Trade-offs among competing uses of a Malaysian forested catchments

SHAHWAHID H. O. MOHD, NOOR A. G. AWANG, RAHIM N. ABDUL, Y. ZULKIFLI and U. RAZANI

Environment and Development Economics / Volume null / Issue 03 / July 1999, pp 279 - 311
DOI: null, Published online: 02 April 2001

Link to this article: http://journals.cambridge.org/abstract_S1355770X99000200

How to cite this article:
SHAHWAHID H. O. MOHD, NOOR A. G. AWANG, RAHIM N. ABDUL, Y. ZULKIFLI and U. RAZANI (1999). Trade-offs among competing uses of a Malaysian forested catchments. Environment and Development Economics, null, pp 279-311

Environment and Development Economics 4 (1999): 279–311

Trade-offs among competing uses of a Malaysian forested catchments

MOHD SHAHWAHID H. O.
Associate Professor, Faculty of Economics and Management, Universiti Putra Malaysia

AWANG NOOR A. G.
Lecturer, Department of Forest Management, Faculty of Forestry, Universiti Putra Malaysia

ABDUL RAHIM N.
Director, Division of Techno Economics, Forest Research Institute of Malaysia

ZULKIFLI Y.
Senior Research Officer, Forest Research Institute of Malaysia

RAZANI U.
State Director of Forestry, Selangor

ABSTRACT. In this project, an attempt is made to estimate the costs and benefits of managing forested catchments in Malaysia. Three land use options are simulated for four selected catchments in the Hulu Langat Forest Reserves (HLFR), Selangor, Malaysia. These options are no logging or catchment protection (CP), reduced impact logging (RIL) and conventional logging (CL). The potential sedimentation impacts of each option on the dam and water intake ponds in the catchments are calculated. The benefits derived from logging, hydro-electric power (HEP) generation and the water regulatory dam for water treatment and the external costs emanating from the sedimentation under the three options are estimated. The computations are based on data collected from previous

This project is one of the projects in the Sub-programme B: Valuation of non-timber forest goods and services of the Malaysia-UK Conservation, Management and Development of Forest Resources Programme. It is funded by the Economy and Environment Program for S.E. Asia (EEPSEA) Centre File: 92-0419-16.
The authors acknowledge the research grant provided by EEPSEA, travel arrangements and support by IIED/ODAUK, and other support from UPM and FRIM. The suggestions and advice provided by E. Barbier from the University of York, J. Bishop and B. Aylward of IIED, J. Vincent of HIID, K. Maler of the Beijer Institute, P. Dasgupta from Cambridge University, Chew T.A. of UPM and D. Glover of EEPSEA are appreciated. The comments and critics by two anonymous reviewers have been very helpful in revising the manuscript.

studies conducted in adjacent areas with similar hydrological parameters, secondary data from published reports by various departmental agencies and from on-site personnel surveys. Analysis at the compartment level suggests that the central issue of joint production in forested catchments is not the selection of which logging methods to adopt. Rather the point is which water use can be combined with timber production that can generate greater NPV than the status quo CP option. Under both logging methods, the returns from timber cannot meet that from the status quo production of treated water. Complementing water uses with logging in forested catchments is efficient in HEP catchments. The efficient choice among the two logging methods is the RIL option because of its higher returns and the lower externality imposed upon the status quo water user. However, despite the imposition of conservational measures, the RIL option still generates sediment loads that impose substantial external costs on the downstream water users. This analysis does not incorporate the effects of the alternative logging options on the other attributes of natural forests such as recreation, bio-diversity values and non-timber forest products (NTFP).

Introduction

Forested catchments provide various use and non-use goods and services including commodities like water, timber and rattans, and environmental services such as carbon storage, climate regulation, nutrient cycling, flood control and bio-diversity conservation. Not all of these goods and services are being extracted on an industrial scale, nor do these goods and services have a significant impact on the economy. Some of the benefits of bio-diversity species have not even reached the prospecting stage while those of the environmental services that are of global importance are not largely realised locally. Timber and water use benefits appear to be the two most important goods and services from forested catchments that have significant impact on the economy. In fact, virtually all of the fresh water used in Malaysia for agriculture, industry and household and recreational uses are drawn from forested catchments. Hydro-electric power (HEP) generation requires water flows from catchment forests to run the turbines, and constitutes 17.7 per cent of the total energy production. Log production from the natural forest comprised 89.6 per cent of the total national log production. It is not known if any of these logs are derived from catchment forests.

The rapid economic development experienced by Malaysia raises the demand for utilities, particularly treated water and electricity, and material inputs for manufacturing, including timber. Consumption of treated water and electricity is for both domestic, as well as for manufacturing purposes. Electricity consumption has increased by 14.6 per cent in 1995 while treated water consumption experienced an estimated growth of 10.8 per cent in the same year (Ministry of Finance, 1995). In 1995, Peninsular Malaysia alone consumed 33,310 million kWh for industrial, commercial, household and public lighting uses. No estimate is available for the entire country. Malaysia consumed 7,000 million litres per day of treated water in the same year. Installed capacity in the generation of electricity also increased by 12.1 per cent in 1995. It is expected to increase further between 1995 and 2000 with the commissioning of various electricity generation projects by the independent power suppliers. Likewise, water output capacity has increased by 8.9 per cent in 1995, and its annual growth is expected to continue. These demands on utilities and timber have direct implications on land uses in forested catchments.

In Peninsular Malaysia, log consumption by the two main processing industries (sawntimber and plywood) was 9.2 million cubic metres in 1994 (Department of Forestry, Peninsular Malaysia 1994) and did not show any sign of decreasing. Thus, the peninsula is hard-pressed to maintain current log production levels to feed these industries. The log production level from the natural forest has remained 10.2 million cubic metres during the last two years. Yet, the government forest conservation policy calls for a reduction of the annual logging area (in the productive forest reserves) and an intensive agricultural management programme whereby the clearance of stateland forests would decline (Mohd Shahwahid, 1995). Thus, it is expected that areas available for logging are getting scarcer with logging areas in stateland forests being rapidly exhausted and the annual logging coupes from the productive forest reserves getting smaller. The official annual logging coupes have been reduced from 52,250 ha per year during the Sixth Malaysia Plan (1991–5) to 45,100 ha per year in the Seventh Malaysia Plan (1996–2000). With the more accessible forests, both within and outside the productive forest reserves, being exhausted, it is expected that there will be increasing pressure to log the forested catchments.

With growing demand for both water and timber, and the potential adverse impacts of logging on the hydrological attributes of forested catchments, forest managers are paying increasing attention to an integrated water and timber production objective. Substantial areas of forested catchments that are previously managed mainly for water, will need to be reassessed in terms of their role in both water and timber productions. However, in highly unstable areas, some forest areas may ultimately be designated solely for watershed protection. To assist forest managers, improved methods are needed to evaluate watershed protection benefits in specific sites and to assess the economic trade-offs between timber production and watershed protection objectives. Ultimately, new forest management systems that integrate timber production, watershed protection and other objectives will be required.

A fundamental question is how to assess the potential physical impacts of timber production on reservoir management and downstream activities. Further, there is a need to value and compare the intangible and non-priced benefits of forested catchment protection to the tangible economic benefits of timber production. This need must be addressed since policy makers in developing countries, like Malaysia, require estimates in monetary terms to help them make decisions on land use options. To ensure a comprehensive assessment of all the costs and benefits of different forest land use options and to achieve sustainable forest management, an integrated and multi-disciplinary research amongst the hydrologists, foresters and natural resource economists is necessary.

This study will make an important contribution to this effort. Practical and reliable methods for measuring the physical impacts will be tested and developed, and the benefits and costs of alternative land uses in forested catchments will be looked at. The trade-offs between environmental and production objectives will be assessed. The project is thus of direct and immediate relevance not only to Malaysian forestry but also to the environment at large. In addition, the study has potential global significance to the extent that it generates new and original results in a field characterised by a lack of empirical research.

Objectives

Specifically, this study is concerned with the valuation of the benefits, costs and trade-offs of managing forest land for timber and/or water supply. Forested land may be managed for three different outputs: single use – either timber or water, or multiple uses – timber and water jointly produced in technically variable proportions. The objectives of the study are (i) to identify the uses of the forested catchments, (ii) to model sediment yield in forested catchments under total protection and logging land use options and (iii) to value the benefits and costs of managing forested catchments for water production with and without logging options. Finally the trade-offs between these different objectives are estimated.

Theoretical framework

One of the research interests in the economics of joint production in forestry (often termed multiple-use forestry) relates to the circumstances in which joint production would be superior to dominant or specialisation of land use. In the context of this study, the on-site protection of forested catchments against logging but permitting off-site utilisation of the raw water flow for activities like treated water or HEP production is a specialised land use option.

An analysis probing the economic potential of joint production does not only evaluate the profitability of individual activity, but also assesses how each activity would affect the production of the other. A land use option involving on-site timber production would require evaluating its physical impacts on inputs, notably raw water, that would be utilised by the off-site production system. The profitability of the off-site production system is dependent on the quantity and quality of the raw water inputs which is indirectly dependent on the intensity of log production and logging practices.

The theory of joint production between water and timber production in forested catchments adapted from Aylward *et al.* (forthcoming), Beattie and Taylor (1985) and Maler *et al.* (1994) can be illustrated by the following relationships. The production of timber, q_T depends on its production function as illustrated below

$$q_T = f(X) \tag{1}$$

where X is a vector of factor inputs used in production. X could include inputs such as capital investments on logging roads, felling and transportation, labour, felling area (total area net of buffer strips) and timber stocks allocated for felling (total stocks net of residual stocks reserved for subsequent harvesting cycle). Production is assumed to be an increasing function of X.

The production of goods and services using raw water as an essential input, q_W can be given by the production function below

$$q_W = f(X, S) \tag{2}$$

where X again is a vector of factor inputs used in production and S is the vector of the environmental input. X could include inputs such as capital investments on water treatment or hydro-electric power plants and labour. As in timber production, q_W is assumed to be an increasing function of X.

