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Effect of Forest Thinning on Water Yield in a Sub-Humid Mediterranean Oak-Beech Mixed Forested Watershed

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Abstract Forested watersheds provide fresh water with best quality and forestry practices play important role on the water production in the watersheds. Therefore, the objective of this study was to investigate the effect of 18 % thinning, which was under the 20 % threshold value reported in the literature on water yield in a forested watershed. Two experimental watersheds with similar ecological conditions in the Belgrad Forest of Istanbul were studied. Following a 6-year calibration period from December 2005 to October 2011, a simple linear regression equation was developed between the monthly streamflows of two watersheds with a significantly high correlation coefficient (r = 0.95). After 18 % of standing volume was removed from one watershed and the other was left untreated as a control, the streamflow was monitored for 2 years starting in January 2012 in both watersheds. The change in the monthly runoff was estimated as the difference between measured and values calculated with the linear regression equation. Average monthly streamflows were about 19, 15 and 10 mm in the control and 21, 20, and 11 mm in the treatment watersheds for calibration, first and second post-treatment periods, respectively. Paired watershed analysis showed that monthly streamflow did not significantly increase in either watershed for the first or the second year after the harvest. The results revealed that thinning intensity had to be greater to increase water yield significantly in this forest ecosystem and the threshold value for a streamflow increase was greater than 18 % for this region.

Keywords Forest thinning · Streamflow response · Deciduous forest ecosystem · Oak-beech forest

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1 Introduction

Forest ecosystems are important because of the various ecosystem services they provide. These services include internal nutrient cycling, recreation, habitat for wildlife, soil conservation, climate regulation, biodiversity conservation, and aesthetics in addition to water supply (Núñez et al. 2006). Since forested watersheds provide the most suitable, good quality water sources (Neary et al. 2009) and forest covered watersheds have been intensively managed in order to meet the demand of growing population, studies on forest-water interactions are essential. Therefore, the management of forested watersheds requires special attention to minimize adverse effects on forest services. On the other hand, forest ecosystems can affect the proportion of the precipitation that reaches the soil surface and decrease runoff (Zhang et al. 2014) due to canopy and forest floor interceptions and transpiration depending on intensity and total amount of precipitation, tree density, forest type and structure (Zeppel et al. 2008; Özhan et al. 2010; Tsiko et al. 2012; Neris et al. 2013; Viola et al. 2014). Therefore, the relationship between tree removal and streamflow has received attention from international researchers and a number of studies have been implemented worldwide that started in the early 1900s to investigate the impact of forest harvesting practices on water yield by mostly using the paired catchment method (Stednick 1996; Troendle and King 1985; Lesch and Scott 1997; Lane and Mackay 2001; Troendle et al. 2001; Swank et al. 2001; Caissie et al. 2002; Özyuvacı et al. 2004; Dung et al. 2012). Different timber harvesting practices—such as clear cutting, shelter wood cutting, selective cutting or thinning, and patch or partial cutting—can have different impacts on water yield. Among the timber harvesting patterns, forest thinning and partial cutting generally have less influence on increases in the water yield compared to other timber harvesting patterns because of increases in the use of available soil moisture by retained forest vegetation (Hubbart et al. 2007). Worldwide, forest thinning is usually used as a silvicultural treatment to improve stand structure and timber quality, increase commercial timber production and economic returns by redistributing the growth potential of retained trees (Lesch and Scott 1997; Dung et al. 2012). In the case of forest thinning, not only do decreases in the interception and evapotranspiration losses occur due to reductions in the standing timber volume and overstory canopy cover, but the amount and density of understory vegetation increases as a result of changes in the amount of sunlight reaching into the understory (Troendle et al. 2001; Dung et al. 2012).

Paired watershed studies in forests around the world have shown that streamflow can be increased by timber harvest that reduces the forest canopy interception and increases the proportion of precipitation reaching soil surface, but the magnitude of the water yield increase is irregular and changes with respect to forest ecosystems, intensity of the timber harvest, soil conditions and climatic regions (Bosch and Hewlett 1982; Keppeler and Ziemer 1990; Bari et al. 1996; Stednick 1996; Lesch and Scott 1997; Lane and Mackay 2001; Caissie et al. 2002; Özyuvacı et al. 2004; Brown et al. 2005; Hubbart et al. 2007; Dung et al. 2012; Suryatmojo et al. 2013). In addition to forest types, soil conditions and amount of mean annual precipitation, the intensity of timber harvesting affects the water yield. Bosch and Hewlett (1982); Stednick (1996); Sahin and Hall (1996), and Brown et al. (2005) reviewed literature about the influence of timber harvesting practices on the streamflow. They concluded that timber harvesting increases on water yield depend on the amount of canopy that has been removed. In their review, Bosch and Hewlett (1982) concluded that in order to distinguish changes in water yield, a minimum of 20 % of the watershed must be harvested. Similarly, Stednick (1996) concluded that a minimum of 20 % of the forest land in a watershed should be removed

