HOW MUCH IS THE VALUE OF FOREST HYDROLOGICAL SERVICES FOR ELECTRICITY PRODUCTION: CASE STUDY AT HOA BINH HYDROPOWER RESERVOIR AREA

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SUMMARY

The importance of forests to provide hydrological services is well-known and has been widely documented. This is especially critical for hydroelectricity production where forests contribute to lower soil sedimentation and store water and thus maintain the capacity and prolong the longevity of hydroelectricity plants. However, the empirical evidence on measurable values of forest hydrological services is rare and controversial. We calculate the values of forest hydrological services for Hoa Binh Hydroelectricity Plant in Vietnam. Our valuation is based on the measurement of 240 permanent sample plots in different vegetations at watershed scale from 2001 to 2006, the manipulation with GIS and the simulation of the derived empirical models with different scenarios. Our findings indicate that total economic value of forest hydrological services for electricity production is currently 578.29 billion VND (26.29 million USD) per year and the longevity of the plant can be prolonged by 34.9 to 79.7 years depending on the forest cover in the watershed. Our findings can be used as the basis to identify the level of payment for forest hydrological services in Vietnam, which has been paid a special concern of scholars and policy-decision makers over the last years.

Keywords: Forest hydrological services, Hoa Binh, hydroelectricity plant, Vietnam, watershed.

I. INTRODUCTION

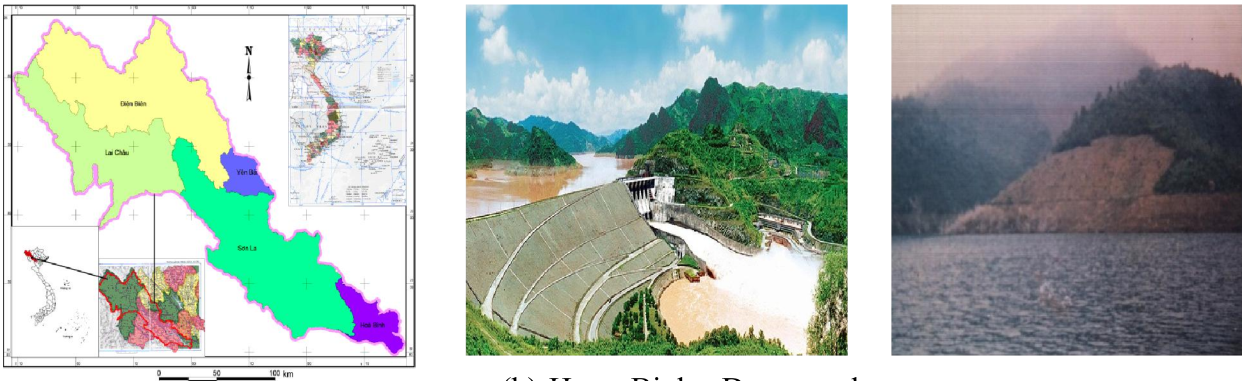
The importance of forests to provide hydrological services is well-known and has been largely documented (Lee 1980, Hewlet 1982, Wu and Wang 2001, Chang 2006). Forest hydrological services are especially important for hydroelectricity production where forests contribute to lower soil sedimentation and store water and thus maintain the capacity and prolong the longevity of hydroelectricity production plants (Nguyen and Vo 1997). Therefore, payment for such services provided by forests has increasingly deserved a special concern of scholars and policy decision makers. However, the basis to identify the proper level of payment is under much discussion and substantially different from case to case. This is partly because of the disciplinary separation between ecological sciences and economics. The scientific underpinning of economic studies is often limited (Brookshire et al. 2007) and ecological models generally lack of appropriate economic considerations (cf. Brouwer and Hofkes 2008). Obviously, integrating economic and ecological sciences into an operational decision support system has been noted to be a key step for global conservation and sustainability (Millenium Ecosystem Assessment 2005).

