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D3.3 Basic Fire Management Suite for Cyprus and the Region

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1 Introduction

The “Southeastern Mediterranean Excellence Development in Fire Research – SEMEDFIRE” project is funded by the European Commission, through Grant Agreement no. 101079337, under its HORIZON EUROPE Programme, and more particularly within the WIDERA-2021-ACCESS-03-01 Twinning Topic.

In full alignment with the WIDERA-Twinning-topic’s requirements, SEMEDFIRE aims to enhance the capacities and knowledge-acquisition of the Widening institution; EUC, in Research-&-Innovation (R&I) and Research-Management-Administration (RMA) relating to Fire Safety and Fire Management. This is aimed through networking activities with five top-class leading counterparts at EU level; IMPERIAL COLLEGE, WAGENINGEN UNIVERSITY, PAU COSTA FOUNDATION, FRENCH GENERAL DIRECTORATE OF CIVIL SECURITY AND CRISIS MANAGEMENT and NIMES-Metropole, which represent a multifaceted, but complementary and synergistic, ‘geography’ of R&I philosophies and approaches, comprising:

- two leading Academic institutes in the area of fire safety and integrated fire management;
- a leading Foundation in investigating fires and communities-engagement;
- a Governmental Agency leading the EU-effort in operationally combating Forest Fires;
- an Agglomeration of Municipalities providing the tangible example of local governance in Forest Fires;
- a representation of both Member States and an Associated Country;
- a linking of the European Research Area (ERA) in a “compass” fashion: from north (UK) to central Europe (FR, NL), to the west (ES), and to the Mediterranean biogeographical region (ES, FR, CY) and its South-Eastern area (CY).

The networking-for-excellence and twinning-contributions of the internationally-leading Advanced Partners in knowledge-transfer and capacity-building, focus on both EUC and within and for its surrounding targeted stakeholders from public governance, industry/ entrepreneurship and civic society, at local and regional levels. It is hence scoped to raise the profile and reputation of EUC to such a level of ERA-excellence that it will be able to become a lighthouse of spreading fire-science excellence in Cyprus and the SE Mediterranean, as well as to nurture a culture of societal fire-safety.

The document at hand, in accordance with the Grant Agreement (GA), constitutes Deliverable **D3.3 Basic Fire Management Suite for Cyprus and the Region,** prepared by EUC. As per the project’s GA, D3.3 is prepared within the context of Task T3.3: “Creation of Fire Management Suite for Cyprus and the Region”, and it aims at: presenting the tools and proposed methodology, based on the knowledge gained by EUC (the Widening Coordinator) from IMPERIAL (Advanced Partner) throughout the actions for completing WP3 - “Fire Modelling and Evacuation Tools”, regarding the establishment of such an important Suite in the near future.

The eastern Mediterranean island of Cyprus faces a constant threat from wildfires. Hot, dry summers and vast swathes of fire-prone vegetation, like maquis and garrigue shrublands, and pine forests, create a tinderbox primed for rapid fire ignition and spread. Further exacerbating the risk, unused croplands within the wildland-urban interface (WUI), especially near villages and bordering forests, is now choked with dry surface vegetation. These wildfires pose a significant threat to human life, property, and the island's fragile ecological balance.


Figure 1: Maquis shrubland & Pine Forests - Typical vegetation in Cyprus

Figure 2: Typical Croplands in Cyprus

The human, economic and ecological damage caused by wildfires in Cyprus can be substantial. The devastating Arakapas Fire of 2021, for instance, caused four deaths, destroyed thousands of hectares of forest, damaged homes and infrastructure, and caused millions of euros in losses [1] [2]. To effectively combat this threat, among other prevention measures a comprehensive fire management suite is needed. Such a suite would integrate various technologies and functionalities to address fire risks throughout their lifecycle – from prevention and early detection to response, suppression, and post-fire recovery. By implementing a robust fire management suite, Cyprus can significantly improve its preparedness and response capabilities, ultimately leading to a safer and more fire-resilient future.

Expanding the suite's capabilities to encompass regional countries like Greece and the Eastern Mediterranean countries holds significant promise. These neighboring countries face similar wildfire challenges due to shared vegetation types, topography, and climate. By extending coverage to these areas, the wildfire management suite can be developed into a comprehensive regional wildfire management tool, applicable across the entire Eastern Mediterranean.

2 The wildfire risk in Cyprus

Wildfires are a constant threat to Cypriot environment and communities. The combination of hot, dry climate, strong winds and flammable vegetation due to low humidity creates a tinderbox environment during every summer. The long summer season from May till late October due to the limited rainfall during these months, escalates the problem adding to the climate conditions the tiredness of the responsible fire-fighting personnel. The main factors contributing to wildfires ignition and spread are:

- **Climate:** Cyprus experiences a long, hot, and dry summer with average temperatures exceeding 30°C, and scarce rainfall. This creates ideal conditions for wildfires to ignite and spread rapidly.
- **Vegetation:** The dominant vegetation types in Cyprus are pine forests, maquis and garrigue shrublands, both highly flammable due to their resinous content and dry leaves. Additionally, there are unused croplands with dry vegetation on WUI boundaries with habitant communities and forest.
- **Topography:** Much of the Cypriot landscape is characterized by rugged mountains and steep slopes, making firefighting efforts more challenging for ground units/crews, and necessitating extensively combined operations with aerial firefighting means for most incidents.

Figure 3: Typical topography of the Cypriot landscape.

- **Human Activity:** Human actions are a major cause of wildfires in Cyprus. These include:
  - Agricultural practices: Burning stubble or clearing land with fire can easily get out of control.
  - Recreational activities: Discarded cigarettes, improperly extinguished campfires, fireworks, hunting activities, high-level cable circuit passing from forests.
  - Arson: Deliberate acts of arson also contribute to the problem.
- **Limited Prevention Measures:** In the case of Cyprus, the main preventive measures, which are taken to reduce the risk of fire outbreaks, include, enforcement of the law, education and publicity, fire danger rating and announcement, picnic sites and Patrolling [3].

In Figure 4 below, the wildfire risk during the years in forest-areas is illustrated in terms of number of wildfire incidents and burned area in ha, under the responsibility of Department of Forests, as reported in its website [3] on the forest fire statistics for the period 2000-2021.

