FOREST FIRE MANAGEMENT AND GIS MODELING

DESIGN AND IMPLEMENTATION OF A FOREST FIRE RISK MANAGEMENT SYSTEM FOR THE SWISS CANTON OF VALAIS

UNIGIS Module 5 – GIS and Modeling, Tutor Assessed Assignment 1

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1. INTRODUCTION

In the geographic information science, modeling is conceived as a set of operations to simulate events occurring in the real world (Goodchild 2005). GIS models are especially appreciated in environmental disciplines, where spatiotemporal simulations are considered to enhance the understanding of complex processes (Goodchild 1996; Martell 2001). In the forest fire risk management, for example, the implementation of GIS models is an essential tool for researchers, professionals and decision makers (Valese *et al.* 2010). In this context, the present assignment aims to investigate modeling methods for forest fire risk management, by applying them in a concrete case-study prototype.

The selected case-study deals with the design and implementation of a Forest Fire Risk Management System prototype for the Swiss canton of Valais. The study area is situated in the southwestern part of the alpine range, dominated by the wide valley of the Rhône. From it, numerous side valleys develop, where most of the region's glaciers and peaks – exceeding 4,500 meters – are situated (Canton du Valais 2013). In spite of its harsh topographic conditions, the canton Valais is one of the driest parts of Switzerland. For this reason, the forest fire risk is generally significant, especially in association with the recent global climatic changes (Zumbrunnen *et al.* 2009).

This assignment begins with an overview of the datasets used in the case-study. Afterwards, the modeling methods applied in the Forest Fire Risk Management System prototype are presented and summarized in a diagram. The prototype combines three distinct modules for the forest fire risk management: the Outbreak Detection module, the Risk Area Prediction module and the Potential Cost Estimation module. The prototype implementation within a chosen GIS software package is then described and tested trough the input of the previously selected datasets and the visualization of the outputs. In the conclusions, limits and potentialities of the employed modeling methods and techniques are discussed.

2. SELECTED DATA

Forest fire management specialists agree on the fact that forest fire risk management systems are based at least on four thematic datasets (Chuvieco and Congalton 1989; Jaiswal *et al.* 2002). These describe the **TOPOGRAPHIC CHARACTERISTICS** (elevation, slope, aspect etc.), the **LAND COVER TYPOLOGIES** (urban area, forest, plantation etc.), the **WEATHER CONDITIONS** (precipitation, temperature, wind etc.) and the **FIRE OUTBREAK INFORMATION** (location, extent etc.). The relief and land cover data are generally relevant for medium-long periods, while weather and fire outbreak information need to be regularly updated (Jaiswal *et al.* 2002).

The geographical situation of the canton Valais is determinant in the data selection, design and implementation of the Forest Fire Risk Management System prototype. Because of the relatively small surface and the complex topography of the study area, the data quality and reliability have to provide significant information to be integrated in the prototype (Zumbrunnen *et al.* 2009). For this reason, data issued from Swiss national administrative offices have been primarily considered. The selected thematic datasets (in small caps) and the preliminary GIS transformations performed in ESRI ArcGIS 10.0 (between square brackets) are described hereafter.

The **TOPOGRAPHIC CHARACTERISTICS** are presented through a Digital Elevation Model raster dataset. The ELEVATION raster dataset is issued from the height information of the Swiss National Map 1:25,000, where a 200 meters grid has been interpolated (SwissTopo 2004). The dataset is clipped to the VALAISREGION vector data [Mask Tool], to fit to the extent of the study area (see Figure 1). The ASPECT raster dataset (see Figure 12) is generated from the ELEVATION raster dataset through a standard GIS operation [Aspect Tool].

Figure 1. The relief elevation for the canton Valais.

The **LAND COVER TYPOLOGIES** are issued form the Swiss National Map 1:200,000 and include land cover, building, transportation and hydrographic network thematic data. The LANDCOVER vector data presents the main surface typologies, among others: urban area, forest, glacier, rock etc.. The

BUILDING vector data presents the buildings' footprints. The ROADWAY and the RAILWAY vector data present the transportation network, where the type of infrastructure is described. The HYDROGRAPHY vector data presents the hydrographic network (SwissTopo 2012). The data are clipped to the VALAISREGION vector data [Mask Tool], to fit to the extent of the study area (see Figure 2 and 3).

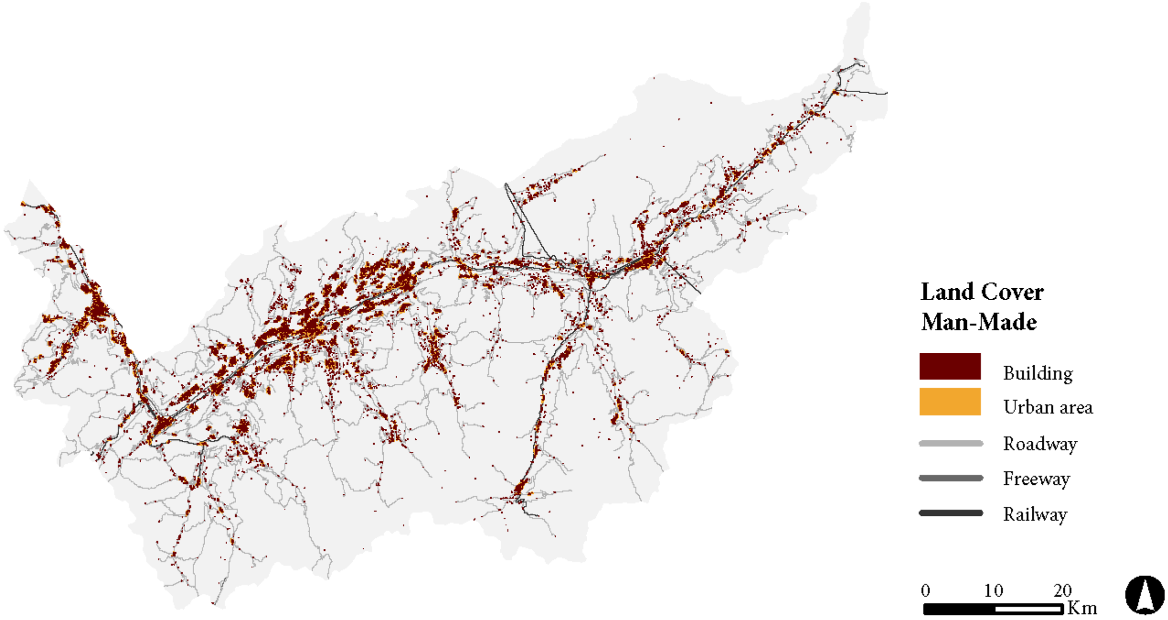


Figure 2. The man-made land cover typologies for the canton Valais.

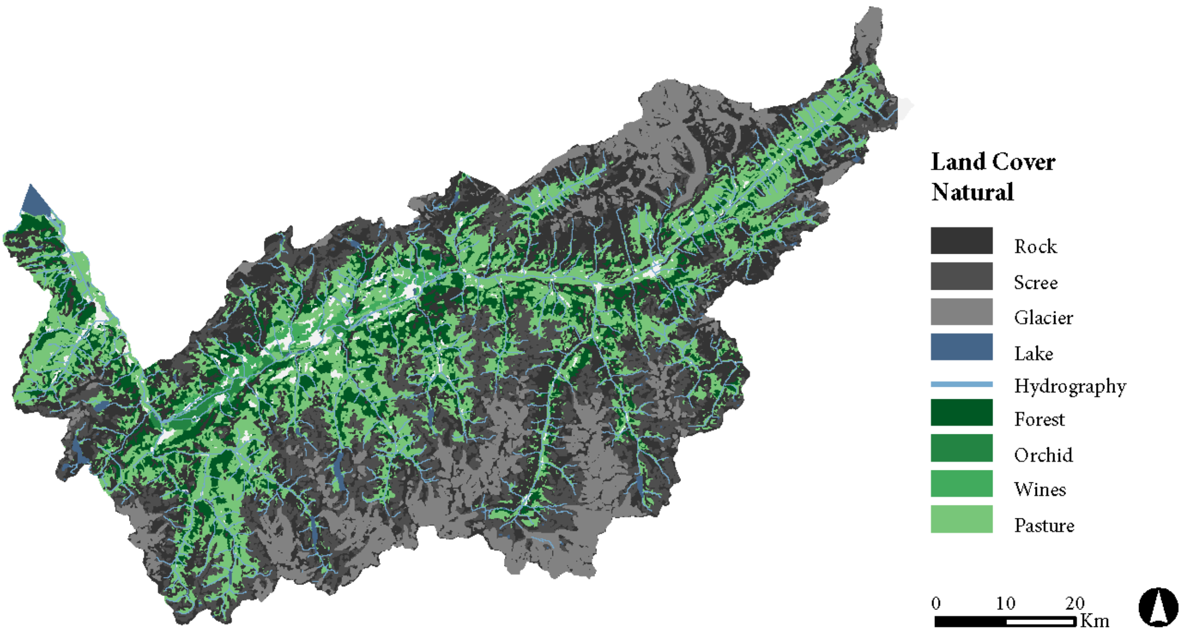


Figure 3. The natural land cover typologies for the canton Valais.

