15 Small Catchment Studies in the Tropical Zone

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15.1 INTRODUCTION

In tropical Latin America the main riverine and lacustrine basins are characterized by large dimensions. The Amazon basin, the largest hydrographical basin of the world, is located here, comprising 7 x 10^6 square kilometres. The rapidly increasing exploitation of the hydrological and mineral resources and accelerated urbanization and industrialization of these lands makes gathering of reliable basic environmental information an imperative necessity. Catchments of all size classes from a few square kilometres to 7 x 10^6 km^2 can be found forming a very complex hydrographical network. Very often, small catchments of the tropics are valleys of headwaters of big streams situated in mountainous areas which, as Gibbs (1967) pointed out, are important sources of suspended matter. Simultaneous research on small catchments may contribute to tackling some of the main environmental problems of tropical Latin America, yielding complementary information that would be difficult to obtain exclusively through large catchment studies. An interdisciplinary approach will give a comprehensive view of the complex interactions among different environmental parameters of the catchments. Furthermore, the results of the studies conducted on the perturbation-sensitive small catchments will be applicable further downstream to combat adverse effects of improper land-use and management practices.

In this chapter, the focus will be on: (1) pointing out some of the most critical environmental problems affecting tropical Latin America at present; (2) illustrating the relevance of small catchment research through examples and case studies in which the majority of the data comes from tropical Latin America and one example was drawn from humid tropics of Malaysia; (3) brief discussion of the common constraints of small catchment studies in tropical countries, and (4) issuing recommendations useful for future small catchment research in the tropics.

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15.2 MAIN ECOSYSTEM DISTURBANCES AND USEFULNESS OF SMALL CATCHMENT STUDIES

15.2.1 DEFORESTATION

In the past, human impact on tropical rain forest was limited only to establishment of small clearings following the old style technique of slash-and-burn shifting cultivation. In such conditions, soil erosion was insignificant and water regime as well as nutrient cycling were not seriously affected, allowing regrowth of a vigorous secondary forest (Sioli, 1984). Recently, however, industrialization and urbanization have led to large-scale deforestation with irreversible destructive consequences (Bruenig and Schmidt-Lorenz, 1985). The most significant environmental changes resulting from interventions and their unfavourable effects on terrestrial ecosystems have been compiled by several authors (Sioli, 1984; De Melo-Carvalho, 1984; Perry and Maghembe, 1989). Along with their envisioned consequences these changes can be listed as follows:

1. *Circulation of nutrients and changes in nutrient reserves*. Loss of forest cover removes a major sink of nutrients in large areas and alters the nutrient cycling. It interrupts the internal cycling of nutrients which has been taking place through generations of organisms living in the ecosystem.
2. *Surface soil erosion*. Removal of forest will lead to enhanced soil erosion. In flat areas, removal of fine particles by selective erosion may cause a relative increase in the content of coarser particles of the sand fraction (sandification).
3. *Climatic changes*. Large-scale deforestation will cause changes in water balance that, in turn, may lead to (micro- and meso-) climatic changes. Lack of sufficient water vapour will promote changes in the seasonality of rains and much more pronounced dry seasons.
4. *Regime and sediment load of the rivers*. A change in pluvial regime together with an increase of surface runoff will cause instability of the river regime. An increase of the sediment load due to enhanced erosion of soils can also be expected. According to Zink (1986), topographic and bioclimatic factors also play a fundamental role in the ability of the system to retain its integrity. Zink states that, after forest removal, the released nutrients are lost rather by soil truncation than by deep leaching. Thus, after deforestation, the mechanical stability of the environment may play a more important role in terms of resilience of the ecosystem than biogeochemical cycling.

15.2.2 BURNING

In tropical savannas, fire is a secular land-use practice and is also employed by some Indian cultures for other purposes. In many cases, fires are uncontrolled and expand very rapidly. These effects might not be foreseen, because humid tropical forests normally respond to clearing or burning with a regrowth of secondary forests. Observations of Fölster (1986) indicate that the regeneration of vegetation is poor and sensitive to subsequent fires, thus leading to a progressive conversion of the affected area into bush savanna and, eventually, to pure savanna. The fire impact on forest might only be explained against the background of latent instability and low resilience of the forest vegetation. Continuous chemical and hydrological stress would explain these ecological features of the forest. Among the most important stressing and straining processes Fölster (1986) points out the followings: (a) natural soil acidification through weak acids; (b) sensitivity to water stress enhanced by slope and soil conditions; (c) lack of balance between uptake and release of nutrients by the forest system.

Fölster (1986) explains the instability of the savanna vegetation and its further degradation by nutrient losses due to frequent burning, and by mineral and organic matter losses by surface wash. Thus, the effect of soil acidification on ammonia and aluminium saturation, depletion of basic cations (specially Ca) and toxicity of aluminium should be analysed. These factors may be responsible for high mortality, shallow rooting depth and concentration of roots close to the soil surface. The impact of episodic droughts on the rate of mineralization of organic matter and on the efficiency of root systems seems to affect the nutrient balance. Small catchment research may serve to analyse the stressing processes and particular environmental characteristics that favour the aggradation of savanna–forest ecosystems.

15.2.3 MINING

South America has sizeable mineral resources consisting mainly of metal ore deposits mined for industry (iron, copper, lead, zinc, tin and aluminium), fossil fuels (crude oil), precious metals (gold) and gemstones (diamonds). The mineral resources are being exploited by large enterprises and non-regulated small mining operations with serious environmental impacts. To open a mine, the overlying soils and vegetation must first be removed. As a rule, the resulting perturbation is very severe. Water courses are especially affected by an increase in suspended load with solid particles like sand and mud, and by soluble and toxic chemicals used for treatment of ores in copper, gold and aluminium (bauxite) mines. Due to its importance, metal mobilization will be the subject of a separate section (see below under Section 15.2.5). Mercuric pollution of rivers caused by gold extraction deserves particular attention. Furthermore, in the proximity of the extraction facilities, heavy industry centres are cropping up and these will create further industrial and domestic pollution problems unless adequate preventive measures are taken.