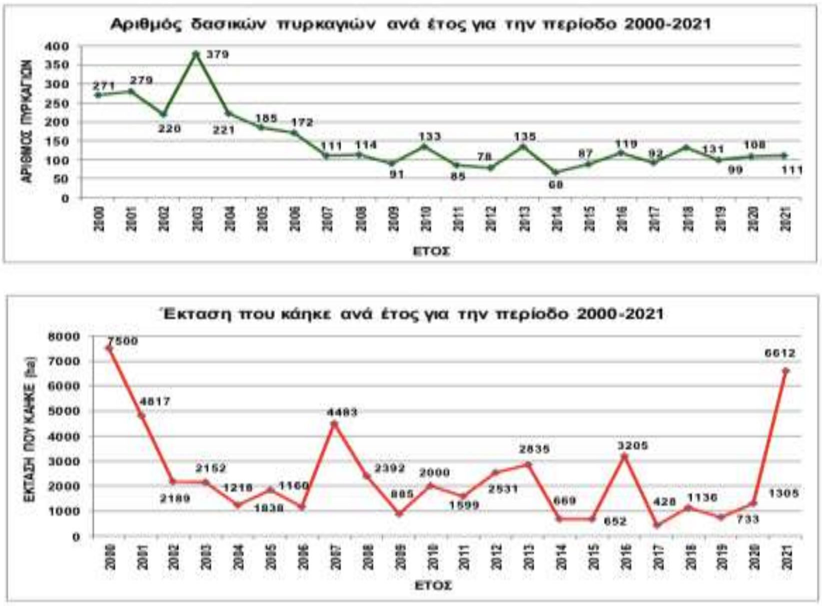


Figure 4: (1) The number of forest fires for the period 2000-2021 & (2) The burned area in ha for the period 2000-2021, as provided by the Department of Forests [3]

2.1 Arakapas Wildfire - July 2021

The most catastrophic wildfire as recorded by the responsible authorities, Department of Forests and Cyprus Fire Service, was the Arakapas Fire. The Arakapas fire broke out in the afternoon of Saturday the 3rd of July 2021 in the Limassol district, near the village of Arakapas and the fire resulted in 4,445 ha of burned area in less than 48 hours and four men died during the incident [2].

During the previous week and the specific day heatwave conditions with temperatures of 40+ degrees Celsius were observed. The fire danger on that specific day, based on the European Forest Fire Information System (EFFIS) forecast was extreme, see Figure 5. More specifically the weather conditions, according to the nearest meteorological station at Eptagonia at the time the fire broke out, reported a temperature of 35,1° C, humidity of 13%, wind speed at 6 bf and zero precipitation during the last 30 days.

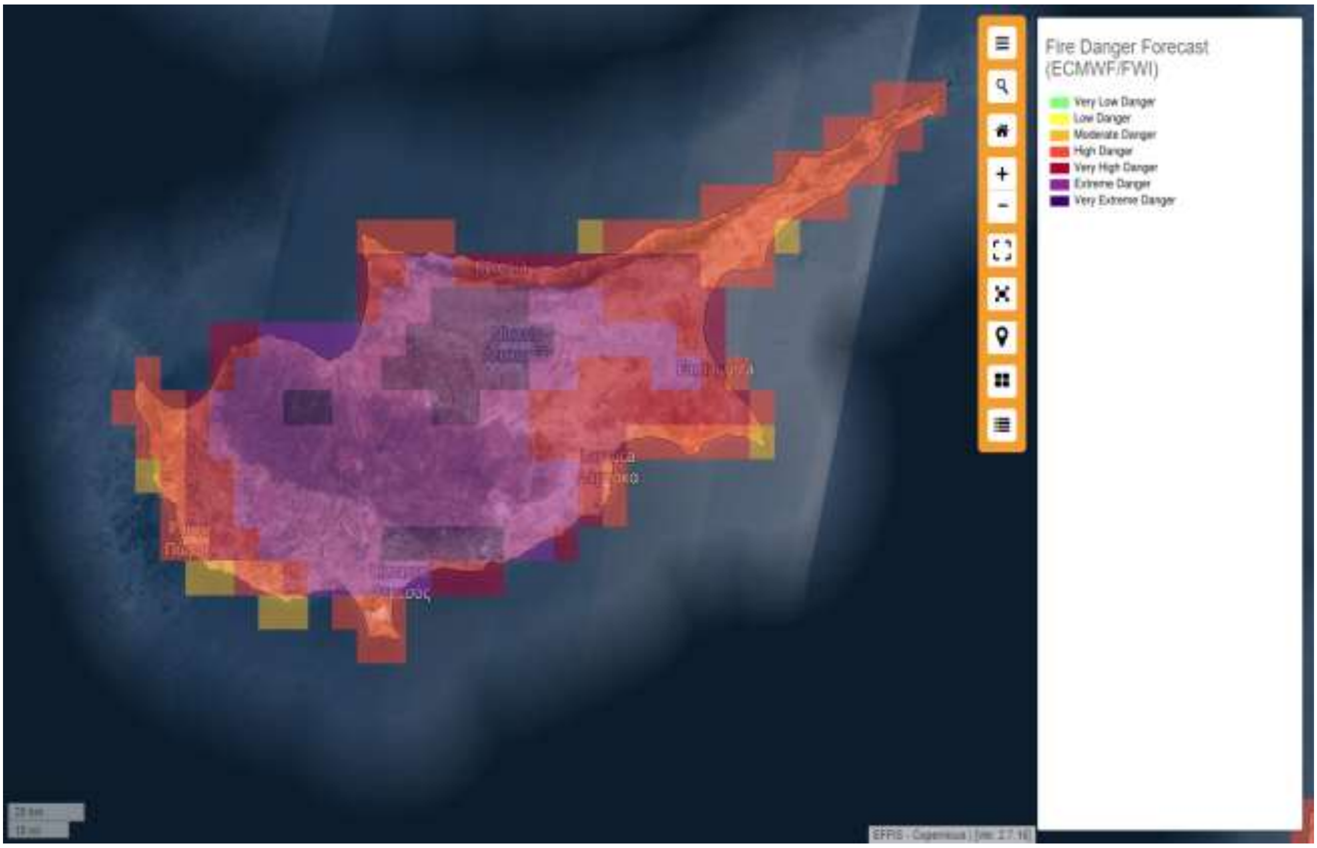


Figure 5: EFFIS fire danger forecast for the 3rd of July 2021(https://effis.jrc.ec.europa.eu/apps/effis_current_situation/ Accessed on 13.05.2024)

The burned area during the 2021 Arakapas fire event crosses the boundaries of the Limassol and Larnaca districts. The area is a small valley located in the southern hills of the Troodos Mountain range, spanning an elevation of about 250-1250 meters above sea level, see Figure 6. Several small villages are located in the valley and seven of them have been affected by the fire. Geologically, the area forms part of the Troodos Ophiolite with predominant occurrence of diabase.

The vegetation of the area varies between agriculture fields around the villages; maquis and garrigue shrubland with sclerophyllous vegetation, and on the outskirts of each village there are patches of forest with mixed broadleaf and coniferous trees, dominated by Anatolia pine (Pinus bruit), see Figure 6, Figure 7 and Figure 8. The cultivated land comprises of various crops, fruit plantation, olive trees and carobs trees.

Figure 6: The Valley where Arakapas Fire occurred June 2021, picture taken by EUC researchers

Figure 7: Mixed coniferous and broadleaf vegetation in Arakapas area one year after the fire, picture taken by EUC researchers

Figure 8: Mixed and broadleaf vegetation burning (photo courtesy of Cyprus Fire Service)

According to the information shared by the Cyprus Police in court on the 6th of September 2021, during the pre-trial procedures of the suspect who was arrested after the Arakapas fire, the fire was allegedly ignited when the man had been burning stubble earlier on the day.