The **WEATHER CONDITIONS** are presented through the information published in the MeteoSwiss website. The RADARIMAGE raster datasets are issued from the Swiss weather radar network system (MeteoSwiss 2013a). The datasets have a 500 meters resolution and pixels store the precipitation amount values. After being downloaded from the MeteoSwiss website, the datasets are georeferenced [Georeferencing Tool] and clipped [Mask Tool] to the VALAISREGION vector data. TEMPERATURE and WIND information are tabular data issued from the MeteoSwiss website, which are collected for the weather stations of Visp and Zermatt (MeteoSwiss 2013b; 2013c).

The **FIRE OUTBREAK INFORMATION** is issued from a MODIS Airborne Simulator image presenting the site of a large forest fire in Aspen (United States). The FALSECOLOR raster dataset is a false color image, displaying the medium infrared wavelengths (NASA 2003). These frequencies are previously selected [Make Raster Layer Tool] from the 38 bands provided by the MODIS sensor (NASA 2012). The image visualization is improved through brightness and contrast tuning [Histogram Stretch Tool]. The FALSECOLOR dataset is selected because of the unavailability of remote sensed images for Valais and is therefore artificially georeferenced [Georeferencing Tool], to fit to the study area.

NAME	DESCRIPTION	OPERATION	DATA TYPE	ATTRIBUTES	SOURCE
VALAISREGION	Study area boundary	None	Vector polygon	Region name and surface	*SwissTopo*
ELEVATION	Digital height model	Clip	Raster	Meters above the sea level (m)	*SwissTopo*
LANDCOVER	Primary land cover typologies	Clip	Vector polygon	Land cover typology and surface	*SwissTopo*
BUILDING	Building footprint	Clip	Vector polygon	Surface	*SwissTopo*
HYDROGRAPHY	Hydrographic network	Clip	Vector polyline	Waterway type (canal, river etc.)	*SwissTopo*
ROADWAY	Paved roadway network	Clip	Vector polyline	Infrastructure type (bridge, tunnel etc.)	*SwissTopo*
RAILWAY	Railway network	Clip	Vector polyline	Infrastructure type (bridge, tunnel etc.)	*SwissTopo*
RADARIMAGE	Radar detected precipitation	Import and Georeference	Raster	Precipitation amounts (mm/h)	*MeteoSwiss*
WINDSPEED	Real-time wind speed	Import	Tabular data	Average wind speed (Km/h)	*MeteoSwiss*
TEMPERATURE	Real-time temperature	Import	Tabular data	Average air temperature (°C)	*MeteoSwiss*
FALSECOLOR	Remote sensed surface image	Georeference and Select Band	Multiband Raster	Infrared sensed surface features	*MODIS Simulator*

Table 1. The selected data to be implemented in the case-study prototype.

The vector data (see Table 1) is selected to present the study area's physical and climatic characteristics, since no georeferencing is needed for the GIS implementation of the Forest Fire Risk Management System prototype. The remote sensed dataset issued from the MODIS airborne device is selected because of the geographical situation of Valais. In a relatively small area with a harsh topography, the forest fire detection is generally performed trough sensing devices providing outstanding data quality and reliability (Barducci *et al.* 2002; SwissTopo 2003). The modeling methods employed in this case-study prototype are presented in the next section.

3. Design methods

Modeling methods for forest fire risk management have been widely investigated in scientific literature and implemented in GIS projects at different geographical scales (Valese *et al.* 2010). From the supranational to the regional level, there is a concordance on the thematic datasets employed in assessing the fire risk. On the contrary, the prototype design and implementation in a selected GIS software package strictly depend on the geographical situation of the study area (Global Fire Monitoring Center 2013). The modeling methods applied in the Forest Fire Risk Management System prototype are therefore linked to the ass canton Valais' assumed specific situation (Zumbrunnen *et al.* 2009).

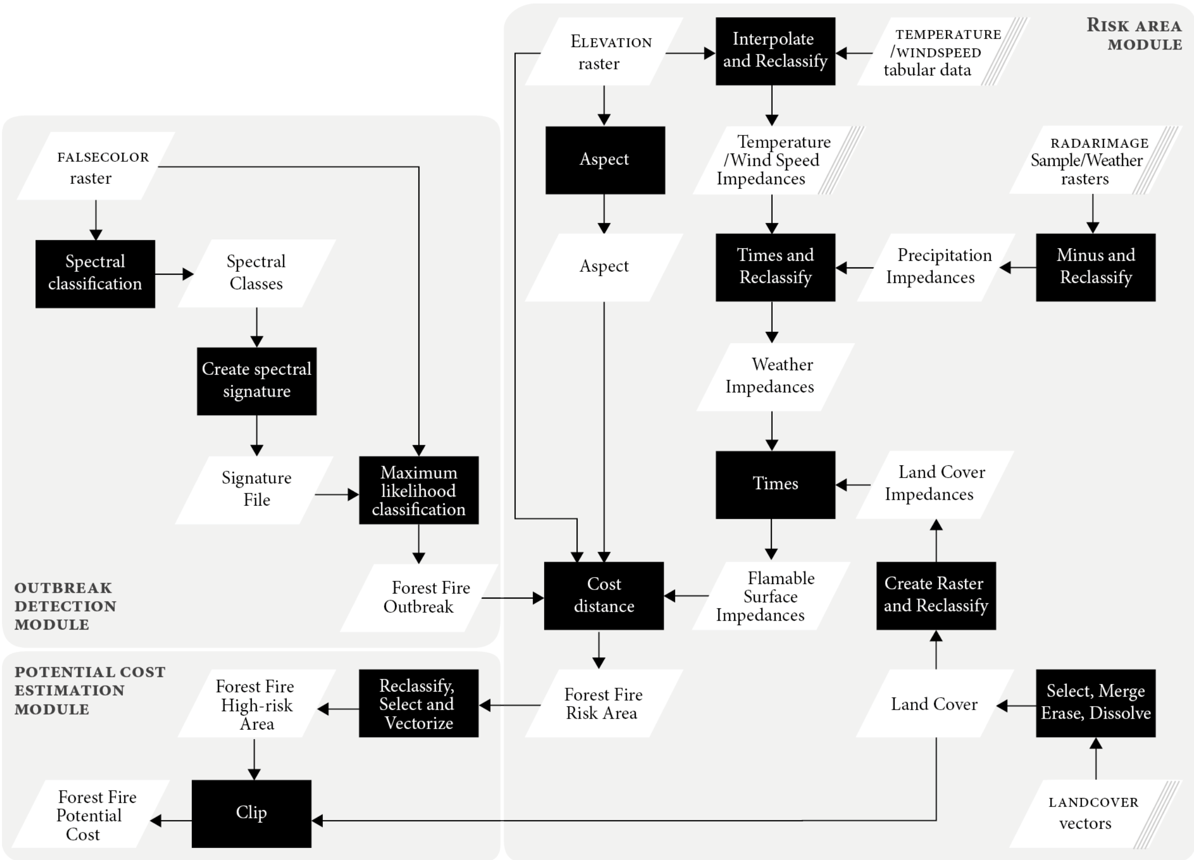


Figure 4. The case-study prototype modules (light gray), components (black) and processes (white).

The case-study prototype combines three specific modules (see Figure 4). The Outbreak Detection module provides information about the fire location and extent. The Risk Area Prediction module links a set of criteria to locate the area at fire risk. The Potential Cost Estimation module quantifies the expected damage for the area assuming the highest fire risk. The three prototype modules use the output of the previous module as an input. The modeling methods on which each module is designed and the preconized GIS operations in ESRI ArcGIS 10.0 software are presented hereafter.

The **OUTBREAK DETECTION MODULE** is based on the detection and extraction of forest fire information from remote sensed images, which are issued from a MODIS Airborne Simulator device. A forest fire is commonly detected through the analysis of specific spectral ranges, belonging to the medium infrared, which captures the medium infrared surface reflectance (Barducci *et al.* 2002). The highest reflectance values usually identify the fire front, while the lower ones the burned surface (Barducci *et al.* 2002). The quality and reliability of the datasets is meant to precisely locate the extent of the fire front and burned surface for the study area (NASA 2003).

