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Full Length Research Paper

A conceptual model of forest stand hydrologic effect: Potential application in the forest management practice

Sinan Destan

Department of Forest Management, Faculty of Forestry, Istanbul University, 34473 Bahcekoy/Istanbul/Turkey.
E-mail: destans@istanbul.edu.tr.

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The objective of this illustrative study was to obtain realistic data about the age and period of hydrologic maturity of forest stands in order to use these indicators for planning the forest management activities in water catchment basins located to the north of Istanbul. On the basis of data and aggregate data summaries obtained from numerous studies in Central Europe, the Balkans, Southern Ukraine, the lower forest vegetation zone of Caucasus, and Northern Asia Minor, the first stage of the study involved the development of a hypothetical hydrologic water budget model of the dominant tree species in the studied forests. The next stage was to calibrate this model using data from specific climate, hydrologic and soil studies in the area under investigation. The third stage covered the comparison between the actual and optimal age stand structure in the studied catchment area, and these were used to calculate several variants of hypothetical water yield. On the basis of the upper limit of the period of hydrologic maturity and the forest management analysis made, the harvest rotation of the hydrologic forest management class was determined. The final part of the study used the already determined period of effective precipitation and dynamics of soil moisture during the growing season to make recommendations for the forest management practice in the studied area.

Key words: Forest management, water yield, temperate zone.

INTRODUCTION

Forest management can impact the water cycle through changes of the vegetation cover. The smallest element of impact, silviculturally speaking, is the individual tree; on the level of plant succession, it is the “simple forest”; and from the viewpoint of forest management – the forest stand with its composition and structure. All these elements have an impact of their own, and, to a certain degree, have an impact on the total hydrologic forest stand effect. Using them together with other important indicators such as climate norms, frequency of characteristic meteorological phenomena, relief, the body of sound reference materials and regulations as well as the results of conducted studies makes it possible to assess the approximate hydrologic suitability of a given stand. In practical terms, assessing this suitability allows to determine the optimal conditions for the water cycle of forest ecosystems. From a practical point of view, this also means that a functional stand structure is achieved in both hydrologic and economic aspects. This functional structure is different for each stand age class which, therefore, has a different hydrologic effect. Forest hydrology has termed the stand age that ensures maximum water yield “age of hydrologic maturity”, and the period of time characterized with the highest water yield – “period of hydrologic maturity”. The specific hydrologic maturity within one year is difficult to determine. For this reason, it is accepted as a short period of 10 to 15 years. The same is true of the period of hydrologic maturity whose lower and upper limits may vary even within one age class.

Due to the lack of data about the age and period of hydrologic maturity, the loudly announced “functional planning” implemented in many forest stands remains, in essence, “functional zoning” (allocating territories for particular use of their forest resources). It stands to reason that in order for the product of forest management activities to be considered a “plan”, reference materials and regulations should be used. For example, the management of drinking water protection areas in Bulgaria has led to the adaptation of special regulations, guidelines and instructions which establish specific rules for research activities and forest management practices

(Nedyalkov and Raev, 1988). With the help of a specially designed classification scheme (Raev et al., 1980) the drinking water and soil protection class of each forest stand, plot and whole catchment area is determined. Similar regulations exist in many Central and Eastern European countries, USA and some countries in North Africa and Asia (Rules and instructions for development of water catchment forests – eg http://www.fao.org/docrep/; www.aseanforest-chm.org/.../annex_2_forest_management_planning_rules_uidelines_state_forest_management_plan.pdf; nepis.epa.gov/Exe/ZyPURL.cgi). They are a valuable achievement which is a result of extensive studies. It is true that they allow the implementation of hydrologic zoning, the classification of areas on the basis of their soil and water protection significance, and the establishment of criteria for sustainable conservation of the environmental forest functions on the basis of the different levels of human intervention.

However, these activities do not directly “assess” the hydrologic effect of forests. This is so because their results have been obtained with the help of general recommendations, instructions and guidelines. However, similarly to the way any other forest management plan is developed, this practice applies forest management methods (age classes, diameter classes and etc.), but these do not account for hydrologic maturity. Strictly speaking, the lack of data about stand hydrologic maturity makes it impossible to calculate scientifically-grounded weighted average age and period of hydrologic maturity, rotation of hydrologic forest management class, optimal levels of timber harvest by area etc. Silviculturally, it is impossible to determine the stand’s target structure without which the optimization of any forest function cannot be carried out. The same problems occur when determining the optimal parameters in selection forests, which are thought to be the most suitable, as water protection forests in view of their form and structure (Raev et al., 1980). There are similar problems with the forest management method based on individual stands etc. Due to the complex nature of the hydrologic processes taking place in the diverse forest ecosystems, forest hydrology is still not capable of producing a sufficient number of similar models for practical purposes as the yield tables used for timber production. Undisputedly, hydrologic studies are empirical in nature and, therefore, long-term. The results of these studies usually show the hydrologic effect of the studied forest stand – but only for a given age class and condition. The lack of information for the other age classes makes it impossible to determine the two required indicators: age and period of hydrologic maturity.

To overcome these problems – or to put it more precisely – to “get round” them, the following approaches have been adopted: hydrologic modelling of catchments (Running and Coughlan, 1988; Cannata, 2006; Koike, 2010; Yu, 2010) spatial and temporal analysis (White and Running, 1994; Razavi and Tolson, 2010), integrated river basin management (Kojiriet et al., 2010), use of satellite imaging, geostatistics and geographical information systems (GIS, ArcGIS and ArcHydro), or Hydrologic Information System (HIS) supported by climatic databases (Dominique et al., 2010; Lee, 2008) or geological and edaphic databases (Su, 2010; Li, 2010; Thorne and Woo, 2010; Muerth et al., 2010). The models can be used for forecasting and keeping track of complex hydrodynamic processes in river catchment systems at a regional level. There are various methods which can be applied in order to find a suitable balance between timber production and water protection, including simulation and mathematical programming. However, as Gadow and Yan Hui (2008) argue, highly sophisticated modelling approaches are not necessarily more effective than simpler ones. What is more, is that they do not meet the requirements of forest management as well. The objective of this illustrative study was to obtain realistic data about the age and period of hydrologic maturity of the targeted forest stands, in order to use these indicators for planning the forest management activities in the studied water catchment basin.

