CHAPTER 6

Hydrological assessment of forest-cover change and intensification strategies in Ho Ho sub-watershed, Northcentral Coast Viet Nam

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Summary

To enhance the contribution of forest land to local livelihoods and environmental functions, the Government of Viet Nam formulated Forest Development Strategies 2006–2020. Long-term timber plantations were planned to be developed on production forest land across the country, combined with forest protection efforts, especially within watersheds to improve watershed services. In this chapter, we present the impact on hydrological functions of three forest-intensification scenarios in Ho Ho sub-watershed, Northcentral Viet Nam. The scenarios represent government planning as well as local expectations. The Generic River model was used to assess the impact on river flow of various forest scenarios.

Compared to scenarios with higher tree-canopy density, the conversion of degraded forests into short-term acacia plantations would lead to higher river flow and higher surface run-off with accompanying risk of severe soil erosion because most of the forest area is sloping land. In contrast, expansion of long-term timber plantations in the forest-restoration scenario would result in less river flow compared to an expansion of acacia plantations and less surface run-off with higher groundwater storage. The lowest surface run-off was found in the forest-restoration scenario. Owing to the projected unfavourable impact on river flow of higher tree-canopy cover and density, we recommend that local authorities carry out a trade-off analysis between environmental benefits that forest-intensification strategies can provide—such as carbon sequestration and biodiversity protection—and water provision. We also highlight the need to develop innovative forest-plantation models that can minimize soil loss, especially on sloping land, for example, by adopting agroforestry, which optimises the spatial and temporal aspects of systems. Finally, we emphasize the urgency in accomodating additional ecosystem services other than only water provision in the current Payment for Forest Ecosystem Services decree, to encourge smallholder forest owners to participate in forest-protection and -restoration efforts.

1. Introduction

Viet Nam has relatively successful forestry programs that have brought the country from extensive and severely degraded forests in the 1960–1980s to the present stage of reforestation and net forest increase. This achievement is mainly due to the government's effort in allocating forest land and devolving rights to households and communities since the 1990s, coupled with massive afforestation programs, such as Greening the Barren Hills (aka Programme 327) and Five Million Hectare Reforestation Programme (5MHRP). The latter replaced the first in 1998 and was implemented until 2010 (Clement and Amezaga 2009, To et al 2013).

The afforestation programs introduced exotic tree species, such as eucalyptus and acacia. The latter has been promoted as a fast-growing timber tree species that can restore soil fertility. Nowadays, the short-rotation acacia system for pulp and paper is the most popular forest-plantation system in Viet Nam. It dominates production forests (Tran et al 2014, Trieu et al 2016). The acacia system has improved the livelihoods of many smallholders and improved soil fertility in various regions but, despite this, recently several livelihoods and environmental issues have been observed (Chapter 4 of this volume). There is a tendency toward the acacia pulp and paper market becoming saturated, with a decline in log price over the last three years. Furthermore, farmers in different regions have reported cases of serious soil erosion in acacia plots mostly located on sloping uplands, particularly, between the clear felling and replanting stage. The slash-and-burn system practised in the short-rotation system is also a source of greenhouse-gas emission and not in line with the country's commitment to reduce emissions from the agricultural and forestry sectors.

To meet the national demand for timber—imports account for 80% of supply—the government has planned to gradually convert degraded production forests and short-term acacia plantations into long-term timber plantations. This plan has been translated by sub-national authorities into provincial or district targets for areas under long-term timber plantation and levels of production. In Viet Nam, production-forest land can belong to non-State groups, such as households, individuals, or communities, or State bodies, such as forest management boards (FMB) and State forest entreprises (SFE), currently known as forest companies (FC). The other forest types, that is, protection and special-use forests, are generally not allocated to communities or households but are fully managed by State bodies.

Short-rotation acacia plantations are popular in Northcentral Viet Nam, especially since the 2000s, thanks to government extension and subsidies. This region is known as one of the most vulnerable areas in the country to climate change and variability (Casse et al 2015, Nguyen et al 2014) owing to its massive area of degraded forest land (for example, see Nguyen et al 2016) as well as its geographical location on the coast, exposing it to different seasonal and cyclonal climatic hazards. For example, in September 2017 the strongest cyclonal storm in Viet Nam during the last decade hit the region, with Ha Tinh as one of the most affected provinces. In terms of the forestry sector, similar to other regions, the local authorities also formulated forest development strategies, including the development of long-rotation timber plantation on the land owned by smallholders as well land owned by the provincial FMBs and SFEs. The national guidance includes the Forest Development Strategy 2006–2020 that was built upon the previous 2001–2010 strategy and approved by the Ministry of Agriculture and Rural Development (MARD) and the Forest Sector Support Program (VAFS 2007). The Strategy aims to augment the contribution of the forestry sector to the livelihoods of local people and to the provision of environmental functions, such as biodiversity and soil protection, which should be associated with the protection of watersheds across the region.

The existing literature mainly focuses on the impact on local livelihoods of forest-cover change or carbon sequestration for climate-change mitigation and rarely addresses the hydrology of watersheds. However, the same attention should be paid to the impact on water and river flow since forests and trees are ones of prime regulators of water cycle (Ellison et al 2017, van Noordwijk et al 2014). A comprehensive literature review has also indicated that interaction between forest, water and energy plays an important role in storing carbon, cooling terrestrial surfaces, and distributing water resources (Ellison et al 2017). Particularly in the context of watersheds, land-use and forest-cover change will influence the daily water balance and determine the fresh water supply for local livelihoods. Moreover, National Decrees 99 and 147 on PFES have formulated payments mainly for forest functions as watershed services, where the single indicator for calculating payments for service buyers is the quantity of water from the watershed that they use for different purposes, such as production of hydroelectric power or potable drinking water, eco-tourism activities or other commercial purposes. Payments for other forest ecosystem services, such as carbon sequestration or biodiversity protection, have not yet been formulated in a detailed regulation.

