Joint production of timber and water: a case study

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Abstract

The integration of water production values for forest ecosystems into forest management models has become increasingly important in sustainable forest management in recent years because forests play a vital role in the quantity and quality of surface and ground water resources. The main objective of this work was to develop a multiple use forest management planning model, focusing on the economic effects of some forest management policy constraints on timber and water production values for forest ecosystems. Each forest value is functionally linked to stand structure and is quantified economically. Various forest management planning scenarios were developed to be applied in a typical forest that has the potential to yield timber and water benefits. The analysis was performed by formulating a linear programming-based multiple-use forest management planning model. The results show that the total net present value (NPV) of timber and water production profits would be reduced by up to 25.3% when area and timber volume policy constraints are incorporated into an unconstrained forest management planning model. The results also indicate that, if forests are managed to meet some forest management policy constraints, the NPV of timber production is considerably reduced. In addition, the interactions between timber and water are found to be complementary, depending on the assumed relationships between forest ecosystem structure and forest values. In terms of forest management, the issue of water quality and quantity is likely to become even more important in the future, due mainly to increasing demand on water.

Keywords: Forest management; Net present value (NPV); Optimization; Timber production; Water quality and quantity

1. Introduction

Forest ecosystems provide many functions, goods and services such as gas regulation, climate regulation, water supply and regulation, soil conservation, biological diversity, recreation, food, medicinal resources, raw materials and cultural values (Groot et al., 2002). The values of forest ecosystems are also influenced by forest ecosystem characteristics. Water quantity and quality are two of the most important values of forests. Forest ecosystems play a vital role in the quality and quantity of water resources. Furthermore, forests are the major sources of the world’s scarce freshwater resources.


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However, the water quality and quantity of forest ecosystems have been affected by a number of parameters of forest stands\textsuperscript{1} such as tree species, crown closure of stands, basal area, mean diameter of stand, number of stems, standing timber volume and leaf area index of trees (Hof & Bevers, 2000; Turner et al., 2002; Başkent & Keleş, 2009).

Nowadays, population growth and socio-economic activities are putting a huge pressure on fresh and drinkable water resources, and they have often contributed to the destruction of water-related ecosystems with negative effects on natural water resources (Enderlein & Bernardini, 2005). Shortages in fresh and drinkable water have become limiting factors in maintenance of economic productivity, social well-being and lifestyle. Furthermore, increasing pollution of water resources affects the maintenance of nature and ecosystem services of many countries and regions. Under these conditions, assessing and managing water resources is vital. The rational use and protection of water resources are among today’s most acute and complex scientific, economic and technical problems (Turner et al., 2002; Groot et al., 2002; Enderlein & Bernardini, 2005; Başkent & Keleş, 2009).

Recently, emphasis in forest management planning has been placed not only on timber production but also on such values as amenity, recreation, soil protection, carbon sequestration and biodiversity (Kangas & Kuusipalo, 1993; Hoen & Solberg, 1994; Pukkala et al., 1995; Hof & Bevers, 2000; Bertomeu & Romero, 2001; Krcmar et al., 2001; Diaz-Balteiro & Romero, 2003; Kazana et al., 2003; Backéus et al., 2005; Keleş & Başkent, 2007; Keleş et al., 2007; Başkent et al., 2008). Thus, the meaning of sustainable forest management has broadened in some areas from sustained timber management to ecosystem-based multiple use forest management. As the concept of multiple use forestry has become more widely accepted, forest planning is practiced based with a more holistic approach, where the multiple uses of the forest are considered simultaneously. While multiple use forestry is accepted as a leading forest management policy, there is still a need to develop planning models that adequately incorporate multiple uses of the forest as management objectives. Among studies about multiple use forest management planning, a limited number of research initiatives have presented quantitative estimates of how forest management policy constraints may influence timber and water production values. Rowse & Center (1998) examined the economic effects of joint production of timber and water production for three block sizes in a forested area in Canada, using a linear programming model. Turner et al. (2002) compared two important forest management planning packages in the context of their ability to handle large multi-objective forest management problems, including water and sediment yield objectives as well as timber production. Hof & Bevers (2000) developed a simple model that focuses on the spatial relationships over time between timber harvesting and sediment levels in water runoff courses throughout the watershed being managed. Hof & Bevers (2001) also developed a spatial linear model that strategically arranges forest treatments so as to meet peak stormflow objectives. Loehle (2000) studied the incorporation of water quality restrictions into timber-oriented forest management and controlling storm runoff from a forested watershed. Rauscher et al. (2000) developed a practical decision-analysis process for forest ecosystem management, and one of the goals in their model was to limit peak flows by reducing erosion, silting, and flooding in a watershed. Başkent & Keleş (2009) analyzed the interactions between timber production, water production and carbon sequestration values in a case study area in Turkey. However, there is also a need to study the economic

