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EPIC FORCE

Evidence-based Policy for Integrated Control of Forested River Catchments in Extreme Rainfall and Snowmelt

Instrument: Specific Targeted Research Project

Thematic Priority: Specific Measures in Support of International Cooperation, Developing Countries, A.2 Rational Use of Natural resources, A.2.1 Managing humid and semi-humid ecosystems

Deliverable 14 (Revised)
Model Analysis of Land-use Impact on Flood Response for the EPIC FORCE Focus Areas

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EXECUTIVE SUMMARY

The impact of forest management on river basin response (in terms of water flow and soil erosion) 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 reduce floods for small storms, there is evidence that this effect is increasingly reduced as rainfall increases. Therefore, through a combination of model development and the analysis of data from focus areas, the EPIC FORCE project examined the hypothesis that, as the size of the flood peak increases, the effect of land use becomes less important. This report (Deliverable 14) describes model applications in the project focus areas in Costa Rica, Ecuador, Chile and Argentina to examine the impact of forest cover on peak discharge for floods ranging from the moderate to the extreme.

A model of each focus basin was constructed using the SHETRAN physically based, hydrological and sediment transport modelling system. Each model was calibrated for the outlet river discharge, as far as was possible with existing data. However, it was not expected that the models should reproduce the basins and their responses exactly: rather it was intended that they should be generally representative of the principal characteristics of the basins, and especially of their flood responses. For each focus basin, a 1000-year synthetic rainfall time series was generated, representative of the current climate. This time series was then used to run the calibrated model for the basin with contrasting land use scenarios (generally with and without a forest cover). The peak discharges for the contrasting scenarios were then compared and analyzed to show the extent to which the responses converged as the size of the peak discharge increased.

In Costa Rica the focus site is the 131-km^2 Pejibaye basin. This was simulated with its current vegetation cover (agricultural) and with a complete forest cover, in each case with the same 1000 years of input data. Comparison of the maximum daily discharges for the two vegetations shows that, in general, as the discharge increases, the absolute difference between the two becomes smaller. These results therefore support the hypothesis. However, the simulations were then repeated with an increased overland flow resistance for the forested case compared with the current vegetation, resulting in divergence of the responses. Support for the hypothesis therefore appears to be sensitive to the exact model characterization.

In Ecuador, two small basins were modelled: Lise (2.34 km^2, largely forested) and Panamá (10 km^2, largely grassland). The Panamá basin was simulated with its current vegetation cover and with a full forest cover (using the vegetation parameter values from the Lise basin calibration), in each case with the same 1000 years of input data. Comparison of the corresponding maximum discharges for each day of the simulations shows that the discharge difference between the two land use cases remains constant in an absolute sense but decreases as a percentage of the discharge as discharge increases. This precisely mirrors the field data analysis in deliverable D16.

In Chile the focus site is La Reina basin (35 ha). This was calibrated for two observed land uses: plantation forest (1997-1999) and in a logged condition (2000-2001). The calibrated models were then run with the same 1000-year synthetic rainfall time series. Comparison of the corresponding maximum discharges for each day of the simulation showed that the difference in peak discharge between the two cases is affected by season, type of event, soil depth and antecedent soil moisture condition. For shallow and moderate soil depths, there is convergence of the responses as discharge increases, either in an absolute sense or as a percentage of the discharge. The reasons for this are that: a) the wetter the antecedent conditions, the smaller is the difference in discharge between the forested and logged cases, at least as a percentage of discharge; b) higher discharges occur only when the antecedent conditions are wet; and therefore c) the difference in response decreases as discharge increases. For deep soil there is no convergence.

In Argentina the focus site is the 12.9-km^2 Buena Esperanza basin in Tierra del Fuego. Hydrological response is affected by snowmelt as well as by rainfall. The basin was simulated for a 1000-year period and for the largest recorded flood (in 1954) both with its current vegetation cover (which includes partial forest cover) and with the forest cover removed. In general, removal of the trees increases the outlet river discharge but, for certain conditions of snowmelt, there can be a reduction in discharge. The results agree with the field analysis in deliverable D18 in indicating the complicating impact of snowmelt and the difficulty in distinguishing trends concerning land use effect on peak discharges for extreme events. However, inclusion of the 1954 event in the analysis of land use impact suggests that there may be at least relative convergence of peak discharge for extreme events.

Overall the simulations support the hypothesis that, as the size of the flood peak increases, the effect of land use becomes less important. However, the pattern is complicated by a number of factors, such as soil depth. Also the result is probably most relevant to small basins, of the size of the test sites in Ecuador, Chile and Argentina.

Sediment transport simulations were carried out 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.

CONTENTS

Model Analysis of Land-use Impact on Flood Response for the EPIC FORCE Focus Areas

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1 INTRODUCTION

1.1 Context of Report

The impact of forest management on river basin response (in terms of water flow and soil erosion) 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 reduce floods for small storms, there is evidence that this effect is increasingly reduced as rainfall increases. EPIC FORCE therefore aimed to improve fundamental understanding of forest impacts on floods. Building on this knowledge it also aimed to improve the integrated management of forest and water resources at the river basin scale through the development of policies based on sound science. Its focus was the impact of forest management on river basin response for extreme rainfall and snowmelt events, in the Latin American environment. The project achieved its aims by linking scientific, management and policy research via the following 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 hydrological model application and analysis of field 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, to form a set of matrix-based guidelines;

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, countries which represent a range of humid forest and rainfall/snowmelt regimes with major flood and erosion problems and which suffer from a lack of integrated water and forest policies.

This report (Deliverable 14) describes the application of the hydrological model to the four focus areas to examine the impact of forest cover on peak discharge for floods ranging from the moderate to the extreme. This work contributed towards achieving Objective (1).

1.2 Modelling Approach

A particular impediment to the study of forest impacts on response to extreme rainfall/snowmelt events has been the lack of data on such events, which by their nature are rare at any given location. One means of extracting as much information as possible out of existing data sets is to use them to calibrate mathematical models which are then applied to scenario events, such as extreme floods. Such models can be powerful tools for providing important insights into the controls on basin response to land use change (e.g. Bultot et al., 1990; Nandakumar and Mein, 1997; Storck et al., 1998; Lukey et al., 2000; Niehoff et al., 2002; Ranzi et al., 2002). Within the EPIC FORCE project, the Latin American partners identified appropriate river basins for study, assembled datasets on the hydrological, sediment and land use characteristics of those basins and analyzed the flood response for sub-basins with different levels of forest cover and for at least one extreme event. This work was carried out within Work Packages 1-4 and is reported in Deliverables 15-18. The work described here, carried out in Work Package 5, extends this analysis through the application of a hydrological model to quantify systematically the impact of land use on flood peak and sediment yield in each focus area. The work was carried out by Newcastle University, with support from the Latin American participants.

Physically based models form the most suitable basis for extrapolating to land use and climate conditions not included in the available data record. The work was therefore 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 basin 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).

Construction and validation of a fully representative SHETRAN model for each of the individual sub-basins in each focus area was not possible within the project timeframe. Therefore SHETRAN was applied generically. Models were set up to be generally representative of each focus area in terms of vegetation cover, soil type and topography but not to reproduce it exactly. Similarly model validation did not seek the exact reproduction of the observed hydrographs and discharge time series. Instead the aim was to ensure that the models were representative at the level of derived data such as annual flood series, flow duration curves and sediment yields normalized for basin area. Nevertheless, in most cases it was also possible to achieve a good agreement between the observed and simulated discharge time series.

The general modelling approach for each focus basin was as follows:

1) Calibrate SHETRAN as far as possible for the focus basin;
2) Apply the model to contrasting land use scenarios (generally with and without a forest cover) for a range of flood events;
3) Compare the peak discharges for the contrasting scenarios;
4) Investigate the extent to which the contrasting responses converge as the size of the flood peak increases;

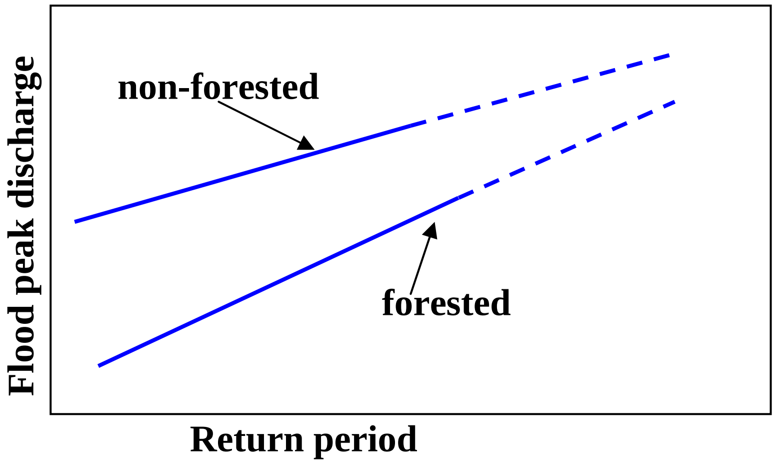

Figure 1.1 The hypothesis was tested that, as the size of the flood peak increases, the effects of land use become less important

5) Investigate the effect of forest cover on soil erosion and basin sediment yield for the range of flood events.

The hypothesis which was examined is illustrated in Fig. 1.1, 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, 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.

It is the physical basis of the SHETRAN model which allows it to be used to investigate the effects of changes in vegetation cover. Thus evaporation and interception are modelled with equations which are based on the physics of the relevant processes. Their parameters have a physical meaning and can be altered in value using physical reasoning to represent different vegetations. For example, one option in the model is for actual evapotranspiration to be modelled with the Penman-Monteith equation. This contains the parameter aerodynamic resistance: physical reasoning suggests that the resistance should be lower for trees than for grass and indeed experimental measurements have provided typical values of 50 s m^{-1} for grass and 5 s m^{-1} for forest.

1.3 Focus Basins

The basins selected for simulation were as follows:

Costa Rica	Ecuador	Chile	Argentina
Pejibaye, (131 km^2)	Panamá (10 km^2) and Lise (2.3 km^2), sub-basins of the Rio Chanchán (1409 km^2)	La Reina (0.35 km^2)	Buena Esperanza (12.9 km^2) and Hambre (18 km^2)

A general overview of the focus areas, taken from the project Details of Work, is shown in Table 1.1.

1.4 Overview of Results

The SHETRAN simulations are presented in the order of the project partner numbers: Costa Rica, Ecuador, Chile and Argentina. However, at the start of the project the data availability was more complete for the Chile focus site than for the other sites and that site was therefore modelled first. Consequently the general modelling approach was devised using that site and the results are most complete for that site. The reader may therefore wish to examine the section on the Chile simulations first.

A consistent result was obtained across the four focus areas, with the simulations supporting the hypothesis overall. Loss of forest cover raises annual runoff totals and flood event peak discharges. Forests can thus reduce flood peaks at low to moderate flows. However, as the peak discharge increases to extreme levels, the overall difference in peak discharge between the forest and non-forest scenarios decreases either absolutely or relatively. The reasons for this are that: a) the wetter the antecedent conditions, the smaller is the difference in discharge between the forested and logged cases, at least as a percentage of discharge; b) higher discharges occur only when the antecedent conditions are wet; and therefore c) the difference in response decreases as discharge increases. The convergence is less clear for deeper soils. Also, 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.

Simulations of soil erosion and sediment transport completed for the Chile site show that there is a clear benefit from forest cover in terms of protection against erosion.

Table 1.1 Overview of the four focus areas

Focus area and location	Climatic characteristics	Land use	Problem impacts	Needs
Pejibaye basin, 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
Chanchán basin, 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 basins 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
Two 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.	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

2 PEJIBAYE BASIN, COSTA RICA

2.1 Description of Basin

Pejibaye is a 131-km^2 basin in Costa Rica. Figure 2.1 shows the shape of the basin with elevations ranging from 345 m at the outlet up to 1100 m. The basin has mainly cultivated land or grassland cover with some forest (around 13% of the basin), mostly found on the steeper and higher ground in the south and west of the basin. In 1948 around 95% of the basin was forested but between then and 1961 there was a major clearance and by 1961 forest cover was reduced to around 25%. Mean annual precipitation is around 2200 mm with slightly higher values in the upper part of the basin and lower values towards the outlet. Most of the precipitation falls during the wet season from May to November. More details of the basin can be found in Deliverable 15.

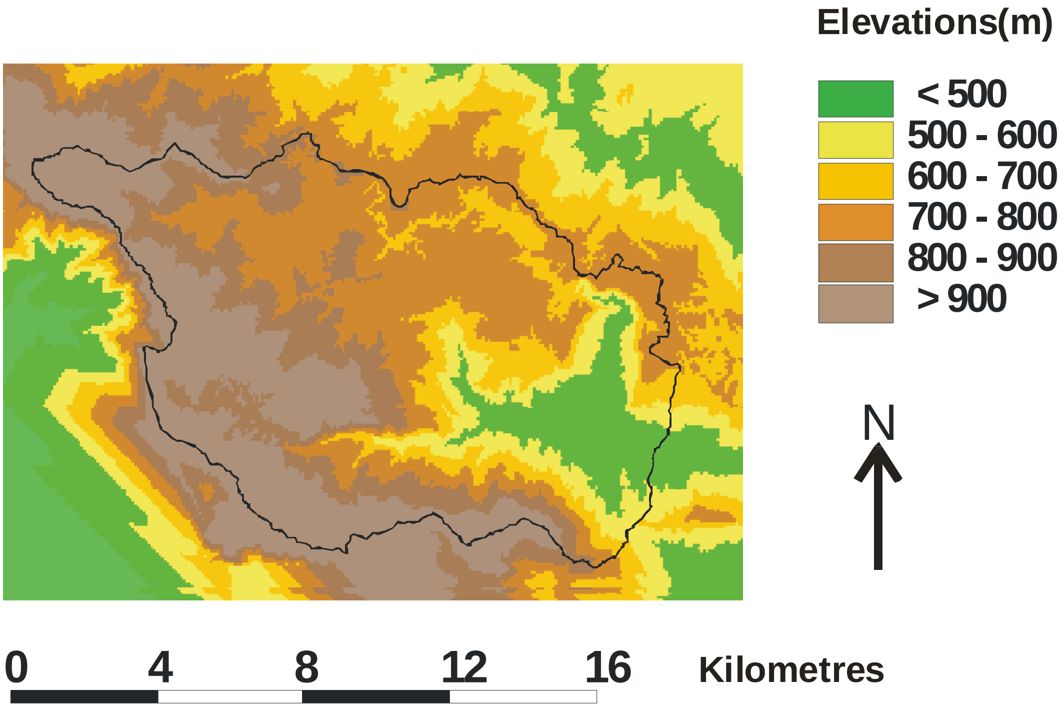

Figure 2.1 The Pejibaye basin

2.2 Data Collection

Data for the basin are provided by the Universidad Nacional de Costa Rica (UNCR), as described in D15.

2.2.1 Spatial data

A DEM and river network data are available. Satellite imagery has been used to investigate the spatial distribution of soil type and vegetation properties. Soil pits have been dug at various points in the basin to investigate the soil properties.

2.2.2 Time series data

Monitoring of the Pejibaye basin has been carried out for a number of years. From around 1970 onwards daily precipitation data have been measured at three sites in and around the basin: Bolivia situated near the middle of the basin, Aguas Buenas in the north-west corner of the basin and Cristo Rey around four kilometres north of the basin. For 1991-1993, hourly precipitation data is also available for Bolivia. Data for mean daily discharge at the outlet are available from 1969 to 1996 together with the highest maximum discharge for each month. Daily potential evaporation has been measured at Bolivia since 1972.

2.3 Model Set-up

2.3.1 Basin set-up

The SHETRAN mesh for the Pejibaye basin uses 511 500-m x 500-m grid squares and 137 river links (20 m wide) that run along the edge of the grid squares (Figure 2.2). The modelled elevations can be seen in Figure 2.2. The simulation period was 1/1/1991 to 31/12/1993 for which hourly precipitation data is known. The simulation used precipitation from only the Bolivia raingauge in the centre of the basin. Additional work was carried out using data from the Aguas Buenas site in the north-west corner of the basin but this did not improve the simulations. The simulation period includes the extreme hurricane event on 14th September 1993 when 331.5 mm of rain fell in 13 hours and, at its most intense, 78mm fell in 1 hour.

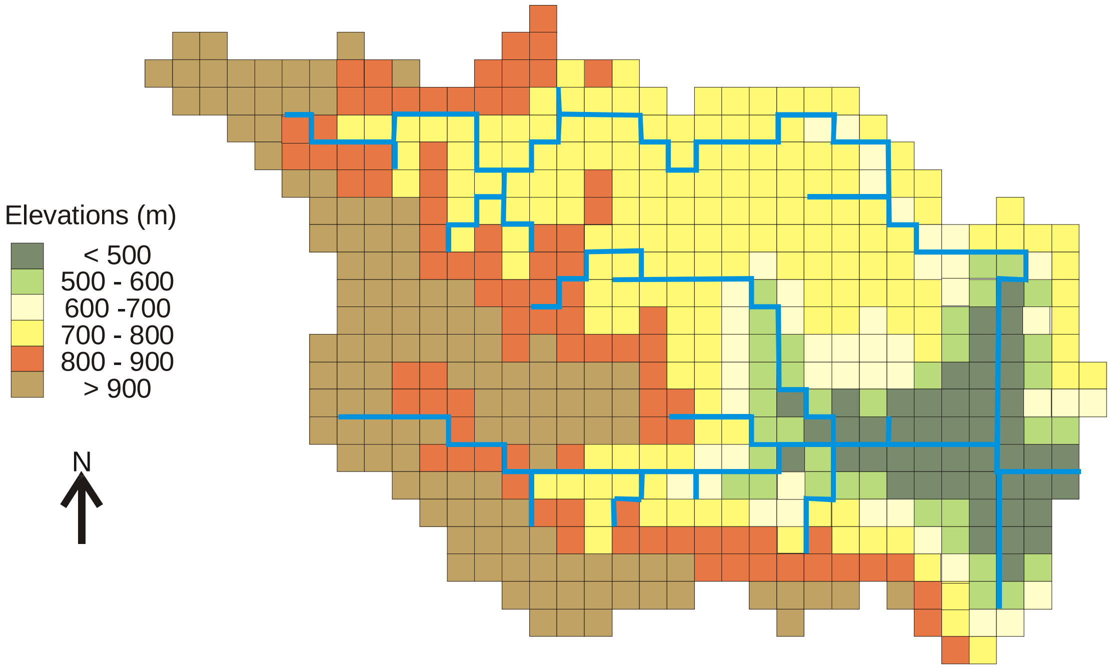

Figure 2.2 SHETRAN mesh (500-m grid squares) and elevations for the Pejibaye basin. The stream channels run along the edge of the grid squares

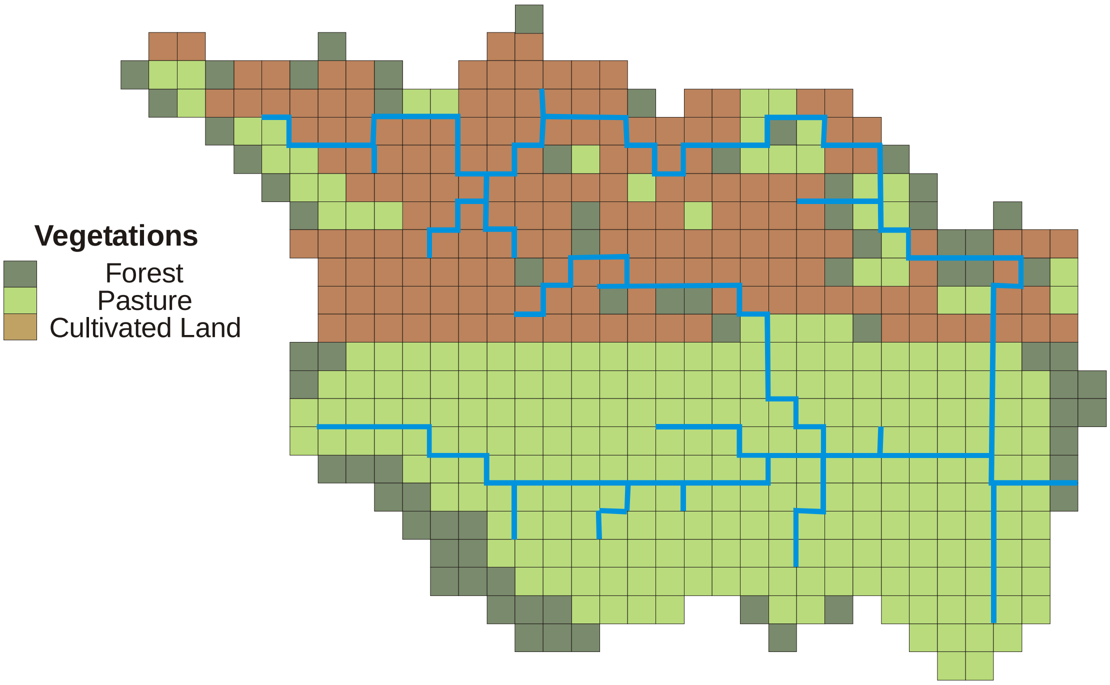

Figure 2.3 SHETRAN vegetations for the Pejibaye basin

The vegetation type for each grid square can be seen in Figure 2.3. Three different vegetation types are specified. Forest is found mainly in the south-west part but there are also pockets scattered throughout the rest of the basin. Cultivated land is mainly found in the flatter northern part of the basin, with grassland in the steeper southern part. The spatial distribution of soil texture contains three classes (Figure 2.4). The northern part of the basin has fine soils which, for the SHETRAN model, were considered to have a silty clay texture. The southern part has moderately fine soils which were considered to have a silty loam texture and the area around the river near the outlet of the basin has larger particles and was considered to have a sandy loam texture. Based on data supplied by UNCR soil depths in SHETRAN were set to 2m.

The vegetation parameters used in the SHETRAN simulations can be seen in Table 2.1. Given the available information on evaporation, the actual evaporation is calculated using the Penman equation. It uses a function relating the ratio of actual /potential evaporation to the soil moisture tension. This function takes into account the reduced evaporation as the soil dries. However, using the Penman equation does not take into account the lower aerodynamic resistance of forest cover and, as a consequence, the considerably higher interception evaporation. To simulate this effect, a canopy storage higher than typical measured values was used in the forest (Table 2.1). The effect of the lower aerodynamic resistance was also taken into account by having a higher actual / potential evaporation ratio in the forest than in the grassland and cultivated land (Table 2.1).

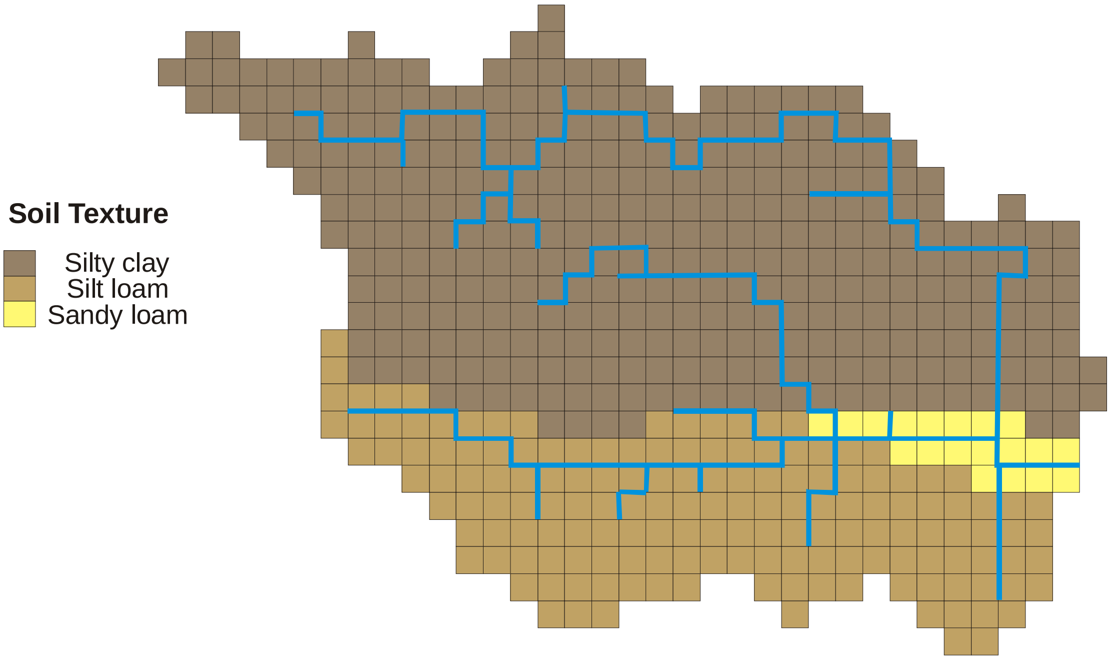

Figure 2.4 SHETRAN soils for the Pejibaye basin

Table 2.1 Vegetation parameters used in the SHETRAN simulation of the Pejibaye basin. The AE/PE ratio is the actual evaporation divided by the potential evaporation at field capacity. In the model the ratio decreases with increasing soil moisture tension

Vegetation	**Canopy Drainage**		**Canopy Storage (mm)**	**Rooting Depth (m)**	**Leaf Area Index**	**AE/PE Ratio**
	Ck(mm s^{-1})	**Cb (mm^{-1})**				
Forest	1.0E-5	5.1	5.0	1.2	5.0	0.7
Grassland	1.0E-5	5.1	3.0	0.5	3.0	0.4
Cultivated	1.0E-5	5.1	3.0	0.5	1.0	0.4

Initial simulations using standard soil parameters for the measured textures found in the basin (Figure 2.4) produced a poor comparison between the simulated and measured flows. Various combinations of soil hydraulic conductivity and overland flow parameters were therefore tried to improve the simulation. For simplicity during each simulation all the soil types were given the same hydraulic parameters, which are typical of a silt loam: porosity of 0.452, residual moisture content of 0.093, Van Genuchten alpha parameter of 0.052 cm^{-1} and a van Genuchten n parameter of 1.7. The soil hydraulic conductivity and overland flow parameters were then calibrated to give a good match between the measured and simulated discharges at both an hourly and daily scale. The results were a saturated hydraulic conductivity of 10 m day^{-1} and an overland flow Strickler resistance coefficient of 4.0 $m^{1/3}$ s^{-1}. The value of 10 m day^{-1} for the saturated conductivity is considered to be typical of what is expected if some macropore flow is present.

Total monthly sediment yield data was supplied by UNCR. Basic SHETRAN sediment yield simulations were carried out with the following soil size distribution selected from the SHETRAN library, with the percentages shown in brackets: 0.1 mm (60%), 0.37 mm (20%), 0.89 mm (10%), 1.59 mm (5%), 2.25 mm (3%), 3.5 mm

(2%). The most important parameters affecting soil erosion are the raindrop impact and overland flow erodibility parameters. These were assumed to be constant for all the soil and land use conditions and calibrated values are shown in Table 2.2.

Table 2.2 Sediment parameters used in the SHETRAN simulation of Pejibaye basin

Raindrop erodibility coefficent J^{-1}	**Overland flow soil erodibility coefficient $kg\ m^{-2}\ s^{-1}$**
0.8	$1*10^{-10}$

2.3.2 Water flow calibration

The comparison between the simulated and measured discharges for January 1991 – December 1993 can be seen in Figure 2.5. The comparison is for the mean daily discharge. SHETRAN simulations were actually run using an hourly timestep and hourly precipitation input but the results were averaged over the 24 hours to allow comparison with the measurements. The discrepancy between the simulated and measured discharges at the start of the period arises from the use of uncalibrated initial conditions in the simulation. (There was no preceding run-in period.). Most of the events in 1993 have simulated values higher than the measured values. This is thought to be due to the use of a single raingauge to represent the entire basin, whereas in reality there is a significant spatial variation. Otherwise, though, throughout the entire period the simulations show an excellent match with the measured values (Nash-Sutcliffe efficiency = 0.85). In particular the major event on 14th September 1993 is well captured.

Figure 2.6 shows the simulated and measured maximum monthly discharges. Again there is a generally good match between the simulated and measured cases. The biggest event on 14th September 1993 is so much larger than the rest that it is not shown on the figure. The measured value of 1373 m^3/s is considerably larger than the simulated value of 985m^3/s. However, this is considered acceptable considering the use of a single rain-gauge, and the problems of measuring precipitation and discharge for this sort of extreme event.

Analysis of the annual mass balance (Figure 2.7) shows that the total measured and simulated discharges are similar in all years. In 1992 the simulated discharge is slightly lower than the measured value and in 1993 it is slightly higher. Again, this appears to be due to the use o0f a single rain-gauge for the entire basin. Interception evaporation accounts for 49% of the simulated evaporation, equivalent to 21% of the precipitation, while the remainder comes from transpiration and bare soil evaporation.