In Vietnam although forest hydrological services have been considered important, the legal framework of the payment for forest ecosystem services in general and for forest hydrological services in particular was established only in 2010 with the promulgation of the Government's decree No. 99/2010/ND-CP (see GOV 2010). The decree stipulates that forest hydrological services for hydroelectricity production are realized and must be paid, indicating the need for the valuation of those services in order to provide a basis for the required payment. In this study we were motivated with the two research questions: (1) how much is the total value of forest hydrological services for hydroelectricity production? and (2) as forests belong to different forest owners, how to identify the level of payment for a specific forest stand? We focused our analysis on the two most important forest hydrological services for hydroelectricity production, water provision and sedimentation prevention. This is because, first, water is stored by forests in rainy reasons and released for hydroelectricity production in dry reasons; and second, forests reduce soil erosion and thus lower the level of sedimentation. This can prolong the longevity of hydro electricity plants. We applied our framework to Hoa Binh reservoir in the North of Vietnam. We hope that our findings will shed some light for future policy formulation for more sustainable forest management in this country.

II. METHOD AND DATA

2.1. Site Description

Hoa Binh reservoir on Da River is about 75 km away from Hanoi, the capital of Vietnam. The river runs from China via Vietnam to the East Sea. The length of the river in Vietnam's territory is 493 km and the average width is 1 km (maximum width of 3 km). Total surface area of Da river watershed is 2.6 million ha, covering 4 provinces of Hoa Binh, Son La, Dien Bien and Lai Chau (Figure 1a).



(a) Geographical position

(b) Hoa Binh Dam and Hydroelectricity Plant

(c) Part of the watershed

Figure 1. The study site

A long Da River, there are two hydroelectricity plants, Hoa Binh and Son La. The construction of Hoa Binh Hydroelectricity Plant was started in 1979 and completed in 1994 with the capacity of 1920 MW and the annual electricity production of 9 billion kWh. The construction of Son La Hydroelectricity Plant was started in 2005 and is planned to be completed in 2015 with the designed capacity of 2400 MW and annual electricity production of 9 billion kWh. As Son La Hydroelectricity Plant is not yet completed, our valuation of forest hydrological services is only for Hoa Binh Hydroelectricity Plant (Figures 1b and 1c). The maximum water level of Hoa Binh Dam is 120 m; and the dead water level is 80 m. The maximum water carrying capacity of the Dam is 9.5 billion m^3. The water discharge varies substantially between dry and rainy seasons, from 1,000 m^3/s to 10,000 m^3/s. The exhaustion of water in dry seasons leads to decreased electricity production. Thus, the provision of water for the plant in dry seasons is very critical, especially in the case of Vietnam, where the shortage of electricity is currently considered one of the bottlenecks for economic growth.

The climatic conditions of Da River watershed are tropical monsoon. The average temperature is from 22.5 - 23.2°C. The average annual precipitation is from 1,300 - 2,200 mm of which about 85% is in the rainy season from May to September. The average annual humidity is about 80 - 85%. The topography is complicated with the popular elevation of 300 - 1,000 m above the sea level and the slope of about 10° to more than 50°. There are 4 main soil types with the soil erodibility of 0.06 - 0.30. The current forest cover is high, about 39.3% in 2009 (DOF, 2010). However, forest distribution is uneven, mainly with secondary degraded forest stands. Based on forest regulations of Vietnam, the forests in the watershed are classified into 3 categories: very critical protective forest, critical protective forests, and less critical protective forest. The two first categories are under the management of governmental Protection Forest Management Boards (PFMBs). These boards then contract with farm households for the protection of forests. The last category is allocated to farm households for direct protection and management with the area of 3 - 20 ha (Vuong 2007). This is to say that the sharing of payment for forest hydrological services is very important with regard to the equality among forest owners and/or forest managers.