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\textsuperscript{1} A forest stand refers to a spatially homogeneous patches of forests differentiated from its surroundings based on development stages, crown closure, species mix and site quality.
effects of forest management policy constraints on joint production of water and timber in current forest management philosophy.

The main objective of this paper was to develop a multiple use forest management planning model focusing on the joint production of timber and water in a forest area. Timber and water production values are functionally linked to forest structure, and predicted quantitatively and economically in forest management planning process. Alternative forest management planning scenarios based on linear programming were developed to determine the effects of various forest management policy constraints on joint production of timber and water. The model includes the economic value of timber and water production, and provides information on the amount of water, timber and on the state of the standing and harvested forest. A case study was designed to materialize the model solutions as results and discuss the interactions between timber and water production.

2. Water production value of forest ecosystems

Forest ecosystems play an important role in the quantity and quality of water. They regulate water flows and supply. Water from forested watersheds also facilitates a number of ecological, economic and social functions. Several characteristics of forests aid in the production of clean water. Forests improve water quality by withholding sediment production and reducing soil erosion, and forest ecosystems improve peoples’ health due mainly to the effect of cleaner water (Groot et al., 2002; Enderlein & Bernardini, 2005; Başkent & Keleş, 2009). Water has ecological functions because it is critical to the sustenance of human life, plants, animals and other living and other living organisms. They provide many opportunities and social functions for society, such as recreation, fishing, camping, water bird sighting and rafting. Further, water from forests has economic functions. For example, in Switzerland, 38% of the water supplied is untreated. The use of groundwater, mostly from forested watersheds, which needs no treatment, saves Swiss consumers US$ 64 million per year (Enderlein & Bernardini, 2005).

The factors affecting water quality and quantity from forested watersheds are generally atmospheric elements, watershed parameters and land use. Precipitation in a watershed varies from year to year but is generally constant, and it is not possible to increase or decrease it. Watershed parameters like geographical position, area, shape, altitude and geology are not changeable over time and they do not have important effects on water yield. Soil may affect water quality and quantity positively or negatively depending on the applied interventions. The use of any area for forest, agriculture, pasture or settlement is the most important factor affecting water quality and quantity. However, forest ecosystems and forest management activities are the most striking way to control and regulate water resources (Özhan & Gökbulak, 2001).

Water yield mainly depends on the role of forest ecosystems in hydrologic cycles. Paired catchment studies have been widely used as a means of determining the magnitude of water yield changes resulting from changes in forest ecosystem structure. Forest stand parameters such as tree species, stand age, stand basal area, number of trees, leaf area, crown closure and development stages are the main parameters affecting water quality and quantity in forested watersheds. Paired catchment studies generally include the use of two catchments with similar characteristics in terms of slope, aspect, soils, area, climate and vegetation located adjacent or in close proximity to each other (Brown et al., 2005). The paired catchment studies have reported that reducing forest cover causes an increase in water yield and that increasing forest cover causes a decrease in water yield (Bosch & Hewlett, 1982; Hornbeck et al., 1993; Whitehead & Robinson, 1993; Stednick, 1996; Sahin & Hall, 1996; Brown et al., 2005).
3. Analytical framework

This paper examines the effects of various forest management policy constraints on joint production of timber and water. Timber yields were estimated using the forest inventory data for the case study area and the stand density yield tables for spruce (*Picea orientalis*) forest stands (Ercanlı, 2003). Volumes of various timber assortments (sawlogs, mining pole, industrial wood and firewood) as a result of clearcutting and thinning at any age were determined by product rates of stand age and mean stand diameter of the relevant species (Sun *et al*., 1977). Revenues and costs from timber were determined by the volume of various product types and their associated values. All financial calculations were discounted with a 3% interest rate, as generally applied to the financial evaluation of forestry projects in Turkey.