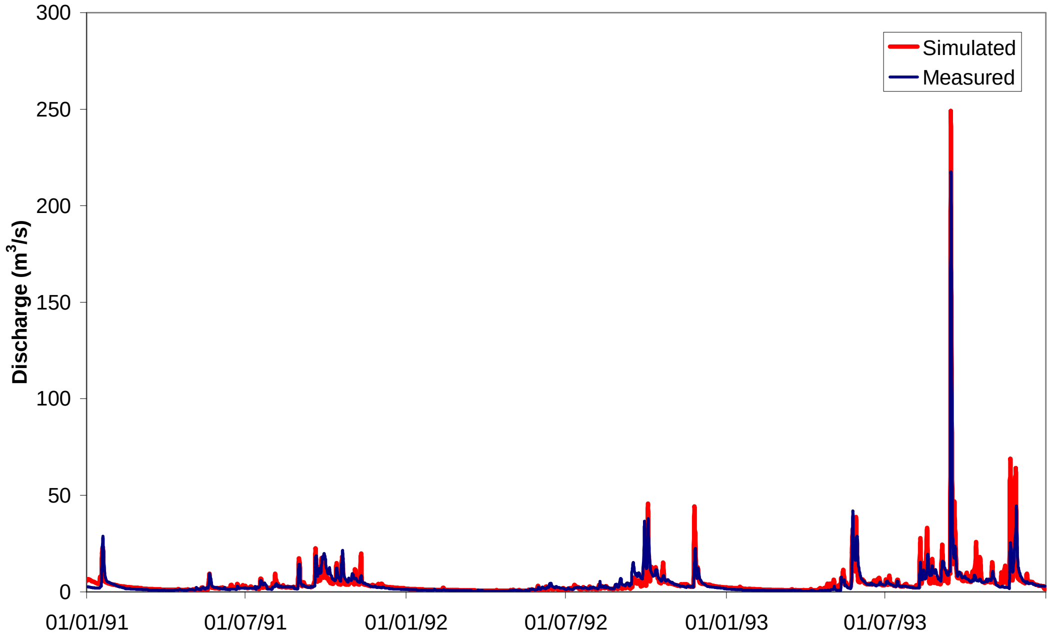

Figure 2.5 Simulated and measured mean daily discharges at the Pejibaye basin outlet, January 1991 – December 1993

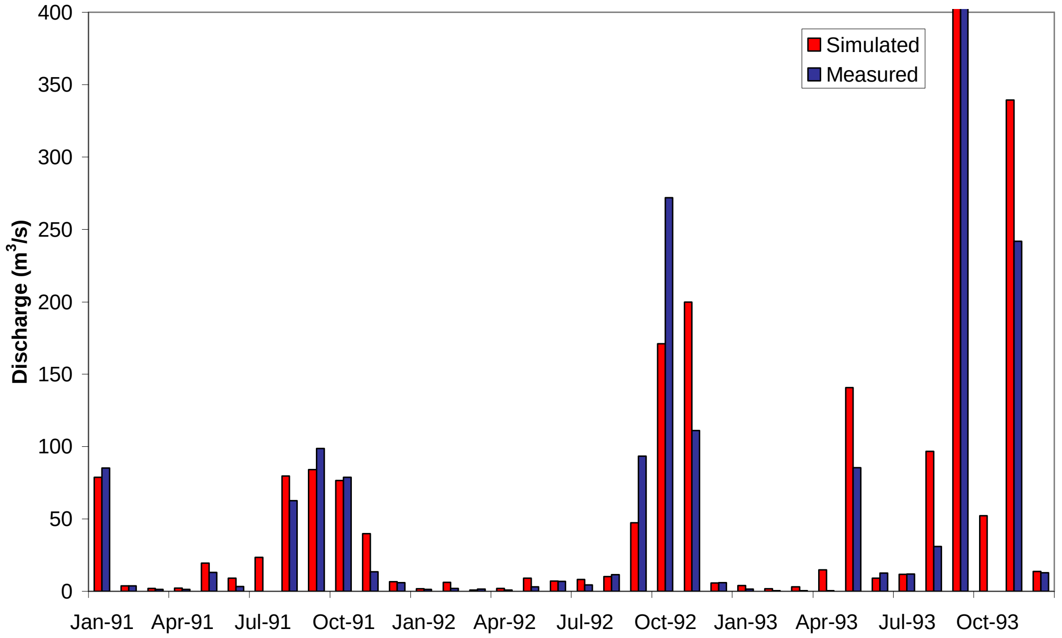

Figure 2.6 Simulated and measured maximum monthly discharges at the Pejibaye basin outlet, January 1991 – December 1993. In September 1993 the simulated value is 985 m^3/s and the measured value is 1373 m^3/s. There are missing measured data in July 1991 and October 1993

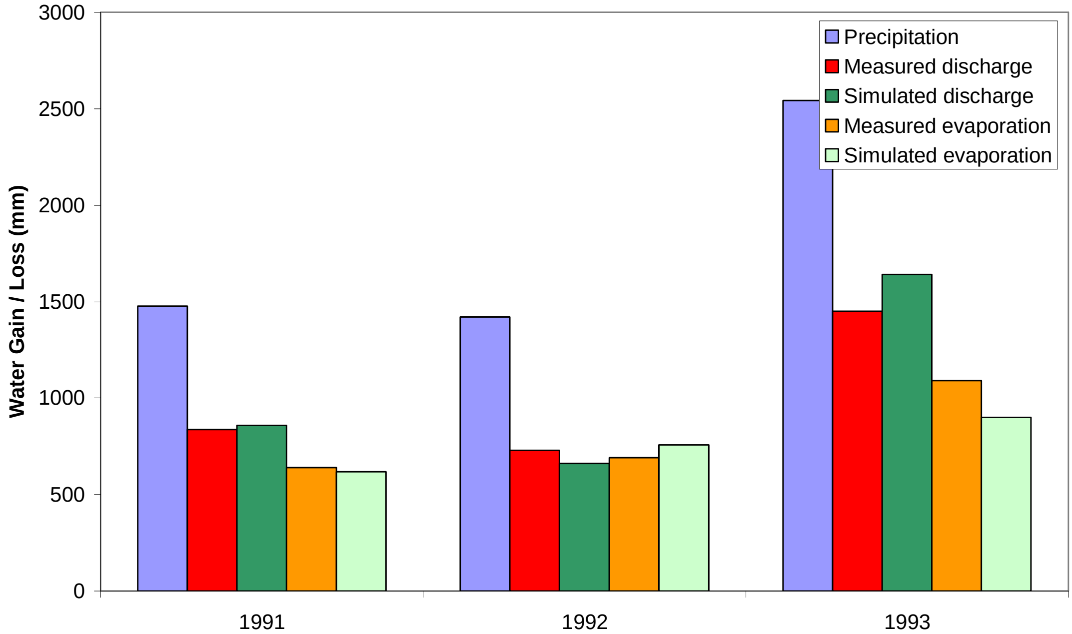

Figure 2.7 Simulated and measured mass balances for the Pejibaye basin, January 1991 – December 1993

2.3.3 Sediment yield calibration

The comparison between simulated and measured monthly sediment yields can be seen in Figure 2.8. Generally there is a reasonable agreement. In most months the simulated values are slightly higher than the measured values, whereas in September 1993 (which includes the major event on September 14th) the simulated total is smaller than the measured total. The total simulated sediment yield of 1.43 t ha^{-1} yr^{-1} is similar to the measured value of 1.27 t ha^{-1} yr^{-1}.

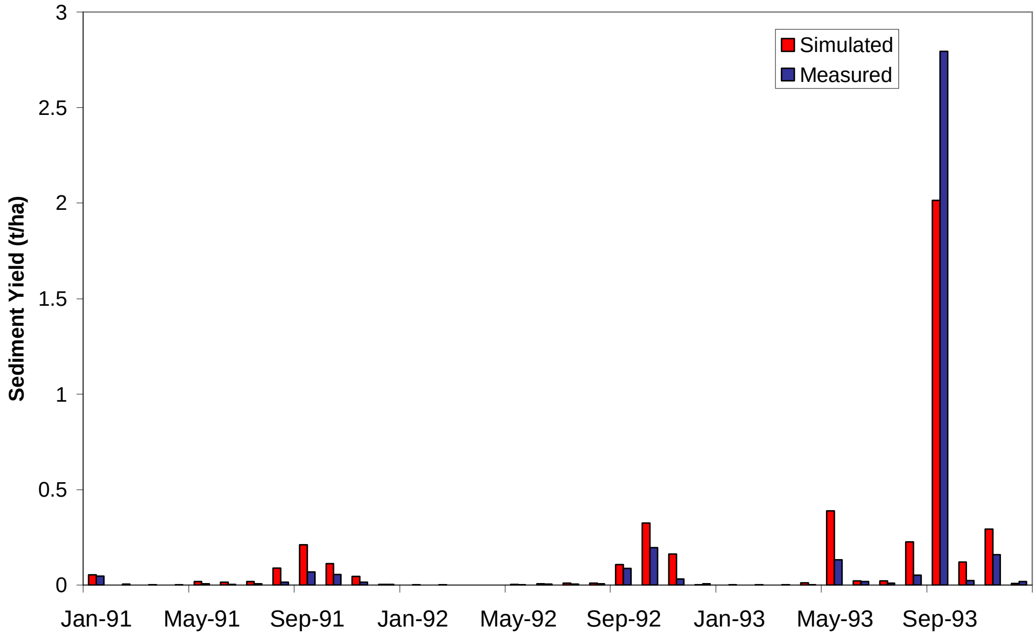

Figure 2.8 Simulated and measured sediment yields at the Pejibaye basin outlet, January 1991 – December 1993

2.4 Modelling Strategy

The aim of the modelling is to test the hypothesis that, as the size of the flood peak increases, the effect of land use becomes less important. To achieve this aim, SHETRAN was used to simulate the flood response for the period January 1991 - December 1993 and for a 1000-year time series of precipitation data representative of current climatic conditions (see Section 4.4 for an explanation). In both cases these simulations were run for the current basin vegetation cover and for the conditions before 1948 when at least 95% of the basin was forested. The corresponding maximum daily discharges for each day of the two simulations were then plotted against each other to see if there were progressive differences in their relationship between low and high flow conditions.

In Chile and Ecuador, data were available to calibrate SHETRAN under different land-uses (Sections 3 and 4). For the Pejibaye basin, though, this was not the case. To simulate forest cover the vegetation parameters were changed on the basis of past experience (Table 2.1) but no information was available about the Strickler overland roughness coefficient. For the Chile and Ecuador simulations this parameter value was not changed under different land-uses and so this approach (Scenario A) was used here. However, as a sensitivity test (Scenario B), a reduced roughness coefficient (from 4 $m^{1/3} s^{-1}$ to 1 $m^{1/3} s^{-1}$) was also tested to investigate the effect on flood peaks.

The 1000-year time series of precipitation data was derived using daily precipitation data from the Bolivia site for 25 years from 1971-2005 and the three years of hourly data from the same site. An hourly time series was obtained by combining the monthly statistics for the daily data with the variance and skew statistics for the hourly data in the Newcastle University Rainsim statistical model.

2.5 Simulations and Results

2.5.1 Scenario A

The Pejibaye basin was simulated under the current vegetation and under complete forest cover for January 1991 to December 1993 (Figure 2.9). This scenario used the same overland flow roughness coefficient for the forested and current land uses. As expected the results show that the forested basin has more evaporation and so a lower discharge. This difference in discharge between the two cases varies depending on the antecedent conditions. However, even for the major event on 14 September 1993, when 331 mm of rain fell in 13 hours, the discharge under the forest (928 $m^3 s^{-1}$) is still lower than with the current vegetation (985 $m^3 s^{-1}$).

The maximum daily discharges for the two cases for the 1000-year simulation are compared in Figure 2.10. As expected, the highest discharge events take place in August, September and October corresponding to hurricane events. Figure 2.10 shows that there can be a range of “current” responses for a given “forested” discharge, depending on antecedent soil moisture conditions. At the start of the wet season in June there is a bigger difference in the antecedent soil moisture conditions between the “current” and “forested” vegetations and so in general a bigger difference in the discharge between the two cases. Thus the points in Figure 2.10 representing the start of the wet season lie further from the line of equality. By contrast, in November at the end of the wet season, there is a smaller difference in antecedent soil moisture and the discharges in the two cases are more similar with points nearer the line of equality. If all the events are considered it can be seen that in general, as the discharge increases, the absolute difference becomes smaller. The maximum difference is for an event in August which has a difference of over 200 $m^3 s^{-1}$ between the “current” and “forested” cases (382 $m^3 s^{-1}$ for forest and 591 m^3/s for the current vegetation). For the largest ten events (discharges exceeding 1000 $m^3 s^{-1}$), though, the difference is around 100 $m^3 s^{-1}$ or less.

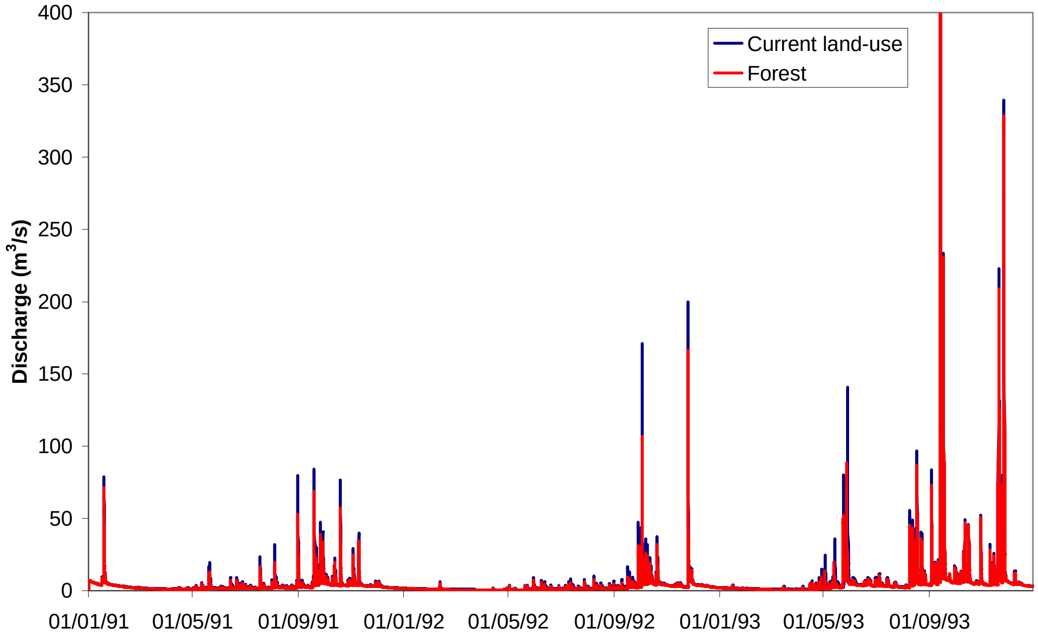

Figure 2.9 Scenario A comparison of hourly discharges (m^3 s^{-1}) for current vegetation and forested conditions from SHETRAN simulations of the Pejibaye basin for January 1991 - December 1993. On September 14th 1993 the peak discharge is 985 m^3 s^{-1} for the current land use and 928 m^3 s^{-1} for the forest cover

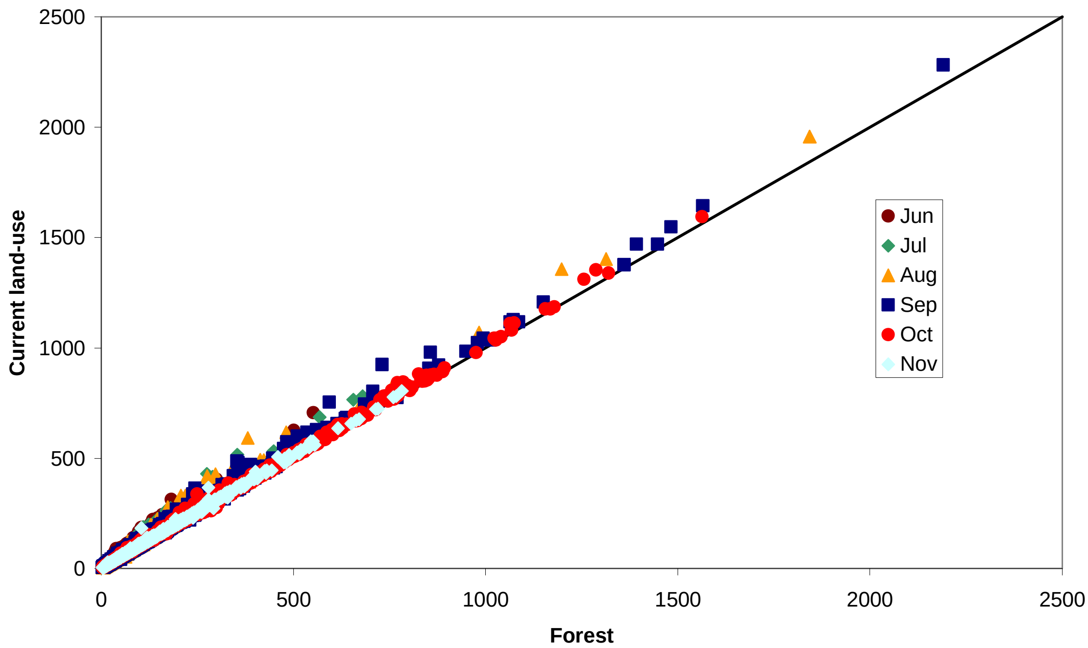

Figure 2.10 Scenario A comparison of maximum daily discharges (m^3 s^{-1}) for current vegetation and forested conditions from the 1000-year SHETRAN simulations of the Pejibaye basin. Line is line of equality. There are no major events from December through to May

2.5.2 Scenario B

In Scenario B (as in Scenario A) the Pejibaye basin was simulated under the current vegetation cover and under complete forest cover from January 1991 to December 1993. However, in this case the Strickler overland flow roughness coefficient was reduced (i.e. the resistance was increased) from 4 $m^{1/3}$ s^{-1} under the "current" vegetation to 1 $m^{1/3}$ s^{-1} under "forest". The results can be seen in Figure 2.11. As in Scenario A, these show that the forested basin has more evaporation and so a lower discharge. However, the difference between the two vegetation types for peak events is considerable greater than in Scenario A. The effect of the reduced Strickler coefficient for the forest is to reduce the size of the peak discharge and extend the length of the tail. The current vegetation therefore produces the higher peak flows. However, if the hydrograph recession extends across more than one day, there may then be a higher discharge under the forest than under the current vegetation.

The maximum daily discharges for the two vegetations are compared for the 1000-year simulation in Figure 2.12. In this case the bigger the discharge, the greater is the difference between the "current" and "forested" cases (although the percentage difference remains similar as the event size increases). However, for smaller events which are later in the recession following a rainfall event, the "forested" discharge is sometimes greater and so points below the line of equality can be seen. The forest can be thought of as slowing down the flow of surface water for big events and so it reduces the peak discharge but increases the length and size of the recession.

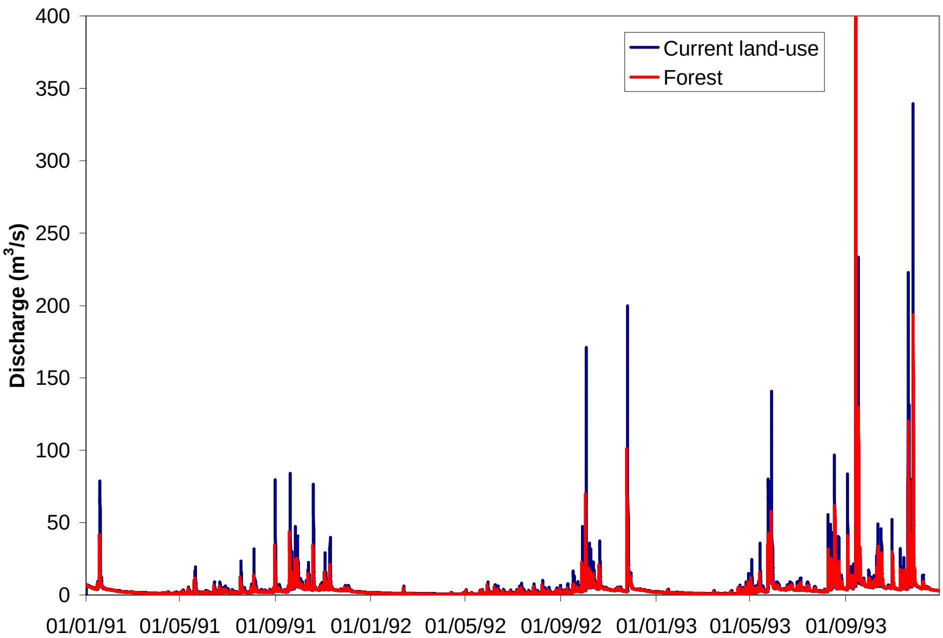

Figure 2.11 Scenario B comparison of hourly discharges (m^3 s^{-1}) for current vegetation and forested conditions from SHETRAN simulations of the Pejibaye basin for January 1991 - December 1993. On September 14th 1993 the peak discharge is 985 m^3 s^{-1} for the current land use and 772 m^3 s^{-1} for the forest cover

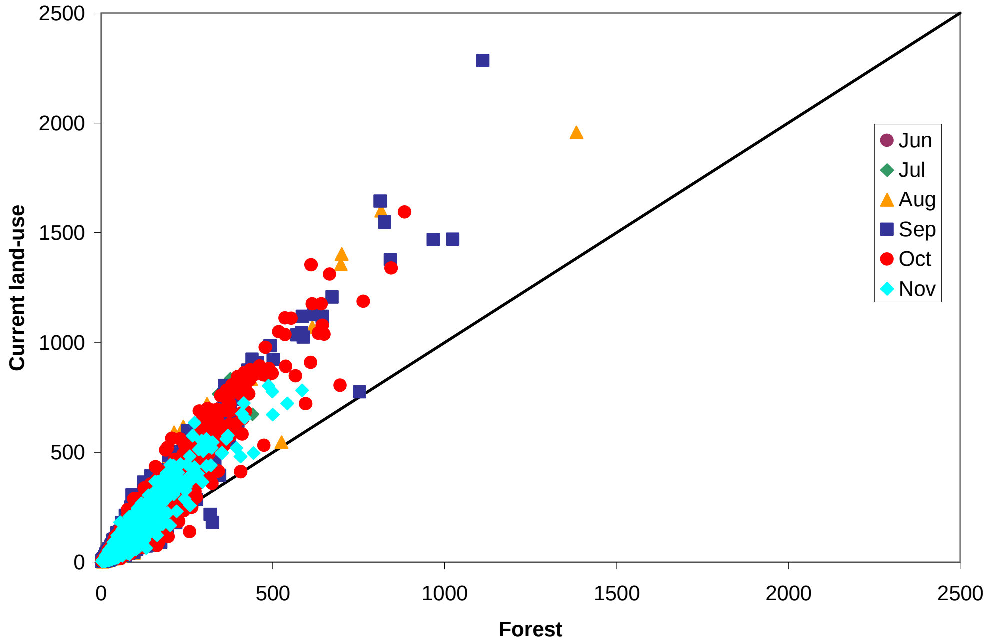

Figure 2.12 Scenario B comparison of maximum daily discharges ($m^3\ s^{-1}$) for current vegetation and forested conditions from the 1000-year SHETRAN simulations of the Pejibaye basin. Line is line of equality. There are no major events from December through to May

2.6 Discussion of Land-use Impacts

In Scenario A, when the same overland flow roughness coefficient is used for both the forest and current land-uses, the results suggest that the effect of land use on the peak discharge becomes less important for the bigger events. The discharge difference becomes slightly smaller for bigger events and the percentage difference decreases considerably. In scenario B a reduced overland flow roughness coefficient (i.e. higher flow resistance) is used for the forest. In this case the percentage difference remains similar whatever the size of the event. Therefore, in this scenario there is no evidence to suggest that for bigger events the effect of land use becomes less important. The calibrations for forested and non-forested catchments in Chile and Ecuador (Sections 3 and 4) suggest in fact that it is not necessary to represent forest with a reduced overland flow roughness coefficient compared with non-forest covers. However, should such a difference exist, it would have had a major effect on the difference in the size of the flood peaks between the two cases.

2.7 Conclusions

The aim of the model applications is to test the hypothesis that, as the size of the flood peak increases, the effects of land use become less important. In Costa Rica, the 131-km^2 Pejibaye basin has been selected to test this hypothesis. Simulations were run from January 1991 to December 1993 for the current vegetation, with a good match between the simulated and measured discharges. Reasonable sediment yield results were also obtained for this period. Simulations were then carried out for the same period but with the vegetation in the entire basin changed to forest. To investigate the effect of land use on flood peak discharge, the two catchment cases were simulated using the same synthetic 1000-year rainfall time series and the peak daily discharges were compared. In Scenario A the same overland flow resistance was selected for the forest and non-forested cases, whereas in Scenario B the forest had a reduced overland flow resistance. The scenario A simulations suggest that the effect of land use on the peak discharge becomes less important for the bigger events. The discharge difference becomes slightly smaller for bigger events and the percentage difference decreases considerably. The scenario B simulations show that the percentage difference remains similar whatever the size of the event, i.e. the effect of land use does not become less important. The result highlights the complexities involved in representing differences in land use. The Chile and Ecuador simulations suggest that it is not necessary to represent a difference in flow resistance between forest and non-forest vegetation covers. However, should a difference in fact be necessary, the scenario B simulations show that there would be a significant impact on the comparison of discharges between the land use cases.

3 LISE AND PANAMÁ BASINS, ECUADOR

3.1 Description of Basins

Lise (2.34 km^2) and Panamá (10.0 km^2) are two small basins within the Rio Chanchán (1409 km^2) basin in the Andes region of central Ecuador. Figure 3.1 shows the shape of the basins and how they are positioned next to each other. Lise is the steeper basin with elevations ranging from 1680 m at the outlet up to 3240 m and is mainly covered with native forest. Elevations at Panamá range from 2053 m at the outlet up to 3100 m; the native forest in this basin has been mostly removed and replaced by pasture. Annual precipitation is around 600 mm at Lise and 1000 mm at Panamá, mostly falling from December to May. Annual potential evaporation is around 900 mm, depending on the elevation. More details can be found in Deliverable 16.

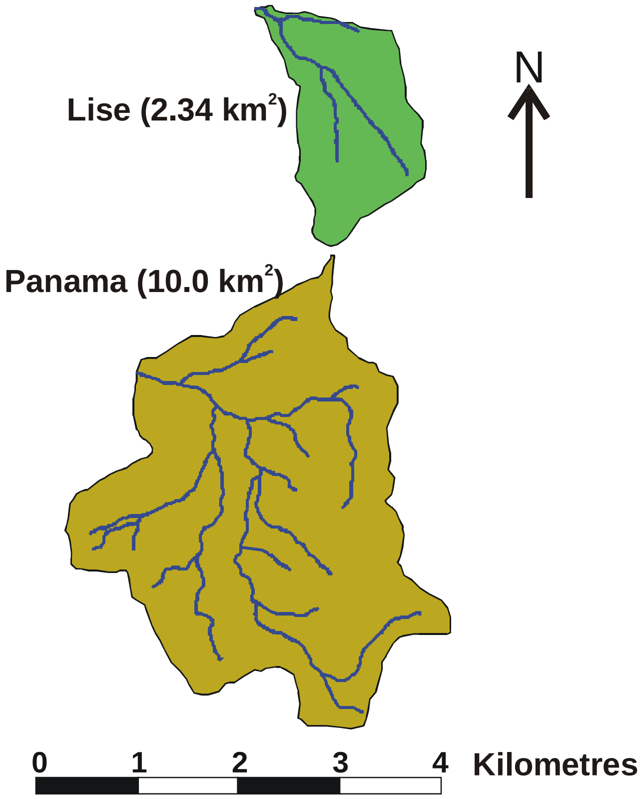

Figure 3.1 The Lise and Panamá basins

3.2 Data Collection

Data for the basin are provided by the Universidad de Cuenca (UCUE), as described in D16.

3.2.1 Spatial data

DEM data and river network data have been collected for the Lise and Panamá basins by UCUE. Satellite imagery was used to investigate the spatial distribution of soil type and vegetation properties. Soil pits were dug at various points in the basin to investigate the soil properties.

3.2.2 Time series data

Intensive monitoring of the Lise and Panamá basins started in 2005. Hourly discharge at the outlet of the Panamá basin has been measured from 6/5/2005 to 25/5/2006. Hourly discharge from the Lise basin has been measured from 11/2/2005 to 1/6/2006, although there are some gaps in the record. Precipitation has been measured from six raingauges around the Lise and Panamá basins. Details can be seen in Table 3.1. Basin precipitation was calculated by UCUE using a Theissen polygon approach with the weightings shown in Tables 3.2 and 3.3. If data from one of the raingauges were not available the weighting was modified accordingly. Potential evaporation has been calculated by UCUE for the Namza Lise site from 3/6/2005 to 1/6/2006. Reductions in the potential evaporation rate as a function of increase in elevation have also been calculated. In addition to the recent data, 23 years of daily precipitation were supplied for the Compud weather station, 6 kilometres from the middle of the Panama basin. These include the El Niño years of 1982-1983 and 1997-1998. More details on the data collection can be found in D16.

Table 3.1 Availability of precipitation data up to 1st June 2006

Raingauge	Llagos	Joyagshi	Pacchala	Santa Rosa	Puñay	Namza Lise
Start Date	4/3/05	11/2/05	11/2/05	12/2/05	20/4/05	5/3/05
End date	1/6/06	1/6/06	25/5/06	1/6/06	10/3/06	1/6/06

Table 3.2 Calculated raingauge weightings for Panamá basin using the Thiessen polygon approach

Rain gauge	Llagos	Joyagshi	Pacchala	Santa Rosa	Puñay
Area (ha)	325	231	148	260	37
Weighting fraction	0.32	0.23	0.15	0.26	0.04

Table 3.3 Calculated raingauge weightings for Lise basin using the Thiessen polygon approach

Rain gauge	Namza Lise	Puñay
Area (ha)	106	128
Weighting fraction	0.45	0.55

3.3 Model Set-up

3.3.1 Basin set-up

The SHETRAN mesh for the Panamá basin uses 442 150-m x 150-m grid squares and 134 river links (2 m wide) that run along the edge of the grid squares (Figure 3.2). The elevations can also be seen in Figure 3.2. The simulation was run from 4/3/2005 (when the measured rainfall record begins) to 25/5/2006. Calibration of the model was carried out for the period from 6/5/2005 (when the measured discharge record begins) to 25/5/2006. The SHETRAN mesh for the Lise basin uses 367 80-m x 80-m grid squares and 63 river links which are 2m wide (Figure 3.3). The elevations can also be seen in Figure 3.3. The simulation was run from 5/3/2005 to 25/5/2006. Calibration of the model was carried out for the whole of this period but there are some missing discharge data. Evapotranspiration was modelled with the Penman-Monteith equation: for the period in 2005 before 3/6/2005 (which was outside the measurement period) the corresponding values from 2006 were used. In order to produce the correct initial conditions both simulations also had an initial one-year run-in period, which used appropriate meteorological data.

