Introduction

This book reviews the current state of knowledge of forest hydrology and related land-water management issues in the humid tropics. As happened earlier in the related field of soil erosion and conservation, the days are long gone when land–water issues could be approached in a purely technical manner (cf. Hudson, 1971; Critchley, this volume), so much so that in a recent overview of responses to land degradation (Bridges *et al*., 2001), the majority of chapters dealt with socio-economic, institutional and policy-related aspects rather than the physical aspects of soil erosion. In view of the importance of policy and governance aspects in environmental management, in particular the involvement of local communities and other resource managers, the present book also aims to bring together scientific, policy and management perspectives. Such perspectives address tropical forest–land–water management issues and concurrently also seek optimum solutions for the benefit of all interest groups involved. Of late, the term 'Blue Revolution' has been coined to describe the shift from the traditional technical approach to one that gives due consideration to socio-economic factors as well (Calder, 1999).

The contents of this book are based on contributions made to a joint UNESCO International Hydrological Programme (IHP) – International Union of Forestry Research Organisations (IUFRO) Symposium and Workshop *Forest–Water–People in the Humid Tropics : Past, Present, and Future Hydrological Research for Integrated Land and Water Management*, hosted by Universiti Kebangsaan Malaysia, Kuala Lumpur, Malaysia, 30 July – 4 August 2000. The Symposium was planned with the same structure as this book so that each were complementary, although a number of chapters were added after the meeting to achieve more complete coverage. The IHP-IUFRO Symposium originated from the UNESCO-IHP Humid Tropics Programme which was launched in 1990 as part of the Fourth Phase of the IHP (1990–1995). To mark the latter occasion, the book *Hydrology and Water Management in the Humid Tropics: Hydrological Research Issues and Strategies for Water Management* (Bonell *et al*., eds. 1993) was published by Cambridge University Press, based on the First International Colloquium of the same title held in July 1989. In addition, the Humid Tropics Programme published *Hydrology of Moist Tropical Forests and Effects of Conversion : A State of Knowledge Review*, by L. A. Bruijnzeel, in 1990. More recently, UNESCO IHP Technical Document in Hydrology No. 52 *Hydrology and Water Management in the Humid Tropics* (Gladwell, ed., 2002) was published which included separate sections devoted to the hydrology of small islands and montane cloud forests, as well as sections on urban hydrology, groundwater and water quality issues. The current book complements and updates all these publications. It also marks the closure of the Humid Tropics Programme at the end of the Fifth phase of the IHP (1996–2001), and is a contribution to the new HELP (Hydrology for the Environment, Life and Policy) Programme within UNESCO (HELP Task Force, 2001; http://www.unesco.org/water/ihp/help) as part of IHP-VI (2002–2007).

At the First International Symposium on Forest Hydrology, held in 1965 at Pennsylvania State University (Sopper and Lull, 1967), only one contribution dealt explicitly with tropical land use hydrology (Pereira, 1967). Seen from this perspective, we have come a long way since then. As indicated however within the introductory paragraph, tropical forest hydrology is changing from the relatively limited study of how water and the transport of associated solid-debris and chemical species move through forested catchments, to how forest lands should be managed to maximise the environmental services and benefits they bring to the people living in, or downstream, of these forests. The tropics themselves are changing too: demographic and economic changes and, above all, the over-riding need to improve the livelihoods of the poorer strata in humid tropical societies all create massive pressure for both the exploitation and conversion of the remaining forest. Part of this quest for economic development concerns planned, government-based forest clearance and conversion to uses that are considered more profitable (e.g. large-scale cattle breeding, oil palm and cocoa plantations, irrigated rice cultivation in former wetlands). Elsewhere, closed forests are becoming degraded or disappear altogether as a result of continued, unplanned slash and burn activities by poor, land-hungry farmers (Drigo, this volume).

The structure of this book reflects the changing nature of tropical forest and land use hydrology although the emphasis is still on physical hydrology.