The water production response functions used in this paper were developed by Yolasiğmaz (2004) for spruce stands in the case study area. The amount of water production in forest ecosystems is linked to stand basal area, a fairly good driving parameter in determining the amount of water produced in forest ecosystems (Tecle *et al*., 1998; Asan & Şengönül, 1987; Başkent & Keleş, 2009). The coefficient of determination of the equation indicates a fairly good relationship:

\[
WP = 475.181 \times e^{-0.0232 \times BA} \quad \text{(for softwood)} \quad R^2 = 0.68
\]

where \(WP\) = annual water production \((\times 10^1 \ \text{ton/ha})\), \(BA\) = residual stand basal area \((\text{m}^2/\text{ha})\), and \(e = 2.71828\).

Water produced in forests has a value in the form of both quantity and quality. Assigning an ideal financial value to water originated from forests poses difficult problems, since water markets in Turkey are not well developed. In this study, the economic value of forest water is estimated as follows (Rowse & Center, 1998): municipal, agricultural and industrial water use in Turkey is generally broken down into 15%, 75% and 10%, respectively; net returns for municipal, irrigation and industrial water use are $0.56, $0.01 and $1.4 per m³, respectively (SPO, 2009); using a weighted average of these net returns, it was found that the economic value of water is $0.23 per m³. The use of such an economic value of water is also used in other studies (Rowse & Center, 1998; Keleş, 2003; Yolasiğmaz, 2004; Başkent & Keleş, 2009). In this study, the quantity of water was taken into consideration due to insufficient data and information about water quality which is extremely important in deciding the more accurate economic value of water in forest ecosystems. All financial calculations were discounted with a 3% interest rate, as used for the timber production value.

A linear programming model was formulated to represent the joint production of timber and water. The model maximizes the total net present value of timber and water production. A number of forest management planning scenarios were developed depending on various forest management policy constraints. The linear programming-based multiple use forest management model was formulated as:

\[
\text{max } NPV_T + NPV_W
\]

subject to:

\[
\sum_{i=1}^{I} \sum_{j=1}^{J} npv_{ij} x_{ij} = NPV_T
\]

(2)

(3)
\[
\sum_{i=1}^{I} \sum_{j=1}^{J} npv'_{ij} x_{ij} = NPV_T
\]
\[
\sum_{i=1}^{I} \sum_{j=1}^{J} V_{ij} x_{ij} = H \quad \text{for all } j
\]
\[
\sum_{i=1}^{I} \sum_{j=1}^{J} w_{ij} x_{ij} = W \quad \text{for all } j
\]
\[(1 - \alpha)H_j - H_{j+1} \leq 0\]
\[(1 + \alpha)H_j - H_{j+1} \geq 0\]
\[
\sum_{i=1}^{I} \sum_{j=1}^{J} x_{ij} = OPA \quad \text{for all } j
\]
\[(1 - \beta)OPA_j - OPA_{j+1} \leq 0\]
\[(1 + \beta)OPA_j - OPA_{j+1} \geq 0\]
\[
\sum_{j=1}^{J} x_{ij} = A_i
\]

where \(J\) is the number of planning periods; \(I\) is the number of stands; \(npv'_{ij}\) is net present value of the timber production per hectare harvested from stand \(i\) in period \(j\); \(npv'_{ij}\) is net present value of the water production per hectare produced from stand \(i\) in period \(j\); \(x_{ij}\) is the area of stand \(i\) harvested in period \(j\); \(H_j\) is the timber volume harvested in period \(j\); \(V_{ij}\) is the harvested volume from stand \(i\) in period \(j\); \(w_{ij}\) is the water production from stand \(i\) in period \(j\); \(OPA_j\) is the optimal periodic area in period \(j\) (total forest area divided by the planning horizon (100 years) and multiplied by planning period (10 years)); and \(A_i\) is the area of stand \(i\).

