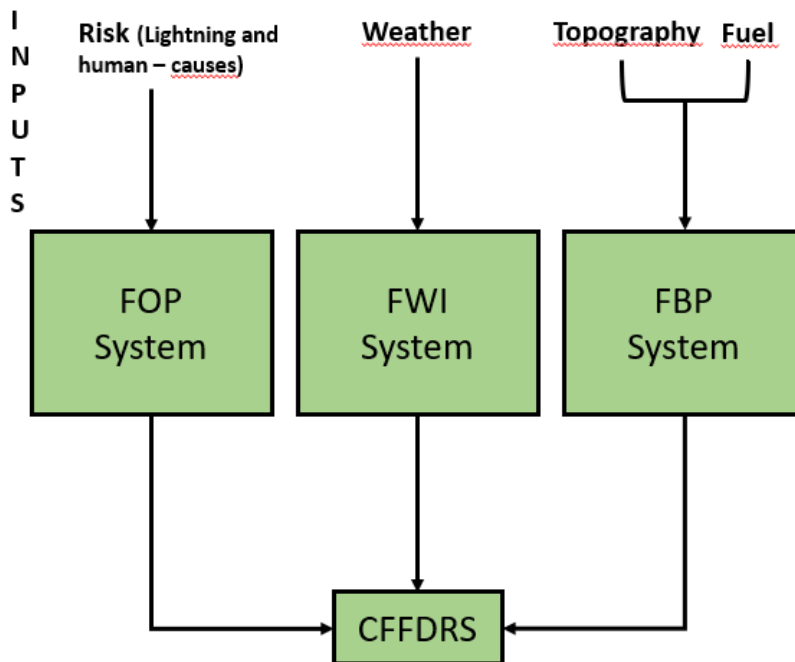


Figure 4: Illustration of the elements included in the CFFDRS. The figure is created with inspiration from Nat Resources Canada, 2022.

### 3.5.1.1 Fire Weather Index (FWI)

Fire Weather index (FWI) is a model that predicts the risk of ignition and the potential fire behaviour. The model originates from Canada but is used in areas of similar environment and landscape across the world (for example UK (CBC, 2022) and Sweden (MSB, 2022)). When calculating the value of FWI, different input data is required: FFMC, DMC, DC, ISI and BUI (Figure 5) (MSB, 2022; EFFIS, 2022; Nat Resources Canada, 2022).

#### FFMC (Fine Fuel Moisture Code)

Humidity of the shallow soil (0-2 cm). A high value indicates that the shallow ground layer is dry and easily can ignite (MSB, 2022).

#### DMC (Duff moisture code)

Humidity of the soil measured at 5-10 cm below surface level. A high value indicates that a wildfire can burn deeply with a lot of fuel to boost the fire (MSB, 2022).

#### DC (Drought Code)

Humidity of the soil that is measured at 10-20 cm below surface level. A high value indicates that a wildfire can burn deeply with a lot of fuel to boost the fire. Both DMC and DC are less sensitive to rain with comparison to FFMC. It also takes a longer time for the DMC and DC layers to dry up (MSB, 2022).

#### ISI (Initial Spread index)

$ISI = FFMC + \text{wind}$ . If wind is added to the FFMC value, a value of how intense/fast the fire will spread after ignition will be received, the ISI value. The ISI value is highly dependent on the wind. An increase of 3.6 m/s doubles the value (MSB, 2022).

#### BUI (Built Up Index)

The BUI value is a measure of both DMC and the DC combined. It will tell how dry the main bulk of the available fuel is (MSB, 2022).

#### FWI (Fire Weather Index)

The FWI value is a merge of both the BUI and the ISI values. The values combined will provide a rough measure of the fire intensity i.e., the FWI value (MSB, 2022).

See Appendix E for a specification of values related to the FWI parameters above.

### 3.5.1.2 Fire Behaviour Prediction (FBP)

Fire Behaviour Prediction is a tool for further analysis of the wildfire behaviour. Additional data is added for a more precise analysis. The fuel types are added, i.e., the type of forest that will burn or have burned in the area. There are 17 different fuel types specified in the FBP analysis system (Appendix D.4). Other factors included in the FBP analysis are topography (aspect, slope, elevation) and time of the day. With this information, it is possible to predict a rate of spread of the fire. And with the rate of spread, it is possible to predict where the fire will be at a given time. For a FBP analysis, more data is needed compared to a FWI analysis which also means that it is more time consuming if hand calculations are used (MSB, 2022; Nat resources Canada, 2022; Taylor & Alexander, 2016).

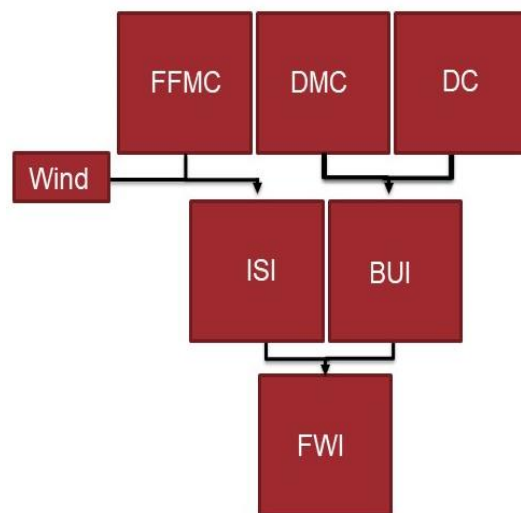


Figure 5: Illustration of the component that makes up the Fire Weather Index system. The image is created with inspiration from Nat resources Canada, 2022.

## 3.6 GIS tools

GIS tools (Geographical Information System) can be used to modify or create maps. Down below is a presentation of GIS tools used, tested or discussed during this work.

### 3.6.1 ArcGIS and QGIS

ArcGIS and QGIS are Geographic Information Systems that enable the user to develop, modify and present geographical data. ArcGIS is developed by ESRI and is commercially available. QGIS is an open-source software that is free and available for everyone. ArcGIS only runs on Windows PC, while QGIS runs on Windows, Mac or Linux computers (Dempsey, 2012).

### 3.6.2 Arcfuels

Arcfuel is a toolbar that can be installed in ArcMAP (a version of ArcGIS) or ArcGIS. Arcfuels was developed with the purpose of fuel management planning, wildfire behaviour modelling and wildfire risk assessment. Using Arcfuels, landscape files can be created that is needed by WUI-NITY in order to run simulations with respect to the landscape presented in the area. Arcfuels is managed by USDA Forest Fire Service Missoula Fire Lab (USDA, 2016).

### 3.6.3 BrandGIS

A tool called *BrandGIS (FireGIS)* is currently being developed by Swedish authorities (MSB, the County administrative boards of Sweden etc). BrandGIS is a tool that can be integrated into any GIS program (preferably ArcGIS or QGIS). BrandGIS contains the SiTaC-symbols (symbols for wildfire suppression tactics) that will enable the user to insert symbols for example fireline, waterdrop-zone, direction of spread and tactical recourses straight on the map. By that, a situational map will be provided that can be essential for the personnel out in the field and the incident command. An addition feature will probably be included in the future, enabling the user to simulate wildfire spread in a given area (probably by the use of Prometheus) (Länsstyrelserna, 2022).

## 3.7 Earth Explorer

Earth Explorer is provided by NASA and USGS (United States Geological Survey). Earth explorer provides the user with geo-spatial datasets, satellite imagery, elevation data, data of land coverage and much more. By using specific coordinates, data can be downloaded over a desired area (EROS, 2022). Earth Explorer was used to retrieve topographical data during the process of applying WUI-NITY to Swedish locations (see *Appendix A* for more details).

## 3.8 EFFIS

EFFIS (European Forest Fire Information System) is a service that provides fire danger forecast up to 6 days in advance and also detects active fires. The system uses satellite detection by the satellites named MODIS (NASA) and VIIRS (Suomi NPP). EFFIS is supported by experts from 43 countries. EFFIS can provide updated and reliable information on wildfires in Europe. The services use the CFFDRS system as the fire prediction and analysis tool (EFFIS, 2022). EFFIS was used to retrieve a fuel map over Europe that was filtered down to the areas of Bottnaryd and Dorotea. EFFIS also provided with data regarding the canopy cover (See *appendix A* for more details).

### 3.8.1 Canopy Cover

Canopy cover contains information regarding how thick and dense the forest is, as well as the crownbase height. The canopy cover is needed in the process of creating a landscape file (section 3.1.2.2)



### 3.9 SMHI – Wildfire forecast

SMHI is short for Swedish Meteorology and Hydrology Institute. SMHI together with MSB (Swedish Civil Contingencies Agency) provides a service based on the CFFDRS system. The service provides information about for example the risk of grassfire, risk of wildfire and how the fuel (soil) is drying up or moistened up. SMHI also provides a service translated to *Wildfirerisk – In forest and land* (Brandrisk i skog och mark). To access that service, you need a username and password. That service provides information about FWI and its components (BUI, ISI, DMC, DC, FFMC) were values (*Appendix E*) is received hour by hour for two days in advance, and daily values for six days in advance. Other features provided by the service include thunder risk forecast, fuel dehydration, grass fire risk and satellite detection of wildfires. SMHI Wildfire forecast and Wildfire risk – in forest and land is used by the Swedish authorities and fire departments to predict the risk of ignition, how a wildfire might propagate and how big of a threat an existing wildfire possess (SMHI, MSB. 2022a: SMHI, MSB. 2022b).

### 3.10 MSB's Fire Fuel mapping

During the years of 2014-2020 a company called Metria AB received an assignment from MSB to map vegetation with respect to burn characteristics. Metria created a map for the area of Sweden where different fuel types is presented by colour. Each colour represents a type of fuel (tree type, bush etc). And each colour is then linked together with a raster code (number). The numbers, which range from 201 – 244 can be found in a separate document that describes the burn characteristics in detail to the specific fuel types. (Metria, 2021: Gilljam & Ahlkrona, 2016: MSB, 2021a: MSB 2021b). MSB's Fire Fuel mapping is currently under development to match simulations done by Prometheus (Länsstyrelserna, 2022).

### 3.11 LANDFIRE

In the US, it exists a mapping over the country of all the needed geo-spatial data that is required to create a .lcp file. A program was created by the increasing concern about the threat of larger, more frequent and the severity of wildfires. The program is called LANDFIRE. LANDFIRE consist of 25 geo-spatial layers (vegetation, fuel distribution, topography data etc) (U.S Department of Agriculture & U.S Department of the Interior, 2022).

### 3.12 The national road database (NVDB)

The database contains data about road network for cars, bicycle and pedestrians. The network consists of data for roads own by the state, municipality and by private owners. Also included is for example road speed and who is the maintainer of a specific road (Trafikverket, 2022).

## 4. Results

The process of determining if and how WUI-NITY can be applied with respect to the Swedish environment was thoroughly documented, as shown in *Appendix A*. The purpose of documenting the process was both to identify and highlight gaps in the current version of WUI-NITY, but also to present an *application protocol* of how to set up the program with respect to the Swedish (and similar) landscape (i.e. to combat these gaps where possible).

*Section 4.1* is the application protocol that provides the user with guidance on how to apply WUI-NITY to the Swedish (and countries with similar) landscape. The user can follow the protocol instead of starting from scratch and make the same time-consuming missteps and errors that this work has entailed. *Section 4.2* describes the gaps discovered throughout the process. *Section 4.3* present required knowledge to set up WUI-NITY to a new location. *Section 4.4* presents output data generated by simulations in WUI-NITY.

### 4.1 Application protocol – Applying WUI-NITY to a new location

The *application protocol* below is created by the result and knowledge retrieved during the process, documented in detail in *Appendix A*. As described in *Appendix A*, some steps have been very time-consuming with none or a very small reward. And some steps have been a stride in the wrong direction. Those steps are left out in the protocol below. The protocol is the result of spending a lot of time examining WUI-NITY's applicability to the Swedish landscape. The process progressed and was studied so carefully that a complete application protocol could be devised, with the purpose of simplifying further work.

The protocol has already been tested by professionals. Vai Saran (*Graduate Advisor, Movement Strategies*) used the application protocol for a location in the UK – Marsden Moor. The United Kingdom are using the CFFDRS system and has similar landscape and environment as Sweden (CBC, 2022). Vai successfully applied WUI-NITY to the new location. This application protocol is currently being used to apply WUI-NITY to additional countries, for example Australia.

Application protocol – Applying WUI-NITY to a new location	
1	<p>Receive the latest version of WUI-NITY. At the time of writing (November 2022), the latest is version 0.15 and was retrieved from Jonathan Wahlqvist (the head developer of the model). Note that if other versions of WUI-NITY are used, the application process might differ slightly. The OS tested for the application is Windows and Linux. If other OS is used, the process might differ.</p> <p>After installation, other files must be downloaded to support installation and application of the model, along with ensuring that the system meet certain software requirements:</p> <ul style="list-style-type: none"> <li>• .NET 35 (.NET 35 is often preinstalled on the computer). The package can be downloaded from here: <a href="https://www.microsoft.com/sv-se/download/details.aspx?id=21">https://www.microsoft.com/sv-se/download/details.aspx?id=21</a> (accessed 2022-12-12).</li> <li>• A computer with sufficient hardware must be used. It is recommended to use a computer with an EGPU and sufficient RAM (this thesis has not examined specific requirements in detail).</li> <li>• For any firewall installed on the computer, an exception for WUI-NITY needs to be added.</li> <li>• <i>Population database</i>: Download following: gpw-v4-population-density-rev10_2020_30_sec_asc from: <a href="https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11/data-download">https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11/data-download</a> (accessed 2022-12-12). (data from 2020 is the latest GPW update). <ul style="list-style-type: none"> <li>- Once the files are downloaded, extract and place them in the WUI-NITY root: folder\external_data\gpw-v4-population-density-rev10_2020_30_sec_asc.</li> </ul> </li> <li>• <i>Mapbox token</i>: A Mapbox token is needed to access maps. Create an account and receive a token from: <a href="https://account.mapbox.com/auth/signup/">https://account.mapbox.com/auth/signup/</a> (accessed 2022-12-12) Add the token to the WUI-NITY root: folder\WUIinity_Data\Resources\Mapbox\MapboxConfiguration.txt</li> <li>• <i>OpenStreetMap (OSM)</i>: Download the desired OpenStreetMap data from: Geofabrik Download Server. <ul style="list-style-type: none"> <li>- Make sure to click on Europe, then choose Sweden (or another desired country). If OSM data for the whole of Europe is downloaded, the file will be too large to handle for WUI-NITY.</li> </ul> </li> </ul>
2	<p><i>Start WUI-NITY – Load inputs</i> – click on either the roxborough.wui or example.wui file retrieved (they are the same).</p> <ul style="list-style-type: none"> <li>• A map representing the test case is then opened in WUI-NITY (map over the Roxborough area, <i>Figure 6</i>).</li> <li>• Test the program and learn the functions and features. The example/test case, <i>the Roxborough case (.wui file)</i>, is created by Jonathan Wahlqvist with data generated from Gwynne et al, 2020. In 2019 there was a community evacuation drill in Roxborough Park (USA) (a fictional wildfire initiated the evacuation). And the actual drill was then compared with simulations done by WUI-NITY. The file created to simulate the Roxborough case is called roxborough.wui or example.wui. Included in the Roxborough / example case folder is a bunch of other files necessary to set up WUI-NITY. They will be addressed accordingly below.</li> </ul>

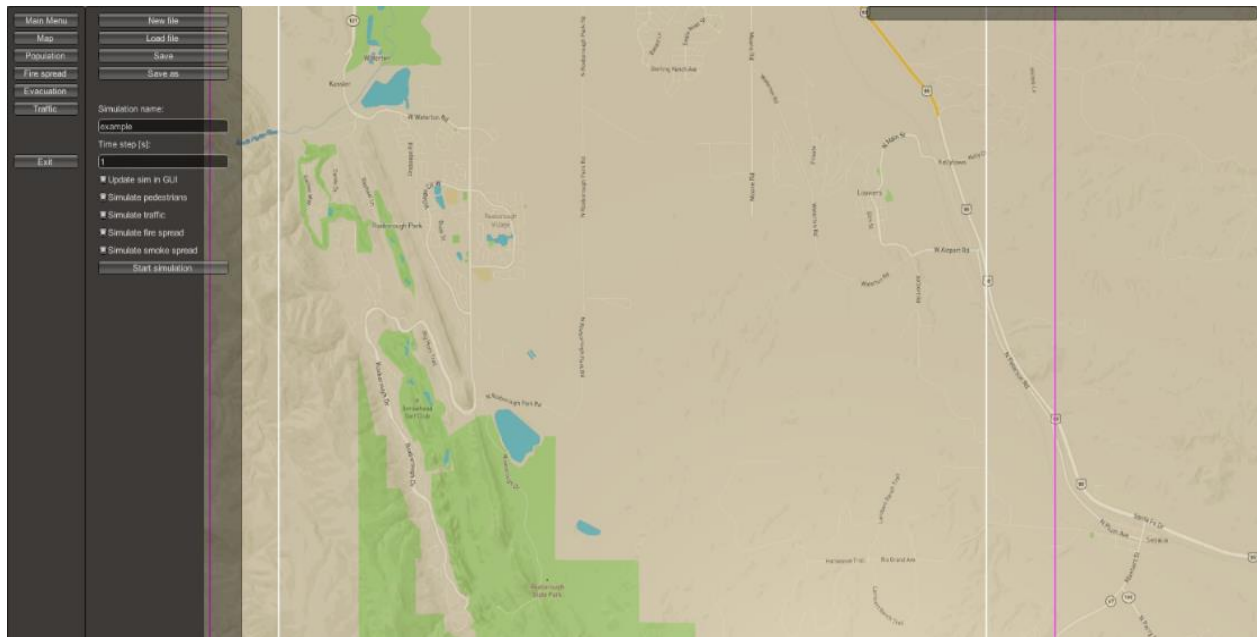


Figure 6: When the roxborough.wui / example.wui is loaded, this map is loaded. Inside the purple line is where OSM data will be filtered, the white line is the simulations area (the image is cropped, otherwise it will show a white and purple square around the simulated area).

- 3 The next step is to configure WUI-NITY and set up the program to be suitable for a Swedish location (or another desired location with similar landscape and vegetation). By opening the roxborough.wui / example.wui file in notepad++, the coordinates can be changed manually to fit the location of choice (Figure 7). Hence forward, use that file as a base-file, i.e. make changes to the .wui file and save it with another name in a new folder. The coordinate system must be in UTM. If not, the desired map will not show. An easy way to find coordinates for the location of choice is by using google maps. Click on the area and the coordinates will show. Google maps uses WGS84 (UTM) as coordinate system (same as WUI-NITY). It is recommended to use WGS84 consistently throughout the process.

<pre>"simName": "example", "deltaTime": 10.0, "maxSimTime": 864000.0, "stopWhenEvacuated": true, "numberOfRuns": 1, "stopAfterConverging": true, "lowerLeftLatLong": {   "x": 39.409924,   "y": -105.104505</pre>	<pre>"simName": "bott", "deltaTime": 1.0, "maxSimTime": 864000.0, "stopWhenEvacuated": true, "numberOfRuns": 1, "stopAfterConverging": true, "lowerLeftLatLong": {   "x": 57.74615,   "y": 13.794459</pre>
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Figure 7: (left) The roxborough.wui / example.wui code-file opened in Notepad ++. In order to change the map, the coordinates for X and Y needs to be changes according to the area of choice (lower left corner). (right) Changed coordinates for the municipality of Bottnaryd, Sweden.

4 When the map is set to the right location (by changing the coordinates), safe areas can be determined. A Safe area is a location to which the population will evacuate. During the simulations, a part of the population will escape to each safety area. The proportion of people escaping to each area can be defined by the user, or generated automatically (*step 5*). To change the safe areas, open the file named GoalX.ed (X = some letter). In that file, coordinates can be changed. Once again, UTM coordinates has to be used (use google maps and click on the locations for the safety area, the coordinates will show in WGS84). The GoalX.ed file is linked to the .wui file as shown in *Figure 8*.

```
"evacuationGoalFiles": [
    "goalE",
    "goalR",
    "goalF"
```

Figure 8: Codelines present in the .wui file that links the .ed files with the .wui file. Make sure to add additional codelines and .ed files if more safe areas are needed.

Also, if the .eg (egress groups) files are opened, the probability of escaping to a certain safe area can be changed. If more safe areas are added, code for these must also be added to the .eg files and to the .wui file. *Figure 9* present the location of the safe areas presented visualised by WUI-NITY for the Bottnaryd case.

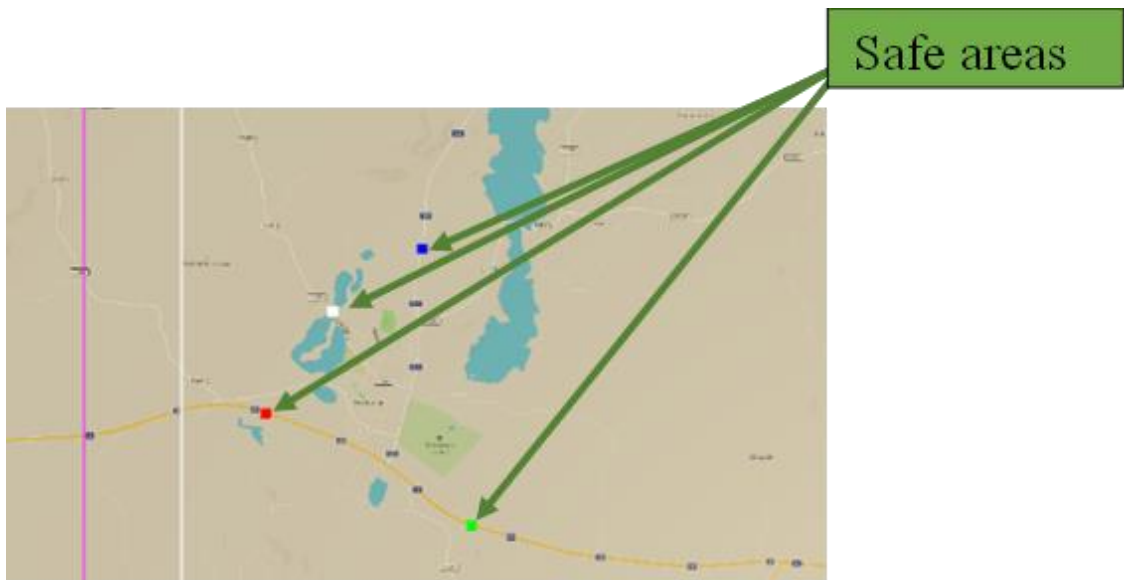


Figure 9: The map is set to the location of Bottnaryd according to the coordinates in Figure 6. The safe areas are shown in different colours on the map. The population of Bottnaryd will escape to those locations when running the simulation. When all the people deciding to leave the area, has reached a safe area, the simulation will complete.

5 Now, the .osm file (OpenStreetMap) must be filtered to only include the area of choice.

- When the .wui file is loaded, click on *traffic - load OSM file*. Once Sweden.osm (or other location) file is loaded into WUI-NITY - Click on *load roterdb*.
- By loading the roterdb, a filtering process will start that takes a couple of minutes (up to 20 min). WUI-NITY will filter out the selected map from the .osm file. A file named *filtered-xx.osm* is created (xx is the name of the case, in this study files named *filtered-dorotea.osm* and *filtered-bottnaryd.osm* was created in the process of examine WUI-NITY). The filtered version will be created in the case-folder (same place as were the .wui file is located). Note that the .osm file should be with the suffix .pbf (filtered-xx.osm.pbf).

6 Load the population data. The population data shows the number of people and where they live in the area. By including the population data together with the map and the .osm file, a realistic evacuation of a community can be simulated.

- To load the population data into WUI-NITY, click on *population – set global GPW folder – choose the folder described in step 1 above – Build local GPW file*. Now a .pop and a .gpw file will be created and added to the case-folder. The distribution of the population can be shown (an example can be seen at *Figure 10*). Note that if the computer used does not have sufficient hardware, the .pop file can not be created by using GPW data.
- If the .pop file can not be created by GPW data. The file must be created manually with the function – *Create/edit custom population*. The number of people in the area can be specified, and the location of those can be drawn on the map. That will do it as well, but the result won't be as precise.
- WUI-NITY will now be able to run simulations with respect to the specific road network and population at a new location of choice.

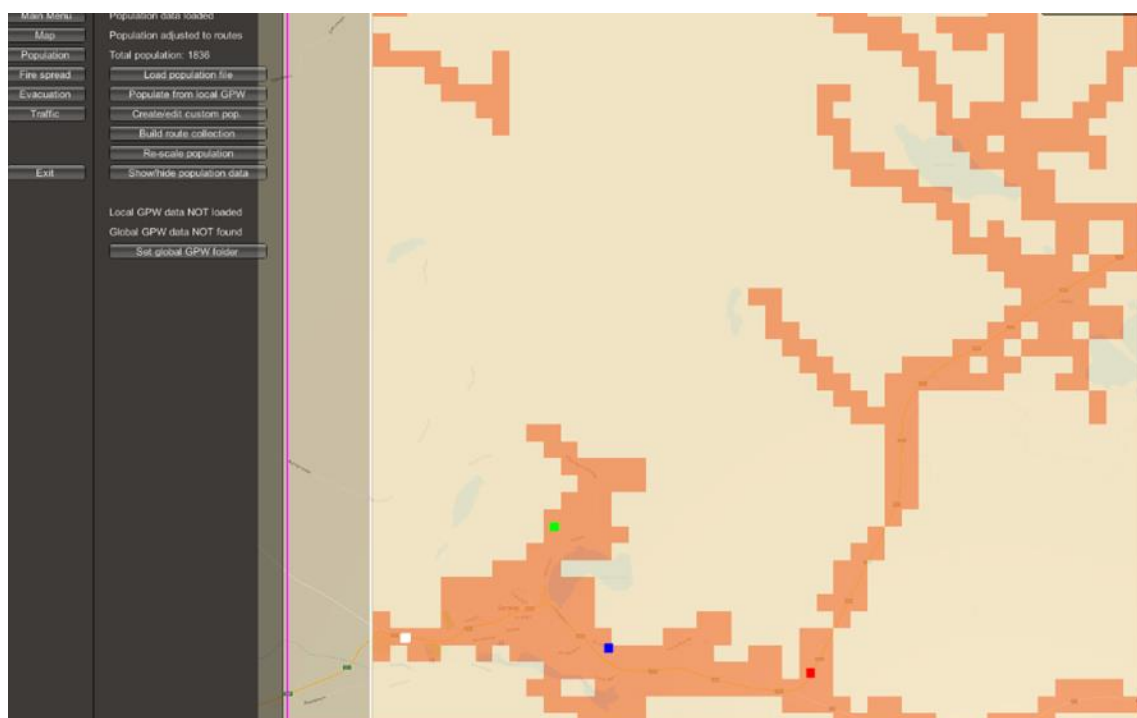


Figure 10: Distribution of the population in the area around Dorotea. The darker orange colour indicates where the people are located.

7 As mentioned, simulations can now be done at the new location of choice. Output data will be generated with respect to people escaping by using the road network. Data will be provided about the evacuation time, people staying behind, number of people evacuation by car, by foot etc. But in order to simulate a fire in WUI-NITY that will burn with respect to the local landscape and affect the evacuation, more input data is needed. Preferably, a trigger buffer tool should be used together with the fire simulation, that will give the user an indication of when the community should be evacuated with respect to the location and properties of the fire. PERIL (Section 3.2) was before included in WUI-NITY as a trigger buffer tool but is excluded in version 0.15.

- To run simulation without the fire present, open the .wui file in notepad ++ and inactivated the fire as below: (the fire can also be inactivated directly in WUI-NITY).

”runFireSim”: true, (Default)

”runFireSim”: false, (Changed)

8	<p>In the roxborough.wui case, there is an example fire included (even though there was not a real fire during the evacuation drill). But it is worth stating that the included fire represents the type of fire that might be present in the Roxborough area. That fire can not be used when running simulations in the Swedish landscape. In the Roxborough area, other vegetation types as well as different climate can be expected.</p> <p>To run a simulation with respect to the local topography and vegetation, the outlining of the landscape has to be included. That is done by creating a landscape file (.lcp). A landscape file is required by FARSITE (<i>Section 3.4</i>). FARSITE is integrated in WUI-NITY as the fire-modelling tool). A .lcp file includes different geo-spatial data as for example elevation, fuel type and fuel density. In the US, it exists a mapping over the country of all the needed geo-spatial data that is required in order to create a .lcp file. The program is called LANDFIRE (consists of 25 geo-spatial layers, see <i>Section 3.11</i>). A similar mapping does not exist in Sweden nor Europe (not what could be found during this thesis study). By that, it is required to go through a number of time-consuming steps in order to create a .lcp file containing correct geo-spatial data for the Swedish environment that WUI-NITY will accept. Step 9 to 14 in this application protocol describes that process (for a more detailed process, see <i>Appendix A</i>).</p>
9	<p>The .lcp file can be created by two different programs, FlamMap (<i>Section 3.3</i>) or ArcGIS (<i>Section 3.6.1</i>) + Arcfuels (<i>Section 3.6.2</i>). Either way will create the same type of file. Regardless of which way that will be used, follow raster data is needed:</p> <ul style="list-style-type: none"> <li>• Slope</li> <li>• Aspect</li> <li>• Elevation</li> <li>• Canopy Cover (CBH, CBD)</li> <li>• Fuel data (types of trees etc that is presented in the area)</li> </ul> <p>To manage the data, a GIS program is needed. In this study, both QGIS and ArcGIS were examined with the conclusion that either of the program will do. If ArcGIS is used, then the .lcp file can be created by either FlamMap or by using the Arcfuels toolbar. If QGIS is used, FlamMap must be used to create the .lcp file.</p>
10	<p>The Roxborough case is developed by using LANDFIRE data (<i>step 8, Section 3.11</i>). This thesis has not identified any equivalent service that provides aggregated raster data over the Swedish soil. This means that the respective geo-spatial layers (that is needed by FlamMap or Arcfuels) needs to be collected from different sources and then manually modify the data to be suitable for usage by WUI-NITY. The .lcp file can be created by using several images that together contains the needed data, or by using one image that contains all the needed data.</p>

## 11 Slope, Aspect, Elevation:

- During the process of retrieving topographical data for the case of Dorotea it was discovered that certain services could not provide data over the northern parts of Sweden (*more details in Appendix A*). That is due to the satellites used by those services not mapping the northern parts of Europe in full extent. Both Earth Explorer and Earth Engine (free services) did not contain data for the Dorotea case. The picture below (*Figure 11*) defines the area of where data is present in Earth Engine (same in Earth Explorer due to using the same satellites). A rough line can be drawn with the help of the Swedish road – E16. Above E16, other types of services are needed to collect the topographical data.
- If data is to be collected in the defined area (*Figure 11*), Earth Engine or Earth Explorer can be used (Earth Explorer was used in this thesis). To collect data in the area that is not defined (*Figure 11*) it is then recommended to either contact *Lantmäteriet (The land surveyor of Sweden)*, they can provide detailed topographical maps over Sweden. But the service is not free. Or a contact can be made with a GIS-expert from the municipality (the city planning office) or *Länsstyrelsen (County administrative board)*. They might be able to provide a map over the desired area. Note that maps provided has to be in UTM coordinates (for example WGS84 or SWEREF99). All the maps must be set to the same system. As mentioned before, it is recommended to use WGS84. Note that the topographic data retrieved has to be set to a resolution of 10 x 10 meters. If the resolution is more detailed or rough, GIS can be used to modify it to 10 x 10 meters. *Figure 12* shows modified raster-images containing aspect, slope and elevation data.
- It is important to know that the raster-image retrieved by Earth Engine and Earth Explorer only contains data about the elevation. If images are retrieved from *Lantmäteriet*, the city planning office or the county administrative board – the image might also only contain data about the elevation. Then aspect and slope data need to be created manually from the elevation data. More about this in *step 14* in this application protocol, and *step 48, 49 and 52* in *Appendix A*.

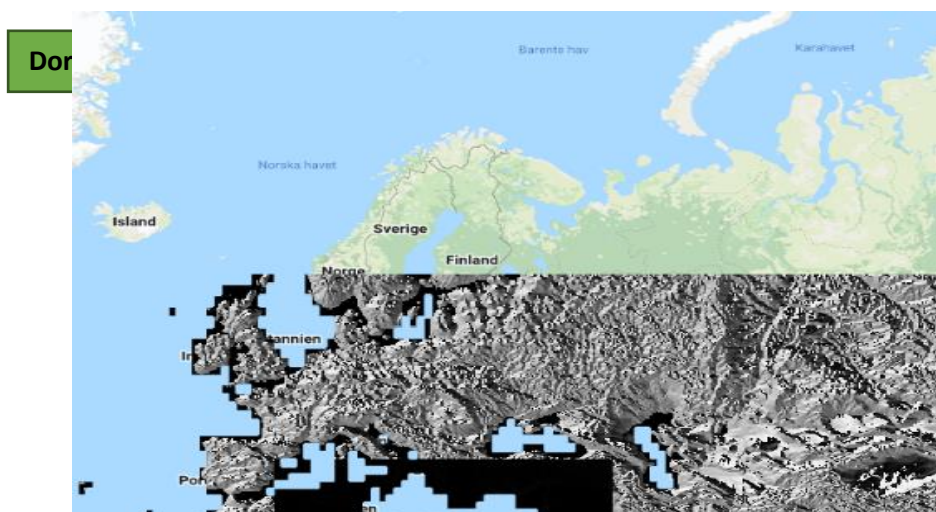


Figure 11: The grey on the picture shows where topographical data is defined. And as shown, a large part of Sweden is not defined.



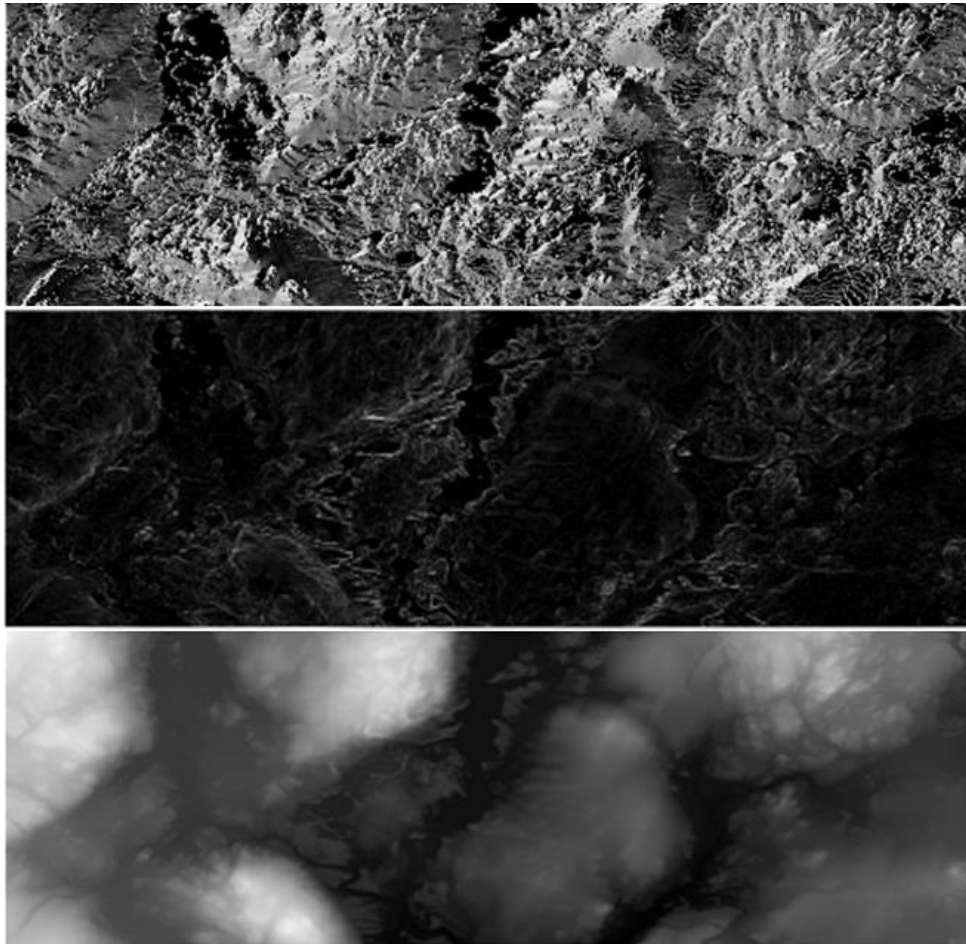


Figure 12: (Top) Aspect data. (Mid) Slope data. (Bot) Elevation data. The images above contain the needed topographic data in order to create a .lcp file. The data was retrieved from the County administrative board of Jönköping and modified with the help of ArcGIS to fit the requirements of a resolution of 10 x 10 meters and a UTM coordinates system (WGS84). The aspect and slope data was created by using the elevation data. See step 14 for how this is done.

