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Small reservoirs and their sustainable role in fires protection of forest resources

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ABSTRACT

The main purpose of this research is examining the compatibility of the spatial arrangement of two of the most important renewable resources: the forests and the water potential of small watercourses, based on the statistically processed data of the observed fires, territorial modeling of Fire Weather Index, the analysis and quantifying the waters needed to extinguish fires, as well as based on researching the favorability of locations to build small hydropower plants (SHPP). The research period is spanned from 2004 to 2012 and it refers to the Republic of Serbia. The results and the conclusions are valid even beyond this territory. The transactional analysis proved a firm spatial and functional correlation connection between the layout of SHPP and the pertaining small accumulations with forest surfaces in the context of decreasing fire risks, which can be used in further research as an additional benefit in defining the justification for SHPP.

With the construction of SHPP and small reservoirs and by putting them in function, less time is needed for extinguishing the fire. Also, consequential or incidental damages are diminished in the destroyed and damaged wood volume. It is reflected in the loss of protective and other functions of forests, appearance of Eolian and water erosion, degradation of forest land, roads endangerment, filling up the water reservoirs, and especially in the environmental damages that are immeasurable.

Contents

1. Introduction

A large number of forest fires and burnt areas of several thousand acres are registered every year in the Republic of Serbia. In addition to the property damage they cause, extinguishing costs, repairs and new afforestation significantly affect its final "- price." A plan to protect forests from fires, on the territory of the Republic of Serbia, stipulates water as one of the fastest and most efficient measures for the protection of forests from fire. Hence the need for small reservoirs, in the areas of large forests, especially in coniferous forests, which are more sensitive to ignition and burning due to the presence of resins and essential oils. The construction of such reservoirs would help

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with the production of renewable energy as well as in the fight against forest fires.

The forests in Serbia take up 29.1% of its territory (7.1% in Vojvodina, and 37.6% in Central Serbia), which makes it the country of average forestation [1]. Over the past 50 years, in the Republic of Serbia, a lot of forestation has been done in the areas of bare land together with the melioration of degraded stands of broadleaves. It is estimated that there are over 150.000 ha of successfully planted cultures and conifer forests [2]. The danger of forest fires increased with that trend and thus there is need for more efficient protection measures.

The fires, whether they are natural or man-made, have the same outcome: temporary or permanent loss of forests. In the course of history, strenuous efforts were put toward their control as soon as they appeared. The most important role in preventing the fires from spreading was always the timely detection; the quicker it was detected the quicker it was extinguished. Its appearance is, in most cases, sudden and people are responsible for it in 95% of the cases [3,4]. With the help of certain weather conditions, such as wind and high temperatures, they can spread quickly and compromise large areas.

Fire affects not only the site which is compromised, but it lingers in the surrounding area. Great fires can influence the climate and weather changes, and cause pollution of atmosphere [5]. Carbon-dioxide (CO2) is released, in the burning process, into the air leading to greenhouse effect, endangerment of biodiversity (flora and fauna) and poor people health (caused by smoke) [6–8]. It takes years to heal from all the consequences, and in most cases the damage is permanent.

Water is the best extinguisher for all kinds of fires if there is enough of it. The Republic of Serbia is one of those countries which are rich in water. Such potential gives the ideal opportunities for construction of small and big reservoirs, and is invaluable as a source of renewable energy [6]. Electricity and drinking water are the prime aims when constructing reservoirs. Nevertheless, they are also one of the main problems because those constructions serve one purpose only and the water, as a renewable resource, is not used enough.

For quick fire extinguishing, in its initial phase, firefighters must have an easy access to water supplies in the forests. Terrain accessibility and roads, leading to water, are the key factors in fire extinguishing. The roads are of the utmost importance, when preventing fires in forests, for they provide preventive and repressive protection. Preventive protection not only stops the fires from breaking out, but it also eliminates all the things that lead to it, as well [9]. Hence the need for constant maintenance of the road network in order to be completely usable during the fire season. Communication is also one of the key aspects in the fight against forest fires. It is vital that the local authorities are notified, as soon as possible, when a fire occurs. The fire, which is discovered at an early stage, is easier to extinguish than the one that is burning, due to lack of communication, for some time. After the fire detection and rapid information flow, firefighters can quickly reach the place of the initial outbreak and try to suppress it.