2.2. Method

Our methodological procedure for the valuation of these two services included the following steps. First, we conceptualized that the services mainly depends on 4 groups of factors, namely rainfall, topography, soil properties, and vegetations. These are purposely represented by rainfall erosibility index (R_p, foot-tons/acre), land slope (α, °), soil erodibility index (K), and vegetation index (Z), respectively. In the watershed, we classified R_p into 3 levels, α into 5 levels, K into 4 levels, and Z into 4 types (grassland, shrub land, natural forest, and man-made forest or plantation). Thus, in total we had 3 x 5 x 4 x 4 = 240 combinations of these 4 factors (see Figure 2a, 2b, and 2c). For each of the combinations, we established 1 experiment (1 sample plot, 400 m^2) to measure the soil loss, the amount of water components of water balance cirle in both dry and rainy seasons, the physical and chemical characteristics of soil and literfall, etc (see Pham 2009). Our measurement was conducted in 6 years from 2001 - 2006. We thus identified the amount of overland flow water in the rainy reason and the annual amount of water retaining capacity of soil. Part of overland flow water in the rainy season (we followed Vuong 2007 that this part is 20%) and all soil-retained water are used for hydroelectricity production.

Second, from the experimental data and the characteristics of 4 influencing groups of factors described above, we derived empirical regression models (see Nguyen 1982, Chiang 2003, Freedman 2005) for the relationship between the percentage of overland flow water (BM, %) (per total rainfall), percentage of soil-retained water (Ws, %) (per total rainfall), and the amount of soil loss (A, tons/ha/year) with the above groups of factors. The relevant maps and GIS were used for the computation of required parameters. The experimentally-derived empirical models are the backbone of our analysis at the watershed scale to quantify the hydrological services under different rainfall erosibilities, land slopes, soil erodibilities, and types of vegetations. Our manipulation is essentially based on these models. We were thus able to identify the increased quantity of water provision (in m^3) and reduced soil loss (in tons).

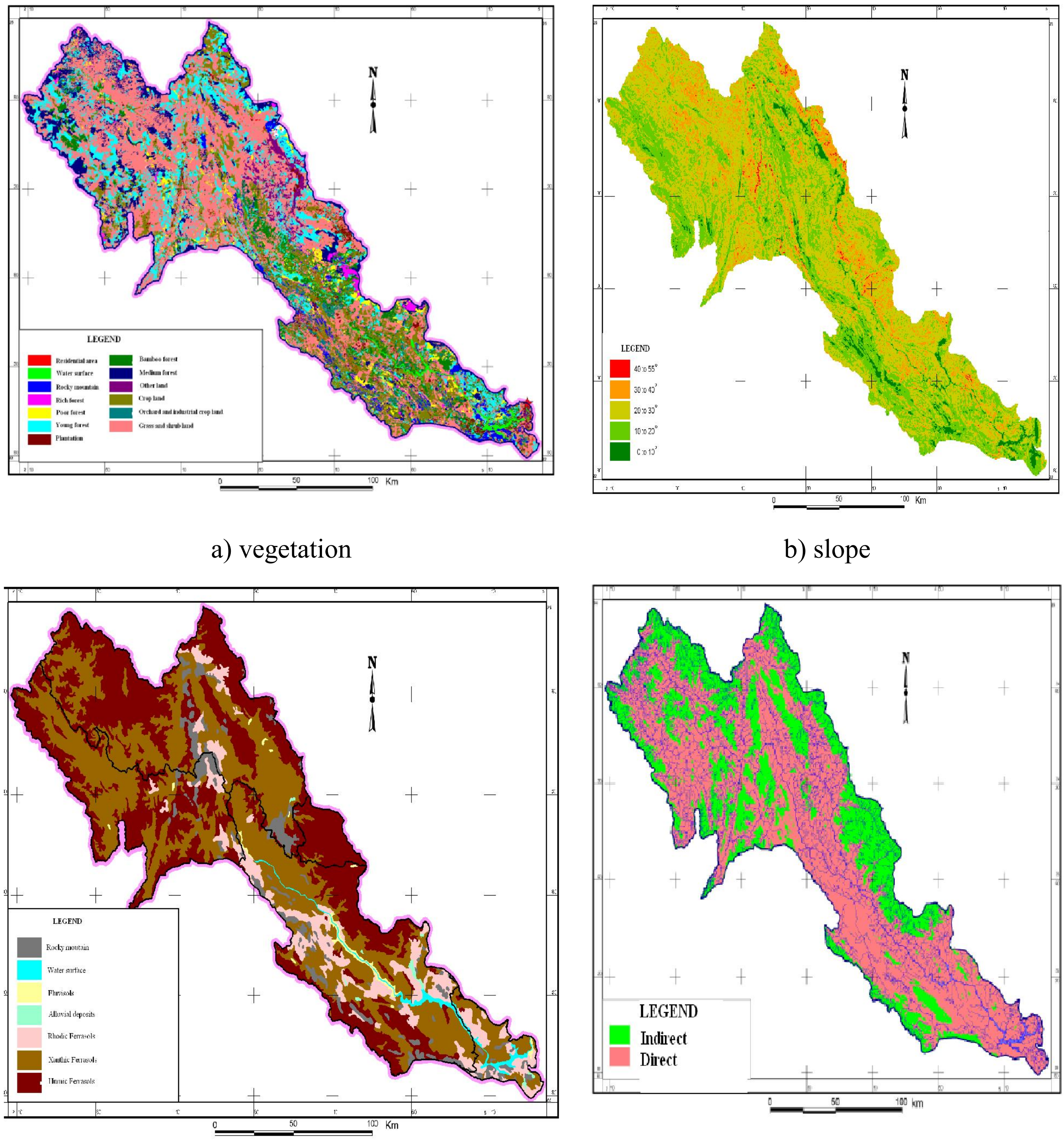
Third, as the capacity of water storage and soil loss prevention is different among vegetation types, it was needed to standardize this capacity of all vegetation types into a comparable unit. We selected the soil loss prevention capacity as the criterium for the standardization. Any soil loss quantity can actually be used as "*the standard*" in this procedure. Our experiments showed that the average soil loss ranges substantially from 4.5 - 24.8 tons/ha/year depending on the vegetation types, and the soil loss under natural rich forests is the lowest (from 4.5 to 6.5 tons/ha/year). We thus chose the soil loss of 5.5 tons/ha/year as the standard. Consequently, the standarized area ($A_{S(i)}$, ha) of a ha of a vegetation and total standardized area (A_F, ha) in the whole watershed were calculated as $A_{S(i)} = \frac{5,5}{SL_i}$ and $A_F = \sum_1^m A_i A_{s(i)}$ where A_i and SL_i are the area and the soil loss of, e.g., forest stand i, respectively, m is the number of forest stands in the watershed. In this way, the current forest cover of 39.3 % was actually equal to the standardized forest cover (C_S, %)of only 30.8%.