The book has five parts: Part I provides an overview of the current trends and perspectives on people–land–water issues in the humid tropics, where the use of the term 'humid tropics' is based on the criteria given by Chang and Lau (1993). Part I includes nine contributions which assess the rates, causes and patterns of land use change linked with policy within the broad dimensions of socio-economics, culture and governance. Particular emphasis is placed on the importance of incorporating local communities in the land use decision-making process. Part II presents an overview of the humid tropical, meteorological and climatic settings and outlines the biophysical aspects of tropical forest functioning through a systematic description of the principal hydrological, geomorphological and biogeochemical processes taking place in old-growth ('undisturbed') forest. Separate chapters are devoted to two special and hitherto under-researched rainforest types, swamp forest and montane cloud forest. The nine chapters making up Part II provide a baseline against which to not only evaluate the environmental impacts associated with forest disturbance (both natural and man-caused) and conversion, but also the changes accompanying forest recovery or reforestation and other rehabilitative measures such as agroforestry, as detailed in the eight chapters making up Part III. Next, the eight chapters of Part IV discuss the potential application in the tropics of a number of new tools for evaluating the biophysical impacts of land use change, including the transfer of technology and experience from more temperate latitudes. Examples include new sensors used in remote sensing, statistical techniques related to time series analysis, and several model approaches of varying complexity, some of which are particularly suited for use in data-poor areas such as the humid tropics. Consideration is also given to an assessment of the potential for using aquatic organisms as indicators of water quality. The four chapters constituting Part V present a critical appraisal of best management practices within the contexts of timber harvesting, land clearing and post-forest agricultural cropping. A concluding chapter provides a synthesis of the key issues emerging from the book, one of which is the overwhelming need for more integrated, multidisciplinary approaches in future tropical forest and land use hydrological research programmes. No chapter is devoted solely to groundwater, despite the fact that groundwater remains a neglected area of research in the humid tropics (see reviews by Foster and Chilton, 1993; Foster *et al*., 2002). However, several contributions highlight the need for a better coupling of surface water–groundwater interactions in future assessments of the hydrological consequences of land use change. Examples where greater attention needs to be given to surface water–groundwater coupling include hillslope runoff generation (Bonell, this volume), nutrient retention in the riparian zone (Proctor, this volume), and the effects of reforestation on dry season flows (Scott *et al*., this volume).

This book was conceived as a state-of-the-art record of tropical hydrological knowledge at the turn of the millennium. Several of the contributors commenced their careers during the first global programme devoted to hydrology and water resources, the UNESCO International Hydrology Decade (IHD), 1965–1974; and one of the aims of the Kuala Lumpur meeting, and this book, has been to capture their experiences to pass on to younger scientists. It is this younger generation who will have to take forward the recommendations made here for implementation in tropical forest-land-water management as well as addressing the associated research gaps. Their task is not made any easier, however, by the fact that there has a been decline of global hydrological monitoring networks especially in the humid tropics (Rodda, 1999). Moreover, at the national and international level there has been a progressive erosion of the longer-term vision that prevailed at the time of the IHD when the need for long-term monitoring and research to address environmental and water resource management concerns was still widely recognised by national governments (Bonell, 1999). Indeed, most of the hydrological data sets now proving so valuable for assessing the impacts of climatic variability, and global change in general, (e.g. the UNESCO IHP FRIEND project; Gustard and Cole, 2002) originate from the era of the IHD. Yet, during the initiation of the IHD, neither the notion of climate change nor global change were commonly part of the scientific vocabulary.

In more recent times, however, especially during the last decade, there has been a shift towards funding more short-term, high visibility international projects connected with water and climate. Partly, this reflects how science is managed nowadays in most developed countries where there is a need for 'products' over a one- to three-year economic cycle. As highlighted by Matsuura (2000), within this age of globalisation, we are also in an age of urgency, impatience and immediacy. Thus it would seem that international donors have become more inclined to sponsor high profile international meetings on water policy (Yamaguchi and Wesselink, 2000) rather than fund time-consuming technical-socio-cultural field studies. It is also pertinent to note that in some quarters there is a mistaken notion that 'we know enough science now'. On the one hand, this reflects the fact that many scientists are insensitive to relevant policy questions and usually preoccupied with their disciplinary orientation. At the same time, however, resource managers and policy makers also lose credibility because they lack an interest in incorporating new research results in their policies. The hydrological role of a good forest cover provides a case in point. Often, trees are planted in degraded areas within the context of massively funded watershed management projects, not only to arrest soil erosion and reservoir sedimentation but also in the expectation of restoring streamflow regimes (i.e. reduce

'floods' and enhance low flows; cf. Kaimowitz, this volume). Yet, the results of most hydrological research suggest a further lowering of stream discharges after reforestation, particularly during the dry season (Bruijnzeel, 1990, 1997; Scott *et al*., this volume). Other solutions are needed, therefore, based on a sound understanding of the various processes governing the magnitude of dry season flows (Sandström, 1998; Bruijnzeel, 2005).

It is evident from the above and other examples given in this book that it is important to shift back towards a longer-term vision and maintain at least a number of longer-term experimental catchment projects. Such steps are imperative if we are to address adequately the impacts of such high-profile issues as climate variability and global change (Entekhabi *et al*., 1999) but also other, less publicised issues, such as diminishing low flows, faced by tropical governments and their citizens. This time, however, it is essential to ensure the active involvement of major stakeholders outside scientific circles, notably local communities and institution-based resource managers, as well as government policy-makers, in helping to set the environmental research agenda (Bonell, 1999; Calder, 1999; HELP Task Force, 2001). This approach will improve the chances of research results becoming incorporated into national resource policy formulations and more specific guidelines for on-site land and forest management (Cassells and Bruijnzeel, Thang and Chappell, both this volume). In addition, the same approach will also aid the actual application of these guidelines, thereby providing such tangible benefits as improved agricultural production whilst maintaining water quality standards (Deutsch *et al*., Critchley, both this volume).