In this chapter, we present the results of a hydrological assessment of forest-cover change and intensification strategies in Ho Ho sub-watershed, Ha Tinh Province, Northcentral Viet Nam. The hydrological assessment used the Generic River (GenRiver) flow model (van Noordwijk et al 2011) that can link land-use change in a landscape to water balance in a watershed, including projection of water flow from each sub-catchment to the main river or basin. Our study investigated the impact of three different forest land-cover scenarios: 1) expansion of short-term acacia plantations; 2) forest protection and restoration; and 3) expansion of long-term timber plantations according to the strategy formulated by local authorities. There were two specific research questions to answer: 1) What might be the impact of each of the three forest land-cover scenarios on the hydrological functions in the sub-watershed reflected by the amount of water flow to the main river and to the Ho Ho river basin and hydropower plant as the final outlet? 2) What might be the impact of the each scenario on the current level of PFES received by the smallholders in the sub-watershed? We also compared the results of the assessment with the expectations of local stakeholders that forest land intensification would mitigate the intensity of droughts and flooding and, overall, increase the total annual river flow in the sub-watershed.

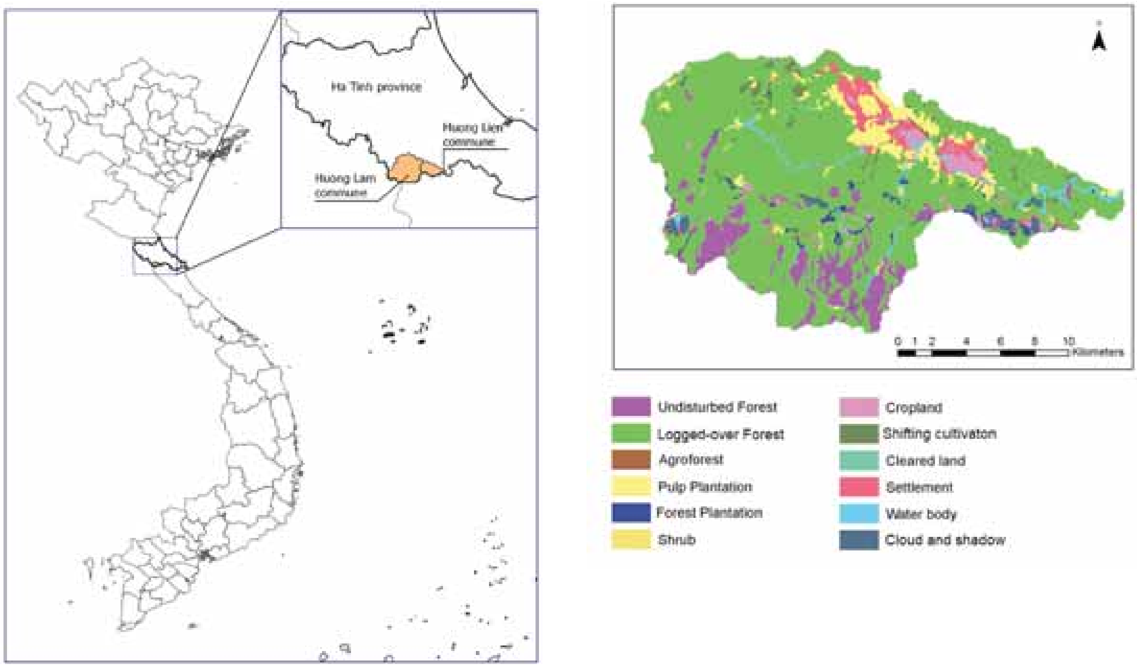
2. Materials and methods

Study site

Ho Ho sub-watershed is located in Ha Tinh province, Northcentral Coast, Viet Nam and mainly covers two communes of Huong Khe District: Huong Lam and Huong Lien (Figure 27a). It has the Ho Ho river basin and hydropower plant at the border of Huong Lien Commune (105° 50’ E, 18° 2’ N) operated since 2013. The sub-watershed has a total population of 3500 households (10,400 people) according to the 2014 census and covers an area of 27,600 hectares with 70% being logged-over forest (that is, degraded natural forest) and 7.5% being short-term acacia plantations (Figure 27b). Scattered, undisturbed natural forests still exist in the southern part of the sub-watershed thanks to difficult access owing to steep slopes and rugged terrain while the acacia plantations and farms mainly occur in the northern part of the sub-watershed closer to settlements.

The sub-watershed consists of tributaries that all feed into the Ngan Sau River, which drains into the reservoir of the Ho Ho hydroelectric plant (HEP). The reservoir is used by downwstream beneficiaries as a source of potable water and irrigation.

The sub-watershed experiences a tropical monsoonal Summer and Winter. The Summer extends from April to August with dry and hot climatic conditions. In particular, the area is severely affected by southwest winds between June and July. The cold season starts in November and ends in March with the northeast monsoon. The average annual temperature in the area is 24.5 °C, with 29.5 °C as maximum, usually observed in June and July, and 18 °C as minimum between December and January. The annual rainfall ranges 1,590–2,400 mm, with an average rainfall of around 390 mm in the wet season between August and September and 40 mm in the dry season between January and February. Agriculture is the main source of local livelihoods, with annual crops such as peanut, rice, maize, sweet potato, green bean and cassava. Livestock includes pig, cow, buffalo and chicken. Local people usually cultivate fruit trees in homegardens, such as orange or pomelo, with timber trees, such as *Aquilaria crassna* and *Dalbergia tonkinensis*, used as windbreaks or borders. On forest land, the common system is short-term acacia of 4–5 years rotation for pulp and paper. Some farmers also earn income from non-farm jobs, such as construction labour, as well as from public and private employment.



a) b)

Figure 27. (a) Location of Ho Ho sub-watershed as the study site; (b) 2014 land-cover distribution in the sub-watershed

Hydrology issues

In the sub-watershed, the local people use water from different sources, such as dug wells, artesian wells, streams, rivers, dams, pond/rain, and channel (Dam et al. 2015). The water from wells is for daily and domestic uses, such as cooking, drinking, washing clothes and bathing. River, stream and dam water is more commonly used for animals and for irrigating annual crops. In recent years, the water from these sources has been reported as being smelly, containing alum, contaminated by rubbish and muddy. The causes of the problems were claimed to come from household waste, defoliation, remaining branches after forest exploitation, and animal corpses after heavy flooding. After logging, defoliation and small branches of trees are carried in surface run-off to rivers and streams and even as far as the dam.