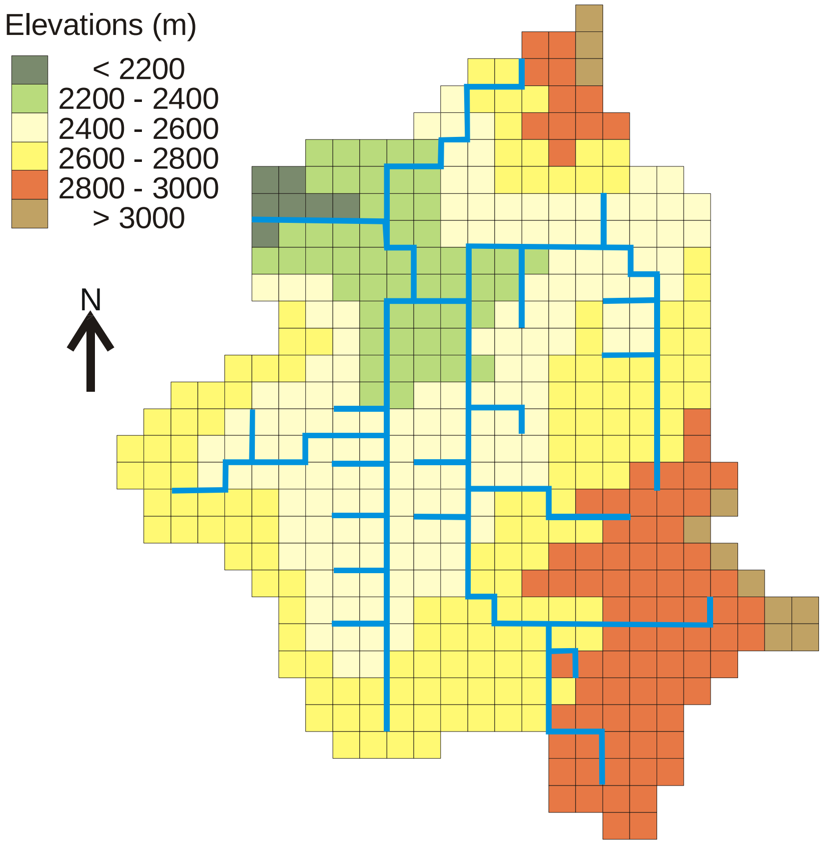

Figure 3.2 SHETRAN mesh (150-m grid resolution) and elevations for the Panamá basin. The stream channels run along the edge of the grid squares

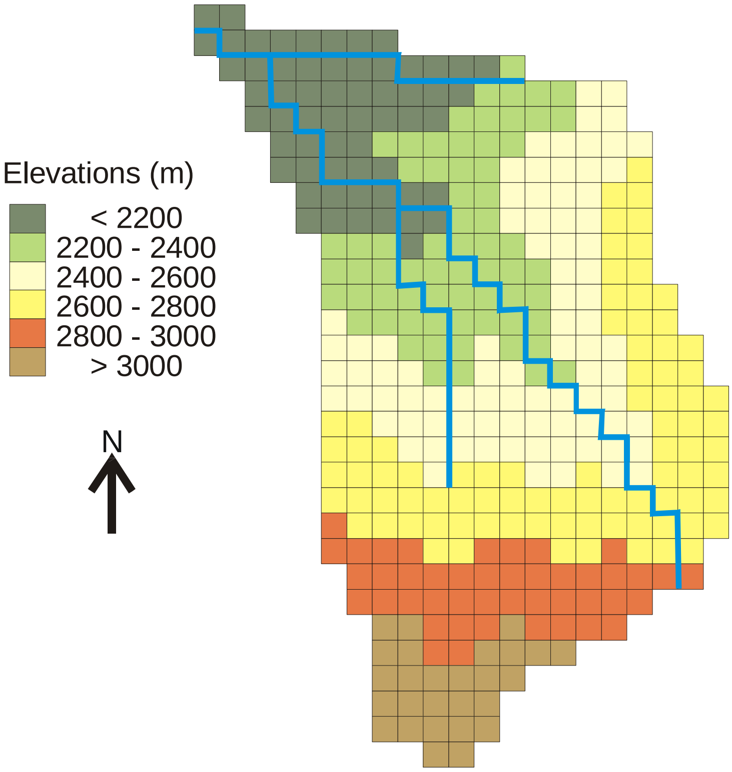

Figure 3.3 SHETRAN mesh (80-m grid resolution) and elevations for the Lise basin. The stream channels run along the edge of the grid squares

The two neighbouring basins were selected as the dominant vegetations are different. In Panamá 57% of the basin is pasture and another 16.5% is characterized by a rotation of crops and grassland. Only 16.5% is covered with native forest. By contrast, 69.2% of the Lise basin is covered with native forest. The vegetation types used in the SHETRAN application can be seen in Figures 3.4 and 3.5 for the Panamá and Lise basins, respectively. The main difference between the forested and non-forested vegetations is the lower aerodynamic resistance in the forest, which produces higher evaporation (and in particular interception evaporation). The overland flow Strickler resistance coefficient was calibrated at 0.1 for all vegetation types. Table 3.4 shows the vegetation parameters used in the SHETRAN simulations.

Table 3.4 Vegetation parameters used in the SHETRAN simulation of the Panamá and Lise basins. The given canopy resistance is the value at field capacity; in the simulation it increases with soil moisture tension

Vegetation	**Canopy Drainage**		**Canopy Storage (mm)**	**Rooting Depth (m)**	**Aerodynamic Resistance (s/m)**	**Leaf Area Index**	**Canopy Resistance (s/m)**
	CK(mm s^{-1})	**Cb (mm^{-1})**					
Natural forest	3.0E-5	3.7	5	1	10	5	50
Eucalyptus forest	3.0E-5	3.7	5	1	10	5	50
Natural grassland	3.0E-5	3.7	5	0.4	30	2	50
Pasture	3.0E-5	3.7	5	0.4	30	2	50
Grass/crop rotation	3.0E-5	3.7	5	0.4	30	2	50

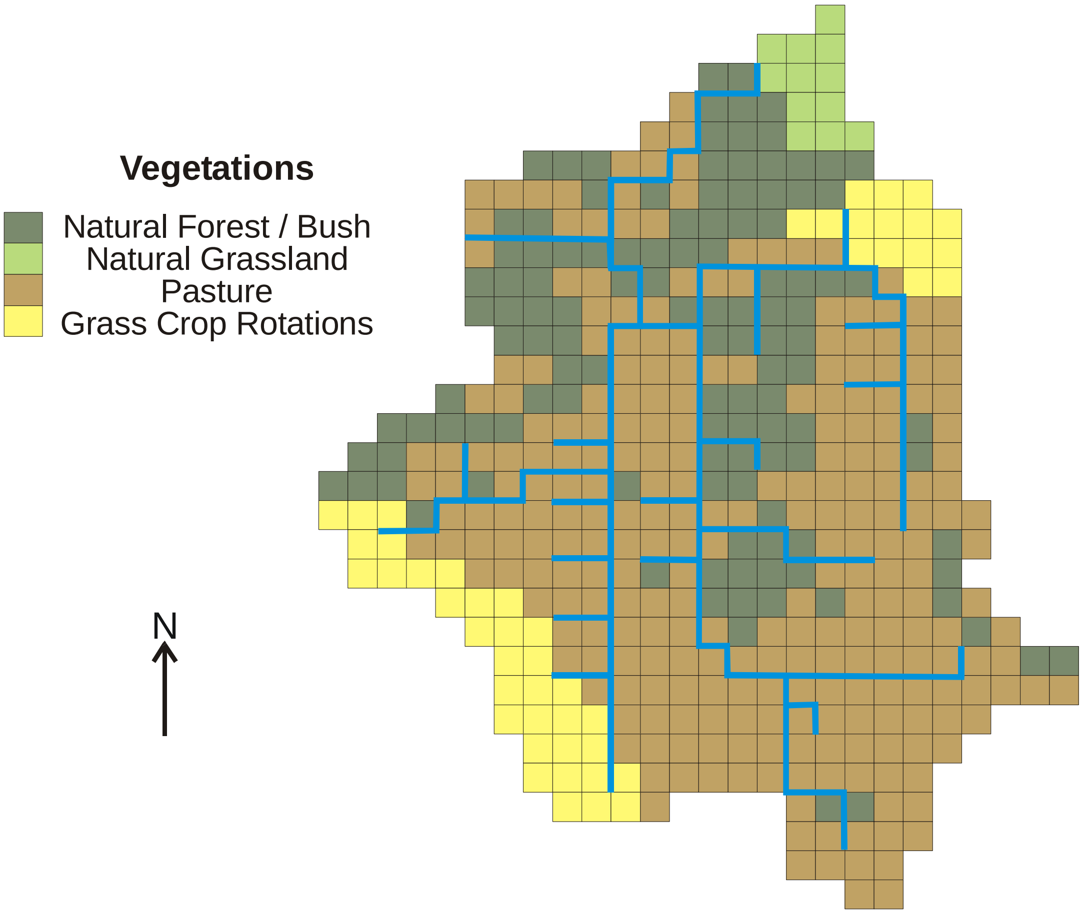

Figure 3.4 SHETRAN vegetations for the Panamá basin

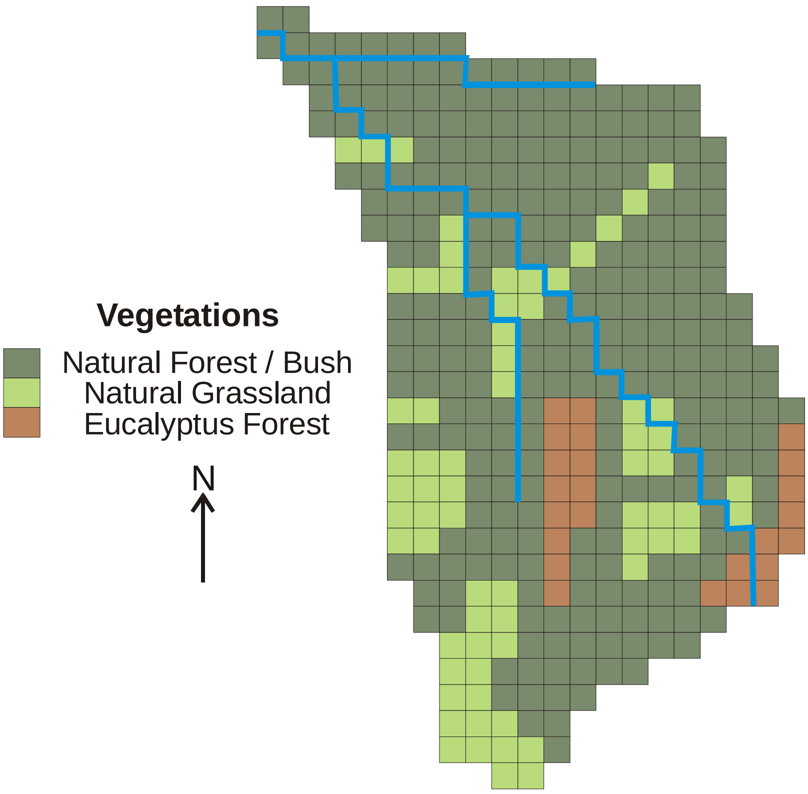

Figure 3.5 SHETRAN vegetations for the Lise basin

The soils in the Panamá and Lise basins can be seen in Figures 3.6 and 3.7, respectively. In Panamá the main soils are the Umbrisol and Leptosol and in Lise the main soil type is the Umbric Leptosol. Most of the soils have two layers with depths of around 0.4 m for the top layer and around 1.2 m for the lower layer. However, the Leptosols have only one thin (0.3 m) layer over rock. Measurements of the soil properties of each of these soils have been carried out by UCUE. For the top layer (Soil 1) the parameters adopt conventional values (Table 3.5). However, the deeper soils (Soil 2) have porosities up to 0.8 and soil water retention curves that produce a sudden drop in the moisture content for a small change in the soil water tension. Average values of measurements for the porosity, residual moisture content and the van Genuchten parameters (which describe the soil water retention curve) are used in the model (Table 3.5). Measurements also suggest high conductivities in the deeper soils and modelling work suggests that these conductivities give fast subsurface flow and produce the long recessions and large base flows that UCUE staff have commented on. These conductivities were calibrated at 30 m day^{-1}. The model soil parameters are based on the measured property data but, as these data are insufficient to justify differences between the soils, the same parameter values are applied to all the soils. The soil depths can be seen in Table 3.6

Table 3.5 Soil parameters used in the SHETRAN simulation of the Panamá and Lise basins

Soil type	**Porosity**	**Residual moisture constant**	**Saturated hydraulic conductivity (m day^{-1})**		**Van Genuchten Coefficient**	
			Horizontal	**Vertical**	**alpha (cm^{-1})**	**n**
Soil 1	0.6	0.1	1.0	1.0	0.01	1.8
Soil 2	0.8	0.1	30.0	30.0	1.0	1.1

Table 3.6 Soil depths used in the SHETRAN simulation of the Panamá and Lise basins

Soils	**Soil depth (m)**	
	Soil 1	**Soil 2**
Andosol	0.4	1.2
Andosol 1	0.4	1.2
Andosol 2	0.4	1.2
Phaeozem	0.4	1.2
Umbrisol	0.4	1.2
Leptosol	0.3	
Cambisol	0.4	1.2
Umbric Leptosol	0.6	

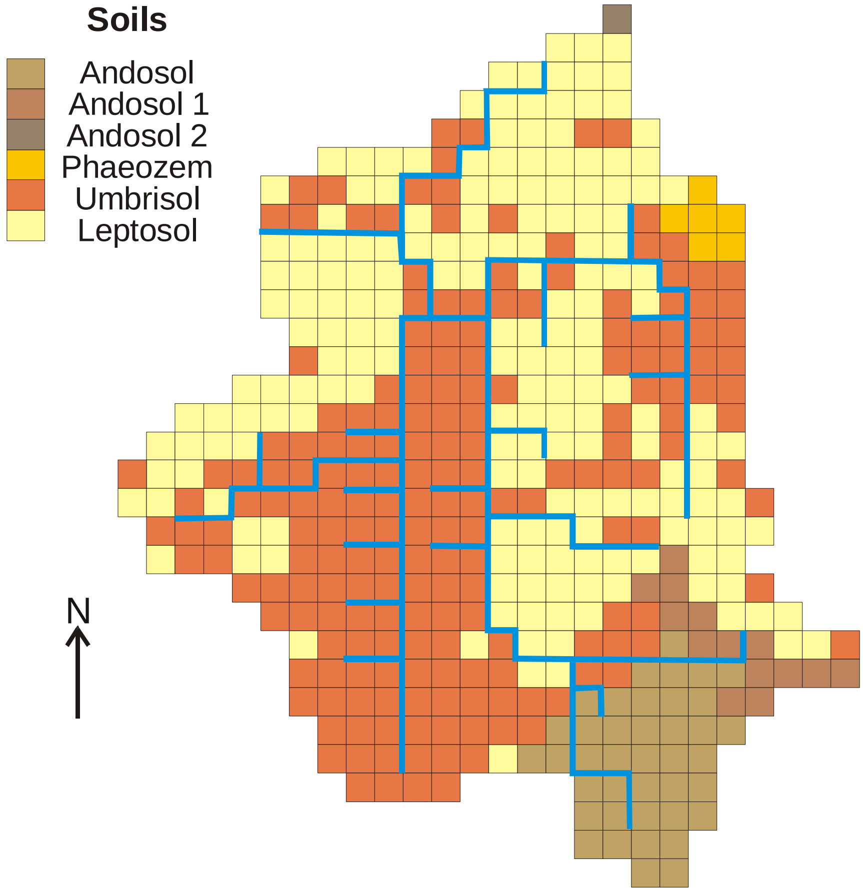

Figure 3.6 SHETRAN soils for the Panamá basin

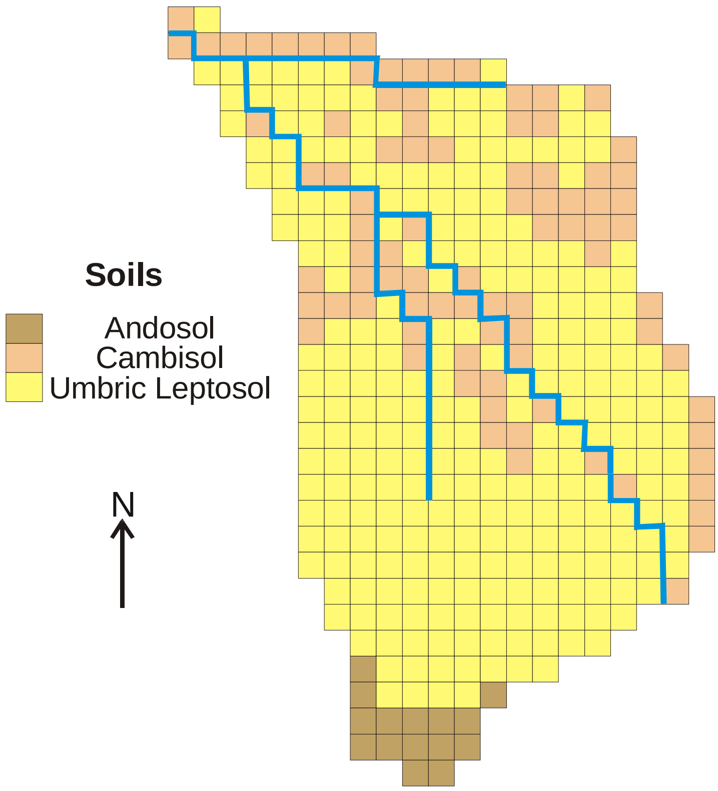

Figure 3.7 SHETRAN soils for the Lise basin

3.3.2 Panamá calibration

The comparison between the simulated and measured discharges for May 2005 – May 2006 can be seen in Figure 3.8. Overall, the correspondence is excellent (Nash-Sutcliffe efficiency = 0.92) and, in particular, the shape of the recessions following precipitation events is well captured. Analysis of the annual mass balance (Figure 3.9) also shows that the total measured (399 mm) and simulated (400 mm) runoffs are almost identical. This gives annual evaporation rates of around 562 mm. Figure 3.10 shows that in the simulation 360 mm of this is as a result of interception evaporation and 202 mm is evaporation from the bare soil and transpiration.

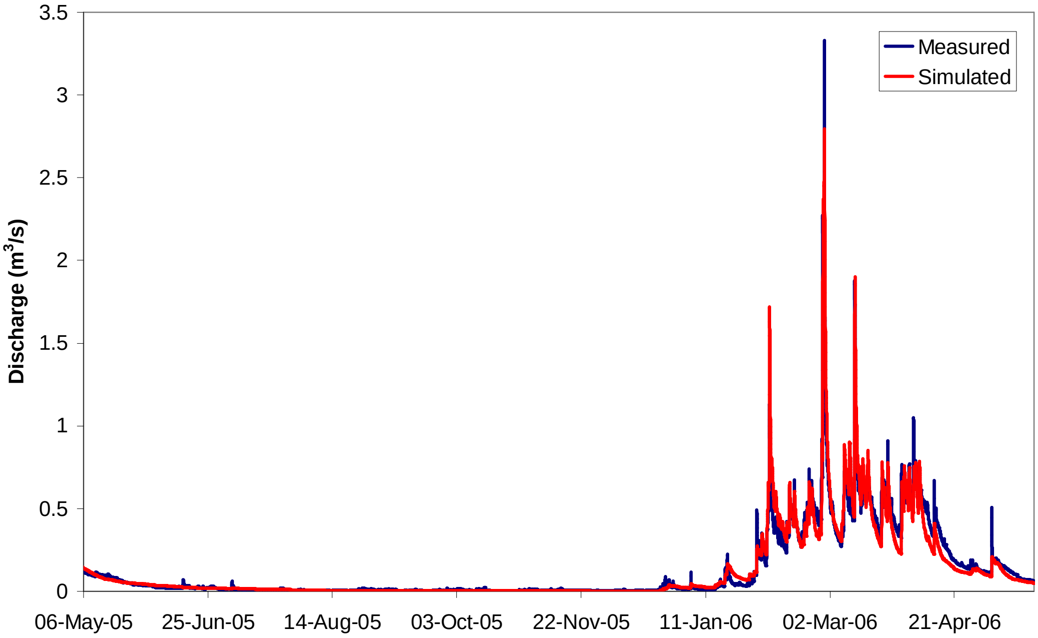

Figure 3.8 Measured and simulated discharges at the Panamá basin outlet for 2005-2006

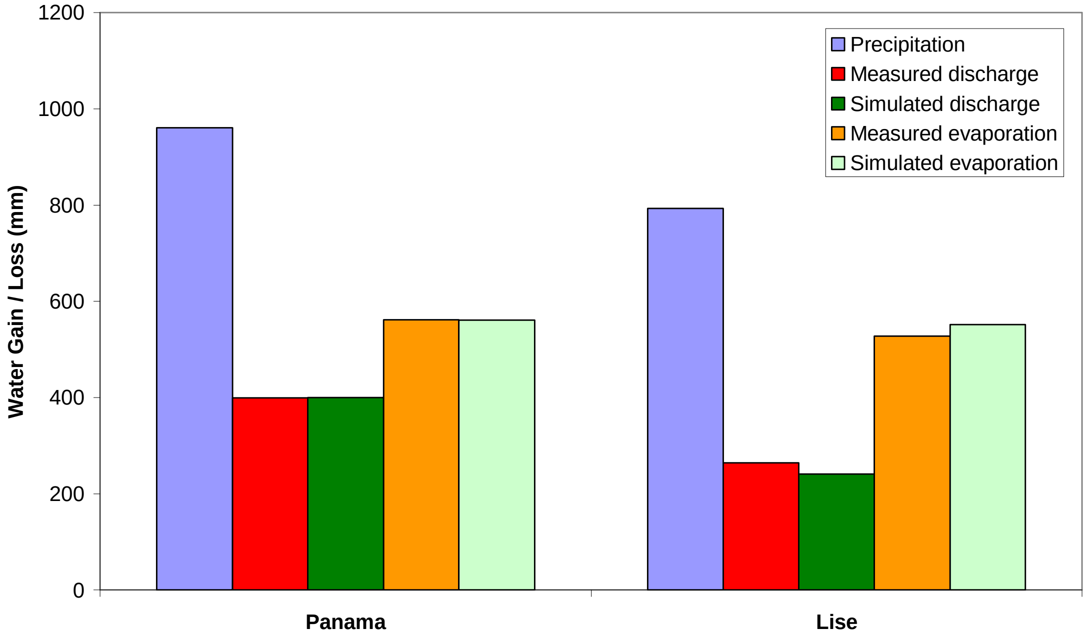

Figure 3.9 Simulated and measured mass balances for the Panamá and Lise basins for 2005-2006. Gaps in the measured discharge record for the Lise basin are infilled with simulated discharges

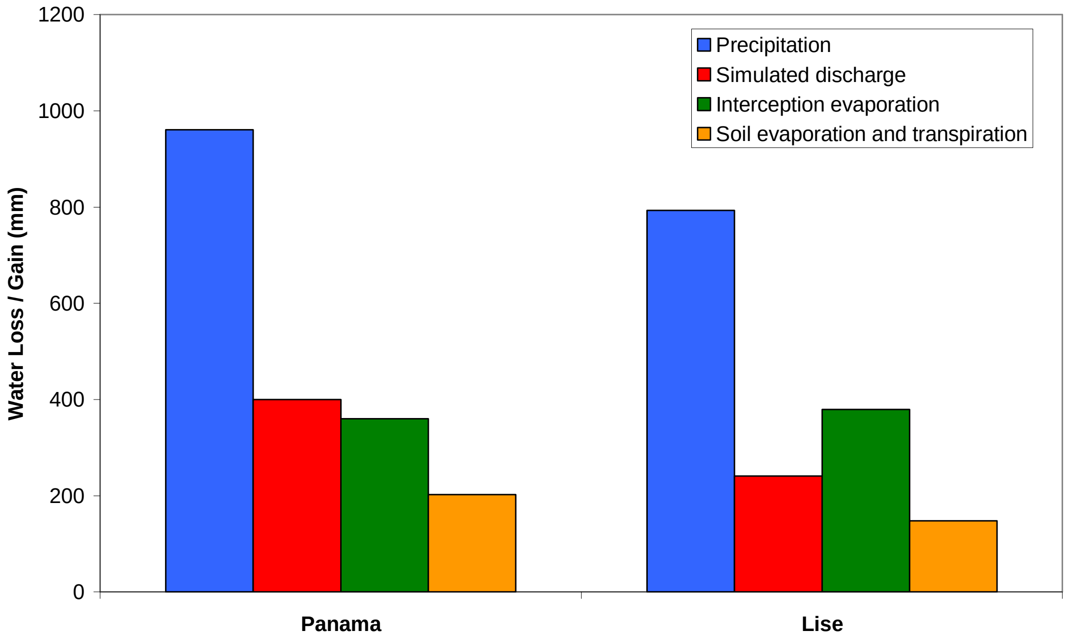

Figure 3.10 Simulated mass balances (including evaporation losses) for the Panamá and Lise basins for 2005-2006

3.3.3 Lise calibration

The comparison between the simulated and measured discharges for March 2005 – March 2006 can be seen in Figure 3.11. The simulation covered the period from March 2005 to May 2006 but owing to some gaps in the discharge data (in the 2006 wet season) the whole period is not shown here. The correspondence between the simulated and measured discharge is good (Nash-Sutcliffe efficiency = 0.81) but less so than for the Panamá simulation. The main problem is the poor simulation for the last major event in the 2005 wet season. The measured data show a fast recession and then an almost constant base flow throughout the entire dry season. The simulation shows a slower recession and then the base flow reduces to almost nothing by the middle of the dry season. However, the project is focusing on the peak discharges and these seem reasonably well simulated.

Analysis of the annual mass balance (Figure 3.9) also shows that the total measured (265 mm) and simulated (241 mm) runoffs are similar. This gives annual evaporation rates of 528 mm and 552 mm for the measured and simulated evaporations. The annual evaporation is slightly smaller than for the Panamá basin but is a result of significantly smaller precipitation in the Lise basin (793 mm compared with 961 mm). Precipitation in the Lise basin similar to that of the Panamá would produce considerably higher evaporation, mainly as a result of higher interception evaporation from the forest (Figure 3.10).

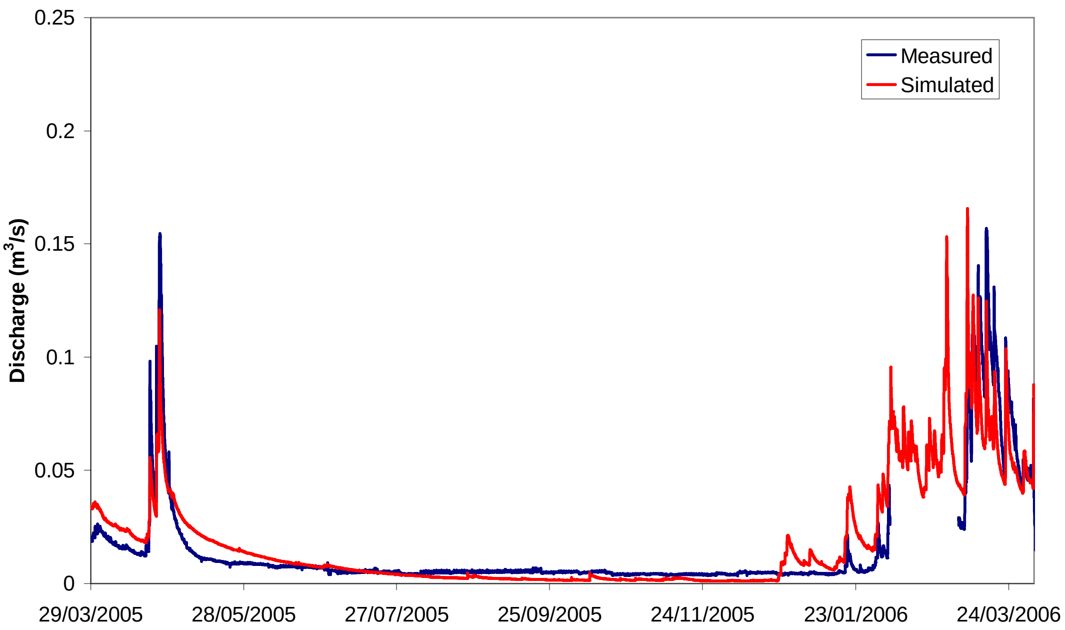

Figure 3.11 Measured and simulated discharges at the Lise basin outlet for 2005-2006

3.4 Modelling Strategy

The aim of the modelling is to test the hypothesis that, as the size of the flood peak increases, the effect of land use becomes less important. To achieve this aim, SHETRAN was used to simulate the flood response of the two neighbouring basins: the Panamá basin which has mainly pasture cover and the Lise basin which has mainly native forest cover. Good simulations were obtained for both basins using the same soil parameter values but different vegetation parameters. The effect of changing the vegetation type in the Panamá basin from pasture back to native forest could therefore be analysed for the measured precipitation data and for a-1000 year time series of precipitation data which includes conditions typical of El Niño years. The Panamá basin was therefore simulated both for its current cover and for a full forest cover (using the vegetation parameter values from the Lise basin calibration). For the 1000-year simulations, the corresponding maximum daily discharges for each day of the two simulations were then plotted against each other to see if there were progressive differences in their relationship between low and high flow conditions.

Typical monthly precipitation data for two periods for the Compud weather station (6 kilometres from the middle of the Panamá basin) are shown in Figure 3.12 and show how the annual precipitation in the El Niño years of 1982-1983 is more than twice the value for 2004-2005 (a more normal year). In particular, the length of the wet season has increased to the period October to May.

Using the 23 years of measured daily Compud data (including the El Niño periods of 1982-1983 and 1997-1998) and the existing measured hourly data from 2005-2006, a 1000-year time series of synthetic hourly data was generated. This was achieved by combining the monthly statistics for the Compud data with the variance and skew statistics for the hourly 2005-2006 data in the Newcastle University Rainsim statistical model.

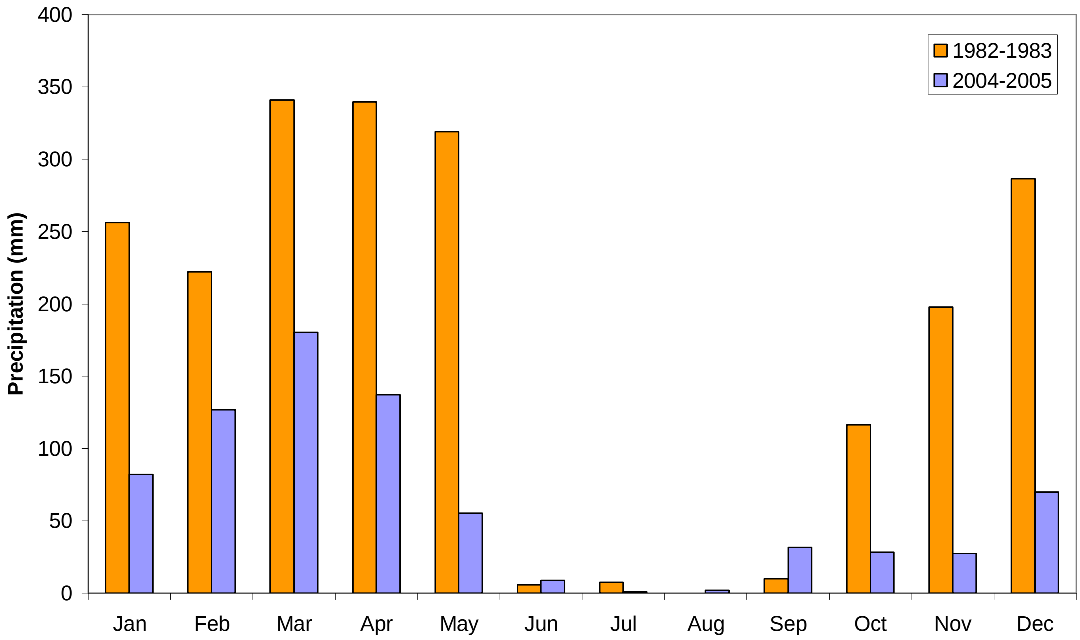

Figure 3.12 Mean monthly precipitation data for the Compud weather station

3.5 Simulations and Results

The results of simulating the Panamá basin with the current vegetation conditions and with the entire area covered by forest are shown in Figure 3.13. The soils are the same in the two simulations but the vegetation parameters are different. With the forest, evaporation is considerably higher and this reduces the discharge at the outlet. This reduction in discharge appears throughout the wet season.

