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FORESTS AND FLOODS IN LATIN AMERICA: SCIENCE, MANAGEMENT, POLICY AND THE EPIC FORCE PROJECT

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Abstract

The EPIC FORCE project (Evidence-based Policy for Integrated Control of Forested River Catchments in Extreme Rainfall and Snowmelt), aimed to clarify the issue of forest impact on flood response for extreme rainfall and snowmelt events and thence to develop science-based policy recommendations for integrated forest and water resources management, relevant to the Latin American environment (specifically Costa Rica, Ecuador, Chile and Argentina). Data analysis and model application support the hypothesis that, as the size of the flood peak increases, the effect of forest cover becomes less important. Guidelines for integrated water and forest resources management are developed which recognize this effect but emphasize the role that forests play in reducing the flood levels of more moderate events and in reducing soil erosion and sediment loads. Large woody debris in river channels is shown to have important benefits. The research findings are transferred to policy-making for the four Latin American focus countries, taking into account the institutional frameworks, achievable policy objectives and key stakeholders. Policy briefs have been produced at the local, national and international level and project results have been adopted in national policies. The project shows how an advance in scientific understanding can support improvements in management practices and policy formulations which affect people and the environment in which they live.

Introduction

Deforestation and logging are regularly blamed by the public and the media for exacerbating the disastrous effects of floods generated by extreme rainfall, such as hurricanes. Consequently large sums of money are invested by governments and development agencies in foresting headwater areas of river basins and land use controls are imposed on the (typically poor) populations living in these areas (CIFOR and FAO, 2005; Calder, 2005; Calder and Aylward, 2006). However, the impact of forest management on river basin response for extreme rainfall events is an area in which there is considerable scientific uncertainty as well as poorly conceived policy. In particular, while forests may be helpful in moderating floods for small storms, there is evidence that this effect is increasingly reduced as rainfall amounts increase (Thomas and Megahan, 1998; Beschta et al., 2000; La Marche and Lettenmaier, 2001; Brath et al., 2006). There is a need, therefore, for research into the impacts of forest management on response to extreme rainfall (DeWalle, 2003). Further, this research needs to be transformed into policies for the integrated management of water and forest resources which are then justified by an objective science basis rather than subjective public perception. This paper therefore presents the results of research carried out to achieve these aims through the EPIC FORCE project (Evidence-based Policy for Integrated Control of Forested River Catchments in Extreme Rainfall and Snowmelt), funded by the European Commission. The project aimed to develop policy recommendations for the integrated management of forest and water resources in the Latin American environment, based on improvements in understanding of the effects of land use on river basin response for extreme rainfall and snowmelt events and the creation of a framework within which to develop management strategies. In line with DeWalle (2003), it was intended that the results should serve as a reference for guiding the practice of forest management at a national scale and should help to reshape the attitudes of the general public. The paper proposes a definition for an extreme event, describes the project methodology and focus areas and summarizes the results concerning forest impacts, the development of improved strategies for integrated water and forest resource management and the development of evidence-based policies. It offers new insights into the effect of forest cover on flood peak discharge in extreme events and demonstrates how science, management and policy research can be integrated to develop evidence-based policy recommendations relevant to a range of national and international stakeholder interests.

Extreme events

For the purposes of the paper, "extreme rainfall" refers to high rainfall, generating floods, and does not include low rainfall, or a lack of rainfall, responsible for droughts. In order to place such extreme rainfall in context, a conceptual model was developed for defining the different scales of flood events and assessing the associated requirement for management strategies for prevention and mitigation of damage.

The traditional approach to defining an extreme event, as one which occurs infrequently, i.e. with a long recurrence interval, is not entirely suitable for hurricanes, which are certainly extreme events but which may affect a site relatively frequently. Also, relatively low magnitude events, with short recurrence intervals, can cause significant damage, especially in areas of poor land management. It is proposed, therefore, that an extreme event should be defined as one that causes damage over a certain acceptable level. The occurrence of a damaging event depends on both the generating process (i.e. the precipitation characteristics) and the catchment response. The greater the rainfall intensity, the greater the spatial occurrence and the rarer the rainfall event, the greater is likely to be the impact in terms of, for example, floods and landslides. The catchment response depends on its various characteristics, some of which are relatively little affected by human activities (e.g. geology and topography), others of which can be strongly affected (e.g. vegetation cover, land use and river channel morphology). While human activities often worsen the flood impact, they can also be directed to lessening the damage, for example through tree cover to reduce soil erosion. Plotting a precipitation index (involving intensity, spatial distribution and frequency distribution) against catchment characteristics (including human interventions as well as natural conditions) enables different levels of events to be defined (Fig. 1). These are catastrophic, disastrous, major and minor: suggested definitions are given in Table 1. Categorization of an event is useful for the development of different policies and management strategies to avoid or minimize the associated damage. Figure 1 also shows how human interventions (represented by a change in catchment characteristics) can affect the potential for different levels of event. The dashed curves represent a catchment with poor land management while the solid curves show the result of well planned management.

The EPIC FORCE project

To achieve its aims, the project had three major objectives:

1) To examine the hypothesis that, as the size of the flood peak increases, the effect of land use becomes less important; this was addressed through a combination of model application and analysis of data from focus areas in the Latin American countries;

2) To develop improved strategies for integrated forest and water management relevant to extreme events, including the management of large woody debris, such as logs, within river channels; this was addressed by combining the results of the land use impact study with field analysis and with reviews of current management practice and of best international practice;

3) To develop evidence-based policy recommendations for national agencies and for the EU and World Bank, by proposing improvements to the basis of existing national policies in the focus countries in the light of the impact and management studies.

