African Journal of Agricultural Research Vol. 4 (11), pp. 1241-1250, November, 2009
Available online at http://www.academicjournals.org/AJAR
ISSN 1991-637X © 2009 Academic Journals

Full Length Research Paper

Integrating soil conservation, water production and timber production values in forest management planning using linear programming

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Accepted 2 October, 2009

Forest management focuses on the control of forest ecosystems based on the sustainable use of forest values without damaging ecological integrity. Although, timber would easily be characterized and valued, it is difficult to quantify the amount and monetary value of water production and soil conservation. In this study; soil conservation, water and timber production values of forests were taken into consideration. These values were associated with basal area using a regression model to create soil loss, water and timber production yield tables. All forest values were then expressed as monetary value by logical estimations. An LP based forest management model was developed to integrate the values and solved by LINDO™. Six alternative planning strategies were developed based on the integration of various objectives such as maximization of net income obtained from timber and water production and minimization of soil loss with 10% harvest flow and even age class distribution constraints. When NPV (Net Present Value) of three forest values were compared for each strategy; strategies to maximize water production created the highest and the strategies to minimize soil loss generated the lowest NPV at the end of 100 year planning horizon. In conclusion, forest management plans must be prepared to consider multi objectiveness about multiple products and services. Economical values of all forest objectives must be handled in preparation and implementation of management plans. Modeling is an inevitable process in integrating economical, ecological and socio-cultural values of forest ecosystems.

Key words: Linear programming, forest ecosystem, soil conservation, water production, timber production, net present value**.**

INTRODUCTION

Forests provide a great variety of environmental services, including carbon sequestration, conservation of biodiversity, watershed protection and scenic beauty (Pearce and Moran, 1997; Groot et al., 2002). The ecosystem services and the natural capital stocks that produce them are critical to the functioning of the Earth's life-supporting system. They contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet (Costanza et al., 1997; Guo et al., 2001).

Today, there is an increasing recognition of other values all but timber production, as well as conservation targets within a number of international conventions. This has broadened the scope of forest management towards ecosystem-based approaches aiming to sustain the capacity of forest ecosystems to continue delivering a wide range of goods and services (Anon., 1998; Hunter, 1999; Schlaepfer and Elliot, 2000; FAO, 2001; Angelstam, 2002). This underlines the need to effectively combine production and conservation goals in practical forest management especially timber and water production and soil conservation values.

A conventional timber production oriented forest management process has created forest ecosystems that have critical impacts on habitats for biodiversity. This process may affect other ecosystem services, such as cycling of nutrients and water, species abundance and composition, and recreational values (Christensen et al.,

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1996; Daily et al., 1997; Lindenmayer, 1999; Naeem et al., 1999; Loreau et al., 2002). One of the leading problems is the accommodation of timber and other values in forest management plans while protecting forest ecosystem. Soil conservation and water production values are two critically important forest values for Turkey.

Turkey is a mountainous and hilly country with an average altitude of 1132 m, surrounded by the seas from the north (Black Sea), south (Mediterranean Sea) and the west (Aegen Sea). It is a peninsula which accounts for the great differences in climate, soil and the other ecological properties. Due to land use, climatic and topographic condition, Turkey is one of the most soil losing countries. Soil loss per area in Turkey is 2 times more than Asia, 6 times more than North America and 22 times more than Africa. Approximately 86% of Turkish land is susceptible to erosion (Çepel, 1997; Özden et al., 2007).

Forests regulate quality as well as quantity of water, being the base for an integrated management of hydrological resources in forested watersheds. Hence, water supply provides an important argument for forest sustainable management and protection around the planet (Twery and Hornbeck, 2001; Dudley and Stolton, 2003). As most of the countries, Turkey is suffering from water shortage as compared with other countries and world's average considering per capita utilizable water. Countries having 10,000 m^3 annual average of per capita utilizable water were accepted as water rich countries. However, Turkey is far behind the world average of 3690 m^3 (Anonymous, 2001). Because of the water deficiency and land limitation 20% of irrigable land can be hardly irrigated. Severe effects of the water deficiency may be seen in the future (Özden et al., 2007).

Any management interventions to produce wood and other services from forests have a certain effect on the quality and quantity of water and soil loss. It is important to sustain the values of forest resources using appropriate harvest scheduling methods and techniques (Başkent et al., 2000). Various planning techniques such as Linear Programming (LP), Genetic Algorithm, Tabu Search and Simulated Annealing have been widely used in forest management planning to accommodate forest values into planning (Turner et al., 2002).