During the time of the event, in July 2021, there were two (02) fire stations near the area of the reported fire. One was located at the village of Eptagonia around 5km from the fire-starting point and it was managed by the Cyprus Fire Service and one in the village of Parekklissia which is 15km from the area of the fire and is managed by the Cyprus Department of Forests. At that time, the personnel and the firefighting equipment and vehicles of the two fire stations were corresponding to a fire near the A1 Nicosia-Limassol highway at a distance of 25km from the Arakapas village, causing a series of delays in ground forces reaching the Arakapas area. By the time that Fire Engines from Nicosia fire stations (c.a.60 km away) tried to approach the fire the roads were blocked by fire not allowing the ground forces to approach. It should be recorded that the Eptagonia fire station was destroyed by the fire that reached the outskirts of the village.

According to Cyprus Fire Service reports the first firefighting airplane arrived at the area of the Arakapas fire approximately ten (10) minutes after the first call was received and water drops commenced immediately. The first ground forces arrived at the area at around 14:15 EET, thirty minutes after the first call was received. The emergency services that responded to the fire event faced significant difficulties to organise and manage the operations to control the fire.

As mentioned above, due to fact that personnel and equipment of the two neighbouring fire stations were responding to another fire event, authorities and ground forces required approximately ninety minutes (90) after the first call to engage in full power and capacity to the fire in Arakapas. Also, due to the electricity power outage that was caused by the damages to electricity poles and transformers in the area, most fire-hydrants and water pumps were out of order. Water supply for fire trucks of the Cyprus Fire Service, the Cyprus Department of Forests, and for private tankers called to assist, was conducted in the village of Parekklisia, causing serious delays of fifteen (15) to twenty (20) minutes in the ground operations.

Cyprus Fire Service protected residential areas and in cooperation with the Cyprus Civil Defence, the Cyprus Police and local authorities evacuated the affected villages, Arakapas, Melini, Ora, Odou, Sykopetra, Eptagonia, Ayioi Vavatsinias and Vavatsinia, and the Cyprus Department of Forests took over the control and fighting the fire in the remaining areas.

As the wildfire was under development and spreading rapidly, the RescEU mechanism was activated at 15.50 EEST time with aerial forces arriving from Greece next morning. Additional assistance of two (2) Air-tractors airplanes was provided the following morning from Israel via a bilateral agreement between the two countries. Thus, a total of 15 firefighting aircrafts responded to assist with the control of the wildfire:

- 04 airplanes and 05 helicopters from the Republic of Cyprus,
- 02 helicopters from the British Sovereign Bases in Cyprus,
- 02 air-tractors from Israel,
- 02 "Canadair" airplanes from Greece via the RescEU mechanism.

In total the ground forces responded with 70 fire engines, 14 bulldozers and 20 water tanks. The personnel involved included 600 firefighting personnel from:

- Cyprus Fire Service officers,
- Department of Forests,
- Cyprus Police,
- National Guard,
- British Sovereign Bases,
- Local Authorities- Community Councils,
- Game and Wildfire Service,
- Volunteers from Civil Protection.

The fire was reported to be under control on Monday, 5th of July at 8.00 am.

Several challenges contributed to the delay of firefighting response which led to the fire's fast spread that resulted in burning a total of 4,445 ha in less than 48hours. Firstly, the communication between the authorities was not satisfactory due to the fire but also due to the old technology used at the time and the poor management plan in place. Secondly, the road network was blocked by private cars and volunteer groups that tried to reach the area without co-operation and co-ordination with the responsible authorities. Finally, the topology and strong winds which were enforced with turbulences due to the fire.

As noted in above the extreme weather conditions before and during the wildfire ignition day contributed dramatically to the fire behaviour and spread. The prolonged hot temperatures of +40°C, the early dry season in Cyprus with zero recorded rainfall recorded in the area 30 days before the incident. Additionally, the beneficial rainfall from previous winter months for land and agriculture in Cyprus, had led to an increased wild plantation which transformed into the ideal fuel load for a wildfire due to the non-appropriate cleaning and management.

The fire affected an area of 4,445 ha in less than 24 hours, see Figure 10. A running fire was clearly developed in a short period of time with an estimated, by the authorities, maximum speed of 7km/hr (118m/min).

The winds recorded in the area at the time of the incident reached 6 BFT, were reinforced after the fire development due to the high temperatures and pressure difference. The typology of the area - a small valley surrounded by mountains also contributed to the behaviour of the wildfire, assisting to the development of high temperatures and turbulence in many directions.

In just 5 hours the wildfire passed through a total of 8 km horizontal extension of land, burning a perimeter of 40km. The total burned area according to the Cyprus Department of Forests was 4,445 ha. This resulted to the tragic loss of four (04) human lives, a total of 50 houses and premises damaged or destroyed, dead livestock animals including a whole chicken farm and unrecorded number of wild animals, see Figure 9. The public roads to and from the villages were destroyed and the Eptagonia fire station was destroyed by the fire that reached the outskirts of the village. According to official statements from the Electricity Authority of Cyprus on 06th of July 2021, more than 350 electricity poles and 15 aerial electricity transformers were burned during the fire. As noted previously the damages in the electricity network made the firefighting operation even more challenging.

It should be noted that the smoke was visible to other areas of the island such as Nicosia on the North-side, Limassol on the South-side and Ayia Napa on the South-East side of the fire location.

Figure 9: Damage Properties and Plantation Trees at Arakapas Village picture taken by EUC researchers

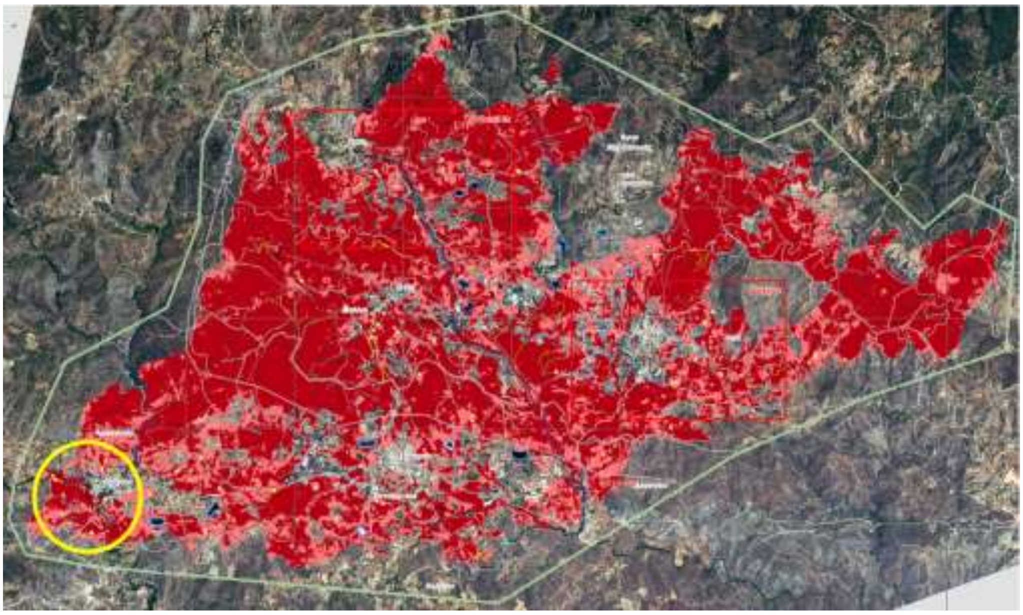


Figure 10: Copernicus 2021-EMSR515 The map shows the damage grade assessment in Melini/Arakapas

Figure 11: The fire spread over the hills with the fire-fighting forces continuing operations during the night (courtesy of Cyprus Fire Service)

The aftermath of this wildfire incident was discussed in Cyprus Parliament with the participation of the First Response authorities and the affected municipalities in order to develop measures and law enforcement on fires caused by humans by both arson and accident. Even though, there is a law in place forbidding the starting of fires during the summer months in any private or public area, the majority of wildfires reported in Cyprus in recent years were caused by the specific factor. Thus, the enforcement of higher fines and penalties was deemed critical.