15.2.4 ACIDIFICATION

In spite of the relatively low proportion of industry when compared with highly industrialized countries, attention must be paid to acidification even in tropical developing countries (see SCOPE report of Rodhe and Herrera, 1988). The first reason is obvious, the growing industrial activity will give rise to enhanced emissions of acidifying compounds like SO_2 and NO_2 to the atmosphere in a relatively short time. The second reason is the well-known sensitivity of most tropical ecosystems to acidification due to their low buffering capacity. Some tropical soils are naturally acidic, showing low pH and cation exchange capacity (CEC), and high exchangeable aluminium content (Paolini, 1986). Knowledge on sulphate adsorption capacity, sulphate mobility, leaching and losses of major nutrients, mobilization of toxic metals and changes in microbial activity in tropical soils is required for the assessment of future changes caused by anthropogenic acidification. Similar to soils, many tropical South American rivers are acidic (Sioli, 1984; Vegas-Vilarrúbia and Paolini, 1988 a,b). Humic acids are an important component of the river water and may be responsible, together with the absence of carbonate rocks, for most of their acidity. Our understanding of the chemical and biological systems which prevail in aquatic environments with high humic acid content is insufficient. The role of humic acids in the transport and biological uptake of essential nutrients (P, N) and metals also has to be clarified. Small blackwater creeks and their catchment areas would be appropriate for such studies. Tropical vegetation growing under acidic conditions is known to be tolerant to natural acidity. The high ecological costs of living in such environments call in question the ability of the vegetation to tolerate further increase in acidity (Cuenca and Herrera, 1986).

15.2.5 HEAVY METAL MOBILIZATION

Metal mobilization in the tropics may be a consequence of both natural acidification and mining activity. Particular attention should be given to aluminium and mercury, because both are potentially harmful. Aluminium is easily mobilized by acidification, while mercury is too often used for gold extraction in an uncontrolled way. Evaluation and quantification of their potentially harmful effects is essential not only for ecosystem management, but also for human health. Therefore, identification of species that may be bioavailable and toxic, and knowledge of their chemical reactivity and transformations in natural environments is required. Questions concerning occurrence, natural concentrations, release patterns, mobility and toxicity of metals could be simply addressed in small catchments affected by mining activities, or by acidic environment, respectively.

None of the above mentioned problems is yet fully understood or explained. The focus must be put on understanding of the basic processes among biotic and abiotic constituents.

15.3 CASE STUDIES

Six of the following case studies were conducted in areas of Latin America shown in Figure 15.1, while the seventh example is drawn from Malaysia.

Figure 15.1 Location map of small catchments referred to in Sections 15.3.1 to 15.3.5: (1) Chamela watershed (Mexico); (2) Gran Sabana; (3) Catchments of Tijuca National Park; (4) Mantecal; (5) Manaus free Zone Authority.

15.3.1 THE CHAMELA WATERSHED PROJECT: A STUDY OF THE STRUCTURE AND FUNCTIONING OF A TROPICAL DECIDUOUS FOREST IN WEST MEXICO

Five small catchments have been selected as experimental units for a long-term ecosystem research project aimed at understanding the structure and function of the tropical deciduous forest, and developing ecologically sound management practices for its use and conservation. The forest research sites are under administration of the Chamela Biological Reserve located in Jalisco, Mexico (105°W, 20°N).

More than 200 tree species have been identified in the area. Above-ground living biomass ranges between 50–85 Mg ha^{-1} (Martínez-Yrízar *et al.* unpubl. data), with a root/shoot biomass ratio of 0.59. Below-ground biomass is estimated at 30 Mg ha^{-1}. Nearly two-thirds of all roots occur in the 0–20 cm soil layer and about one-third of all roots are 5 mm in diameter (Castellano *et al.*, unpubl. data). Only one-third of the standing crop dead wood biomass decomposes in the forest floor, the rest is attached to living or dead standing trees (Maass *et al.* 1990). About 70% of the litterfall are leaves, 17% woody material, 6–9% reproductive organs remain and 5% are made up by fragmented debris (Patiño, 1990). The annual rate of leaf litter decomposition averages 0.5% (Martínez-Yrízar, 1980).

Soils are slightly acid (pH around 6.5) and have low inorganic matter content (2.5%). Nitrogen transformations in the soil have been studied in detail. Fluxes of nitrous oxide averaged 0.91 ng cm^{-2} ha^{-1} during wet season and were virtually absent in the dry season (Vitousek *et al.*, 1990).

In the last 25 years, the tropical deciduous forest has been subjected to an intense transformation. Usually the forest is burnt after clearing with axe and machete. Maize is planted for two years at most, and then replaced with grass for pasture. Small plot experiments are being carried out prior to catchment manipulation to obtain an insight into the ecosystem response to different land-uses, and to develop erosion-control techniques for the area (Maass *et al.*, 1988).

15.3.2 EFFECTS OF CLIMATE AND FIRE ON SMALL CATCHMENT ECOSYSTEMS IN SE VENEZUELA

The knowledge of ecosystem responses to external disturbances is necessary for predictive models, as well as for planning of their use. In most tropical areas where historical data are not available the responses of ecosystems can be derived using palaeoecological studies.

Gran Sabana is a region with a typical warm and wet tropical climate (Galán, 1984) and a contrasting open, graminous vegetation. Forests are present only along river courses, and on some mountain slopes (Huber, 1986). Several natural and anthropogenic factors have been proposed as the cause for a hypothetical deforestation (Fölster, 1986; Hernández, 1987) but none of these hypotheses has been confirmed. Three small catchments were selected to test these hypotheses, using palynological analyses of peat and lake sediments. The results showed the influence of climate and fire on the reduction of former forests (Rull, 1991). Both dryness and fire contributed to the replacement of forests by open savanna, but time scales and transient communities were different. These substitutions were not reversible, although a subsequent humid phase occurred. *Morichales* (a type of gallery forests dominated by the palm *Mauritia flexuosa*) settled along river courses, and open savanna landscapes remained. To explain these changes, the hydrological and nutritional properties of soils must be considered (Fölster, 1986).