The S input of concern here is raw water which can take two forms, S_1 as quantity of water intake and S_2 as quality of water intake. The S input is not independent of the production of timber. Rather the S input is dependent on the intensity of q_T which has a physical relationship with the quantity flow of water into the river, erosion rate and eventual quantity of sediments flowing into the river and into the water intake ponds of the treated water and HEP plants. In the short term, the level of S_1 is expected to increase with higher levels of q_T whereby the removal of more trees and larger harvesting areas (higher road densities and smaller buffer strips) would reduce the rate of evapo-transpiration which would raise the ability of the catchment to retain water from the atmospheric loss and which would increase the quantity of baseflow. This relationship is depicted in equation (3). As the residual trees grow and forest regeneration occurs, the baseflow would recede to the normal flow. The level of S_2 is expected to rise with higher levels of q_T whereby the building of logging roads and the felling of more trees on larger land areas would contribute to increased levels of sedimentation into the river. However, the level of S_2 would be dependent on whether logging is a one time activity or recurring annually in the catchment. If logging is done once, S_2 is expected to taper off to the pre-logging state after several years. Recurring annual logging would result in continued high levels of S_2 for as long as logging is conducted.

$$S = f(T, RD, HA) \tag{3}$$

and hence

$$q_W = f[X, S(T, RD, HA)] \tag{4}$$

where T is the number of trees extracted, RD is the road density, and HA is the harvesting area.

Within a certain threshold level, a rise in S_1 contributes to higher levels of q_W. On the other hand, a rise in S_2 would be a negative externality. The physical effect of S_2 is to reduce production of q_W that requires continual suspended sediment-free raw water input being pumped through pipelines from a water intake pond or dam. When the sediment yield has filled up the water intake pond or dam, no raw water input is available causing the idling of plant production capacity until the sediment in the pond or dam is dredged out.

The one-way interdependence of water uses with timber production can be seen from Clawson's (1975) compatibility matrix of forest uses. Accordingly, timber and water uses are moderately compatible, suggesting that limited harvesting is permitted with restrictive harvesting requirements. A change in logging intensity can be related to the level of timber extraction, the size of buffer strips along rivers, and the density of logging roads to facilitate the extraction efforts in less accessible and steeper terrains. It is implied that at low logging intensity, joint production may be tolerable (Gregory, 1987). Otherwise, the negative impacts from logging activities would impair the economic profitability of the production of water uses. At very high logging intensities, the output of water uses would rapidly decline owing to falling profitability from increasing external costs of sedimentation. Eventually, as the timber production intensity rises further, the level of sedimentation flowing into the intake points of the water use plant reaches a threshold level. The accumulated external cost would engulf the potential revenues, making it no longer financially feasible for water use generation.

The economic framework for formalising the potential for joint production or multiple uses in forested catchments is a comparative assessment of the land use options. The most commonly used assessment method is benefit–cost analysis (BCA) in which all costs and benefits of the options are specified in monetary terms. The principles of accounting these costs and benefits have some similarities to that of Reyes and Mendoza (1983), Cruz *et al*. (1988) and Aylward *et al*. (1995). Reyes and Mendoza studied the management and erosion control of the Pantabangan Watershed of the Philippines while Cruz *et al*. conducted a valuation of off-site economic effects of soil erosion in the Magat and Pantabangan Watersheds also of the Philippines. Aylward *et al*. (1995) have presented a conceptual framework of analysing watershed land use decision-making by departing from a private incentives issue towards a societal incentives issue.

The joint-production land use option being considered in this analysis is water uses and timber production which will be compared to the background option of catchment protection where logging is not permitted but the raw water from the catchment is being utilised either for treated water or hydro electric power production. Currently, no logging is being conducted in gazetted catchment areas. The comparison of land use options should not necessarily be limited between with and without logging. The dependence of q_W on S which in turn is influenced by the intensity of q_T, further suggests the need to look at at least two levels of logging options. The conventional selective logging practices (*CL*) can be taken as an option to be compared to an improved or reduced impact logging (*RIL*) which may involve redesigning and limiting road density and the provision of wider buffer strips adjacent to rivers. Thus, it is advantageous to compare the background land use option of catchment protection with two joint production land use options of (i) water use with *CL* and (ii) water use with *RIL*.

The CBA framework can be presented in the following manner:

$$NPV_{CP} = \sum_{it}^{n} (BWCP_{it} - DCW_{it})/(1 + r)^t \tag{5}$$

$$NPV_{JPij} = \sum_{ijt}^{n} \{(BWJP_{it} - DCW_{it} - ECL_{ijt}) + (BL_{jt} - DCL_{jt})\}/(1 + r)^t \tag{6}$$

where

NPV_{CP} is the net present value of catchment protection option;

$BWCP_{it}$ is the benefit derived from water use activity *i* of catchment protection option;

DCW_{it} is the direct cost of water use activity *i*;

NPV_{JPij} is the net present value of joint production between water use activity i and timber production under activity *j*;

$BWJP_{it}$ is the benefit derived from water use activity *i* of joint production option;

ECL_{ijt} is the external cost incurred in water use activity *i* arising from timber production under activity *j*;

BL_{jt} is the benefit derived from timber production under activity j;
DCL_{jt} is the direct cost of timber production under activity j;
r is the rate of discount;
i is either the treated water or HEP production activity;
j is either the conventional logging or reduced impact logging activity;
t is the year of occurrence of cost and benefit items beginning year 1 to the end of the period of analysis in year n.

Equation (5) shows the NPV of background land use option involving water use production activities. Since the catchment is protected from environmentally disturbing activities, no external costs are being incurred by existing water use production activities. Equation (6) reflects the NPV of joint production land use option involving water use and timber production under either the conventional logging system or reduced impact logging. An external cost is included in Equation (6) to reflect the change in quantity and quality of the environmental input (raw water) utilised by the water use production system as a result of the two kinds of logging activities.

The cost–benefit analysis (CBA) decision rule was used to compare these alternative land use options. Joint production is a better land use option over catchment protection if both NPV_{JPij} exceed NPV_{CP}, i.e., the incremental $NPV_{JPij\text{-}CP}$ is positive. Similarly, comparisons can also be made between the two joint production options. Ideally, all benefits and costs should be included in the analysis. However, some of these values (non-timber forest products, recreation, etc.) at both levels (on-site and off-site) are not included in the analysis since they are relatively small and not significant, at least in the study site. The external cost arising from the change in the environmental input (raw water) is limited to that due to increased sedimentation only. The external benefit arising from increased quantity of baseflow is not included for lack of basic research in this area in the country. This would be a good area for further inquiry in understanding the trade-off between logging and total protection.

Many of the uses not included in the analysis, except for increased quantity of baseflow, are more likely to be more available in protected catchments. Thus, we would expect the NPV_{CP} computed in this study to be biased downwards. As a result, our analysis is likely to discriminate against catchment protection.

In conducting the CBA, the time horizon of the project and physical impacts arising from the land use options would have to be identified and valued in monetary terms. The issue of the time horizon to choose is guided by the period logging is spread over, sustainability of timber production between current and future cycles, and the period for sedimentation rates to revert to background levels. Annual harvesting areas per license are small (with 100–200 ha per license considered normal). The size of the forested catchment being analysed is not large (the largest is only 3,823 ha). The annual logging activity can be spread over the normal 30 year cutting cycle in C1 but for the other three compartments logging is distributed over 4 years owing to their smaller area. In this regard, a time horizon not exceeding a cutting cycle is sufficient for the analysis as sedimentation levels would fall back to background levels after a few years. This factor is not expected to be an important determining factor in the selection of long time horizon as the full impacts on water uses would have been known in a relative short time. Instead a more important factor is the expected decline in timber yield with subsequent cutting cycles. Thus, a time horizon for the study would have to cover at least two cutting cycles to incorporate (i) the rehabilitation costs and (ii) second cycle timber yield and its effect on the sustainability of the natural capital or timber resource. Any longer period is not expected to change the analysis, especially when the rate of discount used is 10 per cent. This is the discount rate being used by the National Economic Planning Unit. This rate can be considered quite high given that the real rate of interest of treasury bills in the country is approximately 4 per cent. The appropriate rate is influenced by many factors including different investment portfolios and risks, transaction costs and individual marginal tax rates. An analysis using discount rates within the above range (4–10 per cent) would be attempted to observe any significant change in the direction of the finding.

The valuation aspect of the study involves two levels; (i) enumerating the physical impacts of logging and (ii) conducting a valuation of these physical impacts. The nature of the physical impacts of the above alternative land use options can be better understood by referring to Table 1 below in terms of changes to the sedimentation yield, timber harvests, loss of live storage of dam and loss of hydro-electric power generation. The environmental effects studied from these land uses are limited to sedimentation and did not cover changes to baseflow for the reasons mentioned earlier. Quantitative estimates of the hydrological impacts can be obtained by transferring the existing data from nearby sites. Rainfall and streamflow data have been measured at four catchments namely, the catchments of the Lui, Batangsi, Chongkak and Lawing Rivers. Two Ph.D. theses (Lai, 1992 and Low, 1971) have been completed based on sediment rate data from both undisturbed and disturbed (logging) catchments. Information on impacts on timber harvests, and production of treated water and HEP have to be computed by relying on field surveys.