On governmental level it was decided to invest in an up-to-date emergency response centre and develop better coordination systems between the first responders' services. The Cyprus Fire Service has also suggested an increase of the firefighting personnel.

The Arakapas fire unfortunately revealed the challenges the responsible authorities are facing during the summer period due to the non-enough personnel and the immediate need for an increase, improvement on the firefighting means, both for the ground forces and the aerial means. However, it mostly showed the requirement for a coordination system and strategies, design of emergency road system for firefighting and evacuation, relevant training for the authorities on the wildfire behaviour, upgraded prevention measures including technological tools, such as wildfire modelling, evacuation training of the fire prone of communities supported by modelling scenarios.

3 Proposing Wildfire Management Systems

3.1 Existing Fire Management Systems

Cyprus currently has a forest fire management system in place, outlined by the Department of Forests [3]. This system focuses on prevention measures like, creating Fire Breaks, silvicultural treatments of the vegetation as part of the land management strategies (LMS) from the forest areas and boundaries (but not prescribed burning), public awareness campaigns, along with detection through lookout towers along the Troodos Mountain with 24/7 personnel during the summer period including a new team (of limited resources) of specialised designed drones and trained pilots for those, and for quick response there are fire-hoses systems installed in dedicated areas along the forests along with water tanks, hydrants and water valves [3]. Additionally, response protocols involve dispatching firefighting crews and equipment during an incident.

However, limitations exist in the current system. Controlled burns to reduce fuel loads are not applied as a forest management practice in Cyprus, as in other European member states like Spain, Portugal, and Sweden. Furthermore, depending on traditional detection methods can lead to delays in identifying fires, especially during periods of low visibility, thus the reinforcement on the specialised drones' team would be essential. Additionally, there are limited resources for aerial firefighting means located permanently on the island, and limited public education campaigns exacerbate the issue. The lack of a centralized data platform for real-time fire risk assessment and resource allocation can hinder response efficiency.

Furthermore, advanced technologies like satellite monitoring and fire risk prediction models could be used in a fire management system. Analysing the strengths and weaknesses of these existing systems can provide valuable insights for developing a more robust fire management suite in Cyprus. Neighbouring countries with research on using these technologies, such as Israel and Greece, could share their knowledge and experience via the fire management suite.

3.2 Wildfire Risk Mapping

Fire risk mapping plays a crucial role in fire prevention efforts. Geographic Information Systems (GIS) and remote sensing data, such as satellite imagery and LiDAR (Light Detection and Ranging), can be utilized to create detailed fire risk maps. These maps consider factors like vegetation type, fuel load, topography, and historical fire data to identify areas with a higher risk of fire ignition and spread [4].

By integrating fire risk maps into a fire management suite, authorities can prioritize prevention efforts in high-risk areas through targeted controlled burns, fuel management practices, and public awareness campaigns [5].

The Forest Department is performing periodic surveys recording the typical vegetation of the island and sharing these non their website (https://www.moa.gov.cy/moa/fd/fd.nsf/fd04_gr/fd04_gr?OpenDocument), publications [6],the relevant European Commission JRC EU Science platform, EFFIS and GWIS (https://gwis.jrc.ec.europa.eu/apps/country.profile/overview). However, the use of more advanced methods as described above and applied by other EU members states is limited and their implementation would be beneficial on the wildfire risk prevention.

Creating the fuel loads topography data based on the vegetation types is the biggest challenge faced by the researchers worldwide depending on the country or regions in interest. An initial step has been made as part of Task T3.3 - "Creation of Fire Management Suite for Cyprus and the Region" actions on creating fuel loads topography data for Cyprus, by creating a basic fuel models directory based on the ***Fire Behaviour Fuel Models (FBFM)*** by Scott& Burgan, created for ***FlamMap*** and ***FARSITE*** wildfire modelling tools [11]. This analysis is presented in detail in Section 6.2, which is the main contribution of this document into the preparation of the **Fire Safety Management Suite** as per the related tasks under WP3.

3.3 Fire Detection & Early Warning Systems

Early detection is critical for effective fire suppression. Traditional methods like lookout towers, forest telecommunication system and fire patrols can be supplemented by technological advancements. Additionally to the newly founded Drones-team, more examples of technological systems are: (A) Real-time satellite data analysis which can detect smoke plumes and potential fire outbreaks at their nascent stages, and (B) camera networks strategically placed in high-risk areas to provide visual confirmation and improve situational awareness for fire crews [6] [7].

Early warning systems play a vital role in disseminating timely alerts to firefighters and potentially at-risk communities. These systems can leverage various communication channels, including SMS, phone calls, and mobile applications, ensuring rapid response and evacuation if necessary.

These technological advancements can be seamlessly integrated into the proposed fire management suite for Cyprus. A real-time fire detection module, incorporating satellite data analysis and camera network feeds, would provide invaluable early warnings [7]. This early detection capability, coupled with a robust early warning system disseminating alerts through SMS, phone calls and mobile applications, would ensure swift response and potential evacuation of at-risk communities. This for instance can be achieved with a complete integration of the European emergency number 112. By embracing these technological advancements, Cyprus can significantly strengthen its wildfire management capabilities, fostering a more fire-resilient future for the island and the Eastern Mediterranean region.

3.4 Decision Support Systems for Fire Response

Fire response is a complex operation requiring real-time decision-making. Decision support systems (DSS) can be integrated into the fire management suite to assist firefighters and command centres in allocating resources effectively. These systems utilize fire behaviour models, weather data, and real-time fire information to provide recommendations on deployment strategies, resource allocation, and containment tactics [9] [10].

3.5 Post-Fire Recovering Planning

Fire management extends beyond initial response and suppression. Post-fire recovery planning is crucial for restoring fire-damaged landscapes and mitigating long-term ecological and economic impacts. A comprehensive fire management suite should incorporate tools for post-fire damage assessment, including burn severity maps generated from satellite imagery, for instance from Copernicus Sentinel-2 satellites recording the disastrous wildfires.

Furthermore, the suite could provide access to resources on post-fire rehabilitation strategies like reseeding native vegetation, erosion control measures, and wildlife habitat restoration plans [8].