This research is focused on several aspects that refer to extinguishing forest fires. The general purpose of the research is to analyze the favorability to build and use the already existing small accumulations in forest surroundings so that the accumulated water could be used as defense in case of a fire happening. The research also has the following specific aims that relate to the analysis of the forest fires in the Republic of Serbia from 2004 to 2012, that clearly shows how big the fire affected areas are and that there is a need for a long term planning of water sources for the fires to be extinguished and also to point to the implementation of the forest preservance methodology that could help to a substantial prevention of fire occurrences and their spreading.

That is why the main aim of the research is to examine the compatibility and justification of the strategy to develop two important renewable resource at the same time: the forests and the water potential of small watercourses, based on the statistically processed fires, sorted by regions in Serbia, territorial modeling of the fire risk assessment (Fire Weather Index), analysis of water supplies to extinguish fires and examining the favorability of locations to build SHPP. Damages caused by fires are quantified by regions, by the number of fires, the fired area (ha) and the damaged felled timber (m^3). The analysis and the calculations were done for both state and privately owned forests [10], since both sector represent the natural wealth of renewable resources of the biomass that is of general interest.

2. Materials, methods and criteria

Based on the collected data Statistical Office of the Republic of Serbia and the Republic Hydrometeorological Service, a number of forest fires has been noted from 2004 to 2012 in state and private forests, fired areas, damaged felled timber and assessment has been done regarding the hazard of forest fires occurrence. Possible locations for the construction of small reservoirs with multiple purposes (protection against erosion, sediment retention and flood protection, water, fishing, etc.) were named, based on data taken from scientific papers on coniferous stands [11] (which were artificially planted and have already been mentioned as the most endangered). They also used the data from the cadastre of small hydropower plants (SHPP) as a possible convenient location for water use in the event of a forest fires.

When collecting the data in the Republic of Serbia, non-reactive method and its basic techniques was used as a specific scientific method for this research: content analysis or the observation of documents and the use of existing statistics, documents and their secondary analysis [12].

Table 1
Classification of FWI values (Fire Weather Index FWI) according to the Canadian system for determining the danger index of forest fires used by Republic Hydrometeorological Service of Serbia [16].

FWI—Interpretation of classes	
Very Low	There are no favorable conditions for fire ignition and the possibility of ignition is slight. If the fire occurs, it spreads slowly or extinguishes. Very little burning material is caught in fire and it is mostly the upper ground layer.
Low	Ignition can occur by lasting fire source, like the camp fires. Fire spreading through the woods is slow and medium in open areas. Thus, only leaves burn in small surface (low) fire with weak flames. Fire control is achieved easily and swiftly, so that less effort is needed for fire extinguishing.
Moderate	Fire control is not difficult, if the action is fast. A match can cause fire. Fire spreading is medium within the woods, but swift in the open area. The fire burns on the surface in medium flames.
High	A match can always cause fire and it spreads fast. Fire can be very hot when transported to the foliage of the trees. A lot of organic mass burns out. Fire control is very difficult.
Extreme	Fire can be ignited by a spark. Spreading of the fire is very fast. Fire is very swift and spreads to tree foliage in wider areas. Organic matter starts to burn in deeper layers and normally wet locations. Fire control is extremely difficult. In fire control, extraordinary efforts must be exerted and all available means employed.

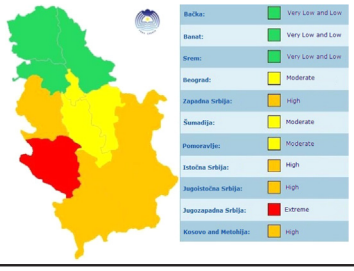
Certain criteria, when selecting the most suitable locations for the construction of small reservoirs [13], were identified: the water should flow throughout the whole year and should not dry out, the cross section should be as narrow as possible and the fall of the longitudinal profile as small as possible, the profile above, if possible, should have an extension for the greater water accumulation, the riverbed should not have too much silt, catchment area next to the profile should not be too big, the profile should be accessible and well connected to the road network, the location should be close to forest plantations [14].

