# POSSIBILITIES OF FOREST FIRE MODELING IN SLOVAK CONDITIONS

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**Abstract.** In the article, there is introduced an approach to forest fire modeling using Farsite software. We consider the meteorological characteristics that significantly influence the fuel moisture and correctly identified and quantified fuel models as the most important characteristics. The described approach to forest fire modeling was verified by regressive simulation of forest fire in Slovak Paradise in 2000. The main problem seems to be the data input. Based on deficit of data about fuel from Slovak literature, there is need to take data from foreign literature based on comparison of photo documentation to already identified fuel models. In this case, there can come to errors, either from the ecosystems different species composition reason or from not correct assigning of these fuel models reason. In the future, there is also need to aim the effort to more precise fire start place localization using GPS, to solve the problem of the meteorological data interpolation in indented mountain terrain and to consider the possibility of some fuel models consolidation based on their similarity.

**Keywords:** Farsite, forest fire, fuel model, modeling, GIS

## 1 Introduction

Hundreds of forest fires occur in Slovakia yearly, that result in great damages on forest stands. Let's not forget that forest fire can threat people and settlements as well [1].
In connection with forest fires one of the important question to answered nowadays is how to prevent damages mentioned above. We can find deal with this question on several levels from estimate a fire risk to manage fire suppression following with effective land renovation. One of these levels is to predict behavior and mainly the spread of forest fire based on simulation models. This approach can support decisions during fire suppression works and on the other hand it can help with precaution of potential pending fires [2].

## 2 Problem

There are different specifications (classifications) of fuel models. They are different mainly from input data necessary for categorization point of view. Many of these models do not handle forest fire as one complex but deal with individual aspects e.g. surface or crown fire, speed of stationary spread or acceleration. Therefore it is necessary for the practical use compose models to the programs to describe cardinal aspects of the forest fire. One of the most used programs-simulators of the forest fires is fire behavior and growth simulator FARSITE [3]. To run FARSITE is required to use geographic information system (GIS) because it requires spatial landscape information to run. This simulator describes fire behavior on basis of various fuel, terrain and meteorological attributes of given territory. The most important are fuel attributes that are describe as Fuel models - the main entrances into the various models for calculating the physical parameters of the fire. During the last few decades arise a lot of sets of fuel models that are more or less comprehensively describing variability of forest surroundings [4], [5], [6], but these models are designed especially for conditions of their origin (e.g. North America).

First fuel model specification was used by Albini in 1976 for construction of nomograms. In his work he specified and described 13 fuel models, which are now common as NFFL (Northern Forest Fire Laboratory) fuel models (classes – short grass, timber grass, tall grass, chaparral, short brush, dormant brush, southern rough, closed timber litter, hardwood litter, timber litter (also understory), light slash, medium slash, heavy slash). Later, there was produced also their photo documentation. Photos of individual fuel models and their characteristics were published by Anderson [4]. The National Fire Danger Rating System organization uses in classification 20 fuel models.

In the European conditions these fuel models are applied as such [7] or modified on the basis of different nature conditions to reach better results of retrogressive simulation [8]. More complicated but more accurate is to create a new fuel models that represent different natural conditions of each country and than get more precisely simulation. This is approach of Switzerland [9] and Germany, where the creation of a FARSITE simulation reaches good fit to the observed fire behavior of the managed forest fire [2].

The goal of this paper is to present our approach to creating fuel models for Slovak conditions, that we tried to verify on simulation of the forest fire that affect Krompla -Tri kopce locality in Slovak Paradise National Park in the year 2000.

In process of fuel models selection and specification for Slovak region we should orientate to research results from Switzerland in combination with knowledge from Rothermel`s model (1972), together with forest environment information extraction from existing data resources (e.g. forest management plan). Owing to correct specification of fuel model type, it is necessary to know given problem, area and its character and some other indicators as individual vegetation type domination, probable fuel layer specification as a fire spreading factor, fuel depth and compactness, critical fuel classes for fire spreading in area of interest, except other.