Description of the study site

The study site selected is the Hulu Langat Forest Reserve (HLFR), located in the state of Selangor, Malaysia. This site was selected based on a range of physical and economic criteria, notably the availability of inventory data of potential timber and hydrological data, and the economic significance of

Table 1. *Hypothetical physical impacts of alternative land use options in the selected HLFR catchments*

Land use options	*Sedimentation*	*Timber harvests*	*Enhanced dam storage loss*	*Enhanced HEP loss*
Catchment protection	Low	None	Normal	Normal
Reduced impact logging	Medium	Medium	Medium	Medium
Conventional logging	High	High	High	High

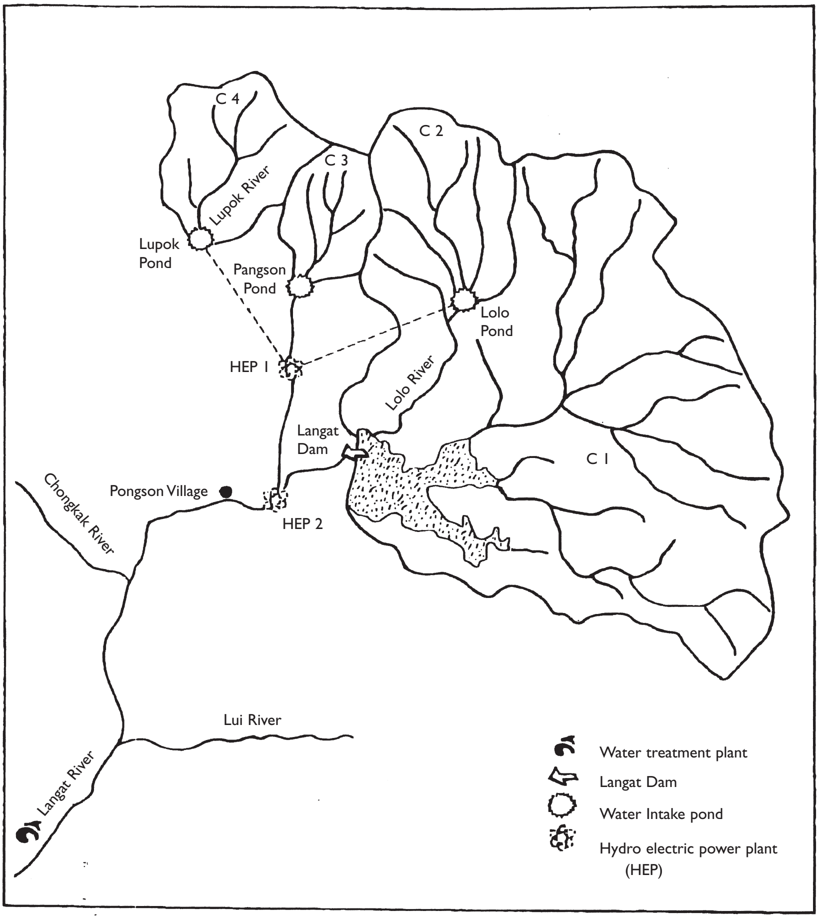

Figure 1. *Hulu Langat Forest Reserve study site*

water uses or protection services linked to the site, in particular for industrial water supplies, and the generation of HEP.

The selected forest reserve is one of the nine reserves (representing about 26 per cent of the total forest reserves) in the state. The vegetation of the HLFR is covered with hill Dipterocarp tree species. The altitude ranges from 120 m to 1,265 m, above sea level. The main river in the HLFR is the Langat River, which flows in a south-westerly direction into the Straits of Malacca on the West Coast (Figure 1). Although the downstream reaches of the Langat River are not actively being used by local people, there are occasional leisure fishing and recreational use. The locals obtain drinking water that is supplied by the Water Supply Department from a water treatment plant (recently privatized to a private company) which receives regular supply of untreated water from the Langat River. There are several upland catchments, each named after the stream draining the respective basins, namely Langat, Lupok, Pangson, Lolo, Chongkak and Lui Rivers. These streams are tributaries of the Langat Main River.

The Langat Dam is located within the Langat Catchment (C1). The total area of this catchment is 3,823 ha of which 272 ha is inundated. The main direct use of the catchment management in C1 is the impoundment of water in the Langat Dam. The dam forms part of the Langat River Scheme which was designed to augment water supply to the capital city of Kuala Lumpur and surrounding areas. This program was implemented in 1976 by the Selangor State Government with a total investment of RM31.8 million (USD 1 = RM 3.8 in 1998). The dam impounds 37.5 million m^3 of water at top water level of 220 m and regulates the flow of the Langat River in the dry season according to the demand of the water treatment plants located 13 km downstream. The reservoir serves as a security to enable 386.4 thousand m^3 per day of water to be continuously abstracted at the existing river intake for the water treatment plants. The water production capacity of the Langat treatment plants is 141.0 million m^3 per annum. In Lolo Catchment (C2 with an area of 473 ha), Pangson Catchment (C3, area 265 ha) and Lupok Catchment (C4, area 455 ha) three mini-dams are located. These mini-dams serve as the water intake points through a system of pipe lines for two HEP plants. The HEP facility is operated by an independent power supplier and has a potential generating capacity of up to 33 kV (37,440 kWh) of electricity per day.

Apart from the above major uses of the HLFR, the rural community collects non-wood forest products (NWFP) from the forests. A socio-economic survey is conducted to obtain information on the current status of the utilisation of goods and services from the study area by the community. In general, the local community are involved in the collection of various traditional goods, and the business of providing lodgings and food to picnickers. There is limited use of the river water for daily domestic use since the communities living downstream from the Langat Dam are supplied with piped water.

The local community in the study area comprises of the indigenous people from the Temuan tribe who live adjacent to the forest reserve; Malay villagers a few miles downstream along the river system and Chinese residents in the nearest town of Simpang Balak. The population of the indigenous people totals 60 households (population of 585) living in a 2.5 ha village. The population of the Malay and Chinese residents is estimated at 30 households with a population of about 150.

A total of 22 households (19 indigene, 1 Malay and 2 Chinese) known to be involved in utilising goods and services from the study site were surveyed to gather information on NWFP utilization. All of the 19 indigenous villagers collect traditional goods from the forest while the other 3 residents are not involved. Among the traditional goods collected are wild fruits such as durian, petai and bananas, vegetables and condiments, fibre materials such as bamboo, bertam and rattan, and medicinal plant extracts. The Malay resident operates a lodge for recreationists during the weekends while the other two Chinese residents process the bamboo bought from the indigenous people into joss sticks for the making of incense sticks used in praying.

Table 2. *Full range of goods and services obtained from the study site as per household surveyed*

Items	*Physical quantity*	*Gross income or sales turnover*[a] *(RM/month)*[b]
Banana leaves	1,700/month	120
Leaf shoots	120 bundles/month	12
Banana	45 kg/month	22
Petai	Seasonal	17
Durian	Seasonal	82
Fibers		
• Bertam	1,900 pieces/month	63
• Bamboo	135 pieces/month	147
• Rattan	20 manau pieces/month	60
Medicinal herb	4 packs/month	40
Joss sticks	0.7 million sticks	3,043
Lodge rental (family size)	Seasonal	30[c]
Hydroelectric power generation	1,560 kWh continuously	185,328
Water treatment	141 million m^3/yr	3,878,636

Notes: [a] Average collection of households involved in individual activity. [b] US$ 1 = RM3.80 (1998). [c] Per night.

The full range of goods and services provided by the HLFR, including information on the average physical unit of utilisation and sales turnover or income derived are given in Table 2. On average, a household could obtain RM217/month from the collection of traditional goods from the HLFR. The local Malay villager can obtain rental income of about RM240/month, assuming the lodge is fully rented during the weekends. The Chinese entrepreneur who processes bamboo can obtain an average income of RM3,043/month.

Land use options

This study involves catchments C1, C2, C3 and C4 which respectively have a water regulatory dam and three mini hydro-electric dams. Based on the above description, the main uses from these catchments would include potential extractions of timber on a sustainable basis and water impoundment at the Langat Dam for abstraction into a water treatment plant and HEP generation. There are other uses that are NWFPs but as shown above these are not very significant to the national economy. The simulations are based on three land use options in these catchments, namely catchment protection (CP), conventional logging (CL) and improved or reduced impact logging (RIL).

The first land use option is the status quo whereby the four catchments are being used as sources of water for intake ponds for the HEP plant and as a water regulatory dam. The catchments are protected and no logging activity is permitted. Hence, there will be no timber benefits realised as well as no negative externalities from the logging operations except for the natural rate of sedimentation from natural forests, which is acceptably low.

Logging practices vary with regard to the status of forest lands. In state-land forests (forest land due for conversion to non-forest uses), clear felling is practiced and there is no minimum-diameter cutting limit. In the production forest reserves where logging is permitted, selective logging based on the Selective Management System (SMS) is practiced where strict rules and regulations are imposed. This system attempts to prescribe cutting regimes that yield an economically viable harvest volume while leaving sufficient residual trees of advanced regeneration to ensure future harvests at intervals ranging from 30 to 35 years. In practice, the SMS is implemented by setting minimum-diameter cutting limits for Dipterocarp and Non-Dipterocarp trees and by analysing data from pre-felling (pre-F) inventories. Cutting limits typically are no lower than 50 cm diameter at breast height (dbh) for Dipterocarps and 45 cm dbh for Non-Dipterocarp timber species. Minimum residual stocking is also required, which should not be less than 32 marketable trees of good quality from diameter class 30 to 45 cm or its equivalent per ha.

In this study, we differentiate selective logging practices into two options: CL and RIL. Various RIL guidelines have been documented (e.g., Hamilton and King, 1983; Department of Forestry, Peninsular Malaysia, 1988). The existing guidelines generally encompass aspects of harvesting technique, silvicultural system, infrastructure (logging roads, log landings, skid-tracks) and log extraction. One important practice is to leave a buffer strip alongside streams.

In forestry, buffer strip or stream protection zone comprises land areas of varying size along water channels which need to be left untouched during forestery operations. Although, buffer strips may occupy only a small proportion of a catchment, they represent an extremely important component of the overall landscape. The importance of buffer strips has long been recognised, especially for filtering sediment and other forms of pollutants from entering streams, thus maintaining water quality. Hill slopes beside streams are considered ecologically sensitive areas, for they contribute a primary source of saturation landflow, and as such may transport considerable amounts of sediment when the vegetation is removed. The usually wet soil zones beside streams are prone to compaction when encroached by heavy machinery. Keeping a certain width of buffer strip can ensure that streambanks will remain intact, thereby maintaining streambank stability and low channel erosion rate. In addition, the overstorey canopies protect streamwater from direct sunlight, thus maintaining stream temperature and protecting aquatic flora and fauna.

An overriding issue, however, is determining the suitable width of buffer strip that can serve effectively. Very narrow buffer strips may not be adequate to filter sediment while too wide a buffer strip may increase forgone income to loggers. Essentially, the size of buffer strips must take into account soil erodibility, slope, stream condition and the intensity of disturbance. In tropical rainforests, a minimum width of 20 m on each side of streambanks was found to be adequate to protect the quality of streamwater reasonably (Abdul Rahim and Zulkifli, 1994). Thus, an important element of RIL in this study is the setting aside of 20 m buffer strips. While in the CL option, a buffer strip of 5 m was assumed. The hypothetical width of the buffer strip in the latter is prescribed to provide an indication that without proper supervision, the SMS logging specifications may be difficult to monitor and enforce.

Cost and benefits of alternative land use options

The valuation of the physical impacts arising from the land use options could be quite direct with the exception of computing the logging-induced sedimentation yields and their impacts on revenues and costs of the production of treated water and HEP. In assessing the value of these impacts, the changes in productivity approach is adopted. The study involves two levels, (i) enumerating the direct costs and revenues of alternative options and (ii) establishing the quantum of the sedimentation yields into water channels and valuing the impacts on downstream users, water treatment and HEP plants.

