Thessaloniki’s suburban forest degradation–Its interrelation with the urban pollution and the effect on the microclimate

Vasiliki Blougoura

SCHOOL OF SCIENCE & TECHNOLOGY

A thesis submitted for the degree of

*Master of Science (MSc) in Energy Systems*

OCTOBER 2012

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Disclaimer

This dissertation is submitted in part candidacy for the degree of Master of Science in Energy Systems, from the School of Science and Technology of the International Hellenic University, Thessaloniki, Greece. The views expressed in the dissertation are those of the author entirely and no endorsement of these views is implied by the said University or its staff.

Signed.....................................

Name: Blougoura Vasiliki

Date: October 2012
Abstract

This dissertation was written as a part of the MSc in Energy Systems at the International Hellenic University.

The peri-urban forest of Thessaloniki plays an important role in the urban environment, and in the social and cultural life of the residents of the city. It acts as a biological barrier against pollution providing high benefits to people and to the environment in general.

However, the alteration of the forest due to forest fires with that of 1997 being the most prominent has negative impact on the urban microclimate, worsening the living conditions. This fact will be described and assessed through this dissertation.

Special thanks to Dr. George Martinopoulos, to the assistant professor of Forestry Evaggelos Karagiannis, to the Forest Directorate of Thessaloniki and the Municipality of Thessaloniki. This dissertation would not have been carried out without their guidance and support.

Vasiliki Blougoura

October 2012
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Chapter 1

Introduction

Forest consists of biomass which is a renewable natural source (Ministry of Rural Development and Food, 2007). It is a nature’s gift with priceless contribution to people’s life, providing high potential for economic, sociopolitical and environmental welfare. However, every year forest areas are destroyed, either by fires or by manmade activity, reducing their function.

Nowadays, forests cover more than 25% of Greece (Ministry of Rural Development and Food, 2007). This percentage was higher in the past but through the years it kept minimizing. Since the 80’s there was an almost exponential rise in the number of fires and of burnt forest areas (Dimitrakopoulos, 2009). These damages were mainly due to anthropogenic activities (agricultural fires) and/or negligence (cigarettes) and to a lesser extent, from natural causes.

The objective of this dissertation is a survey of the peri-urban forest of Thessaloniki before and after the great forest fire of 1997 that destroyed more than 55% of the forest and the influence that it had on the air quality of the city. Furthermore, this dissertation examines how these variables have affected Thessaloniki’s microclimate and finally possible measures for improvement will be proposed. The dissertation is divided in 3 parts:

- The first part covers the initial condition of the forest and its function; it offers protection from flooding and erosion. Also it has the ability to absorb CO\textsubscript{2} and other pollutants from the atmosphere, improving air quality and it also captures solar radiation balancing extreme temperatures. In addition, forest supports the conservation of biodiversity.

- However, the contribution of the forest was diminished after the fire. It was a disastrous fire with huge ecological implications. The largest percentage of the forest, almost 55%, was burnt. As a consequence, the flooding protection was reduced while the pollution was increased; so the microclimate of the city was altered, and how the polluted air of the city affects the vegetation. This state constitutes the second part.
• The final, third, part includes some restoration projects took place after the fire and some proposals. There was significant natural regeneration (of the preexisting species) but rehabilitation projects, with plantation of new species, were conducted as well.

Primarily, some definitions are important in order to have a clear view of the matter.

1.1 Forest, forest environment, forest fire

Forest is referred to only when trees and bushes live together in a large surface in a close “social relationship” between them and at a specific distance so that their canopy cover can create a separate environment, the forest environment, and with other species, plants and animals, creating a separate bio-community, the forest bio-community (Dafis, 1986).

Forest environment is completely different from its surroundings. Inside the forest the temperature is stable, there are no wide fluctuations in air and soil temperatures since sun radiation and precipitation do not reach ground directly as they are obstructed by trees. Also wind speed is reduced as trees act like natural windbreakers.

Forest fires are caused due to:

1. climatic conditions,
2. human activities and/or negligence,
3. lack of institutional measures.

General speaking the fire causes in Greece are highly dependent on the social conditions and the economic activities and change proportionally to the specific time period.

Some of the most important consequences of the fires are:

1. increase of CO₂ in the atmosphere due to limited absorption as trees are reduced,
2. enrichment of atmosphere with CO₂ and CH₄ emerging as combustion products,
3. CO₂ in the atmosphere traps solar radiation reflected back by the earth’s surface, increasing temperature (Greenhouse effect), and finally
4. global climate changes.

The magnitude of the consequences depends on the kind of soil, the intensity and the frequency of fires.
1.2 Urban environment, Urban microclimate

The urban environment is actually the city. City is an urban area with a relative density of population (at least 10.000 inhabitants), with public buildings and services respective to the population.

Urban climate is characterized by the conditions prevailing in large urban centers which differ from the climate of its rural surroundings (Farlex, 2012). It is distinguished by different climatologic conditions as well as by increased concentration of pollution sources.

Some characteristics of the urban climate are the urban heat island and the urban canyon. Urban heat island is the center of a city which is hotter than the surrounding rural areas. It appears as an “island” in the pattern of isotherms on a surface map. (American meteorological society, 1996). Urban canyon seems to a natural canyon but in the urban environment (Farlex, 2012).

The variables that define the microclimate are the density of the city, the traffic congestion and the ratio of the height of the buildings to the width of the street in combination to the climatic conditions (high sunshine and low winds) (Organization of Planning and Environmental protection of Thessaloniki).

1.3 Air pollution

Air pollution is the existence of pollutants in the atmosphere (chemicals, noise and other particulate matter) that can be harmful to people or environment.

Air pollution is mainly caused by anthropogenic activities and can be classified in three categories (Moussiopoulos, 2003):

1. industrial activities (emissions and wastes),
2. transportation (car exhaust emissions) and
3. households’ consumption.

Air pollution can also come from natural sources such as: forest fires (PMs, CO₂, etc), volcanoes (SO₂, CH₄, etc), soil erosion and decomposition of plants and animals (hydrocarbons).
Pollution has significant implications to the environment and also to humans. The most direct impact is air quality degradation that leads to degradation of human health. Flora and fauna are also affected.
Chapter 2

The peri-urban forest of Thessaloniki

The peri-urban forest of Thessaloniki is called Seich Sou. Its name was given during the era of the Turkish occupation and it means “the water of Sheikh”.

The forest, in its current form, was created in the ’30s, by reforestation, replacing an oak forest that preexisted with appropriate species capable of growing in the degraded land (mainly conifers), creating a precursor forest. The objective was the recovery of the degraded ecosystem and the protection of the city, by preventing floods. The area was led to this degradation by overexploitation of the land, overgrazing and constant logging. Reforestation had begun gradually from the west side of the forest. So, the peri-urban forest of Thessaloniki is an artificial forest, a result of 70 years of effort.

2.1 Boundaries, area, general description

Thessaloniki’s peri-urban forest has a total area of 3019 ha (30,018.840 m²) and it is located northeastern of the city at a relatively short distance from the center of Thessaloniki. It extends on the southern and the southwestern sides of Hortiatis mountain and up to the road of Eptapyrgio- Asvestochori. More specifically the forest covers an area which is defined by:

**N- NE:** from the public street of Neapoli, Pefka, Asvestochori, Eksochi, Hortiatis,

**E:** from the public street of Panorama- Hortiatis,

**S- SW:** from the public street of Panorama- Pylaia and the provincial road and particularly the section of Ano Toumpa- Pylaia,

**W:** from the outskirts of the northeastern edge of the city (Gatzogiannis et al, 1996).

The coordinates of the Seich Sou forest park are:

- Latitude: 40°35,5’- 40°39,5’
- Longitude: 22°57’- 23°04’
The forest was dominated by forested areas, followed by the area of infrastructure while the agricultural lands cover the smallest part, mainly in the N and NE sides of the forest. The proportion of the coverage has changed after the fire (as it will be explained later on in paragraph 2.1.4) but accurate data for its current situation are not available. Table 2.1 presents the initial state of the forest (appendix 1 map 4).

Table 2.1: Forest coverage

<table>
<thead>
<tr>
<th>Form of land cover</th>
<th>Area (m²)</th>
<th>Proportion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forested area</td>
<td>24.004.200</td>
<td>79.51</td>
</tr>
<tr>
<td>Partly forested area</td>
<td>1.925.500</td>
<td>6.38</td>
</tr>
<tr>
<td>Agricultural land</td>
<td>1.327.500</td>
<td>4.4</td>
</tr>
<tr>
<td>Grasslands and barren area</td>
<td>306.100</td>
<td>1.01</td>
</tr>
<tr>
<td>Infrastructure area</td>
<td>2.625.100</td>
<td>8.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>30.018.840</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
2.2 Description of the natural environment

In general, in the peri-urban forest area, environmental conditions are not particularly favorable for vegetation. Low precipitation combined with swallow soils leads to reduced water capacity affecting plant growth rate.

2.2.1 Climatic conditions

The climate of the forest, according to the bioclimatic map of Greece (Mavrommatis, 1980), is characterized between strong to weak mean Mediterranean. Precipitation is not distributed uniformly all over the year but it appears mainly in the form of rapid rains and storms. As a consequence, water resources cannot be fully exploited as large quantities flow superficially ending in streams and small torrents of the region. Snow is rare, once or twice per year, from December up to February.

- Overall average annual rainfall is 447.8 mm with 40% of this amount corresponding to the vegetation period. Rainfall gradually decreases from May, reaching its minimum in September.
- Average annual air temperature is 15.8 °C. The coldest month is January, while the warmest is July.
- Snow is thin (5-20 cm) and remains on the ground 2-4 days.
- Average annual air humidity is 67%. It ranges from 10-60% during summer and 30-100% during winter.
- Wind in the area appears strong (40 km/h) with prominent direction on the N-S axis. This strong wind acts as an inhibiting factor in plant growth as it accelerates water evaporation from ground horizons, preventing it from being absorbed by plants (Gatzogiannis et al., 1996).

From the climatic data, the most important are the average rainfall, its monthly distribution and the air temperature, as shown in Table 2.2. This data occurred from processing data from the meteorological observations of the Meteorological station of the Aristotle University for the period 1992-2002. Figure 2.2 presents the mean monthly precipitation and temperature for the decade.
### Table 2.2: Meteorological data 1992-2002

<table>
<thead>
<tr>
<th>Months</th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean temperature</td>
<td>6,3</td>
<td>7,7</td>
<td>10,1</td>
<td>14,2</td>
<td>19,4</td>
<td>24,1</td>
<td>26,4</td>
<td>26,2</td>
<td>21,6</td>
<td>16,9</td>
<td>11,6</td>
<td>7,4</td>
</tr>
<tr>
<td>(°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean maximum</td>
<td>8,5</td>
<td>10,9</td>
<td>14,2</td>
<td>16,4</td>
<td>20,9</td>
<td>25,3</td>
<td>27,8</td>
<td>27,6</td>
<td>24,4</td>
<td>18,8</td>
<td>14,8</td>
<td>9,3</td>
</tr>
<tr>
<td>temperature</td>
<td></td>
<td></td>
<td></td>
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<td>(°C)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean minimum</td>
<td>3,1</td>
<td>4,8</td>
<td>7,7</td>
<td>10,6</td>
<td>17,7</td>
<td>23,4</td>
<td>24,9</td>
<td>24,6</td>
<td>19,7</td>
<td>13,7</td>
<td>8,3</td>
<td>2,4</td>
</tr>
<tr>
<td>temperature</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation</td>
<td>31,9</td>
<td>32,9</td>
<td>29,1</td>
<td>40,4</td>
<td>49,3</td>
<td>17,2</td>
<td>28,2</td>
<td>17</td>
<td>24,9</td>
<td>35,7</td>
<td>48,5</td>
<td>51,9</td>
</tr>
<tr>
<td>(mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative humidity</td>
<td>75</td>
<td>70,3</td>
<td>67,2</td>
<td>66,6</td>
<td>65,4</td>
<td>59,1</td>
<td>57,5</td>
<td>59,4</td>
<td>63,1</td>
<td>71,5</td>
<td>74,2</td>
<td>78,6</td>
</tr>
<tr>
<td>(%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean wind speed</td>
<td>6,2</td>
<td>7,2</td>
<td>7,4</td>
<td>6,5</td>
<td>6,2</td>
<td>6,3</td>
<td>5,7</td>
<td>5,7</td>
<td>5,6</td>
<td>5,2</td>
<td>5,6</td>
<td>5,4</td>
</tr>
<tr>
<td>(m/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2.2:** Ombrothermic chart
2.2.2 Relief and hydrological conditions

The relief is smooth and the area is characterized as hilly and sub mountainous. The inclinations that prevail vary between 20-50%. However, in some locations the inclination becomes less steep (0-15%). The oversea height of the forest ranges from 80 to 563 m.