15.3.3 EFFECT OF DIKING ON SMALL CATCHMENT ECOSYSTEMS IN VENEZUELAN FLOODED SAVANNAS

The factors that regulate the loss of critical nutrients from mature, undisturbed ecosystems are not well understood. Most of our knowledge on nutrient budgets is obtained on small watersheds located in forested ecosystems of the northern temperate zone, extremely limited knowledge exists for watershed systems in tropics, where nutrient budgets were studied far less frequently than in the temperate zone (Meybeck, 1982; López-Hernández *et al.*, 1983, 1986). Accumulation of elements is associated with a significant biomass increment which, in the case of forested ecosystems, could be ascribed to an early successional stage. Although a small negative balance may be a consequence of the normal weathering of the landscape, a large negative balance indicates an important disruption of ecosystem processes, e.g. clearcutting or herbicide treatments (Bormann *et al.*, 1968).

In 1970 the government of Venezuela started a management programme of small dikes (called modulos) over 250 000 ha of savanna affected by seasonal floods. Primary and secondary production under the modular (diked) system have been reported to increase. A high rate of plant decomposition has also been observed, especially at the beginning of the flooded period. Accordingly, it was assumed that a considerable amount of nutrients is lost from the ecosystem through the floodgates.

A multidisciplinary team has been working in the Experimental Module, Mantecal-MEM zone to understand the structure and function of a flooded savanna. Specifically, the research adresses two objectives: investigation of the nutrient budget of elements over a two-year period and analysis of the main inputs and outputs in a seasonally flooded savanna.

The site is located between the rivers Arauca and Apure (7°8'N and 68°45'W) and it is a flooded savanna which originated under alluvial sedimentation processes. Soils in the study area are characterized by common natural fertility. Dominant species are *Leersia hexandra* and *Himenachne amplexicaulis*, species with a high above-ground net primary production (5.5–9.1 Mg ha^{-1} $year^{-1}$; López-Hernández, 1991). The climate of the region is of the type Awig (Koeppen) with a maximum average temperature of 27°C and continuous precipitation from May to October.

Table 15.1 summarizes the information about inputs, outputs and budgets of macroelements (Na, K, Ca and Mg) and microelements (Zn, Cu and P) entering

Table 15.1a Macroelements budget for Modulo Experimental (kg ha^{-1} $year^{-1}$

Cation	1980 Input	1980 Output	1980 Net	1981 Input	1981 Output	1981 Net
Na	13.92	18.29	−4.37	5.96	22.19	−16.23
K	2.62	12.89	−10.27	3.81	12.44	−8.63
Ca	7.96	11.26	−3.30	2.88	15.54	−12.66
Mg	0.68	7.34	−6.66	1.03	4.91	−3.88

Table 15.1b Microelements (P, Zn, Cu) budget for Modulo Experimental. P losses include export by wading birds (kg ha^{-1} $year^{-1}$)

Cation	1980 Input	1980 Output	1980 Net
P	0.193	0.101	0.092
Zn	0.595	0.214	0.382
Cu	0.244	0.0604	0.164

the ecosystem by wet precipitation between 1980 and 1981. Assuming that most of the soils are poorly drained after reaching field water saturation capacity, the percolation of water by drainage is minimal. Consequently, losses of elements from the watershed by deep seepage are negligible. Nutrient budgets are therefore calculated as the difference between annual input (entering via precipitation) and output (leaving in lateral drainage) for a given chemical element.

Net negative fluxes of sodium, potassium, calcium and magnesium were obtained in the two-year period.

Flux of chemical elements in precipitation is a significant input into oligotrophic environments such as flooded savanna. Net cation losses, although larger than in non-flooded savanna, did not show that large-scale nutrient cycling disruption is taking place in the diked savannas of Montecal. Net losses of potassium in the diked savanna were particularly high relative to published data.

Output fluxes of phosphorus, zinc and copper were low and positive budgets were reported for these elements. Phosphorus, zinc and copper accumulate within the ecosystem in significant quantities, their major loss being particulate matter.

The prolonged water saturation may be considered as a nutrient-conserving management technique. Biomass doubled after the construction of dikes. That enhanced biomass accumulation is responsible for further increase in nutrient uptake and immobilization (Odum, 1969) which, in turn, diminishes nutrient losses.

15.3.4 A SMALL CATCHMENT STUDY IN THE BRAZILIAN TROPICS

A multidisciplinary project has been conducted by the National Research Institute of Amazonia (INPA) (Ribeiro *et al.*, 1982). The study was executed in an experimental basin (23.5 km^2) situated in the agricultural and forest reserve of the Manaus Free Zone Authority. The climate is tropical, rainy, with mean annual temperature 26°C, relative humidity 79% and precipitation 2200 mm. The forest region is drained by a system of three rivers; their water is usually acidic (pH 3.9–5.0) and of extremely low conductivity (less than 20 $\mu S\ cm^{-1}$). River water is black-coloured where the river drains sandy soils with slow and incomplete decomposition of litter, and "clear" where it drains heavy clay soils.

The measurement of the rainfall interception by the canopy has shown that 22% of the total rainfall intercepted by the tropical forest was returning to the atmosphere through evaporation, and 78% reached the soil surface as throughfall. The stemflow represented only 0.3% of the total. The rate of evapotranspiration estimated through measurements of the overall water balance was 4.1 mm day^{-1} while the average transpiration was 2.7 mm day^{-1}, representing about 48.5% of the total water balance. To simulate surface water runoff, a conceptual model, based on a cascade of reservoirs, was developed.