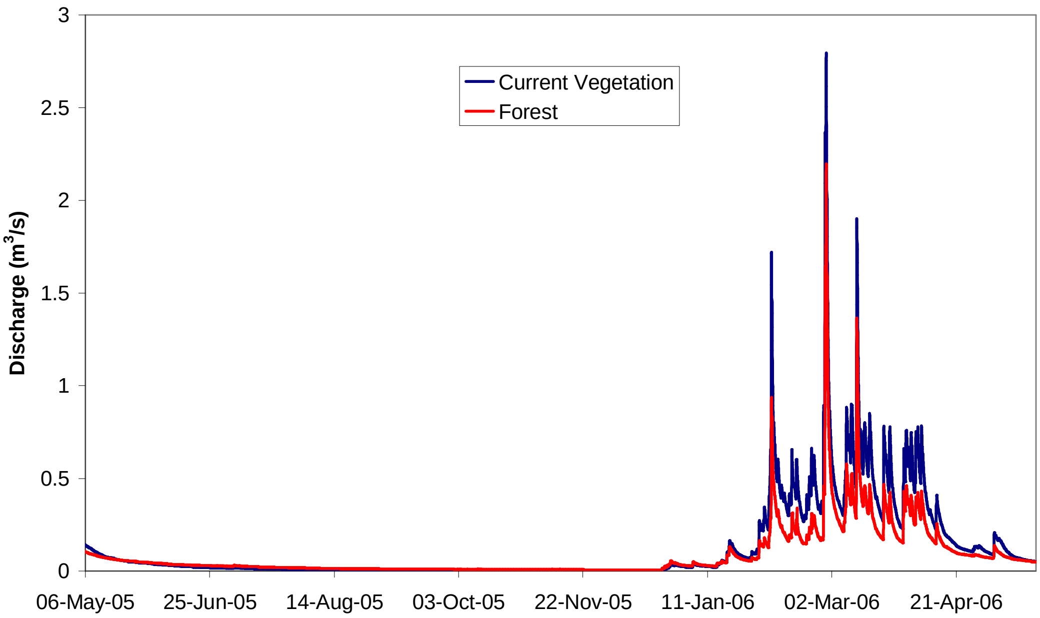

Figure 3.13 Comparison of discharges (m^3/s) for current and forested conditions from the SHETRAN simulations of the Panamá basin for 2005-2006

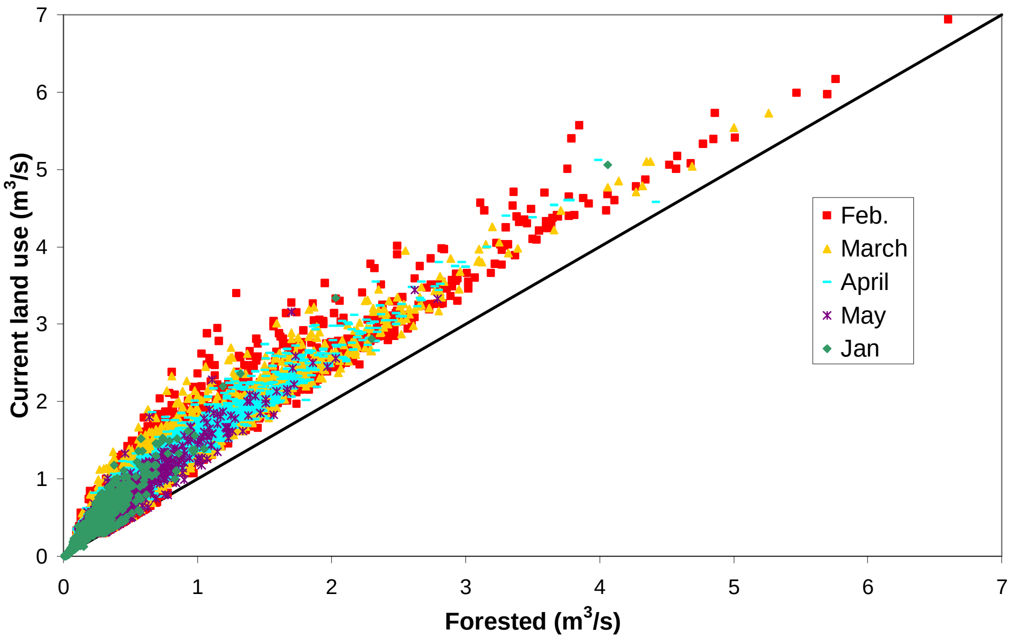

Figure 3.14 Comparison of maximum daily discharges (m^3/s) for current vegetations and forested conditions from 1000 years of SHETRAN simulation for the Panamá basin. Line is line of equality. There are no significant events from June to December

The simulations were also run with the 1000 years of hourly precipitation data described in Section 3.4. Figure 3.14 compares the maximum daily discharges for each day of the 1000 years for the current vegetation and forested cases. As expected, the highest discharge events take place in February and March corresponding to the biggest rainfall events. Figure 3.14 shows that there can be a range of "current" responses for a given “forested” discharge, depending on antecedent soil moisture conditions. At the start of the wet season in January there is a bigger difference in the antecedent soil moisture conditions between the “current” and “forested” vegetations and so in general a large difference in the discharge between the two cases. The points for the start of the wet season are therefore further from the line of equality. By contrast, in May at the end of the wet season there is a smaller difference in antecedent soil moisture and the discharges in the two cases are more similar with points nearer the line of equality. If all months are considered it can be seen that as the discharge increases, the absolute difference remains similar, but the percentage difference decreases (i.e. as a percentage of the discharge). It appears that the high soil conductivities used in the simulation result in water draining from some of the soil columns faster than it arrives from precipitation. These columns therefore always have some soil storage capacity and this is greater under forested conditions (as there is higher interception evaporation). Consequently the simulations always show higher discharges under the current vegetation than under forested conditions.

3.6 Discussion of Land-use Impacts

As expected, with the forest cover, evaporation is considerably higher and this reduces the discharge at the outlet. This reduction in discharge appears throughout the wet season. Comparison of the maximum daily discharges for the forested and current vegetation states shows there can be a range of “current” responses for a given “forested” discharge, depending on antecedent soil moisture conditions. The pattern is largely constant for the range of discharges simulated. It is likely that, with the high soil conductivity used here, the simulations will always show higher discharges under the current vegetation than under forested conditions. However, because the absolute difference is constant, it decreases as a percentage of discharge as the discharge increases. Therefore, in a relative sense, the effect of land use on peak discharge decreases as discharge increases. This supports the hypothesis being tested.

3.7 Conclusions

The aim of the model application is to test the hypothesis that, as the size of the flood peak increases, the effects of land use become less important. In Ecuador two adjacent basins have been modelled. Lise is a 2.34-km^2 basin in which the dominant vegetation is forest and Panamá is a 10.0-km^2 basin in which the dominant vegetation is grassland. In both cases, SHETRAN simulations were run for around a year up to 25/5/2006 and an excellent comparison was achieved between the measured and simulated discharges. The same soils were defined for both simulations but to achieve the good simulation results a high lateral hydraulic conductivity was required in the lower soil layer. The forest cover in the Lise basin resulted in a relatively higher water loss through interception evaporation compared with the Panamá basin. Following calibration for current conditions, the Panamá simulation was run with the vegetation changed entirely to forest (using the parameter values from the Lise calibration). As expected, with the forest, evaporation is considerably higher and this reduces the discharge at the outlet. This reduction in discharge appears throughout the wet season.

Maximum daily discharges for the forested and current vegetation states were compared for the 1000-year simulations. There can be a range of “current” responses for a given “forested” discharge, depending on antecedent soil moisture conditions. As the discharge increases, the difference remains similar in an absolute sense but decreases as a percentage of discharge. The results therefore support the hypothesis. It should be noted, though, that this result is for small basins in which response times are short, there is little variation in response time from different parts of the basin and the vegetation is relatively homogeneous.

4 LA REINA BASIN, CHILE

4.1 Description of Basin

La Reina is a 0.35-km^2 basin in Region 10, 41°S, in Chile (Figure 4.1). A view of the lower part of the basin and the outlet flume in the mid 1990s can be seen in Figure 4.2. Until January 2000 there was a commercial radiata pine forest (with some deciduous areas). The entire basin was then logged in that month and in January 2001 it was replanted. Soils are mainly well drained and around 0.5-2 m deep. Annual precipitation is around 2500 mm year^{-1}, mostly from frontal rainfall in the winter (June – August). Annual potential evaporation is around 1000 mm year^{-1}. More details of the basin can be found in Deliverable 17.

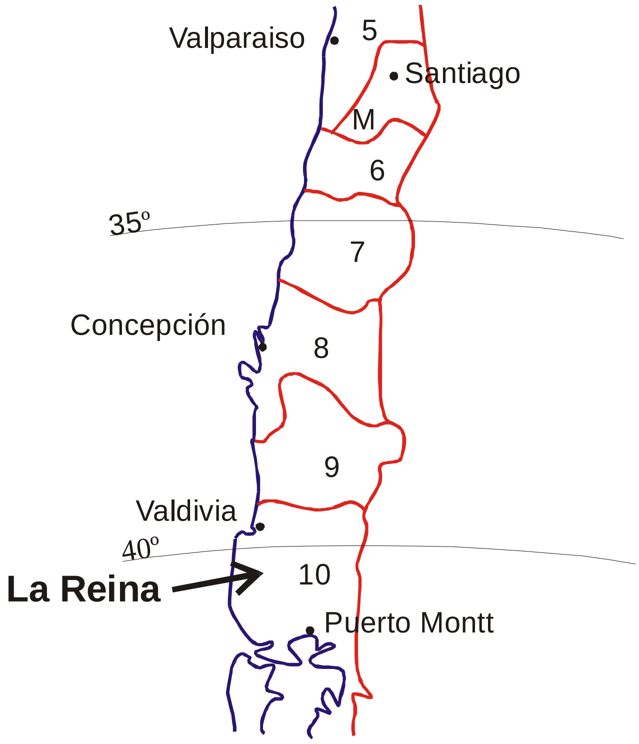

Figure 4.1 Location of La Reina basin in Chile. Numbers show national regions

4.2 Data Collection

Data for the basin were provided by the Universidad Austral de Chile, as described in D17.

4.2.1 Spatial data

DEM data and river network data are available for the basin. Soil pits were dug at various points in the basin to investigate the soil properties and the spatial distribution of soil depths. A vegetation survey was carried out before logging took place, to find the spatial distribution of the deciduous and pine forest.

Figure 4.2 View of the lower part of La Reina basin and its outlet flume

4.2.2 Time series data

The analysis uses data from the intensive monitoring of La Reina basin that was carried out between 1996 and 2003. These include hourly discharge data from the flume at the basin outlet and hourly meteorological data from a site at the edge of the basin. The data are generally of a good quality although some infilling of the meteorological data has been necessary (from June to September 2002 because of problems with the precipitation measurements). There are also some uncertainties with the discharge data from 2002. There has been some suspended sediment sampling at the outlet but this is not sufficient to calibrate the sediment transport component of the SHETRAN model. Forty-five years of daily precipitation data were available for the Isla Teja weather station at Valdivia and these were used with the La Reina data to create a 1000-year rainfall time series (see Section 4.4). More details of the data collection can be found in Section 4 of D17.

4.3 Model Set-up

4.3.1 Basin set-up

The SHETRAN mesh for La Reina basin uses 141 50-m by 50-m grid squares and 53 river links (3 m wide) that run along the edges of the grid squares (Figure 4.3). The elevations can also be seen in Figure 4.3. Calibration of the model was carried out for two periods: firstly for 1997-1999 when the basin was forested and secondly for 2000-2001 when the basin had been logged and then replanted (Figure 4.4). The simulations for these two periods used exactly the same soil parameters but different vegetation parameters. A 2.5-m deep soil was specified throughout the basin (compared with measured values in the range 0.5-1.9 m) and the following parameter values were used: a saturated water content of 0.44 $m^3\ m^{-3}$, a residual moisture content of 0.096 $m^3\ m^{-3}$, a saturated conductivity of 1 m day^{-1}, a van Genuchten alpha value of 0.008 cm^{-1} and a van Genuchten n value of 1.4 (the van Genuchten equation describes the hydraulic properties of the soil). The parameter values were based on measurements (Duhalde Schwarzenberg, 1999; Sáez García, 1999), although the conductivity was calibrated (the mean measured value was 4.18 m day^{-1} from 5 infiltration tests). The Strickler overland flow resistance coefficient was calibrated as 0.1. The vegetation parameters for the two periods can be seen in Table 4.1. These were based on previous simulations in the UK (Dunn and Mackay, 1995) and measured values from other basins collated by Bruer et al. (2003), although there was some minor calibration. Evaporation was simulated using the Penman-Monteith equation with the measured hourly meteorological data. The aerodynamic and canopy resistance values used can be seen in Table 4.1. These are again based on measured values (Dunn and Mackay, 1995; Bruer et al. 2003) although there has been some calibration. The difference in aerodynamic resistance between the forest (3.5 s m^{-1}) and the cleared ground (40 s m^{-1}) has a particularly important effect on the results; this is discussed in the next sections.

Soil samples collected from three soil pits (two samples in each pit) by the Corporación Nacional Forestal give sand-silt-clay percentages of 47.6, 33.8 and 18.6% respectively. These were represented by the following distribution selected from the SHETRAN library, with the percentages shown in brackets: 0.1 mm (60%), 0.37 mm (20%), 0.89 mm (10%), 1.59 mm (5%), 2.25 mm (3%), 3.5 mm (2%). The most important parameters affecting soil erosion are the raindrop impact and overland flow erodibility parameters, shown for the forest and logged vegetation in Table 4.2.

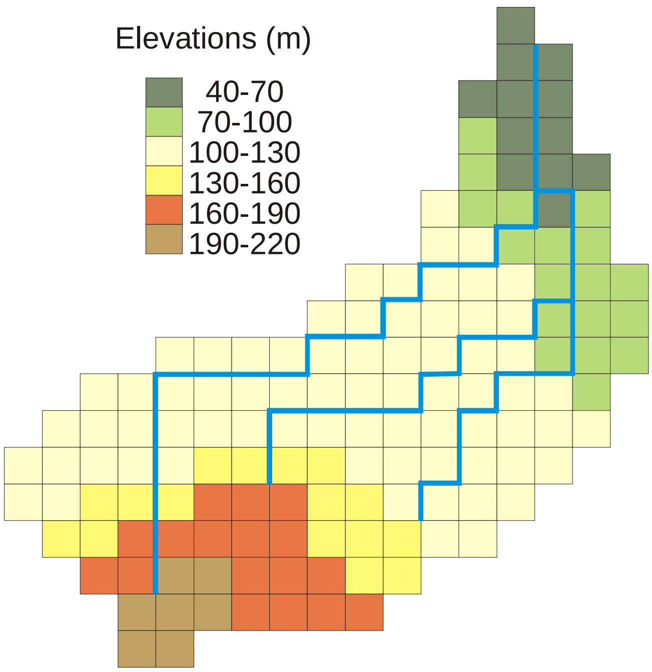

Figure 4.3 SHETRAN mesh (50-m grid squares) and elevations for La Reina basin. The stream channels run along the edge of the grid squares

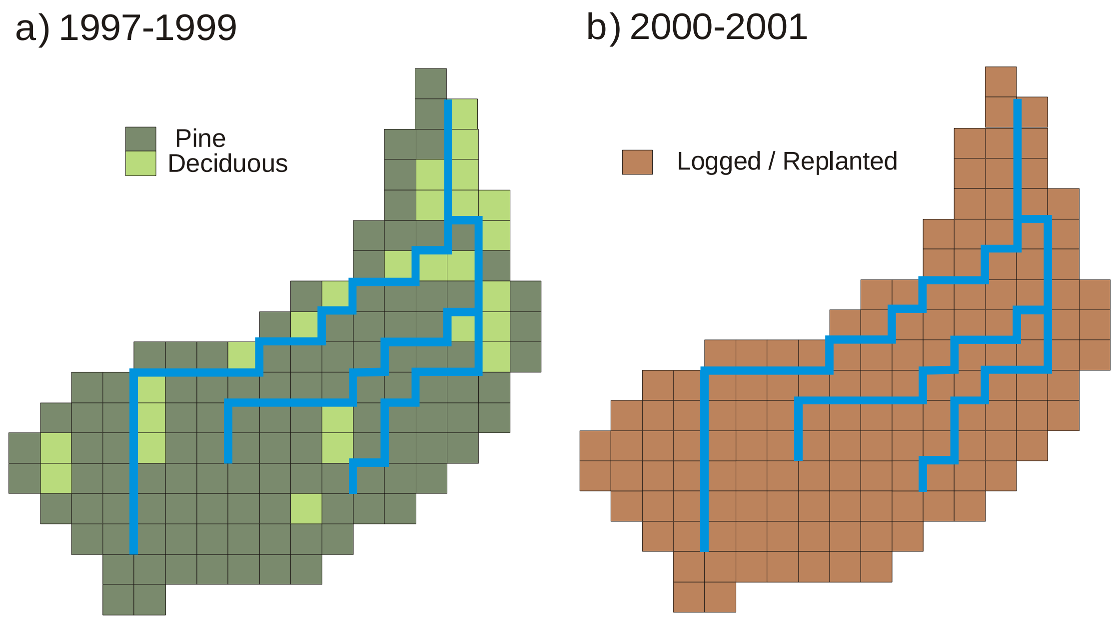

Figure 4.4 SHETRAN vegetations for La Reina basin for the two calibration periods

Table 4.1 Vegetation parameters used in the SHETRAN simulation of La Reina basin. The given canopy resistance is the value at field capacity: in the model it increases with soil moisture tension

Vegetation	**Canopy Drainage**		**Canopy Storage (mm)**	**Rooting Depth (m)**	**Aerodynamic Resistance (s/m)**	**Leaf Area Index**	**Canopy Resistance (s/m)**
	CK(mm s^{-1})	**Cb (mm^{-1})**					
Pine	1.9E-5	3.7	1.5	1.8	3.5	6.0	100
Native forest	1.9E-5	3.7	2.0	1.8	3.5	6.0	100
Logged	1.9E-5	3.7	0.5	0.1	40.0	1.0	65

Table 4.2 Sediment parameters used in the SHETRAN simulation of La Reina basin

Vegetation	**Raindrop erodibility coefficent J^{-1}**	**Overland flow soil erodibility coefficient kg m^{-2} s^{-1}**
Pine	0.05	$2*10^{-8}$
Native forest	0.05	$2*10^{-8}$
Logged	0.05	$2*10^{-8}$

4.3.2 Forest calibration 1997-1999

Rainfall data are available from June 1996 but the discharge record starts in April 1997. The simulations were therefore started in June 1996, so as to provide a 10-month run-in period for the main simulation period.

The comparison between the simulated and measured discharges for 1997-1999 can be seen in Figure 4.5. Overall, the correspondence is good (Nash-Sutcliffe efficiency = 0.81) and importantly for this work the peaks are reasonably well captured by the simulation. The simulated discharge for the major event on 28th July 1997 is 0.314 m^3

s^{-1} compared with the measured peak of 0.349 m^3 s^{-1}, while for the major event on 9th August 1999 the simulated peak is 0.263 m^3 s^{-1} compared with the measured value of 0.24 m^3 s^{-1}. The main discrepancy with the simulation is that the simulated discharges during the dry year in 1998 are too high, although this is not considered to be a major problem given the focus on flood events. The annual mass balances for 1997, 1998 and 1999 can be seen in Figure 4.6. Again this shows good correspondence between the measured and simulated values for 1997 and 1999 but less so for 1998.

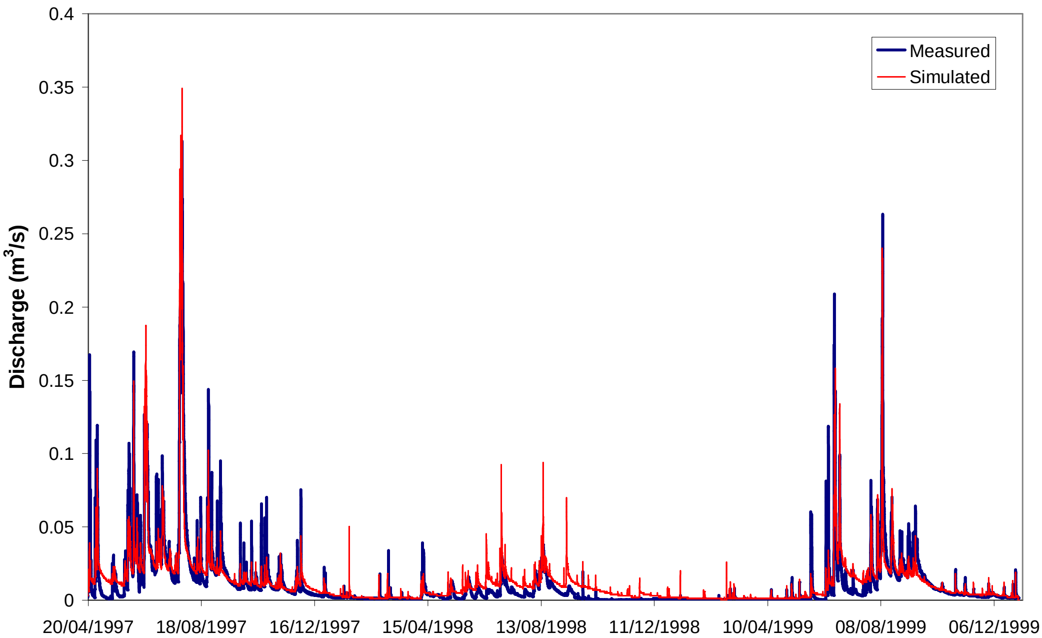

Figure 4.5 Measured and simulated discharge at La Reina basin outlet for 1997-1999

The measured data here and from Iroumé et al. (2006) for two other nearby basins give total annual evaporation losses of between 48% and 79% of precipitation for a mature radiata pine. Oyarzun et al. (1998) give an annual evaporation rate from a native pine forest in the same region as 45% of precipitation. These evaporation losses give annual evaporation totals greater than potential evaporation rates, which are around 1000 mm. (This value was calculated from the site data and corresponds to short grass cover. Annual pan evaporation has been measured nearby by Iroumé and Huber (2002) at around 800 mm.) For example, in 1997 measured evaporation was over 1500 mm. Much of this evaporation is a result of large interception losses of water from forest canopies, which Calder (1999) showed are expected with low intensity rainfall in temperate climates and are a result of the lower aerodynamic resistance of the forest. Huber and Iroume (2001) studied evaporation and throughfall for a range of forest types at nine sites in temperate Chile. Overall, interception losses accounted for between 10 and 40% of precipitation depending on the type and age of the trees. Iroume and Huber (2002) also show that similar interception losses and wet evaporation rates from the canopy of up to 1mm hr^{-1} can take place even in winter. These high interception losses have also been found by other researchers (Schellekens et al., 1999; Dykes, 1997; Waterloo et al. 1999). The simulated losses from interception can be seen in Figure 4.7, with losses of around 30% of the precipitation in 1997, 1998 and 1999 and wet evaporation rates of up to 2 mm hr^{-1} in summer. These results were obtained using the Penman-Monteith equation with a low aerodynamic resistance for the forest cover and it is encouraging that the simulated results correspond with what is known about evaporation losses from experimental data.

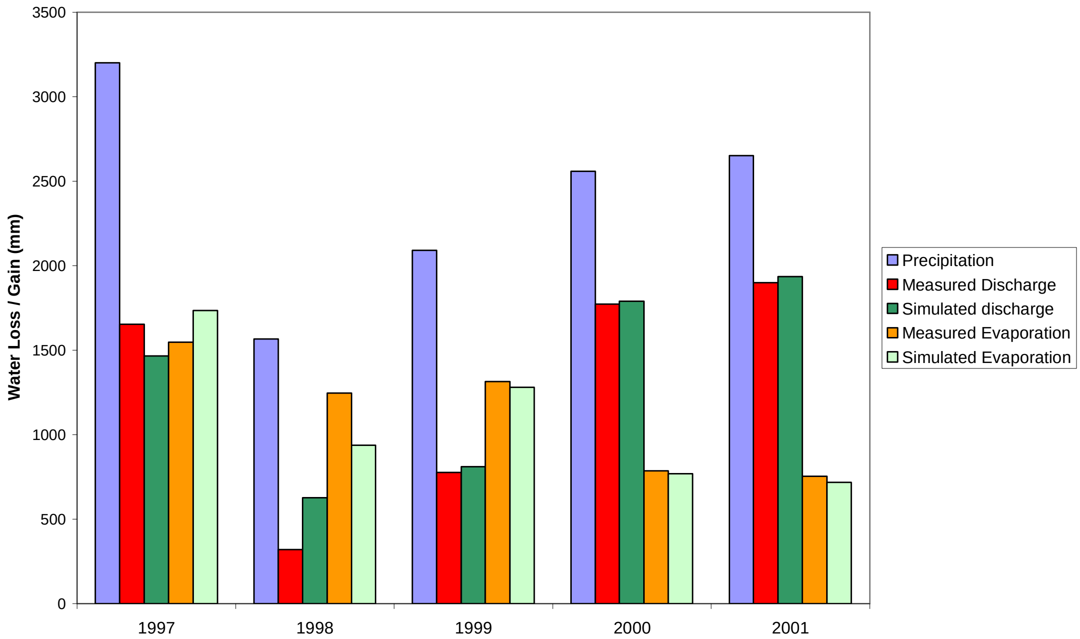

Figure 4.6 Simulated and measured mass balances for La Reina basin for 1997-2001

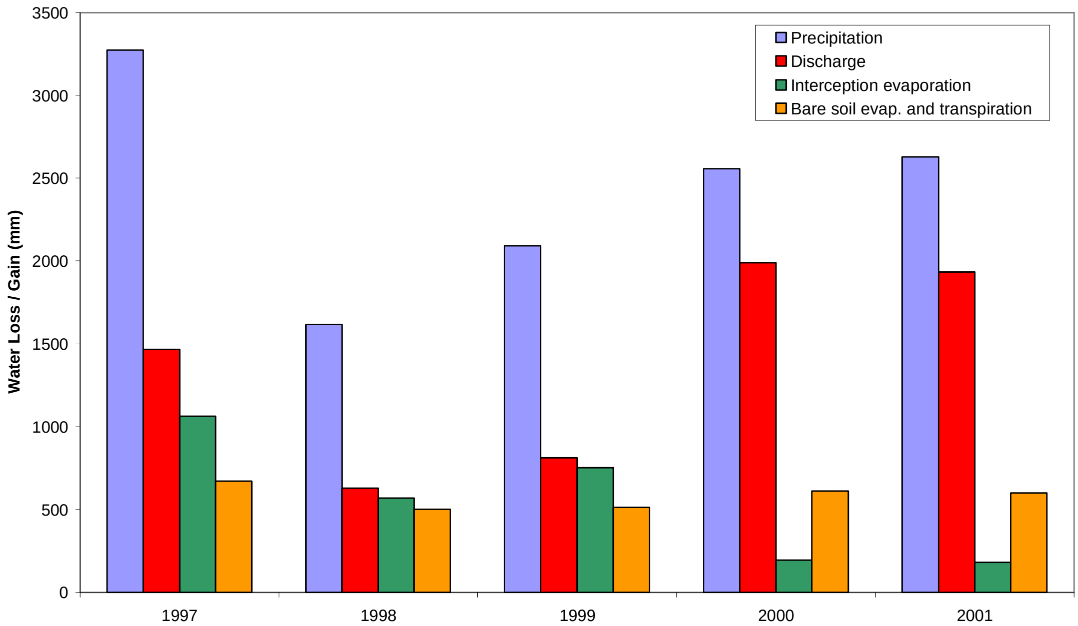

Figure 4.7 Simulated mass balance (including evaporation losses) for La Reina basin for 1997-2001

4.3.3 Logged calibration 2000-2001

The comparison between the simulated and measured discharges for 2000-2001 can be seen in Figure 4.8. No run-in period was provided and therefore there is a discrepancy between the measured and simulated discharges at the start of the simulation period. Overall, though, the correspondence is excellent (Nash-Sutcliffe efficiency = 0.89) and, importantly for this work, the peaks are well captured by the simulation. The comparison for 2002 is not shown as there are some data missing from the discharge record. The annual mass balance in Figure 4.6 also shows excellent agreement.

Iroumé et al. (2006) found that mean annual runoff increased by 110% after logging in La Reina basin. This increase in annual runoff agrees with the trend found at other sites (Bruijnzeel, 2004; Bosch and Hewlett, 1982; Stednick, 1996). The main reason for this is the reduction in interception caused by the removal of the trees. This shows up well in Figure 4.7 with the intercepted evaporation decreasing considerably in 2000 and 2001 compared with the years before logging. The bare soil evaporation and transpiration is altered very little as a result of the logging.