The forest consists of 6 basins, the water of which is concentrated in the 11 streams that flow through the city. These basins are shown in appendix 1, in map 1 and they are:

I. Torrential stream “Eleonas”
II. Torrential stream “Agios Panteleimonas”
III. Torrential stream “Kipos tou Kalou”
IV. Torrential stream “Ano Toumpa”
V. Torrential stream “Konstantinidis”
VI. Torrential stream “Xeropotamos”

2.2.3 Geological and soil conditions

The peri-urban forest soils consist generally of brown forest soils, genetically immature. Their mechanical composition is moderate to severe, while they do not have differences in structure between the sites of different qualities. Moreover, the erosion of the area is large due to the damage from the protective vegetation from land reclamation, irregular logging, forest fires and overgrazing.

The formation age of the region is determined between the Paleozoic and Mesozoic century.

The geological base, in the north side consists of metasedimentary rocks while in the south side consists of sedimentary and metamorphic.

The petrological composition is shown in Table 2.3 (map 2 appendix 1). The forest consists mainly of gneiss (almost 35%), calcitic phlysch and quartzites (almost 26%), while in smallest proportion is found gabbro (almost 1,5%) (Gatzogiannis et al., 1996).
Table 2.3: Petrological composition of the peri-urban forest of Thessaloniki

<table>
<thead>
<tr>
<th>Rocks</th>
<th>Area (m²)</th>
<th>Proportion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gabbro</td>
<td>466.200</td>
<td>1,54</td>
</tr>
<tr>
<td>Red clays</td>
<td>6.862.500</td>
<td>22,71</td>
</tr>
<tr>
<td>Gneiss</td>
<td>10.541.300</td>
<td>34,88</td>
</tr>
<tr>
<td>Dunes and peridotites</td>
<td>1.413.400</td>
<td>4,68</td>
</tr>
<tr>
<td>Limestone</td>
<td>1.118.700</td>
<td>3,70</td>
</tr>
<tr>
<td>Calcitic phlysch and quartzites</td>
<td>7.836.500</td>
<td>25,93</td>
</tr>
<tr>
<td>Phylites</td>
<td>1.981.600</td>
<td>6,56</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>30.220.200</strong></td>
<td><strong>100,00</strong></td>
</tr>
</tbody>
</table>

2.2.4 Vegetation

The forest belongs to the Para Mediterranean vegetation zone “Quercetalia pubescentis” and more specifically to the alliance of “Ostryo carpinion”.

The species found in the peri-urban forest are pines: Pinus brutia (highest percentage), Pinus pinea and Pinus halepensis, cypresses (Cupressus sempervirens), oak trees (Quercus coccifera) and arizonas (Cupressus arizonica).

Along the streams mixed clusters are also found, with other species like poplars (Populus), willows (Salix), plane trees (Platanus) and others (Gatzogiannis et al., 1996). Table 2.4 shows the characteristics of the main species of the forest park.
Table 2.4: Characteristics of the main species of Seich Sou forest

<table>
<thead>
<tr>
<th>Species</th>
<th>General description</th>
<th>Biological requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinus pinea</td>
<td>Height: 15-25m. Crown: initially spherical form, later vaulted; like umbrella.</td>
<td>Requires sunlight, indifferent to the soil composition.</td>
</tr>
<tr>
<td>Cupressus sempervirens</td>
<td>Height: 20-30m. Crown: conical.</td>
<td>Develops in hot and dry climates with low requirements from ground and indifferent to its mineral constitution.</td>
</tr>
<tr>
<td>Quercus coccifera</td>
<td>Height: 10-15m, shrub form.</td>
<td>Requires sunlight, develops in hot climates with low soil requirements.</td>
</tr>
<tr>
<td>Cupressus arizonica</td>
<td>Height: 25-30m. Crown: wide conical and horizontal branches.</td>
<td>Low requirements, develops in hot climates. It can grow in shallow, rocky soils.</td>
</tr>
<tr>
<td>(foreign species)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Populus</td>
<td>Deciduous, fast growing, tall trees. The genus includes more than 100 species.</td>
<td>All species are mainly Requires sunlight and more or less moist soils. Some species can also grow in arid soils.</td>
</tr>
<tr>
<td>Salix</td>
<td>Deciduous shrubs or trees. The genus includes roughly 300 species.</td>
<td>They are mostly frugal and grow in cool, moist soils but some species develop in barren, dry soils as well.</td>
</tr>
<tr>
<td>Platanus</td>
<td>Deciduous trees with large leaves. It consists of 6-7 species.</td>
<td>Need deep, wet soils rich in nutrients.</td>
</tr>
</tbody>
</table>

Source: Athanasiadis, 1986
In majority, most clusters are loose and the grade of their canopy cover ranges between 36-44%. The closed clusters cover a very small area of the forest (only 6%), while the rest is covered by split clusters (Gatzogiannis et al., 1996).

✓ Loose clusters (loose grade of canopy cover): when trees have a certain distance so that there is not any interaction between them. However, the interstitial spaces are so small that not even one tree, with normal canopy, can interfere.

✓ Closed clusters, with condensate grade of canopy cover: the branches of one tree enter the crown of another tree, resulting in deformation of the crowns and acquiring an asymmetric form.

✓ Split clusters: when for the restoration of normal canopy the insertion of whole teams or thickets is required.

These are 3 of the grades of canopy grades that are distinguished in silviculture. In total there are 7 grades which are: closed grade of canopy cover, normal, luminous, loose, thin, gap and split. Canopy grade cover is the ratio of the sum of the projection from the trees crowns of a cluster to its overall surface (Dafis, 1989).

2.2.5 Wildlife
Seich Sou forest was declared a Permanent Shelter of Natural habitat that is a protected fauna area. So, although the forest is close to Thessaloniki and residents visit it, animal population increases and there is a big biodiversity. In particular, there are several micromammals like hares, foxes, ferrets, a large number of birds and reptiles and amphibians as well (Gatzogiannis et al., 1996).

2.3 Forest fires
In the last two centuries forest fires mainly occur in the southern and central Greece and along the coasts of the country. Peri-urban forest fires are a typical problem in Greece as more than 80% of the population lives in the Mediterranean climatic zone along the coastlines and in low altitudes so there are large anthropogenic impacts that change land usage, including increased building activities in forest areas, around city centers or large touristic value areas (Dimitrakopoulos, 2009).
2.3.1 Typical burning conditions

Forest fires represent one of the most important environmental hazards as they are the main component of the three largest global environmental problems: greenhouse effect, earth climate change and land desertification (Dimitrakopoulos, 2009).

All forest fires are not the same and they do not have the same properties. Although they have a common start basis, their spread varies.

Most of the fires take place in normal conditions, when air temperature is between 26-30°C and humidity between 41-70%. Any increase in temperature affects the size of the burnt areas but not the frequency of their start. On the other hand an increase in humidity leads to a decrease of the burnt areas size.

The biggest percentage of forest fires, almost 85%, has been observed during the official fire period, 1st May- 31st October. Generally, forest fires are distributed in the four seasons of the year as following: 50,25% in summer, 35,76% in autumn, 9,74% in spring and 4,25% in winter, with 51% of the all fires having been recorded during daytime, between 1200 and 1700 (Dimitrakopoulos, 2009).

The initiation of the fire requires oxygen, heat and depends on the burning material, while the spread of the fire depends on the burning material, the topography and the meteorological conditions.

2.3.2 Fire characteristics and classification

Fire variables are the measurable terms that characterize a fire. These variables are:

- Fire intensity: the amount of heat released per meter of burning front of the flame.
- Thermal flow: the amount of heat released per unit area in unit time.
  (fire intensity>thermal flow)
- Flame length: the distance from the top of the flames up to the middle of the burning zone of the fire.
- Flame height: the distance from the ground up to the highest point of the fire.
- Burning time: the time interval that the burning front of the fire remains above ground.
Firespread speed: the speed with which the fire is spread.

The formulas describing these variable characteristics can be found in Appendix 2.

Forest fires can be classified in 4 categories:

1. Ground fires or underground: the organic substance of soil or the humus is burnt.
2. Surface fires: the burning material on the ground is burnt.
3. Canopy fires: canopy leaves are burnt in the air.
4. Mixed fires: surface and canopy are burnt simultaneously

The most common is the surface fire, while the ground and underground fires are the rarest (Dimitrakopoulos 2009).

2.3.3 Fire management

Fire management is the most important procedure in order to control a fire. It includes all necessary measures and it is distinguished in 3 steps, prevention, pre-suppression and suppression and afterwards restoration of the burnt areas.

- Prevention is the sector involved in taking measures in order, either to avoid fires or for their timely extinction in case they eventually start.
- Pre-suppression includes all actions for the alertness of the suppression mechanism and the maintenance of firefighting means.
- Suppression concerns the treatment of fire after its initiation in the most efficient way and with the less possible implications.

2.4 Forest fires in Seich Sou

Fires in Seich Sou are common, as they occur almost annually. Some are large and destructive while others are small, insignificant with small ecological implications. In this thesis only the fire of 1997, which is the largest, will be examined.