The object of study

The object of study is Bentler Forest district which is part of Belgrade forests located just north of Istanbul with a total area of 2,622.07 ha and the following Greenwich coordinates: 45°58′ - 45°66′ N and 28°56′59″ - 29°01′04″ E (Figure 1). The area consists of low hills with an average altitude of 140 m and a wet climate ($I = 61.3$), very similar with regard to precipitation amount to the maritime climate, but with much wetter winters and semi-dry summers ($I_a = 21.9$). The average annual precipitation is 1.083 mm, and the mean annual temperature is 12.7°C. The prevailing winds, ranked by priority, are from the north, northeast, southeast and south (Destan, 2001). The object of study are 6 catchment basins with a total area of 1.779 ha (Table 1). The calibrated hypothetical water budget model was applied to 183 stands grouped in 32 types. Their area distribution by age class (with intervals of 20 years) is shown in Table 2. The main tree species are oak (*Quercus ssp*), eastern beech (*Fagus orientalis* L.) and considerable quantities of hornbeam (*Carpinus betulus* L.) and sweet chestnut (*Castanea sativa* Mill.). Considering their species composition, the stands are pure or mixed. There are also coniferous stands of the introduced Austrian pine (*Pinus nigra* Arn).

METHODS

The first stage of the study involved the development of a hypothetical hydrologic model of the water yield of the main stand-forming tree species found in the studied forests. For this purpose, all the available data obtained from forest hydrologic studies of the temperate climatic zone (mainly the zone of the Black Sea, the Balkans and Central Europe) had been used. The hypothetical

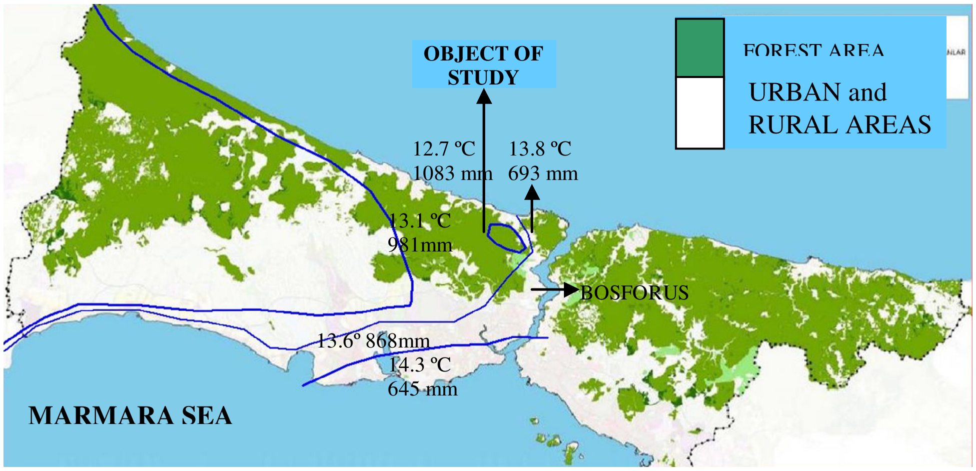

Figure 1. Location of the object of study.

Table 1. Water catchment basins in the studied area and their hydrologic measurements

Catchment	Büyük	Kömürcü	Kirazlı	Valide	II. Mahmut	Topuzlu
Area (A) (ha)	714	455	262	181	80	78
Stream frequency (A/Ns)	7.68	4.62	4.95	7.18	4.98	6.40
Total stream length (L) (km)	12.71	15.54	5.63	3.99	1.77	0.91
Drainage density	2.79	2.18	2.14	2.20	2.20	1.16
Catchment length (L) (km)	2.53	3.60	2.06	1.78	1.41	1.35
Form factor (A/L^2)	0.71	0.55	0.62	0.57	0.40	0.43

Table 2. Distribution of the studied stands by age class.

Age class	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Area (ha)	45.2	98.2	132.7	122.7	254.7	106.7	127.7	290.2	276.7	272.2	0.0	0.0

model was developed differentially using the following water budget elements: total annual precipitation P (%); throughfall P' (%); stem flow-Fga (%); effective precipitation-(P'+Fga) P'' (%); Interception-Ei(%); evaporation-Es(%); transpiration-Et(%); evapotranspiration-Ev(%); surface runoff (biotic) 10-20º Fov(%); infiltration-$Finf$(%); subsurface flow and ground flow - * Fg (%); soil moisture change coefficient-(0-50 cm)(1/n) $W(50)$, (0-100 cm) (1/n) $W(100)$, (0-150 cm) (1/n) and $W(150)$; soil moisture change coefficient (total)-(1/n) $W(Tot)$; litter layer moisture content potential WII(coef) = (t/ha) * (g/cm^3) *Wöö*(*coef*); litter layer moisture content/permeability coefficient - (*t/ha*) * (g/cm^3)* *Por*(%)*(*mm/s*). The role of each element in the water budget was established on the basis of the summarized conclusions of hundreds of studies conducted by dozens of authors. Using such studies, Nedyalkov and Raev (1988) and Raev et al. (1980) made final summarized conclusions, and established the approximate average, minimum and maximum values for various tree species.

Preference in this study was given to only statistically significant forest hydrologic studies. When there was a lack of data about a water budget element for a given age class or classes, graphs were produced in order to analyze the course of the effect for the respective age class. After excluding the extreme values, the respective interpolations were made. The data used for the analyses was obtained from hydrologic studies carried out in the semi-mountainous and lower forest areas of the South Caucasus and the eastern (Bityukov, 1972; Koval and Bityukov, 1973) and southern coast of the Black Sea (Ozturk et al., 2001; Korkanç, 2006; Hizal et al., 2008), the lower semi-mountainous and hilly regions of the Southern Balkans (Nedyalkov and Raev, 1988; Raev et al., 1980; Mandev, 1998) which are similar to the climate and relief of Belgrade forests. Next, the obtained values for the elements were compared to the aggregate results obtained by Nedyalkov and Raev (1988) of a higher rank: total evaporation, average annual soil moisture, total runoff, water budget of whole forest ecosystems by tree species. The aim of this comparison was to avoid grave mistakes and fundamental discrepancies from the viewpoint of forest hydrology. At the same time, in order to find out the effect of tree canopy cover on water budget elements, a number of studies on different trees species were used; their summarized results were obtained from Nedyalkov and Raev (1988), Gokbulak et al. (2008) and Balci et al. (1992). The results were used to create a hypothetical water budget model in two variants: the first was a general basic model for normal canopy cover (≥0.9), the second – for medium canopy cover (0.7). The second stage of the study covered the calibration of the general model with the available data from specific climate studies, (Irmak et al., 1980; Destan, 2001), hydrologic studies (Balci, 1958; Çepel, 1965a; Çepel, 1965b; Çepel, 1971; Uslu, 1971; Ozhan, 1977; Ozhan, 1982; Balci et al., 1992;

Hizal and Ozer, 1998; Ozyuvaci et al., 2004; Gokbulak et al., 2008; Ozhan et al., 2010; Destan and Serengil, 2010) and soil hydrologic studies (Kantarci, 1980) conducted in the studied area. The calibration was made in a similar way, and in essence, it involved using specific results for the general (hypothetical) water budget model converted into percentages, the results for each water budget element for a given age class were accepted as values of the functional curve of the general model.