The focus areas were in Costa Rica, Ecuador, Chile and Argentina. They represent both tropical and temperate rain forests and are subjected to extremes of rainfall from hurricanes, El Niño events, mid-latitude depressions and snowmelt. They also extend the previous research into the effects of forests on flood peaks into the Latin American environment. In addition these countries suffer major problems of flooding and erosion, are characterized by rapid forest conversion or extensive forestry activities and suffer from a lack of integrated and consistent water and forest management policies.

The EPIC FORCE project was led by the University of Newcastle upon Tyne (UK). The other partners were the Università degli Studi di Padova (Italy), the Universidad

Politécnica de Madrid (Spain), the Universidad Nacional de Costa Rica, the Universidad de Cuenca (Ecuador), the Universidad Austral de Chile, the Universidad Nacional de La Plata (Argentina) and the Secretaría de Desarrollo Sustentable y Ambiente de Tierra del Fuego (Argentina). The project website is at http://www.ceg.ncl.ac.uk/epicforce.

Full details of the results achieved for each of the above objectives are given on the project website and are to be published elsewhere: this paper can provide only an overview.

Impact of land use on peak discharge for extreme events

Data analysis was carried out to quantify directly the impact of land use, and forest cover in particular, on basin response to extreme rainfall or snowmelt for each of the focus areas. It was recognized, though, that this analysis would be limited by the available data and instrumented basins and that it might not be possible to use a common analytical approach across the four focus areas. Therefore model applications were performed to extrapolate the analyses to a wider range of conditions and to provide a systematic analysis of the impact of land use on flood peak discharge using a standard approach.

The hypothesis being examined is illustrated in Fig. 2, which shows the relationship between peak discharge and flood frequency (quantified by return period) for basins which are identical except for the level of forest cover. In both cases, the less frequent the flood (i.e. with a greater return period), the greater is the peak discharge. For moderate floods, which are relatively frequent, the forested basin is able to absorb more rainfall into the soil and therefore has lower peak discharges than the non-forested basin. This is because the greater interception of rainfall by the forest, combined with a higher transpiration by the trees, allows the build up of greater soil moisture deficits compared with the non-forested case. However, the impact of this effect is expected to decrease as rainfall amounts increase. The diagram thus proposes a convergence of peak discharge response for the more extreme floods.

Focus sites

Table 2 summarizes the general environments and management needs of the focus basins. Although they are mostly small (for reasons of practicality and data availability), in Costa Rica and Chile it was possible to extend the analysis to larger basins, hundreds to thousands of square kilometres in area. It is important to consider the larger scale because: 1) it is possible that responses observed at small scales may be attenuated or diluted at larger scales, especially where forest logging or plantation is phased across the basin or where only part of the basin is forested; and 2) larger scales are more relevant to planning considerations and provide a more appropriate basis for making policy recommendations to national agencies.

Methodology – data analysis

Because of the different availabilities of instrumented basins, different approaches to the data analysis were followed in the focus areas.

Costa Rica. Flood regimes were analyzed as a function of the history of land use, both for the Pejibaye catchment (which has been largely deforested) and the larger (1475-km^2) Matina catchment (in which the forest cover has remained constant at about 81% since the 1970s).

Ecuador. The relationships between peak stream discharge and rainfall return period were compared for neighbouring paired basins, selected for their contrasting vegetation covers, for the period 2005-2007, e.g. the 10-km^2 Panamá catchment (mainly grassland cover) and the 2.3- km^2 Lise basin (largely forested).

Chile. Peak flow characteristics were compared for La Reina basin for a full forest cover (1997-1999) and following clearfelling of the *Pinus radiata* plantation that covered 79.4% of the basin (2000-2002). The analysis was extended to three larger basins (Caramávida, 94 km^2; Mulchén, 434 km^2; and Duqueco, 1545 km^2) which have undergone significant plantation affecting at least 30% of the catchment area.

Argentina. An analysis of the effects of forest cover on seasonal snow accumulation and melt was carried out, based on experience reported in the scientific literature and adapted to the particular conditions of the Buena Esperanza focus basin.

Methodology – model application

Simulations were carried out using the SHETRAN modelling system (Ewen et al., 2000). This is a physically based, spatially distributed modelling system for flow and sediment transport, relevant at the catchment scale. It includes components for modelling vegetation interception and transpiration, snowmelt, overland flow, subsurface unsaturated and saturated flow, river/aquifer interaction and sediment yield (including inputs from landslides).

Within the data limitations, SHETRAN was calibrated against the discharge record for each basin. Then a 1000-year synthetic hourly rainfall time series, representative of current conditions, was generated from available rainfall data, so as to provide an appropriate statistical basis for defining the flood response for events with return periods of up to 100 years or so. SHETRAN was then applied to contrasting land use scenarios (generally with and without a forest cover) using the generated rainfall time series. The maximum daily discharges for the contrasting scenarios were compared for each day of the 1000-year simulations so as to investigate the degree to which the contrasting responses converge as the size of the flood peak increases. Comparison simulations were carried out as follows for the four focus areas:

Costa Rica. Simulation of the Pejibaye basin with the current vegetation cover and with a hypothetical full forest cover.

Ecuador. Simulation of the Panamá basin both with its current mainly grassland cover and with a hypothetical forest cover (using model vegetation parameters calibrated for the largely forested Lise basin).

Chile. Simulation of La Reina basin in its observed forested and logged states.

Argentina. Simulation of the Buena Esperanza basin with its current vegetation cover (which includes a native forest cover over about 36% of its lower to middle area) and in a hypothetical state without its tree cover.