The objective function is to maximize the net present value of timber (\(NPV_T\)) and water (\(NPV_W\)) productions in Equation (2). Equations (3) and (4) are accounting variables estimating the net present values of timber and water, respectively. Equations (5) and (6) are also accounting variables estimating the amount of timber and water production for each period. The timber volume control Equations (7) and (8) are harvest flow controls, restricting the harvest volume to decrease or increase a maximum of the given proportion (\(\alpha\)) from one period to the next. Equation (9) is an accounting variable estimating the harvested area in each period; it also defines the number of hectares belonging to each one of the final age classes and uses when a regulated forest is wanted at the end of the forest planning horizon. Equations (10) and (11) are the regenerated area flow constraints (called the optimal periodic area),
restricting the harvested area to decrease or increase a maximum of the given proportion ($\beta$) from one period to the next. Equation (12) is an area control and ensures that the sum of the hectares harvested in each period is equal to the area corresponding to each forest stand.

It is possible to produce a number of forest management planning scenarios with the model developed in this paper. However, only some forest management planning scenarios have been introduced, to illustrate the economic effects of various forest management policy constraints on timber and water values of forest ecosystems (Table 1). For example, scenario SO (unconstrained forest management planning model) corresponds to the maximization of the total net present values of timber and water, and does not include any constraints. Scenario SAH3 also maximizes the total net present value of timber and water, and includes two main constraints: an even flow of timber production, and harvested area from period to period. In this table, $\alpha$ and $\beta$ are statistical symbols showing the maximum fractional increase and decrease, respectively, allowed in the area and timber harvest volumes of the forest between periods. Area and volume control policies are extremely important constraints and regulations for sustainable forest management.

4. The case study

A joint production model of timber and water was implemented in an area of the Artvin Forest Management Planning Unit in northeastern Turkey (Figure 1). In the context of this paper, only a 643.2 ha spruce ($Picea orientalis$) forest area was subjected to harvest scheduling. The case study area surrounds the city of Artvin and is characterized by a dominantly steep and rough terrain with an average slope of 62% and an altitude of from 400 to 2,200 m above sea level. It extends along the northeastern Black Sea region of Turkey. Mean annual temperature of the study area is 11.9°C, and mean annual precipitation is 719.7 mm. The main soil types are sandy clay loam, clay loam and sandy loam. The total initial growing stock of spruce forest is 258,687 m$^3$. The planning area consists of 185 stands (polygons or sub-compartments) that are subject to certain management interventions. Each stand has different species, age, development stages and site qualities.
5. Results and discussion

In the reference case (S0), the NPVs of timber and water production were $2,508,757 and $1,323,873, respectively, at the end of the planning horizon. The total NPV was $3,832,630. Table 2 shows that the area control policies decreased the NPVs of timber and water both separately and together. In other words, the area control constraints were binding. In scenario SA1, with an area variation limit of 0% (with an even flow of area) which is more restrictive, the total NPV of timber and water decreased by about 21.15% (from $3,832,630 in the reference case to $3,022,094). By limiting the area variation within 10% in scenario SA2 and 20% in scenario SA3, the total NPV of timber and water decreased by about 14.61% (from $3,832,630 in the reference case to $3,272,622) and 9.28% (from $3,832,630 in the reference case to $3,476,940), respectively.