Four, we simulated our quantity of the services with the following scenarios: (1) baseline scenario with the current land use of 2009 (the real forest cover of 39.3% or standardized forest cover of 30.8%); (2) without-forest scenario where current forests are converted to grassland or shrub land. This scenario is revelant as in the watershed, agricultural shifting cultivation (slash and burn) still exists; and (3) better-forest scenario where the standardized forest cover increases to 35%, 40%, 45%, 50%, and 55%. This scenario is also very relevant as the importance of forests in the watershed is realized, especially in the case where payments for hydrological services are realized. The increase of the standardized forest cover can be implemented in 2 ways: (1) by increasing current forest area (W1), or (2) by increasing the quality of current forest area (W2). Our simulation results included the quantity of the services under these scenarios.

Five, based on the agreement between Hoa Binh Hydroelectricity Plant and the forest owners in the watershed that the plant would pay 40% and 10% of its increase of hydroelectrity revenue for these services (the increase due to the services), we were able to calculate the total monetary values of these services, and identify the average payment for the services per ha of forests, per ton of soil loss prevention, or per kWh of electricity. As the hydroelectricity revenue depends on its price, the payment obviously also depends on the price. As the price can change over time and the inflation rate in Vietnam has recently been high, we proposed that the payment should not be in absolute monetary value, but proportional to the price.