The Department of Forests has in place strategies and methodologies for restoration which have been applied after an incident. These include among others the management of increased flood risk, erosion and sediment management in watercourses, protection of surface and ground water from pollution, ground preparation for planting trees if considered necessary.

4 Responsible Authorities in Cyprus

When wildfires erupt in Cyprus, two primary authorities take centre stage in combating the blazes and protecting human lives and property. The Department of Forests, has primary authority for wildfires within forests and up to 2km from their boundaries, and the Cyprus Fire Service that has the main responsibility for protecting people and the communities that might be affected during a wildfire incident.

Crucially, these two firefighting authorities collaborate closely during wildfires. The Department of Forests handles the initial response within forests, while the Cyprus Fire Service tackles fires spreading beyond the forest or in rural areas. They also extend cooperation to the Civil Defence Force and trained volunteers' members, for providing additional manpower and support during such emergencies. In severe incidents of wildfires, the Cyprus National Guard might also be asked to assist. Where communities' evacuation is needed then the Civil Defence Force along with the Cyprus Police Force are responsible of notifying and assisting people to evacuate safely.

Through the meetings scheduled during SET 2 and detailed in D3.1 - "Report on the WP3 Staff-Exchange Twinning Visits") and preparation of HOT 1, as described in D3.2 - "Report on the WP3 Hands-On Training") and participated by the IMPERIAL and EUC researchers with the Department of Forests and Cyprus Fire Service, the collaboration between the firefighting authorities was discussed. The need of improvement for preparedness in facing the future extreme wildfires due to the weather conditions and longer summer periods was also discussed, and forces expressed their willingness to participate in training seminars by experts from academic institutions and practitioners, as well as the increase of the use of technological tools for prevention and decision-making process for addressing an incident.

The basic fire management suite could act as a central nervous system, integrating training programs, as presented in HOT 1 - "Hands-On Training in the Development of Fire and Evacuation Modelling Tools" (D3.2- "Report on WP3 Hands-On Training") and preventative measures like fuel mapping. Fuel mapping could also be used on DSS level Joint training exercises and become even more effective when informed by real-time data and insights provided by the fire management suite, which could be supported by a proposed future work under relevant European Funding.

Furthermore, the collaboration of countries facing similar challenges with wildfires in the region, sharing expertise, specialised training and input data can be used for fuel mapping, wildfire prediction modelling and communities' evacuations. Ultimately, this translates to safeguarding lives, property, and precious ecosystems from the devastating effects of wildfires.

5 Integrating Training Programs

A robust fire management suite can act as a central education hub for integrating fire-related training programs. This platform would offer both in-person and remote learning opportunities, allowing participation from diverse locations. EUC researchers and other experts in wildfire behaviour and modelling would develop the curriculum, focusing on preventative measures and preparedness. The training would encompass:

As described in detail in D3.2 - "Report on the WP3 Hands-On Training", EUC researchers were trained by IMPERIAL researchers on how to develop a complete training program including basic theory, design of corelated practical training, and its validation via laboratory scale experimental procedures. The practical training could be both on the field with small scale-controlled fire demonstrations and use of modelling tools.

In the portfolio of training programs evacuation modelling and training of the fire prone communities can be added, as briefly described in Section 7 of the current document.

The success of the HOT-1 training program demonstrates the value of well-structured, professional-led training. This platform could offer targeted training modules on specific skills to each authority. For example, firefighting personnel could be trained on advance fire suppression techniques, while forestry officers can hone their expertise in prescribed burns or fuel management strategies.

Building on the knowledge gained from other Work-Packages of SEMEDFIRE, the Fire Management Suite can offer additional training programs on:

- **Using Wildfire Models in Decision Support Systems (DSS):** This future training would leverage WP3's experience to integrate model results during wildfire incidents.
- **Integrated Fire Management Strategies:** This training would be based on knowledge gained from WP4, led by WU.
- **Fire Prone Community Engagement:** This training, based on WP5 led by PCF, would equip communities with engagement plans to manage wildfire risks.
- **Land Management Strategies (LMS):** PCF, the WP5 leader, can provide expertise on applying effective LMS for wildfire prevention. This training would target authorities and communities.
- **Collaboration During Wildfires:** This training, based on WP6 led by DGSCGC, would equip firefighting authorities, civil protection, and volunteers with effective collaboration skills for wildfire response.

Trainers involved in the fire management suite should continuously update their knowledge. Continuous collaboration with wildfire behaviour experts, risk management professionals, practitioners, and other stakeholders is crucial for this ongoing learning process.

The benefits of this training platform extend far beyond the Department of Forests and the Cyprus Fire Service. Here's how various stakeholders can participate and gain value:

- **Volunteers:** Online modules can equip volunteers with basic fire preparedness and response skills, significantly bolstering firefighting efforts.
- **Land Managers:** Training on creating firebreaks, fuel reduction techniques, and early fire detection empowers private landowners and agricultural workers to be active participants in wildfire prevention.
- **Schools and Universities:** Educational institutions can integrate fire safety and awareness programs into their curriculum using the suite. This can cultivate a generation of citizens prepared to manage wildfire risks.

By integrating training programs, the fire management suite fosters collaboration and shared knowledge across all stakeholders. This promotes a unified approach to wildfire management, from prevention and preparedness to response and recovery. Ultimately, it empowers individuals to contribute to a safer and more resilient Cyprus and the Region.

6 Fire Modelling Tools

6.1 FlamMAP - FARSITE: Powerful Tools for Cyprus' Fire Management Suite

The fire management suite proposed for Cyprus can benefit significantly from incorporating ***FlamMap*** and ***FARSITE***, software developed by the Missoula Fire Sciences Laboratory in the United States. These complementary tools offer powerful functionalities for fire behaviour prediction, risk assessment, and ultimately, improved fire management strategies.

FlamMap, a spatial fire behaviour mapping and analysis program, excels at calculating potential fire behaviour characteristics like spread rate, flame length, and fireline intensity across a landscape. It analyses each pixel within a map (representing a specific location) independently, considering terrain, fuel type, and weather conditions. This allows for detailed, spatially explicit fire behaviour predictions across the entire landscape.

FARSITE, on the other hand, focuses on fire growth simulation. It incorporates weather sequences, allowing for the modelling of fire progression under changing environmental conditions. This is particularly valuable for Cyprus, where weather patterns can shift rapidly during fire season. By combining FlamMap's spatial analysis with Farsite's temporal modelling capabilities, the fire management suite could generate highly realistic fire spread simulations.

These simulations can be instrumental in various aspects of fire management:

- **Fire Risk Mapping:** FlamMap's ability to analyse potential fire behaviour across the landscape can be used to create highly detailed fire risk maps. By integrating these maps with the suite's fire risk module, authorities can prioritize prevention efforts in high-risk areas.
- **Strategic Planning and Resource Allocation:** Farsite's fire growth simulations can be used to evaluate different fire scenarios and potential containment strategies. This allows for pre-emptive resource allocation, ensuring firefighting crews and equipment are deployed to the most critical areas during a real fire event.
- **Decision Support Systems:** Integrating FlamMap and Farsite data with decision support systems within the suite can provide real-time fire behaviour predictions and recommendations for firefighting tactics. This empowers fire commanders to make informed decisions based on the specific characteristics and predicted behaviour of the fire.
- **Regional Collaboration:** Sharing FlamMap and Farsite generated fire risk maps and fire behavior simulations with neighboring countries like Greece and Israel can facilitate regional fire management efforts. This allows for a more comprehensive understanding of fire risks across the Eastern Mediterranean region, enabling coordinated responses to large-scale fire events.

