Identifying runoff sources across scales in Amazon watersheds: an LBA synthesis effort.

Joaquín Chaves[1], Christopher Neill[1], Mark Johnson[2], Helmut Elsenbeer[3], Sonja Germer[3], Alex Krusche[4], Trent Biggs[5], Ricardo Figueiredo[6], Johannes Lehman[7], Linda Deegan[1].

[1]The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02543

[2]Department of Geography, University of British Columbia, Canada

[3] Universität Potsdam, Institut für Geoökologie, Potsdam, Germany

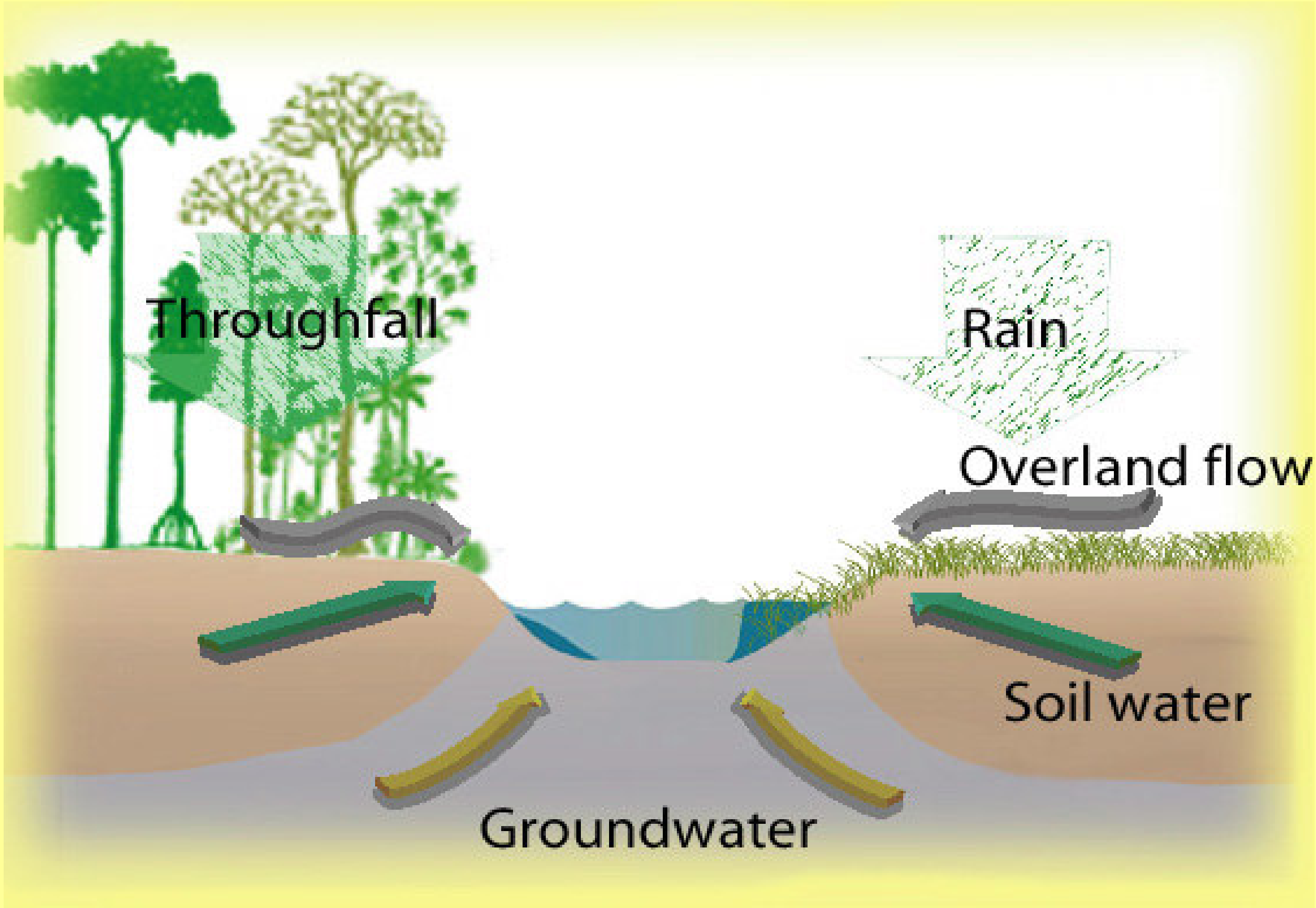
[4]Laboratório de Ecologia Isotópica, CENA –USP, Piracicaba, SP, Brasil

[5]Department of Geography, San Diego State University

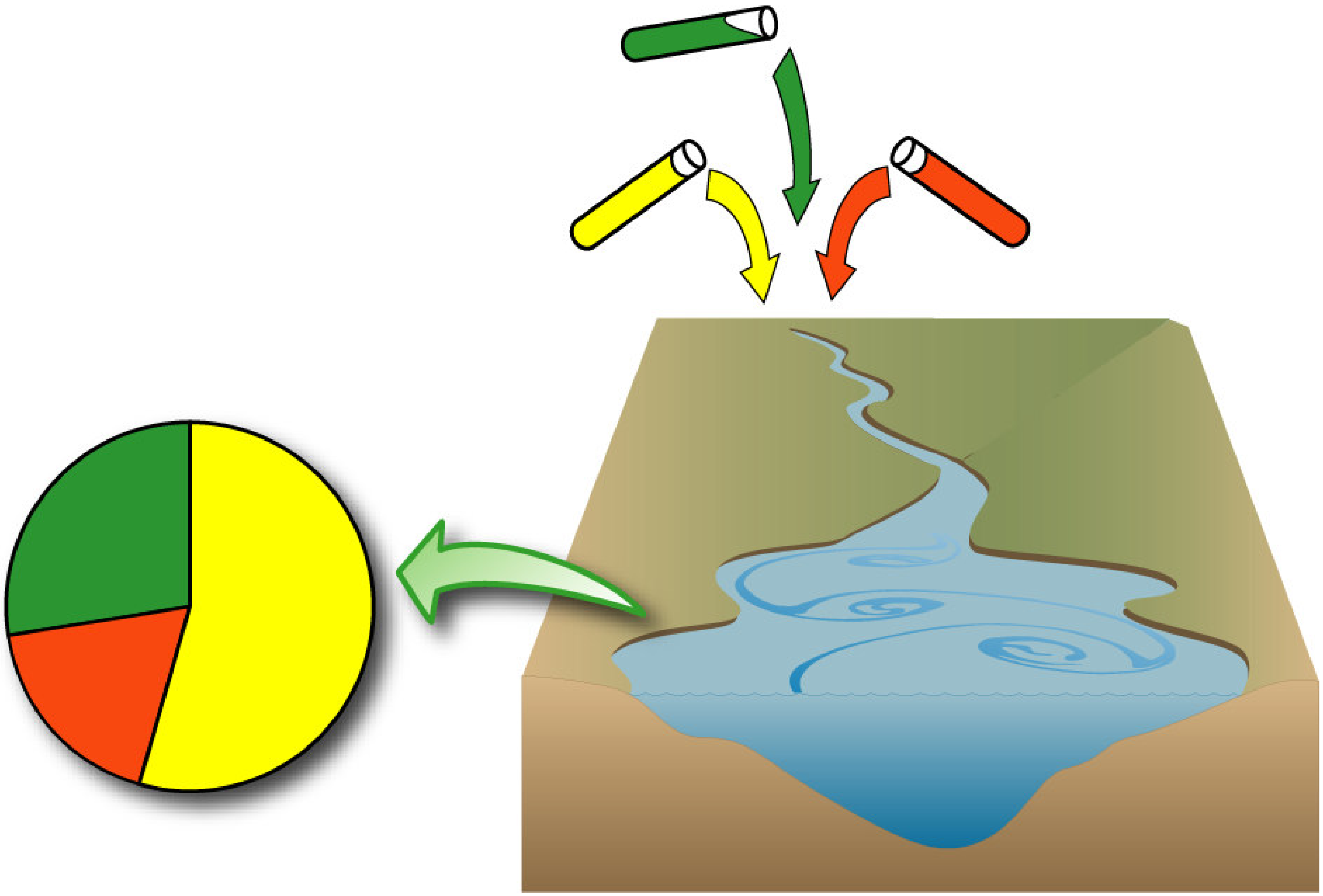
[6]Embrapa Amazônia Oriental, Belem, Para

[7]Department of Crop and Soil Sciences, Cornell University

Potential Sources of Streamflow:



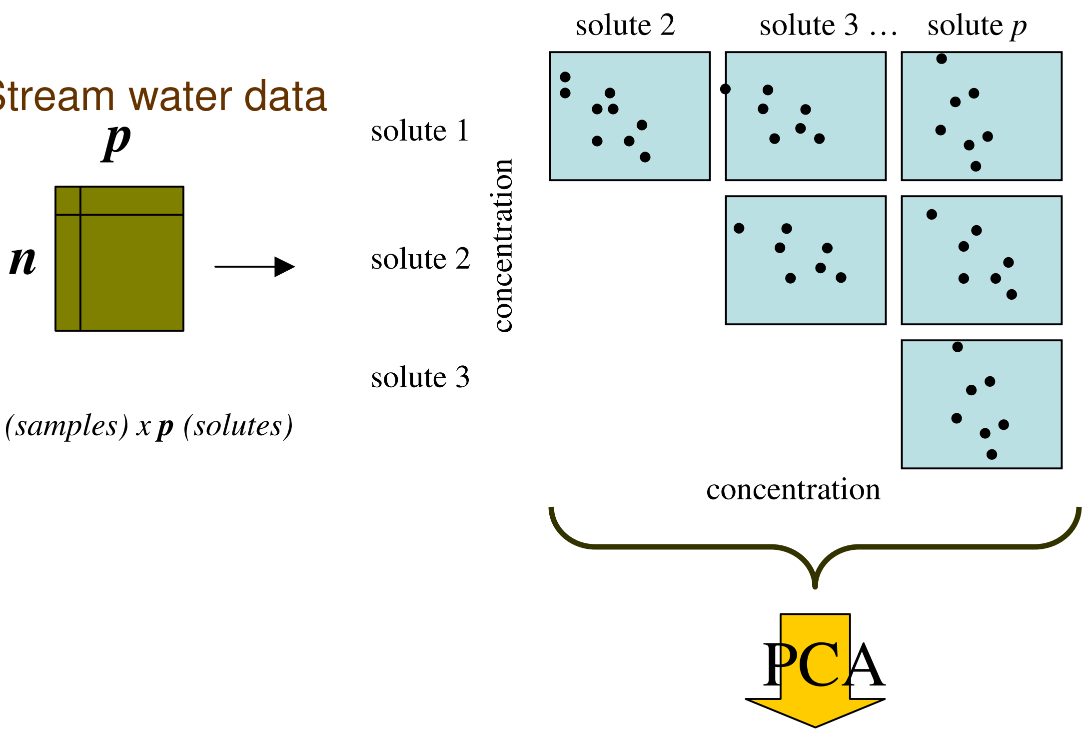
End-Member Mixing Analysis (EMMA)



End-Member Mixing Analysis (EMMA)

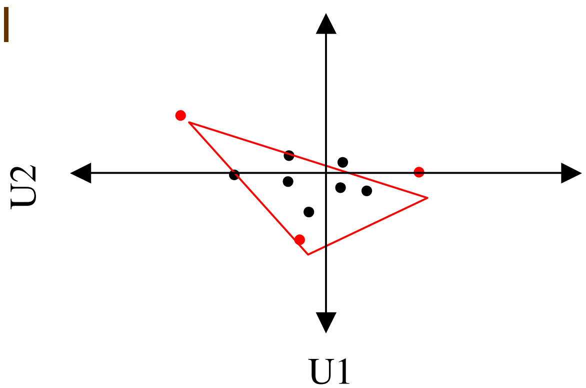
❖ Principal Component Analysis (PCA)…*in a nutshell*

Stream water data



***n** (samples) x **p** (solutes)*

Lower-dimensional U space



$$\begin{pmatrix} 1 & 1 & 1 \\ -1.96 & 7.37 & 1.36 \\ -1.15 & 2.76 & -0.88 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 1 \\ -2.8 \\ 2.6 \end{pmatrix}$$

Fazenda Rancho Grande, Rondônia

HYDROLOGICAL PROCESSES
Hydrol. Process. **21**, 0–0 (2007)
Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/hyp.6803

Land management impacts on runoff sources in small Amazon watersheds

Joaquín Chaves,[1]* Christopher Neill,[1] Helmut Elsenbeer,[2] Alex Krusche,[3] Sonja Germer,[2] and Sergio Gouveia Neto[3]

[1] *The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02543, USA*
[2] *Universität Potsdam, Institut für Geoökologie, Potsdam, Germany*
[3] *Laboratório de Ecologia Isotópica, CENA—USP, Piracicaba, SP, Brazil*

Abstract:

Forest clearing and conversion to cattle pasture in the lowland Amazon region has been linked to soil compaction and increased soil water storage, which combine to diminish soil infiltration, enhance quick lateral flows and increase the stream flow response to precipitation. Quantifying the importance of quick surficial flow in response to this land use change requires identification of water sources within catchments that contribute to stream flow. Using an end member mixing analysis approach, potential contributing sources of stream flow were evaluated during an entire rainy season in a forest and a pasture watershed drained by ephemeral-to-intermittent streams in the south-western Amazon. Water yield was 17% of precipitation in the pasture and 0·8% of precipitation in the forest. During the early rainy season, throughfall, groundwater, and soil water contributed 79%, 18%, and 3%, respectively, to total forest stream flow. Over the entire rainy season, throughfall, groundwater, and shallow soil water provided 57%, 24%, and 19%, respectively, of stream flow. In the pasture watershed, overland flow dominated stream flow both in the early (67%) and late (57%) rainy season, with a mean contribution of 60% overland flow, 45% groundwater, and 5% soil water•. The uncertainty associated with those estimates was studied using a Monte Carlo approach. In addition to large changes in total surface flow, marked differences were found in the proportions of total stream flow in the second half of the rainy season between the forest and pasture watershed. These results suggest that (1) there is great potential for alteration of the hydrological budgets of larger watersheds as the proportion of deforested land in the Amazon increases, and (2) as more rainfall is diverted into fast flowpaths to streams in established pastures, the potential to deliver water with higher solute concentrations generated by erosion or by bypassing sites of solute removal increases. Copyright © 2007 John Wiley & Sons, Ltd.

KEY WORDS Amazon; hydrology; streams; deforestation; rain forest; pasture; EMMA

Received 14 November 2006; Accepted 1 May 2007

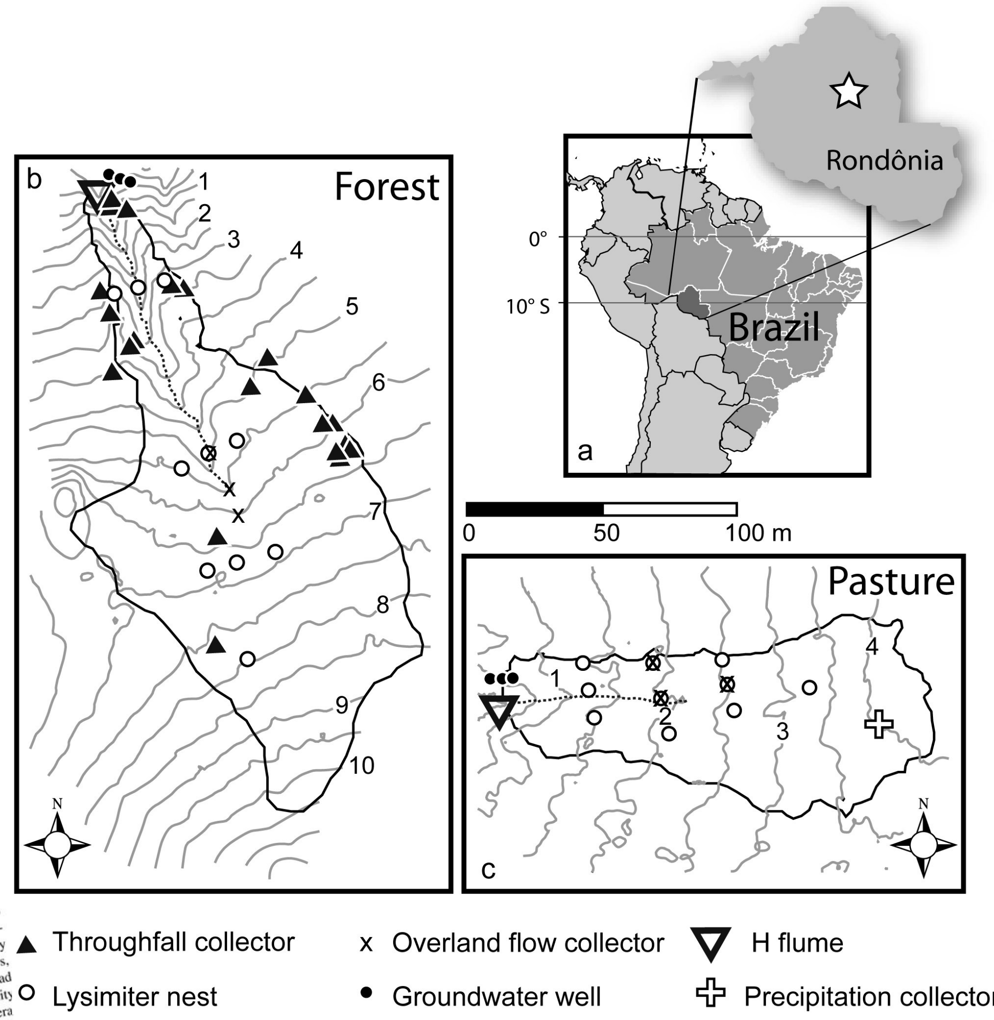
INTRODUCTION

Precipitation falling in watersheds may take a number of pathways to streams. Soil physical characteristics and topography interact with rainfall intensity and amount to determine what flowpaths exist, what specific flowpaths are activated and what sources of water contribute to stream flow (Dunne, 1978). Understanding the origin of stream water and the paths that precipitation follows en route to streams is important because the rates of water movement and the conditions encountered by water along flowpaths control biogeochemical transformations that ultimately determine stream water chemistry (Hill *et al.*, 2000; McClain *et al.*, 2003).

