GIS-BASED SPATIAL MODEL FOR WILDFIRE SIMULATION: MARMARİS – ÇETİBELİ FIRE

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Approval of the Graduate School of Natural and Applied Sciences.

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ABSTRACT

GIS-BASED SPATIAL MODEL FOR WILDFIRE SIMULATION: MARMARİS – ÇETİBELİ FIRE

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Each year many forest fires have occurred and huge amount of forest areas in each country have been lost. Turkey like many world countries have forest fire problem. 27 % of Turkey's lands are covered by forest and 48 % of these forest areas are productive, however 52 % of them must be protected. There occurred 21000 forest fires due to several reasons between 1993 and 2002. It is estimated that 23477 ha area has been destroyed annually due to wildfires.

The fire management strategies can be built on the scenarios derived from the simulation processes. In this study a GIS – based fire simulating model is used to simulate a past fire occurred in Marmaris – Çetibeli, Turkey, in August 2002.

This model uses Rothermel's surface fire model, Rothermel's and Van Wagner's crown fire model and Albini's torching tree model. The input variables required by the model can be divided into four groups: fuel type, fuel moisture, topography and wind. The suitable fuel type classification of the vegetation of the study area has been performed according to the Northern Forest Fire Laboratory (NFFL) Fuel Model. The fuel moisture data were obtained from the experts working in the General Directorate of Forestry. The fire spread pattern was derived using two IKONOS images representing the pre- and post-fire situations by visual interpretation. Time of arrival, the rate of spread and the spread direction of the fire were obtained as the output and 70 % of the burned area was estimated correctly from the fire simulating model.

Keywords: Fire Management, Fire Behavior Model, GIS, NFFL Fuel Model, Marmaris – Çetibeli.

ÖZ

CBS TABANLI MEKANSAL ORMAN YANGIN SİMULASYONU: MARMARİS ÇETİBELİ YANGINI

TAŞEL, ERDİNÇ

Yüksek Lisans, Jeodezi ve Coğrafi Bilgi Teknolojileri Bölümü

Tez Yöneticisi: Y. Doç. Dr. Zuhal AKYÜREK

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Diğer dünya ülkelerinde olduğu gibi Türkiye'de de orman yangını problem teşkil etmektedir. Her yıl çok sayıda orman yangını meydana gelmekte ve bu yangınlar sonucunda çok geniş orman alanları yok olmaktadır. Türkiye topraklarının % 27'si ormanlarla örtülü olup bu alanın % 48' si ekonomik açıdan değerlidir, fakat bu ormanlık alanların % 52' si koruma altındadır. 1993 ile 2002 yılları arasında yaklaşık 21000 adet orman yangını çeşitli nedenlerden ötürü meydana gelmiş, yıllık kaybedilen orman alanı 23477 hektar olarak belirlenmiştir.

Orman yangını yönetimi, simülasyonlar sonucunda elde edilen orman yangını senaryoları üzerine kurulabilir. Bu çalışmada Coğrafi Bilgi Sistemleri

(CBS) tabanlı yangın simülasyon modeli kullanılarak 2002 Ağustos ayında Marmaris – Çetibeli’nde meydana gelen orman yangını simüle edilmiştir. Bu model Rothermel örtü yangın modeli, Van Wagner tepe yangın modeli ve Albini tutuşan ağaç modellerını bileşik bir şekilde kullanmaktadır. Modelin çalışması için gerekli veri değişkenleri yakıt cinsi, yakıt nemi, topoğrafya ve rüzgar olarak 4 gruba ayrılır. Çalışma alanının yakıt modeli Northern Forest Fire Laboratory (NFFL) yakıt modeline göre en uygun olacak şekilde belirlenmiştir. Yakıt nem verisi Orman Genel Müdürlüğü’nde çalışan uzmanlardan elde edilmiş olup yangın öncesi ve sonrasına ait IKONOS görüntüleri kullanılarak yangının yayılım dokusu görsel olarak belirlenmiştir. Yangın simülasyon modeli tarafından yangının ulaşım zamanı, yayılım hızı ve yönü çıktı olarak oluşturulmuş ve toplam yanan alanın % 70’ i doğru olarak tahmin edilmiştir.

Anahtar Kelimeler: Yangın Yönetimi, Yangın Davranış Modeli, CBS, NFFL Yakıt Modeli, Marmaris – Çetibeli.

Dedicated to people who sacrificed their lives for Green Earth

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CHAPTER 1

INTRODUCTION

Forests are one of the most valuable natural resources because of adjusting the natural balance, affecting the climate and water body of the region, preventing air pollution and erosion. In addition to this, they are important for community to meet the demand of products made of timber.

Forest protection is an important part of silviculture, which is the science, art and practice of caring for forests with respect to human objectives. There are lots of injurious activities and many of them are so destructive. Valuable and healthy timber production is unattainable if adequate protection and preservation are not afforded.

Injurious agencies may be potentially very hazardous to forests and in contrast because of silvicultural operations in woodlands, impairment may be minimized. Injurious agencies can be listed as follows:

1. Forest fires.

2. Plants, including fungi, mistletoes, and forest weeds.
3. Insects.
4. Domestic animals.
5. Wildlife (animals other than insects and domestic species).
6. Atmospheric agencies. Under this heading the injuries from heat, frost, drought, water (including injury from floods, erosion caused by water, landslides, snow, ice, hail, and avalanches), air movements (including the effects of drifting sand and erosion caused by wind), lightning, poisonous gases, and smoke are included (Hawley and Stickel, 1948).

Forest fires occur either because of anthropological or natural causes. The majority of fires around the globe are caused by human activities. Lightning is probably the most common natural cause of fire. They have an instantaneous, often within a few hours, and enormous destruction. They consume forests, buildings and also cause damage to human life. The impacts of forest fires can have global consequences: Forest fires also produce gaseous and particle emissions that impact the composition and functioning of the jet stream and the global atmosphere, exacerbating climate change. Tropical forest destruction, through fire, could also spiral our weather systems in new and unpredictable directions. Therefore, forest fires have taken the first place among injurious agencies.

According to the World Wildlife Fund (WWF), the forest areas of the world have high wildfire risk. The Mediterranean Countries have forest fire problem due to their location and meteorological conditions. Turkey has also large amount of forest, which are extremely sensitive to fire, and they are located in west and south regions.

The suitable response to forest fires depends on the evaluation of risks, hazards and values, which form fire management strategies. Risk is the chance of a fire starting. If the risk is high, fire prevention and detection are very cost-effective. Hazard is defined as simply the amount, condition and structure of fuels that will burn. Lastly, values are the change detection in resource condition. Fire management requires an understanding of how fire starts and spreads; the behavior of fires, fuels and how they are suppressed. Many fire managers are searching the appropriate ways to manage fires rather than simply suppress them (Edmonds et al., 2000).

Geographic Information System (GIS) can be used to model the fire behavior where spatial and nonspatial features can be handled within the system. Fire prediction systems model the fire behavior using site specific data, which are weather, topography, fuel type and condition. All the needed data are spatial. Geographic Information System technology has been gaining reputation for its ability to integrate large amount and type of information about environmental and public factors, which are spatially and temporally dynamic. It is preferable to integrate fire behavior modeling into GIS framework in order to analyze the simulation of the fire.

In Turkey, the responsibility of the interference to the wildfire belongs to General Directorate of Forest in fire management. The availability of GIS – based fire prediction models can help forest managers during struggling wildfires and fire management. In this study, a GIS – based fire simulation model is used in a case study of Marmaris Çetibeli fire by using FARSITE, Fire Area Simulator Model (Finney, 1998) in order to check the suitability of the model. The vegetation of the area was adapted to the Northern Forest Fire Laboratory (NFFL) Fuel Model (Anderson, 1982). After that, the Çetibeli fire has been simulated in order to test the suitability of the model and to define techniques that help to improve the simulation.

1.1.Objectives

The main objective in this thesis is to test the suitability of a GIS – based forest fire simulation model and determine the requirements of the model for Turkey.

In this study, it is intended to extract the burned parts of the study area using remote sensing techniques and ancillary data. Generation of the necessary and suitable spatial and nonspatial input files in order to perform the simulation and defining the vegetation types of the study area according to the NFFL Fuel Model (Anderson, 1982) are also considered. To calibrate the parameters of the model in order to acquire the real situation of the fire area and to find the accuracy and reliability of the model by comparing the extracted and simulated burned area in Marmaris – Çetibeli fire are additional objectives in this study.

1.2. Outline of the Thesis

In Chapter 2, in order to meet the objectives stated in Section 1.1., firstly the character, origins and impact of forest fires were described, the forest fire situations in Turkey and a detailed review of the literature associated with fire behavior models, the simulation modeling systems with GIS were depicted.

In Chapter 3, application areas of a GIS – based fire simulation model, FARSITE Fire Area Simulator and its capabilities were described. After that data requirements and their explanations were declared. At the end of this chapter, limitations and assumptions of fire simulation model were mentioned.

Chapter 4 gives information about Marmaris – Çetibeli fire, the study area and the generation of input files. The simulation of the case study Marmaris – Çetibeli wildfire were explained in detail with discussion of their results.

Chapter 5 constitutes the conclusion reached in this study and the recommendation for future work.

CHAPTER 2

FOREST FIRES

Forest fires are the major ecological agent in Turkey's forests. They can be thought as a force of renewal in the forest, it can also place people's lives and property at risk. They may be seen as a natural and hence desirable process, or they may be thought as a destroyer of forest recourse. These competing realities of the role of fire result from the different values; whether it is seen as simply a source of economically valuable material, or integral part of the earth's life support system.

2.1.What are Forest Fires?

The definition of the forest fire mainly depends on how the forest is valued. According to industrial perspective, a forest fire consumes valuable timber and it may be a threat for property and settlement areas even life. From tourism and recreational perspectives forest fire forces tourist areas and destroys view sheds. Conversely, environmental perspectives include that forest fire endangers sensitive old-growth forest habitat and it retains forest-opening environments.

A natural forest fire has one of usual origins, for example lightning, and is not caused by humans; however wildfire is an unplanned, out of control forest or grassland fires. According to The American Heritage® Dictionary of the English Language, Wildfire means that “A raging, rapidly spreading fire”

Fire has three components; fuel, heat, oxygen which are named as “fire triangle”. Figure 2.1 shows the two dimensional triangle explaining the combustion process. When all sides of the triangle are intact in proper state and proportion, fire takes place.

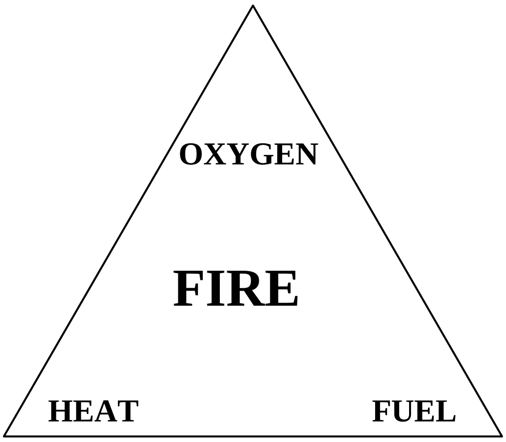

Figure 2.1. Fire Triangle

The world countries have forest fire problems. The fire situation of some Mediterranean Countries for last 10 years can be seen in Table 2.1 and graphs were drawn in Figure 2.2 and 2.3. It has been estimated by the World Wildlife Fund (WWF) that annually up to 500 million hectares of woodland, open forests, tropical and sub-tropical savannahs, 10-15 million hectares of boreal and temperate forest and 20-40 million hectares of tropical forests in the world are burned.

Table 2.1. The Number and Burned Area of Forest Fires in Some Mediterranean Countries (General Directorate of Forests in Turkey, 2002)

Year	**TURKEY**		**FRANCE**		**GREECE**		**ITALY**		**SPAIN**	
	Number	**Area (ha)**	**Number**	**Area (ha)**	**Number**	**Area (ha)**	**Number**	**Area (ha)**	**Number**	**Area (ha)**
1992	12232	2117	16607	4008	71410	2582	105695	14641	105277	15955
1993	15393	2545	16695	4765	54049	2406	209314	15380	89331	14253
1994	38128	3239	25872	4633	57908	1763	68828	11588	437635	19263
1995	7676	1770	18118	6545	27202	1438	46466	7378	143468	25828
1996	14922	1645	11210	6400	25310	1508	57986	9093	59814	16771
1997	6316	1339	20500	8000	52373	2273	103015	11612	98503	22319
1998	6764	1932	20880	5600	92901	1842	140432	10155	133643	22445
1999	5804	2075	17605	5170	8289	1486	61989	7235	82217	18237
2000	26353	2353	23700	5600	145033	2581	114648	10629	188586	24312
2001	7394	2631	17000	4103	18221	2535	76427	7134	66075	19631
TOTAL	**140982**	**21646**	**188187**	**54824**	**552696**	**20414**	**984800**	**104845**	**1404549**	**199014**

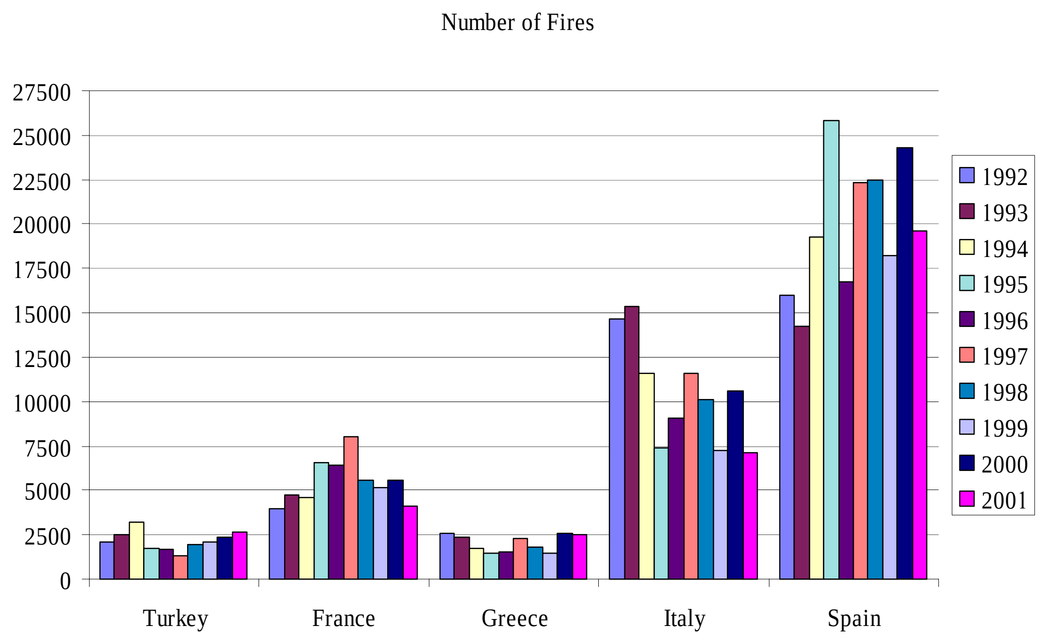

Figure 2.2. The Number of Forest Fires in Some Mediterranean Countries (General Directorate of Forests in Turkey, 2002)

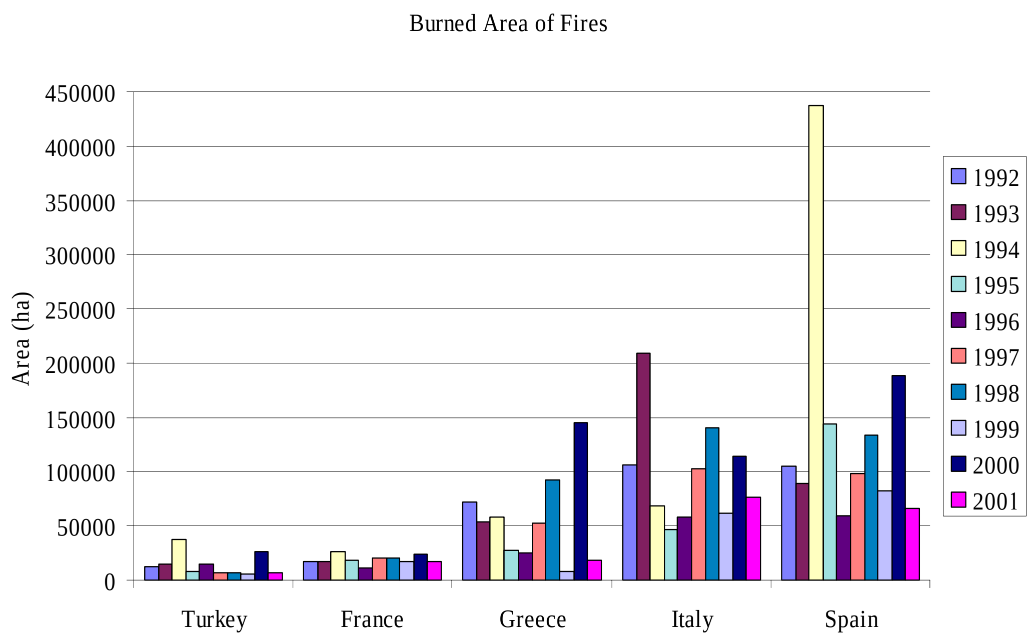

Figure 2.3. The Burned Area of Forest Fires in Some Mediterranean Countries (General Directorate of Forests in Turkey, 2002)

Turkey has a significant amount of forest land areas most of them are located through the coast of Mediterranean, Aegean Region and the coast of Black Sea Region. The land of Turkey has been divided into regions by General Directorate of Forest. The forests located in these regions are handled by the directorates belonging to these regions. The information about the forests for each region is tabulated in Table 2.2. Most of the forest areas consist of red pine forests, which are extremely sensitive to forest fire.

2.2. Character of Forest Fires

Generally, forest fires can be classified according to the mode of spread, type of damage and development characteristics of each kind of fires. Forest fires are divided into 3 classes, namely ground fire, surface fire and crown fire. Additionally, spotting is also an important event occurring during fire, as seen in Figure 2.4.

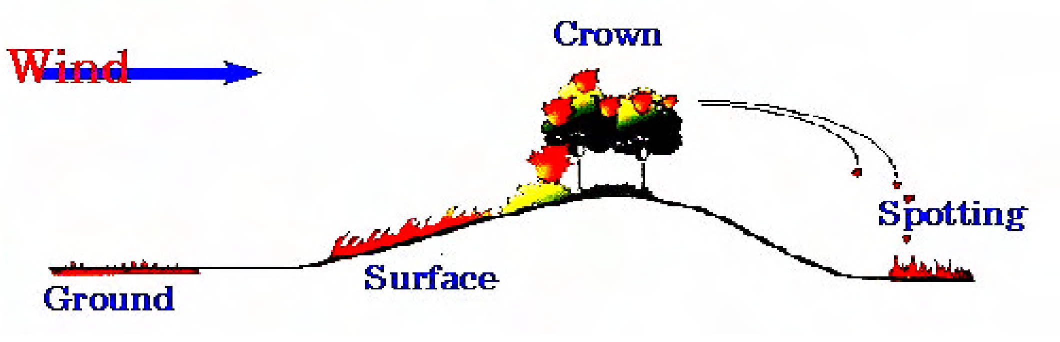

Figure 2.4. Types of Fires (http://www.noaa.gov)

Table 2.2. The Situation of the Turkey's Forests (General Directorate of Forests in Turkey, 2002)

Directorate of Regions	**TOTAL**		**Fire Sensitivity Classes**									
			Class 1		**Class 2**		**Class 3**		**Class 4**		**Class 5**	
	Forest Area	**Red Pine Area**	**Forest Area**	**Red Pine Area**	**Forest Area**	**Red Pine Area**	**Forest Area**	**Red Pine Area**	**Forest Area**	**Red Pine Area**	**Forest Area**	**Red Pine Area**
ADANA	847927	294046	359076	193487	234183	87277	141170	10812	113499	2470		
ADAPAZARI	358205	24837	180600	24085	86000	752	21852		69753			
AMASYA	1845895	125796			555591	74580	916752	45789	373552	5427		
ANKARA	606215	16286	45201				274127	3719	286847	12567		
ANTALYA	1119364	543876	817851	483780	301513	60096						
ARTVİN	428694						130037		298657			
BALIKESİR	652070	147462	553581	124516	98489	22946						
BOLU	591725	9189			242310	9189	284611		64804			
BURSA	754966	110790	506936	97862	114871	9099	103159	3829				
ÇANAKKALE	636747	205629	384127	177082	252620	28547						
DENİZLİ	714014	282948	311218	110872	402796	172076						

Class 1: Most Sensitive to Forest Fire, Class 5: Less Sensitive to Forest Fire. Area Units are hectares.

Table 2.2. The Situation of the Turkey's Forests (General Directorate of Forests in Turkey, 2002) (Continued)

Directorate of Regions	TOTAL		Fire Sensitivity Classes									
			Class 1		Class 2		Class 3		Class 4		Class 5	
	Forest Area	Red Pine Area	Forest Area	Red Pine Area	Forest Area	Red Pine Area	Forest Area	Red Pine Area	Forest Area	Red Pine Area	Forest Area	Red Pine Area
ELAZIĞ	2080089	3327					556197	1978	1045402	1349	478490	
ERZURUM	401006								283489		117517	
ESKİŞEHİR	518293	21694			355200	2483	163093	19211				
GİRESUN	424114						156973		78110		189031	
ISPARTA	716967	129597	189545	76954	527422	52643						
İSTANBUL	592038	20118	170423	19096	262340	910	82040	112	77235			
İZMİR	991255	620029	991255	620029								
K.MARAŞ	937320	296975	412480	187889	252356	52071	272484	57015				
KASTAMONU	772553	5967			398989	2494	256461	3048	121103	425		

Class 1: Most Sensitive to Forest Fire, Class 5: Less Sensitive to Forest Fire. Area Units are hectares.

Table 2.2. The Situation of the Turkey’s Forests (General Directorate of Forests in Turkey, 2002) (Continued)

Directorate of Regions	TOTAL		Fire Sensitivity Classes									
			Class 1		Class 2		Class 3		Class 4		Class 5	
	Forest Area	Red Pine Area	Forest Area	Red Pine Area	Forest Area	Red Pine Area	Forest Area	Red Pine Area	Forest Area	Red Pine Area	Forest Area	Red Pine Area
KONYA	733045	46439			181052		409198	35078	142795	11361		
KÜTAHYA	563436	44954	356307	37053	183797	7901	23332					
MERSİN	803987	415675	803987	415675								
MUĞLA	1130344	726252	1130344	726252								
SİNOP	320209	37050			239908	37050			80301			
TRABZON	528812						185105		39598		304109	
ZONGULDAK	565299	11689			130743	9763	434556	1926				
TOTAL	20763248	4140625	7212931	3294632	4820180	629877	4411147	182517	3075145	33599	1089147	

Class 1: Most Sensitive to Forest Fire, Class 5: Less Sensitive to Forest Fire. Area Units are hectares.

“Ground fires burn in the duff, humus, and peaty layers lying beneath the litter or undecomposed portion of the forest floor.” (Hawley and Stickel, 1948). Ground fires burn in natural litter, duff, roots or sometimes high organic soils very slowly but continuously with powerful heat and they are uniformly destructive (Hawley and Stickel, 1948). Once they start, detection and control of ground fires are very difficult.

Surface fires are the most common kind of fire that occurs on the ground and burn the land vegetation covers, brushes and the lower branches of the trees. This kind of fire is strongly affected by surface winds hence surface fires spread rapidly and they have high flame height and heat, however they are deflated soon. Usually, all fires start as surface fires. After requisite conditions occur, crown fire may develop from surface fires.

Crown fires simply burn at the top of the trees and they depend on species that have inflammable foliage. The conifer forests are mainly affected by crown fires however, the foliage of most deciduous species is less flammable. There are two types of crown fires, namely, “the running crown fire and the dependent crown fire” (Hawley and Stickel, 1948). The running crown fire is burning independently through the crowns of the trees and it spreads very rapidly but not as fast as surface fires. The next one, dependent crown fire, is supported by the surface fires and burns together. “The burning material on the ground furnishes the volume of heat which ignites the crowns and maintains the crown fire.” (Hawley and Stickel, 1948). When the crown fire starts, it is very difficult to take under control and be suppressed since wind plays an important role in spreading crown fires.

Spotting is a form of mass transfer, movement of heat by active firebrands, which are lifted by convective updraft, and it is brought over the main perimeter of the fire. Spotting distance may be extremely long. For example, in the 1991 Oakland fire in USA, the spot passed easily over eight-lane freeways. In very intense fires with great uplifting in Washington and Australia, spot fires have been reached to the 25 km-away from main line front. The spotting fuels consist of small cones, piece of bark, grass clumps and other such fuels. Once spotting begins, it is very difficult to take under control. Spot fires extensively increase the rate of fire spread and because of this, many fire fighters have been trapped in unexpected situations of fire and they have been injured, even lost their lives (Edmonds et al., 2000).

2.3. The Impacts of Forest Fires

The main injurious to forest protection and ecosystem is forest fires. The first visible and immediate impact of forest fires are destruction to human communities and forest ecosystems. On the other hand, the potential adverse effects of the forest fires are supply of ecosystem services necessary for the health of human communities. Disorder of forest ecosystem causes increase in the soil erosion, decrease in the infiltration capacity of the soils, loss of valuable soil nutrition and change in the quality and quantity of water, both in streams and ground water. Defeat of biological diversity due to forest fire alters the species composition and distribution even causes species extinction.

Some of forest fires injuries can be classified under the following heads: injury to trees containing merchantable material and young growth, injury to soil, injury to the productive power of the forest, injury to recreational and scenic values, injury to wildlife, injury to forage, injury to human life and others.

During fire, trees take damage at the scale of trivial wound at the base to complete consumption of the tree. Tree death occurs when the cambium or living layer between bark and wood of the tree is killed. If the trees that have an economic value are killed due to fire, they should be cut and utilized before the timber decays or is attacked by insects. It is strongly advised that merchantable trees injured but not killed by fire should be removed because decay and insects of trees frequently increase the final loss of the timber consumed by the fire. Many years must elapse in order to become as a merchantable tree. During this time growing trees can be infected by insects and fungi from the fire scars and finally within one or two years, the trees practically become worthless after fire.

Forest fires affect the physical properties, particularly penetrability and porosity of soil more critically than its chemical properties. “Physical properties of soils are influenced by fires through decrease in the humus content.” When the humus in the soil is once influenced, the repeated fires seriously injure the humus content of the soil. The forest litter contains nutritive materials mainly, nitrogen, calcium, phosphorus and potash. The most important material is nitrogen because it is volatile and lost to the soil when fire consumes the forest litter.

In some places forest areas grows on the rocky areas only a few inches below the surface. This thin soil layer that consists of largely organic materials completely consumed due to fire. As a consequence, the soil valuable for forest is entirely destroyed.

Another fire injury to the forest is the productive power of the forest. The composition of the forest type is changed due to fire. Many of the valuable tree species is more sensitive to fire than others and fire kills the sensitive species and leaves the resistant ones and the more resistant and less valuable species form the dominant vegetation cover of the area. If frequently happens, brush and woody shrubs cover the burned area. Sometimes fire destroys whole vegetation cover and becomes barren or the trees must be cut because of fire scared. Therefore the capability of producing good timber crops has been decreased.

The most visible injury of the fire is demolishment of the recreational and scenic values of the area. Community income from the tourism is adversely affected because of fire. Also, fires affect the wildlife directly and indirectly. Many animals can not escape and actually burned to death. An indirect effect of the fire is destruction of the food and cover that is important for animals as shelter. Fire destroys plants and dry grass that have a forage value. When the intensity of fire is sufficient, fires kill the roots of the plants, reducing the density of stocking.

The most valuable duty of the forests is protection of the areas against erosion, avalanches, landslides and shifting sands. As well as fire adversely affects the nature and ecosystem, it also threat the property of human beings, buildings, live stocks, farms and even towns, and even their lives.

Beside of adverse effects, forest fires have also beneficial effects if the burning is occurred under control. Fire can be used as a tool for establishing natural reproduction of the desired species. Fire can improve the physical condition of the soil by aerating and increasing its temperature. Additionally, fire may be useful for controlling plant diseases. The most important beneficial use of prescribed fire is prevention of more destructive fires (Hawley and Stickel, 1948).

2.4. The Origins of Forest Fires in Turkey

Fire is a natural and usual part of the ecosystem; however it is strongly affected by the human activities both directly and indirectly. The reasons of the forest fires change according to the society, activity that is performed at the wild area. The variableness of the reasons of the forest fires influences the time of the fires.

In accordance with 10-year data, 47 % of the forest fires are caused by negligence, carelessness and accident, 13 % are incendiary, 6 % is caused by lightning and 34 % is due to unknown reasons. In 2002, the 55 % of the forest fires were started because of negligence, carelessness and accident, 15 % of them are incendiary, and 12 % is due to lightning (Figure 2.5). However, the reason of 18 % of the 2002-forest-fire is unknown (General Directorate of Forests in Turkey, 2002).

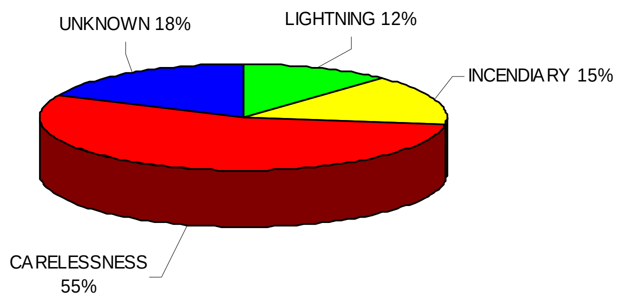

Figure 2.5. The Reasons of the Forest Fires in Turkey in 2002

Among the wildfires whose source is negligence, carelessness and accident, 9.7 % of the fires and 6 % of the burned areas are due to debris burning, 8.5 % of the fires and 45.6 % of the burned area are Camp Fire burned by shepherd and lastly 9 % of the fires and 1.8 % of the burned area in 2002 are owing to smokers.

In the last few years, the number of wildfires caused by energy transfer lines increased. 3 % in 1997, 15 % in 1998, 2 % in 1999, 5.1 % in 2000, 2.5 % in 2001 and 3.3 % of the fires were burned in 2002 and in addition to this, respectively, 3 %, 15 %, 7.5 %, 19.7 %, 5.3 % and 24.8 % of the total burned area have been lost annually from 1997 to 2002 (General Directorate of Forest in Turkey, 2002).

According to Hawley and Stickel (1948), the causes of the fires is classified as camp fire, debris burning, that is fires originally set for clearing land for any purpose, incendiary, lightning, lumbering, railroad, smoker and miscellaneous. The classification method of fire reasons is used by most fire control organizations and grouping fire reasons in the same way for all the regions in the country and it is an advantage for fire management.

In conclusion, human beings are the main reason of forest fires directly or indirectly. 90 % of the total fires are man-caused and could be prevented.

2.5. Forest Fires in Turkey

27 % of Turkey's lands are covered by forest (Figure 2.6). 48 % of this forest areas are productive however, 52 % must be protected. The number of total forest fires between 1937 and 2002 is 72316 so the number of yearly fires has been found as1096.

Between 1993 and 2002, 21000 forest fires have been occurred and the yearly average has been calculated as 2100 (Figure 2.7). In 2002, the first 5 regions where the most of the fires have occurred can be listed as Muğla (232 fires), İzmir (232 fires), Amasya (194 fires), Istanbul (170 fires), Antalya (166 fires) and Balıkesir (153 fires).

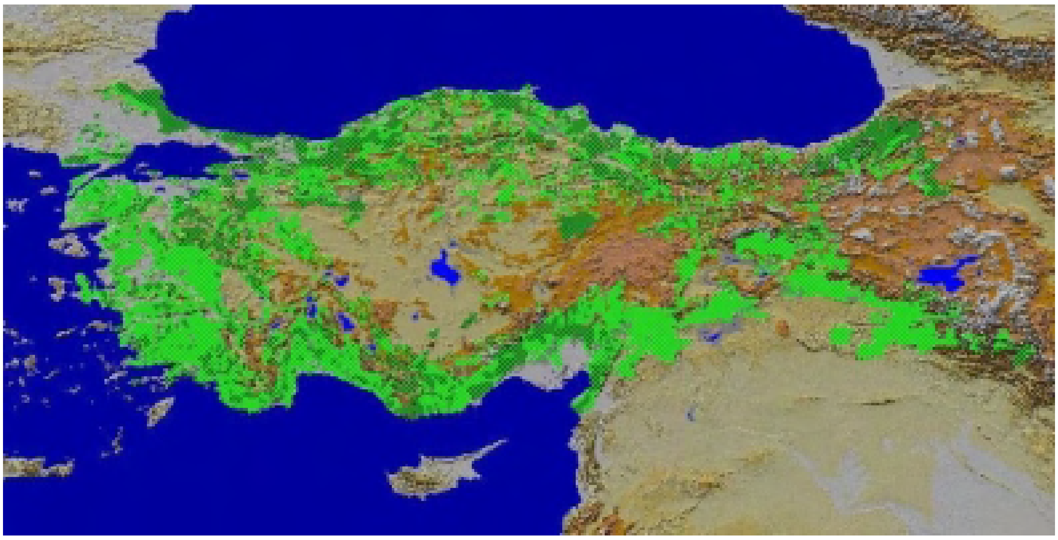

Figure 2.6. The Overall View of the Forest Areas in Turkey (The color, Green shows forest areas, brown shows DEM) (http://www.ogm.gov.tr)

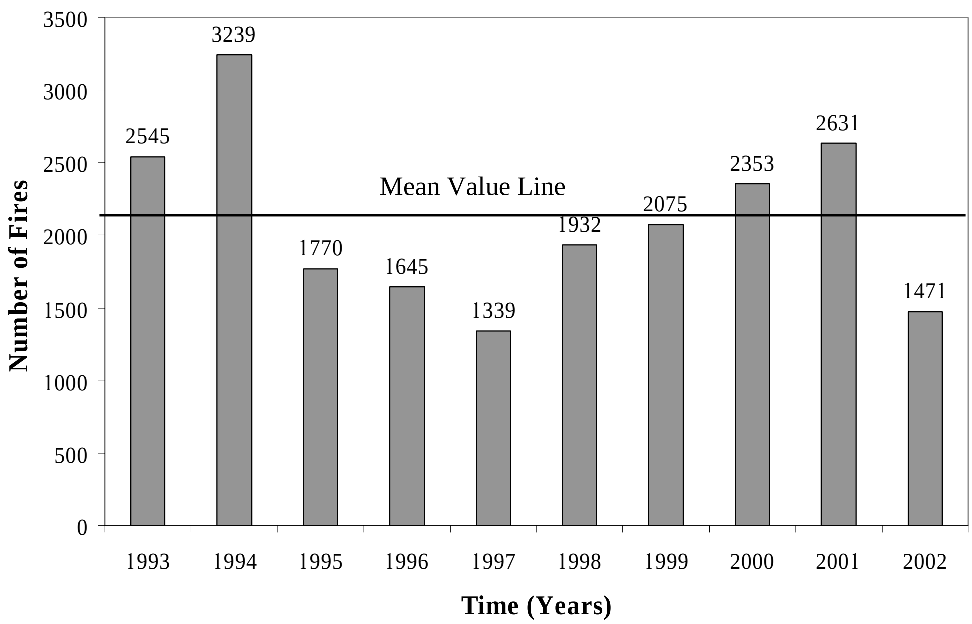

Figure 2.7. The Distribution of Number of Forest Fires between 1993-2002 (General Directorate of Forest in Turkey, 2002)

From 1937 to 2002, 1,549,506 hectare area have been burned and according to this, around, 23,477 ha area has been destroyed annually (Figure 2.8). If the data of last 10 years have been examined in accordance with the Region Head Offices, Muğla (1958 ha), İzmir (1475 ha) and Antalya (1352 ha) have taken the first 3 places in ranking. In 2002, the most damaged area belonged to Balıkesir (3634 ha), Muğla (2072 ha), Antalya (450 ha), Mersin (421 ha) and İzmir (309 ha).