## 3 Metodology and results

### 3.1 Methodology of fuel models specification for conditions of Slovakia

Due to the environment variability mainly from fuel varility, terrain and climate conditions point of view we choose for mapping of Slovakia approach throught geobiocenotical classification of Slovak republic forests. It is the most comprehensive forest classification that comes up from evolutionary, growing indicating and differentiating principles and from principle of indication by the environment characteristics [11].
Basic typological unit of geobiocenotical classification is forest type that is in core permanent ecological conditions type. It is an unit with narrow ecological range for wood growth, its production and reconstruction as well as for required species and spatial composition of forests. Associate unit of forest type is forest types group that represents group of forest types grouped on base of their similarity in management changed forests based on similarity of understory cover.
We chose forest types group for fuel model classification. Despite it is not the unit that characterizes forest ecosystem most precise, for lesser number of forest types groups against number of forest types is more suited for following fuel models quantification process. Forest types groups are better accessible from database of forest management plan as well, and they take note of biotic as well as abiotic condition of the forest stand, too.
After analysis of basic works about forest types groups [10], [11], we have divided forest types groups into associations based on dominant herbal species occurrence, their physiognomy and particularly also on their cover density, wood species composition and moisture conditions. By this way divided forest types groups into associations of forest types groups introduce initial fuel models that represent areas with similar ground fuel with herbal cover and natural wood species composition [12].
After analysis of new created association of forest types groups we considered these for homogenous from fuel characteristic point of view important for ground forest fire spreading. In this research phase we decided that these characteristics will by further investigated as fuel model characteristics. For simpler distinguishing we added fuel model numbers to every association of forest types groups. Individual fuel model we specified had been numbered following:

| FM Nb. | Association of forest types groups |
|---|---|
| 21 | Mosses + Lichens |
| 22 | Grasses up to 30 cm |
| 23 | Grasses + Herbs up to 30 cm |
| 24 | Herb + Grasses + Mosses up to 30 cm |
| 25 | Herbs up to 15 cm |
| 26 | Herbs up to 30 cm |

| FM Nb. | Association of forest types groups |
|---|---|
| **27** | **Tall Herbs up to 100 cm** |
| **28** | **Without dominant herbal cover - Pauper** |
| **29** | **Grasses + Herbs up to 30 cm of drier chalky areas** |
| **30** | **Grasses + Herbs up to 30 cm of wetter chalky areas** |

Such defined fuel models are valid in forests with natural wood species composition. These forests are already identified and accessible from Forest management information system of Slovakia[13].

### 3.2 Fuel models characteristics quantification

The primary aim was to quantified fuel models that cover our target area Krompla – Tri Kopce stricken by the fire in 2000.
For every fuel model in FARSITE software are important following characteristics:

A. Fuel loading in 5 fuel types:

I. Dead fuel particles of ∅<0.6 cm ($m_1$)
II. Dead fuel particles 0.6<∅<2.5 cm ($m_2$)
III. Dead fuel particles 2.5<∅<7.5 cm ($m_3$) [$t.ha^{-1}$]
IV. Live herbaceous fuel particles ∅<0.6 cm ($m_4$)
V. Live woody fuel particles ∅<0.6 cm ($m_5$)

B. Surface to Volume Ratio (σ) in 3 fuel types:

I. Dead fuel particles ∅<0.6 cm ($\sigma_1$)
IV. Live herbaceous fuel particles ∅<0.6 cm ($\sigma_4$) [$cm^{-1}$]
V. Live woody fuel particles ∅<0.6 cm ($\sigma_5$)

C. Fuel bed depth (δ) [cm]

D. Moisture of Extinction (Mx) [%]

E. Heat Content [$kJ.kg^{-1}$]

Fig.1 Fuel model 30

Since there was no other research of fuel characteristics except herbal biomas investigate more minutely, we used different approaches to their quantification according to our opportunities. One of them was derivation of characteristics based on photo documentation of other fuel models. For characteristics possible to derive from another characteristics using relation-equations (e.g. determine surface to volume ratio based on its diameter), we used approach of Swiss researches [9], that made research in conditions similar to Slovak ones. Few characteristics, that have been investigate in Slovakia we used after consideration such as [14] [15], [16], [17], [18], [19], [20], [21], [22]. We used this procedure for fuel model 25, 27 and 30 that cover our area of interest (Fig. 1,2).