Among them, LP has been widely used in forestry and forest resources planning, as it is a powerful tool to generate an optimal solution and enables further sensitivity analyses. However, very few studies have been conducted in Turkey and some other countries alike to integrate soil protection and water production into forest management plans with economic analyses. Rowse and Center (1998) maximized NPV of water and timber production to investigate the economic structure in presence of different forest products in a forested watershed in Canada using LP. They found that when harvesting occurs in smaller cutting blocks, water production and also expenditures increases. Gül (1998) divided a forest into six planning units of timber, soil, water, oxygen production and nature protection and aesthetics value and developed LP model to maximize NPV of allowable cut on a stand type basis without spatial characteristics. Mısır (2001) considered timber production, water production and soil protection values and implemented optimization of these values using goal programming without economic values. Turner et al. (2002) tried to handle timber production, water production and soil loss values of forests in multi objective manner comparing LP and heuristic search optimiser. Karahalil (2003) optimized soil protection and timber production values of forests and Keleş (2003) optimized water production and timber production values using LP. Recently, Keleş et al. (2007) integrated six important selected forest values (soil conservation, carbon sequestration, visual quality, timber, water and oxygen production) into a linear programming-based forest management planning model. Selected forest values were linked to forest stand characteristics and a number of forest management strategies were developed to evaluate the trade-offs among forest values. Soil losses and water productions of forest ecosystems decreased, when residual basal area of forest stands increased.

Therefore, few studies considered more than two forest values such as water, soil and timber. These researches, however generally do not include economical comparison and outputs to evaluate all values together during the decision making process. Moreover, basic decision variables are related to age classes or clumped stand types rather than individual stands, leaving operations on the ground difficult.

This study attempts to accommodate water production, soil protection and timber production into forest management planning using sequential LP. Water and timber production and soil loss yields as well as economic values for each stand, were developed using the statistical relations between forest structure and values. Planning outputs of different strategies were displayed as performance indicators to understand the forest dynamics under various regulations.

MATERIALS AND METHODS

Study area

Karanlıkdere Planning Unit, located in 40º 16´ 07´´- 40º 21´ 38´´ north latitudes and 39º 03´ 46´´- 39º 21´ 59´´ east longitudes in Gümüşhane province, was selected as a study area (Figure 1). The area covers 26118 ha., with 956 stands (polygons). While 866 stands are forest, others are non forest areas such as agricultural area (330.2 ha), pasture (5104 ha) and lake (6.32 ha). Open forest lands or treeless forest areas cover 11914 ha. Rest of the area is under stock forest stands. Average volume per hectare is very low (65 m^3). The basic tree species are Scots pine (*Pinus sylvetris*) and Caucasian fir (*Abies nordmanniana* subsp. *nordmanniana*) (Anonymous, 1984).