The following tables show the fires in the forest for the past 35 years. Table 2.4 concerns the years from 1974 to 1997, when the fires were under the jurisdiction of the Forest Service. Table 2.5 shows the burned area from 2000 to 2009, when fires management passed to the Fire Department (Stergiadou, Eskioglou, 2012).
### Table 2.5: Fires of the peri-urban forest for the period 1974-1997

<table>
<thead>
<tr>
<th>Year</th>
<th>Fire Number</th>
<th>Burned area (m²)</th>
<th>Forest Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>4</td>
<td>2.300</td>
<td>Rough pine, Brushwood</td>
</tr>
<tr>
<td>1975</td>
<td>4</td>
<td>4.150</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1976</td>
<td>5</td>
<td>12.700</td>
<td>Rough pine, Cypress</td>
</tr>
<tr>
<td>1977</td>
<td>7</td>
<td>5.250</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1978</td>
<td>7</td>
<td>6.240</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1979</td>
<td>1</td>
<td>500</td>
<td>Rough pine, Cypress</td>
</tr>
<tr>
<td>1980</td>
<td>1</td>
<td>120.000</td>
<td>Rough pine, Cypress</td>
</tr>
<tr>
<td>1981</td>
<td>3</td>
<td>413.000</td>
<td>Rough pine, Cypress</td>
</tr>
<tr>
<td>1982</td>
<td>2</td>
<td>1.100</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1983</td>
<td>1</td>
<td>2.000</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1984</td>
<td>3</td>
<td>4.000</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1985</td>
<td>3</td>
<td>30.000</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1986</td>
<td>7</td>
<td>48.400</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1987</td>
<td>5</td>
<td>34.000</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1988</td>
<td>3</td>
<td>7.100</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1989</td>
<td>2</td>
<td>6.000</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1990</td>
<td>1</td>
<td>1.000</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1991</td>
<td>1</td>
<td>1.000</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1992</td>
<td>2</td>
<td>1.100</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1993</td>
<td>3</td>
<td>551.000</td>
<td>Rough pine</td>
</tr>
<tr>
<td>1994</td>
<td>4</td>
<td>7.000</td>
<td>Rough pine, Grassland</td>
</tr>
<tr>
<td>1997</td>
<td>17</td>
<td>16.980.000</td>
<td>Rough pine</td>
</tr>
<tr>
<td>Total</td>
<td>86</td>
<td>17.787.040</td>
<td>Rough pine, Cypress, Grassland plants</td>
</tr>
</tbody>
</table>

### Table 2.6: Fires of the peri-urban forest for the period 2000 - 2009

<table>
<thead>
<tr>
<th>Year</th>
<th>Burned area(m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1.400</td>
</tr>
<tr>
<td>2001</td>
<td>1.300</td>
</tr>
<tr>
<td>2002</td>
<td>300</td>
</tr>
<tr>
<td>2003</td>
<td>0</td>
</tr>
<tr>
<td>2004</td>
<td>0</td>
</tr>
<tr>
<td>2005</td>
<td>1.400</td>
</tr>
<tr>
<td>2006</td>
<td>6.000</td>
</tr>
<tr>
<td>2007</td>
<td>30.000</td>
</tr>
<tr>
<td>2008</td>
<td>6.000</td>
</tr>
<tr>
<td>2009</td>
<td>900</td>
</tr>
<tr>
<td>Total</td>
<td>47.300</td>
</tr>
</tbody>
</table>
2.5 The fire of 1997

The fire started, as it is recorded in the Fire Statement of the Forest Directorate of Thessaloniki (appendix 2), on 6/7/1997 at 16:00 o’clock. The first announcement was made at 16:10 from the patrol that was already on alert in the forest firefighting station “Lyomeno” in the forest park. It concerned the existence of smoke in the position “Firing Ground of Krioneri”. At 16:13 the first intervention took place. Afterwards, the airplanes on fire-patrol, noticed 2 fire outbreaks in the above mentioned point and one more to the west, in the chapel of “Agios Vasileios” in the woods.

Almost simultaneously with the fire in Seich Sou, at 16:30, fires also occurred in Oreokastro, Melissochori, Liti, Lagina and Filiro complicating the coordination of the firefighting operations. Therefore after 4 hours the county of Thessaloniki was declared in a state of emergency and the implementation of the “Xenocrates” project began. At midnight the situation was out of control and the front of the fire reached 30km.

The fire was burning for almost 3 days and finally, its extinction was completed on 9/7/1997 at 10:00 o’clock. For the extinction of the fire terrestrial, as well as, aerial means were used in a cooperation between the Forest Service (56 foresters and 39 forest firefighters), the Fire Department (42 firefighters), the Army (150 persons) as well as 31 individuals.

The fire was a canopy fire (3rd category) and in combination with the weather conditions, accelerated the evolution of the fire. The weather data, as they were recorded in the Fire Statement from the closest to the forest park meteorological station were:

- Wind speed: 7 Beaufort (=15m/s)
- Wind direction: undetermined
- Air temperature: 39°C
- Air humidity: 20% (Forest Inspection).

For the evaluation of the causes of the fire data were initially gathered. The natural environment of the forest (climate geomorphology relief and vegetation), management and protection methods, ownership, social factors, different activities taking place in the forest and data for the fire were taken into consideration.
The possible causes of the fire were thought to be:

- favorable conditions of vegetation (conifers domination with high degree of flammability) and with favorable climatic conditions (high temperature and strong winds led to the fast evolution of the fire),
- accumulation of garbage in different locations throughout the forest,
- possible negligence of the visitors,
- unresolved property issues in connection with the great value of plots close to the forest and the inability of the state to give solutions in these issues and (Forestry research institution, Gatzogiannis, 2001).

However, after the preliminary inquiry and the site investigation, the final decision of the Forest Service cites as the most possible cause of the fire, was *arson*.

In the 3 days, in total 12 fire outbreaks occurred and 16.980 acres (16,980,000 m²) were burnt, of which 15.431 acres (15,431,000 m²) were inside the forest park of Seich Sou while 1.549 acres (1,549,000 m²) were in the wider area (outside of the forest). From the burnt area 14.468 acres (14,468,000 m²) were public land and only 950 acres (950,000 m²) were non public. The burnt forest area was 15.418 acres (15,418,000 m²) and the burnt area corresponding to non forest area, agricultural land, was 1.562 acres (1,562,000 m²). The distribution of the species in the burnt forest area corresponds to: 14.476 acres (14,476,000 m²) Pinus brutia, 143 acres (143,000) Pinus pinea, 30 acres (30,000 m²) Cupressus sp. and 499 acres (499,000 m²) of oak trees (Forest Inspection).

As far as the consequences of the fire were concerned, 55% of the vegetation was burnt and the whole ecosystem was disrupted. As more than half of the forest was destroyed, degradation also occurred to the rest of the forest (flora and fauna), which was not burnt. The danger of erosion increased and the flood risk as well. Except for the ecological damage, the destruction of the forest had also implications on the residents of the surrounding area who lost the recreation services of the forest.

The distribution of the burnt area can be analyzed further, if classified in the 6 basins, as cited previously (paragraph 2.2.2). The distribution of the burnt area is shown in table 2.7.

\* Note: mixed clusters appear in the predominant kind
More than the half of the basins was burnt reaching the 64 %. In appendix 1, maps with the vegetation of the basins before and after fire are found.

**Table 2.7:** Distribution of the burnt areas in the basins of the peri-urban forest

<table>
<thead>
<tr>
<th>Basins</th>
<th>Total area (m²)</th>
<th>Non burnt area (m²)</th>
<th>Percentage (%)</th>
<th>Burnt area (m²)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>8.424.500</td>
<td>4.187.600</td>
<td>49,71</td>
<td>4.236.900</td>
<td>50,29</td>
</tr>
<tr>
<td>II.</td>
<td>5.750.900</td>
<td>1.264.100</td>
<td>21,95</td>
<td>4.493.800</td>
<td>78,05</td>
</tr>
<tr>
<td>III.</td>
<td>3.027.900</td>
<td>666.400</td>
<td>22,01</td>
<td>2.361.500</td>
<td>77,99</td>
</tr>
<tr>
<td>IV.</td>
<td>2.865.800</td>
<td>964.400</td>
<td>33,66</td>
<td>1.901.200</td>
<td>66,34</td>
</tr>
<tr>
<td>V.</td>
<td>3.090.700</td>
<td>829.500</td>
<td>26,84</td>
<td>2.261.200</td>
<td>73,16</td>
</tr>
<tr>
<td>VI.</td>
<td>2.931.000</td>
<td>1.545.900</td>
<td>52,74</td>
<td>1.385.400</td>
<td>47,26</td>
</tr>
<tr>
<td>Total</td>
<td>26.098.100</td>
<td>9.458.100</td>
<td>36,24</td>
<td>16.640.000</td>
<td>63,76</td>
</tr>
</tbody>
</table>

Source: Stefanidis, 2001
Chapter 3

Climate, pollution and vegetation

3.1 The impact of meteorological conditions on air pollution

The concentration of pollutants in the atmosphere is highly dependent on the meteorological conditions. The atmosphere acts like a medium which carries the discharged pollutants away from the sources and its condition defines the period of time, the frequency and the concentration of the exposure of any receptor (Wexler, 1961). Hence, the meteorological parameters influence the dispersion process of the air pollutants and govern whether the air pollutants will be dissolved in the atmosphere or they will reach the ground.

On the other hand the role of the atmosphere in the control or the elimination of pollution is limited as it cannot affect the strength of the emission source and as interventions, in the atmospheric processes that govern the dispersion of pollutants, are not possible (Wexler, 1961).

However, the impact of the meteorological conditions on the concentration of pollutants in the atmosphere is different for every region at a specific time period. The relief of the area and the urban plan affect the concentration or the dispersion of pollutants.

3.1.1 The city and its climate

The climate of the large urban centers has changed due to the intense activities, the population and the tall buildings. The so-called “urban heat islands” are characterized by high temperatures in the center of the city. In particular these big cities are less cold in winter and hotter in summer, and also the nights have higher temperature as well as the days than the rural areas. Furthermore, the plan of the city and the height of the buildings affect the air movement, which acquires an upward trend when in the surrounding area is covered by low buildings while in downtown tall buildings prevail (Kailidis, 1985).

3.1.2 Temperature inversion from radiation

During night, the ground reflects radiation back to the atmosphere and the air on the soil surface is cooled. However, at a height of 250 m above ground the temperature remains
high, creating 2 air mattresses; a cold in the ground level and a warmer to the upper layer. At noon, due to sun light, the air on the ground is heated again and the inversion phenomenon stops while in the afternoon ground air temperature rises even more (Manion, 1981). The pollutants emitted, during inversion, are concentrated in the atmosphere causing air pollution.

3.1.3 Relief inversion
As the wind from the sea, with high content of vapors, meets mountains rises higher and is cooled. Then the vapors are condensed and heat is given off, simultaneously heating the surrounding air and passes above mountains. During this inversion pollutants are emitted in cold air but as they are, also, cold they cannot pass through the air so they are scattered. From this photochemical reaction large quantities of O$_3$ are produced.

3.1.4 Valleys inversion
As mentioned previously, during night ground reflects back radiation cooling the air above it. The cold water is heavy and tends to move down. If the area around is higher, the cold air mass is trapped under the hot air layers, leading to pollutants concentration.

3.1.5 Inversion from anticyclones
This inversion is caused when an anticyclone or a high pressure point remain at a specific location for several days. But this phenomenon does not occur in Greece.

3.1.6 Frontal inversion
This inversion is similar to the inversion from anticyclones. Immobile air fronts may concentrate pollutants above the phytotoxic level, as well as the mobile air fronts. The electrical storms form ozone (Kailidis, 1985).

3.1.7 Inversion from turbulence
It is caused by air that moves in low altitudes in region with abnormal topographical configuration. This up down air movement creates a cold upper and a hot lower layer that cannot be mixed. This kind of inversion can transfer pollutants at long distances (Manion, 1981).
3.2 Impact of climatic conditions on plant physiology

It is known that the pollutants enter in the mesophyll of leaves through the stomata. Stoma is a pore, found in the leaf and stem epidermis, used for gaseous exchange. Air enters the plants through stomata and, carbon dioxide contained in air is used for photosynthesis while oxygen for respiration. Then the oxygen produced by photosynthesis exits the plants from the same openings. (Esau K., 1977). When air is polluted all pollutants contained enter the plants as well. That is the reason why every factor that keeps the stomata open favors the entrance of pollutants in the leaves. These factors are: light intensity, air humidity and soil humidity. The damage is higher at noon.

![Figure 3.1: Leaf structure-stomata](image)

3.3 Impact of pollutants on forest trees physiology

The effect of the air pollutants on plants differs depending on the season of the year (conifers, and especially deciduous are tolerant in winter), the topographical formulation (whether it favors pollutants concentration or not) and their distance from the pollution source (affecting the severity of the infection) (Kailidis, 1985). Generally, in industrial areas there is increased release of pollutants. It is considered that the combination of pollutants is more detrimental than each pollutant separately (Guderian, 1977).
The pollutants are distinguished in *local or indigenous*; produced in an area and pollute at a distance of a few or more kilometers, and *imported or foreign*; pollutants are transferred to long distances (more than 1000km) changing country.