3. Results and discussion

3.1. The meteorology implementation in the forest protection against fire

The Republic Hydrometeorological Service of Serbia uses a Canadian method for assessing the danger of forest fires. It is determined based on the index of the danger of forest fires (Fire Weather Index, FWI) [15]. The method is based on the assessment of forest flammability of combustible materials in accordance with the current and past weather conditions. Factors that influence the risks of forest fires are: air temperatures, wind speed, relative humidity and rainfall over the past 24 h. The aim of this method is organized fire protection of forests throughout the territory of the Republic of Serbia. Tables 1 and 2 show the risk index of forest fire occurrence Fire Weather Index, according to the Canadian FWI model.

Table 2
Daily index prediction based on the risk of forest fire occurrence [16].



3.2. Forest fires in the Republic of Serbia for the period 2004–2012

The greatest numbers of fires occur during the spring and summer, during the dry season.

According to data Statistical Office of the Republic of Serbia [17] for the period from 2004 to 2012, on the territory of the Republic of Serbia, there were a total of 898 forest fires in the state forests, or an average of 99 fires per year. At the same time, taking private forests into account as well, the fired area amounted to 34,693 ha, or an average of 3854.7 ha per year with the damage of 105,754 m^3 to the felled timber. The years of 2007 and 2012 were extremely hot in Serbia which led to a great number of fires. The data, which are presented in Table 3, clearly indicate that much more attention should be given to forest fires. They show that a large number of fires have caused, over the years, an irreparable material and environmental damage, and that there is a huge need for water as a natural extinguisher.

According to recorded data on forest fires, and their most common occurrence, from 2004 to 2012 in Central Serbia and Vojvodina (Table 4) and fires from 2010 to 2012 in the regions—Belgrade, Sumadija, West Serbia, South and East Serbia and Vojvodina (Table 5), the following location for the construction of small multi-purpose reservoirs can be proposed.

3.3. The need of water for extinguishing a forest fire

It is very difficult to determine, exactly, the amount of water required for extinguishing any forest fire. It depends on numerous factors such as: the type of fire (underground, surface, or high), the size of the affected area, season, weather conditions, the type of the burning wood (broadleaves or conifers), terrain, accessibility of the place of fire, support from the air (airplanes or helicopters for firefighting) and so on. There is very little research that have been done on fire extinguishing, where water is used as the primary agent, about how much water there is and the water supply needs to put

Table 3
Damages caused by forest fires in Republic of Serbia in period 2004–2012 according to data Statistical Office of the Republic of Serbia.

Year		2004	2005	2006	2007	2008	2009	2010	2011	2012	Total	Total State and Private Forests
Number of fires	State forests	50	11	47	328	48	41	26	65	282	**898**	**898**
	Private forests	–	–	–	–	–	–	–	–	–	–	–
Fired area, ha	State forests	115	30	348	7801	423	253	280	707	5108	**15065**	**34693**
	Private forests	87	22	146	14360	152	957	223	1329	2352	**19628**	
Damaged felled timber, m^3	State forests	310	430	1073	3157	5996	1897	16	21740	30377	**64996**	**105754**
	Private forests	1192	98	7	2661	1153	35	41	2830	32741	**40758**	

Table 4
Damages caused by forest fires in Republic of Serbia in period 2004–2009 in Central Serbia and Vojvodina according to data Statistical Office of the Republic of Serbia.

Region	Year		2004	2005	2006	2007	2008	2009	Total	Total State and Private Forests
Central Serbia	Number of fires	State forests	38	11	43	301	43	32	**468**	**468**
	Fired area, ha	State forests	83	30	314	7640	315	221	**8603**	**24327**
		Private forests	87	22	146	14360	152	957	**15724**	
	Damaged felled timber, m^3	State forests	1502	430	1056	2266	5119	1897	**12270**	**17416**
		Private forests	1192	98	7	2661	1153	35	**5146**	
Vojvodina	Number of fires	State forests	12	–	4	27	5	9	**57**	**57**
	Fired area, ha	State forests	32	–	34	161	108	32	**367**	**367**
		Private forests	–	–	–	–	–	–	–	
	Damaged felled timber, m^3	State forests	–	–	17	891	877	–	**1785**	**1785**
		Private forests	–	–	–	–	–	–	–	

Table 5
Damages caused by forest fires in Republic of Serbia in period 2010–2012 by Regions according to data Statistical Office of the Republic of Serbia.