To establish the calibration functions (these specified for the studied area), at least three average (aggregate) values were used for different age stand classes (young, mature and overmature stands). In order to establish the validity of the specific data in relation to the trend of the general model, we used the mathematical functions calculated for the water budget elements by the aforementioned researchers. However, as it has already been pointed out, these functions did not show all stages of stand developement (if otherwise, the general model would not be needed), but only the effect of a given stand age and condition. For this reason, linear equations were used for them. Extrapolating them to adjacent age classes (one or a maximum of two classes) for which there were no available data, the probable values (in numbers and percentages) were calculated. Through interpolation of the results, the probable curves of the effect by age class were produced, and subsequently, these were compared with their respective curves of the general model. When the deviation of the probable curves of some water budget elements from the respective curves of the general model was greater, the reasons for this deviation were looked into, and justifiable adjustments were made. As in the first stage, the obtained values for each water budget element were compared to aggregate values of a higher rank. But unlike the control data used for the general model, the control data for the calibration results was limited within a given age class and research period.

When there were deviations from the totals, further adjustments of the values of the water budget elements were made. This was required due to the fact that the sum of the empirically established values of the water budget elements hardly ever coincided with the values of empirically established totals. The reasons can be found in the various approaches and methods for studying the water budget elements, and the methods for obtaining the totals. In the light of the silvicultural and forest management practice, the hydrologic effect of tree canopy cover and stand density was established using the empirical data of the studies by Chepel (1965a, b), Ozhan (1982), Nedyalkov and Raev (1988), Gokbulak et al. (2008) and Ozhan et al. (2010). The approach for establishing this effect by age class was analogous to the aforementioned one. In addition, the results were compared to those obtained from studies in areas with similar conditions (Elmali Water Catchment Areas and Omerli Watershed). At the end of this stage of the study, the period of effective precipitation in eastern beech stands of age class V was established (Balci et al., 1992). To establish the periods of effective precipitation, the results of similar climate studies by Destan (2001) over a 39-year-long period were also used. For this purpose, data on the distribution of precipitation (mm) by duration and intensity (mm/h) was obtained and analyzed. At the same time, the study used aggregate data on the interception from empirical studies in Belgrade forests (Chepel, 1965a, b; Ozhan, 1982), results from studies in beech and oak stands in adjacent areas with similar climate, relief and soil conditions (Florov and Dimitrov, 1968), results from studies on beech[1] (Gadow and YanHui, 2008) and oak (Florov and Dimitrov, 1968) in similar areas in the temperate climatic zone whose results were summarized by Nedyalkov and Raev (1988).

For the practical purposes of silviculture and forest management aiming at achieving the targeted (functional) stand structure, maps were produced that show the soil moisture deficiency (in number of days) during the growing season, in the plant root zone and surface soil layers. This task required the use of the soil hydrologic studies by Kantarci (1980) and Tunckale (1965) and interpolation of the inventory results of 2002 of 598 sample areas (Anonymous, 2003). For the practical purposes of silviculture, the following tasks were completed:

a) Comparison and analysis of the data from growth and yield tables (Nedyalkov, 2004; Carus, 1998) and the empirical data (Anonymous, 2003) on density ($G_{1,3}/ha$), number of trees per hectare (*N/ha*) and current increment ($Z^{current}/ha$). At 180 years of age, the number of trees per hectare (*N/ha*) in the oak stands (site class III) begins to decrease, and at 220 years of age their canopy cover is 0.8 to 0.7. At 160 to 170 years of age, their current increment equals their mortality, whereas at 180 to 190 years of age their mortality exceeds their current increment that is the process of degradation begins. The difference is between 10 and 15 years for the lower and higher site classes. In the stands of eastern beech (site class III), the age is between 220 and 230 years, and the difference between the current increment and mortality becomes insignificant at 240 to 250 years of age. In addition, the studies by Kantarci (1980) showed areas with stagnant groundwater where beech stands begin to suffer from stem rot at 100 to 120 years of age. This means that they cannot be managed on the basis of their hydrologic maturity but on the basis of the so-called "pathological maturity". The empirical data obtained for the oak stands in the studied area showed an earlier age (with about 10 years less) for the decrease of the canopy cover and the beginning of the degradation process, which is due to the fact that part of the trees are of coppice origin. The findings coincided with the results of the studies by Evcimen and Eraslan (1967) conducted in these areas;

b) Analysis of the data on stand vigour and regeneration capabilities for the higher age classes and under various soil conditions (Anonymous, 1990) The results show that regeneration processes in 200-year-old (XII) oak stands become less effective, which is related to the decreased number of trees per hectare (*N/ha*), and the decreased seed quantity and quality. The risk increases dramatically in 250 to 260-year-old stands, especially in those with high moisture deficiency in the surface soil layers during the growing season. In beech stands, the problem is mainly due to poor seed quantity and quality.

On the basis of the conducted analyses, harvest rotation (T) was scientifically determined in relation to age (A^M) and period of maturity (P^M) of the hydrologic forest management class obtained from the calibrated hypothetical water budget model for forest stands. In order to meet the requirements of the "age class method" and to determine the optimal age structure of the stands in the catchment area, the normal periodic harvesting area (NPHA) for the hydrologic forest management class was calculated using the formula:

$$NPHA = \{F/(U/n)\}, \quad (1)$$

This formula was used to compare the actual and optimal age structure of the stands in the catchment area. Using the data obtained from the calibrated water budget model for the tree species (oak, Oriental beech and Austrian pine), area distribution and age class of each stand, the actual water yield was determined. In the mixed stands, it was calculated on the basis of the main (oak and eastern beech) tree species. As it has been noted, under the same other conditions, water yield depends on forest stand structure (especially average height, number of tree per hectare and canopy cover). Also, depending on their site index, the stands achieve the same targeted structure (and the same hydrologic maturity, respectively) at different ages. As the model was valid for

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[1] Eastern beech (*Fagus silvatica* L.)

site class III (the average one for the studied area), the stand growth was adjusted using reduction factors (coefficients) as follows: 1.356 for site class I; 1.178 for site class II; 1.000 for site class III; 0.822 for site class IV and 0.644 for site class V (Anonymous, 2003). Using the same reduction coefficients and optimal area distribution by age class, the potential water yield was calculated. All stands composed of introduced coniferous species in the studied area are located on unsuitable broadleaved sites, and had a negative hydrologic effect. This is due mainly to their high interception, 36% according to Ozhan (1982). Therefore, when the actual and potential water yields were calculated the second time on the basis of the potential stand structure, these coniferous stands were accepted as broadleaved stands. Their potential species composition was determined on the basis of the forest type[2] (Destan, 2001) to which they would belong.