Results

The most significant results are as follows.

Costa Rica. Nationally there has been an increase in the number of floods in the last 30 years, coinciding with the conversion of forest to farming and urban areas. However, the forested Matina catchment has experienced a similar increase in floods. The conclusion is that land use change is not responsible for the increase and that forest cover does not eliminate the threat of floods: they are part of the normal hydrological behaviour. Analysis for the Pejibaye catchment shows that the reduction in the percentage of the catchment covered by native forest from about 20% to 3.5% during 1970 to 2000 is too small to have had a significant impact on mean annual discharge or flood return periods. Runoff is instead dominated by rainfall, with significant interannual variations.

Ecuador. Data analysis for two pairs of catchments and the simulation results support each other. A forested catchment has lower flood peak discharges than a grassland catchment but the difference between the two decreases as discharges increases; the convergence may be absolute or relative (i.e. the difference between the two is constant but decreases as a percentage of the discharge as discharge increases) (e.g. Fig. 3). The two responses are similar for return periods of 10 years and greater.

Chile. Comparison of peak flows for La Reina catchment between the pre- and post-harvesting conditions shows that the percentage change for “large” rainfall events (for rainfall volumes greater than 50 mm) is less than that for “medium” events (rainfall volumes of 10-50 mm) and “small” events (rainfall volumes of 5-10 mm). The simulations show that the difference in peak discharge between the two cases is affected by season, type of event, soil depth and antecedent soil moisture condition. However, for shallow and moderate soil depths, there is convergence of the simulated responses as discharge increases, either in an absolute sense or as a percentage of the discharge. For each of the large basins the relationships between the event rain volume and the peak flow for the pre-plantation and post-plantation periods were compared. Extrapolation of these relationships suggests that, for events with return periods greater than 5 years, the peak flows are not significantly affected by the plantation development. Comparison of peak discharges for paired events from the pre-plantation and post-plantation periods show the same effect (Fig. 4).

Argentina. Scientific considerations suggest that: tree cover has a significant influence on the accumulation, redistribution and melting of snow, acting to reduce peak flows in rain-on-snow events; that forest clearings promote greater snow accumulations and more active melting; and that forest cover acts as a barrier to the redistribution of snow by wind from higher elevations to the lower elevations where higher temperatures support more rapid thawing. The simulations of the Buena Esperanza basin show that, in general, removal of the trees increases the peak river discharge but, for certain conditions of snowmelt, there can be a reduction. These results indicate the complicating effect of snowmelt and the difficulty in distinguishing trends concerning land use effect on peak discharges for extreme events.

In addition to the flow simulations, sediment transport simulations were carried out but for the Chile site only. They showed a clear benefit from forest cover in protecting the soil from erosion for all rainfall conditions and thus in reducing the sediment transport in the river system.

Overall the impact studies support the hypothesis that, as the size of the flood peak increases, the effect of forest cover becomes less important. Figures 3 and 4, for example, support Figure 2. This result is evident not only for small catchments (less than 10 km^2) but for larger catchments (greater than 1000 km^2) as long as a significant proportion of the catchment is affected by the change in forest cover. However, the pattern is complicated by a number of factors. The convergence of response at high flows is not necessarily absolute but may be relative. This means that forest cover may continue to moderate the flood peak discharge even though the relative effect is less noticeable. Further, the effect of the forest cover depends on more than the size of the rainfall event: factors such as soil depth, antecedent moisture content and season also play a role. Other anthropogenic impacts (e.g. the effects of roads) and climate changes may have greater effects and so drown out the forest signal. In catchments with snowmelt regimes, forest cover can both increase and decrease peak discharges relative to the unforested case and it is difficult to perform a clear test of the hypothesis.

Strategies for water and forest resources management relevant to extreme events

A framework of guidelines was created within which strategies for integrated water and forest resources management could be developed for a catchment. The framework was required to combine the best management practice at the international level with a sound scientific basis (including the above results concerning extreme events), while remaining sufficiently flexible to incorporate the individual characteristics of the range of Latin American catchments.

Recognizing a) that a catchment cannot be managed in isolation from the needs of its inhabitants (often poor) who make their living off its water, soil and forest resources, and b) that it would be necessary to combine mitigation of the impacts of floods with the management of water resources under all hydrological conditions, including periods between floods, the framework took as its starting point two principal objectives:

1) The management of the catchment to protect its inhabitants against the impacts of rainfall and snowmelt events (both moderate and extreme) such as floods, soil erosion, debris flows and sediment depositions;

2) The optimal management of the water and soil resources in support of a sustainable way of life for the inhabitants of the catchment.

Achieving these objectives requires an understanding of the characteristics of the catchment and a means of predicting its response to the full range of rainfall events.

The major components of the framework are:

1) A matrix of scenarios for water and forest resources management in a catchment. The catchment is divided into an upper, headwater, part and a lower part, such that developments in the former could have an impact on conditions in the latter. Each of these parts is further divided into two zones of higher and lower altitudes. Against each of these four divisions are set two slope conditions, greater or lower than 20%. Eight scenarios are thus proposed, defined according to the physical and flood characteristics of the zone and providing a guide to selection of the appropriate flood control and other mitigation measures, including the potential for using forest cover.

2) A matrix which synthesizes the information relevant to management for rainfall events (moderate and extreme), snowmelt events and periods between events. The information includes the hydrological phenomena, the hydrological impacts, the science basis for event and process analysis, the data required for impact analysis, mitigation techniques, the principal steps in planning the management, and recommendations for taking extreme events into account.