Region of	Year		2010	2011	2012	Total	Total state and private forests
Belgrade	Number of fires	State forests	–	–	20	**20**	**20**
	Fired area, ha	State forests	–	–	55	**55**	**61**
		Private forests	–	–	6	**6**	
	Damaged felled timber, m^3	State forests	–	–	–	–	–
		Private forests	–	–	–	–	
Sumadija and West Serbia	Number of fires	State forests	20	35	96	**151**	**151**
	Fired area, ha	State forests	277	480	1316	**2073**	**3285**
		Private forests	20	272	920	**1212**	
	Damaged felled timber, m^3	State forests	16	15320	29497	**44833**	**77026**
		Private forests	8	950	31235	**32193**	
South and East Serbia	Number of fires	State forests	–	20	95	**115**	**115**
	Fired area, ha	State forests	–	214	3510	**3724**	**6410**
		Private forests	203	1057	1426	**2686**	
	Damaged felled timber, m^3	State forests	–	5904	785	**6689**	**10108**
		Private forests	33	1880	1506	**3419**	
Vojvodina	Number of fires	State forests	6	10	71	**87**	**87**
	Fired area, ha	State forests	3	13	227	**243**	**243**
		Private forests	–	–	–	–	
	Damaged felled timber, m^3	State forests	–	516	95	**611**	**611**
		Private forests	–	–	–	–	

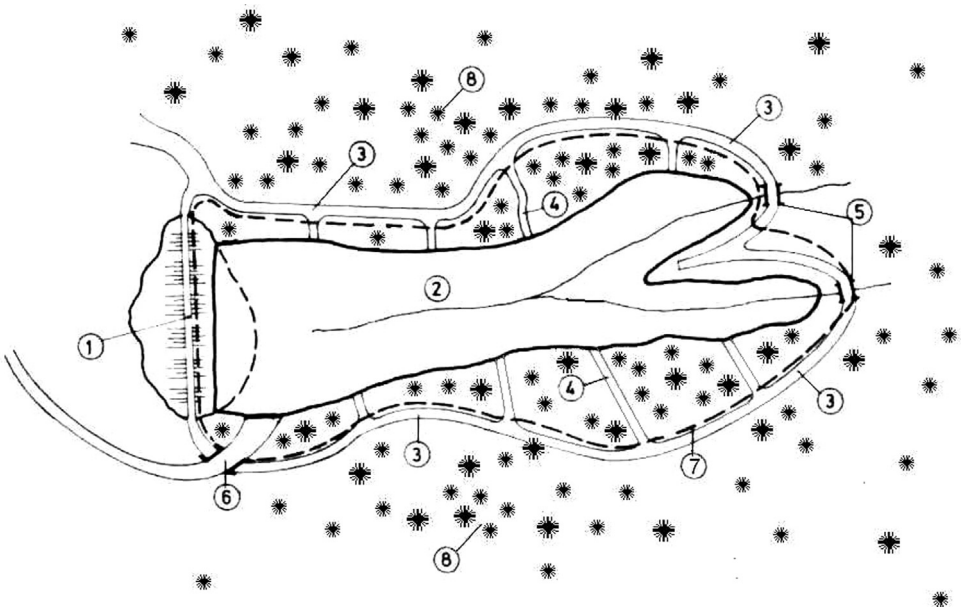


Fig. 1. Schematic view of small reservoirs in forest ecosystems (1 dam, 2 reservoirs, 3 path around the reservoir, 4 access paths to the reservoir, 5 culverts in watercourses, 6 the bridge on weir, 7 the maximum water line, 8 forest). Adapted from [32].

out the forest fires. Water is a highly applicable medium, not only for putting out fires but also for fire prevention and fire spreading. Its main advantages are in low price, cooling effect and availability in nature. Hansen [18] emphasizes that determining the water supplies needed to put out forest fires depends on the various types of combustible materials and observing the length of the flame and the size of the active zone of burning, while some authors [19,20] base their statistic data about the water supply needed to put out forest fires on the fire department statistics. According to data from Wildland Fire Suppression Tactics Reference Guide (1996) [21], if the fire is extinguished at a distance of 200 m from the road, water jet from a hose connected to the tank, is used with the assistance of backpacks, while with the fire in rough terrains, in addition to aviation aid (if any), backpacks are used exclusively. 12 people with 6 backpacks should make one unit for extinguishing forest fires. Backpack should hold from 15 to 25 l of water. Full jet range is 5 m and it spreads to 10 m, while its capacity is 2–3 l/min, which means that one unit of fire extinguishers should be provided with 12–21 l/min. There are also a variety of pumps with reservoirs built on the small terrain vehicles. The distance of water transport and the effect of extinguishing the fire depend on their power.