to be able to perceive changes in annual water yield. Somewhat conversely, Sahin and Hall (1996) concluded that a 10 % decrease in forest cover would be enough to measure changes statistically in water yield. Brown et al. (2005) also reported that although similar changes in water yield were determined in the long term after the treatments, the time for reaching a new equilibrium established was shorter under deforestation experiments than afforestation experiments. Özyuvacı et al. (2004) investigated the effect of 11 % thinning on water yield in the same experimental watersheds where this present study was conducted and they found that water yield increased significantly only for the month immediately after the thinning treatment, and by approximately 7.5 mm. It seemed that any treatment removing timber volume over 11 % could increase water yield in this deciduous forest ecosystem in contrast to conclusions made by Bosch and Hewlett (1982) and Stednick (1996).

Thinning is a common silvicultural treatment in commercial forestry in Turkey, but the impact of thinning intensity in fresh water producing watersheds has not been clearly investigated yet and scientific knowledge is limited in terms of the relationship between timber harvesting and streamflow response (Özyuvacı et al. 2004; Serengil et al. 2007). On the other hand, the study region lies in a transition zone between sub-humid Southern Europe and semi-arid Northern Middle East regions. The amount of precipitation changes from year to year and there is a diverse vegetation covers from rangelands to various woody vegetation covered areas including deciduous and coniferous tree covers, shrub and brush vegetation. Therefore, to discover the impacts of forest management activities on water yield and identify the most suitable vegetation management practices for water production in forested watersheds, more studies should be carried out under different precipitation regimes and vegetation covers, timber harvesting types and intensities. Applying timber harvests with different intensities can help researchers determine a threshold value for this subhumid forest region and make forestry employees aware of the potential impacts of thinning on streamflow. Therefore, the purpose of this study was to test the effect of 18 % thinning, which was more than the previously investigated 11 % thinning in the same experimental watersheds but under the 20 % threshold value reported by Bosch and Hewlett (1982) and Stednick (1996) on water yield in an oak-beech mixed deciduous forested watershed.

2 Material and Methods

2.1 Study Site

This study was conducted in two experimental watersheds located approximately 1400 m apart and with similar characteristics in terms of climate, vegetation, slope, drainage and road densities, slope and aspect in the Belgrad Forest, Istanbul, Turkey (41°13′00″– 41°14′13″ N latitude, 28°54′25″-28°56′37″ E longitude). The experimental watersheds have a humid, mesothermal and maritime climate with a moderate water deficit in the summer months according to the Thornthwaite method (Özyuvacı 1999). Average annual precipitation is about 1129 mm and mostly falls between October and April and the mean annual temperature is about 12.3 °C. August has the highest daily average temperature (21.7 °C) while February has the lowest daily average temperature (4.2 °C) (Özhan et al. 2008).

Forest cover in the experimental watersheds consists mainly of *Quercus petraea* (Mattuschka) Lieb, *Q. frainetto* Ten., *Q. cerris* L., and *Fagus orientalis* Lipsky. Other tree species include *Populus tremula* L., *Alnus glutinosa* L., *Carpinus betulus* L., *Acer trautvetteri*

Med., *Acer campestre* L., *Castanea sativa* Mill., *Ulmus campestris* L., and *Sorbus torminalis* Crantz. (Yaltırık 1966). The mull type forest floor consisting of fresh litter, partially decomposed litter and particulate litter layers has an average depth of around 4.0–6.0 cm. The fresh litter layer was approximately 3.0–4.0 cm in depth, the partially decomposed litter layer was about 1.0–2.0 cm, and particulate litter layer including the humus mineral horizon was less than 1.0 cm. Parent material of the sites consists mainly of carboniferous clay schists and Neogene loamy, gravelly deposits. Soil depth changes from moderately deep to deep with medium to good permeability rates and soils have organic matter content over 3 % (Özhan et al. 2010). Experimental watersheds have Vertic Xerochrept soil types [USDA (Unites States of Department of Agriculture) 1996] with a field saturation capacity about 40 % in the topsoil and 25 % in the subsoil (Özhan 1977). The topography is not steep and the elevation in the watersheds ranges from about 95 to 190 m. Even though both watersheds have similar characteristics (Table 1), W-IV (Treatment watershed) has a slightly greater area, slope, drainage density, elevation range, and slope-length and slope steepness factor than W-I (Control watershed) (Table 1).