The damage can be distinguished in *acute*, which is characterized by fast destruction of chlorophyll and it some occasions it may lead to drying of the tree and in *chronic*, which is characterized by growth reduction and subsequently to secondary attack by insects. In chronic pollutions, frequently there are no signs or visible damage to plants. This is the so-called *sleeping damage* (Kailidis, 1985).

Air pollution causes disturbances in the ecosystem, such as alteration of vegetation structure and composition, reduction of biomass and productivity and changes in biodiversity (Kozlowski and Constantinidou, 1986 No1). Moreover, air pollution, apart from reduction in productivity, causes growth reduction resulting in death of trees (Smith, 1981, Schutt and Cowling, 1985). Effects of pollutants have also been observed on the physiological and metabolic activities, like composition of chlorophyll, in photosynthesis, transpiration, respiration and enzymatic activity (Kozlowski and Constantinidou, 1986 No1).

The following sections present the harmful effect of each pollutant separately on the forest vegetation and in specific species.

### 3.3.1 Sulfur dioxide- SO$_2$

SO$_2$ in content 0,5 ppm provokes acute damages while in content 0,1-0,03 ppm, under favorable conditions, in sensitive plants, causes chronic damages (Smith 1970). According to other researchers, (Ranet. Dassler, 1972) susceptible plants are damaged in contents 0,5-1,2 ppm while tolerant plants in even higher concentrations. *

It has been observed that sulfur dioxide affects germinants photosynthesis. The proportion of the impact depends on the pollutants concentration and the duration of exposure (Smith 1970).

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*Note: in order to convert ppm into $\mu$g/m$^3$, the molecular weight (in 25$^\circ$C and 1 bar pressure) of each gas should be known.*

1 ppm = (24,45 * 1 mg/m$^3$) / MW

1 mg/m$^3$ = 1000 $\mu$g/m$^3$. 
The symptoms of infestation from SO$_2$ in monocotyledons appear as light-colored spots in the edges of the leaves or as kurtosis of the leaves. In dicotyledons, in acute conditions, necrosis in the edge of the leaves or in the nerves is caused (Smith 1970). In broadleaves, peripheral necrosis, as well as necrosis in the area among the nerves is observed and spots or even shrinkage of the leaves, while in conifers the necrosis is at strips or at the edges of the needles as well as chlorosis of tissues (Brandt, Heck 1967, Linzon 1965).

Indicatively are mentioned some forest species classified according to their tolerance (Cormis, Bossary et al., 1972):

- Too sensitive: Cedrus atlantica (cedar), Pinus strobilus (pines), Sequoia sempervirens (sequoia).
- Sensitive: Picea excelsa, Pinus pinaster, Pinus sylvestris, plane trees, Populus robusta, pseudoacacia, Larix leptolepis etc.
- Tolerant: Acer campestre, Betula verrucosa, Cupressus arizonica, Fagus sylvatica, Quercus penduculata etc.

SO$_2$ in the atmosphere is oxidized in SO$_3$ which dissolved in raindrops, contributes to the formation of acid rain, which is also harmful for the forests (sub-session 3.3.6).

### 3.3.2 Nitrogen dioxide - NO$_2$

Nitrogen dioxide (and the NO) is the most harmful, of all nitrogen oxides, on plants. It constitutes the main cause of the photochemical reactions of pollution type Los Angeles and Athens (Petrakis 1982). The concentration of NO$_2$ ranges between 1-8 μg/m$^3$. It is responsible for the brown color of the photochemical smog. In large urban centers NO$_2$ can remain in the atmosphere for 3-4 days. NO$_2$ in the atmosphere, when it does not participate in smog formation, is oxidized in NO$_3$, also responsible for acid rain (Petrakis, 1982).

Nitrogen oxides in high concentrations provoke in plants brown to black-brown necroses around the leaf, as well as spots. In concentrations between 2-10 ppm NO$_2$ creates spots similar to those of SO$_2$ (Brandt, Heck, 1967).
In conifers the symptoms, initially, appear as white rings near the base of the needles. In more serious the whole needle area is whitened leading to progressive necrosis. In some occasions the necrosis may be rapid starting from the older needles, from the top to the base (Oikonomou, 1989). In broadleaves, at the beginning, discoloration is caused mainly close to the leaf margin followed by intense discoloration and necrosis in the form of irregular spots (Oikonomou, 1989).

3.3.3 Ozone - $O_3$

Ozone is contained in smog. The largest quantity of ozone is at a height of 25-30km, mainly in areas with high solar radiation intensity; in small latitudes (Zerefos, 1984). More specifically, the optimal conditions that favor the formation of ozone are the dry and hot climates and the densely populated cities (Gusten et al., 1988).

Ozone is a threat for plants productivity and ecosystems health, as well as for their stability (Laurence 1998). The symptoms from the damage of $O_3$ appear in the upper surface of the leaves which become silver, they present chlorosis, dark or bright spots and necrotic spots. It has been observed that species with slim leaves are more sensitive, and in general the higher the photosynthesis the higher the damages and also that evergreen species are more tolerant than deciduous (Kadota, 1972). Almost the same applies for the conifers; the species with thicker skin are tolerant than those with thin skinned needles (Evans, Miller, 1972).
The damage from O$_3$ may be immediate; leading to cell death in few hours or days after the first exposure expressed by spots, whitening or necrosis, or chronic; in the form of chlorosis, stigmatization, premature aging and finally, necrosis after long-term exposure of the plant to ozone (Dizengremel, 2001, Reich and Arnundson, 1985, Karnosky et al., 2006).

Kailidis (1985) supports that ozone in Greek mountains is found in large quantities as in beech leaves and old needles of forest pine white spots have, many times, been observed.

### 3.3.4 Carbon oxide- CO

Carbon monoxide provokes damages to plants in concentrations higher than 1000 ppm. In busy streets the concentration of CO is at about 200-500 ppm (Smith, 1970). The damages from this pollutant appear as elongation of plant parts, yellowing and fall of leaves and expansion of side leaves.

### 3.3.5 Particulate matter- PM$_{10}$

PM$_{10}$ damage the plant physiology. This damage is associated with the chemical composition of the matter. Some toxic matters and heavy metals are responsible for the death of different forest species. They may lead in light absorption reduction by chloroplasts inhibiting photosynthesis and closure of stomata interrupting the exchange of gases with the air. Disturbances also appear in blooming and insemination of the plant. Furthermore, indirect effects caused by the infection from particle matter have been cited. These are attacks by pathogenic microorganisms and change of the genetic composition of the trees (Beckett et al., 1998).

The impact of one specific pollutant has been detected, experimentally, and it is well known. However, in industrial areas there is release of more pollutants. The connection of several pollutants is considered to be more dangerous than their implications separately (Guderian, 1977). Hence, the impact of the polluted air on forests is complicated and difficult to define.

The damage of combined pollutants depends on: a. relative concentration of

a. pollutant compared to the concentration at which lesions begin,

b. the concentration ratio of one pollutant to the others and
c. from the implementation period of the combined pollutants; continuously or interminently (Kozlowski and Constantinidou, 1986 No2).

Combined air pollutants can act in synergy (Carlson 1979), additively (Tingey and Reinert, 1975) or competitively (Costonis, 1973). As an example, could be mentioned the similarity between the impact of SO₂ and NO₂, combined to the impact of O₃ or O₃ combined to SO₂ (Kozlowski and Constantinidou, 1986 No2).

3.3.6 Acid rain

Although it is not an air pollutant it is important to mention the impact of the acid rain on the forest species and the environment as it constitutes one of the most severe environmental problems.

As mentioned previously, acid rain consists mainly from sulfur and nitrogen oxides. In fact it is the consequence of the transformation of these oxides into SO₃ and NO₃, respectively, which fall in the ground as precipitations (rain, snow, fog).

Acid rain is the rain with pH<5,6 as theoretically the pH of the rain ranges between 5,6-6 due to the influence of the carbonic acid with the CO₂ of the atmosphere (Kailidis, 1985).

In Greece the rains from 1977-1980 had pH>5,65 so they were considered to be alkaline but from 1980 had already started to be acidic pH 4,3-4,7, starting from Thessaloniki (Mourkidis and partners, 1981).

The impact of the acid rain on forests varies, depending on the region and the acidity of the rain, from minimum up to severely hazardous. In general, acid rain causes trees growth reduction since it damages the stomata of leaves, defoliation leading to reduced vitality up to necrosis. In addition, pollution reduces the increase of the annual rings and indirectly, because of the soil acidification, wash off of nutrients from ground is caused (Athari, Kramer, 1983). The lost nutrients from ground lead to deceleration or even inhibition of growth. Hence, the damage from acid rain is divided in 2 ways: through roots and through leaves. The damage through leaves includes destroy of canopy, reduced production or/and dilution of canopy, death of canopy and complete necrosis of the tree (Vardaka, 2006).
So summarizing, the acid rain causes soil acidification, decelerates the decomposition of the organic matter, changes the organic synthesis of soil by

a. washing off the nutrients (like calcium, potassium, magnesium) and

b. mobilizes the ions of heavy, poisonous metals (lead, mercury) and damages the plants rootlets (Vardaka, 2006). Table 3.1 presents the effect of different proportions of pollutants on plants.
<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Symptoms</th>
<th>Doses of pollutants and effect time</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td>Angiosperms: necrosis among nerves. Gymnosperms: red-brown necrosis at the needles edges or necrotic strips.</td>
<td>0,7 ppm (=1820 μg/m³ air) for 1 hour, 0,18 ppm (=468 μg/m³) for 8 hours, 0,008-0,017 ppm (=21-44 μg/m³) for vegetation period.</td>
</tr>
<tr>
<td>NO₂</td>
<td>Angiosperms: necrotic spots among nerves (similar to previous). Gymnosperms: red-brown necrosis at the edges.</td>
<td>20 ppm (=38*10³ μg/m³) for 1 hour, 1,6-2,6 ppm (=3000-5000 μg/m³) for 48 hours, 1 ppm (=1900 μg/m³) for 100 hours.</td>
</tr>
<tr>
<td>O₃</td>
<td>Angiosperms: spots in the upper surface of the leaves. Gymnosperms: spots at the edges of the needles, small needles.</td>
<td>0,2-0,3 ppm (=392-588 μg/m³) for 24 hours, in some conifers 0,8 ppm (=157 μg/m³) for 12-13 hours.</td>
</tr>
<tr>
<td>Acid rain</td>
<td>Angiosperms: necrotic spots. Gymnosperms: necrosis at the edges of the needles.</td>
<td>pH&lt;3</td>
</tr>
</tbody>
</table>

Source: Smith 1981
Chapter 4

Pollution

4.1 The nature of the problem

Air pollution is a consequence of unexpected increased emissions and, when combined with the occurrence of bad meteorological conditions, creates a difficult situation, called Smog (Organization of Planning and Environmental protection of Thessaloniki).

The main source of pollution is anthropogenic activities. As population and industrial activities increase anthropogenic emissions increase as well. As these emissions increase, the balance of the atmospheric environment is disturbed. The existing balances of the atmospheric environment are, initially, affected on a small scale but then they extend in a global scale. Typical examples of this worldwide downgrade are the Greenhouse effect and the Ozone hole.

Intense sunlight and high temperatures, which characterize the climate of Greece, favor the development of photochemical reactions that worsen the conditions.

4.2 The problem in Thessaloniki

The city of Thessaloniki is among the most polluted cities in Europe. Its significant air pollution problem is associated with the emissions from various sources, the climatic conditions and the topography of the area.

4.2.1 Description of the region

The climate of Thessaloniki is Mediterranean with cold, wet winters and hot, dry summers. Nevertheless, in winter mild and sunny days are also observed.