3) A matrix of the criteria relevant to cost/benefit analysis for the proposed management strategy. The criteria include the mitigating effects of the strategy, methods for quantifying those effects (e.g. mathematical models), and economic criteria for evaluating the benefits of the strategy. A graphical scheme is also proposed for determining the cost (or damage) of an event on the basis of the conceptual model outlined in Fig. 1. This could be applied using an understanding of the catchment characteristics and response mechanisms together with model simulations of the response for required event magnitudes. The conceptual model provides a means of developing appropriate management strategies for the different levels of event (minor, major, disastrous, catastrophic).

Within the Latin American context, it is proposed that interventions should not be undertaken for extreme events because of the cost and because the required level of intervention could limit the use of the catchment by its inhabitants. It is recognized that there is not necessarily a perfect management solution: the catchment hydrological functioning, the expected level of protection and the use of soil and water resources must be balanced against the quality of life of the inhabitants. Successful strategies are likely to involve continuous adaptation and maintenance of implemented measures.

The framework of guidelines was used to develop management strategies for each of the project focus areas. Each application involved a brief description of the catchment, identification of the most appropriate management focus and the production of tables summarizing the management strategy.

Costa Rica. The Pejibaye catchment has been largely deforested and is characterized by cultivation and pasture. In general there is a need to provide flood protection and maintain the long-term sustainability of agriculture. Soils are vulnerable to erosion, especially by shallow landslides, so there is a need to maintain vegetation cover and apply soil conservation measures. It is noted that secondary forest can quickly establish itself if so allowed, with good hydrological and soil protection benefits. It is proposed, therefore that secondary forest should be allowed to develop in the more vulnerable areas of steep slopes and river banks.

Ecuador. The Chanchán catchment has been largely deforested and agriculture has spread to all areas, including steep slopes and the headwater páramo zone characterized by andosols which provide valuable soil water storage. Once these soils are ploughed their hydrological function is lost irreversibly and they are easily eroded. The catchment is subjected to spectacular rotational landslides. In general there is a need to provide flood protection and soil conservation while maintaining the long-term sustainability of agriculture. The prime management recommendation is conservation of the andosols, for example through reforestation and subsequent sustainable exploitation of the trees. In addition, reforestation could be targeted on steeper slopes showing signs of erosion or shallow landsliding.

Argentina. The Buena Esperanza catchment is used for water supply for Ushuaia and recreation. Important management objectives are the maintenance of the forest in its lower zone as protection for Ushuaia against rain and snowmelt floods and sediment depositions, sustainable use of the water resources and maintenance of the forest ecosystem for tourism and national heritage reasons. The benefit of the forest can be quantified by calculating the cost of the infrastructure which would otherwise be needed to provide the same level of protection for the urban area. It is recognized that the forest may not provide complete protection against a flood derived from an extreme event but it nevertheless protects very efficiently against a range of moderate to high floods, minimizing maintenance costs for roads for example.

Chile. The above approach to management strategies is less relevant to the managed forest plantation in the Chilean focus area. However, good practices can still be defined to support forest management which is sustainable from the environmental and socio-economic points of view, with the aim of enabling forestry companies to achieve environmental certification for their operations. A major objective is to minimize sediment production and so maintain stream water quality, both for human consumption and for forest and aquatic habitats. The required practices are well known and include the use of buffer strips to protect stream environments, design and use of forest roads to minimize drainage and sediment fluxes into streams, and minimization of soil disturbance by machinery and other forestry activities.

The guidelines recognize that afforestation may not be an effective technique for reducing the peak discharges of floods derived from extreme but infrequent rainfall events. However, forests remain effective in reducing the flood levels of more moderate events (which occur more frequently) and are a potent means of reducing soil erosion and sediment loads at all levels of event. Conversely, it has long been understood that forest cover reduces annual runoff from a catchment.

Full details of the framework of guidelines and its applications are given in Mintegui and Robredo (2008).

Impact and management of Large Woody Debris (LWD)

Flood damage can be exacerbated by the battering effect of logs carried by the flow or by the sudden release of water (and sediment) when a log jam fails. The project therefore examined the role of large woody debris in river channels and the means that are available for managing its impact.

Measurements of woody debris characteristics in two Chilean headwater streams in the Andes foothills and in the Buena Esperanza stream in Argentina (Andreoli et al., 2007; Comiti et al., 2008) showed that old-growth forest in Chile in particular could yield high in-channel storage of wood, over 500 m^3 per kilometre length of channel. Significant differences in characteristics occur as a function of catchment history (e.g. supply of wood from forest fire or wind throw). However, it was found that the log jams formed by large woody debris in the stream channel can account for 25% of the total elevation drop along the channel and can store over 1000 m^3 of sediment per kilometre length of channel, which is comparable with annual yields. To these beneficial effects may be added the greater diversity of ecological habitat. It is therefore recommended that the removal of woody debris and riparian trees should be carried out only locally, for example where the failure of a log jam could have dangerous consequences. In general, removal is expensive and may ultimately be counter-productive, with adverse impacts on stream morphology, stability and ecological status.

Best practice guidelines for managing large woody debris were produced, with particular relevance to the protection of downstream urban areas. The guidelines provide details on the design and construction of control structures such as check dams, rope nets, and cable filters, as well as riparian woodland management. However, control structures are expensive and decisions on their installation should involve cost-benefit analysis. A separate and detailed guide was provided for the design and use of check dams constructed from natural materials such as logs and boulders, with particular relevance to restoration of degraded rivers.

As much of the available literature concerns relatively small streams, the project research was specifically extended to larger rivers, where the impacts of large woody debris on settlements and infrastructure can also be serious (e.g. bridge blockage). A means of detecting and quantifying woody debris volumes in large gravel-bed rivers using high-resolution aerial photographs was successfully tested.