Two 90° and 120° concrete sharp-crested V-notch weirs were constructed at the W-I and W-IV outlets and automatic water level recording systems were installed. Stage heights were determined at 10-min intervals with a water level recording system inside stilling wells connected to the weirs and stream flows were estimated as cubic meter per second based on the stage height by using the following formula:

$$Q = C \times H^n$$

where;

Q was the runoff ($m^3\ s^{-1}$), H was the stage height (m), n was a coefficient taken as 2.48, and C was a constant and varied depending on the angle of the notch and units of measurement (Özhan et al. 2010). Monthly precipitation was recorded by an automatic tipping-bucket type pluviometer that was installed near the watersheds.

Streamflows from both watersheds were monitored for 6 years from December 2005 to October 2011 and a linear regression equation was established between the watersheds. The equation was Y = a + b*X, where Y was the measured streamflow (mm $month^{-1}$) at the W-IV (treatment watershed) while X was the measured streamflow (mm $month^{-1}$) at the W-I (untreated control watershed). Even though monthly data are less commonly used than annual

Table 1 Listed below are some of the characteristics of the control (W-I) and the treatment (W-IV) watersheds (modified from Özhan et al. 2005 and Özhan et al. 2010)

Watershed characteristics	Control watershed (W-I)	Treatment watershed (W-IV)
Area (ha)	71.90	77.50
Slope (%)	10.00	14.00
Drainage density (km km^{-2})	3.60	3.80
Road density (m ha^{-1})	12.93	12.36
Elevation range (m)	104–158	97–187
Litter depth (cm)	4.0–6.0	4.0–6.0
Crown closure (%)	75–100	74–100
Slope-length and slope steepness factor (LS)	4.71	8.31

data in the paired watershed studies (Brown et al. 2005), we used monthly data in this study because more monthly data values were available compared to annual data values (Watson et al. 2001).

After a linear regression equation was established between the monthly discharges from the control and treatment watersheds during the calibration period, Watershed–I (W-I) was kept untouched as a control and 18 % (4880 m^3; derived from Belgrad Forest Management Plan) of standing timber volume from Watershed-IV (W-IV) was removed between October and December in 2011 following a 6-year calibration period. Streamflows from treated and control watersheds were also recorded for 2 years after watershed IV was thinned. Measured streamflow data from W-I were then used in the equation to predict the runoff from the treated watershed that would be expected if the treatment were not applied. A paired t-test was used to compare predicted and measured streamflow data from the treatment watershed ($P < 0.05$) (Zar 1996) and accordingly, the water yield attributed to the forest thinning was estimated as a difference between the measured and estimated monthly discharges from the treatment watershed.

3 Results and Discussion

Average monthly precipitation was 84.88 mm and ranged from 291.79 (October 2006) to 0.80 (April 2010) mm during the calibration period, whereas the averages were 84.15 and 49.70 mm and ranged from 211.20 (December 2012) to 0.00 (July 2012) mm and from 84.08 (October 2013) to 6.35 (July (2013) mm during the first and second treatment years, respectively (Fig. 1; Table 2). Monthly average precipitation varied considerably over the course of this 8 year period and caused unpredictability in the monthly runoff especially for the first treatment year compared to the calibration period and the second treatment year in the treatment watershed. Both watersheds received higher precipitation in the calibration period compared to the second post treatment period and most of the precipitation, 72 % during the calibration and 75 % during the treatment periods, fell between October and March (Fig. 1). Although monthly precipitation showed a similar trend in the pre-and post-treatment periods, average monthly precipitation did not change very much in the first treatment year, whereas it decreased about 41 % in the second treatment year and 21 % in the overall treatment period