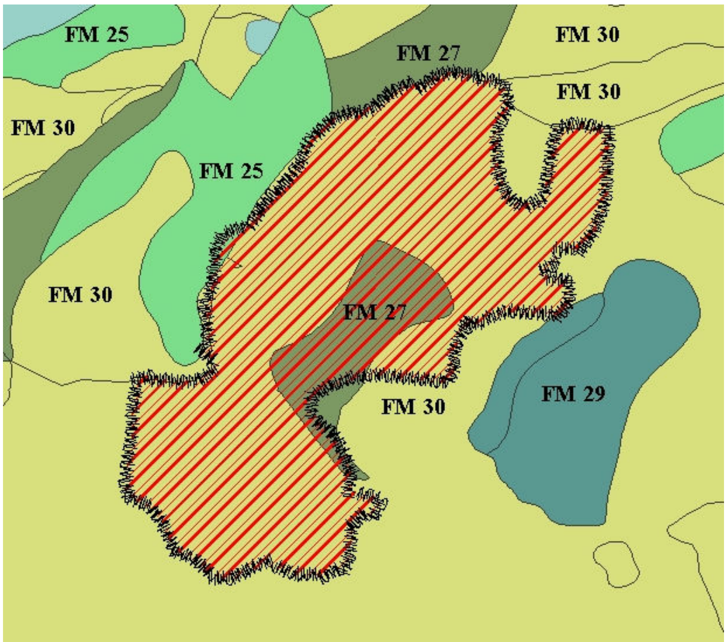



Fig. 2 Krompla – Tri Kopce area. Burned area and fuel models (FM)

As a second approach to the fuel models quantification we used field data collection. We followed Swiss model of field work [9]. Because of its time consumption and technical demendingness we simplified it partialy [12]. Based on field detection we specified area of interest as more or less homogenous and labeled one upspring fuel model as “TER”.
Results of four fuel model quantification are showed in table 1.

| | **FM 25** | **FM 27** | **FM 30** | **FM „TER“** |
|---|---|---|---|---|
| **$m_1$ [t.ha$^{-1}$]** | 6.6 | 7.35 | 6.6 | 5.842 |
| **$m_2$ [t.ha$^{-1}$]** | 2.47 | 1.85 | 1.85 | 3.499 |
| **$m_3$ [t.ha$^{-1}$]** | 0.0 | 0.0 | 0.0 | 0.339 |
| **$m_4$ [t.ha$^{-1}$]** | 0.7 | 0.7 | 0.7 | 0.473 |
| **$m_5$ [t.ha$^{-1}$]** | 1.24 | 1.24 | 1.57 | 1.57 |
| **$\sigma_1$ [cm$^{-1}$]** | 56.84 | 60.36 | 60.36 | 60.36 |
| **$\sigma_4$ [cm$^{-1}$]** | 49.20 | 49.20 | 49.20 | 49.20 |
| **$\sigma_5$ [cm$^{-1}$]** | 49.20 | 49.20 | 49.20 | 49.20 |
| **$\delta$ [cm]** | 28 | 33 | 35 | 32 |
| **Mx [%]** | 26 | 26 | 25 | 27 |
| **Heat Content [kJ.kg$^{-1}$]** | 18600 | 18600 | 18600 | 18600 |

### 3.3 Specification of other inputs for fire simulation in FARSITE

These can be divided into two groups:

- Inputs typical for abiotic environment – terrain characteristics (altitude, slope, aspect), meteorological conditions (number of precipitation and its taking time, minimum and maximum day temperature, air moisture) and wind characteristics (wind speed and direction) and cloudness.

- Inputs typical for forest vegetation except fuel models characteristics – canopy cover, crown base height, stand height, crown bulk density, duff loading ($O_f$ and $O_h$ horizont) and dead wood.

In our research we used only following inputs: terrain altitude, slope and aspect, canopy cover, meteorological and wind characteristics and fuel moisture. These characteristics are necessary for surface fire simulation. Another are important for more detailed modeling of surface and other fire types.
All inputs were in ASCII grid format created in GIS software environment.