Direct costs and revenues of alternative options

Information on the physical quantities of inputs and outputs, production costs and prices are provided in Appendix I. In timber production, the log prices vary by species and quality ranging from RM75/m^3 to RM700/m^3. The average net timber yield, after deduction for defects and damages, is 49.3 m^3/ha in both CL and RIL options. The average net timber yield is expected to be lower in the second cycle and its estimation is discussed below. Timber revenues are lower in RIL owing to wider buffer strips. The revenue generated from logging vary among the four catchments depending on their area. The total loggable area in a 30 year cutting cycle for each compartment is given in Table 2. Logging is annually conducted throughout the two 30 year cutting cycle periods in C1 while only for the first four years of each cycle in C2, C3 and C4. The direct logging cost used is RM70/m^3 and the annual forest management and administration cost incurred is RM21/ha. The other activities conducted prior to harvesting and their costs are reported in Appendix I.

The forested catchment provides water for utilisation, either as a raw material for further processing (as in water treatment plant) or as a service to run the turbines (as in HEP plant). To determine the net revenues derived by each land use option involving water uses in compartment C1, requires the apportioning of the volume of treated water produced from raw water sourced from the Langat Dam. The production figures of the water treatment plants cannot be used to measure the beneficial role of catchment C1 since the water intake at the these plants are sourced from the Langat River and not directly from the Langat Dam. The water input is abstracted from the Langat River which is fed by the Chongkak, Lawing and Lui Rivers as well as by the Langat Dam for a limited number of days when the Langat River is experiencing low water levels. Water is only released from the Langat Dam during the dry period, estimated at about 68 days based on the rainfall records at the HLFR. There is a need to apportion water intake volumes from the dam and from the other tributaries feeding into the Langat River. During the dry period, a water deficit of 0.13 million m^3 per day is avoided at the intake point. The estimated annual volume of water intake by the treatment plants which is sourced from the Langat Dam is 8.84 million m^3.

The prices of treated water and HEP sold by the independent water and HEP suppliers to the Waterworks Department and National Electric Company respectively are used in this study. The price of treated water is RM0.33 per m^3, while the price of HEP is RM0.165 per kWh. The revenue generated in the HEP plants varies with the kWh of HEP production. HEP production is dependent on the quantity of water turning the turbines which is influenced by the level of sediment yield accumulated at the intake pond. In the case of the treated water plant, the quantity of water produced from water released by the dam remains constant under the alternative options (i.e., 8.84 million m^3 per annum worth RM2.92 million per annum). Sedimentation accumulation in the dam has no direct impact on quantity of water being released into the Langat River. It is assumed that the direct production cost for HEP generation is constant irrespective of the level of water intake to turn the turbines. Variation in kWh production does not affect direct cost as the marginal cost of water use is zero.

The production costs of both HEP and water treatment vary with the quality of the water input. The alternative options have different impacts on the flow of sediment yield which affects the suspended sediment level of the water feeding the HEP and water treatment plants. The direct production costs for HEP and water treatment at zero sediment yield are computed to be RM0.125/kWh and RM0.114/m^3 respectively. Under the alternative land use options where there are various sedimentation levels, the production cost per unit is expected to rise. This change in the cost will be treated as an externality for permitting logging in water catchments.

Impact on rehabilitation cost and second cutting cycle harvest

Forest management aims at sustainable resource development. The SMS requires rehabilitation activities to be conducted after post-felling inventories. The inventory evaluates the status of residual tree stocking and recommends appropriate silvicultural treatments. Depending on the status of residual tree stocks, three options are available; climber cutting operations if sufficient stock remains; enrichment planting with seedling stocks if moderate availability of residual stocks; and even-aged plantations if the logged compartment is destroyed. Based on previous trends of selective logging on production forest reserves in the state of Selangor, 87 per cent of the rehabilitated area required climber cutting operations and 13 per cent called for enrichment planting (Suhaimi, 1997). Thus, in the CL option a mix of the two rehabilitation activities in accordance with the above proportion was specified. In RIL only climber cutting operations were simulated. The costs of conducting both rehabilitation operations are given in Appendix I.

The above rehabilitation operations were assumed to help the compartments regrow and provide the second cycle of harvests. To forecast the net growth in the second cutting cycle, we adopt Vincent's (1997) logistic relationship between standing volume per ha (net of defect) and age as follows

$$q(t) = 0.65 * 132\, e^{1-60/t} \tag{6}$$

where $q(t)$ is the cumulative standing volume t years after the first cycle of logging, t being the period of the cutting cycle of 30 years. This assumes that timber yield in the second cycle is only 31.6 m^3/ha.

The selection of two cutting cycle periods in this study is now very clear as it is able to incorporate the cost of rehabilitation operations and the second cycle timber yields which are much lower than in the first cycle.

Impact on sediment yield

The calculation of sediment input into the reservoir and water intake ponds resulting from the three land use options is based on sediment yield values expressed as the volume of material removed per unit area within a given time. This involves the conversion of the sediment yield into volume basis using information on the density of the sediments as shown in (7) and (8).

$$SR = SY/CA \tag{7}$$

$$SY = (SS + BS)/SD \tag{8}$$

where

SR is the sedimentation rate in m^3/ha/year;
SY is the sediment yield in m^3/year;
CA is the catchment area in ha;
SD is the sediment density in metric tonne/m^3;
SS is the weight of suspended fine materials in metric tonne/m^3;
BS is the weight of coarse materials normally deposited as bed materials measured in metric tonne/m^3.

Sedimentation from logging is sourced from the opening of canopy and ground cover during road and log landing construction, tree felling and log skidding. The sedimentation process does not only occur during the time of harvesting but is spread over several years. Logging roads are known to contribute significantly to the total amount of sediment even after the area has been logged, particularly the main forest road. After harvesting, the main road is used as access to transport out logs and to carry out silvicultural treatments in the operated area.

Previous studies have revealed that the rate of sedimentation tends to recover after five years of logging operation provided that no further encroachment occurs in the logged area (Abdul Rahim, 1988 and Baharuddin, 1988 and 1995), but there is no specific model developed yet showing the path of the post-harvest sediment yield recovery period. The path of this recovery period varies depending on the intensity of the logging activity, area of soil disturbance, topography, soil types, rainfall frequency and intensity, and canopy cover. Experiences from year to year field measurements have provided for both a gradual decline, as well as an increasing and decreasing decline. The latter paths would see either a small initial decline in the first two years after harvesting followed by larger rates of decline as they approach back to the natural rate of sedimentation or a large initial decline followed by eventual marginal reductions. In this study, the gradual declining sedimentation rates are reported first while those of the alternative paths will be elaborated at the end of the paper, where a sensitivity analysis is conducted.

One of the main elements imposed for the logging options is the provision of a buffer strip of 5 m in the CL option and 20 m in RIL. Retention of buffer strips in both options accordingly reduce the harvestable forest areas. RIL can significantly reduce the amount of sediment yield due to the impositions of further control measures such as better road planning, and monitoring and enforcement of forest management specifications. In this regard, a sediment yield reduction factor of 0.6 is being adopted to be associated with RIL. Basically this factor describes how much lower the rate of sedimentation is when the improved and more supervised logging method is adopted over the more conventional technique. Using data from Baharuddin (1988) a factor of 0.5 is obtained. However, this factor requires adjusting upwards since the improved logging option set by Baharuddin also reduced the timber yield per ha, apart from reserving a similar area of buffer strip as in our study. In this study timber yield per ha is set at a similar level for both logging options as determined by the Forestry Department.

Sediment deposition in the reservoir is normally governed by the characteristics of the inflow channel and the reservoir bed which is captured in the formulation above by a trap efficiency factor. Trap efficiency is the percentage of sediment retained to total sediment inflow. Some portions of the sediment flowing into the channel will be retained along the channel. A trap efficiency with approximately 70 per cent is assumed based on personal interviews with a few hydrologists. The sediment yield for each logging option is computed using equation (9).

It should be noted too that even under the CP option, there are natural erosions occurring in the undisturbed forested catchment, but the sediment yield is small, mainly generated because of rainfall impact. The annual sediment yield is easily estimated from the natural rate of erosion over the whole area of the catchment and multiplying this by the trap efficiency factor.

$$SY = e\sum_{c=1}^{2}\sum_{t=1}^{30}\sum_{h=1}^{30}\sum_{r=1}^{5}\left\{d[(HA_t * SH_h) + (\mathrm{HA}_{t+1} * \mathrm{SR}_r)] + (\mathrm{TA}\text{-}CHA_t)SU\right\} \qquad (9)$$

where

SY is sediment yield (m^3/year);
SH is sediment from harvesting (m^3/year);
SR is sediment from road maintained for rehabilitating activities (m^3/year);
SU is sediment from undisturbed forest or remaining area (m^3/year);
HA is harvesting area (ha);
CHA is cumulative harvested area (ha);
TA is total forest area (ha);
c is the first and second cutting cycle;
t is period from first cutting block to the 30th cutting block;
h is recovery path of sediment rates from the first five years of logging in a cutting block before going back to the natural rate beginning from year six until the next cycle of harvesting;

r is period when main road is maintained beginning one year after logging;
d is reduction factor of 0.6 for RIL and 1 for CL option;
e is trap efficiency factor;

Impact on the water treatment plants

Sediment retention into the reservoir affects the suspended sediment (SS) level of the water release into the Langat River which in turn raises the sediment concentration of the water uptake at the treatment plants. Sedimentation concentration measures the weight of sediment available per unit volume of water. The cost of treating raw water for domestic uses is expected to increase with the level of sediment concentration. Mohd Akbar and Rusnah (1997) found a linear function in the following form

$$CT_t = 0.1143 + 0.0005\, SC_t \tag{10}$$

where
CT_t = treatment cost at year t (RM/m^3);
SC_t = sediment concentration at year t (mg/l);

Sediment concentration is dependent on the quantum of sediment yield (SY) and the ratio of suspended sediment to sediment yield (k) as shown in equation (11). A value of 0.69 was adopted for k (Lai, 1992).

$$SC_t = [(k * SY_t * SD)/ROV_t] \times 10^6 \tag{11}$$

$$ROV_t = ROC * RF_t \tag{12}$$

where
SY_t = Sediment yield at year t (m^3);
ROV_t = Annual runoff volume at year t (m^3);
SD = Sediment density (1.5 metric tonne/m^3);
ROC = Runoff coefficient;
RF_t = Annual rainfall average at year t (mm);

The annual rainfall average at the site is 2,346 mm/yr. The annual runoff volume can be determined by multiplying the annual rainfall with a run off coefficient. It should be noted though that the rainfall average is a stock of rainfall per annum whereas the runoff provides the annual flow of water via the river channel. Based on two years rainfall and runoff data, a runoff coefficient of 0.44 was obtained (Lai, 1992). The estimated annual runoff is 1,032 mm.