Creating yield curve and NPV of timber production

Forest inventory data were updated to determine the current forest

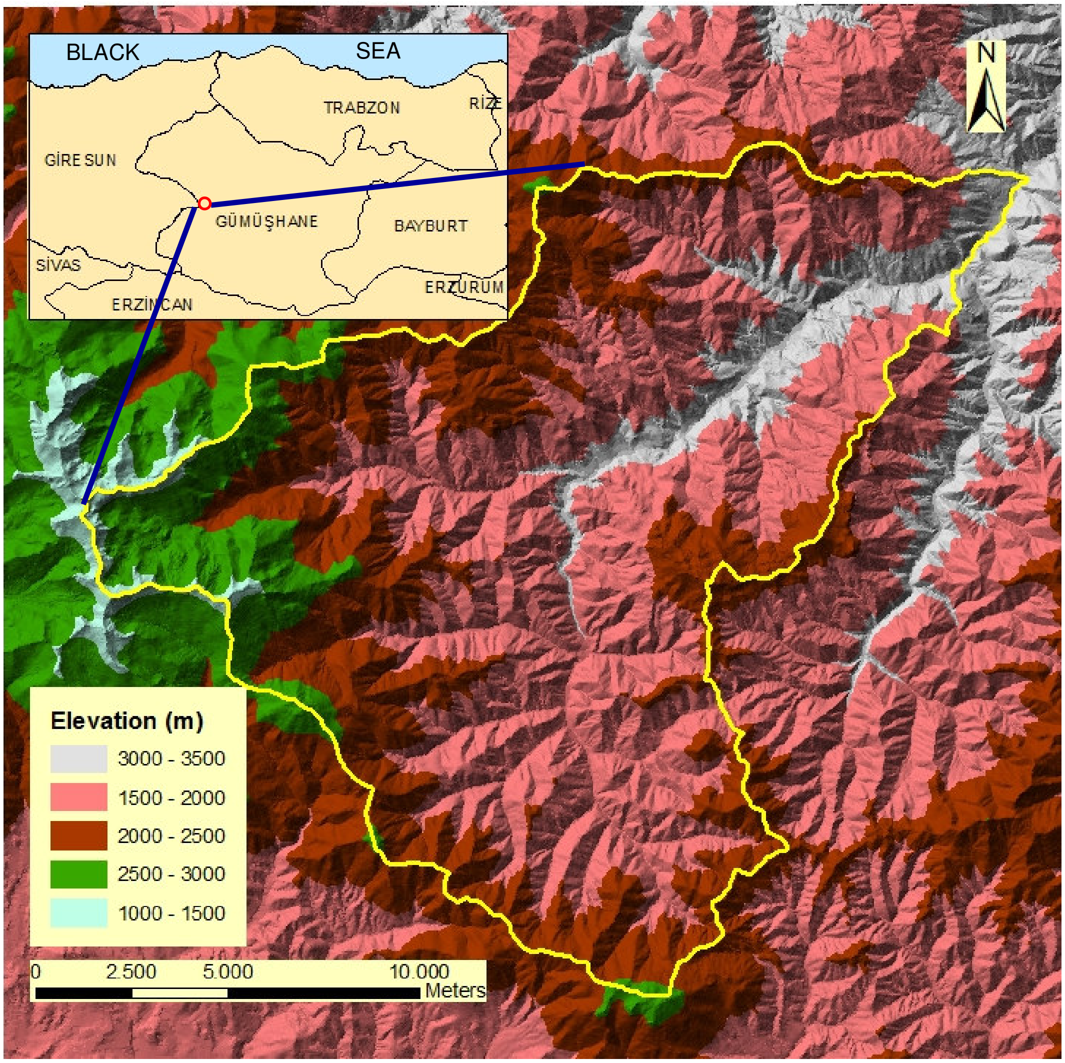

Figure 1. Location of the research area.

structure (forest composition) using Karanlıkdere Forest Management Plan (Anonymous, 1984). For future forest structure, empirical yield tables for Scots pine developed by Alemdağ (1967) were used. Kazdağı Fir yield table developed by Asan (1984) was used instead of Caucasian fir stands having similar biological growth because there is no yield table for even aged Caucasian fir. Mid points of planning periods were used in calculation of yield curve data.

Low interest rate was used in forest management considering safe management structure in terms of revenue and capital, increasing and diversification of demands day by day. When studies were analyzed for Turkey and forestry developed countries, interest rate was generally selected between 1.5 and 5%, predominantly 3% (Türker, 2008). So, in this study, 2002 was accepted as base year to approximate income and expenditures to today with a 3% guiding interest rate for amount of harvested timber, water yield and soil loss.

Gümüşhane Forest Enterprise annual financial statement of the year 2002 was used to calculate economic value of timber harvested. The major income of the enterprise consists of forest products such as saw timber, pole, industrial and firewood that are provided from harvesting activities. Average market prices were considered in determining incomes. Wood products assortments were used based on age and mean diameter of relevant tree sp$-ecies after regeneration and thinning at any age (Sun et al., 1977).

The expenditures include logging, general administration, regeneration, forestation, forest maintenance expenses and forest roads construction and maintenance costs. Here, logging expenses consists of logging, skidding, transportation, loading and scaling costs. General administration costs include; salaries, health and social aids, traveling expenses, rentals, insurances, facilities and repairing and taxes costs. Forest maintenance expenses include site preparation, weeding, precommercial thinning, protecting of regeneration areas and forest protection costs. Nonetheless, varying factors like inflation and spatial attributes of stands were not taken into consideration.

Characterizing and determining water production values

There is a reverse relation between stand basal area and water yield. When stand basal area increases, water yield decreases (Kalıpsız, 1982). Equation 1, developed by Keleş (2003) was used to estimate the amount of water production.

$$WP=6.1599-0.0632*BA\ (R^2 = 0.83) \quad (1)$$

Where;

WP = Water production value (10^3 m^3/ha/year);
BA = Stand Basal Area (m^2/ha).

Keleş (2003) used Thorntwaite water tables produced for ecological soil series of the planning unit (Bakkaloğlu, 2003). 83 sample plots were taken from the study area by 300 x 300 m^2, grids to develop water production equations.

Water production was estimated with stand basal area, calculated using the following equation (Equation 2), because of the absence of growth models based on permanent sample plots, future actual basal area of the stands at certain ages were estimated using this equation.

$$G_{act} = (G_{opt}*V_{act})/V_{opt} \quad (2)$$

Where;

G_{act} = Actual stand basal area (m^2/ha).
G_{opt} = Optimal (fully stocked) stand basal area (m^2/ha).
V_{act} = Actual stand volume (m^3/ha).
V_{opt} = Optimal (fully stocked) stand volume (m^3/ha).

To build economic values of water production, price of 1 m^3 water must be determined. Water is used in three different fields; drinking, industrial and irrigational use (agriculture). Therefore, average net income from these three different utilizations was calculated to determine the price of 1 m^3 water.