Because the focus areas for the large woody debris study were within the temperate zone, the methods and results which were developed should be applied with caution to tropical river systems, for which further investigations on in-channel wood dynamics are needed.

Development of evidence-based policy briefs and recommendations for water and forest resource management

EPIC FORCE was designed as a policy-oriented project, paying particular attention to the involvement of local stakeholders and the joint development of recommendations based on local conditions and interests. Research has shown that the quality of this interaction can be explained by three key factors: the policy context, the adequacy of the evidence and the existence of appropriate links between researchers and stakeholders (Crewe and Young, 2002; Young, 2005). In each of the four Latin American focus countries, the project partners developed a strategy for policy impact paying attention to these three factors. The variety of local conditions and interests meant that the modes of interaction were different in each country. A common key feature, though, was the establishment of National Working Groups (NWG) at the very start of the project, to provide the views of key stakeholders (such as national water and forest agencies) and the necessary legitimacy and policy links. The evidence basis was supplied by the forest impact research, the evaluation of forest and water resources management options and the analysis of existing national policies. The final outcome of the project is a set of policy briefs for the Latin American countries and for international agencies, integrating the impact, management and policy research. These briefs are being published by UNESCO's Regional Science Office for Latin America and the Caribbean (in Montevideo, Uruguay) as part of its International Hydrological Programme, in partnership with the Programme of Ecohydrology at the Universidad Nacional de La Plata, Argentina.

As part of the methodology which underpinned the policy research, reviews were conducted of the current scientific understanding of the links between forest and water and of the best international practice on interfacing research and policy. The main steps in the policy research were then as follows, for each Latin American country:- review of the institutional framework for relevant policy-making; presentation of the strategies that could be followed to maximize policy-impact in the three-year lifetime of the project; overview of the importance of extreme events; review of the institutional framework for the management of extreme events and forest and water resources; identification of the lessons emerging from the impact, management and policy research and from the stakeholder interaction; and production of consolidated policy recommendations. A set of eight policy briefs provide a summary of the general principles and findings of the project on extreme events, use of modelling and field data to support policy making, the interaction between forests and water, the role of forests in extreme events, catchment restoration and management of large woody debris. Sets of policy briefs were also written on topics specifically relevant to each focus country. The policy developments for each country are as follows.

Costa Rica. A strategy for policy impact was devised with a bottom-up approach working at the local level (Pejibaye focus catchment), national level (National Working Group) and Centro-American region level (Centro-American Support Group), following a multi-stakeholder approach (Warner, 2005). An important element was the development of a methodology for creating participatory policies for catchment management. The overall theme was catchment protection for extreme events; in spite of the frequent emergencies due to hurricanes, the country does not have a long term policy for land management to mitigate the impact of extreme events. Targeted policy briefs were produced for the main national policy development and implementation agents in Costa Rica as follows:- (1) policies based on scientific evidence for managing the impact of land use on river discharge for extreme hydrometeorological events; (2) building institutional capacity for managing the Pejibaye River catchment, in Canton Pérez Zeledón; (3) management of the Pejibaye River catchment for extreme events; (4) agro-ecological restoration of the Pejibaye catchment; and (5) health policy and extreme events. These have been disseminated at a variety of levels. At the national level, the experience in Canton

Pérez Zeledón was used to generate a discussion on policy areas which could incorporate the project results with the help of the members of the NWG. The extrapolation of these policy improvements to other countries in the region will be promoted through the Centro-American Support Group.

Ecuador. The institutional framework for forest and water management in general, and in relation to extreme events in particular, is quite chaotic and has been changing constantly over the last 20 years. There is a whole set of applicable legislation but it is not clearly understood by the different actors and therefore not generally applied in practice. However, the Ecuadorean Constitution is currently being reviewed, which has opened new windows of opportunity for influencing policy. Accordingly, targeted policy briefs have been written specifically as a means of communicating key messages to the working groups of the Constitutional Review. They cover: (1) the need to use best scientific evidence for the development of policies relevant to extreme events; (2) protection against landslides triggered by extreme events; (3) protection of the páramo soils; and (4) protection of the native forests in headwater catchments. These briefs have been presented directly to policy makers in Quito, emphasizing the role of research in the development of evidence based policies for the challenge of managing heavily used Andean catchments subject to El Niño events and frequent landslides.

Chile. The presence or variation of forest cover in large catchments is not perceived to be an influencing factor on the impact of extreme floods. The country does not have a specific policy to mitigate the impact of extreme events. However, the presence of a big industrial forestry sector provides the opportunity to influence the practices of the main forestry companies. The project therefore concentrated on achieving agreements to incorporate improved management practices in the main certification systems operating in the country, involving companies and certifiers at an early stage of the process. It also sought to reach agreements with the forest public administration to incorporate improved practices as administrative rules in forest management plans. Success saw a range of proposals accepted for improvement of the forest plantation standard CERTFOR. Also a Best Management Practice Guide for minimizing soil erosion during forestry activities was produced and will be considered as a working tool by the CERTFOR Forest Plantation Standard (Gayoso and Gayoso, 2008). Following review, the guide will be published on CERTFOR's home website and will be recommended for used by forest owners. Targeted policy briefs were produced on the issue of the impact of forest growth on water resources at local and catchment levels and the improvement of the certification standards mentioned above. These have been disseminated within the forest and water resources industry. The certification developments will continue beyond the end of the project, ensuring a potential long term impact of EPIC FORCE results in Chile.