On the basis of the aggregate empirical data on interception obtained for varying rates of precipitation intensity and duration, and the accepted interception range values, the period of effective precipitation in a year was determined. In order to do this, the following data was used: the data from the climatic studies by Destan (2001) over a 39-year-long period, the data and data summaries by Nedyalkov and Raev (1988) and the results of the studies on these forest stands by Chepel (1965a, b) and Ozhan (1982). Then the results were compared with the soil moisture deficiency during the growing season. This served as the basis for determining, silviculturally, the optimal stand structure by age class. In addition, recommendations on the regeneration processes in the studied area were made.

RESULTS

The results are presented in the sequence of the stages of this study. The calibrated hypothetical water budget model by tree species is presented in a concise form, and it contains the most important elements of the water budget. Due to the relatively small area of the stands of introduced conifers (108 ha) and their low average age (age classes II and III), their water yield in the studied area is only shown up to age class V. The oak coppice stands are from age class I and II, and their water yield is shown using one empirical result from the studies by Ozhan (1982) conducted in the mixed oak and hornbeam stands in this area (Table 3). Accepting a minimum threshold of water yield of ≈200 mm (0.200 m^3/m^2/year), the period of hydrologic maturity of oak stands covers a period from 120 years of age to 250-260 years of age (~140 years). In eastern beech stands, this period is 200 years (from 110 to ~270 years of age). However, the analysis of the results obtained both through calculations or empirically shows that the highest age to which, without any risks for regeneration, decrease of canopy cover under 0.7 or structural degradation, the oak stands in the studied area can be managed is 220 to 230 years of age. In eastern beech stands (with the exception of those located in the areas with poor drainage), this age is250 to 260 years.

Considering the fact that a large part (81%) of the stands are mixed (oak+beech; beech+oak), the accepted rotation for the whole forest management class is 240 years (age class XII) with age class intervals of 20 years. Using this rotation, the normal periodic harvesting area (NPHA) of the hydrologic forest management class (143.9 ha) was calculated with the help of formula (1). The NPHA ensures the optimal age structure for the stands in the water catchment area (Figure 2). Figure 3 shows, in a graph form, the water yield of the hydrologic forest management class in two variants: actual and optimal stand distribution by area and age class. It should be noted that the optimal distribution was determined using hypothetical stands of broadleaved species, typical for the studied sites, instead of the existing coniferous stands. The annual average (potential) water yield of the hydrologic forest management class is, respectively, 3,230,929 and 3,232,800 m^3/year for the actual and optimal stand distribution by area and age class. When replacing the coniferous stands for broadleaved ones, the water yield is 3,232,800 and 3,510,720 m^3/year, respectively. The graph of the period of effective precipitation and the maps of soil moisture deficiency during (Root-Drought and Upper Soil Drought) the growing season in the studied area are shown in Figures 4 and 5 respectively. The total distribution of throughfall is as follows: average annual precipitation, P_{an}=1,083 mm; annual throughfall, P'_{an}=985 mm (85% of P_{an}); throughfall outside the period of effective precipitation, P'_{noneff}=193 mm (17.8% of P_{an} and 21% of P'_{an}).

CONCLUSIONS AND RECOMMENDATIONS

The comparison of the calibrated curves with those of the general model shows that they have similar average values for the age classes (from 83 to 94%). All studies conducted in these forest stands indicate 25 to 29% runoff coefficient for average annual precipitation of 1,005.0 to 1,090.5 mm. For example, Zengin's (2009) mixed integer programming model of the catchment basins in Belgrade forests calculated water yield of 3,132,192 m^3/year, a result, which is within the range of the calibrated model. The calibrated model's trend show that the maximum total forest stand evaporation and interception coincides with the phase of maximum height increment and maximum leaf surface. After this phase, the hydrologic effect of forest ecosystems gradually increases with age, and reaches maximum water yield (age of hydrologic maturity) at an advanced age. This effect is due to the small number of trees (*N/ha*) with declining physiological functions, with wide-spreading crowns (providing normal canopy cover) with relatively small leaf surface and coarse dead woody debris, characteristic of this age.

After this age, water yield begins to decrease slowly at first, then faster with age. This is due to the steady decrease of canopy cover resulting from the decreased number of trees, the increase of actively transpiring understorey and live groundcover, the delayed

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[2] From the point of view of plant succession.

Table 3. Conceptual water budget model calibrated with result of local studies for oak, beech and black pine trees in temperate forest region.