In the FALSECOLOR raster dataset, the shortwave infrared frequencies are assigned to the red channel, the near infrared to the green channel, and the green to the blue channel (NASA 2012). The visualization of these channels makes the extent of the burning area easier to detect (Barducci *et al.* 2002). The spectral classes of selected elements of interest (see Table 2) are subsequently determined [Image Classification Toolbar] and stored in a signature file [Generate Signature File Tool]. The signature file is used in the classification of the FALSECOLOR raster dataset [Maximum Likelihood Classification Tool], to generate a raster dataset locating among others the fire outbreak extent.

SURFACE CLASS	VALUE
FIRE FRONT	1
BURNED SURFACE	2
FOREST AND PASTURE	3
ROCK AND SCREE	4

Table 2. The remote sensed pixel classes.

The **RISK AREA PREDICTION MODULE** defines the flammable surfaces spreading impedances, in order to simulate the fire potential development (Rego and Catry 2006). The encounter of spreading impedances is linked to the fire development direction, which is derived from the outbreak location. The more impedances the fire encounters in its development, the less is the risk of further spreading. The module is therefore based on two distinct sub-modules combined in a cost distance algorithm [Cost Distance Tool]: the presence of flammable surfaces spreading impedances and the direction of the fire development (Ntaimo *et al.* 2004). The output of this module is a raster dataset locating the area at fire risk.

The presence of flammable surfaces spreading impedances is at first determined through the modeling of the study area land cover typologies (Jaiswal *et al.* 2001). The selected landcover vector data are combined through specific GIS operations [Buffer, Erase, Merge and Dissolve Tools] to create a classified raster dataset [Polygon to Raster and Reclassify Tools] where flammable surfaces opposing the greater obstacles have the highest pixel values (see Table 3). Then, the weather impedances are modeled by combining [Times Tool] the precipitation, wind speed and temperature dynamic sub-models.

The precipitation sub-model is issued from the subtraction [Minus Tool] of a SAMPLE RADARIMAGE raster dataset for a dry period to an updated WEATHER RADARIMAGE raster dataset. The output is reclassified [Reclassify Tool] to present the rainy area only (see Table 4). The temperature and wind speed datasets are calculated [Math Tool] through a basic interpolation, based on the least squares method (UNIGIS 2013). This technique has been selected because the temperature generally decreases homogenously with the altitude (Ishida and Kawashima 1993) and the wind speed increases with the altitude (Cattin *et al.* 2002). The input data for the model are updated TEMPERATURE and WIND information, issued from the weather stations of Visp and Zermatt, and the ELEVATION raster dataset. The resulting raster datasets are reclassified [Reclassify Tool] to locate the area where temperatures and wind speed conditions oppose the greatest impedances to the fire development (see Table 4). The outputs of the Land Cover Impedances model and the Weather Impedances model are combined [Times Tool] in a raster dataset locating the co-presence of flammable surfaces spreading impedances.

LAND COVER TYPE	VALUE
URBAN AREA	2
BUILDING	1
ROADWAY	5
FREEWAY	6
RAILWAY	6
FOREST	1
ORCHARD	2
VINES	3
PASTURE	4
HYDROGRAPHY	6

Table 4. The land cover typology values.

PRECIPITATION	VALUE
0 mm/h	1
> 0 mm/h	null
TEMPERATURE	
≤ 5 °C	null
> 5 °C and ≤ 15 °C	2
> 15 °C	1
WIND SPEED	
≤ 10 Km/h	2
> 10 Km/h	1

Table 3. The weather condition classes.

The fire development direction is modeled from the relief characteristics only. The ELEVATION raster dataset determines the fire vertical development, while the derived ASPECT raster dataset defines the fire horizontal development (ESRI 2007). This method has been chosen since a forest fire generally develops up-hill and on the same flank of the valley (Butler *et al.* 2007; Jaiswal *et al.* 2002). The case-study prototype does not consider the relief slope and wind direction, because the modeling for the study area requires too many resources (Butler *et al.* 2007; Cattin *et al.* 2002).

The **Potential Cost Estimation module** uses the fire risk area raster dataset generated in the previous module to locate the area exposed to the highest fire risk. In doing so, the risk-area is reclassified using five risk classes [Reclassify Tool] according to the Jenkins classification method. The area belonging to the highest risk-class is then selected [Select Tool] and converted in a vector data [Raster to Polygon Tool]. This is employed to clip [Clip Tool] the LANDCOVER vector data, to locate the surfaces that are likely to be damaged by the forest fire. The costs, in terms of potentially affected surfaces, are determined by simply interrogating the attribute table of the module output's vector data.

The modeling methods previously presented are combined in order to design the Forest Fire Risk Management System prototype. Once the fire outbreak location has been detected through the analysis of the MODIS Airborne Simulator image (Outbreak Detection module), the output is used as input in the definition of the risk area (Risk Area Prediction module), which in its turn is used as input to define the potential damages (Potential Cost Estimation module). The concrete combination of these three modules within the selected GIS software package is described and tested in the next section.

4. System implementation

The concrete implementation of the Forest Fire Risk Management System prototype in a GIS software package relies on many factors, among others data and resources availability (UNIGIS 2013). Due to lack of resources, especially time, the design of the system components and the GIS modeling process are voluntarily simplified in the case-study prototype. The GIS implementation presented is therefore to be considered as the result of an exploratory study, investigating different designs methods and GIS techniques, and is yet to be refined and validated through further tests and analysis (UNIGIS 2013).

The modeling methods employed in the Forest Fire Risk Management System prototype are issued from two distinct approaches, determining the concrete implementation in the selected GIS software package (UNIGIS 2013). The Outbreak Detection module is based on natural analogues, where the state of the system is modeled through the examination of images of fire outbreak. The Risk Area Prediction and the Potential Costs Estimation modules are based on mathematical models simulating the possible outputs of the system through rules and algorithms (UNIGIS 2013). The implementation of these approaches in the ESRI ArcGIS 10.0 software is described and tested hereafter.

4.1. Outbreak Detection module

The implementation of the Outbreak Detection prototype module in the ArcGIS 10.0 software uses techniques for the analysis and extraction of fire information from remote sensed images. In the software, the classification process is a multi-step semi-automated workflow, which is managed through the Image Classification Toolbar (ESRI 2012). The first step consists in the selection of the image to be detected and the sample to generate the spectral signature file used in the image classification. In the case-study prototype, the FALSECOLOR raster dataset (see Figure 5) is employed as input for the image detection and as sample to create the signature file.

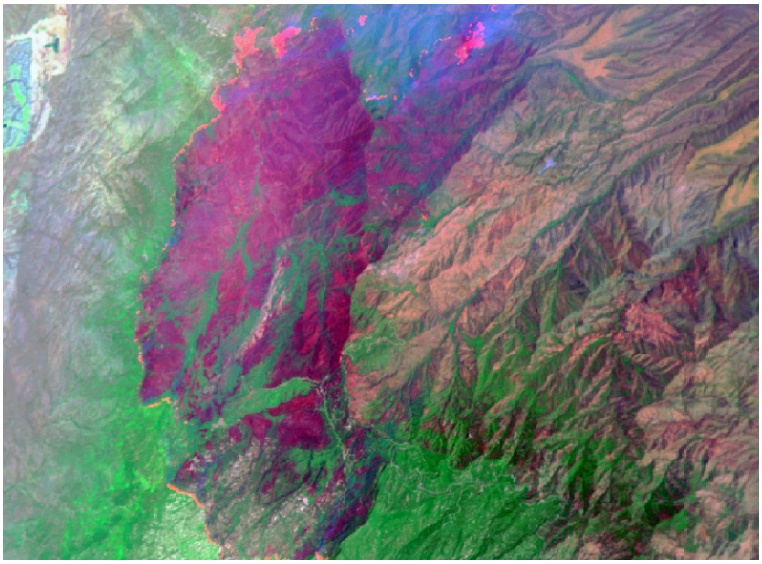


Figure 5. The FALSECOLOR raster dataset.

The second step is the generation of the raster signature file, through the analysis of the selected sample (ESRI 2012). The Image Classification Toolbar allows determining pixels classes, by simply drawing on the sample (see Figure 6). The FALSECOLOR raster dataset is classified according to four surface classes: the fire front, the burned surface, the forest and pasture, the rock and scree. The selected frequency channels allow an easy classification of the elements of interest. The fire front appears as a bright orange-red area around the purple burned surface. The forest and pasture appear as green and the rock and scree as different levels of brown.