Key informant interviews revealed that the level of water flow in Ngan Sau River had been very low at times in the past decade. In 2003, the Ho Ho hydropower plant officially reported that river flow was about 19 $m^3 s^{-1}$ but the average between 2013 and 2015 was only 8 $m^3 s^{-1}$. It was also reported that rainfall patterns in the sub-watershed had changed in the last ten years. Nowadays, a stronger rainfall gradient was apparent between dry and wet seasons. The dry season restricted a second cropping season in many villages while flash floods in the wet season had become more intense. As a consequence, the Ho Ho hydropower plant has also had to operate below the minimum water level in the dry season and far above the maximum in the wet season.

PFES in the sub-watershed

Although globally the impact of forest-cover change to hydrology of watersheds is rarely addressed, Viet Nam is the first country in Southeast Asia that integrates PFES into national strategies and policies (McElwee 2012), formulating the payment rate for forest water service beneficiaries. In 2008, the Government of Viet Nam promulgated Decision No. 380/2008/QD-TTg to pilot the implementation of PFES in Son La (Northwest) and Lam Dong (Central Highlands) provinces for a two-year period (2008–2010). Learning from this pilot, in 2010 the government issued Decree No. 99/2010/ND/CP to mandate and apply PFES nationwide and issued revised Decree 147/2016/ND/CP in 2016. According to the new Decree, hydropower companies must pay VND 36 (USD 1 ≈ VND 22,000) per kWh of generated electricity, while the payment rate for water-supply companies is VND 52 per m^3 water used, and for organizations or individuals engaged in tourism businesses is 1–2% of their annual income. Based on this regulation, the smallholder forest owners in the sub-watershed receive about VND 30,000 (≈ USD 1.5) per hectare per year. To increase the amount of PFES, local stakeholders in the sub-watershed expressed the need for forest restoration, especially, in the upstream part of the sub-watershed.

GenRiver hydrological model

Hydrological models have been used to make projections of river flow through a water-balance process. They can also be described as watershed models. The water-balance process usually takes into account rainfall as input distributed to different river-flow components, such as surface, sub-surface and ground flows. Compared to other hydrological models, such as MIKE-SHE (https://www.mikepoweredbydhi.com/products/mike-she) or SWAT (http://swat.tamu.edu/), we chose GenRiver because it required less parametes but could still be used to make projections of the impact on river flow of land-cover changes in a

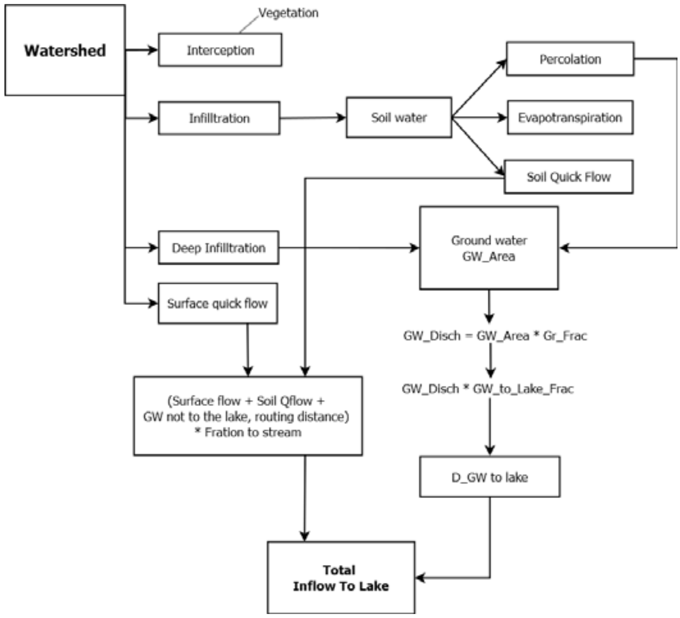


Figure 28. Water-balance process in the GenRiver model

watershed. The model was designed with the Stella platform and runs in daily time-steps.

In the model, rainfall as input is divided into four basic components: 1) canopy interception; 2) infiltration; 3) deep infiltration; and 4) surface quick flow (Figure 28). The interception rate varies depending on the land-use or vegetation type. A part of the sub-surface infiltration will evaporate. The rate depends on vegetation transpiration and soil evaporation. The rest will be stored as sub-surface or ground water. The simulated watershed can be divided into a maximum of 20 sub-catchments and the total amount of water flows from each sub-catchment will be the sum of surface run-off, sub-surface and ground flows.

Input maps and parameter values

The model simulations require maps and parameter values for input. A land-cover map was produced by interpreting LANDSAT imagery and a land-use map from MONRE as reference (Nguyen et al 2015). A soil map was provided by the Viet Nam National Institute of Agricultural Planning and Projection. Other maps, including administrative and river networks, were obtained from MONRE (Table 24). Climate data (that is, daily rainfall and air temperature) were obtained from the Viet Nam Institute of Meteorology, Hydrology and Climate Change recorded at Huong Khe weather station (18°11’N, 105°43’E), 19.5 km to the northwest of Ho Ho dam. They constituted more than 30 years of rainfall and air-temperature data (1982–2014) and were used for model simulation as well as to investigate climate change and variability in Huong Khe District.

The sub-catchment boundary within the sub-watershed was delineated by the ArcHydro tool available as part of ArcGIS software. The procedure included the elimination of water traps in Digital Elevation Model, determining the formation of streams by the terrain, defining the flow direction and routes, defining the stream network, dividing the stream network into a given number of sub-catchments, and defining the area of the sub-watershed surrounding each sub-catchment. Based on this procedure, the Ho Ho sub-watershed with area of about 27,000 ha can be divided into 19 sub-catchments. From each sub-catchment, a routing distance to Ho Ho dam and the HEP was calculated as the nearest distance from the centre point of the sub-catchment to the river and the routing distance followed the river path to the Ho Ho dam and the HEP.