Pure oak stand	**Balance elements**	**Average age**													
		20	**40**	**60**	**80**	**100***	**120**	**140**	**160**	**180**	**200**	**220**	**240**	**260**	**280**
Total annual precipitation (1083 mm)	*P (%)*	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Total (P'+Fga)	*P'' (%)*	88.04	84.30	86.00	86.55	87.48	88.04	90.47	91.59	92.53	94.9	96.57	97.36	98.21	98,21
Total evaporation (Ei+Es+Et)	*E (%)*	53.36	65.9	63.4	62.8	53.02	49.06	44.53	41.71	39.17	33.4	35.4	36.54	44.6	44.6
Surface flow (biotical)10-20º slope	*Fov(%)*	6.3	4.0	4.8	4.6	3.7	2.8	1.6	1.6	1.5	1.8	2.2	3.6	4.1	4.1
Infiltration*	*Finf (%)*	40.34	30.1	31.8	32.6	43.3	48.1	53.9	56.7	59.3	64.8	57.1	43.1	32.1	32.1
Subsurface flow and ground flow	*Fg (%)*	13.0	9.7	11.5	13.3	15.1	16.9	18.8	19.7	20.6	22.6	19.6	15.0	10.1	10.1
Soil moisture change (total expenses) (1/n)	*W(Tot)(coef)*	0.83	1.00	0.86	0.85	0.84	0.83	0.83	0.78	0.77	0.75	0.75	0.72	0.72	0.72
Deficient of Field Capacity January+February/2	*Wd*	0.83	1.00	0.86	0.85	0.84	0.83	0.83	0.78	0.77	0.75	0.73	0.70	0.70	0.70
Water holding capacity of liter cover[(t/ha)*(g/cm^3)]	*Wll(coef)*	0.08	0.13	0.18	0.23	0.24	0.38	0.45	0.53	0.60	0.75	0.75	0.68	0.58	0.58
Perm. capacity[cm*(t/ha)*(g/cm^3)*Por(%)*(mm/s)]	*Wpc*	0.42	0.77	2.15	3.22	5.32	10.11	14.40	18.10	22.10	30.10	30.10	26.10	25.20	22.20
Water efficiency* = Fg + Fov	SV (%)	13.0	9.7	11.5	13.3	15.2	17.1	19.0	19.9	20.1	22.9	22.7	21.8	20.4	15.5
Water efficiency* = Fg + Fov (normally closed)	SV (m^3)	0.142	0.106	0.126	0.146	0.165	0.185	0.206	0.216	0.226	0.248	0.246	0.236	0.217	0.168
Water efficiency* II-nd option (0.7 closed)	SV (m^3)	0.195	0.164	0.170	0.172	0.196	0.205	0.217	0.224	0.230	0.245	0.239	0.237	0.219	0.209
Pure beech stand															
Total annual precipitation	*P (%)*	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Total (P'+Fga)	*P'' (%)*	86.9	76.30	80.30	80.80	81.90	83.58	87.25	90.68	92.78	93.25	93.55	93.87	94.68	96.10
Total evaporation (Ei+Es+Et)	*E (%)*	47.50	70.70	64.40	63.50	54.30	49.42	44.25	39.32	35.72	33.75	31.95	32.70	33.45	34.20
Surface flow (biotical)10-20º slope	*Fov(%)*	2.9	2.1	2.8	1.8	1.5	1.5	1.4	1.0	0.6	0.3	0.5	0.6	1.0	1.4
Infiltration*	*Finf (%)*	49.7	27.2	32.8	34.7	44.2	49.1	54.3	59.7	63.7	65.9	67.6	64.1	60.2	53.4
Subsurface flow and ground flow	*Fg (%)*	8.1	5.8	8.3	11.1	14.8	18.4	20.4	22.4	24.4	26.4	28.4	25.9	22.8	19.1
Soil moisture change (total expenses) (1/n)	*W(Tot)(coef)*	0.79	1.00	0.82	0.81	0.80	0.79	0.75	0.74	0.73	0.72	0.71	0.73	0.80	0.82
Deficient of Field Capacity January+February/2	*Wd*	0.79	1.00	0.82	0.81	0.80	0.79	0.75	0.74	0.73	0.72	0.71	0.73	0.80	0.82
Water efficiency* = Fg + Fov	SV (%)	12.1	10.2	12.3	13.0	16.7	18.4	20.3	22.4	23.9	24.7	25.3	25.1	23.7	19.7
Water efficiency* = Fg + Fov (normally closed)	SV (m^3)	0.131	0.109	0.133	0.141	0.181	0.199	0.228	0.243	0.259	0.268	0.274	0.272	0.257	0.213
Water efficiency* II-nd option (0.7 closed)	SV (m^3)	0.240	0.181	0.197	0.199	0.223	0.236	0.249	0.261	0.270	0.275	0.280	0.274	0.250	0.233
Pure black pine stand		**20**	**40**	**60**	**80**	**100***	**120**	**140**	**160**	**180**	**200**	**220**			
Total annual precipitation	*P (%)*	100	100	100	100	100	100	100	100	100	100	100			
Total (P'+Fga)	*P'' (%)*	81.15	75.03	75.90	75.90	78.29	80.95	83.64	86.33	89.02	91.72	94.42			
Total evaporation (Ei+Es+Et)	*E (%)*	79.8	87.9	74.3	70.6	65.7	61.9	56.4	52.2	48.0	43.8	39.6			
Surface flow (biotical)10-20º slope	*Fov(%)*	4.00	3.10	3.54	3.10	2.21	1.77	1.33	1.33	0.89	0.89	1.33			
Infiltration*	*Finf(coef)*	16.2	9.0	22.2	26.3	32.1	36.3	42.3	46.5	51.1	55.3	59.1			
Subsurface flow and ground flow	*Fg (%)*	3.4	2.4	5.1	6.9	7.6	8.3	9.0	9.7	10.4	11.0	11.7			
Soil moisture change (total expenses) (1/n)	*W(Top)(coef)*	0.91	1.00	0.95	0.94	0.91	0.91	0.87	0.86	0.85	0.84	0.83			

Table 3. Contd.

Deficient of Field Capacity January+February/2	*Wd*	0.91	1.00	0.95	0.94	0.91	0.91	0.87	0.86	0.85	0.84	0.83
Water efficiency* = Fg + Fov	SV (%)	3.4	2.4	5.1	6.9	7.6	8.3	9.0	9.7	10.4	11.0	11.7
Water efficiency* = Fg + Fov (normally closed)	SV (m^3/m^2)	0.045	0.036	0.077	0.104	0.115	0.125	0.136	0.147	0.157	0.167	0.177
Water efficiency* II-nd option (0.7 closed)	SV(m^3/m^2)	0.125	0.115	0.133	0.137	0.144	0.149	0.156	0.161	0.167	0.172	0.178

	Average results			**Empirical results in Belgrade forest**		
Pure oak stand	**Min (%)**	**Aver. (%)**	**Max (%)**	**Growing season (mm, %)**	**Average (mm, %)**	**Dormant season (mm, %)**
Total annual precipitation (1083 mm)	100	100	100	438 (40)	1095.6(100)	690.5(60)
Total (P'+Fga)	70.9	87.5	98.9	349.8(79.7)	924.3(84.4)	601.1(87.1)
Total evaporation (Ei+Es+Et)	-	-	96.1	-	944.7(86.2)	-
Surface flow (biotical)10-20º slope	0.9	3.7	12.8	17.2 (3.7)	43.4(4.0)	27(4.2)
Infiltration*	-	-	-	-	-	-
Subsurface flow and ground flow	-	15.1	-	-	120.6(11.0)	-
Soil moisture change (total expenses) (1/n)	-	-	-	488.5(44.6)	912.8(83.3)	2 m
Deficient of Field Capacity January+February/2	-	-	-	-	39.4(3.3)	-
Water holding capacity of liter cover[(t/ha)*(g/cm^3)]	-	-	-	-	10.7(0.97)	380%
Perm. capacity[cm*(t/ha)*(g/cm^3)*Por(%)*(mm/s)]				-	-	-
Water efficiency* = Fg + Fov	-	15.1	-	-	164(15.0)	-
Water efficiency* = Fg + Fov (normally closed)			Özhan (1982); valid only for soil depth of 2 m.			
Water efficiency* II-nd option (0.7 closed)						
Pure beech stand						
Total annual precipitation	100	100	100	429.2(40.0)	1072.9(100)	643.7(60.0)
Total (P'+Fga)	72.2	82.2	95.6	363.2(33.9)	927.2(86.5)	564(52.3)
Total evaporation (Ei+Es+Et)	28.8	55.0	57.0	-	872.2(81.3)	-
Surface flow (biotical)10-20º slope	-	1.5	-	-	21.5(2.0)	-
Infiltration*		50.5	-	-	-	-
Subsurface flow and ground flow	9.0	18.4	68.5	-	-	-
Soil moisture change (total expenses) (1/n)	-	-	-	723.0	963.0	
Deficient of Field Capacity January+February/2	-	-	-	-	-	-
Water efficiency* = Fg + Fov		15.5		-	181.0 (16.9)	-
Water efficiency* = Fg + Fov (normally closed)			Çepel (1965); valid only for soil depth of 2 m.			
Water efficiency* II-nd option (0.7 closed)						
Pure black pine stand						
Total annual precipitation	100	100	100	438(40)	1095.6(110)	690.5(60)