Partly in response to economic pressures from funding bodies for more immediate 'products', coupled with the reduction in funding for longer-term field research signalled earlier, there has been a movement in hydrology and related sciences over the last two decades in favour of mathematical modelling and associated computer simulation. On the one hand, these developments have led to a greatly increased understanding of land surface – atmosphere interactions and the beginnings of an answer to the vexed question as to what extent the presence or absence of forest influences rainfall (Dolman *et al*., 2004; Kabat *et al*., 2004; cf. Costa, this volume). On the down side, however, the recent emphasis on modelling has also been at the expense of, rather than a complement to, field hydrological process studies (Philip, 1991; Klemeš, 1997; Shiklomanov, 2001). This book attempts to redress this imbalance by reporting on recent progress in both hydrological modelling and field studies in the humid tropics. Moreover, a fundamental message of the book is the need for a more integrated scientific approach to be adopted in future efforts which couple surface hydrology, groundwater, and ecohydrological aspects wherever required (cf. Sandström, 1998). Such an approach is advocated also within the HELP Programme (HELP Task Force, 2001; UNESCO-IAEA, 2002) to complement in-depth research along more traditional systematic disciplinary lines. Furthermore, strong emphasis is placed here on lateral fluxes of water, sediment and solutes at the small catchment scale (typically <10 km^2), i.e. the scale at which specific guidelines are usually applied in on-site land and forest management. In this regard, the technical aspects of this work complement the similarly ambitious overview by Kabat *et al*. (2003) which has a much greater focus on land surface – atmosphere interactions (notably exchanges of sensible and latent energy) and emphasises the impacts of global change on climate and the hydrological cycle from the regional up to the continental scale. The present book, however, also includes several chapters which 'bridge' these contrasting scales of scientific enquiry (notably those by Mahé *et al*. and Costa). Similarly, the present effort is also complementary to another end of millennium overview (Bridges *et al*., 2001) which focuses on the extent, causes of, as well as possible remedies for land degradation. As indicated previously, the latter publication emphasises socio-economic, institutional and governance aspects rather than the more physical aspects of soil erosion. Moreover, the focus of attention of Bridges *et al.* (2001) is very much the farmer's field rather than downstream impacts of land degradation such as siltation of streams, irrigation works and reservoirs. Several chapters in the present book deal explicitly with erosion and sediment dynamics, both under undisturbed conditions and upon forest disturbance and conversion. In doing so, particular attention is paid to linking hillslope processes with the drainage network (i.e. streams) and the functioning of riparian buffer strips (see chapters by Douglas and Guyot; Chappell *et al.*; Tych, and Yu) whereas the chapter on soil and water management in humid tropical steeplands by Critchley typically acts as a 'bridge' to what might be called the 'land husbandry' community (Bridges *et al*., 2001).

On a final note, this book also highlights the increasing tensions and inherent incompatibility between the goals of neo-classical economic development on the one hand and those of environmental sustainability on the other. Usually, the policy of rapid economic development is undertaken by way of a top-down type of governance and planning. This is shown by several contributors to be an important cause of degradation of tropical forests and associated land – water resources. The question is thus raised whether a new, 'biophysical' approach to economics is required, which focuses more on ways of increasing economic outputs for less material and energy inputs. Such an approach resembles the ecological economics vision which is becoming more widely accepted of late (Daley, 1998; Matthews, 2002). This new paradigm recognises that ecosystems are suppliers of all kinds of services to the economy and that these services represent a benefit (or a loss in the case of their disappearance) that needs to be incorporated into economic analysis before a decision is taken (cf. Hall and Ko, this volume; Aylward, this volume). Arguably, such an approach would also provide a much better framework for the incorporation

and application of research outputs into forest and land management and policies (cf. Cassells and Bruijnzeel; Murdiyarso, both this volume).

We hope that this book will contribute towards the revival of some of the longer-term visionary values of the International Hydrological Decade within future national and international hydrological research agendas. We consider this vital if we are to adequately address the continued degradation of forest, land and water resources in the humid tropics. Such concepts are in line with the conclusions from the recent *World Summit on Sustainable Development* (WSSD, 2002) with its emphasis on a commitment to undertaking concrete actions and measures at all levels, and the recent 'Shiga Declaration on Forests and Water' (Shiga Declaration, 2002). Such world summits and declarations however, are of little use without commensurate action on the ground.