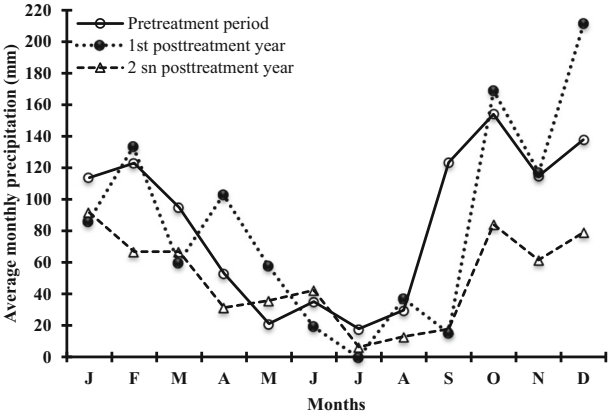


Fig. 1 Distribution of average monthly precipitation in the calibration period and two consecutive post-treatment years

Table 2 Average monthly (mean ± SEM) streamflow, precipitation and runoff coefficients during the study periods

Study periods	Watersheds	Runoff (mm)	Runoff coefficient	Precipitation (mm)
Calibration period	W-I	18.73 ± 4.65	0.22 ± 0.03	84.88 ± 14.42
	W-IV	20.92 ± 5.95	0.24 ± 0.05	
Treatment period 1 st year	W-I	15.26 ± 5.47	0.18 ± 0.03	84.15 ± 18.79
	W-IV	20.03 ± 8.18	0.24 ± 0.05	
Treatment period 2 nd year	W-I	9.86 ± 4.05	0.20 ± 0.05	49.70 ± 8.42
	W-IV	10.80 ± 4.68	0.22 ± 0.06	
Overall treatment period (2012–2013)	W-I	12.56 ± 3.38	0.20 ± 0.03	66.93 ± 10.68
	W-IV	15.41 ± 4.71	0.23 ± 0.04	

compared to precipitation in the calibration period (Table 2). During the calibration period, the simple linear regression equation developed between the control and treatment watersheds showed highly significant relationship with a correlation coefficient of 0.95 at the 0.001 level (Fig. 2). This relationship was similar to that reported in an earlier study carried out in the same watersheds (Özyuvacı et al. 2004). In the calibration period, the treated watershed had a slightly higher average of monthly water yield than the controlled watershed. The treated watershed had an average monthly runoff of 20.92 mm with a range of 132.31 mm – 0.10 mm, whereas the controlled watershed had an average monthly runoff of 18.73 mm with a range of 166.26–0.19 mm (Table 2). Depending on distribution of precipitation, both W-I and W-IV showed a similar trend to each other in the water discharges with runoff coefficients of 0.22 and 0.24, respectively in the calibration period (Table 2; Fig. 3). In the treatment period, runoff coefficients varied between 0.18 and 0.24 and W-IV had greater runoff coefficients during the whole study period than W-I. This could be the result of having a little bit larger drainage area, steeper slope, and greater drainage density in the treatment watershed (Table 1). In contrast, factors that directly affect surfaceflow—such as litter depth, canopy closure and road density—were similar between the two watersheds. Although W-IV had numerically greater runoff coefficients during the both pre-and post-treatment periods than W-I, there was no significant difference between runoff coefficients regardless of the watershed types or the study periods

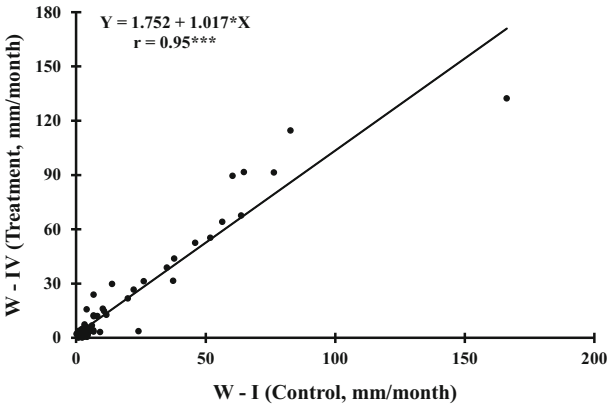


Fig. 2 Relationship between the control (W-I) and treatment (W-IV) watersheds during the calibration period

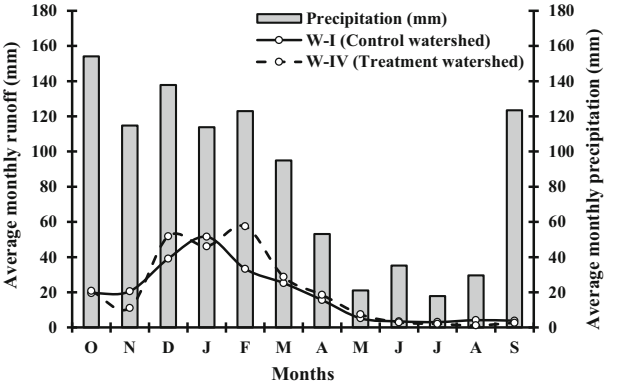


Fig. 3 Average monthly streamflow from the control and treatment watersheds and precipitation during the calibration period from December 2005 to October 2011

($P > 0.05$; Table 2). Runoff coefficients in this study were within the range of 0.20–0.29 and consistent with what was reported in a long-term study implemented in the same oak-beech mixed forest ecosystem (Özhan et al. 2010). Runoff coefficients in the present study were smaller than those found in a coniferous and deciduous trees mixed forest in Canada (Caissie et al. 2002).