Last was the question of how much the payment should be in practice for a specific forest stand. As previously mentioned, currently forests are managed by different forest owners (see Nguyen 2005) and different forest stands have different advantages and disadvantages for the management and protection (illegal exploitation is still existing). Thus, we needed to construct an adjustment factor to ensure a certain level of payment equality among forest owners. This adjustment factor ($C_{G(i)}$) was identified based on (1) the slope of the forest stand (C_α) and (2) the level of influence of the forest stand to the dam (C_E). C_α of the stand was identified by compinging the slope of the stand with the average slope of the whole watershed of 23°. C_E of the stand was classified as having direct or indirect influence on the dam (soil loss from the stand goes directly or indirectly to the dam, see Figure 2d). $C_{G(i)}$ of a stand was calculated as the product of C_α and C_E ($C_{G(i)} = C_\alpha \times C_E$). Therefore, if P is the total payment for a service, the payment for a ha of standardized forest was calculated as

$p_s = \frac{P}{A_F}$ and the payment for a stand (p_i) with the standardized area of $A_{S(i)}$ was calculated as $p_i = A_{S(i)}.p_s.C_{G(i)}$.



a) vegetation b) slope

c) soil types d) levels of influence

Figure 2. Maps of vegetation, slope, soil types, and levels of influence as described in the text

III. RESULTS

Our derived regression models for the relationship between our dependent variables (BM, WS, and A) and the influencing factors as previously conceptualized are as follows: BM (%) = $129.833.(Z/(K.\alpha)^{-0.57609}$; W_S (%) = $31.11690 - 229.5701/(Z/(K.\alpha)$; A (tons/ha/year) = $0.23082.R_P.(Z/(K.\alpha))^{-0.83334}$ (Figure 3). In Figure 3, BM and W_S are described for all R_p but for the simplification A is drawn only for R_p of 800 foot-tons/acre (in the two other cases of R_p of 600 and 400 foot-tons/acre, the curves are also in similar form but under the current A curve).

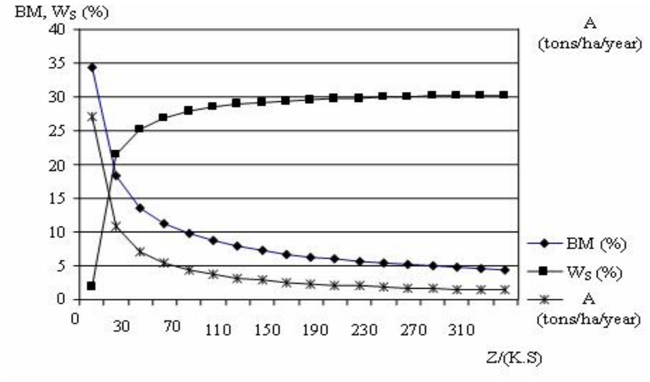


Figure 3. Relastionship between BM, Ws, and A with the influencing factors

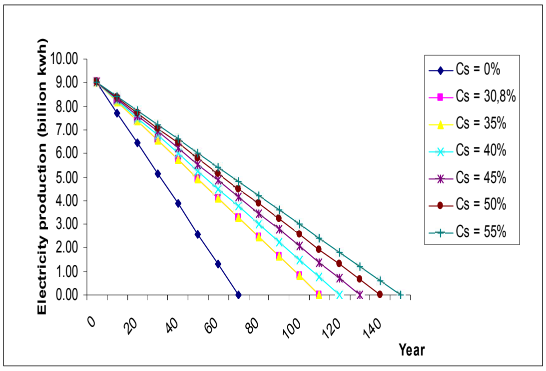


Figure 4. Hydroelectricity production and longevity of the dam with different standardized forest covers (C_s)

The results showed that with the standardized forest cover of 0% (without-forest scenario), 30.8% (baseline scenario), 35%, 40%, 45%, 50%, and 55% (better-forest scenario), the longevity of the dam would be 69.5 years, 104.4 years, 110 years, 117.8 years, 126.7 years, 137 years, and 149,2 years, respectively. Thus, forests would contribute to increase the longevity of the dam by 34.9 to 79.7 years. The hyroelectrictity production is also different with different standardized forest covers (Figure 4). In the baseline scenario, the quantity, value and payment of forest hydrological services were calculated in Table 1. Total value of the forest hydrological services for hydroelectricity production in the whole watershed was calculated as 578.34 billion VND/year (or 26.29 million USD/year). Thus, the payment for each ha of standardized forest, for each ha of real forest, and for kWh was 733,000 VND, 575,000 VND, and 78.4 VND, respectively (currently 1 USD = 22,000 VND).