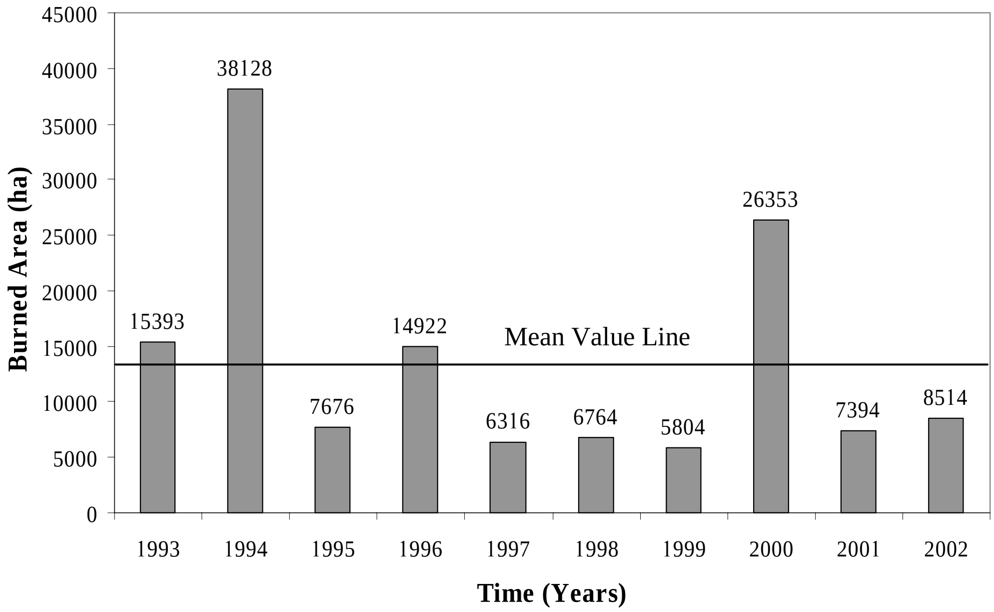

Figure 2.8. The Distribution of Burned Area between 1993-2002 (General Directorate of Forest in Turkey, 2002)

The forest fires have been classified and defined according to the burned area by General Directorate of Forest in Turkey. The classes of the forest fires are denoted as A, B, C, D, E, F, G1, G2 and G3 in accordance with the size of burned areas in an ascending order (Table 2.3).

G3-class forest fires, have occurred in Balıkesir-Kepsut, where 3573 ha forest area has been lost, and Marmaris – Çetibeli, where 1775 ha forest area has been lost in 2002. 62.8 % of the total area has been destroyed in these forest fires. C, D, E and F class medium forest fires formed the 26 % of the total area. Although the percentage of A and B class forest fires was 92 according to the number of fires, the burned area formed the 11.1 % of the total area. The number and area of the forest fires between 2000 and 2002 according to the sizes can be seen in Table 2.3.

Table 2.3. The Classes of Fires According to Sizes (General Directorate of Forest in Turkey, 2002)

Classes	**Number of Fires**			**Area of Fires**		
	2000	**2001**	**2002**	**2000**	**2001**	**2002**
A (<1 ha)	1602	1907	1108	548	636	343
B (1.1 – 5.0 ha)	507	531	246	1361	1451	607
C (5.1 – 20.0 ha)	136	143	90	1465	1471	635
D (20.1 – 50.0 ha)	55	31	8	1898	1044	279
E (50.1 – 200.0 ha)	34	15	11	3293	1146	1020
F (200.1 – 500.0 ha)	9	2	1	3236	515	280
G1 (500.0 – 800.0 ha)	2	2		1184	1131	
G2 (800.1 – 1500.0 ha)	4			4471		
G3 (>1500.0 ha)	4		2	8897		5348
TOTAL	2353	2631	1471	26353	7394	8514

General Directorate of Forest that consists of 27 head offices manages the forests in Turkey. These offices are divided according to the density of the forest areas (Figure 2.9). These forest areas were degreed from 1 to 5 in accordance with

Figure 2.9. The Head Offices of General Dircetorate of Forest in Turkey

the fire risk. Degree 1 shows the most sensitive areas and decrease to Degree 5. Figure 2.10 and Figure 2.11 show the fire risk consistent with all type of forest areas and red pine forest areas. Therefore, the distribution of the forest fires depends on the fire risk and can be seen in Figure 2.12 and Figure 2.13 according to number and area of fires in 2002.

2.6. Using Geographic Information Systems in Fire Management

Forest fires are spatial phenomena so they can be modeled using geo-spatial technologies, such as geographic information systems (GIS) and remotely sensed high resolution imagery. Buckley (2001) provides a review of applications in remote sensing and GIS technologies for fire and fuel management. In this work, vegetation of United States Marine Corps. Camp Lejeune are mapped to Northern Forest Fire Laboratory (NFFL) fuel models. The elements of wildland risk and hazard are defined, modeled and mapped levels of concern allowing for regular updating due to changes in fuels and land use. Jaiswal et al. (2002) used GIS for combining different forest fire causing factors for determining the forest fire risk zone map. “Forest fire risk zones were delineated by assigning subjective weights to the classes of all the layers according to their sensitivity to fire or their fire-inducing capability” (Jaiswal et al., 2002). It was concluded that GIS-based forest fire risk model was in strong agreement with actual fire affected sites. Hardwick (1999) evaluated the GIS the use of GIS technology as a tool in reducing large fire costs, and to identify the benefits of GIS to incident management efforts. Both quantitative and qualitative benefits were examined and

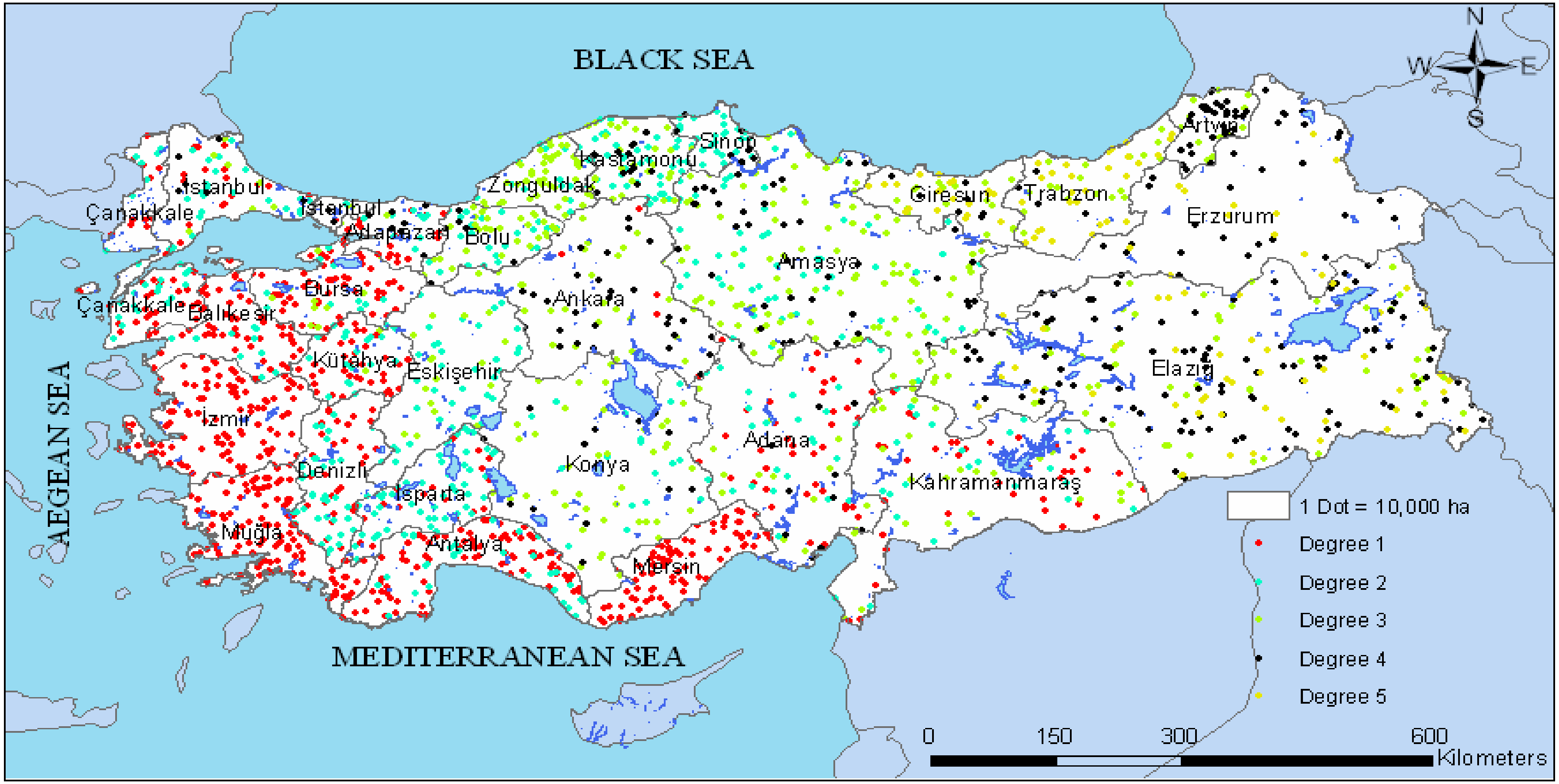

Figure 2.10. The Distribution of Forest Areas According to Fire Risk Degrees in 2002 (Data Source: General Directorate of Forest in Turkey, 2002)

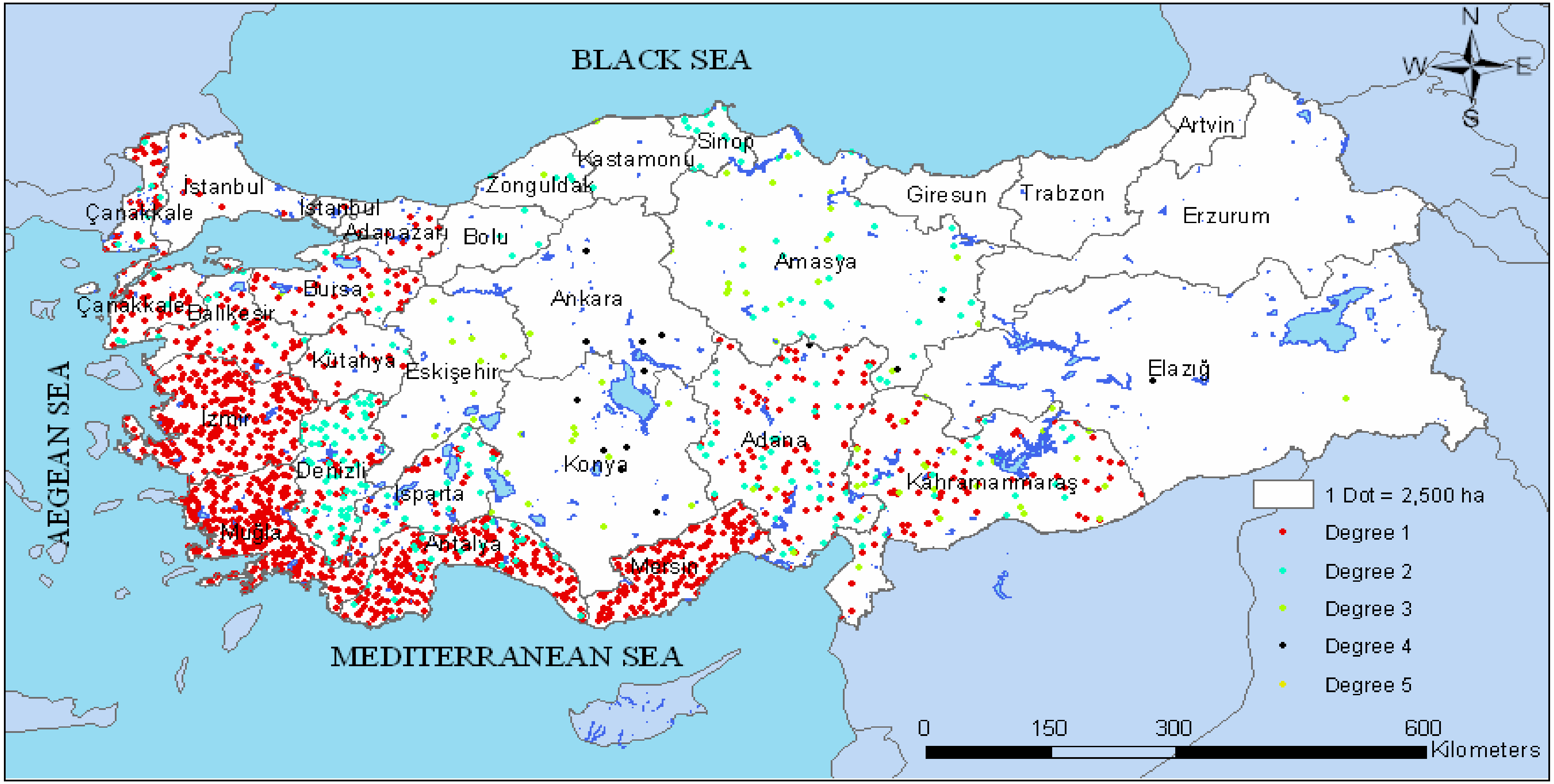

Figure 2.11. The Distribution of Red Pine Forest Areas According to Fire Risk Degrees in 2002 (Data Source: General Directorate of Forest in Turkey, 2002)

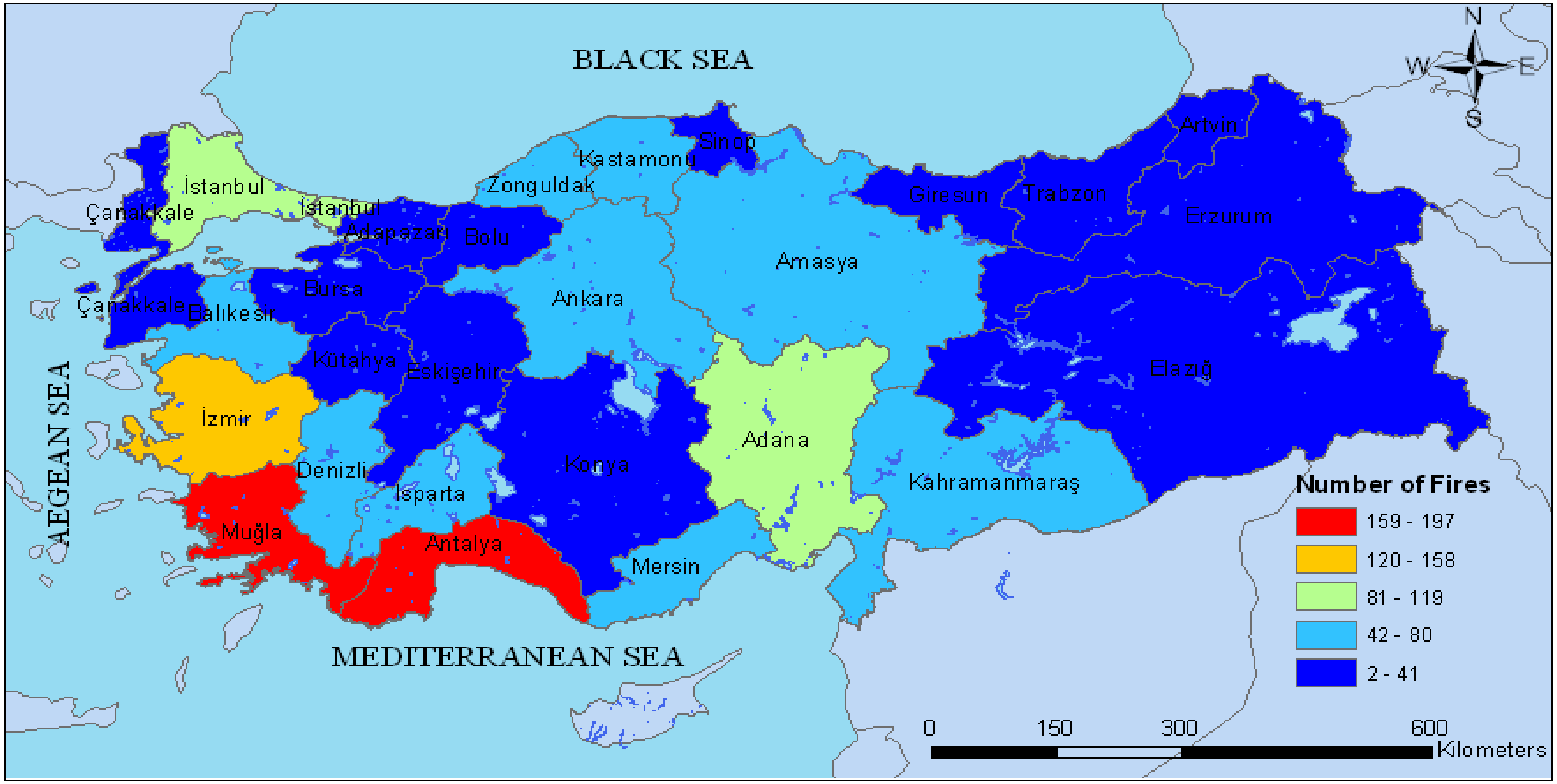

Figure 2.12. The Distribution of Forest Fires According to Number of Fires in 2002 (Data Source: General Directorate of Forest in Turkey, 2002)

Figure 2.13. The Distribution of Forest Fires According to Area Burned in 2002 (Data Source: General Directorate of Forest in Turkey, 2002)

it was found that GIS would be a useful tool for large fire management.

Fire prediction systems model the fire behavior using site specific data, which are weather, topography, fuel type and condition. Albright and Meisner (1999) listed four types of fire prediction models: physical, physical-statistical, statistical and probabilistic.

Physical models are based on the physics of heat transfer and combustion, for example Albini (1986) (Albright and Meisner, 1999). It is not currently used due to the requirement of huge amount of data. The most commonly used models are physical – statistical fire prediction models. They combine the physical theory with statistical correlation. Rothermel's (1972) model, approximating the solution from laboratory experiment, and The Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group, 1992 in Albright and Meisner, 1999) are examples of physical – statistical models. Statistical fire predication models use equations derived from test fires. Their success depends on the conditions similar to the test fires. McArthur's fire danger meters (McArthur, 1966 in Albright and Meisner, 1999; Noble et al., 1980) are the examples of statistical fire prediction models. The last fire prediction models are probabilistic that are based on contingency tables (Albright and Meisner, 1999).

Some of the GIS – based fire simulation systems can be counted as FARSITE (Finney, 1998), FIREMAP (Ball and Guertin, 1992 in Albright and Meisner, 1999), WILDFIRE (Wallace, 1993 in Finney, 1998) and DYNAFIRE

(Kalabokidis et al., 1991 in Albright and Meisner, 1999). These systems are based on physical- statistical model. Except for FARSITE, all of simulation systems have been developed for simulating the low to moderate intensity surface fires. FARSITE can simulate the spread and behavior of wildland for both surface and crown fire. The outputs of all prediction systems include GIS vector and raster files with different format (Albright and Meisner, 1999).

Hawkes et al., (1997) have developed a prototype wildfire threat rating system (WTRS) via Geographic Information System (GIS) technology. This system is based on fire risk, values at risk, fire behavior, and suppression capability. They have been determined as a function of 13 factors, which are Digital Elevation Model, aspect, road, etc. Wildfire threat consists of four main components and a number of factors contribute to each of these components.

A fire simulation application, called as FIRE!, has been developed by the Weinstein et al., (1995). It integrates the fire behavior modeling into the ARC/INFO GIS environment. "FARSITE interacts seamlessly within the ARCINFO environment as a component of FIRE!..." (Weinstein et al, 1995). At this study, forest fire behavior model integrates the spatial 13 type NFFL Fuel Model, topographic data, temporal weather and wind settings and initial fuel moistures into the prediction of forest fire behavior across both time and space. Liu and Chou (1997) provide a cell automation method to simulate wildfire growth by using a grid – based GIS. Rothermel's model was used to estimate the rate of spread and fire intensity.

Vega et al., (1998) have developed specific equations to predict rate of spread and flame length for Galician shrublands. “Fire behavior data recorded from field experimental fires carried out in Galician shrublands have been used to compare predictions from different existing models to observed data.” Also Fernandes (2001) has developed a preliminary model to predict rate of spread in shrub fuel model by analyzing the relationship between fire spread and environmental variables in Portugal.

FARSITE has been used by Noonan (2002) in order to test the effectiveness of fuel treatments in a shrub and timber area in the Eastern Sierra Nevada. It has been concluded that the treated fuel decreases the dangerous fire behavior, especially shrub. Fujioka (2001) simulated the Bee Fire with given landscape, fuel and weather conditions. The aim of the simulation is describing a new methodology to evaluate the uncertainties of fire spread simulation. The resultant fire spread simulations were moderately successful comparing with Bee Fire. In addition to these studies, Van Wagtendonk (1996) have tested the various fuel treatments in mixer conifer vegetation via FARSITE model. Fuel treatment scenarios have been formed by changing the fuel model values for load and depth, in other words defining custom fuel models. Also Stephens (Stephens, 1995 in Van Wagtendonk, 1996) used for testing fuel treatments for protecting the Tuolumne Grove of giant sequoias at the head of North Crane Creek in Yosemite National Park. Removals of ladder fuels and salvage logging with and without slash treatment have been tested as moderate intensity of burn. His study increases the importance of fuel treatments for example prescribed burning and defensible fuel profile zones in critical areas.

CHAPTER 3

FARSITE: FIRE AREA SIMULATOR MODEL

Forest fires which occur in the arid and semi-arid regions of the world have disastrous social, ecological and economic impacts, causing loss of life and property, loss of vegetation, oil and water resources. Computers and electronic devices are increasingly being employed in spotting, monitoring and combating forest fires, providing assistance to the tools traditionally used in fire management.

In this chapter, two-dimensional computer simulation model, FARSITE, that incorporates existing fire behavior models for surface, crown, spotting, point source fire acceleration is discussed. Application areas, capabilities, and data requirements are briefly explained. After that, limitations and assumptions are listed.

Fire Area Simulator, FARSITE, is a deterministic computer based program designed to model the spread and behavior of fires spatially and temporally under conditions of heterogeneous terrain, fuels and weather. It was based on the implementation of Huygens' Principle of wave propagation for simulating the growth of a fire front. Fire behaviors and perimeters are manageable numerically, graphically and spatially to other PC and GIS applications. However, in order to get these advantages, the more organized and GIS based spatial data on the topography, fuels and weather data are required. The PC version of FARSITE requires the GIS software ARC/INFO or GRASS to generate, manage and provide spatial data layers, these are fuels and topography (Figure 3.1) (Finney, 2003; Finney and Andrews, 1999). Finney and Andrews (1999) state that "FARSITE is widely used by the State and Federal agencies as well as private parties in the United States, who recognize the value of having GIS-based data on fuels and vegetation for a variety of applications."

"The Microsoft Windows interface offers flexibility for office or field prediction of fire growth. Fire growth and behavior scenarios can be developed relatively quickly using short term weather forecasts or long term weather projections (ideally based on historic records)" (Finney, 2003).

3.1. The Application Areas

The FARSITE model was initially developed to support the management prescribed natural fires (pnfs), which is now called as fire use and it was aimed for operational and planning parts. The National Wildfire Coordinating Group (NWCG), which coordinates interagency federal fire management, defined the wildfire as "…an unwanted wildland fire" and prescribed fire as "…the purposeful application of fire under predetermined conditions of fuels, weather, and topography to achieve management objectives" (Edmonds et al., 2000). The terminology prescribed natural fires (pnfs) was defined as "…naturally ignited ignition that is allowed to burn under an approved management plan that includes monitoring" (Edmonds et al., 2000). In the new terminology, term of prescribed natural fires is redefined as a managed wildland fire.

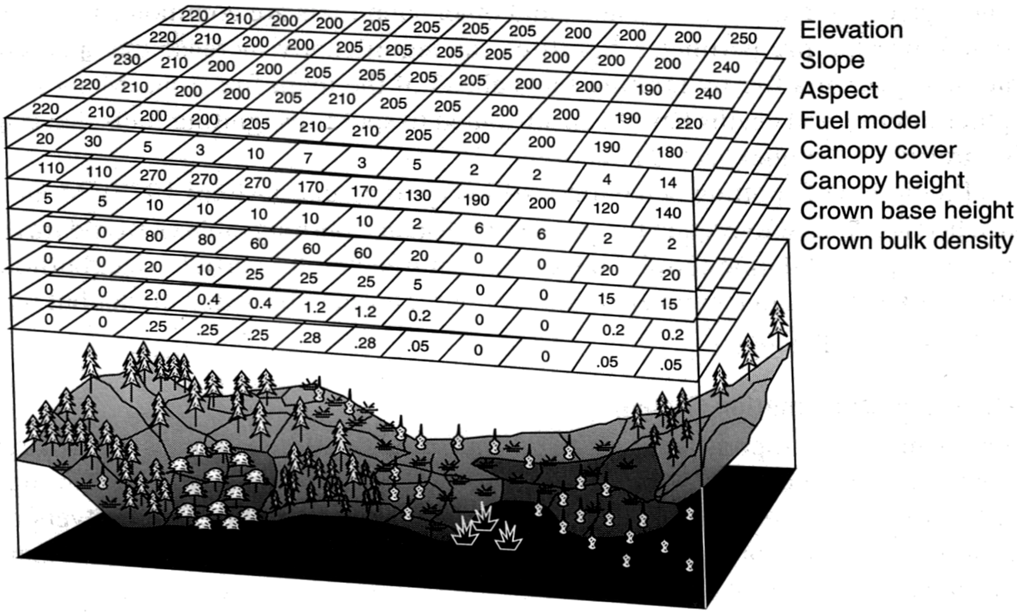

Figure 3.1. Raster Input Layers Generated by the Geographic Information Systems for FARSITE Simulation (Finney, 1998)

According to Edmonds et al., (2000) it is used to support decision making for park and wilderness managements. "Based on expected or historic weather patterns, fire spread and intensity can be simulated over time, providing information for monitoring strategies, fire suppression strategies, assigning priorities to multiple fires, and other uses. It can be used to simulate either prescribed fires or wildfires, and has important forest health management implications for planning" (Edmonds et al., 2000). It is stated in Finney (2003) that the most relevant intended usage are short and long term simulation of active and potential fire.

The FARSITE model has three main uses, which are simulation of past fires, active fires and potential fires. Simulation of past fires assists to understand how well it generates known fire growth model and fire spread pattern according to given available data. “Simulating past fires is critical in developing confidence for using FARSITE to project the growth of active fires.” (Finney and Andrews, 1999)

FARSITE was originally developed for long – range active prescribed fires on national parks and wilderness areas. 1 or 2 – day short – range projections on large fires have also been simulated and simulation results can be used to support strategic firefighting decisions. Moreover, partial section of fire fronts can be simulated for immediate interest (Finney and Andrews, 1999). According to Finney (2003), the intended usage of active fires have been described as preparing daily fire situation analysis for short term projections; forecasting fire monitoring activities based on fire line arrival, fire behavior and fire effects; defining long term fire variability and range of outcomes and lastly assigning the priorities to multiple fires for both short and long term projections.

The most appropriate and common application of FARSITE is fire planning activities. For example, they include analyzing fire management alternatives and examining suppression opportunities for fires that start in various locations or weather scenarios. Potential fires at different locations can be examined under a variety of fuel and weather conditions (Finney and Andrews, 1999). Actual weather records following suppression could be used for simulating the likely burn extent and behavior for planning later prescribed burning of the area at a more suitable time" (Finney, 2003).

During fire suppressions, comparison of the effectiveness of different strategies under varying weather scenarios and suppression efforts with and without fuel treatment programs can be performed by FARSITE. Lastly, cost of suppression strategies can be estimated (Finney, 2003).

3.2. Capabilities

FARSITE uses raster data as inputs for all spatial data on topography, fuels, and crown structure. It can also export fire behavior information as raster themes to use in a GIS.

Van Wagtendonk (1996) has stated that utilizing the spatial database capabilities of Geographic Information Systems, FARSITE allows the users to simulate the spatial and temporal spread and behavior of the fire over heterogeneous terrain, fuels and weather. Therefore it is more realistic and accurate modeling of actual fire growth, as well as the efficiency and capacity for investigating effectiveness of fuel treatments design to diminish hazard. In addition to this spotting and crowning model allows to provide an ideal tool for investigating extreme fire behavior.

Finney (1998) states that FARSITE calculates the surface fire behavior, crown fire behavior, fire acceleration, and fuel moisture. The surface fire model developed by Rothermel (1972) is connected to the Van Wagner (1977; 1993) and Rothermel (1991) crown fire model in order to simulate the movement of fire to crown. Torching tree model developed by Albini (1979) is used to simulate spotting distance (Finney and Andrews, 1999).

FARSITE produces the fire growth perimeters and fire behavior maps in ARC/INFO, ArcView, and GRASS GIS based formats. Fire perimeter outputs are in vector format as either line or polygon. Raster maps are also produced to show fire behavior at each cell in any resolution. They include Time of Arrival, Fireline Intensity, Flame Length, Rate of Spread, Heat per Area, Reaction Intensity, Crown Fire Activity and Spread Direction. While GIS based output maps are produced, also table and graph based output data are generated.

Environmental and combustion raster maps can also be generated by FARSITE. Environmental maps display fuel moistures and weather conditions across the landscape at a specific time. It is useful to understand the effects of topography, forest canopy structure, and weather. In addition to this, instantaneous fire activity can be recorded and viewed for all areas within the fire area by using combustion map (Finney, 2003).

FARSITE can simulate the fire suppression by means of ground and aerial attack tactics. Ground attack tactics consist of direct, indirect and parallel attack. Direct attack is applied as following the instant perimeter of the fire using data on fireline production rate according to crew type and fuel model. Indirect attack is building impermeable fireline along a predetermined direction. Parallel attack is similar to direct attack except for building fireline at a specific constant distance from the fire front. Air attack features allow the user to locate the retardant drops for a defined aircraft (Finney and Andrews, 1999).

3.3. Data Requirements

FARSITE requires several types of data files within GIS environment. Required data consist of three legs of the fire triangle (Figure 2.1). Fuel and topography are required as spatial GIS based raster themes whereas weather data are formatted as stream or ASCII formatted values. Eight cell-based layers consist of elevation, slope, aspect, canopy cover, fuel model (Anderson, 1982), live crown base height, crown bulk density, and tree height or canopy height. The first five raster data sets are required in order to run FARSITE (Finney, 1998).

FARSITE requires the support of Geographic Information System to generate, manage and provide spatial data themes as GRASS ASCII or ARC GRID ASCII format and they are combined into a single landscape (*.LCP) file in FARSITE. All themes must be co-registered in order to have the same reference point, projection and units. Identical resolution of raster themes must be the same and finally all raster data sets must be in the same extent (Finney, 2003). Spatial themes are provided in raster format because of providing rapid access by the model to the necessary spatial data. 25 to 50 m raster resolutions are fairly enough to provide accurate level of detail (Finney, 1998).

Optional data themes are required only to calculate some aspects of fire behavior, such as crown fire and fuel consumption. Surface fire simulation can be performed without optional GIS data themes (Finney, 2003)

FARSITE also requires weather and wind data in order to perform simulations. FARSITE input data files are tabulated in Table 3.1.

3.3.1. Landscape File

According to the Finney (2003), the extension of the Landscape File is .LCP and it contains all the rasterized data themes imported from GIS. It includes 5 basic themes; elevation, aspect, slope, fuel model, canopy cover and optional files for stand height, crown base height, crown bulk density, duff loading, and course woody profiles. These optional parameters can be assigned constant unless they are provided.

A landscape file is a binary file and it consists of a header and a body of short integers for each theme. The header contains information about the bounds of area, cell resolutions and units of each theme.

Table 3.1. FARSITE Input Data Files (Finney, 2003)

File Name	**File Ext.**	**File Type**	**Required**	**Optional**
Landscape	.LCP	Raster	Fuel Model, Slope, Aspect, Elevation, Canopy Cover	Crown Bulk Density, Crown Base Height, Stand Height, Duff Loading and Coarse Woody themes
Weather	.WTR	Text	At least one file	Use up to 5 .WTR files in a simulation
Wind	.WND	Text	At least one file	Use up to 5 .WND files in a simulation
Adjustment	.ADJ	Text	Although required, this file can consist of all zeros	Adjustment factors other than zero are optional
Initial Fuel Moisture	.FMS	Text	Needs moistures at least one day before the beginning of the simulation	none
Fuel Model Conversion	.CNV	Text	none	yes
Custom Fuel Models	.FMD	Text	none	For fuel models other than the 13 standard NFFL models
Fire Acceleration	.ACL	Binary	none	yes
Air Attack Resources	.AIR	Text	none	Needed to implement the air attack functions
Coarse Woody Profiles	.CWD	Text	none	Specifies > 3" fuels for the Coarse Woody GIS theme used by Post Frontal Combustion Model.
Burn Periods	.BPD	Text	none	Specifies a daily burn period by date
Gridded Weather and Winds	.ATM	Text	none	Uses gridded weather files if a weather model to provide them is available
Ground Attack Resources	.CRW	Text	none	needed to implement the air attack functions

The landscape file is generated by FARSITE through obtaining each ASCII grid files and specifying their units.

i. Fuel Model Theme

Fuels consist of the various components of live and dead vegetation that occur on a site. Type and quantity of fuels depend on the soil, climate, geographic features, and the fire history of the site.

The mathematical model of fire behavior requires the description of fuel properties as inputs to calculation of fire behavior. The collection of fuel properties is known as fuel models and it is divided into four groups: grass, shrub, timber, and slash. “The differences in fire behavior among these groups are basically related to the fuel load and its distribution among the fuel particle size classes” (Anderson, 1982). Fuel models are the tools that help the user to estimate fire behavior realistically.

Fuel model theme must consist of integer index to a fuel model. Between Model numbers 1 and 13 were reserved for standard NFFL Fuel Model. Detailed information on NFFL Fuel Model is given in Appendix A (Anderson, 1982). Numbers 0, 98 and 99 are used for non fuel raster cells, such as water and rocky ground.