Table 3. Contd.

Total (P'+Fga)	-	78.20	-	317.9(72.5)	785.4(71.7)	495.5(71.9)
Total evaporation (Ei+Es+Et)	39.6	76.9	87.9	-	985.7(68.5)	-
Surface flow (biotical)10-20º slope	0.2	1.8	4.6	12.4(2.6)	33.8(3.1)	22.1(3.4)
Infiltration*	-	-	-	-	-	-
Subsurface flow and ground flow	3.9	6.9	15.6	-	81.2(7.3)	-
Soil moisture change (total expenses) (1/n)	-	-	-	622.4(56.8)	1003.7(91.6)	2 m
Deficient of Field Capacity January+February/2	-	-	-	-	72.7(6.6)	-
Water efficiency* = Fg + Fov	-	-	-	.-	7.7.	.-
Water efficiency* = Fg + Fov (normally closed)				Özhan (1982); valid only for soil depth of 2 m.		
Water efficiency* II-nd option (0.7 closed)						

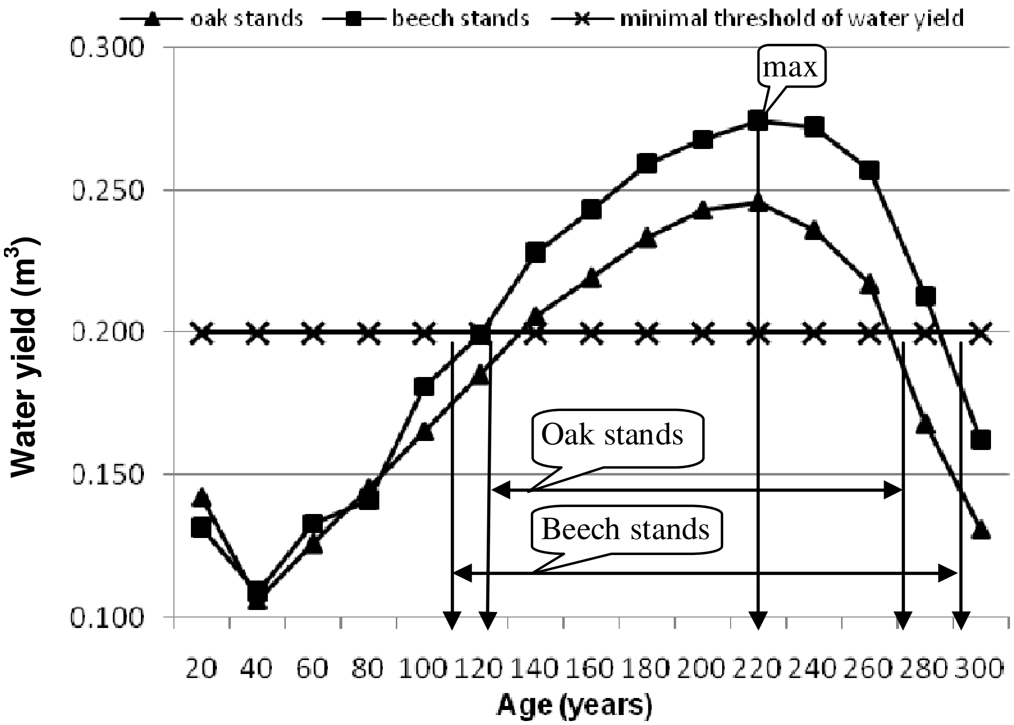


Figure 2. Water yield and hydrologic maturity of the oak and beech stands in the studied area.

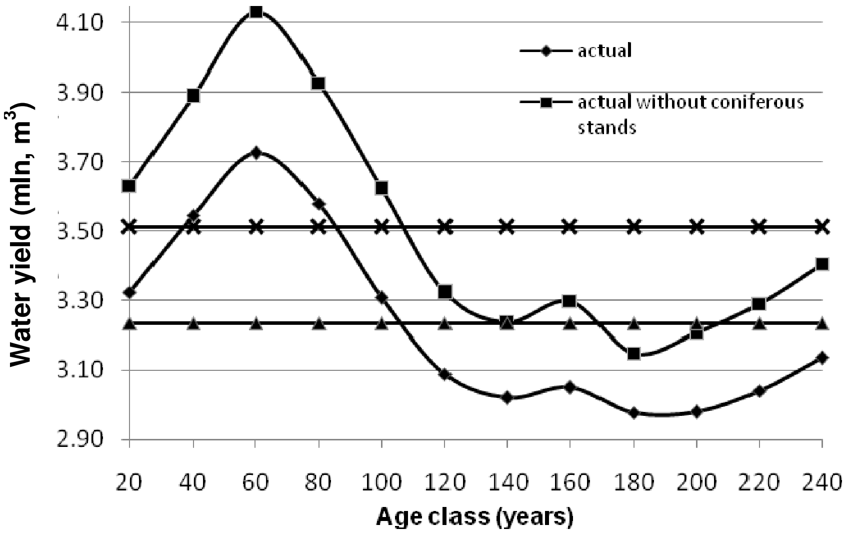
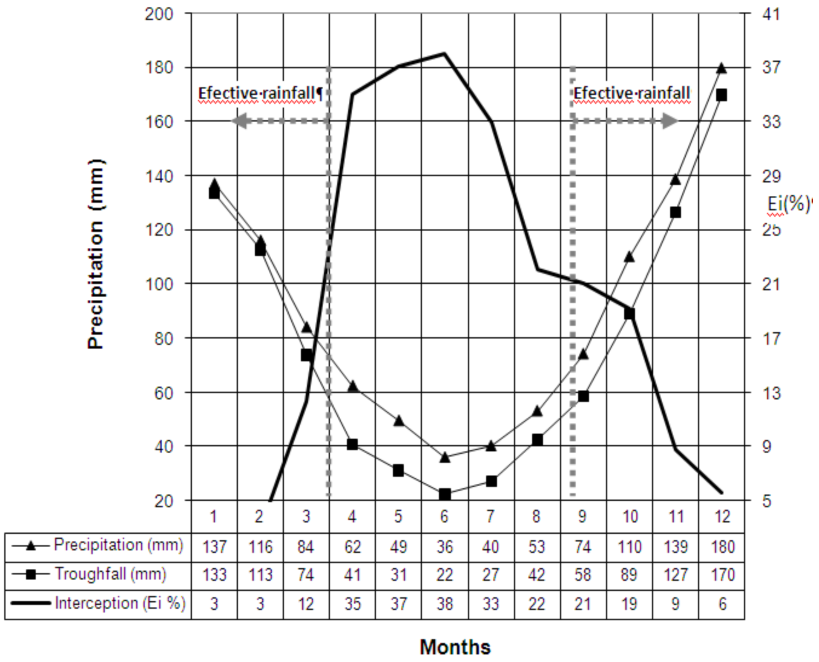