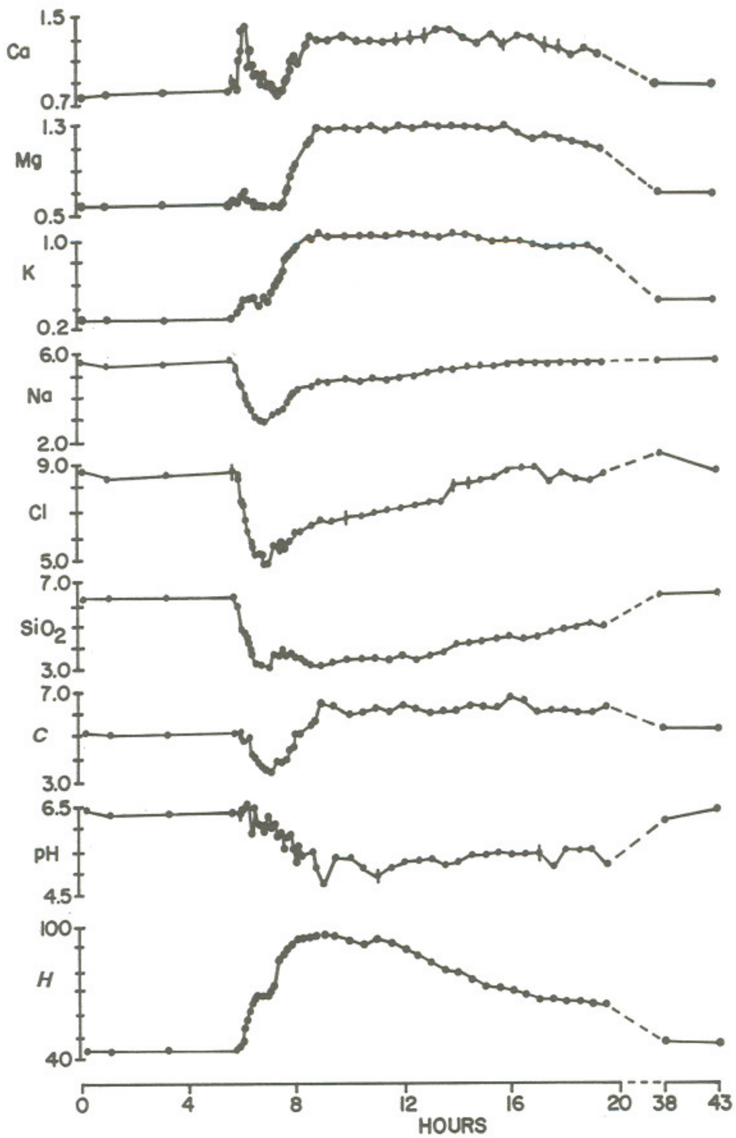

Figure 15.2 Variations in the water chemistry of the stream during the storm. Gauge height (*H*) in cm, Conductivity (*C*) in µS cm^{-1}, others in mg l^{-1}.

15.3.5 EFFECT OF STORM EVENTS ON STREAM CHEMISTRY IN AN ATLANTIC BRAZILIAN COASTAL FOREST

The catchment area studied is located on the Atlantic side of Tijuca Massif, Tijuca National Park, and belongs to the dominant ecosystem of the eastern Brazil coast, the Brazilian Coastal Forest.

Figure 15.2 shows stream chemistry variations during a storm event in this premontane basin. Chemical changes suggest that two chemically different waters reach the stream channel: a small water volume with a lower ionic content in the first rising of stream height, followed by a major water volume with higher ionic content. The large drop in SiO_2, Na and Cl concentrations during the initial rise could be associated with a water that was inside the basin before the storm began. The increase in stream element concentrations related to interactions between vegetation and soil with rainwater occurred in the second rise reflected by Ca, Mg, K, Na, Cl and conductivity behaviour. Based on a three-year study of stream output from the study area, it could be estimated that the contribution of these storms to the annual output in this period amounted to 6.3–22.3% depending on the element and the year (Table 15.2).

Table 15.2 Storm runoff (kg ha^{-1}) and stream output (kg ha^{-1} $year^{-1}$) during 1983-85 in Tijuca National Park, Brazil (Ovalle *et al.*, 1987). The percentage of contribution of storms with precipitation higher than 50 mm day^{-1} is also shown

	Storm	1983	%	1984	%	1985	%
SiO_2	0.48	59	8.1	30	6.3	39	7.4
Cl	0.87	86	10.1	42	8.3	57	9.1
Na	0.56	58	9.7	27	8.5	37	9.2
K	0.17	11	15.5	5.5	12.3	8.2	12.2
Ca	0.16	9.7	16.5	3.8	16.8	4.3	22.3
Mg	0.13	6.7	19.4	2.4	21.7	5.9	13.2

15.3.6 RESEARCH ON EROSION AND CARBON EXPORT IN SMALL CATCHMENTS

All the large rivers draining the tropical regions deliver large masses of sediments into the oceans (Milliman and Meade, 1983). Not only a large mass of inorganic particles—a product of intense tropical weathering—is exported from the continents, but also organic constituents which play a significant role in the biogeochemistry of river systems and of coastal areas (Degens *et al.*, 1991). Tropical rivers with relatively low total suspended sediment concentration (TSS) have the largest particulate organic carbon (POC) contribution to their suspended loads (up to 15%), a significant part of which are amino acids (about 35%) and carbohydrates (about 15%), the so-called "labile fraction" available for heterotrophic consumption (Ittekot and Laane, 1991).

Large river systems are fed by extensive networks of small, first- or second-order streams with basin areas with a high relief rarely exceeding a square kilometre. Numerous small catchments are often major sources of organic and inorganic phases for the larger systems.

It is a well-established fact that, as effective precipitation increases, the amount of eroded sediment rises steeply. Further, an inverse relationship exists between catchment area and sediment yield. Hence, although vegetation cover is an effective protection against erosion, some tropical small catchments which have totally or partially lost their vegetation cover through human intervention exhibit exceedingly large erosion rates (e.g. 500–800 t km^{-2} $year^{-1}$). Clearcutting could increase the sediment yield by a factor of 100 during storm events (Meybeck, 1989). The specific export rate of total organic carbon (TOC) is the highest in tropical regions, fluctuating between 3 and 15 t km^{-2} $year^{-1}$ (Meybeck, 1981). Although it is known that the dissolved-to-particulate organic carbon ratios (DOC/POC) fluctuate between 5 and 12 in wet tropical regions (Ittekot and Laane, 1991), it is not possible to elaborate further on the dynamics of carbon in small tropical catchments due to the paucity of existing data.