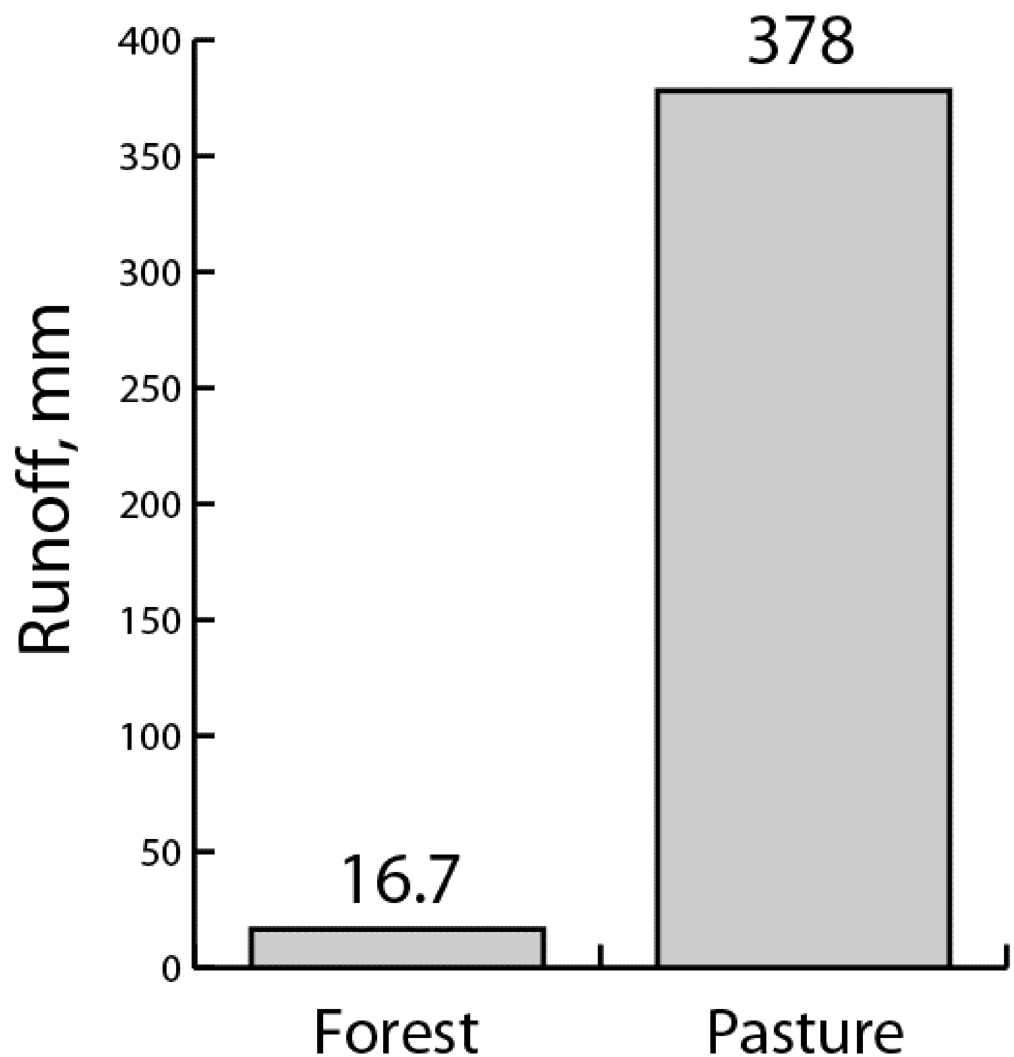
In humid tropical forests, early perceptions of runoff generation were influenced by the notion that high infiltrability and permeability in undisturbed soils led to predominantly vertical flowpaths, precluding fast lateral flows such as overland flow except on steep hillslopes (Elsenbeer, 2001; Bonell, 2005). Recent work shows that in many locations that support moist, lowland tropical forest, rainfall intensities may exceed permeability at shallow depths, which leads to shallow lateral flows capable of triggering widespread overland and return flows (Elsenbeer and Lack, 1996; •Schellekens, 2000; Godsey *et al.*, 2004; Johnson *et al.*, 2006). While increasingly recognized as potentially important, a quantitative understanding of the importance of these shallow lateral flow contributions to stream flow across the lowland tropical landscapes is still lacking. Because the properties of vegetation and soils play such a large role in structuring the origin and flowpaths of water within catchments, changes to land use that influence soils and vegetation have the potential to cause large changes to both the amount of water reaching streams and the flowpaths of water in watersheds. This issue is particularly important in humid tropical regions. In these places, high rainfall intensities combine with the widespread occurrence of soils with strong near-surface permeability contrasts, creating the potential for widespread genera tion of saturation overland flow, a potential that is apt to increase upon disturbance (Bonell, 2005). Decreased

* Correspondence to: Joaquín Chaves, The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02543, USA.
E-mail: jchaves@mbl.edu

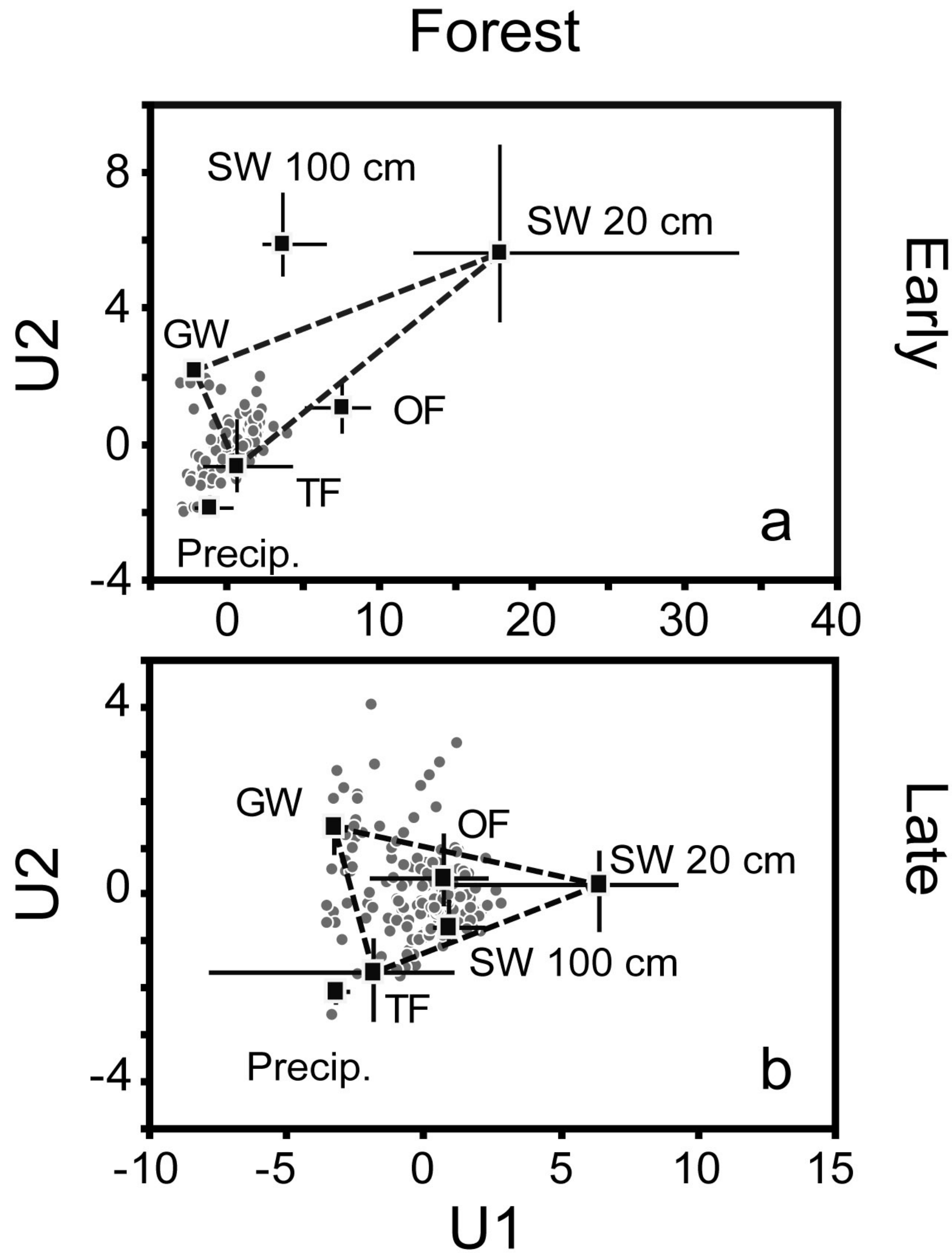
Copyright © 2007 John Wiley & Sons, Ltd.