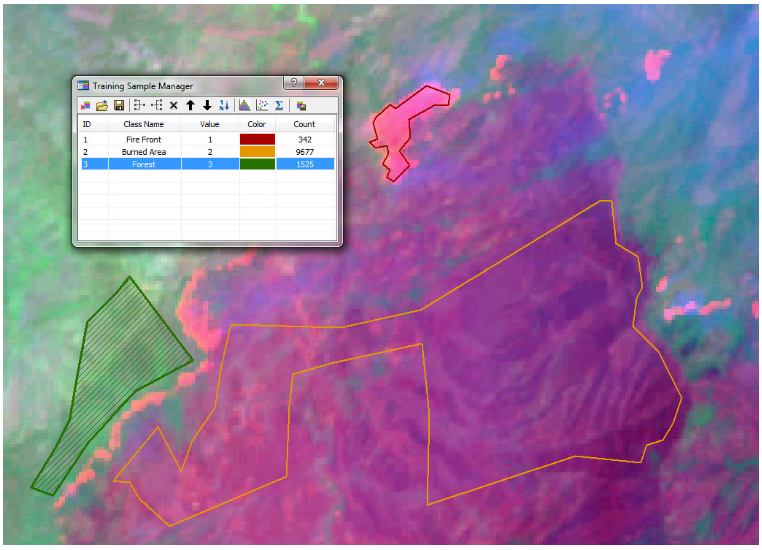


Figure 6. The FALSECOLOR raster classification process in ArcGIS 10.0.

The result of this procedure is a series of polygons identifying the spectral characteristics of each class. To avoid misrepresentations, the spectral characteristics are analyzed and compared through the Histogram Window (see Figure 7). The output is stored as a signature file [Create Signature File Button] that can be used in further analysis. Once the signature file is generated, the classification of the FALSECOLOR raster dataset can be effectuated [Interactive Supervised Classification Tool]. This procedure [Maximum Likelihood Classification Tool] is straightforward and carried out with default parameters (ESRI 2012). The output of the FALSECOLOR raster classification is a raster dataset, presenting the classes determined in the signature file. This allows locating the fire outbreak (fire front and burned surface) according to the corresponding pixel values.

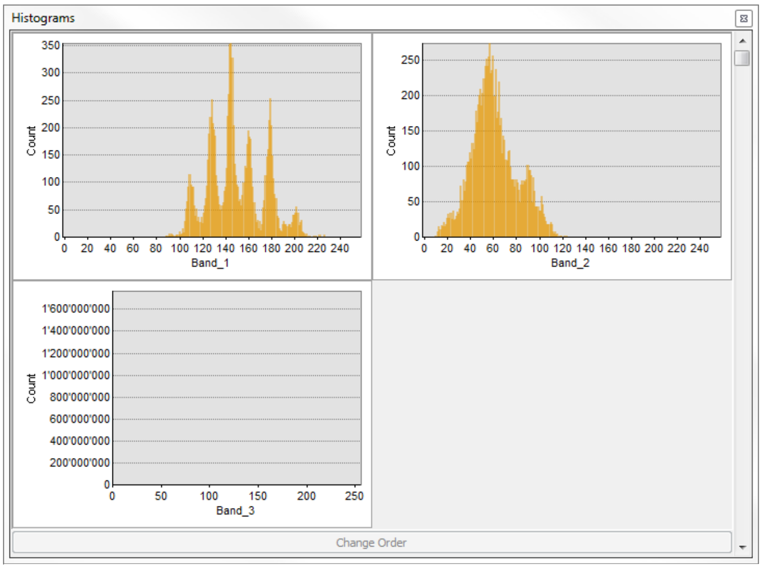


Figure 7. The histogram window for the sample classes.

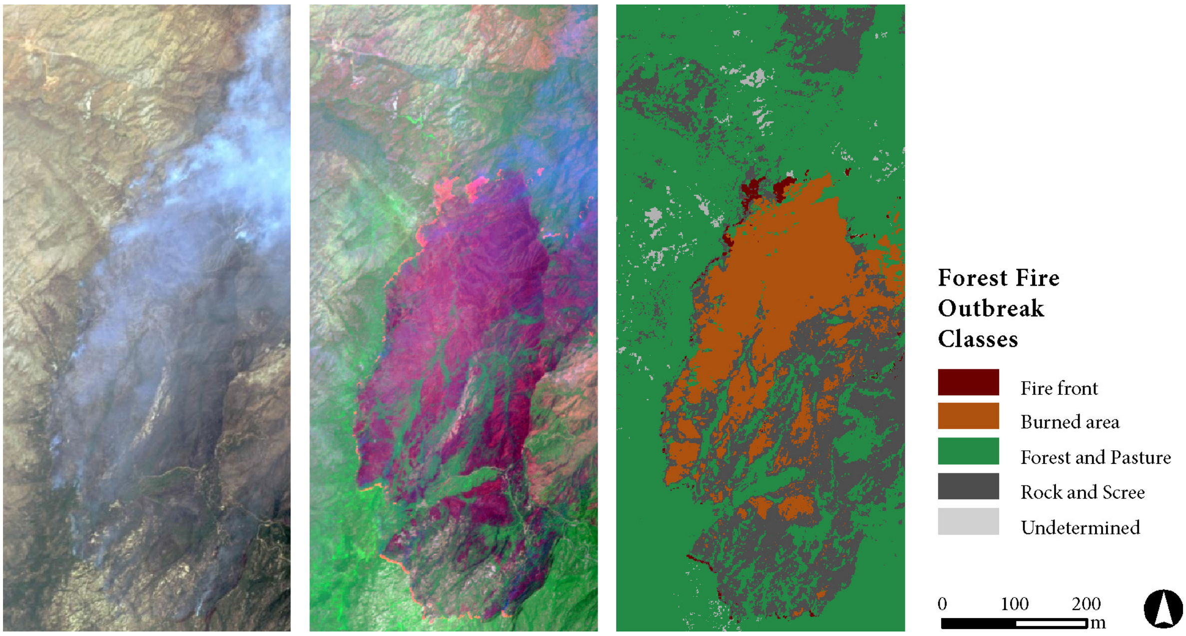


Figure 8. The Aspen fire true color image, false color image and classified raster dataset output of the Outbreak Detection module.

The FALSECOLOR raster dataset reclassification shows that the use of the selected frequencies channels makes the extent of the fire front and burned surface easier to detect, by penetrating the fire smoke (see Figure 8). Moreover, the generated signature file allows automatically extracting information from additional MODIS remote sensed images of the study area. This feature can be used in monitoring and comparing the spatiotemporal development of the forest fire (Barducci *et al.* 2002; Martell 2001). The fire front and the burned surface extent location are used as input for the next module, where the fire risk area is determined (Rego and Catry 2006; Sibanda 2011).

4.2. Risk Area Prediction module

The implementation of the Risk Area Prediction prototype module in the ArcGIS 10.0 software uses basic mathematical techniques simulating the possible fire development and the risk area from a series of inputs data (Rego and Catry 2006; UNIGIS 2013). This module is designed from two sub-modules, which define the flammable surfaces spreading impedance and the fire development direction. The result of these sub-modules is then combined to the outbreak location raster dataset in a cost-distance algorithm to determine the fire risk area (Ntaimo *et al.* 2004). The prototype module operations are semi-automated, as implemented in the ArcGIS 10.0 Model Builder (see Annex 1-3).

The **Flammable Surfaces Spreading Impedances sub-module** is mainly built on modeling rules for the land cover typologies (see Annex 1). At first, the flammable surfaces are selected from the LANDCOVER vector data [Clip Tool] and merged [Merge Tool] to the BUILDING vector data. The BUILDING surfaces have been previously erased [Erase Tool] form the LANDCOVER vector data to avoid the polygons' superposition. The ROADWAY, RAILWAY and HYDROGRAPHY vector data are then buffered (20 meters radius) [Buffer Tool] and merged [Merge Tool] to combine the possible spreading impedances surfaces. These are previously erased [Erase Tool] from the LANDCOVER vector data to avoid the polygons' superposition and then merged [Merge Tool] to the flammable surfaces vector data. The output is dissolved [Dissolve Tool] to keep the land cover typologies information only. The polygons are finally converted in a raster dataset [Polygon to Raster Tool], and reclassified [Reclassify Tool], according to the land cover typologies value (see Table 3). The derived raster dataset locates the flammable surfaces, which are classified according to their spreading impedance value (see Figure 9).