Figure 3. Variants of water yield on the stand distribution by age class for the forest management class.



	1	2	3	4	5	6	7	8	9	10	11	12
▲ Precipitation (mm)	137	116	84	62	49	36	40	53	74	110	139	180
■ Troughfall (mm)	133	113	74	41	31	22	27	42	58	89	127	170
— Interception (Ei %)	3	3	12	35	37	38	33	22	21	19	9	6

Figure 4. Interception in the eastern beech stands of age class in v Belgrade forest (north of Istanbul).

decomposition of dead woody debris resulting from the temperature change and decreased water holding capacity. In essence, this is the phase of degradation of overmature stands and their replacement with a new generation. It should be noted that these forests have experienced cases of replacement with unwanted scrub vegetation as a result from stand overmaturity and incapability for self-regeneration. The parameters of the period of effective precipitation are important for the targeted stand structure and productivity of the studied forest management class. The studies conducted by Akkemik et al. (2006) on the radial increment of Belgrade forests showed that almost 90% of annual ring's width is formed in May to June, and the rest - by the end of July. This means that physiological transpiration (which is related to biomass production) almost ceases at the beginning of July, and continues as physical one but only in the warm months. At the same time, the length of the growing season in the studied area is about 220 days (approximately from 30th April to 5-6th of December).

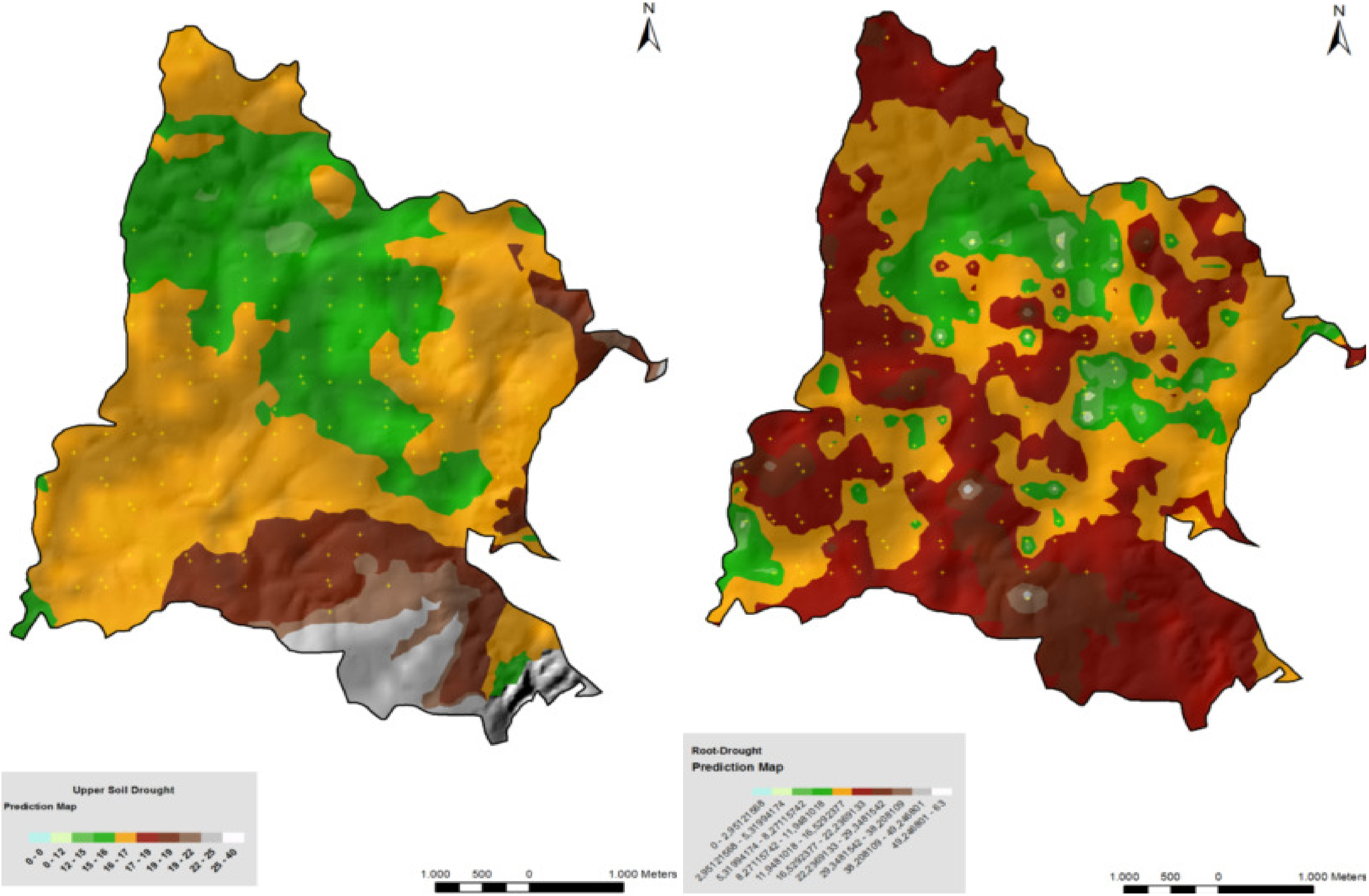


Figure 5. Soil moisture deficiency in the plant root zone and surface soil layer during the growing season.