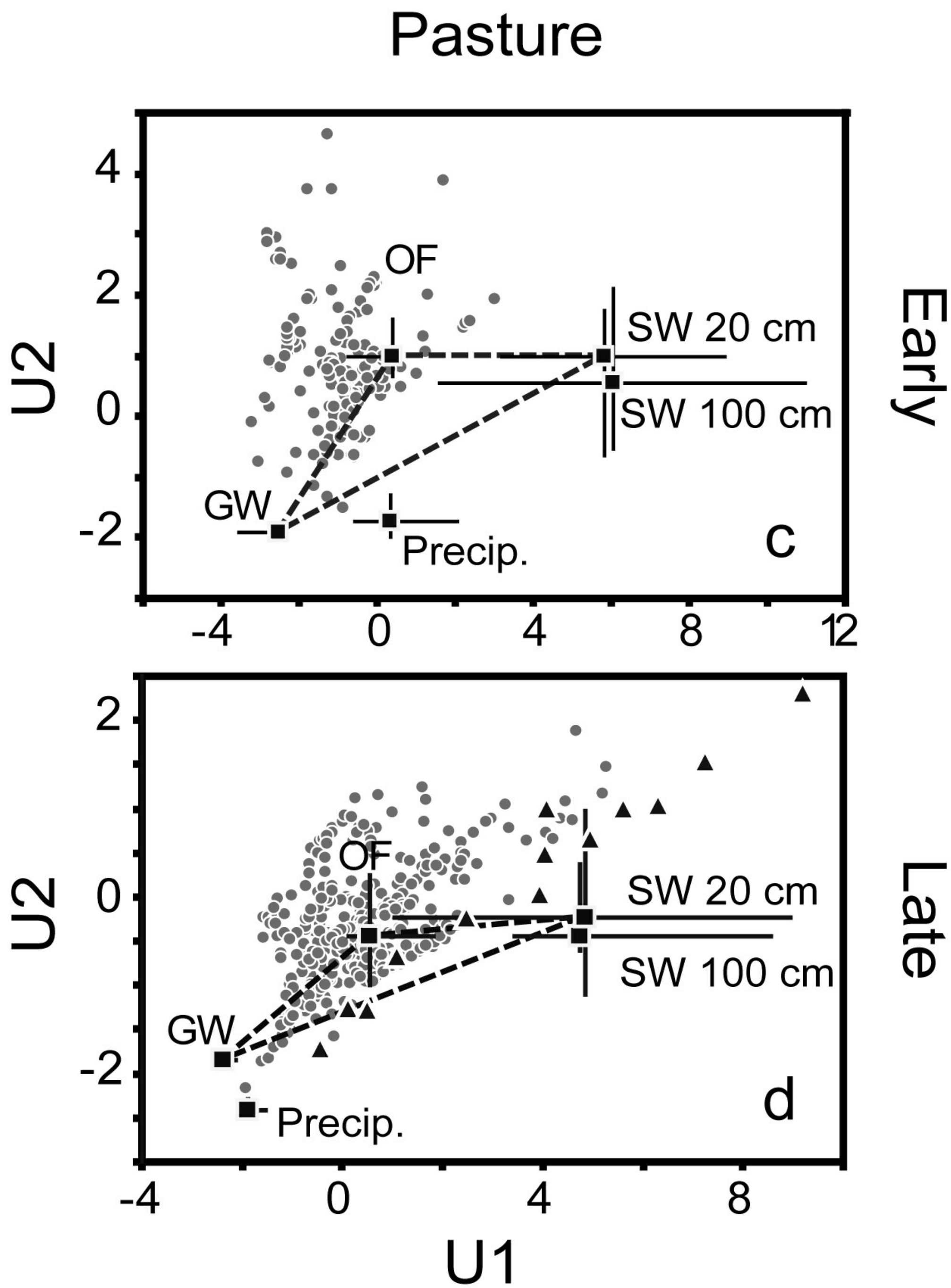
Water yields



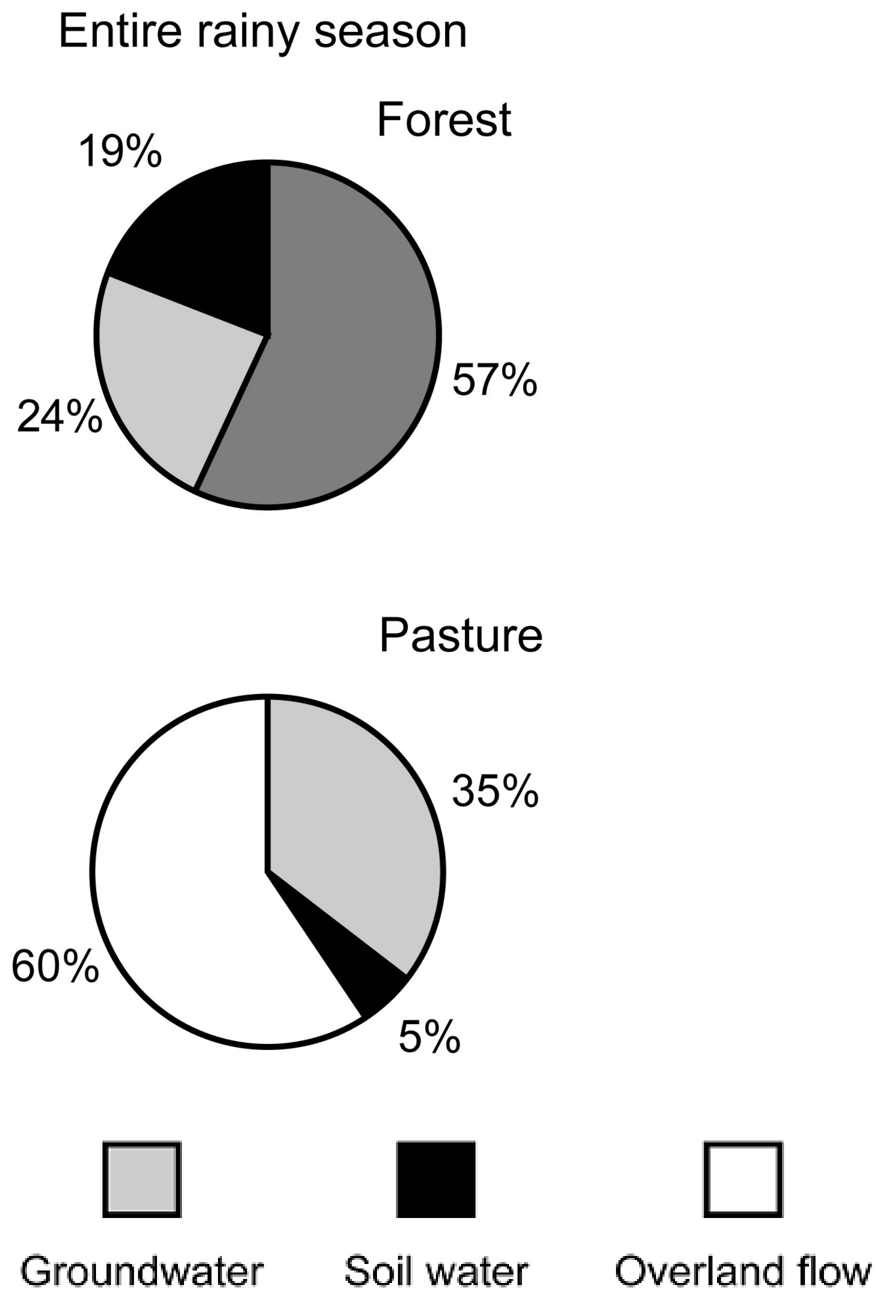
Mixing Diagrams:



Mixing Diagrams:



Overall Results:



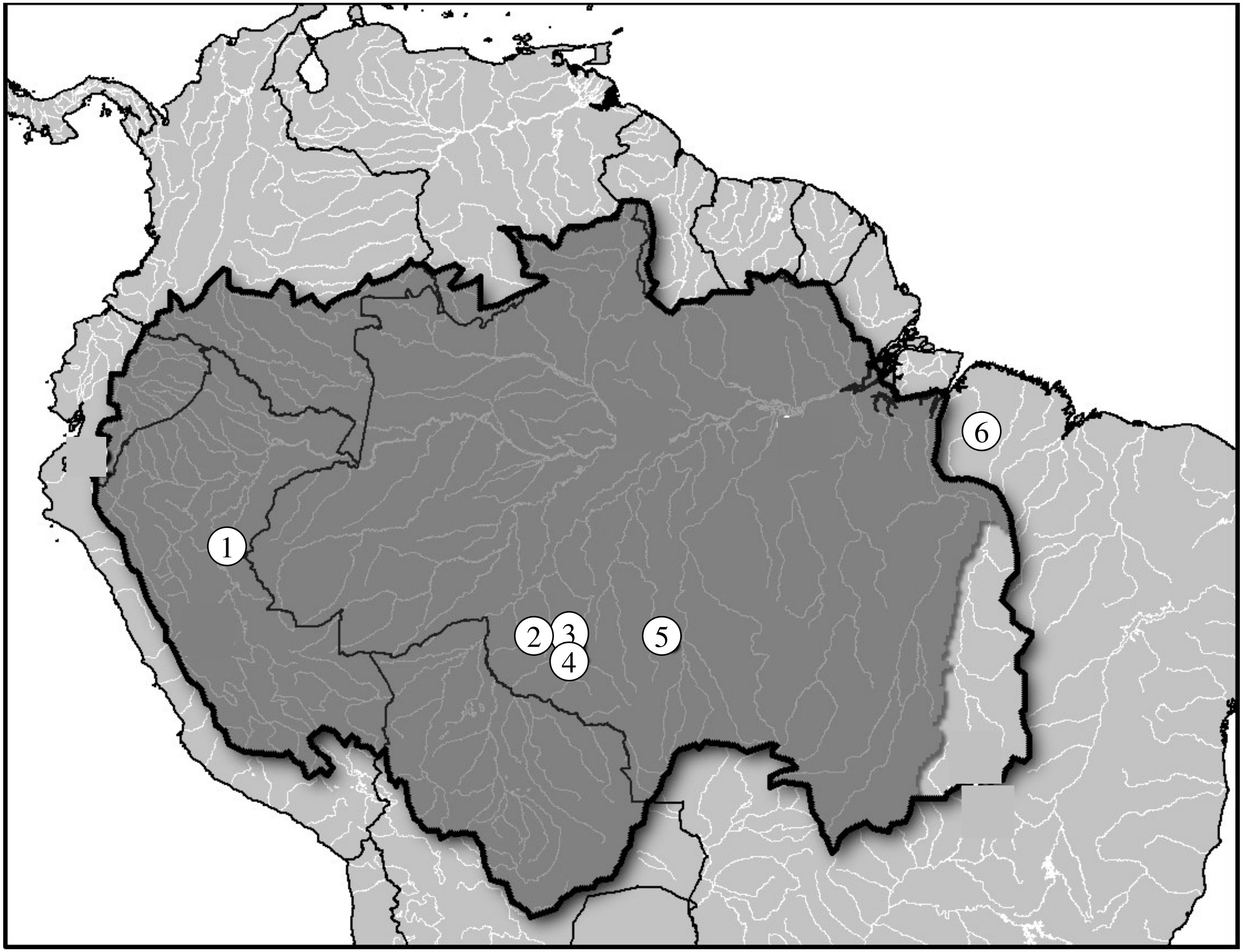
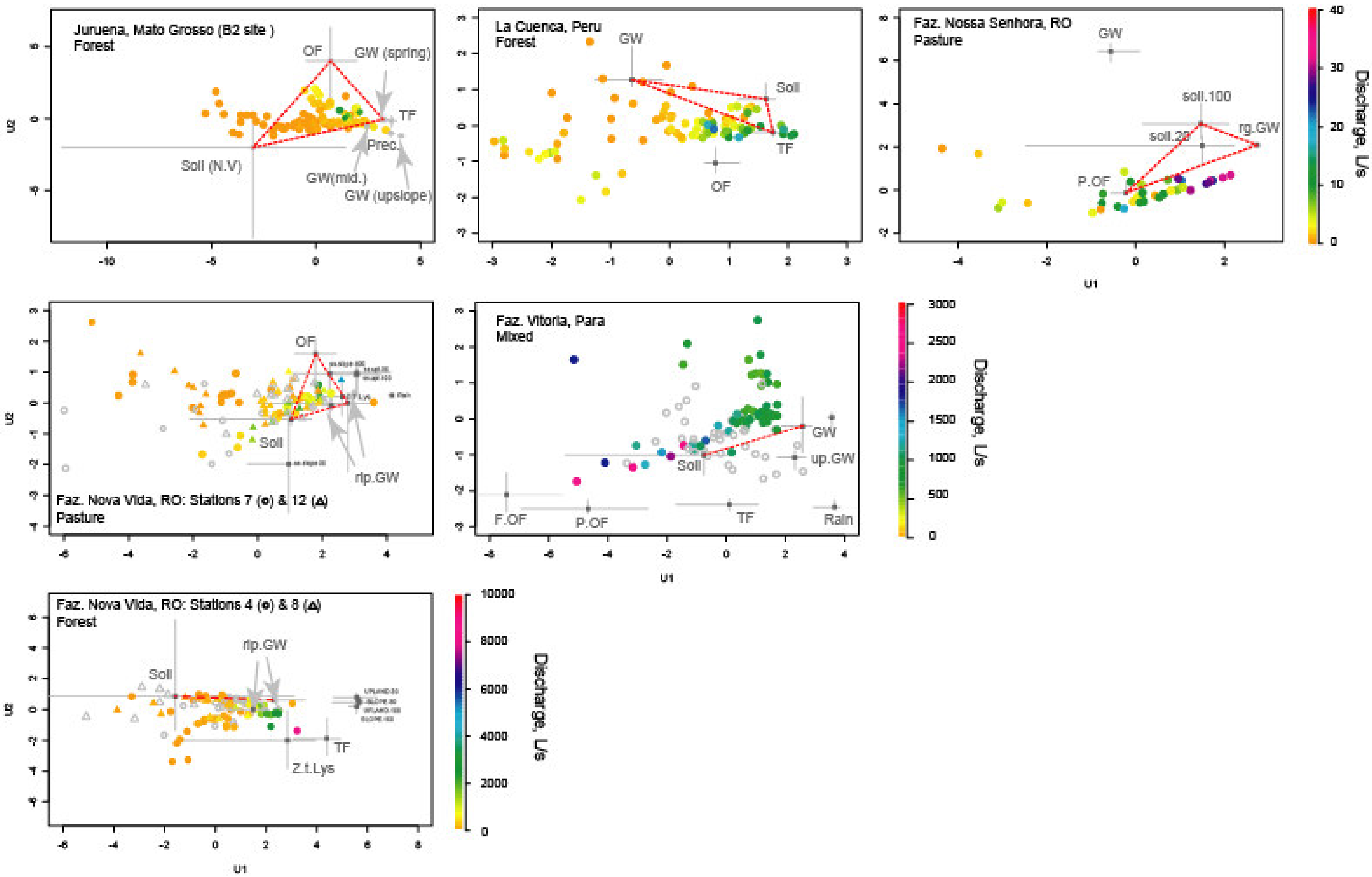