15.3.7 EFFECTS OF LOGGING ON MALAYSIAN RAIN FOREST

Solute loads exported from steep upland catchments in the mid range of peninsular Malaysia and the effects of logging and land conversion on stream sediment loads and water quality have been investigated since the 1960s (Bishop, 1973, Douglas, 1969, 1978; Peh, 1981). Since the 1970s catchment studies have been undertaken by the Forest Research Institute Malaysia (FRIM) and related national institutions (Salleh *et al.*, 1983; Lai and Samsuddin, 1985; Rahim and Zulkifli, 1986; Zulkifli *et al.*, 1987; Zulkifli, 1989). The most important catchment experiment was the Sungei Tekam study (Law *et al.*, 1989) which examined the hydrological and water quality effects of tropical rain forest conversion to cocoa and oil palm plantations.

Recent studies by Lai (1992) in peninsular Malaysia (Figure 15.3) aided by use of automatic runoff samplers provide a reliable estimate of solute fluxes under natural conditions and under disturbance by selective commercial logging. Most older studies, however, were plagued by less frequent sampling during storm events resulting in chemical and flux data biased by the higher solute concentrations, typical of baseflow.

In the undisturbed steepland catchment on a granitic substrate (Sg.Lawing) the total solute output was 11.5 t km^{-2} $year^{-1}$; while the logged catchment (Sg. Batangsi) had a solute output of 14.9 t km^{-2} $year^{-1}$ and a greatly increased particulate sediment load. The highest solute output (27.6 and 23.2 t km^{-2} $year^{-1}$ in two successive years) was observed in catchment Sg.Chongkak where logging had just ceased (Lai, 1992).

Table 15.3 summarizes the major solutes output from undisturbed, logged and recovering catchment. All catchments have quartz-rich granitic bedrock. Silica

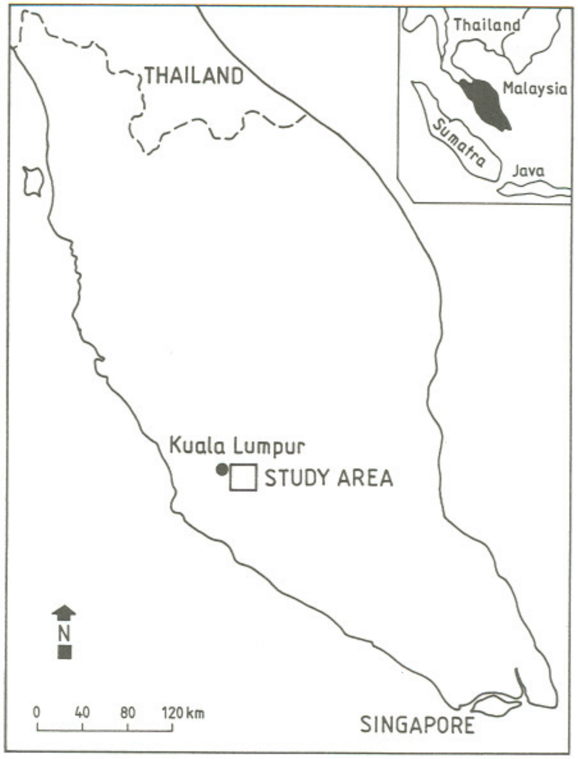

Figure 15.3 Location of the peninsular Malaysia study area and of Malaysian Borneo.

dominates the solute output in the natural catchment (56–62% of total). Percentage of silica increases in connection with logging, possibly due to increased export of sediment, composed mainly from fresh quartz and feldspar grains.

Potassium release from disturbed catchments was 1.4–2 times higher than from the undisturbed Sg. Lawing catchment (Lai, 1992), reflecting the disturbance of forest floor and the plant communities in the rain forest. Percentage of potassium increased during the logging period but decreased later.

The effect of logging on stream sediment and solute outputs was also investigated in the lowland dipterocarp rain forest in the Ulu Segama area of Sabah, Malaysian Borneo (Douglas *et al.*, 1990). Baseflow runoff chemistry does not differ between disturbed and undisturbed catchment (Douglas *et al.*, 1992). Baseflow chemistry is controlled by weathering reactions which are essentially the same at both sites.

The time evolution of the ratio Ca+Mg/Na+K (EPM) (Figure 15.4) in logged and undisturbed catchment illustrates the effect of logging. The ratio in stream draining the logged area dropped well below that for the natural site throughout

Table 15.3 Yields of major solutes (t km^{-2} $year^{-1}$) from steepland catchments in peninsular Malaysia (from Lai, 1992). For location of catchments see Figure 15.3

Catchment	Ca	K	Mg	Na	Fe	Al	Si	Total
Sg. Batangsi[a]	0.143	2.088	0.031	3.192	0.215	0.497	8.750	14.916
Sg. Chongkak,[b] first period	1.385	2.910	0.368	4.665	0.635	0.508	17.169	27.640
Sg. Chongkak,[b] second period	1.393	2.208	0.364	4.658	0.426	0.421	13.764	23.235
Sg. Lawing[c]	0.689	1.458	0.170	2.369	0.217	0.130	6.484	11.517
Sg. Lui[d]	0.812	1.083	0.309	1.616	0.335	0.117	4.822	9.094

[a]Sg. Batangsi is undergoing active logging.
[b]Sg. Chongkak ceased to be logged during the first period and was recovering from logging in the second period.
[c]Sg. Lawing is a natural, undisturbed catchment.
[d]Sg. Lui was partially logged 25 years ago and has a little active logging and an agricultural area in the lower reaches.