However, limitations exist when using FlamMap and Farsite. Both programs rely on accurate input data, including fuel maps, topography, and weather conditions. Data quality and consistency are crucial for generating reliable fire behaviour predictions. Additionally, these pieces of modelling software require specialized training for users to interpret the complex outputs effectively.

6.1.1 Vegetation Fuel Models

Accurate and spatially explicit information on forest fuels is crucial for developing reliable wildfire models. Fuel characteristics are critical for estimating fire danger, predicting fire propagation, and modelling emissions [11]. As is well known, wildfire behaviour is a complex interplay of three factors: weather, topography, and fuel. These factors influence fire initiation, spread, and impacts.

Among these factors, fuel (vegetation) characteristics are the only ones that can be managed to some extent to reduce fire propagation. Additionally, fuel properties play a vital role in fire ignition and spread, as well as the smouldering-flaming ratio, which in turn affects fire emissions [11].

Vegetation types with similar fire behaviour are grouped into fuel types and models. Fuel types categorize vegetation based on shared characteristics relevant to fire behaviour. Fuel models, on the other hand, define the specific parameters needed to model fire behaviour, such as fuel height, load, and particle size. Fuel types can be classified as either surface fuels or canopy fuels. Forest understory and low vegetation formations are considered surface fuels, while elevated fuels, typically forest crowns, represent canopy fuels. Fires typically start in surface fuels but may transition to canopy fuels, leading to crown fires. Crown fires are more dangerous than surface fires as they release more energy, spread across larger areas, and are harder to control [12].

Therefore, fuel type mapping is an essential tool for fire risk prevention, planning, and real-time fire management across various spatial scales. It allows for the spatial characterization of a key factor that fire managers can influence. Fire scientists rely on accurate and up-to-date fuel maps to support strategic fire planning within comprehensive fire danger assessment systems. However, fuel mapping is challenging due to the high temporal and spatial variability of fuels [13].

The first step in fuel type mapping involves defining the fuel classification system to be used, which encompasses both the fuel types themselves and the associated fuel models (parameters). Many fuel classification systems have been developed, and all phases of their development process heavily involve expert knowledge, from fire suppression specialists to researchers. This is due to the high diversity of fuels, their temporal and spatial variability, and the lack of comprehensive fuel data across regions [11].

Some of the most used fuel classification systems include:

- The Northern Forest Fire Laboratory (NFFL) system,
- The Fire Behaviour Fuel Models (FBFM),
- The Fuel Characteristic Classification System (FCCS) (all developed for the United States),

- The Canadian Fire Behaviour Prediction System,
- The Mediterranean-European Prometheus system.

Many of these systems include default parameters and only focus on surface fuels, limiting their ability to prevent and manage crown fires (the most severe type) [11]. While developed for specific regions and conditions, they have been widely applied for fuel type mapping in other regions as well [11].

Fuel maps exist at various scales, ranging from continental (e.g., South America [14] and Africa [15]) to global scales [15]. In Europe, however, fuel mapping has primarily been developed for local and regional scales [16]. The only Europe-wide fuel map is the 2000 EFFIS fuel map (European Forest Fire Information System (EFFIS)), which is based on land cover and vegetation maps and uses the NFFL system. Other efforts have focused on mapping FBFM fuel models [17] at the European subcontinental scale, such as the Iberian Peninsula [13].

Due to current limitations in creating dedicated fuel maps for Cyprus – fieldwork, remote sensing, and other mapping techniques are not within the scope of Work Package 3 (WP3) or the SEMEDFIRE project in general – it has been decided to adopt the FBFM standard fuel models [17]. This system is widely used and offers flexibility. Additionally, the parameters of the standard FBFM models are the default fuel vegetation input used by FARSITE, a fire modelling software, including the moisture of extinction for each model. The parameters included in each FBFM model provide a characterization of surface fuels and can serve as a baseline for surface wildfire spread and behaviour modelling. While canopy parameters would need additional estimation, this could be incorporated into future work and potentially utilize airborne and satellite LiDAR systems [11, 13].

6.2 FBFM models for Cyprus wildfire modelling

The fuel vegetation refers to the pars of plane that can readily catch fire and contribute to the spread of wildfires. In the Mediterranean climate of Cyprus and other similar regions several types of vegetation contribute to fire hazards. As illustrated in Figure 12 the vegetation on the island are forests see Figure 13, maquis and garrigue shrubs. Depending on the latitude and exact location those differ in size and moisture of extinction.