1
2
3
4
5
6

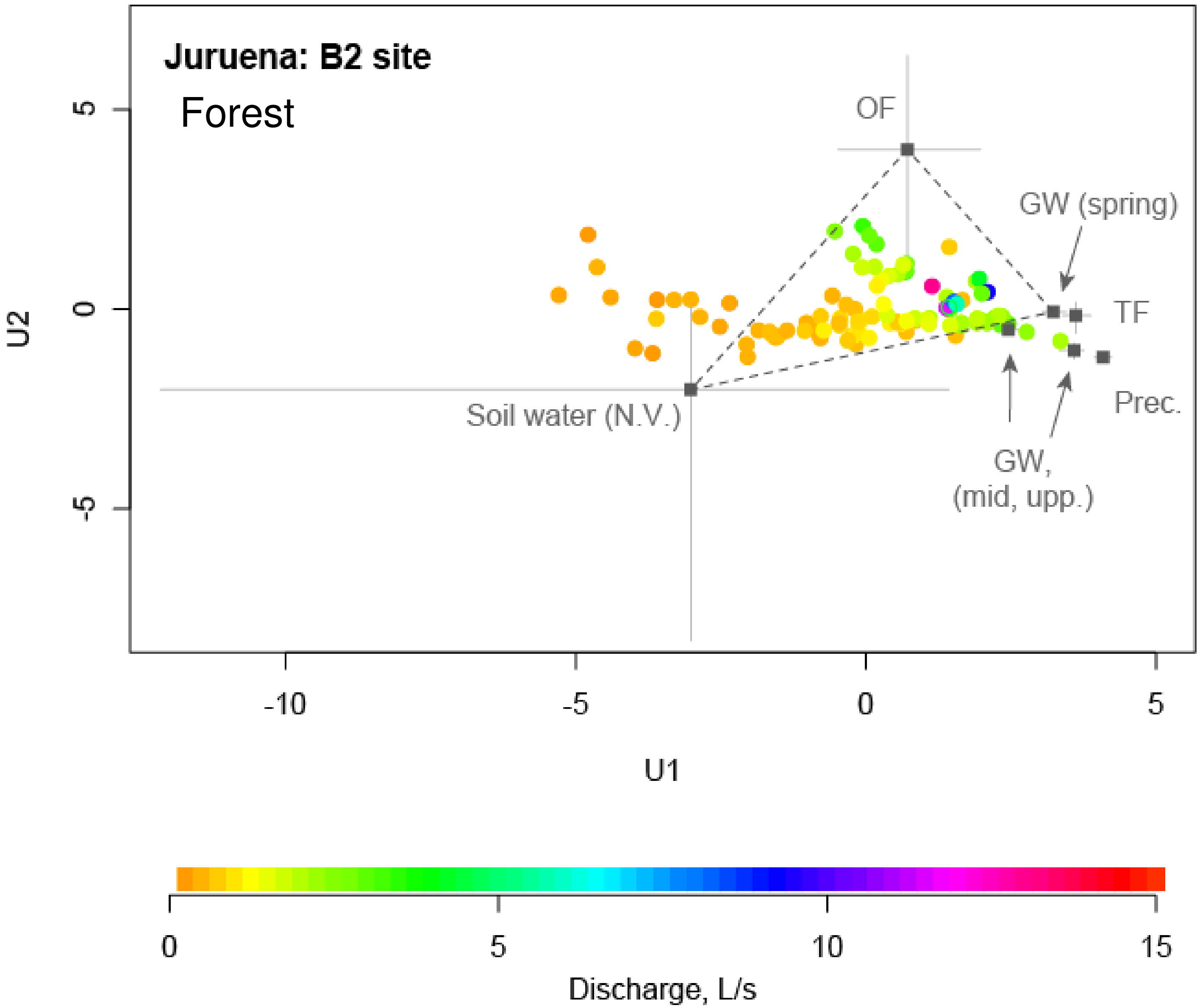
Table 1. Locations used for the EMMA analysis.

Location	Landcover type	Site	Area, ha	Flow type, soil	References
Fazenda Nova Vida, Rondônia	Forest	Station "4"	17400	Perennial, Ultisol	(Neill *et al.*, 2001)
	Forest	Station "8"	250	"	
	Pasture	Station "7"	130	"	
	Pasture	Station "12"	720	"	
Fazenda Rancho Grande, Rondônia		Forest	1.4	Ephemeral, Ultisol	(Chaves *et al.*, 2007)
		Pasture	0.7	"	
Fazenda Vitoria, Pará	Mixed	Igarape 54	14000	Perennial, Oxisol	(Markewitz *et al.*, 2004)
Juruena, Mato Grosso	Forest	"B2"	1.9	Perennial, Ultisol	(Johnson *et al.*, 2006)
La Cuenca, Peru	Forest		0.7	Ephemeral, Ultisol	(Elsenbeer and Lack, 1996)
Fazenda Nossa Senhora	Pasture		3.9	Ephemeral, Ultisol	(Biggs *et al.*, 2006)