## 12 Fuel data:

- Fuel data is needed to specify what kind and the location of the vegetation types (tree types, bushes, lakes, fields etc) in the area where the simulations will take place. The fuel data map describes the different types of fuel (fuel = burnable vegetation types) with different colours. Each colour is then connected to a number. The number is then specified in the .fuel file (*Appendix B.2, Appendix F, Section 3.1.2.6*) regarding the attributes (HRR,  $\Delta H^\circ$ , fuel load, fuel moisture etc) of the specific fuel type.
- To retrieve a fuel map, contact can be made with EFFIS (*step 25, 26 Appendix A, Section 3.8*). They can provide a map with the resolution of 50 x 50 m. WUI-NITY requires the resolution to be at 10 x 10 meters. If the EFFIS fuel map is used, the resolution must be changed by using a GIS program to match that (*see step 14*).
- Another way of retrieving fuel data for Sweden is by using MSB's *brandbränsleklassificering* (fire fuel mapping) (*step 47 Appendix A, Section 3.10*). It is a service that provides the user with detailed mapping of different fuel types scattered across the country. The resolutions of the MSB's fire fuel map is set to 10 x 10 as default, and the coordinate system is set to SWEREF99 (change it to WGS84, see *step 14*).

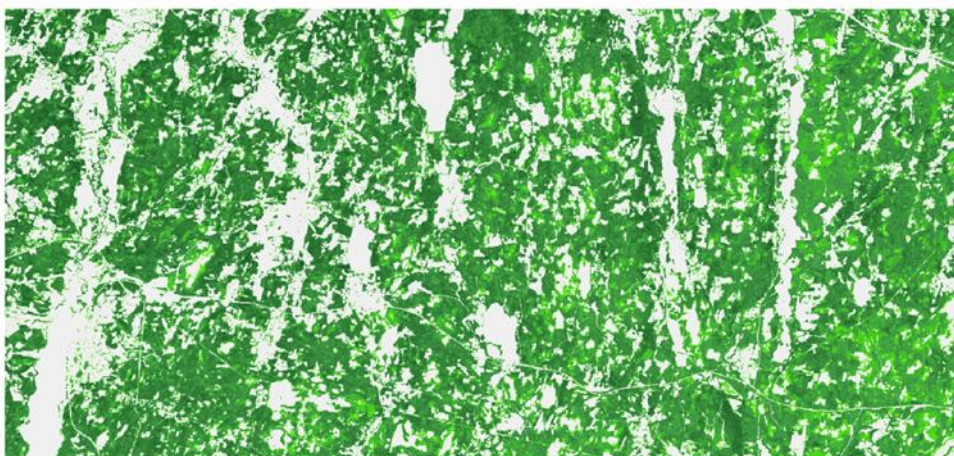
13 *Canopy cover:*

- The Canopy cover (the density of the fuel) can be retrieved by either EFFIS or MSB's fire fuel mapping (might exist more sources that has not been identified in this work). If the data is downloaded by EFFIS, use the service called *Copernicus*. The map that should be downloaded is named *Tree cover density – status map (year)*. By downloading that map, following raster data is retrieved from one image:

- Forest Canopy Cover
- Forest Canopy Height
- Forest Canopy Base Height
- Forest Canopy Bulk Density

An example of a canopy cover images can be seen in *Figure 13*.

- To download the map, use this path:  
<https://land.copernicus.eu/> – *Pan-European-High Resolution Layers – Forests – Tree Cover Density – Status Maps – Tree cover Density (year)*.
- See *Appendix A, step 25 for more details*.



*Figure 13: Canopy Cover data retrieved from Copernicus (EFFIS). The file downloaded was named "Tree cover density" - status map 2018 of Sweden. The image is cropped to match the location of Bottnaryd.*

14	<p>The needed raster data (<i>step 9</i>) is now retrieved) as well as the canopy cover and the fuel model. But before creating the .lcp file, it is important to make sure that the images is set to the correct coordinate system (WGS84), correct grid resolution (10 x 10) meters and that the images align on each other (same size). Also, it is important to make sure that the aspect and slope data is created by using the retrieved elevation data.</p> <p><i>For modifying the raster images using ArcGIS:</i></p> <ul style="list-style-type: none"> <li>- To create aspect and slope data – use the <i>aspect-slope</i> function (ESRI, 2022a).</li> <li>- To change the grid resolution to 10 x 10 meters – use the <i>interpolation</i> method (ESRI, 2022b).</li> <li>- To changes the coordinate system – use the <i>to specify a coordinate</i> method (ESRI, 2022c).</li> <li>- To align the images (same size) – crop the images using the same corner coordinates, or by cropping with one of the rasters used as the clip extent.</li> <li>- Check <i>step 48 – 49</i> in <i>Appendix A</i> for more details.</li> </ul> <p><i>For modifying the raster images using QGIS:</i> (the process below is created and tested by Vai Saran, <i>Gradute Advisor, Movement Strategies</i> – by the help of the author of this thesis):</p> <ul style="list-style-type: none"> <li>- Make sure any base map used is set to EPSG:4326 WGS84.</li> <li>- Create and save slope and aspect file from the elevation file, use the tools in Raster -&gt; Analysis.</li> <li>- Draw a shapefile around your target area.</li> <li>- Geoprocessing Tools -&gt; use the shapefile to 'Clip' the elevation file to create a 'Clipped Extent' layer.</li> <li>- Set all raster layers to the same properties: use 'Save as' to change projection, change resolution and clip it to the 'clipped extent' layer</li> </ul> <p style="padding-left: 40px;"><i>Note about resolution:</i></p> <p style="padding-left: 80px;">If the units are in meters, set the resolution to 10 x 10m.</p> <p style="padding-left: 80px;">If the units are in decimal degrees, set the units to 0.00009093 degrees.</p> <ul style="list-style-type: none"> <li>- Check <i>step 52</i> in <i>Appendix A</i> for more details.</li> </ul>
15	<p>When the raster images are modified and the aspect and slope data is created, it is time to create the .lcp file. The .lcp file can be created by either using FlamMap or the Arcfuels toolbar in ArcGIS</p> <p>Using <i>FlamMap</i>:</p> <ol style="list-style-type: none"> <li>1. Open FlamMap</li> <li>2. Click on: Landscape</li> <li>3. Click on: Create Landscape file</li> <li>4. Insert the geo-spatial data under “required themes”</li> <li>5. Click on “save as”</li> <li>6. Save the file as a .lcp file</li> </ol> <p>Using <i>ArcGIS + Arcfuels</i>:</p> <ol style="list-style-type: none"> <li>1. Open ArcGIS</li> <li>2. Click on: Build LCP (Arcfuels toolbar)</li> <li>3. Click on: Build LCP using Raster Data</li> <li>4. Add the needed raster images (containing geo-spatial data) under the tab “Raster Data”</li> <li>5. Click on the output tab</li> <li>6. Use coordinates or another layer do define the boundaries of the LCP image</li> <li>7. Click on: Build LCP</li> </ol>

16 When the .lcp file is created successfully (if not, check *Appendix A* for troubleshooting), the next step is to specify the attributes of the fuel types provided by the fuel map. The fuel map can either be opened in FlamMap, ArcGIS or QGIS (or other similar programs). When opened, the colours and numbers will show. To interpret the properties of the different fuel types, one or a couple of fuel models are required.

- 1-13 Andersons original 13 (*Appendix D.1*)
- 91-204 Scott & Burgan (*Appendix D.2*) (Check the source: Scott, 2005 as well)
- 1-244 MSB’s Fire fuel mapping – classification. Use the source: Metria AB, 2021 as well as *Appendix D.3* to retrieve the information. Note that the numbers 201-244 is specific for MSB’s fire fuel mapping.

When the fuel types and attributes are identified, open the .fuel file used by WUI-NITY and add/change the fuel data there. See *Appendix B.2* for an example of how the .fuel file can be constructed, *Appendix F* for attributes regarding different fuel types for the Andersons original 13 and Scott & Burgans fuel model. *Figure 14* and *15* displays fuel maps retrieved from EFFIS and MSB.



Figure 14: (Left) Fuel map retrieved by EFFIS, opened in FlamMap 6 after successfully creating a .lcp file. (Right) Numbers that corresponds with the colours on the map.



Figure 15: (Left) Fuel mapping retrieved by MSB’s fire fuel mapping. (Right) Numbers that corresponds with the colours on the map.

17 When the .fuel file is changed to match the local landscape for a new location of choice in, other wildfire influencing factors can be modified to make the fire as realistic as possible. The following files can be opened in notepad++ to be changed:

- .fmc – Modify the fuel moisture code (similar to the FPMC-value, *Section 3.3.1.1*)
- .ign – Modify the location of where the fire will start (UTM – WGS84)
- .wtr – Modify the temperature at different times during the simulation
- .wnd – Modify the wind inflicting the spread of the fire  
(See *Appendix B* for examples of the files above and *Section 3.1.2* for a more detailed description of the files)

18 The final step before starting the simulations is to make sure that the .wui refers to the external files correctly. Check the codelines below and change the pathways and filenames to make sure that the .wui file refers to the local files on the computer used. The pathways and filenames below are used by the author of this application protocol, those must be changed for the case to run correctly in WUI-NITY.

```

"evacGroupFiles": [
  "group1",
  "group2",
  "group3"
],
"traffic": {
  "osmFile": "C:\\Users\\jovlu\\WUNITY\\0.15\\Bott\\filtered_Bottnaryd.osm.pbf",
  "osmBorderSize": 1000.0,
  "evacuationGoalFiles": [
    "goalE",
    "goalR",
    "goalF"
  ],
  "population": {
    "gpwDataFolder": "C:\\Users\\jovlu\\WUNITY\\0.15\\Bott\\gpw-v4-population-density-rev10_2015_30_sec_asc",
    "localGPWFile": "C:\\Users\\jovlu\\WUNITY\\0.15\\Bott\\bott.gpw",
    "populationFile": "C:\\Users\\jovlu\\WUNITY\\0.15\\Bott\\Bottnaryd.pop"
  },
  "fire": {
    "lcpFile": "C:\\Users\\jovlu\\WUNITY\\0.15\\Bott\\Bott.lcp",
    "fuelModelsFile": "C:\\Users\\jovlu\\WUNITY\\0.15\\Bott\\default.fuel",
    "initialFuelMoistureFile": "default",
    "weatherFile": "example",
    "windFile": "example_seconds",
    "ignitionPointsFile": "example",
    "spreadMode": 1,
    "windMultiplier": 1.0,
    "useRandomIgnitionMap": false,
    "randomIgnitionPoints": 0,
    "useInitialIgnitionMap": false
  }
}

```

The .eg files (group) should be named as stated here. If more .eg files are added, include them as new codelines.

A pathway to the filtered osm file needs to be changed to fit the local pathway.

The .ed files (goal) is the safety area files. They should be named as stated her. If more .ed files are added, include them as new codelines.

Change the pathway for the GPW data folder, the generated GPW data (.gpw) and the generated .pop file.

Change the pathway for the .lcp file and the .fuel file. Make sure that the names on the .finc, .wtr, .wnd, .ign is the same as shown in the .wui file.

- 19 Simulations can now be done in WUI-NITY.
1. Start the latest version (in this case, it is version 0.15).
  2. Click on *load file* and choose the .wui file used in the process.
  3. Click on *population – load population file*. Choose the file generated from the GPW data.
  4. Click on *fire spread – load LCP file*. Choose the .lcp file created with the collected geo-spatial data required.
  5. Click on *traffic – load router database*. Also, click on *select OSM source file*. Chooses the file filtered from the Sweden.osm file (or data from another country). The name should be *filtered-casename.osm.pbf*
  6. Click on *main menu – start simulation*.

The simulation should now start, output data will be generated in the output folder. Excel-files will be provided with data from the evacuation. If an error occurs, use *Appendix A and Appendix G* to troubleshoot.

## 4.2 Important findings and gaps discovered

When working with the process of applying WUI-NITY to a new location in Sweden, some important findings and gaps were discovered – presented in this section.

### 4.2.1 The integrated wildfire simulation tool

FARSITE (*Section 3.4*) is a fire modelling tool that is integrated into WUI-NITY. With that (together with necessary data), wildfires can be simulated in a given area with respect to the landscape and weather factors. FARSITE is developed in the United States and is by that suitable for the landscape present there (Finney, 1995). In other words, FARSITE is not adopted to the Swedish vegetation / landscape. The program does not take the humidity in the deep soil into account (Finney, 2004). According to Hansen, 2003 & MSB, 2022, the Swedish environment consist of burnable materials deep down in the soil. Prometheus (*Section 3.5*) is another wildfire simulations tool based on the CFFDRS system (*Section 3.5.1*). The CFFDRS system is also used in Sweden due to the similarities between the Canadian and the Swedish landscape. Prometheus would therefore be the better option for the integrated wildfire modelling tool.

### 4.2.2 The process of creating an .lcp file

The environment of the area studied can not be changed directly in WUI-NITY. To do that, an .lcp file is needed. As described in *Appendix A*, the process of creating an .lcp file to a new location in Sweden is very time consuming. Even if you are an expert in GIS, it will take a long time to gather necessary data and modify it exactly the way either ArcFuels or FlamMap wants it to create the .lcp file. Also, it takes a lot of time to create the needed data and to change the code to fit the given location. A lot of different code files needs to be set up. If the purpose is to use WUI-NITY as a tool for decision-making during a real time wildfire in Sweden, it is important to have good knowledge about the program, how to gather the correct data, how to modify the input-data and also how to use GIS. It will still be time consuming to set up the case, but it will surely help.

### 4.2.3 Lack of a trigger buffer program

To fully simulate an evacuation to determine when to evacuate, a program that generates trigger buffers is desired. A trigger buffer is a zone around a community which tells when to evacuate the community if everyone is to get out in time. This zone is generated with respect to ASET and RSET. ASET is generated by the spread of the fire and represents how much time that is available before the fire will reach the community, i.e., when the community needs to be completely evacuated. RSET represents how long time it will take for the community to be safely evacuated. If ASET and RSET is used, a perimeter can be created around the community which tells you when the fire reaches a certain point, evacuation is needed. And the modelling tool that provides this information in WUI-NITY is called PERIL (*Section 3.2*). But PERIL is not a part of WUI-NITY anymore (version 0.15). If a perimeter is to be drawn around a community, it must be hand calculated as of version 0.15 of WUI-NITY. The time of evacuation can be calculated by WUI-NITY. And the time of when the fire will reach the community can be calculated by FARSITE, or by hand. But due to PERIL not being included in WUI-NITY, a perimeter is not calculated directly in the program. It is then needed to either hand calculate the fire spread, or by visually determine when the fire is reaching the community, and by that calculating how far away the fire has to be when an evacuation order is needed. If PERIL is integrated into WUI-NITY once again, this process will be simpler and more reliable. The current version of PERIL is run using matlab. Programming skills together with knowledge about matlab is then necessary to use the program at its current version.

#### 4.2.4 Limitations of the computer hardware

When working with WUI-NITY, it was discovered that the computer hardware was important. When the GPW data was to be filtered, it could not be done on a computer using 4 GB RAM, IGPU and intel i3 processor 2.4 GHz. When a computer with 48 GB of RAM, EGPU and intel i7 processor was used, the filtering process succeeded. The same issue was encountered when trying to use the program *Prometheus*. The program could not run on a low budget computer. This thesis has not specified the exact hardware requirements. During the study a Windows computer (Windows 10) was used, Jonathan Wahlqvist uses Linux when running WUI-NITY. It has not been tested if other operating systems will be able to run WUI-NITY.

#### 4.2.5 Lack of literature available

During the literature review it was discovered that it exists only a small number of scientific articles and studies about wildfire evacuations occurred in Sweden. An explanation for that is because there have only been a few large wildfires in Sweden in modern times. The articles found did not present any detailed data of the evacuations initiated by those wildfires. It is therefore hard to validate the output data generated from the simulations at Swedish locations – if articles regarding Swedish wildfire evacuations is used.

#### 4.2.6 Lack of topographical data

In the process of collecting topographical data (elevation, aspect, slope) the programs Earth Engine and Earth Explorer was used. It was recommended that data generated from a satellite called SRTM 1 arc-second global should be used. It was discovered that topographical data for approximately 3/5 of Sweden was missing. Data could only be downloaded for the southern parts of Sweden, above Gävle / Falun no data could be found. That resulted in a change of location during the ongoing process of examine WUI-NITY's applicability to the Swedish landscape (the location was changed from Dorotea to Bottnaryd). To collect necessary topographical data above Gävle / Falun (a line can be drawn with the road E16), other services need to be used. This thesis has not found any free service for that area. The Swedish land surveyor can be contacted to retrieve the data. Also, contact can be made with GIS engineers by the local municipality office or the county administrative board (Länsstyrelsen).

#### 4.2.7 Modifying the collected data

When retrieving all the data needed to create the .lcp file, it was important that the raster images containing the geo-spatial data was set to the same coordinate system and to the same resolution. The coordinates had to be set to the UTM system (preferably WGS85) due to WUI-NITY using the UTM system in the code. The spatial resolution had to be set to 10 x 10 meters due to WUI-NITY's underlay map is set to 10 x 10 meters resolution.

#### 4.2.8 Road network data

It was also discovered that it exists a Swedish mapping of the road network – the NVDB (Nationella Vägdatan – National Road database, *Section 3.12*). To include the road network data into WUI-NITY, a .osm file is required (*Section 3.1.2.4*). To make the simulations more detailed the NVDB could be used instead of OSM data for simulations in the Swedish landscape.

#### 4.2.9 Addressing errors in the WUI-NITY code

During the process of application, some errors in WUI-NITY were identified which required recoding - generating new versions of WUI-NITY throughout the process of application. For instance, during the development of this thesis, seven different version of WUI-NITY was used – reflecting the code updates required.

The new versions were created due to addressing errors in the code (See *Section 4.4.3*). Example of errors found by the author of this study that was corrected together with Jonathan Wahlqvist:

- Some of the code referred to local files found on Jonathan’s computer. The code was changed to match any computer – general code. A new version of WUI-NITY was provided.
- When changing the resolution of the map from 10000 x 10000 m to 9000 x 10000 an error was discovered. The code stated that the resolution in the x direction should be the same as the resolution in the y direction, i.e.,  $x = y$ . So, when  $x \neq y$ , the map did not load. The code was corrected, and WUI-NITY was then able to show the map with different resolution in x and y direction. A new version of WUI-NITY was provided.
- When creating the population at a new location, GPW data was used. It was discovered that WUI-NITY could not load the GPW correctly to create a .pop file. The code was changed making it possible to use GPW for a location of Sweden. A new version of WUI-NITY was provided.

*Table 2* shows the errors that were related to the simulations in WUI-NITY, which case that was examined and which version of WUI-NITY that was used when these errors were detected.

*Table 2: A presentation of errors found working with different cases in WUI-NITY. The table shows the nature of the error and how the error was addressed for different cases and different versions of WUI-NITY. The errors are described in Appendix A and is summarised in this table.*

Case	Did the simulation finish?	Version of WUI-NITY used	Error?	How was the error addressed?
Roxborough	No	0.1	Code that referred to local files on the computer used to develop the current version.	The code was changed to fit simulations done other computers (with some code-modification done by the user). A new version was provided, version 0.03_pre-alpha.
Roxborough	Yes	0.03_pre-alpha	No error	
Dorotea	No	0.03_pre-alpha	The traffic did not start, and pedestrians evacuated in an unrealistic pattern that did not reflect the underlying Dorotea case. They moved in a cluster over lakes, in the woods, etcetera.	Issues in the mapping of the Roxborough conditions to the Dorotea case. The .lcp file for the Roxborough case was used for the Dorotea case. New .lcp file had to be created.



Dorotea	No	0.03_pre-alpha	To large OSM file (Europe.osm) was used during the filtering process.	Sweden.osm was downloaded and used in the filtering process.
Dorotea	No	0.03_pre-alpha	GWP data not loaded, unable to create a .pop file. The issue is due to limitations of the computer hardware.	GPW data is loaded by the use of a more powerful computer. Additional GWP issues was addressed as well, generating a new version, version 0.1.1.
Dorotea	No	0.1.1	The area of simulation was outside the boundaries of the map, making the simulation not to start.	Changing the mesh from 10000 x 10000 to 10000 x 9000.
Dorotea	No	0.1.1	<p>After running the simulation for a while, 272/1803 of the people deciding to leave, did not leave the area causing the simulation not to end.</p> <p>Somewhere in the code there was a codeline that stated that the mesh should be <math>x=y</math>. And due to changing the mesh making <math>x \neq y</math> (from 10000 x 10000 to 10000 x 9000) a mismatch was created caused issues in the execution of the model.</p>	<p>The simulation could be ended manually by the button - <i>end simulation</i>. By that, output data was generated. But the output data was as faulty.</p> <p>The code was updated and <math>x \neq y</math>. A new version of WUI-NITY was received, version 0.1.2.</p>
Dorotea	Yes	0.1.2	No output data was received	The code was changed making WUI-NITY generate output data when the simulation completed. It was not tested at the Dorotea case. Version 0.13 was created.
Bottnaryd	Yes	0.13	No error	New version was provided due to updates (0.13b). A feature for visible smoke had been added, some bugs were fixed.

Bottnaryd	Yes	0.13b	No error	A new version was provided, version 0.15. Version 0.15 was almost the same as the previous one. The biggest change was that the .wui file and the associated input files had been modified. New files had been created that the .wui file referred to (less data in the .wui file, more data in separate files). Example on new files created: Weather (.wnd), wind (.wnd), Safe Areas (.ed), fuel moisture (.fmc) and fuel file (.fuel).
Bottnaryd	Yes	0.15	No error	Output data was received, presented in <i>Section 4.4.2</i> .

#### 4.2.10 Summary of important findings and gaps discovered

As a summary, the process of applying WUI-NITY to the Swedish landscape generated a good number of gaps and findings in need of discussion. It is recommended to read *Appendix A* to get a full picture of how these gaps and findings were discovered. In *step 52 and 53* is a description about the final steps in applying WUI-NITY to a new location. Vai Saran (*Graduate Advisor, Movement Strategies*) managed to apply WUI-NITY to the UK landscape, Marsden Moor, by the use of the *4.1 application protocol*. And due to similarities between UK and Swedish landscape – a conclusion is drawn: WUI-NITY should now be applicable to the Swedish (and similar) landscape, given recent changes to the model. It must also be mentioned that the *4.1 application protocol* is currently being used to apply WUI-NITY to other countries, for example Australia. This thesis has also been used by developers of WUI-NITY to influence the new GUI-design for future version of the program. The professionals working with the application protocol and the GUI-design has submitted a number of questions. Those questions have been answered and are presented in *Appendix G*.

## 4.3 Knowledge required to set up WUI-NITY to a new location

During the process of applying WUI-NITY to a Swedish location, problems were encountered. To be able to solve these problems or collect necessary data to make the process progress, deep knowledge in specific areas was required to set up WUI-NITY to a new location. It is therefore important with knowledge regarding:

- **GIS** – To create and modify collected raster images. The images have to be modified to fit the requirements of WUI-NITY (10 x 10 meters grid resolution, UTM coordinates). The images also need modifications in the process of creating an .lcp file. Both ArcGIS + Arcfuel and FlamMap needs the same grid resolution, the same coordinate system, and the same size of the images. It could also be necessary to use GIS to create raster data. For example, by using GIS, aspect and slope data can be created from an image containing elevation data.
- **Wildfire behaviour (CFFDRS)** – This is specific to a location of choice. If simulations are to be carried out in the Swedish landscape, it is recommended to use Prometheus. Prometheus is a wildfire simulation tool based on the CFFDRS system. It is therefore important to have knowledge about the CFFDRS system for the purpose of analysing the behaviour of the simulated fire.
- **Coding knowledge** – When working with WUI-NITY, some basic knowledge of coding is required. WUI-NITY code can be modified and created by using notepad++. UNITY 3D is written by C++ and C#. The WUI-NITY code must be studied for learning and for managing to apply WUI-NITY to a new location.
- **General computer knowledge** – During this thesis, a lot of time has been spent troubleshooting identified errors. To do that, general computer knowledge is essential. It is also important to be able to process the generated data etc.
- **Local knowledge about the location** – There may possible be local deviations that needs to be handled to set up WUI-NITY properly to the location. Therefore, local knowledge is important.

## 4.4 Simulated data

As shown in *Appendix A* and *Section 4.2*, this thesis has proven that WUI-NITY is applicable to the Swedish landscape, and other countries with similar landscape. But a functional .lcp file was not created for the Swedish cases, therefore the data below was generated without including the fire during the simulations. In other words, without a loaded .lcp file. However, the data is still interesting to discuss (*Section 5.2*). It reflects the evacuation time of this community given that the wildfire did not block a route or significantly affect the speed at which evacuating vehicles were able to drive.

*Section 4.4.3* describes the process of running simulations with different versions of WUI-NITY at different locations, and errors that was discovered and adressed.

### 4.4.1 The Dorotea case

The figures below present output data generated by WUI-NITY reflecting the Dorotea scenario (using version 0.1.1). Note that the fire was inactivated during the simulations (the .lcp file was not included – only the evacuation was simulated). The simulations of the Dorotea case was not succesful due to problems with loading the GPW data into the simulated case. 272/1803 (15 %) of the people, and 36/684 (5,3 %) of the households in the area initiated an evacuation, but did not reach a safe area (i.e. got stuck somewere) making the simulation not run to completion. The data below (*Figure 16, 17, 18 and 19*) was generated from the simulation done were 272/1803 stayed behind. The simulation was stopped manually at  $t = 12100$  s, when constant values was retrived for a longer time duration (i.e. no more evacuees were arriving). In a later iteration (version 0.1.2) of the Dorotea case, the GPW error was addressed. Everyone that decieded to leave reached a safety area. A total of 60/1804 (3.3 %) of the population decided to stay behind. The simulation completed, but no outputdata was recived. Version 0.1.3 was created to adress the output data error. That version was not tested for the Dorotea case, it was tested for the Bottnaryd case sucessfully.

#### Information about the case

- *Location:* Dorotea, Dorotea municipality
- *Coordinates* (LowerLeftLatLong): x: 64.236438, y: 16.375513 (WGS84)
- *Simualted area:* 9000 x 10000 m
- *Population in the area simulated:* 1803:
- *Surrounding vegetation:* 201, 202 (dominant), 203, 205, 207, 208 (use *Appendix D.3* to interpret the numbers)
- *Safe areas:* Four safe areas was choosen at the roads E45 and RV92. It was assumed that when a person has reached a safe area, they will be far away from the fire with the possibility to drive safely from there on.
- *Versions of WUI-NITY used:* 0.03\_pre-alpha, 0.1.1 (used to generat the outputdata below), 0.1.2

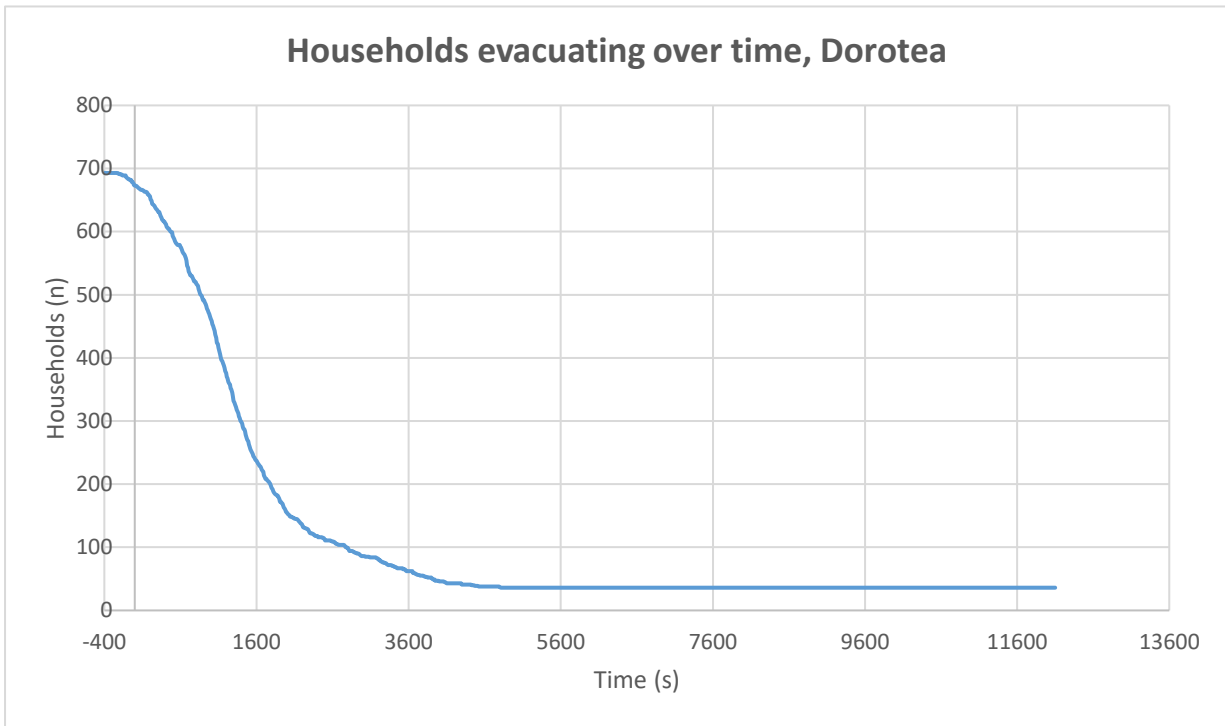


Figure 16: Household evacuating over time.

As shown in *Figure 16*, the values became constant with 36 households left. In total 684 households were located in the area resulting in  $36/684 = 5,3\%$  of the household staying behind, i.e., not evacuating as they should. *Figure 16* shows the total number of households initiating an evacuation, by that, the number should go down to 0 when all the households starting the evacuation has reached a safety area. But an error prohibits 36 households to leave making the simulation run to infinity. The error was due to problems loading GPW data into the case.

The simulation was interrupted at 12100 s after the evacuation order ( $t = 0$  s), as no further arrivals were expected. As shown, the households started to move at  $t = -400$  s., i.e., 400 s before the evacuation order. That was due to a standard setting in WUI-NITY not being changed – indicating that in reality a certain proportion of people will evacuate prior to the evacuation order.

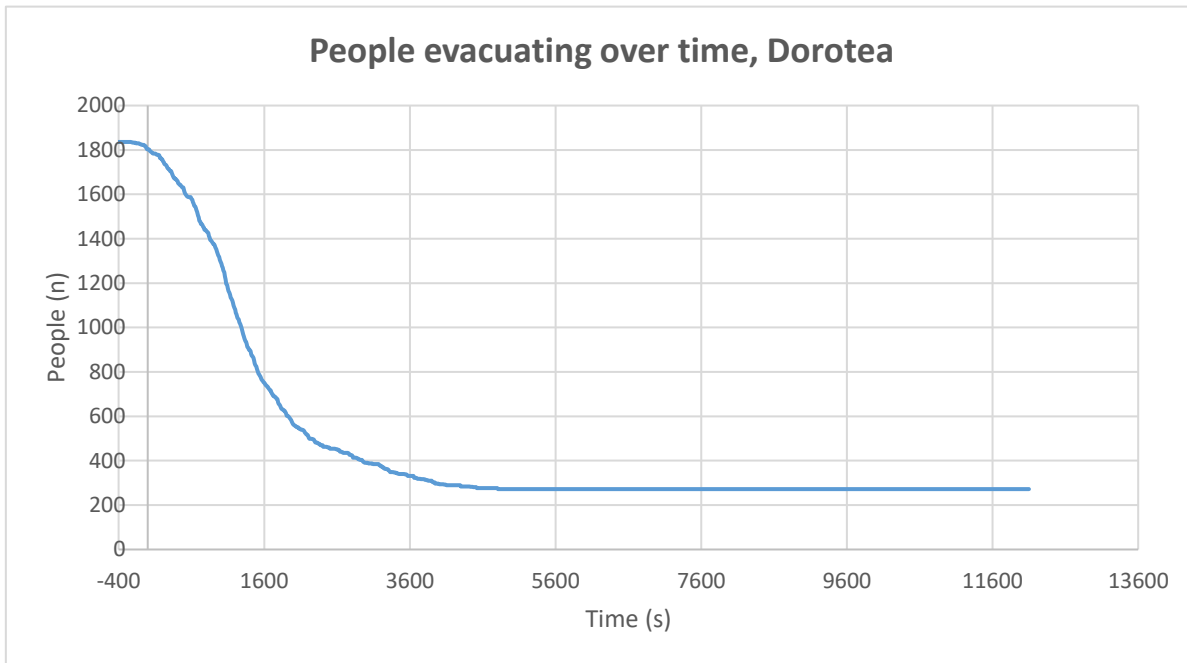


Figure 17: People evacuating over time.

Figure 17 displays that the values became constant with 272 people left behind. In total  $272/1803 = 15\%$  of the population stayed behind during the simulation even though they should evacuate. The number should go down to 0 making the simulation to complete. But an error prohibited this. It is also worth stating that a greater number of people (15 %) than households (5.3 %) are getting stuck. It was assumed that the number of people getting stuck is counted as *people per stuck household* + *people stuck between the path of evacuation from the household to the safe area* (5.3 % + 9.7 %). That is why the number of people and number of households differ. The evacuation started at  $t = -400$  s and was interrupted at  $t = 12100$  s.

