4 Monitoring and modelling hydrological fluxes in Amazonian rain forest ecosystems

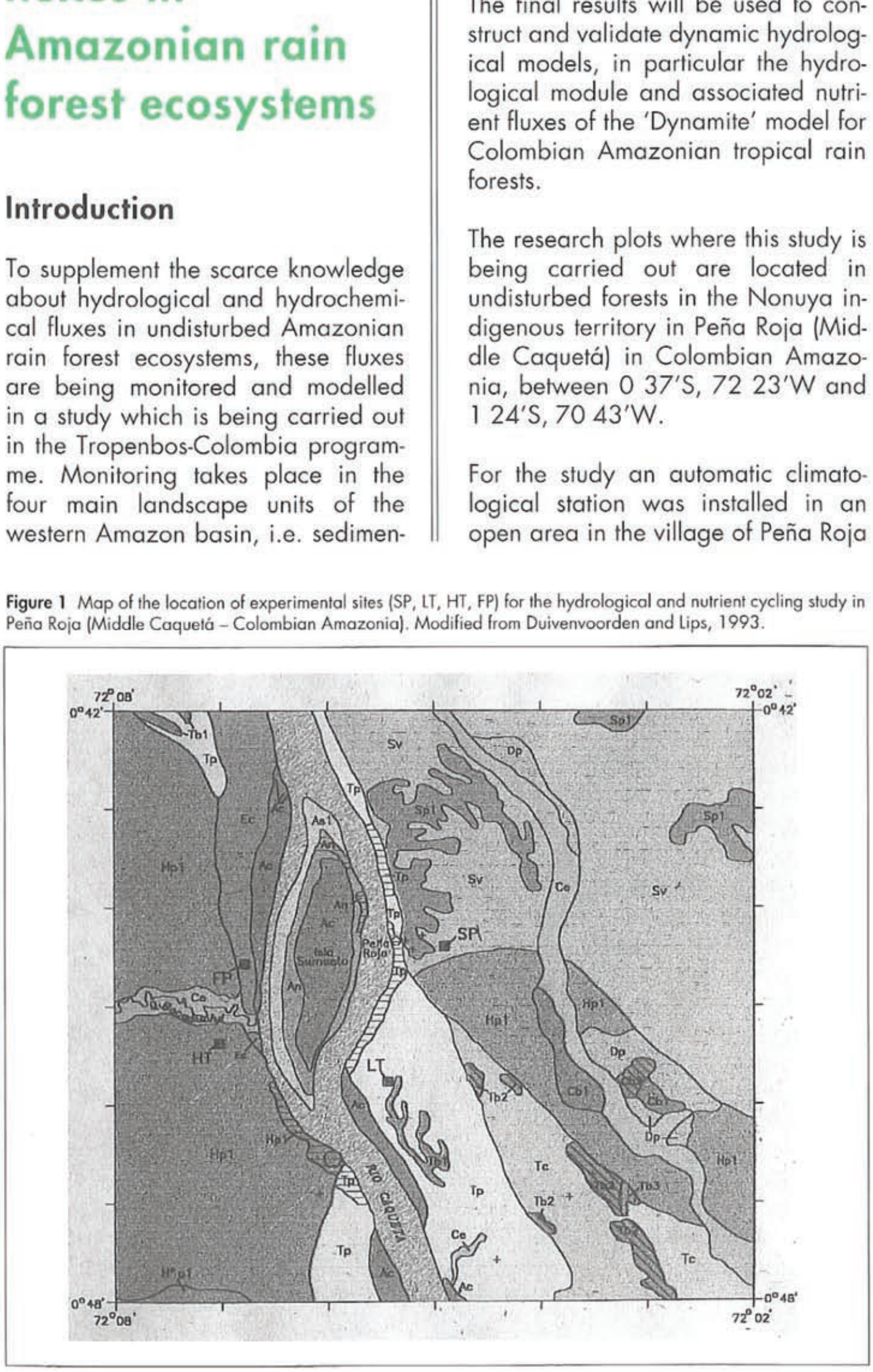
Introduction

To supplement the scarce knowledge about hydrological and hydrochemical fluxes in undisturbed Amazonian rain forest ecosystems, these fluxes are being monitored and modelled in a study which is being carried out in the Tropenbos-Colombia programme. Monitoring takes place in the four main landscape units of the western Amazon basin, i.e. sedimentary plain, high terrace, low terrace and flood plain. The knowledge obtained will serve to better understand the nutrient dynamics in these ecosystems, and will also enable the identification and quantification of factors which control these dynamics. The final results will be used to construct and validate dynamic hydrological models, in particular the hydrological module and associated nutrient fluxes of the 'Dynamite' model for Colombian Amazonian tropical rain forests.