Prices (incomes and costs) of three water usage were taken from DPT (State Planning Organization), DSI (General Directorate of State Hydraulic Works) and local municipalities. To calculate net income for 1 m^3 drinking-use and industry water, a rate for Turkey developed by DPT (half of the sale price) was used (Anonymous, 2001). Consequently, 1 m^3 net income of drinking-use, industry and irrigation water was calculated as $0.36, 0.84 and 0.01, respectively. Given three different uses, a combination of them was taken into consideration. Based on the average use rate for irrigation, drinking-use and industry are 75, 15 and 10% of 1 m^3, respectively in Turkey (Anonymous, 2001). As such these rates were assumed to be valid for Gümüşhane province as there were no specific regional prices for each water use category. Therefore, the price of 1 m^3 water was calculated as the weighted average of net income obtained from three different uses resulting in $ 0.14 and used in calculation of NPV of water production.

Determining soil loss value

The amount of soil loss from stands was calculated with the formulation developed by Karahalil (2003) using Universal Soil Loss Equation (USLE) for the study area. Data from 83 sample plots were used to construct the equation (Equation 3).

$$\mathit{ln}SL = 2.553079 - 0.065*BA\ (R^2 = 0.67) \quad (3)$$

Where;

SL = Approximate soil loss (m^3/ha/year);
ln =Natural logarithm

Several techniques like; hedonic pricing, replacement costs and change of productivity are commonly used to assess the costs of soil erosion as well as cost and benefits of soil conservation (Enters, 1998). But, considerable difficulties arise in the valuation procedure and there is no single recognized method for the valuation. Mostly, soil seldom traded directly in the market place so its economic values have to be inferred using mentioned techniques (Clark, 1996). Nevertheless on particular occasions, soil can be exchanged in the market place associated with costs or benefits. In this study, the cost of a m^3 soil was taken from KTU forest nursery garden. This nursery garden get large amount of soil from a close forest enterprise for cash. Soil density changes according to soil texture and organic matters. Density of sandy soils can be accepted as 1.9 gr/cm^3 (Irmak, 1972). Thus, 1 m^3 of soil is 1.9 tones. When organic matter is considered (10% mould), cost of 1 ton soil can be determined as $19.20

The discount rates used in a selection of cost benefit analyses of soil erosion and/or conservation appears in wide range as 1 to 20% and in the time periods 5 to 100 years. The choice of discount rate is affected by the country in which the analysis is based and the perspective from which the analysis is carried out (the farmer, project or government) and that the discount rate and time period are inter-dependent (Clark, 1996). So, in this study, 3% interest rate was selected calculating soil and water NPV.

Riparian areas

Riparian buffers were designated for protecting and maintaining the water quality as well as certain wildlife habitat values. As such, they represent a balance between overall natural resource conservation and use. The purposes of the zones are to protect water quality by reducing sediment flow, nutrients, logging debris and chemicals. Zones are subject to specific criteria that define operational restrictions, and specific management objectives. In addition, zones have a specific width which is based on the size and type of water body involved. In this study, 50 m distance for perennial streams and 25 m for seasonal streams were used to determine buffer areas (Anonymous, 2008; Philips et al., 1999).

General structure of the planning model

Different planning strategies were developed with various characteristics and solved with LINDO™ (LINDO, 2008). MODEL I approach was used to develop linear programming model (Leuschner, 1990; Davis et. al., 2001). There are certain assumptions about the characteristics of the problem, to help develop the model easier for forest management settings. 1) Stands are the basic components of the model. 2) Planning horizon is 100 years and planning period is 20 years. 3) Natural stands younger than 100 years and afforested stands younger than 90 years exempted from harvesting. 4) Bare lands in riparian areas are afforested in period 1. Other bare lands were allowed forestation any period during the planning horizon. 5) Stands over 70% forest canopy is subjected to natural regeneration, others to artificial regeneration. There is no delay in the regeneration. 6) All except the protection zone must be cut once over the planning horizon. 7) Regenerated stands grow according to normal yield tables. 8) 3% interest rate was used to calculate NPV of forest values. 9) No commercial thinning on stands between 10 and 40% crown closure.

Given these assumptions, the following mathematical equations are used to build the model.

Objective functions

$$Z_{max} = TNPVH;\ Z_{max} = TNPVW;\ Z_{min} = TNPVS \quad (4)$$

Subject to:

$$\sum_{j=1}^{n}\left(\sum_{i=1}^{m} a_{ij}x_{ij}\right) - NPVH_j = 0 \quad (5)$$

$$\sum_{j=1}^{n}\left(\sum_{i=1}^{m} b_{ij}x_{ij}\right) - NPVW_j = 0 \quad (6)$$

$$\sum_{j=1}^{n}\left(\sum_{i=1}^{m} c_{ij}x_{ij}\right) - NPVS_j = 0 \quad (7)$$