The hydrographs drawn from both estimated and measured monthly runoff values followed each other closely throughout the post-treatment period. Monthly precipitation peaked in December 2012 and January 2013 while monthly runoff values reached peaked in February 2012 and January 2013 (Figs. 1 and 4). As reported in other studies (Keppeler and Ziemer 1990; Lewis et al. 2000; Hubbart et al. 2007), the streamflow hydrograph followed a similar trend to monthly precipitation and greater increases occurred in wetter winter months, but the water yield increase was not significant in both treatment years. The large differences between predicted and measured streamflow values can be attributed to high precipitation in the wetter months (Hibbert 1967; Özyuvacı et al. 2004; Yao et al. 2015). In contrast, estimated monthly

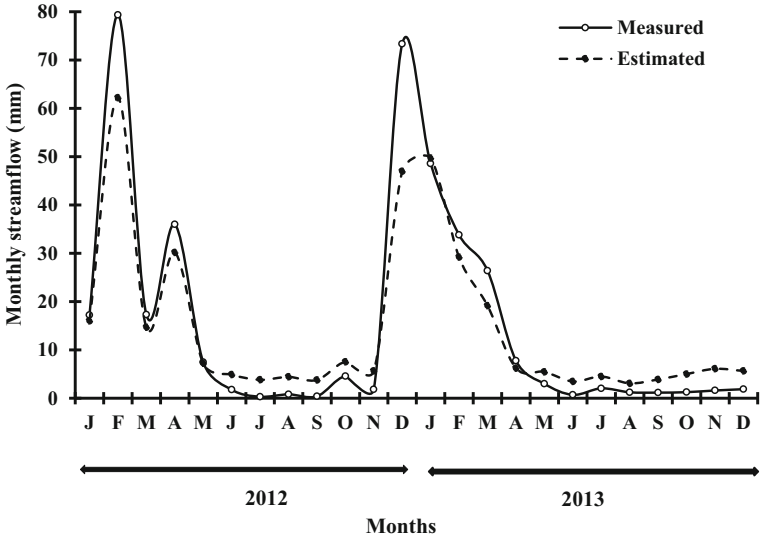


Fig. 4 Average monthly runoff from the treatment watershed during the treatment period

runoff values were greater than measured streamflow values during the dry periods and streamflow dropped under the pre-treatment level from June through November in the first treatment year and from May through December in the second treatment year (Fig. 4). In order to examine the effect of timber harvesting on water yield, it is much more appropriate to investigate the treatment effect of timber harvesting on a yearly basis immediately rather than considering study period collectively since the largest streamflow increases occur the first year after the thinning and the relation between change in the water yield and amount of forest cover reduction can disappear in the long treatment period (Hibbert 1967; Swank et al. 2001). Therefore, changes in the water yield were expressed as an average monthly value on yearly basis immediately after the forest cover reduction. The comparison of measured and estimated streamflow values indicated that an 18 % thinning increased the average monthly streamflow to about 2.8 mm above the runoff expected without timber harvesting in the treatment watershed for the first treatment year, but the magnitude of the water yield increase was not great enough to be statistically significant ($P = 0.34$). Thereafter, an insignificant increase in the average monthly flow disappeared and significant increase was not observed in the streamflow in the second year after thinning ($P = 0.37$). Although overall average monthly water yield in the treated watershed for the post-treatment period was about 1 mm (0.89 mm) above the pre-treatment level, it was not statistically significant ($P = 0.56$). There was a significantly high correlation between average monthly precipitation and average monthly streamflow for pre-treatment period ($r = 0.68$, $P < 0.05$) and first treatment year ($r = 0.77$, $P < 0.01$). This significant relationship disappeared in the second treatment year after cutting in the treatment watershed (Fig. 5). As pointed out by Branson et al. (1981), slopes of the regressions equations developed between average monthly precipitation and runoff for both the calibration period and the first treatment year in the treatment watershed did not show significant change in the water yield after timber harvesting either (Fig. 5). In other words, both linear regression lines developed between monthly precipitation and streamflow for both calibration and treatment periods fell into the same confidence interval. If the area between