Any fuel model other than standard 13 NFFL fuel models (Anderson, 1982) can be described in a Custom Fuel Model (.FMD) file, which is described in Section 3.3.2.

ii. Slope Theme

One of the required raster themes is the slope theme and its values should be integer although decimal values can also be read. Slope units can be degrees or percent of inclination from horizontal and it is needed in order to figure slope effects on fire spread and solar radiance (Finney, 2003).

iii. Aspect Theme

The aspect theme is one of the required raster themes and contains values for topographic aspect. If the aspect data are from a GRASS ASCII file all values are oriented counterclockwise from east. Aspect values from ARC/INFO must be azimuth values (degrees clockwise from north) and can be integer or decimal values (Finney, 2003).

iv. Elevation Theme

Elevation theme can have units of either meters (m) or feet (ft) above sea level. In order to adjust adiabatic temperature and humidity, this theme is required and it is necessary for conversion of fire spread between horizontal and slope distances (Finney, 2003). In addition, slope and aspect themes are derived form elevation theme.

v. Canopy Cover Theme

One of the essential themes is named as canopy cover due to compute shading and wind reduction factors for all fuel models. Canopy cover is the horizontal percentage of the ground surface that is covered by tree crowns and it is measured as the horizontal fraction of the ground that is covered directly overhead by tree canopy (Finney, 2003).

The units of canopy cover theme can be selected either categories (1 to 4) or percentage values (0 to 100). Percentage values can be categorized as

1. 1 – 20 %
2. 21 – 50 %
3. 51 – 80 %
4. 81 – 100 %

and zero cover is assigned by 0 or 99.

Furthermore, as well as fuel model, canopy cover can be assigned as a constant value across the whole landscape. Since canopy cover theme controls how FARSITE uses other themes, it is important and required in order to run simulation. If the value of a cell in the canopy cover theme is assigned zero, FARSITE understand that there is no tree cover at this location and then it ignores the values of stand height, crown base height, and crown bulk density for the same cell (Finney, 2003).

vi. Stand Height Theme

Stand height theme is one of the optional spatial data themes and it is used to compute spotting distances, wind reduction to midflame height, and crown fire characteristics. Stand height is displayed in Figure 3.2. The values can be either integer or decimal in the units of meters or feet. The precision of fire behavior calculations is limited to 1/10th of the units (Finney, 2003).

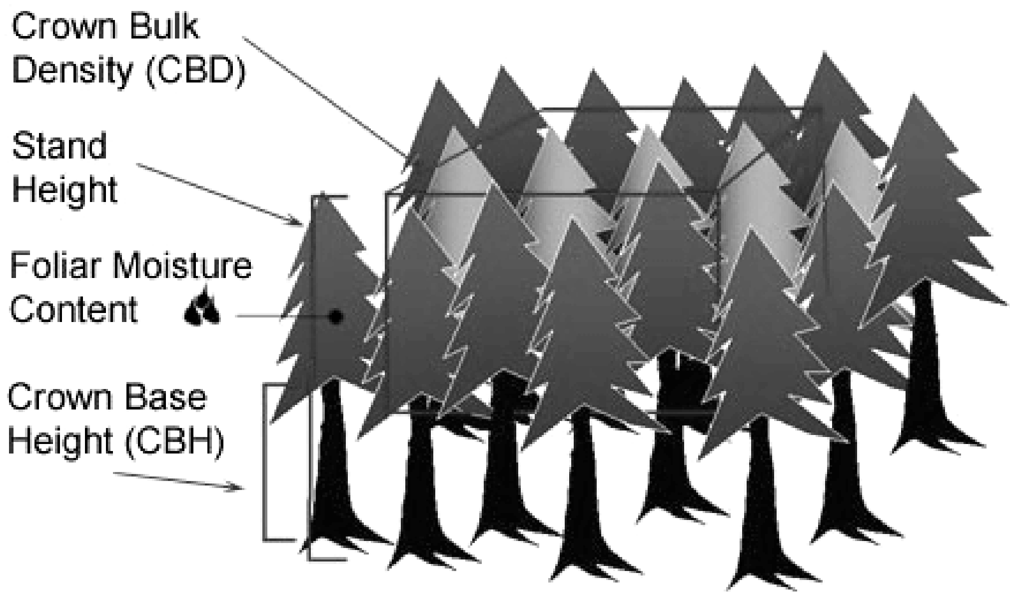

Figure 3.2. Definition of Crown Fuel Data Used in FARSITE (Finney, 2003)

vii. Crown Base Height (CBH)

Crown base height (CHB) is important for determining transition from surface fire to crown fire. It is the height to the bottom of the live crown (Figure 3.2). CHB should include ladder fuels effects in increasing vertical continuity and assisting shift to crown fire. The precision of crown base height is same as stand height theme (Finney, 2003).

viii. Crown Bulk Density (CBD)

Crown bulk density (Figure 3.2) is used to determine the spread characteristics of crown fires. The values of raster themes can be integers or decimal values in either kg/m^3 or lb/ft^3. "The precision of crown bulk density values are used to the nearest 100th kg/m^3 or 1000 lb/ft^3. Thus, if you have integer values in your crown bulk density theme, you must use the calculator features of your GIS to multiply the original crown bulk density units by 100 (kg/m^3) or 1000 (lb/ft^3). This conversion is optional for decimal bulk density values" (Finney, 2003).

There are two options for generating crown bulk density information. The first one is that Crown Bulk Density is linked to the canopy cover theme. In this method, only maximum crown bulk density for each forest type is entered and canopy cover is assumed to be 100 %. During the simulation, actual crown bulk density for each raster cell is computed by the multiplication of entered crown bulk density and canopy cover fraction. The second option is using independent crown bulk density theme developed by GIS (Finney, 2003).

Moreover, there are also two optional raster themes, namely Duff Loading and Coarse Woody, which are necessary for utilization of the Post-Frontal Combustion model. "Post-Frontal combustion refers to the burning of woody surface fuels, litter, and duff behind the moving forward edge of the flaming zone" (Finney, 2003).

Raster file data units and raster themes in order to generate landscape file and their usage were summarized in Table 3.2 and Table 3.3.

Table 3.2. Raster File Data Units (Finney, 2003)

File Theme	Required	Default Units	Alternate Units
Elevation	yes	Meters	feet
Slope	yes	Degrees	percent
Aspect	yes	categories 1-25	degrees
Fuel model	yes	13 NFFL (Anderson, 1982) models	custom or converted models
Canopy cover	yes	categories 1-4	percent
Tree height	no	meters*10	meters, feet, feet*10
Crown base height	no	meters*10	meters, feet, feet*10
Crown bulk density	no	kg/m^3*100	kg/m^3, lbs/ft^3, lbs/ft^3*100
Duff loading	no	Mg/ha	Tons/acre
Coarse woody	no	coarse woody models	none

Table 3.3. Raster inputs to FARSITE and their usage in the simulation (Finney, 1998)

Raster Theme	**Units**	**Usage**
Elevation	m, ft	Used adiabatic adjustment of temperature and humidity from the reference elevation input with the weather stream.
Slope	percent	Used for computing direct effects on fire spread, along with Aspect, for determining the angle of incident solar radiation (along with latitude, date, and time of day) and transforming spread rates and directions from the surface to horizontal coordinates.
Aspect	° Az	See slope
Fuel Model		Provides the physical description of the surface fuel complex that is used to determine surface fire behavior (see Anderson 1982). Included here are loadings (weight) by size class and dead or live categories, ratios of surface area to volume, and bulk depth.
Canopy Cover	percent	Used to determine an average shading of the surface fuels (Rothermel et al., 1986) that affects fuel moisture calculations. It also helps determine the wind reduction factor that decreases windspeed from the reference velocity of the input stream (6.1 m above the vegetation) to a level that affects the surface fire (Albini and Baughman, 1979).
Crown Height	m, ft	Affects the relative positioning of logarithmic wind profile that is extended above the terrain. Along with canopy cover, the influences of the wind reduction factor (Albini and Baughman, 1979), the starting position of embers lofted by torching trees, the trajectory of embers descending through the wind profile (Albini, 1979).
Crown Base Height	m, ft	Used along with the surface fire intensity and foliar moisture content to determine the threshold for transition to crown fire (Alexander, 1988; Van Wagner, 1977).
Crown Bulk Density	kg m^{-3}, lb ft^{-3}	Used to determine the threshold for achieving active crown fire (Van Wagner, 1977; 1993).

3.3.2. ASCII Input Files

ASCII text file consists of weather (.WTR), wind (.WND) and Fuel Files; these are Adjustment (.ADJ), Moisture (.FMS), Conversion (.CNV), Custom Models (.FMD) and Coarse Woody (.CWD). Weather, wind, adjustment, and fuel moisture text files are required. In this section, the information about these input files is presented.

The format of all ASCII input files are space delimited and it can be created and edited via text editing application such as Microsoft Notepad or by using FARSITE editor. The parameters and its definitions of ASCII input files and also examples have been given in Appendix B.

i. Weather (.WTR)

The weather file is a required ASCII text file in order to perform any simulation. A weather file must contain daily observations on temperature, humidity and precipitation specified below. All input must be integer value in English or metric units.

The usage of weather information is to interpolate temperature and humidity for hours between the maximum and minimum values of each day. Also these data are extrapolated to different elevations by using the elevation theme in the landscape.

Five weather streams can be used and this feature permits to approximate some spatial variation in weather. In order to use multiple weather stations, some overlaps in each weather file must exist (Finney, 2003).

ii. Wind (.WND)

As well as weather file, wind file is also one of the required input files and can be as a stream of data in a wind file (.WND) or as a gridded weather (.ATM) file, described in gridded weather and winds section. And also up to 5 wind files can be used as input for a project to simulate spatially varying winds, for example ridge winds vs. slope winds.

Although winds vary in space and time, FARSITE assumes that winds are constant in space for a given wind stream but variable in time. In other words, there are no topographic effects on winds. The wind inputs can be at any temporal resolution, hourly or sub-hourly and it must be integer. FARSITE allows weather inputs in English or metric units, stated at the first line of the Wind (.WND) file. Additionally, wind observation can be on irregular interval, for example every 10 minutes during day and only every 2 hours at night (Finney, 2003).

iii. Adjustment Factors (.ADJ)

Adjustment Factors File is required in order to adjust spread rate of fire according to the user experienced judgment or local data to tune the simulation to observed or actual fire spread patterns (see Section 3.4). “Factors are fuel model specific and are multiplied by the rate of spread to achieve the specified adjustment” (Finney, 2003).

Only rate of spread for a simulation is modified by adjustment factors. In order to change the all fire behavior parameters, heat per unit area, fire intensity etc., Custom Fuel Model must be created by using adjustment factors. Additionally, adjustment factors for each custom model used must be specified (Finney, 2003).

iv. Initial Fuel Moisture (.FMS)

“The fuel moistures at the beginning of the simulation must be set for each fuel type. These fuel moistures are required to begin the process of calculating site specific fuel moistures at each time step throughout the simulation.” If custom models are used, they too must have initial fuel moistures specified in this file (Finney, 2003).

v. Fuel Model Conversion (.CNV)

Fuel conversion file is an optional ASCII text file. If the fuel model numbers in the raster fuel model theme do not match directly to the 13 NFFL (Anderson, 1982) or custom fuel models files, Fuel Model Conversion (.CNV)

File can be used. Another usage is for changing the fuel model that a particular fuel attribute represents.

vi. Custom Fuel Models (.FMD)

Custom Fuel Model is an optional ASCII text file for FARSITE. Fuel models different than standard 13 NFFL fuel model (Anderson, 1982) must be defined in a Custom Fuel Model (.FMD) File and they are assigned model numbers 14 through 50. The unit of fuel model input can be either English or metric, that is inserted at the first line of custom Fuel Model (.FMD) File. Its parameters are specified below (Finney, 2003).

Individual custom fuel models can be tuned by changing the fuel model parameters. When using adjustment file, only the spread rate are modified. In order to adjust fire behavior parameters, fuel models must be tuned by using tuning feature of FARSITE (Finney, 2003).

vii. Fire Acceleration (.ACL)

Fire Acceleration (.ACL) File allows controlling point and line fires acceleration for each fuel type. “Fire acceleration is defined as the rate of increase in spread rate/fire line intensity from a given source.” The type of acceleration definition files are in binary format so that they can be modified only by using the Fire Acceleration command in FARSITE (Finney, 2003).

viii. Air Attack Resources (.AIR)

Information of aerial fire fighting resources is stored in Air Resource (.AIR) File. These files include the capabilities of different aircraft (air tankers, helicopters dropping water or retardant). More than one aircraft information can be defined in one file. For each aircraft, specific name have to be assigned. The resource name must begin and end with character ‘#’.

Line length is the altitude of retardant drops for each coverage levels. Coverage levels need to be higher in heavier fuels to be effective. For line length, to acquire realistic numbers in fuel types, experience and/or consultancy of literatures are needed (Finney, 2003).

ix. Coarse Woody Profiles (.CWD)

Coarse Woody Profile is an optional ASCII text file required to run the Post-Frontal Combustion Model in FARSITE. The file has profile numbers between 1 and 99. The units are defined by the words ENGLISH or METRIC at the first line of file. The file can contain multiple lines per profile.

The header consists of two lines. The first line starts with the word “MODEL”, the fuel model number (integer) and brief description of the model. The second line starts with the word “DEPTH” and the depth of the profile (decimal) in feet or centimeters (Finney, 2003).

x. Burn Period (.BPD)

The burn period file specifies daily burning periods. It is an optional file that consists of dates and times of burns. It is used to stop the simulation during periods of low activity to correct the inclination to over predict fire growth rates when environmental conditions essentially stop fire spread.

This feature also speed up simulations by stopping the simulation during periods of low fire behavior that affects the result of fire behavior slightly (Finney, 2003).

xi. Gridded Weather File (.ATM)

FARSITE accepts gridded inputs for weather and wind variables. Weather variables are temperature, humidity and precipitation; wind variables are wind speed and direction, and also cloud cover.

Data units are same as weather and wind stream inputs for FARSITE to allow compatibility with both GRASS and ARC GRID data. The six gridded input files are temperature (Fahrenheit), humidity (Percentage), Precipitation (Inches ×100), Wind Speed (MPH), Wind Direction (Azimuth Degrees), and Cloud Cover (Percentage). Formats of all gridded input files are similar to traditional GRASS or ARC GRID ASCII raster. The filenames of the gridded input files must be included into an Atmosphere (.ATM) File to define the date and time of each raster files. The format of the atmosphere file changes according to using gridded inputs for either weather and wind variables or only wind variables (Finney, 2003).

Examples of Gridded Weather (.ATM) File can be seen in Appendix B.

xii. Ground Resources File (.CRW)

Ground resources file (.CRW) is an optional ASCII file needed to simulate fire suppression with ground resources. Ground base fire fighting resource information is defined in this file. These files describe the capabilities of different resources, these are had crews, engines, equipments etc.

3.4. Limitations and Assumptions

Some assumptions had to be made to model fire growth. Models are valid and useful if the scopes of the assumptions are clearly understood. The following paragraphs explain the major assumptions of the models used in FARSITE.

1. "The shapes of fires are elliptical under uniform conditions." (Finney, 1998) This assumption was verified by Van Wagner (1969). Different fire shapes have been reported by Peet (Peet, 1967 in Finney, 1998), Albini (1976), Anderson (Anderson, 1983 in Finney, 1998), Alexander (Alexander, 1985 in Finney, 1998) and Byram (Byram, 1959 in

Finney, 1998). Richards (Richards, 1993 in Finney, 1998) analyzed that none of fire shape alternatives could explain variation in windspeeds or direction of spread. Richards (Richards, 1993 in Finney, 1998) assumed that "fire spread was independent of the shape or length of the fire front". An elliptical fire shape assumption is true only in continuous fuels so fire shapes due to discontinuous fuels will not be effectively modeled.

2. "Fire spread rate and intensity at a given vertex is assumed to be independent of fire and environmental interactions." (Finney, 1998) according to Cheney et al., (Cheney et al, 1993 in Finney, 1998) and Weber (Weber, 1989 in Finney, 1998), field observations and analysis suggest that flame length of line fire affects the spread rate and fire shape.

3. "Fire acceleration is assumed to be dependent on fuel type but independent of fire behavior." (Finney, 1998). This means that time period must be constant for given fuel type in order to reach steady-state spread rate regardless of environmental conditions. Acceleration rate for each fuel type must be assigned (McAlpine and Wakimoto, 1991 in Finney, 1998).

4. “Fires are assumed to instantly achieve the expected elliptical shape when burning conditions change (such as changes in windspeed or slope)” (Finney, 1998).

5. “The elliptical shapes are assumed to be fuel independent, meaning the fire shape (not size) is only determined by the resultant wind – slope vector” (Finney, 1998).

6. “The origin of an elliptical fire is assumed to be located at the rear focus of the ellipse.” (Finney, 1998) Most of the model using elliptical fire (Alexander, 1985 in Finney, 1998; Anderson, 1983 in Finney, 1998; Andrews, 1986) accept this assumptions due to providing an implicit means to determine backing fire spread rate.

7. “The spread of a continuous fire front can be approximated using a finite number of points.” (Finney, 1998). The accuracy of this assumption depends on the spatial resolution determined by the user and the resolution specified for the simulation. “It is assumed that a resolution can be specified that preserves the "important" features of fire growth but ignores irrelevant spatial detail. This is dependent on the purpose and requirements for the simulation” (Finney, 2003).

8. FARSITE model has not been developed to determine whether a fire will spread or not. It has not been only designed for spread of fire but

also spread rate results can be adjusted by the use of adjustment and custom fuel models (Finney, 2003).

CHAPTER 4

THE CASE STUDY: MARMARİS- ÇETİBELİ WILDFIRE

Fire Area Simulator Model, FARSITE, is used in modeling the fire behavior in order to develop fire management strategies. The suitability of the model for modeling the wildfires in Turkey is tested and the appropriate fire model parameters are obtained.

In this chapter, the forest fire, which started in Marmaris Çetibeli on the 15th of August and lasted till 27th of August, 2002, has been simulated. The information about the simulation sites and wildfire, the preparation of the required input data of FARSITE have been explained. Digital elevation model (DEM) of the area has been generated from 1:25,000 scale maps by digitizing contours. The weather and wind data have been gathered and put into appropriate GIS layers. Afterwards, the 13 Northern Forest Fire Laboratory Fuel Model of the area have been determined according to vegetation map, which was prepared by General Directorate of Forest. The IKONOS images acquired on the dates April 22, 2002 and August 21, 2002 are used to define the fuel model of the area by using visual interpretation. The production of FARSITE input data files is explained briefly.

Since the exact fuel model is not available for Turkey, the model is used to calibrate the fuel model belonging to the study area. The burned area is extracted form the fire reports and IKONOS images.

4.1. The Study Area

The Aegean and Mediterranean Regions, covered by red pine (*Pinus brutia*) forests, are the most sensitive areas to fire in Turkey. The red pine forests located around Çetibeli District in Marmaris have burned 3 times, these are the largest forest fires occurred in this area, as presented in Table 4.1. Since it is a fire occurred recently, the documentation of the fire is better than the others. Therefore, the Çetibeli fire started at 15^{th} of August, 2002 is studied in this study.

The study area is located in Muğla, in the south border of Aegean Region, the position of burned area is about 1 km south east of Çetibeli district and it is elongated with west to east direction. The main road, named D 400, passes from west of the region. Elevations vary from 10 to 600 m along North West to South East direction. The location of the study area can be seen in Figure 4.1.

The climate in Çetibeli is warm like Mediterranean type, which is cold rainy winters, short wet springs and autumns, and hot dry summers. However, general climatic characteristics vary locally in the high mountainous areas. The area is mainly covered with red pine (*Pinus brutia*), which is the dominant vegetation species of the Mediterranean Region.

Table 4.1. The Largest Forest Fires in Turkey (General Directorate of Forest in Turkey, 2002)

Directorate of Region	Directorate of Management	Management Chief	Start Date	End Date	Burned Area (ha)	Reasons
Adana	Osmaniye	Osmaniye	9/30/99	10/2/99	1200	Incendiary
Balıkesir	Bandırma	Aladağ	4/5/00	4/6/00	1267	ETL[1]
Muğla	Marmaris	Hisarönü	8/11/97	8/13/97	1385	Carelessness
Muğla	Aydın	Söke	7/27/96	7/30/96	1438	Unknown
Denizli	Denizli	Buldan	7/13/00	7/14/00	1459	Carelessness
Çanakkale	Keşan	Çınarlıdere	9/1/00	9/3/00	1689	Carelessness
Antalya	Antalya	Düzlerçam	7/21/97	7/22/97	1715	Carelessness
Muğla	Marmaris	Çetibeli	8/15/02	8/17/02	1776	ETL
Bursa	Orhaneli	Merkez	4/5/00	4/6/00	1970	Carelessness
Antalya	Taşağıl	Karabük	8/3/00	8/5/00	2102	Incendiary
Adana	Karaisalı	Akarca	8/3/00	8/6/00	3138	Carelessness
Balıkesir	Balıkesir	Kepsut	8/12/02	8/13/02	3573	Unknown
Çanakkale	Çanakkale	Eceabat	7/25/94	7/27/94	4049	Debris burning
Muğla	Marmaris	Çetibeli	7/27/96	8/1/96	7090	Carelessness
Muğla	Marmaris	Çetibeli	3/23/79	10/2/79	13260	Unknown

i. Information about Çetibeli Wildfire

The information about Çetibeli forest fire was reported on 11st of November, 2002 by the Directorate of Marmaris Forest Management (Marmaris Orman İşletme Müdürlüğü) and Çetibeli Forest Management Chief (Çetibeli Orman İşletme Şefliği). Starting time of fire is 15th of August, 2002 at 18:23. It started at Çetibeli Forest Management Region and passed to the Gökova Forest Management Region on 16th of August, 2002 at 16:45. The fire is reported by the people who live in Çetibeli District and Altınsivri Watch Tower (Figure 4.1).

[1] Energy Transmission Line

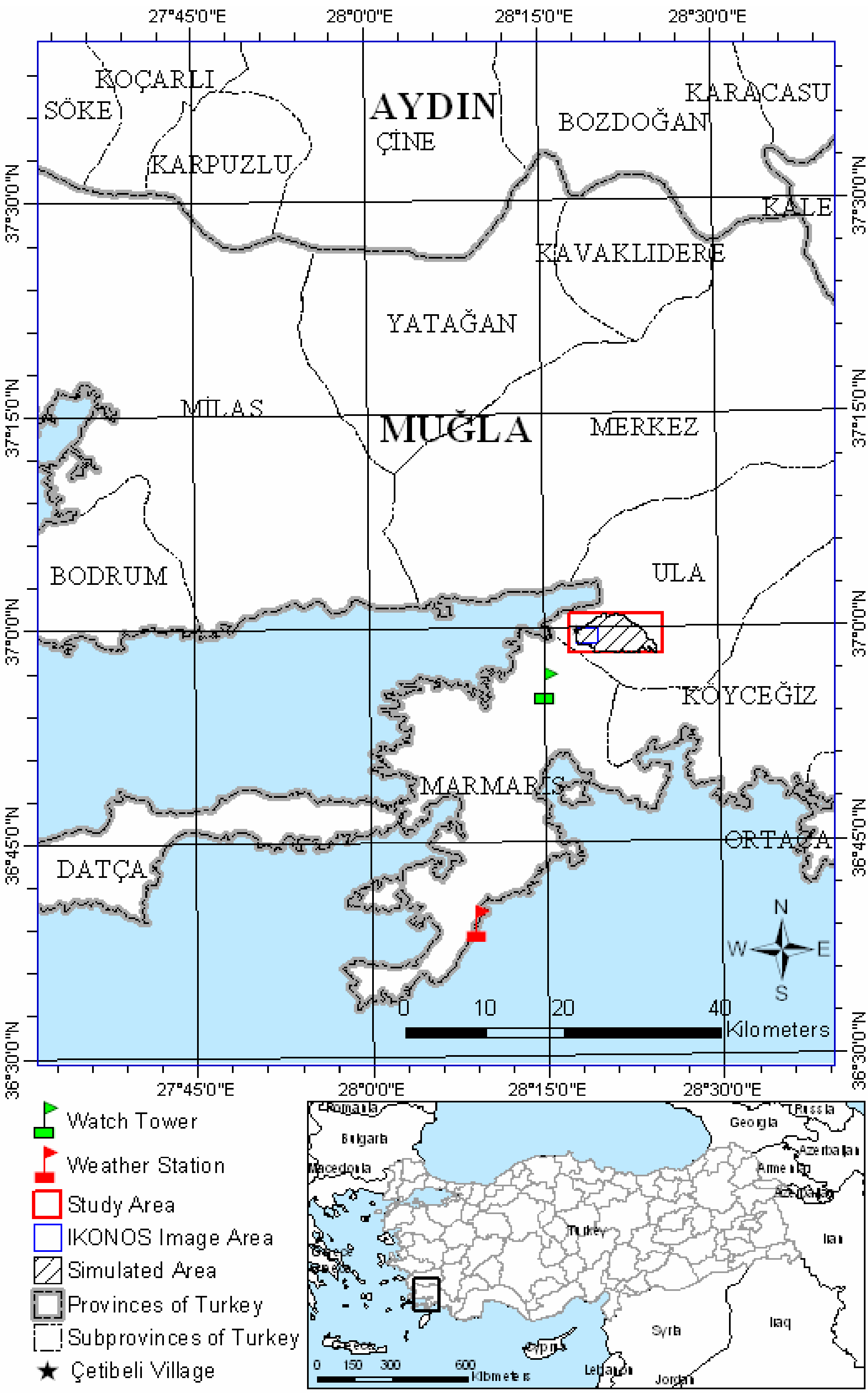

Figure 4.1. Location of the Study Area

The first interference was made at 18:30 on 15th of August, 2002 by fire fighters. The starting location of the fire was near transformer, that is about 90 m distant to the asphalt road and the slope of the starting location is about 20 %. Fire started as surface fire and continued as surface and crown fire due to strong wind. The rate of spread of fire was about 900 m /hr and intensity of fire was very high. The flame height was measured about 20 to 2500 cm. The vegetation types of the forest were red pine trees and dense bushes. This area has been burned before in 1955, 1979 and 1996 (Table 4.1). The data representing the meteorological conditions during fire are tabulated in Table 4.2.

The equipments used to suppress fire consist of scratch, some sort of knifes, saws, dozers, helicopter and planes. The fire fighters have tried to suppress the fire by means of direct, indirect and parallel attack. The squads of Marmaris, Muğla, İzmir, Antalya, Denizli, Mersin, Bursa and Ankara Forest Management have joined the fire battle. In addition to this, some planes that have come from İstanbul, Çanakkale and İzmir and two military planes have participated into fire suppression by dropping retardant water.

Table 4.2 Meteorological Conditions during Fire (obtained from Muğla Meteorological Station)

	Maximum	Minimum
Temperature (°C)	34	24
Humidity (%)	70	35
Wind Direction and Speed (km/h)	5-6 N NW	2-4 N NW

The number of people who have attended in order to suppress fire was arranged as 3 managers, 62 forest engineers, 40 park rangers, 1125 fire fighters, 300 volunteers, 300 soldiers, 15 police officers and 30 gendarmes. The used vehicles and machines are 17 planes, 13 helicopters, 27 dozers, 25 trailers, 1 excavator, 1 break down lorry, and 83 fire trucks. The registry report of fire is given in Appendix C.

Finally fire was taken under control on 17th of August, 2002 at 21:00 and it was suppressed completely on 27th of August, 2002 at 18:30. It took 288 hours and 7 minutes. The total burned area was measured as 1775.5 hectares.

On the other hand, the starting location of the fire is not known precisely. The progressing time and location of the fire, the local weather and wind data, and the information about suppression tactics, types, time, number of workers and squad and the interfere location of ground and aerial forces during fire fighting have not been reported. Moreover, the feature which could be valued as fire barrier should have been noted.

ii. Fire Cost Analysis

The cost analysis has been made by the Çetibeli and Gökova Forestry Chief on 13rd of September, 2002. The total cost was tabulated in Table 4.3.

Table 4.3. Total Cost of Çetibeli Fire (Marmaris – Çetibeli Forest Management Chief, 2002a)

Costs	**($\times 10^6$ TL)**
Tree Cost	233,154 TL
Reforestration Cost	3,107,125 TL
Feeding Cost	22,985 TL
Worker Cost	213,990 TL
Timber Cost	233,519 TL
Gasoline Cost	33,712 TL
Dozer Cost	42,450 TL
Trailer Cost	4,100 TL
Saw Cost	500 TL
Plane Rent Cost	331,335, TL
Helicopter Rent Cost	1,054,397 TL
Fire Truck Cost	126,000 TL
Total	**5,403,267 TL**
	$ 3,235,489[2]

4.2. The GIS Data Preparation

i. The Preparation of GIS Data Files for Çetibeli

In this section, the preparation steps of required data for Çetibeli are explained. The optional landscape input files of FARSITE could not be generated due to lack of information and impossibility of measurement at field. Registration and generation of GIS themes have been performed by using ArcGIS 8.1 and its extensions, which are Spatial Analyst and 3D Analyst. First of all, topographic maps of the area were registered to UTM ED 1950 zone 35N coordinate system. The 3rd order polynomial transformation method was used and they were rectified by using Bilinear Interpolation. Each topographic paper map was georeferenced

[2] 1$ = 1,670,000 TL

using a set of 30 ground control points (Figure 4.2). The detailed coordinate system parameters, the link table of each registered maps and all of layers created for simulation can be seen in Appendix D. The contours, roads, rivers and energy transfer lines were digitized from the rectified topographic maps.

ii. Selection and Processing of Satellite Images

NFFL Fuel Types (Anderson, 1982) of the study area have been classified according to the vegetation map of the study area and pre-fire satellite image. The vegetation map has been drawn by the General Directorate of Forest. IKONOS image acquired on 22nd of April, 2002 was used as the pre-fire satellite image. The radiometric resolution of the post and pre-fire images are 11-bit, the visible and near infrared bands have 4 m spatial resolution and the panchromatic bands have 1 m spatial resolution. The image acquired on 21st of August, 2002 is used as post-fire image. The overall view of the images can be seen in Figure 4.3 and Figure 4.4. The satellite images do not cover all of the study area (Figure 4.1).

ERDAS Imagine 8.5 software was used in order to handle satellite images. For both images, red, green, blue and near infrared layers of each image were stacked into single file and spatially enhanced by merging with 1-m resolution panchromatic image. The projections of the images are UTM and their datum and spheroid are World Geodetic System 1984 (WGS 84). The datum and spheroid of the images are transformed to the European Datum 1950 and International 1909.