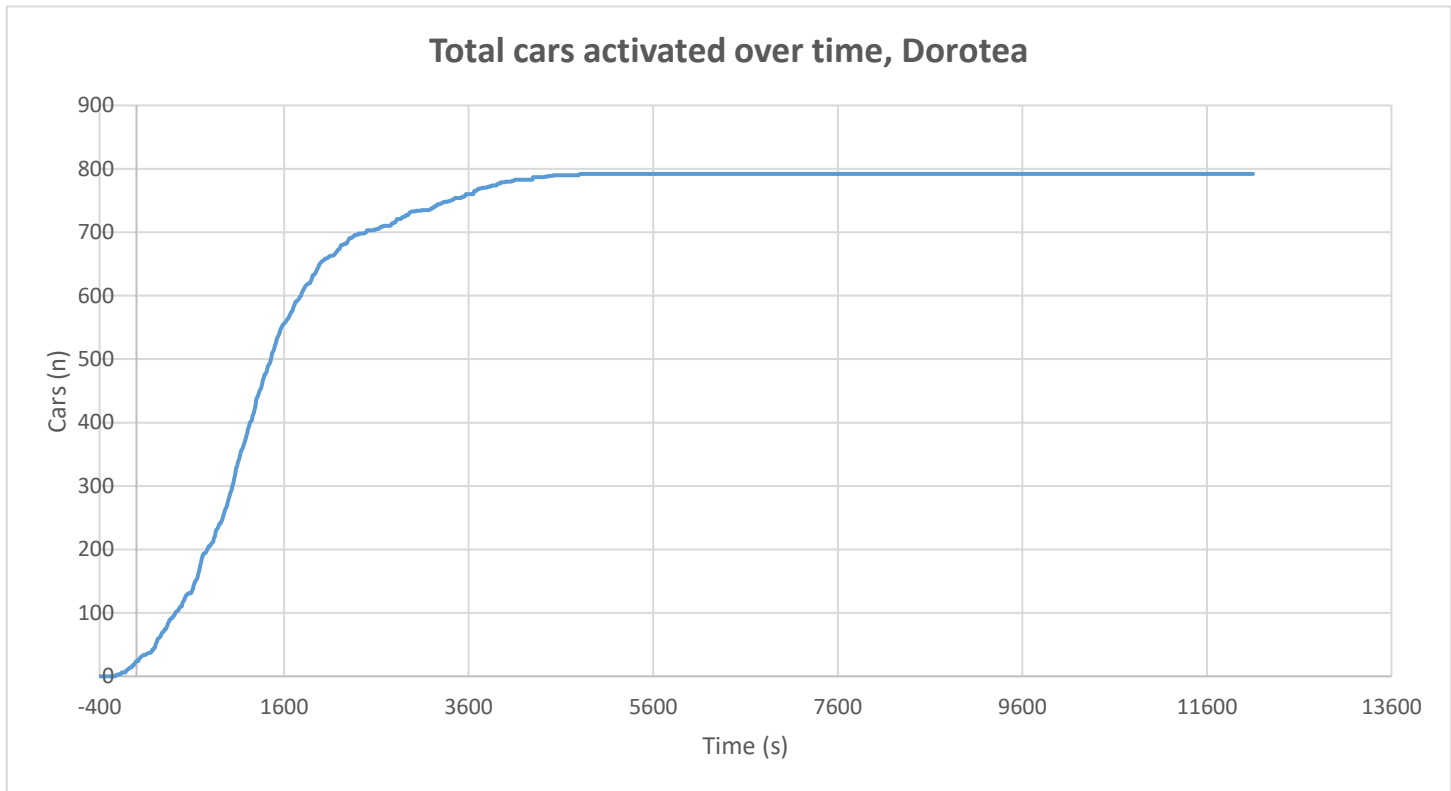


Figure 18: Number of cars activated over time.

In total, 792 cars were activated during the simulation according to *Figure 18*. After  $t = 4680$  s, no more cars were activated. The simulation started at  $t = -400$  s and was interrupted at 12100 s. Activated means cars used by those evacuating.

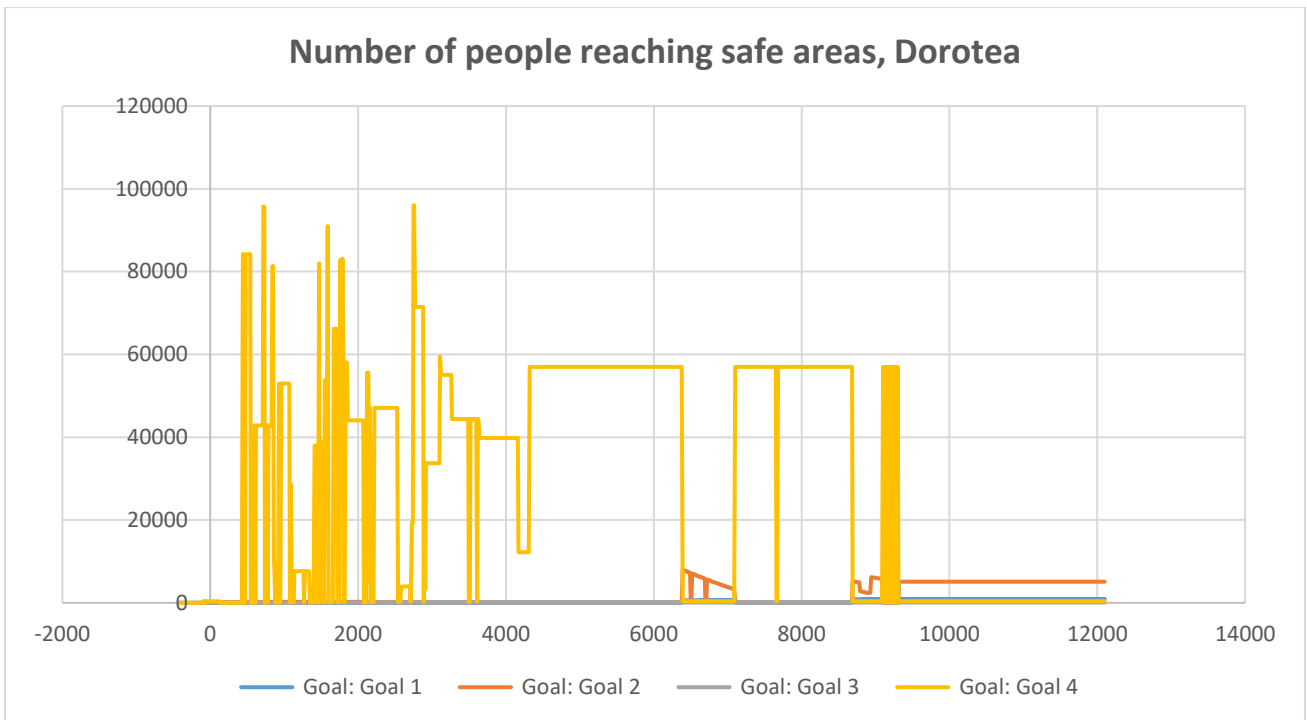


Figure 19: People reaching safe areas over time for Goal 1 - Goal 4. – The data is unrealistic and cannot be used.

The output data shown in *Figure 19* is faulty. A very large number of people is shown in the y-axis. And the number of people reaching the safe areas is shown as a flow instead of a total number. It is uncertain what cause this error. As can be seen in *Section 4.4.3*, due to GPW errors discovered during simulations for the Dorotea-case by version 0.1.1. A new version (0.1.2) was created by Jonathan Wahlqvist. Jonathan addressed the GWP issue, although no output data was received due to the simulations not completing (which also was addressed and a new version was provided, 0.1.3). Version 0.1.3 was not tested for the Dorotea case.

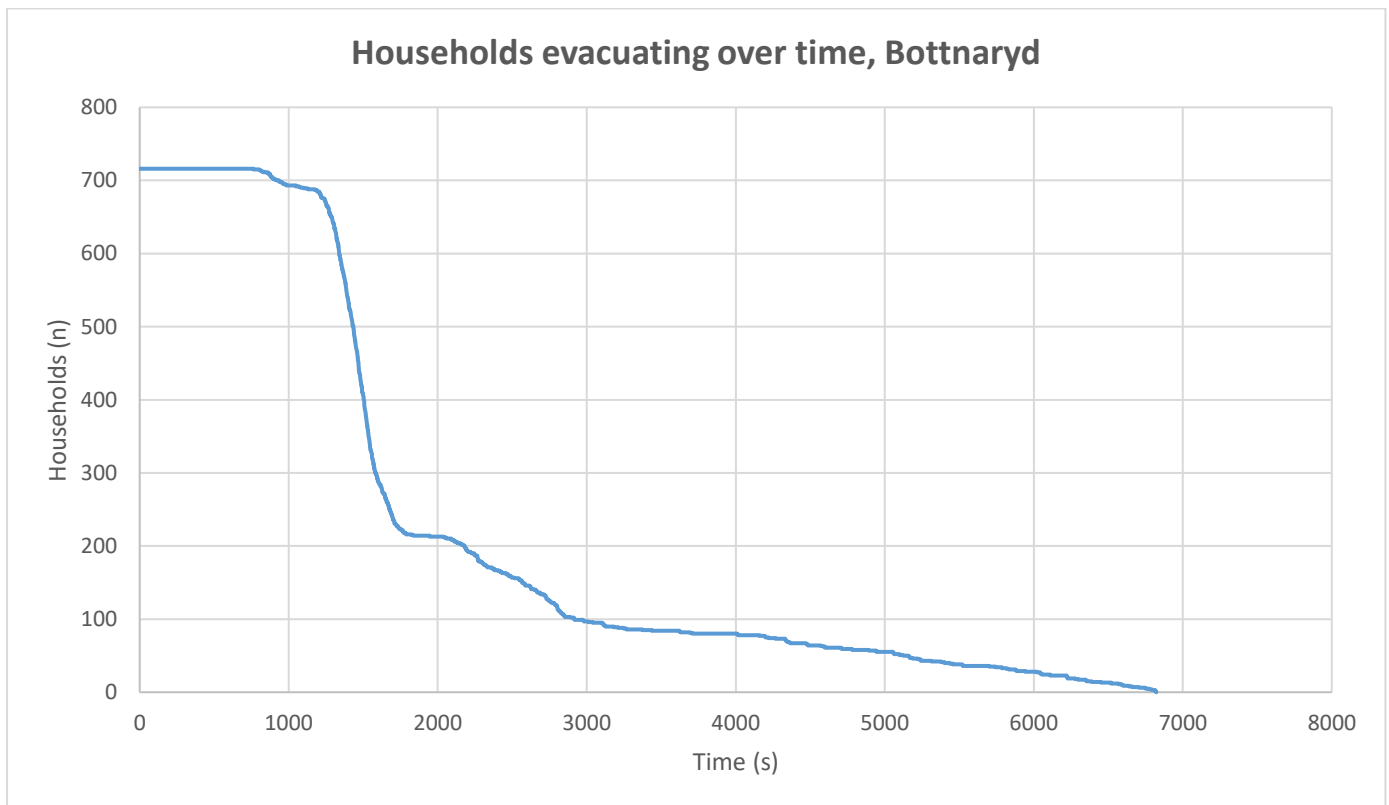


#### 4.4.2 The Bottnaryd case

Down below is a presentation of output data generated from the Bottnaryd case using WUI-NITY 0.15. Note that the fire was inactivated during the simulations (the .lcp file was not included – only the evacuation was simulated). As can be seen in *Figure 23*, the simulations finished at 14710 sec  $\approx$  4h when everyone had arrived at an Safe Area.

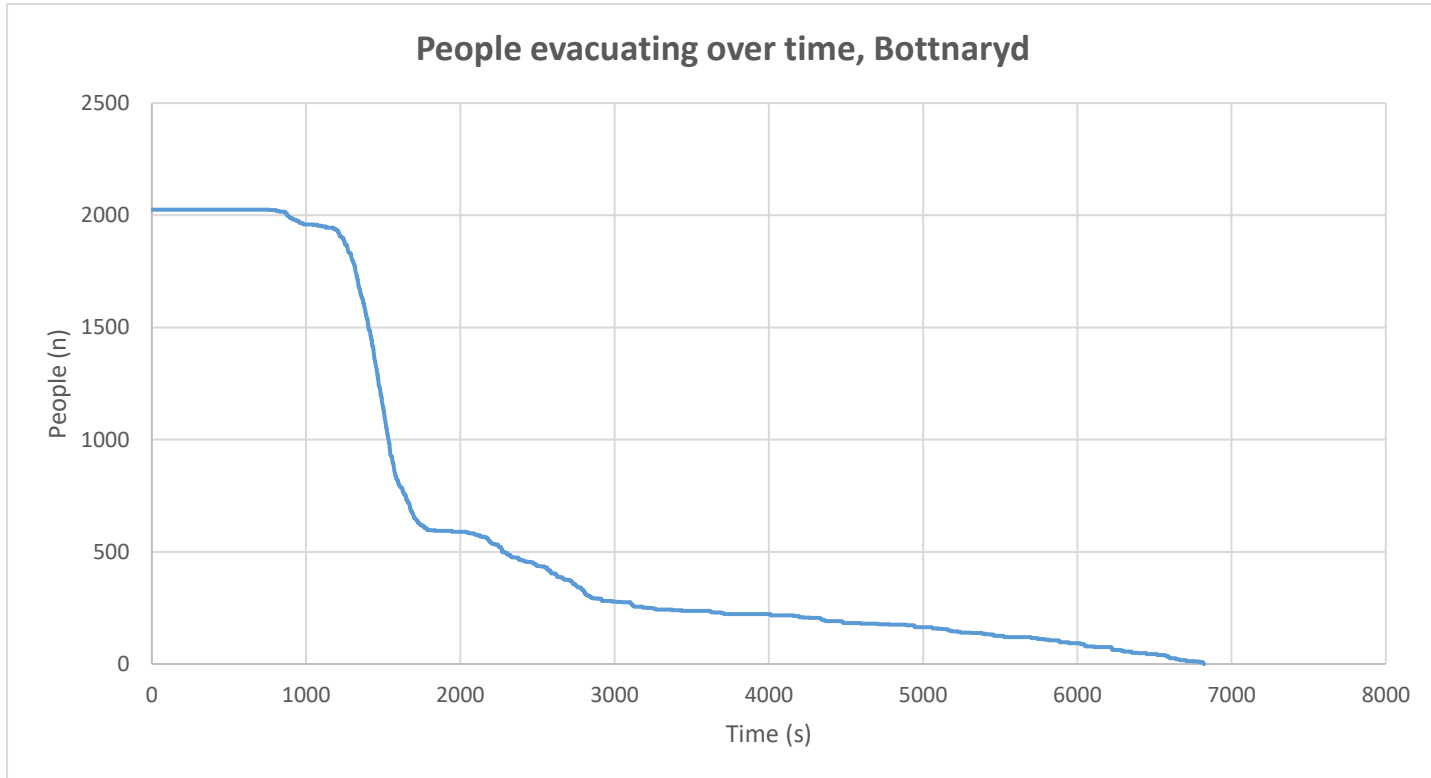
##### Information about the case

- *Location:* Bottnaryd, Jönköping municipality
- *Coordinates (LowerLeftLatLong):* x: 57.74615, y: 13.794459 (WGS84)
- *Simualted area:* 9000 x 9000 m
- *Population in the area simulated:* 2025:
- *Surrounding vegetation:* 201, 202 (dominant), 203, 205, 207 (use *Appendix D.3* to interpret the numbers)
- *Safe areas:* Three safe areas was choosen at the roads RV40 and RV185. It was assumed that when a person has reached a safe area, they will be far away from the fire with the possibility to drive safely from there.
- *Version of WUI-NITY used:* 0.15



*Figure 20: Household evacuating over time. Note that the starting time is set to 0 s. The default setting of -400 sec was changed – reflecting that the evacuation order is received at  $t = 0$  s.*

In *Figure 20*, total of 716 households evacuated during the simulation. The simulation started by the evacuation order at  $t = 0$  s. By the time of  $t = 6820$ , all the households deciding to leave the area was either at a safe area or on the move. *Figure 20* only shows the number of households starting to move and completing the evacuation, it does not show the number of households staying behind choosing not to evacuate.



*Figure 21: People evacuated over time.*

In *Figure 21*, total of 2025 people evacuated during the simulation. The simulation started by the evacuation order at  $t = 0$  s. By 6820 s after the evacuation order, all the people deciding to leave the area was either at a safe area or on the move. *Figure 21* only shows the number of people starting to move and completing the evacuation, it does not show the number of people staying behind choosing not to evacuate.

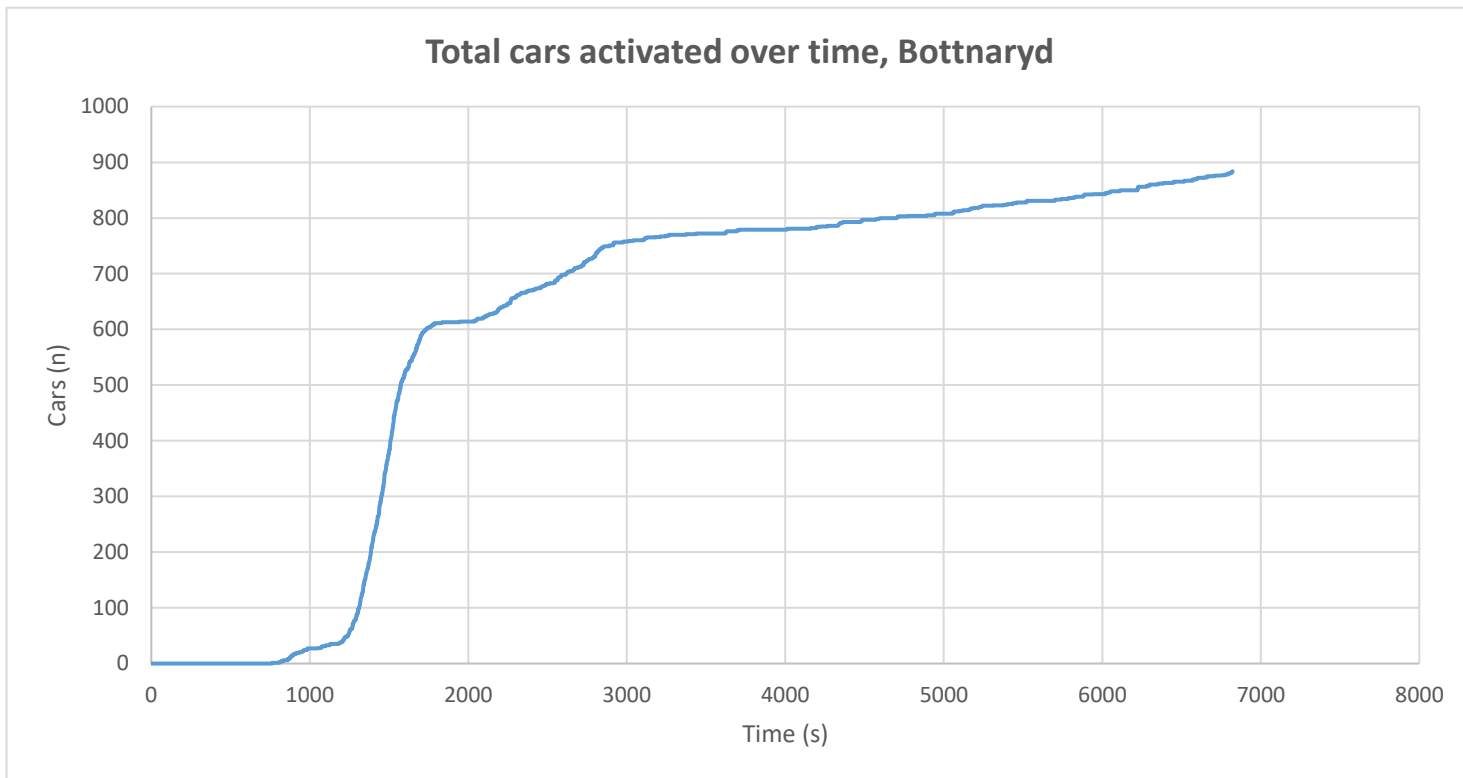


Figure 22: Total number of cars activated.

In total 883 cars evacuated during the simulation (Figure 22). The simulation started by the evacuation order at  $t = 0$  s. By 6820 s, all the cars used in the simulation had been activated.

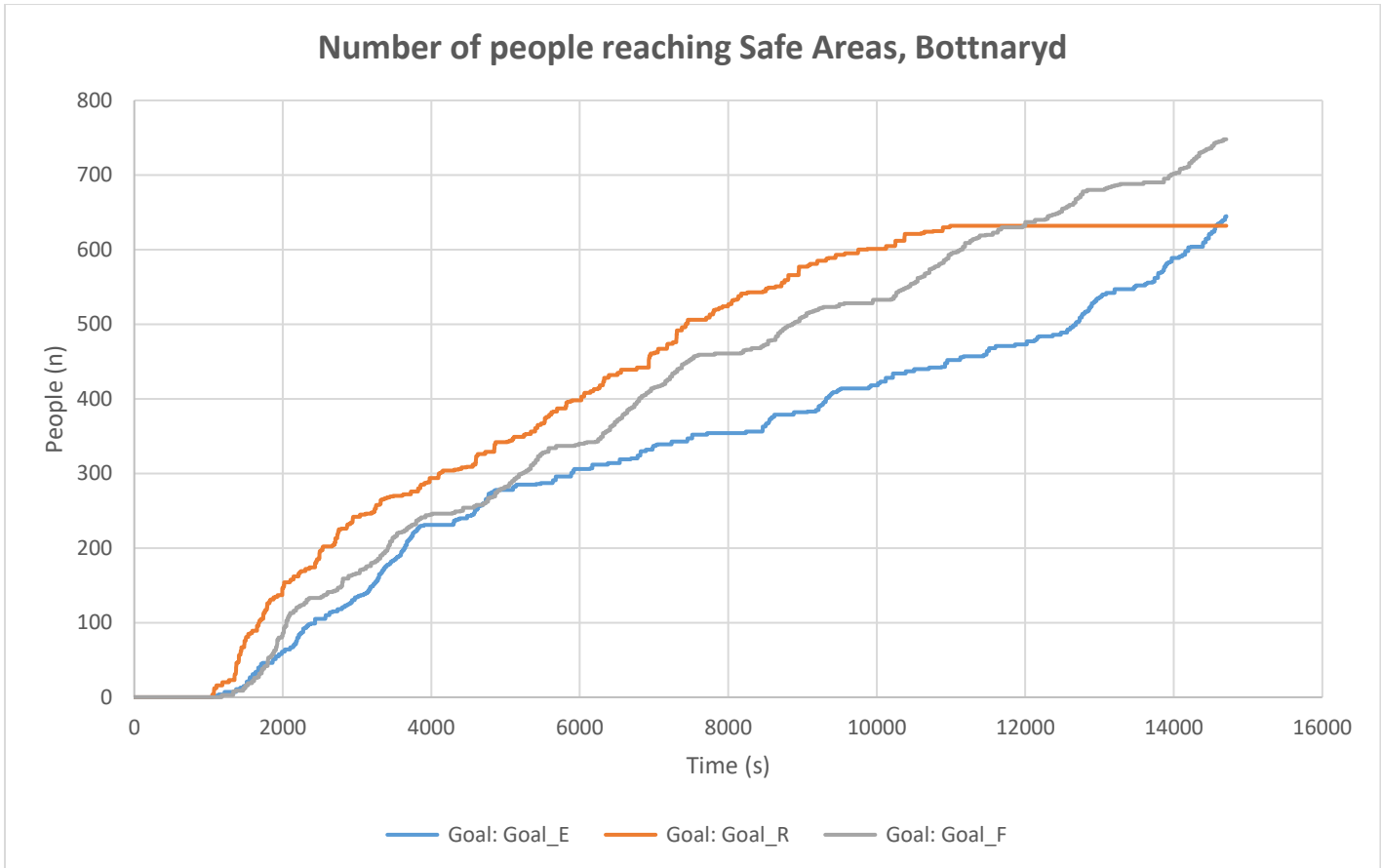


Figure 23: Number of people reaching three different Safe Areas over time. Goal = Safe area.

In total, 2025 people reach the safe areas (Figure 23). The simulations started at  $t = 0$ . The people deciding to leave the area was either at a safe area or on the move at  $t = 6820$  s. At  $t = 14710$  s, all people evacuating the area had arrived at a safe area completing the simulations. People escaping was distributed accordingly:

Goal E:  $n = 645$

Goal R:  $n = 632$

Goal F:  $n = 748$

$\text{Sum}_n = 2025$  people

## 5. Discussion

In this section, the methodology, the result, and uncertainties are discussed together with relevant literature. The outcome of the discussions is presented in *Section 6. Conclusions and suggestions of improvements*.

### 5.1 Methodology discussion

The most time-consuming part of this study was to set up the program to be functional for a Swedish location of choice (approximately 600 h). After all, that was the purpose of this work. At the very beginning of this thesis project, the focus was on the generated result from simulations done in the Swedish landscape. And with that, a comparison with expected conditions – assuming that the application would have been simple, and the interpretation of the results would represent the bulk of the work. However, during the process of configuring the program, difficulties were encountered at key points, that needed to be addressed before progressing - difficulties that were also not immediately apparent to the model developers. It led to a change of direction: instead of focusing on a comparison with output data from WUI-NITY with real-life evacuations, the problem statement was changed to identify gaps and explore challenges of applying WUI-NITY to the Swedish landscape, in addition to the secondary generation of results. In essence, generating a checklist (the application protocol) of steps that captured this process was deemed more important (and more challenging) and was therefore documented (see *Section 4.1* and *Appendix A*), becoming the key-result of this study.

It was also discovered that the work done in this thesis could be used to apply WUI-NITY to other locations outside of Sweden. The *Application protocol* and *Appendix A* was used by professionals to apply WUI-NITY to a location in the UK, Marsden Moor (*step 52-53, Appendix A*). This demonstrates that the methodology of the application protocol now enables application of the model to locations outside of North America – and to locations comparable to Sweden (in terms of the modelling challenges faced and resources available). As described in *step 53 Appendix A*, an .lcp file was not successfully created to be included for one of the cases tested in Swedish landscape due to limitations in time. But the United Kingdom and Sweden have similar landscape. Both Sweden and the UK are using the CFFDRS as the wildfire prediction tool. If WUI-NITY can be applied in the UK by using the *application protocol* of this thesis, then a conclusion can be made - WUI-NITY is applicable to the Swedish landscape. When a .lcp file is created successfully for a case in Sweden it should be possible to carry out simulations in WUI-NITY.

It is important to mention that WUI-NITY has not been validated at the new locations during this study. The next step is thus to validate the output data generated from simulations done at the applied locations. It is also recommended to address uncertainties in the model before/at the same time as the validation process. Uncertainties discovered in this study are presented at *section 5.3*. As mentioned earlier, in the literature study, it was discovered a lack of data for evacuations at Swedish locations. Given that, it might be necessary to validate WUI-NITY by the use of data from evacuations occurred in other countries – with similar landscape. It might also be worth to think about how precise the output data needs to be, how much uncertainties that can be allowed.

When working with this thesis project it was discovered that deep knowledge and experience with GIS was essential – given that the application process needed to be fully understood and omissions identified. That was an area of the engineering spectrum that was almost unknown to the author of this thesis. That was also a very time-consuming part of the process. Both ArcGIS and QGIS had to be learned during the process of applying WUI-NITY to the Swedish landscape. In retrospect, only

one of those programs was necessary to be learned – although some benefit was gained from exploring and comparing their capabilities. During the process, additional programs were used to either collect or modify the data. FlamMap 6, ArcFuel, FVS, Behaveplus 6, Earth Explorer, Earth Engine, Google Earth pro, Prometheus, WindNinja, Redist, C++, matlab and of course WUI-NITY had to be learned. Not all programs turned out to be useful in the end, but to examine if the programs were essential, they had to be learned and tested. That was a time-consuming process due to building knowledge about the programs.

When working with WUI-NITY during this thesis, a standard laptop was used (HP pavilion, 4 GB, RAM, intel i3-7100U processor 2.4 GHz, IGPU, Windows 10 64 bit). It was discovered that some of the issues that were encountered, was due to limitations of the computer used. A population file (.pop) could not be created by using GPW data when working with the laptop, also, Prometheus was not able to run. When a more powerful computer was used, the issues were solved. It would have been better to start the thesis by working on a computer that could run and process WUI-NITY properly. However, this is a result and a gap/limitation of the tool. And if the errors had not been discovered, the use of different computers would not have been explored. It was discovered that WUI-NITY (in its current version) demands a powerful computer to function properly. If decision makers or other persons of interest is to use the program in the future, they might also need to buy a new computer. This thesis has not examined what kind of computer specifications that is needed, just identified that a standard laptop with 4 GB RAM, intel i3-7100U processor 2.4 GHz and IGPU is insufficient for this application.

As a summary, the method of application was a time-consuming process exploring and solving an unexplored problem. To apply WUI-NITY to a Swedish location, several people were crucial for the process to progress in the right direction. Without those persons, the outcome of the result would not have been the same (those persons are mentioned under *acknowledgement*). As described thoroughly in *Appendix A*, mistakes, handling errors and strides in the wrong direction was made by the author of this thesis. The aim was to apply WUI-NITY to a new location and identify gaps and limitation along the way. It would not have been possible to go through this process without all those errors, mistakes, and missteps – they built the foundation of the result. The *4.1 Application protocol* might be the most important result of this study. And it would not be possible to create it without making a few (or maybe a lot) of detours and mistakes.

## 5.2 Result discussion

The result of this study is presented in *Sections 4.1 – 4.4*. A lot of interesting findings as well as simulated data and the application protocol are presented in those sections, that is discussed below.

Instead of using FARSITE, Prometheus would be the better option of a wildfire simulation tool to include in WUI-NITY when running simulations in Sweden (due to Sweden using the CFFDRS, which Prometheus is based on). That is considered an important finding in order to produce reliable output data. It is also something to consider when trying to set up WUI-NITY in other countries with different landscape and vegetation. The fire behaviour modelling tool needs to match the given landscape and vegetation types.

The process of setting up WUI-NITY for just one location in Sweden was time-consuming. It took a lot of hours (approximately . > 300 h) just to create the files necessary. Programs had to be learned and research had to be made. Although, if that was to be completed a second time, the process would have gone faster. A conclusion is that the current version of WUI-NITY needs to be more user friendly for decision-makers (e.g the Fire Department) to use the program during a live wildfire. It will take too much time just to set up the program for the given community and the wildfire afflicting it.

A proposition to the future is to develop the program with all the input data included. The program should include the necessary landscape data for the whole country, which eliminates the time-consuming process of creating a landscape file. Another suggestion is to connect the program with SMHI (Swedish Metrology and Hydrology Institute). By SMHI, environmental data can be retrieved, but also Fire Weather Index data hour by hour. If weather and FWI data is included by SMHI in real-time, and if WUI-NITY is using Prometheus as a fire modelling tool instead of FARSITE. The fire growth can be simulated live for a given area. That would be very useful for decision makers, both regarding the growth of the fire, but also when to evacuate a community. BrandGIS is a tool being developed as of right now with the purpose of creating a situational map of a live wildfire (*Section 3.6.3*). If WUI-NITY and BrandGIS are combined in the future, it could give the decision makers a powerful tool of how to suppress the fire, and when to evacuate the communities close by. And if PERIL is included once more, trigger buffer perimeters can also be simulated in real time.

A limitation of the study is the lack of real-world evacuations that has occurred in Sweden in modern time. There is lack of literature containing data about evacuations that has occurred. By that, if simulations in the Swedish landscape are done by WUI-NITY, there is not much data to compare with. Instead, it might be necessary to use data from evacuations occurred in countries with similar landscape and vegetation as Sweden. That could for example be Canada, UK, Norway, or Finland. Advantageously, data from Canada can be used because that country has a long history of large wildfires that required evacuations. A recommendation for further research at Swedish locations; look for countries that have adapted the CFFDRS – system. If so, it is likely that the landscape and vegetation is similar.

When starting this project, it was discovered that PERIL was no more a part of WUI-NITY. By that, the functions of PERIL in the Swedish environment could not be examined. If PERIL is to be included in WUI-NITY in the future, an assessment of its applicability to the Swedish environment is needed. There is a function in WUI-NITY that allows the user to manually select the trigger-buffer perimeter, I.e., when a community needs to be evacuated. However, that needs an estimation or a hand calculation of how long time it will take for the fire to reach the community. If PERIL is included in WUI-NITY in the future, its applicability to the Swedish landscape needs to be tested.

WUI-NITY requires a grid resolution of 10 x 10 meters and a coordinate system of UTM (preferably WGS 84) when creating the .lcp file. If the person gathering the necessary data required to create the .lcp file has good knowledge in GIS, she or he can modify the data to fit the requirements. If not, the amount of data that could be used will be limited. To be able to follow the application protocol (*Section 4.1*) presented in the thesis, good knowledge about GIS is necessary. During the process, a lot of troubleshooting and error corrections was necessary as well as interpretation of the generated output data. To be able to do that, it is recommended that the user have general knowledge about computers and coding. On the other hand, this thesis has already addressed a lot of those errors which mitigates the need of advanced computer knowledge. But new errors can be encountered when simulations are to be done at new locations.

When collecting geo-spatial data, it was discovered that some of the data were missing for the middle and northern parts of Sweden. Topographical data could not be retrieved using Earth Engine nor Earth Explorer for that area. If simulations are to be done in those parts of Sweden (or nearby countries). The topographical data must be retrieved by another method. This thesis might have missed other sources that could provide with necessary topographical data for the area mentioned, but additional sources could be the Swedish land surveyor, the municipality city office or the country administrative board.

When including data regarding the local road network, a filtered .osm file is used. The .osm data contains information of the location, speed limits etc of the road network. It was discovered that in Sweden, another service is available – the NVDB (National Road Database). The NVDB contains detailed information of the road, pedestrian and bicycle network as well as speed limits, maintenance of the roads etc. This thesis has not examined if the NVDB is more suitable than OSM data. It is therefore recommended to examine this in the future for further simulations in the Swedish landscape. In addition, if simulations are to be carried out in other countries it might be of interest to examine the most suitable traffic database there. Potentially, it could also be of interest to study other input variables in the future - more suitable for the studied area.

In *Section 4.4*, data is presented generated by WUI-NITY for the Dorotea and the Bottnaryd case. The data presented there was retrieved from simulations done by WUI-NITY without the .lcp file included. That is due to not fully completing the process of creating a functional .lcp file for a Swedish location. The output from the Dorotea case is faulty due to a lot of people staying behind making the simulation run to infinity. A conclusion was made that the local GPW data was loaded incorrectly (by a low budget computer). In some way, a lot of people decided to stay behind. When the problem with the GPW data was addressed, far more people evacuated. But there were still errors with the resolution of the map, which also was an improvement when fixed. It is assumed that some of the settings for the Roxborough case was implemented into the Dorotea case – generating the error of the large number of people getting stuck. It is worth mentioning that the simulations that was done at the Dorotea case was made with version 0.03\_pre-alpha, 0.1.1 and 0.1.2. By that, the data received from the Dorotea case cannot fully be compared with the Bottnaryd case. For the Bottnaryd case, version 0.15 was used. Instead, the result presented at *Section 4.4.1 – 4.4.3* can be used for further development of the program.

For the Bottnaryd case, good data was received. All the files needed functioned properly except the .lcp file. If the .lcp together with an active fire would've been present during the simulations, the output data received might have been different. That is due to roads being blocked by the fire, smoke influencing the speed of the cars etc. If all the inhabitants would've been able to evacuate before the fire reaches the community, the result would be the same even if the .lcp file together with an active fire would be present. That is due to the fire not interfering with the escaping community. The time of the completed evacuation (4 h) is compared with the Roxborough drill (2,5 h). During the Roxborough drill, 133 households participated. During the Bottnaryd case, 716 households evacuated. By that, it is concluded that 4h is a realistic time of evacuation.



*Appendix C.1* is a case study of a real Swedish wildfire which occurred during the summer of 2014, starting in Sala municipality. For the simulated Bottnaryd case, 2025 people was evacuated during 4 h. During the Sala fire 2014, 1000 people was evacuated during 24 h. The time difference is 20 h, even though that it was twice as many evacuating during the Bottnaryd simulation. It looks strange if the data is directly compared. Even if a case for Sala is set up in WUI-NITY, the existing data is not detailed enough to fully compare WUI-NITY with the real world evacuation. The available data describes that the evacuation order was initiated during the day when the highest FWI values was measured, the 4<sup>th</sup> of august (during that day, the fire grew from 2700 hectares to 13 000 hectares). And the evacuation was completed the 5<sup>th</sup> of august, 24 hours later – when the FWI values had lower, reducing the intensity and spread rate of the fire. During those 24 hours village by village was evacuated (due to the fire spreading and threatening different villages at different times). During the first hours, the focus was to evacuate one village with X people involved. And during the next hours another village with Y people was evacuating. This dragged out the time period of how the total time of evacuation was measured. In WUI-NITY, the evacuation order is received by all the inhabitants at the same time. Those who decides to evacuate, will do that under the same conditions. It is therefore important to study the real world wildfire and how the time of evacuation is measure if a comparison is to be made with simulations done by WUI-NITY. Preferably a time of evacuation for each of the villages would be more suitable if data from WUI-NITY is to be compared.