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Part I
Current trends and perspectives on people–land use–water issues

SUMMARY

The extensive conversion of tropical forests to other land uses during, especially, the last four decades has raised global alarm on the threats posed by continued forest conversion to climatic stability and the hydrological functioning of river basins, next to the well-being of forest dwellers and the conservation of biodiversity. This part consists of nine chapters setting the scene for this book. It starts off with an account of the rates and underlying causes of deforestation in the three main tropical rainforest regions during the last two decades. This is followed by a critique of neo-classical market-based economics which are held responsible for stimulating environmental degradation. The next three chapters (Chapter 3–5) describe the adverse socio-economic consequences of large-scale planned forest conversions for forest dwellers and other poor strata in society in Latin America and South East Asia. After concluding that governments and donor organisations, whilst well aware of tropical environmental degradation, generally have no new ideas on how to mitigate the effects of adverse practices (Chapter 6), the final three chapters highlight ways of using economic theory to improve the negotiating position of upland farming communities and of actively involving these communities in the identification and solving of local environmental problems.

Setting the pan-tropical scene, Drigo discusses *how the latest FAO Tropical Forest Assessment and various related efforts (i.e. TREES II high resolution survey) to quantify the extent and rates of tropical deforestation* reveal a rather complex picture of a reduction in higher biomass densities during the last two decades, despite different definitions of various vegetation classes used in the respective surveys. A shift is noted in the rate of forest loss from the moist deciduous zone towards the wetter evergreen rainforest formations of late. The principal reasons for the observed changes in forest cover are either degradation or conversion to other land uses. The main driving force behind unplanned forest degradation is rural population pressure with its corresponding subsistence and energy demands. In contrast, planned activities result in immediate conversion of forest to other land uses within the framework of government-driven resettlement programmes, cattle ranching and permanent agriculture, as well as commercial plantations. Regional ecological and socio-economic settings are seen to determine many of the causes and factors influencing forest conversion. Africa differs from Latin America, for example, in that the process of forest conversion has been more progressive, i.e. a stepwise degradation to other land uses rather than outright forest clearance. On the other hand, Latin America, and the Amazon Basin in particular, depicts more the impacts of planned direct conversion of forest to large-scale cattle ranching and permanent agriculture. The highest rates of forest degradation, as well as forest conversion, occur in Asia, however, where the changes in forest cover reflect both the effect of population pressure (shifting cultivation) and centrally planned conversion to agriculture (e.g. irrigated rice in peat swamps) or commercial plantations (notably oil palm, some timber), with a gradual shift towards the latter during the last decade in particular.

Next, Hall and Ko *examine the economic efficiency of natural resource use in 12 tropical countries*. Focusing on the relationship between energy use and economic activity (expressed as gross domestic product, GDP), they find that greater use of energy (e.g. the use of energy-intensive fertilisers in agriculture) does not necessarily imply greater economic efficiency. Rather, there proves to be a strong positive correlation between GDP and energy use, and even more so with population growth. Although there is a positive correlation between the extent of forest conversion and economic growth, it is relatively weak and explained by the fact that most of the countries examined have already largely depleted their forest resources. In contrast, there is a strong positive linear relation between economic growth and water use. Consequently, 'market-based' economies do not lead to an efficient use of natural resources and, indeed, the imposition of the western model of economic sustainability is in direct opposition to the concept of environmental sustainability. The authors call for a new approach through 'biophysical' economics, which focuses more on increasing economic outputs for less energy or material inputs. Such new economics would take a more realistic position on available biophysical resources and economic possibilities

and should therefore help to arrest the continued depletion of natural resources and ensure that basic needs (e.g. clean water) remain available to the populace. However, Hall and Ko emphasise that the issue of escalating populations should also be addressed. Otherwise, they argue, the persistent use of neo-classical economics is equivalent to 'an excuse to plunder'.

Serrao and Thompson, in their discussion of *the resource management situation in the Brazilian Amazon, provide an example of the environmental and socio-economic impacts of centrally planned (and therefore large-scale) forest conversion to (mostly) cattle ranches*. Resource management in Amazonia has a strong top–down character, with the federal and the state governments being by far the largest land managing bodies. In recent times the government has tried to establish more sustainable policies to correct for its earlier mismanagement (notably with respect to forest dwellers such as Indian Reserves) but at the same time such steps have come into conflict with the strong political desire for rapid economic development in the form of hydroelectric power generation (requiring the construction of huge dams), cattle ranching and, to a lesser extent, other forms of agriculture and commercial plantations. Ironically, an important psychological impediment to achieving environmental sustainability appears to be the sheer size of the Amazonian forest which not only gives the impression of inexhaustable abundance, but also tends to render the perceived environmental costs of forest conversion rather insignificant. Similarly, the existence of generally ample water resources in the area tends to negate the rather more short-lived, negative perception of (El Niño–Southern Oscillation-related) droughts which are often used to reinforce the environmental argument. Possible solutions centre around the need for strengthening institutional structures at the community level, coupled with economic incentives for reforestation as well as greater attention to socially and environmentally sustainable objectives, to balance the drive for economic development.