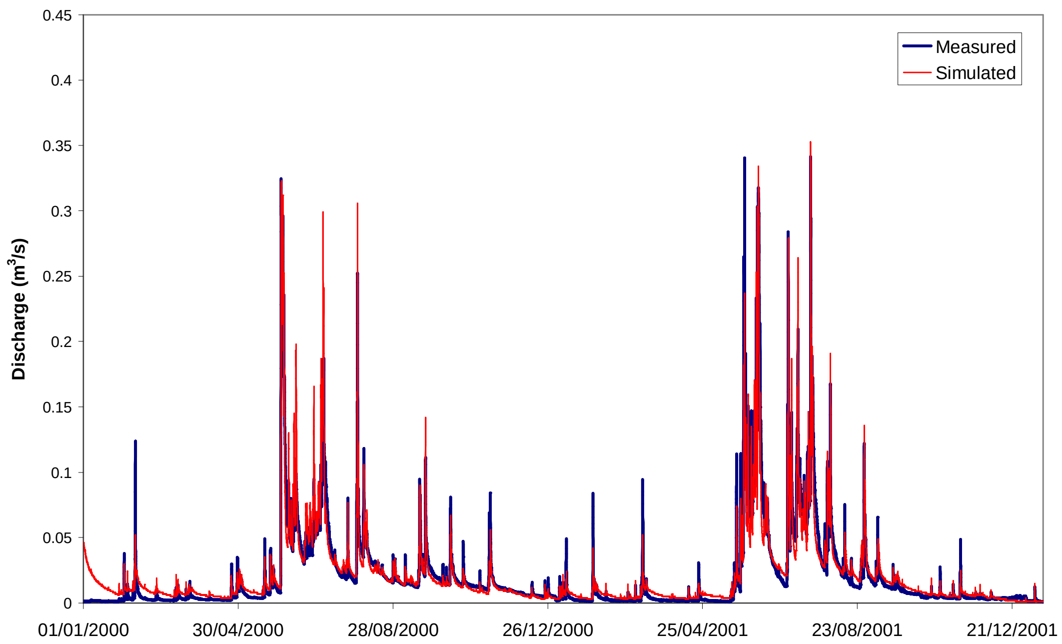

Figure 4.8 Measured and simulated discharges at La Reina basin outlet for 2000-2001

4.4 Modelling Strategy

The aim of the modelling is to test the hypothesis that, as the size of the flood peak increases, the effect of land use becomes less important. To achieve this aim, SHETRAN was used to simulate the flood response of La Reina basin in its forested and logged conditions, for the same rainfall events. Initially the model was run simply with generated rainfall events of different return periods, for two possible antecedent soil moisture conditions, wet and dry. However, the results were too limited to be useful. In particular, the method did not take into account sufficiently the possible range and combination of rainfall events and antecedent conditions.

A second method was therefore devised based on a long time series of synthetic rainfall. On the basis of the available rainfall data a 1000-year synthetic hourly rainfall time series was generated. SHETRAN simulations were then carried out for the forested and logged cases using the synthetic rainfall and the resulting flood characteristics for each day of the simulation were obtained. The corresponding maximum daily discharges for each day of the two simulations were plotted against each other to investigate convergence of the two responses at high flows. The simulations were carried out for the standard soil depth of 2.5 m and also for depths of 0.5 m and 10 m.

It is emphasized that the 1000 years of data are a statistical representation of current rainfall conditions. They do *not* form a prediction of rainfall over the next 1000 years. Generation of 1000 years of data provides an appropriate statistical basis for defining the basin flood response for events with return periods of up to 100 years or so. In other words, the current data base may not contain events with such large return periods. However, a long time series generated statistically from the current record effectively extends the range of return periods. The longer the current record, the more accurate that extension is likely to be.

The 1000-year synthetic rainfall record was developed using a seven-year hourly rainfall record for La Reina basin and a 45-year daily rainfall record for Isla Teja in Valdivia. Isla Teja is in the same general region as La Reina and has a similar annual and monthly rainfall distribution (Figures 4.9 and 4.10). Nevertheless it is not local to La Reina and its record therefore had to be correlated with La Reina's record before it could be used. A Gumbel plot of annual precipitation (Figure 4.11) shows that La Reina basin is generally wetter than Isla Teja and also that the 1997-2003 data include the wettest and driest years out of the 45-year record. A Gumbel plot of maximum daily precipitation (Figure 4.12) also shows that La Reina basin has larger daily precipitation events than Isla Teja.

Within the 1997-2003 period, there are six complete years with a full rainfall record at La Reina basin and Isla Teja. Therefore, for these six years, monthly statistics of corresponding daily data for the two stations were compared for mean, variance, auto correlation, skew and proportion of dry days (Figures 4.13-4.15). Using the resulting relationships the 45 years of daily Isla Teja data were modified to be appropriate for La Reina daily rainfall. The modified series of daily data was then combined with the variance and skew statistics for the hourly La Reina data in the University of Newcastle's Rainsim model to generate a 1000-year time series of hourly rainfall. The model uses a statistically based process for the rainfall generation. As a check (Figure 4.16), the 1000 years of data were converted into 142 periods of seven years for comparison with the original seven years of La Reina data: plotted as the frequency curve for annual maximum 24-hour rainfall, the data for La Reina fall within the range of the 142 sets of generated data.

Mean monthly evapotranspiration was calculated with the Penman-Monteith equation (with parameter values appropriate to the vegetation) and automatic weather station data and the same values were used for each year of the 1000 years.

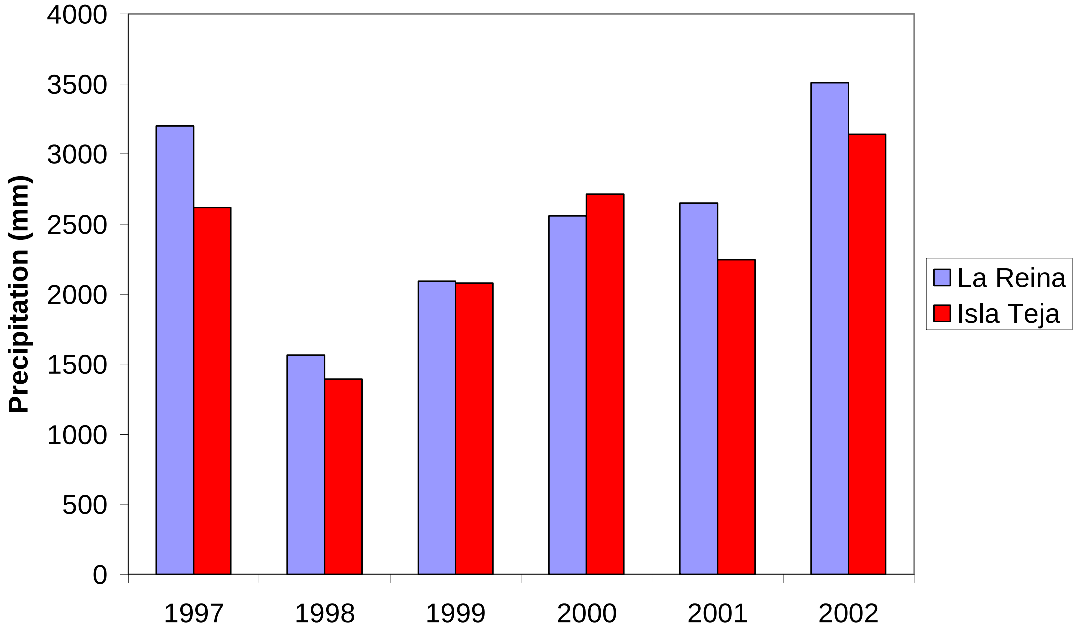

Figure 4.9 Annual precipitation totals at La Reina basin and Isla Teja for 1997 – 2002

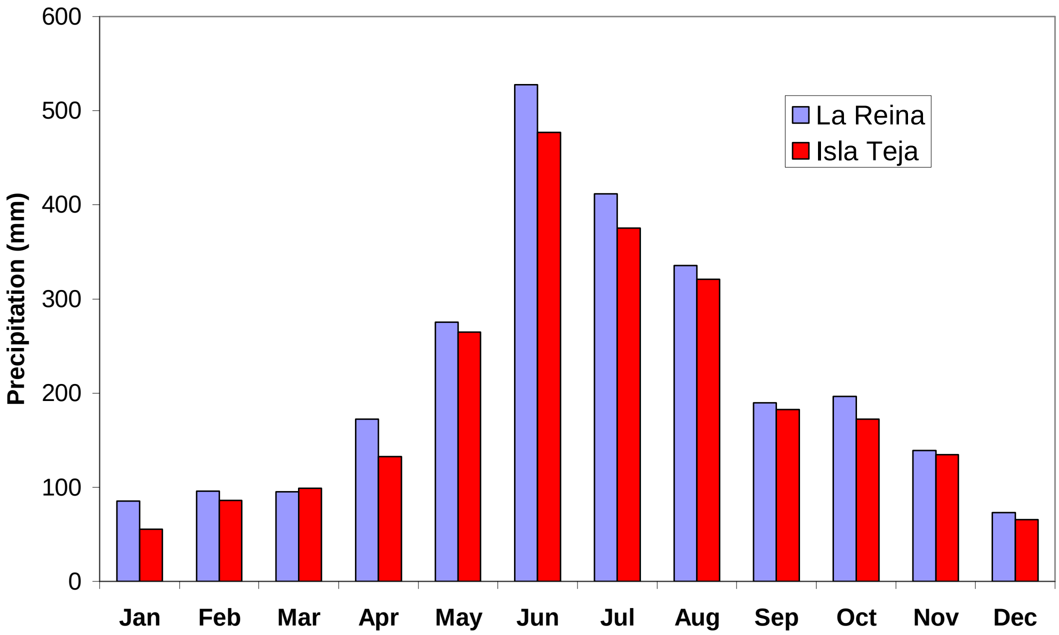

Figure 4.10 Mean monthly precipitation totals at La Reina basin and Isla Teja for 1997-2003

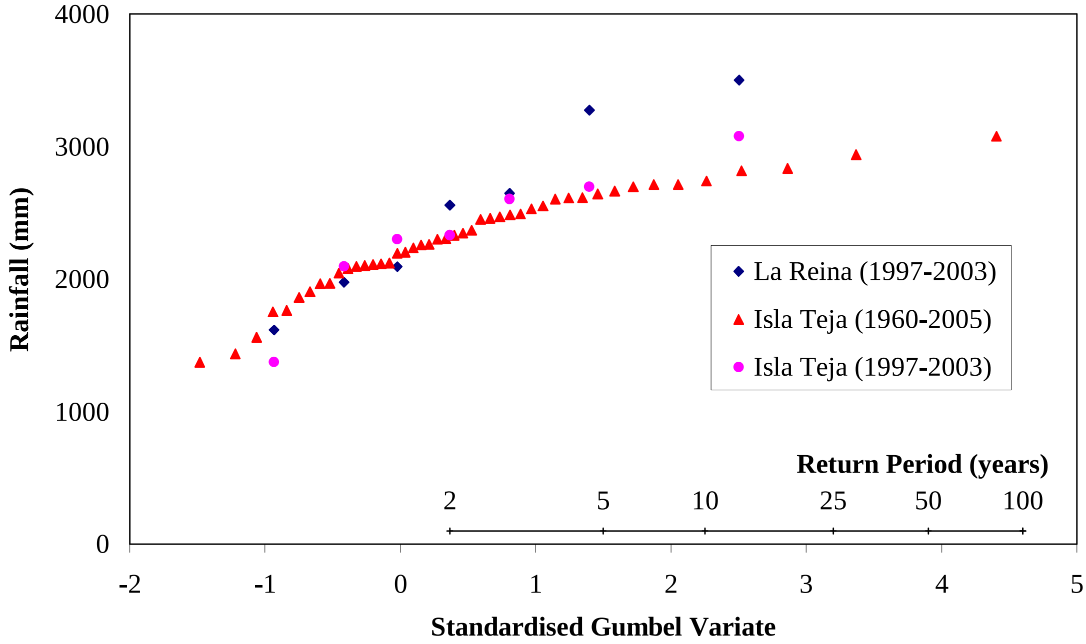

Figure 4.11 Gumbel plot of annual precipitation for La Reina and Isla Teja meteorological stations

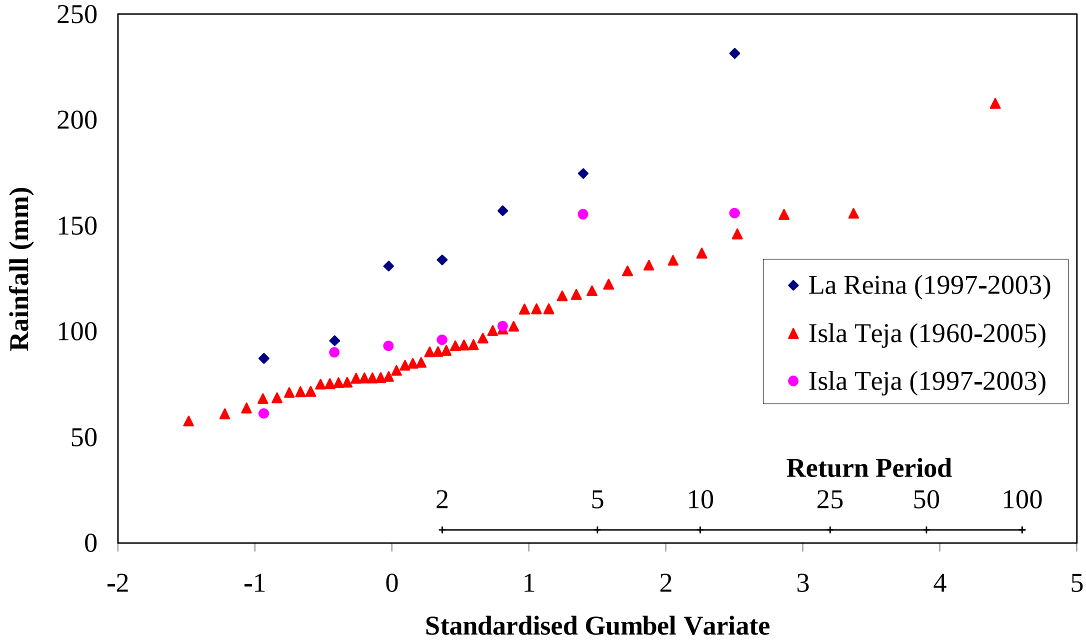

Figure 4.12 Gumbel plot of maximum daily precipitation for La Reina and Isla Teja meteorological stations. Return period in years

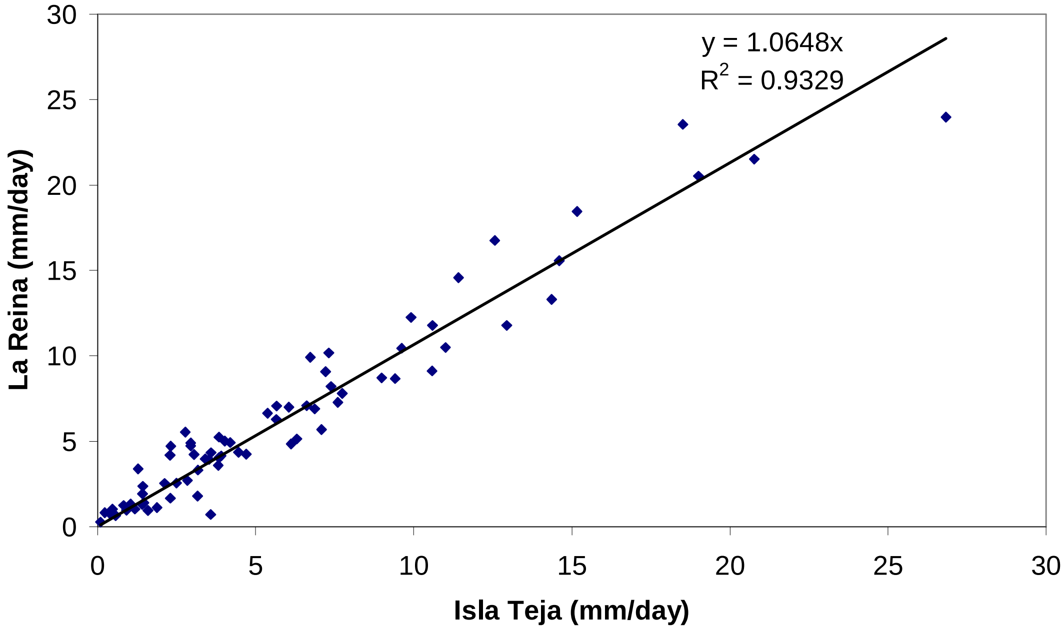

Figure 4.13 Comparison of mean daily precipitation between La Reina basin and Isla Teja for each month of a six-year period within 1997-2003

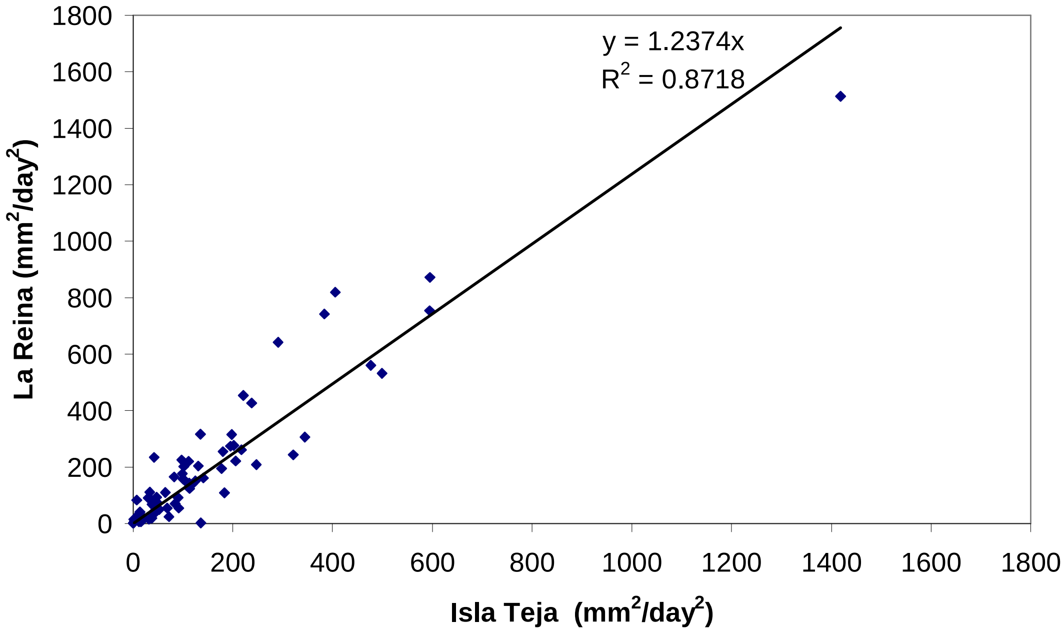

Figure 4.14 Comparison of the variance in daily precipitation between La Reina basin and Isla Teja for each month of a six-year period within 1997-2003

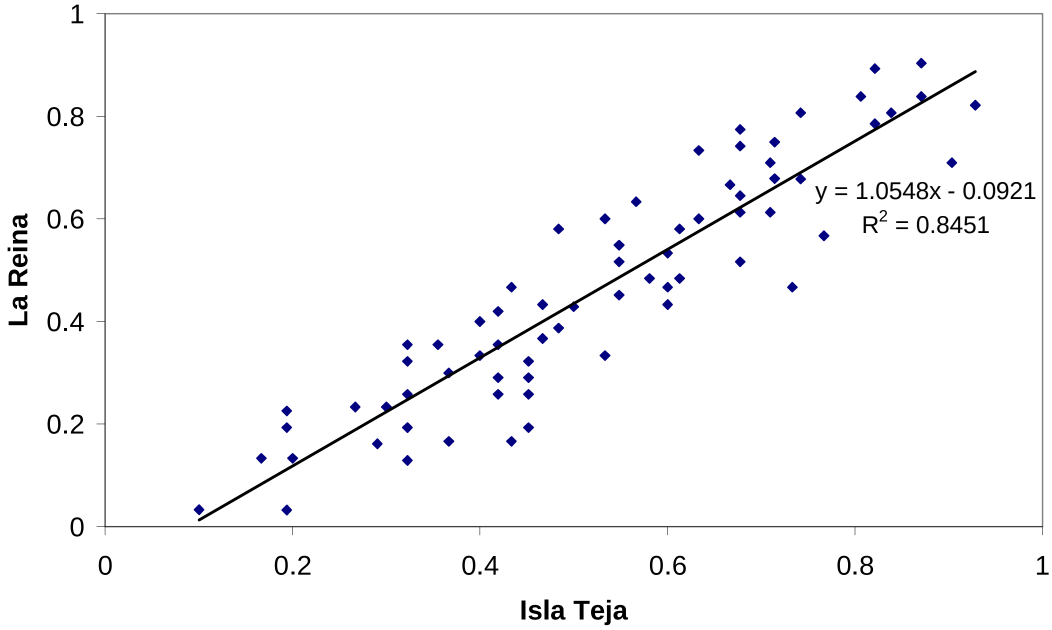

Figure 4.15 Comparison of the proportion of dry days between La Reina basin and Isla Teja for each month of a six-year period within 1997-2003

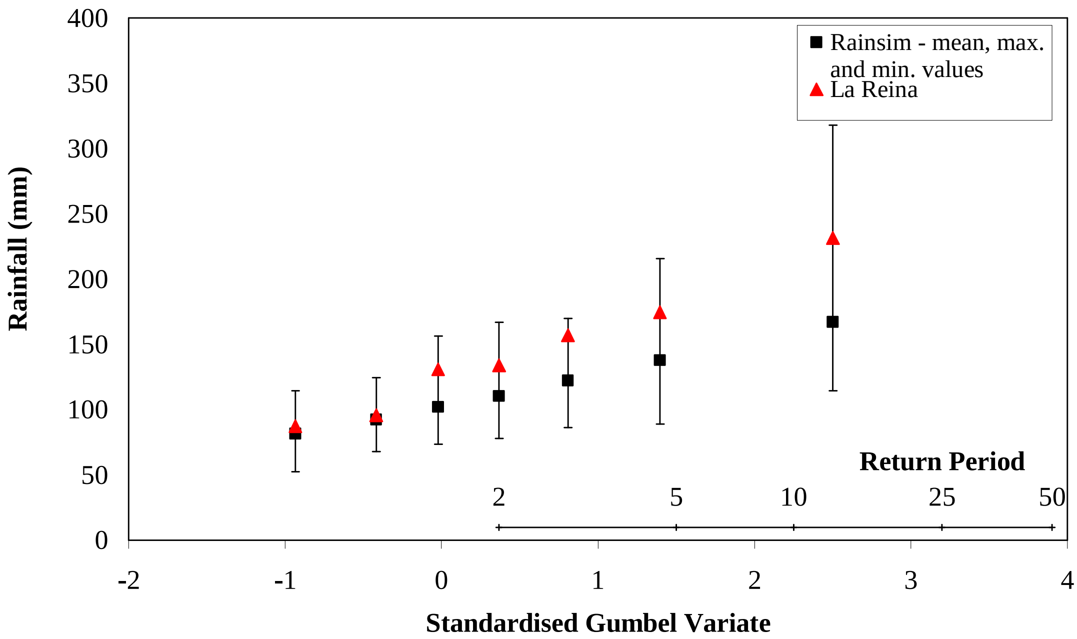

Figure 4.16 Gumbel plot of maximum daily precipitation for La Reina data 1997-2003) and 142 periods of seven-year Rainsim generated data

4.5 Simulations and Results

4.5.1 Water flow

The results of simulating La Reina basin with its standard soil depth of 2.5 m are shown in Figure 4.17. The figure compares the maximum daily discharges for each corresponding day of the 1000-year simulations for the forested and logged cases and shows that there can be a range of “logged” responses for a given “forested” discharge. In some cases there is no difference between the two discharges, in others there is: if the soil under the forest is very wet, the response is similar to the logged case. The difference between the two cases is least in the winter and greatest in the summer (when trees have the least and greatest effects respectively on soil moisture). Whatever the discharge, the range of “logged” discharges for a given “forested” discharge remains similar, although, as a percentage of the discharge, the range decreases as the discharge increases. It appears that antecedent moisture conditions determine the response and that it needs to have rained heavily before the actual date if similar responses are to occur. This is confirmed by a further set of simulations that was carried out to explore the impact of antecedent soil moisture. First, a three-year simulation was run for each vegetation case (using La Reina data for 1997-1999). From the results, soil moisture conditions were selected from the end of each month (a total of thirty-six with a mixture of wet and dry conditions). The conditions were different for the forested and logged cases but were from the same points in the respective simulations. Second, three daily events were selected from the 1000-year series, corresponding to the three largest discharge differences between the logged and forested cases. Each event was then run for each of the thirty-six soil moisture conditions. The results (Figure 4.18) show a slight convergence of the forested and logged cases as discharge increases, in correspondence with wetter soil. What is very clear, though, is that the difference between the forested and logged cases decreases as a percentage of discharge as the discharge increases. There is a similar response for the three events, although event 3 has less precipitation so the discharges are smaller.

Figure 4.18 contrasts with Figure 4.17 in that the responses lie approximately in line and there is a much reduced range of logged responses for a given forested response. This confirms the effect of seasonality and suggests that the type of event is also important. The three events represented in Figure 4.18 are all similar (short, sharp autumn rainfalls) and were selected for having the largest discharge differences between the logged and forested cases. Hence their responses in Figure 4.18 are similar. However, simulations (not shown here) with ten different types of event but the same antecedent condition show a wider range of logged responses. Thus season and event type can affect the absolute difference between the logged and forested cases, while antecedent conditions determine the extent to which, for a given season or event type, the responses converge at high discharges

The reason for the different responses from the forested and logged catchments can be seen in Figures 4.19 and 4.20, using rainfall event one with the antecedent conditions that produce the discharge shown by the enlarged point in Figure 4.18. Figure 4.19 shows how throughout the basin in the forested simulation the soils have less stored water at the start of the rainfall event, which is a result of higher evaporation losses. This means that the forested soils can store more rainfall before saturation excess overland flow occurs than can the logged soils. The ranked soil moisture storage from each grid square can be seen in Figure 4.20. The difference between the curves for the logged and forested storages is the additional water storage that would need to be added to the forested catchment for the outlet discharges to be the same. During the rainfall event more of the basin saturates for both the logged and forested simulations. However, the saturated area is always greater for the logged simulation, so by the time

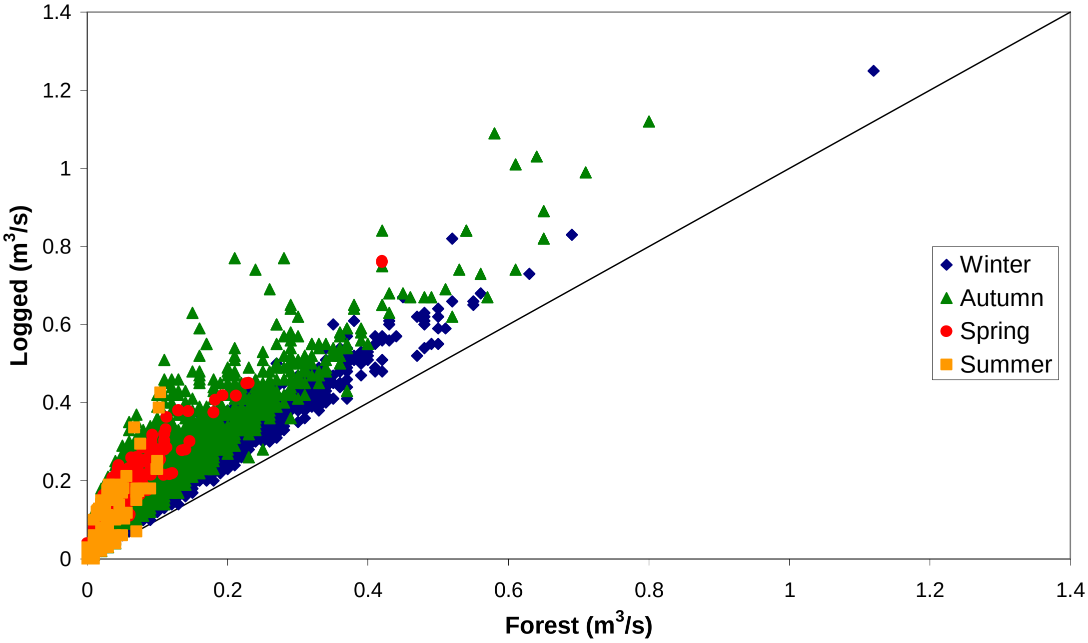

Figure 4.17 Comparison of corresponding maximum daily discharges (m^3 s^{-1}) for forested and logged conditions from the 1000-year SHETRAN simulations of La Reina basin. Line is line of equality

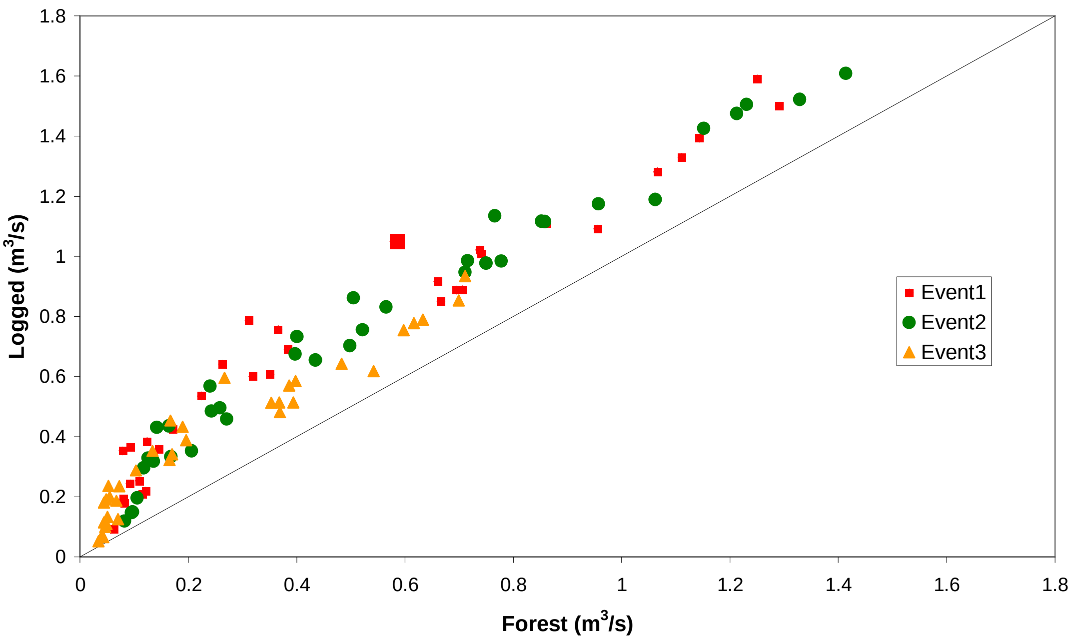

Figure 4.18 Comparison of corresponding maximum discharges (m^3 s^{-1}) for the forested and logged conditions from the SHETRAN simulations for three rainfall events with 36 different antecedent soil moisture conditions at La Reina basin. The enlarged data point shows the event and condition used in Figures 4.19 and 4.20. Line is line of equality