Table 24. Input maps and data for GenRiver simulation in the Ho Ho sub-watershed

Data	Source	Date range	Resolution
Daily maximum and minimum tempera-tures	Viet Nam Institute of Meteorology, Hy-drology and Climate Change	1982–2014	Daily
Daily precipitation	Viet Nam Institute of Meteorology, Hy-drology and Climate Change	1982–2014	Daily
Elevation (m)	ASTER	2010	30 x 30 m
Soil type (FAO stan-dard)	Viet Nam National Institute of Agricultur-al Planning and Projection	2010	1:1,000,000
Land-use map	Nguyen et al (2015)	2010, 2014	1:100,000
Water level in reservoir	NEDI-1 JSC. (owner of Ho Ho HEP)	2013–2014	Daily
Base map (boundaries, roads, river system)	National Administration Map		
Provincial agricultural planning map	Ha Tinh Provincial People's Committee	2011	

Thirteen land-cover types were simulated (Appendix 1). Their properties—such as interception capacity and transpiration rate—were estimated from the default values in the model's land–cover library that included different types of forest land-cover, annual crops and perennial systems, such as agroforestry. A detailed description of input-parameter values and the modelling concept can be found in van Noordwijk et al (2011).

Model validation

For validating the model, we estimated the historical river-flow based on the levels of water recorded in the Ho Ho dam during the period 2013–2014. There was no hydrological station close to the sub-watershed that had ever recorded the river's flow rate. The data from the Ho Ho company included the daily water levels in the reservoir, hours of turbine operation and electricity production. The river-flow estimation was based on the standard table and conversion method suggested by the company that defines the relationship between water level and water volume in the reservoir, and the relationship between electricity production and outflow rate. The estimated historical river flow was compared to the model projection for 2013–2014 using land-cover maps for 1990, 2000 and 2014 and the rainfall and air temperature data from 1990–2014. The model allowed four transition periods in the simulation, with different input land-cover maps, to capture changes in land cover during the assessment period.

Forest intensification scenarios

We assessed the impact of three forest-land intensification scenarios, that is, the expansion of short-term acacia plantations (AE); enrichment of degraded forest land with native tree species (FE); and expansion of long-term timber plantations (TP). The latter was based on the 2011–2020 Provincial Forest Protection and Development Plan formulated by the Ngan Sau Forest Management Board and Chuc A State Forest Enterprise while the former two were based on local stakeholders' expectations, providing the worst and the best cases from the perspective of forest tree-cover in the sub-watershed.

Short-term acacia plantations were still of high interest to local people in the sub-watershed owing to easy maintenance and a relatively stable market. The AE scenario simulated a case in which areas within 3 km of a main road and 1 km from the river—that is, the areas confirmed by local knowledge as potential sites for conversion into acacia plantations, constituting 38% of the total area of the sub-watershed—were completely converted from degraded forest land into short-term acacia plantations with a 5-year rotation cycle (Figure 29a). The FE scenario simulated a case in which areas were protected for forest restoration and enriched by planting native tree species (Figure 29b). This reflected the most extensive form of forest restoration and represented local expectations of restoring natural forest land to increase the level of river flow. Local people mentioned native tree species, such as *Erythrophleum fordii* and *Dalbergia tonkinensis*, were suitable for forest restoration. In the TP scenario, the production forests managed by FMB and SFE would be converted into long-term timber plantations (Figure 29c). The total area of the production forest land constituted 43% of the total area of the sub-watershed. The suitable tree species for this type of plantation, according to the authority's plans, were acacia, *Michelia mediocris* Dandy or *Erythrophleum fordii*. The two latter species usually have a rotation cycle of 15 years or more while acacia plantations for timber purposes usually have a shorter period, such as 8–12 years. For the model simulation, we assumed the rotation cycle for long-term timber plantations was 15 years. All scenarios were assessed over a 30-year period to allow the forest land in the FE scenario to reach a higher stage of development. The model assumed that the current degraded natural forests had a timber volume of 100 m^3 ha^{-1} and, with a forest protection and enrichment strategy as formulated in the FE scenario, the forest land would develop into enriched medium forests with a timber volume or more than 150 m^3 ha^{-1} in 30 years' time. This projection was based on a study by Vu (2010) of forest development in Viet Nam.

All scenarios used the 2014 land-cover map for initial land-cover distribution. For climatic conditions, the rainfall and air temperature in 2014 were based on empirical data whereas from 2015 onwards the daily rainfall and air temperature were the average from the last 10 years (that is, 2005–2014). To capture climate variability, all scenarios were also assessed under three different rainfall regimes: 1) with annual rainfall of 2,600 mm, constituting average annual rainfall for the last 10 years; 2) 1,300 mm per year or half of the average; and 3) 3,900 mm year per year or 1.5 times the average.

3. Results

Historical water debit and model validation

The estimated time-averaged historical water debit based on the observed height of water levels in the dam was 8 m^3 s^{-1} in 2013 and 3.5 m^3 s^{-1} in 2014. The latter is much lower than the first because the 2014 rainfall was lower than 2013. Compared to the rate of 19 m^3 s^{-1} in 2002, as reported in PECC (2002), the level of water flow in Ngan Sau River has decreased significantly. The estimated historical water debits capture the variation in rainfall (Figure 30a) and the values are close to the projected water debits by the GenRiver model (Figure 30b).