3.4. Location convenience for the construction of small reservoirs

Technical literature has not uniformly adopted the terminology on small reservoirs or micro accumulations, micro retention, retaining structures, etc. According to FAO organization terminology (Food and Agriculture Organization – service for land and water usage) [22] artificially accumulated water supplies, mainly from dams and embankments of earth, should fall into small reservoirs, where accumulation should not have volume larger than 3,000,000 m^3 and 100,000 m^3 volume of the dam. If the volume of accumulated water is below 50,000 m^3 then it is micro retention, where the volume of earth dams and embankments should not exceed 15,000–

20,000 m^3. In the case of micro retention with the volume below 10,000 m^3 of accumulated water, and the volume of earth dam or embankment below 3000 m^3 we get a pond. When some authors Maarten, Cao and Lineu [23–25] talk about small reservoirs they think of artificial lakes with the volume of up to 1,000,000 m^3.

When building the reservoir downstream the dam, a guaranteed flow rates, necessary for the survival and development of downstream biocenosis, must be provided (waterworks minimum). Quantities of water, discharged from reservoirs, must not be less than the quantities needed for downstream ecosystems. They must meet rational needs of downstream water users and conserve the prescribed river quality [26]. Areas with water sources and nature under protection must not be used for the reservoirs construction. The study of the impact of changing water regimes on watercourse flora and fauna must be carried out. Neither small reservoir should be built on a large basin, nor a large reservoir on the small basin. It is further stated that the small reservoir on a large basin would quickly be inundated by both tracted and suspended sediment. Also, by building a large reservoir on the small basin another problem would emerge—the reservoir could never get filled up. Given the relatively small volume of water, small reservoirs do not have too much negative impact on the environment. When compared to large reservoirs there is neither flooding of wide areas nor damaging the surrounding ecosystems. The negative impact of small reservoirs can only be reflected in their construction, in the cutting of a small number of trees, in order to obtain the surface for future accumulation and accessible forest roads. The reservoir which is not accessible by a motor vehicle cannot be used extensively. So, some changes, which can affect the environment, are necessary during the construction. As a rule, the small reservoirs are built to solve local problems: the protection from torrential water, irrigation, ponds' forming, recreation, making of artificial snow, and can be used for energy purposes [27]. In Serbia, there are sites that, without any additional interventions, meet all the necessary conditions for unimpeded use of water for extinguishing forest fires (e.g., well of the river Mlava).