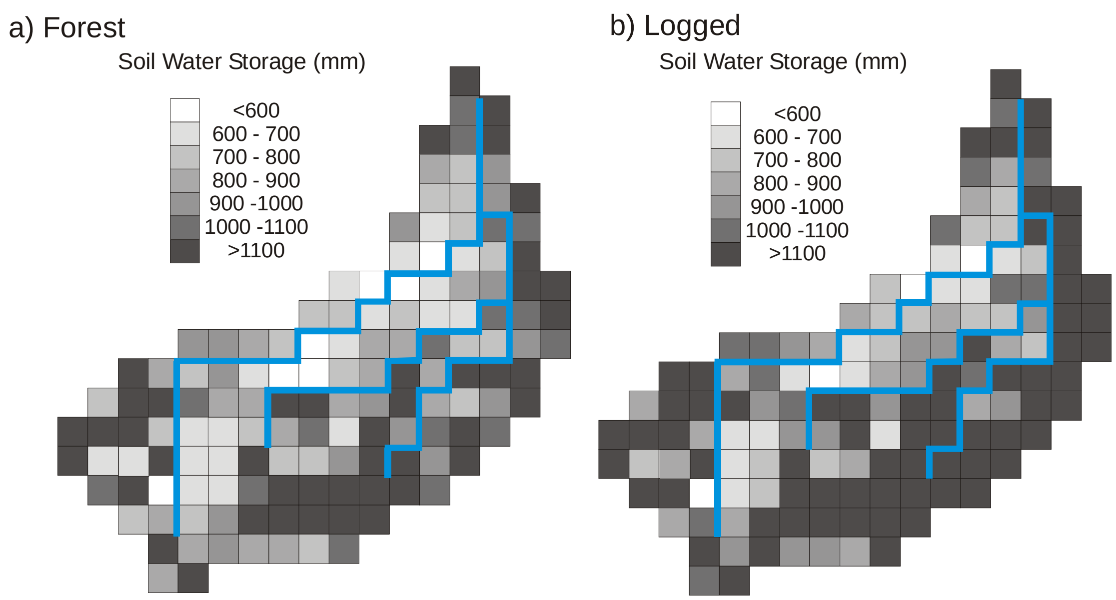

Figure 4.19 Comparison of soil water storage for forested and logged conditions from the SHETRAN simulations of La Reina basin at the start of the simulation for the enlarged data point in Figure 4.18

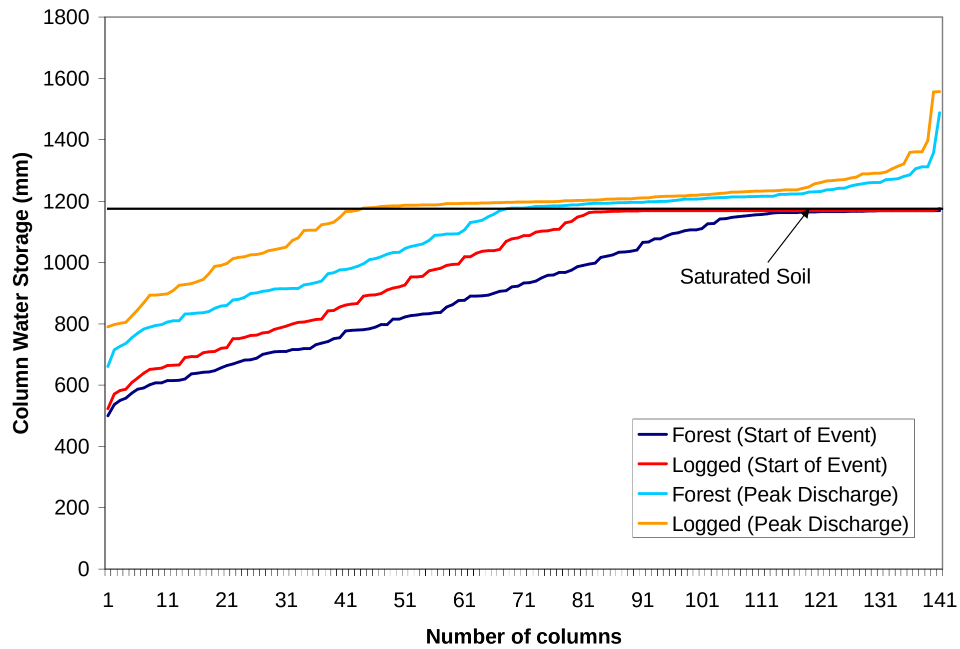

Figure 4.20 Ranked water storage in the soil column at each grid square for the forested and logged conditions from the SHETRAN simulations of La Reina. Curves are shown for the start of the simulation and for the peak discharge for the enlarged data point in Figure 4.17

of the peak of the rainfall event the area saturated for the logged simulation (100 out of the 141 grid squares) is greater than for the forested simulation (75 squares). The outlet discharge is produced mainly as a result of saturation excess overland flow and so the difference in saturated area produces the difference in peak outlet discharge between the two simulations (1.049 $m^3 s^{-1}$ for the logged simulation and 0.583 $m^3 s^{-1}$ for the forested simulation).

The above simulations are for the standard soil depth of 2.5 m; they were repeated with shallow (0.5 m) and deep (10 m) soils. The results (Figure 4.21) for the same 1000-year precipitation time series show that, as expected, the shallow soil has bigger discharges than standard and deep soils. In the shallow soil more of the basin is saturated and the higher runoff is a result of the more extensive saturation excess overland flow. What is also clear is that for the shallow soil case there is an absolute convergence of the logged and forested responses at higher discharges. For the deep soil the difference between the forested and logged conditions as a percentage of discharge seems to remain similar whatever the size of the discharge event.

Following the procedure used for the standard soil depth, additional simulations were carried out to examine the effect of the antecedent conditions. Figure 4.22 shows the results for the shallow soils for the three rainfall events with 36 different initial conditions. This shows that, the wetter the initial conditions, the less is the difference between the forested and logged cases, so that under very wet antecedent conditions their discharges are almost the same. The same procedure for the deep soils (Figure 4.23) shows the opposite response: the wetter the initial conditions, the larger is the difference between the forested and logged cases. In this case, the difference as a percentage of discharge remains similar as the discharge increases.

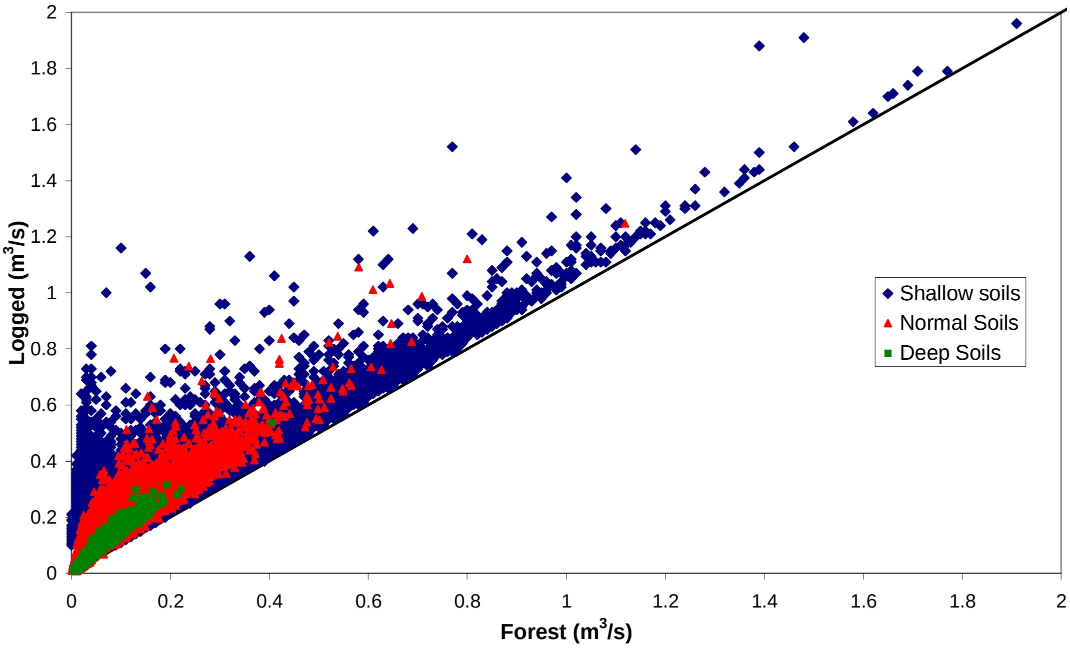

Figure 4.21 Comparison of corresponding maximum daily discharges ($m^3 s^{-1}$) for the forested and logged conditions from the 1000-year SHETRAN simulations of La Reina basin for three different soil depths. Line is line of equality

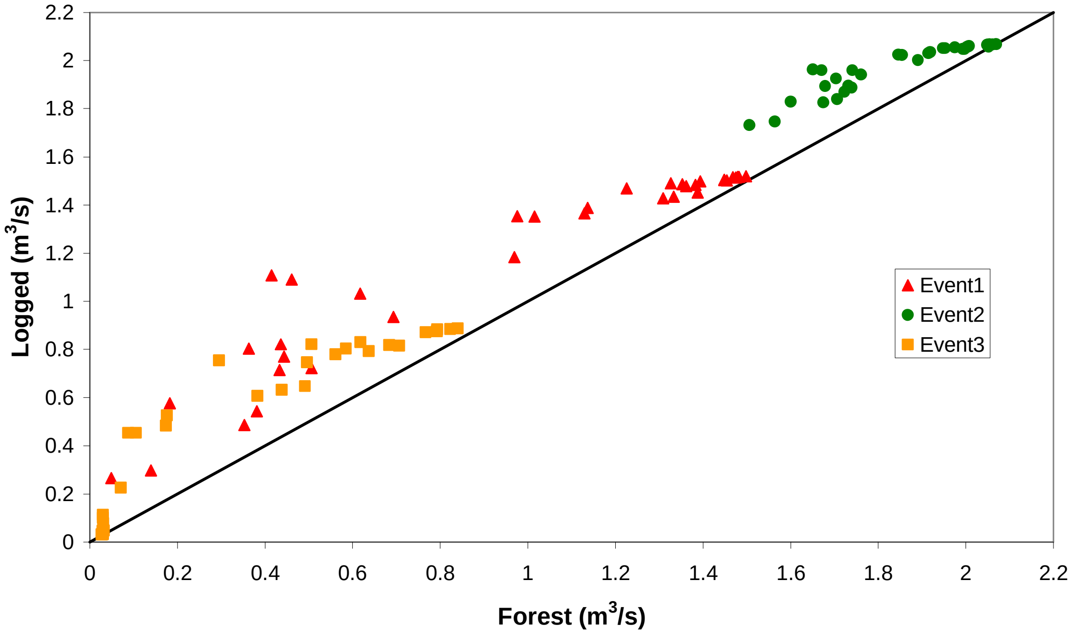

Figure 4.22 Comparison of corresponding maximum discharges (m^3 s^{-1}) for the forested and logged conditions from the SHETRAN simulations at La Reina basin with a shallow (0.5-m deep) soil for three rainfall events with 36 different antecedent soil moisture conditions. Line is line of equality

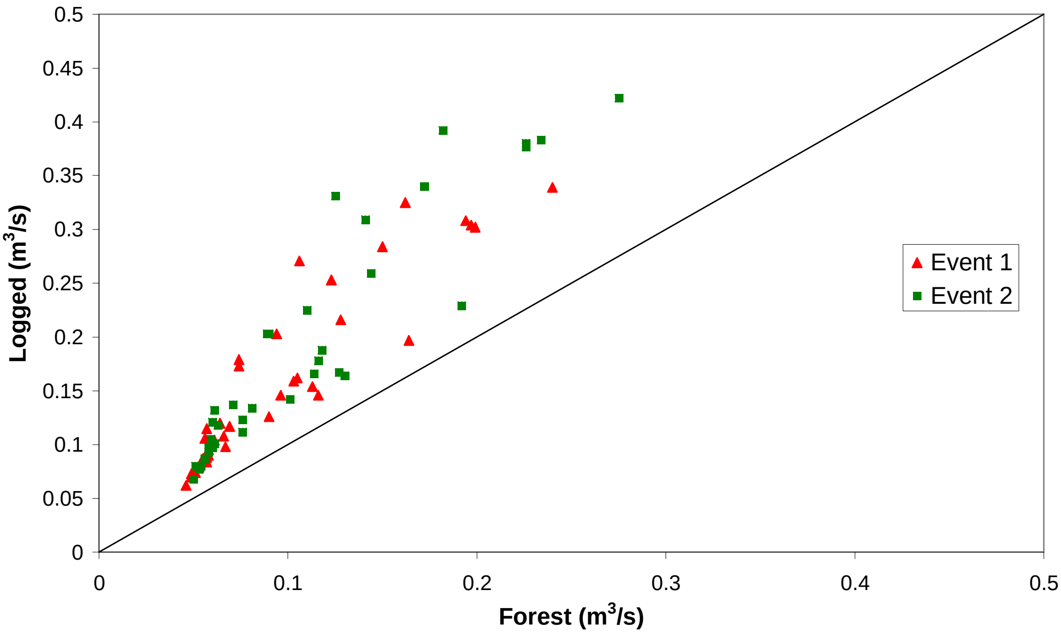

Figure 4.23 Comparison of corresponding maximum discharges (m^3 s^{-1}) for the forested and logged conditions from the SHETRAN simulations at La Reina basin with a shallow (10-m deep) soil for two rainfall events with 36 different antecedent soil moisture conditions. Line is line of equality

4.5.2 Sediment transport

Sediment transport simulations were carried out for the 1997-1999 period with forest and then for the same period with forest removed, i.e. as if logged. The simulations are driven by the calibrated water flow models (soil depth 2.5 m) and use the soil erodibility coefficients shown in Table 4.2. The results constitute the basic sediment transport models for La Reina basin. Figures 4.24 and 4.25 show the time series of sediment discharge at the outlet and the annual mass balance for the two vegetation cases. There is a significant increase in sediment yield from 3 t ha^{-1} yr^{-1} for the forest to 9.43 t ha^{-1} yr^{-1} for the logged catchment. The forest value is in good agreement with an initial analysis based on limited sediment transport measurements for 1997-1998 (corresponding to the forested state) which gave yields of 3.9-11.1 t ha^{-1} yr^{-1} depending on the technique used to derive continuous suspended sediment concentration (Menke de la Peña, 1999). Comparison is also possible against measurements from other sites. Bosch and Hewlett (1982), Stednick (1996) and Bruijnzeel (2004) have all reviewed the effect of vegetation on sediment yields. Clearing of forests produces an increase in catchment sediment yield, although the increase varies depending on the vegetation types and the climate. A review of small basin and plot measurements in Chile, currently in preparation by staff of the Universidad Austral de Chile, shows mean yields of 47 t ha^{-1} yr^{-1} for bare soil and 3.9 t ha^{-1} yr^{-1} for forest plantations. However, the plantation yields are averaged over a 20-year period, so may not reflect the relatively high values typically observed in the year or two following logging. Likewise, plot data from Chile suggest that soil loss after logging is around 2-5 t ha^{-1} yr^{-1} for sites where the forest residue is burnt and the soil has no cover, is around 0.5-2 t ha^{-1} yr^{-1} for sites where the forest residue is retained, and is around 0.1 t ha^{-1} yr^{-1} for control sites with no logging (Oyarzun and Peña, 1995; and the above mentioned review). The SHETRAN simulations are supported by the limited field data and the above mentioned review but are high compared with certain plot measurements.

As with the water flow, long term sediment transport simulations were run for the logged and forested cases, using the basic sediment transport models. In this case 100-year simulations were run and the maximum transport rates for each day for the two cases were compared (Figure 4.26). The logged case always has a higher transport rate than the forested case, indicating a clear benefit from forest cover in terms of protection against erosion.

The impact of a buffer strip in reducing sediment delivery to the channel was then investigated for the logged basin by introducing a 10-m wide grass strip along the channel system and running the simulation for the 1997-1999 rainfall. As SHETRAN cannot simulate the filtering effect of a strip on sediment transport directly, the effect was represented indirectly by increasing the flow resistance for the overland flow. On this basis it was found that the buffer strip has little effect on water discharge but reduces sediment yield to the level of the forested basin yield (Figures 4.24 and 4.25). Because of the approximations in the simulation, the magnitude of the simulated effect may not be entirely correct but the result does indicate the direction of change associated with the introduction of a buffer strip.

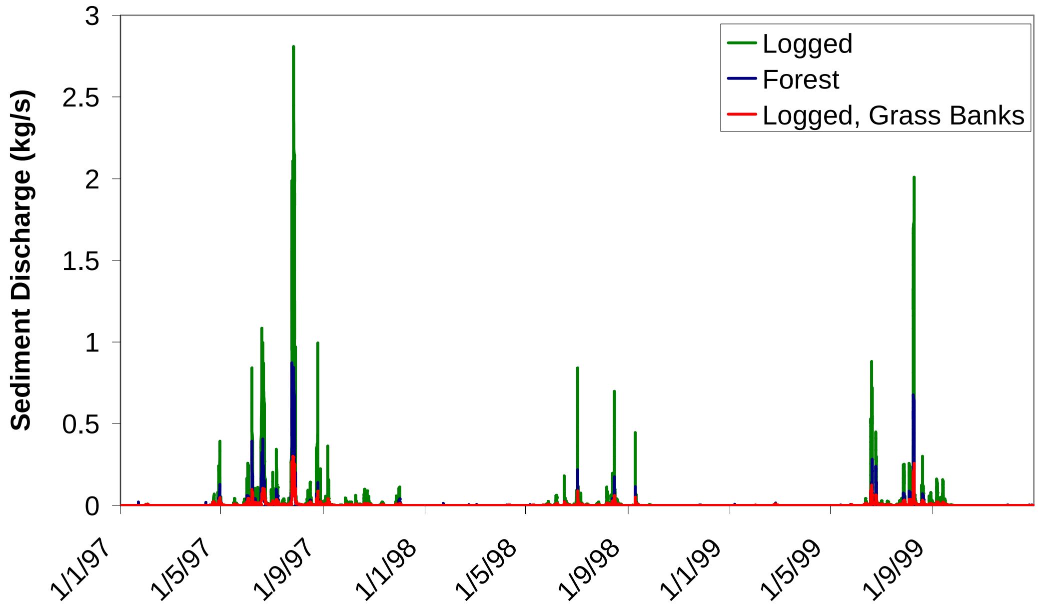

Figure 4.24 Simulated sediment discharge at La Reina basin using the 1997-1999 rainfall

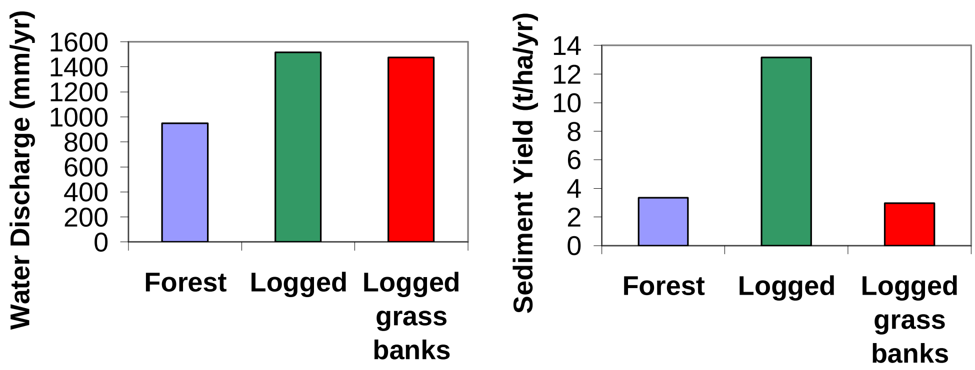

Figure 4.25 Simulated annual water discharge and sediment yield at La Reina basin using the 1997-1999 rainfall for forested, logged and buffer strip cases

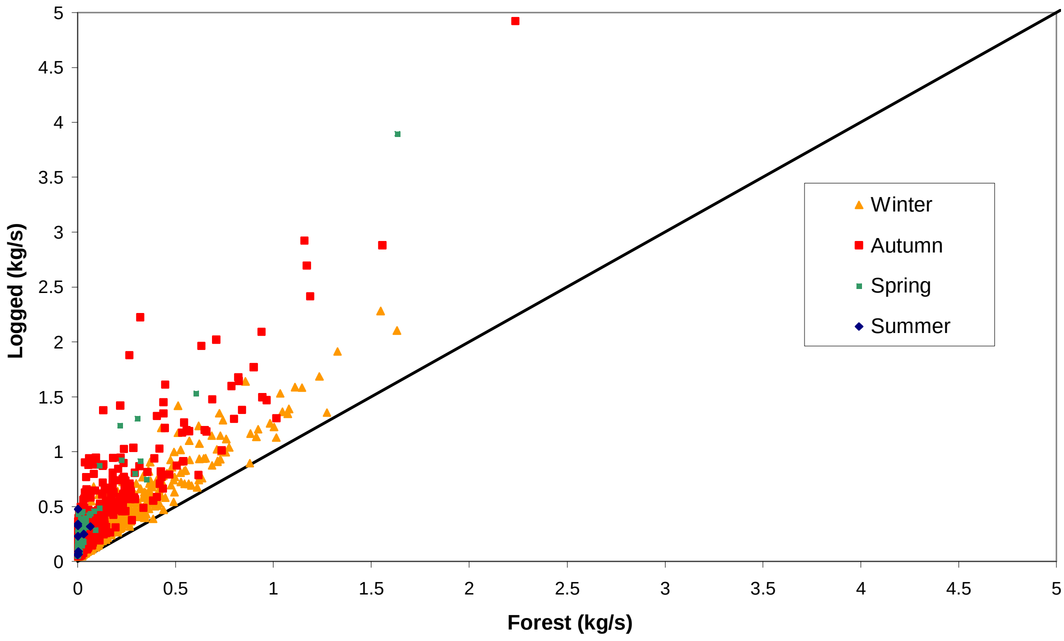

Figure 4.26 Comparison of corresponding maximum sediment discharges (kg s^{-1}) for the forested and logged conditions from the 100-year SHETRAN simulations of La Reina basin. Line is line of equality

4.6 Discussion of Land-use Impacts

La Reina is an excellent case study as it is generally homogeneous and the entire area was logged in January 2000 (i.e. practically instantaneously). The effect of the forest cover (in terms of water loss by transpiration and interception) is shown by the measured 110% increase in annual water yield following logging (Iroumé et al., 2006). The soils in La Reina are well drained so there appears to be little or no infiltration excess runoff. Thus the discharge response is a function of saturation excess runoff. Therefore, the discussions here are not relevant to those basins where infiltration excess runoff is important.

The simulations conform with observation in showing that discharges from the forested catchment are generally lower than discharges from the logged catchment, because of the difference in transpiration and interception. However, when considering the maximum daily discharges, the simulations also show that there can be a range of "logged" responses for a given "forested" discharge, depending on season, type of event and antecedent soil moisture conditions. Overall, for the simulations with the standard soil depth of 2.5 m, the range of differences remains approximately constant as discharge increases. However, as a percentage of discharge, the range decreases as discharge increases. The reasons for this are that: a) the wetter the antecedent conditions, the smaller is the difference in discharge between the forested and logged cases, at least as a percentage of discharge; b) higher discharges occur only when the antecedent conditions are wet; and therefore c) the difference in response decreases as discharge increases.

This pattern, however, varies as a function of soil depth. Shallow soils can store less water before becoming saturated and therefore accentuate runoff effects. Deeper soils store more of the rainfall and therefore moderate the runoff response. Thus, for the shallow soil (0.5m), there is an absolute convergence between the discharge response for the forested and logged cases as discharge increases. By contrast for deep soils (10m) there is no convergence (at least for the range of discharges simulated) and the difference between the discharges for the logged and forested cases stays roughly the same as a percentage of discharge as discharge increases. These results show the complexity of the issue. Even for a single homogeneous basin different responses can be seen for different soil depths. For shallow and medium depth soils, the simulations support the hypothesis that, as the size of the flood peak increases, the effects of land use becomes less important. For deep soils, though, there is no support for the hypothesis.

By contrast, as far as soil erosion is concerned, there is no equivocation. For all the conditions simulated, forest cover protects the soil from erosion (through protection against raindrop impact erosion or through reduced overland flow) and therefore reduces the sediment transport in the river in comparison with the logged case.

Logging operations can affect runoff and sediment yield not only through the change of vegetation cover but also through associated activity such as road construction and soil compaction by machinery. If such activities are poorly conceived and unsympathetically managed, they may be responsible for the majority of the impact, especially as far as sediment yield is concerned. It is emphasized, therefore, that the simulations discussed here refer only to the effect of the change of vegetation cover.

4.7 Conclusions

The aim of the model application is to test the hypothesis that, as the size of the flood peak increases, the effects of land use become less important. For Chile the 35-ha La Reina basin was modelled and excellent model calibrations for both the forested conditions (1997-1999) and logged conditions (2000-2001) were achieved. The difference between them was produced entirely by appropriate changes in the vegetation parameters, while keeping the soil and overland flow resistance characteristics the same.

A 1000-year synthetic rainfall time series was generated, representative of the current climate at La Reina basin. With the series as input, simulations were run with the calibrated models for both the logged and forested cases. Comparison of the corresponding maximum daily discharges for the two cases shows that there can be a range of “logged” responses for a given “forested” discharge, depending on season, type of event and antecedent soil moisture conditions. Season and event type affect the absolute difference between the forested and logged discharges: differences are least in winter and greatest in summer, when trees have their least and greatest effects respectively on soil moisture. Additional simulations with a given type of event and season but varying antecedent conditions illustrate how the antecedent conditions control convergence of the two responses as discharge increases. For the simulations with the standard soil depth of 2.5 m, the absolute discharge difference remains approximately constant as discharge increases: thus, as a percentage of discharge, it decreases. The reasons for this are that: a) the wetter the antecedent conditions, the smaller is the difference in discharge between the forested and logged cases, at least as a percentage of discharge; b) higher discharges occur only when the antecedent conditions are wet; and therefore c) the difference in response decreases as discharge increases. Simulations with different soil depths show different results, because depth affects how much water can be stored in the soil column before saturation occurs and runoff is generated. Thus with a shallow soil there is absolute convergence as saturation can occur for both land covers. With a deeper soil, saturation is rarely achieved so the forested catchment is always able to absorb more rainfall than the logged catchment and there is no convergence of response. For shallow and medium depth soils, therefore, the simulations support the hypothesis that, as the size of the flood peak increases, the effects of land use becomes less important. For deep soils, though, there is no support for the hypothesis.

The sediment transport simulations show that forest cover provides a clear benefit in protecting the soil from erosion and therefore reducing the sediment transport in the river in comparison with the logged case.

The results are relevant to small basins in temperate Chile. The impact of forest cover on flood peak discharge for extreme events in large basins is examined in Deliverable 17.

5 BUENA ESPERANZA BASIN, ARGENTINA

5.1 Description of Basin

Buena Esperanza is a 12.9-km^2 basin that debouches into the city of Ushuaia in the Tierra del Fuego province of Argentina. Figure 5.1 shows the shape of the basin with elevations ranging from 140 m at the outlet up to1250 m. The basin is forested up to 550 m, with bare ground above this level and with small cirque glaciers located at the basin head. Mean annual precipitation ranges from 530 mm in Ushuaia to 1300 mm in the upper part of the basin. It is spread evenly throughout the year, failing mainly as snow in the winter (May to September). There is currently no forest logging, although there has been some in the past. More details of the basin can be found in Deliverable 18.

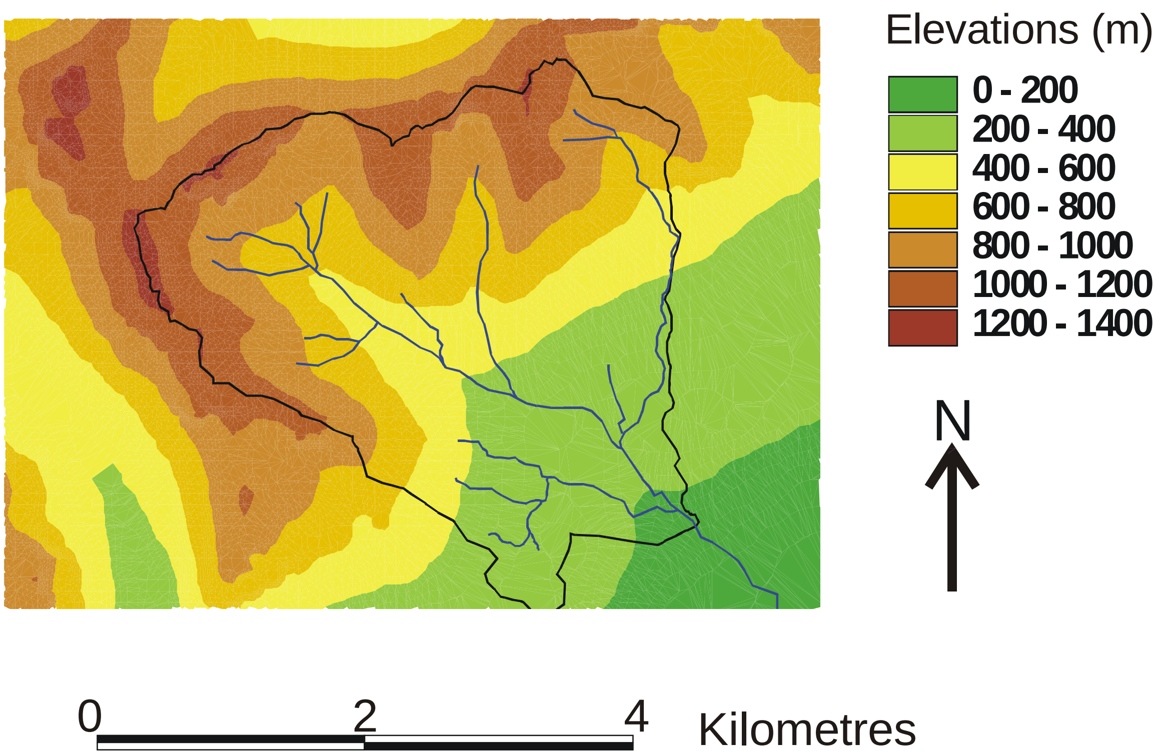

Figure 5.1 Buena Esperanza basin

5.2 Data Collection

Data for the basin are provided by the Subsecretaría de Recursos Naturales de Tierra del Fuego (SRNTF), as described in D18.

5.2.1 Spatial data

A DEM and river network data are available. Satellite imagery has been used to investigate the spatial distribution of soil type and vegetation properties. Soil pits have been dug at various points in the basin to investigate the soil properties.