A very important step in the process have been to identify gaps in the configuration and coding in WUI-NITY. Those gaps have been addressed by the author of this thesis and corrected together with Jonathan Wahlqvist (The errors corrected are presented in *Section 4.2, 4.4* and *Appendix A.*). Due to correcting the identified errors, WUI-NITY have been enhanced for further usage. New versions of WUI-NITY addressing those errors have been provided during the course of this project. In other words, this thesis has contributed not only to examine the applicability of WUI-NITY to the Swedish landscape, but also to improve the program itself.

It must also be mentioned, once again, that the application protocol (*Section 4.1*) has already been used by professionals with the purpose of applying WUI-NITY to other countries than Sweden. An application has been completed for the location of Marsden Moor, UK. The result of that application indicated that WUI-NITY is applicable to the Swedish landscape (and similar countries). There is also an ongoing process to use the *4.1 application protocol* to additional countries, for example Australia. The main focus of this work was to analyse if and how WUI-NITY could be applicable to the Swedish landscape. However, the result of this study is proven to be applicable when setting up the program in other countries as well. The process of application to another country will be quite similar. Depending on the country, other sources to collect necessary data might be needed. As described above, an important finding in this study was that a more suitable fire modelling tool should be integrated into WUI-NITY to generate more reliable output data when running simulations in the Swedish landscape (Prometheus instead of FARSITE). It is then important to analyse what fire modelling tool is most suitable to be integrated into WUI-NITY with respect for the studied country's landscape. If the discussion regarding the most suitable input data is resumed in this context, it is recommended to examine if more adequate input data is available in the country being studied (for example input data for the road network and the populations distribution).

Additionally, at the time of writing, a new GUI design for WUI-NITY is being developed by Movement Strategies, London. This thesis has influenced that design. As a summary, the result of this study has already made a big impact on future development of the program as well as applying WUI-NITY to additional locations in other countries.

### 5.3 Uncertainty discussion

When working with computer models, uncertainties are always present. Input data might be wrong, or slightly wrong, the calculations done by the model might not fully represent the real world. When Ronchi et al., 2020 compared the Roxburgh drill with simulations done by WUI-NITY, the time of completing the simulations differed by 30 minutes. That was two years prior to the work performed in this thesis, so the model is probably more accurate as of today. But still, it consists of some uncertainties that needs to be addressed, especially when applying the tool to a different landscape then what it is developed for in the first place.

As describe before, FARSITE is not the best choice when running wildfire behaviour/spread simulations in the Swedish landscape. By using FARSITE, the fire might not behave correctly in WUI-NITY with a comparison with the real-world fire. To solve that, or to mitigate the uncertainty, it is suggested that Prometheus integrated into WUI-NITY as the wildfire simulation too when running simulations in the Swedish landscape.

When simulating the fire, you must manually write/modify codelines about the input variables. Those input variables directly affect the fire behaviour. That includes the wind, the fuel moisture, time of the day, temperature etc. A brief time after you have inserted the correct values for those input variables, the values is not up to date anymore. If there is a scenario when for example the Fire Department is working with a real time fire, someone needs to manually update the input variables hour by hour. If that is not done, there will be uncertainties in the behaviour of the fire that will grow as the time passes. That is the reason why a real time update from SMHI integrated into WUI-NITY would be a good upgrade. One of the main factors that afflict the fire behaviour is the direction and the speed of the wind. If the direction changes 180 degrees, it might affect a different community with a much larger population, or it might not affect a community at all. That also implies the need of a real time update of the weather factors affecting the behaviour of the fire.

It is also hard to estimated exactly where an ignition has occurred. The coordinates for the ignition point/points needs to be manually written in the code. The exact location of the ignition might be hard to match in WUI-NITY. That is also an uncertainty that might affect the output data generated from WUI-NITY. A solution to that can be to include satellite detection into WUI-NITY, by that, a more precise location might be retrieved.

When working with the current version of WUI-NITY, population data from 2015 was used. It is therefore an uncertainty how many people that actually lives in the WUI community. The numbers have probably grown for most of the communities. And a few communities have lesser population due to urbanisation. It would be better to use data from the current year.

As with the ignition points, the *safe zone* where people evacuated to also needs to be determined manually by changing coordinates in the code. That is also an uncertainty. The simulation is done when all the evacuating people have reached any of the safe zones. If a safe zone is changed to a distance further away, the evacuation time will be longer and vice versa. It is hard to determine when a person is safe or not in the model. That is a factor to consider when evaluating the output data generated by WUI-NITY.

The road network is updated when the .osm file is downloaded. That implies that if a road is blocked or under construction when the .osm file is downloaded. It will stay that way until a new .osm file is included in WUI-NITY. If the .osm file is not updated continuously, the road network in WUI-NITY might not fully represent the real-world road network. That will also affect the output data and the evacuation time to be either longer or shorter than the real-world evacuation. A suggestion to address this uncertainty would be to include a function in WUI-NITY that updates the road network in real time. It might also be worth to consider using the NVDB instead of .osm data, that might as well mitigate the uncertainty. Additionally, to mitigate uncertainties due to time delays, it would then be of interest to include live update of the NVDB – generating the latest updates of the road network (construction sites, new roads etc).

It is worth mentioning the temporal aspect that affects the contribution of certain fuels to the fire spread. For example, some fuels might affect the fire spread in a greater extent early in the fire season, while other fuels are more prominent later in the season. WUI-NITY does not take this into account during the simulations. A service provided by MSB provides data regarding the grass-fires season as well as when the forest fire season is starting. To include this service in WUI-NITY might address the uncertainty mentioned.

In this section, as well as in other sections, gaps and uncertainties regarding both the process and the program has been discussed. The output data generated is given in terms of evacuation over time (people, households, cars) or evacuation-flow per second (people/second, households/second cars/second), a total time of evacuation is of course also received. Due to the uncertainties mentioned, it would additionally be of interest to receive a statical distribution for the total evacuation time. If a large number of simulations using the Monte Carlo method are carried out, a statistical probability distribution can be created. It will tell what the most likely total time of evacuation is – due to randomly selecting a large number of data from each uncertainty variable (in a given range).

To be noted as a summary, the purpose of this work has not been to generate reliable output data for locations in Sweden. The main purpose was to apply WUI-NITY to the Swedish landscape and identify gaps and errors that needed to be addressed in order to produce reliable output data. This thesis can be seen as pioneering work, paving the way for future refinement of the program – generating more accurate data.

## 6. Conclusions and summary of suggested improvements

The aim of this study was to apply WUI-NITY to the Swedish landscape, and to identify challenges and gaps with that application. A conclusion can be made after the process of application: WUI-NITY is now applicable to the Swedish landscape, as well as countries with similar landscape. The goal was to use the findings and the documented process, to create a step by step guide on how to apply WUI-NITY to new locations – making the process more efficient. The *4.1 Application protocol*, full fills that goal. Two questions were to be answered during this study (*section 1.3.1*)

*How is WUI-NITY applicable to the Swedish landscape?*

By the use of the *4.1 Application protocol* as well as by the use of *Appendix A*.

*What improvements can be made to the program as well as for the process of application?*

During the process of application, improvements have been made - generating new versions of WUI-NITY. The error addressing process is described in detail in *Appendix A*. This thesis has also identified gaps and important findings – summarised below.

Important findings and suggestions of improvements are summarised below – indicating the impact from this thesis as well as future needs to continue the development of the program.

- It is important to use a suitable wildfire simulation model for the specific location. Therefore, FARSITE should be replaced with Prometheus when simulations are carried out in the Swedish landscape. If the program is set up at another country, it is important to analyse what is the most suitable wildfire simulation tool there.
- A lot of time was spent trying to create a landscape file for the Swedish landscape. It would be very useful to create a detailed map over Sweden with all the necessary geo-spatial data included in the same layer. That enables the user to easily create an .lcp file (suitable for the wildfire simulation tool used). The map can then advantageously be integrated into WUI-NITY eliminating the need of creating a landscape file. That will also eliminate the lack of geo-spatial data available for the northern parts of Sweden. The map must of course be updated continuously.
- When simulations are carried out in WUI-NITY during a live wildfire, the input data can quickly become outdated (as in terms of weather and FWI data). It will require a tremendous amount of work to keep the data fully up to date. Therefore, it is recommended to integrate a live update of the weather and FWI data. To do that, SMHI-services could be used. It is also recommended to always use the latest GPW and OSM data available.
- WUI-NITY is developed for US simulations. To mitigate uncertainties in the model, it might be necessary to examine if other options of input data is available. For example, instead of OSM data, the NVDB could be used for simulations in the Swedish landscape. It might also be of use to receive a statistical probability distribution along with the other output data, addressing the uncertainties in the input variables – the Monte Carlo method could be used.

- As WUI-NITY, BrandGIS is a program under development. BrandGIS is a tool to help decision makers creating a situational map during the suppression phase of a wildfire. If BrandGIS and WUI-NITY is combined in the future, it could be possible to give the decision makers a powerful tool of both how to suppress the fire and when to evacuate communities afflicted by the wildfire.
- When delivering WUI-NITY to a new user, it is recommended to provide additional education about GIS and the CFFDRS (if Prometheus is used). The GIS knowledge is essential in the process of creating a landscape file (if an LCP map is integrated into WUI-NITY, the need for GIS skills could be played down). The CFFDRS knowledge is important for the understanding of the underlying factors that decides the behaviour of the fire. It is also useful to have basic knowledge about coding and general knowledge about computer modelling before WUI-NITY is learned and used.
- It was discovered that PERIL is not a part of WUI-NITY at its current version. If PERIL is included in WUI-NITY in the future, its applicability to the Swedish, and countries with similar landscape, needs to be tested.
- During the process, important gaps in the code have been identified. These gaps have been notified to Jonathan Wahlqvist (creator of WUI-NITY) who has since fixed them and by that provided new versions of WUI-NITY. This thesis has had an impact on the development of the program and made some important improvements.
- The application protocol (*Section 4.1*) has already been used by professionals and developers with the purpose of applying WUI-NITY to other countries as well as influencing the new GUI design for future versions. By the use of the *application protocol*, WUI-NITY has successfully been applied to the UK landscape (Marsden Moor).
- To test the reliability and the preciseness of the output data, evacuation occurred in the past can be used. Through a literature review, it was discovered that it exists only a limited amount of data for Swedish evacuations. Therefore, it could then be needed to use data from other countries with similar landscape and vegetations. Canada is a good example of that. It is important to compare the right type of evacuation data in order to make conclusions from it.
- It was discovered that some of the problems encountered was due to limitations of the computer's hardware. Although this thesis has not examined the specific specs required, it is recommended to use a computer with a good amount of RAM and EGPU.
- Early in the process, it was learned that PERIL was not a part of WUI-NITY anymore. To give an indication of when to evacuate a community with respect to the threatening wildfire, PERIL can be a good tool. It might be worth including PERIL once more during future development.

## 7. References

- Alberta Agriculture and Forestry. (2022). *Understanding Fire Weather*. Retrieved 2022-10-7, from: <https://wildfire.alberta.ca/wildfire-status/fire-weather/understanding-fire-weather.aspx>.
- Beverly, J., Bothwell, P. (2011). *Wildfire Evacuations in Canada 1980-2007*. Natural Hazards. DOI: 10.1007/s11069-011-9777-9
- CBC. (2022). *To rate wildfire danger, Britain looks to Canada*. Retrieved 2022-11-19 from: <https://www.cbc.ca/amp/1.6544860>
- Dempsey, C. (2012). *QGIS versus ArcGIS*. Retrieved: 2022-07-18, From: <https://www.gislounge.com/qgis-versus-arcgis/>
- EFFIS. (2022). *European Forest Fire Information System*. Retrieved 2022-06-02, From: <https://effis.jrc.ec.europa.eu/>
- Eriksson Pagnon, C., Johansson, N., McNamee, M. (2022). *The Performance of Wildfire Danger Indices: A Swedish Case Study*. Division of Fire Safety Engineering, School of Engineering, Lund University.
- EROS. (2022). *Earth Explorer*. Retrieved 2022-06-03 from: <https://www.usgs.gov/educational-resources/earth-explorer>
- ESRI. (2022a). *Aspect – slope function*. Retrieved 2022-07-28, From: <https://pro.arcgis.com/en/pro-app/latest/help/analysis/raster-functions/aspect-slope-function.htm>
- ESRI. (2022b). *Altering the resolution of a raster*. Retrieved 2022-07-28, From: <https://pro.arcgis.com/en/pro-app/2.8/tool-reference/spatial-analyst/altering-the-resolution.htm>
- ESRI. (2022c). *Specify a coordinate system*. Retrieved 2022-07-28, From: <https://pro.arcgis.com/en/pro-app/latest/help/mapping/properties/specify-a-coordinate-system.htm>
- Finney, A. (2004). *FARSITE: Fire Area Simulator – Model Development and Evaluation*. USDA, Rocky Mountain Research Station.
- Finney, A. (1995). *FARSITE: A Fire Area Simulator for Fire Managers*. USDA. The Biswell symposium: Fire Issues and solutions in Urban interface and wildland ecosystem. Pg 55-56
- Finney, A., McAllister, S., Grumstrup, T., Forthofer, Jason. (2021). *Wildland Fire Behaviour: Dynamics, Principles, and processes*. CSIRO Publishing, Melbourne.
- Gilljam, C., Ahlkrona, E. (2016). *Metodutveckling för kartering av brandbränsle i Sverige*. Metria AB: Stockholm.
- Hansen, R. (2003). *Skogsbrand – Släckning*. Räddningsverket: Elanders Skogs Grafiska AB.

Intini, P., Ronchi, E., Gwynne, S., & Pel, A. (2019). *Traffic Modeling for Wildland – Urban Interface Fire Evacuation*. *Journal of Transportation Engineering, Part A: Systems*, 145(3), 1–15. <https://doi.org/10.1061/JTEPBS.0000221>.

Kelly, J., Ibáñez, T., Santín, C., Doerr, S., Nilsson, M-C., Holst, T., Lindroth, A., Kljun, N. (2021). *Boreal forest soil carbon fluxes one year after a wildfire: Effects of burn severity and management*. *Global change biology*, vol: 27, pg 4181 - 4195. Doi: <https://doi.org/10.1111/gcb.15721>

Kolstela, J. (2019). *Simulating a 2014 wildfire in Lieksa (Finland) using the Canadian Prometheus fire growth simulation model*. FMI's climate Bullentin. doi: 10.35614/ISSN-2341-6408-IK-2019-16-RL

Kuligowski, E. (2020). *Evacuation decision-making and behaviour in wildfires: Past research, current challenges, and a future research agenda*. *Fire Safety Journal*, (May). <https://doi.org/10.1016/j.firesaf.2020.103129>

Lantmäteriet. (2022). WGS84. Retrieved 2022-06-12, From: <https://www.lantmateriet.se/sv/geodata/gps-geodesi-och-swepos/Referenssystem/Tredimensionella-system/WGS-84/>

Länsstyrelserna. (2022). BrandGIS. Retrieved: 2022-10-26, From: <https://ext-geoportal.lansstyrelsen.se/arcgis/apps/storymaps/collections/7b8f0317581240f9b8d6beacd840ad1e?item=2>

Metria AB. (2021). *Bränsleklassificering – Klassberskrivning*. MSB

Mitchell, H. (2019). *PERIL: Wildfire Behaviour and Optimum Evacuation of the Population in the Wild-Urban Interface*. Imperial College, London.

MSB. (2021a). *Brandbränsleklassificering*. Retrieved 2022-06-05 From: <https://msb-bbk.metria.se/>

MSB. (2021b). *Bränsleklassificering, klassbeskrivningar*. Version 1.0

MSB. (2022). *Vägledning i skogsbrandssläckning. 3:e utgåvan 2022*. DanagårdLiTHO: Karlstad.

NASA, SEDAC (2022). *Gridded Population of the World (GPW), v4*. Retrieved 2022-04-12, From: <https://sedac.ciesin.columbia.edu/data/collection/gpw-v4>

National Wildfire Coordinating Group. (2014) *Fire Behaviour Fied Reference Guide*. PMS 437

Natural resources Canada (gov). (2022). *Canadian Forest Fire Dange Rating System (CFFDRS)*. Retrieved 2022-07-28, from: Canadian Wildland Fire Information System | Canadian Forest Fire Danger Rating System (CFFDRS) ([nrcan.gc.ca](http://nrcan.gc.ca))

Open Street Map. (2022). *Open Street Map*. Retrieved: 2022-11-22, From: <https://www.openstreetmap.org/about>



- Ou, T. (2017). *Droughts and wildfires in Sweden – past variation and future projection*. University of Gothenburg: MSB.
- Ronchi, E., Gwynne, S., Rein, G., Wadhvani, R., Intini, P., & Bergstedt, A. (2017). *e-Sanctuary : Open Multi-Physics Framework for Modelling Wildfire Urban Evacuation*. Quincy, MA, USA
- Ronchi, E., Gwynne, S. M. V, Rein, G., Intini, P., & Wadhvani, R. (2019). *An open multi-physics framework for modelling wildland-urban interface fire evacuations*. *Safety Science*, 118(March), 868–880. <https://doi.org/10.1016/j.ssci.2019.06.009>
- Ronchi, E., Wahlqvist, J., Gwynne, S., Kinatader, M., Benichou, N., Ma, C., ... Kimball, A. (2020). *WUI-NITY : a platform for the simulation of wildland-urban interface fire evacuation*. Quincy, MA, USA. <https://doi.org/10.1016/j.ssci.2017.07.015>
- Ronchi, E., Wong, S., Suzuki, S., Theodori, M., Wadhvani, R., Vaiciulyte, S., ... Gwynne, S. (2021). *Case studies of large outdoor fires involving evacuations*. Working Group of the International Association for Fire Safety Science, 2021 February. Doi: 10.5281/zenodo.450485
- SCB. (2019). *Skogsmarken dominerar Sverige*. Retrieved 2022-11-17, from: <https://www.scb.se/hitta-statistik/statistik-efter-amne/miljo/markanvandning/markanvandningen-i-sverige/pong/statistiknyhet/markanvandningen-i-sverige2/>
- Scott, H., Burgan E. (2005). *Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model*. USDA
- SEDAC. (2022). *Gridded populations of the world*. Retrieved: 2022-11-22, From: <https://sedac.ciesin.columbia.edu/data/collection/gpw-v4>
- SMHI., MSB. (2022a). *Brandrisk skog och mark (Wildfire risk – In forest and land)*. Retrived 2022-07-27, from: [www.smhi.se/brandrisk](http://www.smhi.se/brandrisk)
- SMHI., MSB (2022b). *Brandriskprognoser (Wildfire forecast)*. Retrieved 2022-07-27, from: [www.smhi.se/vader/varningar-och-brandrisk/brandrisk](http://www.smhi.se/vader/varningar-och-brandrisk/brandrisk)
- Taylor, S.W., Alexander, M.E. (2016). *Field Guide to the Canadian Forest Fire Behaviour Prediction (FBP) System*. National Resources Canada. ISBN: 978-0-660-04333-3
- Trafikverket. (2022). *Vägdata*. Retrived: 2022-11-18, from: <https://bransch.trafikverket.se/tjanster/data-kartor-och-geodatatjanster/las-om-vara-data/vagdata/>
- Tymstra, C., Bryce, R.W., Wotton, S.W., Armitage., OB. (2010). *Development and Structure of Prometheus: the Canadian Wildland Fire Growth Simulation Model*. Natural resources Canada: Canadian Forest Service Northern Forestry Centre.
- United Nations Environment Programme & Grid-Arendal. (2022). *Spreading like wildfire: The rising threat of extraordinary landscape fires – A Rapid Response Assessment*. <https://wedocs.unep.org/20.500.11822/38372>.

USDA. (2020). *FlamMap*. Retrieved 2022-07-11 from: <https://www.firelab.org/project/flammap>

USDA. (2016). *ArcFuels*. Retrieved 2022-07-18 from: <https://www.fs.fed.us/wwetac/tools/arcfuels/>

U.S Department of Agriculture, U.S Department of the Interior. (2022). *LANDFIRE*. Retrieved 2022-10-19 from: <https://landfire.gov/index.php>

US Forest Service. (2017) *Appendix N – Fuel models*. Received 2022-11-20, from: <https://www.fs.usda.gov/nrm/fsveg/index.shtml>

Wahlqvist, J., Ronchi, E., Gwynne, S. M. V., Kinateder, M., Rein, G., Mitchell, H., ... Kuligowski, E. (2021). The simulation of wildland-urban interface fire evacuation: the WUI-NITY platform.

Wong, S., Broader, J., Shaheen, S. (2018). *Can Sharing Economy Platforms Increase Social Equity for Vulnerable Populations in Disaster Response and Relief? A Case Study of the 2017 and 2018 California Wildfires*. Transportation Research Interdisciplinary Perspectives, Vol 5. <https://doi.org/10.1016/j.trip.2020.100131>

## 8. Appendix

In the subsections, appendices are presented that are necessary to complement the thesis. Following appendices are presented below:

- Appendix A – Documentation of the process
- Appendix B – WUI-NITY code
- Appendix C – Case studies
- Appendix D – Fuel models
- Appendix E – Specifications of the FWI data
- Appendix F – Fuel data related to the .fuel file
- Appendix G – Questions and Answers

### Appendix A - Documentation of the process

This appendix presents the complete process of applying WUI-NITY to the Swedish landscape. From this documentation, the *4.1 application protocol* was created – a refined version of the methodology, without all the missteps and errors, of applying the program to a new location.

1. A version of WUI-NITY (version 0.1) was received from the creator of the program (*Jonathan Wahlqvist, Fire Engineer and Scientist at Lund University*). The first task was to test the program for learning purposes, but also to make sure that WUI-NITY could be set up properly for further simulations. In other words, installing the program correctly and testing its functions. For that, the Roxborough Park case was used. The casefile (a .wui-file, *Section 3.1.2.1*) itself is created by Jonathan. The inspiration for the Roxborough Park case is taken from Gwynne et al, 2020. In 2019 there was a community evacuation drill in Roxborough Park (USA). And the actual drill was then compared with simulations done by WUI-NITY (the roxborough.wui case).
2. After downloading and installing WUI-NITY, other required files were downloaded to support the installation and application of the model. A brief model guidance was provided by Jonathan. A mapbox token and GPW-data (Gridded Populations of the World) was downloaded and put into folders. However, the roxborough.wui case did not work at this stage. It was discovered that the current version contained code that was linked directly to Jonathans local computer. Contact with Jonathan Wahlqvist was made once more, he made some changes to the code and provided a new version of WUI-NITY (v0.03\_pre-alpha). The roxborough.wui case was successfully simulated after the newer version was used.

*Population database:* Download following: gpw-v4-population-density-rev10\_2020\_30\_sec\_asc from: <https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11/data-download>.

(data from 2020 is the latest GPW update).

- Once the files are downloaded, extract and place them in the WUI-NITY root: folder\external\_data\ gpw-v4-population-density-rev10\_2020\_30\_sec\_asc.

*Mapbox token:* A Mapbox token is needed to access maps. Create an account and receive a token from: <https://account.mapbox.com/auth/signup/>

Add the token to the WUI-NITY root:

folder\WUInity\_Data\Resources\Mapbox\MapboxConfiguration.txt

*OpenStreetMap (OSM):* Download the desired OpenStreetMap data from:  
Geofabrik Download Server.

- Make sure to click on Europe, then choose Sweden (or another desired country). If OSM data for the whole of Europe is downloaded, the file will be too large to handle for WUI-NITY.
3. The process of setting up the model to be applicable to the Swedish landscape was initiated, both WUI-NITY and PERIL (*Section 3.2*) was supposed to be tested. Earlier versions of WUI-NITY did include PERIL as a trigger buffer tool with the purpose of calculate when the evacuation order is needed with respect to RSET and ASET. But when WUI-NITY was tested for learning purposes, it was discovered that PERIL was not included as a trigger buffer tool. A contact was made with Steve Gwynne, who provided with contact information to Nikolaos Kalogeropoulos (*PhD Fire Science, Imperial Collage London*), and Guillermo Rein (*Professor of Fire Science, Imperial Collage London*). When waiting for response about PERIL, the work regarding setting up WUI-NITY to a Swedish location continued.
  4. Four candidate Swedish locations was selected - to test the model application: *Lena, Norberg, Bottnaryd* and *Dorotea*. From these, Dorotea was deemed to be the most applicable and was selected for further analysis given that it:
    - is a small town in northern Sweden with a population of approximately 1850 people.
    - is surrounded by a lot of woods, which is typical for a small town/society in Sweden, i.e. a WUI-community.
    - the main vegetation is pine and that is a fire-friendly fuel. Pine is a very common fuel type in Sweden.

The other locations were also worthy for further analysis, but Dorotea seemed to be the most suitable with the above motivation.

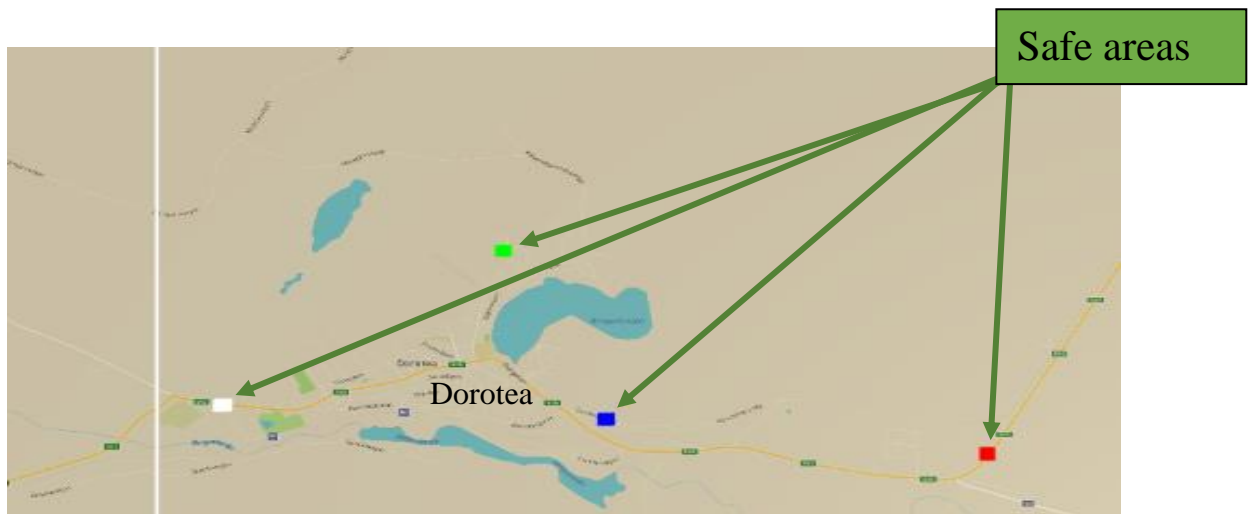
- The next step was to manage to apply the model (suitably configured) and to simulate conditions in a Swedish location of choice, Dorotea. For that, the roxborough.wui file was used. The file was opened in notepad++ and changes was made to the code in the file. Firstly, the location was changed by adding new coordinates – i.e., representing the location of Dorotea rather than in the US (*Figure a.1*). The coordinates were changed to match a point in the lower left corner of the map presented in WUI-NITY. Coordinates for the *safe areas* was also changed to match the new location – to reflect via refugee locations representative of the Swedish location (*Figure a.2*). “Goal 1” represents *safe area 1*. More safe areas can be added by copying the code, change ta a new location on the map, and change the number of the goal.

```
{
  "simName": "Dorotea",
  "deltaTime": 1.0,
  "maxSimTime": 864000.0,
  "stopWhenEvacuated": true,
  "numberOfRuns": 1,
  "lowerLeftLatLong": {
    "x": 64.236438,
    "y": 16.375513
  },
},
```

*Figure a.1: The coordinates in the red rectangle was changed in the roxborough.wui file, and the case was renamed. The coordinates presented represents the Dorotea-case.*

```
{
  "name": "Goal 1",
  "latLong": {
    "x": 64.255118,
    "y": 16.481501
  },
},
```

*Figure a.2: Four "safe areas", named "Goal 1 – Goal 4" was located on the road network of the test-cases. The coordinates were changed in notepad++ to match new locations for the Dorotea case.*



*Figure a.3: The map of Dorotea as presented by WUI-NITY after changing the coordinates to match that location. The colours on the map indicates the safe areas, locations of which the inhabitants will evacuate to.*

\*If the letter ‘a’ is in front of the figure number, it shows that the figure is presented in 8. Appendix.

6. In the roxborough.wui case, there was an example fire included (even though there was not a real fire in the evacuation drill). But it is worth stating that the included fire represents the type of fire that might be present in the Roxborough area, given the vegetation and landscape present there.

The fire is mapped according to roads, lakes etcetera. That means, if a lake is in the way of the fire, it won't continue across it. But if the same fire was used in the Dorotea.wui case, it did not take the local landscape into account. To clarify what that means: In order to run a simulation with respect to the local landscape, data has to be included about the landscape's configuration. A mapping processes needs to be done in order to specify where the lakes are located, what fuel types and fuel density is present in the area, as well as topographic data - elevation/slope/aspect of the terrain.

If you can do that and simulate a fire in those conditions, you will have a fire that takes the local landscape and vegetation into account. That was the main purpose of this work, to examine the applicability of WUI-NITY to the Swedish landscape. If only the location as described in *step 5* is changed, the fire won't take the local landscape and vegetation into account, the fire will not register what fuel types that is located in the area, if there is a slope or if there is a lake in the way of the fire. At this stage, the fire was ignored and not activated in WUI-NITY due to the above statement (more about the process of including the fire later). It can also be inactivated in notepad++ (.wui file) by changing:

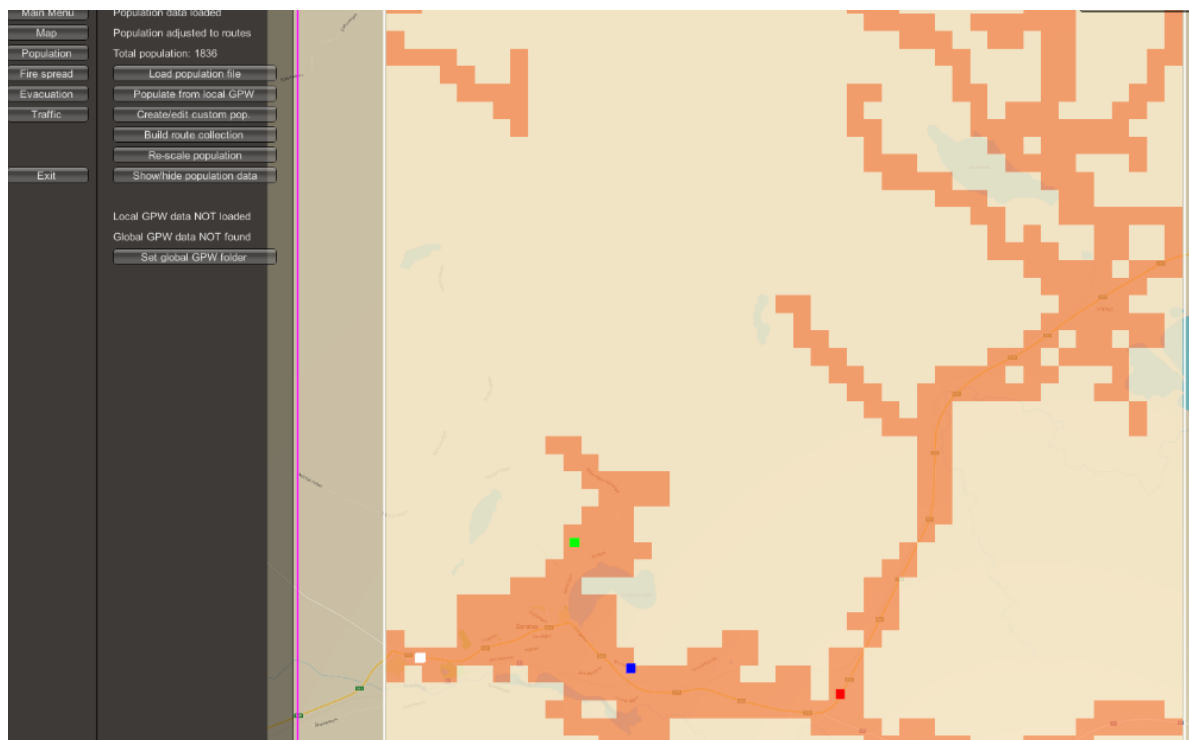
"runFireSim": true, (Default)

"runFireSim": false, (Changed)

7. When the coordinates were changed, a test-simulation was completed. The simulation did not work. The traffic did not start, and pedestrians evacuated in an unrealistic pattern that did not reflect the underlying Dorotea case. They moved in a cluster over lakes, in the woods, etc. That was due to issues in the mapping of the Roxborough conditions to the Dorotea case. Some of the Roxborough conditions was still affection the simulation in the Dorotea case, that had to be addressed in order to continue the process.

8. In the Roxborough case, there was an .osm file (OpenStreetMap) included. The .osm file is a mapping of the road-network. A .osm file with a mapping of the road network at the location of Dorotea was needed as in this case. First a .osm file for Europe was downloaded. Due to the file being too large, WUI-NITY couldn't handle all the data which resulted in errors. Also, it is assumed that the hardware of the computer used was a limitation as well. So, a more refined file was needed to accommodate the processing power of the systems, Sweden.osm was downloaded. But Sweden is also a large area with a lot of data regarding the road network. The Sweden.osm file was also needed to be filtered to just match the map of Dorotea and its surrounding area. Sweden.osm was included in WUI-NITY by clicking on *load osm file* under the *Traffics* menu. When the .osm file was included, the function *load router database* was used. By that, a filtering process started. The process took approximately 20 minutes. A file called *filtered-dorotea.osm* (with a suffix of .pbf) was received in the Dorotea-case folder. That file was then used successfully in the Dorotea.wui case. Note that the suffix of the .osm file has to be .pbf. I.e the filtered file should be named *filtered-casename.osm.pbf*
9. When the .osm file was successfully filtered and included. The GPW data had to be included as well. GPW stands for Gridded Population of the World, in other words, a mapping of where people live across the globe. It is a detailed mapping that shows the number of people in each household. By including the real population data together with the map and the .osm file, an evacuation of a community can be made. To load the population data into WUI-NITY, following steps was done: *population menu – populate from local GPW – choose the folder described in step (WUI-NITY root) – Load population data*. Now a .pop file will be created and added to the case-folder. The .pop should then be included into the simulation by clicking on *load population*. But when trying to run a simulation with both the .osm and .pop file included, an error message was received: 'Population file is not loaded'. It implied that the GPW data did not work. As stated in *step 2* above, GPW-data of the world was downloaded. And that should have worked for any case that is simulate across the globe. It seemed that the limitations of the computer being used prevented the inclusion of the GPW data into WUI-NITY (4 GB of RAM, IGPU, intel i3 processor – 2.4 GHz).
10. The population was included manually in WUI-NITY instead. There is a function called *create/edit custom pop* which enables the user to manually insert the number of people and the location of where those people live. By doing that, dorotea.pop (population file) was created in the Dorotea-case folder. The method is not as precise compared to using the GPW data. But in the process of testing WUI-NITY:s application, the exact number and location of the inhabitants is not important at this stage. The Dorotea.pop file created by the manually function was included in WUI-NITY. But that did not solve the error. The same error-messages popped up.

11. The mesh of the area of interest was changed from 10000 x 10000 to 1000 x 1000 just to test if the simulation could be completed with respect to lesser information. The area then simulated was reduced so that fewer calculations and information transfers was required. The problem was not solved by this. That implied that the problem with the .pop file was not due to restriction in the hardware of the computer. It can also be concluded that the error was not due to the software (WUI-NITY) requiring to be made more efficient. The error was not solved with the .pop file and another approached was then necessary.
  