$$\sum_{j=1}^{n} NPVH_j - TNPVH = 0 \quad (8)$$

$$\sum_{j=1}^{n} NPVW_j - TNPVW = 0 \quad (9)$$

$$\sum_{j=1}^{n} NPVS_j - TNPVS = 0 \quad (10)$$

$$\sum_{i=1}^{m}\left(\sum_{j=1}^{n} x_{ij}\right) <= T_i \quad (11)$$

$$\left(-(1-y)NPVH_j + NPVH_{j+1}\right) \geq 0 \quad (12)$$

$$\left(-(1+y)NPVH_j + NPVH_{j+1}\right) \leq 0 \quad (13)$$

$$\sum_{j=1}^{n}\sum_{i=1}^{m} x_{ij} - A_j = 0 \quad (14)$$

$$x_{ij} \geq 0 \quad (15)$$

Where;

x_{ij} = Area of stand *i* cut in period *j* (ha);

a_{ij} = NPV of one ha timber production of stand *i* cut in period *j* ($);

b_{ij} =NPV of one ha water production of stand *i* cut in period *j* ($)

c_{ij} = NPV of one ha approximate soil loss of stand *i* cut in period *j* ($)

Accounting variables

$NPVH_j$: Total NPV of timber production in period *j* ($)

$NPVW_j$: Total NPV of water production in period *j* ($)

$NPVS_j$: Total NPV of approximate soil loss in period *j* ($)

$TNPVH$: Total NPV of timber production at the end of the planning horizon ($)

$TNPVW$: Total NPV of water production at the end of the planning horizon ($/year)

$TNPVS$: Total NPV of approximate soil loss at the end of the planning horizon ($/year)

m : Number of stands (*I* =1 to 866).

n : Silvicultural treatment options

y : The change rate between periods (10%)

T_i : Area of stand *i* (ha)

A_j : Optimal periodic area in period *j* (regulated forest)

Equation 4 represents the objective functions of three forest values. Equations 5, 6 and 7 represent total NPV of timber production, water production and approximate soil loss in each period. Equations 8, 9 and 10 embody total timber production, water production and approximate soil loss at the end of the planning horizon. Using “<=” in Equation 11 ensures that each stand will be cut at once except for stands in the conservation zone. Equations 12 and 13 represent the NPV of periodic timber flow. Finally, Equation 14 ensures optimal age class distribution at the end of the planning horizon.

Forest management strategies

A number of management strategies are developed to examine the options or any management opportunities and reflect the sensitivity of various constraints (Table 1). While one would generate tremendous number of strategies, we selected few reasonable ones to test and understand forest dynamics toward a better solution.

RESULTS

When all planning strategies are considered, the highest timber NPV was obtained from STR2 followed by STR1, as $ 10.7 million and $ 9.9 million, respectively (Figure 2). STR3 and STR4 yielded the highest water NPV, as $ 565.1 million and $ 543.5 million, respectively (Figure 3).

The strategies that generated the lowest NPV of soil loss are STR5 ($ 66.0 million) and STR6 ($ 66.01 million). These are followed by STR1 ($ 78.1 million), STR2 ($ 101.6 million), STR4 ($ 116.7 million) and finally STR3 ($ 133.7 million) (Figure 4).

Planning strategies were also compared to each other in terms of total NPV at the end of the planning horizon. Incomes obtained from water and timber production were added and NPV of soil loss values were subtracted from total value. In conclusion, positive NPV obtained from planning all strategies at the end of the planning horizon are; $ 433.3 million in STR3, $ 428.9 million in STR4, $ 424.0 million in STR2, $ 410.8 million in STR1, $ 405.7 million in STR6 and $ 404.7 million in STR5. These results indicated that strategies with water production objective can have more income.

Many factors such as legal arrangements, supply and demand, staff and economical conditions of the enterprise

Table 1. Descriptions of the forest management strategies tested.

Strategies	Objective function	Constraints
STR1	Max TNPVH	10% NPV of timber flow between periods
STR2	Max TNPVH	even age class distribution
STR3	Max TNPVW	no constraints
STR4	Max TNPVW	TNPVS ≤$ 116.78 million
STR5	Min TNPVS	no constraints
STR6	Min TNPVS	TNPVH ≥ $ 8.75 million