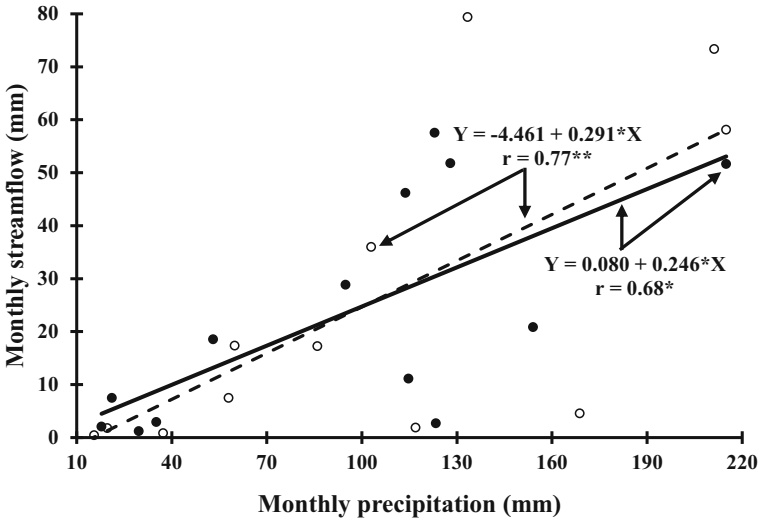


Fig. 5 Relationship between average monthly precipitation and average monthly runoff for the pre-treatment period (*solid line*) and for the first post-treatment year (*dashed line*) in the treatment watershed

regression lines developed between mean monthly precipitation and streamflow for both the pre-and first post-treatment year in the treatment watershed, then it was considered as a water yield due to the effect of treatment as shown by Branson et al. (1981) and Neary et al. (2009). Figure 5 shows that streamflow started to increase as a result of the timber harvesting when average monthly precipitation exceeded about 101 mm where the two regression lines intersected (Zar 1996). In addition to low timber harvesting intensity, the lower amount of precipitation during the treatment period compared to the calibration period did not cause significant increase in the water yield in this forest. Hence, decreases in the average monthly precipitation influenced streamflow discharge and caused reductions in the water yield in this study, as had been found in other studies (Keppeler and Ziemer 1990). As seen in Fig. 6, there was a significantly high correlation between watersheds for water yield during the post-treatment years ($r = 0.98$ and $r = 99$, $P < 0.001$) and mean monthly runoff decreased in both watersheds depending on the average monthly precipitation (Fig. 6).

Besides decreases in the precipitation during the treatment period, insignificant change in the water yield can be attributed to rapid regrowth of dense understory vegetation and replenishment of canopy cover which increased interception and transpiration losses causing a decrease in streamflow (Bari et al. 1996; Lane and Mackay 2001). The results of this study were consistent with the conclusions made by Bosch and Hewlett (1982) and Stednick (1996) in their studies that suggested a reduction less than 20 % in timber harvesting did not cause an increase in the water yield in this oak-beech dominated watershed, while the result was not consistent with Sahin and Hall (1996) study that found a 10 % decrease in the forest cover could cause detectable changes in the water yield. These studies indicate that thinning intensity or harvest type are not the only factors responsible for changes in the water yield. In other words, it means that timber harvesting with a lower intensity can increase water yield in high precipitation regions, whereas timber harvesting with a higher intensity may not cause an increase in the water yield in the low precipitation regions. In general, forest reductions with high intensity increase water yield (Hibbert 1967; Hubbart et al. 2007; Dung et al. 2012) and the greatest increase occurs in high precipitation areas (Stednick 1996). Change in the water yield likely is a function of interactions among the intensity and type of timber harvest, vegetation type, amount of precipitation and watershed characteristics such as aspect, elevation, and soil and topographical conditions, and therefore the streamflow response to timber