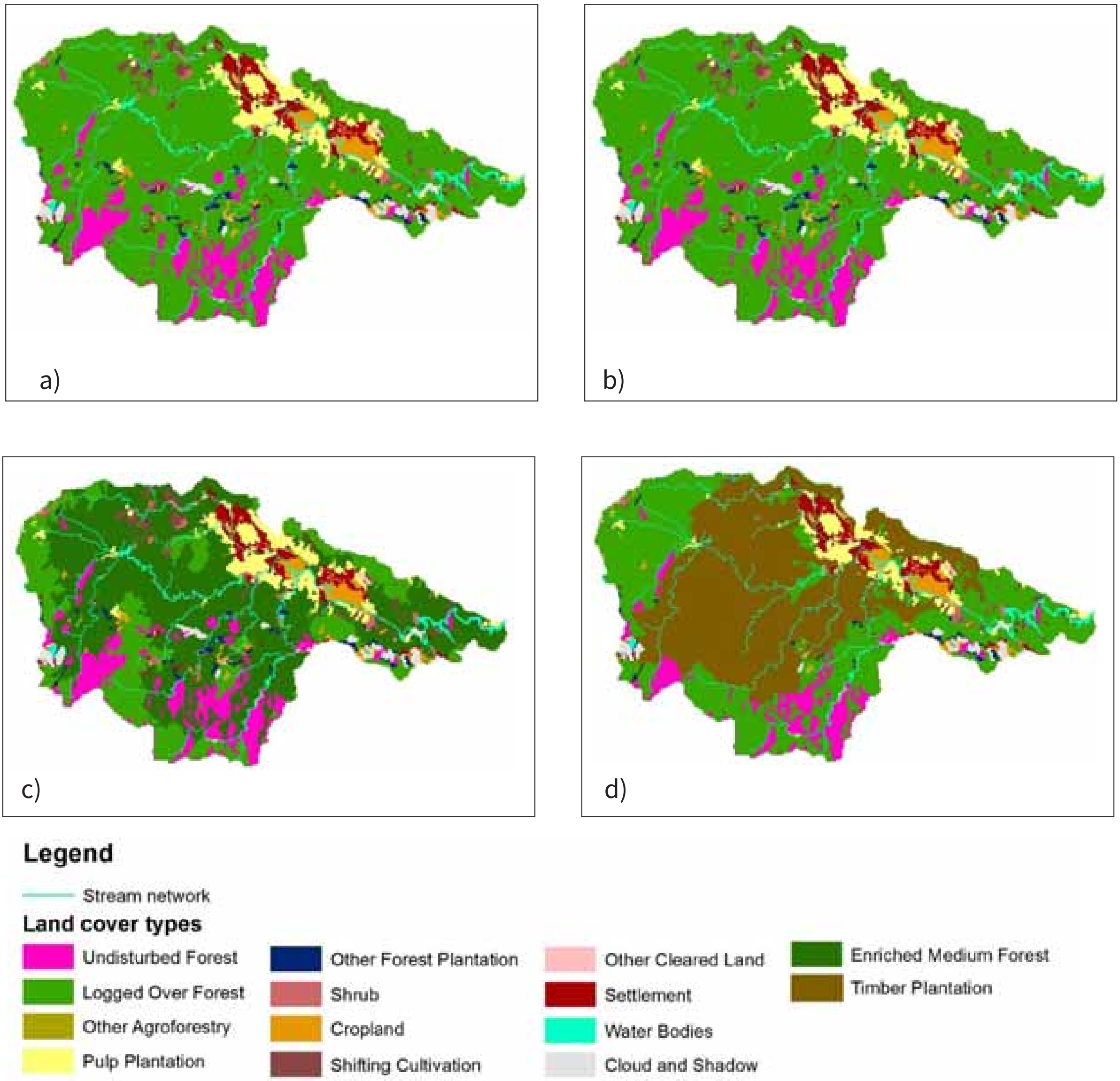
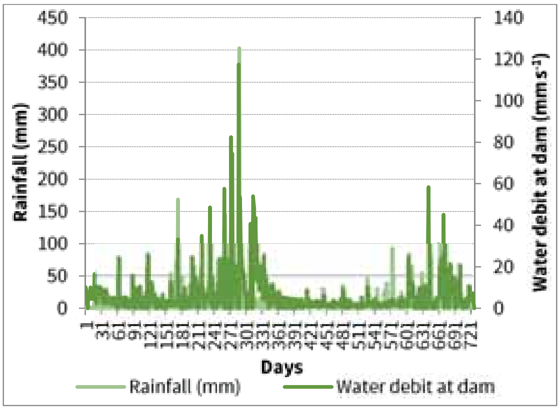
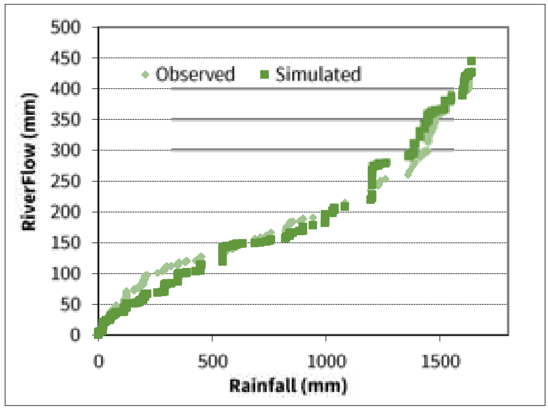


Figure 29. Land-cover distribution in Ho Ho sub-watershed according to (a) 2014 land-cover situation; (b) acacia expansion scenario (AE); (c) forest enrichment scenario (FE); and (d) long-term timber plantation scenario (TP)



a)

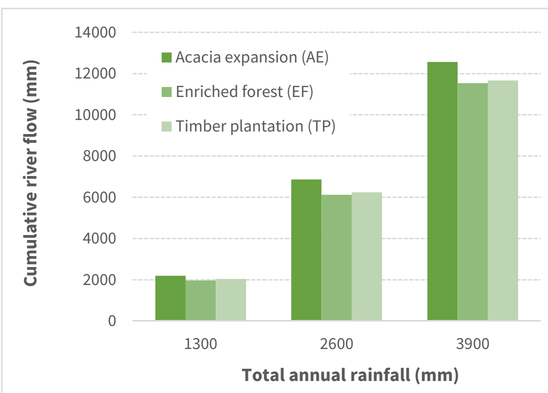


b)

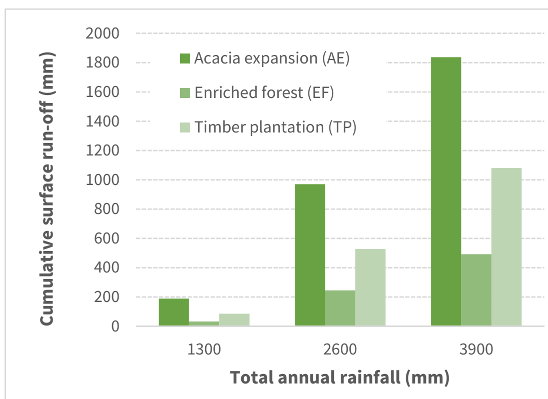
Figure 30. (a) Rainfall and historical water debit at Ho Ho dam, 2013–2014; (b) Observed and simulated water debits for 2013–2014