#### 3.4 Set of the simulation – description of the forest fire

There was one more input that need to be set before the simulation will start – duration of the simulation. Basic knowledge about the forest fire development comes from the data files of the nearest fire department in Spišská Nová Ves [23].
According to these files, the fire was first time noticed late afternoon 23.10.2000, but localized only next morning 24.10.2000. In this day started extinguishing of the fire with basic equipment and with the hepl of local forest workers and volunteers. Area of the fire was estimated from 3 to 6 hectares at noon. (Fig. 3)

*Fig.3. Area of the fire afternoon 24.10.2000*

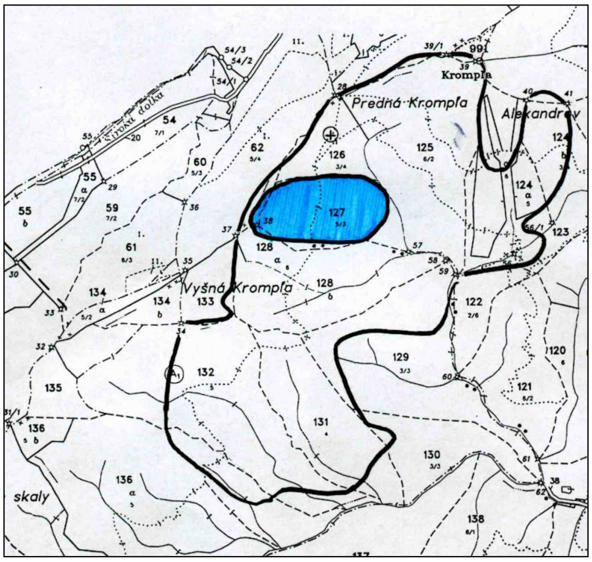
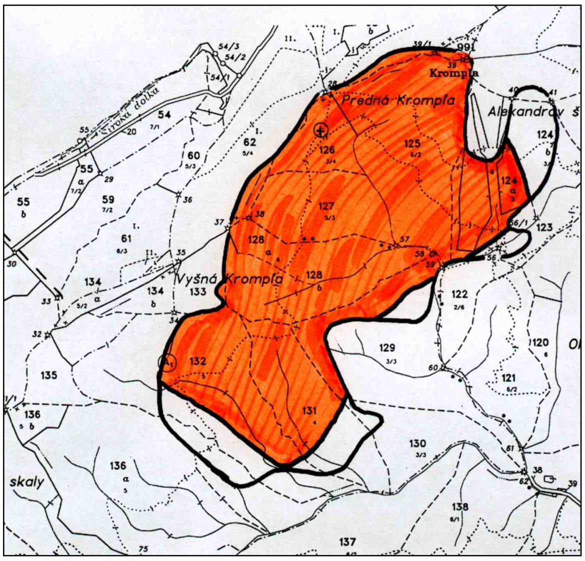



*Fig. 4. Area of the fire evening 25.10.2000*




Soon after noon has happened tragedy, when fire has hit and killed six people and after that was fire spreading without any control untill the next morning. Next day 25.10.2000 was extinguishing running mainly on north-west fire border on the ridge and this border was stabilize. Fire was spreading that day mainly to the north-east and south-west. In the evening was the fire area estimate to 45 hectares (Fig. 4). Through the next days a lot of aeronautical and terrestrial extinguish engineering was integrated to the extinguishing works also with big number of people and they got the fire under control. On the base of these facts we set the duration of the fire for the simulatio from 12 o'clock AM of 23.10.2000 to 6 o'clock PM of 25.10.2000. Possible starting point of the fire is indicated on Figure 2.

#### 3.5 Simulation with fuel models 25, 27 and 30

For this simulation we used three derived fuel models and as data of the moisture we used data measured through the field work at the same season of the year as the fire occurred. Fire spreading of this simulasion was unfortunately too fast in comparison to the real fire spreading. Direction of spreading was different to the real as well. In the real the fire spread mainly east, but spreading of the simulated fire was at the bigging uniform to each direction.
High speed of spreading could by consequence of the fact that model of fire spreading in FARSITE deal with continuity and homogeneity of fuel particles in the forest but this is different to the real

situation of the fuel distribution [24]. Because of the motley terrain at the area of interest with alternation of narrow dells and rocky ridges where bedrock often come up to the surface, we set lower the speed of spreading to the 0.7 multiple of original speed with Spread rate adjustment module. Despite of this adjustment the speed of spreading was still overrated and burned area covered 209 hectares already at 6 o'clock PM 24.10.2007 (Fig. 5).
White borders on the map are 6 hour time steps of the simulation and the red border is border of the total burned area. White point shows place of ignition.