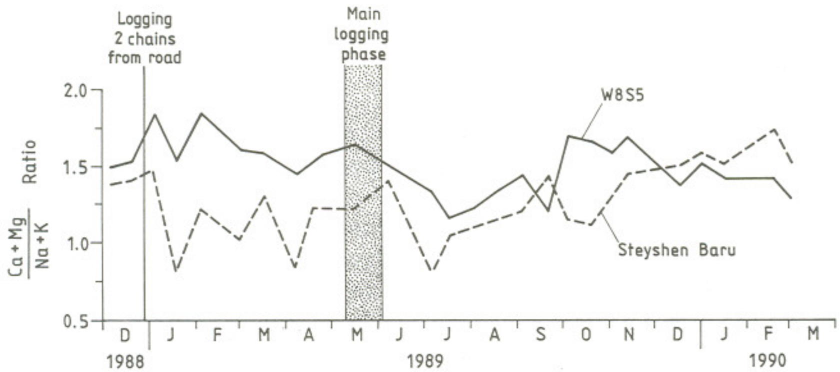

Figure 15.4 Change in the Ca+Mg/Na+K ration (EPM) in the two catchments located in the Ulu Segama area during and after the logging period. W8S5 is an undisturbed natural catchment (1.1 km^2), the logged catchment Steyshen Baru has an area of 0.54 km^2.

logging and through the next four months, then recovering and actually exceeding values reported for undisturbed catchment.

Decrease of the index does not reflect change in baseflow chemistry following the logging, but an effect of substantial dilution of solute concentrations during storm runoff because of the occurrence of rapid runoff over compacted bare surfaces and logging tracks. An increase in silica export occurs as a consequence of the high sediment supply to the logged stream (Douglas *et al.*, 1992).

Observations of storm-period decreases in solute concentrations, but increases in macro nutrient exports following logging correspond to the same pattern observed in the temperate forests of the USA (Bormann and Likens, 1979; Lynch and Corbett, 1991). The study in Ulu Segama is continuing to follow the post-logging recovery at least for five years.

Several important studies of the effects of land-use change in small catchments have been carried out in Indonesia and have been summarized by Bruijnzeel (1983, 1989, 1990). These studies emphasize that while progress has been made in monitoring the biogeochemistry of South East Asian rain forests, it has been hampered by lack of good instrumentation and inability to pursue long-term studies. A great effort to stimulate research in this field has been made by the ASEAN Water Resources programme and by the Asia–Pacific Watershed Network whose newsletter was issued by the Environment and Policy Division of the East–West Center, Hawaii. Recently this newsletter was amalgamated with the Asia–Pacific Uplands Newsletter issued by Dr Ron Hill, Department of Geography and Geology, University of Hong Kong, Hong Kong, on behalf of the Pacific Science Association.

15.4 CONSTRAINTS OF THE SMALL CATCHMENT STUDIES IN LATIN AMERICA

15.4.1 ECOLOGICAL CONSTRAINTS

Small catchment research in the tropics presents some limitations that have to be carefully considered in order to obtain reliable results that eventually could lead to generalizations.

In Europe and North America, small catchments with areas of 1–10 km^2 have proved to be useful to show the complex interactions among different environmental parameters. In tropical Latin America, it still remains to be seen which is the ideal size of catchments representing the smallest functional unit. On the one hand, studying such small catchments in countries where large rivers prevail might seem irrelevant. In fact, there are relatively few published studies on small catchments in tropical Latin America. On the other hand, catchments that may serve as "natural laboratories" cannot be too large, otherwise data interpretation becomes difficult. Heterogeneity of environmental factors and biodiversity suggest that catchment area might be somewhat larger. Biodiversity of the tropics has become legendary and does not need to be reiterated here. Therefore, catchment size selection in tropical Latin America has to balance both ecosystem representation and practical considerations. Extrapolation of results to a regional scale may be much more difficult and must be handled with caution.

15.4.2 TECHNICAL AND SOCIOECONOMICAL CONSTRAINTS

Like every ecological research, catchment studies require background information (climatic records, detailed topographic maps, geological surveys, data on flora and fauna). These data often do not exist or access to them is difficult.

Scientific equipment, chemicals, etc., normally have to be imported. To spend precious foreign currency on this purpose does not always get top priority in developing countries.

Catchment studies require a close cooperation of scientists from different fields such as soil science, hydrology, biology, etc. In tropical countries the number of scientists is limited and they are frequently occupying administrative positions. This makes interdisciplinary work difficult.

Catchment studies usually are long-term projects which require stable conditions. Due to the lack of funding and political interference, many scientific institutions in the tropics are subject to a frequent change of staff, which hampers long-term scientific projects.

15.5 CONCLUSIONS AND RECOMMENDATIONS

15.5.1 SMALL CATCHMENTS MODELLING VS. LARGE CATCHMENTS

Scientific research in the tropics has so far been conducted mainly on large catchments, while small catchments have received little attention. One inductive way to relate small with large catchments might be based on experiments and modelling from the former, and adequate testing on the latter. As a first step, characteristic small catchment processes should be studied, their functioning modelled and their key parameters identified. The second step involves provoking low- to high-level disturbances, recording catchment responses and setting up more general models. The third step implies the selection of more suitable models for potential extrapolation and comparison of key parameter measurements in large basins with small catchment predictions. The main limitation for this approach in tropical Latin American countries is the lack of basic, descriptive information on the functioning of ecosystems.

15.5.2 FIRST DISTURBANCE TESTING

In many northern temperate regions, land-use and related environmental modifications are a secular practice to the extent that most landscapes are practically man-made environments. In tropical countries, anthropogenic disturbances are still relatively small, and most catchments are virtually undisturbed. The term "undisturbed" does not strictly mean untouched, because anthropogenic influence can be clearly recognized. However, both type and magnitude of these effects place the tropics in a different context, where indigenous and mechanical land-use techniques converge, both acting on relatively undisturbed ecosystems with unknown potential responses. The behaviour of catchments from northern temperate secularly managed ecosystems can definitely not be extrapolated to the systems such as those described in this chapter. Thus the term "first disturbance" seems appropriate to emphasize the difference between the starting point of most tropical and temperate human-induced processes. Small catchment experiments may be a good approach to test and predict natural responses to these first disturbances associated with minimum damage. Otherwise, environmental changes leading to artificial human-made environments are a latent danger.