The average annual temperature ranges at 16°C, with the mean lower temperature in 5,5°C and the mean higher temperature is roughly 26°C. The coldest month is January and the hottest is July. The annual precipitation is roughly 500mm while snow is common in winter
but it is thin and melts in few hours; it usually snows from December to March. The winds vary seasonally; in winter the northern winds dominate while in spring the southern, in summer the northern and southwest and from November the northern and western start dominating again (Greek-weather.org).

Thessaloniki (metropolitan area) is a populous city with tall buildings and narrow streets. Its population has exceeded 1.000.000 residents, according to the 2001 census. The density of the population in the city combined with the road traffic (more than 400.000 vehicles), which keeps increasing, has led to an increase of air pollutants. The existence of high buildings and narrow streets and the rare open spaces in the city in conjunction with the density of the city and the climatic conditions that dominate favor the concentration of pollutants in the atmosphere; so the living conditions become more uncomfortable.

The concentration of pollutants is greater in the center of the city than in the eastern and western regions and often certain pollutants exceed the limit value of pollution. Ozone is an exception to that as it presents the highest prices in the peri-urban area rather than in the center (Organization of Planning and Environmental protection of Thessaloniki).

Seasonally, in winter the concentration of pollutants is higher while in summer there is a significant decrease. This is a consequence of the combination of human activities and climatic conditions. In winter the activities are more and the climate favors the pollutants concentration while in summer the activities are reduced and ventilation conditions are enhanced.

Daily, the highest concentration is observed in morning hours (7\textsuperscript{00}-11\textsuperscript{00}) and late in the evening (19\textsuperscript{00}-23\textsuperscript{00}), particularly during working hours.

4.2.2 Pollution monitoring stations
The data for the pollution that will be used in the present thesis comes from the nearest to the peri-urban forest monitoring stations. These stations are in, Eptapirgio, and Ano Toumpa and they belong to the network of the Municipality of Thessaloniki.

Comparatively, some data from the station of Egnatia-Venizelou in the center of Thessaloniki, will also be used in order to point the difference with the outskirts of the city.
Table 4.1 presents the characteristics of each station and the monitoring pollutants. Figure 4.1 pictures the spatial distribution of the 3 stations in Thessaloniki.

- **Station of Eptapirgio**

This station started operating in 1992. It is situated on the limits of the municipality of Thessaloniki and of Neapolis-Sykies, at the intersection of the street Agrafon and Agias Anastasias in Ano Poli. More specifically, it is on the crest of a hill inside the walls of the historical city.

- **Station of Ano Toumpa**

Ano Poli station started operating in 1995. Its location is on the limits of the municipality of Thessaloniki and of Pylaia-Xortiatis, at the junction of the streets of Labraki and Perevou.

- **Station of Egnatia**

Egnatia station started operating in 1989. It is located in the old city hall, in the center of the city, at the junction of Egnatia and Venizelou streets (Municipality of Thessaloniki).

<table>
<thead>
<tr>
<th>Monitoring Station</th>
<th>Eptapirgio</th>
<th>Ano Toumpa</th>
<th>Egnatia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of operation (year)</td>
<td>1992</td>
<td>1995</td>
<td>1989</td>
</tr>
<tr>
<td>Longitude</td>
<td>22 57’ 41” E</td>
<td>22 56’ 08” E</td>
<td>22 56’30’ E</td>
</tr>
<tr>
<td>Latitude</td>
<td>40 38’ 41” N</td>
<td>40 36’ 39” N</td>
<td>40 38’ 15” N</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td>203</td>
<td>76</td>
<td>12</td>
</tr>
<tr>
<td>O₃</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>SO₂</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>CO</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>NOₓ</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Source: Municipality of Thessaloniki, Environmental Department
4.2.3 The pollutants: description, sources and impact

**Ozone** (O$_3$)

Ozone is a secondary pollutant. It is a colorless with specific smell gas, heavier than air. It is unstable, soluble in water and easily degradable. O$_3$ is formed as a result of the chemical reaction between oxygen and volatile substances (VOCs) and nitrogen oxides (NO$_x$) under sun radiation. The emission sources of the precursor substances responsible for the ozone formation are vehicles, factories, chemical solvents and fuel stations.

Ozone, in high concentrations, is harmful to human health. Prolonged and repeated exposure can cause respiratory problems (asthma). In addition, ozone has a negative impact on the natural environment, having as an effect the reduction of agricultural cultivation and inhibition of forest vegetation.
Higher concentrations of ozone have been observed in the peri-urban area of Thessaloniki rather than in the center of the city. This makes sense taking under consideration its physicochemical attitude.

According to the Directive 1992/72/EEC the maximum daily eight-hour value is 110 μg/ m³ and it should not be exceeded for more than 25 times per year, while for the protection of the vegetation the limit is 200 μg/ m³ on an hourly basis and 65 μg/ m³ on a day basis (Petrakakis, et al, 2005).

**Sulfur dioxide (SO₂)**

Sulfur dioxide is a colorless gas, with a characteristic odor. When it comes in contact with the atmosphere’s humidity it becomes unstable H₂SO₃. Sulfur dioxide results from the combustion of sulfur which exists in solid and liquid fuels (coal, diesel). The main sources of SO₂, in urban areas are power plants, oil and ore refineries, house heating systems and diesel cars.

SO₂ is dangerous for people’s health. Long term exposure causes cardiovascular problems. In high concentration it damages vegetation and causes corrosion. SO₂ are the main components of acid rain contributing to lakes and rivers acidification. Seasonally, the highest concentrations of sulfur dioxide are observed in winter.

According to the Directive 1999/30/EC the limit value of sulfur dioxide is (Petrakakis, et al, 2005):

- 350 μg/ m³ on 1 hour time basis and it should not be exceeded more than 24 times per calendar year.
- 125 μg/ m³ on a daily basis and it should not be exceeded more than 3 times per calendar year.
- Hourly limit value for the protection of the ecosystems: 20 μg/ m³ for the winter (1 October- 31 March).

**Carbon monoxide (CO)**

It is the most widespread pollutant. Carbon monoxide is colorless, odorless and slightly soluble in water gas.
Most of the emissions come from the incomplete combustion of coal and hydrocarbons in general. The main emission source of CO in the atmosphere is the transportation sector. Peak concentrations occur at street level in busy urban centers, in closed spaces like parking spaces and in poorly ventilated subways.

Carbon oxide affects mostly the cardiovascular and nervous system. The maximum daily limit value of CO, according to the Directive 2006/69/EC, is 10 μg/ m³ for 8 hours rolling rate.

**Nitrogen dioxide (NO₂)**

Nitrogen dioxide is a gas with brown-yellow color and caustic odor. It is considered as a secondary pollutant as it is produced by the reaction of NO with oxygen. NO₂ is a pollutant while NO is thought to be a precursor association of nitrogen dioxide (Petraakis, et al, 2008). Burning of fossil fuels in power stations, vehicles and domestic central heating produces NO which in the atmosphere it is oxidized in NO₂. NO₂ may also lead to formation of HNO₃ which causes acid rain.

Human exposure to high concentration of NO₂ can cause respiratory problems. Also very important are the implications on the vegetation, especially because of the acid rain. Also in the atmosphere, under the influence of solar radiation NO₂ plays an important role in the formation of photochemical smog.

The limit value of NO₂, according to the Directive 1999/30/EC is 200 μg/ m³ on an hour time basis. This value should not be exceeded more than 18 times per year. The hourly limit value for the protection of the ecosystems is 30 μg/ m³ per calendar year (Petraakis, et al, 2005).

**Particulate matter (PM₁₀)**

Particulate matter is defined as small parts of matter in solid or liquid phase that can be airborne for a long period of time. They differ in shape, size and chemical composition depending on the emission sources. They are mainly emitted from combustion sources like automobile (car exhaust) and power plants, quarry and cement industries and house heating. Characteristic examples of particle matter are dust, smoke and fly ash. Particulate matter is classified in 2 categories: PM₁₀ and PM₂,₅. PM₁₀ refers to particulate matter with a diameter of 0,1-10μm.
They cause serious damage to human health, like all the above pollutants, harming the respiratory system, lungs and heart. The limit value of PM$_{10}$ is 50 μg/m$^3$ and should not be exceeded for more than 35 times per year, Directive 1999/30/EC (Petrakakis, et al, 2005).

4.2.4 Temporal evolution in average values of pollutants

In order to assess the evolution of the pollutants, data for the concentration of the pollutants in the above mentioned monitoring stations, around the forest, is used. This data covers a period of 10 years (1992-2002), 5 years before and after the fire of 1997.

The results came after processing the daily concentrations of pollutants, as gathered from the Department of Environment of the Municipality of Thessaloniki, and the graphs are based on these results.

Figures 4.2-4.6 illustrate the trend of each pollutant for the 3 stations under investigation. Their values are pictured in tables 4.2-4.6 and figures 4.7-4.9 show for each station all pollutants in aggregative for the time period before and after the forest fire.

Table 4.2: SO$_2$ concentration (μg/m$^3$)

<table>
<thead>
<tr>
<th>Date</th>
<th>Egnatia (μg/m$^3$)</th>
<th>Eptapirgio (μg/m$^3$)</th>
<th>Toumpa (μg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>69,31</td>
<td>8,06</td>
<td>-</td>
</tr>
<tr>
<td>1993</td>
<td>56,11</td>
<td>9,40</td>
<td>-</td>
</tr>
<tr>
<td>1994</td>
<td>51,42</td>
<td>8,96</td>
<td>-</td>
</tr>
<tr>
<td>1995</td>
<td>42,68</td>
<td>15,56</td>
<td>16,05</td>
</tr>
<tr>
<td>1996</td>
<td>38,62</td>
<td>15,36</td>
<td>16,56</td>
</tr>
<tr>
<td>1997</td>
<td>34,09</td>
<td>13,36</td>
<td>18,34</td>
</tr>
<tr>
<td>1998</td>
<td>22,14</td>
<td>11,72</td>
<td>11,72</td>
</tr>
<tr>
<td>1999</td>
<td>20,85</td>
<td>15,12</td>
<td>14,62</td>
</tr>
<tr>
<td>2000</td>
<td>25,17</td>
<td>17,25</td>
<td>13,34</td>
</tr>
<tr>
<td>2001</td>
<td>34,61</td>
<td>18,52</td>
<td>15,58</td>
</tr>
<tr>
<td>2002</td>
<td>23,76</td>
<td>19,14</td>
<td>13,52</td>
</tr>
</tbody>
</table>
As observed from figure 4.2, the most aggravated area, in SO$_2$, is the center of the city unlike the Eptapirgio which displays the smallest concentrations. However, in Egnatia station, as well as in Toumpa, there is a decreasing trend in the concentration of the pollutant while in Eptapirgio a rise in its rate is observed. The decrease is due to improvement of fuel quality, the use of natural gas in house heating, improvement of public means of transportation and relocation of industry at the outskirts of Thessaloniki, in the industrial area. The slight increase concerns the expansion of the city in the surrounding area and the traffic increase on the ring road. During the studied decade the limit value of sulfur dioxide, as set by the EU, has not been exceeded.
As shown in the figure there is a downward trend for PM$_{10}$ in all 3 stations examined but their concentration still remains higher than the set limit value. In fact, this decrease, although small, is very important when taking under consideration the increase in urban activities, of vehicles and the tendency of residents to move to the outskirts. The infringement of the set limit is more intense in the center (Egnatia) due to the traffic.
problem, the dense structure of the city and bad ventilation. In Eptapirgio the condition seems improved as it is located at a higher altitude and it is not affected by the intense relief of the city. The decreasing trend becomes more evident from the 1999 with the fuel change, the car withdrawal and the decongestion of the city (operation of the ring road).