The research plots where this study is being carried out are located in undisturbed forests in the Nonuya indigenous territory in Peña Roja (Middle Caquetá) in Colombian Amazonia, between 0 37'S, 72 23'W and 1 24'S, 70 43'W.

For the study an automatic climatological station was installed in an open area in the village of Peña Roja in 1992. Data are being collected at twenty minute intervals for rainfall, temperature, air humidity, incoming radiation, wind speed and wind direction. Data on class A pan evaporation are also collected twice a day. In addition, data are also collected on a large number of hydrological parameters. These include precipitation, throughfall, stemflow, litter interception, soil water contents, soil water tension and depth of phreatic level. Additionally, in two catchments, discharge is being recorded, allowing for the calculation of a water balance at catchment scale.

Figure 1 Map of the location of experimental sites (SP, LT, HT, FP) for the hydrological and nutrient cycling study in Peña Roja (Middle Caquetá – Colombian Amazonia). Modified from Duivenvoorden and Lips, 1993.



For the hydrological part of the project, a preliminary study was carried out to determine the minimum plot size, the number and distribution of the collectors, and to estimate the throughfall more accurately. In the four landscape units, nine plots were selected to study forest hydrology and soil water dynamics. In the plots, gross precipitation is monitored with four collectors installed above the canopy and hanging from a cord between two emergent trees. Precipitation was measured manually on a five day basis and automatically with a tipping bucket connected to a CR10 datalogger.

Throughfall is measured using 20 collectors per plot, randomly distributed in a 50 by 20 m area. This was based on a preliminary study on the effect of the number and distribution of collectors on the accuracy of throughfall measurements. Furthermore, within each plot, 15 trees of different species were selected to measure stemflow.

In two units, areas of 20 x 50 m within each plot, 15 plates collecting litter flow were installed under the litter layer. Litter flow was measured every five days. Additionally, samples of 1 m^2 of saturated litter were collected and air dried to determine litter water storage.

To study soil moisture dynamics, eight Time Domain Reflectometry (TDR) sensors were installed per plot to monitor soil water contents at different depths through the TDR technique (by Tectronix 1552b instrument). Soil water tension is being measured by a tensiometer installed near the TDR sensors at the same depths. For two of the plots (sedimentary plain and high terrace) drainage from the catchment areas is being automatically recorded, employing V-notch triangular weirs and pressure transducers, connected to CR10 dataloggers. Data on discharge are collected at five minute intervals during rainfall.

Samples of water are being collected every five days to measure pH and EC. Samples, collected on a monthly basis, are analysed for their chemical composition by the University of Amsterdam. Results pertaining to solute fluxes will be used to quantify nutrient cycling in the undisturbed forests studied. At the same time, they will serve to illustrate how results from the hydrological research can be applied in nutrient cycling studies.

Preliminary results

Climate

Climate in the project area (Middle Caquetá) is tropical humid (Afi according to the classification of Köppen). Four seasons can be distinguished: the long rainy season from March till the end of July, a short dry season from August till September, a short rainy season from October till December and the long dry season from January till the middle of March. In fact, a really dry season does not exist – the average precipitation during the driest month (generally February) is about 100 mm. In the wettest month, total precipitation is about 400 mm. Average annual rainfall during the period from August 1992 to December 1994, was 3460 mm. The year 1995 was exceptionally dry with only 3155 mm.
Maximum humidities (98%) occur during the earliest hours of the day and during long rainfall, when humidity increases rapidly and strongly. Minimum humidities (45%) occur generally in the afternoons around 13.00 to 15.00 hours. Mean wind speed is around 1.6 m/s. Wind speed increases during the day and decreases at night. Wind speed is generally higher immediately before heavy storms (4.4 m/s). Winds are dominantly southeastern, but this may be due to the position of the climatological station, which is at the shore of the Caquetá river.

Incoming radiation for the study site averages 550 W/m^2 and peaks in February with a maximum of 1175 W/m^2, while in June it reaches a minimum of 430 W/m^2 (daily data between 9.00 to 16.00 hours). Maximum values for incoming radiation are measured in the early afternoon (between 13.00 and 15.00 hours).