The adverse socio-economic and cultural impacts of forest disturbance and conversion on forest dwellers in South East Asia are highlighted by Schweithelm. The author notes that the activities of forest dwellers (including shifting cultivation) were sustainable at the population densities prevailing during the pre-colonial era. The forests provided food and shelter, as well as medicinal and trade products. Significantly, the institutional arrangements at the community level were strong then in terms of land tenure (ancestral claims) and legal rights (customary laws). The colonial era saw a shift towards legal control being taken over by Governments; a process which was accelerated once the emergent nations gained independence after World War II. Thus the forest dwellers' system of forest management came into direct conflict and became subordinate to national government policies of commercialisation (timber harvesting, clearing for plantations), at the expense of forest conservation. The dramatic shift from a subsistence-orientated (community-based) type of forest management to commercial (government-controlled) operations has not only resulted in the degradation of forests but also in water quality. Traditional institutional and legal structures have become radically weakened or lost altogether, causing mass migration to jobs in the market economy. Also, existing laws often do not recognise the legal land rights of forest dwellers. In recent times there has been an increasing recognition by governments that forest dwellers have rights in the remaining forests within the framework of a cash economy. Nonetheless in practice, governments have remained reluctant to transfer such rights back to the forest dwellers. Sadly enough even where ownership of the forest is retained, one consequence of forest dwellers suddenly becoming exposed to the cash economy is that the selling of timber concessions to logging companies, to maximise short-term financial returns, may still result in long-term environmental damage. The final chapters in this section explore ways of involving local communities to avoid such adverse practices whilst maintaining or even improving the people's livelihoods.

The next appraisal by A. Hall *of the fate of local populations in tropical forests builds on the above assessment by Schweithelm and confirms the adverse impacts of market-based economies signalled earlier* by C. Hall and Ko. The arrogance implied by the blanket application of 'western' economic thought to the forest dweller situation is still exhibited by many governments and international donor agencies, as well as by large-scale corporate and export-orientated enterprises, who tend to view forest peoples as an archaic legacy of a pre-industrial era. Further, forest people are considered to represent a hindrance to 'progress' (i.e. economic development) and national sovereignty with nothing to contribute to development and economic policy and thus expendable in the cause of modernisation. Hall highlights the commonalities here with Hardin's 'Tragedy of the Commons' hypothesis, that is, a progressive degradation of common property resources such as forests based on the assumption that individual, short-term, profit maximisation (the neo-classical economics of C. Hall and Ko) will always outweigh longer-term considerations of the collective good. However, since the 1990s there has been a shift in the policy of some national governments (e.g. Brazil) and donor agencies, towards recognising that for successful management of tropical forests, local communities must be integrated into policy formulation and implementation. Various well-publicised conflicts between forest dwellers and commercial interests have contributed to this shift. For example, in Brazil, rubber tappers and fishing communities successfully challenged commercial ranchers, loggers and fishing enterprises to secure territorial integrity of large areas of communal forests and waterways. The above change in policy also recognises that conservation and law enforcement within overall forest management are both expensive and labour intensive. Centralised 'command and control' methods usually

result in a lack of human and financial capacities (or political will) to achieve these goals. Local populations, on the other hand, can offer the required institutional support based on their traditional knowledge, physical presence and customary systems of collective governance. Nonetheless, Hall too warns that the continued quest for economic development will put further pressure on the remaining tropical forests, thereby potentially jeopardising any recent advantages resulting from improved integration of local communities. He also cautions against the romanticised view that traditional groups have 'an inherent predisposition to conserving forest regardless', observing that the latter only applies as long as livelihoods are maintained and ecosystem carrying capacities are not exceeded. Further, once the equilibrium is disturbed, then the struggle to survive will inevitably outweigh environmental concerns.

In the next chapter, Kaimowitz *explores the myths and realities that surround the hydrological role of tropical forest in relation to watershed rehabilitation strategies followed by governments and major donors*. Particular attention is paid to the perceived ability of forest to control reservoir sedimentation, prevent downstream flooding and maintain dry season flows. Various examples from Central America are used to illustrate that, despite massive funding from governments and international donors, the positive impacts of recommended measures to control reservoir siltation (usually soil conservation schemes and reforestation) are usually meagre and at times perhaps even counterproductive. In some cases, this lack of a positive result is caused by the poor hydrological databases on which the evaluations were based, in others it also reflects a lack of understanding of the true role of forest in checking sediment production at the catchment scale. A case in point is provided by the massive landsliding associated with the extreme rainfall brought down by Hurricane Mitch in Honduras and Costa Rica. As explained later in the chapters by Douglas and Guyot (Part II) and Scatena *et al*. (Part III), the root system of a forest may provide some slope stabilisation with respect to shallow landslips but deeper mass movements are governed almost exclusively by geological and climatic factors. In other words, on certain geological substrates, extensive sediment production will still occur during excessive rains, regardless of whether they are covered with a well-developed rainforest or not. Furthermore, large-scale reforestation programmes recommended to reduce the risk of reservoir sedimentation, as for example in the Panama Basin, may even have an unintended adverse impact on dry-season flows. Whilst the traditional view maintained by most tropical foresters and donor agencies is that tree planting will lead to improved water yields, most experimental work suggests the contrary. The higher water use of forest vegetation compared to more shallow-rooted grass and crops may have a stronger (negative) effect on streamflow than the positive effect afforded by the higher infiltration rates commonly associated with forest, thereby creating a reduction in baseflows as the net result of forestation (see Scott *et al*., Part III, for a detailed discussion of this complex subject). Despite the high degree of awareness of governments and donors of environmental degradation in the tropics, no 'new' ideas (i.e. based on current scientific understanding) on how to best mitigate the adverse effects of land-use change seem to have emerged. For example, Kaimowitz observes that follow-up proposals for catchment management in Central America after Hurricane Mitch focus again on 'the form of small-scale reforestation and soil conservation efforts implemented in the past and will probably have similar outcomes'. One may conclude that political expediency apparently still overrides scientific knowledge when it comes to implementing forest-land-water management policies in the tropics.