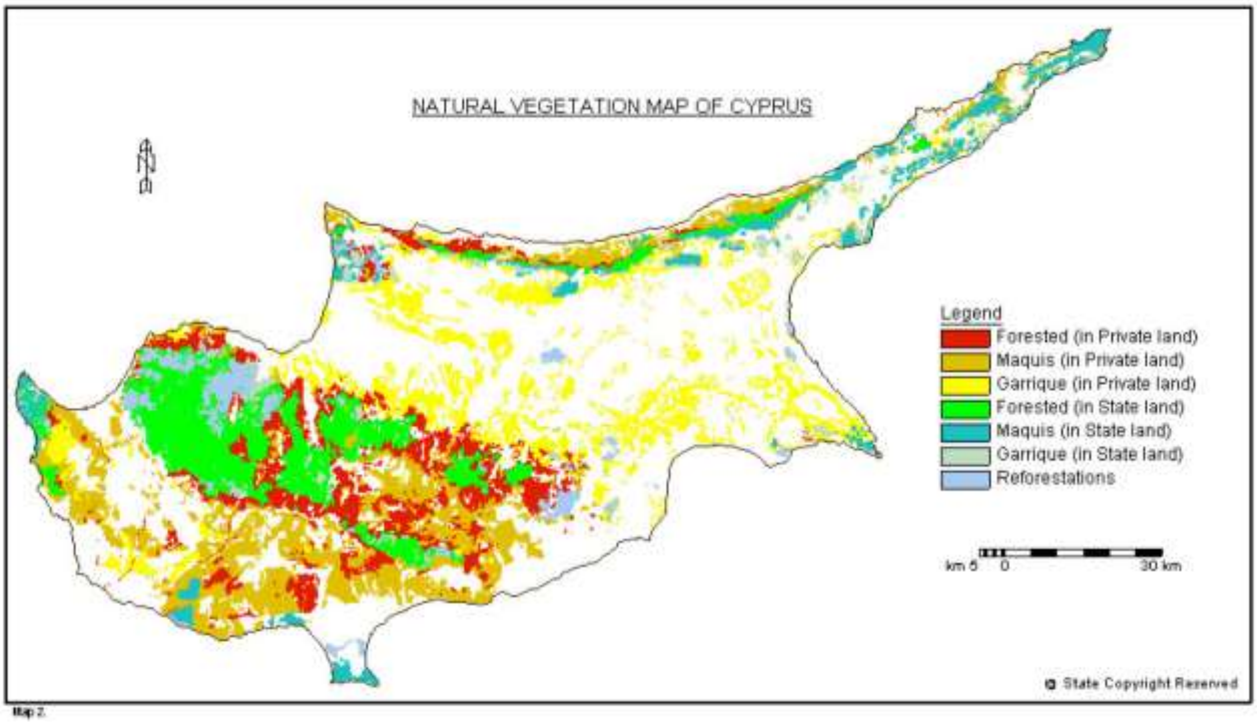


Figure 12: Vegetation types as recorded by the Ministry of Agriculture

Figure 13: National Forest of Machairas

In the forest areas dry dead leaves, needles and twigs, also known as litter, spread on the surface of the forest floor act as kindling for fire, they ignite easily and help flame reach the canopy, see Figure 14 [8].

Figure 14: Dry leaves on the forest floor

The low-growing shrublands of maquis and garrigue often contain flammable oils and resins [8]. These can form a continuous layer of fuel that carries fire quickly across the landscape, see Figure 15. Additionally, grasses and herbaceous plants can dry quickly during the hot and long summer periods and become flammable, see Figure 16 [8].

Figure 15: Maquis and Garrigue plants

Figure 16: Dry Grass

The proposed fuel mapping for Cyprus with the FBFM fuel models [17] are presented on Table 1.

Table 1: FBFM fuel models to be used for Cyprus vegetation

FBFM Fuel Model	%of use for Cyprus Vegetation	Description
NB1	5.43	Urban/Developed
NB8	0.59	Open Water
NB9	3.12	Bare Ground
GR3	29.54	Low Load, Very Coarse, Humid Climate Grass
GR6	22.28	Moderate Load, Humid Climate Grass
GS3	16.46	Moderate Load, Humid Climate Grass-Shrub
TU2	3.61	Moderate Load, Humid Climate Timber-Shrub
TL6	1.16	Moderate Load Broadleaf Litter
TL8	17.82	Long-Needle Litter

6.2.1 Data Collection

The weather and topography data are available via several national and EU platforms online with public access for all the EU member states and other countries. For instance, the European Centre for Medium-Range Weather Forecasts (ECMWF): ECMWF provides historical and forecast weather data for Europe. They offer a variety of data products, including temperature, precipitation, wind speed and direction, and humidity. Their data is available through their website, although some datasets may require registration. The required weather data could be also available by the national meteorological services.

Regarding the required topography data, including the slope, aspect and elevation could be downloaded by the EU Digital Elevation Model (EU-DEM) on high-resolution elevation data for all of Europe. This data can be downloaded for free from the website of the European Environment Agency (EEA): https://www.eea.europa.eu/en/datahub/datahubitem-view/d08852bc-7b5f-4835-a776-08362e2fbf4b.

It is important to note that the data from any resources may be available in a variety of formats, thus those should be chosen to be compatible with FARSITE's formats.

6.2.2 Arakapas Fire- FARSITE

As described previously Arakapas fire in July 2021 has caused several impacts environmental and social-economical in the communities affected. Additionally, it did reveal the challenges the firefighting authorities have overcome in large wildfire incidents. The intense of the wildfire lead to the recording of it by Copernicus and the activation of RescEU. Hence, it was considered as an adequate example for testing the selected FBFM fuel models in Table 1and provide the required training to EUC researchers.

The results of the analysis are illustrated below on Figure 17 and Figure 18.