Empirical estimates

NPV of timber production

The harvestable areas (after deducting for the buffers) of the four catchments are given in Table 3. The buffer area within a compartment normally depends on the width of the buffer as well as the stream mileage. While the width of buffer may vary depending on the management decision, the latter factor is a function of drainage characteristics including stream order, drainage density and drainage perimeter. The largest channel in the catchment is categorised as fifth order, basically indicative of a large

Table 3. *Harvestable forest area [ha] and sediment yield [m^3] for the compartments in HLFR*

Land use option	*Catchment protection*	*Reduced impact logging*	*Conventional logging*
Catchment 1			
Total area (ha)	3,551	3,551	3,551
Harvesting area (ha)	—	2,871	3,381
Buffer area (ha)	—	680	170
Sediment yield (m^3)	99,428	319,754	490,947
Catchment 2			
Total area (ha)	473	473	473
Harvesting area (ha)	—	388	452
Buffer area (ha)	—	85	21
Sediment yield (m^3)	13,244	60,405	100,778
Catchment 3			
Total area (ha)	265	265	265
Harvesting area (ha)	—	217	253
Buffer area (ha)	—	48	12
Sediment yield (m^3)	7,420	33,797	56,608
Catchment 4			
Total area (ha)	455	455	455
Harvesting area (ha)	—	373	435
Buffer area (ha)	—	82	21
Sediment yield (m^3)	12,740	58,078	96,789

Table 4. *Costs and revenues of timber production (RM and %*[a]*)*

Present value of benefits and costs	*Catchment protection*	*Reduced impact logging*	*Conventional logging*
Revenue	—	15,943,777	18,688,932
Direct logging Cost	—	6,369,888 (83.4%)	7,466,641 (83.7%)
Rehabilitation cost	—	272,155 (3.6%)	466,896 (5.2%)
Administrative and management cost[b]	—	992,968 (13.0%)	992,968 (11.1%)
Total cost	—	7,635,011 (100.0%)	8,926,505 (100.0%)
Net present value	—	8,308,766	9,762,427

Notes: [a] Cost items as percentage of total cost.

[b] No administrative and management cost is allocated to CP because no logging and rehabilitation activity will be conducted in the catchment. Hence negligible manpower and planning activity is committed to the catchment.

stream size with an in-feed of four upstream networks. The higher the order of the main channel the longer will be the summation of the stream network mileage. The lengths of these river networks are 170 km in C1, 21 km in C2, 12 km in C3 and 21 km in C4. In the CP option, the catchment is protected from logging activities and hence does not generate either timber revenue or cost. CL can produce higher present value of timber than RIL as the latter has more buffer areas (Table 4). However, in terms of percentage, CL incurs slightly higher rehabilitation costs owing to a larger area requiring rehabilitation, of which a portion needed enrichment planting which costs more than climber cutting operation.

Although the present value gross revenue of CL is RM2.7 million more than that from RIL, the incremental net present value is only RM1.5 million. The higher logging and rehabilitation cost of timber production under the CL option greatly reduces its NPV.

Sediment yield

The logging options create off-site impacts, in particular sedimentation into the Langat Dam and water intake ponds of the HEP plants. The volume of this sediment yield must be determined to measure the external cost imposed on downstream users. The annual sediment yield arising from logging is computed using equations (6)–(9). Sedimentation data reported by Lai (1993) in the adjacent catchment, Batangsi River, were used. This particular catchment shared similar physical characteristics to the catchments in HLFR. The suspended sediment yield from the logging activities amounts to 28.3 metric tonne/ha/yr. The above study also showed that the bed-load total is 12.67 metric tonne/hr/yr. Thus, the total sediment yield due to logging is 40.97 metric tonne/ha/yr. Using a sediment density value of 1.5 metric tonne/m^3, the total sediment yield is 27.31 m^3/ha/yr. Therefore, the sediment yield which reverts back to the background rate of 0.67 m^3/ha/yr after five years, is assumed to decrease at the rate of 5.26 m^3/ha/yr. It is assumed that harvesting operations provide only 10 per cent of the sediment yield with the rest contributed by the logging road system. The entire forest road system occupies 15 per cent of the area with 46.7 per cent of this being occupied by the main roads. The main roads are maintained for post-harvest rehabilitation activities for at least five years. The rate of sedimentation from the undisturbed catchment (CP option) is 0.67m^3/ha/yr or equivalent to the rate on the sixth year of logging. The trend of the sediment yield in each of the four catchments for the three land use options is illustrated in Figures 2a–2d and the accumulated volumes are given in Table 3.

Sediment concentration and NPV of treated water production

Water is released from the Langat Dam during the dry period of about 68 days based on the rainfall records at the HLFR. There is a need to apportion water intake volumes from the dam and from the other tributaries feeding into the Langat River. During the dry period, a water deficit of 0.13 million m^3 per day is avoided at the intake point. This intake level does not vary with the three alternative land use options. It is estimated that the

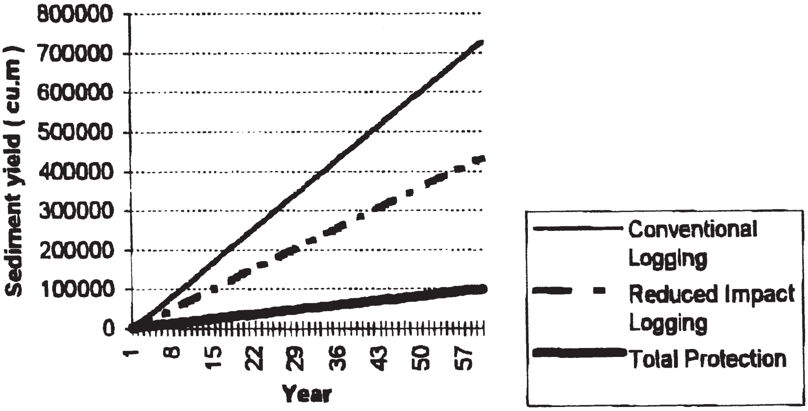

Figure 2a. *Sediment yield in Langat Dam (C1)*

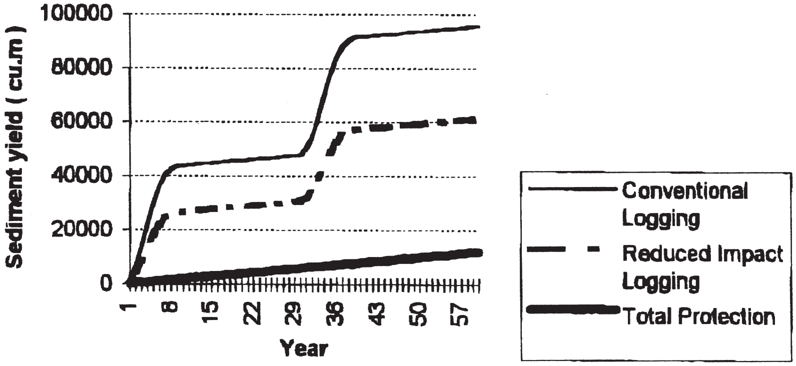

Figure 2b. *Sediment yield in water intake pond (C2)*

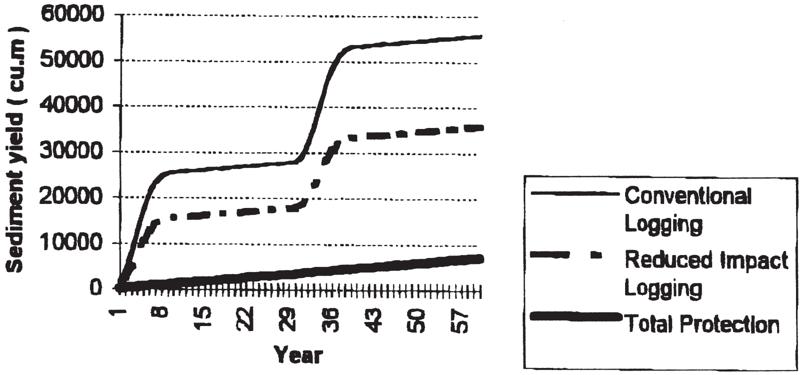

Figure 2c. *Sediment yield in water intake pond (C3)*

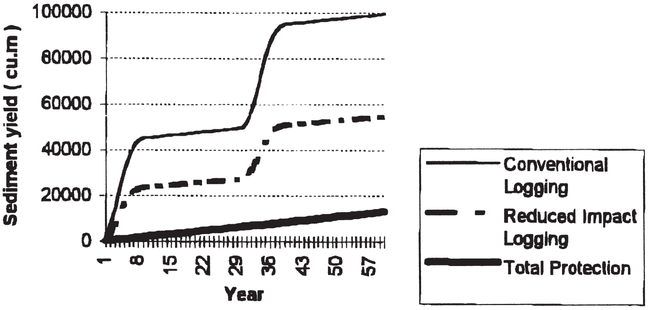

Figure 2d. *Sediment yield in water intake pond (C4)*

volume of water from the Langat Dam utilised by the treatment plants is 8.84 million m^3. The revenue generated from the production of treated water is not affected by the three land use options. This revenue is a function of the quantity not quality of water abstracted and treated. Any water quality variation related to the three land use options is caused only by sediment concentration of the water released from the Langat Dam. The total sediment concentration during the 60 year study period is computed using equations (11) and (12) and is given in Table 5. The treatment cost, computed using equation (10), increases with the level of sediment concentration which is influenced by the sediment yield collected in the dam. Logging options have higher sediment yield and hence treatment costs (Table 6). The total treatment cost of CL is more than one and a half times that of CP option.

Another potential economic cost is the opportunity cost of storage loss of the dam. As can be seen, the loss in live storage capacity in the case of the Langat Dam when logging operations are simulated is small (1.8 per cent under RIL and 2.8 per cent under CL) as illustrated in Appendix II.