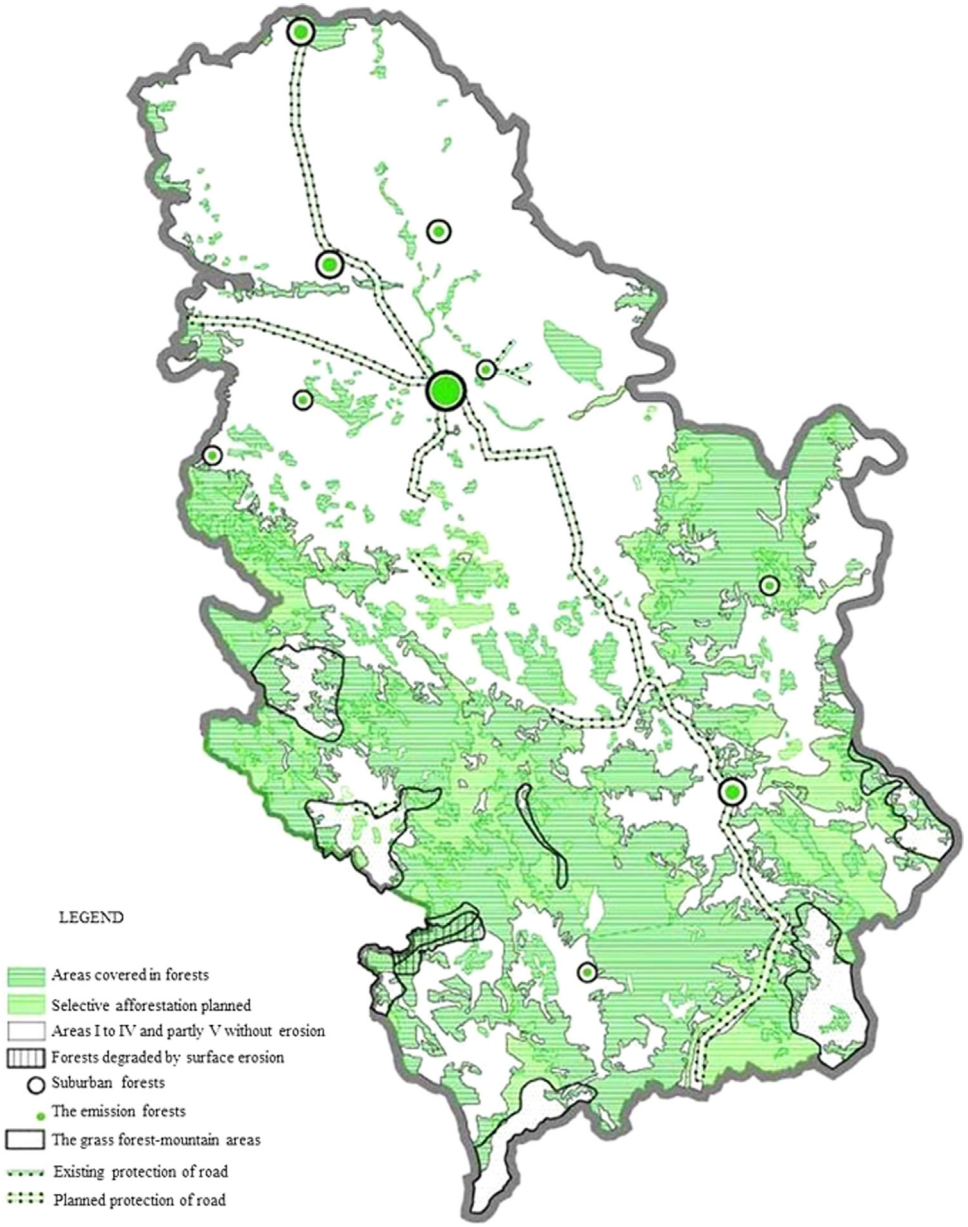


Fig. 2. The map of rearranges forests in Republic of Serbia. Adapted from: Spatial Plan of the Republic of Serbia [36].

Small reservoirs are an integral part of planning a water basin. When designing and determining the construction site and its role in the watershed, certain phases can be singled out: determining the purpose of the reservoir, selecting the location in relation to future users, technical characteristics of the reservoir and dam, the dynamics of implementation.

Having in mind the areas where afforestation over large areas was carried out and where the danger of forest fires is huge, the convenient locations, for the construction of small reservoirs, should be chosen. Their purpose would be rapid and efficient extinguishing. When selecting the most suitable location for the construction of small reservoirs with the purpose of extinguishing a forest fire, you should consult the experts in the field of water management and forestry. Their knowledge of the terrain, on which water for extinguishing fire is accumulated, is by far the best. Looking at the areas that were afforested over the last decades, some locations for the construction of small reservoirs can be pointed out. Areas afforested with Austrian pine (*Pinus nigra*) and Scots pine (*Pinus sylvestris* L.), which is most often used in reforestation of most unfavorable terrain, have been of particular importance. The largest part of the pine cultures in Serbia was built on treeless terrain of hilly and mountainous areas, where water erosion is the main factor of soil degradation. Bearing in mind that the black and white pine species that are especially demanding regarding their habitat (this especially refers to Austrian pine), they can be successfully used when afforestating the land that lacks nutrients [2,28,29]. The total area of artificially planted stands—coniferous stands in Serbia (excluding Kosovo) is 124,800 ha, of which pine trees occupy 86,000 ha or 68.9% [30]. The first major afforestation in Serbia started in Uzice region in the mid 20th century, followed by the Ibar gorge, Pester plateau, Vlasinska area, Grdelica Gorge and other extremely degraded areas [31]. A big part of the Serbia, which is now afforested, was once a