River flow to the dam

Under all rainfall conditions, the projected river flow was higher in AE than in the two other scenarios (Figure 31a). Under average annual rainfall (that is, 2,600 mm), the cumulative river flow in the scenario with short-term acacia plantations over five years—the complete rotation cycle—was 6,861 mm compared to 6,123 mm for EF and 6,242 mm for TP. The latter two, respectively, reflect 1) cumulative river flow over five years under enriched medium forest, namely, 25–30 years after degraded forest land was enriched by native tree species; and 2) the scenario with long-term timber plantations, namely, 10–15 years after planting. The difference in cumulative river flow in the scenarios is largest with higher annual rainfall (Figure 31a). For example, with 3,900 mm annual rainfall the difference in cumulative river flow between AE and the two other scenarios is 900–1,000 mm whereas with 1,300 mm and 2,600 mm annual rainfall the differences are 100–200 mm and 600–700 mm, respectively. No substantial difference in cumulative river flow was found between EF and TP for all rainfall regimes, which was most likely owing to comparable levels of tree cover in the two scenarios.



a)



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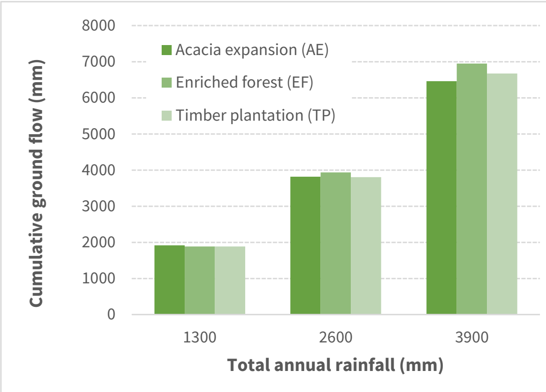

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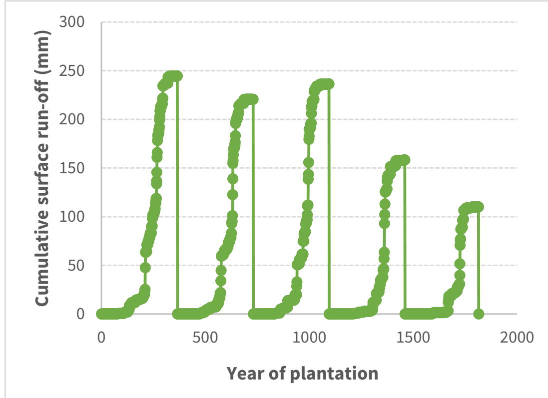


d)

Figure 31. Five-year cumulative river flow (a), surface run-off (b), and ground flow (c) in the three forest intensification scenarios under three rainfall regimes, and surface run-off by plantation year (d) in the acacia expansion scenario

More contrasting differences among scenarios were found related to surface run-off (Figure 31b). Under all rainfall regimes, the 5-year cumulative surface run-off in AE was much higher than in the two other scenarios. This is likely because of less canopy cover in short-term acacia plantations than in enriched medium forests or long-term timber plantations, which leads to lower canopy interception and higher rainsplash. For example, with average annual rainfall the cumulative surface run-off in AE was 970 mm compared to 244 mm in EF and 527 mm in TP. Owing to less canopy cover, the surface run-off in TP was also much higher than in EF: more than double than under average annual rainfall. Since surface run-off is related to the erosion/sedimentation rate, even though AE has a higher total river flow the level of water turbidity from short-term acacia plantation was higher than from the two other land-use types. Lowest turbidity pertains to the enriched medium forest.

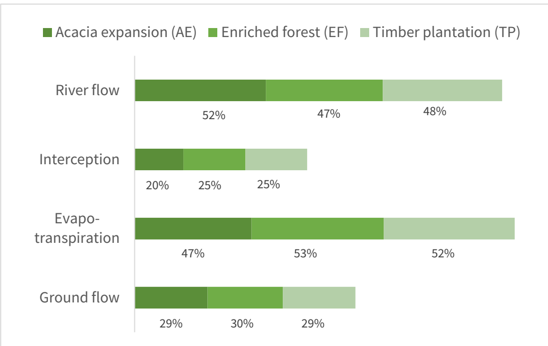
An opposite trend was found related to groundwater flow, where the 5-year cumulative flow in AE was lower than in the two other scenarios, particularly, under the highest rainfall regime (3,900 mm) (Figure 31c). Ground flow is part of deep infiltration and percolation and it is likely that these two water-balance components were lower in AE owing to higher surface run-off. On the other hand, the low surface run-off makes the enriched medium forest have higher groundwater storage and ground flow to the river. With the 3,900 mm rainfall, cumulative ground flow in EF was 6,950 mm whereas in AE and TP were 6,457 mm and 6,676 mm, respectively.

Surface run-off from acacia-plantation

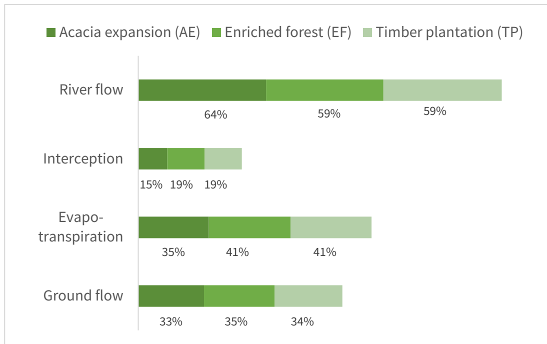
A high erosion rate in plots of acacia between clear felling and replanting and during the early plantation stage was reported by local people during key informant interviews. This risk of soil loss was also reflected by the model's projection of surface run-off during the 5-year acacia plantation cycle (Figure 31d). The annual surface run-off in the first year of a plantation reached about 250 mm, with a decreasing trend by plantation year, and about 110 mm at the end of the rotation cycle. In the long-term timber plantations, high erosion rates likely still occured between two rotation cycles but were not as frequent as in the short-term acacia plantations.