15.5.3 AWARENESS AND SCIENTIFIC COOPERATION

There is still a lack of awareness of the importance of using catchments as management or experimental units in tropical Latin America. Therefore, active diffusion of the usefulness of results obtained from pilot small catchment research is needed.

Technical and some socioeconomical constraints can be overcome through close cooperation with scientific institutions of industrial countries. Mutual exchange of scientists, launching common research programmes, workshops, delivery of scientific equipment on favourable terms are conceivable. Efforts of international bodies towards institution-building and strengthening of the existing institutions could also prove helpful. Additionally, certain sociological domestic problems must be solved.

15.6 REFERENCES

Bishop, J.E. (1973) Limnology of a small Malaysian river. *Monographiae Biologicae 22*. Junk Publisher, The Hague.

Bormann, F.H. and Likens, G.E. (1979) *Pattern and Process in a Forested Ecosystem*. Springer-Verlag, New York.

Bormann, F.H., Likens, G.E., Fisher, D.W. and Pierce, R.S. (1968) Nutrient loss accelerated by clear cutting of forest ecosystems. *Science* **159**: 882–884.

Bruenig, E.F. and Schmidt-Lorenz, R. (1985) Some observation of the humic matter in Kerangas and caatinga soils with respect to their role as sink and sources of carbon in the face of sporadic episodic events. *Mitt. Geol.-Palaeont. Inst. Univ. Hamburg, SCOPE/UNEP Sond.* **58**: 107–122.

Bruijnzeel, L.A. (1983) Hydrological and geochemical aspects of man-made forests in south-central Java. Frije Universiteit, Amsterdam.

Bruijnzeel, L.A. (1989) Nutrient cycling in moist tropical forests: the hydrological framework. In Proctor, J. (Ed.): *Mineral Nutrients in Tropical Forest and Savanna Ecosystems*. Blackwell, Oxford, pp. 383–416.

Bruijnzeel, L.A. (1990) Hydrology of tropical moist forests and effects of conversion: a state of knowledge report. Frije Universiteit, Humid Tropics Programme, UNESCO/IHP, Amsterdam.

Cuenca, G. and Herrera, R. (1986) Environmental acidity and natural vegetation in Venezuela. In Rhode, H. and Herrera, R. (Eds): *Acidification in Tropical Countries*. SCOPE 36. John Wiley & Sons, New York, Chichester, pp. 221–228.

Degens, E.T., Kempe, S. and Richey, J. (Eds) (1991) *Biogeochemistry of Major World Rivers*. SCOPE 42. John Wiley & Sons, Chichester, 356 pp.

De Melo-Carvalho, J.C. (1984) The conservation of Nature in the Brazilian Amazonia. In Sioli, H. (Ed.): *The Amazon*. Dr W. Junk, Dordrecht.

Douglas, I. (1969) The efficiency of humid tropical denudation systems. *Transactions Institute of British Geographers* **46**: 1–15.

Douglas, I. (1978) Denudation of silicate rocks in the humid tropics. In Davies, J.L. and Williams, M.A.J. (Eds): *Landform Evolution in Australasia*. ANU Press, Canberra, pp. 216–237.

Douglas, I., Greer, T., Wong, W.M., Spencer, T. and Sinun, W. (1990) The impact of commercial logging on a small rainforest catchment in Ulu Segama, Sabah, Malaysia. In *Publications International Association Scientific Hydrology 192*, pp. 165–173.

Douglas, I., Spencer, T., Greer, T., Kawi Bidin, Sinun, W. and Wong W. M. (1992) The impact of selective commercial logging on stream hydrology, chemistry and sediment loads in the Ulu Segama Rain Forest, Sabah. *Phil. Trans. R. Soc. London B* **335**: 397–406.

Fölster, H. (1986) Forest–savanna dynamics and desertification processes. *Interciencia* **11**(6): 311–316.

Galán, C. (1984) *Memoria explicativa del mapa de zonas bioclimáticas de la cuenca del Río Caroní*. CVG-EDELCA Internal Report, Caracas, 74 pp.

Gibbs, R. (1967) The geochemistry of the Amazon River Basin. Part I: The factors that control the salinity and the composition and concentration of suspended solids. *Bull. Geol. Soc. Am.* **78**: 1203–1232.

Hernández, L. (1987) Degradación de los bosques de la Gran Sabana. *Pantepui* **3**: 11–25.

Huber, O. (1986) La vegetación de la cuenca del Río Caroní. *Interciencia* **11**(6): 301–310.

Ittekot, V. and Laane, R. (1991) Fate of riverine organic matter. In Degens, E.T. Kempe, S. and Richey, J. (Eds): *Biogeochemistry of Major World Rivers*. SCOPE 42. John Wiley & Sons, Chichester.

Johnson, P.L. and Swank, W.T. (1973) Studies of cation budgets in the Southern Appalachians on four experimental watersheds with contrasting vegetation. *Ecology* **54**: 70–80.

Lai Food See (1992) Sediment and solute yields from logged steep upland catchments in peninsular Malaysia. Unpublished Ph.D. thesis, University of Manchester, 590 pp.

Lai Food See and Samsuddin, M. (1985) Suspended and dissolved sediment concentrations of two disturbed lowland forested waterheds in Air Hitam Forest Reserve, Selangor. *Pertanika* **8**: 115–122.

Law, K.F., Cheong, C.W., Ong, T.S., Mustafa Kamal, B., Tengku Bakry Shah, T.J., Maketab, M., Foong, S.F., Che Hashim, H., Mohd. Nizum, M.N., Abdul Tahim, N., Zulkifli, Y., Low, K.S. and Lai, F.S. (1989) *Sungai Tekam Experimental Basin Final Report July 1977 to June 1986*. Water Resources Publication 20. Kuala Lumpur: Bahagian Pengairan dan Saliran, Kementarian Pertanian, Malaysia.

López-Hernández-Sosa, D., Sosa, M., Niño, M. and Yanes, L. (1986) Balanca de elementos en una sabana inundable (Módulo Experimental Mantecal, Edo. Apure, Venezuela). I. Entradas y salidas de materiales. *Acta Cientifica* **37**: 174–181.