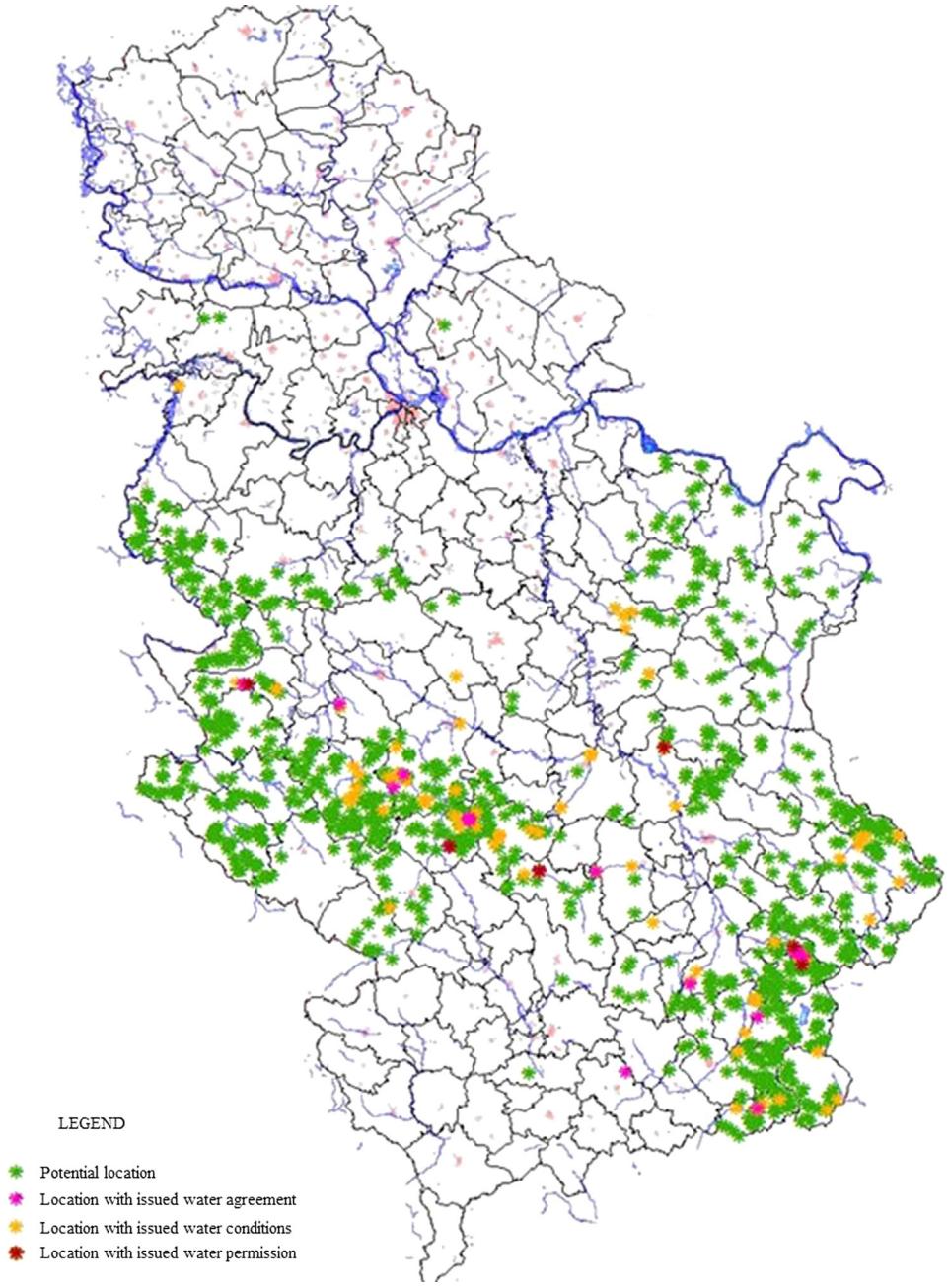


Fig. 3. The map of small hydropower plants in Republic of Serbia. Adapted from: VIS—Water Management information System [37].

barren land, i.e. the treeless terrain. Therefore, these sites, due to the inaccessible terrain, stand out as the most vulnerable by fire and in need of water for fire extinguishing. Of course, broadleaves forests are not excluded from the risk of fire too, especially during the season of high temperatures, and the locations for the construction of small reservoirs are required in all forest areas where there is no presence of major water sources.

In Fig. 1 you can see one small reservoir with all the necessary infrastructure for its functioning and uninterrupted use when extinguishing the forest fire.