Water flows relative to rainfall

Under average annual rainfall of 2,600 mm, the cumulative river flow in the AE scenario constitutes 52% of total rainfall, with less proportion in the two other scenarios, namely, 47% in EF and 48% in TP (Figure 32a). The lower proportions were partly driven by a higher canopy interception rate in the EF and TP scenarios, which reached 25% of total rainfall, compared to 20% in AE. Another factor affecting the lower proportions to river flow was the evapotranspiration rate, which constituted 47% in AE and was 5–6% higher in the EF and TP scenarios. Related to ground flow, there was not much difference between the three scenarios, as is reflected in Figure 31c above. With higher annual rainfall (3,900 mm), a similar pattern was found when comparing the proportions of river flow, canopy interception, evapotranspiration, and ground flow between the three scenarios (Figure 32b). In the latter (that is, ground flow), the proportion between scenarios was slightly different, as reflected in Figure 31c.



a)



b)

Figure 32. Proportion of water flows relative to total rainfall in the three scenarios, under (a) average annual rainfall (2,600 mm); and (b) higher rainfall (3,900 mm)

PFES after forest restoration

The lower cumulative river flow in EF compared to the two other scenarios indicates that forest restoration would not necessarily lead to higher water levels in Ngan Sau River and Ho Ho dam, as expected by local stakeholders in the sub-watershed. Since PFES from hydropower companies as regulated in the national decree is solely based on water input and generated electricity, the local people would not receive higher PFES payments from forest restoration under the current PFES decree. Conversely, the low cumulative river flow in the forest restoration scenario would lead to lower PFES payments than the USD 1.5 per hectare per year received by smallholder forest owners in the sub-watershed at the time of writing.

4. Discussion

Our assessment of the impact of forest-cover change and intensification in Ho Ho sub-watershed showed that increasing tree-canopy cover and density leads to lower cumulative river flow. Higher transpiration was likely the most determining aboveground factor and better infiltration was the belowground factor. IIED (2002) claimed that most of the studies on watershed services reported a decrease in river flow with higher forest cover in a watershed. For example, in Viet Nam, river flow with forest cover has been found to be 2.5–2.7 times less than flow under agricultural crops (Do et al 2002). They (IIED 2002) also mentioned that a number of studies in Viet Nam have shown that natural forest is more effective than plantations in reducing river flow owing to higher quantities of litterfall and humus in soils and because some tree plantations use heavy machinery that compact the soil. Observation of the impact of tree cover on river flow in Dong Cao Catchment, Northern Viet Nam by Lacombe et al (2015) also found that land with annual crops and herbaceous plants provided higher flow to rivers than land with trees, such as mixed-tree plantations or forests. Their results are in line with an earlier study by Podwojewski et al (2008) that found that the annual surface run-off from annual crops, fodder and fallow land was higher than from eucalyptus and other tree-based plantations. They also found that in acacia plantations, soil surface cover by acacia litterfall can decrease surface run-off by 50%. A kind of forest type that can provide an opposite effect, namely, higher river flow, is presumably only cloud forests at high altitudes because the canopy has a rougher surface that increases the quantity of intercepted water directly from the clouds (IIED 2002).

On the other hand, the majority of local people worldwide still believe that the presence of forests can help provide more water in a river. Rather than claiming that this local knowledge is not correct, we acknowledge that the water-balance process is complex and variations in the impact of reforestation on river flow might exist owing to influences from local and large-scale atmospheric conditions as well. For example, owing to wind patterns, atmospheric moisture from forest evapotranspiration might not remain within the watershed boundary but could be transported across much larger scales, such as a continent (Ellison et al 2017). The opposite can also be true, in that atmospheric moisture from other areas can be brought in by prevailing winds across a watershed boundary. It has also been reported that trees are able to trigger rainfall owing to their microbial flora and biogenic volatile organic compounds (Ellison et al 2017). They can also generate additional moisture through fog and cloud interception. This indicates that tree and forest cover can also modify rainfall patterns. The large spatial and temporal variations of atmospheric conditions might help to explain the divergent impact of forest cover on river flow reported from different study areas. The projection of the impact of generated atmospheric moisture by forests on changes in rainfall pattern is, however, beyond the scope of most (if not all) watershed models owing to the larger scale of atmospheric conditions involved.

The claim that forests usually reduce river flow implies that they to some extent can control flooding as long as water input does not exceed their storage capacity. For example, Lacombe et al (2015) noted that while in the dry season the presence of tree-based systems and forests that reduce total river flow might have a negative impact on irrigation of annual crops, the higher capacity to store water owing to better soil porosity and inflitation might help to reduce flood intensity in the wet season. Tan-soo et al (2014) investigated the impact of deforestation on flood occurences in Peninsular Malaysia during 1984–2000—drawing on a large dataset on flood events and land-use changes in 31 river basins—and found that the conversion of inland tropical forests to tree plantations, such as oil palm and rubber, substantially increased the number of flood days during the wettest months of the year. They also suspected that the uncertainty about the role of forests in flood control was owing to the problem of defining variables to measure, making previous studies not able to be analysed for the impact of deforestation on the number of flood days. They also highlighted, however, that the link between deforestation and flood mitigation depended on the land use to which forests were converted and on the type of converted forest land.

Local people in the sub-watershed expected the problem both of water quantity and quality could be solved by restoring degraded forest land. While the impact of forest restoration on water quantity is not promising, low surface run-off most likely would reduce the problem of water quality, at least reducing the level of water turbidity. The low erosion rate associated with less surface run-off would also avoid serious sedimentation in Ho Ho dam. This is very important for the long term, ensuring that the dam can store water according to its capacity.