On a more positive economic note, the chapter by Aylward *represents a valiant attempt to 'translate' the hydrological consequences of land use change in economic terms*. In doing so, Aylward takes up known hydrological functions from existing scientific research (albeit undertaken at headwater down to slope and plot scales) rather than from some of the 'myths' described in the previous chapter. A set of basic mathematical equations is derived to describe the economic utility (in terms of production and consumption) of various hydrological functions at the catchment scale (notably water yield, flow regime, flooding, sediment yield and water quality) and changes therein due to changes in land use (called 'externalities'). In developing countries the greatest hydrological impact of land-use change on rural upland populations is usually connected with the production of food through subsistence farming. This may lead to various degrees of soil degradation and therefore diminished on-site productivity but also to enhanced surface runoff during intense rainfall, possibly to the extent that groundwater recharge becomes sufficiently impaired to cause a reduction in subsequent dry season flows. The latter, in turn, implies reduced availability of water for drinking, irrigation or hydropower generation whereas the increased peak flows during the wet season cause economic havoc downstream in the form of silted up streams, irrigation canals, reservoirs and ports (apart from direct lowland damage caused by floods). Examples of various attempts to mesh economics with hydrology in relation to land-use change are given for both tropical and non-tropical areas. Significantly, the much greater number of studies of the externalities associated with sedimentation (34 case studies) than with water quantity (13 case studies) suggests a greater ignorance of the biophysical impacts of land use change at the river basin scale. A further problem, common to most of the case studies, is an incompatibility in time scales between the short-term, economic policy-orientated work and the need for long-term monitoring to understand the hydrological system. Most of the case studies do not have a history of good hydrological measurement and evaluation, particularly with respect to water quality impacts. On the basis of

his review Aylward suggests that watershed management policies should move away from the traditional emphasis on the protective values of forest because the hydrological externalities of land-use change are not necessarily always negative (e.g. increased water availabilty after conversion to well-managed grazing). Moreover, Aylward argues that, in economic terms, the production benefits of post-forest land use (from agricultural outputs, livestock, timber plantations) would have to decline significantly towards negative externalities of hydrological functions before rehabilitation could be considered economically justified, thereby indirectly confirming the concerns expressed by various authors earlier on in this section.

Turning next to *the governance aspect of water resources management in areas experiencing major land use change, Murdiyarso uses examples from Indonesia and the Mekong River basin to highlight the common mismatch in scale between public, land–water resources management policies at the national scale and the physical impacts of land-use change on water supply*. The latter is most significant at the local scale and directly affects communities. Governments, Murdiyarso argues, usually focus on the demand rather than the supply side of things and this easily leads to over-use of (limited) natural resouces. The bulk of forest conversion and land degradation in the humid tropics occurs generally in the uplands where many landless poor reside. Because the adverse environmental impacts of upland degradation (see previous chapter) often affect large downstream populations as well, Murdiyarso (like Aylward) proposes the introduction of a reward mechanism to transfer payments from (downstream) beneficiaries of environmental services (such as stable and high-quality streamflow) maintained by sound land husbandry practices to the providers in the uplands of these services. For this to be successful, however, greater decentralisation of decision-making down to the community level is needed through the involvement and capturing of local concerns within overall water–land resources policy formulation. Continued adjustments in governance to accommodate the above suggestions would be needed. In Indonesia, for example, recent decentralisation efforts have overestimated the capacity (human and technical) of local (district) governments to manage their natural resources sustainably. This capacity has not been correspondingly reinforced to meet the demands of decentralisation. Within the context of improved governance, Murdiyarso identifies the roles (often conflicting) of the three major stakeholder groups – scientists, policy-makers and resource managers (including local communities). It is felt that most scientists are insensitive to relevant policy questions and usually preoccupied with their disciplinary orientation. Consequently, research findings are often neglected in the public policy-making process. At the same time, policy-makers also lose credibility because they lack the scientific background or interest to utilise new research findings. To add to the complication, resources managers often follow their own business-orientated agenda. To reduce potential conflicts between different stakeholder groups, Murdiyarso calls for the development of decision support systems that are able to summarise quantitatively the detailed components of local concerns, thereby enhancing the negotiating position of poor local communities. Moreover, he emphasises the need for scientists to consider policy-relevant questions before a research agenda is designed. Equally, policy-makers and resource managers need to gain a better appreciation of the science to help focus research questions of practical relevance to policy formulation and environment (land–water–forest) resource management.