Evaporation values follow those for temperature and radiation, January, February and August being the months with highest evaporation (approximately 120 mm). Data from the Peña Roja station are used to calculate the potential evapotranspiration, using the modified Penman method (Monteith, 1965). Calculated values closely follow incoming radiation (see Table 1).

Table 1 Annual climatological data from the Peña Roja station. Potential evapotranspiration was calculated by using the Penman-Monteith equation.

Year		*Precipitation mm.*	*Temperature °C*	*Humidity %*	*W. Speed m/s*	*Solar R. W/m^2*	*Evaporation mm*	*Evapotranspiration mm*
1993	Total	3425					1265	1499
	Maximum		32.9	98	4.6	1020		
	Minimum		16.2	47				
	Daily mean		23.2	82	1.8	540		
1994	Total	3469					1232	1473
	Maximum		33.6	98	4.4	1120		
	Minimum		17.5	48				
	Mean		23.4	79	1.6	515		
1995	Total	3155					1312	1538
	Maximum		34.8	97	4.2	1175		
	Minimum		18.9	40				
	Mean		24.2	74	1.5	595		

Table 2 Water fluxes through the various compartments in tropical rain forest ecosystems of Colombian Amazonia.

Precipitation mm	*Throughfall %*				*Stemflow %*	*Litterflow %*
	Sed. plain	*High terrace*	*Low terrace*	*Flood plain*	*Mean range*	*Mean range*
< 1	0	0	0	0	0	0
2.1	66.0	50.2	43.6	22.4	0.2 – 0.3	37.7 – 40.0
21.4	91.5	84.1	69.1	68.8	0.4 – 0.6	40.1 – 43.9
44.0	94.6	93.1	84.0	86.8	0.7 – 0.9	55.3 – 59.1
85.2	94.7	95.4	84.4	85.9	1.1 – 1.3	60.0 – 66.2
167.0	97.4	96.6	92.2	91.2	1.3 – 1.6	75.1 – 87.0

Hydrology

Amounts of throughfall were found to differ from plot to plot. For the same rainfall occurrence, throughfall is higher in the sedimentary plain than in the other plots, but it is very close to that in the high terrace. Throughfall amounts were found to be related, among others, to the gap fraction of the forests. These gap fractions were measured by taking black and white hemispherical photographs of the forest canopy. Net precipitation follows the trend of the gap fraction very closely. Analysis of data for different rainfall occurrence and at the same plot show that throughfall is higher (88 to 96%) when the rain has a high intensity and long duration (more than 25 mm and longer than 30 minutes), and is lower (43 to 66%) if the occurrence is longer, but with low intensity (less than 10 mm and longer than 40 minutes).

Throughfall amounts were very much dependent on antecedent moisture conditions of the tree canopy. The data show that rainfall on an already wet canopy resulted in a distinctly higher throughfall than on a dry canopy. The same trend was observed with stemflow and litterflow.

To calculate net precipitation, stemflow is measured and amounts for each tree are related to tree characteristics (top crown area, stem area, bark texture and leaf position). In contrast with other studies, in the current project stemflow is considered a relevant parameter as it contributes rather significantly to the nutrient cycling in the ecosystems and to the net precipitation. Preliminary results indicate that mean stemflow accounts for 0.85 to 4.1% of gross precipitation, and show that these amounts depend on tree characteristics and on the intensity, duration and distribution of precipitation. In spite of stemflow magnitude being smaller and rather less important than throughfall in hydrological studies, it may be considered an important parameter for nutrient cycling because stemflow amounts are absorbed by the litter and infiltrate soil layers at the base of the trees. This may increase the availability of water and nutrients for a forest in oligotrophic environments. Data on throughfall and stemflow per rainfall occurrence are used to calculate net precipitation on the forest floor (Table 2).

Results on litterflow show that 37.7 to 87% of net precipitation is intercepted by the litter layer and that this amount depends on the thickness of this layer and on rainfall distribution, duration and intensity. Litter in the research plots is mainly composed of living and dead fine roots and dead leaves. The analyses of water retention by the litter layer indicate that the greater the amount of fine roots the greater is the water retention capacity. The maximum water storage of a litter layer with a mean thickness of 14 cm is 6.4 mm.