5.2.2 Time series data

Intensive monitoring of the Buena Esperanza basin has been carried out for a number of years and an excellent set of data is available from 1/5/2005 to 30/4/2007. This includes hourly discharge at the Buena Esperanza outlet and the Martial and Godoy sub-basins. These data are available for most of the year, apart from gaps of four months in the 2005 winter and one month in the 2006 winter. Hourly precipitation has been measured at the Aerosilla site (at 500 m elevation within the Buena Esperanza basin) for the entire period. However, this raingauge is not suitable for snow collection and so precipitation data in the winter are underestimated. There are also daily precipitation data (and some hourly data) at Ushuaia (at sea level) for the entire period, which include rain and snow. Hourly temperature data are available for the entire period at Ushuaia and the Martial glacier (1000 m elevation). In addition there is estimated daily potential evaporation at elevations of 120 m and 600 m.

5.3 Model Set-up

5.3.1 Basin set-up

The SHETRAN mesh for the Buena Esperanza basin uses 398 180-m by 180-m grid squares and 102 river links (2 m wide) that run along the edge of the grid squares (Figure 5.2). The modelled elevations can also be seen in Figure 5.2. The simulation period was for 1/5/2005 to 30/4/2007. May-October 2005 is effectively a run-in period as, with no discharge measurements in this winter, it could not be calibrated.

The vegetation type for each grid square can be seen in Figure 5.3. Six different vegetation types are specified. The lower part of the basin is a mainly a pine forest, apart from the flatter areas where it is marshy. Above this there is deciduous forest and then grassland in the upper main valley bottom. Owing to the extreme conditions the remainder of the basin is made up of rock debris of different thicknesses. The soil types follow a similar pattern to the vegetation types (Figure 5.4). Under the forests there is an organic soil on top of a glacial till and in the marshy areas there is a deep peat soil. The grassland area also has an organic soil on top of a glacial till and higher that there is little or no soil.

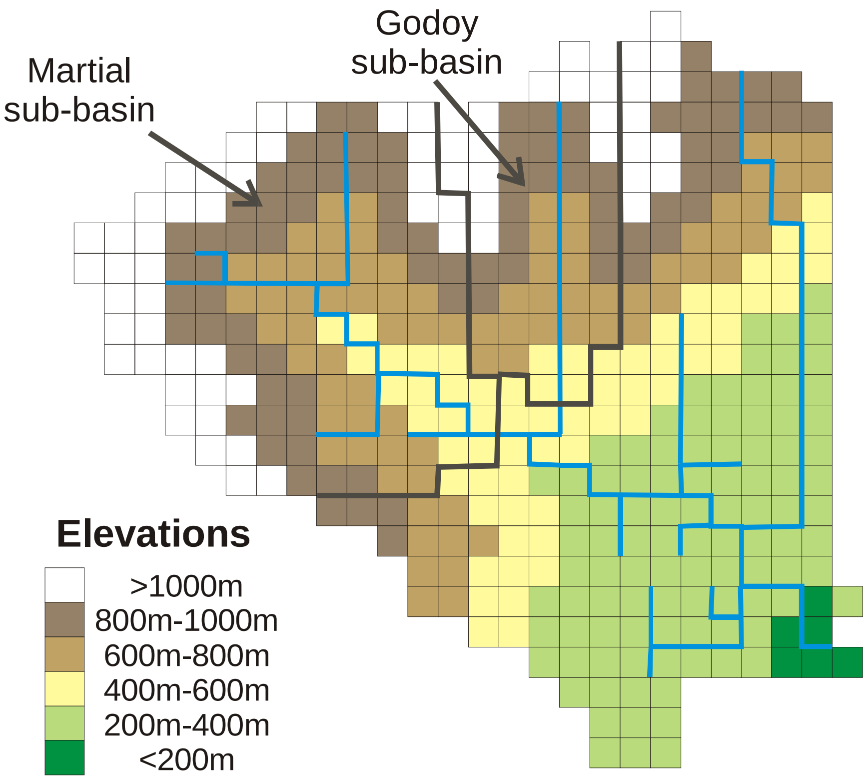

Figure 5.2 SHETRAN mesh (180-m grid squares) and elevations for the Buena Esperanza basin. The stream channels run along the edge of the grid squares. The Martial (4.8 km^2) and the Godoy (1.5 km^2) sub-basins are also shown

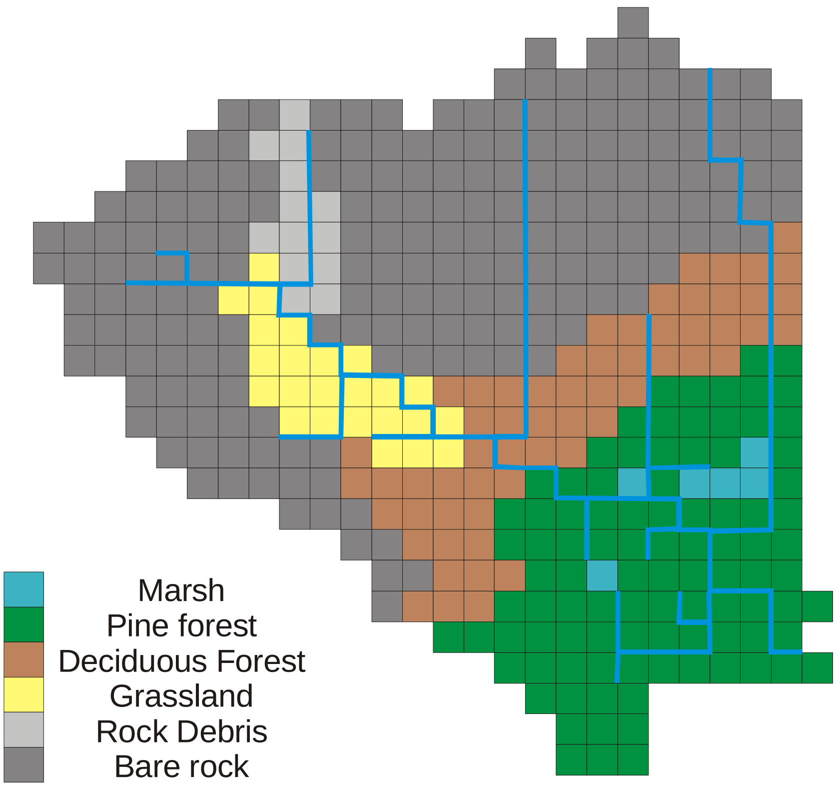

Figure 5.3 SHETRAN vegetations for the Buena Esperanza basin

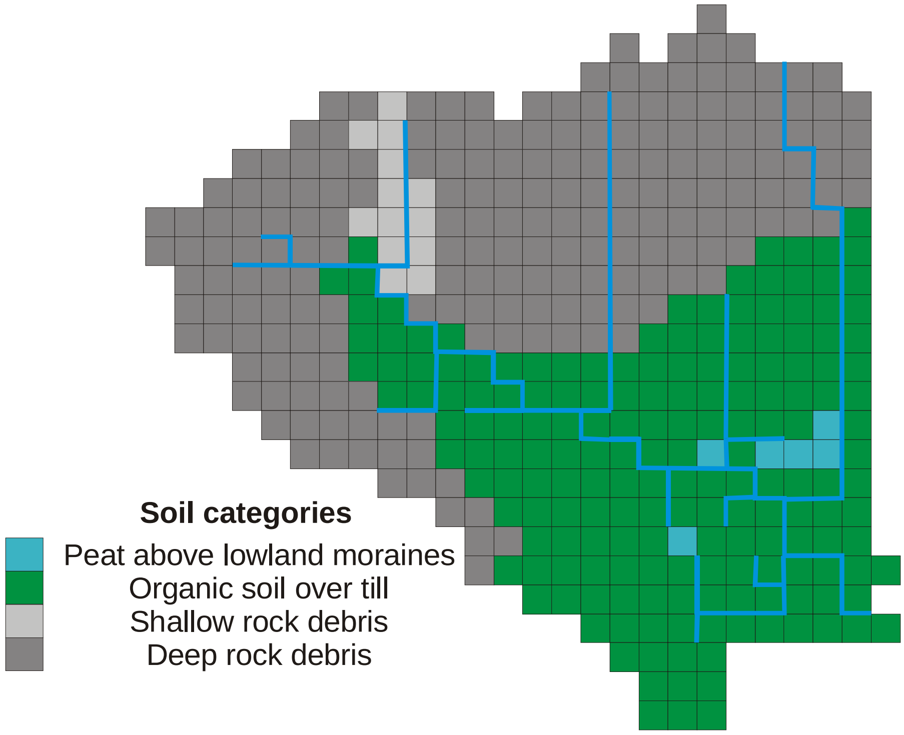

Figure 5.4 SHETRAN soils for the Buena Esperanza basin

Table 5.1 shows the vegetation parameters used in the SHETRAN simulations. The main difference between the forest and non-forest vegetations is the lower aerodynamic resistance in the forest, which produces higher evaporation (and higher interception evaporation in particular). (Evapotranspiration was modelled using the Penman-Monteith equation.) The rock cover has no canopy storage or drainage.

Table 5.1 Vegetation parameters used in the SHETRAN simulation of the Buena Esperanza basin. The given canopy resistance is the value at field capacity; in the simulation it increases with soil moisture tension

Vegetation	**Canopy Drainage**		**Canopy Storage (mm)**	**Rooting Depth (m)**	**Aerodynamic Resistance (s/m)**	**Leaf Area Index**	**Canopy Resistance (s/m)**
	CK(mm s^{-1})	**Cb (mm^{-1})**					
Marsh	3.0E-5	3.7	0.05	0.2	40.0	0.05	70
Pine forest	3.0E-5	3.7	2.0	2.8	3.5	5.0	70
Deciduous forest	3.0E-5	3.7	2.5	2.8	3.5	5.0	70
Grassland	3.0E-5	3.7	3.0	0.2	40.0	2.0	50
Rock debris	-	-	0.0	0.0	40.0	0.0	-
Bare rock	-	-	0.0	0.0	40.0	0.0	-

The parameters for the different soils (Fig. 5.4) can be seen in Table 5.2 (obtained by measurement or calibration). The category of peat has 8 m of organic topsoil above 2 m of compacted till. The organic layer over till category has 0.5 m of organic topsoil above 9.5 m of compacted till. The deep rock debris category has a depth of 1.2 m and the shallow rock debris has a depth of 0.6m. The storage and conductivities in the rock debris were calibrated using discharge data from the Martial and Godoy sub-basins. The depth of 10 m for the two categories of peat and organic layer over till is

Table 5.2 Soil parameters used in the SHETRAN simulation of Buena Esperanza basin

Soil type	Porosity	Residual moisture constant	Saturated hydraulic conductivity		Van Genuchten Coefficient	
			Vertical (m/day)	Horizontal (m/day)	alpha (cm^{-1})	n
Organic Topsoil	0.95	0.3	10.0	2.0	0.012	1.5
Compacted Till	0.35	0.15	0.3	0.3	0.006	1.5
Rock Debris	0.40	0.05	5.0	5.0	0.8	1.1

assumed, based on guidance from SRNTF, so as to provide an appropriate model boundary.

The overland flow Strickler coefficient was calibrated at values ranging from 0.08 for forests up to 0.12 for the rock debris.

The Buena Esperanza basin shows a large variation in meteorological conditions from Ushuaia just below the outlet to the top of the basin. The vegetation forms effectively a series of altitudinal bands and the meteorological inputs are distributed accordingly. The simulation is based on hourly precipitation from the Aerosilla site which is situated at an elevation of 500 m within the basin. The gauge at Aerosilla is not suitable for measuring precipitation in the form of snow. Thus in the winter period of May – September daily precipitation from Ushuaia is used. This daily precipitation is disaggregated into a triangular shape so that it takes place over a period of 8 hours with a peak after 4 hours (the actual disaggregation method is not important as much of the precipitation is snow and there are only small discharge events). Based on measurements a multiplication factor of 1.5 was used to convert the Ushuaia data to Aerosilla data. The precipitation for each vegetation band was calculated by multiplying the hourly data for Aerosilla by a precipitation factor determined for each band (Table 5.3). The factors were determined from the measured post-2005 Buena Esperanza data.

The temperature for each vegetation band was calculated (Equation 5.1) by using the temperature factor (T_f) and the measured temperatures at Ushuaia (T_0) and the Martial glacier (T_{1000}) (based on a lapse rate of 0.65 C° per 100 m). T_f values of 0 and 1 give the temperature at respectively Ushuaia and the Martial glacier.

$$T = (1-T_f) * T_0 + T_f * T_{1000} \tag{5.1}$$

Table 5.3 Modification factors for time series data for each vegetation type

Vegetation	Precipitation factor	Temperature factor (T_f)
Marsh	0.9	0.4
Pine forest	0.9	0.4
Deciduous forest	1.1	0.5
Grassland	1.3	0.6
Rock debris <800m	1.4	0.8
Rock debris >800m	1.5	0.9

The degree-day approach was used to model snowmelt. The degree-day approach is a simplification of the more complex energy balance approaches but it often has a similar performance. Ohmura (2001) found this was due to the high correlation between temperature and several energy balance components. Hock (2003) reviewed snowmelt modelling in mountain areas and found the degree-day approach was the most commonly used method. This is mainly due to air temperature data being easily available and the method being easy to use and generally performing well.

In the degree-day approach there is a direct relationship between the air temperature above a base value and the snowmelt. If the base value is 0 ºC the term is called the 'degree day factor' and if a different base value is used (usually greater than zero) the term 'melt factor' is used (Hock, 2003). In this work the 'melt factor' uses a threshold (or base) temperature of 4 ºC. Using measured data from Ushuaia a temperature of 4 ºC is also used to define the transition between rainfall and snowmelt

Studies on snow accumulation and melting generally show more accumulation and faster melting on open land compared with in forests (Pomeroy and Brun, 2001). However, Pomeroy and Brun note that, owing to wind displacement, lower snow depth accumulation can also be found in open areas and this is a significant factor in the Buena Esperanza basin. The approach adopted for this basin is therefore to assume that there is no difference in accumulation under different vegetations but to use faster melting in open areas. This is achieved by using different melt factors for forests and open areas. Kuusisto (1980) measured 96,000 snow depths for forested and open sites in Finland and found degree-day factors about 50% higher in open sites. Talbot et al. (2006) found degree-day factors 100% higher in open areas compared with in forests at a site in Quebec, Canada.

The situation at Buena Esperanza is complicated because the elevation, as well as the different vegetations, has a major effect on the snow melt. Following the suggestion by Hock (2003) a melt factor increasing with increasing elevation is used. Thus the same vegetation type at a higher elevation has a higher melt factor. As with many snow-melt models a seasonal melt factor is also used, in this case the method of Braun et al. (1993) with a maximum value in the middle of summer (21 December) and a minimum in the middle of winter (21 June). Melt factors calibrated for the different vegetation types of the Buena Esperenza basin can be seen in Table 5.4. There is a big difference between the lowest value of 4.3 mm $^{\circ}C^{-1}$ day^{-1} for forest at low elevations and 13.0 mm $^{\circ}C^{-1}$ day^{-1} for rock debris at high elevation.

Table 5.4 Melt factors used in the SHETRAN simulation of Buena Esperanza.

Vegetation	**Average Melt Factor mm $^{o}C^{-1}$ day^{-1}**
Marsh	6.9
Pine forest	4.3
Deciduous forest	5.2
Grassland	9.0
Rock debris < 800m	10.0
Rock debris> 800m	13.0

5.3.2 Calibration

The comparison between the simulated and measured discharges for August 2005 – April 2007 can be seen in Figure 5.5. There are some gaps in the measured discharge record during the winter period (May-September) but during this part of the year there is snow over most of the basin and discharges tend to be small. There are several sources of error in the time series data used in this simulation. The main problem is the precipitation data which is mainly based on data from Aerosilla (at 500 m altitude within the basin): values for the rest of the basin are modified to account for an increase/decrease of precipitation with altitude. There are occasions when this will overestimate the precipitation at higher altitudes and other occasions when it will underestimate the precipitation. Similarly, the temperature data vary with altitude and although this variation is better defined with known values at 0 m altitude (Ushuaia) and 1000 m altitude (Martial glacier) there will still be errors at intermediate values. Despite these problems the simulated discharge shows good agreement (Nash-Sutcliffe efficiency of 0.83) with the measured discharge, with approximately the correct peak discharges and the base flow well matched to the measured value. The main problem is the peak on 11/11/2005 where a discharge of 4.1 $m^3 s^{-1}$ was simulated compared with a measured value of 3.0 $m^3 s^{-1}$. This appears to be a rain on snow event and the discrepancy is discussed more when the sub-basins are considered.

The hydrology in the basin is complex. For most of the winter the entire basin is covered with snow. Then snow in the lower basin starts to melt in September whilst it is still accumulating in the upper basin. By November the lower basin is usually snow free and the upper basin is beginning to melt. By the end of December the entire basin (apart from the glaciers) is snow free. Thus the discharge from the outlet can be snowmelt events, rainfall events or a combination of the two. The biggest events such as the major event in 1954 are generally rain on snow events. Figures 5.5 and 5.6 show that two big events are the result of different processes. The event of the 14/11/06 is a result of snow melt. There is very little precipitation on that day but mean daily temperature in Ushuaia is 15 ºC. This is high enough to cause significant melt throughout the basin. By contrast the event on 20/1/06 involves precipitation intensities of 6 mm hr^{-1} at Aerosilla and up to 9 mm hr^{-1} higher in the basin for several hours. All the snow has melted by this time and so the event is a result of the rainfall.

Measured and simulated discharges for the Martial and Godoy sub-basins can be seen in Figures 5.7 and 5.8. Again there is a good match with Nash-Sutcliffe efficiencies of 0.78 (Martial) and 0.76 (Godoy). It is very encouraging that, as well as the main outlet discharge, the simulation for these sub-basins higher up within the basin is also good. This suggests that the modelled increase in precipitation with altitude is reasonably accurate. The snow melt at these altitudes also appears to be reasonably well modelled. The simulated discharge during the spring/summer melt for November 2005 – January 2006 agrees well with the measured discharge for both sub-basins. However, for November 2006-January 2007 the match is less good. It is not clear why these simulated discharges are poor during this second year.

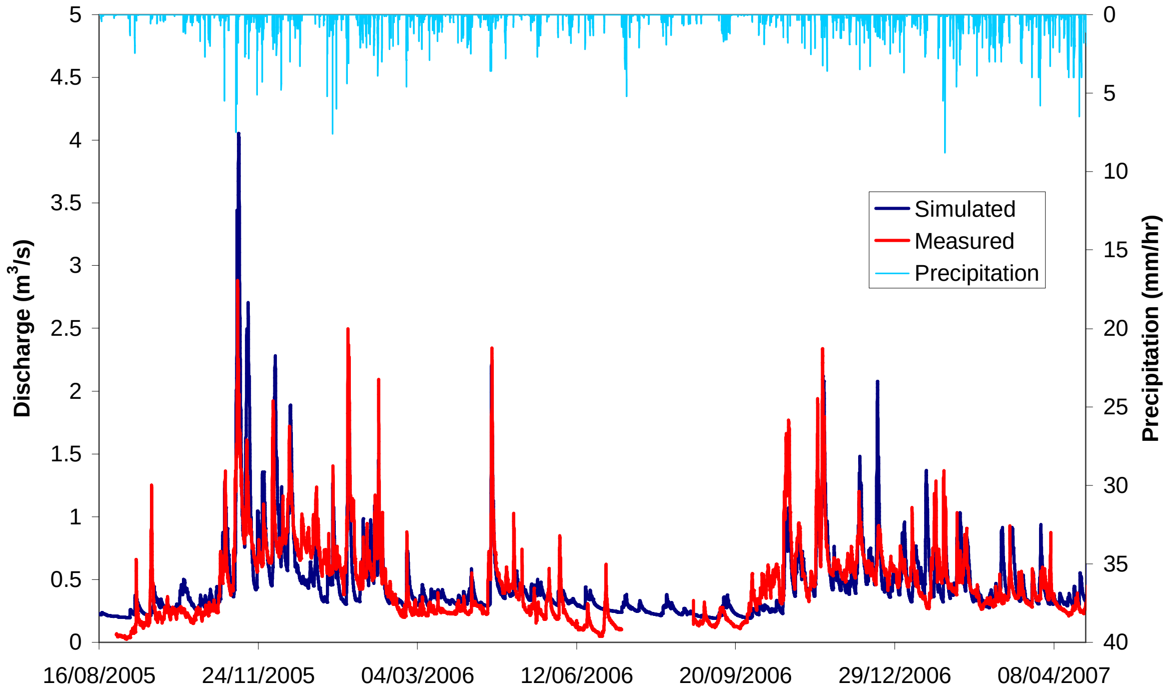

Figure 5.5 Measured Aerosilla precipitation and measured and simulated hourly outlet discharges for the Buena Esperanza basin, August 2005 – April 2007

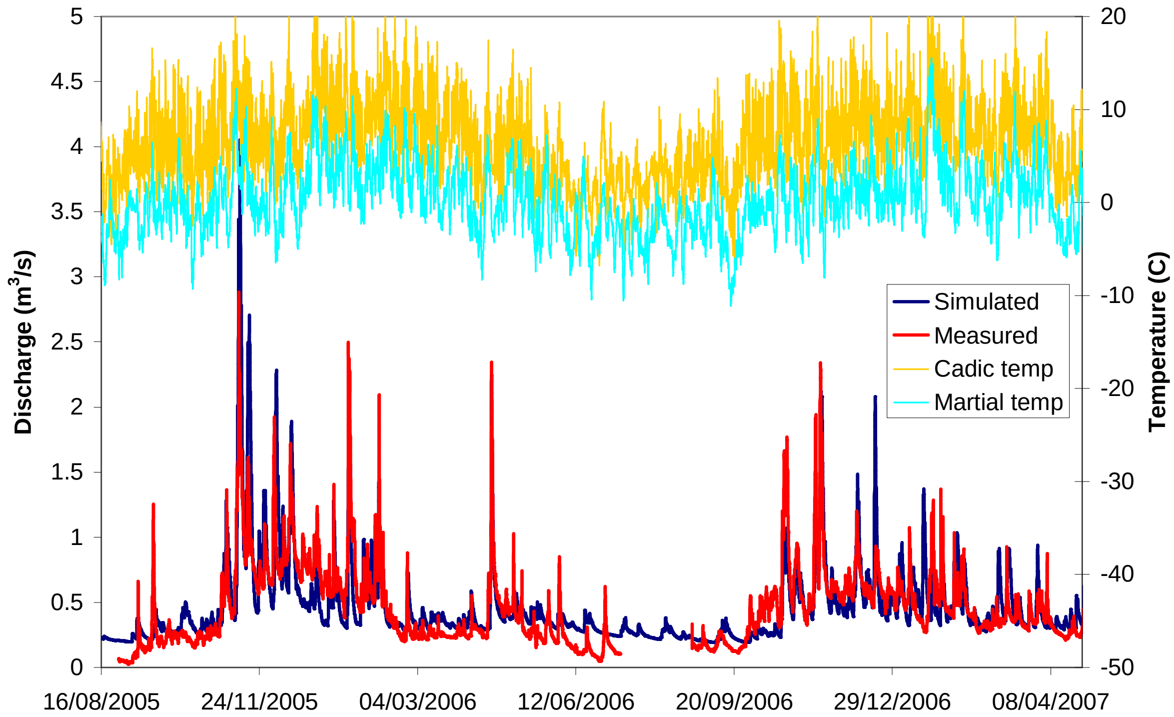

Figure 5.6 Measured temperature and measured and simulated hourly outlet discharges for the Buena Esperanza basin, August 2005 – April 2007. CADIC is at Ushuaia

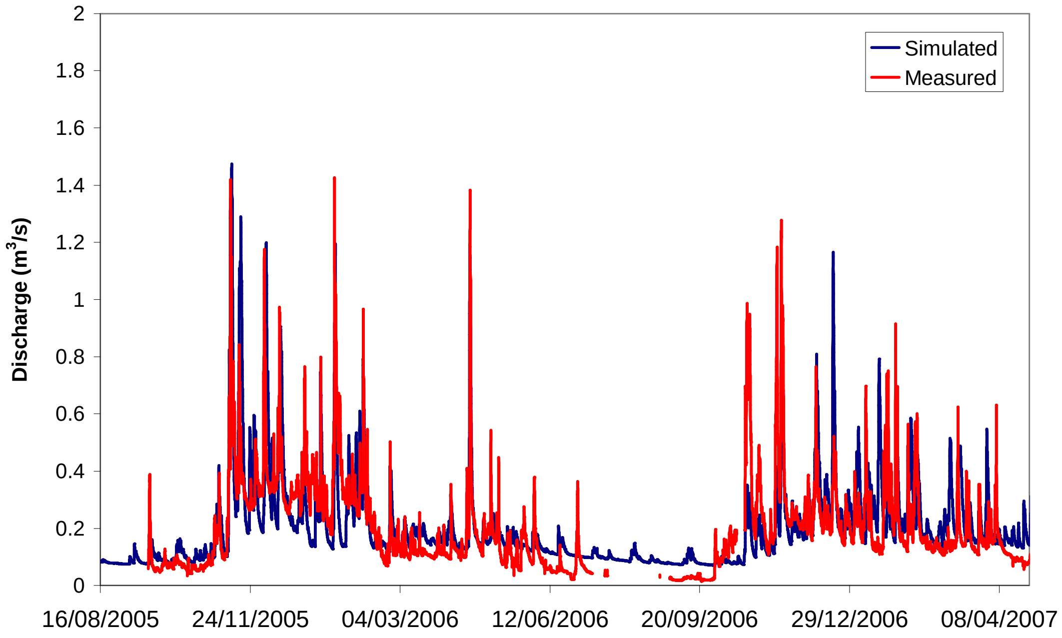

Figure 5.7 Measured and simulated hourly discharges for the Martial sub-basin, August 2005 – April 2007

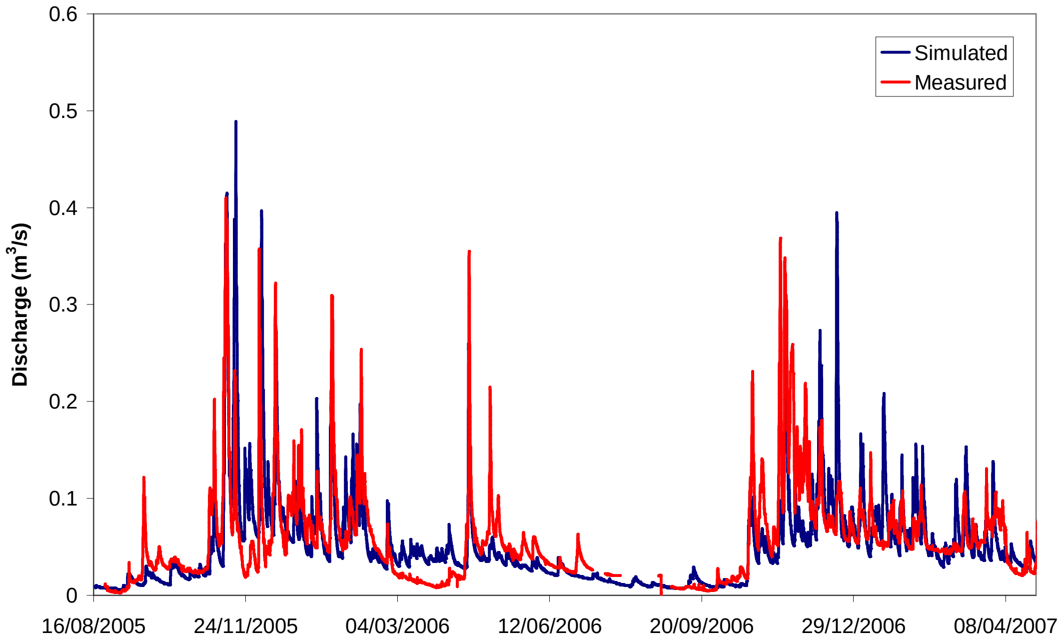

Figure 5.8 Measured and simulated hourly discharges for the Godoy sub-basin, August 2005 – April 2007

The sub-basin results also shed some light on the difference between the simulated (4.1 m^3 s^{-1}) and measured peak discharges (3.0 m^3 s^{-1}) at the main outlet on 11/11/2005. This event has both high precipitation rates (8 mm hr^{-1} at Aerosilla) and high temperature (mean daily temperature of 15 ºC at Ushuaia). In both sub-basins this peak is very well simulated with values of around 1.4 m^3 s^{-1} in the Martial basin

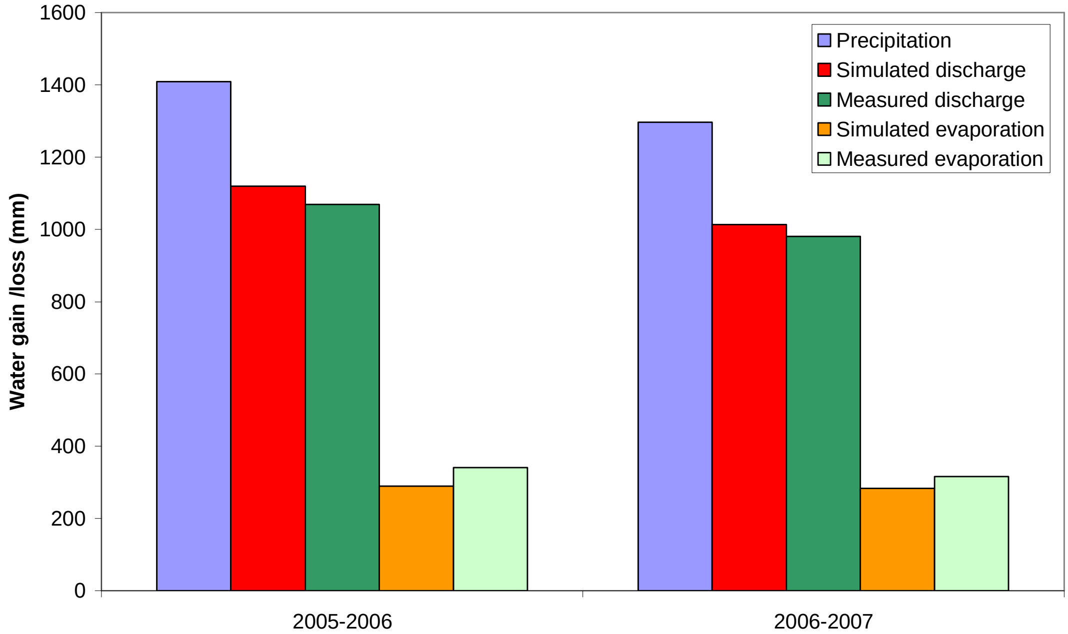

Figure 5.9 Simulated and measured mass balances for the Buena Esperanza basin, May 2005 – April 2007. Gaps in the measured discharge record are in-filled with simulated discharges

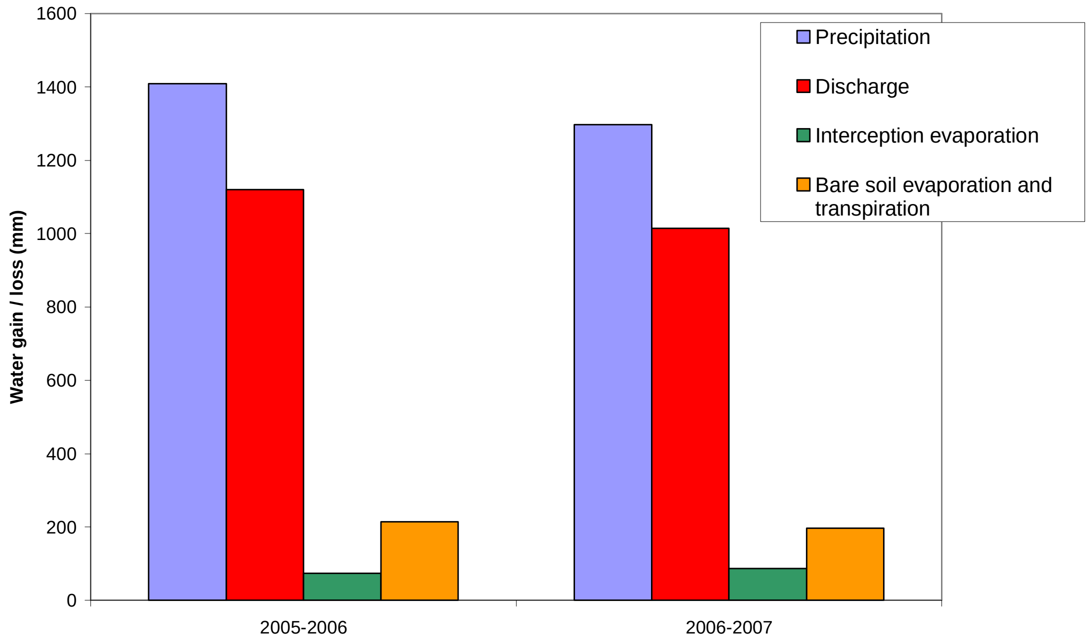

Figure 5.10 Simulated mass balance (including evaporation losses) for the Buena Esperanza basin, May 2005 – April 2007

and 0.4 $m^3 s^{-1}$ in the Godoy basin. This means that the source of the error is an overestimation of the discharge in the lower basin. It appears that in the simulation the snow at lower altitudes is still melting during this event whereas in reality the snow had finished melting. There are two possible reasons for this. Firstly, the melt factor is too low for this spring or secondly in the simulation too much snow accumulated during the winter period as a result of errors in estimating the precipitation at these altitudes. There are insufficient data to work out which is the case.