12. Instead of focusing on the .pop file created manually, the .GPW error was once again addressed. As stated at *step 9 above*, the GPW data could not be used due to limitations of the computer that was used. A more powerful computer was then used instead (48 GB of RAM, EGPU, Intel i7 processor). That solved the error. A .pop could be created with the GPW-data available. The .pop file was included in WUI-NITY with the use of the less powerful computer specified at *step 9*. The population was then distributed correct according to the GPW data. In other means, the real-world data from 2015 (newer versions exists), collect by NASA (NASA & SEDAC, 2022) via GPW was included in the model (*Figure a.4*). The error is fixed. At the same time, a new version of WUI-NITY was received (version 0.1.1). Some errors regarding the inclusion of the GPW data was addressed.



*Figure a.4: Distribution of the population in the area around Dorotea. The darker orange colour indicates where the people are located.*

13. When the .osm and .pop files was included, a new attempt of starting a simulation was made. A new error message occurred that stated ‘object reference not set to an instance of an object’. After some research, it was found that the boundaries of the simulated area were outside the limit of the map (the purple line in *Figure a.4* was outside the map area). The mesh was then changed (the area of simulation) to 10000 x 9000. The purple line moved inside the map area solving the error message, the simulation started.



14. The traffic was simulated at this stage, in other words, you could see the cars moving on the map. The cars are represented by red dots moving on the road network. But after running the simulation for a while, 272/1803 of the people deciding to leave, did not leave the area causing the simulation not to end. This prevented output data being generated and a conclusion could be made - there is still some problems to solve with the case. The simulation could be ended manually by the bottom “end simulations”. By that, output data was generated. But the output data was as mentioned, faulty.

It is worth stating that it is expected that a small number of people will stay behind and not evacuate the area. But WUI-NITY simulates the number of people deciding to leave, and how long time it will take for those people to reach the Safe areas. When the simulations are completed, the number should thus be 0. WUI-NITY will also give you a number of those not deciding to leave. The data from this simulation are presented in *Section 4.4*.

15. Contact was made once again with the creator of WUI-NITY (Jonathan Wahlqvist) who discovered the following: Somewhere in the code there was a codeline that stated that the mesh should be  $x=y$ . And due to changing the mesh making  $x \neq y$  (from 10000 x 10000 to 10000 x 9000) a mismatch was created caused issues in the execution of the model. The code was updated and  $x!=y$ . A new version of WUI-NITY was received (version 0.1.2).
16. The error was fixed due to redefining the mesh according to *step 15*. The simulation did work. The number of people deciding to evacuate was the same, but everyone deciding to evacuate reached a safe area – making the simulations to complete. WUI-NITY also provided a number of people deciding not to leave,  $n = 60$ .  $60/1803 = 3,3 \%$  - a realistic number. Simulation was completed, but no output data was received. There were still some errors not generating the desired data. Jonathan was once again contacted.
17. When the simulations could run and complete with respect to the local road network and the population that is located in the area, the next step was to include the fire (at the same time, Jonathan worked with the error regarding no output data being generated). By including the fire, the case becomes specific to the Swedish landscape. That is due to the fire spreading with respect to the fuel type and topography in the area (*see step 6*). WUI-NITY includes the fire by adding a .lcp file (Landscape File, *Section 3.1.2.2*). A .lcp file contains different geo-spatial data as for example elevation, fuel type and fuel density.

18. In the US, there is a mapping of geo-spatial data that is called LANDFIRE (*Section 3.11*). LANDFIRE contains a complete fuel-mapping of the country. A similar mapping does not exist in Sweden nor Europe (not what could be found during this thesis study). And as described at *step 17* a new .lcp file was needed in order to simulate the fire at a Swedish location. To be able to create the .lcp file, a couple of programs needed to be downloaded and studied. Jonathan Wahlqvist recommended to use ArcGIS + ArcFuels toolbar to create the file.
- First, ArcGIS was downloaded.
  - Then ArcFuel was downloaded and integrated into ArcGIS. ArcFuel is a toolbar needed to create the .lcp file.
  - FVS (Fuel Vegetations Simulator) was also downloaded. FVS is a program that allows you to build your own fuel maps (.lcp file) from scratch. FVS is used in ArcGIS by the ArcFuel toolbar.
19. A file was missing (winsvs.exe) in the downloaded folder for FVS, that file was essential to run FVS. An email was sent to the creators of FVS as a request for the missing file.
20. At the same time, contact with Nikolaos Kalogeropoulos (*PhD in Fire Science, Imperial College, London*) was made. Nikolaos gave information about an alternative way of creating a .lcp file. For that, FlamMap 6 (*Section 3.3*) was downloaded with FARSITE (*Section 3.4*) included. FlamMap is a program that allows the user to create and simulate wildfires in a given area. The program can create a .lcp if the correct raster-data is used. FlamMap 6 needs following data to be able to create a .lcp file:
- Elevation
  - Slope
  - Aspect
  - Canopy Cover
  - Fuel model
  - Canopy data (optional)

21. An email from the creators of FVS was received with the missing file (winsvs.exe). An additional attempt with the first method was made, but now with the winsvs.exe file included. In the downloaded ArcFuels map, there was a test case included - the Mt. Emily case. The Mt. Emily case was used in the process of configuration before creating a .lcp file manually. But there were still issues with FVS. Some of the input data couldn't be loaded. It was also discovered that the .lcp file could be created by the ArcFuels toolbar by include raster images. But at this stage, the second method was examined further (FlamMap 6, *step 20*).
22. As the learning process of ArcGIS proceeded (with purpose of modifying raster images to fit FlamMap (and in a later stage, to test the .lcp function in ArcFuels)), Prometheus was downloaded with the purpose of investigate if an .lcp file could be created by that program as well. Prometheus (*Section 3.5*) is a program similar to FARSITE. But Prometheus uses the components of the CFFDRS as fire modelling tools (*see Section 3.5.1 for more information*), which is more suitable for Swedish landscape and vegetation. Prometheus also requires the following programs: C++, update Java, WindNinja and Redist 3.1.1. When downloading Prometheus, it was learned that the latest version of both java and Redist was needed. This versions were downloaded, but there was some bug in the installation wizard (to install Prometheus) that prohibited the installation to complete. Contact was made with the providers of Prometheus. The issue seemed to once again be the limitation of the computer hardware, *see step 9*.
23. At the same time, there were issues with ArcGIS. Access via the LTH GIS-server was denied, making ArcGIS unavailable. QGIS (*Section 3.6.1*) was installed instead. QGIS is a free open-source software and is similar to ArcGIS.
24. After learning the ropes of QGIS, Google Earth pro was downloaded. A raster image was created by downloading data from Google Earth pro and cropping it in the right size for the Dorotea case. The idea was to use Google Earth pro to retrieve data for elevation/aspect/slope. The image was included in FlamMap 6 with the purpose of testing the application of creating a .lcp file. When doing this, two error message occurred 'Error reading Landscape Header for GDAL data source' and 'GeoTIFF landscapes must contain at least 8 bands, this file only contains 4 bands'.

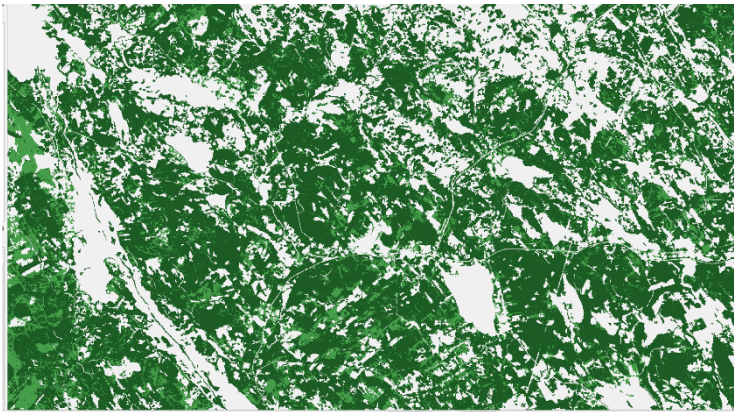
By downloading an image from Google earth pro, it was not sure what kind of data that was received, if any. Google Earth Pro might be useful in some way, but the idea of using that program for the elevation/aspect/slope data was discarded.

25. EFFIS (European Forest Fire Information System, *Section 3.8*) was also contacted with the request of geo-spatial data (raster data). They responded by email with information about raster data for canopy cover that could be downloaded by Copernicus. Data for *Tree cover density – Status map 2018 - Sweden* was downloaded. A image containing the area of Dorotea was selected amongst all the downloaded images, and was then saved for later modifications in QGIS and usages in FlamMap 6. In the downloaded folder, images with canopy data over the whole region of Sweden was retrieved. The right image had to be selected including the area of Dorotea, *Figure a.5, a.6*. By that following raster data was retrieved from one image:

- Forest Canopy Cover
- Forest Canopy Height
- Forest Canopy Base Height
- Forest Canopy Bulk Density

To download the map, following path was used:

<https://land.copernicus.eu/> – *Pan-European-High Resolution Layers – Forests – Tree Cover Density – Status Maps – Tree cover Density (year)*



*Figure a.5: Canopy cover data over a region of Sweden were Dorotea is located.*



*Figure a.6: A zoomed-in image over Dorotea, the Canopy Cover are presented in the green areas.*

26. EFFIS also provided a fuel map over Europe. The fuel map contains data about where different types of vegetations are located (*Figure a.7*). The difference in the grayscale indicates different fuel types. Each grayscale colour represents a number that is connected to a specific fuel type with specific burn characteristics. At this stage, following data has been retrieved from EFFIS:

- Fire Behavior Fuel Models
- Forest Canopy Cover
- Forest Canopy Height
- Forest Canopy Base Height
- Forest Canopy Bulk Density



*Figure a.7: Fuel map (fuel model) of Europe retrieved from EFFIS. The difference in the colour indicates different vegetation-types (fuels). A cropped image over the Dorotea area can be seen in figure a.12 below.*

27. In order to create an .lcp file, topographic data (elevation/aspect/slope) was still needed to be found. Google Earth pro was discarded as mentioned above (did not find a good way to make sure the data was good). Earth Engine was tested instead. Earth engine is a program provided by google. In Earth Engine you can extract raster data for elevation/aspect/slope with some simple codelines. Following code was used in earth engine with the purpose of exporting a raster file with the needed topographic data:

```
// A digital elevation model.
var dem = ee.Image('NASA/NASADEM_HGT/001').select('elevation');
// Calculate slope. Units are degrees, range is [0,90).
var slope = ee.Terrain.slope(dem);

// Calculate aspect. Units are degrees where 0=N, 90=E, 180=S, 270=W.
var aspect = ee.Terrain.aspect(dem);
// Display slope and aspect layers on the map.
Map.setCenter(16.245999, 64.156000, 11);
Map.addLayer(slope, {min: 0, max: 89.99}, 'Slope');
Map.addLayer(aspect, {min: 0, max: 359.99}, 'Aspect');

// Use the ee.Terrain.products function to calculate slope, aspect, and
// hillshade simultaneously. The output bands are appended to the input image.
// Hillshade is calculated based on illumination azimuth=270, elevation=45.
var terrain = ee.Terrain.products(dem);
print('ee.Terrain.products bands', terrain.bandNames());
Map.addLayer(terrain.select('hillshade'), {min: 0, max: 255}, 'Hillshade');

// Load a landsat image and select three bands.
var landsat = ee.Image('LANDSAT/LC08/C01/T1_TOA/LC08_123032_20140515')
.select(['B4', 'B3', 'B2']);
// Retrieve the projection information from a band of the original image. // Call getInfo() on the
projection to request a client-side object containing // the crs and transform information needed for
the client-side Export function. var projection = landsat.select('B2').projection().getInfo();
});
```

28. When the coordinates were entered for Dorotea, the map was situated in the middle of the Arabic Sea. The input of the coordinates is inverted in Earth Engine. It should be in the format (Long, Lat) and not (Lat, Long). For Dorotea, the coordinates were changed to (16.245999, 64.156000) instead of (64.156000, 16.245999), and the map was centred correctly. The next step was to export the data, new codelines were added:

```
// Create a geometry representing an export region.
var geometry = ee.Geometry.Rectangle([16.301179, 64.241270, 16.531128, 64.292162]);
// Export a cloud-optimized GeoTIFF.
Export.image.toDrive({
  image: landsat,
  description: 'imageToCOGeoTiffExample',
  crs: projection.crs,
  crsTransform: projection.transform,
  region: geometry,
  fileFormat: 'GeoTIFF',
  formatOptions: {
    cloudOptimized: true
  }
});
// Define a Geometry object.
var geometry = ee.Geometry({
  'type': 'Polygon',
  'coordinates':
    [[[16.313712, 64.247115],
     [16.310279, 64.313863],
     [16.523139, 64.313342],
     [16.526229, 64.253305]]]]
```

29. As *Figure a.8* shows, the landsat file (topographic data) that was generated in Earth Engine was not defined for the region of Sweden where Dorotea is located. Also, when running the code an error message occurred: 'Unable to export unbounded images (Error code: 3)'. That was due to the fact that Dorotea was not defined in the landsat file.

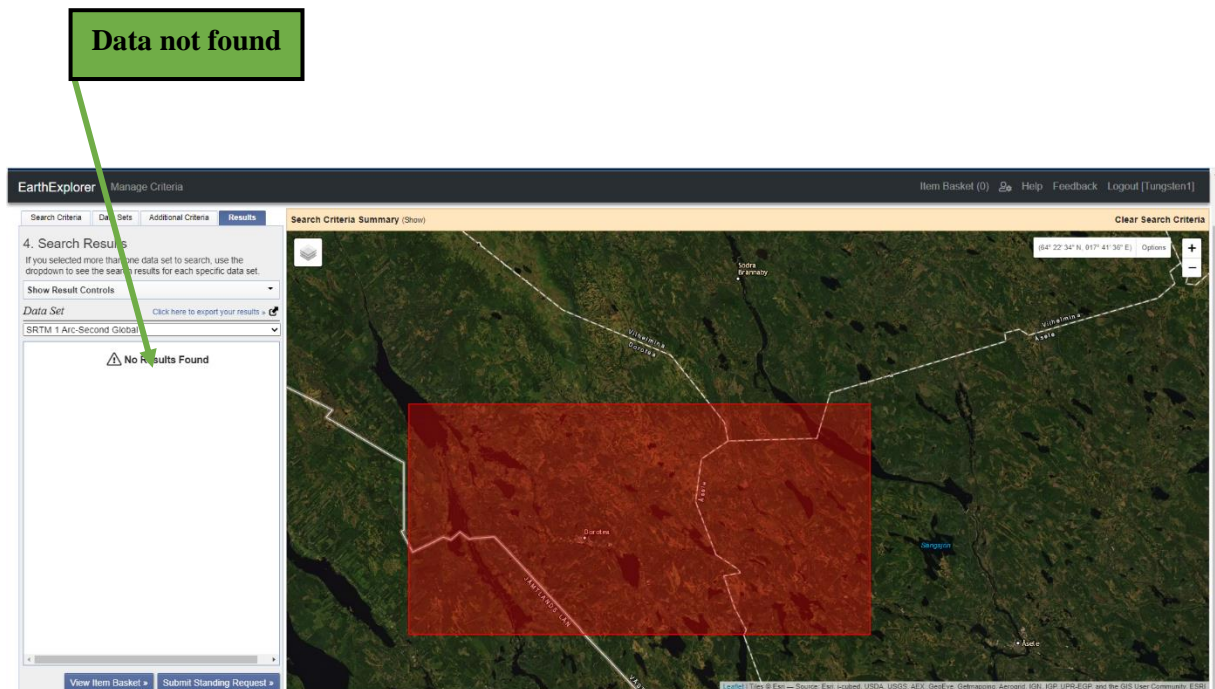


*Figure a.8: Loaded landsat data into Earth Engine. The area of Dorotea is not defined.*

30. Contact was made with Nikolaos once more and another option was provided for retrieving the topographic data. *Earth Explorer* (Section 3.7) was examined instead. Earth Explorer uses satellite images for the creation of raster data and is provided by NASA and USGS (United States Geological Survey). Nikolaos had not use Earth Explorer himself but stated that the data that was needed could be found by downloading the SRTM3 1-arcsecond geospatial data. SRTM3 1-arcsecond is global elevation data that is provided for free. To access the data, two different account was needed to be created. Both on <https://urs.earthdata.nasa.gov/profile> and <https://earthexplorer.usgs.gov/>.



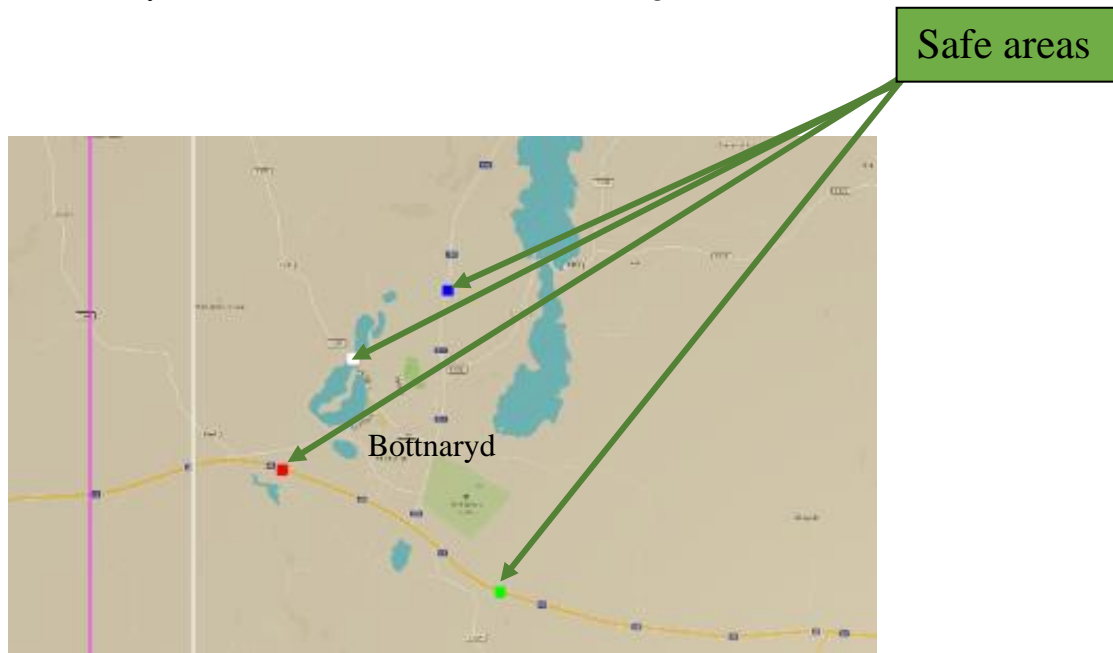
31. After creating the accounts, the SRTM3 1-arcsecond data was needed to be found. But it couldn't. So SRTM 1-arcsecond was used instead. The same problem popped up as before, there was no data to be found in the area of where Dorotea is located (*Figure a.9*).



*Figure a.9: SRTM 1-arcsecond data could not be found for Dorotea with the use of Earth Explorer.*

32. At this point some success had been made. But also, a lot of errors and data that couldn't be found. Elevation data for Dorotea was not defined either by Earth Engine nor Earth Explorer. A decision had to be made to either examine additional programs that might use other satellites to map the topographic data, or to change the Swedish location. Due to spending a lot of time trying to receive data for Dorotea that could not be found, the decision was made - a more southern location was selected that was defined in the area where elevation data could be found. Instead of Dorotea, *Bottnaryd* was chosen. Bottnaryd is also a good example of a small town surrounded by typical Swedish vegetation and landscape. Although, the forest is not as thick as the surroundings in Dorotea, Bottnaryd is also a good case to analyse further. Bottnaryd inhabits 807 persons (2020) and is surrounded mostly by pine and mixed-forest. Bottnaryd is located 25 kilometres west from a larger town called Jönköping. But before moving forward with Bottnaryd, a quick check was made to see if topographic data could be found. And yes, there was existing data in Earth Explorer that could be downloaded for the area of Bottnaryd.

33. Now the process had to start over almost from the beginning. But due to documenting the process, the change of location was done quickly enabling the work to continue – but with another case. Some of the steps done, was also beneficial for the Bottnaryd case (eg: downloading a mapbox token, the fuel map and Sweden.osm). First the coordinates were changed to match the location and relevant safe areas in the surroundings of Bottnaryd (*step 5, Figure a.1, a.2*). Then the .osm file was filtered to match the area (*step 8*). The population was distributed manually (*step 10*) and a .pop file was created. It did work this time, the GPW data was discarded at this step of the process (no need for a detailed mapping). Now the next step was once again to create a .lcp file. But as mentioned, the data was defined for the area of Bottnaryd. The new location is illustrated in *Figure a.10*.



*Figure a.10: The location and the safe-areas was changed to the small town of Bottnaryd.*

34. Topographic data (SRTM - 1arcsecond) was downloaded from Earth Explorer, completing the needed data for creating the .lcp file. The same data that was downloaded from Copernicus (EFFIS) at *step 25* could be used here as well, *Tree cover density – Status map 2018 - Sweden*. That was due to the images retrieved containing data for all of Sweden. The raster image containing the area of Bottnaryd was selected in the downloaded map instead. The fuel map, *step 26*, could be used as well. The received fuel map contains fuel data across the entire surface of Europe. At this point following raster data had been collected:

- Topographic (Elevation, Slope, Aspect)
- Fire Behavior Fuel Models
- Forest Canopy Cover
- Forest Canopy Height
- Forest Canopy Base Height
- Forest Canopy Bulk Density

35. And that is all the data that was needed. An attempt was made to create a .lcp file with FlamMap 6. But errors occurred due to the images not being in the same size. To solve the error, the raster images (three images containing the raster data above) needed to be cropped into the same size at the same location according to the same coordinates.
36. At this step, Jonathan had completed the task of addressing the problem with WUI-NITY not generating output data. A new version was provided (first version 0.1.3, and then 0.1.3b). The Dorotea case was not tested due to the process of the Bottnaryd case had progressed so far.
37. ArcGIS was first used for the process of cropping the images (at this stage access was again provided by Lund University). The Canopy Cover and the Fuel Model was able to be cropped at the same size and to the same location (Bottnaryd). The plan was to do the cropping by defining the same x max/min and y max/min coordinates. But it was discovered that the raster images were made in different coordinate systems. The Canopy Cover and Fuel Model was based on the same coordination system, called: ETRS 89-Extended. The topographic data was based on an unknown coordination system. An attempt was made to change the coordinate system for the topographic raster image to ETRS 89-Extended by using ArcGIS, but the attempt was not successful. The importance of using UTM coordinates was also discovered. Due to WUI-NITY using UTM, the images used must be in that format. Following systems could be used: WGS 84, ETRS 89 or SWEREF 99, preferably WGS84 but the others will do as well. It is important that all of the images are using the same system.

38. QGIS was tested instead. By using a function that allowed the user to crop an image by the boundaries of another image, the raster images were successfully cropped into the same size (Figures a.11, a.12, a.13).

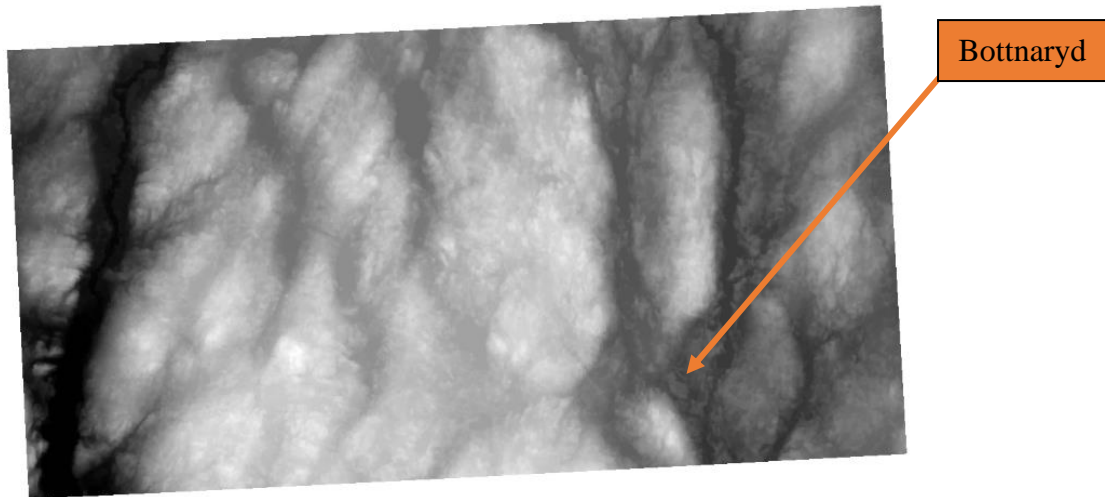


Figure a.11: Topographic data retrieved from Earth Explorer. The raster image is cropped to match the location of Bottnaryd. Even though the image is not straight, FlamMap 6 accepted it (it was later discovered that the skewness of the image was due to issues with the coordinate system used)

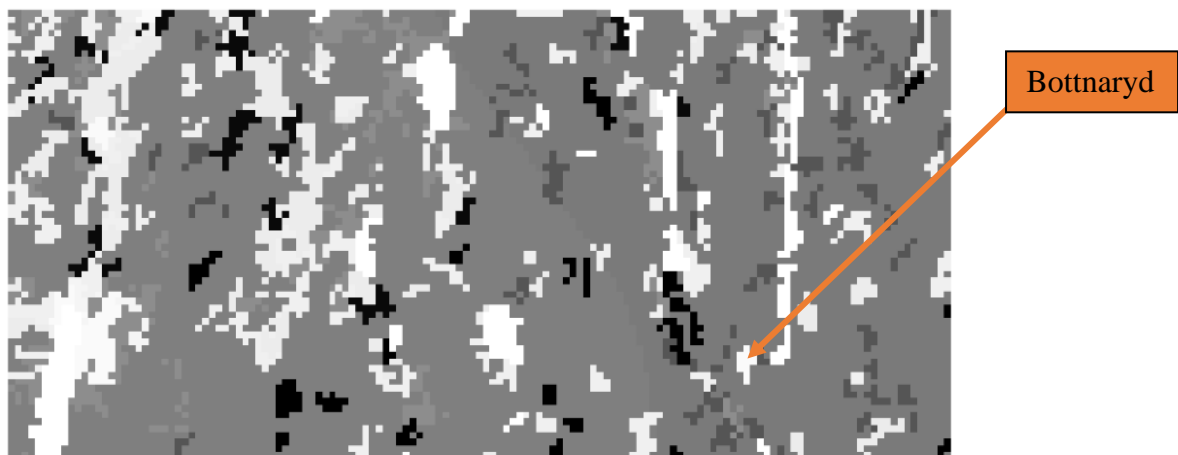


Figure a.12: Fuel model data retrieved from EFFIS. The image is cropped from the fuel map of Europe (figure a.7) to match the location of Bottnaryd.

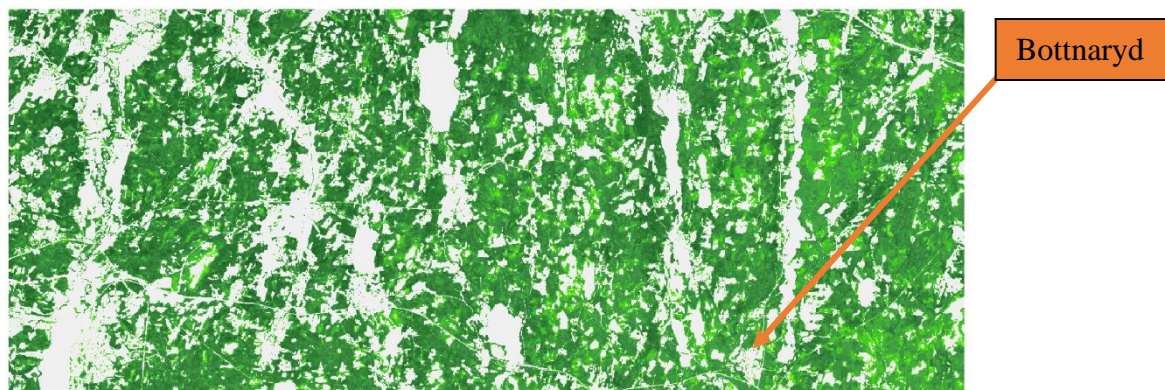
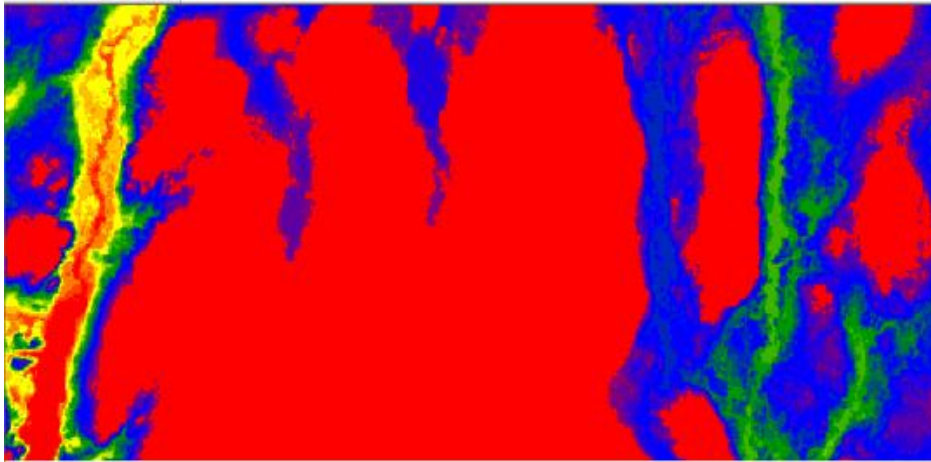


Figure a.13: Canopy Cover data retrieved from Copernicus (EFFIS). The file downloaded was named "Tree cover density" - status map 2018 - Sweden. The image is cropped to match the location of Bottnaryd.

39. The cropped images were once again used for the creation of the .lcp file. FlamMap 6 accepted the three raster images containing the needed raster data. A .lcp file was successfully created with the following steps:

- Open FlamMap
- Click on: Landscape
- Click on: Create Landscape file
- Insert the geo-spatial data under “required themes”
- Click on “save as”
- Save the file as a .lcp file

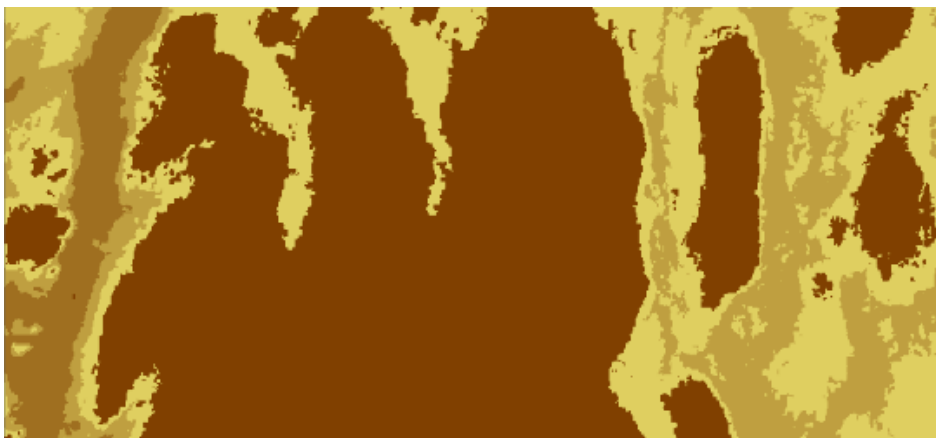
40. The .lcp file was then opened successfully in FlamMap 6. The raster data was present as shown in *Figures a.14 - a.18*.



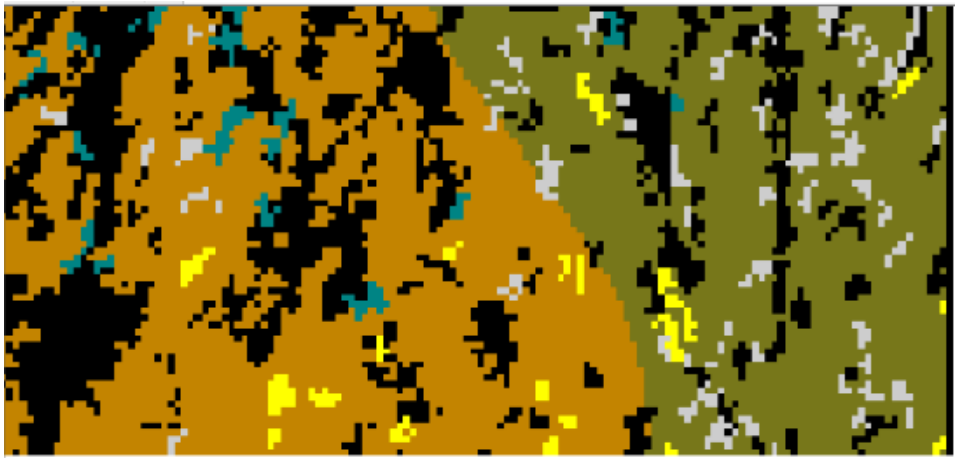
*Figure a.14: Elevation data as presented by FlamMap 6*



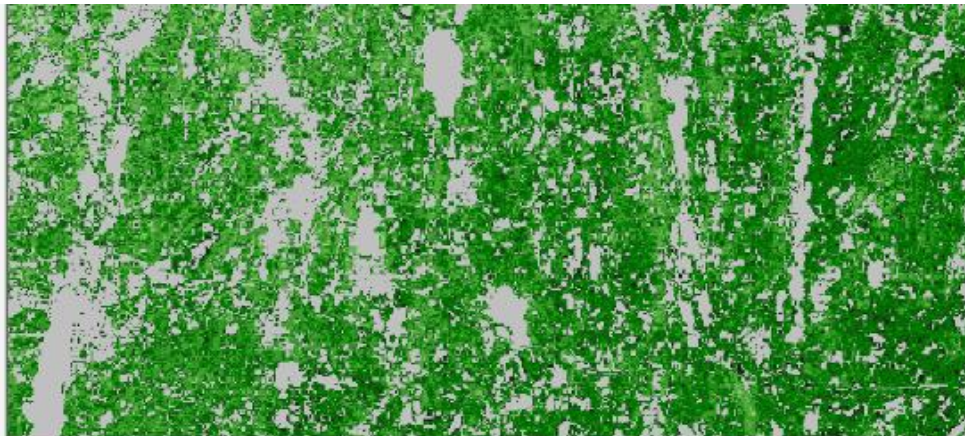
*Figure a.15: Slope data as presented by FlamMap 6.*



*Figure a.16: Aspect data as presented by FlamMap 6.*



*Figure a.17: Fuel data as presented by FlamMap 6.*



*Figure a.18: Canopy cover as presented by FlamMap 6.*

41. When the Landscape file was opened in FlamMap 6. The next step was to create a wildfire in the environment next to Bottnaryd. To do this a function called 'new FARSITE run' was used. The data required was:

- Weather inputs
  - Fuel Moisture File
  - Fuel Model File
  - Wind (speed and direction)
- Weather stream and burn periods
- Model settings
- Outputs – Chosen by the user
  - Arrival time
  - Flame length
  - Rate of Spread
  - Fire line intensity
  - Spread Direction
  - Heat per unit area
  - Crown fire activity
  - Reaction intensity
  - Ignition grid
  - Perimeters
  - Spot fire locations
  - Spot fire list
  - Wind vectors

42. The data required of FlamMap 6 in the process of creating the fire could be defined, all except the Flame Model File (.FMD). The program requires an existing .FMD file which is missing. Contact was made with the creators of FlamMap 6, but they could not provide additional help. A new approach had to be taken.