The present value revenues of all three options are similar but after taking into account the economic costs of production, the net present values of treated water production under logging options diminished with the greater intensity of logging activities. Although the decline in RIL's NPV relative to the background CP option is already high (RM5.0 million) but this is smaller than the decrease recorded by the CL option of RM8.7 million. The external cost from more intensive timber production greatly reduces the profitability of the downstream water treatment plant.

Table 5. *Sediment concentration under the alternative options*

Land use option	*Catchment protection*	*Reduced impact logging*	*Conventional logging*
Run-off (in mm)	61,934	61,934	61,934
Run-off volume (in mn m^3)	2,199	2,199	2,199
Sedimentation concentration (mg/l)	2,807	12,206	20,531

Table 6. *Costs and revenues of treated water production (RM and %[a])*

Present value of benefits and costs[b]	*Catchment protection*	*Reduced impact logging*	*Conventional logging*
Revenue	29,076,191	29,076,191	29,076,191
Direct production cost[c]	10,078,537 (82.0%)	10,078,537 (58.3%)	10,078,537 (49.0%)
Treatment cost[d]	2,212,842 (18.0%)	7,210,940 (41.7%)	10,490,613 (51.0%)
Total cost	12,291,379 (100.0%)	17,289,357 (100.0%)	20,569,150 (100.0%)
Net present value	16,784,812	11,786,714	8,507,041

Notes: [a] Cost items as percentage of total cost.
[b] Another potential economic cost is the opportunity cost of storage loss of the dam. But owing to the large storage capacity of the Langat Dam, the loss in live storage capacity is small when logging operations are simulated. This resulted in no significant opportunity cost of storage loss.
[c] When there are zero sediment yield.
[d] Cost of treating water pollution due to sedimentation.

NPV of HEP production

The present value revenues of HEP production is higher in CP than in the logging options owing to the variation in quantity produced. Production is affected by the extent of idle capacity, which depends on the maintenance work needed to dredge sediment from the water intake ponds (Table 7). In the CP option, the catchment is protected from logging activities and hence requiring less dredging of sediments (33 thousand m^3). With logging, collected sediments are several times more than in CP, ranging from five times more in RIL to eight times more in CL.

The direct production costs for HEP generation is invariant to the different levels of water intake to turn the turbines caused by sedimentation accumulation. Variation in kWh production does not affect direct cost as the marginal cost of water intake is zero. The main direct cost comprises labour and plant operation costs which are already committed. Of more relevance are the other types of cost, particularly from maintenance cost and foregone revenues caused by the sediment accumulation in the intake ponds. Dredging of the sediments from the intake ponds is needed to ensure that sufficient water can be fed into the pipelines to turn the turbines at the hydro-electric power plants. The maintenance cost and foregone revenues are influenced by the frequency and length of dredging needed to avoid a prolonged period of idle production capacities.

The frequency of dredging work is assessed by dividing the volume of sediment trapped at the intake ponds by the capacities of the intake ponds. These intake ponds constructed at each catchment are simple concrete dams strengthened with concrete banks. The capacities of the sediment ponds for C2, C3 and C4 are 205 m^3, 113 m^3 and 195 m^3 respectively. The frequency of dredging throughout the year is multiplied by the cost of dredging to obtain the increase in annual maintenance cost of each pond. The logging options incur maintenance costs several times greater (six

Table 7. *Net present values of hydro-electric power production (RM and %ᵃ)*

*Present value of benefits and costs*ᵇ *(RM)*	*Catchment protection (RM)*	*Reduced impact logging (RM)*	*Conventional logging (RM)*
Revenue	22,474,186	22,474,186	22,474,186
Production cost	17,025,898 (98.3%)	17,025,898 (90.3%)	17,025,898 (84.1%)
Production losses	267,289 (1.5%)	1,635,775 (8.7%)	2,865,827 (14.2%)
Maintenance cost	32,493 (0.2%)	198,828 (1.0%)	348,520 (1.7%)
Total cost	17,325,680 (100.0%)	18,860,502 (100.0%)	20,240,245 (100.0%)
Net present value	5,148,506	3,613.684	2,233,941

Note: [a] Cost items as percentage of total cost.
[b] The marginal cost of additional HEP production is assumed to be zero.

times for RIL and ten times for CL) than in the CP option. The foregone revenue from HEP production loss is assessed from the foregone value of the idle capacity during the maintenance operation. As with the maintenance cost, the logging options incur production losses several times more than with the CP option. Hence as in treated water production, the present value revenues of HEP production declines with more intensive logging.

Table 8 provides the economic trade-offs of the three simulated land use options over the whole four catchments in aggregate. Based on the benefit–cost analysis framework described earlier, the NPVs of the two logging options are compared to the base case situation of total catchment protection. It is observed that logging resulted in higher net present values than the base case situation of catchment protection only under the RIL option. It can be suggested that the status quo use of the catchment as a protected reserve is a less efficient land use option than permitting timber harvesting. The RIL option is superior with 8.1 per cent higher returns than

Table 8. *Net present values of the three land use options*

Uses	*Catchment protection (CP) (RM)*	*Reduced impact logging (RIL) (RM)*	*Conventional logging (CL) (RM)*	*Incremental NPV (RIL-CP) (RM) & %**	*Incremental NPV (CL-CP) (RM) & %**
Sub-total timber	—	8,308,766	9,762,427	+8,308,766	+9,762,427
Treated water	16,784,812	11,786,714	8,507,041	−4,998,098 (−29.8%)	−8,277,771 (−49.3%)
Hydro-electric power	5,148,506	3,613,684	2,233,941	−1,534,822 (−29.8%)	−2,914,565 (−56.6%)
Sub-total water benefits	21,933,318	15,400,398	10,740,982	−6,532,919 (−29.8%)	−11,192,335 (−51.0%)
Total net present values	21,933,318	23,709,164	20,503,409	+1,775,847 (+8.1%)*	−1,429,909 (−6.5%)*

Note: * As a percentage of CP option.

Table 9. *Net present value of the three land use options by compartments*

Uses	*Catchment protection (CP) (RM)*	*Reduced impact logging (RIL) (RM)*	*Conventional logging (CL) (RM)*	*Incremental NPV (RIL-CP) (RM)*	*Incremental NPV (CL-CP) (RM)*
Compartment 1					
Timber	—	4,264,141	5,074,782	+4,264,141	+5,074,782
Treated water	16,784,812	11,786,714	8,507,041	−4,998,098	−8,277,771
Sub-total	16,784,812	16,050,855	13,581,823	−733,957 (−4.4%)	−3,202,989 (−19.1%)
Compartments	2,3&4				
Timber	—	4,044,625	4,687,645	+4,044,625	+4,687,645
Hydro-electric power	5,148,506	3,613,684	2,233,941	−1,534,822	−2,914,565
Sub-total	5,148,506	7,658,309	6,921,586	+2,509,803 (+48.7%)	+1,773,080 (+34.4%)
Total net present values	21,933,318	23,709,164	20,503,409	+1,775,846 (+8.1%)*	−1,429,909 (−6.5%)*

Note: * As a percentage of base case.

the CP option. Apparently the combined net values of the joint production between timber and water uses can match the net values derived from the catchments when solely protected as raw water supplier for treated water and HEP production opportunities. However, the added timber returns from increasing logging area under CL could not outweigh the net benefits from these water uses. There is little advantage in allowing conventional logging when downstream users have to bear losses arising from increased sedimentation.

The above finding is aggregative without a clue as to which compartment and combination of joint production are providing the superior incremental NPV for the RIL option. Each compartment has a status quo usage for the production of either treated water or HEP. It is necessary to ascertain in which compartment the returns from the combined uses of timber and water independently outweigh the net benefit of catchment protection for water uses. Table 9 suggests that logging options can provide timber returns in excess of the incremental loss from HEP production making it profitable to allow both logging options in compartments C2, C3 and C4. The opposite case was observed in compartment C1 where even the RIL option was found not profitable relative to the CP base option.

This observation helps explain the outcome when the analysis is done for all four compartments in aggregate. What has happened is that the incremental net benefit gain in compartments C2, C3 and C4 is high enough to outweigh the net benefit loss in compartment C1 for the RIL option but not for the CL option. This has provided the misleading conclusion that the RIL option is an efficient land use in the forested catchments.

One is left to ponder on the appropriate trade-off decision. Whether it is a decision to allow only RIL in all the catchments, or to permit logging, even under the conventional method, in HEP catchments only and not in the catchment functioning as a water impoundment for the water treatment plant. Water serves different purposes for the water treatment and HEP plants. The water treatment plant requires quantity and quality water since they produce treated water for consumptive purposes. The cost of treating raw water by the treatment plant is dependent on sediment concentration. In contrast, the HEP plants need continuous water flow to turn the turbines with water quality, in terms of sediment concentration, not being critical as long as the sediments are trapped in the intake ponds prior to flowing into in-feed pipes.

The compartment level analysis has helped us identify the central issue of joint production in forested catchments. The issue is not the selection between logging methods, but rather which water use can be combined or is compatible with timber production that can generate greater NPV than the status quo CP option. Under both logging methods, the returns from timber cannot meet that from the status quo production of treated water. It can be concluded that if joint production involving timber and the two water uses is to be permitted, it can only be done in HEP catchments. The efficient choice among the two logging methods is the RIL option owing to the higher returns and the lower externality imposed upon the status quo water users.

It should be noted too that the above finding is obtained without incorporating the tangible benefits from sustainable harvesting of non-wood commodities and the intangible benefits from bio-diversity conservation, carbon sequestration and aesthetic values, which are more likely to be greater in a CP option. Thus, as much as the finding indicates the superiority of logging in forested HEP catchments, it should not be given complete support i.e., not until the impacts on these other attributes are incorporated into the study.

Sensitivity analysis

The above analysis combines data from a number of sources to synthesize physical and financial effects under the three alternative options to draw clear management conclusions. However, these data are from unrelated point estimates and some from another catchment. Hence, a sensitivity analysis of feasible modifications of these input and output variables is undertaken (Table 10). Considering that the combinations are large, only data variations causing the greatest changes, including factors having influence on sediment yield, timber harvest, prices and cost of production, and choice of discount rates, are discussed.