Figure 3 shows that the period of effective precipitation begins in the middle of September, and ends at the time of leaf mass growth, at the beginning of April. This period shows variations associated with the climate, altitude and tree species composition. Therefore, the interception threshold with regard to the period of effective precipitation varies by tree species, altitude zone, climate and soil conditions. For example, the studies by Nedyalkov and Raev (1988) on mountainous spruce forests showed that the period of effective precipitation (with an interception threshold under 35%) starts at the beginning of May, and ends in the middle of November.

These variations are essential for determining the targeted stand structure. For this reason, if the canopy cover of Belgrade forests decreased[3] (to up to 0.7) with the aim of reduced interception, this would not increase the water yield. The conclusions of the same authors showed that reduced interception after thinning does not make up for the increase of soil surface evaporation and especially of transpiration, which results in an increase of total evaporation by about 10%. This finding is even more valid for the studied forests (Figure 3). The same authors made the following claims about the impact of thinnings on total evaporation: total evaporation increases in younger stands as well as in drier sites, whereas, in older stands, it is directly proportional to stand stocking and density. The results by Serengil et al. (2007) and Gokbulak et al (2008) obtained from their studies of these forests supported this conclusion. Even the slight decrease of the canopy cover (from 1.0 to 0.8-0.9) of a sample plot following the felling of 11% of its growing stock led to a noticeable increase of turbidity (SiO_2 mg/L), water temperature, ground surface air temperature and water yield. Quantitatively, these indicators do not have direct environmental impact; however, they show the negative consequences for the total evaporation and water quality. Studying the surface water runoff and soil erosion under various land use conditions in close proximity to the studied area, Uslu (1971) found out that 0.1 to 4% surface runoff in oak stands with normal canopy cover. This value increased as the canopy cover decreased, and reached its maximum of 11% (up to 18% depending on the slope) in degraded forests in the initial stage of grassy formation. However, the final formation of vigorous herbaceous and shrubby cover (scrub vegetation) led to minimum water runoff comparable to the water runoff from forests (Özhan et al., 2005). Moreover, Chepel (1971) pointed out even more impressive results from studies conducted in Belgrade forests: 36% surface runoff for grassy formations, and 56% for bare soil. The parallel studies by Balci (1958) in the adjacent area called Elmali catchment basin showed almost the same results, with the author linking them to dramatic erosion consequences. Also, according to Nedyalkov and Raev (1988), the best indicator of soil protection is the surface water runoff rate.

The results show that, for annual average precipitation of 1,083 mm, the annual average periodic water yield of the hydrologic forest management class for both the actual and optimal stand distribution by area and age class is practically the same. This is also true for the water yield calculated when the existing coniferous stands are hypothetically accepted as broadleaved ones. However, in contrast to the optimal stand distribution by area and age class, the water yield under the actual distribution varies from +16 to -10% (Figure 3). This difference is a result from the uneven stand distribution by area and age class. The water yield also depends on the precipitation amount, but their relationship is not linear. For example, Serengil (2002), modeling the water yield of two water catchments in Belgrade forests, found out that as precipitation decreased by 26.7% (from 1,006 mm in 2000 to 737 mm in 2001), water yield decreased by 47.4% (from 257 to 135 mm). Also, according to the widely used method for soil hydrological classification of Thorntwaite, the decrease was 21% (from 607 to 472 mm). Ozhan et al. (2010) calculated the evapotranspiration (ET) and potential evapotranspiration (PET) in relation to the precipitation variation in Belgrade forests over a 17-year-long period (using the Thorntwaite method). While the PET was around 750 mm and varied by 1 to 2%, the ET variation in relation to the precipitation amount reached 40%. What is more, the results showed that for the same (or very similar) amounts of precipitation, the ET values varied (by up to ±25%). If these results are linked to the water moisture deficiency during the growing season in the studied area (Figure 4), it is possible to obtain models for various precipitation values. These models will be realistic enough regarding the moisture distribution in the plant root zone and surface soil layer. These factors are essential for planning the vegetation cover in catchment areas. Therefore, it can be said that the PET is a good indicator, but watershed planning should preferably rely on empirical results. For example, low canopy of oak forests in Nord Thrace Makineci (1993) found higher soil moisture, this is probably due to coppice origin of these forests and this fact has changed strategy in forestry management regime.

The age class method has been selected to determine the structure and form of the forest stands belonging to the water protection forest management class. However, the inventory characteristics (species composition, stand productivity, regeneration requirements and etc.) as well as the fact that it is hardly possible to grow large enough groups of forest stands of the same type in the studied area, show that the selected forest planning method cannot be mechanically applied, but it should be considered in relation to the forest management method. This consideration requires that the following most important conditions are met: the area of periodic

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[3] In accordance to scientific discussions, professional opinions and specific suggestions made for decreasing the canopy cover of the watershed forest stands in the area of Belgrade forests.

regeneration should be equal to the normal periodic harvesting area (143.9 ha); the optimal stand distribution by area and age class should be determined; the forest management method of each stand (or each stand type) should be identified with regard to its inventory structure and species composition. Regarding the silvicultural treatments, the following recommendations can be made: the silvicultural treatments should ensure the normal growth and development of young stands, as specified by the growth and yield tables. This approach will make sure in advance that the stems are well pruned and the crowns evenly-shaped. To achieve the targeted (hydrological) stand structure, the number of trees per hectare should be gradually reduced approximately one age class before the period of hydrological maturity (120 years of age in oak, and 110 years of age in beech). As the two main tree species are capable of growing wide spreading crowns, the canopy cover should be maintained close to the norm (0.9).

This process may continue for 160 to 180 years in oak stands, and 180 to 200 years in beech stands. Mixed stands require a differentiated approach aiming at maintaining their species composition, and based on the forest type to which they belong. This forest management practice will ensure the growth of tall trees with short (1/4 of the stem length), but wide crowns with a relatively low leaf index, normal canopy cover and coarse dead woody debris. After the period of hydrological maturity, the formation of second-layer vegetation and increase of live groundcover should not be allowed. The period of regeneration fellings should not exceed the age class interval (20 years); otherwise stands would become uneven-aged, and this would lead to an unwanted change of the forest management method. Hydrologically, uneven-aged stands are an advantage in the mountains, but not in plains and hilly areas. The regeneration may exceed the age class interval (20 years) only in periods of drought with chronic moisture deficiency in surface soil layers (Figure 4). This will require assisted regeneration through silvicultural activities such as artificial re-planting and understorey maintenance. This approach, tied to a specific age and period of hydrological maturity no analogies in their area. It cannot be compared with some hydrological studies (Ozturk, 2010) of forests in the Black Sea coast with application of habitat simulation methods and holistic methods for environmental flow calculation methods.

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