<table>
<thead>
<tr>
<th>Date</th>
<th>Egnatia (μg/m^3)</th>
<th>Eptapirgio (μg/m^3)</th>
<th>Toumpa (μg/m^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>4,05</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1993</td>
<td>3,98</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1994</td>
<td>4,48</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1995</td>
<td>4,21</td>
<td>-</td>
<td>1,56</td>
</tr>
<tr>
<td>1996</td>
<td>3,51</td>
<td>-</td>
<td>1,47</td>
</tr>
<tr>
<td>1997</td>
<td>2,99</td>
<td>-</td>
<td>0,98</td>
</tr>
<tr>
<td>1998</td>
<td>2,34</td>
<td>-</td>
<td>0,91</td>
</tr>
<tr>
<td>1999</td>
<td>1,77</td>
<td>-</td>
<td>0,66</td>
</tr>
<tr>
<td>2000</td>
<td>1,99</td>
<td>-</td>
<td>1,23</td>
</tr>
<tr>
<td>2001</td>
<td>1,85</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2002</td>
<td>1,82</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4.4: CO concentration (μg/m^3)

![Figure 4.4](image1.png)

Figure 4.4: CO concentration (μg/m^3)
Carbon monoxide has a decreasing trend from the 1999. During the decade of 90’s the center of Thessaloniki had very high percentages in CO but after the substitution with catalytic cars the concentration started falling gradually, due to the efficient conversion of CO in CO₂. The fact that the highest concentration is observed in Egnatia indicates the existence of the “urban canyon” phenomenon; accumulation of pollutants at low street level, at relatively narrow streets with big traffic and tall buildings (Petrakakis, et al, 2008).

<table>
<thead>
<tr>
<th>Year</th>
<th>Egnatia (μg/m³)</th>
<th>Eptapirgio (μg/m³)</th>
<th>Toumpa (μg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>90,16</td>
<td>10,12</td>
<td>-</td>
</tr>
<tr>
<td>1993</td>
<td>91,17</td>
<td>12,76</td>
<td>-</td>
</tr>
<tr>
<td>1994</td>
<td>90,19</td>
<td>7,13</td>
<td>-</td>
</tr>
<tr>
<td>1995</td>
<td>90,12</td>
<td>16,22</td>
<td>34,12</td>
</tr>
<tr>
<td>1996</td>
<td>87,51</td>
<td>16,09</td>
<td>40,11</td>
</tr>
<tr>
<td>1997</td>
<td>93,66</td>
<td>16,02</td>
<td>35,37</td>
</tr>
<tr>
<td>1998</td>
<td>83,16</td>
<td>34,98</td>
<td>41,87</td>
</tr>
<tr>
<td>1999</td>
<td>81,12</td>
<td>36,08</td>
<td>37,85</td>
</tr>
<tr>
<td>2000</td>
<td>82,01</td>
<td>34,11</td>
<td>41,72</td>
</tr>
<tr>
<td>2001</td>
<td>81,98</td>
<td>31,17</td>
<td>37,70</td>
</tr>
<tr>
<td>2002</td>
<td>72,11</td>
<td>34,63</td>
<td>41,65</td>
</tr>
</tbody>
</table>

**Table 4.5: NO₂ concentration (μg/m³)**

**Figure 4.5: NO₂ concentration (μg/m³)**
The concentration of nitrogen dioxide is stable with not any abrupt change in the decade. There is a slight downward trend in Egnatia station in contrast to the Eptapirgio station where the concentration of NO₂ is low appearing a constant increase. This increase is caused by the reconstruction at the area and the overload of the ring road. Indicative to mention that, according to the census of 2001, from 1991 until today the population of the municipality of Eptapirgio has showed an increase of 22.5%, over the previous census, while the corresponding increase of the country was 7% in average (Petrakakis, et al, 2002).

<table>
<thead>
<tr>
<th>Date</th>
<th>Egnatia (μg/m³)</th>
<th>Eptapirgio (μg/m³)</th>
<th>Toumpa (μg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>-</td>
<td>28.71</td>
<td>-</td>
</tr>
<tr>
<td>1993</td>
<td>-</td>
<td>28.86</td>
<td>-</td>
</tr>
<tr>
<td>1994</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1995</td>
<td>45.67</td>
<td>21.81</td>
<td>38.34</td>
</tr>
<tr>
<td>1996</td>
<td>44.42</td>
<td>51.29</td>
<td>33.75</td>
</tr>
<tr>
<td>1997</td>
<td>43.11</td>
<td>45.31</td>
<td>32.92</td>
</tr>
<tr>
<td>1998</td>
<td>41.14</td>
<td>46.45</td>
<td>43.25</td>
</tr>
<tr>
<td>1999</td>
<td>32.34</td>
<td>53.78</td>
<td>50.28</td>
</tr>
<tr>
<td>2000</td>
<td>40.24</td>
<td>50.38</td>
<td>50.81</td>
</tr>
<tr>
<td>2001</td>
<td>45.45</td>
<td>48.51</td>
<td>50.46</td>
</tr>
<tr>
<td>2002</td>
<td>32.71</td>
<td>50.20</td>
<td>50.62</td>
</tr>
</tbody>
</table>
During the 1992-2002 decade there was not a substantial change in the concentration of ozone. Although there is stability, the values in Eptapirgio and Toumpa are high with a tendency to surpass the set limit value. Egnatia station has the lower concentration in O\textsubscript{3} and with a downward trend while the regional stations have the highest concentrations. More specifically, Eptapirgio shows the greatest upward trend while the highest prices and the greatest number of exceedances appear in Toumpa station.

**Figure 4.7**: Egnatia, all pollutants concentration (\(\mu g/m^3\))

**Figure 4.8**: Eptapirgio, all pollutants concentration (\(\mu g/m^3\))
As it can be observed in the aggregative diagrams the regional stations (Toumpa- Eptapirgio) have higher concentration of ozone while the station of Egnatia has higher concentration of NO₂.

For a better understanding of the implication that the fire had on the atmosphere, atmospheric data for several months before and after the fire were examined separately. Figures 4.10-4.14 present the trend of each pollutant for all stations 3 months before and after the fire (from April up to October). However, the impact of the fire on the concentration of pollutants is not accurately represented due to lack of measurements for the specific dates. Especially, for the 3 days of the fire there are no data at all.
Figure 4.11: The trend of PM$_{10}$ from April to May of 1997

Figure 4.12: The trend of CO from April to May of 1997

Figure 4.13: The trend of NO$_2$ from April to May of 1997
Figures 4.15-4.28 present the evolution of the concentration of each pollutant in the three stations 2 years before and after the fire (1995-1999). This approach is important in order to assess the implication, if there is any, of the forest destruction on the concentrations. *

* Note: there are missing observations for specific dates.
Figure 4.16: The concentration of PM10 in Egnatia station (1995-1999)

Figure 4.17: The concentration of CO in Egnatia station (1995-1999)

Figure 4.18: The concentration of NO$_2$ in Egnatia station (1995-1999)
Figure 4.19: The concentration of $O_3$ in Egmatia station (1995-1999)

Figure 4.20: The concentration of $SO_2$ in Eptapirgio station (1995-1999)

Figure 4.21: The concentration of $PM_{10}$ in Eptapirgio station (1995-1999)
Figure 4.22: The concentration of NO$_2$ in Eptapirgio station (1995-1999)

Figure 4.23: The concentration of O$_3$ in Eptapirgio station (1995-1999)

Figure 4.24: The concentration of SO$_2$ in Toumpa station (1995-1999)
Figure 4.25: The concentration of PM$_{10}$ in Toumpa station (1995-1999)

Figure 4.26: The concentration of CO in Toumpa station (1995-1999)

Figure 4.27: The concentration of NO$_2$ in Toumpa station (1995-1999)
4.3 Results

As it is indicated by the figures, air pollutants in the atmosphere of Thessaloniki display a declining trend, with a stabilization tendency for some of them. Nevertheless, ozone is characterized by volatility rather than tendency for stabilization.

This observation, at the monitoring stations around the forest (Eptapirgio, Toumpa) leads to the conclusion that the degradation of the forest has not affected the concentration of the so-called “urban pollutants” (SO₂, PM₁₀, NO₂, CO) which are directly linked to the urban activities but has affected the concentration of ozone (“peri-urban pollutant”) for which the impact of the forest is more intense. Taking into consideration the average values for 2 years before and after the forest fire (shown in Table 4.7), this conclusion is reaffirmed.

Table 4.7: Average values of pollutants 2 years before and after the forest fire

<table>
<thead>
<tr>
<th>(μg/m³)</th>
<th>Toumpa</th>
<th>Eptapirgio</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td>16,3</td>
<td>13,6</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>43,7</td>
<td>58,6</td>
</tr>
<tr>
<td>CO</td>
<td>1,5</td>
<td>0,8</td>
</tr>
<tr>
<td>NO₂</td>
<td>37,0</td>
<td>39,8</td>
</tr>
<tr>
<td>O₃</td>
<td>35,9</td>
<td>47,0</td>
</tr>
</tbody>
</table>
Air pollution is highly affected by the meteorological factors; wind direction and intensity, solar radiation intensity, sunshine duration, precipitation, relative humidity and temperature (Region of Central Macedonia). For this reason the climatic data for several years before and after the fire incident were also taken into consideration. Table 4.8 pictures the direction of wind for these years and Table 4.10 shows the air temperature for the same period.

Table 4.8: Wind direction 2 years before and after the forest fire

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>N, SSW, SE</td>
<td>SW, NE, SE</td>
<td>NE, SW</td>
<td>SW, NE</td>
<td>SW, NE</td>
</tr>
<tr>
<td>February</td>
<td>SW, E</td>
<td>NE, SE, SW</td>
<td>NE, SW</td>
<td>SW, NE</td>
<td>NE, SW</td>
</tr>
<tr>
<td>March</td>
<td>N, E</td>
<td>SW, NE, SE</td>
<td>NE, NW</td>
<td>NE, SW</td>
<td>SW, NE</td>
</tr>
<tr>
<td>April</td>
<td>SW, N</td>
<td>SW, SE</td>
<td>SW, NW</td>
<td>SW, SE</td>
<td>SW, NW</td>
</tr>
<tr>
<td>May</td>
<td>SW, N</td>
<td>SW, SE</td>
<td>SW, NW</td>
<td>SW, NW</td>
<td>SW, SE</td>
</tr>
<tr>
<td>June</td>
<td>SSW, SW</td>
<td>SW, NW</td>
<td>SW, NW</td>
<td>SW, NW</td>
<td>SW, NW</td>
</tr>
<tr>
<td>August</td>
<td>N, SSW, SE</td>
<td>SW, NE</td>
<td>SW, NW</td>
<td>SW, SE</td>
<td>SW, SE</td>
</tr>
<tr>
<td>September</td>
<td>SW, SSW, N</td>
<td>NE,SW</td>
<td>SW, SE</td>
<td>NE,SE</td>
<td>NW,SW</td>
</tr>
<tr>
<td>October</td>
<td>SW, N, ESE</td>
<td>NE, SW</td>
<td>N, NE</td>
<td>SW,NE</td>
<td>SW,SW</td>
</tr>
<tr>
<td>November</td>
<td>N, SSW</td>
<td>SW, SE</td>
<td>SW, NE, SE</td>
<td>SE,NE</td>
<td>NE,SE</td>
</tr>
<tr>
<td>December</td>
<td>N, SSW</td>
<td>SW, NE</td>
<td>SW, NE</td>
<td>NE,SE,SW</td>
<td>SW,NE</td>
</tr>
</tbody>
</table>

Table 4.9: Wind speed and direction 3 months before and after the fire

<table>
<thead>
<tr>
<th>Month</th>
<th>Speed</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>8,8</td>
<td>SW, NW</td>
</tr>
<tr>
<td>May</td>
<td>7,1</td>
<td>SW</td>
</tr>
<tr>
<td>June</td>
<td>5,3</td>
<td>SW</td>
</tr>
<tr>
<td>July</td>
<td>7,7</td>
<td>SW, NW</td>
</tr>
<tr>
<td>August</td>
<td>5,3</td>
<td>SW, NW</td>
</tr>
<tr>
<td>September</td>
<td>5,6</td>
<td>SW</td>
</tr>
<tr>
<td>October</td>
<td>5,2</td>
<td>SW</td>
</tr>
</tbody>
</table>

At the Aristotle University of Thessaloniki’s meteorological station, from where meteorological data were taken, the wind direction is mainly SW and NE while the highest speeds are obtained when the wind blows from N, NNW and SSW. As mentioned in chapter 2.1 the forest park extends to the northeastern of the city. Hence, the most sensible
conclusion is that all pollutants are transferred towards the forest direction. The forest acts as a filter reducing pollution but by taking into consideration the average values of the years before and after the fire there is not a significant change in pollution. This is due to the fact that the monitoring stations are located before the forest so they are influenced by air pollution before the function of the forest. At this stage it should be pointed out that although pollution seems constant other factors like congestion, population increase etc that also influence pollution are not taken into consideration.