Age–class structure over time is a very important forest performance indicator in analyzing the effects of forest management practices on forest values (Başkent et al., 2008; Başkent & Keleş, 2009). The age structure of the forest at the end of the planning horizon associated with different forest management scenarios was shown in Table 3. As expected, even flow of area distribution in scenario SA1 was provided. On the other hand, the age–class structure in scenarios SA2 and SA3 at the end of the planning

Fig. 1. Map of the case study area.
horizon were within the intervals of 10% and 20% change of the regulated forest structure. On the contrary, in reference case scenario (S0), most of the stands were harvested when they reach the minimum cutting age to increase timber and water production values, because efficient forest management planning for timber production needs harvesting and regeneration of old forest stands (Zhou, 2007). When forests are managed without any regulatory constraints, all the old stands should be harvested in period 1 (Zhou & Gong, 2004). Similar results can also be found in Başkent & Keleş (2009).

On the other hand, volume control policies decreased the NPVs of timber and water. In other words, the timber volume constraints were binding. Compared to S0, the reductions in the total NPV of timber and water in scenarios SH1, SH2 and SH3 were about 25.22% (from $3,832,630 in scenario S0 to $2,866,099), 14.77% (from $3,832,630 in scenario S0 to $3,266,429) and 6.31% (from $3,832,630

Table 2. Relative changes in the NPV of timber and water productions according to the alternative forest management policy constraints.

<table>
<thead>
<tr>
<th>Forest management scenarios</th>
<th>NPV (in $ and as percentage deviation from the reference case)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Timber</td>
</tr>
<tr>
<td>Reference case (S0)</td>
<td>$2,508,757</td>
</tr>
<tr>
<td>SA1</td>
<td>-25.49%</td>
</tr>
<tr>
<td>SA2</td>
<td>-17.56%</td>
</tr>
<tr>
<td>SA3</td>
<td>-11.10%</td>
</tr>
<tr>
<td>SH1</td>
<td>-30.41%</td>
</tr>
<tr>
<td>SH2</td>
<td>-17.76%</td>
</tr>
<tr>
<td>SH3</td>
<td>-7.57%</td>
</tr>
<tr>
<td>SAH1</td>
<td>-30.65%</td>
</tr>
<tr>
<td>SAH2</td>
<td>-18.52%</td>
</tr>
<tr>
<td>SAH3</td>
<td>-11.63%</td>
</tr>
</tbody>
</table>

Table 3. Distribution of the age classes of forest management planning scenarios at the end of the planning horizon (in ha).

<table>
<thead>
<tr>
<th>Age classes</th>
<th>Scenarios</th>
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<tbody>
<tr>
<td></td>
<td>S0</td>
</tr>
<tr>
<td>0–10</td>
<td>0.00</td>
</tr>
<tr>
<td>11–20</td>
<td>0.00</td>
</tr>
<tr>
<td>21–30</td>
<td>24.20</td>
</tr>
<tr>
<td>31–40</td>
<td>0.00</td>
</tr>
<tr>
<td>41–50</td>
<td>68.78</td>
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<tr>
<td>51–60</td>
<td>31.55</td>
</tr>
<tr>
<td>61–70</td>
<td>80.73</td>
</tr>
<tr>
<td>71–80</td>
<td>0.00</td>
</tr>
<tr>
<td>81–90</td>
<td>206.07</td>
</tr>
<tr>
<td>91–100</td>
<td>231.88</td>
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</table>
in scenario S0 to $3,590,687), respectively. In any case, however, the variation in timber volume flow was within the given fractional changes in these scenarios and thus volume control policies were effectively carried out in the model (Table 4). Compared to the scenarios including volume control policies, scenario S0 created non-regulated timber volume flow over time, and focused on cutting more stands in the first two periods to increase timber and water productions. Nonetheless, in the other scenarios, except for SH1 and SAH1, periodic harvested timber production was decreased (within the fractional decrease and increase of volume variation allowed) from the first period to the last period to produce more NPV of timber and water profits.