43. Instead of creating the characteristics of the fire by the help of FlamMap 6, the .lcp file was inserted in WUI-NITY with the idea of using the existing fire from the Roxborough case, at the place of Bottnaryd. In other words, using the landscape data for Sweden, but the characteristics of the fire from the Roxborough case. The reason why the Roxborough fire can be used is that right now, it is not important exactly how the fire behaves – the main thing is that the fire take the local landscape and vegetation into account.

But when the newly created .lcp file was opened in WUI-NITY. A couple of problems was discovered. Firstly, the .lcp file did not match the underlying map of WUI-NITY (the map of Bottnaryd). The resolution of the .lcp file was too rough (*Figure a.19*).



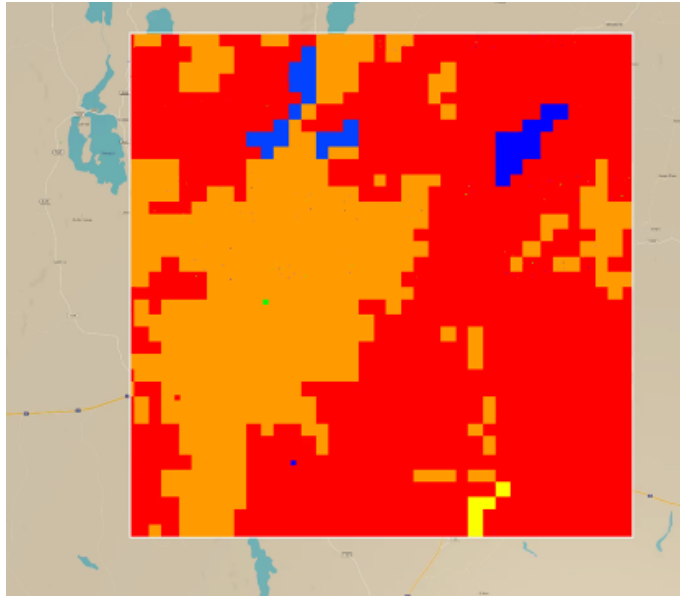
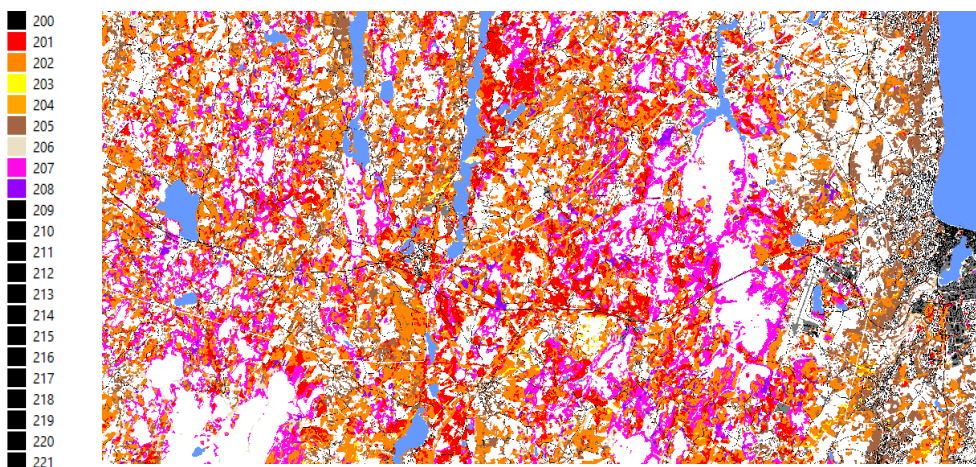


Figure a.19: .lcp-file shown in WUI-NITY with the underlying map showing. A conclusion can be made: The LCP-file has a rougher grid resolution and do not match the underlying map.

44. At the same time, Jonathan provided a new version of WUI-NITY, version 0.15. Version 0.15 was almost the same as the previous one. The ability to simulate visible smoke has been added and some bugs fixed. The biggest change was that the .wui file and the associated input files had been modified. A lot of data from the .wui file had been lifted out and placed in separate files. It meant that new files had been created that the .wui file referred to (less data in the .wui file, more data in separate files). Example on new files created: Weather (.wnd), wind (.wnd), Safe Areas (.ed), fuel moisture (.fmc) and fuel file (.fuel).
45. Another problem with the .lcp file used in WUI-NITY was shown when examining the fuel file and the fuel map. The example.fuel file that was provided with version 0.15 consisted of code and data for Andersons 13 fuel models (*Appendix D.1*). But the .lcp file referred to the fuel types 1, 9, 91, 99, 122, 144. The numbers above 13 referred to Scott & Burgan's fuel models (*Appendix D.2*) instead of Andersons 13 fuel models. The numbers referring to Scott & Burgan's fuel models had to be inserted in the .fuel file manually. And also, the characteristics of the fuel types presented had to be written in the code. The fuel map can either be opened in FlamMap, ArcGIS or QGIS (or other similar programs). When opened, the colours and numbers will show. To interpret the properties of the different fuel types, one or a couple of fuel models are required.
- 1-13 Andersons original 13 (*Appendix D.1*)
  - 91-204 Scott and Burgan (*Appendix D.2*)
  - 201-244 MSB's Fire fuel mapping – classification. (*Appendix D.3*)

When the fuel types and attributes were identified, the .fuel file was opened and changes were made regarding for example the heat of combustion ( $\Delta H^\circ_c$ ), flame length and fuel moisture. *Appendix B.2* shows how the .fuel file was constructed. Note that some of the fuel types was set to default. In a more detailed process, those would've been set to match the specific fuel type in order to simulate a fire as realistic as possible.

46. A further analysis of the mismatch of the .lcp file to the map of Bottnaryd in WUI-NITY was made in order to troubleshoot the problem. It was discovered that the resolution of the grid was set to 58 x 58 meters. That explained the problem shown in *Figure a.19*. A conclusion was made that the fuel map received from EFFIS was too rough. To use it, modifications had to be made in a GIS program. It was also discovered that the file downloaded from Earth Explorer (*Figure a.11*) did not contain any data for aspect and slope, only elevation data. That explains why the *Figures a.14, a.15 and a.16* look almost the same, the images only contains elevation data. During the analysis, an additional finding was that the coordinate systems of the elevation data did not match the fuel map (*Figure a.12*) nor the map containing data about the canopy cover (*Figure a.13*). That was the reason why *Figure a.11* was not straight. Due to all these errors, it is unclear how a .lcp could be created in the first place using FlamMap 6. Nevertheless, the errors had to be fixed and a new attempt on creating a faultfree .lcp file had to be made.
  
47. To fix the problem with the resolution of the fuel map, another fuel map was used instead of the one retrieved from EFFIS. MSB's "Brandbränslekartering" (Fire fuel mapping) was downloaded for the area of Bottnaryd (*Figure a.20*). MSB's fire fuel mapping consist of a detailed map over Sweden with different fuel types shown in different colours. Each colour is connected to a number. And that number specifies the attributes of the vegetation type (*Appendix D.3*). The numbers 201-244 is used by MSB's fire fuel mapping. The good part about that fuel model is that the resolution is set to 10 x 10 meters by default, the same resolution that WUI-NITY requires. But the elevation data retrieved from Earth Explorer and the canopy cover retrieved from EFFIS did not match the resolution of 10 x 10 meters. That had to be addressed.



*Figure a.20: Fuel data retrieved from MSB's fire fuel mapping. The bar to the left indicates which fuel type that is present in the area.*

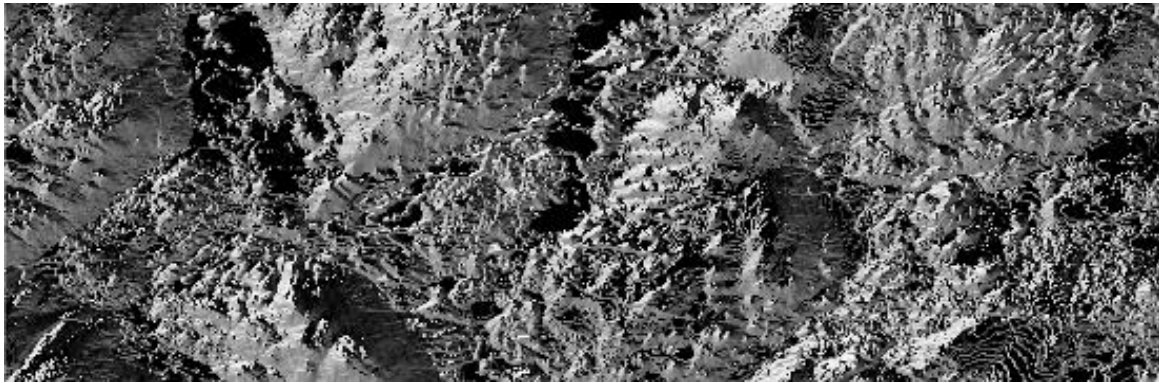
48. A GIS-coordinator named Henrik Lundqvist from the County administrative board of Jönköping was contacted. Henrik proved an elevation map with the resolution of 10 x 10 meter over the area of Bottnaryd. But the map retrieved from Henrik did not contain any data regarding aspect and slope. By the help of Henrik's knowledge and experience in GIS programs, both the aspect and slope data were created by using a function called *aspect-slope function* in ArcGIS (Figure a.21, a.22, a.23). More can be read about the function from ESRI, 2022a.

Henrik also provided help to modify the fuel density file to match the resolution of 10 x 10 meters. This was done by using the *interpolation method* in ArcGIS. More can be read about the function from ESRI, 2022b.

49. It was then crucial to make sure that the coordinate systems for the different raster images matched. The fire fuel mapping from MSB was set to the coordinate system SWEREF99 by default, that was also the case for the file retrieved from the GIS-coordinator Henrik. WUINITY prefers a coordinate system called WGS84. Both SWEREF99 and WGS84 are variations of the UTM coordinate system. According to the land surveyor of Sweden WGS84 and SWEREF99 differs by 0.7 - 0.8 meters (Lantmäteriet, 2022). If images with both SWEREF99 and WGS84 is used, the images grid resolution will not match perfectly. When creating a .lcp file, the images will have to align on top of each other with the same size, the same coordinate system, and the same grid resolution.

The fuel density file (canopy cover) was set to WGS84 as default. MSB's fuel mapping and the elevation, slope and aspect raster images was set to SWEREF99 and had to be changed to WGS84. This was done by ArcGIS. More can be read about the function from ESRI, 2022c.

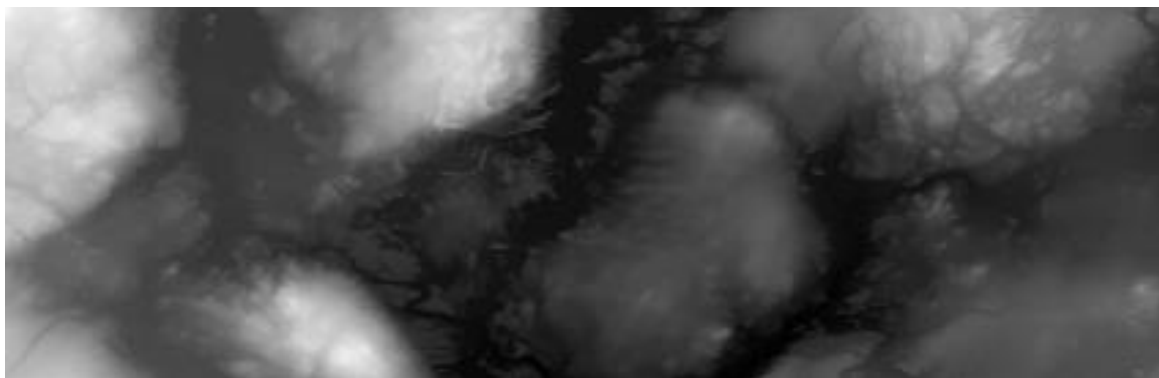
As a result, when changing the coordination system to WGS84 for all the images, they align perfectly on each other with matching grid resolution. No skewedness was shown.



*Figure a.21: Aspect data over Bottnaryd and its surroundings.*



*Figure a.22: Slope data over Bottnaryd and its surroundings*



*Figure a.23 : Elevation data over the area of Bottnaryd and its surroundings*

50. The images were inserted in ArcGIS with ArcFuels installed as a toolbar. The aim was to create a new .lcp file that could be used in WUI-NITY. But when the images (containing all the raster data) were inserted into ArcFuels an error message popped up: 'Cell size could not be determined'. The reason behind the error message could not be found. The images had matching coordinate systems, the same cell size and grid resolution. All the files was set to 10 x 10 meters.

An attempt with FlamMap was also made, without success. An error message was presented there as well stating 'Error, incorrect cell size field. Expected 0.000347, found 0.000347'.

51. The raster images used had been modified into the right size and coordinate system, and should be good to use in either ArcFuels or FlamMap to create the .lcp. It was then necessary to troubleshoot. First, the MSB fire fuel mapping was studied in order to make sure that the grid resolution was set to 10 x 10 meters. Metria, 2016 stated that it should be 10 x 10 meters. That was also confirmed by opening the map in GIS. It is assumed that the error received was due to the modifications done in GIS in some step/steps earlier. Somewhere along the way, a handling error could've been made which causing problems with the grid resolution in some or one of the images. That was examined thoroughly during this step, but the error could not be found. If the author of this thesis had better knowledge and experience in GIS, it is likely that the problem would have been solved.

Regardless, this process has progressed so far that the only thing left is to make sure to modify the data so that ArcGIS + Arcfuels or FlamMap will accept it. When the .lcp file is created it should be possible to carry out simulations in WUI-NITY at the location of Bottnaryd.

52. Contact was made with Steve Gwynne (*Industrial Professor of evacuation and pedestrian dynamics, Supervisor of this thesis*) about the problem. Steve sent this thesis to his colleagues, developers of WUI-NITY. Peter Thomson, *Executive Advisor – Movement Strategies*, took part of the content in this thesis during his process of developing WUI-NITY's new user GUI. Peter sent over some questions which the author of this thesis answered (*Appendix G*). In conclusion, Peter used the content of this thesis to develop the new user interface for the next version of WUI-NITY.

Vai Saran, *Graduate Advisor, Movements Strategies*, also reached out after learning the content of this thesis. Vai used the *4.1 Application protocol* with the aim of applying WUI-NITY to a location in the UK, Marsden Moor. During that process, Vai sent over some questions (*Appendix G*). As this thesis has discovered, Vai also experienced that the trickiest part of the application was to create the .lcp file. Therefore, the content of the questions was mostly regarding that process. The questions were answered, and a while later, Vai got in touch and informed that the GIS problem was solved. A .lcp file was successfully created and used by WUI-NITY to run simulations in Marsden Moor, UK.

Instead of using ArcGIS to modify the images (aspect, slope, elevation), Vai used QGIS3 (with some help of the author of this thesis). To modify the topographic raster images Vai went through the following steps:

- Use *4.1 application protocol* to set up the program and obtain elevation, canopy, and fuel file.
- Make sure any base map used is set to EPSG:4326 WGS84.
- Create and save slope and aspect file from the elevation file by the use of QGIS3, use the tools in Raster -> Analysis.
- Draw a shapefile around your target area.
- Geoprocessing Tools -> use the shapefile to 'Clip' the elevation file to create a 'Clipped Extent' layer.
- Set all raster layers to the same properties: use 'Save as' to change projection, change resolution and clip it to the 'clipped extent' layer
  - Note about resolution:
    - If the units are in meters, set the resolution to 10x10m.
    - If the units are in decimal degrees, set the units to 0.00009093 degrees.

53. If the process described by Vai in *step 52* is compared with the one done by ArcGIS. A conclusion can be made that the processes is very similar (although Vai used QGIS and is more experience with working in GIS). It enhances the hypothesis that a handling error was the factor behind the error messages received trying to create a .lcp file after modifying the images with ArcGIS.

Due to a limitation in time, it was not possible to start the process over with the modification of the topographical images for the Bottnaryd case, but with QGIS instead of ArcGIS. But the United Kingdom and Sweden have similar landscape. Both Sweden and the UK are using the CFFDRS as the wildfire prediction tool. If WUI-NITY can be applied in the UK by using the *4.1 application protocol* of this thesis, then a conclusion can be made - WUI-NITY is applicable to the Swedish landscape. When the .lcp file is created for a case in Sweden it should be possible to carry out simulations in WUI-NITY. A decision is thus made to end the process to answer the following question:

*Is WUI-NITY applicable to the Swedish landscape?*

Yes - The program itself can be used to run simulations in the Swedish landscape. But many uncertainties and gaps have been discovered during this process of application. If those gaps and uncertainties are not managed, it is uncertain whether the data generated by WUI-NITY is useful. It is possible that the uncertainties are too great for the data to be reliable. *Section 4.2* describes the gaps discovered. *Section 5.2 and 5.3* discuss those gaps as well as uncertainties about the application and the model itself. If the gaps and uncertainties are managed, it is likely that that the data generated by WUI-NITY at a Swedish location becomes useful.

The data from *Appendix A. Documentation of the process* was used to create the *4.1 Application protocol*, which is deemed to be the most valuable result of this thesis. *Section 4.2 and 4.3* is also created with result generated from this appendix.

## Appendix B – WUI-NITY code

The codelines below was used for the Bottnaryd-case. Code from some of the files are not included, that is due to the files being too large to be open by Notepad++.

The following files could not be opened by Notepad++:

.egs, .gfi, .lcp, .rc, .routerdb, .pop, .osm, .gpw.

### Appendix B.1 The .wui file

```
"simName": "bott",  
  "deltaTime": 1.0,  
  "maxSimTime": 864000.0,  
  "stopWhenEvacuated": true,  
  "numberOfRuns": 1,  
  "stopAfterConverging": true,  
  "lowerLeftLatLong": {  
    "x": 57.74615,  
    "y": 13.794459  
  },  
  "size": {  
    "x": 9000.0,  
    "y": 9000.0  
  },  
  "zoomLevel": 13,  
  "runEvacSim": true,  
  "runTrafficSim": true,  
  "runFireSim": true,  
  "runSmokeSim": true,  
  "evac": {  
    "routeCellSize": 200.0,  
    "allowMoreThanOneCar": true,  
    "maxCars": 2,  
    "maxCarsChance": 0.30000001192092898,
```

```

"minHouseholdSize": 1,
"maxHouseholdSize": 5,
"walkingDistanceModifier": 1.0,
"walkingSpeedMinMax": {
  "x": 0.699999988079071,
  "y": 1.0
},
"walkingSpeedModifier": 1.0,
"evacuationOrderStart": 420.0,
"responseCurveFiles": [
  "Observed_average",
  "Reported_average"
],
"blockGoalEvents": [
  {
    "startTime": 3.4028234663852887e38,
    "goalIndex": 0
  }
],
"evacGroupFiles": [
  "group1",
  "group2",
  "group3"
]
},
"traffic": {
  "osmFile": "C:\\Users\\jovlu\\WUNITY\\0.15\\Bott\\filtered_Bottnaryd.osm.pbf",
  "osmBorderSize": 1000.0,
  "evacuationGoalFiles": [
    "goalE",

```



```
"goalR",
"goalF"
],
"routeChoice": 3,
"stallSpeed": 1.0,
"backGroundDensityMinMax": {
  "x": 0.0,
  "y": 0.0
},
"visibilityAffectsSpeed": false,
"opticalDensityFile": "",
"opticalDensity": 0.05000000074505806,
"roadTypesFile": "default",
"saveInterval": 600.0,
"trafficAccidents": [
  {
    "startTime": 3.4028234663852887e38,
    "endTime": 3.4028234663852887e38,
    "isActive": false
  }
],
"reverseLanes": [
  {
    "startTime": 3.4028234663852887e38,
    "endTime": 3.4028234663852887e38,
    "isActive": false
  }
],
"trafficInjections": [
  {
```

```
"cars": 1,
"latLong": {
  "x": 0.0,
  "y": 0.0
},
"desiredGoal": {
  "name": "New goal",
  "latLong": {
    "x": 0.0,
    "y": 0.0
  },
  "color": {
    "r": 1.0,
    "g": 1.0,
    "b": 1.0,
    "a": 1.0
  },
  "blocked": false,
  "maxFlow": 3600.0,
  "goalType": 1,
  "maxCars": -1,
  "maxPeople": -1
},
"pickGoalFromMap": false,
"timeFlow": [
  {
    "x": 0.0,
    "y": 0.0
  },
  {
```

```

        "x": 0.0,
        "y": 0.0
    }
]
}
],
"trafficProbes": [
    {
        "nodeID": 0
    }
]
},
"population": {
    "gpwDataFolder": "C:\\Users\\jovlu\\WUNITY\\0.15\\Bott\\gpw-v4-population-density-
rev10_2015_30_sec_asc",
    "localGPWFile": "C:\\Users\\jovlu\\WUNITY\\0.15\\Bott\\bott.gpw",
    "populationFile": "C:\\Users\\jovlu\\WUNITY\\0.15\\Bott\\Bottnaryd.pop"
},
"itinero": {},
"farsite": {
    "outputPrefix": "bott"
},
"visuals": {
    "drawRoads": false
},
"fire": {
    "lcpFile": "C:\\Users\\jovlu\\WUNITY\\0.15\\Bott\\Bott.lcp",
    "fuelModelsFile": "C:\\Users\\jovlu\\WUNITY\\0.15\\Bott\\default.fuel",
    "initialFuelMoistureFile": "default",
    "weatherFile": "example",
    "windFile": "example_seconds",

```

```

    "ignitionPointsFile": "example",
    "spreadMode": 1,
    "windMultiplier": 1.0,
    "useRandomIgnitionMap": false,
    "randomIgnitionPoints": 0,
    "useInitialIgnitionMap": false
  }
}

```

## Appendix B.2 The .fuel file

fuelModelNumber, code, name, fuelBedDepth, moistureOfExtinctionDead, heatOfCombustionDead, heatOfCombustionLive, fuelLoadOneHour, fuelLoadTenHour, fuelLoadHundredHour, fuelLoadliveHerbaceous, fuelLoadliveWoody, savrOneHour, savrLiveHerbaceous, savrLiveWoody, isDynamic, isReserved

```

1, "FM1", "Short grass [1]", 1.0, 0.12, 8000, 8000, 0.034, 0, 0, 0, 0, 3500, 1500, 1500
2, "FM2", "Timber grass and understory [2]", 1.0, 0.15, 8000, 8000, 0.092, 0.046, 0.023, 0.023, 0, 3000, 1500, 1500, false, true
3, "FM3", "Tall grass [3]", 2.5, 0.25, 8000, 8000, 0.138, 0, 0, 0, 0, 1500, 1500, 1500, false, true
4, "FM4", "Chaparral [4]", 6.0, 0.2, 8000, 8000, 0.230, 0.184, 0.092, 0, 0.230, 2000, 1500, 1500, false, true
5, "FM5", "Brush [5]", 2.0, 0.20, 8000, 8000, 0.046, 0.023, 0, 0, 0.092, 2000, 1500, 1500, false, true
6, "FM6", "Dormant brush, hardwood slash [6]", 2.5, 0.25, 8000, 8000, 0.069, 0.115, 0.092, 0, 0, 1750, 1500, 1500, false, true
7, "FM7", "Southern rough [7]", 2.5, 0.40, 8000, 8000, 0.052, 0.086, 0.069, 0, 0.017, 1750, 1500, 1500, false, true
8, "FM8", "Short needle litter [8]", 0.2, 0.3, 8000, 8000, 0.069, 0.046, 0.115, 0, 0, 2000, 1500, 1500, false, true
9, "FM9", "Long needle or hardwood litter [9]", 0.2, 0.25, 8000, 8000, 0.134, 0.019, 0.007, 0, 0, 2500, 1500, 1500, false, true
10, "FM10", "Timber litter & understory [10]", 1.0, 0.25, 8000, 8000, 0.138, 0.092, 0.230, 0, 0.092, 2000, 1500, 1500, false, true
11, "FM11", "Light logging slash [11]", 1.0, 0.15, 8000, 8000, 0.069, 0.207, 0.253, 0, 0, 1500, 1500, 1500, false, true
12, "FM12", "Medium logging slash [12]", 2.3, 0.20, 8000, 8000, 0.184, 0.644, 0.759, 0, 0, 1500, 1500, 1500, false, true

```

13, "FM13", "Heavy logging slash [13]", 3.0, 0.25, 8000, 8000, 0.322, 1.058, 1.288, 0, 0, 1500, 1500, 1500, false, true

85, "XX85", "Unknown [85]", 3.0, 0.25, 8000, 8000, 0.322, 1.058, 1.288, 0, 0, 1500, 1500, 1500, false, true

91, "NB1", "Urban/developed [91]", 0.0, 0.0, 0, 0, 0.0, 0.0, 0.0, 0, 0, 0, 0, 0, false, true

99, "NB4", "Bare ground [99]", 0.0, 0.0, 0, 0, 0.0, 0.0, 0.0, 0, 0, 0, 0, 0, false, true

122, "GS2", "Moderate Load, Dry Climate Grass-Shrub [122]", 3.0, 0.25, 8000, 8000, 0.322, 1.058, 1.288, 0, 0, 1500, 1500, 1500, false, true

127, "ZZ7", "Unknown2 [127]", 3.0, 0.25, 8000, 8000, 0.322, 1.058, 1.288, 0, 0, 1500, 1500, 1500, false, true

141, "SH1", "Low Load, Dry Climate Shrub (Dynamic) [141]", 3.0, 0.25, 8000, 8000, 0.322, 1.058, 1.288, 0, 0, 1500, 1500, 1500, false, true

### Appendix B.3 The .gpw file

57.74615 13.794459 9000 9000

10800

10200

-1.0231815394945E-11

-3.4106051316485E-12

0.0083333333333329

-9999

5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504  
5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504  
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5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504  
5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504  
8.925671 14.20233 5.599504 5.600221 8.635514 13.90868 16.31564 20.19876 5.599504 5.599504  
5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504 5.599504

19 11

57.7416666666603 13.791666666657

-165.8869322774 -499.082176640131

9406.2662674906 10204.2824074069

650

## Appendix B.4 The .fmc file

The codelines below is by default:

FuelMod, 1Hour, 10Hour, 100Hour, LiveH, LiveW

1, 6.0, 7.0, 8.0, 60.0, 90.0

2, 6.0, 7.0, 8.0, 60.0, 90.0

3, 6.0, 7.0, 8.0, 60.0, 90.0

4, 6.0, 7.0, 8.0, 60.0, 90.0

5, 6.0, 7.0, 8.0, 60.0, 90.0

6, 6.0, 7.0, 8.0, 60.0, 90.0

7, 6.0, 7.0, 8.0, 60.0, 90.0

8, 6.0, 7.0, 8.0, 60.0, 90.0

9, 6.0, 7.0, 8.0, 60.0, 90.0

10, 6.0, 7.0, 8.0, 60.0, 90.0

11, 6.0, 7.0, 8.0, 60.0, 90.0

12, 6.0, 7.0, 8.0, 60.0, 90.0

13, 6.0, 7.0, 8.0, 60.0, 90.0

## Appendix B.5 The .ign file

Latitude, Longitude, IgnitionTime

57.774425, 13.872016, 0.0

## Appendix B.6 The .roads file

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    {
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      "maxCapacity": 75.0,
      "canBeReversed": true
    },
    {
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      "maxCapacity": 75.0,
      "canBeReversed": true
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"maxCapacity": 75.0,
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},
{
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  "lanes": 1,
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},
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},
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},
{
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{
```

```
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},
{
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},
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"canBeReversed": false
},
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},
{
"name": "living_street",
"speedLimit": 5.0,
```

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},  
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"canBeReversed": false  
},  
{  
"name": "shuttle_train",  
"speedLimit": 10.0,  
"lanes": 1,  
"maxCapacity": 50.0,  
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},  
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"maxCapacity": 50.0,
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  },
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    "canBeReversed": false
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  {
    "name": "custom2",
    "speedLimit": 40.0,
    "lanes": 1,
    "maxCapacity": 50.0,
    "canBeReversed": false
  },
  {
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    "speedLimit": 40.0,
    "lanes": 1,
    "maxCapacity": 50.0,
    "canBeReversed": false
  },
  {
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    "speedLimit": 40.0,
    "lanes": 1,
    "maxCapacity": 50.0,
    "canBeReversed": false
  },
}
```

```
{
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  "maxCapacity": 50.0,
  "canBeReversed": false
}
]
}
```

### Appendix B.7 The .wtr file

Month, Day, Precip, Hour1, Hour2, Temp1, Temp2, Humid1, Humid2, Elevation

7, 15, 0, 4, 16, 13, 33, 10, 10, 1803

7, 16, 25, 4, 16, 10, 30, 18, 15, 1803

### Appendix B.8 The .wnd file

Seconds, Speed, Direction, CloudCover

0, 10, 0, 0

3600, 2, 180, 0

7200, 10, 360, 0

### Appendix B.9 The .ed file (Goal E)

Name: "Goal\_E"

Latitude: 57.768522

Longitude: 13.808666

Goal type: "Exit"

Max flow: 3600.0

Car capacity: -1

People capacity: -1

Initially blocked: "false"

Color: 1.0, 0.0, 0.0

### Appendix B.10 The .eg file (Group 1)

Name: "Group\_1"

Response curves: "Observed\_average"

Response curve probabilities: 1.0

Destinations: "Goal\_E", "Goal\_R", "Goal\_F"

Destination probabilities: 0.4, 0.7, 1.0

Color: 1.0, 1.0, 0.0

### Appendix B.11 the .rsp file

Time, Cumulative probability

0, 0

300, 0.037

1080, 0.67

1860, 0.76

1980, 0.85

6300, 1

### Appendix B.12 the .odr file

time, optical density [1/m]

0.0, 0.0

1200.0, 0.05

3600.0, 0.1

7200.0, 0.2

10800.0, 0.0



## Appendix C – Case Study

Below is a presentation of a case study, the Västmanland fire (also named – ‘the sala fire’). The case is discussed at *Section 5.2* together with generated outputdata from WUI-NITY for the Bottnaryd case.

### Appendix C.1 Västmanland fire (Sweden), 2014

The 2014 Västmanland wildfire was a wildfire that started during the afternoon of the 31<sup>st</sup> of July 2014 on the border between Sala Municipality and Surahammar Municipality in Västmanland, Sweden. It was Sweden’s largest wildfire in 40 years. It is suspected that the fire was start by a vehicle near a wildfire prone region which was exposed to severe weather in the summer season. The information about the case is taken from Ronchi et al., 2021. In other words, Ronchi et al., 2021 is the author of the information below.

<b>1</b>	Where?	Sala Municipality, Västmanland, Sweden
<b>2</b>	When?	31/07/2014 – 11/09/2014
<b>3</b>	How was the fire started?	Accident: fire started in a ground-preparation vehicle (scarification machine) in the forest
<b>4</b>	Initial fire size	30x30 m then 400x600 m (after 40 min)
<b>5</b>	Area affected (burned area)	138 km <sup>2</sup>
<b>6</b>	Fuels involved in the fire	Ground was extremely dry after a heat wave. Coniferous forest (86%) mostly made of pine forest (65%). Only 4% covered by deciduous forest. Forest floor was made of berry bushes. Low moisture content due to the weather. Structures
<b>7</b>	WUI, urban, wildland or informal settlement fires?	WUI and it threatened the urban area of Ängelsberg and the world heritage site Engelsberg.
<b>8</b>	Average weather conditions	It happened after a month of hot and dry weather (forest fire index was 5E which corresponds to the highest scale, extreme high fire risk [Swedish forest fire risk is calculated using the Canadian Fire Weather Index (FWI) system]. Less than 20 mm of rain during the month before the fire. Relative humidity was at 50-60% daytime in July and it dropped to 30-40% some days before ignition. Wind was at 40 km/h on 31/07, 43 km/h on 01/08, 22 km/h on 02/08 and 43 km/h on 03/08 and 04/08. On the 4-5/08 peaks of 27-34° C.
<b>9</b>	Geographical highlights	Mostly flat with an altitude of 100-120 m (above sea level), except from the northernmost part where there is the Stora Hoberget mountain (178 m above sea level)

<b>10</b>	Was there any fire break? (natural or artificial)	Kolbäcksån river valley and the lakes Virsbojön and Åmängen limit the fire on the West. Svartån river valley and the lakes Fläckesjön and Hördesjön limit the fire on the East. Lake Snyten is a limit in the north.
<b>11</b>	Did the Fire Service report extreme fire behaviour?	High spread rate
<b>12</b>	Number of structures and infrastructures affected (damaged)	30 properties destroyed The roads 256 (Norberg-Hastebäck Västerfärnebo), 664 (Västanfors-Ängelsberg), 668 (Ramna-Virsbo-Ängelsberg-Hastebäck), 681 (Rörbo-Västerfärnebo), 685 (Ramna-Rörbo), 756 (Olsbenning- Karbenning-county road 256), 758 (Karbenning - Karbenning church) and 759 (Hökmora-Karbenning church) were closed entirely or partly. The entire airspace over the fire area was blocked to other aircraft than those used in the rescue work. The evening of August 4 the forest fire caused a power outage in Vattenfall's network.
<b>13</b>	Estimated direct and indirect economic damage	138 km <sup>2</sup> of forest destroyed. Preliminary figures for the insurance is between 196,000 SEK (or US\$23500) (Norberg) and 720,000 SEK (or US\$86500) (Sala) for the four municipalities directly affected. 5,000,000 SEK (US\$0.6million) per day were estimated by the Norberg Municipality to be spent on rescue operations on the 7 <sup>th</sup> of August. 300,000,000 SEK (US\$37million) were allocated by the government to the Swedish Contingency Agency for expenses (250million SEK for firefighting and 50million SEK for surveillance and other activities). Approximately 98% of the 9 600 ha of forest was affected by the fire, with a subsequent economic loss of almost 1 billion SEK (US\$123 million).
<b>14</b>	Did it occur in conjunction with multiple fires in the country?	No
<b>15</b>	Countries involved	National, Sweden (initially), then support for special forest-fire airplanes from Italy and France (delayed by bad weather, they arrived on the 6 <sup>th</sup> of August).