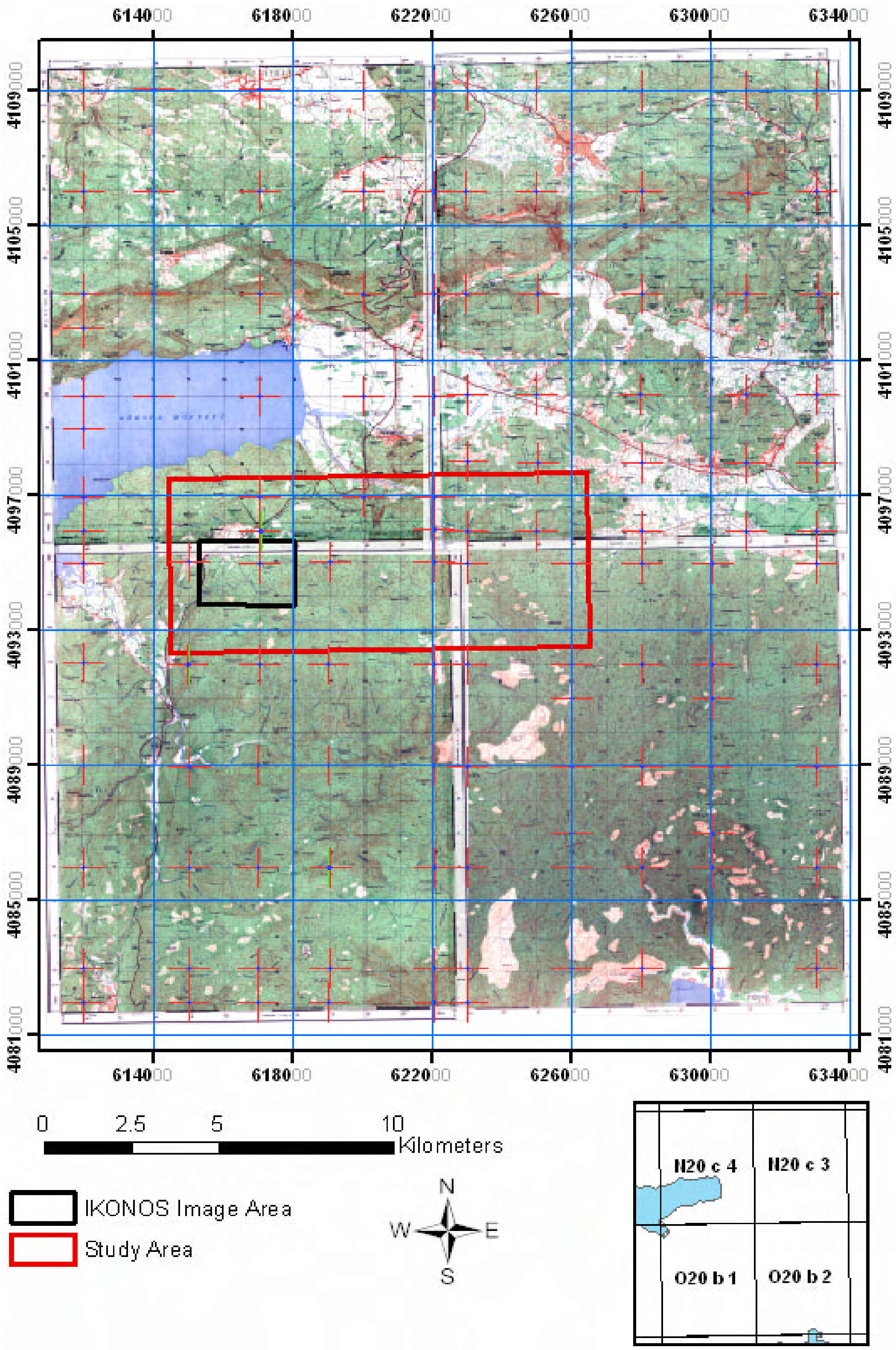

Figure 4.2. Ground Control Points on the Topographic Maps Belonging to the Study Area

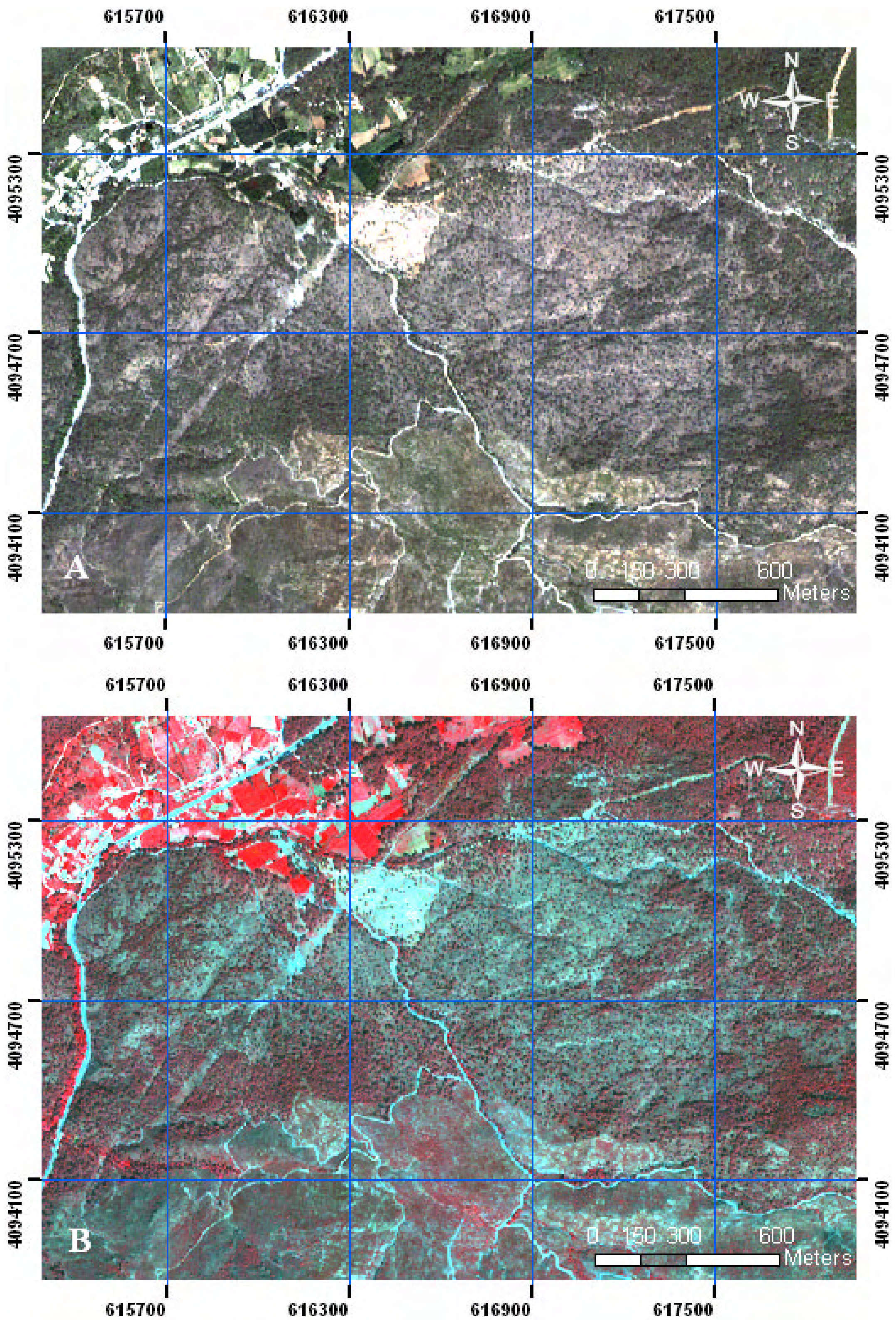

Figure 4.3. Pre-fire IKONOS Satellite Image, (22nd of April, 2002 at 09:05) (A) Visible Spectrum, (B) Near Infrared

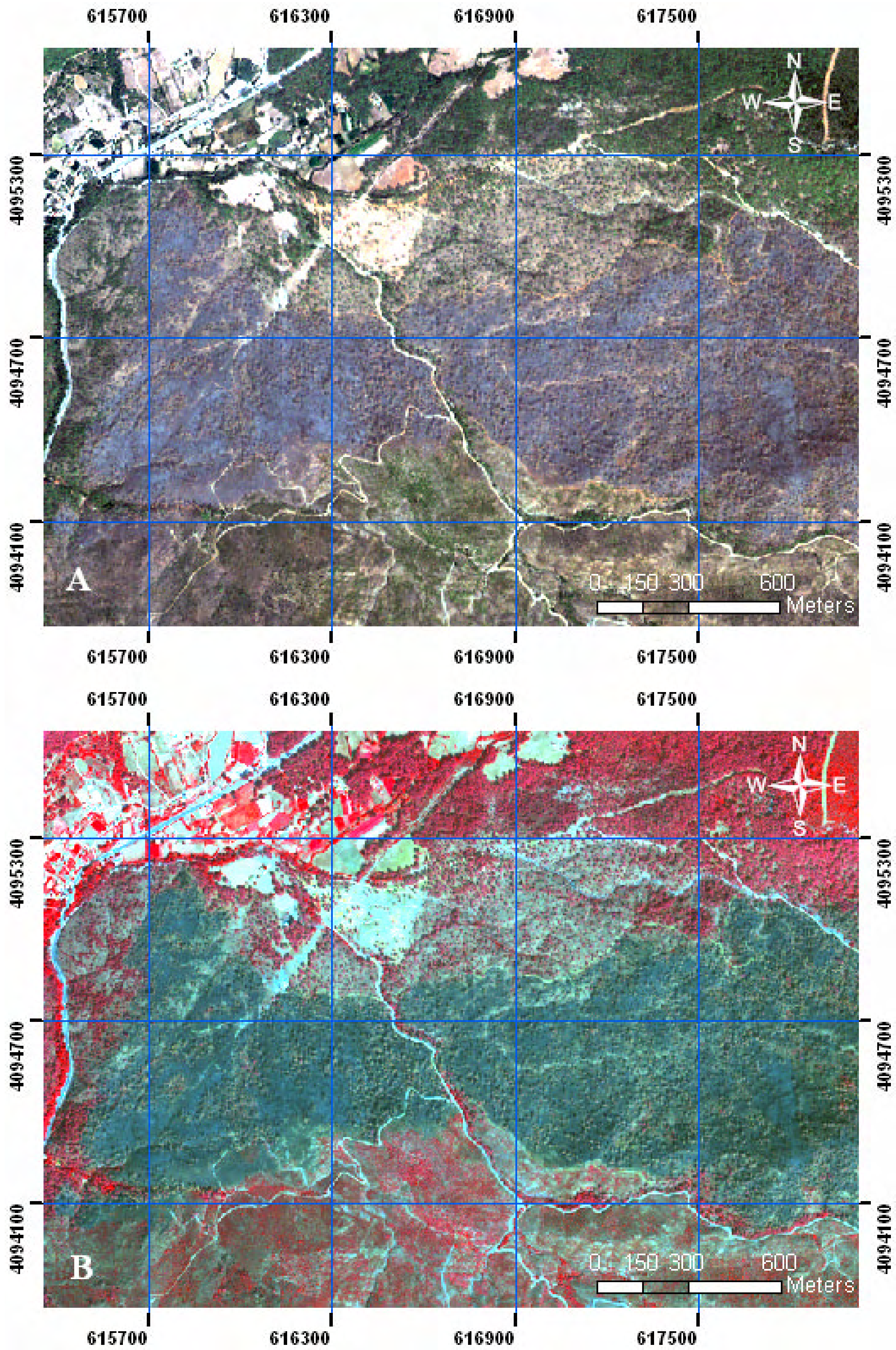

Figure 4.4. Post-fire IKONOS Satellite Image, (21st of August, 2002 at 09:15) (A) Visible Spectrum, (B) Near Infrared

iii. Identification of Fuel Types and Canopy Cover

Northern Forest Fire Laboratory (NFFL) in United States of America has classified the vegetation types into 13 standard fuel models. FARSITE uses 13 - NFFL fuel types as fuel model themes (Anderson, 1982).

In Turkey, forest areas were divided into sections according to terrain or geographic features such as rivers. These sections were separated into subsections whose vegetation types show the same characteristics, cover density and age and they are named as special codes such as Çzc1 etc. These codes are tabulated in Appendix E. The dominant vegetation species of the study area was red pine (*Pinus brutia*) with different cover density and age. Some part of the area covered with bushes and field, that is, open land. Generally, identification of the fuel types was built upon vegetation maps and satellite images. The vegetation map of Çetibeli has been obtained from General Directorate of Forest. This vegetation paper map has been scanned into digital format and registered via collecting reference points from topographic maps. After registration process, each polygon in vegetation map has been digitized and the vegetation codes have been stored in its database. Entire fuel map of the study area has not been digitized because digitized area is sufficient for performing simulation and it covers the burned area.

According to NFFL fuel model description (Appendix A) the vegetation of the study area was tried to be estimated by the help of the pictures of the fuel models, vegetation map and experiences of fire engineers and it was checked via satellite image visually. Since the satellite image does not cover entire study area, only the covered part has been verified. Fuel types of uncovered parts have been assigned by the help of estimated areas and vegetation map. Sorting the records by common name helped to speed up the categorization process (Finney, 2003).

"Canopy cover is measured as the horizontal fraction of the ground that is covered directly overhead by tree canopy" (Finney, 2003). Coverage units can be categorized with numbers 1 – 4 or percentage values of the cover. The main source of the classification of the canopy cover was vegetation map and satellite images. Canopy cover of the subsections was decided as 1 – 4 categorization scale due to codes, which were assigned by the forest engineers who have drawn the map and they were compared with satellite image.

4.3. Generation of Landscape Input File

The landscape file consists of 5 themes; elevation, slope, aspect, canopy cover and fuel model. In order to generate elevation theme, Digital Elevation Model (DEM) of the terrain was generated by using spatial interpolation of digitized contour lines from the 1: 25,000 scale (contours every 10 m) paper maps. Kriging method was performed in order to interpolate to raster. However, DEM could not be generated from polyline contour coverage hence Triangulated Irregular Network (TIN) of the area was produced and TIN was converted to point features by using 3D Analyst. After that, the coverages, elevations of top points digitized from paper maps and elevation generated from TIN, were merged by

Geoprocessing Wizard and the final elevation coverage was produced. Ordinary Kriging method was selected and the Search Radius Type was fixed. The default Output Cell Size was calculated 23.14533128 meter but it is fixed to 20 meters. According to ArcGIS Desktop Help, the Search Radius Distance should be 5 times greater than output cell size. The parameters of the Kriging interpolation method were reported in Lineage Report in Appendix D (Figure 4.5).

Slope and aspect of the area were derived from DEM of the area by means of Spatial Analyst Extension of ArcGIS. The output cell size was the same as DEM and output unit of slope was selected as degree. Aspect of the area was calculated as azimuth angle from the North. Elevation, slope and aspect of the work area can be seen in Figure 4.5.

After fuel models and canopy cover of the area have been decided, all of these vector features were converted to raster by using fuel model and canopy cover fields separately with the same cell size, 20 m. Overall view of fuel models and canopy cover are presented in Figure 4.6. Finally all of these landscape themes, elevation, slope, aspect, fuel model and canopy cover were exported to ASCII Raster format via ArcView GIS 3.2 with Spatial Analyst extensions. However, entire work area (Figure 4.1) have not been converted into ASCII format. FARSITE can be run if all of the required data themes of the area exist. Hence, before exported to ASCII Raster format, elevation, slope and aspect themes of the area have been clipped according to the spatial extent of fuel model theme. It has been dissolved by Geoprocessing Wizard into one polygon and

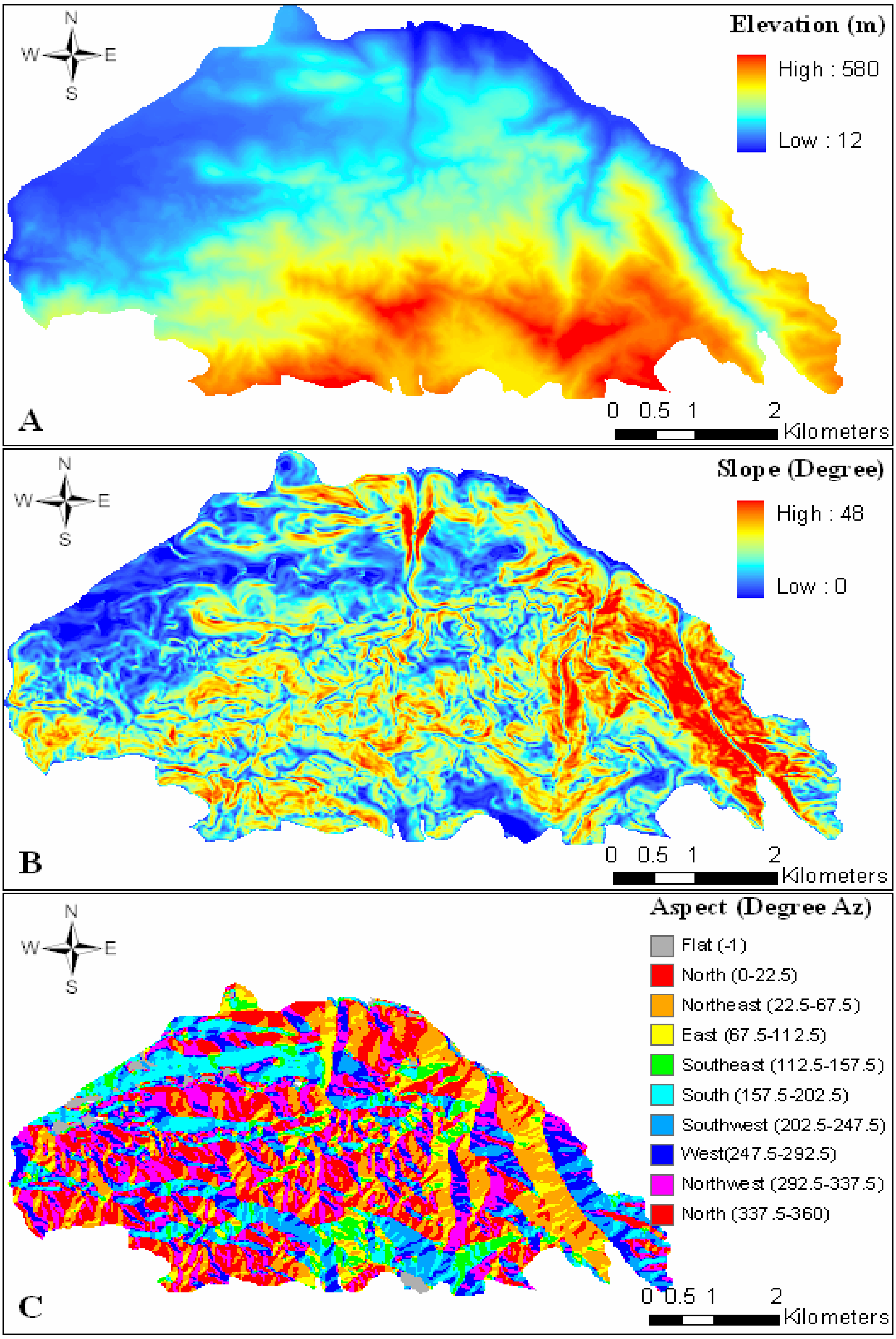

Figure 4.5. Data Themes of Landscape File. (A)Elevation, (B) Slope, and (C) Aspect of Çetibeli

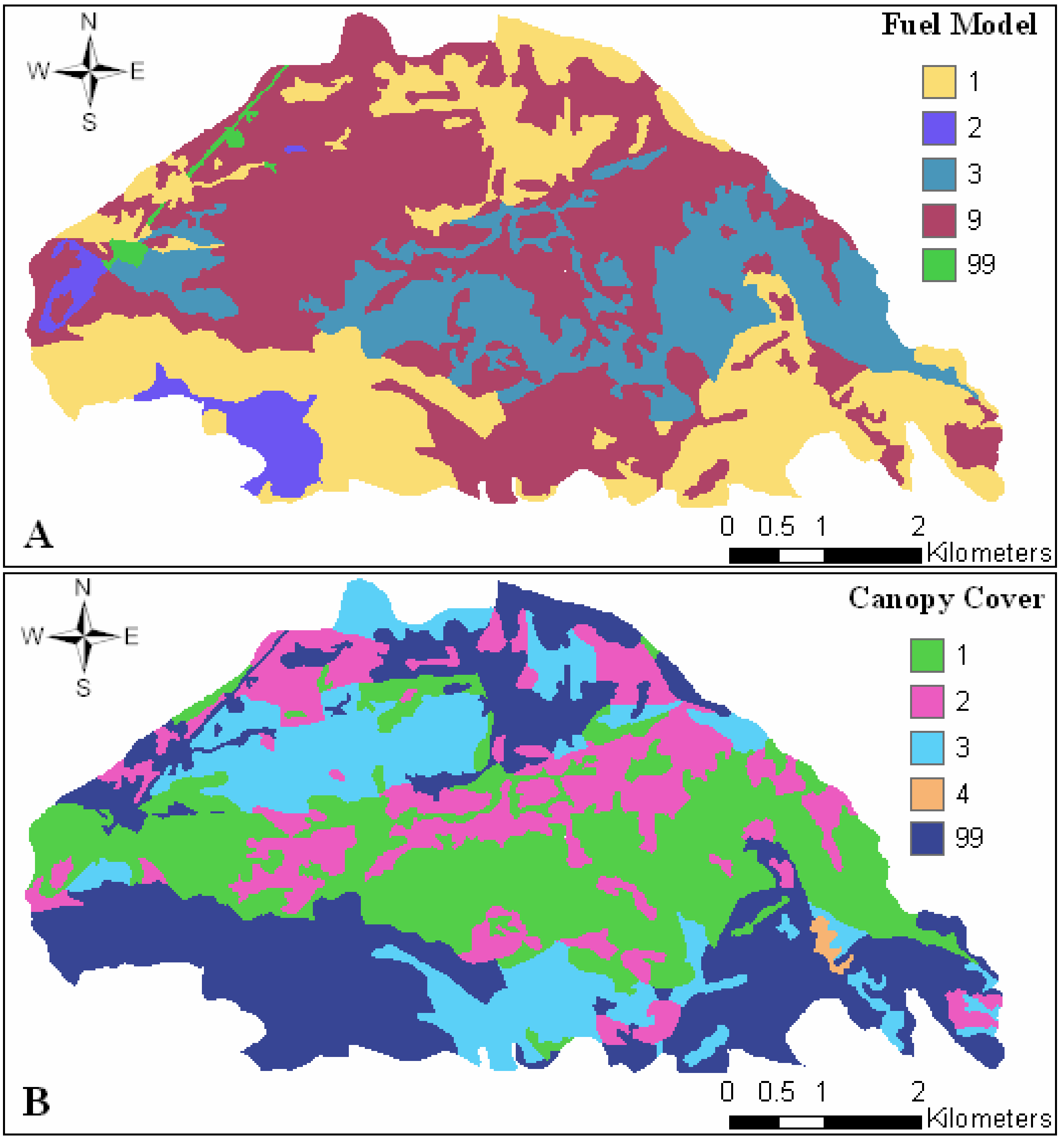

Figure 4.6. The (A) Fuel Model and (B) Canopy Cover of the Study Area

converted to raster format. By using raster calculator, clipping has been carried out by multiplying both themes. The important point is that all data themes of landscape file must have the same cell size, and spatial extent.

The vector themes can also be used as fire barrier and improvement of visibility.

4.4. Creating ASCII Input Files

FARSITE uses some required and optional input files. All of these input files are ASCII text format so they can be created, edited or viewed by any text editor such as Microsoft Notepad. The required ASCII input files are weather, wind, adjustment, and initial fuel moisture.

Meteorological data was obtained from Turkish State Meteorological Organization (Appendix F). The name of station is Marmaris located at 28.16° latitude, 36.51° longitude (Figure 4.1) and it has an elevation of 16 m from sea. The data taken from Meteorological Organization can be listed as air temperature (hourly), wind direction (16 directions) measured hourly, and wind speed (m/s), humidity (%) and cloudiness (%) recorded 3 times (7:00, 14:00, 21:00) in a day. Wind data are measured at 10 m high from the ground.

Weather data consist of precipitation, minimum and maximum temperature and their record time, minimum and maximum humidity, elevation and precipitation time period with daily observation. The starting date of the weather file must be one day before the fire starts because it is needed to calculate initial fuel moisture of the fuel. The weather data were generated by using meteorological data.

Weather and wind data were prepared by using software Microsoft Excel in order to facilitate formatting and converting to appropriate unit. Afterwards, tabulated data were exported to ASCII text files.

Adjustment Factors File was left with default values at first because it is used for adjusting the rate of spread of fire. The final adjustment factors are achieved after the calibration is performed by running the simulation until the expected result is acquired.

The ASCII input files of Çetibeli are documented in Appendix G

4.5. Simulation Process of Çetibeli Wildfire

The information of Çetibeli Wildfire has been summarized in Section 4.1. In this section, the Çetibeli Wildfire has been simulated and according to the known information of the fire, real situation has been tried to be set in order to obtain the real fire spread and behavior.

By the help of Fire Evaluation Reports (2002b) and satellite images, the information about burned areas, ignition points and the spread location at a specific time have been extracted. The ignition point has been reported as being near the transformer building. By the help of these information and satellite image, the location of the ignition point has been estimated as North – West of burned area near Çetibeli Village, illustrated in Figure 4.7.(A).

The burned area has been plotted on vegetation map by forest engineers, who joined the fire suppression. By the help of post-fire satellite image, the burned area covered by satellite image has been digitized. However, the east part of the burned area has been digitized according to the sketch which shows the burning sections. The burned area and the ignition point are illustrated in Figure 4.7.(B).

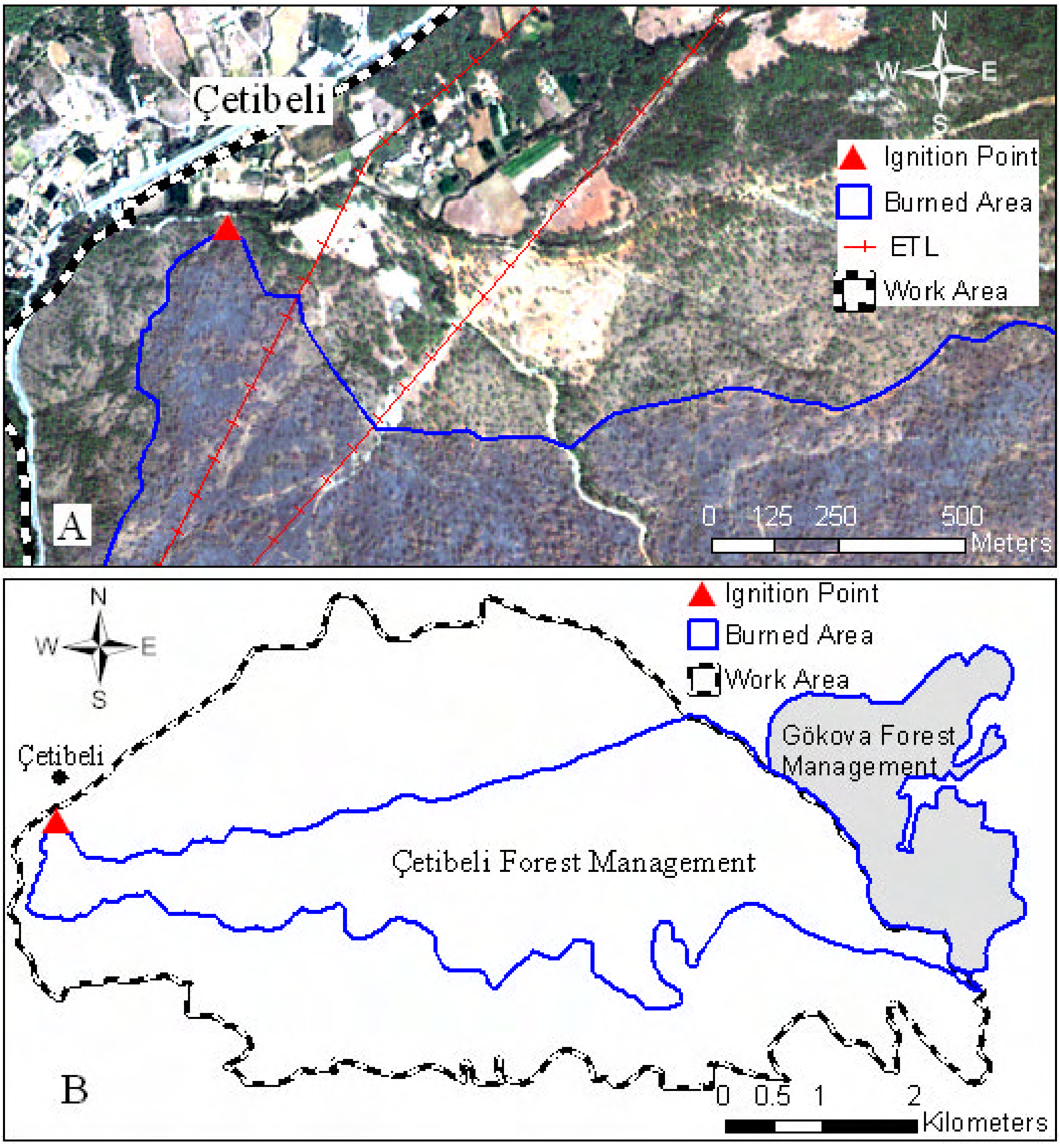

Figure 4.7. The View of (A) Ignition Point and (B) Burned Area

The time and location of the fire was known while passing from Çetibeli Forest Management Region to Gökova Forest Management Region on August 16th, 2002 at 16:45 and the fire has been simulated until this time at that location. Since the passing way was not known, it was assumed that fire spread has reached at this location as surface and crown fire.

The FARSITE simulation consists of a series of preparation steps. First step is preparation of spatial and nonspatial data as input. Other is selecting model settings and options and the last one is controlling the simulation process (Figure 4.8).

FARSITE requires and generates many types of data files. In order to prevent confusion, two directories, “input” and “output”, were created. Input directory contains GIS themes, ASCII input files, project, landscape and bookmark files. Output Directory contains the product of simulation.

i. Building Landscape (.LCP) File

The Landscape (.LCP) File is generated by inputting the ASCII raster files. Five required themes have been loaded and correct units have been selected. In this project, SI units are used. The latitude of the work area has been entered as 37 N. Once landscape file was created, there were no need to load ASCII raster themes. Figure 4.9 shows the landscape file generation window of Çetibeli Project.

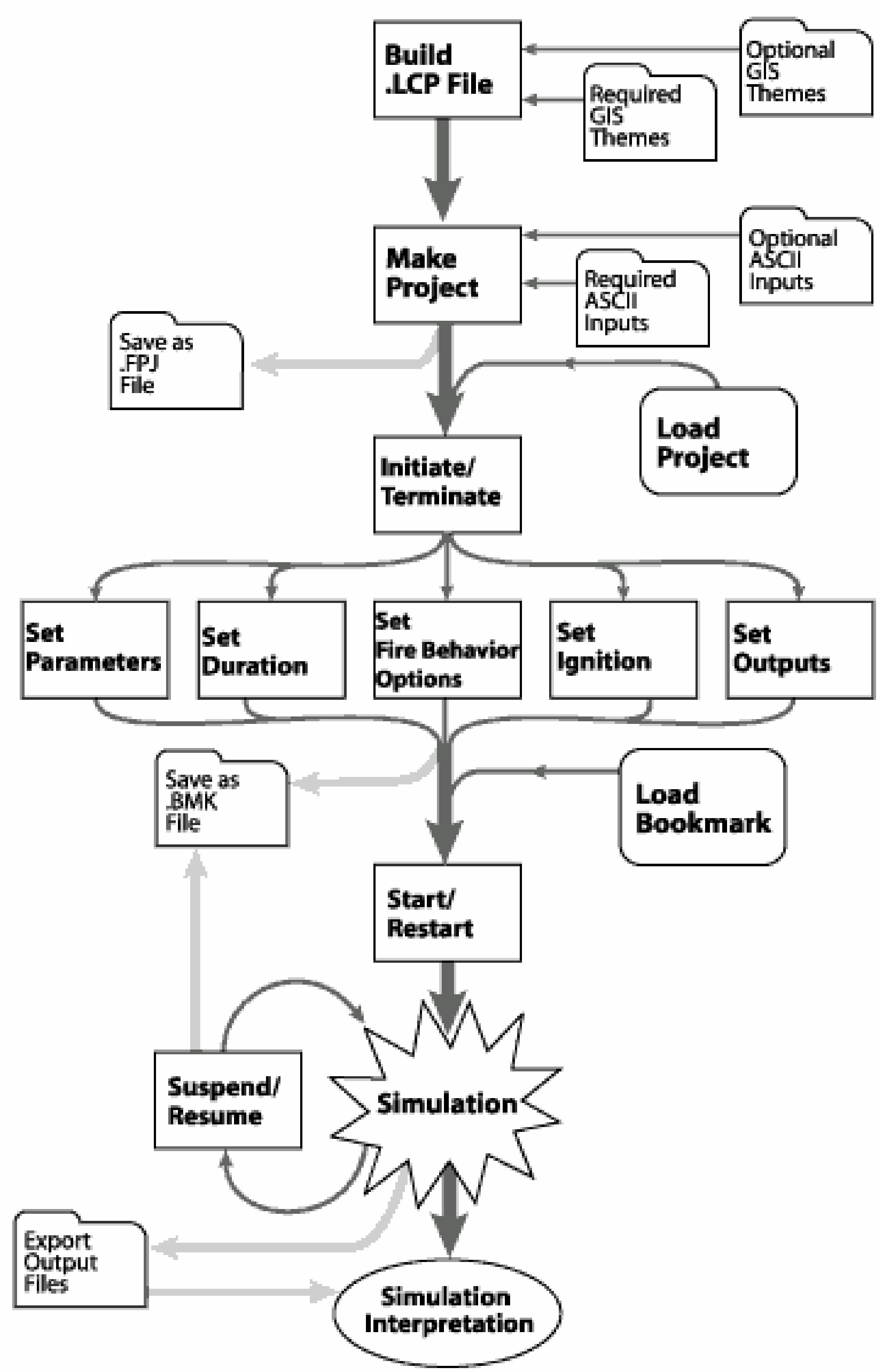

Figure 4.8. Flow Diagram of FARSITE (Finney, 2003) Model

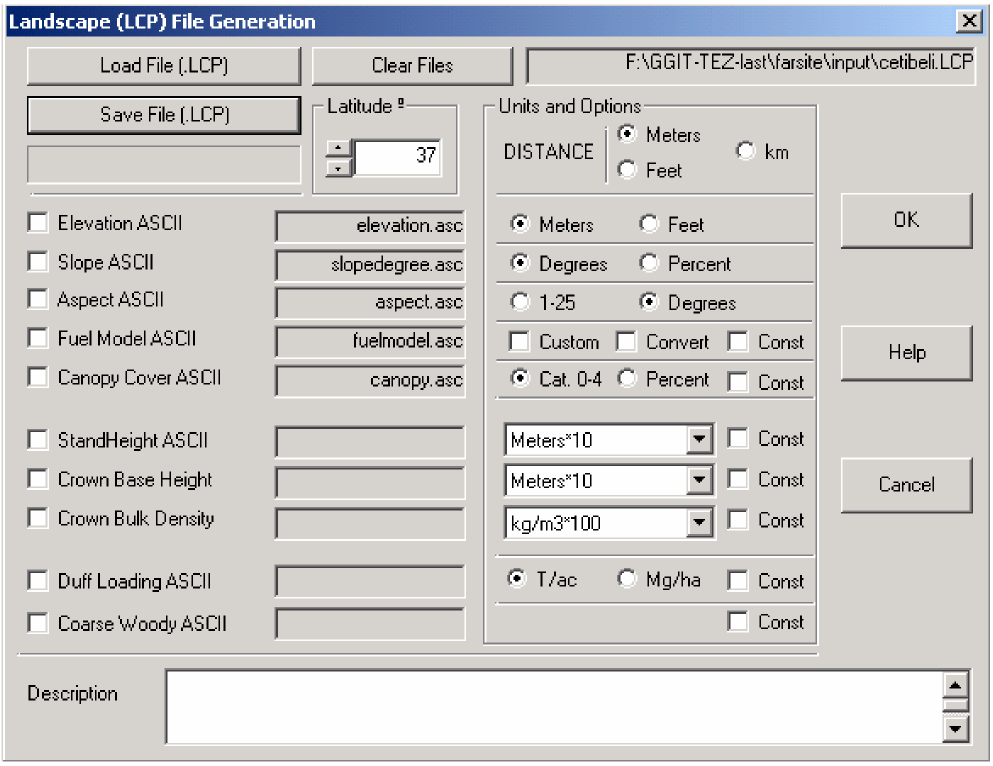

Figure 4.9. Landscape (.LCP) File Generation.

ii. Generation of FARSITE Project (.FPJ) File

A Project (.FPJ) File contains the spatial, i.e. landscape file, and nonspatial inputs of the simulation. The project file has been saved at the same directory of input files as required. It has been generated because it speeds up the loading of input files and their settings. However, it does not contain any run time information about starting and ending time, ignition location, parameters and options. Figure 4.10 illustrates the Project Inputs; Landscape, Adjustment, Fuel Moisture, Weather and Wind Files. All ASCII files have been given in Appendix G.

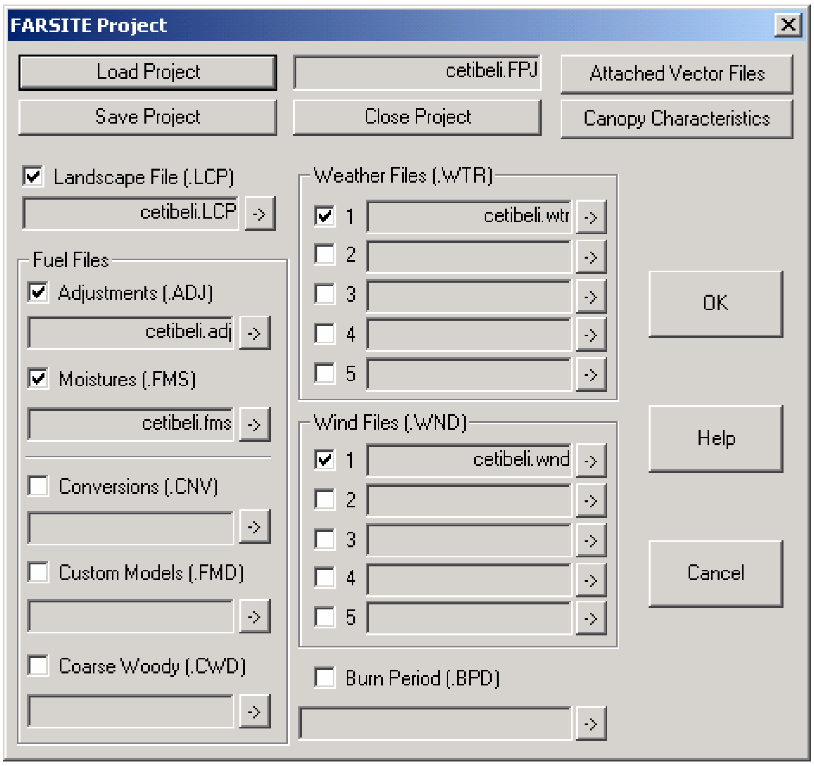

Figure 4.10. FARSITE Project File Generation

After generating project file, simulation can be initiated. In order to start simulation, the parameters and options of the simulation are set and the location of ignition points and the output files are selected.

iii. Model Parameters Settings

The spatial and temporal detail of the fire behavior calculations are determined by the Model Parameters (Finney, 2003). There are no correct settings because the suitability of the model settings depends on the purpose of the simulation. Model parameters must be set for each simulation. Model parameters are time step, visible step, perimeter resolution and distance resolution (Figure 4.11).