Results on soil water content and soil water tension are very preliminary. They show that between 17–38% of the incoming water to the soil surface is percolated and drained out of the catchment area (drainage). In the sedimentary plain plot, with soils classified as Kandiudults and Paleudults, water drains vertically to a depth of about 110 cm, where it drains horizontally along the slope. There is almost no effect of precipitation on water content and water tension for a depth larger than 120 cm.

At the ecosystem level, atmospheric deposition (dry and wet) results in nutrient inputs, while drainage causes nutrient outputs. The available chemical analyses (Table 3) show that during the dry period the ecosystem is a sink of nutrients. Nutrient concentrations in throughfall increase relative to those in gross precipitation, apparently due to washing of nutrients previously deposited on the leaves and/or leached from these. Concentrations are even higher in stemflow than those in throughfall.

Concentrations decrease after passage of the litter layer and further decrease in the discharge, reaching concentrations lower than those in the gross precipitation.

In a rainy period, the situation is different. Nutrient concentrations are only slightly higher in the throughfall and stemflow relative to gross precipitation. They decrease after passage of the litter layer, but in the drainage water concentrations are higher than in gross precipitation.

Table 3a Profile of solute concentrations in hydrological compartments of four undisturbed forest ecosystems. Sampling followed by a dry period.

Landscape unit	*Compart.*	*NH_3-NH_4*	*PO_4*	*K*	*Mg*	*SO_4*	*HCO_4*	*pH*	*Ec*
				mg/l				*s/cm*	
Sedimentary plain	Rain	0.13	0.20	0.2	0.02	0	5.5	5.1	6
	Through.	0.85	0.02	1.4	0.07	0	7.0	5.8	11
	Stemflow	1.92	0.11	2.9	0.16	0	5.5	4.3	38
	Drainage	0.15	0	0.2	0.02	0	7.0	5.5	7
High terrace	Through.	0.56	0.18	1.2	0.06	0.14	7.0	5.7	10
	Stemflow	2.20	0.10	5.1	0.26	0	6.0	4.3	48
	Drainage	0.09	0	0.3	0.02	0	6.0	5.7	7
Low terrace	Through.	0.69	0.16	1.5	0.11	0.14	7.5	5.7	14
	Stemflow	1.11	0.10	6.3	0.53	0.14	18.0	5.5	35
Flood plain	Through.	1.67	0.23	4.8	0.31	0	10.0	4.8	39
	Stemflow	1.33	0.14	16.5	1.14	0	28.5	6.1	78

Final remarks

The hydrological cycle and associated nutrient fluxes play a crucial role in the functioning and vulnerability of tropical rainforest, since these determine the availability of nutrients and water, as well as catchment output. Knowledge of these allows for the evaluation of the role of atmospheric deposition versus mineral nutrient stocks in nutrient cycling in these forests, and of the impacts of deforestation on catchment discharge and river hydrology. If translated into validated models, it can be used to assess the impact of land use at various scales and provides a means to quantify these impacts as well as the possibilities for ecosystem recovery after impacts. In addition, the research provides fundamental information on water and nutrient fluxes in virgin tropical rain forest with site conditions ranging from rather eutrophic to extremely oligotrophic. It therefore allows to quantify the impact of nutrient status on nutrient and water fluxes. Such information is extremely scarce and valuable for land evaluations at reconnaissance level or smaller scales. ■

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References:
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Montheith (1965). Evaporation and environment: the state and movements of water in living organisms. in 19th Symp. Soc. Exp. Biol. Vol. 19. Cambridge University, London, United Kingdom.

Table 3b Profile of solute concentrations in hydrological compartments of two undisturbed forest ecosystems. Sampling followed by a wet period.

Landscape unit	*Compart.*	*NH_3-NH_4*	*PO_4*	*K*	*Mg*	*SO_4*	*HCO_4*	*pH*	*Ec*
				mg/l				*s/cm*	
Sedimentary plain	Rain	0.23	0.02	0.59	0.06	0.14	0	4.2	7.5
	Through.	0.38	0.02	0.46	0.05	0	0	4.1	8.4
	Stemflow	1.57	0.18	0.86	0.20	0	0	3.8	24.0
	Drainage	0.35	0	0.4	0.05	0	0	4.5	7.1
High terrace	Through.	0.68	0.20	0.82	0.08	0	0	4.8	10.0
	Stemflow	1.57	0.13	0.99	0.16	0	0	3.9	25.4
	Drainage	0.23	0	0.22	0.03	0	0	4.8	4.8