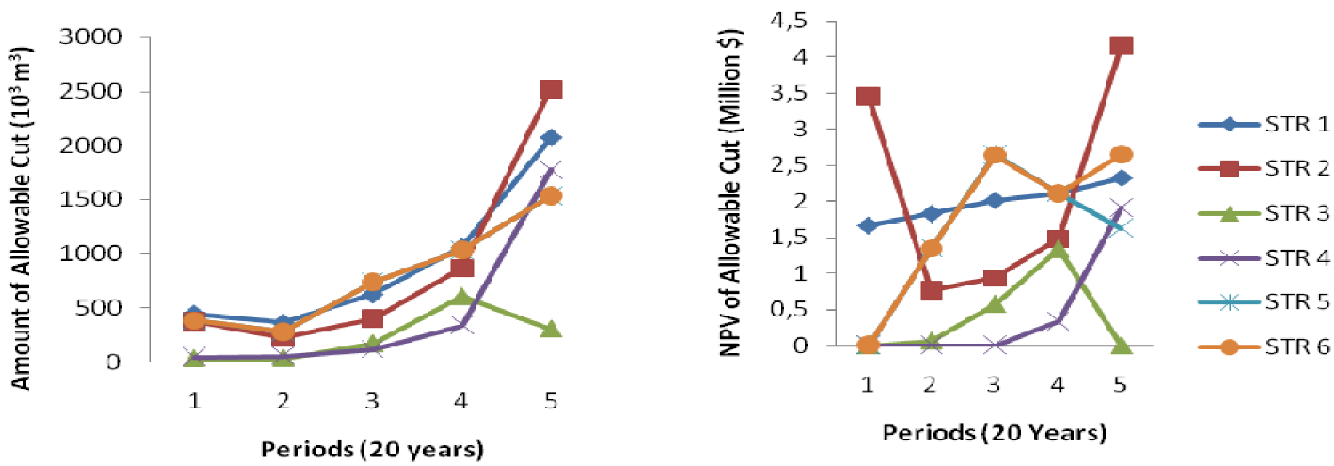

Figure 2. The flow of allowable cut levels and its NPV over 100 years.

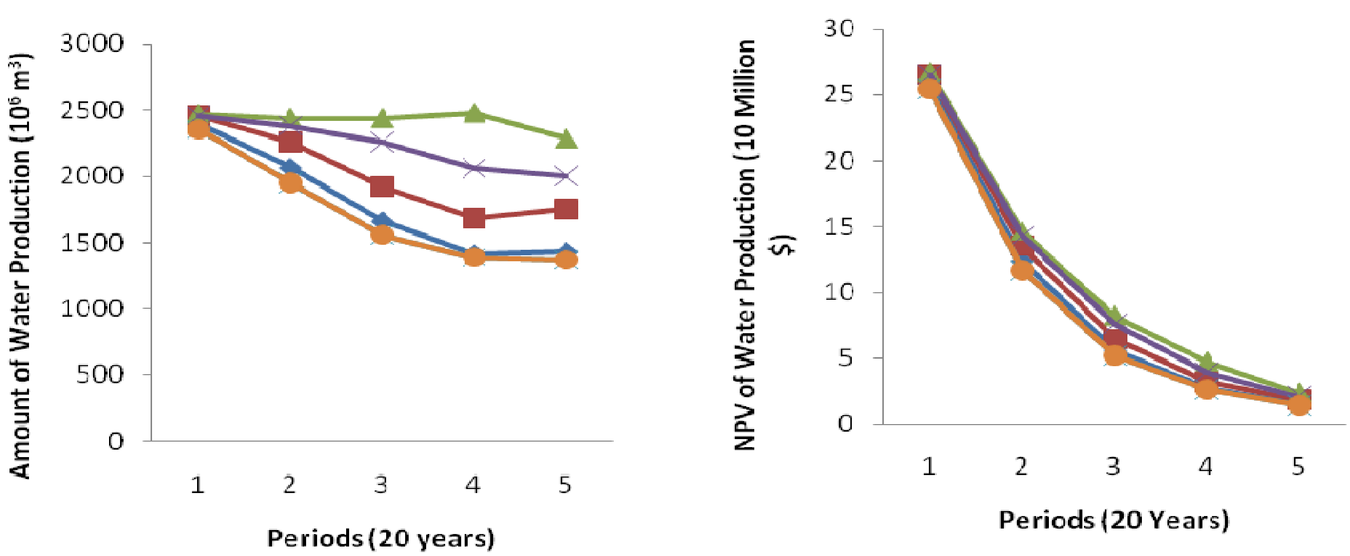

Figure 3. The flow of water levels and its NPV over 100 years.

must be taken into consideration when determining the appropriate strategy to implement. Among six strategies, the second strategy with the maximal total NPV of timber production and equal age class distribution can be selected. When this strategy is implemented, 3839 ha will be regenerated, 4162 ha afforestrated and 379493 m^3 total