Taking into consideration the wind direction from April to October and from the observation of figures 4.10-4.14 for the same period the effect of the fire on the pollution can be determined. SO$_2$ shows an increase in Toumpa from August and a downward trend in Eptapirgio from May which is stabilized from June. PM$_{10}$ shows an increasing trend in Toumpa from June and in Eptapirgio from July. CO is increased in Toumpa from July but there are no measurements for Eptapirgio. NO$_2$ indicates a decline in Toumpa from July but stabilization in Eptapirgio. O$_3$ in both peri-urban stations has a declining trend from July. These conclusions are indicative and not accurate because, although the wind for the specific period favored the concentration of pollutants at the peri-urban stations data for many months were missing (as it can be seen by the diagrams as well).

High concentrations of secondary (photochemical) pollutants are mainly associated with southern winds. In case of weak or absence of concise flow, north winds are a result of sea breeze, which favors the development of high concentration of photochemical pollutants (Region of Central Macedonia).

| Table 4.10: Average values of temperature 2 years before and after the forest fire |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °C | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 95-96 | 5,7 | 8,0 | 8,4 | 13,4 | 20,0 | 24,4 | 25,9 | 25,5 | 20,5 | 15,5 | 10,4 | 8,6 |
| 98-99 | 6,7 | 7,7 | 9,4 | 15,2 | 19,1 | 24,6 | 26,9 | 27,0 | 22,0 | 17,6 | 11,6 | 6,9 |

The implication of the forest destruction on the urban microclimate is reflected by an increase in temperature. The augmentation is obvious in summer as well as in winter, but given the fact that the meteorological station is located in the center of the Thessaloniki (in AUTH), some kilometers away from Seich Sou, it is not entirely affected by the forest absence.
Chapter 5

Restoration projects

After the destruction of the forest park from the disastrous fire of the 1997, more than 55% of the area was burnt, the restoration projects for the flood protection and the recovery of the ecosystem were urgent; a large-scale plantation took place, aiming in gradual reestablishment of the preexisting natural vegetation of the area. The rehabilitation projects were undertaken by the Reforestation Directorate while some flood protection projects were performed by the Sewage Organization of Thessaloniki.

5.1 Rehabilitation projects

The first steps, before the restoration projects, are logging and removing of residues of burnt trees, for inclinations smaller than 50%. In rocky soils with inclination more than 50% trees were logged and formatted but they were not removed acting like anticorrosion barriers (Grammatikopoulos, Tourlakidis, 1997). Table 5.1 shows the distribution of logging area per basin.

<table>
<thead>
<tr>
<th>Basin</th>
<th>m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>227.000</td>
</tr>
<tr>
<td>II</td>
<td>321.500</td>
</tr>
<tr>
<td>III</td>
<td>55.000</td>
</tr>
<tr>
<td>IV</td>
<td>230.000</td>
</tr>
<tr>
<td>V</td>
<td>2.000</td>
</tr>
<tr>
<td>VI</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>835.500</td>
</tr>
</tbody>
</table>

Source: Stefanidis 2001
The role of the anticorrosion projects is the soil protection from erosion. These projects can be classified in 2 constructive methods. The first, concerns the construction of hardwood cuttings-grating logs with the residues of the burnt trees. This construction has limited lifetime (3-5 years). Then the wood rots so the construction is self-destructed. The second construction concerns the deep ground grooving with machinery (Stefanidis 2001). The goal is the increase of the water permeability and the restrain of water flow and brought matter. The grooving takes place between the previous constructions in soils with less than 30% inclination. The grooving depth is at least 0,70m and the total grooving length is 6.308 acres (Grammatikopoulos, Tourlakidis, 1997). Table 5.2 presents the concentration of logging residues per basin and table 5.3 shows the acres of grooving per basin.

**Table 5.2: Concentration of logging residues**

<table>
<thead>
<tr>
<th>Basin</th>
<th>Quantity (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>136.212</td>
</tr>
<tr>
<td>II</td>
<td>142.561</td>
</tr>
<tr>
<td>III</td>
<td>126.300</td>
</tr>
<tr>
<td>IV</td>
<td>115.878</td>
</tr>
<tr>
<td>V</td>
<td>87.955,5</td>
</tr>
<tr>
<td>VI</td>
<td>53.870</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>662.776,5</strong></td>
</tr>
</tbody>
</table>

Source: Stefanidis 2001

**Table 5.3: Grooving acres**

<table>
<thead>
<tr>
<th>Basin</th>
<th>m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1.630.000</td>
</tr>
<tr>
<td>II</td>
<td>1.472.000</td>
</tr>
<tr>
<td>III</td>
<td>1.223.000</td>
</tr>
<tr>
<td>IV</td>
<td>748.000</td>
</tr>
<tr>
<td>V</td>
<td>673.000</td>
</tr>
<tr>
<td>VI</td>
<td>562.000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6.308.000</strong></td>
</tr>
</tbody>
</table>

Source: Stefanidis 2001
The flood protection projects include wood dams (temporal construction projects) and low height dams (permanent construction projects). The wood dams are classified in 4 categories according to the riverbed section: 3, 4, 5, and 6m. Their height is 1m while the flood gate opening is 1m for the 3 and 4m riverbed section and 1,5m for the 5 and 6m. The construction is built by chestnut pilings of 1,5m tall. The low height dams are cement dams, with small height without reinforced concrete and without predams. Their goal is the restrain of water and brought matters and the deceleration of the water flow (Stefanidis, 2001). Table 5.4 shows the wood dams in each basin and table 5.5 pictures the low height dams per basin.

Table 5.4: Distribution of wood dams

<table>
<thead>
<tr>
<th>Basin</th>
<th>Quantity (pieces)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>64</td>
</tr>
<tr>
<td>II</td>
<td>35</td>
</tr>
<tr>
<td>III</td>
<td>26</td>
</tr>
<tr>
<td>IV</td>
<td>17</td>
</tr>
<tr>
<td>V</td>
<td>26</td>
</tr>
<tr>
<td>VI</td>
<td>20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>188</strong></td>
</tr>
</tbody>
</table>

Source: Stefanidis 2001

Table 5.5: Distribution low height dams

<table>
<thead>
<tr>
<th>Basin</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>2</td>
</tr>
<tr>
<td>II</td>
<td>1</td>
</tr>
<tr>
<td>III</td>
<td>1</td>
</tr>
<tr>
<td>IV</td>
<td>1</td>
</tr>
<tr>
<td>V</td>
<td>1</td>
</tr>
<tr>
<td>VI</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7</strong></td>
</tr>
</tbody>
</table>

Source: Stefanidis 2001
The reforestation concerns natural and artificial reforestation. The natural reforestation that took place has created a forest similar to the precursor (burnt) forest. In the initial stage the higher percentage of the composition was covered by oak trees. The new artificial forest is a mixed forest that consists 70% from conifers and 30% from broadleaves (mainly evergreen species). Reforestation is important in order to maintain the lost goals of the destroyed forest (Grammatikopoulos, Tournakidis, 1997):

- Protection of the city from floods and other torrential problems,
- Landscape aesthetics upgrade,
- Supply leisure to the residents,
- Ecological contribution to flora and fauna of the area and
- Forest protection from future fires, land revaluations, etc.

The rehabilitation of the forest should serve multiple usages so the choice of the species was according to that scope. Due to the fact that the goal is not a productive forest but a protection forest there is wider array of species used. The parameters that were taken into consideration for the right election of the species used are:

- Climatic and soil conditions of the area,
- The existing vegetation and the historic evolution of the vegetation,
- The behavior of the imported species during previous reforestations and
- The resistance of the species against sicknesses and their fire tolerance.

According to the study “Structural analysis of mixed stands coming from natural regeneration and plantations after fire”, 12 years after the fire, the mixed stands present different coverage rate on the north rather than on the south site. On the northern, mainly Pinus brutia (42%), Quercus pubescens (27%) and Cupressus sempervirens (29%) dominate. While on southern site, the mixed stands are dominated at a greater percentage by Pinus brutia (81%) and less by Quercus pubescens (19%). The participation of the other species does not exceed the 10%. The mixture of the stands was per lines and patches as a result of the planting design (Tsitsoni, Tsakaldimi, Simeliadou, Fouska, 2010).
5.2 The later project

In 2003 the Region of Central Macedonia in cooperation with the Organization of Planning and Environmental Protection of Thessaloniki implemented the project named “Protection and upgrading of the peri-urban forest of Thessaloniki (Seich Sou)”. Other bodies involved in the project were: the Reforestation Directorate, the Sewage Organization of Thessaloniki and the Forest Inspection.

The aim of the project was the enhancement of the protection and management of the forest in order to serve the principles of sustainability and public utility. More specifically, the project can be classified in the following categories- actions (seihsou.gr):

- Flood protection
- Fire protection
- Environmental upgrade
- Awareness

The flood protection contains mountainous water management and control projects (102 dams were constructed and new roads of 8.100 m length for the access to the dams were opened) and flood protection projects of “Eleorama” (three parts of Eleorama of total length to around 660m. were managed and a new bridge was built).

The fire protection includes

1. design and development of fire protection system,
2. improvement and construction of forest firewall road network (improve and widening of forest roads of total length of 58.838,53 km, 122 culverts were built and installed, ditch rainwater was drilled and the old water pipe was replaced by a new of 3.492km length),
3. upgrade and completion of water supply system (3 water tanks of 75 m3 capacity were constructed and a 10.376 m pipeline for water transportation was placed and 20 hydrants were connected to the pipeline),
4. forestry handling projects of fire control (cleaning and pruning of conifers and hollies in an area of 3.565,82 acres were executed).
The environmental upgrade includes environmental actions and supplementation and enhance of vegetation (223,660 trees of 9 species of conifers and 60 species of broadleaves were plant) and leisure projects (2 new paths with 5.5 km length and 4 new parking spaces were constructed and 10 existing recreation areas and 4 existing paths of 7 km were improved).
Chapter 6

Proposals-Management measures

6.1 Urban environment

The urban ecosystem consists of the “grey” and “green” elements. The grey elements are all structures (buildings, roads, etc), resulting from human activities. Green elements include urban and peri-urban vegetation (Kontogianni, et al, 2010).