The annual mass balance (Figure 5.9) shows that the total measured and simulated discharges are very similar in both years. Assuming that the amount of water stored in the basin is similar at the start of May in each of the years, the simulated evaporation loss is around 280 mm in 2005-2006 and 290 mm in 2006-2007, with the measured values slightly higher. The simulation (Figure 5.10) shows this is made up of around 80 mm of interception evaporation while the rest is evaporation from bare ground and transpiration. The interception evaporation is low because almost 50% of the basin has bare ground and consequently no interception.

The simulated snow depth (Figure 5.11) shows significant differences between the different vegetation types. As expected, the forest in the lower part of the basin accumulates less snow and this melts before the snow on the rock debris higher up (even with a lower melt factor than that for the rock debris). This is a result of lower precipitation and higher temperatures. There have been some measurements of snow depths and there is some information about when the snow disappears from the various parts of the basin. When compared with this information, the simulations seem approximately correct for snow accumulation amount and snowmelt time.

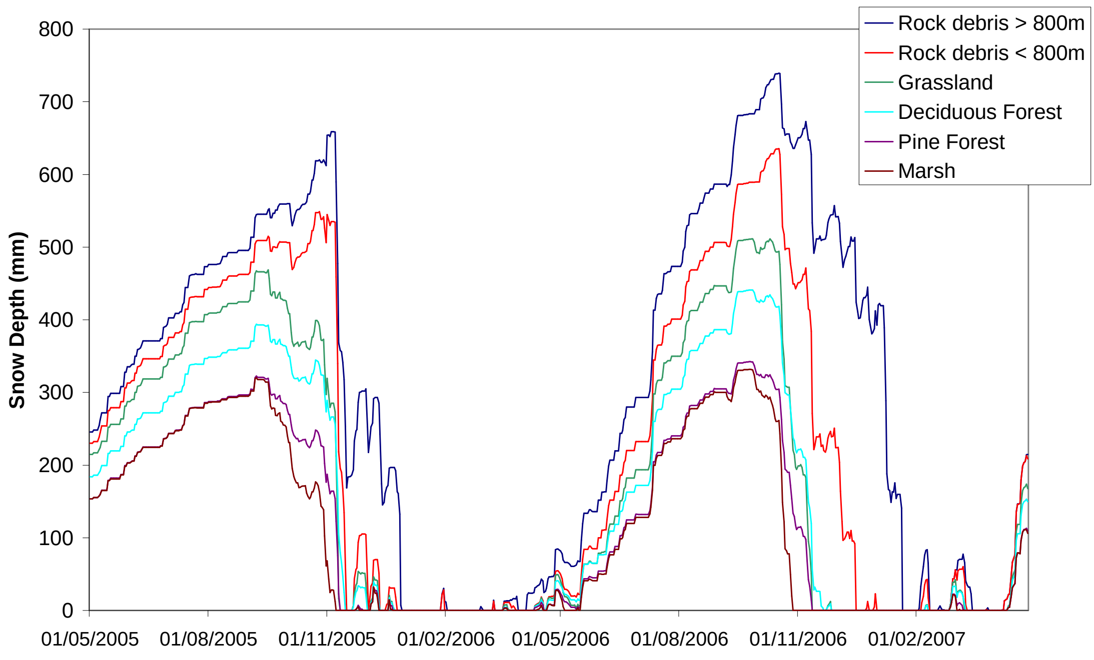

Figure 5.11 Simulated snow depths for the Buena Esperanza basin, May 2005 – April 2007

5.3.3 Calibration for event of 5/11/1954

The event of 5/11/1954 caused major flooding in Ushuaia with a peak discharge of around 13 $m^3 s^{-1}$. This was a major rain event, with high temperatures and snow present over much of the basin, so the high discharge was a result of both the rain and the snow melt. Precipitation of 42 mm occurred at Ushuaia in 9 hours with a corresponding estimated value of 94.5 mm above 600 m. Temperatures of up to 15ºC occurred at Ushuaia which meant the precipitation fell as rain over the entire basin and there was melt of existing snow.

The simulation of this event used hourly precipitation, discharge and temperature data from Ushuaia to simulate the flood event. The precipitation data were disaggregated from daily data by SDSATF and precipitation and temperature dependencies on altitude were similar to those of the simulations for 2005-2007. The Ushuaia precipitation data were multiplied by 1.5 so as to correspond to the Aerosilla data and the temperature on the Martial glacier was set at 6.2 ºC lower than the Ushuaia temperature. The simulation was run from 1/5/1954 so that the soil moisture conditions and snow depth were appropriate at the start of the event. The measured and simulated discharges for the event can be seen in Figure 5.12. The simulated discharge is very similar to the measured discharge with a similar peak value and a similar shape. In both cases there is a non-negligible discharge at the start of the rainfall event, as a result of snowmelt. The discharge increases during the rainfall event and peaks three hours after the rainfall peak. Most of this delay is associated with the travel time of the water through the snowpack. It is encouraging that the simulated discharge is such a close match to the measured discharge.

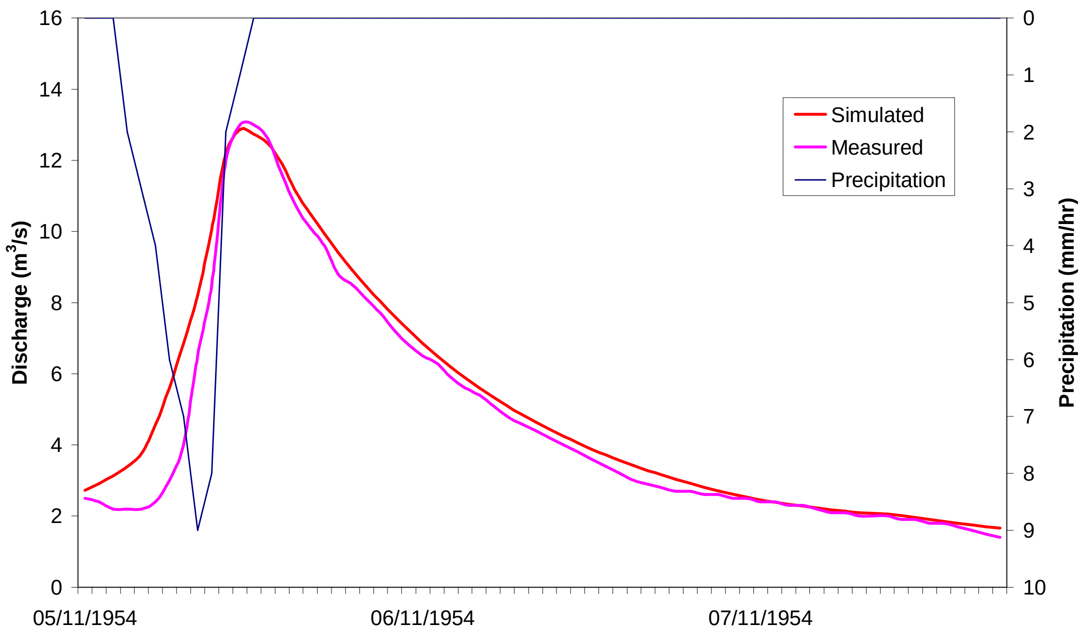

Figure 5.12 Measured and simulated discharges at the Buena Esperanza basin outlet for the major event in November 1954

5.4 Modelling Strategy

The aim of the modelling is to test the hypothesis that, as the size of the flood peak increases, the effect of land use becomes less important. To achieve this aim, SHETRAN was used in three different simulations. Firstly, the flood response for the period May 2005 to April 2007 (as shown in Section 5.3), both with the current basin vegetation cover and with the forest (which is found in lower part of the basin) removed. The flood responses for the two vegetation covers were then compared. Secondly, the extreme event of 5/11/1954 was simulated for the current vegetation and with the forest removed. Thirdly, simulations were carried out with a 1000-year time series of precipitation and temperature data, with the current vegetation and with the forest removed. For the 1954 event and the 1000-year simulation the corresponding maximum daily discharges for each day of the two simulations (current vegetation and removed forest) were plotted against each other to see if there were progressive differences in their relationship between low and high flow conditions.

The 1000-year time series of precipitation and temperature data was produced using daily and hourly data from Ushuaia. The daily data consisted of 36 years of precipitation, maximum temperature and minimum temperature from 1970 to 2005. The hourly data consisted of six years of hourly precipitation data in the summer and two years in the winter. The 1000-year time series of synthetic hourly rainfall data was generated by combining the monthly statistics for the daily precipitation data with the variance and skew statistics for the hourly precipitation data in the Newcastle University Rainsim statistical model. Regression relationships were then fitted between temperature and precipitation using the measured daily data. These relationships were used with the 1000-year synthetic hourly rainfall data to produce 1000 years of daily maximum and minimum temperatures consistent with precipitation. A sinusoidal curve was fitted through the derived temperatures to produce hourly temperature data. This assumed a maximum temperature at 4pm and a minimum temperature at 4am. Details of the procedure can be seen in Kilsby et al. (2007). It is interesting to note that because the 1000-year time series data was set-up without any data from the 1954 event, events of this magnitude do not appear in the time series. The effect of this can be seen in the next section.

5.5 Simulations and Results

The Buena Esperanza basin was simulated for the current vegetation and with the forest completely logged for the period from May 2005 to April 2007. The results for are shown in Figure 5.13. About 40% of the basin is currently forested, so 60% remains unaltered by the vegetation change. The soils are the same in the two simulations but the vegetation parameters are different for the logged area. Also changed in the logged area is the melt factor for snowmelt, with the value for the pine forest increasing from 4.3 mm $^{\circ}C^{-1}$ day^{-1} (forest) to 6.9 mm $^{\circ}C^{-1}$ day^{-1} (logged) and for the deciduous forest from 5.2 mm $^{\circ}C^{-1}$ day^{-1} (forest) to 7.8 mm $^{\circ}C^{-1}$ day^{-1} (logged) On an annual scale, the simulated discharge for the logged basin is considerably higher than for the current vegetation, owing to the lower evaporation once the forest has been removed. However, the pattern for individual events is considerably more complex. Figure 5.13 shows that in the spring, when the entire basin in both cases is covered by snow, the discharge is higher for the logged basin. This is due to the higher melt factor in the logged area producing greater snowmelt. However, for the major event on 11/11/2005 the situation is reversed, with the logged basin having a discharge (3.2 m^3 s^{-1}) which is lower than for the basin with the current vegetation (4.1 m^3 s^{-1}). This event is driven by snowmelt and precipitation. In the simulation with the current vegetation, snow still remains within the forest and its melt contributes to the discharge. By contrast, for the logged case the snow has already completely melted from this part of the basin and so cannot contribute to the discharge. Once the snow has finished melting under the pine and deciduous forest the discharge reverts back to the case of higher discharges in the logged basin than for the basin with the current vegetation. This can be seen for the discharge event on 20/1/2006. This event is driven by precipitation and so discharge is higher for the logged basin (2.7 $m^3 s^{-1}$) than under the current vegetation (2.1 $m^3 s^{-1}$). This is due to greater evaporation from the forest producing drier soil and a greater ability to store the precipitation.

The discharge for the event on 5/11/1954 was also run for the current vegetation and for the logged basin (Figure 5.14). Discharges are greater for the logged basin for two reasons. Firstly, greater snowmelt due to the higher melt factor in the logged part of the basin (this part of the basin is covered by snow throughout the rainfall event in both simulations). Secondly, wetter soils as a result of lower evaporation in the logged part of the basin.

Figure 5.15 compares the corresponding maximum daily discharges for each day of the 1000-year simulation (together with the 1954 event) for the basin with the current vegetation and for the logged basin. The results show that there can be a range of "logged" responses for a given "current" discharge, depending mainly on the time of year and which parts of the basin are covered in snow. As discussed above it is possible to have a lower discharge for a "logged" response than for the "current" response. These points can be seen below the line of equality. The points for the individual months can be seen in Figure 5.16. There are a few points below the line of equality in September but many more during October to December. These points occur for the short time each year when there is still snow under the forest in the "current" simulation but it has finished melting in the "logged" simulation. The timing depends on the amount of snow that accumulates over the winter and the temperatures during the spring snow melt. Table 5.5 shows the gradient and the R^2 value of the trend-line fitted through the points for each month. The gradient is lowest in November at 0.9 which means the fitted trend-line is below the line of equality. In December the fitted line is also below the line of equality whereas in October it is slightly above. The fitted lines for these three months have the lowest R^2 values as there is considerable scatter, with some points above the line of equality and some below, depending on the accumulation and melting that occurs in that year. From January through to August similar gradients and R^2 values can be seen. These give a gradient greater than one as the evaporation is less under the "logged" vegetation than under the "current" vegetation. R^2 values are high although there is some difference between events depending on the initial conditions. The highest gradient (1.3) occurs in September owing to the much higher snowmelt under "logged" conditions compared with "current" conditions.

The situation in the Buena Esperanza basin is complicated by the snow accumulation and melt. However, from January through to April there is no difference in discharge between the "logged" and "current" cases as a result of snowmelt (there is still snow in the higher parts of the basin but this is the same in both simulations). The situation in these months is therefore similar to the other three project focus basins. Under these conditions there does not seem to be much sign of a reduction in the difference in discharges between the logged and forested cases for bigger events. However, the forests are simulated as being over 0.5m of organic soil on top of 9.5m of glacial till. This soil depth is the same as that in the deep soil simulation for La Reina basin in Chile (Section 4.5.1) and in that case the difference between the discharges for "current" and "logged" vegetations increased for bigger events.

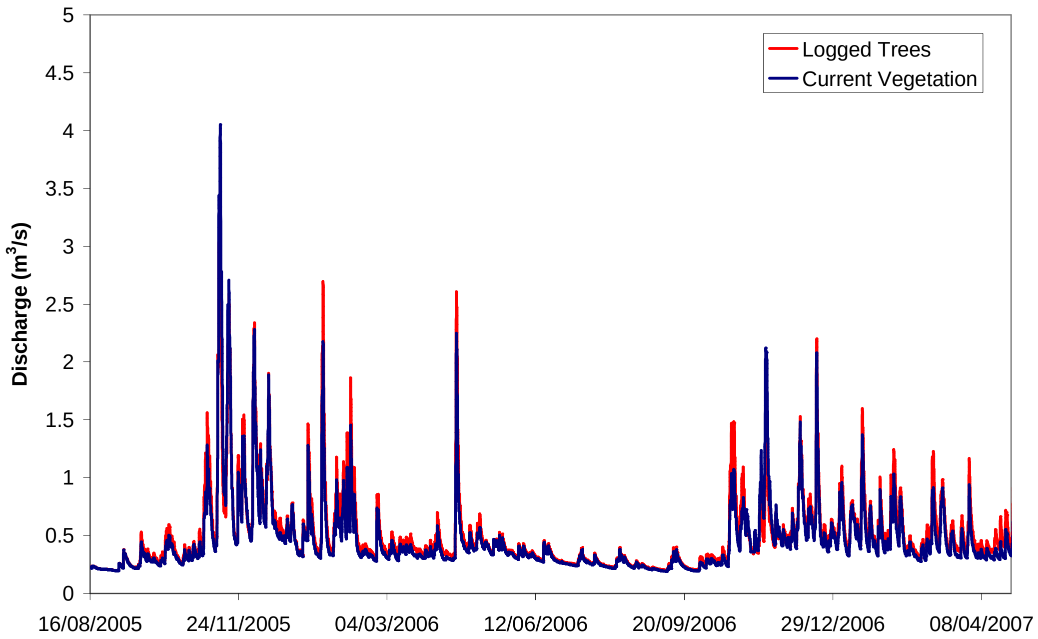

Figure 5.13 Comparison of mean hourly discharges (m^3 s^{-1}) for current vegetation and logged conditions from SHETRAN simulations of the Buena Esperanza basin for August 2005 – April 2007.

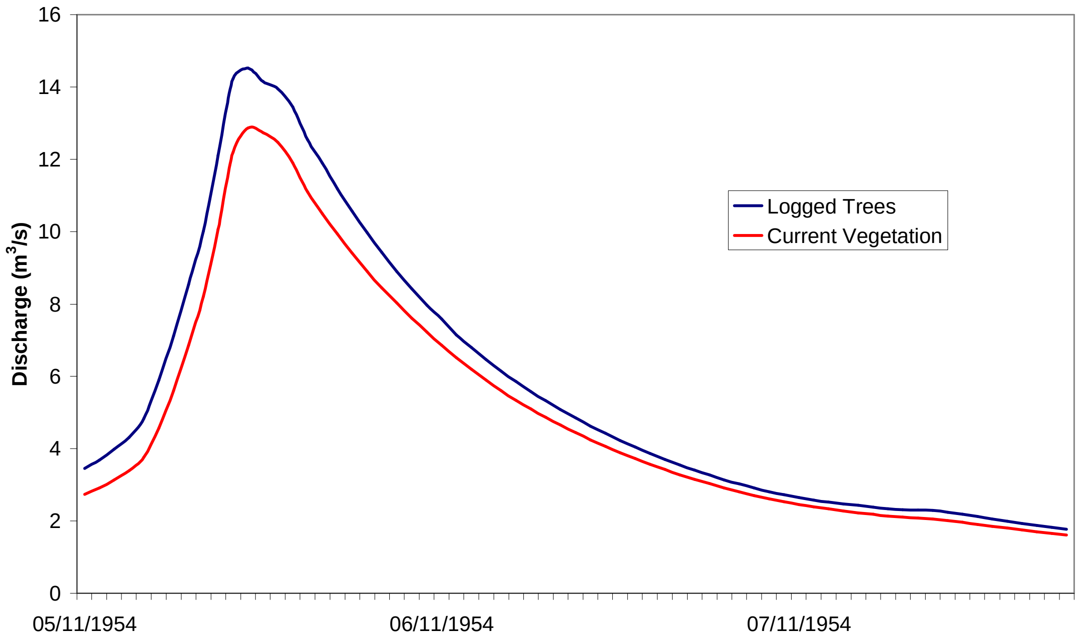

Figure 5.14 Comparison of mean daily discharges (m^3 s^{-1}) for current vegetation and logged conditions from SHETRAN simulations of the Buena Esperanza basin for the major event in November 1954

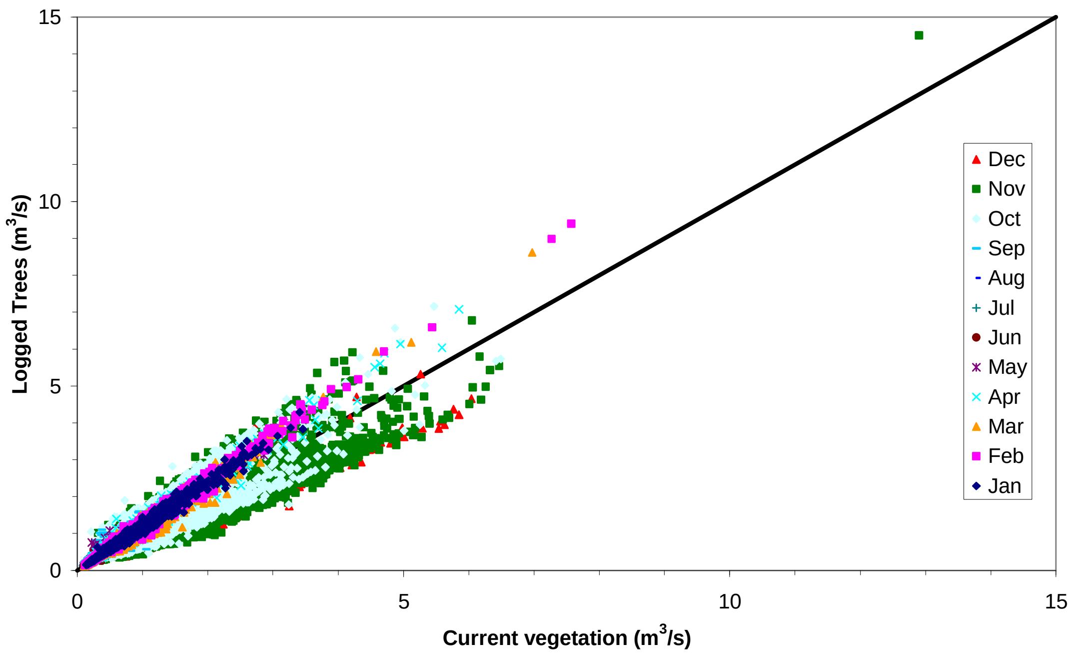

Figure 5.15 Comparison of maximum daily discharges ($m^3\ s^{-1}$) for current vegetation and logged conditions from SHETRAN simulations of the Buena Esperanza basin for the 1000-year period and the 1954 event (highest point). Line is line of equality

Table 5.5 Monthly comparisons of gradient and R^2 values for the fitted trend-line relationships between maximum daily discharges ($m^3\ s^{-1}$) for current vegetation and logged conditions from SHETRAN simulations of the Buena Esperanza basin. Based on data in Figure 5.16

Month	Gradient	R^2
January	1.19	0.98
February	1.22	0.99
March	1.21	0.96
April	1.20	0.97
May	1.18	0.97
June	1.15	0.95
July	1.15	0.97
August	1.21	0.94
September	1.31	0.90
October	1.09	0.76
November	0.9	0.78
December	0.95	0.82

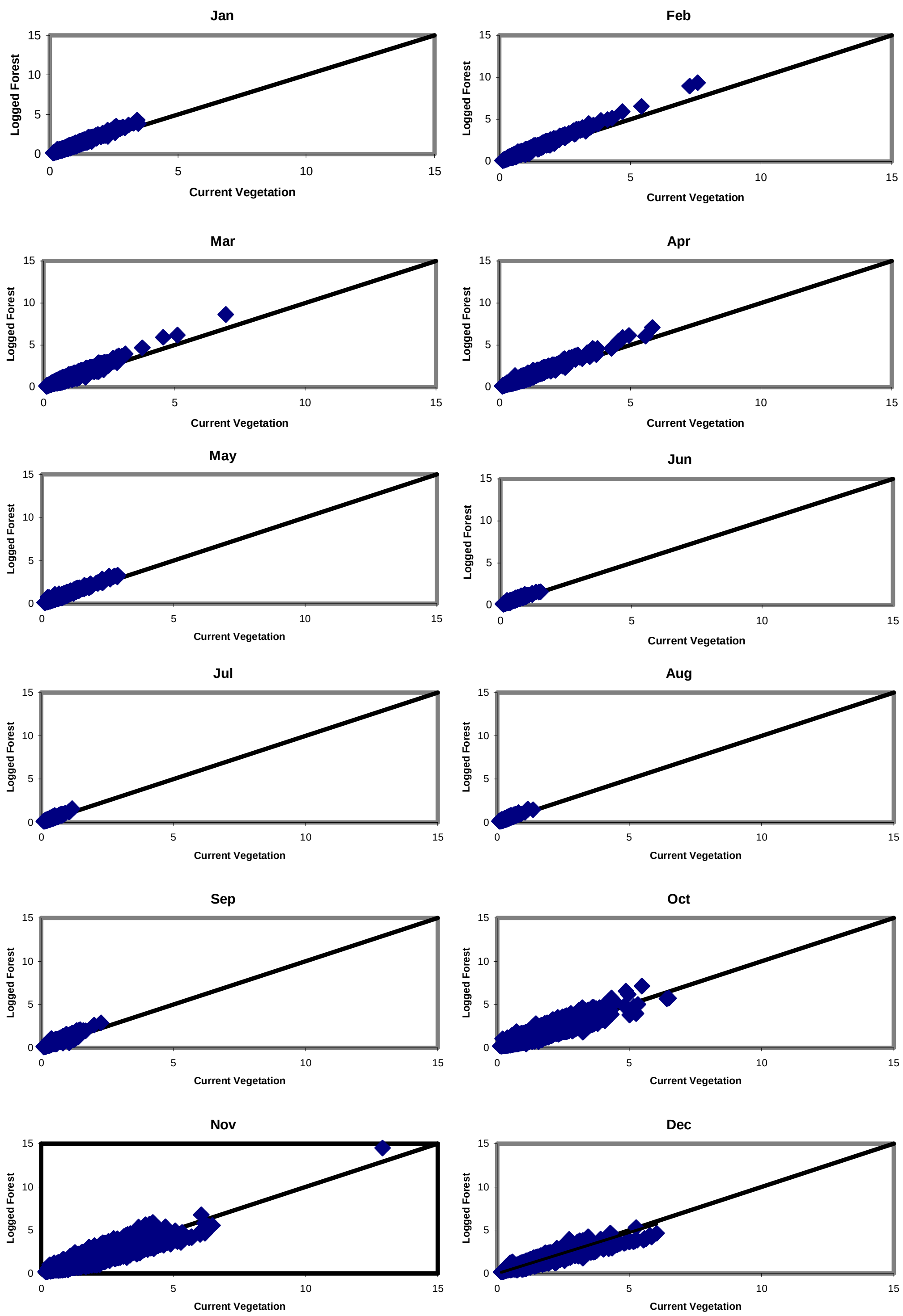

Figure 5.16 Monthly comparisons of maximum daily discharges (m^3 s^{-1}) for current vegetation and logged conditions from SHETRAN simulations of the Buena Esperanza basin for the 1000-year period and the 1954 event. Line in each plot is line of equality

5.6 Discussion of Land-use Impacts

The simulations show that, in general, logging the trees increases the discharge at the outlet but the situation is complicated by the timing of the snowmelt. For certain snowmelt conditions, logging the trees actually reduces the discharge. This occurs when the discharge is mainly a result of snowmelt and there is still snow lying in the forest, whereas it has already disappeared for the logged case. The 1954 event shows an increase in discharge under the logged basin partly as a result of higher snowmelt; the difference in the peak discharge is 1.6 $m^3 s^{-1}$. For the 1000-year time series data for the period January to April the effect of different snowmelt rates under the two scenarios is removed. In these months there is a direct correspondence between the two cases whereby the bigger the event, the bigger is the difference, i.e. there is no convergence for bigger events. There are two possible reasons for this. Firstly, the 1000-year time series did not include any extreme events. It was based on data from 1970 to 2005 but this period did not include any events of the magnitude of the 1954 event. It is possible that with these big events there may be some convergence. Thus the point with the largest discharge in Fig. 5.15 represents the observed 1954 event. The difference in peak discharge for this event is similar to those for the points in the moderate discharge range, suggesting that there may be relative convergence of response for extreme events. Secondly, the soils under the trees are deep and, as was shown in Section 4.5.1 for La Reina basin, such a soil depth appears inimical for convergence.

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5.7 Conclusions

The aim of the model application is to test the hypothesis that, as the size of the flood peak increases, the effects of land use become less important. In Argentina, the 12.9-km^2 Buena Esperanza basin has been selected. Simulations were run for the period May 2005 to April 2007. A good comparison was achieved between the simulated and measured discharges. The major event in November 1954 was also satisfactorily simulated. The basin was also simulated with the forest that covers 40% of the basin logged. This was achieved by changing the vegetation parameters and also increasing the melt factor in the affected area. Increasing the melt factor increases the snowmelt where the forest has been removed, with the increase corresponding to field measurements that have been carried out in various parts of the world. The simulations show that, in general, logging the trees increases the discharge at the outlet but the situation is complicated by the timing of the snowmelt. For certain conditions, logging the trees actually reduces the discharge. This occurs when the discharge is mainly a result of snowmelt and the snow in the forest is still melting, whereas for the logged case the snow has already completely melted. The 1954 event shows an increase in discharge under the logged basin partly as a result of higher snowmelt. However, the difference in peak discharge between the two land use cases for this event is similar to those for the points in the moderate discharge range, suggesting that there may be relative convergence of response for extreme events.

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