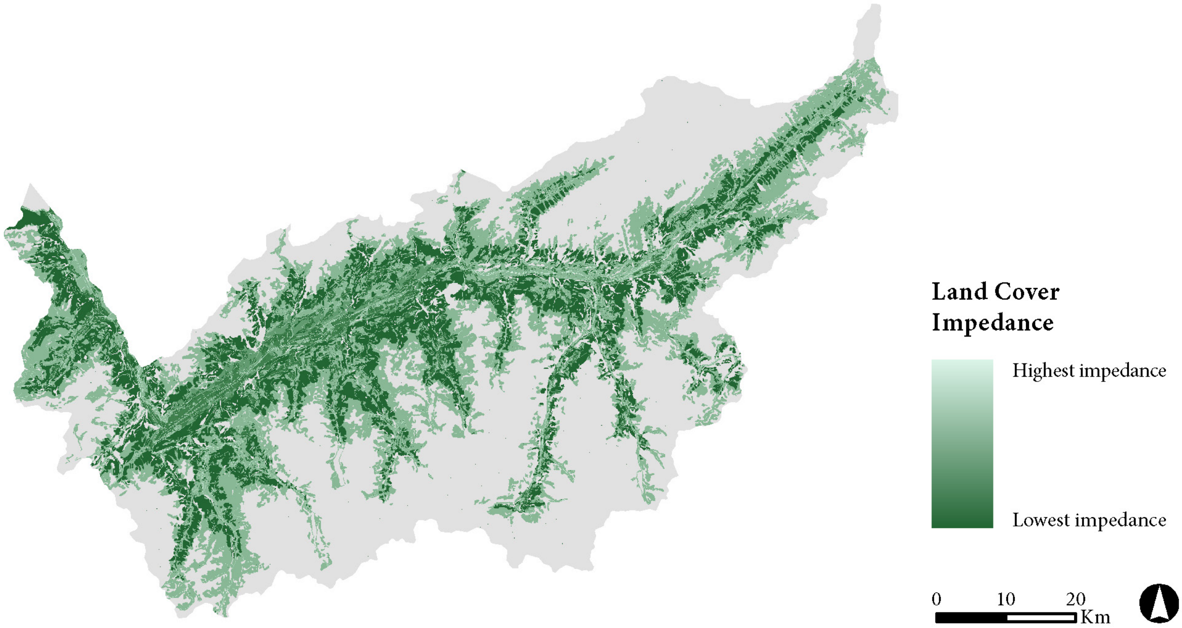


Figure 9. The land cover (man-made and natural) flammable surfaces spreading impedances.

The flammable surfaces fire development is also influenced by weather conditions. The selected weather parameters are the precipitation, wind speed and temperature. The precipitation is modeled through the simple subtraction [Minus Tool] of a SAMPLE RADARIMAGE raster dataset (without precipitation) from an updated WEATHER RADARIMAGE raster dataset (see Annex 2). This raster dataset is one of the model parameters and can be constantly updated. The result is finally reclassified [Reclassify Tool] to locate area where precipitation occurs (see Table 4). In the case-study prototype, the WEATHER RADARIMAGE raster dataset shows no precipitation on the study area (see Figure 10) generating a constant raster dataset with value 1. The temperature and wind speed are modeled according to a simple interpolation method, based on the least squares method (see Annex 2). The algorithm is based on the following equation: $\boldsymbol{E=Ha+b}$, where $\boldsymbol{E}$ is the event value (TEMPERATURE or WINDSPEED), $\boldsymbol{H}$ the altitude, $\boldsymbol{a}$ and $\boldsymbol{b}$ the two variables of the equation (UNIGIS 2013). In the case-study prototype, $\boldsymbol{a}$ and $\boldsymbol{b}$ are calculated [Math Tool] from the values for the weather stations

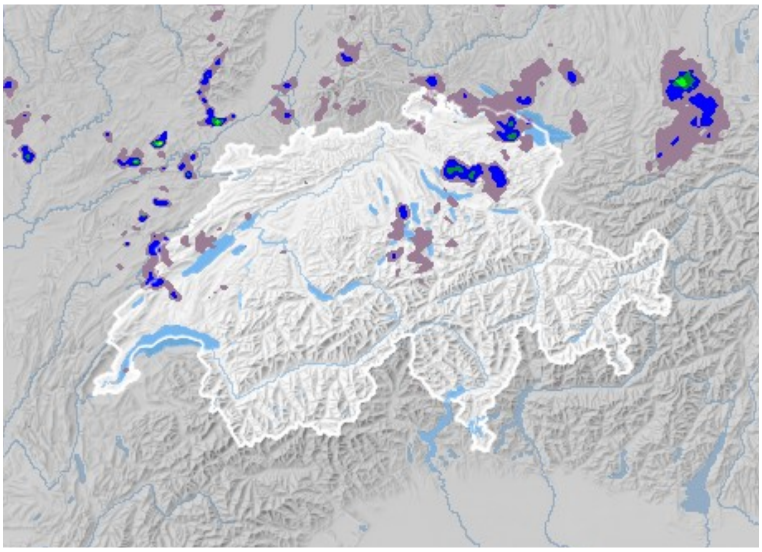


Figure 10. The WEATHER RADARIMAGE raster dataset for the 11.03.2013 (MeteoSwiss 2013a).

of Visp and Zermatt and then applied to the ELEVATION raster dataset in order to determine the ***E*** value for the study area. The selected values (see Table 5) are used as the model's parameters and can be constantly updated. Once the temperature and wind impedances raster datasets have been created and reclassified [Reclassify Tool] (see Table 4), they show the fire development weather impedances (1 and 2 values) and serious impedances (*null* value), where the fire development is impossible. The three resulting weather impedances raster datasets are combined [Time Tool], by amplifying the co-presence of weather impedances. This shows that the bottom of the valleys offer greater weather impedances, because of the wind speed weakness, while the highest areas' weather impedances are moderate, because of the low temperatures (see Figure 11).

VISP WEATHER STATION	
Elevation (m)	650
Temperature (°C)	20
Wind speed (Km/h)	7
ZERMATT WEATHER STATION	
Elevation (m)	1600
Temperature (°C)	14.5
Wind speed (Km/h)	14.5

Table 5. The event values for the Visp and Zermatt weather stations.

Figure 11. The weather conditions flammable surfaces spreading impedances.

The results of the land cover and weather conditions sub-models are combined through a multiplication [Times Tool] to locate the flammable surfaces spreading impedances. Finally, the **FIRE DEVELOPMENT DIRECTION SUB-MODEL** simply consists in the ELEVATION raster dataset and the derived ASPECT raster dataset (see Figure 12). The ELEVATION dataset determines the fire development vertical direction, while the ASPECT dataset refers to the fire development horizontal direction. In the implementation of this prototype module, it is considered that a forest fire generally develops up-hill and on the same flank of the valley (Butler *et al.* 2007; Jaiswal *et al.* 2002).

Figure 12. The relief aspect derived from the Digital Elevation Model for the canton Valais.

Once the outputs for the sub-modules have been generated it is possible to run the cost distance algorithm [Cost Distance Tool] (see Figure 13). This process calculates, for each cell, the least accumulative cost distance to the nearest source, considering surface distance, horizontal and vertical cost factors (ESRI 2007). The input raster dataset is issued from the Outbreak Detection module. The cost factor input is issued from the Flammable Surfaces Spreading Impedances sub-module. The Fire Development Direction sub-model raster datasets determine the vertical and horizontal parameters. The vertical cost follows an inverse linear function of the vertical relative moving angle, while the horizontal cost follows a linear function of the horizontal relative moving angle (ESRI 2007). Default parameters have been used for the parameter settings. The output locates the fire development from the outbreak location (see Figure 14).

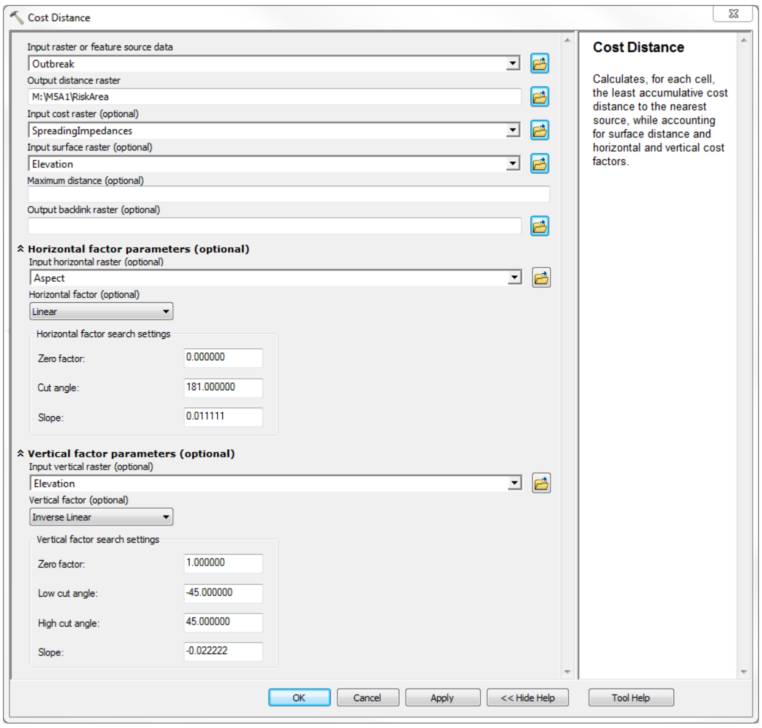


Figure 13. The Cost Distance Tool settings window in ArcGIS 10.0.