In response to the calls for greater community involvement made in several of the previous chapters, Deutsch *et al*. *provide a particularly inspiring example from the island of Mindanao, the Philippines, on how to involve community groups within a partnership of researchers, non-governmental organisations and government officials for assessing water quantity and quality within the 36 000 km^2 Manupali River basin*. The results of a survey conducted by members of the communities themselves revealed a clear west-to-east pattern of progressive land degradation that was closely associated with increasing population pressure and corresponding changes in land use (notably from forest to fire-climax grassland and subsistence cropping). The steep environmental gradient towards progressively greater environmental degradation while moving eastwards, of which changes were well within living memory, provided a truly dynamic appreciation of the project's results by the local communities. 'Put simply,' say Deutsch *et al*., 'a person in the middle of the watershed could "look west" to see where their environment had come from, and "look east" to see where it was going'. Although Deutsch *et al*. appreciate that their community-based surveys do not have the same rigour as scientific research (e.g. in the absence of automated recording and sampling equipment annual water and sediment yields are more than likely to be severely underestimated), the present approach does bring home the main points for environmental policy formulation and implementation of remedial measures. It may also assist in the formulation of working hypotheses for subsequent more rigorous research efforts. Most importantly, however, the involvement of local communities is shown to lead to a much better chance that research results actually have a policy impact. As such, it is heartening to note that the approach pioneered by Deutsch *et al*. is being adopted rapidly, not only elsewhere in the Philippines but also in mainland South East Asia and Latin America.

1 Trends and patterns of tropical land use change

R. Drigo
Formerly of FAO Forest Resources Assessment Programme

INTRODUCTION

Tropical regions have undergone dramatic land use changes in the last few decades. The myriad of changes that have, and still are, taking place are the effect of an equally large number of local causes and factors, highlighting a complexity that tends to defy easy generalisations. Major background driving forces can be recognised, however, such as rapid demographic expansion, with consequent booming demands for agricultural land and woodfuels, plus a change from a subsistence-based to a market-orientated economy, with the associated heavy pressure on natural resources to fuel economic growth and development or, in some regions, political instability and incurable conflicts.

From this complexity of tropical land use dynamics, one single resulting element has been recognized with considerable alarm over the past decades. This is the progressive depletion of natural tropical forests. It is in fact to assess the remaining area of forest and its rate of change, rather than to study the complexity of tropical land use dynamics per se, that large-scale studies have been carried out over tropical regions. From a hydrological point of view, the removal of forest cover causes important changes in runoff and sediment yields (cf. Grip *et al.*, this volume). Moreover, global concern over the fate of tropical forest has been coupled, especially during the last decade, with similar global concerns over the build-up of greenhouse gases in the atmosphere and the negative role that tropical deforestation plays in this regard (cf. Costa, this volume).

The key questions concerning the depletion of tropical forests that this chapter seeks to address include:

(1) How much forest is being lost?
This is a call for a quantification of the phenomenon and basically requires an estimation of annual rates of forest loss.
(2) Where? What are the 'hot fronts' of deforestation and degradation?
This is a call for a geographical definition of priority areas.
(3) How is forest depletion taking place? What are the processes, the cause-effect mechanisms and the trends?
This is a call for a deeper understanding of the phenomenon. Rather than a summary of the net effect, the need is to know the different forms of forest depletion (deforestation, degradation, fragmentation, etc.) and their relative importance; to know what happens to deforested lands; to know what are the processes associated with the land use change; to know the trends (deceleration, acceleration of deforestation and degradation rates).

In the last few years the understanding of the patterns and causes of land use change in the tropics has deepened considerably, highlighting the complexity of the processes involved, as well as their discontinuous and simultaneous character and, in summary, the extreme difficulty of developing the predictive models that are demanded so strongly by global change analysts (Lambin and Geist, 2001). In view of these limitations, in this chapter use is made of the information generated by large-scale scientific studies based on direct observations rather than predictive models and other more or less educated guesses. In line with this approach, the present analysis of patterns and trends in tropical land use change is based primarily on the information produced by the Forest Resource Assessment Programme (FRA) of the FAO and by the High Resolution Survey of the Humid Tropics carried out in the framework of the TREES II project (Achard *et al.*, 2002) of the Joint Research Centre of the European Commission. Of particular relevance in the analysis of processes influencing tropical land cover change and trends was the Remote Sensing Survey of tropical regions, carried out in the framework of FAO's FRA Programme during its most recent editions (FRA 1990 and FRA 2000; FAO, 1996, 2001a, 2003). These studies are all very recent and at the time of writing the available results were still rather 'crude' or available in summary format only with limited additional documentation, especially the TREES study and FAO

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Remote Sensing Survey. In some cases this has reduced the depth of the comparative analysis.