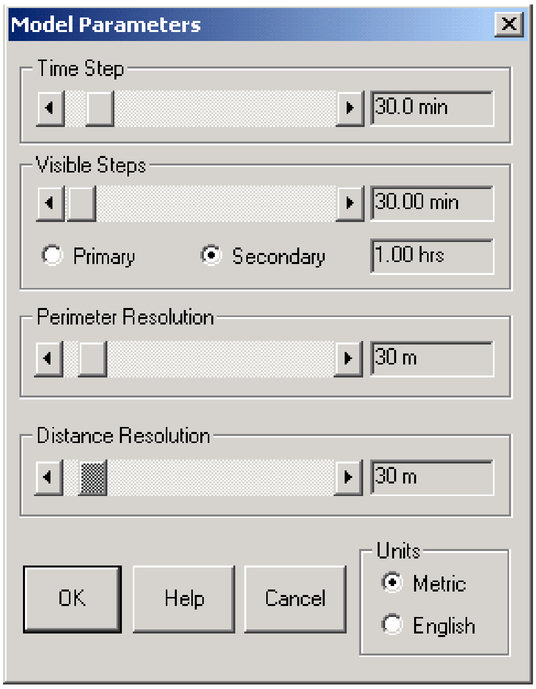

Figure 4.11. Model Parameters

The definition of the time step is the maximum amount of time that the conditions at a given point are assumed constant in order to calculate position of fire front. The positions of all fires are calculated at this time step so that possible merges can be computed (Finney, 2003).

Time step is inversely proportional to the fire spread rate. Finney (2003) states the time step values of surface fire as approximately 30 to 120 minutes for timber fuels, 10 to 20 minutes for brush and dry grass. For extreme surface fires or torching / crowning fires, time step may be set as 5 to 10 minutes for all fuel types. According to these proposals, time step has been set as 30 min.

The time step has the secondary importance when compared with the spatial resolution of the calculation. “The internal time step used by the simulation is constantly changing according to the minimum time required for the fire to spread the distance equaling the distance resolution. The actual time step is thus, only used as a consistent period during which all fires will be projecting to a coincident time before mergers and spotting are computed” (Finney, 2003).

Visible time step is only used for the graphical representation of fire spread and behavior. It is always a multiple of the actual time step in order to avoid unnecessary temporal detail in fire perimeter positions. Setting of primary visible time step is required but secondary visible time step is optional and only used to differentiate fire growth at two meaningful time periods. The fire front is drawn according to these intervals and visible time step affects the time resolution of vector output file from the simulation. The primary and secondary visible time steps have been set as 30 minutes and 1 hour, respectively.

Perimeter resolution determines the maximum distance between points used to define the fire perimeter. It is defined as resolution of a fire front in the direction tangential to the fire perimeter at each point. Setting of perimeter resolution is essential due to the determination of the amount of landscape information used in the simulation. In addition to this, it controls the detail of the fire front to respond to heterogeneities occurring at a fine scale.

Meaningful perimeter resolution can be set by means of practical knowledge gained through mapping of actual fire fronts. Finney (2003) states that logical perimeter resolution are not more than about twice the raster resolution of 30 m. The raster resolution of Çetibeli inputs are 20 m so perimeter resolution has been set as 30 m.

The distance resolution means the maximum spread distance from any perimeter point. “This distance can not be exceeded in a time step before new fuels, weather and topography data are used to compute the spread rate.” The distance resolution can not be greater than the perimeter resolution due to the detection and elimination methods of crossovers. FARSITE calculates and automatically adjusts the distance resolution. The value that has been set in Model Parameters is the maximum value of distance resolution. “The most logical value for distance resolution would be approximately the same as that for the perimeter.” (Finney, 2003) Therefore, distance resolution has been entered 30 m., same as perimeter resolution.

All of the model parameters are illustrated in Figure 4.11.

iv. Duration Settings

Duration of fire must be set for every FARSITE simulation after weather and wind file have been loaded. The starting time of the Çetibeli fire simulation has been set on 15th August at 18:23 and ending time has been set on 16th August on 16:45 (Figure 4.12). Fuel conditioning period is an option to adjust fuel moistures before the starting of the simulation. “When the Use Conditioning Period for Fuel Moistures check box is selected, *FARSITE* starts with values in the Initial Fuel Moisture (.FMS) File and calculates fuel moistures across the landscape based on elevation, aspect, slope, and shading before the Starting Time of the simulation” (Finney, 2003). If conditioning periods are not used, fuel moistures at every point across the landscape are used from the Initial Fuel Moisture File. The effect of conditioning period is different in shorter simulations with longer timelag fuels. Conditioning period has been checked at this simulation.

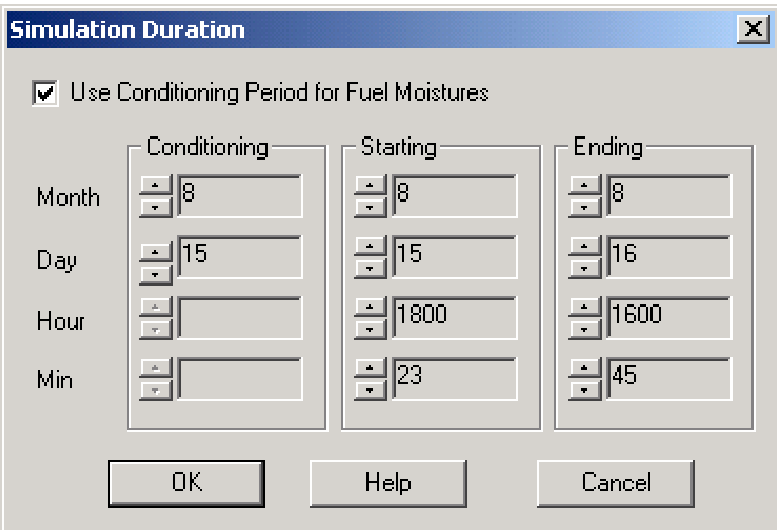

Figure 4.12. Simulation Duration

v. Fire Behavior Options Settings

Fire Behavior Option Settings controls the burn methods. Fire behavior calculations and other option, especially crown and spot fire settings, can be modified. Simulation of crown fire can be enabled or disabled depending on the crown fuel conditions and surface fire behavior. In order to simulate crown fire accurately, the Crown Base Height (CBH), Crown Bulk Density (CBD) and Stand Height Themes should exist in the Landscape File. However, constants for crown fuels can be defined for entire landscape to simulate crown fire. Selecting this option does not force to occur crown fire. Only it allows the FARSITE model to determine if transition occurs. Initially, only the surface fire has been simulated at the first run so this option has been remained unchecked.

Crown Bulk Density is critical parameter to determine crown fire spread. If constant Crown Bulk Density value is used, in order to modify Crown Bulk Density at each cell, link crown density and cover option are checked. In Figure 4.13, the settings of fire behavior options have been illustrated.

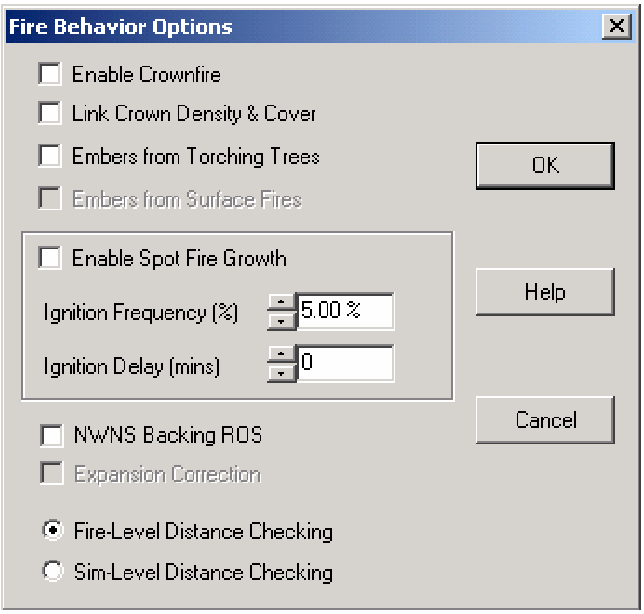

Figure 4.13. Fire Behavior Options

vi. Ignition Point Settings

There are two primary methods to locate the ignition source of simulation. First one is locating by the ignition mode on map. Next one is importing a point, line or polygon vector file. The ignition location of Çetibeli fire has been discussed before. The ignition location Arc Shape file has been imported.

Usually there are barriers to prevent fire spread on terrain such as highways, roads, or streams. Barriers can be located like ignition, manually or importing vector file. Any barrier has not been set initially.

vii. Output Settings

The other information except for area and perimeter calculation, perimeter can be exported as vector and fire behavior parameters are exported as raster files. Raster files can be viewed in FARSITE or GIS and remote sensing applications. There are four functions of output settings.

- Setting units of outputs as Metric or English,
- Determining the file names and formats of the vector fire perimeters,
- Selecting the eight different fire behavior characteristics raster files, their name and resolution

- Option of creating output log files with information on the parameters used, simulation inputs, and start/end times for each vector or raster file created (Finney, 2003).

Table 4.4. Raster Output Themes Filename Extensions and Units (Finney, 2003)

Parameters	**Extensions**	**Metric**	**English**
Time of Arrival	.TOA	hours	hours
Fire Line Intensity	.FLI	kW/m	BTU/ft/sec
Flamelength	.FML	m	ft
Rate of Spread	.ROS	m/min	ft/min
Heat per Unit Area	.HPA	kJ/m^2	BTU/ft^2
Reaction Intensity	.RCI	kW/m^2	$BTU/ft^2/sec$
Crown-NoCrown	.CFR	1=surface, 2=passive, 3=active	1=surface, 2=passive, 3=active
Spread Direction	.SDR	0-359 ° Azimuth	0-359 ° Azimuth

All units have been selected as Metric. Fire perimeters have been exported as polygon Arc Shape file. Only Crown Fire Activity raster output file has not been selected because crown fire was not simulated. Raster fires have been exported as GRID ASCII format at 20 meter resolution. The export and output options can be seen in Figure 4.14.

Except output files, the tabulated output data and graphs can be also exported to text files. If simulation is suspended at any time, the visible fire perimeter being generated by the current simulation can be saved.

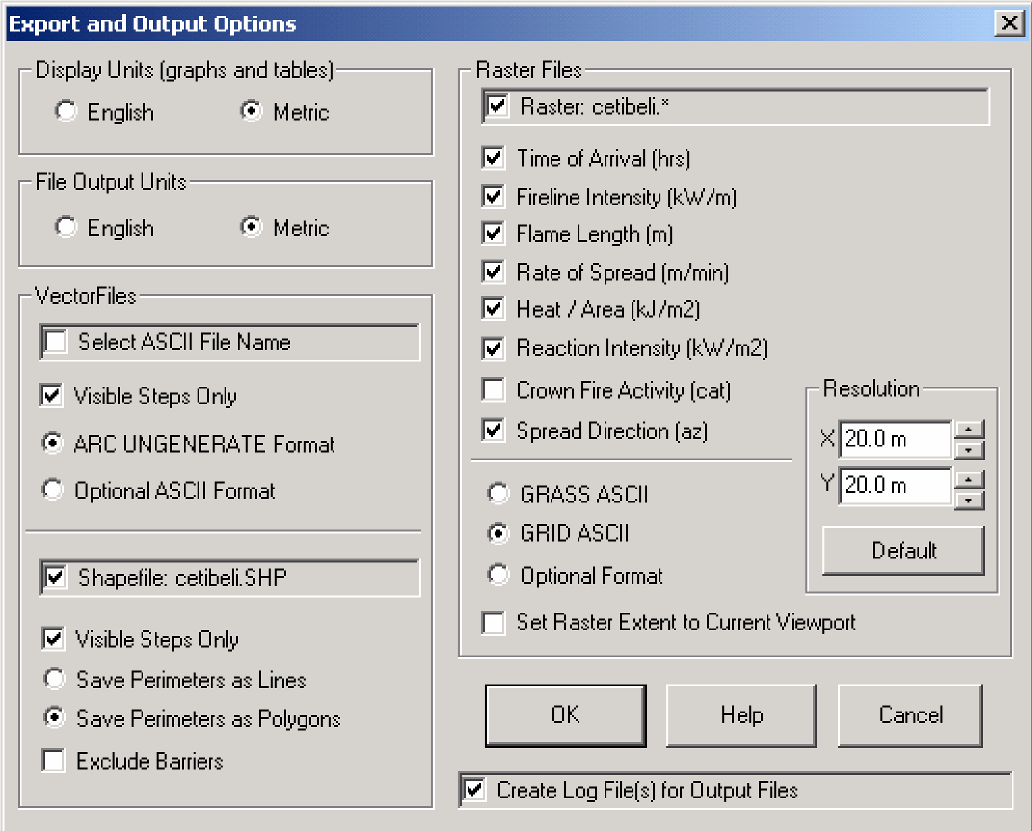

Figure 4.14. Export and Output Options of Çetibeli Fire Simulation

After all of these steps have been completed, Çetibeli Fire was ready to be simulated.

4.5.1. Çetibeli Fire Simulation Run

In this section, Çetibeli fire has been simulated by changing simulation parameters in order to approach the real fire spread. All of the simulation parameters log file generated by FARSITE can be seen in Appendix H. The fire attack inputs and parameters could not be set because of the real situation, location and information about crews, equipments and vehicles are unknown. The view of the FARSITE before and during simulation run has been illustrated in Figure 4.15 and Figure 4.16.

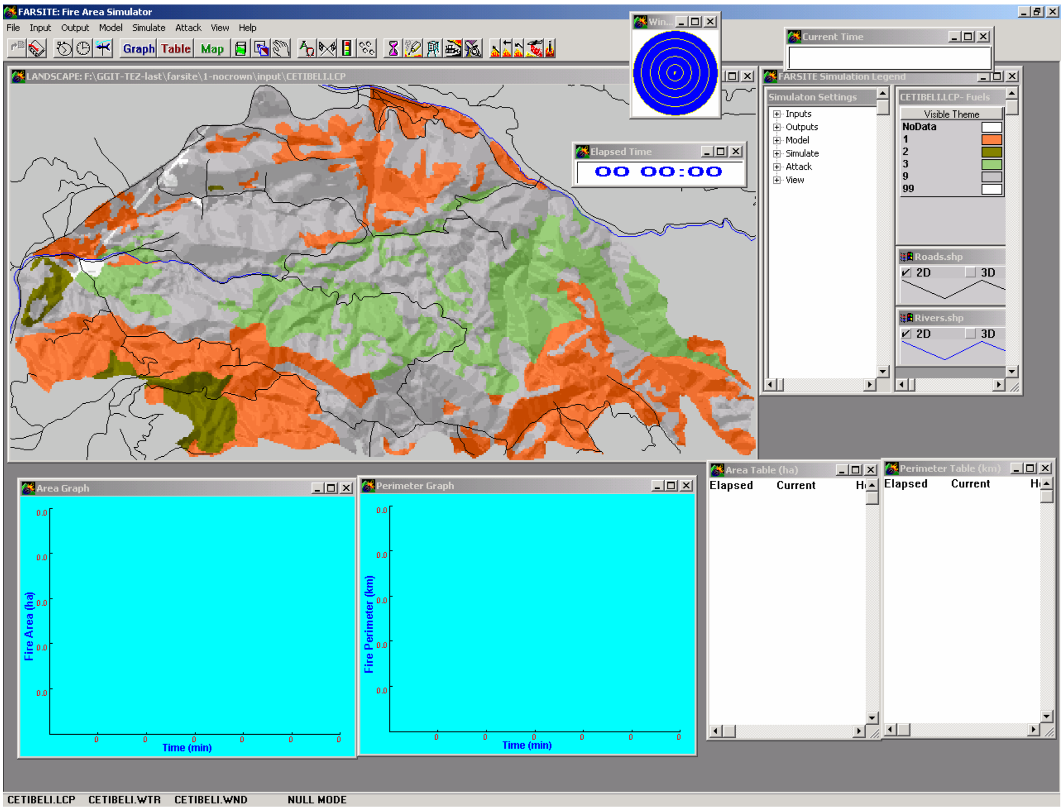

Figure 4.15. The View of FARSITE Before the Run

After every simulation has been completed, visible fire perimeters of vector files and fire behavior raster files, which are Time of Arrival, Fireline Intensity, Flame Length, Rate of Spread, Heat/Area, Reaction Intensity and Spread Directions, have been generated. Also area and perimeter table of fire at each elapsed time have been saved. All of raster and vector GIS output projections have been defined by ArcToolbox 8.1. ArcGIS 8.1. is used for analysis and demonstration of outputs.

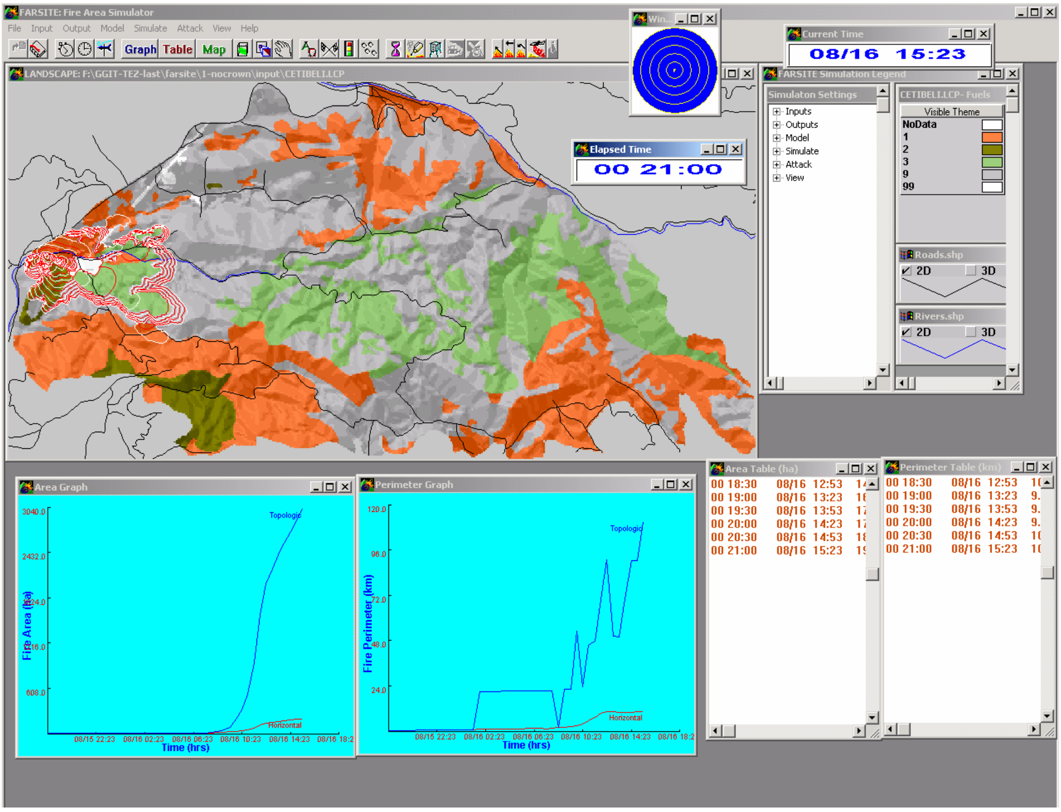

Figure 4.16. The View of FARSITE During the Run

Only the surface fire has been simulated at the first run. According to the real fire information, the fire should have spread up to the end of the work area during fire duration. However, the fire could not reach the expected point at the end of the simulation. The simulated burned area has been calculated as 339 ha and only 115 ha of the real burned area could be estimated correctly; displayed as hatched in Figure 4.17. 224 ha area has been over estimated. The ratio of correctly estimated area to the actual burned area is obtained as an accuracy measure of the simulation. In this run, the accuracy is calculated as 9%. Under these circumstances, the simulation of the fire should be improved.

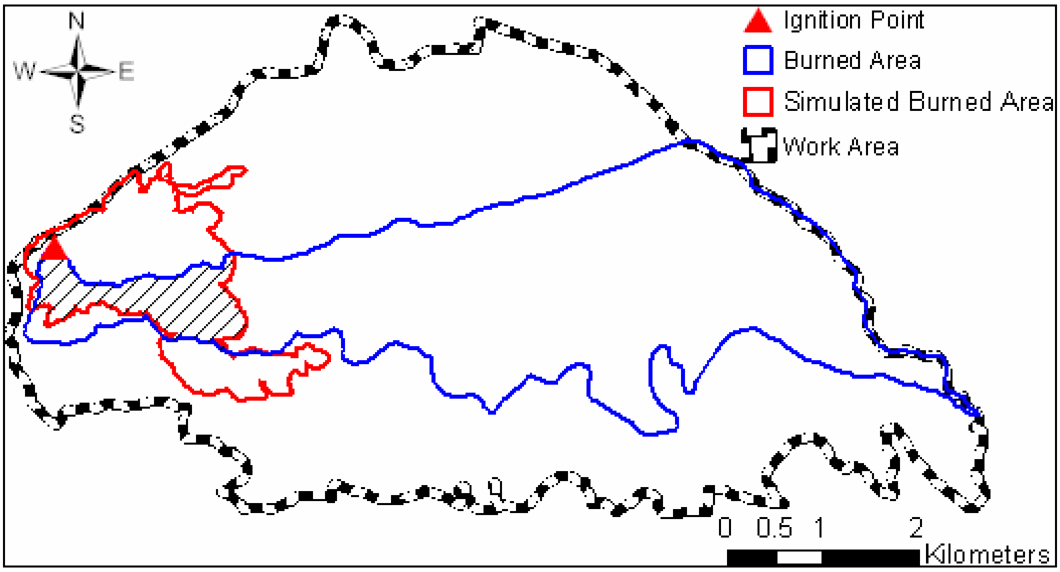

Figure 4.17. Simulated and Real Burned Area (First Run)

The raster outputs of fire behavior have been also generated at the end of the run. In addition to this, some optional raster outputs, fuel moisture, air temperature, mid flame wind, relative humidity and solar radiation of the terrain have been produced. These output files can be generated at any time during simulation. The fire behavior themes can be seen in Figure 4.18. In this figure, air temperature theme shows the temperature of the air on August, 16th at 16:45.

4.5.2. Calibration and Adjustment of Çetibeli Fire Simulation

Interpreting the output of the simulation and comparing the real fire information suggest that simulation of Çetibeli fire growth needs to be improved. Finney (2003) defined the calibration as "the process of diagnosing problems and making improvements to the simulation, usually compared to observations of actual fire behavior".

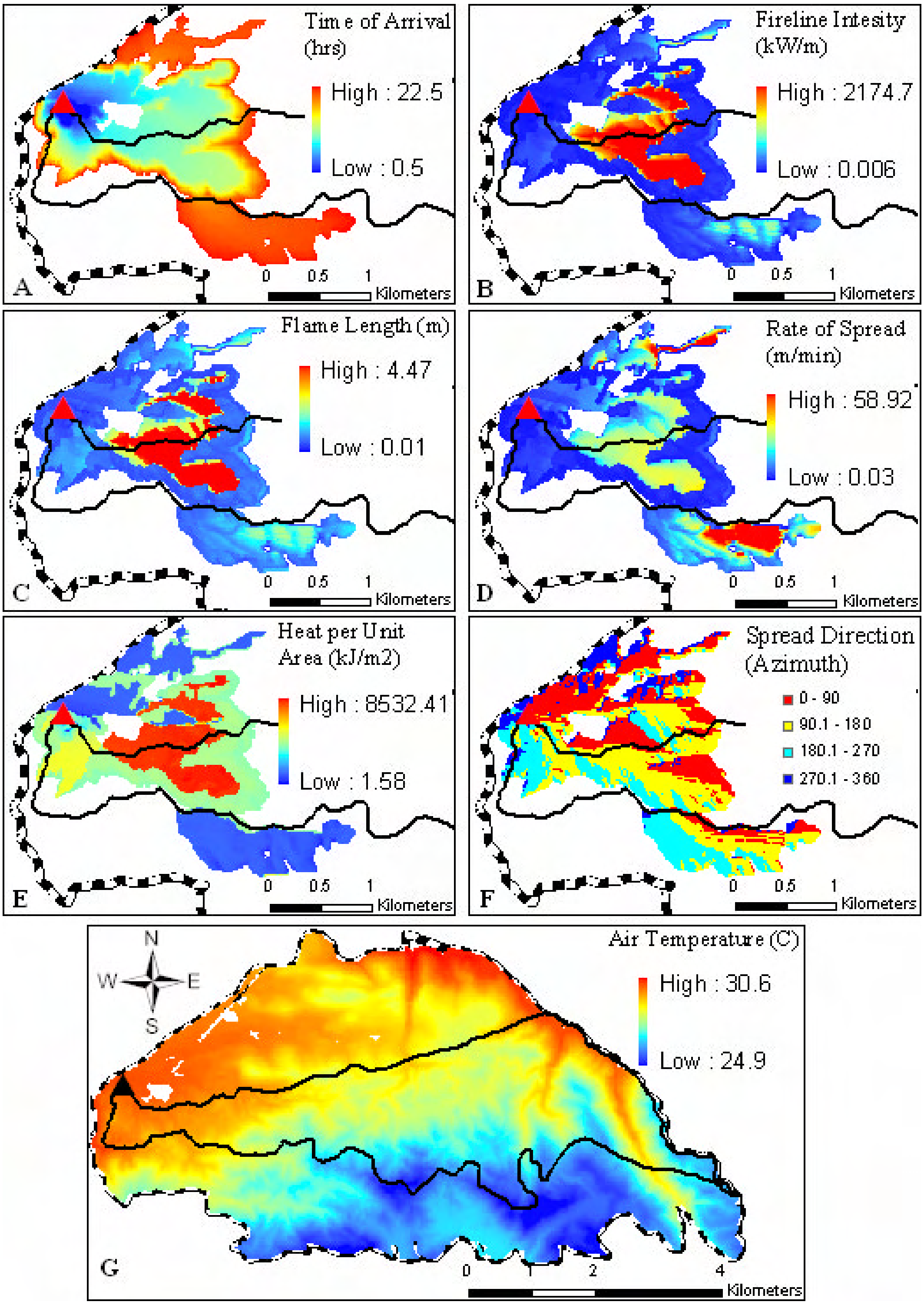

Figure 4.18. Fire Behavior Outputs. (A)Time of Arrival, (B) Fireline Intensity, (C) Flame Length, (D) Rate of Spread (E) Heat Per Unit Area, (F) Spread Direction, (G) Air Temperature

Calibration is necessary for many reasons. These reasons can be categorized into 3 caption; input data, parameters and settings, fuel and fire behavior models. Selected models may not reflect the reality of fire or the suitable model may not be selected. The variability and inaccuracies in input parameters and settings are reasons to do calibration (Finney, 2003).

At the second run, crown fire model is also simulated with surface fire. According to the fire registry reports, crown fire exists and it must be simulated with surface fire although optional raster GIS themes required for crown fire simulation, Crown Base Height, Crown Bulk Density and Stand Height, are not available. Hence constant values have been used. Average height of red pine trees was assumed as 10 m, so Stand Height and Crown Base Height values were entered as 10 and 6 m. Crown Bulk Density value was selected as 0.2 kg/m^3. FARSITE generated these optional themes according to their constant values.

In Fire Behavior Options, crown fire option was enabled and “Link Crown Density & Cover” option was checked. By this option, Crown Bulk Density was generated in respect of canopy cover because Crown Bulk Density was set as constant but some areas on the landscape was not covered by trees.

After simulation has been performed, the total simulated burned area has been calculated as 424 ha. 135 ha of the burned area (Figure 4.19) have been estimated correctly. Accuracy of the model run is calculated as 10 %. However, overestimation of burned area is 289 ha. Fire spread rate is still slow according to the real spread rate and almost similar to the first run spread rate.

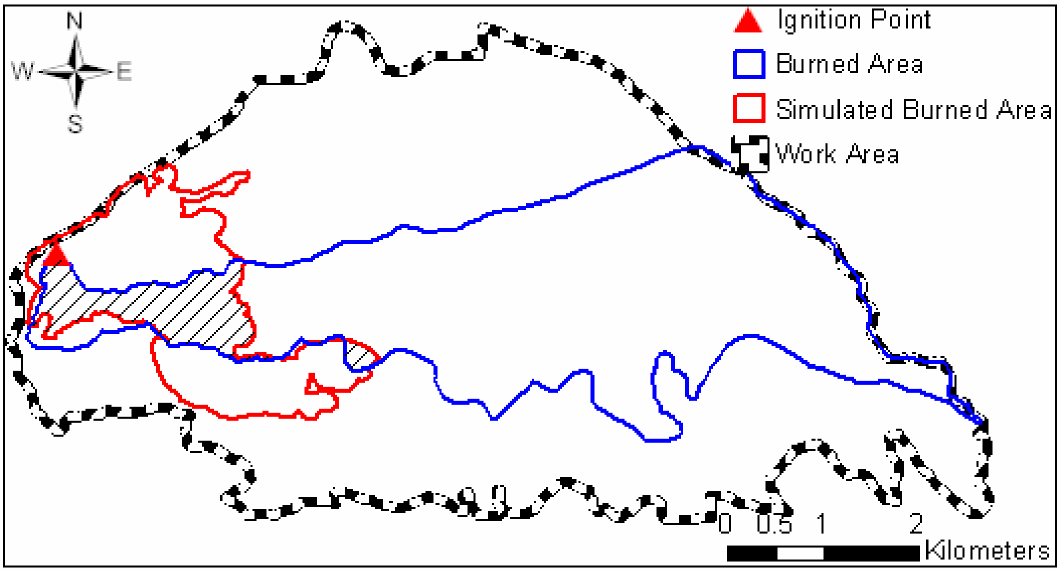

Figure 4.19. Simulated and Real Burned Area (Second Run)

Rate and direction of fire spread depend on mainly the fuel model and wind speed. Wind speed and direction can not be edited because it has been measured by the station. The only parameter that can be changed was fuel model. The adjustment factors adjust the spread of each fuel model but they do not affect the fire behavior.

At the third run, the simulation has been performed after adjustment factors and acceleration value of fire have been changed. When fuel model map has been examined, the real burned area covers mainly the fuel model 1, 3 and 9. Hence adjustment factors of these fuel models have been changed as 0.3, 3.8 and 3.8, respectively. Acceleration values have been adjusted in accordance with the previous runs because fire had to reach the east boundary of the work area at the end of the time.

The total simulated burned area has been determined as 1409 ha. 70 % of the real burned area (911 ha) has been estimated correctly but approximately 500 ha of simulated burned area has been overestimated. Additionally, at the end of the simulation, firefront has almost reached to the east boundary of work area, illustrated in Figure 4.20.

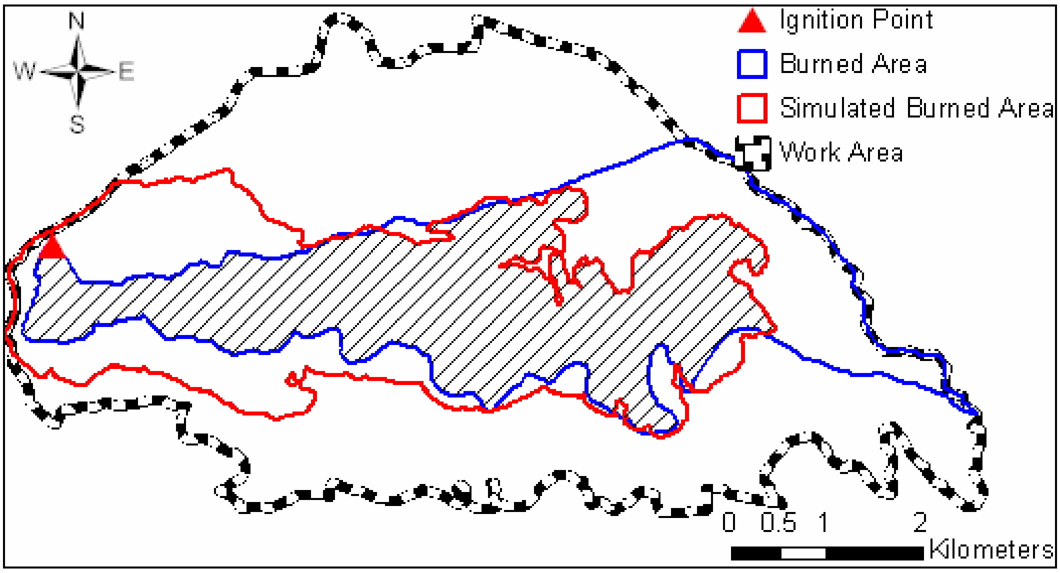

Figure 4.20. Simulated and Real Burned Area (Final Run)

In order to generate the fire behavior outputs, the custom fuel models have been defined according to the adjustment factors because they only affect the spread rate. Custom fuel models have been created by modifying the basic fuel models by using adjustment factors. Rather than regenerating fuel model as a raster theme, Conversion Factor (.CNV) File has been used. The modified ASCII input files have been illustrated in Appendix G.

After modification has been completed, the fire simulation has been performed once more. The fire spread and fire behavior outputs have been generated. The total simulated burned area has been calculated as 1210 ha. 70 %, of the real burned area has been estimated correctly. 360 ha of the area have been simulated incorrectly. The fire spread has been illustrated in Figure 4.21.

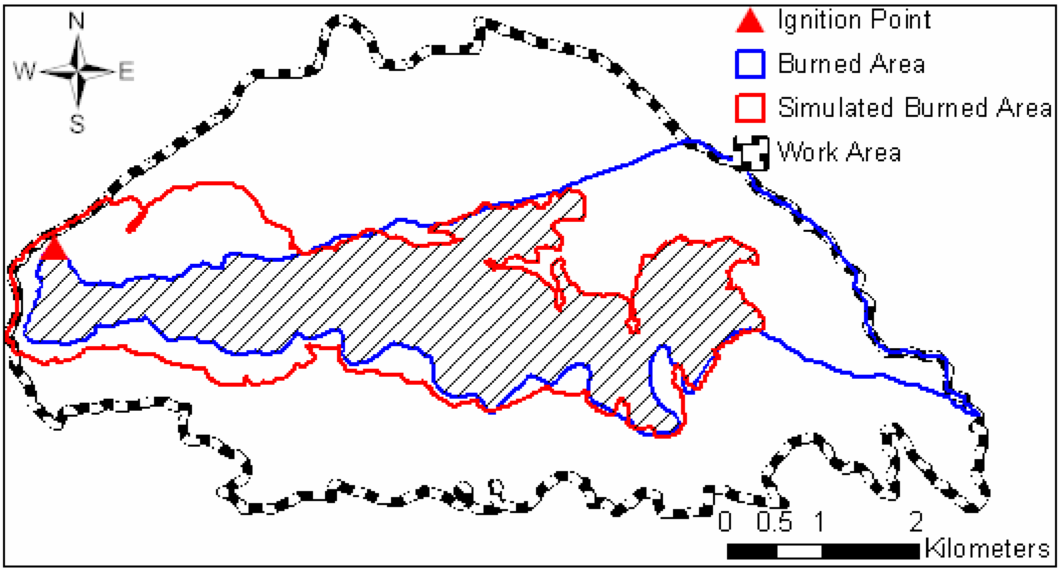

Figure 4.21. Simulated and Real Burned Area (Final Run after Modification)

In addition to this, time of arrival, fire line intensity, rate of spread and spread direction of the fire can be seen in Figure 4.22 and Figure 4.23.