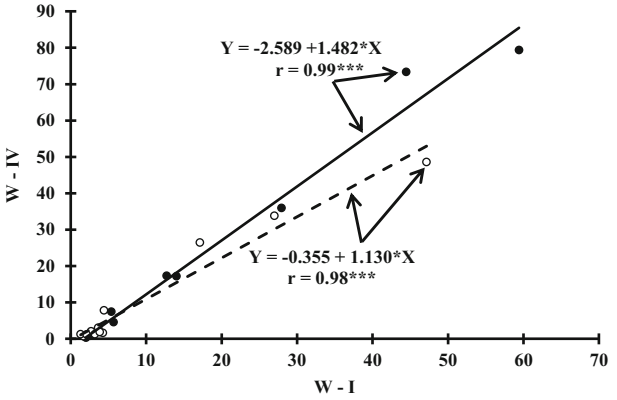


Fig. 6 Relationship between control (W-I) and treatment (W–IV) watersheds for the average monthly streamflows in the first (*solid line*) and the second (*dashed line*) post treatment years

harvesting is variable and unpredictable (Hibbert 1967; Bosch and Hewlett 1982; Stednick 1996; Brown et al. 2005; Hubbart et al. 2007).

4 Conclusions

The main goal of this paired watershed study was to examine the impacts of an 18 % timber volume reduction on the water yield in an oak-beech dominated watershed. The results show that 18 % timber harvesting was not intensive enough to cause detectable change in the streamflow for either of the two separate years and the whole treatment period. This study suggests that the threshold for significant streamflow increase is greater than 18 % for this region. In addition to low thinning intensity, this case can be attributed to decreases in the mean monthly precipitation from year to year after the calibration period. Even though insignificant water yield increases were observed during wetter winter months, planners and practitioners may be able to utilize these findings in future forest management decisions regarding the influence of forest thinning on the water yield in the region. Since the study region is located in a transition zone between sub-humid Southern Europe and semi-arid Northern Middle East regions, the amount of precipitation varies from year to year and vegetation cover has a various woody vegetation types including deciduous, coniferous, shrub and brush vegetation covers. Therefore, further and long-term studies under different scenarios in terms of different precipitation regimes and vegetation covers are needed to discover the influence of different timber harvesting types with various intensities to identify the most suitable vegetation management practices for water production in forested watersheds and to determine the threshold for intensity of timber harvesting, which will cause a significant increase in the runoff of forested watersheds.

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References

Bari MA, Smith N, Ruprecht JK, Boyd BW (1996) Changes in streamflow components following logging and regeneration in the southern forest of Western Australia. Hydrol Process 10(3):447–461

Bosch JM, Hewlett JD (1982) A review of catchment experiments to determine the effect of vegetation change on water yield and evapotranspiration. J Hydrol 55:3–23

Branson FA, Gifford GF, Renard KG, Hadley RF (1981) Rangeland hydrology, second ed. Range Science Series No: 1. Society for Range Management, Denver, Colorado

Brown AE, Zhang L, McMahon TA, Western AW, Vertessy RA (2005) A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. J Hydrol 310:28–61

Caissie D, Jolicoeur S, Bouchard M, Poncet E (2002) Comparison of stream water between pre and post timber harvesting in Catamaran Brook (Canada). J Hydrol 258(1–4):232–248

Dung BX, Gomi T, Miyata S, Sidle RC, Kosugi K, Onda Y (2012) Runoff responses to forest thinning at plot and catchment scales in a headwater catchment draining Japanese cypress forest. J Hydrol 444–445:51–62