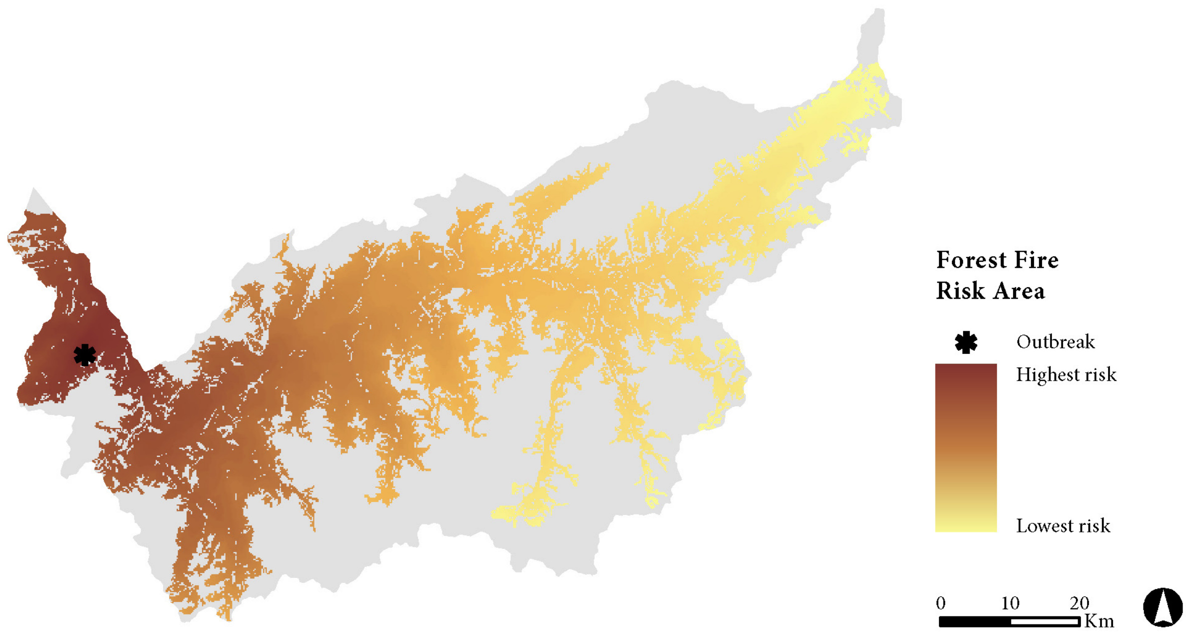


Figure 14. The output of the Risk Area Prediction module.

The output visualization shows that the fire risk generally decreases with the distance and increases up-hill. The presence of flammable surfaces spreading impedances affects the fire risk at a smaller scale. A finer visualization shows that the influence of the land cover and weather impedances are determinant for the forest fire development. The input of updated model parameters in the ArcGIS 10.0 Model Builder allows the monitoring and comparing the spatiotemporal development of the fire risk area. The fire risk area information is used as input for the next module, where the potential costs for high-risk area are estimated.

4.3. Potential Costs Estimation module

The implementation of the Potential Costs Estimation prototype module in the ArcGIS 10.0 software package uses basic mathematical techniques simulating the costs per square meters for the surface that is most likely to be affected by the fire (Rego and Catry 2006; UNIGIS 2013). The first step is determining the area at the highest fire risk. This is a subjective judgment because the conception of concept itself is issued from the human perception of a potential event (Goodchild *et al.* 1996). After several tests the most satisfying result is issued form the classification in five classes [Reclassify Tool] according to the Jenkins method (see Figure 15).

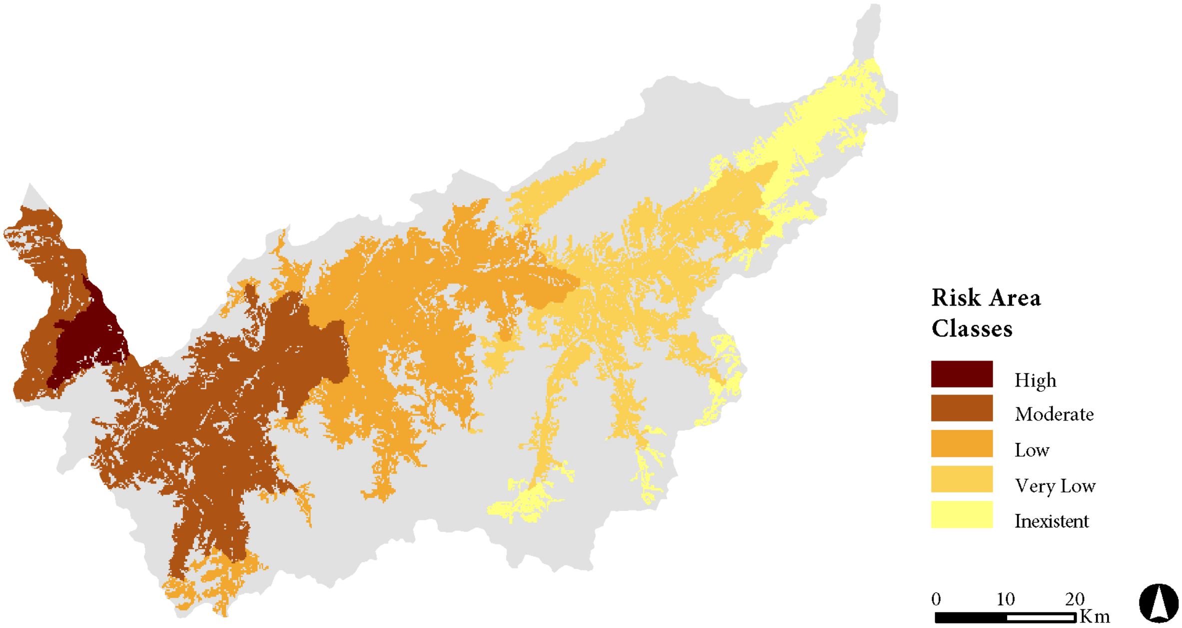


Figure 15. The risk classes of the output of the Risk Area Prediction module.

The surfaces exposed to the highest fire risk are subsequently selected and extracted [Extract by Attributes Tool]. The operation shows that the west of the study area is the one that is most likely to be affected by forest fire. The resulting raster dataset is then converted into a vector data [Raster to Polygon Tool] and used in the extraction [Clip Tool] of the flammables surfaces from the LANDCOVER vector data. The output locates the surfaces exposed to the highest fire risk, according to the land cover typology (see Figure 16).