4.6. Discussion of the Results

After the calibration of Çetibeli fire has been completed, the outputs of the fire behavior, time of arrival, rate of spread, spread direction, and time contour of fire spread have been obtained. Fire behavior outputs could not contain the real

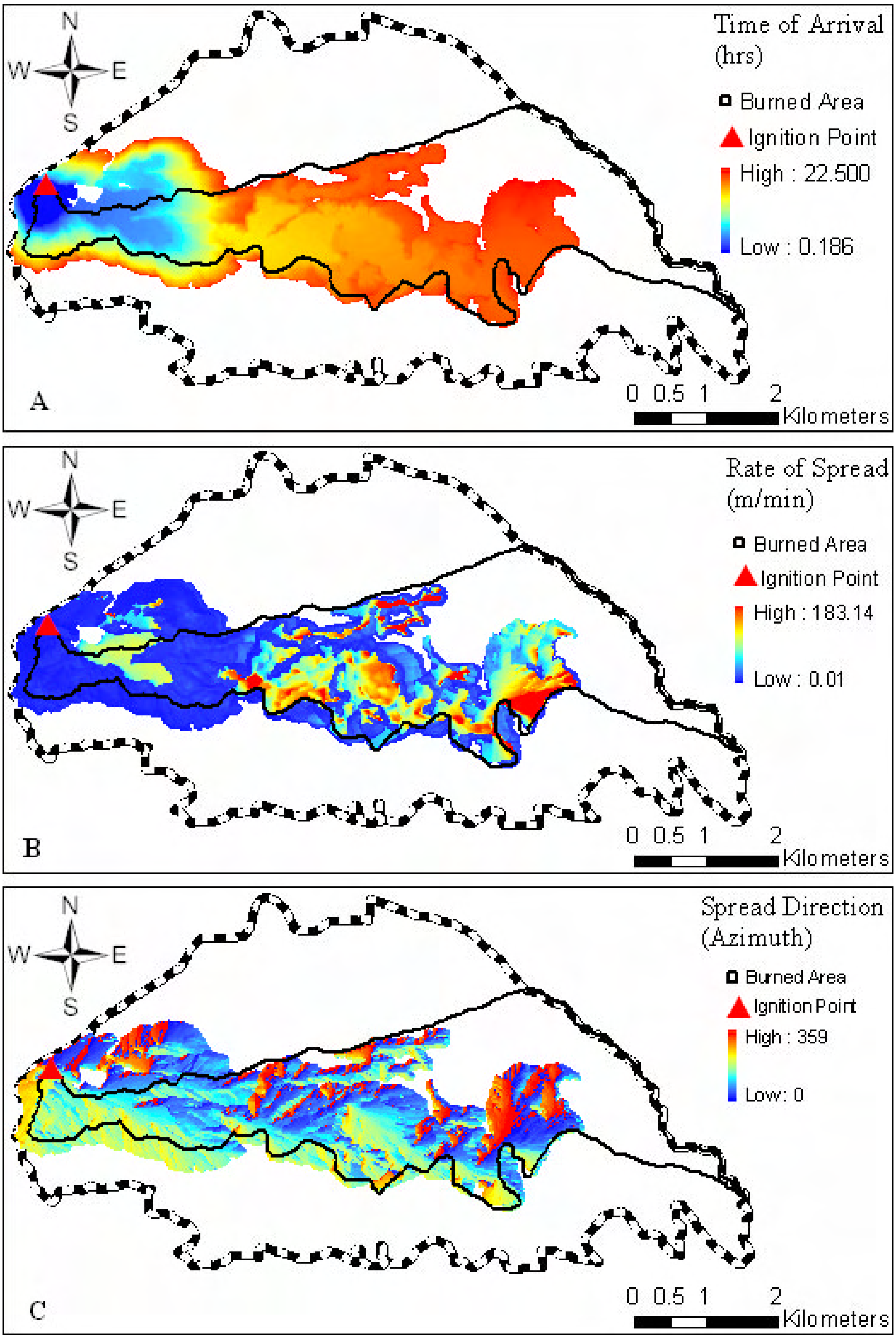

Figure 4.22. The Outputs of (A) Time of Arrival, (B) Rate of Spread and (C) Spread Direction.

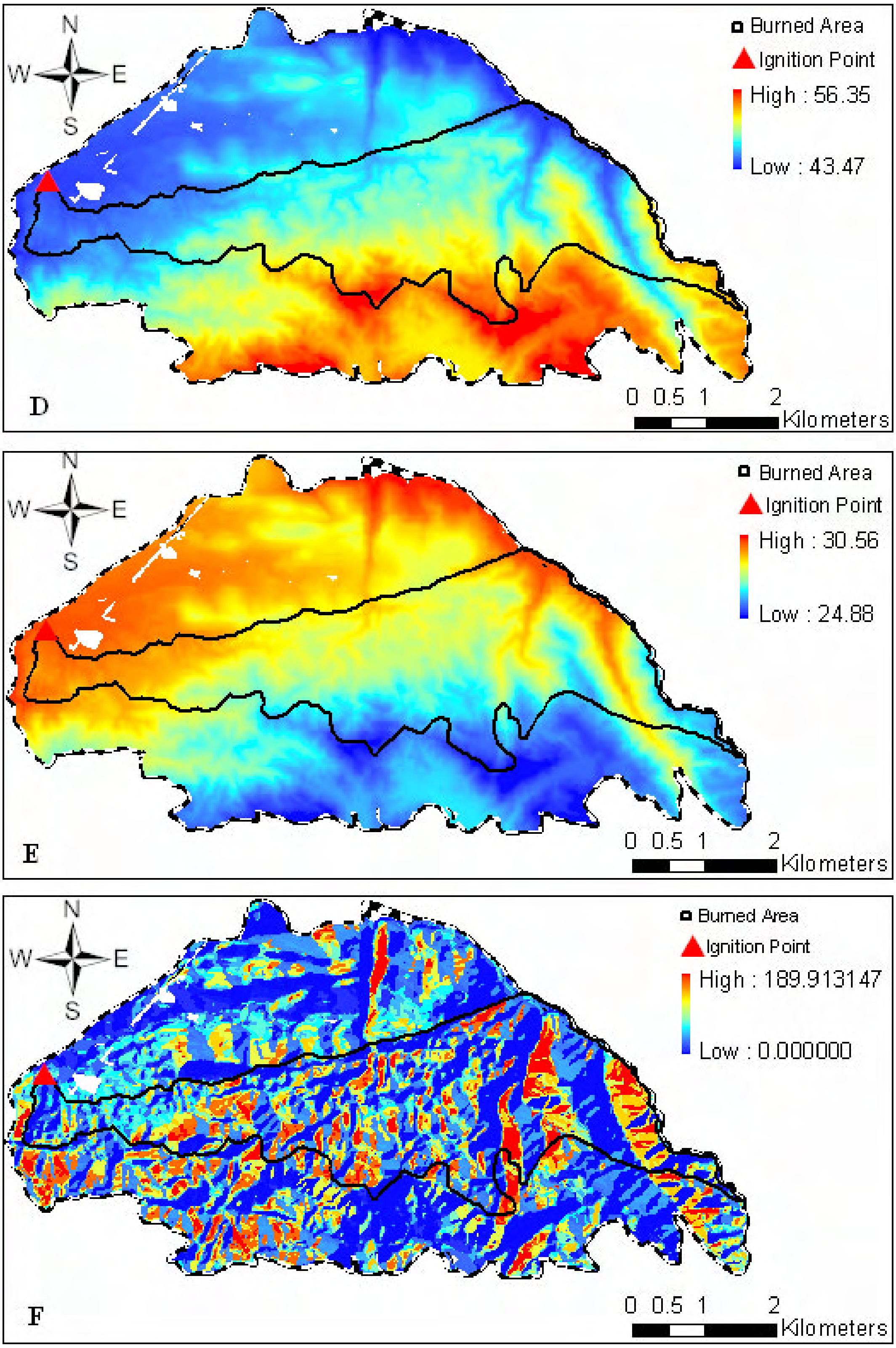

Figure 4.23. The Outputs of (D) Relative Humidity, (E) Air Temperature and (F) Solar Radiation

fire information because there is not any documented information about fire behavior of Çetibeli Fire. The only criteria for comparison are spread rate and direction and also shape of burned area.

According to the fire spread (Figure 4.21), some parts of the burned area are overestimated and some parts are underestimated. These problems lie with inaccurate data of fuel moistures, fuel models of the area and weather data. Wind reduction factors of forested areas and extreme topographic variations, such as sheltering effect on the spread rate of fire in some parts of the landscape. This result indicates how sensitive the fuel model and moisture parameters in the fire simulation modeling.

Fire has different spread directions according to the real burned area. In order to suppress the fire, some interference and attacks have been done by the fire fighters and machines. It was previously mentioned that the location, time of attacks to the fire and information about number of crews and vehicles were not known, so attack simulation could not be performed. Suppression activities affect the fire spread rate, shape and behavior. Because these parameters could not enter for the simulation as input, overestimation in estimating the burned area has occurred. Also fuel model of the area could not be defined properly.

The reasons of underestimation could be due to fuel type and meteorological conditions those do not reflect the real conditions. In addition to this, the types of fire, surface and crown, could not be simulated appropriately because in order to simulate crown fire, some optional landscape data themes such as crown bulk density, crown height are needed. During simulation, these themes were entered as constant values. Also this could be the reason for overestimation.

Finney (1998) states that the disparity of real fire and simulated fire is due to the variance of the scale between the frequency of data inputs to the simulation and the frequency of variation in real environmental conditions affecting a fire. “If the scale of input data to the simulations is much coarser than that of the real environment (fuels, weather and topography), the fire behavior equations will tend to produce equilibrium values rather than reflect the cumulative outcome of fluctuating fire behavior” (Finney, 1988).

When the time contour of fire spread (Figure 4.24) and Figure 4.22.(B) have been examined the fire spread was slow initially. This could be due to the fuel types and meteorological data. Meteorological, i.e. weather data should have been measured on site during fire. Fuel Model 15, modified from Fuel Model 3, burned more rapidly than the others. It is obtained that Fuel Model 15 may be the dominant vegetation of the study area.

The spread of fire is almost similar to the real fire (Figure 4.24). The compatibility of the fire model is acceptable because in spite of lack of information and input data about fire, the accuracy of the simulation in estimating the burned area after calibration has been found as 70 %.

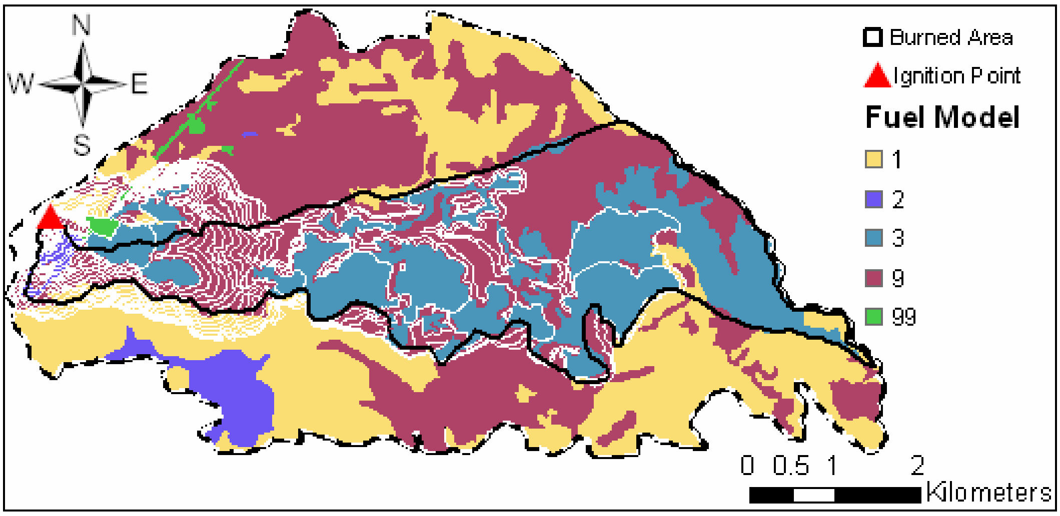

Figure 4.24. Time Contour of Fire Spread (30 min interval) and Fuel Models

The most important input of fire model is fuel model theme. Fire behavior highly depends on fuel model. The second important input is weather data. It should be measured on site and recorded with sufficient time period. The last important input is topography. Approximately 30 m resolution DEM is sufficient for fire modeling. Some topographic features affect fire behavior unexpectedly. This problem can be overcome by experience.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

In this thesis, the suitability of a GIS – based forest fire simulation model has been tested and the requirements of the model have been determined for Turkey by simulating a past fire which occurred in Marmaris - Çetibeli.

Analysis of past fires has been performed for checking the performance and accuracy of the model by means of comparing the satellite images and output maps of the model. During active fires, ground and aerial suppression tactics can be planned more accurately and more rapidly depending on the results of fire simulation models. In addition to this, future planning could be performed easily for forest areas which are extremely sensitive to fire.

The study area has been decided according to previously occurred wildfires and suitable vegetation, weather and topographic data have been obtained. The IKONOS images of the study area have been obtained and burned areas were extracted from them.

The necessary input files of fire model have been generated. Firstly, contour lines of the study area have been digitized. Elevation, slope and aspect layers of study area have been created. Vegetation layer of the study area has been produced from vegetation maps and fuel models of the area have been decided by using vegetation maps and IKONOS Image. Weather data have been obtained from meteorological station and prepared into suitable format.

After preparation of input file, the simulation of both surface and crown fire has been run and the result of the model showing fire spread area was compared with the extracted burned area. Fire did not reach the expected location at the given time duration. This result showed that calibration was needed. Fuel model has been adjusted according to the simulation results. Finally, 70 % accuracy of the fire model run has been achieved and new fuel model parameters have been defined for the study area. In addition to this, fire behavior outputs such as fire intensity, direction, rate of spread have been obtained.

In this study, it is found out that the fuel model and fuel moisture parameters are the most sensitive parameters of the model. The dominant vegetation type indicated as BÇzY in forestry maps was represented as fuel model 15.

Retrieving the vegetation information from satellite images having high spatial resolution increased the accuracy of the vegetation maps. Hence the determination of fuel models from these images was possible. The importance of information about the fire observation is determined and an ideal fire observation data types are given.

The ability to predict wildfire intensity, direction, rate of spread and burned area is extremely important for wildfire management in terms of defining suppression tactics managing financial and equipment resources for potential fires and even active fires.

Fire model is essential for analyzing spatial fuel management activities and examining suppression opportunities for fires that start at different locations or under various weather scenarios. It also helps to determine the economic consequences of potential fires with and without fuel management activities. Lastly, it supports the strategic fire fighting decisions during fire or before fire.

Application of the GIS technology in modeling will decrease the processing time and improves understanding the fire phenomena. Integration of this technology to models is an inevitable part of fire simulation process since it gives the ability of showing and analyzing all parts of the area in terms of fire spread direction and rate, time of arrival, relative humidity.

In this study the suitability of a GIS – based forest fire simulation model, namely FARSITE, is tested and the requirements of the model for Turkey are determined. It should be remembered that fire simulation models can only approximate reality. The output from a fire simulation system cannot replace the knowledge and experience of wildland fire managers. Nevertheless, today's fire simulation systems are important tools that can help fire managers make better decisions while saving time, money, and perhaps even lives.

5.1. Recommendation for Future Work

In order to improve the simulation accuracy of the fire model, some recommendations have been listed.

- The most important parameter of the fire model is the description of the fuel type. Fuel model of the study area must be defined initially. Even, custom fuel models for Turkey can be defined by modeling the past fire or studying test fires.

- During real forest fires, the information about the fireline position, the suppression forces and its locations at a specific time, weather conditions should be watched, measured in field and recorded. The ideal fire observation data sheets and descriptions can be seen in Appendix I. By using more detailed data, the fire behavior model can be calibrated according to the real situations.

- The test fires should be studied for defining the record frequency of data inputs in order to define the real situation.

- Aside from incorporating more sophisticated fire behavior models, other dimensions of fire behavior and effects can be included. For example, postfrontal combustion, spot fire.

- The fire simulation can be done by using various models. All these models can be beneficial while obtaining fire spread area. But the important parameters of these models are the data being used. In order to state the appropriateness of the model, the same model must be validated for another area.

- Especially, personnel that have experience about fire behavior gained from real fire should work with the GIS specialists in order to define the fuel model of the study area and calibrate the fuel model.

- Personnel of the General Directorate of Forest in Turkey should use fire model for fire planning activities, for example, analyzing the effectiveness of fuel treatments or checking the suppression opportunities and tactics for various fires. The outputs of the simulation results can be used to maintain strategic fire fighting decisions.

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APPENDIX A

NFFL FUEL MODEL DESCRIPTIONS

NFFL Fuel Model Description has been taken from the journal called as "Aids to Determining Fuel Models For Estimating Fire Behavior" by Hal E Anderson (1982).

GRASS GROUP

Fire Behavior Fuel Model 1

Fire spread is governed by the fine, very porous, and continuous herbaceous fuels that have cured or are nearly cured. Fires are surface fires that move rapidly through the cured grass and associated material. Very little shrub or timber is present, generally less than one-third of the area. This fuel models correlates to 1978 NFDRS fuel models A, L, S.

Fuel model values for estimating fire behavior

Total fuel load,< 3-inch dead and live, tons/acre	0.74
Dead fuel load, ¼ -inch, tons/acre	.74
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	1.0

Photo1. Western annual grasses such as cheatgrass, medusahead, ryegrass, and rescues.

Photo 2. Live oak savanna of the South-west on the Coronado National Forest.

Photo 3. Open pine – grasslands on the Lewis and Clark National Forest

Fire Behavior Fuel Model 2

Fire spread is primarily through the fine herbaceous fuels either curing or dead. These are surface fires where the herbaceous materials, in addition to litter and dead-down stemwood form the open shrub or timber overstory, contribute to the fire intensity. Open shrub lands and pine stands or scrub oak stands that cover one-third to two-thirds of the area may generally fit this model, such stands may include clumps of fuels that generate higher intensities and that may produce firebrands. Some pinyon-juniper may be in this model. Photographs 4 and 5 illustrate possible field situations.

This fuel model correlates to 1978 NFDRS fuel models C and T.

Fuel model values for estimating fire behavior

Total fuel load,< 3-inch dead and live, tons/acre	4.0
Dead fuel load, ¼ -inch, tons/acre	2.0
Live fuel load, foliage, tons/acre	0.5
Fuel bed depth, feet	1.0

Photo 4. Open Ponderosa pine stand with annual grass understory

Photo 5. Scattered sage within grasslands on the Payette National Forest.

Fire Behavior Fuel Model 3

Fires in this fuel are the most intense of the grass group and display high rates of spread under the influence of wind. Wind may drive fire into the upper heights of the grass and across standing water. Stands are tall, averaging about 3 feet (1 m), but considerable variation may occur. Approximately one-third or more of the stand is considered dead or cured and maintains the fire. Wild or cultivated grains that have not been harvested can be considered similar to tall prairie and marshland grasses. Refer to photographs 6, 7, and 8 for examples fo fuels fitting this model.

This fuel correlates to 1978 NFDRS fuel model N.

Fuel model values for estimating fire behavior

Total fuel load,< 3-inch dead and live, tons/acre	3.0
Dead fuel load, ¼ -inch, tons/acre	3.0
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	2.50

Fires in the grass group fuel models exhibit some of the faster rates of spread under similar weather conditions. With a windspeed of 5 mi/h (8 km/h) and a moisture content of 8 percent, representative rates of spread (ROS) are as follows:

Model	**Rate of Spread**	**Flame Length**
	Chains/hour	Feet
1	78	4
2	35	6
3	104	12

As windspeed increases, model 1 will develop faster rates of spread than model 3 due to fineness of the fuels, fuel load, and depth relations.

Photo 6. Fountaingrass in Hawaii; note the dead component.

Photo 7. Meadow foxtail in Oregon prairie and meadowland.

Photo 8. Sawgrass “prairie” and “strands” in the Everglades National Park, Fla

SHRUB GROUP

Fire Behavior Fuel Model 4

Fire intensity and fast spreading fires involve the foliage and live and dead fine woody material in the crowns of a nearly continuous secondary overstory. Stands of mature shrubs, 6 or more feet tall, such as California mixed chaparral, the high pocosin along the east coast, the pinebarrens of New Jersey, or the closed jack pine stands of the north-central States are typical candidates. Besides flammable foliage, dead woody material in the stands significantly contributes to the fire intensity. Height of stands qualifying for this model depends on local conditions. A deep litter layer may also hamper suppression efforts. Photographs 9, 10, 11, and 12 depict examples fitting this fuel model.

This fuel model represents 1978 NFDRS fuel models B and O; fire behavior estimates are more severe than obtained by models B or O.

Fuel model values for estimating fire behavior

Total fuel load,< 3-inch dead and live, tons/acre	13.0
Dead fuel load, ¼ -inch, tons/acre	5.0
Live fuel load, foliage, tons/acre	5.0
Fuel bed depth, feet	6.0

Photo 9. Mixed chaparral of southern California; note dead fuel component in branchwood

Photo 10. Chaparral composed of manzanita and chamise near the Inaja Fire Memorial, Calif.

Photo 11. Pocosin shrub field composed of species like fetterbush, gallberry, and the bays.

Photo 12. High shrub southern rough with quantity of dead limbwood.

Fire Behavior Fuel Model 5

Fire is generally carried in the surface fuels that are made up of litter cast by the shrubs and the grasses or forbs in the understory. The fires are generally not very intense because surface fuel loads are light, the 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 would qualify: laurel, vine maple, alder, or even chaparral, manzanita, or chamise.

No 1987 NFDRS fuel model is represented, but model 5 can be considered as a second choice for NFDRS model D or as a third choice for NFDRS model T. Photographs 13 and 14 show field examples of this type. Young green stands may be up to 6 feet (2 m) high but have poor burning properties because of live vegetation.

Fuel model values for estimating fire behavior

Total fuel load,< 3-inch dead and live, tons/acre	3.5
Dead fuel load, ¼ -inch, tons/acre	1.0
Live fuel load, foliage, tons/acre	2.0
Fuel bed depth, feet	2.0

Photo 13. Green, low shrub fields within timber stands or without overstory are typical. Example is Douglas-fir-snowberry habitat type

Photo 14. Regeneration shrublands after fire or other disturbances have a large green fuel component, Sundance Fire, Pack River Area, Idaho.

Fire Behavior Model 6

Fires carry through the shrub layer where the foliage is more flammable than fuel model 5, but this requires moderate winds, greater than 8 mi/h (13 km/h) at mid-flame height. Fire will drop to the ground at low wind speeds or at openings in the stand. The shrubs are older, but not as tall as shrub types of model 4. A broad range of shrub conditions is covered by this model. Fuel situations to be considered include intermediate stands of chamise, chaparral, oak brush, low pocosin, Alaskan spruce talga, and shrub tundra. Even hardwood slash that has cured can be considered. Pinyon-juniper shrublands may be represented but may overpredict rate of spread except at high winds, like 20 mi/h (32 km/h) at 20-foot level.

The 1978 NFDRS fuel models F and Q are represented by this fuel model. It can be considered a second choice for models T and D and a third choice for model S. Photographs 15, 16, 17, and 18 show situations encompassed by this fuel model.

Fuel model values for estimating fire behavior

Total fuel load,< 3-inch dead and live, tons/acre	6.0
Dead fuel load, ¼ -inch, tons/acre	1.5
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	2.5

Photo 15. Pinyon-juniper with sagebrush near Ely, Nev. understory mainly sage with some grass intermixed.

Photo 16.Southern hardwood shrub with pine slash residues.

Photo 17. Low pocosin shrub field in the south.

Photo 18. Frost-killed Gambel Oak foliage, less than 4 feet in height, in Colorado

Fire Behavior Fuel Model 7

Fires burn through the surface and shrub strata with equal ease and can occur at higher dead fuel moisture contents because of the flammability of live foliage and other live material. Stands of shrubs are generally between 2 and 6 feet (0.6 and 1.8 m) high. Palmetto-gallberry understory-pine overstory sites are typical and low pocosins may be represente. Black spruce-shrub combinations in Alaska may also be represented.

The fuel model correlates with 1978 NFDRS model D and can be a second choice for model Q. Photographs 19, 20, and 21 depict field situations for this model.

Fuel model values for estimating fire behavior

Total fuel load,< 3-inch dead and live, tons/acre	4.9
Dead fuel load, ¼ -inch, tons/acre	1.1
Live fuel load, foliage, tons/acre	0.4
Fuel bed depth, feet	2.5

The shrub group of fuel models has a wide range of fire intensities and rate of spread. With winds of 5 mi/h (8 km/h), fuel moisture content of 8 percent, and a live fuel moisture content of 100 percent, the models have the values:

Model	**Rate of Spread**	**Flame Length**
	Chains/hour	Feet
4	75	19
5	18	4
6	32	6
7	20	5

Photo 19. Southern rough with light to moderate palmetto undertory.

Photo 20. Southern rough with moderate to heavy palmetto-gallberry and other species.

Photo 21. Slash pine with gallberry, bay, and other species of understory rough

TIMBER GROUP

Fire Behavior Fuel Model 8

Slow-burning ground fires with low flame lengths are generally the case, although the fire may encounter an occasional “jackpot” or heavy fuel concentration that can flare up. Only under severe weather conditions involving high temperatures, low humidities, and high winds do the fuels pose fire hazards. Closed canopy stands of short-needle conifers or hardwoods that have leafed out support fire in the compact litter layer. This layer is mainly litters, leaves, and occasionally twigs because little undergrowth is present in the stand. Representative conifer types are white pine, and lodgepole pine, spruce, fir, and larch.

This model can be used for 1978 NFDRS fuel models H and R. photographs 22, 23, and 24 illustrate the situations representative of this fuel.

Fuel model values for estimating fire behavior

Total fuel load,< 3-inch dead and live, tons/acre	5.0
Dead fuel load, ¼ -inch, tons/acre	1.5
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	0.2

Photo 22. Surface litter fuels in western hemlock stands of Oregon and Washington.

Photo 23. Understory of inland Dougles-fir has little fuel here to add to dead-down litter load.

Photo 24. Closed stand of birch-aspen with leaf litter compacted.

Fire Behavior Fuel Model 9

Fires run through the surface litter faster than model 8 and have longer flame height. Both long-needle conifer stands and hardwood stands, especially the oak-hickory types, are typical. Fall fires in hardwoods are predictable, but high winds will actually cause higher rates of spread than predicted because of spotting caused by rolling and blowing leaves. Closed stands of long-needled pine like ponderosa, Jeffrey, and red pines, or southern pine plantations are grouped in this model. Concentrations of dead-down woody material will contribute to possible torching out of trees, spotting, and crowning.

NFDRS fuel models E, P, and U are represented by this model. It is also a second choice for models C and S. some of the possible field situations fitting this model are shown in photographs 25, 26, and 27

Fuel model values for estimating fire behavior

Total fuel load,< 3-inch dead and live, tons/acre	3.5
Dead fuel load, ¼ -inch, tons/acre	2.9
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	0.2

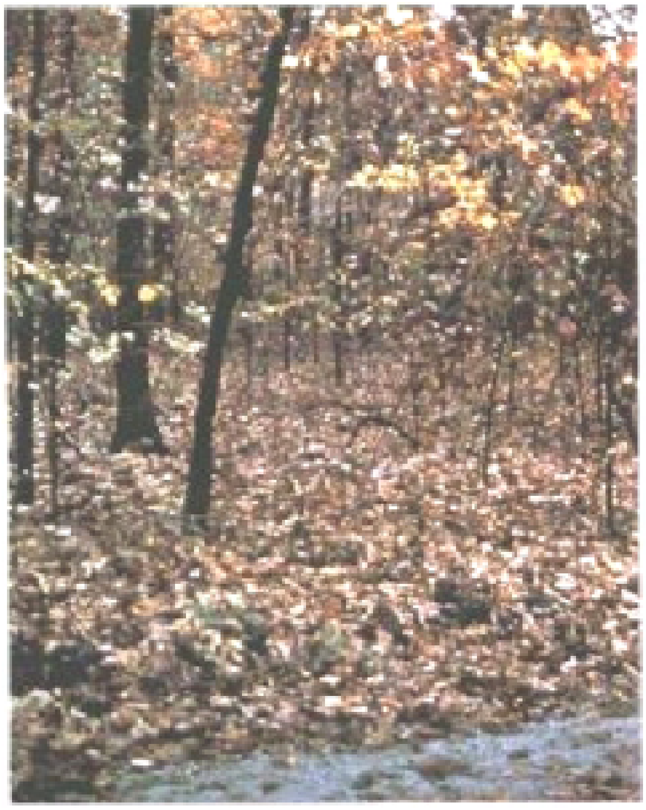

Photo 25. Western Oregon white oak fall litter; wind tumbled leaves may cause short-range spotting that may increase ROS above the predicted value.

Photo 26. Loose hardwood litter under stands of oak, hickory, maple and other hardwood species of the East.

Photo 27. Long-needle forest floor litter in ponderosa pine stand near Alberton, Mont.

Fire Behavior Fuel Model 10

The fires burn in the surface and ground fuels with greater fire intensity than the other timber litter models. Dead-down fuels include greater quantities of 3-inch (7.6-cm) or larger limbwood resulting from overmaturity or natural events that create a large load of dead material on the forest floor. Crowning out, spotting, and torching of individual trees are more frequent in this fuel situation, leading to potential fire control difficulties. Any forest type may be considered if heavy down material is present; examples are insect- or disease-ridden stands, wind-thrown stands, overmature situations with deadfall, and aged light thinning or partial-cut slash.

The 1978 NFDRS fuel model G is represented and is depicted in photographs 28, 29, and 30.

Fuel model values for estimating fire behavior

Total fuel load,< 3-inch dead and live, tons/acre	12.0
Dead fuel load, ¼ -inch, tons/acre	3.0
Live fuel load, foliage, tons/acre	2.0
Fuel bed depth, feet	1.0

The fire intensities and spread rates of these timber litter fuel models are indicated by the following values when the dead fuel moisture content is 8 percent, live fuel moisture content is 100 percent, and the effective windspeed at midflame height is 5 mi/h (8 km/h);

Model	**Rate of Spread**	**Flame Length**
	Chains/hour	Feet
8	1.6	1.0
9	7.5	2.6
10	7.9	4.8

Fires such as above in model 10 are at the upper limit of control by direct attack. More wind or drier conditions could lead to an escaped fire.

Photo 28. Old-growth Douglas-fir with heavy ground fuels.

Photo 29. Mixed conifer stand with dead-down woody fuels.

Photo 30. Spruce habitat type where succession or natural disturbance can produce a heavy downed fuel load.

LOGGING SLASH GROUP

Fire Behavior Fuel Model 11

Fires are fairly active in the slash and herbaceous material intermixed with the slash. The spacing of the rather light fuel load, shading from overstory, or the aging of the fine fuels can contribute to limiting the fire potential. Light partial cuts or thinning operations in mixed conifer stands, hardwood stands, and southern pine harvests are considered. Clearcut operations generally produce more slash than represented here. The less-than-3-inch (7.6-cm) material load is less than 12 tones per acre (5.4 t/ha). The greater-than-3-inch (7.6-cm) is represented by not more than 10 pieces, 4 inches (10.2 cm) in diameter, along a 50-foot (15 m) transect.

The 1978 NFDRS fuel model K is represented by this model and field examples are shown in photographs 31, 32, and 33.

Fuel model values for estimating fire behavior

Total fuel load,< 3-inch dead and live, tons/acre	11.5
Dead fuel load, ¼ -inch, tons/acre	1.5
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	1.0

Photo 31. Slash residues left after sky-line logging in western Montana.

Photo 32. Mixed conifer partial cut slash residues may be similar to closed timber with down woody fuels.

Photo 33. Light logging residues with patchy distribution seldom can develop high intensities.

Fire Behavior Fuel Model 12

Rapidly spreading fires with high intensities capable of generating firebrands can occur. When fire starts, it is generally sustained until a fuel break or change in fuels is encountered. The visual impression is dominated by slash and much of it is less than 3 inches (7.6 cm) in diameter. The fuels total less than 35 tones per acre (15.6 t/ha) and seem well distributed. Heavily thinned conifer stands, clearcuts, and medium or heavy partial cuts are represented. The material larger than 3 inches (7.6 cm) is represented by encountering 11 pieces, 6 inches (15.2 cm) in diameter, along a 50-foot (15 m) transect.

This model depicts 1978 NFDRS model J and may overrate slash areas when needles have dropped and the limbwood has settled. However, in areas where limbwood breakup and general weathering have started, the fire potential can increase. Field situations are presented in photographs 34, 35, and 36.

Fuel model values for estimating fire behavior

Total fuel load,< 3-inch dead and live, tons/acre	34.6
Dead fuel load, ¼ -inch, tons/acre	4.0
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	2.3

Photo 34. Ponderosa pine clearcut east of Cascade mountain range in Oregon and Washington

Photo 35. Cedar-hemlock partial cut in northern Idaho, Region 1, USFS

Photo 36. Lodgepole pine thinning slash on Lewis and Clark National Forest. Red slash condition increases classification from light to medium.

Fire Behavior Fuel Model 13

Fire is generally carried across the area by a continuous layer of slash. Large quantities of material larger than 3 inches (7.6 cm) are present. Fires spread quickly through the fine fuels and intensity build up more slowly as the large fuels start burning. Active flaming is sustained for long periods and a wide variety of firebrands can be generated. These contribute to spotting problems as the weather conditions become more severe. Clearcuts and heavy partial-cuts in mature and overmature stands are depicted where the slash load is dominated by the greater than 3 inches (7.6-cm) diameter in material. The total load may exceed 200 tones per acre (89 t/ha) but fuel less than 3 inches (7.6 cm) is generally only 10 percent of the total load. Situations where the slash still has "red" needles attached but the total load is lighter, more like model 12, can be represented because of the earlier high intensity and quicker area involvement.

The 1978 NFDRS fuel model I is represented and is illustrated in photographs 37 and 38. Areas most commonly fitting this model are old-growth stands west of the Cascade and Sierra Nevada Mountains. More efficient utilization standards are decreasing the amount of large material left in the field.

Fuel model values for estimating fire behavior

Total fuel load,< 3-inch dead and live, tons/acre	58.1
Dead fuel load, ¼ -inch, tons/acre	7.0
Live fuel load, foliage, tons/acre	0
Fuel bed depth, feet	3.0

For other situations:

Hardwood slash ………………………………………………… Model 6

Heavy "red" slash ……………………………………………. Model 4

Overgrown slash ……………………………………………... Model 10

Southern pine clearcut slash ……………………………………. Model 12

The comparative rates of spread and flame lengths for the slash models at 8 percent dead fuel moisture content and a 5 mi/h (8 km/h) midflame wind are:

Model	**Rate of Spread**	**Flame Length**
	Chains/hour	Feet
11	6.0	3.5
12	13.0	8.0
13	13.5	10.5

Photo 37. West coast Douglas-fir clearcut, quantity of cull high

Photo 38. High productivity of cedar-fir stand can result in large quantities of slash with high fire potential.