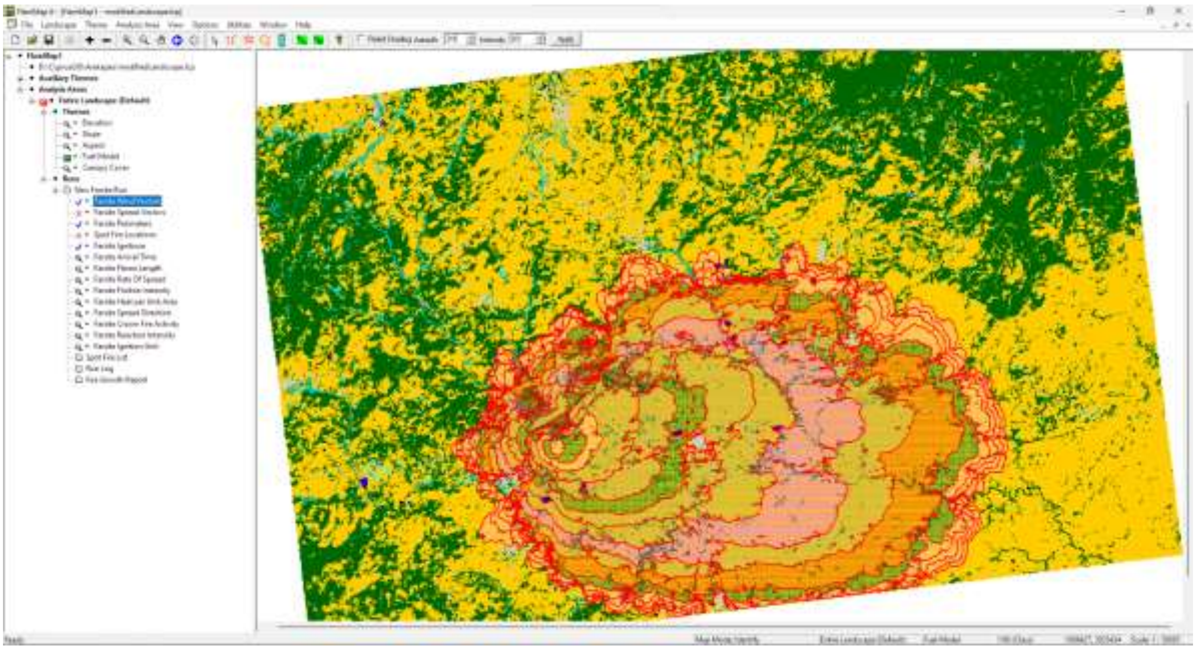


Figure 17:Arakapas Fire- FARSITE model development

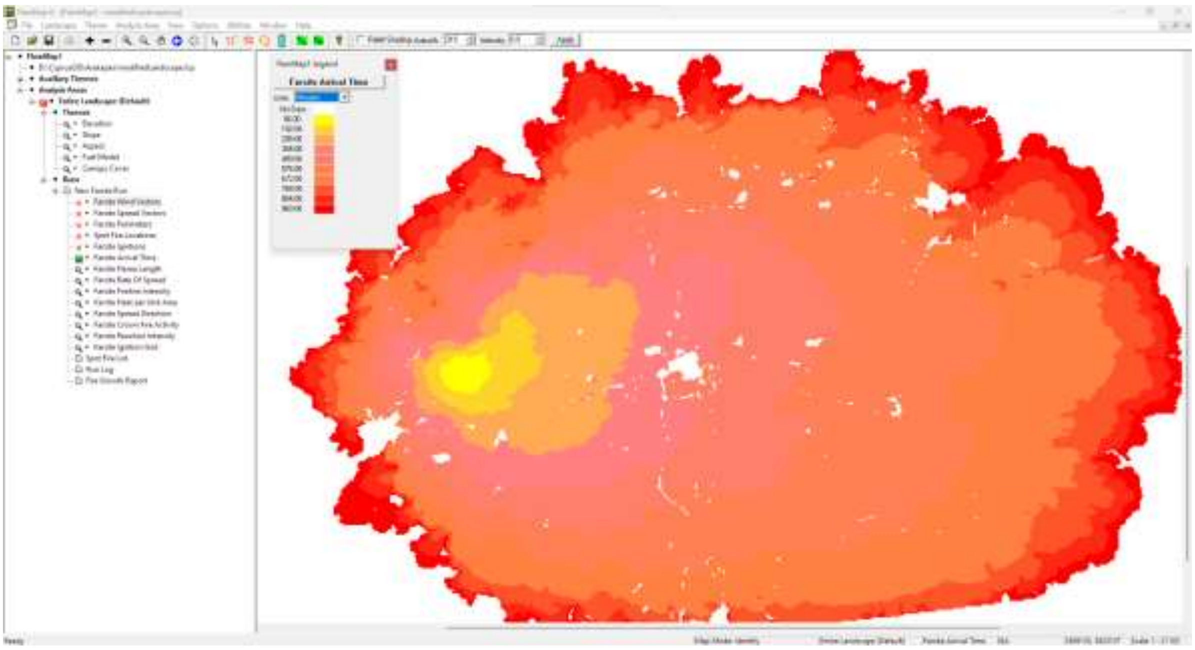
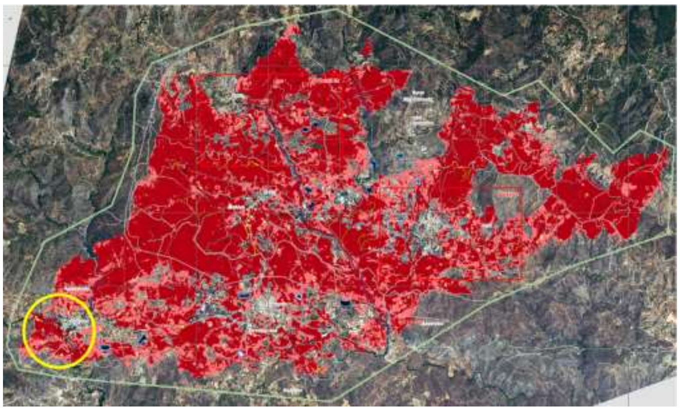


Figure 18:Arakapas Fire spread model prediction

On Figure 19 the wildfire model results with the recorded fire scar by Copernicus 2021-EMSR515 are compared. The wildfire model presents a larger fire scar extended from the fire origin compared to the actual fire scar. This can be justified because the fire-fighting means during the fire development are not considered into the model. Thus, the model is presenting the worst-case wildfire scenario for the fire duration.



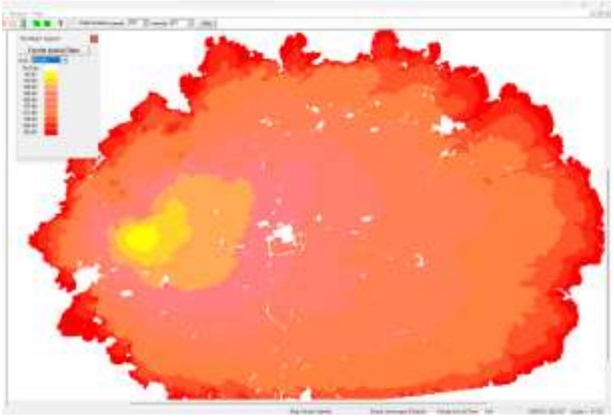


Figure 19: Comparison of Copernicus 2021-EMSR515 recording of Arakapas fire vs the wildfire model developed in FARSITE

7 Evacuation Tools

As with wildfire modelling, evacuation models use various approaches, inputs and concepts to try and simulate human behaviour. Evacuation traffic models are rare, and wildfire-coupled evacuation models are sparse. Avast minority of traffic models also consider and quantify the probabilistic nature of traffic due to the original stochastic conditions, especially so in wildfire evacuations. The wildfire progression also has an active effect on evacuation, whether that is through evacuation triggers like the smoke plume visibility, or through road blockages and limited visibility because of smoke. It is critical that specialised emergency evacuation models be developed so that the evacuation required time values and the stochastic nature thereof can be accurately predicted and quantified [18].

By coupling evacuation and wildfire models, trigger boundaries can estimate the safest time to call an evacuation. Various models have been developed to calculate the trigger boundary around a community, working with different priorities and methodologies. Most existing models are deterministic and produce one boundary based on one evacuation scenario and one wildfire; some stochastic models have been created to output probabilistic boundaries. These models render the decision-making process easier; decision makers use these boundaries as triggers to initiate an evacuation without direct calculation of the speed of the fire or the evacuation dynamics. Trigger boundaries are an invaluable tool in calculating the best times to commence the evacuation of a community under threat of an approaching wildfire [18].

Results from evacuation modelling could demonstrate the potential risks of the wildfire during the evacuation and investigate scenarios for improving the community safety based on the trigger boundaries, such as available roads and if additional are needed and to which direction, and safe assembly areas [18].

Additionally, performing trainings and evacuation drills to fire prone communities could be assisted but also provide data for the models' validation.

8 Conclusion

In conclusion, Cyprus faces a critical juncture as the Climate Crisis intensifies the threat of wildfires. While current fire management practices are commendable, a more comprehensive approach is necessary. A **Wildfire Management Suite** of tools, built on a foundation of advanced wildfire modelling, fuel risk mapping, and integrated training, offers a powerful solution.

Wildfire modelling software, integrated into the suite, will allow for a deeper understanding of fire behavior under various weather and topographical conditions. This will enable proactive planning and resource allocation. Fuel risk mapping, another key component, utilizes GIS technology to pinpoint areas with high fuel loads and susceptibility to ignition. This allows for targeted fire prevention efforts like controlled burns and vegetation management. Equally important is to develop integrated training programs targeting the needs for the Department of Forests, the Cyprus Fire Service, the Civil Defence Force, as well as volunteers and also Academics/Scholars. Collaborative training across these agencies, facilitated by the Wildfire Management Suite, will ensure seamless communication and coordinated response during wildfires.

The success of this initiative hinges on a strong partnership between the Department of Forests, the Cyprus Fire Service, the Civil Defence Force, as well as other national competent Agencies/ Services and local authorities and stakeholders. Investing in a Wildfire Management Suite that prioritizes wildfire modelling, fuel risk mapping, and integrated training is not just an expense, but rather a strategic investment indeed. By proactively preparing for the inevitable, Cyprus can build resilience against wildfires, safeguarding its people, environment, and way of life.

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