There are opportunities to build a number of small reservoirs on the territory of Serbia. Their locations are precisely defined in the 1987 cadastre made by Energoprojekt–Hidroinženjering in cooperation with the Jaroslav Cerni Institute for the Development of Water Resources. The cadastre of small hydropower plants (SHPP) on the territory Republic of Serbia without AP Vojvodina [33], contains information about locations that are suitable for the construction of small hydropower plants and whose purpose may be multiple. It contains data on 856 suitable locations for the construction of SHPP. Locations are generally found in mountainous areas of inaccessible terrain, which indicates that these reservoirs, in addition to the basic purposes, would be used for extinguishing fire, water supply, fisheries, etc. Currently, there are 39 small hydropower plants and more than 100 small reservoirs with various purposes in Serbia [34]. By comparing the map of rearranged forests in Serbia (Fig. 2) to the map of small hydropower plants (Fig. 3), it can be noted that by constructing of SHPP, on potential locations, a large forest area would be supplied with the necessary water. That water would be then used in fight against the forests fires. SHPP with reservoirs would be the most helpful. The derivational and the flow type of SHPP are also considered useful in putting out forest fires, because water can be taken from both accumulations and other belonging facilities such as: water intake structures, power intake canals [35], surge tankes and/or outlet structure, because these are basically places where small reservoirs (tanks) are formed. This is why the identification of the projected location for SHPP is justified, no matter the type, with potential places to take water needed for putting out fires.

Transactional analysis of the spatial arrangement of forest resources and SHPP shows that in Serbia there is a high correlation degree between the two renewable resources. Even the region with the highest FWI degree (see Table 2) matches the zone where the majority of the planned small accumulations and SHPP are, which proves the usability of small reservoirs and SHPP, not only in renewable resources, but also as a significant factor in preserving the renewable forests from fires.

4. Conclusion

It can be concluded that the forest and water potentials of small watercourses as two valuable renewable resources are not significant for the research only individually, but that there is a strong spatial and correlational connection which can be used to prevent fire risks. Based on statistic analysis of the observed fires (ones that took place) and based on the territorial modeling of the fire risk assessment and Fire Weather Index and the analysis of water requirements to extinguish fires and examining the favorability of locations for building SHPP, an overlapping in location (area), forest resources, SHPP and WFI has been proven, which should be one more reason in the further research of the justification to build SHPP to direct the means in research and invest in faster development of SHPP. The water potential (hydro potential) of small watercourses is a renewable resource whose utilization at the same time provides the sustainability of another resource-that of forests. The factor of the potential protection against fires should, in the future research of the optimization cost/benefit analysis of SHPP development, be and could be counted in as an additional benefit. It strengthens the function of sustainability of both resources.

Starting from the fact that forest fires destroy forests which are difficult to renew, that they decrease the forest areas and disturb the natural balance leading to the destabilization of the ecosystem finally they can represent a major danger for man in a substantial degree. Likewise, forest fires cause major material loss and cause ecological consequences due to what, it is of great importance to determine locations, do all preparations and ensure the access to water supply sites, so these influences could be reduced to the smallest possible degree. Along the watercourses, in the areas of endangered forests, the most suitable places for the construction of small reservoirs should be chosen. This way, the unit for extinguishing fires would be more efficient. The efficiency and the speed for extinguishing the fire would be significantly increased by reducing the distance from the reservoir to the site of a fire. Their construction would affect and reduce the displacement of the population in mountainous area due to the possibility to use water for other things (for drinking, irrigation, etc.). In the forthcoming years, one should think about the areas that will be afforested and where there will be a need for water.

Taking into account the layout of forests, the locations with small reservoirs should be put on maps, so that extinguishing of fires, if it comes to it, may be as efficient as possible. It is also necessary to conduct a detailed audit of locations, included in Cadastre SHPP, in order to determine the precise list of feasible locations for the construction of small hydropower plants. There may be some deviations due to changes in hydrogeological conditions or in the state of building construction and infrastructure, changes in the arrangement and use of space. Sometimes it is impossible to build SHPP [38].

Given that the damages and later cost caused by forest fires can be divided into damages caused by fires (on the trees, seedlings, infrastructure, etc.), the cost of fire extinguishing (hired manpower, machinery, etc.) and the cost to recover the destroyed forest (cost of creating recovery plans, clearing the fire affected areas, planting new seedlings, etc.), in the future we must make an extra effort to prevent, detect and suppress forest fires in order to minimize their harmful effects on forests and the environment.

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