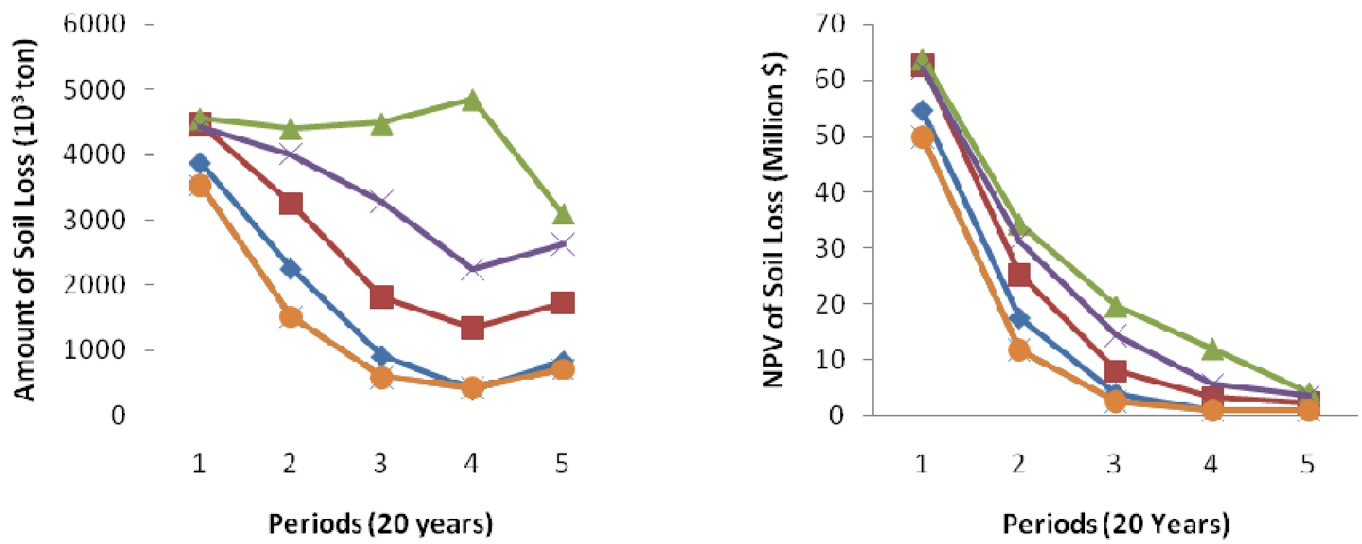

Figure 4. The flow of soil loss levels and its NPV over 100 years.

allowable cut will be harvested.

DISCUSSION

Timber production

STR2 yielded lower allowable cut (4.3 million m^3) than STR1 (4.5 million m^3), when total allowable cut was considered (Table 2). This was because of 10% NPV flow constraint between periods in STR1, which caused forestation of 9700 ha of bare lands (note that 81% of total bare lands) and that caused decreasing of NPV.

STR1 yield 443483 m^3 and STR2 yield 379493 m^3 allowable cut in the first period. Although, it is expected that STR1 could yield more timber NPV than STR2, the first strategy yield two times lower NPV in the first period. The reason for this is the forestation of 9700 ha in period 1 and as a result of the expenditure involved in that forestation. STR3 and STR4 yield the lowest total NPV of timber production. Similarly, the lowest allowable cuts obtained from these two strategies are 1156414 and 2341019 m^3, respectively. When STR3 is evaluated itself, it can be seen that almost all of the bare land (11639 ha) was afforested in the last period. This was because, the model tried to ensure as minimum basal area as possible to achieve the maximum water NPV. Forestation of bare lands was dispersed to the first four periods in STR4. While STR3 regenerated only the existing stands, STR4 regenerated also 1080 ha of 1354 ha afforested areas in the first period.

When the Figures are evaluated, in Figure 2 considering NPV of three forest services, timber NPV displays an irregular trend as compared with the other two values. Although, it is expected an “inverse J” curve like other two values, it seems normal when carefully examined. Nearly half of the study area is bare land, as the periods goes, these areas were forested to perform the given objectives. Thus, NPV of soil loss and water production were gradually decreased. The irregularity in allowable cut except for STR1 according to periods and harvesting of forested bare lands in the last period (that forested in the first period) caused that formless configuration.

Water production

STR4 yield lower NPV and amount of water than STR3 because STR4 has $ 116.7 million soil loss binding constraint in addition to maximizing water production NPV. When afforestration areas are evaluated for the two strategies, bare lands were afforestrated in the first period in STR4 and almost all of the bare lands were afforestrated in the last period in STR3. For this reason, leaving these areas to the last periods in STR4 led more output of NPV and amount of water in the previous periods.

When STR1 and STR2 are considered; afforestration of bare lands were distributed to first four periods in STR2 while huge amount of bare land (9700 ha) were afforestrated in the first period in STR1 (Table 2). Forestation of such large areas caused low amount of water and NPV of water production in the following periods, because, the bare lands turned into fully stoked forest stands. As the basal area of the stands increased the amount of water and NPV of water decreased continuously.

The lowest NPV obtained from water production eventuated in STR5 and STR6 minimizing NPV of approximate soil loss. Here, to obtain the minimum soil loss NPV, the model naturally afforested bare lands in the first period in two strategies, because as the basal area increases, soil loss is reduced (Equation 3). This situation led lower amount of water and water NPV and at the end

Table 2. Some outputs of various planning strategies over the planning horizon.