The climate of urban areas is characterized by reduced evaporation, increased thermal conductivity and heat capacity of building materials (compared to the natural soil), change in air movement (due to altered relief caused by the construction activities), flux of artificial energy (from domestic heating, traffic, etc) and the high concentration of particles in the atmosphere combined with the radiation affect human health as well as the climatic factors (Dafis, 2001).

6.1.1 Green spaces

Green spaces play a crucial role in raising the quality of residents life. They do not only have an ornamental function in urban areas, but they may also improve the quality of urban life (Akbari, 2002; Brack, 2002).

Urban vegetation can improve air quality in several ways; can uptake and accumulate pollutants through their roots and leaf surfaces (Sawidis et al., 1995), various tree configurations can alter wind profiles or create local inversions to trap pollutants (Khan and Abbasi, 2001). Trees can also reduce building energy use by shading buildings and altering air flows, thereby indirectly reducing pollution emission from power plants (Nowak, 1994). Moreover, plants are used for erosion control and management of flowing water and also as noise pollution barriers (Radoglou, 2003).

However, the mere presence of green spaces is not adequate. Their spatial distribution must be uniform in the urban fabric and connected by green zones forming an extensive green network (Tzortzi, 2000).
In the big cities there are many abandoned and neglected areas, parks and squares, and uncovered places of flats which in combination with the roads and the pavements may be green unification areas (Tzortzi, 2000).

6.1.2 Species selection

The proper selection of species is prerequisite since they have to meet the current requirements and have characteristics that allow them survive and grow in the specific locations. From the ecological standpoint, indigenous species (from the natural vegetation of the area) should be chosen that are well adapted to the climatic and soil conditions of the region and better withstand in diseases and infestations (Radoglou, 2003).

Apart from the ecological adaptability the morphological features should also be taken under consideration. These features are:

- The form of canopy,
- The size, texture and color of leaves and
- The existence of flowers.

Concluding, the appropriate species should be perfectly adapted to the environment, have an attractive form, be bred by stems, grow fast up to a certain height and then growth stops and finally resistant to the existing conditions (air pollution, drought, frosts, salty soil, etc) (Radoglou, 2003).
The current situation in Thessaloniki is characterized by few free green spaces, dominated mainly by foreign species and shrubs inappropriate for the existing conditions. Hence, the vegetation should be substituted by indigenous species and increase the green spaces in the city.

### 6.2 Traffic noise barriers

Noise continues to expand with an increasing number of complaints from the residents. Most people are usually exposed to more than one source of noise of which road noise is the main source (OECD-ECMT 1995). This phenomenon is more intense in the large city centers. The peri-urban forest of Thessaloniki borders with the ring road of the city. The traffic of the road is heavy with 3 lanes per direction site. Thus, vegetation has the ability to reduce the noise from the road.

According to the study “The effects of vegetation on reducing traffic noise from a city ring road” vegetation acts as a barrier reducing the A-weighted sound levels. The area was divided into 2 sites, close to the residential area. The first site consisted of grassland while the second is covered by forest trees (Pinus brutia). The size of each site was 500m² and they were 60 m perpendicular to the road. The results of the study confirmed the effect of the vegetation. The noise at the road level was 78 dB and at a distance of 60 m the sound level was reduced to 60 dB in the grass covered area while in the forested area the sound level at the road was 79dB and at 60m inside the forest it was 55dB. As it can be observed the decrease in the forested area was 6dB greater. Hence, when there is need of noise reduction barriers of dense vegetation are appropriate. For better results evergreen trees and shrubs are preferable. The silvicultural characteristics of plants for noise control are: shrubs with height of at least 2–3m, mature trees with height of 15m and the total width of the planted area should be at least 20m (Samara, Tsitsoni, 2010).

### 6.3 Fire-resistant species

Fire-resistant species can be damaged or even killed by fire but they do not ignite readily from different ignition sources due to their foliage and stems structure. Their characteristics are:
• High juice content (like water),
• Leaves are moist and supple,
• Not much dead wood and no tendency to entrap dead material within the crown of the plant,
• Low resin content (Detweiler, Fitzgerald, 2006)*

Most deciduous trees and shrubs are fire-resistant.
Examples of fire-resistant trees: Acer, Aesculus, Cercis, Cornus, Crataegus, Fraxinus, Fagus, Platanus, Populus, Juglans, Prunus, etc.
Shrubs: Cistus, Acer, Cornus, Euonymus, Viburnum, Rhamnus, etc (agro-dasos.blogspot).

6.4 Raising awareness
The most important step is residents’ contribution. Residents must be aware and informed of the environmental problems and of the potential benefits of peri-urban forest usage. The main risks that threaten Seich Sou are associated to human use of the park. Forest protection is a responsibility of its visitors. People should prevent forest from throwing garbage, vandalism, destruction of vegetation, extensive pollution and wildfires. Therefore the creation of citizens’ environmental conscience will favor forests protection as well as it will improve the quality of their lives.

* Note: Fire-resistant does not mean fireproof
In 1997 the most severe fire in the forest park Seich Sou occurred. The fire lasted for 3 days during which 15,431,000 m$^2$ were burnt; more than the half vegetation. The whole ecosystem was disrupted leading to extensive degradation to the non burnt part of the forest, as well, affecting flora and fauna of the area. The destruction of the forest increased the danger of erosion and floods. Apart from the ecological damage, the consequences of the destruction on the residents were important, as Seich Sou constituted one of the main recreational areas of the city. The absence of forest also intensified pollution.

There is an interrelation between forest and pollution. The forest acts as a filter absorbing pollutants while pollution, on the other hand, destroys the forest.

In the specific case of Thessaloniki the existence of high buildings and narrow streets and the rare open spaces in the city in conjunction with the density of the city and the climatic conditions that dominate favor the concentration of pollutants in the atmosphere.

The concentration of pollutants is greater in the center of the city than in the eastern and western regions and often certain pollutants exceed the limit value of pollution. Ozone is an exception to that as it presents the highest prices in the peri-urban area rather than in the center (Organization of Planning and Environmental protection of Thessaloniki).

However, during the decade 1992-2002, from the observation of the monitoring stations of Eptapirgio and Toumpa, pollutants show a downward trend leading to the conclusion that the degradation of the forest has not affected the concentration of the so-called “urban pollutants” (SO$_2$, PM$_{10}$, NO$_2$, CO) which are directly linked to the urban activities but it has affected the concentration of ozone (peri-urban pollutant) at which the impact of the forest is more intense.

The limited downward trend is a consequence of the combination of the expansion of the city in the surrounding area with the degradation of the forest. In addition the fact that the
monitoring stations are out of the forest explains the limited effect of the forest on the pollution as the pollutants are measured before they are filtered by the forest.

After the disastrous fire the restoration projects for the flood protection and the recovery of the ecosystem were urgent; a large-scale plantation took place, aiming in gradual reestablishment of the preexisting natural vegetation of the area. These projects were important for the protection of the forest and the conservation of its sustainability leading to the improvement of people’s life.

Additionally, some proposals that could contribute to the reduction of pollution and to the resistance in forest fires are submitted. These proposals concern management projects with appropriate species for each use:

- green spaces; ornamental function and improve the quality of urban life,
- traffic noise barriers,
- fire-resistant species and
- raising awareness.
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Appendix 1

Maps

1. Basins map
2. Geological map
3. Vegetation map
   3.1 Before the fire
   3.2 After the fire
4. Infrastructural map
5. Restoration projects map
Appendix 2

Formulas

1. Fire variables

2. Fire statement
1. **Fire variables**

- **Fire intensity:** $I_B = W \times Q \times R$
  
  $I_B$: fire intensity (kW/m)
  
  $W$: load of available burnt substance (kg/m$^2$)
  
  $Q$: calorific value of burnt substance (kJ/kg)
  
  $R$: rate of fire spread (m/sec)

- **Thermal flow:** $I_R = I_B/D$
  
  $I_R$: thermal flow of fire (kW/m)
  
  $D$: flaming zone width (m)

  *(fire intensity>thermal flow)*

- **Flame length:** $F_L = 0.0775 \times (I_B)^{0.46}$
  
  $F_L$: flame length of fire (m)
  
  $I_B$: fire intensity (kW/m)

- **Flame height:** $h_F = I_B/385 \times u$
  
  $h_F$: flame length (m)
  
  $I_B$: fire intensity (kW/m)
  
  $u$: wind speed (m/s)

- **Burning time:** $t_r = D/60 \times R$
  
  $D$: flaming zone width (m)
  
  $R$: rate of fire spread (m/sec)
2. Fire statement

ΔΕ Α Τ Ι Ο ΠΥΡΕΛΛΙΑΣ

ΔΗΣΗ ΔΑΣΕΩΝ: ΠΕΡΙΒΕΡΕΙΑΣ ΚΕΝΤ. ΜΑΚΕΔΟΝΙΑΣ
Δ/ΝΗ ΔΑΣΩΝ: ΘΕΣ./ΝΙΜΗΣ
ΔΙΔΑΚΤΗΣ: ΘΕΣ./ΝΙΜΗΣ
ΞΗΜΟΙ: ΠΑΝΟΡΑΜΑΤΟΣ-ΠΥΛΑΙΑΣ
ΚΕΝΤΡΟΤΕΧΝΙΚΟΥ ΛΕΥΚΩΝ
ΔΑΣ. ΘΕΣΗ: ΠΕΡΙΟΔΟΛΗΣ

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ΑΡΙΣΤΑ ΠΥΡΕΛΛΙΑΣ

Ξεκ. : Πιθανά

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1. ΣΥΝΟΛΟ (αβορίες των διατρησιμών μηχ. μηχ. του τομεα-ρυπηρού ατιτ.)

Εξακρίβωση δράσης

[8/1/3/3]
**Καταταγή Λαού Ελλάδας**

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<th>Πεύκη θεμελιάρισμος</th>
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**Στρέμματα**

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**Προμνητική Περιφέρεια**

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**Διευκρίνηση**: Τα μικτά δάση αναγράφονται στο επικρατέστερο είδος.

**Αριθμός**

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**Σημειώσεις Ασακίων Παιών**

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**2. ΕΤΟΙΜΟ**

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1. Στις αριθμημένες στάθμες συμπληρώνεται ένα μόνο τετραγωνάκι σε κάθε στήλη.

2. Σύνολο είναι το αριθμημένο τέμπειο του κοινού σταθμού, της σχετικής υγρασίας, της θερμοκρασίας και των αριθμών των αντίστοιχων τετραγωνίδων που έχουν τετραγωνάκι.
Σημεία εντολής

Αποστολή επιτροπής
Αποστολή τόπων
Αποστολή υποθέσεων
Αποστολή της Νομικής
Αποστολή της Κοινωνικής
Αποστολή της Μηχανικής
Αποστολή της Επιστημονικής
Επικοινωνία
Επικοινωνία με την Τεχνητή Νοημοσύνη

Στοιχεία κατάστησης
Στράτου κατάσβεσης

1. Άσος με ευαίσθητο μέσο
2. Άσος με επίλεγο μέσο
3. Άσος με αριθμό (μικτός)
4. Άσος με αριθμό (μόνο μηχ.)
5. Άσος αντίποινα

6. Άσος κατάσβεσης

Δείγμα προσωπικό
Δείγμα προσωπικού
Δείγμα του προσωπικού
Δείγμα του εργαζομένου
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Προσωπικό
Οχημάτων μηχ/των όπλων

4. ΣΤΙΧΟΛΟ

17.12.87

Ο ΣΥΝΤΑΞΙΣΗΣ

Ε. Νικολαής
Appendix 3

Pollution
1. The concentration of pollutants in Egnatia station 5 years after the fire
2. The concentration of pollutants in Eptapirgio station 5 years after the fire
3. The concentration of pollutants in Toumpa station 5 years after the fire