On the other hand, an increase in PFES payments is considered by local people in the sub-watershed as a co-benefit of forest restoration. However, this cannot be expected under the current PFES decree that only regulates payments related to water provision not other forest ecosystem functions, such as carbon and biodiversity protection. Because of this, there is a need to amend Decree 99/147 to formulate payments related to other forest ecosystem services or to provide guidance for smallholder forest owners as service providers on how to develop a voluntary PFES scheme. Under the current decree, voluntary schemes are encouraged but no guidance is provided. Indeed, more economic benefit from restored forests could be generated through several means, for example, developing and marketing non-timber forest products (NTFPs) or developing eco-tourism that involves the surrounding communities. Local people in the sub-watershed are able to extract some honey or rattan from the natural forests although these forests are quite distant from their settlement. Further study should investigate if the NTFPs contribute to family income. To our knowledge, a plan to develop eco-tourism with restored forests is still absent in the local authority's strategies. However, regionally, eco-tourism has the potential to develop in Northcentral Viet Nam because there are several national parks, such as Pu Mat, Vu Quang, Ben En, Bach Ma and Phong Nha–Ke Bang.

The 2006–2020 Forest Development Strategies try to pursue both livelihoods' and environmental benefits from forest land in Northcentral Viet Nam through 'focusing on establishment and consolidation of protection forests for watersheds', 'protecting the high biodiversity of the region in association with watershed protection', 'establishing and developing timber and NTFP material supply areas', and 'strengthening community-based forest management modality, especially for protection forests in scattered watersheds'. Because of the projected unfavourable impact of forest canopy cover and density on river flow in the sub-watershed, however, we recommend that local authorities analyse the trade-offs between forest ecosystem services, such as carbon sequestration and biodiversity protection on one hand and water provision services on the other. Furthermore, another trade-off analysis should be conducted of the benefit to local livelihoods and ecosystem services at landscape level from land-use strategies planned for the sub-watershed. We also recommend that the local authorities clearly identify which land is highly exposed to environmental hazards, such as soil erosion, and which land is less exposed, and develop more sustainable land-use systems for the critical land, for example, through novel, short-term acacia plantation models on sloping land that integrates grass strips and which still maintain convenience of harvest. In general, it has been shown that mixed systems, such as agroforestry, are effective in reducing soil erosion on sloping land compared to tree or crop monocultures. For example, in the Northwest region of Viet Nam where land is hilly with steep slopes, La et al (2016) reported that soil loss in agroforestry systems was an average 43% lower compared to monocultural systems. The reduced soil loss was valued at USD 250 per hectare, which is the cost of replacing the NPK lost through erosion by purchasing fertilizer. Furthermore, although not specifically mentioned in the case of the Northcentral region, the 2006–2020 Forest Development Strategies emphasize the need for developing agroforestry systems for the uplands in the northern mountainous region of Viet Nam.

5. Conclusions

Amongst the three forest-land intensification scenarios, enrichment of degraded forest land with native tree species would have a reduced river flow but, at the same time, would reduce the risk of severe soil erosion through minimizing surface run-off. The other two scenarios namely expansion of short-term and long-term tree plantations could provide higher levels of river water but also carry a higher risk of soil erosion, especially, related to the short-term plantation system.

In line with the results of hydrology assessment in the sub-watershed, the literature features many cases of how the presence of forests reduce river flow. However, rather than taking this as a general conclusion applicable in all situations, we acknowledge that the water-balance process within a given watershed is complex and that larger-scale atmospheric conditions might affect it. This is likely a factor that could explain variations in the impact of forests on river flow.

Because of the projected negative impact of higher tree canopy cover and density on river flow, there is a need for local authorities in the sub-watershed to conduct a trade-off analysis between the various environmental benefits of forests, for example, between carbon sequestration or biodiversity protection, and water provision. Such an analysis could inform the development of sustainable land-use strategies in the sub-watershed.

Balancing the total area of short-term and long-term tree plantations and the area of protected forests in the sub-watershed based on a trade-off analysis and on the identification of which land is more exposed to environmental hazards, such as soil erosion than another, would be the first step in developing a more approriate land-use strategy but there is also a need to innovate the current monocultural models of tree plantations through adopting the principle of mixed systems, such as agroforestry, which has been proven to reduce soil erosion on sloping land. Another option is to avoid large-scale clearfelling by introducing a gradual transition model of short-term to long-term tree plantations.

The projected unfavourable effect of forest restoration on river flow also indicates that the current PFES decree that only accomodates the water-provision functions of forests as the basis for calculating payments cannot be used to encourage smallholder forest owners to participate in forest protection and restoration efforts. The decree should accomodate other forest environmental functions as well, such as carbon sequestration or biodiversity protection, or provide clear guidance for the ‘providers’ and ‘buyers’ of forest ecosystem services on how to develop voluntary PFES mechanisms.

Appendix 1 Properties of simulated landcover types in Ho Ho sub-watershed by GenRiver model

Land cover types	PI* (mm day^{-1})	RDT+	BD/ BDref	Multiplier of Daily Potential Evapotranspiration											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Undis-turbed Forest	4	0.7	0.8	0.6	0.6	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.6	0.6
Logged-Over Forest	3	0.5	1	0.5	0.5	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.5	0.5
Agroforest	2.5	0.4	1	0.5	0.5	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.5	0.5
Pulp Plantation (acacia)	2.5	0.4	1	0.5	0.5	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.5	0.5
Forest Plantation	2.5	0.4	1	0.5	0.5	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.5	0.5
Shrub	2	0.2	1.2	0.4	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.4	0.4
Cropland	1	0.2	1.2	0.4	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.2	0.2	0.2	0.2
Shifting Cultivation	1	0.2	1.2	0.4	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.2	0.2	0.2	0.2
Cleared Land	1	0.2	1.2	0.4	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.4	0.4
Water body	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Enriched Medium Forest	3.63	0.63	0.88	0.56	0.56	0.66	0.76	0.76	0.76	0.76	0.76	0.76	0.66	0.56	0.56
Long-term Timber Plantation	3.38	0.58	0.93	0.54	0.54	0.64	0.74	0.74	0.74	0.74	0.74	0.74	0.64	0.54	0.54

**Potential interception. +Relative drought threshold*

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