16	Brief timeline of the key events	<p>- On 31 July at 13:29, SOS alarm. Wrong assessment of the initial position of the fire by the fire brigade. Mistake discovered in approx. 30 min. Two fire trucks, a tanker, two passenger cars and two command vehicles arrive on scene after 40 minutes. When fire trucks arrive, the fire is 300x500m. In the afternoon, the incident commander assessed they needed more assistance and alert other stations. Water bombing in the evening with a private helicopter. An armed force helicopter reaches the fire scene in the evening. Request from support to the defence force is left - On 1<sup>st</sup> of August, Sala-Haby rescue service is in command. In reality there are two separate responses by two organisations. Fire intensity increased in the afternoon. Firefighting with water cannons and helicopter doing water bombing (private and from armed force). - On the 2<sup>nd</sup> of August, change in wind direction. 70 firefighters involved. Water bombing with helicopter continues. Police and armed force involved. - On the 3<sup>rd</sup> of August, there was less wind and more humidity in the air. 2700 ha and 100 firefighters are involved. - The 4<sup>th</sup> of August was a warm day with wind, quick fire spread. One person is killed and 1 injured. 200 people involved in response. - On the 5<sup>th</sup> of August, less wind and more humidity and rain. - On the 6<sup>th</sup> of August fire did not spread. Rains produced favourable weather conditions. - On the 11<sup>th</sup> of August it rained again. Response organisations take control of the fire. - On the 11<sup>th</sup> of September, the rescue operation is officially terminated.</p>
17	Time of initial order to evacuate and locations	<p>Afternoon of the 4<sup>th</sup> of August, the decision to evacuate Gammelby is taken. In the evening, also Ängelsberg and Västervåla are evacuated. Evacuation is on route 256.</p>
18	Time when evacuation was considered completed	<p>5<sup>th</sup> of August, 1000 people evacuated.</p>
19	Deaths/Injuries	<p>1 death/1 injury</p>
20	The number of people evacuated	<p>1000+</p>
21	The location people initially evacuated	<p>No information available</p>
22	Reasons why people decided to evacuate	<p>Mandatory order by local authorities (based on parts 17 and 22)</p>

23	Evacuation type	Mostly using public announcement (IPA system, Important Public Announcement). In one of the villages, Gammelby, (on the 04/08, with 100 inhabitants) evacuation was needed so quickly that there was no time for using the IPA. Firemen and policemen perform the evacuation directly doorto-door. An evacuation of 4,500 people was threatened (20 busses were ready in Norberg for this).
24	Any drill/education/instructions on large outdoor fires provided beforehand?	No information available
25	Personnel involved in rescue operations	Swedish defense force, Swedish and rescue services, forest company, private citizens approx. 200 firefighters Private helicopter, Armed force helicopter, Italian and French special forest-fire planes, ground firefighting
26	Did the smoke hindered significantly the evacuation because of low visibility or health problems	Extensive smoke around the fire area, but smoke did not significantly hindered evacuation.
27	Possible causes of issues in management operations	Inadequate situational awareness and great difficulties in the coordination of resources (especially given the number of responding agencies). This is mostly due to the lack of clear procedure in leadership of operations. Delayed intervention due to human error.
28	References	Scientific literature: Bram, S., Amon, F., Reilly, P., Degerman, H., Ronchi, E., Van Heuverswyn, K., ... Criel, X. (2016). Decision-making and human behaviour in emergencies with cascading effects (Report within the FP7 EU CascEff project on Modelling of dependencies and cascading effects for emergency management in crisis situations). SP Sverige. Hahlin, J. (2019). Evacuation behaviour intentions based on the summer 2018 Swedish forest fire season. LUTVDG/TVBB Hagelin, H., & Cluzel, M. (2016). Applying FARSITE and Prometheus on the Västmanland Fire, Sweden (2014): fire growth simulation as a measure against forest fire spread: a model suitability study. Student Thesis Series INES. Nilsson, B., Tyboni, M., Pettersson, A., Granström, A., & Olsson, H. (2014). Punktgittertolkning av brandområden i Västmanland.

		<p>Institutionen för skoglig resurshushållning, Sveriges lantbruksuniversitet.  Uhr, C., Frykmer, T., Koelega, S., Cedergårdh, E., Ekman, O., Fredholm, L., &amp; Landgren, J. (2015). Att astadkomma inriktning och samordning-7 analyser utifrån hanteringen av skogsbranden i Västmanland 2014. Centrum för samhällets resiliens, Lunds universitet.  Websites: Skogsbranden i Västmanland  <a href="https://www.svd.se/skogsbranden-i-vastmanland">https://www.svd.se/skogsbranden-i-vastmanland</a></p>
<b>29</b>	Name/Surname/Email/Date of who filled in this template	<p>Ronchi, E., Rein, G., Gwynne, S., Wadhvani, R., Intini, P., &amp; Bergstedt, A. (2017). e-Sanctuary: Open Multi-Physics Framework for Modelling Wildfire Urban Evacuation. Quincy, MA (USA)</p>

## Appendix D – Fuel models

In this appendix, tables regarding data related to different fuel models are presented.

- Appendix D.1 Anderssons original 13
- Appendix D.2 Scott & Burgan
- Appendix D.3 MSB fire fuel model
- Appendix D.4 Fire Behaviour Prediction (FBP) Fuel Model

### Appendix D.1 Andersson original 13

Table a.1: Original 13 Fuel models. The table is from: US Forest Service, 2017.

Fuel Model	Fuel Model Code	Fuel Model Name	Fuel Type	Model Set	Fuel 1-hr	Fuel 10-hr	Fuel 100-hr	Fuel Bed Depth
1	n/a	Short grass (1 foot)	Grass and grass-dominated	Original 13	0.74	0	0	1
2	n/a	Timber (grass and understory)	Grass and grass-dominated	Original 13	2	1	0.500	1
3	n/a	Tall grass (2.5 feet)	Grass and grass-dominated	Original 13	3.01	0	0	2.50
4	n/a	Chaparral (6 feet)	Chaparral and shrub fields	Original 13	5.01	4.010	2	6
5	n/a	Brush (2 feet)	Chaparral and shrub fields	Original 13	1	0.500	0	2
6	n/a	Dormant brush, hardwood slash	Chaparral and shrub fields	Original 13	1.50	2.500	2	2.50
7	n/a	Southern rough	Chaparral and shrub fields	Original 13	1.13	1.870	1.500	2.50
8	n/a	Closed timber litter	Timber litter	Original 13	1.50	1	2.500	0.20
9	n/a	Hardwood litter	Timber litter	Original 13	2.92	0.410	0.150	0.20
10	n/a	Timber (litter and understory)	Timber litter	Original 13	3.01	2	5.010	1
11	n/a	Light logging slash	Slash	Original 13	1.50	4.51	5.510	1
12	n/a	Medium logging slash	Slash	Original 13	4.01	14.03	16.53	2.30
13	n/a	Heavy logging slash	Slash	Original 13	7.01	23.04	28.05	3

### Appendix D.2 Scott and Burgans fuel model

Table a.2: Scott and Burgans Fuel model, source: The table is from: US Forest Service, 2017.

Fuel Model	Fuel Model Code	Fuel Model Name	Fuel Type	Model Set	Fuel 1-hr	Fuel 10-hr	Fuel 100-hr	Fuel Bed Depth
91	NB1	Urban/ Developed	Non-burnable	Scott and Burgan	0	0	0	0
92	NB2	Snow/Ice	Non-burnable	Scott and Burgan	0	0	0	0
93	NB3	Agricultural	Non-burnable	Scott and Burgan	0	0	0	0
98	NB4	Open Water	Non-burnable	Scott and Burgan	0	0	0	0
99	NB5	Bare Ground	Non-burnable	Scott and Burgan	0	0	0	0
101	GR1	Short, Sparse Dry Climate Grass (Dynamic)	Grass	Scott and Burgan	0.10	0	0	0.40
102	GR2	Low Load, Dry Climate (Dynamic)	Grass	Scott and Burgan	0.10	0	0	1
103	GR3	Low Load, Very Coarse, Humid Climate Grass (Dynamic)	Grass	Scott and Burgan	0.10	0.40	0	2
104	GR4	Moderate Load, Dry Climate Grass (Dynamic)	Grass	Scott and Burgan	0.25	0	0	2
105	GR5	Low Load, Humid Climate Grass (Dynamic)	Grass	Scott and Burgan	0.40	0	0	1.50
106	GR6	Moderate Load, Humid Climate Grass (Dynamic)	Grass	Scott and Burgan	0.10	0	0	1.50
107	GR7	High Load, Dry Climate Grass (Dynamic)	Grass	Scott and Burgan	1	0	0	3
108	GR8	High Load, Very Coarse, Humid Climate Grass (Dynamic)	Grass	Scott and Burgan	0.50	1	0	4

109	GR9	Very High Load, Humid Climate Grass (Dynamic)	Grass	Scott and Burgan	1	1	0	5
121	GS1	Low Load, Dry Climate Grass-Shrub (Dynamic)	Grass-Shrub	Scott and Burgan	0.20	0	0	0.90
122	GS2	Moderate load, Dry Climate Grass-Shrub (Dynamic)	Grass-Shrub	Scott and Burgan	0.50	0.500	0	1.50
123	GS3	Moderate Load, Humid Climate Grass-Shrub (Dynamic)	Grass-Shrub	Scott and Burgan	0.30	0.250	0	1.80
124	GS4	High Load, Humid Climate Grass-Shrub (Dynamic)	Grass-Shrub	Scott and Burgan	1.90	0.300	0.100	2.10
141	SH1	Low Load, Dry Climate Shrub (Dynamic)	Shrub	Scott and Burgan	0.25	0.250	0	1
142	SH2	Moderate Load, Dry Climate Shrub	Shrub	Scott and Burgan	1.35	2.400	0.750	1
143	SH3	Moderate Load, Humid Climate Shrub	Shrub	Scott and Burgan	0.45	3	0	2.40
144	SH4	Low Load, Humid Climate Timber-Shrub	Shrub	Scott and Burgan	0.85	1.150	0.200	3
145	SH5	High Load, Dry Climate Shrub	Shrub	Scott and Burgan	3.60	2.100	0	6
146	SH6	Low Load, Humid Climate Shrub	Shrub	Scott and Burgan	2.90	1.450	0	2
147	SH7	Very High Load, Dry Climate Shrub	Shrub	Scott and Burgan	3.5	5.300	2.200	6
148	SH8	High Load, Humid Climate Shrub	Shrub	Scott and Burgan	2.05	3.400	0.850	3
149	SH9	Very High Load, Humid Climate Shrub (Dynamic)	Shrub	Scott and Burgan	4.50	2.450	0	4.40
161	TU1	Low Load, Dry Climate Timber-Grass-Shrub (Dynamic)	Timber - Understory	Scott and Burgan	0.20	0.900	1.500	0.60



162	TU2	Moderate Load, Humid Climate Timber-Grass-Shrub (Dynamic)	Timber - Understory	Scott and Burgan	0.95	1.800	1.250	1
163	TU3	Moderate Load, Humid Climate Timber-Grass-Shrub (Dynamic)	Timber – Understory	Scott and Burgan	1.10	0.150	0.250	1.30
164	TU4	Dwarf Conifer with Understory	Timber – Understory	Scott and Burgan	4.50	0	0	0.50
165	TU5	Very High Load, Dry Climate Timber-Shrub	Timber – Understory	Scott and Burgan	4	4	3	1
181	TL1	Low Load Compact Conifer Litter	Timber Litter	Scott and Burgan	1	2.200	3.600	0.20
182	TL2	Low Load Broadleaf Litter	Timber Litter	Scott and Burgan	1.40	2.300	2.200	0.200
183	TL3	Moderate Load Conifer Litter	Timber Litter	Scott and Burgan	0.50	2.200	2.800	0.30
184	TL4	Small Downed Logs	Timber Litter	Scott and Burgan	0.50	1.500	4.200	0.40
185	TL5	High Load Conifer Litter	Timber Litter	Scott and Burgan	1.15	2.500	4.400	0.60
186	TL6	Moderate Load Broadleaf Litter	Timber Litter	Scott and Burgan	2.40	1.200	1.200	0.30
187	TL7	Large Downed Logs	Timber Litter	Scott and Burgan	0.30	1.400	8.100	0.40
188	TL8	Long-Needle Litter	Timber Litter	Scott and Burgan	5.80	1.400	1.100	0.30
189	TL9	Very High Load Broadleaf Litter	Timber Litter	Scott and Burgan	6.65	3.300	4.150	0.60
201	SB1	Low Load Activity Fuel	Slash- Blowdown	Scott and Burgan	1.50	3	11	1
202	SB2	High Load Activity Fuel or Moderate Load Blowdown	Slash- Blowdown	Scott and Burgan	4.50	4.250	4	1
203	SB3	High Load Activity Fuel or Moderate Load Blowdown	Slash- Blowdown	Scott and Burgan	5.50	2.750	3	1.20
204	SB4	High Load Blowdown	Slash- Blowdown	Scott and Burgan	5.25	3.500	5.250	2.70

Table a.3: Detailed Descriptions of Andersons 13 and Scott & Burgan's Fuel Model. The table is from: US Forest Service, 2017.

Code	Detailed Description
1	Contains fine, very porous, and continuous herbaceous fuels that have cured or are nearly cured. Generally less than one-third of the area contains shrubs or timber. Grasslands and savanna are represented along with stubble, grass-tundra, and grass-shrub combinations. Annual and perennial grasses are included in this fuel model.
2	Herbaceous material with litter and dead-down stem wood from the open shrub or timber overstory. Open shrub lands and pine stands or scrub oak stands that cover one-third to two-thirds of the area. Stand many include clumps and may include pinyon-juniper.
3	Stands are tall, averaging about three feet, but considerable variation may occur. Approximately one-third or more of the stand is considered dead and cured. May include cultivated grains that have not been harvested, tall prairie, and marshland grasses.
4	Stands of mature shrubs, 6 feet or more tall such as California mixed chaparral, the high pocosin along the east coast, the pine barrens of New Jersey, or the closed jack pine stands of the north-central states. Besides flammable foliage, stand may contain dead woody material. May contains a deep litter layer.
5	Shrubs are young with little dead material, and the foliage contains little volatile material. Usually shrubs are short and almost totally cover the area. Young, green stands with no dead wood qualify: laurel, vine maple, alder, or even chaparral, manzanita, or chamise.
6	The shrubs are older, but not as tall as model 4, nor do they contain as much fuel as model 4. This model covers a broad range of shrub conditions: intermediate stands of chamise, chaparral, oak brush, low pocosin, Alaskan spruce taiga, and shrub tundra. May include hardwood slash that has been cured. Pinyon-juniper shrub lands may be represented.
7	Stands of shrubs are generally between 2 and 6 feet high. Palmetto-galliberry understory, with a pine overstory are typical. Low pocosin may be represented. Black spruce shrub combinations in Alaska may also be represented.
8	Contains closed canopy stands of short needle conifers or hardwoods that have leafed out. The compact litter layer is mainly needles, leaves, and occasionally twigs because little undergrowth is present. Representative conifer types are white pine, lodgepole pine, spruce, fir, and larch.
9	Both long-needle conifer stands and hardwood stands, especially the oak-hickory types, are typical. Closed stands of long-needled pine like ponderosa, Jeffrey, red pines, or southern pine plantations are grouped in this model. May contain concentrations of dead-down woody material.

Code	Detailed Description
10	Dead-down fuels include quantities of 3-inch or larger limb wood resulting from over maturity or natural events that create a large load of dead material on the forest floor. Any forest type may be considered if heavy down material is present; examples are insect- or disease-ridden stands, wind thrown stands, over-mature situations with deadfall, and aged light thinning or partial cut slash.
11	Contains slash and herbaceous material intermixed with slash. Light partial cuts or thinning operations in mixed conifer stands, hardwood stands, and southern pine harvests are considered. Clearcuts generally produce more slash than represented here. The less than 3-inch material load is less than 12 tons per acre. The greater than 3 inch is represented by not more than 10 pieces, 4 inches in diameter, along a 60 foot transect.
12	The visual impression is dominated by slash and much of it is less than 3 inches in diameter. The fuels are well distributed. Heavily thinned conifer stands, clearcuts, and medium or heavy partial cuts are represented. The material larger than 3 inches is represented by encountering 11 pieces, 6 inches in diameter along a 50 foot transect.
13	There is a continuous layer of slash. Large quantities of material larger than 3 inches are present. Clearcuts and heavy partial cuts in mature and over-mature stands are depicted where the slash load is dominated by the greater than 3 inch diameter material. Fuels less than 3 inches are generally only 10 percent of the total load. May include situations where the slash still has "red" needles attached.
91	Land covered by urban and suburban development. The area must not support wildland fire spread. In some cases the area may experience structural fire losses during a wildland fire incident; however, structure ignition in those cases is either house-to-house or by firebrands, neither of which is directly modeled using fire behavior fuel models. If sufficient vegetation surrounds structures such that wildland fire spread is possible, then choose a fuel model appropriate for the wildland vegetation.
92	Land covered by permanent snow and ice. Areas covered by seasonal snow and ice can be mapped to two different fuel models.
93	Agricultural land maintained in a non-burnable condition, examples include irrigated annual crops, mowed or tilled orchards, and so forth. However, there are many agricultural areas that are not kept in a non-burnable condition. For example, grass is often allowed to grow beneath vines or orchard trees, and wheat and similar crops are allowed to cure before harvest; in those cases use a different fuel model.
98	Land covered by open bodies of water such as lakes, rivers, and oceans.
99	Land devoid of enough fuel to support wildland fire spread. Such areas include: gravel pits, arid deserts with little vegetation, sand dunes, rock outcroppings, beaches, and so forth.

Code	Detailed Description
101	The primary carrier of fire in sparse grass, though small amounts of fine fuel may be present. The grass is generally short, either naturally or by grazing, and may be sparse or discontinuous. The moisture extraction is indicative of a dry climate fuelbed, but may also be applied in high-extinction moisture fuelbeds because in both cases predicted spread rate and flame length are low compared to other grass models.
102	The primary carrier of fire is grass, though small amounts of fine dead fuel may be present. Load is greater than 101, and fuelbed may be more continuous. Shrubs, if present, do not affect fire behavior.
103	The primary carrier of fire is continuous, coarse, humid-climate grass. Grass and herb fuel load is relatively light; fuelbed depth is about 2 feet. Shrubs are not present in significant quantity to affect fire behavior.
104	The primary carrier of fire is continuous, dry-climate grass. Load and depth are greater than 102; fuelbed depth is about 2 feet.
105	The primary carrier of fire is humid-climate grass. Load is greater than 103 but depth is lower, about 1-2 feet.
106	The primary carrier of fire is continuous humid-climate grass. Load is greater than 105 but depth is about the same. Grass is less coarse than 105.
107	The primary carrier of fire is continuous dry-climate grass. Load and depth are greater than 104. Grass is about 3 feet tall.
108	The primary carrier of fire is continuous, very coarse, humid-climate grass. Load and depth are greater than 106. Spread rate and flame length can be extreme if grass is fully cured.
109	The primary carrier of fire is dense, tall, humid-climate grass. Load and depth are greater than 108, about 6 feet tall. Spread rate and flame length can be extreme if grass is fully more mostly cured.
121	The primary carrier of fire is grass and shrubs combined. Shrubs are about 1 foot height, grass load is low. Spread rate is moderate; flame length is low. Moisture of extinction is low.
122	The primary carrier of fire is grass and shrubs combined. Shrubs are 1 to 3 feet high, grass load is moderate. Spread rate is high; flame length moderate. Moisture of extinction is low.
123	The primary carrier of fire is grass and shrubs combined. Moderate grass/shrub load, average grass/shrub depth less than 2 feet. Spread rate is high; flame length moderate. Moisture of extinction is high.

Code	Detailed Description
124	The primary carrier of fire is grass and shrubs combined. Heavy grass/shrub load, depth greater than 2 feet. Spread rate high; flame length very high. Moisture of extinction is high.
141	The primary carrier of fire is woody shrubs and shrub litter. Low shrub fuel load, fuelbed about 1 foot; some grass may be present. Spread rate is very low; flame length very low.
142	The primary carrier of fire is woody shrubs and shrub litter. Moderate shrub fuel load (higher than 141), depth about 1 foot, no grass fuel present. Spread rate is very low; flame length low.
143	The primary carrier of fire is woody shrubs and shrub litter. Moderate shrub load, possibly with pine overstory or herbaceous fuel, fuel bed depth 2 to 3 feet. Spread rate is low; flame length low.
144	The primary carrier of fire is woody shrubs and shrub litter. Low to moderate shrub and litter load, possibly with pine overstory, fuel bed depth about 3 feet. Spread rate is high; flame length moderate.
145	The primary carrier of fire is woody shrubs and shrub litter. Heavy shrub load, depth 4-6 feet. Spread rate is very high; flame length very high. Moisture of extinction is high.
146	The primary carrier of fire is woody shrubs and shrub litter. Dense shrubs, little or no herbaceous fuel, fuelbed depth about 2 feet. Spread rate is high; flame length high.
147	The primary carrier of fire is woody shrubs and shrub litter. Very heavy shrub load, depth 4 to 6 feet. Spread rate lower than 146, but flame length similar. Spread rate is high, flame length is very high.
148	The primary carrier of fire is woody shrubs and shrub litter. Dense shrubs, little or no herbaceous fuel, fuelbed depth about 3 feet. Spread rate is high; flame length high.
149	The primary carrier of fire is woody shrubs and shrub litter. Dense, finely branched shrubs with significant fine dead fuel, about 4 to 6 feet tall; some herbaceous fuel may be present. Spread rate is high; flame length is very high.
161	The primary carrier of fire is low load of grass and/or shrub with litter. Spread rate is low; flame length is low.
162	The primary carrier of fire is moderate litter load with shrub component. High extinction moisture. Spread rate is moderate; flame length is low.
163	The primary carrier of fire is moderate forest litter. High extinction moisture. Spread rate is high; flame length is moderate.

Code	Detailed Description
164	The primary carrier of fire is short conifer trees with grass or moss understory. Spread rate is moderate; flame length is moderate.
165	The primary carrier of fire is heavy forest litter with a shrub or small tree understory. Spread rate is moderate; flame length is moderate.
181	The primary carrier of fire is compact forest litter. Light to moderate loads, fuels 1 to 2 inches deep. May be used to represent a recently burned forest. Spread rate is very low; flame length is very low.
182	The primary carrier of fire is broadleaf (hardwood) litter. Low load, compact broadleaf litter. Spread rate is very low; flame length is very low.
183	The primary carrier of fire is moderate load conifer litter, light load of coarse fuels. Spread rate is very low; flame length low.
184	The primary carrier of fire is moderate load of fine litter and coarse fuels. Includes small diameter downed logs. Spread rate is low; flame length low.
185	The primary carrier of fire is high load of fine litter; light slash or mortality fuel. Spread rate is low; flame length low.
186	The primary carrier of fire is moderate load broadleaf litter, less compact than 182. Spread rate is very moderate; flame length is low.
187	The primary carrier of fire is heavy load of forest litter, includes large diameter downed logs. Spread rate is low; flame length low.
188	The primary carrier of fire is moderate load long-needle pine litter, may include small amount of herbaceous load. Spread rate is moderate; flame length low.
189	The primary carrier of fire is very high load, fluffy broadleaf litter. This can also be used to represent heavy needle-drape. Spread rate is very moderate; flame length moderate.
201	The primary carrier of fire is light dead and down activity fuel. Fine fuel load is 10 to 20 t/ac weighted towards fuels 1 to 3 inch diameter class; depth is less than 1 foot. Spread rate is moderate; flame length moderate.
202	The primary carrier of fire is moderate dead and downed activity fuel or light blowdown. Fine fuel load is 7 to 12 t/ac, evenly distributed across 0 to 0.25, 0.25 to 1, and 1 to 3 inch diameter classes, depth is about 1 foot. Blowdown is scattered, with many trees still standing. Spread rate is moderate; flame length moderate.
203	The primary carrier of fire is heavy dead and down activity fuel or moderate blowdown. Fine fuel load is 7 to 12 t/ac, weighted toward 0 to 0.25 inch diameter class, depth is more than 1 foot. Blowdown is moderate; trees compacted to near the ground. Spread rate is high; flame length high.

<b>Code</b>	<b>Detailed Description</b>
204	The primary carrier of fire is heavy blowdown fuel. Blowdown is total, fuelbed is not compacted, most foliage and fine fuel still attached to blowdown. Spread rate is very high; flame length very high.

### Appendix D.3 MSB's fire fuel model

Table a.4: Explanation of the fuel map. Note that the attributes of the fuel types is specified in Metria, 2016. The picture below is created with inspirations from Metria, 2016.

Rastercode	Colour	Description
201		BR 1 – Coniferous Forest, deciduous and rice dominated.
202		BR 2 – Coniferous Forest, moss and rice dominated.
203		BR 3 – Coniferous Forest, herbal dominated.
205		LV 2 – Deciduous or mixed forest, without herbaceous vegetation.
206		LV 3 – Deciduous or mixed forest, with herbaceous vegetation.
207		TV1 – Tree-covered peatland, dominated by pine.
208		TV2 – Tree-covered peatland, without pine.
240		IV1 – Water Surface.
241		IB1 – Hardened ground, Building.
242		IB2 – Hardened ground, Road.
243		IB3 – Hardened ground, not building or Road.
244		IO1 – Open ground without vegetation.



## Appendix D.4 – Fire Behaviour Prediction (FBP) Fuel Model

Down below is a presentation of the FBP fuel model. The model consists of 18 different fuel types with detailed data for each one of them (e.g Intensity class, FWI-values). The data for the fuel types is presented by Taylor & Alexander, 2016 in *Field Guide to the Canadian Forest Fire Behaviour Prediction (FBP) System*.

*Table a.5: A presentation of the 18 different fuel types that the FBP system contains.*

Group	Classification	Specification
Coniferous	C-1	Spruce-lichen woodland
	C-2	Boreal spruce
	C-3	Mature jack or lodgepole pin
	C-4	Immature jack or lodgepole pin
	C-5	Red and white pine
	C-6	Conifer plantation
	C-7	Ponderosa pine/Douglas-fir
Deciduous	D-1	Leafless aspen
	D-2	Green aspen
Mixedwood	M-1	Boreal mixedwood-leafless
	M-2	Boreal mixedwood-green
	M-3	Dead balsam fir mixedwood – leafless
	M-4	Dead balsam fire mixedwood – green
Open	O-1a	Matted grass
	O-1b	Standing grass
Slash	S-1	Jack or lodgepole pine slash
	S-2	White spruce/balsam slash
	S-3	Coastal cedar/hemlock/Douglas-fir slash

## Appendix E – Specifications of the FWI data

The table below (*Table a.6*) shows a hazard rating corresponding to the values of FWI and the sublayers of FWI. The HFI is a rough estimation of the fire intensity. In Sweden, the HFI values range from 1-5E instead of 1-6 as shown below. Source of the table: Alberta Agriculture and Forestry, 2022.

*Table a.6: A presentation of sublayers of the FWI system with corresponding danger rating.*

<b>Hazard Rating</b>	<b>FFMC</b> Fine Fuel Moisture Code	<b>DMC</b> Duff Moisture Code	<b>DC</b> Drought Code	<b>ISI</b> Initial Spread Index	<b>BUI</b> Build Up Index	<b>FWI</b> Fire Weather Index	<b>HFI</b> Head Fire Intensity
<b>Low</b>	0-76	0-21	0-79	<1.5	0-24	0-4	1-2
<b>Moderate</b>	77-84	22-27	80-189	1.5-4.0	25-40	5-10	3
<b>High</b>	85-88	28-40	190-299	4.1-8.0	41-60	11-18	4
<b>Very High</b>	89-91	41-60	300-424	8.1-15.0	61-89	19-29	5
<b>Extreme</b>	92+	61+	425+	>15.0	90+	30+	6

## Appendix F – Fuel data related to the .fuel file

Down below (*Table a.7*) is a presentation of data necessary for the .fuel file. The tables contain data for both Andersson’s 13 and Scott & Burgan’s fuel models.

### Appendix F.1 Grass and grass-shrub fuel model table

*Table a.7: Data for grass and grass-shrub fuel. The table is collected from: National Wildfire Coordinating Group, 2014.*

Carrier	FM #	FM Code	Fuel Model Name	Wind Adj	1hr Load	10hr Load	100hr Load	Herb Load	Woody Load	Total Load	1hr SAV	Herb SAV	Woody SAV	Bed Depth	Moist Extinct	Dead Heat	Live Heat
<b>Dry Climate Fuel Models</b>																	
GR	1	FB1	Short grass	<b>0.36</b>	0.7	--	--	--	--	<b>0.7</b>	3500	--	--	<b>1.0</b>	<b>12</b>	8000	--
GR	2	FB2	Timber grass and understory	<b>0.36</b>	2.0	1.0	0.5	0.5	--	<b>4.0</b>	3000	1500	--	<b>1.0</b>	<b>15</b>	8000	8000
GR	101	GR1	Short, sparse dry climate grass	<b>0.31</b>	0.1	--	--	0.3	--	<b>0.4</b>	2200	2000	--	<b>0.4</b>	<b>15</b>	8000	8000
GR	102	GR2	Low load dry climate grass	<b>0.36</b>	0.1	--	--	1.0	--	<b>1.1</b>	2000	1800	--	<b>1.0</b>	<b>15</b>	8000	8000
GR	104	GR4	Moderate load dry climate grass	<b>0.42</b>	0.3	--	--	1.9	--	<b>2.2</b>	2000	1800	--	<b>2.0</b>	<b>15</b>	8000	8000
GR	107	GR7	High load dry climate grass	<b>0.46</b>	1.0	--	--	5.4	--	<b>6.4</b>	2000	1800	--	<b>3.0</b>	<b>15</b>	8000	8000
GS	121	GS1	low load dry climate grass-shrub	<b>0.35</b>	0.2	--	--	0.5	0.7	<b>1.4</b>	2000	1800	1800	<b>0.9</b>	<b>15</b>	8000	8000
GS	122	GS2	moderate load dry climate grass-shrub	<b>0.39</b>	0.5	0.5	--	0.6	1.0	<b>2.6</b>	2000	1800	1800	<b>1.5</b>	<b>15</b>	8000	8000
<b>Humid Climate Fuel Models</b>																	
GR	3	FB3	tall grass	<b>0.44</b>	3.0	--	--	--	--	<b>3.0</b>	1500	--	--	<b>2.5</b>	<b>25</b>	8000	--
GR	103	GR3	Low load very coarse humid climate grass	<b>0.42</b>	0.1	0.4	--	1.5	--	<b>2.0</b>	1500	1300	--	<b>2.0</b>	<b>30</b>	8000	8000
GR	105	GR5	low load humid climate grass	<b>0.39</b>	0.4	--	--	2.5	--	<b>2.9</b>	1800	1600	--	<b>1.5</b>	<b>40</b>	8000	8000
GR	106	GR6	moderate load humid climate grass	<b>0.39</b>	0.1	--	--	3.4	--	<b>3.5</b>	2200	2000	--	<b>1.5</b>	<b>40</b>	9000	9000
GR	108	GR8	High load very coarse humid climate grass	<b>0.49</b>	0.5	1.0	--	7.3	--	<b>8.8</b>	1500	1300	--	<b>4.0</b>	<b>30</b>	8000	8000
GR	109	GR9	very high load humid climate grass	<b>0.52</b>	1.0	1.0	--	9.0	--	<b>11.0</b>	1800	1600	--	<b>5.0</b>	<b>40</b>	8000	8000
GS	123	GS3	moderate load humid climate grass-shrub	<b>0.41</b>	0.3	0.3	--	1.5	1.3	<b>3.3</b>	1800	1600	1600	<b>1.8</b>	<b>40</b>	8000	8000
GS	124	GS4	high load humid climate grass-shrub	<b>0.42</b>	1.9	0.3	0.1	3.4	7.1	<b>12.8</b>	1800	1600	1600	<b>2.1</b>	<b>40</b>	8000	8000

## Appendix F.2 Shrub and timber understory fuel

Table a.8: Data for shrub and timber understory fuel. The table is collected from: National Wildfire Coordinating Group, 2014.

Carrier	FM #	FM Code	Fuel Model Name	Wind Adj	1hr Load	10hr Load	100hr Load	Herb Load	Woody Load	Total Load	1hr SAV	Herb SAV	Woody SAV	Bed Depth	Moist Extinct	Dead Heat	Live Heat
<b>Dry Climate Fuel Models</b>																	
SH	4	FB4	chaparral	<b>0.55</b>	5.0	4.0	2.0	--	5.0	<b>16.0</b>	2000	--	1500	<b>6</b>	<b>20</b>	8000	8000
SH	5	FB5	brush	<b>0.42</b>	1.0	0.5	--	--	2.0	<b>3.5</b>	2000	--	1500	<b>2</b>	<b>20</b>	8000	8000
SH	6	FB6	dormant brush	<b>0.44</b>	1.5	2.5	2.0	--	--	<b>6.0</b>	1750	--	--	<b>2.5</b>	<b>25</b>	8000	--
SH	141	SH1	low load dry climate shrub	<b>0.36</b>	0.3	0.3	0.0	0.2	1.3	<b>2.0</b>	2000	1800	1600	<b>1</b>	<b>15</b>	8000	8000
SH	142	SH2	mod. load dry climate shrub	<b>0.36</b>	1.4	2.4	0.8	--	3.9	<b>8.4</b>	2000	--	1600	<b>1</b>	<b>15</b>	8000	8000
SH	145	SH5	high load dry climate shrub	<b>0.55</b>	3.6	2.1	--	--	2.9	<b>8.6</b>	750	--	1600	<b>6</b>	<b>15</b>	8000	8000
SH	147	SH7	very high load dry climate shrub	<b>0.55</b>	3.5	5.3	2.2	--	3.4	<b>14.4</b>	750	--	1600	<b>6</b>	<b>15</b>	8000	8000
TU	161	TU1	light load dry climate timber-grass-shrub	<b>0.33</b>	0.2	0.9	1.5	0.2	0.9	<b>3.7</b>	2000	1800	1600	<b>0.6</b>	<b>20</b>	8000	8000
TU	164	TU4	dwarf conifer with understory	<b>0.32</b>	4.5	--	--	--	2.0	<b>6.5</b>	2300	--	2000	<b>0.5</b>	<b>12</b>	8000	8000
TU	165	TU5	very high load dry climate timber-shrub	<b>0.33</b>	4.0	4.0	3.0	--	3.0	<b>14.0</b>	1500	--	750	<b>1</b>	<b>25</b>	8000	8000
TU	10	FB10	timber litter and understory	<b>0.36</b>	3.0	2.0	5.0	--	2.0	<b>12.0</b>	2000	--	1500	<b>1</b>	<b>25</b>	8000	8000
<b>Humid Climate Fuel Models</b>																	
SH	7	FB7	southern rough	<b>0.44</b>	1.1	1.9	1.5	--	0.4	<b>4.9</b>	1750	--	1500	<b>2.5</b>	<b>40</b>	8000	8000
SH	143	SH3	mod. load humid climate shrub	<b>0.44</b>	0.5	3.0	--	--	6.2	<b>9.7</b>	1600	--	1400	<b>2.4</b>	<b>40</b>	8000	8000
SH	144	SH4	low load humid climate timber-shrub	<b>0.46</b>	0.9	1.2	0.2	--	2.6	<b>4.8</b>	2000	--	1600	<b>3</b>	<b>30</b>	8000	8000
SH	146	SH6	low load humid climate shrub	<b>0.42</b>	2.9	1.5	--	--	1.4	<b>5.8</b>	750	--	1600	<b>2</b>	<b>30</b>	8000	8000
SH	148	SH8	high load humid climate shrub	<b>0.46</b>	2.1	3.4	0.9	--	4.4	<b>10.7</b>	750	--	1600	<b>3</b>	<b>40</b>	8000	8000
SH	149	SH9	very high load humid climate shrub	<b>0.50</b>	4.5	2.5	--	1.6	7.0	<b>15.5</b>	750	1800	1500	<b>4.4</b>	<b>40</b>	8000	8000
TU	162	TU2	Moderate load humid climate timber-shrub	<b>0.36</b>	1.0	1.8	1.3	--	0.2	<b>4.2</b>	2000	--	1600	<b>1</b>	<b>30</b>	8000	8000
TU	163	TU3	moderate load humid climate timber-grass-shrub	<b>0.38</b>	1.1	0.2	0.3	0.7	1.1	<b>3.3</b>	1800	1600	1400	<b>1.3</b>	<b>30</b>	8000	8000

## Appendix F.3 Timber litter & slash/blowdown fuel model table

Table a.9: Data for timber litter & slash/blowdown fuel. The table is collected from: National Wildfire Coordinating Group, 2014.