The physical relationship between alternative methods of logging and sedimentation is the main premise of the production trade-off with status quo catchment uses. In computing the sediment yield, a reduction factor of 0.6 was incorporated into Equation (9), to reflect the impact of adherence to logging specifications which is required of a RIL option. Baharuddin (1988) found that a lower factor of 0.5 is more appropriate but this would also require a reduction in the felling of trees resulting in a 15 per cent decline in the estimated timber volume per ha. A re-analysis was con-

Table 10. *Incremental net present values (RM and %) under various simulations*

Data variation	*Treated water and timber*		*Timber and HEP*		*Timber and overall water uses*	
	Compartment C1		*Compartments C2, C3, C4*		*All compartments*	
Incremental NPV	RIL-CP	CL-CP	RIL-CP	CL-CP	RIL-CP	CL-CP
Base case[a]:	−733,957 (−4.4%)	−3,202,989 (−19.1%)	2,509,804 (+48.7%)	1,773,080 (+34.4%)	1,775,846 (+8.1%)	−1,429,909 (−6.5%)
Sediment load path						
Diminishing rates of marginal decline in sedimentation	862,741 (+5.1%)	−511,685 (−3.0%)	2,505,221 (+48.7%)	2,798,855 (+54.4%)	3,367,963 (+15.4%)	2,287,169 (+10.4%)
Increasing rates of marginal decline in sedimentation	−2,268,701 (−13.5%)	−5,760,895 (−34.3%)	2,057,916 (+40.0%)	895,130 (+17.4%)	−210,786 (−1.0%)	−4,865,766 (−22.2%)
Sedimentation reduction factor under RIL[b]						
$d = 0.5$ (Equation (9))	−761,416 (−4.5%)	−3,202,989 (−19.1%)	2,505,358 (+48.7%)	1,773,080 (+34.4%)	1,743,942 (+8.0%)	−1,429,909 (−6.5%)
Second cycle growth/yield						
−20%	−771,736 (−4.6%)	−3,247,206 (−19.3%)	2,475,661 (+48.1%)	1,732,407 (+33.6%)	1,703,925 (+7.8%)	−1,514,799 (−6.9%)
−10%	−752,821 (−4.5%)	−3,225,067 (−19.2%)	2,492,822 (+48.4%)	1,752,896 (+34.0%)	1,740,001 (+7.9%)	−1,472,171 (−6.7%)
+10%	−715,131 (−4.3%)	−3,180,955 (−19.0%)	2,526,658 (+49.1%)	1,793,045 (+34.8%)	1,811,527 (+8.3%)	−1,387,910 (−6.3%)
+20%	−696,333 (−4.1%)	−3,158,955 (−18.9%)	2,543,415 (+49.4%)	1,812,844 (+35.2%)	1,847,082 (+8.4%)	−1,346,111 (−6.1%)
Price increases in water uses (Treated water and HEP); price declines in timber						
+1% water uses −1% timber	−1,463,583 (−7.3%)	−4,062,224 (−20.4%)	2,341,800 (+30.9%)	1,577,222 (+20.8%)	878,217 (+3.2%)	−2,485,002 (−9.0%)
+2% water uses −2% timber	−2,084,690 (−8.8%)	−4,793,663 (−20.2%)	2,193,692 (+20.8%)	1,404,553 (+13.3%)	109,002 (+0.3%)	−3,389,110 (−9.9%)
+3% water uses −3% timber	−2,618,763 (−9.2%)	−5,422,609 (−19.0%)	2,060,652 (+14.4%)	1,249,454 (+8.8%)	−558,111 (−1.3%)	−4,173,155 (−9.7%)
Production cost increases in logging						
+1%	−1,182,294 (−7.0%)	−3,728,495 (−22.2%)	2,394,540 (+46.5%)	1,637,571 (+31.8%)	1,212,246 (+5.5%)	−2,090,924 (−9.5%)
+2%	−1,724,696 (−10.3%)	−4,364,278 (−26.0%)	2,256,901 (+43.8%)	1,475,979 (+28.7%)	532,205 (+2.4%)	−2,888,299 (−13.2%)

Table 10. *Continued*

Data variation	*Treated water and timber*		*Timber and HEP*		*Timber and overall water uses*	
	Compartment C1		*Compartments C2, C3, C4*		*All compartments*	
Incremental NPV	RIL-CP	CL-CP	RIL-CP	CL-CP	RIL-CP	CL-CP
+3%	−2,390,370 (−14.2%)	−5,144,555 (−30.7%)	2,089,571 (+40.6%)	1,279,769 (+24.9%)	−300,799 (−1.4%)	−3,864,786 (−17.6%)
Discount rate						
8%	−1,108,934 (−5.3%)	−4,288,852 (−20.6%)	2,504,367 (+39.1%)	1,595,303 (+25.0%)	1,395,433 (+5.1%)	−2,693,549 (−9.9%)
6%	−1,747,206 (−6.4%)	−7,713,211 (−28.3%)	2,429,016 (+29.1%)	1,237,023 (+14.8%)	681,810 (+1.9%)	−6,476,188 (−18.2%)

Note: [a] With gradual sediment yield recovery path discounted at a rate of 10%.
[b] Along with this is an estimated reduction in timber harvest by 15% (Baharuddin 1988).

ducted incorporating this assumption but there was no significant departure in the direction of the finding.

A major consideration is the path of the post-harvest sediment yield recovery period. The path of this recovery period may not always be declining at a regular pace. Experiences from year to year field measurements have also provided declining paths which are either on an increasing rate or on a diminishing rate. The findings using gradual declining sedimentation rates were reported. Analysis with the two alternative sedimentation paths provides contrasting impacts. A declining path which is on an increasing rate raises the cumulative sediment yield and the eventual external cost making logging options less attractive. A declining path which is on a diminishing rate has the opposite effect, hence, prior identification of the path of sediment yield recovery period is quite critical in conducting the analysis. Subscribing to diminishing marginal rates of decline resulted in a lower cumulative sediment load relative to that of gradual rates of decline. The specific impact is to cause the RIL option to have higher returns than the background CP option in compartment C1 which would allow for logging in a treated water catchment. The overall impact is to make joint production between logging and water uses to be a more efficient use of the HLFR watershed.

A concern among advocates of catchment protection is the suspicion that timber production may not be sustained in the second cycle. Thus, the second timber cycle was incorporated to highlight the fact that subsequent future timber harvests could be maintained but not matching current production levels from harvesting the rich natural forests. Since a model was relied upon to project the second cycle harvest, uncertainties exist on the robustness of the findings. However, varying the second cycle growth rates did not affect the direction of the findings.

The responsiveness of the benefit–cost analysis to changes in prices and costs over a two timber production cycle necessitates evaluation. Historical trends of prices and costs suggest that treated water and HEP prices are expected to rise. The water treatment and HEP plants are serving parts of the population and industrial needs of the Malaysian capital city and its suburbs. The resident population and manufacturing activities are expanding rapidly. In the case of timber, world and domestic prices are holding steady, or declining, while logging costs are rising as verified by field interviews. Thus, a re-analysis incorporating rising real prices of treated water and HEP while letting real prices of timber decline, as well as one incorporating changing production costs, in particular on logging costs, was conducted.

Rising prices of treated water and HEP, and declining prices of timber reinforce the status quo use of catchment C1 while reducing the profitability of joint production in catchments C2, C3 and C4. In fact price increments of 3 per cent per annum for treated water and HEP, and price reductions at the same rate for timber are sufficient to make the RIL option no longer viable when all the four catchments are managed as a whole unit. Similar trends are observed when increments in logging production cost were simulated.

This study selected a discount rate of 10 per cent which is considered high for an analysis covering a long period of two timber cutting cycles. Varying the discount rates downward to 8 per cent and 6 per cent resulted in lower incremental net benefits between logging and the background CP option. Lower timber volumes are projected in the second cycle of the logging options, while even flows of output are assumed for the status quo water uses throughout the analysis. The lower discount rates tend to raise the sum of the discounted values of the even flow annual water related outputs more than the uneven and lower second cycle timber flows. Consequently a lower discount rate tends to favour the status quo catchment protection.

Conclusion and policy implications

In this study, the trade-offs between three land use options in forested catchments are evaluated. Although forested catchments provide natural resource commodities, biodiversity conservation and environmental services, only two tangible goods are considered in this study: timber and water. Thus, the outcome of this study is conditionally qualified and due consideration given to the net change in values from the other attributes of the catchment under the various land use options.

Analysis at the compartment level suggests that the central issue of joint production in forested catchments is not the selection between logging methods, but rather which water use can be combined with timber production that can generate greater NPV than the status quo CP option. The returns from timber cannot meet that from the status quo production of treated water under both logging methods. But, complementing water uses with logging in forested catchments is efficient in HEP catchments. The efficient choice among the two logging methods is the RIL option owing to the higher returns and the lower externality imposed upon status quo water users. Nevertheless, the RIL option still generates sediment loads which imposes substantial external costs on the downstream water users.

This finding cannot be extended to other forested catchments without making adjustments to the numerical results, such as incorporating different rates of sedimentation, rainfall and sediment concentration.

The above study has several policy implications.

1. One of the many issues faced by forest managers and policy makers in managing forested catchments is whether or not to permit logging. This is an important decision to make, as a large portion of catchments in Malaysia are still covered with forests. At the moment, there is no clear policy as to whether logging should be permitted in forested catchments which serve either as domestic water supply or HEP generation. Since forests are under state jurisdiction, some states may allow logging activities in catchment areas while others may not. The present study does provide a basis for promoting joint production between the generation of HEP and timber production, and for catchment protection when the water resource is considered strategic for the production of treated water. Even when adequate conservation measures are taken during logging in forested catchments, the amount of sedimentation flowing into the river channel has high opportunity costs. An important consideration for this is the unclear effects of logging on the other attributes of forested catchments.
2. This study has shown that the HEP water intake ponds are susceptible to sedimentation following logging operations, causing high maintenance costs of regular dredging work and production losses. This finding is important considering that many of the HEP plants located throughout the country are being fed by water sourced from intake ponds classified as mini-dams similar in size to the ponds in the HLFR. Any intention of permitting logging in forested catchments with mini-dams should evaluate the threat from high sedimentation and the eventual external costs. It is recommended that this be an essential consideration prior to the approval of any environmental impact assessment reports on logging in forested catchments.