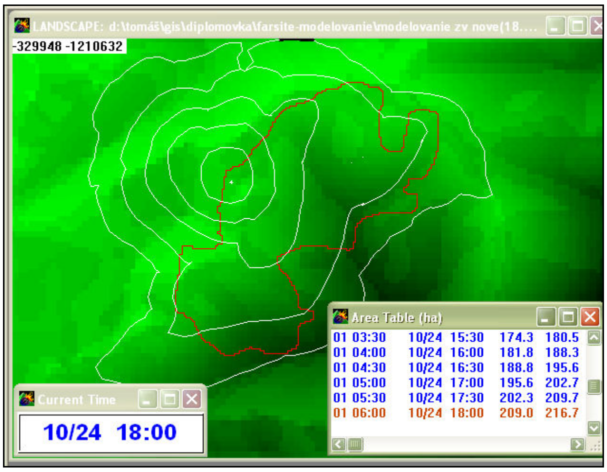


*Fig.5 Simulation with fuel models 25, 27 and 30.*

### 3.6 Simulation with fuel model TER

In this case we thought about whole area as homogenous from the fuel point of view and for that covered with only one fuel model. We based this approach on similarity of three derived fuel models values and on the field observation. Speed of spreading was set lower the to the 0.7 multiple of original speed as in previous case.
Final speed of spreading of this simulation was obviously lower but still too fast and burned area at 6 o'clock PM 24.10.2000 was 121.5 hectares (Fig. 6).
Main reason of reduced speed was lover value of the fuel loading in I. fuel type - dead fuel particles of ∅<0.6 cm ($m_1$).

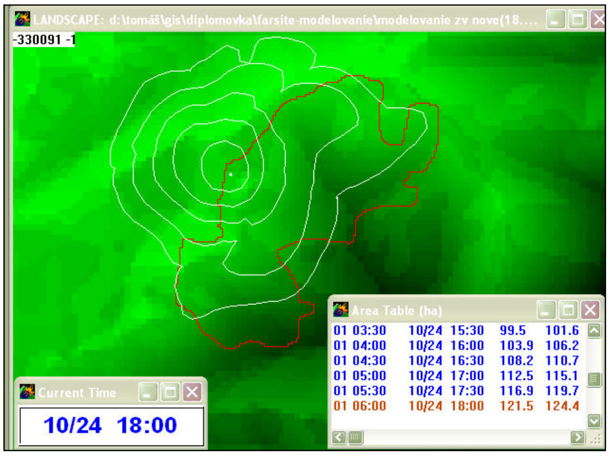


*Fig.6 Simulation with fuel model TER..*

## 4 Discussion

Our research shows few problems that need to by solve, when FARSITE is used to simulate forest fires in Slovak conditions. With methodology we present was hard to reach expected results and simulation in FARSITE was running faster than fire in real conditions and direction of spreading was only partly similar. Different reasons could cause this.

Main problem is to get exact inputs. Cause of the rare occurrence of relevant research about forest as a fire fuel we tried to calculate or derive these inputs but this approach is just approximately and subjective. On the other hand proper field measure of the fuel characteristics could by more exact but is limited of time and resources. For the successful simulation in the Slovak condition is important to make proper basic field measures of fuel loading in each fuel type and measure inputs for calculating surface to volume ratio values.

Other problem we found was moisture of extinction (Mx) calculation. In Swiss methodology was this characteristic depends only on fuel load and its depth (height). When Mx is calculating for driest and hottest period of the year this approach is correct but when temperature is falling down to dew point through the nights in colder periods of the year, this affects the fuel moisture as well and speed of spreading is reduced. This was probably the mail reason of our problems with the fast simulation.