Lynch, J.A. and Corbett, E.S. (1991) Long-term implications of forest harvesting on nutrient cycling in central hardwood forests. In *8th Hardwood Forest Conference*. US Forest Service, NE Forest Experimental Station General Technical Report, NE-148, pp. 500–518.

Maass, J.M., Jordan, C. and Sarukhán, J. (1988) Soil erosion and nutrient losses in seasonal tropical agroecosystems under various management techniques. *J. Appl. Ecol.* **25**(2): 595–607.

Maass, J.M., Patiño, C. and Sánchez, A. (1990) Caracterización de la biomasa leñosa muerta en una selva baja caducifolia. XI Cong. Mex. Botánica. Oaxtepec, México.

Martínez-Yrízar, A. (1980) Tasas de descomposición de la materia orgánica foliar de especies arbóreas de selvas en clima estacional. Graduate thesis, UNAM, Mexico.

Meybeck, M. (1981) River transport of organic carbon to the ocean. In *Carbon Dioxide Effects Research and Assessment Program. Flux of Organic Carbon by Rivers to the Oceans*. Conf-8009140: 219–269.

Meybeck, M. (1982) Carbon, nitrogen and phosphorus transport by world rivers. *Amer. J. Sci.* **282**: 401–450.

Meybeck, M. (1989) Suspended matter in rivers and lakes. In Meybeck, M. *et al.* (Eds): *Global Freshwater Quality. A First Assessment*. Blackwell, Oxford.

Milliman, J. and Meade, R. (1983) World-wide delivery of river sediment to the ocean. *J. Geol.* **91**: 1–21.

Odum, E.P. (1969) The strategy of system development. *Science* **164**: 262–270.
Ovalle, A.R.C., Silva Filho, E.V. and Brown, I.F. (1987) Element fluxes in a tropical premontane forest, Rio de Janeiro, Brazil. In Moldan, B. and Paces, T. (Eds): *Internat. Workshop on Geochemistry and Monitoring in Representative Basins*. Prague, Czechoslovakia, pp. 16–18.
Paolini, J. (1986) Physico-chemical properties of Venezuelan soils and their sensitivity to acidification. In Rhode, H. and Herrera, R. (Eds): *Acidification in Tropical Countries*. SCOPE 36. John Wiley & Sons, Chichester.
Patiño, M.C. (1990) Variación espacial y temporal de la capa de hojarasca (mantillo) en una selva baja caducifolia en Chamela, Jal., México. Graduate thesis. UNAM, México. 78 pp.
Peh, C.H. (1981) The suspended and dissolved load of three small forested drainage basins in peninsular Malaysia. *Malaysian Forester* **44**: 438–452.
Perry, D.A. and Maghembe, J. (1989) Ecosystem concepts and current trends in tropical forest management: time for a reappraisal. *For. Ecol. Manage.* **26**: 123–140.
Rahim, N. and Zulkifli, Y. (1986) Stream water quality of undisturbed forest catchments in peninsular Malaysia. Paper presented at the regional workshop on man's activities in tropical upland ecosystems, Universiti Pertanina Malaysia. 3–6 February 1986, Serdang.
Ribeiro, M.N.G. *et al.* (1982) Bacia Modelo: caracterizaçao ecológica de uma bacia hidrográfica experimental na Amazonia Central. *Acta Amazonica* **12**(3): Suplemento, Manaus-Amazonas.
Rodhe, H. and Herrera, R. (1988) *Acidification in Tropical Countries*. SCOPE 36. John Wiley & Sons, Chichester, 423pp.
Rull, V. (1991) Contribución a la paleoecología de Pantepui y la Gran Sabana, Guayana venezolana: clima, biogeografía y ecologia. *Scientia Guayanae* **2**. XXII + 133 pp.
Salleh, M.N., Abdul Rahim, Nik and Mushrifah, I. (1983) The effect of logging on sediment yield in two forested catchment areas. In Kamis, A., Lai, F.S., Lee, S.S. and Abdul Rahman, D. (Eds): *Proceedings of the Workshop on Hydrological Impacts of Forestry Practices and Reafforestation*. Serdang, Universiti Pertanian Malaysia, pp. 61–69.
Sioli, H. (1984) Former and recent utilization of Amazonia and their impact on the environment. In Sioli, H. (Ed.): *The Amazon*. Dr W. Junk, Dordrecht.
Vegas-Vilarrúbia, T. and Paolini, J. (1988a) A physico-chemical survey of blackwater rivers from the Orinoco and the Amazon basins in Venezuela. *Arch. Hydrobiol.* **111**(4): 491–506.
Vegas-Vilarúbia, T. and Paolini, J. (1988b) Differentiation of some Venezuelan blackwater rivers based upon physico-chemical properties of their humic substances. *Biogeochemistry* **6**: 59–77.
Vitousek, P., Matson, P., Volkmann, C., Maass, J.M. and García, G. (1990) Nitrous oxide flux from seasonally-dry tropical forests: a survey. *Global Biogeoch. Cycles*. (in press).
Zink, A. (1986) Características y fragilidad de los suelos en ambiente de selva nublada: el ejemplo de Rancho Grande. In Huber, O. (Ed.): *La Selva Nublada de Rancho Grande. Parque Nacional `Henri Pittier'*. Fondo Ed. Acta Cient. Venez., Caracas, pp. 31–66.
Zulkifli, Y. (1989) Effects of selective logging methods on dissolved nutrient exports in Berembun watershed, Peninsular Malaysia. Paper presented at the FRIM/IHP/UNESCO regional seminar on tropical forest hydrology, Kuala Lumpur, 4–9 September, 1989.
Zulkifli, Y., Anhar Suki and Mohd. Fauzi, Z. (1987) Effects of selective logging on physical stream water quality in hill tropical rain forest. Paper presented at the workshop on impact of operations in natural and plantation forests on conservation of soil and water resources. Universiti Pertanina Malaysia, 23–26 June, 1987, Serdang.