   A mini-hydro dam (intake pond) is not the most efficient method of generating hydro-electric power as opposed to the conventional type of HEP dam. One of the factors attributing to the lower efficiency is that the operation costs in relation to the generating capacity is relatively higher for the mini-hydro dam than for the conventional HEP dam. This occurs because the mini-dam relies on small rivers or catchments and thus provides less hydraulic head. Any increase in sediment yield in the intake pond drastically affects generation capacity.
3. Despite the imposition of buffer strips, logging causes an increase in sediment yield. Any approval of logging in forested catchments requires close supervision by the Forestry Department. The increase in sediment yield has been shown to be large enough to increase the external costs to the water treatment and HEP plants. Although, one way of mitigating this in HEP generation is the building of larger water intake ponds, the question still remains as to who should bear either the construction cost of this larger water intake pond, the cost of dredging, and the production loss or the increased cost of water treatment. It is suggested that since logging is an alternative option to the status quo of total protection, the Forestry Department can incorporate a requirement in the licensing agreement requiring logging contractors to raise the

amount of deposit payments as security for adherence to good logging specifications. These deposits can be collected into a fund for use to internalise the opportunity cost of increased sediment yield. This is sort of purchasing the rights to pollute/sediment. In the event that this is accepted, there remains the difficulty of appropriating the sediment yield to each license since sediment yields can only be reduced to normality after a period of about five years. This period is long after the completion of the logging operation which normally does not last more than a year.

Alternatively, state governments can impose environmental taxes on loggers based on the polluters pay principle (PPP) because a basis is now available for calculating damages that can be used as inputs into setting taxes on pollution. One criterion of this PPP is that the tax revenues should be returned to the payers according to ability to reduce pollution, without destroying the incentive properties of the tax. The principle is that to avoid the tax, logging contractors have the incentive to adopt a more environmental friendly logging practice, such as reserving sufficient buffer strip and reducing road construction, to reduce the external costs being incurred by off-site users.

Limitations and future studies

Further efforts are needed to improve the study on the economics of forested catchments and the trade-offs among land use options in Malaysia. Amongst these are:

1. The study is limited by its usage of negotiated prices of treated water and HEP as a basis for calculating the net benefits. Future studies should consider using shadow prices of these outputs by estimating the marginal costs of production in a new HEP or water treatment plant or of alternative power plants and production of treated water from alternative sources such as groundwater.
2. The study above is conducted in one site and limited to the trade-offs from water and timber production. Its findings are site-specific and limited to the two uses only. Duplications of this study in other catchments and incorporating the values of production of other forest attributes are necessary before any concrete recommendation can be given to allow logging in forested catchments. Further, the site selected is managed for industrial water use. Other sites can be selected which have other downstream uses such as for irrigation and recreation, as well as the potential for other competing uses such as highland agriculture. Studies of this kind in other sites can provide a more holistic view on the economic trade-offs of various land use options in forested catchments. These studies can help relevant government agencies formulate and classify types of forested catchments that can withstand logging activities without deteriorating the environment.

References

Abdul, Rahim N. (1988), 'Water yield changes after forest conservation to agricultural land use in Peninsular Malaysia', *Journal of Tropical Forest Science* **1**(1): 67–84.

Abdul, Rahim N. and Y. Zulkifli (1994), 'Hydrological response to selective logging in Peninsular Malaysia and its implication on watershed management', in Proceedings of the International Symposium on Forestry Hydrology, Tokyo, Japan, October 1994, pp. 263–274.

Aylward, B., J. Echeverria, and E.B. Barbier (1995), 'Economic incentives for watershed protection: a report on an ongoing study of Arenal, Costa Rica', CREED Working Paper Series No. 3.

Aylward, B., N. Abdul Rahim, H.O. Mohd Shahwahid, A.G. Awang Noor, and Y. Zulkifli (forthcoming), 'Timber production versus watershed protection in the humid tropics: an overview of the issues in Malaysia', A paper submitted to the Environmental Economics Programme Discussion Paper Series.

Baharuddin, K. (1988), 'Effect of logging on sediment yield in a hill dipterocarp forest in Peninsular Malaysia', *Journal of Tropical Forest Science* **1**(3): 1–15.

Baharuddin, K. (1995), 'Effect of logging operations on soil physical properties and soil erosion in a hill dipterocarp forest of Peninsular Malaysia', Research Pamphlet No. 119, Forest Research Institute Malaysia.

Bali, N. (1981), 'Manual of conservation', Department of Drainage and Irrigation, Kuala Lumpur.

Beattie, B.R. and C.R. Taylor (1985), *The Economics of Production*, New York: John Wiley & Sons.

Clawson, M. (1975), 'Forests for whom and for what?', *Resources for the Future*, Washington, DC.

Cruz, W., H.A. Francisco, and Z.T. Conway, (1988), ' The on-site and downstream costs of soil erosion in the Magat and Pantanbagan Watersheds', *Journal of Philippine Development* **15**(1): 85–111.

Department of Forestry, Peninsular Malaysia (1988), 'Guidelines for logging in water catchment areas', Kuala Lumpur.

Department of Forestry, Peninsular Malaysia (1994), *Annual Forestry Report*, Kuala Lumpur.

Gregory, G.R. (1987), *Resource Economics for Foresters*, 'New York: Jon Wiley & Sons.

Hamilton, L.S. and P.N. King (1983), *Tropical forested watersheds: Hydrologic and Soil Response to Major Uses or Conversions*, Boulder, Colorado: Westview Press.

Lai, F.S. (1992), 'Sediment and solute yields from logged, steep upland catchment in Peninsular Malaysia', unpublished Ph.D. thesis, University of Manchester.

Lai, F.S. (1993), 'Sediment yield from logged, steep upland catchments in Peninsular Malaysia', IAHS Publication 216: 219–229.

Low, K.S. (1971), 'Rainfall and runoff on the Sungai Lui Catchment, West Malaysia', unpublished Ph.D. thesis, University of Hull.

Maler, K.-G., I.-M. Gren, and C. Folke (1994), 'Multiple use of environmental resources: a household production function approach to valuing natural capital, Beijer Reprint Series No. 23.

Mohd Akbar, J. and R. Rusnah (1997), 'Water quality: what its worth', Paper presented at World Water Day 1997, Kuching, Sarawak.

Mohd, Shahwahid H.O. (1995), 'Forest conservation and its effects on Peninsular Malaysian log supply', *ASEAN Economic Bulletin* **11**(3): 320–334.

Reyes, M.R. and V.B. Mendoza (1983), 'The Pantabangan watershed management and erosion control project', in L.S. Hamilton, ed., *Forest and Watershed Development and Conservation in Asia and the Pacific*, Boulder, Colorado: Westview Press.

Suhaimi, T. (1997), 'Costing studies of forest management activities in Selangor Darul Ehsan', unpublished project report, Faculty of Forestry, Universiti Putra Malaysia, Serdang, Selangor.

Vincent, J.R. (1997), 'Economic depreciation of timber resources: direct and indirect estimation methods', Development Discussion Paper, Harvard Institute for International Development, Cambridge. Massachusetts.

Appendix I: Physical input and output quantities, and costs and prices of timber, HEP and treated water production

Items	*Physical quantity*	*Cost/unit*	*Price/unit*
HEP production	1,560 kWh	RM0.125/kWh[a]	RM0.165/kWh
Treated water production	8.84 mn m^3/yr	RM0.114/m^{3b}	RM0.33/m^3
Timber production:			
Pre-felling inventory	For determination of cutting/harvesting limits. 2 years before felling	RM70/ha	
Tree marking	For determination of trees to harvest. 1 year before felling	RM70/ha	
Boundary marking	To prevent loggers going out of boundary. On the year of the harvesting.	RM50/ha	
Felling	Yield 49.3 m^3/ha (first cycle) Yield 31.6 m^3/ha (second cycle)	RM70/m^3	Range: RM75/m^3 to RM700/m^3
Annual administration & management cost		RM21/ha	
Silvicultural/rehabilitation activity:	Years after felling:		
Post-felling inventory	2	RM70/ha	
Climber cutting operations	4	RM100/ha	
Enrichment planting	4	RM900/ha	
2nd. post-felling inventory	10	RM70/ha	
Sediment yield recovery path (m^3/year)	Yr 1 2 3 4 5 6		
Gradual decline	27.3; 22.0; 16.7; 11.3; 6.0; 0.7:		
Diminishing marginal decline[c]	27.3; 13.0; 6.2; 2.9; 1.4; 0.7:		
Increasing marginal decline[d]	27.3; 26.3; 24.9; 21.3; 14.3; 0.7;		
Natural rate of sediment yield	0.67 m^3/year		
Sediment density (SD)	1.5 metric tonne/m^3		
Sediment yield reduction factor under RIL option	0.6		
Sediment trap efficiency	0.7		
Ratio of suspended sediment to sediment yield (k)	0.69		
Sediment yield at year t (SY_t)	Annual series computed from Equation (9)		
Run-off coefficient (ROC)	0.44		
Annual rainfall average at year $t(RF_t)$	2,346 mm/yr		
Buffer strip	5 m (CL option) 20 m (RIL option)		
Capacity of HEP sediment ponds	205 m^3 (C2) 113 m^3 (C3) 195 m^3 (C4)		
Technical efficient reservoir capacity of Langat Dam	17.5 mn m^3 (C1)		

Sediment pond & plant maintenance	Vary with catchment	Averaging RM4.96/m^3

Notes: [a] Direct production cost from field interview.

[b] Direct production cost computed from equations (10)–(12).

[c] The rate of decline is simulated by multiplying by a factor of $(1/2.1)^n$ where n is the number of years after logging to reflect the diminishing rate of decline.

[d] The rate of decline is simulated to follow a concave curve to reflect the increasing rate of decline.

Appendix II: Storage loss in Langat Dam

For the purpose of calculating the storage loss due to sedimentation in the reservoir, an average reservoir capacity is adopted which is 3,850 m. gallon or 17.5 m. m^3 after deducting the dead storage of 540 m. gallon. This capacity is 50 per cent of the live storage capacity of Langat Dam. This 50 per cent capacity is adopted following the assumption that a dam would have lost its technical efficiency at this level (Bali, 1981). Accordingly, the loss of storage capacity for C1 after 60 years for various land use options are determined (Table 11).

The loss in live storage capacity in the case of Langat Dam is small when logging operations are simulated. Thus, within the 60 years period, there is no significant opportunity cost.

Table 11. *Storage capacity loss in Langat Dam under different land uses*

Land use options	*Catchment protection*	*Reduced impact logging (RIL)*	*Conventional logging (CL)*
Storage capacity loss (%)	0.6%	1.8%	2.8%