Argentina. The focus was the management of forested catchments for extreme events (including snowmelt) in the Andino-Patagonic region. The implementation of policies for natural resources management (water and forest) at both national and provincial levels is fragmented. It does not consider the hydrological consequences of forest management and does not incorporate the management of forest cover as a tool for water resources management. The policy objectives were centred on the integrated management of water and forest resources in Tierra del Fuego and other provinces of the Andino-Patagonic region. They included the generation of planning guidelines for forested catchments to be used by planning authorities at the municipal and provincial levels, which could be used throughout the Andino-Patagonic region, and the regulation of catchments specifically in Tierra del Fuego province. Interactions with policy-makers were very successful, resulting in the adoption by the Consejo Hídrico Patagónico (COHIPA) of recommendations for the management of Andino-Patagonic catchments in the drafts for the National Water Plan, and in recognition of the significance of the forest cover for the sustainable management of the Buena Esperanza catchment. Targeted policy briefs were produced on: (1) reduction of catchment vulnerability in extreme events; (2) planning of urban areas in torrent catchments; and (3) hydrological risk studies to support preventive planning. The briefs have been presented to the national and provincial water resources authorities via the Federal Water Resources Council COHIFE (Consejo Hídrico Federal) and specifically to the Patagonian Water Resources Council COHIPA (Consejo Hídrico Patagónico).

Conclusion

The EPIC FORCE project aimed to clarify the issue of forest impact on flood response for extreme rainfall and snowmelt events and thence to develop policy recommendations for integrated forest and water resources management, based on sound science. The results obtained from the combination of data analysis and model application, support the hypothesis that, as the size of the flood peak increases, the effect of forest cover becomes less important. This dispels a popular belief to the contrary. It also adds significantly to the previous literature by extending the finding to a range of Latin American forest and climatic environments and showing that the effect may be significant not only for small catchments but for larger catchments as well, as long as the change in forest cover affects a significant proportion of the catchment. There are, however, a number of factors which can complicate the pattern and which should be investigated by further research. Amongst these are that, in catchments with snowmelt regimes, forest cover can both increase and decrease peak discharges relative to the unforested case. A framework of guidelines was created within which strategies for integrated water and forest resources management could be developed. This combines mitigation of the impacts of floods with the management of water resources under all hydrological conditions, in support of a sustainable way of life for the inhabitants of the catchment. The guidelines recognize the limitations of afforestation as a technique for reducing the peak discharges of floods derived from extreme but infrequent rainfall events. They emphasize, though, the role that forests play in reducing the flood levels of more moderate events (which occur more frequently) and in reducing soil erosion and sediment loads at all levels of event. This role is central to the management strategies developed for the four focus areas. Forests also generate large woody debris in river channels. This debris has sufficient beneficial effects (such as slowing the flow, storing sediment and improving biodiversity) that its general removal is not recommended. A range of techniques is available for controlling its movement by high flows.

The forest impact research and the proposals for management strategies enable the basis for policy-making for water and forest resources management to be shifted from misperception to firm scientific evidence. The bases for the transfer of research findings to different spheres of policy-making have been established, with different approaches adopted to suit the different conditions of the four Latin American focus countries. Particular emphasis has been placed on analysis of the institutional frameworks for the management of extreme events and forest and water resources in each of the countries, the identification of achievable policy objectives and the development of links with key stakeholders. Policy briefs have been produced at the local, national and international level and project results have been adopted in national policies. Overall the EPIC FORCE project is a successful demonstration of how the integration of science, management and policy research can not only improve fundamental understanding of the underlying science but also recommend management and policy developments which are adopted at the local, national and international level. The project has used an advance in scientific understanding to improve management practices and policy formulations which affect people and the environment in which they live.

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Table 1 Proposed definitions of event scale and associated policy and management strategies

Event category	**Definition**	**Policy/management strategies**
Catastrophic	Precipitation index implies impacts independent of catchment features. Large changes in river morphology, regional geomorphological impact (e.g. extensive landsliding), extensive damage to main infrastructure and urban areas in the floodplain.	Emergency response, warning systems, vulnerability assessment, policies on infrastructure development and land use in danger areas (e.g. from EPIC FORCE project)
Disastrous	Precipitation index implies impacts where vegetation cover is below a critical level, depending also on catchment physical features. Water and sediment movements outside the floodplain, erosion and sedimentation outside the river channel, damage to bridges and roads outside the floodplain, local changes to geomorphology (landslides)	Land use policies, improvement of adaptation and resilience measures, vulnerability assessment, management strategies for critical catchment areas (e.g. from EPIC FORCE project)
Major	Moderate precipitation index implies impacts depending on vegetation cover and predisposition of catchment to slope failures. Frequent events (recurrence interval 2 years), water and sediment movements within the flood plain, erosion and sedimentation within the river channel, damage to infrastructure within the floodplain, movement of large woody debris in the channel.	Land use regulation, integrated catchment management (to maintain effective vegetation cover), channel engineering, specific management strategies (e.g. from EPIC FORCE project)
Minor	Precipitation index low enough that, depending on vegetation cover and catchment physical condition, there may be no significant hillslope erosion. Frequent events, water and sediment movements within the river channel (bankfull), damage to some infrastructure within the river channel.	Integrated catchment management (to maintain effective vegetation cover)