Carrier	FM #	FM Code	Fuel Model Name	Wind Adj	1hr Load	10hr Load	100hr Load	Herb Load	Woody Load	Total Load	1hr SAV	Herb SAV	Woody SAV	Bed Depth	Moist Extinct	Dead Heat	Live Heat
<b>Timber Litter Fuel Models</b>																	
TL	8	FB8	compact timber litter	<b>0.28</b>	1.5	1.0	2.5	--	--	<b>5.0</b>	2000	--	--	<b>0.2</b>	<b>30</b>	8000	--
TL	9	FB9	hardwood litter	<b>0.28</b>	2.9	0.4	0.2	--	--	<b>3.5</b>	2500	--	--	<b>0.2</b>	<b>25</b>	8000	--
TL	181	TL1	Low load compact conifer litter	<b>0.28</b>	1.0	2.2	3.6	--	--	<b>6.8</b>	2000	--	--	<b>0.2</b>	<b>30</b>	8000	--
TL	182	TL2	low load broadleaf litter	<b>0.28</b>	1.4	2.3	2.2	--	--	<b>5.9</b>	2000	--	--	<b>0.2</b>	<b>25</b>	8000	--
TL	183	TL3	moderate load conifer litter	<b>0.29</b>	0.5	2.2	2.8	--	--	<b>5.5</b>	2000	--	--	<b>0.3</b>	<b>20</b>	8000	--
TL	184	TL4	Small downed logs	<b>0.31</b>	0.5	1.5	4.2	--	--	<b>6.2</b>	2000	--	--	<b>0.4</b>	<b>25</b>	8000	--
TL	185	TL5	high load conifer litter	<b>0.33</b>	1.2	2.5	4.4	--	--	<b>8.1</b>	2000	--	--	<b>0.6</b>	<b>25</b>	8000	--
TL	186	TL6	moderate load broadleaf litter	<b>0.29</b>	2.4	1.2	1.2	--	--	<b>4.8</b>	2000	--	--	<b>0.3</b>	<b>25</b>	8000	--
TL	187	TL7	Large downed logs	<b>0.31</b>	0.3	1.4	8.1	--	--	<b>9.8</b>	2000	--	--	<b>0.4</b>	<b>25</b>	8000	--
TL	188	TL8	long-needle litter	<b>0.29</b>	5.8	1.4	1.1	--	--	<b>8.3</b>	1800	--	--	<b>0.3</b>	<b>35</b>	8000	--
TL	189	TL9	very high load broadleaf litter	<b>0.33</b>	6.7	3.3	4.2	--	--	<b>14.1</b>	1800	--	--	<b>0.6</b>	<b>35</b>	8000	--
<b>Slash/Blowdown Fuel Models</b>																	
SB	11	FB11	light slash	<b>0.36</b>	1.5	4.5	5.5	--	--	<b>11.5</b>	1500	--	--	<b>1.0</b>	<b>15</b>	8000	--
SB	12	FB12	medium slash	<b>0.43</b>	4.0	14.0	16.5	--	--	<b>34.6</b>	1500	--	--	<b>2.3</b>	<b>20</b>	8000	--
SB	13	FB13	heavy slash	<b>0.46</b>	7.0	23.0	28.1	--	--	<b>58.1</b>	1500	--	--	<b>3.0</b>	<b>25</b>	8000	--
SB	201	SB1	low load activity fuel	<b>0.36</b>	1.5	3.0	11.0	--	--	<b>15.5</b>	2000	--	--	<b>1.0</b>	<b>25</b>	8000	--
SB	202	SB2	moderate load activity or low load blowdown	<b>0.36</b>	4.5	4.3	4.0	--	--	<b>12.8</b>	2000	--	--	<b>1.0</b>	<b>25</b>	8000	--
SB	203	SB3	high load activity fuel or moderate load blowdown	<b>0.38</b>	5.5	2.8	3.0	--	--	<b>11.3</b>	2000	--	--	<b>1.2</b>	<b>25</b>	8000	--
SB	204	SB4	high load blowdown	<b>0.45</b>	5.3	3.5	5.3	--	--	<b>14.0</b>	2000	--	--	<b>2.7</b>	<b>25</b>	8000	--

## Appendix G – Questions and Answers

During the process, the *4.1 Application protocol* has been tested by practitioners setting up the program for other locations than Sweden. By using the Application protocol with other versions of WUI-NITY, some questions from the practitioners have been received by the author of this thesis. The questions and the answers to those is presented below.

### Evacuation Goal Files

Question:

*I cannot find the .ed files in the WUINITY case folder, how are these created? I tried directly making changes to the 'evacuation goals' coordinates (UTM) in the .wui file but it seems to break the file, causing it not to load anymore. Could this be because there are no .ed files to reference?*

Answer:

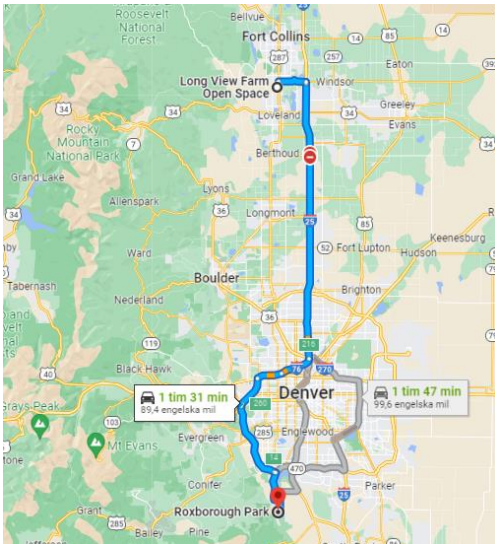
The version of WUI-NITY I'm referring to in the checklist / application protocol is *version 15*. As I can see on your pictures, you are using an earlier version (WUInity\_v0.03\_pre-alpha?). Together with version 15, some of the data from the .wui file was split-up into separate files. The code representing the safe areas (evacuation goals) is as you mention, integrated in the .wui file before version 15. After version 15, some of the .wui code was placed into separate files. For example: The code for the safe areas is now placed in a file called .ed, the code for the weather, wind and fuel moisture is now placed in files called .wtr, .wnd and .fmc. Files for ex the fuel types were included (.fuel) as well, enabling the user to specify the attributes of the burnable materials.

As I understand, you are using a .wui file with all the code included, i.e the separate .ed file was not created when you received your .wui file. So in that case, you do not need to create nor use an .ed file. It should work by only changing the coordinates for the evacuation goals directly in the .wui file.

I had a look at the UTM coordinates you are using for the evacuation goal:

40.466157  
-105.082197

By those coordinates, I received the location of "Long View Farm Open Space" in Fort Collins, US (see picture on next page). As I understand, you would like to run simulations in the Roxborough area. By that, it looks like the coordinates you have entered for the safe area might be slightly off. Note that the UTM system used by WUI-NITY is WGS84. Due to google maps using the same coordinates system, you can retrieve the correct once there. I will gladly help out if you like – In that case, send me a picture over the Roxborough area with positions you would like to act as "Safe areas", and I will give you those coordinates.



## Remembering filenames

Question:

*How do I get WUINITY to remember my filenames under the 'Traffic' menu? They get reset to the default Roxborough case whenever I restart the software At this point I have already completed the filtering process and generated the .osm and .roterdb files.*

Answer:

If you check your .wui file, you will see the pathway for the .osm file (picture below). As you can see on the picture, the pathway and the name of the .osm file is changed. In this case, the OSM data was filtered down to an area of Dorotea (Sweden). And the name of the generated file is named in the pathway. Check your pathway and the name of the .osm file that the .wui file is referring to.

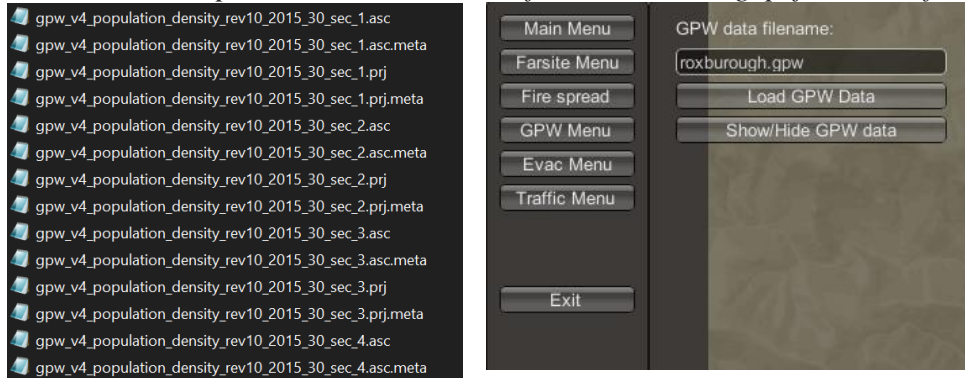
```
"traffic": {
  "osmFile": "E:\\_UNITY\\WUInity\\wui-nity\\external_data\\temp_case\\filtered_dorotea.osm.pbf",
  "osmBorderSize": 1000.0,
  "evacuationGoals": [
```

If you like, you can send me your .wui file and I can have a look if there is something else that is needed to be changed. Also, if you jump to step 17 in the checklist / application protocol, there is a description of which pathways and filenames that needs to be changed. The code there is slightly different compared to your .wui file, but you will get the idea.

## Loading .gpw files

Question:

*Step 6 of the checklist, in my version of WUINITY there is no 'population' menu -> there is no navigation to target folder, I instead need to enter the .gpw filename. How do I create a new .gpw file given there is no option to select the GPW folder containing .prj and .asc filenames?*



Answer:

If you check the .wui file, there are some pathways for the GPW and .pop data (see picture below, the red rectangle highlights the pathway to the folder). If you select the folder which you are referring to for the “gpwDataFolder”, the GPW data should be loaded when you click on “Load GPW data”, and by that a .pop file should be generated in the case folder.

```
"population": {  
  "gpwDataFolder": "E:\\_UNITY\\WUInity\\wui-nity\\external_data\\gpw-v4-population-density-rev10_2015_30_sec_asc",  
  "localGPWFile": "E:\\_UNITY\\WUInity\\wui-nity\\external_data\\temp_case\\Dorotea.gpw",  
  "populationFile": "E:\\_UNITY\\WUInity\\wui-nity\\external_data\\temp_case\\Dorotea.pop"  
}
```

If that does not help, I have attached a .gpw and a .pop file for the rox case in the email, hopefully it will do it.

In the newer versions, there is a function that enables the user to manually populate the area. If you are just testing the application of the model, that might sufficient.

Also, I think it would be a good idea to contact Jonathan as he might be able to provide you with the latest version of the software. I can of course provide you with version 15 (and the new .wui with the separate casefiles) if you like, but check with Jonathan first.



## **.pop files**

Question:

*Another question regarding the .gpw process – the checklist says that a .pop files will be created, however I don't see a roxborough.pop file in my case folder. Has this been superceded by another file?*

Answer:

I've attached an .pop for the rox case in the email if the GPW problem is not solved.

When you load the GPW data into WUI-NITY, by including the GPW folder, a .pop file will be created. WUI-NITY will use the GPW data and filter it down to only contain the area of which you like to simulate. An easy way to put it – the filtered GPW data is your .pop file. When doing this, the .pop file will be created in your case folder. If you are not able to load the GPW data as shown above, you won't be able to create the .pop file.

## Creating .lcp file

Question:

*In order to test the robustness of the UI workflow, I am attempting to create a model for a site in the UK (Marsden Moor). With the exception of fire simulation, I have managed to implement and run a model - I'm still struggling with the preparation of raster data to create an .lcp file.*

Answer:

Glad to hear that you have managed to implement and run a model without the fire included, that is a big step forward. But as you have experienced, the trickiest part is to create the .lcp file.

When the fire departments and other authorities in the UK are working with wildfires, are they using the CFFDRS system? (FWI + FBP) Or are they using the same system as USA? Or maybe another system?





I ask this because if you are to refine the model (WUI-NITY) for UK in the future, it is important to use the most suitable fire modelling tool. FARSITE is included as the fire modelling tool in WUI-NITY today. For Sweden, the fire modelling tool Prometheus would be the better option (based on the CFFDRS system).

## Topographic Data (slope, elevation and aspect)

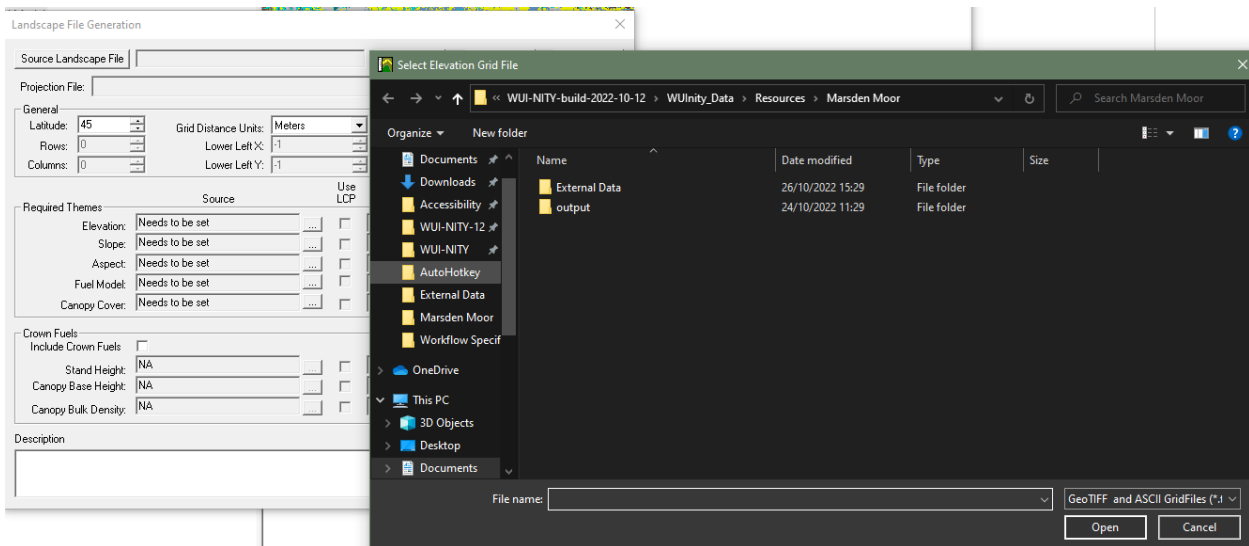
Question:

*I have used Earth Explorer to download the SRTM 1 arc-second dataset – I'm unsure how to input this into FlamMap. FlamMap seems to require three separate files (one each for slope, elevation and aspect) in a GeoTIFF format, however the available downloads are either as a shapefile Zip, or a 'kml' file.*

*SRTM Zip file*

 srtm.dbf	DBF File	1 KB	No	1 KB	44%	07/07/2020 08:39
 srtm.prj	PRJ File	1 KB	No	1 KB	41%	07/07/2020 08:39
 srtm.shp	AutoCAD Shape Source	134 KB	No	465 KB	72%	07/07/2020 08:39
 srtm.shx	AutoCAD Compiled Shape	1 KB	No	1 KB	55%	07/07/2020 08:39

## FlamMap requirements

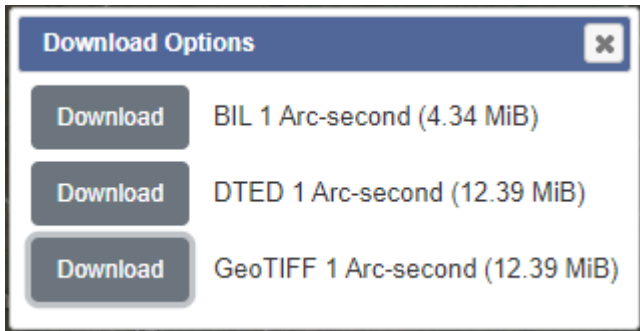


*How do I translate the SRTM zip/kml into a format that FlamMap accepts? I assume I need to provide it with three separate files - one for elevation, slope and aspect.*

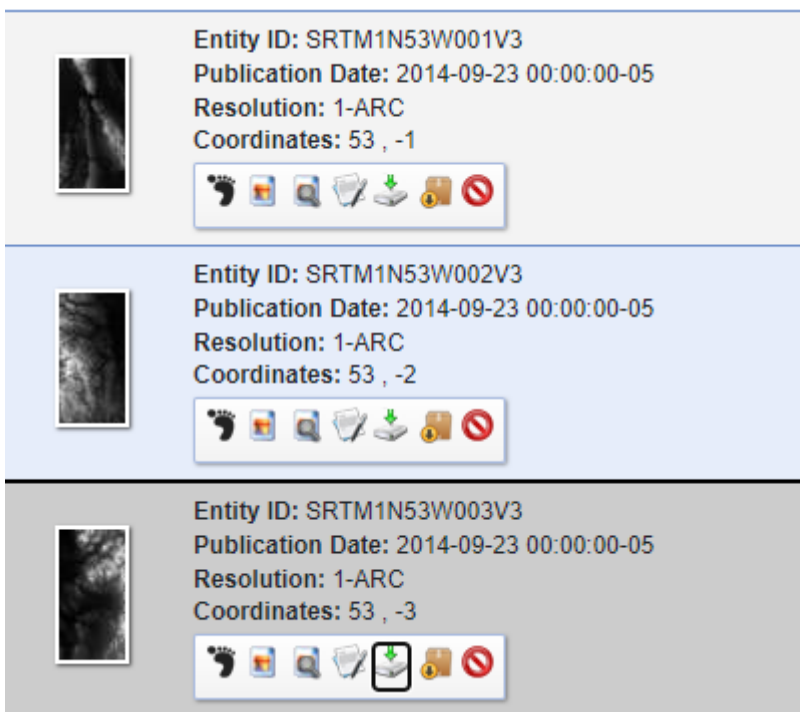
Answer on the next page

Answer:

I checked the area of Marsden Moor in Earth Explorer, when I download the SRTM 1 arc-second dataset, I can choose GeoTIFF format directly. Unsure why you receive a shapefile zip or kml. Here is a print screen:



For the area of Marsden Moor, I receive three different images:



I'm not quite sure exactly what area you are to study for Marsden Moor. But if you check the images, you can compare them with the map to see which one represent your area. It is quite hard to see, so another option is to open the images in GIS together with the fuel map (make sure that the images are using the same coordinate system as the fuel map). Doing this will place the images in the correct positions on the map. Then you can choose the image that represent your area. I have downloaded the three images for you and included them in the email as a ZIP file. By that, you should have the images in GeoTIFF format. If not, you can open the files you have downloaded in GIS and export them as a GeoTIFF, but if you use the images I've sent you, that will not be necessary.

The next question was about FlamMap requirements. You are correct that FlamMap requires aspect, slope, and elevation data to create a .lcp file. You can either insert the same image for aspect, slope and elevation into FlamMap– if that image contains all that data. Or, you can insert one images for aspect, one for slope and one for elevation.

An important note to mention is that the images downloaded from Earth Engine, only contains elevation data. By that, you have to use GIS to create the aspect and slope data. When I did this, I used ArcGIS. As I understand, you are using QGIS. There is a similar function, check this clip: [https://www.youtube.com/watch?v=ccKoG5cRreY&ab\\_channel=QGISWORLD](https://www.youtube.com/watch?v=ccKoG5cRreY&ab_channel=QGISWORLD)

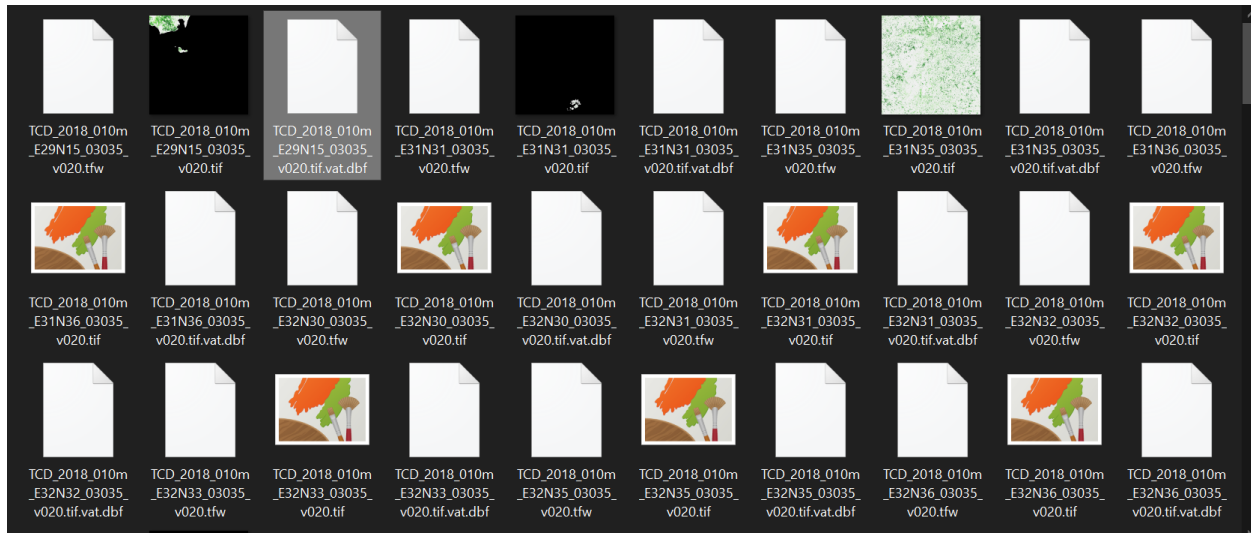
Also, check *Appendix A* in the thesis, step 46-51. There is a description about the problem. I have included the latest version of the thesis in the email.

Note that when you have retrieved data for elevation, aspect and slope. The raster images have to be in the same size (images size), same coordinates system (UTM) and same resolution (10 x 10 m) as your other raster images (fuel map and canopy cover).

## Canopy files

### Question:

*I have downloaded canopy data from <https://land.copernicus.eu/> – Pan-European-High Resolution Layers – Forests – Tree Cover Density – Status Maps – Tree cover Density (year), but again I'm unsure how to input this into FlamMap. In the screenshot of the data folder below, there are dozens of .tif files – do I need to consolidate these into one file?*



### Answer:

Good that you were able to download the canopy data. In that folder, you have canopy data over a quite large area of the UK. As you are to study the area of Marsden Moor, you need to find the one images in the folder that covers that area. I.e, you do not need all the images in the folder. If you like you can open all of them in GIS, and they will create a map over UK (or a large area of UK). Then you will see what piece of the map that includes Marsden Moor – That is the images to be used. Take that image and change the coordinate system, resolution and crop it to match your other images (aspect, slope, elevation, fuel map).

If you are unlucky, the area you are studying is split between more than one image. Then you need put those images together and create a picture containing the full area you are studying.

## **Fuel map**

Question:

*I have downloaded a fuel map from EFFIS, which has a 50x50m resolution. I understand this needs to be modified to a 10x10m resolution using GIS – is this a relatively simple process? I am planning to use QGIS*

Answer:

As can be seen in *Appendix A* in the thesis (step 46-51), I used ArcGIS for that process. If you put some time into it, I do not think it will be a problem using QGIS. Here is some information that might be helpful:

[https://docs.qgis.org/3.22/en/docs/gentle\\_gis\\_introduction/raster\\_data.html](https://docs.qgis.org/3.22/en/docs/gentle_gis_introduction/raster_data.html)

<https://dominoc925.blogspot.com/2015/04/resampling-single-geotiff-image-in-qgis.html>

[https://www.youtube.com/watch?v=NHolzMgaqwE&ab\\_channel=GeoDeltaLabs](https://www.youtube.com/watch?v=NHolzMgaqwE&ab_channel=GeoDeltaLabs) (Check from 41:49).

## .fuel file modification

Question:

*I have been comparing the Roxborough.lcp file to the corresponding .fuel file to understand how to interpret the fuel map colour scheme:*

*In the Roxborough .fuel file below, there are 13 fuel types listed as per the Andersson Original 13 Model.*

```
fuelModelNumber, code, name, fuelBedDepth, moistureOfExtinctionDead, heatOfCombustionDead, heatOfCombustionLive, fuelLoadOneHour, fuelLoadTenHour,
1, "FM1", "Short grass [1]", 1.0, 0.12, 8000, 8000, 0.034, 0, 0, 0, 3500, 1500, 1500
2, "FM2", "Timber grass and understory [2]", 1.0, 0.15, 8000, 8000, 0.092, 0.046, 0.023, 0.023, 0, 3000, 1500, 1500, false, true
3, "FM3", "Tall grass [3]", 2.5, 0.25, 8000, 8000, 0.138, 0, 0, 0, 1500, 1500, 1500, false, true
4, "FM4", "Chaparral [4]", 6.0, 0.2, 8000, 8000, 0.230, 0.184, 0.092, 0, 0.230, 2000, 1500, 1500, false, true
5, "FM5", "Brush [5]", 2.0, 0.20, 8000, 8000, 0.046, 0.023, 0, 0, 0.092, 2000, 1500, 1500, false, true
6, "FM6", "Dormant brush, hardwood slash [6]", 2.5, 0.25, 8000, 8000, 0.069, 0.115, 0.092, 0, 0, 1750, 1500, 1500, false, true
7, "FM7", "Southern rough [7]", 2.5, 0.40, 8000, 8000, 0.052, 0.086, 0.069, 0, 0.017, 1750, 1500, 1500, false, true
8, "FM8", "Short needle litter [8]", 0.2, 0.3, 8000, 8000, 0.069, 0.046, 0.115, 0, 0, 2000, 1500, 1500, false, true
9, "FM9", "Long needle or hardwood litter [9]", 0.2, 0.25, 8000, 8000, 0.134, 0.019, 0.007, 0, 0, 2500, 1500, 1500, false, true
10, "FM10", "Timber litter & understory [10]", 1.0, 0.25, 8000, 8000, 0.138, 0.092, 0.230, 0, 0.092, 2000, 1500, 1500, false, true
11, "FM11", "Light logging slash [11]", 1.0, 0.15, 8000, 8000, 0.069, 0.207, 0.253, 0, 0, 1500, 1500, 1500, false, true
12, "FM12", "Medium logging slash [12]", 2.3, 0.20, 8000, 8000, 0.184, 0.644, 0.759, 0, 0, 1500, 1500, 1500, false, true
13, "FM13", "Heavy logging slash [13]", 3.0, 0.25, 8000, 8000, 0.322, 1.058, 1.288, 0, 0, 1500, 1500, 1500, false, true
```

1. *Inspecting the properties of the Roxborough.lcp fuel model, I see that values 1-13 (Anderssen), and 91-204 (Scott and Burgan) are listed. I am unsure why only those 13 fuel types are included in the .fuel file, and how to determine which values to include:*
  - a. *I assume Values 91-99 have been excluded as they are ‘non-burnable’*
  - b. *Initially, I thought that only with values non-zero frequencies are included – however this can’t be true because Value 7 & 11-13 have been listed although they are zero.*

1		64333 (64333)
2		23790 (23790)
3		3 (3)
4		6 (6)
5		7794 (7794)
6		9488 (9488)
7		0 (0)
8		33768 (33768)
9		6301 (6301)
10		6177 (6177)

Answer:

- a) Yes, that is my understanding aswell. I’ve tried to find information about this but could not find anything. To truly test that assumption, you can insert a fire (after creating the .lcp file) and see if the fire act as the area is “non-burnable” when it reaches a 91-99 value.
- b) I think FlamMap includes all the values for Anderssons 13 as default. If there are zero frequency values, they will show but won’t contribute to fuel map. If a) is correct, my assumption is that all the values for Andersson 13 and Scott and Burgan are included (except the once that are non-burnable (91-99)) even though they represent zero-frequency values.



Question:

*If zero-frequency values are not excluded, why have Values 101-204 been left out of the .fuel file?*

Answer:

Good question. I have not tried to include the zero-frequency values into the .fuel file myself. But my understanding is this: If you include zero-frequency values into the .fuel file. The .fuel file will not find the corresponding fuel/non-fuel type on the fuel map used. By that, it won't matter if you include them or not. I think 7, 11-13 are included just as a default, i.e all the fuel types for Andersson 13 is included. In the future, it might be a good idea to include more fuel types (as default) in the .fuel file. By that, the used do not need to manually include data for needed fuel types when running new simulations.

99		319 (319)
101		0 (0)
102		0 (0)
103		0 (0)
104		0 (0)
105		0 (0)
106		0 (0)
107		0 (0)
108		0 (0)
109		0 (0)
121		0 (0)

Question:

- My second question is about the table of attributes in the .fuel file: there are several fuel type properties that I can't find in the official LANDFIRE source of the Andersson model or the thesis appendix – do you have a more comprehensive source with more attributes, I'm unsure where several values have been source from:

```
fuelModelNumber, code, name, fuelBedDepth, moistureOfExtinctionDead, heatOfCombustionDead, heatOfCombustionLive, fuelLoadOneHour, fu
1, "FM1", "Short grass [1]", 1.0, 0.12, 8000, 8000, 0.034, 0, 0, 0, 0, 3500, 1500, 1500
2, "FM2", "Timber grass and understory [2]", 1.0, 0.15, 8000, 8000, 0.092, 0.046, 0.023, 0.023, 0, 3000, 1500, 1500, false, true
3, "FM3", "Tall grass [3]", 2.5, 0.25, 8000, 8000, 0.138, 0, 0, 0, 0, 1500, 1500, 1500, false, true
4, "FM4", "Chaparral [4]", 6.0, 0.2, 8000, 8000, 0.230, 0.184, 0.092, 0, 0.230, 2000, 1500, 1500, false, true
5, "FM5", "Brush [5]", 2.0, 0.20, 8000, 8000, 0.046, 0.023, 0, 0, 0.092, 2000, 1500, 1500, false, true
6, "FM6", "Dormant brush, hardwood slash [6]", 2.5, 0.25, 8000, 8000, 0.069, 0.115, 0.092, 0, 0, 1750, 1500, 1500, false, true
7, "FM7", "Southern rough [7]", 2.5, 0.40, 8000, 8000, 0.052, 0.086, 0.069, 0, 0.017, 1750, 1500, 1500, false, true
8, "FM8", "Short needle litter [8]", 0.2, 0.3, 8000, 8000, 0.069, 0.046, 0.115, 0, 0, 2000, 1500, 1500, false, true
9, "FM9", "Long needle or hardwood litter [9]", 0.2, 0.25, 8000, 8000, 0.134, 0.019, 0.007, 0, 0, 2500, 1500, 1500, false, true
10, "FM10", "Timber litter & understory [10]", 1.0, 0.25, 8000, 8000, 0.138, 0.092, 0.230, 0, 0.092, 2000, 1500, 1500, false, true
11, "FM11", "Light logging slash [11]", 1.0, 0.15, 8000, 8000, 0.069, 0.207, 0.253, 0, 0, 1500, 1500, 1500, false, true
12, "FM12", "Medium logging slash [12]", 2.3, 0.20, 8000, 8000, 0.184, 0.644, 0.759, 0, 0, 1500, 1500, 1500, false, true
13, "FM13", "Heavy logging slash [13]", 3.0, 0.25, 8000, 8000, 0.322, 1.058, 1.288, 0, 0, 1500, 1500, 1500, false, true
```

List of properties I cannot find a source for:

*moistureOfExtinctionDead, heatOfCombustionDead, heatOfCombustionLive, fuelLoadliveHerbaceous, fuelLoadliveWoody, savrOneHour, savrLiveHerbaceous, savrLiveWoody, isDynamic, isReserved*

Andersson Model csv from Landfire website (has very limited attributes) LANDFIRE Program: LANDFIRE Library - Home 1

Answer:

If you check:

[https://gacc.nifc.gov/oncc/docs/FBFRG\\_2014.pdf](https://gacc.nifc.gov/oncc/docs/FBFRG_2014.pdf)

Pg 59, 61, 63 you will find the data you are looking for. (I have included images of the tables at the end of this document). In those tables you will find data for the Scott and Burgan fuel model as well. If you like to add a couple of lines for the Scott and Burgan's, you can use the data provided by the tables.

Question:

Value	FBFM13	R	G	B	RED	GREEN	BLUE
1	FBFM1	255	255	190	1	1	0.745098
2	FBFM2	255	255	0	1	1	0
3	FBFM3	230	197	11	0.901961	0.772549	0.043137
4	FBFM4	255	211	127	1	0.827451	0.498039
5	FBFM5	255	170	102	1	0.666667	0.4
6	FBFM6	205	170	102	0.803922	0.666667	0.4
7	FBFM7	137	112	68	0.537255	0.439216	0.266667
8	FBFM8	211	255	190	0.827451	1	0.745098
9	FBFM9	112	168	0	0.439216	0.658824	0
10	FBFM10	38	115	0	0.14902	0.45098	0
11	FBFM11	232	190	255	0.909804	0.745098	1
12	FBFM12	122	142	245	0.478431	0.556863	0.960784
13	FBFM13	197	0	255	0.772549	0	1
91	Urban	132	0	138	0.517647	0	0.541176
92	Snow/Ice	159	161	240	0.623529	0.631373	0.941176
93	Agriculture	233	115	255	0.913725	0.45098	1
98	Water	0	0	255	0	0	1
99	Barren	191	191	191	0.74902	0.74902	0.74902
-9999	Fill-NoData	255	255	255	1	1	1

Appendix C.1 of Thesis (has more attributes than the Landfire source but not all of those listed in the .fuel file)

Answer:

Those attributes are related to the .fmc file, see my answer on the next question.

#### Appendix D – Fuel models

##### Appendix C.1 Andersson original 13

Table 1: Original 13 Fuel models, source:

Fuel Model	Fuel Model Code	Fuel Model Name	Fuel Type	Model Set	Fuel 1-hr	Fuel 10-hr	Fuel 100-hr	Fuel Bed Depth
1	n/a	Short grass (1 foot)	Grass and grass-dominated	Original 13	0.74	0	0	1
2	n/a	Timber (grass and understory)	Grass and grass-dominated	Original 13	2	1	0.500	1
3	n/a	Tall grass (2.5 feet)	Grass and grass-dominated	Original 13	3.01	0	0	2.50
4	n/a	Chaparral (6 feet)	Chaparral and shrub fields	Original 13	5.01	4.010	2	6
5	n/a	Brush (2 feet)	Chaparral and shrub fields	Original 13	1	0.500	0	2

## .fmc file

Question:

*I'm unsure what each of the column headers mean in the .fmc file. I understand the file is about humidity of shallow soil, but don't know how each column relates to this*

```
FuelMod, 1Hour, 10Hour, 100Hour, LiveH, LiveW
1, 6.0, 7.0, 8.0, 60.0, 90.0
2, 6.0, 7.0, 8.0, 60.0, 90.0
3, 6.0, 7.0, 8.0, 60.0, 90.0
4, 6.0, 7.0, 8.0, 60.0, 90.0
5, 6.0, 7.0, 8.0, 60.0, 90.0
6, 6.0, 7.0, 8.0, 60.0, 90.0
7, 6.0, 7.0, 8.0, 60.0, 90.0
8, 6.0, 7.0, 8.0, 60.0, 90.0
9, 6.0, 7.0, 8.0, 60.0, 90.0
```

Answer:

The first column is the fuel model (Andersson in this case). The 1 hour, 10 hour and 100 hour columns represent a fuel moisture threshold, called a time lag. Those values are represented by how long time it will take for 2/3 of the dead fuel to respond to moisture in the atmosphere. Small fuels such as leaves, grass etc responds very quickly to changes in the content of moisture in the atmosphere. The 1 h fuel is an indication that it will take 1h for 2/3 of the fuel to respond etc. The 1 hour represent the fine fuel (fuel size of 0 – 6.35 mm). The 10 hour represents fuel ranging from 6.35 mm – 25.4 mm. The 100 hour fuel range from 25.4 mm – 76.2 mm (It also exists a 1000 h fuel). Due to the thickness of a fuel, the moisture content will differ. (The thickness is the diameter of the fuel. Note that the original measurements are in inches – I translated it to mm).

The file you screenshotted above is a default file., you have to change those for a correct representation. You can use *Appendix D* in the thesis for generic values. To get exact values, field sampling and calculations can be done. You can read about it here:

<https://www.wfas.net/nfmd/references/fmg.pdf>

[https://gacc.nifc.gov/oncc/docs/13\\_Aids%20to%20Determining%20Fuel%20Models.pdf](https://gacc.nifc.gov/oncc/docs/13_Aids%20to%20Determining%20Fuel%20Models.pdf)

The sampling won't be necessary at this stage tough, I would recommend you to use the values in *Appendix D*.

LiveH and LiveW represents Living fuel (Live Herbaceous and Live Woody). The dead fuel moisture can exceed 100 % but the live fuel moisture can obtain a maximum value of 100%. The LiveH and LiveW values will be constant throughout the simulation. For the LiveH and LiveW, you can use the default values.