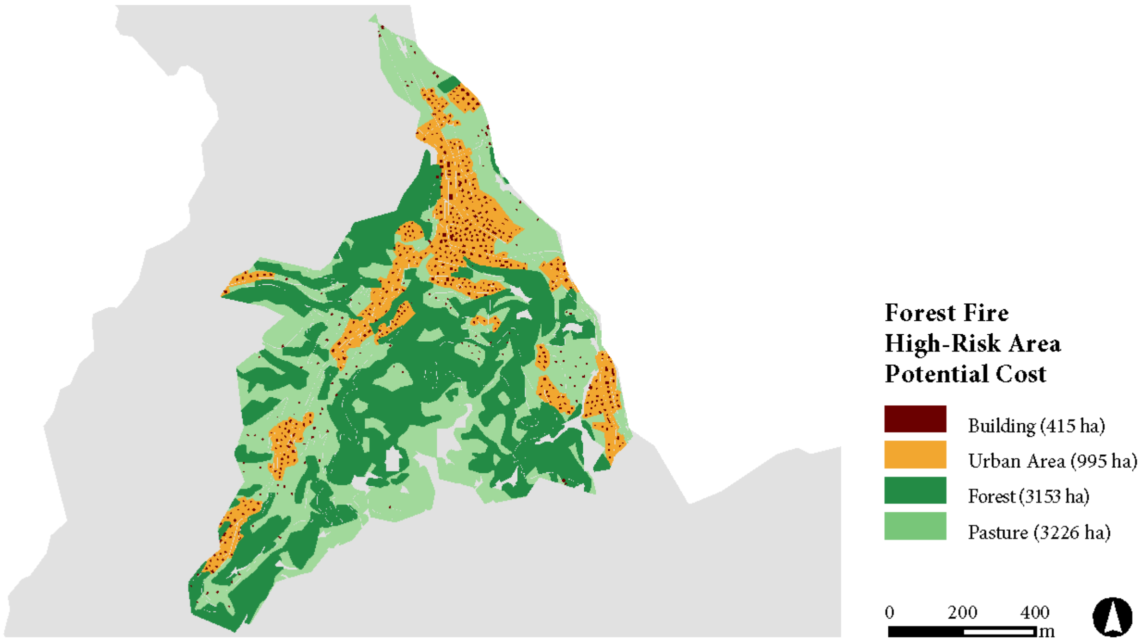
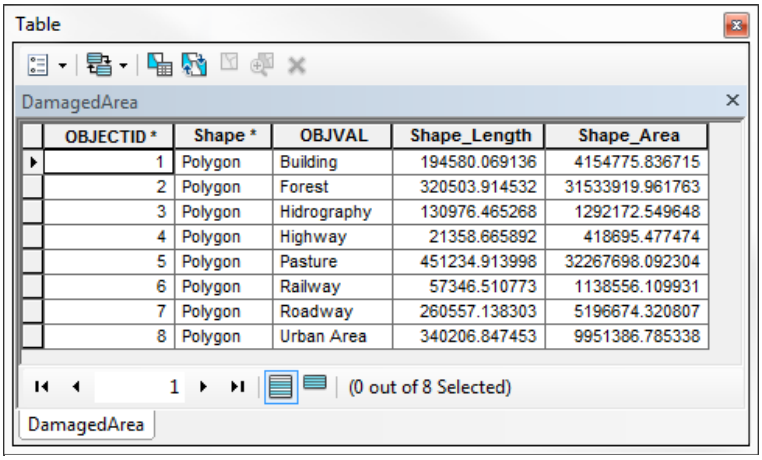


Figure 16. The output of the Potential Costs Estimation module.

The analysis of the output visualization can be improved by querying the vector data attribute. The operation provides the exact surface, in square meters, for each affected land cover typology table (see Figure 17). The module implementation in the ArcGIS 10.0 Model Builder (see Annex 4) allows the operation semi-automation and the creation of constantly updated the expected costs, from the Risk Area Detection module outputs. This allows monitoring and comparing the spatiotemporal development of the expected cost.



OBJECTID *	Shape *	OBJVAL	Shape_Length	Shape_Area
1	Polygon	Building	194580.069136	4154775.836715
2	Polygon	Forest	320503.914532	31533919.961763
3	Polygon	Hidrography	130976.465268	1292172.549648
4	Polygon	Highway	21358.665892	418695.477474
5	Polygon	Pasture	451234.913998	32267698.092304
6	Polygon	Railway	57346.510773	1138556.109931
7	Polygon	Roadway	260557.138303	5196674.320807
8	Polygon	Urban Area	340206.847453	9951386.785338

Figure 17. The vector data attribute table.

As previously described, the Potential Cost Estimation module, together with the Outbreak detection and the Risk Area Prediction modules are combined in the Forest Fire Risk Management System prototype. In the case-study prototype, the implementation using ArcGIS 10.0 software allows the construction of semi-automated GIS operations through the ArcGIS 10.0 Model Builder. These operations create a series of dynamic outputs through the update of the modules' parameters. This feature is extremely important, because spatiotemporal simulations enhance the understanding and the action-planning against a forest fire (Global Fire Monitoring Center 2013).

5. Conclusions

In this assignment, the modeling methods for forest fire risk management are investigated through the design and GIS implementation of a Fire Risk Management System prototype for the Swiss canton of Valais. The geographic situation of the study area influences the whole modeling process, from the data selection, to the prototype design and the GIS implementation. In this case-study, four thematic datasets have been chosen to describe the forest fire risk. These are selected to provide the best quality and reliability and are primarily issued from Swiss national administrative offices.

The case-study prototype combines three specific modules: the Outbreak Detection module, the Risk Area Prediction module and the Potential Cost Estimation module. These modules use the output of the previous module as an input. In spite of the limited available resources, the prototype design provides a basic simulation of real world events determining of the forest fire behavior. The ArcGIS 10.0 software prototype implementation also presents some limitations due to the lack of resources availability. Nonetheless, the use of the ArcGIS 10.0 Model Builder allows the execution of semi-automated GIS operations, where dynamic outputs are generated through update of the modules' parameters.

This assignment allows understanding of the main issues connected with the design and implementation of a spatiotemporal prototype for forest fire risk management. The result of this case-study is therefore to be considered as an exploratory investigation, aiming to bring up different design methods and GIS techniques. The combination of rule-based, empirical and dynamical basic models has been structured according to different existing researches and projects. The employment of various GIS operators, such as the raster subtraction or the cost distance algorithm, allow us to appreciate appreciating the modeling capacities of ESRI ArcGIS 10.0, one of the GIS software package market leaders.

7. REFERENCES

Barducci, A. *et al.*, 2002, Infrared detection of active fires and burnt areas: theory and observations, *Infrared Physics & Technology*, no. 43, pp. 119-125.

Butler, B.W. *et al.*, 2007, Influence of Slope on Fire Spread Rate, *USDA Forest Service Proceedings*, pp. 75-82.

Canton du Valais, 2013, *eAtlas du Valais – Thematique Environment* [Online], Available: http://www2.unil.ch/eatlasvs/geoclipenv [27.02.2013].

Cattin, R. *et al.*, 2002, *Wind Measurement and Modeling in the Swiss Alps* [Online], Available: http://www.meteotest.ch/fileadmin/user_upload/Windenergie/pdfs/paper_dewek02.pdf [27.02.2013].

Chuvieco, E. and Congalton, R.G., 1989, Application of Remote Sensing and Geographic Information System to Forest Fire Hazard management, *Remote Sensing and Environment*, no.29, pp. 147-159.

ESRI, 2012, *Supervised classification Using ArcGIS 10* [Online], Available: http://www. http://gis-services.net/?p=566 [27.02.2013].

ESRI, 2007, *Cost Distance Algorithm* [Online], Available: http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Cost_Distance_algorithm [27.02.2013].

Global Fire Monitoring Center, 2013, *Global Fire Monitoring Center (GFMC)* [Online], Available: http://www.fire.uni-freiburg.de [27.02.2013].

Goodchild, M.F., 2005, GIS and Modeling, In. Maguire, D.J., Batty, M. and Goodchild, M.F. (eds.), *GIS, Spatial Analysis, and Modeling*, ESRI Press: Redlands.

Goodchild, M.F. *et al.* (eds.), 1996, *GIS and Environmental Modeling: Progress and Research Issues*, Wiley: New York.

Ishida, T. and Kawashima, S., 1993, Use of cokriging to estimate surface air temperature from elevation, *Theoretical and Applied Climatology*, vol. 47(3), pp. 147-157.

Jaiswal, R.K. and al, 2002, Forest fire risk zone mapping from satellite imagery and GIS, *International Journal of Applied Earth Observation*, no. 4, pp. 1-10.

King, M.D. et *al.*, 1996, Airborne Scanning Spectrometer for Remote Sensing of Cloud, Aerosol, Water Vapor, and Surface Properties, *Journal of atmospheric and ocean technology*, no. 13(4), pp. 777-794.

Martell, D.L., 2001, Forest Fire Management, In. *Forest Fires: behavior and Ecological Effects*, Johnson, E.A., and Miyanishi, L. (eds.), Academic Press, San Diego, pp. 527-583.

MeteoSwiss, 20113a, *Current weather – Radar Images* [Online], Available: http://www.meteo-swiss.admin.ch/web/en/weather/current_weather/radar-images.html [27.02.2013].

MeteoSwiss, 20113b, *Current weather – Temperatures* [Online], Available: http://www.meteo-swiss.admin.ch/web/en/weather/current_weather.par0001.html [27.02.2013].

MeteoSwiss, 20113c, *Current weather – Current wind direction, speed and gusts* [Online], Available: http://www.meteoswiss.admin.ch/web/en/weather/current_weather.par0013.html [27.02.2013].

NASA, 2012, *Enhanced MODIS Airborne Simulator* [Online], Available: http://www. http://mas.arc.nasa.gov [27.02.2013].

NASA, 2003, *Earth Observatory: Aspen Fire, Arizona* [Online], Available: http://www. http://earthobservatory.nasa.gov/IOTD/view.php?id=3573 [27.02.2013].

Ntiamo, L. *et al.*, 2004, Forest Fire Spread and Suppression in DEVS, *Simulation*, no. 80(19), pp. 479-500.