APPENDIX B

PARAMETERS AND EXAMPLES OF FARSITE ASCII INPUT FILES

i. Weather (.WTR)

Month Day Precip Hour1 Hour2 Temp1 Temp2 Humid1 Humid2 Elevation rt1 rt2

- *Precipitation* is the daily rain amount specified in hundredths of an inch or millimeters (integer).

- *Hour1* corresponds to the hour at which the minimum temperature was recorded (0-2400).

- *Hour2* corresponds to the hour at which the maximum temperature was recorded (0-2400).

- *Temperatures* (Temp1 is minimum; Temp2 is maximum) are in degrees Fahrenheit or Celsius (integer).

- *Humidities* (Humid1 is maximum; Humid2 is minimum) are in percent, 0 to 99 (integer).

- *Elevation* is in feet or meters above sea level. NOTE: these units (feet or meters) do not have to be the same as the landscape elevation theme (integer).

- *Precipitation* Duration is entered with the beginning (rt1) and ending (rt2) times (0-2400) of the daily rain amount. Only one time period per day is allowed.

Examples

```
ENGLISH
8 10 00 600 1500 48 99 94 11 2400
8 11 00 600 1500 46 96 78 14 2400
8 12 07 600 1600 48 90 74 14 2400 1830 2000
```

ii. Wind (.WND)

Month Day Hour Speed Direction CloudCover

- *Hour* is specified as 0-2400, to the nearest minute (integer).

- *Speed* is either the 20ft windspeed specified in miles per hour or the 10m windspeed in kilometers per hour (integer)

- *Direction* is specified in degrees, clockwise from north (0-360), (integer). A "-1" in the direction field indicates the winds to be up slope, similarly downslope winds can be specified with a "-2".

- *CloudCover* is specified as a percentage, 0 to 100 (integer).

Example

```
ENGLISH
8 10 0 1 54 0
8 10 100 2 67 0
8 10 200 2 102 0
8 10 300 1 166 0
8 10 400 3 319 0
```

iii. Adjustment Factors (.ADJ)

FuelMod AdjustmentFactor

- *FuelMod* is an integer value (1-50). As always, model numbers 1-13 are restricted to the 13 standard Fire Behavior fuel models (Anderson 1982). Models 14-50 are for custom models specified in the Fuel Model (.FMD) File.

- The *AdjustmentFactor* can be a floating point number (decimal) specifying the multiplier for rate of spread adjustment (see above). It must be greater than zero.

Example

```
1 .5
2 .75
3 .5
6 .5
7 .5
10 .75
11 .5
12 .5
13 .5
```

iv. Initial Fuel Moisture (.FMS)

FuelMod 1Hour 10Hour 100Hour LiveH LiveW

- Fuel Model (1-50) corresponds to a fuel model specified
    1. on the landscape if no conversions are used, or
    2. in the Fuel Conversion (.FMS) File if conversions are used. Fuel models 1-13 must relate to the Fire Behavior 13 standard fuel models (Anderson 1982). Fuel models numbered from 14 to 50 are for custom models as described in the Custom Fuel Model (.FMD) File.
- Fuel moistures for each category are in percent (integers), and may exceed 100. LiveH and LiveW indicate "live woody" and "live herbaceous" fuels, just like *BehavePlus*. Unlike dead fuels, live fuel moistures remain constant throughout the simulation unless you manually change them

Example

```
1 3 4 6 50 75
2 3 4 6 50 75
3 3 4 6 50 75
4 3 4 6 50 75
5 3 4 6 75 100
6 3 4 6 50 100
7 3 4 6 50 75
8 4 5 7 75 100
9 3 4 5 50 75
10 4 5 7 75 100
11 3 4 6 50 75
12 4 5 7 75 100
13 4 5 7 75 100
```

v. Fuel Model Conversion (.CNV)

ConvertFrom FuelMod

- ConvertFrom is the index or attribute of a fuel type in the fuels theme converted to a fuel model number 1-99, (integer)

- FuelMod can be any fuel model 1-50, (integer)

Example

```
68 2
74 5
86 8
5 6
8 9
```

vi. Custom Fuel Models (.FMD)

FMod 1H 10H 100H LiveH LiveW 1HSAV LiveHSAV LiveWSAV Depth XtMoist DHt LHt

Field	**Name**	**Data Type**	**English Units**	**Metric Units**
FMod	Fuel Model	integer	number 14-50	number 14-50
1H, 10H, 100H, LiveH, LiveW	Fuel Loading	decimal	tons/acre	metric tonnes/hectare
1HSAV, LiveHSAV, LiveWSAV	Surface to Volume Ratio	integer	1/ft	1/cm
Depth	Fuel Bed Depth	decimal	Ft	cm
XtMoist	Moisture of Extinction	integer	percent	percent
DHt, LHt	Heat Content, live & dead fuels	integer	BTU/lb	J/Kg

Example

```
ENGLISH

19 2.250 1.500 3.710 0.000 1.000 2000 1800 1500 0.600 25 8000 8000
```

vii. Air Attack Resources (.AIR)

#name of 1st aircraft#	bracket the "name" with #
Units	METERS or FEET
1 line_length	Coverage level 1, line length a decimal number
2 line_length	Coverage level 2, line length a decimal number
3 line_length	Coverage level 3, line length a decimal number
4 line_length	Coverage level 4, line length a decimal number
6 line_length	Coverage level 6, line length a decimal number
8 line_length	Coverage level 8, line length a decimal number
Return_Time	Return time in minutes
COST_PER_HOUR 0.00	Optional input
#Name of 2nd aircraft#	Append other aircraft descriptions etc.

Example

```
#C-130 3000 gal#
FEET
1 300
2 150
3 100
4 75
6 50
8 40
RETURN_TIME 120
COST 6000
```

viii. Coarse Woody Profile (.CWD)

SizeClass Loading HeatContent S/R Moist

- *SizeClass* - The representative size of the class based on surface to volume ratio. (i.e.; for the 3" to 6" size class the representative size is 4.75, for the 6" to 10" class it is 8.25). A decimal data type, the units are inches or centimeters.

- *Loading* - Fuel loading of the class (decimal), units are tons/acre or kilograms/hectare

- *HeatContent* - Heat content of the class (integer), units are BTU/lb or joules/kilogram

- *S/R* - Sound or rotten is defined by the density of the fuel (lb/ft3, or kg/m3). Typical values are 32 lb/ft3 for sound fuel and 19 lb/ft3 for rotten.

- *Moist* - Moisture content of the size class in percent (integer).

Example

```
ENGLISH
MODEL 8 CWD_for_fm_8
DEPTH 1.64
0.024 1.50 8000 32 4
0.440 1.00 8000 32 5
1.600 2.50 8000 32 7
4.750 1.30 7997 32 11
MODEL 9 CWD_for_fm_9
DEPTH 0.50
0.019 2.92 8000 32 2
0.440 0.41 8000 32 4
1.600 0.15 8000 32 5
4.750 0.60 7997 32 10
```

ix. Burn Period (.BPD)

Month Day StartHour EndHour

Example

```
8 9 0 2400
8 10 0 2400
8 11 800 2400
8 12 800 2400
```

x. Gridded Weather File (.ATM)

The format of both weather and wind variables in gridded is:

WEATHER_AND_WINDS
MONTH DAY HOUR TEMP HUMID PPT WSPEED WDIR CLDCOVER

Example

```
WEATHER_AND_WINDS
7 15 0200 TEST01.TMP TEST01.HMD TEST01.PPT TEST01.SPD TEST01.DIR
TEST01.CLD
7 15 0600 TEST02.TMP TEST02.HMD TEST02.PPT TEST02.SPD TEST02.DIR
TEST02.CLD
7 15 1200 TEST03.TMP TEST03.HMD TEST03.PPT TEST03.SPD TEST03.DIR
TEST03.CLD
7 15 1600 TEST04.TMP TEST04.HMD TEST04.PPT TEST04.SPD TEST04.DIR
TEST04.CLD
7 15 2000 TEST05.TMP TEST05.HMD TEST05.PPT TEST05.SPD TEST05.DIR
TEST05.CLD
```

```
7 16 0200 TEST06.TMP TEST06.HMD TEST06.PPT TEST06.SPD TEST06.DIR
TEST06.CLD
7 16 0600 TEST07.TMP TEST07.HMD TEST07.PPT TEST07.SPD TEST07.DIR
TEST07.CLD
7 16 1200 TEST08.TMP TEST08.HMD TEST08.PPT TEST08.SPD TEST08.DIR
TEST08.CLD
7 16 1600 TEST09.TMP TEST09.HMD TEST09.PPT TEST09.SPD TEST09.DIR
TEST09.CLD
7 16 2000 TEST10.TMP TEST10.HMD TEST10.PPT TEST10.SPD TEST10.DIR
TEST10.CLD
```

The format of only wind variables in gridded format is

WINDS_AND_CLOUDS
MONTH DAY HOUR WSPEED WDIR CLDCOVER

Example

```
WINDS_AND_CLOUDS
7 15 0200 TEST01.SPD TEST01.DIR TEST01.CLD
7 15 0600 TEST02.SPD TEST02.DIR TEST02.CLD
7 15 1200 TEST03.SPD TEST03.DIR TEST03.CLD
7 15 1600 TEST04.SPD TEST04.DIR TEST04.CLD
7 15 2000 TEST05.SPD TEST05.DIR TEST05.CLD
7 16 0200 TEST06.SPD TEST06.DIR TEST06.CLD
7 16 0600 TEST07.SPD TEST07.DIR TEST07.CLD
7 16 1200 TEST08.SPD TEST08.DIR TEST08.CLD
7 16 1600 TEST09.SPD TEST09.DIR TEST09.CLD
7 16 2000 TEST10.SPD TEST10.DIR TEST10.CLD
```

xi. Ground Attack Resources

#name of 1st crew#	bracket the "name" with #
units	METERS_PER_MINUTE, or FEET_PER_MINUTE, or CHAINS_PER_HOUR
FLAME_LIMIT 0.0	meters or feet depending on units designation above
fuel_model line_production_rate	fuel model is an integer, production rate a decimal number
fuel_model line_production_rate	
99	last fuel model line, no production rate
COST_PER_HOUR 0.00	optional input
#Name of 2nd Crew#	Append other crew descriptions etc.

Example

```
#T-Falls Engine#
CHAINS_PER_HOUR
FLAME_LIMIT 6.000000
1 5.00
2 5.00
3 2.98
4 2.98
5 1.50
6 2.98
7 2.98
8 4.00
9 3.50
10 2.98
11 2.98
12 2.00
13 1.50
14 2.98
15 2.98
99
COST_PER_HOUR 85.00
#T-Falls Hand Crew#
CHAINS_PER_HOUR
FLAME_LIMIT 3.000000
1 2.98
2 2.98
3 2.98
```

APPENDIX C

FIRE REGISTER REPORT

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YANGIN SİCİL FİŞİ

1	Yangının yeri ile ilgili bilgiler		3	Yan. ile ilg. zaman	Tarih	Saat
a	Böl. Müd.	Muğla	a	Yangın Başlama	15.08.2002	18.23
b	İşl. Müd.	Marmaris-Muğla	b	İlk Müdahale	15.08.2002	18.30
c	İşl. Şefi	Çetibeli-Gökova	c	Kontrolü	17.08.2002	21.00
d	Serisi	Çetibeli-Gökova	d	Söndürme	27.08.2002	18.30
e	Mevkii	Ferekderesi	e	Yan. Devam süresi	288 saat 8 Dakika	
f	Bölme No.	Toplam: 34 Bölme	4	Müd. kaçıncı yan.	8	Şef.kaçıncı yan. 2
g	İli	MUĞLA	5	Yan.Ami.Ad.S.Ün.	Mustafa ONUR- Hasan GİRGİN İşl.Md.	
h	İlçesi	Marmaris	6	Yan.Haber Veren	Altınsivri kulesi	
i	Köyü	Gökçe	7	Yan. Başlama Nok.	Orman içi	
2	Suçlusu Bul.	TEDAŞ	8	Söndürme Metodu	Doğrudan müdahale	

9	Yangın Nedeni	Yıldırım	Bilinmeyen	Kasıt	İhmal - Dikkat.	Kaza		
		-	-	-	-	Enerji Nakil Hattı		
10	Meteorolojik Bilgiler	Nisbi Nem%	Rüzgar Hızı Km/s	Rüzgar Yönü	Sıcaklık (En Yük)	Yağış Mik. mm	Son Ya.Ka.Geç.	
		80	2-4 /5-6	K- KB	35	-	-	
11	Topografik Bilgiler	Rakım	Meyil	Bakı	Arazi Yüz.	Geniş va.	Dar dere	Kutu dere	Sırt
		50-400	10-40	Kuzey	Kokurdan	X	X	X	X
12	İlk Tutuşma Malzemesi	Ot	Çalı d.ö.	Ölü örtü	Yonga	Odun İs.	Enkaz	Yapacak	Diğer
				X					

13	Yanan Ormanın	İdare Şekli		No.Ko.Ha.	Bo.Ko.Ha.	No.Ba.Ha.	Bo.Ba.Ha.	Maki. Ha.	Ağaç. Ha.	Toplam
a		Meşcere tipi		Çza, Çza3, Çzb1, Çzb2, Çzb3, Çzbc3, Çza, Çza2, Çza3, Çzd1,						
b		Ağaç Türü		(Kızılçam) Çzcd2, Çzd1, Çzd2, BÇZ, ÇBÇZ, ÇBÇZ-ÇBKBt						
c		Yangın Türü	Örtü	32	-	-	-	-	-	32
d			Tepe	1054	689.5	-	-	-	-	1743.5
		Toplam		1086	689.5					1775.5

14	Yanan Ağaç Sahasında Kuruyan Fidan Adedi (7.9 cm'ye Kadar)							
15	Yanan Orman Alanında Ağaç Mik. M3 8 cm. Y.	K.G.H	Tom	Direk	Sa. Od.	Ka.Od.	Lif. Od.	Yak.Od.
		72.883	6000	1300	7700	24900	-	9500
16	Ağaç Zarar Yüzdesi %	-	20	20	20	20	-	20
17	Ağaç İdare Zarar Toplamı M3		1200	260	1540	4980	-	1900

18	Yangında İdare Zararı	233.519.-	
a	Yanan Fidandan İdare Zararı	233.154.-	
b	Yanan Ağaçtan İdare Zararı	Yap. 222.680.-	Lif Od.
		Yak. Od. 10.920.-	Toplam 233.519.-
c	Ağaçlandırma Bedeli	3.107.125.-	

d	İaşe Giderleri	22.985.-	19	Yangına Katılan (Adet)		20	Motorlu Araçlar (Adet)				
e	İşçilik - Prim "	213.990.-	a	Mahalli Yön.	3	a	Pikap	20	i	Dozer	27
f	Akaryakıt "	33.712.-	b	Teknik Eleman	62	b	Kamyonet	10	k	Kurtarıcı	1
g	Taşıt Kira "	-	c	Memur	40	c	Min.Mid.	25	l	Arazöz	83
h	Arazöz "	126.000.-	d	Sön. İşçisi - İşçi	1125	d	Kamyon	15	m	Greyder	1
i	Dozer "	42.450.-	e	Mükellef	300	e	Otobüs	8	n	Treyler	25
k	Treyler "	4.100.-	f	Asker	300	f	Traktör	-	o	B.Kamyon	-
l	Motorlu Tes. "	500.-	g	Polis	15	g	Diğer	-	p	Uçak	17
m	Uçak "	331.335.-	h	Jandarma	30	h			r	Helikopter	13
n	Helikopter "	1.054.397.-		Toplam	1875			78		Toplam	167

d-n	Gider Toplamı	1.829.469.-	21	Toplam İdare zararı tutarı	~~233~~
o	Ölüm Tazminatı	-	a	Emvalden İdare zararı	233.519.-
p	Sakat Tazminatı	-	b	Fidandan İdare zararı	233.154.-
r	Zar. Ziy.Ka.Taz.	-	c	Ağaçlandırma bedeli	3.107.125.-
o-r	Tazminat Toplamı	-	d	Söndürme giderleri	1.829.469.-
		-	e	Tazminatlar	-
a-r	GENEL TOPLAM	5.403.267.-	a-e	GENEL TOPLAM	5.403.267.-

NOT: Bedeller milyon üzerinden hesaplanmıştır.

Bu yangın fişi tarafımdan tanzim edilmiştir. 13.9.2002 İşl.Şefi Okan TURAN — İşletme Şefi Türkay KARACAY — Tasdik olunur İşletme Müdürü Mustafa ONUR

APPENDIX D

LINEAGE REPORT

Projection Parameters

Universal Transverse Mercator European Datum 1950 Zone 35N (UTM ED 50 Zone 35N (International Spheroid 1909))

```
Projection: Transverse_Mercator
Parameters:
  False_Easting: 500000.000000
  False_Northing: 0.000000
  Central_Meridian: 27.000000
  Scale_Factor: 0.999600
  Latitude_Of_Origin: 0.000000
Linear Unit: Meter (1.000000)
Geographic Coordinate System:
Name: GCS_European_1950
Angular Unit: Degree (0.017453292519943295)
Prime Meridian: Greenwich (0.000000000000000000)
Datum: D_European_1950
  Spheroid: International_1924
    Semimajor Axis: 6378388.000000000000000000
    Semiminor Axis: 6356911.946127946500000000
    Inverse Flattening: 297.000000000000000000
```

Aydın N 20 c3

link table

1.634650	0.864550	623000.000000	4096000.000000
1.960928	21.300232	623000.000000	4109000.000000
17.589541	21.056193	633000.000000	4109000.000000
17.270546	0.641050	633000.000000	4096000.000000
9.455173	0.757264	628000.000000	4096000.000000
9.773692	21.177405	628000.000000	4109000.000000
9.691316	16.469064	628000.000000	4106000.000000
9.540174	7.030185	628000.000000	4100000.000000
1.877058	16.592877	623000.000000	4106000.000000
9.612459	11.742522	628000.000000	4103000.000000
17.508491	16.346854	633000.000000	4106000.000000
17.429396	11.624916	633000.000000	4103000.000000

17.359346	6.913005	633000.000000	4100000.000000
1.723297	7.143457	623000.000000	4100000.000000
1.797052	11.863168	623000.000000	4103000.000000
5.081246	21.253460	625000.000000	4109000.000000
5.000231	16.540619	625000.000000	4106000.000000
4.921364	11.815783	625000.000000	4103000.000000
4.847440	7.098215	625000.000000	4100000.000000
4.761110	0.825419	625000.000000	4096000.000000
14.457851	21.104982	631000.000000	4109000.000000
14.376944	16.395997	631000.000000	4106000.000000
14.301435	11.672706	631000.000000	4103000.000000
14.227821	6.958488	631000.000000	4100000.000000
14.142009	0.688322	631000.000000	4096000.000000
1.675670	4.008182	623000.000000	4098000.000000
4.802305	3.962153	625000.000000	4098000.000000
9.496978	3.896749	628000.000000	4098000.000000
14.183354	3.827488	631000.000000	4098000.000000
17.312537	3.779122	633000.000000	4098000.000000

Transformation: 3rd order polynomial
Total RMS error: 5.05341

Rectification:
Cell Size: 3.240321
Resample Type: Bilinear Interpolation (for continuous data)

Aydın N 20 c4

link table

1.772453	1.128789	612000.000000	4096000.000000
17.729381	21.309283	622000.000000	4109000.000000
17.400277	0.896574	622000.000000	4096000.000000
2.102962	21.556195	612000.000000	4109000.000000
9.749527	12.003378	617000.000000	4103000.000000
1.832468	5.835604	612000.000000	4099000.000000
1.907764	10.553003	612000.000000	4102000.000000
9.587899	1.016089	617000.000000	4096000.000000
17.564921	11.882279	622000.000000	4103000.000000
9.913591	21.428875	617000.000000	4109000.000000
9.677290	7.287932	617000.000000	4100000.000000
9.830800	16.726710	617000.000000	4106000.000000
17.489395	7.167833	622000.000000	4100000.000000
17.646470	16.602137	622000.000000	4106000.000000
2.013488	16.850902	612000.000000	4106000.000000
5.221392	21.506123	614000.000000	4109000.000000
5.137576	16.796465	614000.000000	4106000.000000
5.058404	12.076236	614000.000000	4103000.000000
4.982593	7.358601	614000.000000	4100000.000000
4.917522	2.655558	614000.000000	4097000.000000
14.598184	21.358432	620000.000000	4109000.000000
14.516432	16.652304	620000.000000	4106000.000000
14.434168	11.932102	620000.000000	4103000.000000
14.361588	7.217755	620000.000000	4100000.000000
14.293106	2.514407	620000.000000	4097000.000000
9.607990	2.587400	617000.000000	4097000.000000
1.791030	2.697138	612000.000000	4097000.000000

17.423957	2.466320	622000.000000	4097000.000000
1.857558	7.404282	612000.000000	4100000.000000
1.931660	12.126461	612000.000000	4103000.000000

Transformation: 3rd order polynomial
Total RMS error: 5.11556

Rectification:
Cell Size: 3.241644
Resample Type: Bilinear Interpolation (for continuous data)

Marmaris O 20 b1
link table

1.896362	21.429171	612000.000000	4095000.000000
17.193754	0.759066	622000.000000	4082000.000000
17.524501	21.186032	622000.000000	4095000.000000
1.571911	1.004197	612000.000000	4082000.000000
9.711217	21.309665	617000.000000	4095000.000000
12.838356	21.260757	619000.000000	4095000.000000
6.591083	21.358272	615000.000000	4095000.000000
1.821600	16.724312	612000.000000	4092000.000000
1.741816	12.003283	612000.000000	4089000.000000
1.668934	7.273865	612000.000000	4086000.000000
1.595427	2.566307	612000.000000	4083000.000000
6.511907	16.652596	615000.000000	4092000.000000
6.434125	11.927548	615000.000000	4089000.000000
6.355805	7.201642	615000.000000	4086000.000000
6.282494	2.494486	615000.000000	4083000.000000
9.632729	16.605006	617000.000000	4092000.000000
9.552823	11.877379	617000.000000	4089000.000000
9.478828	7.152753	617000.000000	4086000.000000
9.403873	2.446207	617000.000000	4083000.000000
12.757323	16.557545	619000.000000	4092000.000000
12.682603	11.827731	619000.000000	4089000.000000
12.606602	7.103264	619000.000000	4086000.000000
12.535359	2.397598	619000.000000	4083000.000000
17.445005	16.484200	622000.000000	4092000.000000
17.367424	11.752786	622000.000000	4089000.000000
17.288271	7.033196	622000.000000	4086000.000000
17.216716	2.325737	622000.000000	4083000.000000
6.257964	0.928608	615000.000000	4082000.000000
9.379728	0.879948	617000.000000	4082000.000000
12.512181	0.831497	619000.000000	4082000.000000

Transformation: 3rd order polynomial
Total RMS error: 4.47960

Rectification:
Cell Size: 3.242143
Resample Type: Bilinear Interpolation (for continuous data)

Marmaris O 20 b2

link table

1.646805	21.025619	623000.000000	4095000.000000
16.935584	1.920207	633000.000000	4083000.000000
17.256756	20.762152	633000.000000	4095000.000000
1.302053	0.597927	623000.000000	4082000.000000
9.458683	20.894843	628000.000000	4095000.000000
9.373207	16.187377	628000.000000	4092000.000000
9.291548	11.465809	628000.000000	4089000.000000
9.207934	6.751826	628000.000000	4086000.000000
9.133969	2.047194	628000.000000	4083000.000000
17.174447	16.058131	633000.000000	4092000.000000
17.090986	11.342838	633000.000000	4089000.000000
17.012318	6.627345	633000.000000	4086000.000000
1.562389	16.313885	623000.000000	4092000.000000
1.483438	11.595352	623000.000000	4089000.000000
1.402385	6.874850	623000.000000	4086000.000000
6.331901	20.948637	626000.000000	4095000.000000
6.248448	16.238598	626000.000000	4092000.000000
6.166970	11.518297	626000.000000	4089000.000000
6.089065	6.799260	626000.000000	4086000.000000
6.015148	2.097593	626000.000000	4083000.000000
12.574356	20.841992	630000.000000	4095000.000000
12.491779	16.133889	630000.000000	4092000.000000
12.411016	11.413024	630000.000000	4089000.000000
12.331839	6.701476	630000.000000	4086000.000000
12.257021	1.994799	630000.000000	4083000.000000
1.328561	2.172649	623000.000000	4083000.000000
6.220615	14.662159	626000.000000	4091000.000000
12.464279	14.557675	630000.000000	4091000.000000
12.357725	8.268915	630000.000000	4087000.000000
6.112636	8.373853	626000.000000	4087000.000000

Transformation: 3rd order polynomial
Total RMS error: 3.19300

<u>Rectification:</u>
Cell Size: 3.247341
Resample Type: Bilinear Interpolation (for continuous data)

Transformation: 3rd order polynomial
Total RMS error: 4.41897

Cetibeli_mescere_cut

link table

2952.029220	-410.429349	618791.270271	4097572.788479
1161.025634	-511.996115	615949.068459	4097409.452771
1240.406900	-2969.508462	616062.203930	4093487.761052
2778.508318	-2953.365809	618490.635286	4093517.436180
3284.000545	-3570.105985	619280.377414	4092540.114261
3737.887205	-2950.911729	620000.786759	4093522.553842
5151.940884	-3228.631641	622233.528497	4093081.701992
7245.403046	-3263.151541	625535.215515	4093029.145432

```
4201.618498 -2405.221603      620738.257341     4094395.369259
3338.202273 -1069.942098      619381.548596     4096521.920579
7531.363806 -765.839516       626002.421584     4096999.260035
8167.549080 -2653.562364      627002.096983     4094001.058392
6265.792991 -131.782739       624004.478252     4098001.702268
2573.783017 -328.130204       618185.786596     4097694.248947
4624.617482 -1251.209777      621403.729024     4096233.124801
2401.696228 -1800.335044      617892.983549     4095358.088597
```

Transformation: 3rd order polynomial
Total RMS error: 5.58809

Create TIN from Features Parameters

Layers: Contour
Settings for Selected Layer
Feature Type: 3D Lines
Height Source: <Feature Z Values>
Triangulate as: Hard line
Tag value field: None

Interpolate to Raster Kriging Parameters

Input points: Elevation.shp
Z value field: Elevation
Kriging Method: Ordinary
Semivariogram model: Spherical
Search radius type: Fixed
Search Radius Settings
    Distance 100.000
    Minimum Number of Points: 0
Output cell size: 20.000

Table D.1. Comparison of 10 Elevation Data Which Were Read From DEM and Topographic Map

Number	Coordinate X (m)	Coordinate Y (m)	Contour Value (m)	DEM Value (m)
1	617904.731130	4095380.265906	205	206.2699
2	622325.261711	4093897.986090	380	379.9669
3	622465.638234	4093989.647473	450	449.0404
4	624206.709838	4093793.574605	160	160.123
5	618183.743189	4093778.706455	330	330.4601
6	620244.173474	4093578.007321	530	529.9805
7	620366.047750	4096781.060286	60	59.9881
8	619111.804242	4096855.062015	200	199.6599
9	622849.492920	4095734.000660	100	100.2068
10	622497.987262	4092843.071980	440	440.4774

Table D.2. Lineage Information of Digital Maps

File Name	Type	Source	Date	Method of Production	Map Scale	Projection	Spheroid	Datum
Rectifyaydin-n20-c3.tif	Raster	Paper Map	1996	Scanned, registered by ArcGIS 8.1 and rectified.	1:25,000	UTM Zone 35	Int 1909	ED 50
Rectifyaydin-n20-c4.tif	Raster	Paper Map	1996	Scanned, registered by ArcGIS 8.1 and rectified.	1:25,000	UTM Zone 35	Int 1909	ED 50
Rectifymarmaris-o20-b1.tif	Raster	Paper Map	1996	Scanned, registered by ArcGIS 8.1 and rectified.	1:25,000	UTM Zone 35	Int 1909	ED 50
Rectifymarmaris-o20-b2.tif	Raster	Paper Map	1996	Scanned, registered by ArcGIS 8.1 and rectified.	1:25,000	UTM Zone 35	Int 1909	ED 50
River.shp	Vector Polyline	Raster Maps	5/24/2003	Digitized by using ArcGIS 8.1		UTM Zone 35	Int 1909	ED 50
Road.shp	Vector Polyline	Raster Maps	5/24/2003	Digitized by using ArcGIS 8.1		UTM Zone 35	Int 1909	ED 50
contour.shp	Vector Polyline ZM	Raster Maps	5/23/2003	Digitized by using ArcGIS 8.1		UTM Zone 35	Int 1909	ED 50
elevation.shp	Vector PointZM	contour.shp	5/23/2003	Generated from TIN and joined with contour.shpbased on spatial location.		UTM Zone 35	Int 1909	ED 50
marmaris 20	Raster DEM	elevation.shp		Generated by Kriging Interpolation Method		UTM Zone 35	Int 1909	ED 50
cetibelimescere.ecw	Raster	Paper Maps		Scanning and registered by collecting reference points from topographic maps	1:25,000	-	-	-
mescere.shp	Vector Polyline	Cetibelimescere.ecw		Digitized by using ArcGIS 8.1	1:25,000	UTM Zone 35	Int 1909	ED 50
cet00.tif	Raster	IKONOS		Reprojected, stacked and merged with panchromatic image by ERDAS Imagine		UTM Zone 35	Int 1909	ED 50
cet01.tif	Raster	IKONOS		Reprojected, stacked and merged with panchromatic image by ERDAS Imagine		UTM Zone 35	Int 1909	ED 50

APPENDIX E

TABLE OF VEGETATION SYMBOLS

Table E.1. Table of Vegetation Symbols Use by General Directorate of Forest

İBRELİLER			YAPRAKLILAR			YAPRAKLILAR		
Kot No	Sem-bolü	Ağaç Türü	Kot No	Sem-bolü	Ağaç Türü	Kot No	Sem-bolü	Ağaç Türü
01	Çz	Kızılçam	21	Kn	Kayın	41	Cv	Ceviz
02	Çk	Karaçam	22	M	Meşe	42	Zy	Yabanizeytin
03	Çs	Sarıçam	23	Gn	Gürgen	43	Mp	Palamutmeşesi
04	G	Göknar	24	Kz	Kızılağaç	44	Ms	Saplımeşe
05	L	Ladin	25	Kv	Kavak	45	Mz	Sapsızmeşe
06	S	Sedir	26	Ks	Kestane	46	Mc	Macarmeşesi
07	At	Ardıç	27	Dş	Dişbudak	47	Mt	Tüylümeşe
08	Cf	Fıstıkçamı	28	Ih	Ihlamur	48	Mm	Mazımeşesi
09	Sr	Servi	29	Ak	Akçaağaç	49	Ml	Saçlımeşe
10	P	Porsuk	30	Ka	Karaağaç	50	Mr	Pırnalmeşesi
11	Çh	Halepçamı	31	Ky	Kayacık	51	Mk	Kermezmeşesi
12	Çm	Sahilçamı	32	Çn	Çınar	52	Ko	Kocayemiş
13	Çr	P. Radiata	33	Ok	Okaliptüs	53	Ma	Maki
14	D	Duglaz	34	Sğ	Sığla	54		
15	An	Andız	35	Fn	Fındık	55		
16			36	Sö	Söğüt	56		
17			37	H	Huş	57		
18			38	Df	Defne	58		
19			39	Ş	Şimşir	59		
20	Di	Diğer İbreli	40	O	Ormangülü	60	Dy	Diğer Yapraklı

Yukarıdaki tabloda bulunmayan ağaç türleri; ilk harfleri gözönünde bulundurulmak suretiyle sembolleştirilerek ibrelilerde (16 – 19), yapraklılarda (54 – 59) kod numaraları kullanılır. Ancak bu kod numaraları da yetişmediği taktirde; ibrelilerde (Di sembolü) ve (20) kod numarası, yapraklılarda (Dy) sembolü ve (60) kod numarası kullanılır.

Korularda:

Örnek :Çz0 : Prodüktif kızılçam boşaltılmış gençleştirme alanı
Çz0Y : Prodüktif kızılçam boşaltılmış yanık alanı,
Çzc2Y : prodüktif kızılçam boşaltılmamış “ c “ çağlı iki kapalı yanık mesceresi.

Table E.1. Table of Vegetation Symbols Use by General Directorate of Forest (Continued)

Bozuk korularda : Mescere tipleri esas ağaç türünün başına B harfleri konulmak süreti ile sembolleştirilir. Örnek :BÇz : Bozuk kızılçam mesceresi, BÇz0Y : Bozuk kızılçam boşaltılmış yanık alanı, BÇzY : Bozuk kızılçam boşaltılmamış yanık mesceresi. Baltalıklarda : Baltalık kelimesi Bt rumuzu ile gösterilir. Bozuk baltalıkta ise B harfleri konulmak suretiyle sembolleştirilir. Baltalık mescere tipi sembollerinin yazılmasında; karışık ağaç türleri K harfi ile gösterilir. Örnek :MBt2/00 = Meşe baltalığı, 2 kapalı, yeni kesilmiş saha. MBt3/05 = Meşe baltalığı, 3 kapalı, 5 yaşında. MBt2/10 = Meşe Baltalığı, 2 kapalı, 10 yaşında MBt1/15 = Meşe Baltalığı, 1 kapalı, 15 yaşında, KBt3/01 = Karışık baltalık, 3 kapalı, 1 yaşında. KBt2/08 = Karışık baltalık, 2 kapalı, 8 yaşında. KBt1/27 = Karışık baltalık, 1 kapalı, 27 yaşında. BMBt =Bozuk meşe baltalığı. BKBt = Bozuk karışık baltalık.
Ağaç türleri karışık korularda semboller: GL = Göknar Ladin, GKnL = Göknar Kayın Ladin
Mescere tipinde, iki gelişme çağınında yanyana gösterilmesinin zorunlu olduğu hallerde; hakim gelişme çağı rumuzu önce yazılır. Örnek : bc = b çağ sınıfı hakim. cd = c çağ sınıfı hakim.
Ormansız sahaların sembolleri : OT : Ağaçsız orman toprağı. E : Erozyonlu saha. F : Orman fidanlığı. T : Kayalık, Taşlık. Ku : Kum. Bk : Bataklık, Sazlık. Su : Göl, Bent, Baraj, Nehir. Me : Mer’a, Otlak, Yayla, Çayır, Bozkır. İs : İskan sahası, Mezarlık. Dp : Orman deposu ve istif yeri. Z : Tarım arazisi (Tarla, Meyvelik, Sebzelik, Bağlık v.s. gibi)

APPENDIX F

RAW METEOROLOGICAL DATA

The meteorological data, which are hourly air temperature, humidity and cloud cover, and hourly wind speed and direction, have been obtained from Turkish State Meteorological Service.