Hibbert AR (1967) In: Sopper WE, Lull HW (eds) Forest treatment effects on water yield, Proceedings of the International Symposium on Forest Hydrology. Permagon Press, New York, pp. 527–543
Hubbart JA, Link TE, Gravelle JA, Elliot WJ (2007) Timber harvest impacts on water yield in the Continental/ Maritime hydroclimatic region of the United States. For Sci 53(2):169–180
Keppeler E, Ziemer RR (1990) Logging effects on streamflow: water yield and summer low flows at Caspar Creek in northwestern California. Water Resour Res 26(7):1669–1679
Lane PNJ, Mackay SM (2001) Streamflow response of mixed-species eucalypt forests to patch cutting and thinning treatments. For Ecol Manag 143:131–142
Lesch W, Scott DF (1997) The response in water yield to the thinning of *Pinus radiata*, *Pinus patula*, *Eucalyptus grandis* plantations. For Ecol Manag 99:295–307
Lewis D, Singer MJ, Dahlgren RA, Tate KW (2000) Hydrology in a California oak woodland watershed: a 17-year study. J Hydrol 240:106–117
Neary DG, Ice GG, Jackson CR (2009) Linkages between forest soils and water quality and quantity. For Ecol Manag 258:2269–2281
Neris J, Tejedor M, Rodríguez M, Fuentes J, Jiménez C (2013) Effect of forest floor characteristics on water repellency, infiltration, runoff and soil loss in Andisols of Tenerife (Canary Islands, Spain. Catena 108:50–57
Núñez D, Nahuelhual L, Oyarzún C (2006) Forests and water: the value of native temperate forests in supplying water for human consumption. Ecol Econ 58:606–616
Özhan S (1977) Variation in Some Hydrologic Properties of Forest Floor as Related to Certain Environmental Factors in Ortadere Watershed of Belgrad Forest, Istanbul University, Faculty of Forestry Publication Number: 235, Istanbul (in Turkish)
Özhan S, Balcı AN, Özyuvaci N, Hızal A, Gökbulak F, Serengil Y (2005) Cover and management factors for the universal soil-loss equation for forest ecosystems in the Marmara region, Turkey. For Ecol Manag 214:118–123
Özhan S, Hızal A, Şengönül K, Gökbulak F, Serengil Y, Özcan M (2008) Hydrological and hydrochemical modeling of watershed systems in Belgrad Forest. Unpublished research project report (supported by the Scientific and Technological Research Council of Turkey (TUBITAK) with a grant number of TOVAG - 105 0182)
Özhan S, Gökbulak F, Serengil Y, Özcan M (2010) Evapotranspiration from a mixed deciduous forest ecosystem. Water Resour Manag 24(10):2353–2363
Özyuvacı N (1999) Meteorology and Climatology, Istanbul University Publications No. 4196, Istanbul (in Turkish)
Özyuvacı N, Özhan S, Gokbulak F, Serengil Y, Balcı AN (2004) Effect of selective cutting on stream water in an oak-beech forest ecosystem. Water Resour Manag 18:249–262
Sahin V, Hall MJ (1996) The effects of afforestation and deforestation on water yields. J Hydrol 178:293–309
Serengil Y, Gökbulak F, Özhan S, Hızal A, Şengönül K, Balcı AN, Özyuvacı N (2007) Hydrological impacts of a slight thinning treatment in a deciduous forest ecosystem in Turkey. J Hydrol 333:569–577
Stednick JD (1996) Monitoring the effects of timber harvest on annual water yield. J Hydrol 176:79–95
Suryatmojo H, Masamitsu F, Kosugi K, Mizuyama T (2013) Effects of selective logging methods on runoff characteristics in paired small headwater catchment. Procedia Environ Sci 17:221–229
Swank WT, Vose JM, Elliot KJ (2001) Long term hydrologic and water quality responses following commercial clear cutting of mixed hardwoods on a southern Appalachian catchment. For Ecol Manag 143:163–178
Troendle CA, King RM (1985) The effect of timber harvest on the Fool creek watershed, 30 years later. Water Resour Res 21(12):1915–1922
Troendle CA, Wilcox MS, Bevenger GS, Porth LS (2001) The Coon creek water yield augmentation project: implementation of timber harvesting technology to increase streamflow. For Ecol Manag 143:179–187
Tsiko CT, Makurira H, Gerrits AMJ, Savenije HHG (2012) Measuring forest floor and canopy interception in a savannah ecosystem. Phys Chem Earth 47–48:122–127
USDA (Unites States of Department of Agriculture) (1996) Keys to Soil Taxonomy, seventh ed. Washington, DC
Viola MR, Mello CR, Beskow S, Norton LD (2014) Impacts of land-use changes on the hydrology of the Grande River Basin headwaters, Southeastern Brazil. Water Resour Manag 28:4537–4550
Watson F, Vertessy R, McMahon T, Rhodes B, Watson I (2001) Improved methods to assess water yield changes from paired-catchment studies: application to the Maroondah catchments. For Ecol Manag 143:189–204
Yaltırık F (1966) Floristic Analysis of Belgrad Forest and Main Stand Composition, General Directorate of Forestry Publication Number: 6, Ankara, Turkey (in Turkish)
Yao Y, Cai T, Ju C, He C (2015) Effect of reforestation on annual water yield in a large watershed in Northeast China. J For Res 26(3):697–702
Zar JH (1996) Biostatistical analysis, 3rd edn. Prentice-Hall, Upper Saddle River
Zeppel MJB, Macinnis-Ng CMO, Yunusa IAM, Whitley RJ, Eamus D (2008) Long term trends of stand transpiration in a remnant forest during wet and dry years. J Hydrol 349:200–213
Zhang X, Yu GQ, Li ZB, Li P (2014) Experimental study on slope runoff, erosion and sediment under different vegetation types. Water Resour Manag 28:2415–2433