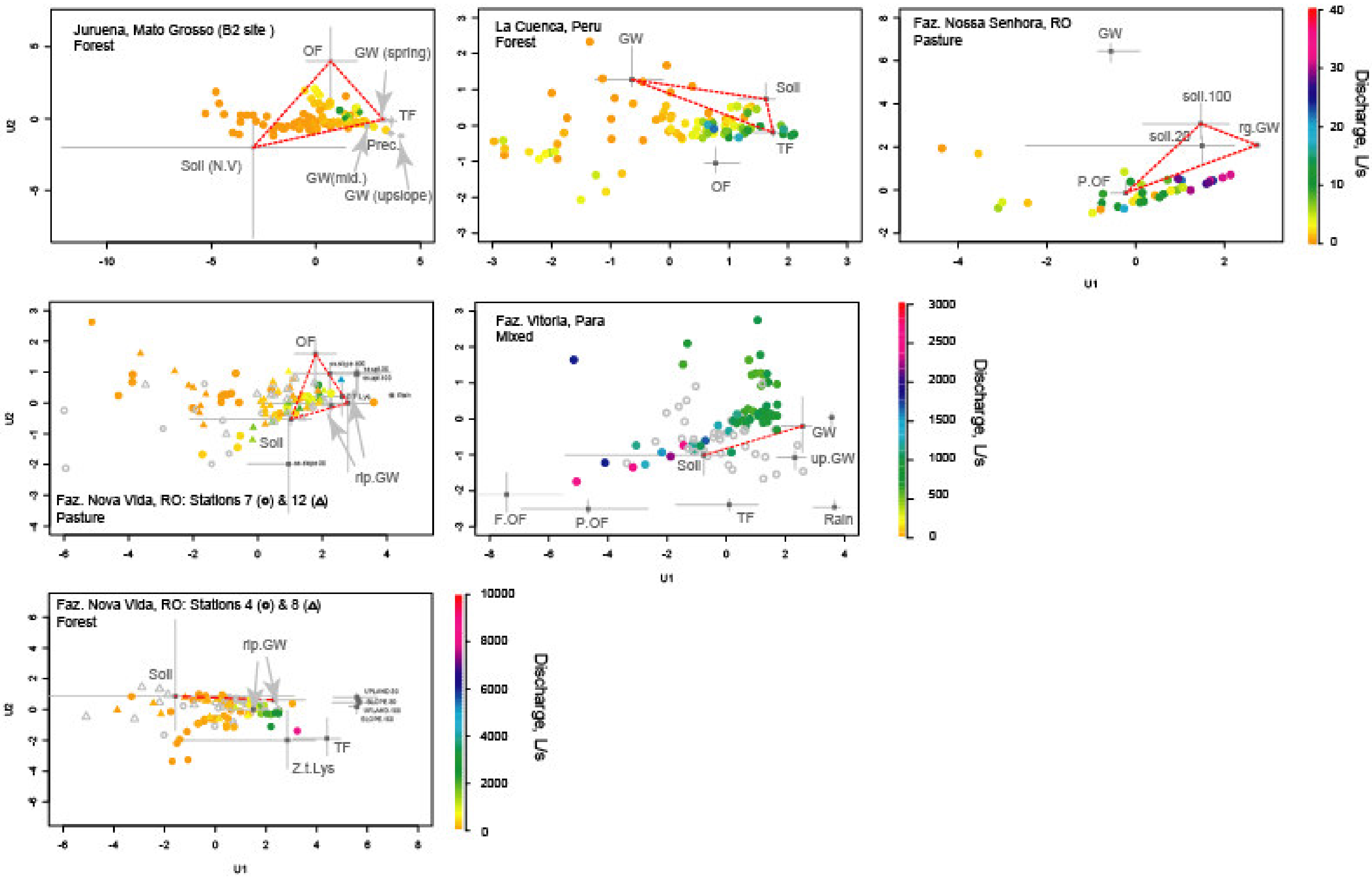
Mixing Diagrams: Amazon Sites



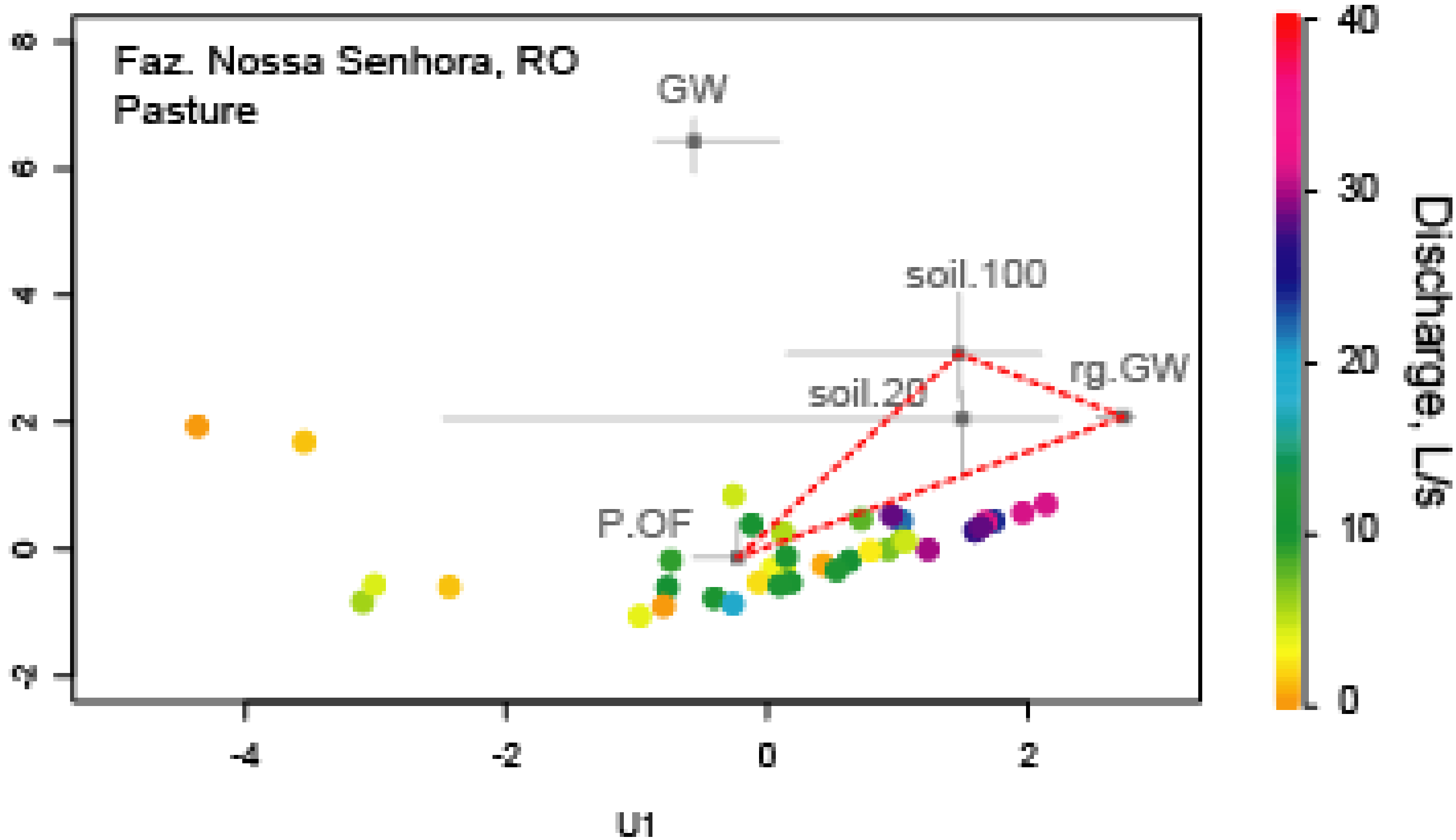
Mixing Diagrams: Amazon Sites



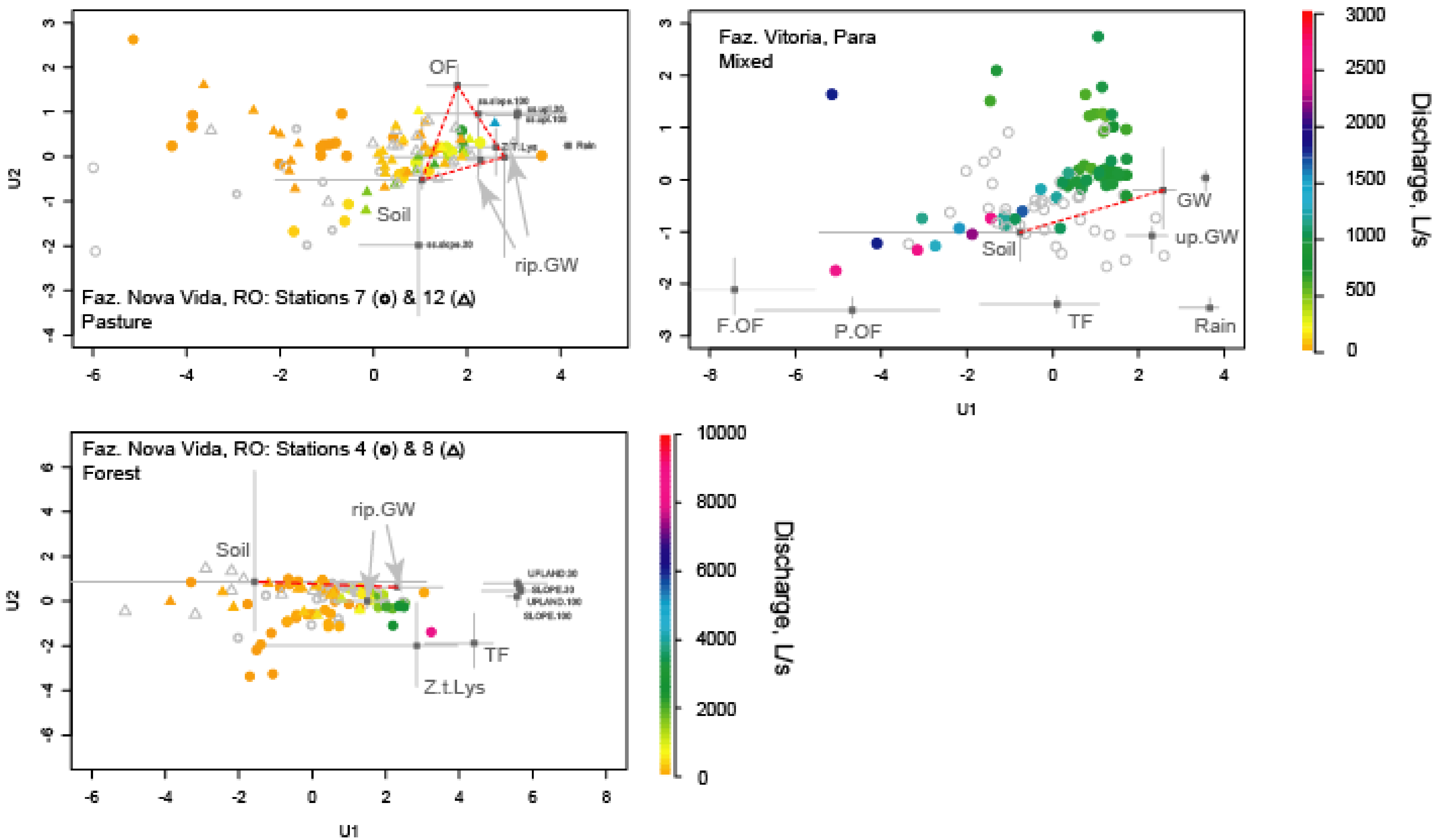
Mixing Diagrams: Amazon Sites