Periods	Strategies					
	Amount of final harvest (m^3)					
	STR1	STR2	STR3	STR4	STR5	STR6
1	431348	367590	7881	19432	367891	367903
2	137543	115656	435	0	0	0
3	0	3084	135175	0	0	0
4	67711	192475	574593	93120	7407	7407
5	1078382	1902821	264927	1390034	441197	442268
Total	1714984	2581626	983011	1502586	816495	817578
Periods	**Amount of commercial thinning harvest (m^3)**					
1	12135	11903	24885	24584	15574	15574
2	224261	105770	37702	57109	277129	277129
3	621624	396599	37635	117189	740103	740103
4	993045	671243	31356	249864	1026591	1026591
5	993574	625185	41825	389687	1092269	1092118
Total	2844639	1810700	173403	838433	3151666	3151515
Periods	**Regeneration areas (ha)**					
1	6477	3839	40	147	6643	6643
2	1766	890	3	0	0	0
3	0	18	940	0	0	0
4	183	3703	3919	834	46	48
5	2328	4121	3790	8791	2024	2026
Total	10754	12571	8692	9772	8713	8717
Periods	**Afforestration areas (ha)**					
1	9700	4162	274	1354	11914	11914
2	0	3231	0	1243	0	0
3	2214	4103	0	4096	0	0
4	0	418	0	5220	0	0
5	0	0	11639	0	0	0
Total	11914	11914	11914	11914	11914	11914
Periods	**Age class distribution at the end of the planning horizon (ha)**					
1	2353	4121	15429	8791	2024	2026
2	183	4121	3919	6054	46	48
3	2214	4121	940	4096	0	0
4	1766	4121	3	1243	0	0
5	14089	4121	314	421	18535	18531
Total	20605	20605	20605	20605	20605	20605

of the planning horizon because of the negative effect of higher basal area on water production (Equation 1).

Nonetheless, when planning strategies were evaluated together, strategies with increasing allowable cut (e.g. STR4) caused decreased water production. The cause is as a result of low level of initial volume of the actual stands and influence of cutting which resulted in high water production after regeneration of these stands than no regeneration. And when regeneration of actual stands were assumed to have grown optimally, stand volumes reached initial actual volumes after one or two periods. Consequently, it is recognized that regeneration of actual stands generated negative effect on NPV and amount of water related to initial forest structure.

Soil loss

Although STR5 and STR6 have different model structure, they generated almost the same NPV of soil loss. Followed by these strategies, STR1 afforestrated almost all of the bare land (9700 ha) in the first period and led positive effect on prevention of soil erosion.

As a result of maximizing water production and water NPV, almost all of the bare lands were afforestrated in the last period in STR1. This situation led the highest amount and NPV of approximate soil loss among all strategies. However, inclusion of $ 116.78 million of soil loss as a binding constraint to the model in STR4 led afforestration of bare lands in the first four periods and lower amount and NPV of approximate soil loss than STR3.

STR5 and STR6, minimizing NPV of approximate soil loss, yielded lower values than strategies maximizing NPV of timber production and yield more values than strategies maximizing water production when considering NPV of timber production and amount of allowable cut. These strategies forested all bare lands in the first period as a result of objecting minimization of approximate soil loss. Consequently, these strategies yielded intensive thinning which resulted in high income in later periods.

Conclusion

This study tried to improve a forest management planning approach attempting to enable sustainable management of forest values (resources) according to criteria and indicators of sustainable forest management. Three important values of forests timber, water and soil were integrated in a forest management plan as economic values using linear programming techniques.

Timber and water production and approximate soil loss values were first of all characterized quantitatively in relation to stand structure. Timber production values were developed using normal yield tables, however water production and soil loss values were developed based on their logical relationship to basal area, one of the stand parameters. NPV of three forest values were developed to display economical sustainability of forest resources.

Contrary to conventional plans, alternative management strategies were developed and many options were presented to decision maker or planner to make the best and accurate decisions. Providing conditions such as being NPV of water and timber production or soil loss at target levels, maintaining harvest flow and achieving regulated forest structure at the end of the planning horizon were satisfied by linear programming.

As multiple products and services presented to society, plans must be prepared with multi objective and operations research techniques. Similarly, multi purpose forest inventory must be conducted with different forestry disciplines and data concerning various values like soil conservation, water production and biodiversity provided by forests must be digitized according to stand parameters and these values must be integrated to forest management plans numerically. Nonetheless, economical inventory of effective factors must be conducted in preparation and implementation of management plans and must be used during decision making.

In conclusion, modeling is an inevitable tool in accommodating biodiversity, forest protection and sustainability in the plan. Planning economical, ecological and socio-cultural values of the forest can provide a wide range opportunities provided by forests to society.

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