Table 1. Quantity and monetary value of forest hydrological services for Hoa Binh Hydroelectricty Plant in the baseline scenrio

No.	Parameter	Value
1	Water increase for hydroelectricity production (million m^3/year)	1271
2	Hydroelectricity increase due to the water provision service (million kWh/year)	318
3	Current price of hydroelectricity (1,000 VND/kWh)	1
4	Revenue increase due to the water provision service (1,000 VND)	317,652,750
5	Payment for the water provision service (40% of the revenue increase) (1,000 VND)	127,061,100
6	Average payment for the water provision service per ha of real forests (1,000 VND/ha/year)	126
7	Payment for the water provision service per ha of standardized forest (1,000 VND/ha/year)	161
8	Payment for the water provision service per kWh (1,000VND/kWh)	0.014

9	Reduce of sediments in the dam (million tons)	17.3
10	Increase of the longevity of the reservoir (years)	34.9
11	Increase of hydroelectricity production due to the sedimentation prevention service (million kWh/năm)	4,513,000
12	Revenue increase due to the sedimentation prevention service (1,000 VND)	4,512,893,983
13	Payment for the sedimentation prevention service (10% of the revenue increase) (1,000 VND)	451,289,398
14	Average payment for the sedimentation prevention service per ha of real forests (1,000 VND/ha/year)	449
15	Payment for the sedimentation prevention service per ha of standardized forests (1,000 VND/ha/year)	572
16	Payment for the sedimentation prevention service per kWh (1,000 VND/ kWh)	0.05

Table 2 describes the services in scenario better-forest when compared with those in scenario without-forest in terms of ΔBM_D (the decrease of the overland flow water), ΔW_{S-NF}(the increase of soil-retained water), ΔW_T (the total increase of water for hydroelectricity production), and ΔSD (the decrease of soil sediments).

Table 2. Some parameters of forest hydrological services for Hoa Binh Hydroelectricity Plant

Parameters	Dimension	C_S (%)					
		30.8	35	40	45	50	55
ΔBM_D	million m^3	841.70	920.10	1014.64	1109.17	1203.70	1298.24
ΔW_{S-NF}	million m^3	2112.31	2309.01	2546.19	2783.37	3020.55	3257.73
ΔW_T	million m^3	1270.61	1388.91	1531.56	1674.20	1816.85	1959.50
ΔSD	million tons	17.31	19.88	21.24	23.38	25.53	27.68

To facilitate payment from the hydroelectricity sector for the forest sector in scenario better-forest, the payment for each kWh of the increase of hydroelectricity production was calculated (Table 3).

Table 3. Payment for the forest hydrological services

Cs (%)	Payment for the forest hydrological services (VND/kWh)		
	Water provision	Sediment prevention	Total
30.8	14.1	64.3	78.4
35	16.0	73.0	89.0
40	18.3	83.4	101.7
45	20.6	93.8	114.4
50	22.9	104.2	127.1
55	25.1	114.6	139.7

Similarly, to facilitate the payment for different forest owners, it was needed to identify the payment for each ha of standardized forest (Table 4).

Table 4. Payment for the forest hydrological services per ha of standardized forest

Cs (%)	Payment for the forest hydrological services of standarized forest (1,000 VND/ha)		
	Water provision	Sediment prevention	Total
30.8	161.1	572.2	733.3
35	155.2	504.3	659.5
40	149.7	444.8	594.5
45	145.4	398.2	543.6
50	142.2	360.5	502.7
55	139.2	329.4	468.6

As previously described, in better-forest scenario, there are 2 ways to increase the standardized forest cover, either by increasing forest area (W1) or by improving the quality of the current forests (W2). These ways lead to different levels of payment for each ha of real forest (Table 5).