In most cases, the integration of regulatory constraints into forest management plans causes losses in both economic profit and timber volume (Field et al., 1980; Hof et al., 1986; Haight et al., 1992; Hoganson & McDill, 1993; Başkent & Keleş, 2006, 2009). For example, Haight et al. (1992) showed that a model including a regulated timber volume constraint results in a NPV reduction of 5% compared to an unconstrained model. Başkent & Keleş (2006) also showed that the area and timber volume control policies decrease the NPV of timber by up to 44.2% depending on various discount rates. In another study (Başkent & Keleş, 2009), the results indicate that the NPV of timber decreases by 24% when an even flow of timber constraint is incorporated into forest management planning. In this study, the results show that, if the forests are managed to meet some forest management policy constraints, the NPV of the profits of timber production is considerably reduced, and this reduction could be as much as 30.6%.

Area and timber volume control policies together decreased the NPVs of timber and water production (Table 2). The reductions in the total NPV of timber and water in scenarios SAH1–SAH3 were greater than those of scenarios with area (SA1–SA3) and timber volume (SH1–SH3) control policies. The reductions in the total NPV varied from 9.71% to 25.32%.

In this study, the numerical results presented above were obtained by solving a single model maximizing the total NPV of timber and water productions simultaneously. In addition, two optimization models maximizing first the NPV of timber and then the NPV of water were also solved separately, and the results analyzed. In such a case, the optimal solutions obtained by maximizing first timber value and then water value were similar to those obtained by maximizing the sum of the NPVs of timber and water productions simultaneously.

<table>
<thead>
<tr>
<th>Table 4. Timber production of various forest management planning scenarios (in m³).</th>
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<tbody>
<tr>
<td>Period</td>
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<tr>
<td></td>
</tr>
<tr>
<td>1</td>
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6. Summary and conclusions

Recently, forest management planning has evolved from classical timber production to ecosystem-based multiple-use forest management planning. In addition to timber, forest ecosystems produce a number of other goods and services such as water production, carbon sequestration, recreation, biodiversity, and soil protection. In recent years, more attention has focused on water in the world. In terms of forest management planning, the quantity and quality of water is of vital importance as present and future demand of water increases.

All forest goods and services also have an economic value. However, many important forest goods and services are not traded in any market; thus, they have no economic value. If a forest ecosystem is planned mainly for timber production, the effects of timber-oriented management on other forest goods and services may be negative. On the other hand, integrating non-timber forest goods and services with their economic values into forest management planning process has the potential of radically changing the sustainable use of forest resources. Furthermore, various forest management policy constraints may heavily reduce the economic output of timber and some other forest values, like water.

In this study, the economic effects of forest management policy constraints on timber and water productions in northeastern Turkey were analyzed. Only two of many additional goods and services accruing from forest ecosystems were included in the analysis. Both timber and water benefits were measured by the net present value of profits. The numerical results showed that the integration of the regulatory constraints of area and timber volume into forest management plans decreased the total NPVs of timber and water production. On the other hand, these constraints also caused considerable losses in the NPV of timber and water, separately. It is believed that this case study provides an insight into the tradeoffs and co-benefits if incentives to produce water are added to current forest management objectives. Findings that show co-benefits in the joint production of timber and water production are perhaps not surprising.

The amount of water production of forest ecosystems in this study was calculated using basal area for softwood species. The value should also be calculated for each species in various forest sites for more accurate assessment. Additionally, the water production response functions relating to other stand parameters such as number of trees, leaf area, crown closure, and stand density should also be developed and used in multiple-use forest management because the quantity and quality of water produced, in general, depends on the quantity and structure of the forest ecosystem. In this study, the quantity of water was taken into consideration because of insufficient data and information about water quality, which is extremely important in deciding the more accurate economic value of water in forest ecosystems.

The structure of forest ecosystem may have certain impacts on various timber and non-timber forest goods and services. The quality and quantity of all forest goods and services are influenced by forest characteristic such as stand structure, spatial distribution, tree species composition, and developmental stage. The interactions among forest goods and services are sometimes complementary (e.g., water and timber production) and sometimes contradictory (e.g., timber production and soil protection), depending on the relationships between forest ecosystem structure and forest goods and services. Therefore, if forest management is to meet public demands for certain forest values, the long term effects of alternative forest management scenarios including various policy constraints and targets should be known.
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Received 27 September 2009; accepted in revised form 31 May 2010. Available online 18 April 2011