Microclimate of the locality is the other important factor that affects spread of the fire. Real forest fire was spreading only little to north-west direction, behind the ridge. FARSITE didn't reach this in the simulation on the base of meteorological and topographical inputs we inserted. The reason of this difference is probably specific microclimate before and during fire and fact that meteorological inputs come from the nearest, but still 12 km faraway meteorological station.

After making provision for advanced mentioned problems and including of corrective arrangements, that are possible done in the FARSITE, was the successful simulation with the aid of this program exerted to image the shape and partly surface of the real fire, that stroke and damaged 64 hectares of forest in the locality of Krompla - Tri Kopce in The National Park Slovak Paradise (Fig.7, 8).

Into future it is necessary to be focused on the more exact localization of the point of origin of a fire by help of GPS, to devote the determination of microclimatic characteristics for broken mountain ground and to take into consideration some possibilities how to realize a fusion of some PM following their similar relation.

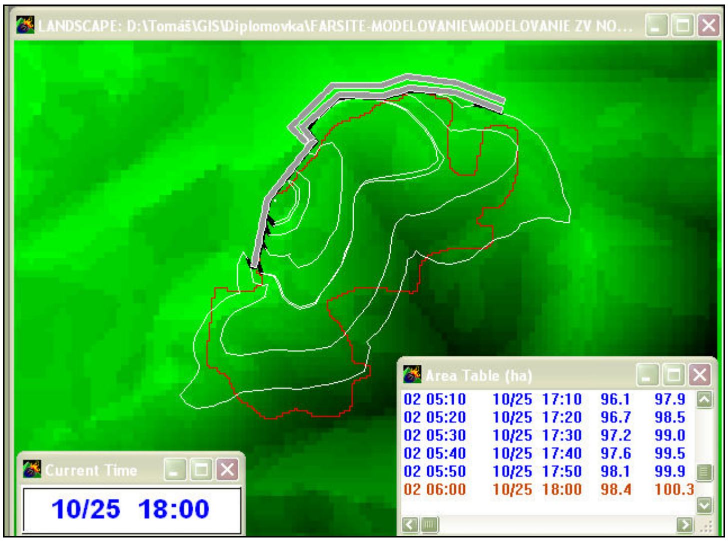



*Fig.7 Simulation with fuel models 25, 27 and 30, Mx=15%, gray lines are borders to prevent spreading behind the ridge.*

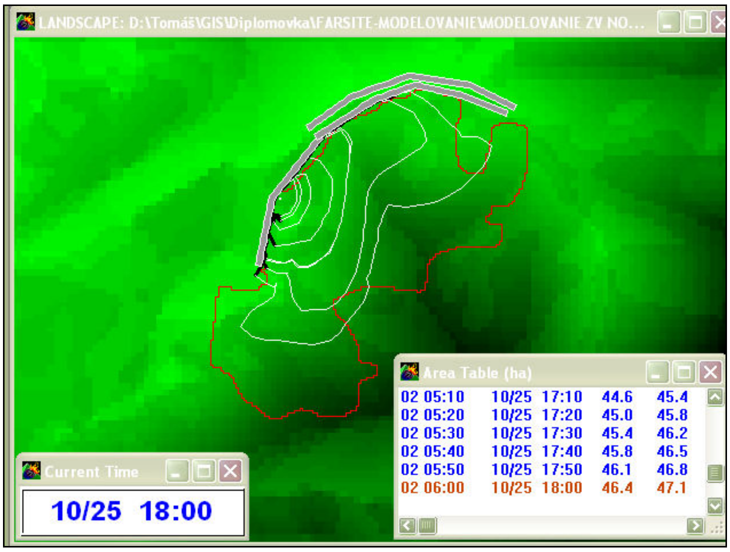



*Fig.8 Simulation with fuel models TER, Mx=15%, gray lines are borders to prevent spreading of fire behind the ridge.*

## 5 Conclusion

Forest fire simulation is common element of Fire management in the world. Its range of activity is of course focused to the places with large scale forest fires. Slovakia is small country with small burned area per year but each approach that will help with the fires in Slovakia is welcomed. Forest fire simulation could help in our condition, but we need to work out the problems mentioned above.

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