Observing land cover, inferring land use

'Land use is characterised by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it' (FAO/UNEP 1999). The term 'land use' is used here to represent the complex system of relations that man establishes with the land. By its very nature, land use definition is a subjective matter and often based on contradictory judgement. It implies not only an objective status, such as a specific cropping system, but may also reflect future intentions (for example, . . . this land is classified as being under forestry use because the owner intends to plant it up, or because it is administered by the Department of Forests . . .). Moreover, multiple uses can overlap on the same piece of land, either at the same time, as is the case for agroforestry practices, or in different periods of the year, as in the case of seasonal rotation between agriculture and pasture. Similarly, to the human mind, land uses, and land use changes, represent a blend of physical and cultural, often political, elements. Knowledge of tropical land use changes over time would help to understand the underlying cause-effect mechanisms and formulate effective remedial policies, but land use changes are often subtle, thereby defying any attempt at objective measurement and leaving room for speculation.

'Land cover is the observed (bio)physical cover on the earth's surface' (FAO/UNEP 1999). Accordingly, 'land cover', which can be considered as the net effect of the land use (or uses) at a given moment, can be measured with some objectivity. Unlike land use classes, land cover classes do have measurable physiognomic or physical characters, such as vegetation height, tree crown and biomass density. As a result, land cover monitoring represents an indirect but more objective method to measure the effects of land use changes over time, whereby complex dynamics are consolidated into net land cover changes and biomass balances. In general, the reliability of the observed land cover changes increases with the time span of the study, since the effects of inter-annual dynamics or seasonal fluctuations are reduced over longer observation periods, while those of true changes are increased.

Practically all studies over large tropical regions have been limited to the observation of land cover types through remote sensing techniques. The quality and 'depth' of the information produced, however, varies enormously, depending on scale and resolution of the imagery, the number of land cover classes observed, measurement reliability and degree of consistency within time series. In this chapter the features and findings of the most consistent and up-to-date studies of tropical regions are reviewed to highlight the trends and patterns of tropical land cover change processes.

During the last 50 years, systematic country-by-country information on the state and change of tropical forests have been produced exclusively by the FAO whose reports, in spite of some criticism (e.g. Stokstadt, 2001), have been the main, and often the only, reference for discussion and analysis at regional and global levels. The FAO's assessment techniques have developed considerably since the initial 'questionnaire' approach that was used until the 1970s, which was based on the information provided by the governments themselves and therefore vulnerable to manipulation. In the 1980 Forest Resources Assessment, the questionnaire was replaced by collection and review, country-by-country, of original references such as national inventory reports, and complemented by expert opinions, especially concerning rates of change. In the 1970s and 1980s the FAO became the world leader in assisting tropical countries with their forest inventory programmes and it could benefit therefore from the advice of a unique pool of forest inventory experts (FAO, 1981a, b, c). This condition has degraded slowly since then, along with the reduction in the FAO's field inventory operations. During the 1990 Forest Resources Assessment (FRA 1990), the assessment of countries' forest areas was based on existing national and sub-national time series of forest area estimates that were integrated by modelling techniques based on ecological and demographic variables. The model, or adjustment function (Scotti, 1990) was used to adjust forest cover areas in standard reference years and assess rates of change only for countries without multiple observations. In addition, to complement country statistics, but also to respond to questions such as 'How do tropical forests change? How much forest is degraded, or fragmented? What are the causes of deforestation? What happens to deforested land?' a pan-tropical remote sensing survey was implemented with the aim of producing consistent, thematically and statistically sound results at the regional and pan-tropical level (FAO, 1996).

The most recent FAO effort, the Forest Resources Assessment 2000 (FRA 2000), continued to collect data per country to extend and improve the time series already available but discontinued the use of mathematical modelling to fill gaps in information. These were now filled by expert opinions, consultations or in-depth studies. The FRA of 2000 continued the remote sensing survey by re-visiting the sample sites on a third date to update change estimates and assess trends. The cited country statistics and the description of regional change processes and trends resulting from the last two global assessments by the FAO, represent the main source of information on the status of tropical forests. Their findings will be discussed in the following sections.

In addition to the FAO studies, the project TREES (Tropical Ecosystem Environment observation by Satellite) of the European Joint Research Centre (JRC) has recently completed an independent survey of humid tropical regions using high resolution satellite data (mainly Landsat) covering the period 1990–1997