Table 2 Overview of the four focus areas

Focus area and location	Climatic characteristics	Land use	Problem impacts	Needs
Pejibaye catchment (131 km^2), southern Costa Rica	Seasonal rainfall including hurricanes (1988, 1989, 1999)	Rapid forest conversion to pasture/coffee plantation; water resource degradation	Flooding and soil erosion forcing home abandonment	Integrated basin management; policies for minimizing poor practice and for supporting sustainable land management
Subcatchments at scale 1-10 km^2 in Rio Chanchán catchment (1409 km^2), Ecuador	Seasonal rainfall with severe El Niño effects (e.g. 1982)	Rapid forest conversion to agriculture/secondary vegetation/exotic plantation	Very high erosion and sediment yield affecting drinking water quality, irrigation systems and port operation	Integrated basin management; identification of sediment sources (including human impact) and control procedures
Experimental forest catchments (especially La Reina, 0.35 km^2) in southern Chile	High seasonal and all year rainfall (up to 4000 mm) with large interannual variability from El Niño effects	Extensive exotic, short rotation plantations; native forest logging and degradation	Flooding, soil erosion and debris flows; water pollution and decreased water yields	Improved forest, native forest and water legislation; best management practice guidelines; rural poverty amelioration schemes
Buena Esperanza (12.9 km^2) and Hambre (18 km^2) catchments in Tierra del Fuego, Argentina	Moderate and frequent precipitation all year from frontal systems, enhanced by orographic effect; extreme events from combined rainfall and snowmelt (e.g. 1954).	Native forest exploitation; forest regeneration impeded by cattle introduction; tourist activities affect the natural environment and water quality.	Flooding and debris flows; landslides and avalanches on steep slopes; soils poorly developed and with poor stability; frequent wind throw of trees.	Integrated basin management; mitigation of human impacts on virgin landscapes; soil degradation control and water quality preservation; best forest management practice; flooding and debris flow control

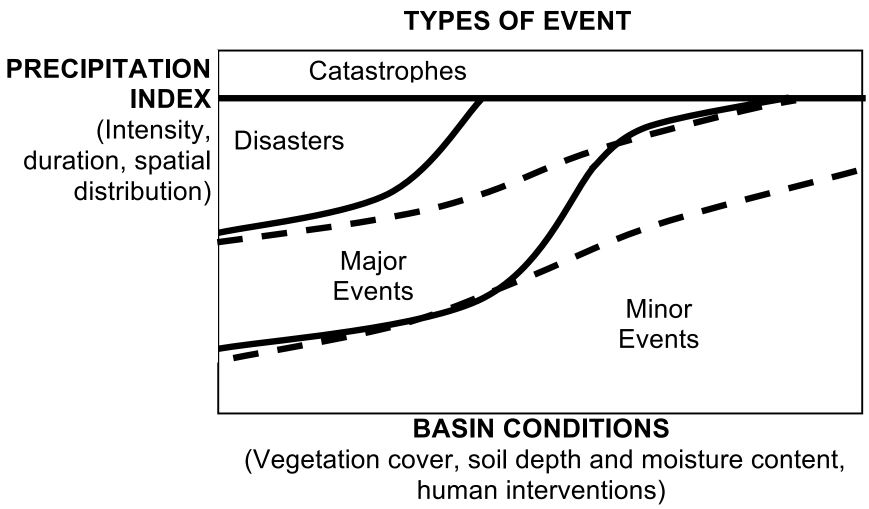
Figure Captions

Figure 1. Plot of precipitation index against catchment response for defining different scales of event. The dashed curves represent a catchment with poor land management while the solid curves show the result of well planned management

Figure 2. The hypothesis that, as the size of the flood peak increases (i.e. the flood has a greater return period), the effect of land use on the flood peak discharge decreases

Figure 3. (a) Comparison of observed peak specific discharges for the Panamá and Lise catchments (Ecuador) for the same storm events; solid line is line of equality. (b) Comparison of maximum daily discharges (m^3 s^{-1}) for the current vegetation and a hypothetical forest cover from the 1000-year SHETRAN simulations of the Panamá catchment; line is line of equality. Both diagrams indicate relative convergence of the catchment responses as discharge increases

Figure 4. Comparison of paired peak discharges from before and after forest plantation in Duqueco catchment, Chile; line is line of equality



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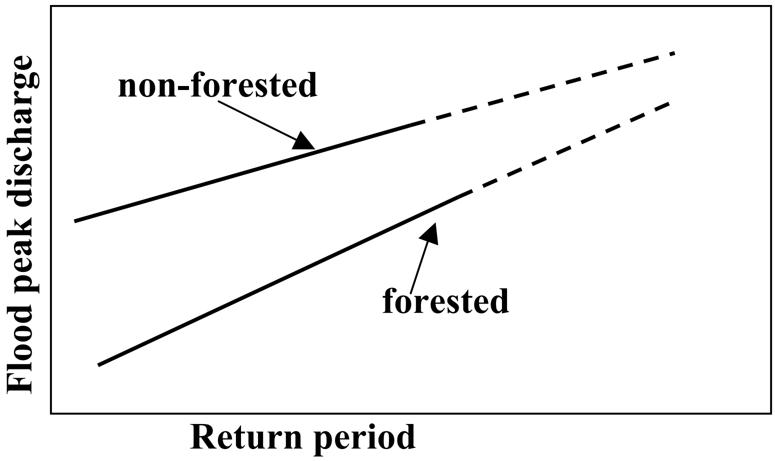