Table 5. Payment for the forest hydrological services per ha of real forest

Cs (%)	W1 (1,000 VND/ha of real forest)			W1 (1,000 VND/ha of real forest)		
	Water provision	Sediment prevention	Total	Water provision	Sediment prevention	Total
30.8	126.3	448.6	574.9	126.3	448.6	574.9
35	127.0	412.6	539.6	143.3	448.6	591.9
40	127.7	379.3	507.0	163.8	452.3	616.1
45	128.3	351.2	479.5	184.3	455.6	639.9
50	128.9	326.7	455.6	204.7	457.9	662.6
55	129.2	305.6	434.8	225.4	460.8	686.2

If W1 is selected, the payment per ha of standardized forest would decrease even though the total value of the services in the whole watershed and the longivity of the dam would still increase. This is because the total value increases more slowly than the area of standardized forest does. If W2 is selected, then the payment per ha of real forest would increase. This suggests that forest owners should enrich the current forests in order to get higher levels of payment for the services.

IV. CONCLUSIONS AND RECOMMENDATIONS

We combined experiments with data manipulation and model simulation to identify the value of the two main forest hydrological services for hydroelectricity production in Hoa Binh reservoir, Vietnam. It was found out that with the current standardized forest cover of 30.8%, total monetary value of these hydrological services is 578.29 billion VND (26.29 million USD) per annum of which about 22% is for the water provision service and the rest is for the sedimetation prevention service. The value of those services increases when the standarized forest cover increases.

Our findings allows us to derive following recommendations: (1) for the relation between hydroelectricity sector and forest sector, as the price of electricity may change, the payment for those services should be paid proportionally with electricity price. The findings indicate that the value of those services is currently 78.4VND/kWh and equivalent to 7.84% of the electricity price. The payment should thus be as

7.84% of the total revenue of electricity sales. This rate can be changed only when the standardized forest cover changes or there is a change of electricity production technology i.e. if Hoa Binh Hydroelectricity Plant can use more water in rainy seasons for production; (2) for the forest owners, in order to increase the level of payment per ha of real forest, it is advisable that they improve the quality of forests (i.e. enrichment of forests). This also means to increase land use values.

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GIÁ TRỊ DỊCH VỤ THỦY VĂN RỪNG CHO SẢN XUẤT ĐIỆN LÀ BAO NHIÊU: NGHIÊN CỨU ĐIỂM TẠI VÙNG HỒ THỦY ĐIỆN HÒA BÌNH

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TÓM TẮT

Tầm quan trọng của rừng trong việc cung cấp dịch vụ thủy văn đã được thừa nhận và được đề cập bởi nhiều tài liệu. Đây là vấn đề rất có ý nghĩa cho sản xuất điện ở những nơi mà rừng có tác dụng làm giảm lượng bồi lắng, tích trữ nước và qua đó duy trì, nuôi dưỡng công suất cũng như kéo dài tuổi thọ của nhà máy thủy điện. Mặc dù vậy, những dẫn liệu thực tế về giá trị bằng tiền của dịch vụ thủy văn rừng vẫn còn ít ỏi và chưa thật thống nhất. Đây là lý do thúc đẩy chúng tôi tính toán giá trị dịch vụ thủy văn của rừng đối với nhà máy thủy điện tỉnh Hòa Bình ở Việt Nam. Nghiên cứu của chúng tôi đã dựa trên 240 ô tiêu chuẩn định vị, phân bố ở các điều kiện thảm thực vật khác nhau ở lưu vực nước trong giai đoạn 2001 - 2006, sau đó xử lý số liệu với sự hỗ trợ của công cụ GIS và mô phỏng bằng các mô hình kinh nghiệm với các kịch bản khác nhau. Những phát hiện của nghiên cứu này là, tổng giá trị kinh tế của dịch vụ thủy văn rừng đối với sản xuất điện là 578,29 tỷ đồng Việt Nam (tương đương 26,29 triệu đô la Mỹ) trên năm (2011), đồng thời tuổi thọ của nhà máy thủy điện có thể được kéo dài thêm 34,9 đến 79,7 năm, tùy thuộc vào độ che phủ của rừng ở lưu vực nước. Những phát hiện này có thể được sử dụng làm cơ sở cho việc xác định mức chi trả dịch vụ thủy văn rừng ở Việt Nam, một vấn đề đã và đang nhận được sự quan tâm của cả các học giả và nhà hoạch định chính sách trong những năm qua.

Từ khóa: Dịch vụ thủy văn rừng, Hòa Bình, lưu vực, nhà máy thủy điện, Việt Nam.

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