Rego, F.C. and Catry, F.X., 2006, Modelling the effects of distance on the probability of fire detection from lookouts, *International Journal of Wildland Fire*, no. 15(2), pp. 197-202.

Scott, S.L. and Ruth, L.W., 2005. Federal forest fire policy in the United States. *Ecological Applications*, no. 15, pp. 532-542.

Sibanda, C., 2011, *Modeling forest fire behavior and carbon emission in the Ludikhola Watershed , Ghorkha District*, Nepal, University of Twente: Twente.

SwissTopo, 2012, *VECTOR200 landscape mode* [Online], Available: http://www.swiss-topo.admin.ch/internet/swisstopo/en/home/products/landscape/vector200.html [27.02.2013].

SwissTopo, 2004, *Digital height model DHM25* [Online], Available: http://www.swiss-topo.admin.ch/internet/swisstopo/en/home/products/height/dhm25.html [27.02.2013].

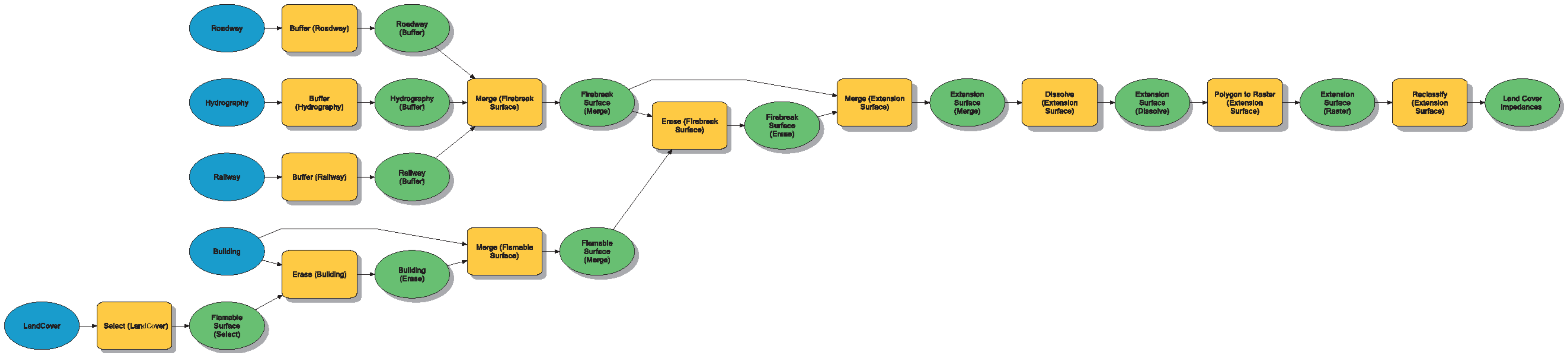
SwissTopo, 2003, *Geodata*, Office fédéral de topographie: Warben.

UNIGIS, 2013, *UNIGIS Module 5: GIS and Modelling*, [Online on Blackboard], Vrije Universiteit: Amsterdam (The Netherlands) [18.01.2013].

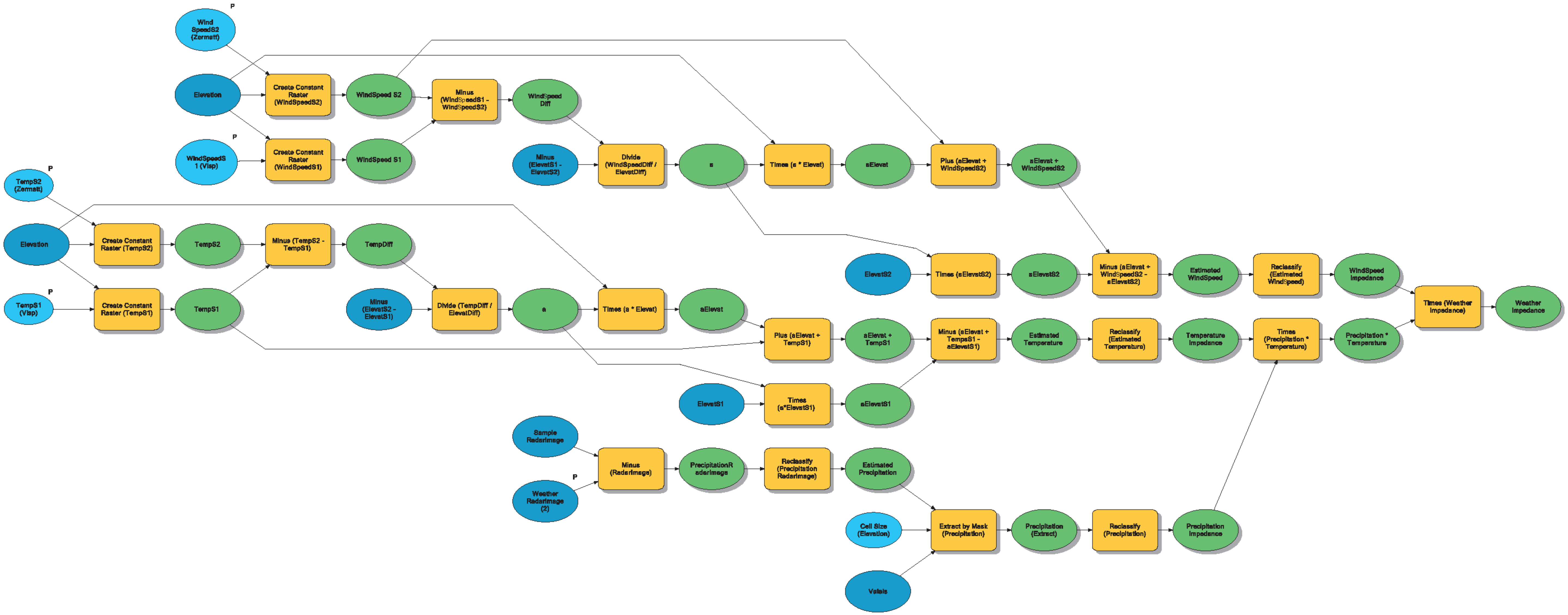
Valese, E. *et al.*, 2010, *The Alpine Forest Fire Warning System (ALP FFIRS) project*, VI International Conference on Forest Fire Research: Coimbra.

Zumburunnen, T. *et al.*, 2009. Linking Forest Fire Regimes and Climate - A Historical Analysis in a Dry Inner Alpine Valley. *Ecosystems*, no. 12, pp. 73-86.

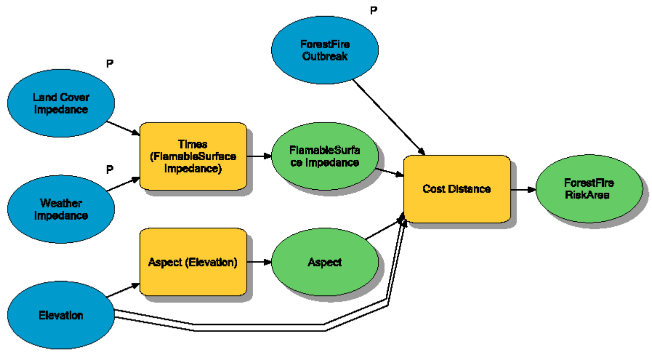
8. Annexes



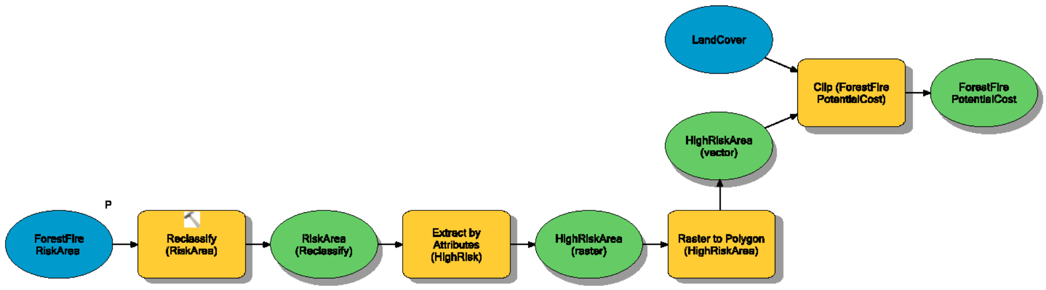
Annex 1. The Land Cover Impedances sub-model implementation in ArcGIS 10.0 Model Builder.



Annex 2. The Weather Impedances sub-model implementation in ArcGIS 10.0 Model Builder.



Annex 3. The Risk Area Prediction model implementation in ArcGIS 10.0 Model Builder.



Annex 4. The Costs Estimation model implementation in ArcGIS 10.0 Model Builder.