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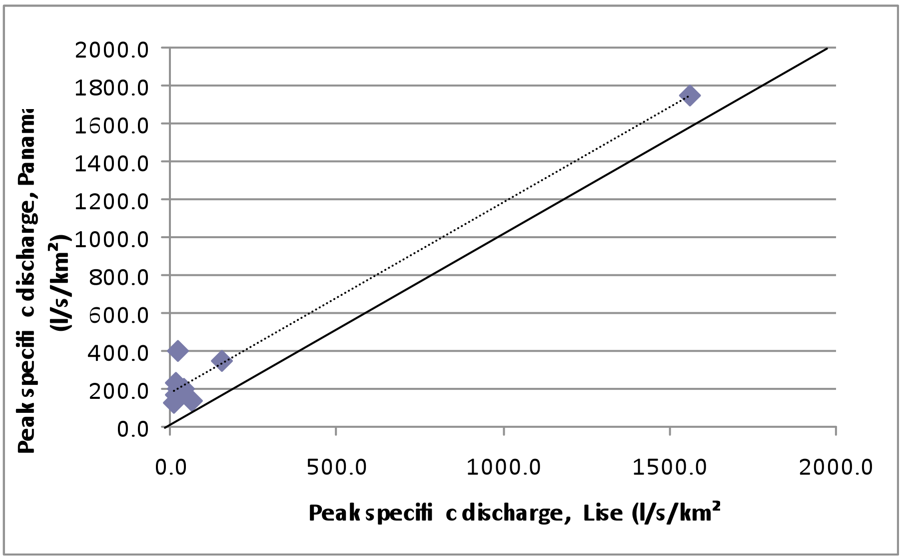
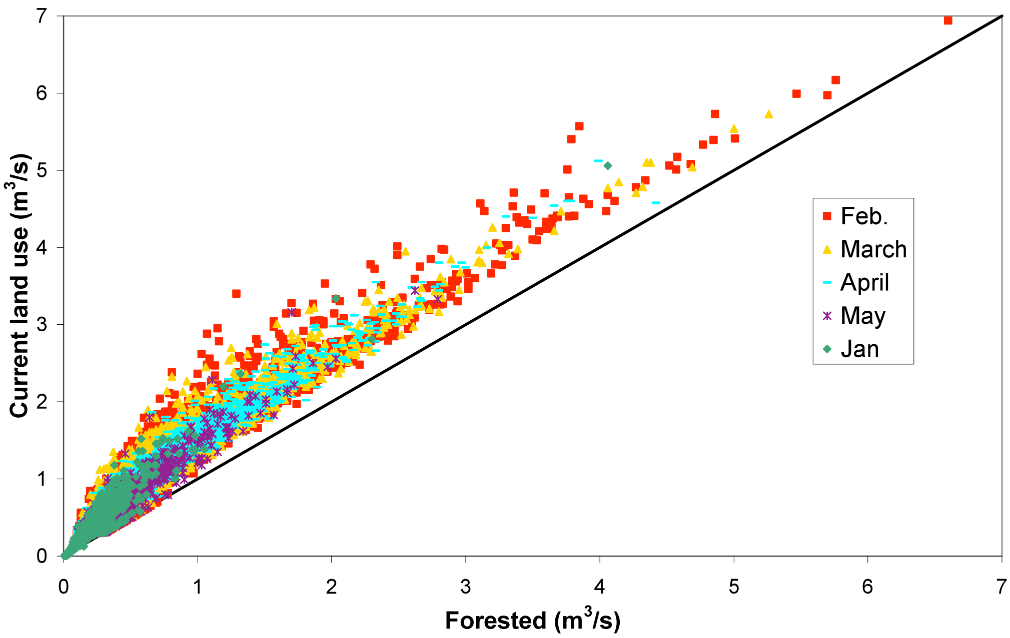
(a)



(b)



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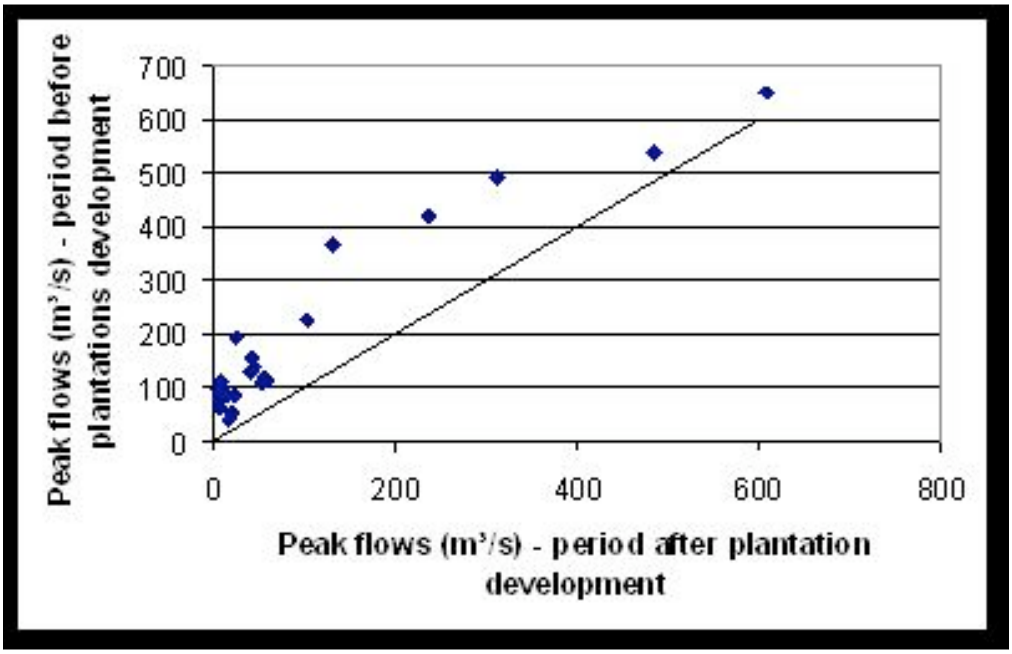

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