İstasyonun Adı: MARMARİS Ayı: Ağustos Yılı: 2002

(18) SAATLİK HAVA SICAKLIĞI (Termograf) (°C) TABLOSU

Günler	SAATLER (Mahalli)																								GÜNLÜK	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Toplam	Ortalama
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NOT: Bu tabloya işlenecek kıymetler, kuru termometreye göre tashih edilmiş saatlik termograf değerleridir.

Mehmet EREN
İstatistik ve Yayın Şb. Md.

İstasyonun Adı: MARMARİS Ayı: Ağustos Yılı: [illegible]

Günler	(7) Buhar Basıncı mb. Tablosu 07	14	21	Ort.	(8) Nispi (bağıl) Nem % Tablosu 07	14	21	Ort.	(9) Higrograf % Tablosu 07	14	21	Ort.	(10) Bulutluluk Tablosu 07	14	21	Top.	(11) Bulutlar Tablosu (Çeşidi ve görüldüğü yön ile tavanın yüksekliği m.) 07	14	21	(12) Ufkî Görüş Km. (Karada) Tablosu 07	14	21
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2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Toplam	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	X	X	X	X	X	X
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Toplam	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	X	X	X	X	X	X
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Toplam	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	X	X	X	X	X	X
Aylık Toplam	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
Aylık Ort.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					

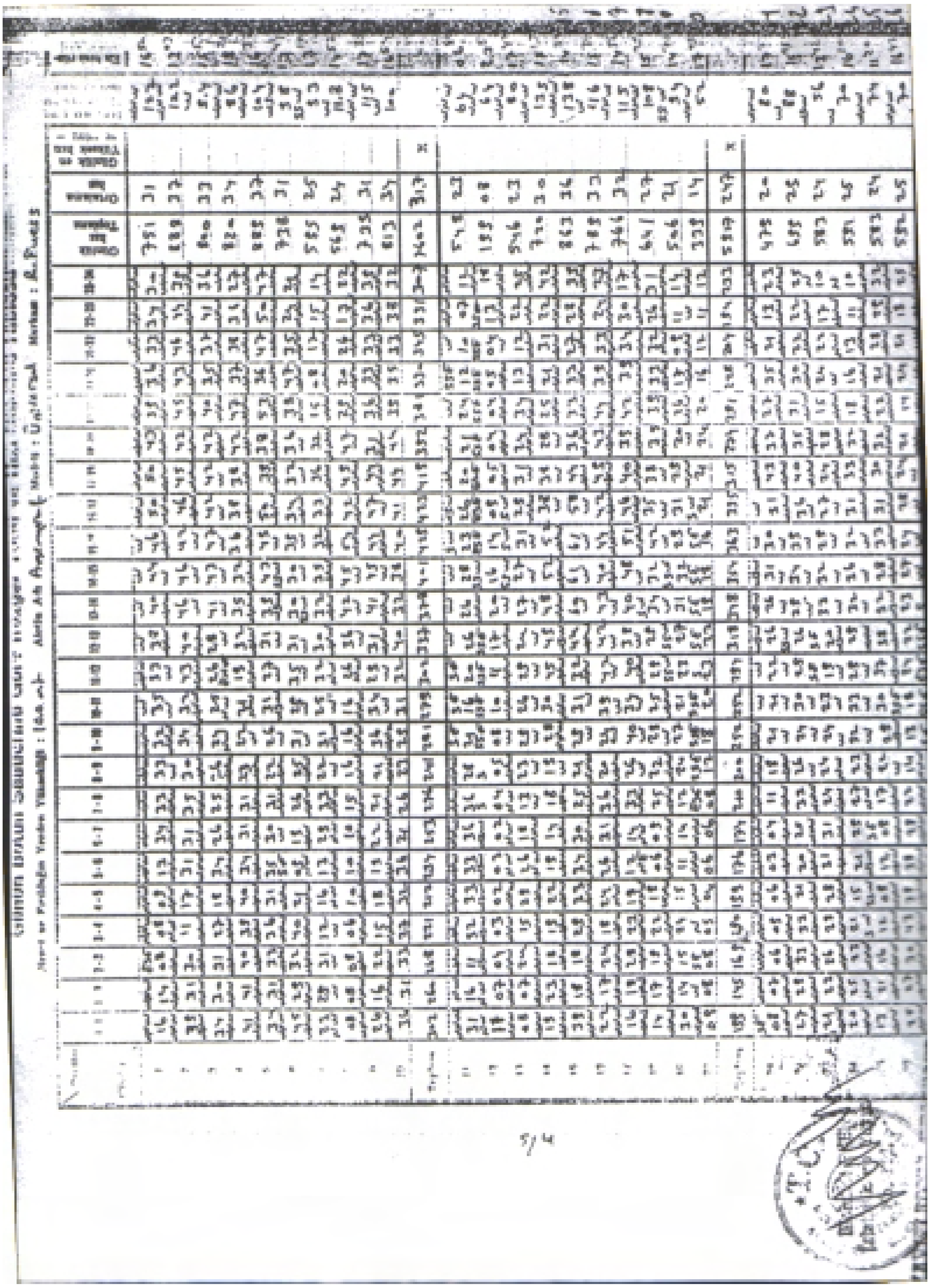
Devreler	[illegible] Top.	Ort.	[illegible] Top.	Ort.	[illegible] Top.	Ort.	Bulutluluk Top.	Ort.	Yağış Top.	[illegible] Top.	Ort.
1 - 5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]
6 - 10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]
11 - 15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]
16 - 20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]
21 - 25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]
26 - 31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]
Toplam	[illegible]	X	[illegible]	X	[illegible]	X	[illegible]	X	—	[illegible]	X

Günler		
[illegible]	30	
[illegible]	1	
[illegible]	—	

Ufkî görüş	07	14	21
20-49 km.	31	31	31
Toplam	31	31	31

Mehmet EKEN
İstatistik ve Arşiv
Şb. Md.

KAYIT[illegible]UYGUNDUR



APPENDIX G

ASCII INPUT FILES OF ÇETİBELİ

Initial ASCII Files

Weather Data File (.WTR)

```
METRIC
8 14 0 600 1400 24 34 71 42 16
8 15 0 600 1200 25 33 67 35 16
8 16 0 500 1400 23 32 63 39 16
8 17 0 600 1400 24 31 70 42 16
8 18 0 600 1300 23 32 83 41 16
8 19 0 600 1400 24 32 82 41 16
8 20 0 600 1600 23 31 87 53 16
8 21 0 500 1300 23 32 91 42 16
8 22 0 600 1400 23 32 73 38 16
8 23 0 300 1500 24 33 78 37 16
8 24 0 500 1400 24 34 82 39 16
8 25 0 600 1400 24 35 94 38 16
8 26 0 600 1300 25 35 74 35 16
8 27 0 600 1400 25 34 79 38 16
```

Wind Data File (.WND)

```
METRIC
8 14 0 7 293 0
8 14 100 8 293 0
8 14 200 6 293 0
8 14 300 7 293 0
8 14 400 8 293 0
8 14 500 7 315 0
8 14 600 5 293 0
8 14 700 6 270 0
8 14 800 7 270 0
8 14 900 10 270 0
```

8 14 1000 11 270 0
8 14 1100 16 270 0
8 14 1200 18 270 0
8 14 1300 17 270 0
8 14 1400 19 270 0
8 14 1500 19 270 0
8 14 1515 49 293 0
8 14 1600 14 293 0
8 14 1700 14 270 0
8 14 1800 10 293 0
8 14 1900 9 293 0
8 14 2000 8 293 0
8 14 2100 11 293 0
8 14 2200 8 293 0
8 14 2300 15 293 0
8 15 0 14 293 0
8 15 100 6 293 0
8 15 200 6 293 0
8 15 300 10 293 0
8 15 400 12 293 0
8 15 500 12 293 0
8 15 600 11 293 0
8 15 700 9 293 0
8 15 800 8 270 0
8 15 900 10 338 0
8 15 1000 11 338 0
8 15 1100 12 293 0
8 15 1200 16 248 0
8 15 1300 22 293 0
8 15 1400 22 293 0
8 15 1434 50 293 0
8 15 1500 22 293 0
8 15 1600 21 270 0
8 15 1700 16 270 0
8 15 1800 13 270 0
8 15 1900 12 293 0
8 15 2000 12 293 0
8 15 2100 10 293 0
8 15 2200 10 293 0
8 15 2300 14 293 0
8 16 0 8 293 0
8 16 100 6 293 0
8 16 200 9 293 0
8 16 300 6 293 0
8 16 400 9 293 0
8 16 500 9 293 0
8 16 600 11 293 0
8 16 700 13 293 0
8 16 800 7 293 0
8 16 900 9 270 0
8 16 1000 14 270 0
8 16 1100 15 293 0
8 16 1200 15 293 0
8 16 1300 15 270 0
8 16 1400 14 270 0
8 16 1500 16 270 0
8 16 1536 42 270 0
8 16 1600 15 270 0
8 16 1700 18 293 0

```
8 16 1800 15 293 0
8 16 1900 16 293 0
8 16 2000 14 293 0
8 16 2100 12 293 0
8 16 2200 9 293 0
8 16 2300 8 293 0
```

Adjustment File (.ADJ)

```
1 1.000000
2 1.000000
3 1.000000
4 1.000000
5 1.000000
6 1.000000
7 1.000000
8 1.000000
9 1.000000
10 1.000000
11 1.000000
12 1.000000
13 1.000000
```

Initial Fuel Moisture (.FMS)

```
1 3 4 6 50 75
2 3 4 6 50 75
3 3 4 6 50 75
4 3 4 6 50 75
5 3 4 6 75 100
6 3 4 6 50 100
7 3 4 6 50 75
8 4 5 7 75 100
9 3 4 5 50 75
10 4 5 7 75 100
11 3 4 6 50 75
12 4 5 7 75 100
13 4 5 7 75 100
```

Modified ASCII Input Files

Custom Fuel Models (.FMD)

```
METRIC
14  0.500  0.000  0.000  0.000  0.000 110 54 41  9.140 12 18592
15 25.650  0.000  0.000  0.000  0.000 47 58 47 289.560 25 18592
16 24.890  3.500  1.290  0.000  0.000 78 54 41 23.180 25 18592
```

Initial Fuel Moisture (.FMS) File

```
1 3 4 6 50 75
2 3 4 6 50 75
3 3 4 6 50 75
4 3 4 6 50 75
5 3 4 6 75 100
6 3 4 6 50 100
7 3 4 6 50 75
8 4 5 7 75 100
9 3 4 5 50 75
10 4 5 7 75 100
11 3 4 6 50 75
12 4 5 7 75 100
13 4 5 7 75 100
14 3 4 6 50 75
15 3 4 6 50 75
16 3 4 5 50 75
```

Fuel Model Conversion (.CNV) File

```
00    0
01    14
02    2
03    15
04    4
05    5
06    6
07    7
08    8
09    16
10    10
11    11
12    12
13    13
14    14
15    15
16    16
```

APPENDIX H

SIMULATION LOG FILES

1st Run

Setting Log File

```
Inputs:
   Landscape: CETIBELI.LCP
   Weather: CETIBELI.WTR
   Winds: CETIBELI.WND
   Adjustments: CETIBELI.ADJ
   Fuel Moistures: CETIBELI.FMS
   Conversions: NONE
   Custom Fuel Models: NONE
   Coarse Woody Fuels: NONE
   Burning Period: NONE
   Project File: F:\GGIT-TEZ-last\farsite\1\input\cetibeli.FPJ
   Bookmark File: F:\GGIT-TEZ-last\farsite\1\input\cetibeli1.BMK
Outputs:
   Shapefile: cetibeli.SHP
   Raster file: Raster File: cetibeli.toa
   Raster file: Raster File: cetibeli.fli
   Raster file: Raster File: cetibeli.ros
   Raster file: Raster File: cetibeli.fml
   Raster file: Raster File: cetibeli.hpa
   Raster file: Raster File: cetibeli.sdr
   Display Units: METRIC
   Output File Units: METRIC
Model:
   Parameters: TimeStep 30.0
   Parameters: Visibles 30.0, 60.0
   Parameters: Perim Res 30.0
   Parameters: Dist Res 30.0
   Options: Crown Fire: DISABLED
   Options: Spotting: DISABLED
   Options: Spot Growth: DISABLED
   Options: Ignition Frequency: 5.0 %
   Options: Ignition Delay: 0 mins
   Options: Fire Level Dist. Check
   Acceleration: ON
   Acceleration: DEFAULTS
```

```
   Post Frontal: OFF
   Dead Fuel Moisture: PRE-CALCULATED
Simulate:
   Duration: Conditioning (Mo/Day): 08/15
   Duration: Starting (Mo/Day Hour:Min): 08/15 18:23
   Duration: Ending (Mo/Day Hour:Min): 08/16 16:45
   Options: Duration Reset: FALSE
   Options: Restore Ignitions: FALSE
   Options: Rotation Sensitive Ignitions: FALSE
   Options: Show Fires as Grown: TRUE
   Options: Ignition Spread Rates: FALSE
   Options: Preserve Inactive Enclaves: TRUE
   Options: Simulation Threads: 01
Attack:
   Ground Resources: NONE
   Air Resources: NONE
View:
   Viewport: MAXIMIZED
```

Output Log After Run

```
Log File:  F:\GGIT-TEZ-last\farsite\1\output\cetibeli.LGS
Date File Created: 08\16\2003
Time File Created: 02:58

Landscape File:  F:\GGIT-TEZ-last\farsite\1\input\CETIBELI.LCP
Weather File 1: CETIBELI.WTR
Wind File 1: CETIBELI.WND
Adjustment File:  CETIBELI.ADJ
Fuel Moisture File:  CETIBELI.FMS
Conversion File:  None
Custom Fuel Model File:  None
Crown Fire: Disabled
Ember Generation: Disabled
Backing Spread: Calculated from Elliptical Dimensions
Acceleration File Used:  Default Values

Simulation Started (Day Hour:Min): 8/15 18:00
Simulation Ended (Day Hour:Min): 08/16  16:23
Elapsed Time (Days Hours:Mins): 00 22:00

Actual Time Step (min): 30.000000
Visible Time Step (min): 30.000000
Perimeter Resolution (m): 30.000000
Distance Resolution (m): 30.000000
```

2nd Run

Setting Log File

```
Inputs:
   Landscape: CETIBELI.LCP
   Weather: CETIBELI.WTR
   Winds: CETIBELI.WND
   Adjustments: CETIBELI.ADJ
   Fuel Moistures: CETIBELI.FMS
   Conversions: NONE
```

```
   Custom Fuel Models: NONE
   Coarse Woody Fuels: NONE
   Burning Period: NONE
   Project File: F:\GGIT-TEZ-last\farsite\2-
crown\input\cetibeli.FPJ
   Bookmark File: F:\GGIT-TEZ-last\farsite\2-
crown\input\cetibeli2.BMK
Outputs:
   Shapefile: cetibeli2.SHP
   Raster file: Raster File: cetibeli2.toa
   Raster file: Raster File: cetibeli2.fli
   Raster file: Raster File: cetibeli2.ros
   Raster file: Raster File: cetibeli2.fml
   Raster file: Raster File: cetibeli2.hpa
   Raster file: Raster File: cetibeli2.cfr
   Raster file: Raster File: cetibeli2.sdr
   Display Units: METRIC
   Output File Units: METRIC
Model:
   Parameters: TimeStep 30.0
   Parameters: Visibles 30.0, 60.0
   Parameters: Perim Res 30.0
   Parameters: Dist Res 30.0
   Options: Crown Fire: ENABLED
   Options: Spotting: DISABLED
   Options: Spot Growth: DISABLED
   Options: Ignition Frequency: 5.0 %
   Options: Ignition Delay: 0 mins
   Options: Fire Level Dist. Check
   Acceleration: ON
   Acceleration: DEFAULTS
   Post Frontal: OFF
   Dead Fuel Moisture: PRE-CALCULATED
Simulate:
   Duration: Conditioning (Mo/Day): 08/15
   Duration: Starting (Mo/Day Hour:Min): 08/15 18:23
   Duration: Ending (Mo/Day Hour:Min): 08/16 16:45
   Options: Duration Reset: FALSE
   Options: Restore Ignitions: FALSE
   Options: Rotation Sensitive Ignitions: FALSE
   Options: Show Fires as Grown: TRUE
   Options: Ignition Spread Rates: FALSE
   Options: Preserve Inactive Enclaves: TRUE
   Options: Simulation Threads: 01
Attack:
   Ground Resources: NONE
   Air Resources: NONE
View:
   Viewport: MAXIMIZED
```

Output Log After Run

```
Log File:  F:\GGIT-TEZ-last\farsite\2-crown\output\cetibeli2.LGS
Date File Created: 08\18\2003
Time File Created: 02:40

Landscape File:  F:\GGIT-TEZ-last\farsite\2-
crown\input\CETIBELI.LCP
```

```
Weather File 1: CETIBELI.WTR
Wind File 1: CETIBELI.WND
Adjustment File:  CETIBELI.ADJ
Fuel Moisture File:  CETIBELI.FMS
Conversion File:  None
Custom Fuel Model File:  None
Crown Fire: Enabled
Crown Density LINKED to Crown Cover
Ember Generation: Disabled
Backing Spread: Calculated from Elliptical Dimensions
Acceleration File Used:  Default Values

Simulation Started (Day Hour:Min): 8/15 18:00
Simulation Ended (Day Hour:Min): 08/16  16:23
Elapsed Time (Days Hours:Mins): 00 22:00

Actual Time Step (min): 30.000000
Visible Time Step (min): 30.000000
Perimeter Resolution (m): 30.000000
Distance Resolution (m): 30.000000
```

Final Run

```
Inputs:
   Landscape: CETIBELI.LCP
   Weather: CETIBELI.WTR
   Winds: CETIBELI.WND
   Adjustments: CETIBELI.ADJ
   Fuel Moistures: CETIBELI.FMS
   Conversions: CETIBELI.CNV
   Custom Fuel Models: CETIBELI.FMD
   Coarse Woody Fuels: NONE
   Burning Period: NONE
   Project File: F:\GGIT-TEZ-last\farsite\3-adjust\input-
1\cetibeli.FPJ
   Bookmark File: F:\GGIT-TEZ-last\farsite\3-adjust\input-
1\cetibeli3-1.BMK
Outputs:
   Shapefile: cetibeli.SHP
   Raster file: Raster File: cetibeli.toa
   Raster file: Raster File: cetibeli.fli
   Raster file: Raster File: cetibeli.ros
   Raster file: Raster File: cetibeli.fml
   Raster file: Raster File: cetibeli.hpa
   Raster file: Raster File: cetibeli.cfr
   Raster file: Raster File: cetibeli.sdr
   Display Units: METRIC
   Output File Units: METRIC
Model:
   Parameters: TimeStep 30.0
   Parameters: Visibles 30.0, 60.0
   Parameters: Perim Res 30.0
   Parameters: Dist Res 30.0
   Options: Crown Fire: ENABLED
   Options: Spotting: DISABLED
   Options: Spot Growth: DISABLED
   Options: Ignition Frequency: 5.0 %
   Options: Ignition Delay: 0 mins
```

```
   Options: Fire Level Dist. Check
   Acceleration: ON
   Acceleration: F:\GGIT-TEZ-last\farsite\3-
adjust\input\cetibeli.ACL
   Post Frontal: OFF
   Dead Fuel Moisture: PRE-CALCULATED
Simulate:
   Duration: Conditioning (Mo/Day): 08/15
   Duration: Starting (Mo/Day Hour:Min): 08/15 18:23
   Duration: Ending (Mo/Day Hour:Min): 08/16 16:45
   Options: Duration Reset: FALSE
   Options: Restore Ignitions: FALSE
   Options: Rotation Sensitive Ignitions: FALSE
   Options: Show Fires as Grown: TRUE
   Options: Ignition Spread Rates: FALSE
   Options: Preserve Inactive Enclaves: TRUE
   Options: Simulation Threads: 01
Attack:
   Ground Resources: NONE
   Air Resources: NONE
View:
   Viewport: MAXIMIZED
```

APPENDIX I

FIRE OBSERVATION DATA SHEETS AND DESCRIPTIONS

(Rothermel and Rinehart, 1983)

Figure 3
FIRE OBSERVATION DATA SHEET

Observer's Name ______________________ Date ____________

Fire Identification ______________________________

Section of line identification ______________________

____

INPUTS							
Start time							
Projection point							
Slope							
Aspect							
Elevation							
Fuel model							
Shade percent							
Dry bulb temp.							
Wet bulb temp.							
Relative humidity							
Live fuel moisture							
20' windspeed							
Handheld anemometer windspeed							
Wind direction							
Fire, wind, slope direction							
FIRE OBSERVATIONS							
Average flame length							
Maximum flame length							
Overstory torching							
Overstory crowning							
Firewhirls							
Spotting occurrence							
Spotting distance							
Spread distance							
End time							

can be sketched. Use a portable tape recorder for making quick verbal descriptions of fire behavior and reasons for starting and stopping test periods. The recorder is superior to written notes because it is much faster, and you can talk while watching the fire.

FIRE OBSERVATION DATA SHEET

Heading

Enter the observer's name and the date on which the data are taken.

Identify the fire.

Identify the section of the fire on which the data are taken.

Space is available for other identifying information.

Start Time

Enter the time of day (24-hour time) that an observation is to begin. This is not time of ignition, but the time that a line of fire has developed that is independent of its ignition source and has reached a relatively steady state. Fuel ahead of the fire should be of the same type for a sufficient distance to obtain a reasonable spread measurement. If the wind changes significantly in speed or direction, the time period may have to be terminated (see End Time).

Projection Point

The designation "projection point" is used to identify the position from which the growth of the fire will be projected and monitored. Identify the projection point on a map.

Inputs

Slope.—Measure the slope. This can be done with a handheld instrument. Learn to disregard undulations that are small with respect to the size of the fire or that the fire may cross in a time short compared to the observed run time. It may be more convenient to measure slope after the fire.

Aspect.—Record the aspect as one of the four cardinal directions or a combination of two of them.

Elevation.—Record the elevation in feet.

Fuel model.—Observe the fuel stratum that is carrying the fire. Photograph the fuel, both with and without fire in the scene. Dictate a description of the fuel into the recorder, noting the type of fuel, e.g., grass, shrubs, litter, or slash. Describe both the living and dead material and the relative abundance of each. Describe the stage of growth or the curing of the live fuel and its coloration. If the fuels are nonuniform, one fuel model may not be satisfactory to represent the area. Another option is to use the two-fuel-model concept (see appendix). Enter two fuel models that describe the area, the first that describes the dominant fuel cover and the second that describes significant concentrations within the first. Below the fuel model number enter the estimated percent cover of each fuel.

Shade factor.—Ignition component and 1-hour timelag fuel moisture calculations are affected by the shading of fuels at the fire site. Shading can result from either cloud cover or canopy cover. Estimate the percent shading.

Dry bulb temperature.—Enter dry bulb air temperature (be sure thermometer is shaded and ventilated).

Wet bulb temperature.—Enter wet bulb temperature. Follow prescribed procedures for accurate measurements.

Relative humidity.—Convert dry bulb temperature and wet bulb temperature to RH, using a chart for the appropriate elevation (not needed until ready to estimate dead fuel moisture and fire behavior).

Live fuel moisture.—Estimate the live fuel moisture from the guide provided by Rothermel (1983). If live fuel moisture is measured include only the foliage and fine stems, and do not mix live and dead samples.

20-ft windspeed.—For exposed fuels that are not beneath a timber canopy, such as grass, shrubs, or logging slash, a continuous measurement of windspeed at the standard 20-ft height can be very helpful. Set the anemometer at a location that will be as representative as possible of the wind that will be blowing over the fire. If possible it should be upwind of the fire on the order of 15 to 20 times the expected flame length from the fire. For example, if the flame lengths are expected to be 4 ft, the anemometer should be at least 60 to 80 ft away. Closer locations will be influenced by indrafts to the fire. Since the system is designed to be a predictive system, it must work with forecasted winds that would be present in the absence of fire. The fire model is designed to account for indrafts to unrestricted line fires in surface fuels.

Handheld anemometer windspeed.—Although 20 ft above the vegetation cover is the standard height for taking windspeed observation (Fischer and Hardy 1976), it must be interpreted to determine midflame windspeed needed by the fire model (Rothermel 1983). A good representation of the midflame windspeed can be measured with an anemometer near eye level. A high quality 3-cup handheld anemometer with low starting inertia is recommended. If one is not available, the pith-ball type of wind meter in the belt weather kit can be used.

A two-person team consisting of an observer and a data recorder may be needed for a short time when fire is moving rapidly. Use two clean pith-ball wind meters, one plugged so that it always reads the high scale, and the other open for reading the low scale. Clamp the anemometers together side by side, place them on a rod that can be rotated, and stick it in the ground. Slide the anemometers to the approximate midflame height. Note the height of the anemometers. Rotate the anemometers directly into the wind and call off the position of the ball of the low or high observation; read the low velocity whenever it is on scale. The observations should be repeated at a uniform rate. The recorder should record all the observations made within each time interval. For short fast runs, readings may be needed as often as every 15 seconds; for slow moving, long duration fires, the interval can be much longer. It is important, however, to take the wind data that coincide with a measurement of a fire run; that is, at the same time and in the same body of air.

An alternative to this procedure is to use an averaging anemometer. This instrument records the total travel distance of the air that passes past it from the time it is turned on. This is easily converted into average windspeed by dividing this total distance by the length of time of the observation.

Wind direction.—Record the direction the wind is coming from. If it is light and variable, note that fact. Record the direction as one of the four cardinal directions or a combination of two.

A tassel of colored yarn attached to the rod described above will indicate wind direction; the observer should keep the wind meters facing into the wind. If it is not possible to locate a measuring point upwind of the fire in a position that is representative of the same slope on which the fire is burning, then it can be located to the side; but care should be taken that the wind being measured has not traveled over a burning area before it reaches the measuring point.

Relative directions, fire, wind, and slope.—Record the direction the head of the fire is spreading with respect to the wind direction and the maximum slope. Examples of four conditions are illustrated in figure 4. It is also possible for the wind to be blowing cross-slope, with the fire spreading fastest in the uphill or downhill direction. A code for recording the directions is given in table 1. Explanation of how to calculate fire spread for cross-slope fires is given by Rothermel (1983). Although the fire model was designed to predict behavior at the head of the fire, it can be adapted to work with backing fires and on the flanks. On a large fire these may be the only accessible places and a record of what the fire spread, wind, and slope directions are at each projection point is essential.

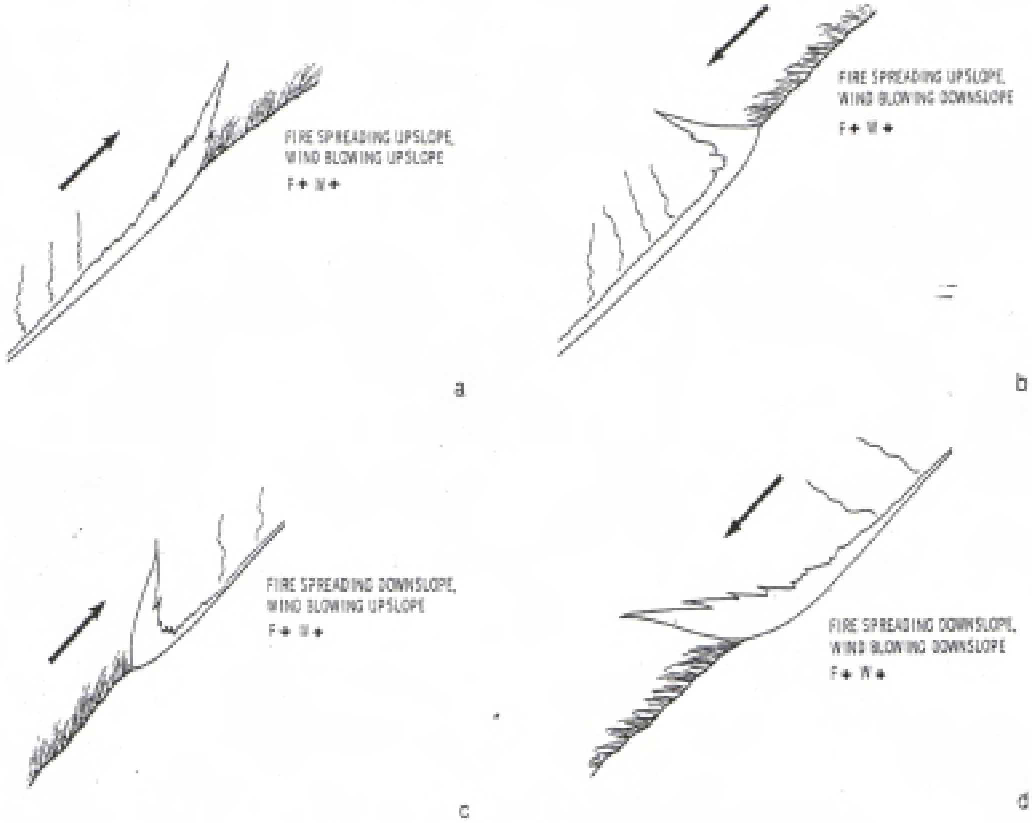


Figure 4.—Flame shapes on slopes as affected by direction of fire spread and direction of wind.

Table 1.—Symbols for indicating fire spread direction with respect to wind and slope

Direction of fire spread	Wind direction			
	Upslope, within ± 30° of maximum	Cross-slope: Upward	Cross-slope: Downward	Downslope, within ± 30° of fall line
Upslope side of fire	F↑ W↑ Wind and fire going upslope as shown in fig. 4–a	F↑ W↗ Upslope side of fire; wind crossing upslope	F↑ W↘ Upslope side of fire; wind crossing downslope	F↑ W↓ Fire spreading upslope; wind blowing downslope; as shown in fig. 4–b
Downslope side	F↓ W↑ Fire backing downslope; wind blowing upslope as shown in fig. 4–c	F↓ W↗ Fire backing downslope; wind crossing upslope	F↓ W↘ Fire spreading downslope; wind crossing downslope	F↓ W↓ Fire spreading downslope; wind blowing downslope as shown in fig. 4–d

Average flame length.—Estimate the average flame length along the fireline. Flame length (fig. 5) is the distance between the tip of the flame and the ground (or surface of the remaining fuel) midway in the zone of active flaming. Do not confuse flame height with flame length. It is extremely helpful to have an object of known length to provide a reference scale. Stakes set in the burn area with 1-foot sections painted alternate colors, or with metal flags attached at known spacing (the spacing depends on the expected scale of the flames) are very helpful. Small trees or a person standing near the fire may also be used for scaling. Measure the tree height before or after the fire.

It is difficult to measure flame length. The flame tip is a very unsteady reference; your eye must average the length over a time period that is representative of the fire behavior. Flame length can be estimated from photos of narrow fuel beds, but photographs of large fires taken from the rear are of little use. Infrared photographs give good quality flame images even through smoke (Britton and others 1977). Photographs alone may not provide the data needed. Supplement photos with visual estimates.

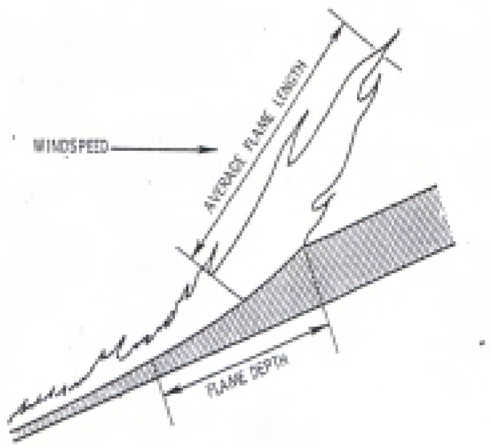


Figure 5.—Flame dimensions for a wind-driven fire on a slope.

Maximum flame length.—Record the maximum flame length observed along the fireline during the time period.

Overstory torching.—Note if torching of overstory trees is occurring.

Overstory crowning.—Note if sustained crowning of the overstory is occurring.

Fire whirls.—Note the presence of firewhirls. Record the conditions under which they develop, such as the direction of the ambient wind, or wind above the fire with respect to slope.

Spotting.—Note if short range spotting is occurring. Note if firebrands landing in front of the fire are starting new fires before the fire front burns over them or if small spot fires are being overrun by the main fire front before significant new fires are started.

If firebrands are being lofted by torching trees or from burning piles, an estimate of the maximum spotting distance can be made using a model developed by Albini (1981). Chase (1981) provides a complete description for predicting the maximum expected spotting distance with Albini's model, using a program developed for the TI-59 calculator. A worksheet is provided and the program can be obtained on a magnetic strip from the Northern Forest Fire Laboratory. We are interested in accurate descriptions of firebrand behavior and spotting distance, and would appreciate receiving this information along with a complete description of the situation as called for by the worksheet in Chase's publication.[1]

Spread distance.—Methods of measuring spread distance depend on the size and rate of spread of the fire, and on the equipment available. It is not necessary to map the entire fire perimeter. Figure 6 indicates the data needed. The following suggested methods have been tried. Choose the one that suits your fire situation.

[1]Send data to: Fire Behavior Project, Northern Forest Fire Laboratory, P.O. Drawer G, Missoula, MT 59806.

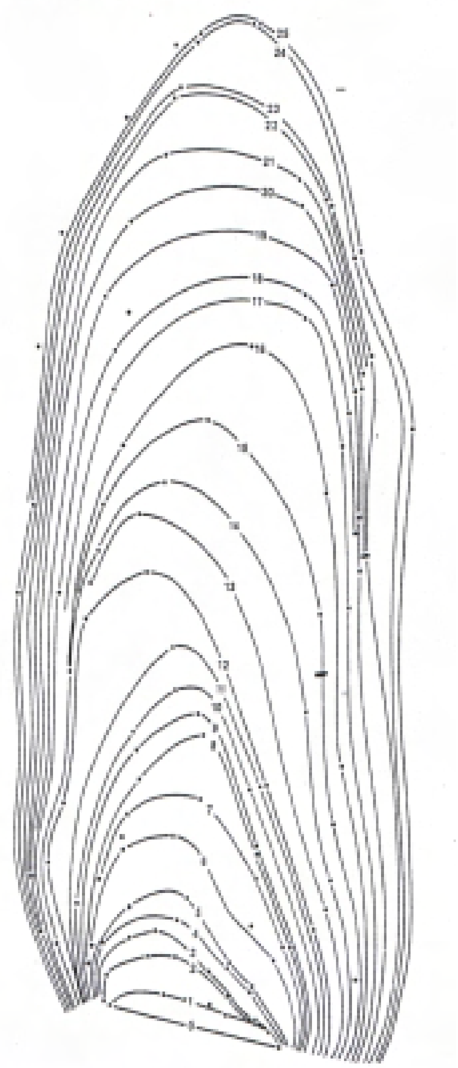


Figure 6.—Fire growth map showing fire position every minute. Data taken and compiled by Phil Cheney in Australia, 1976. Fire burned in grass, primarily sorghum. Original scale was 1 cm = 20 m. Rate of spread for any interval is the distance traveled divided by the time of the interval.