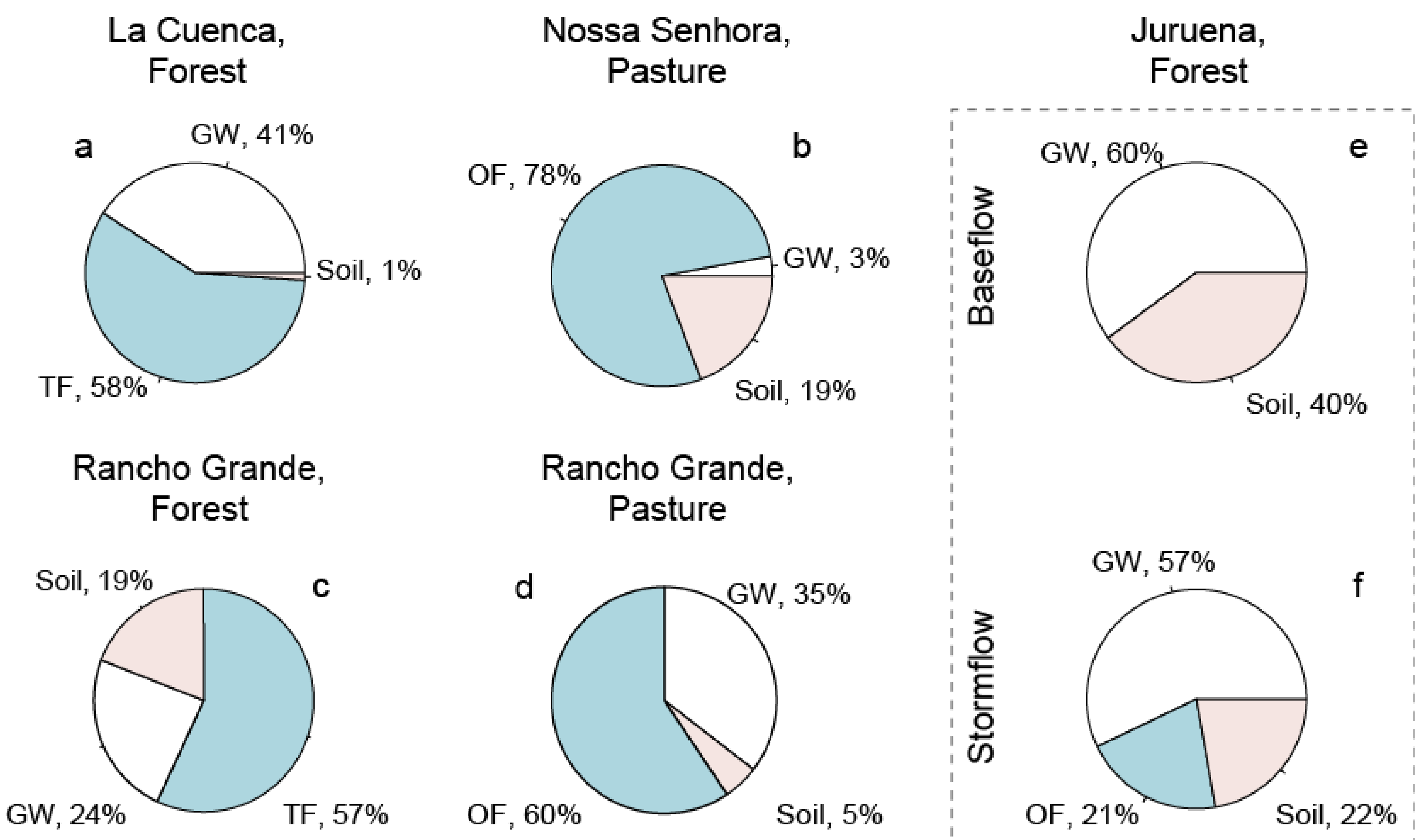
Mixing Diagrams: Amazon Sites

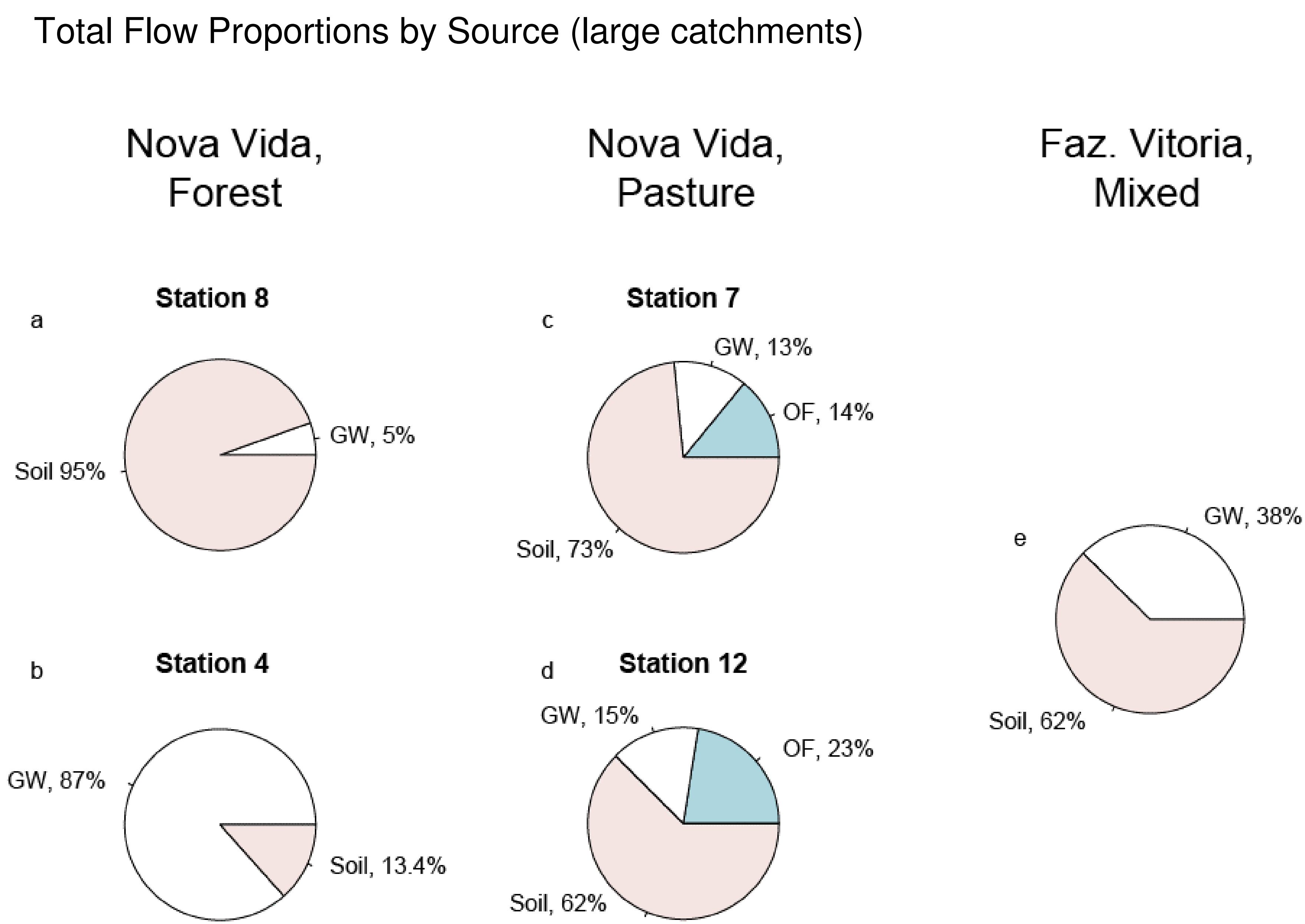


Mixing Diagrams: Amazon Sites (Large catchments)

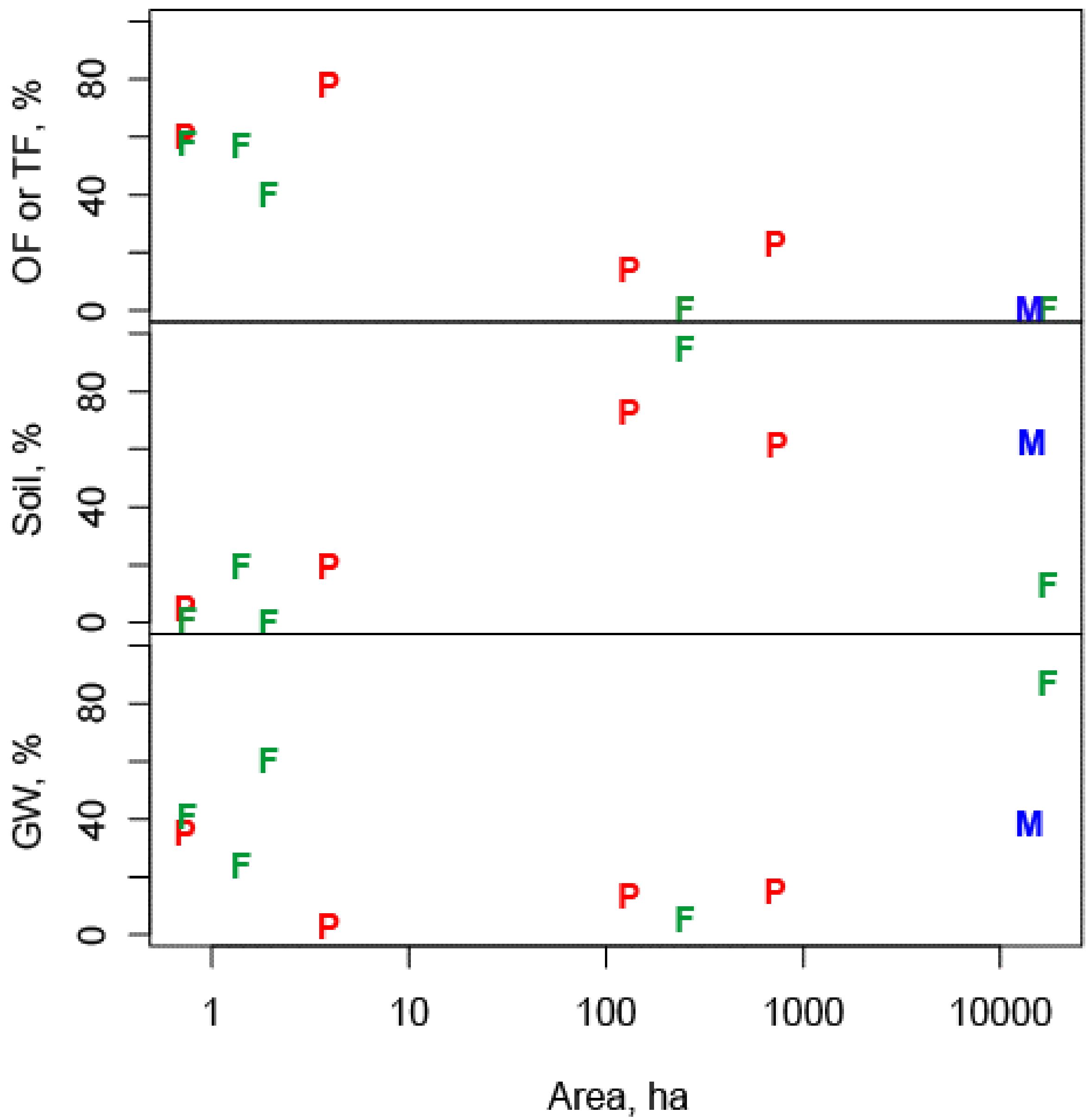


Total Flow Proportions by Source (small catchments)

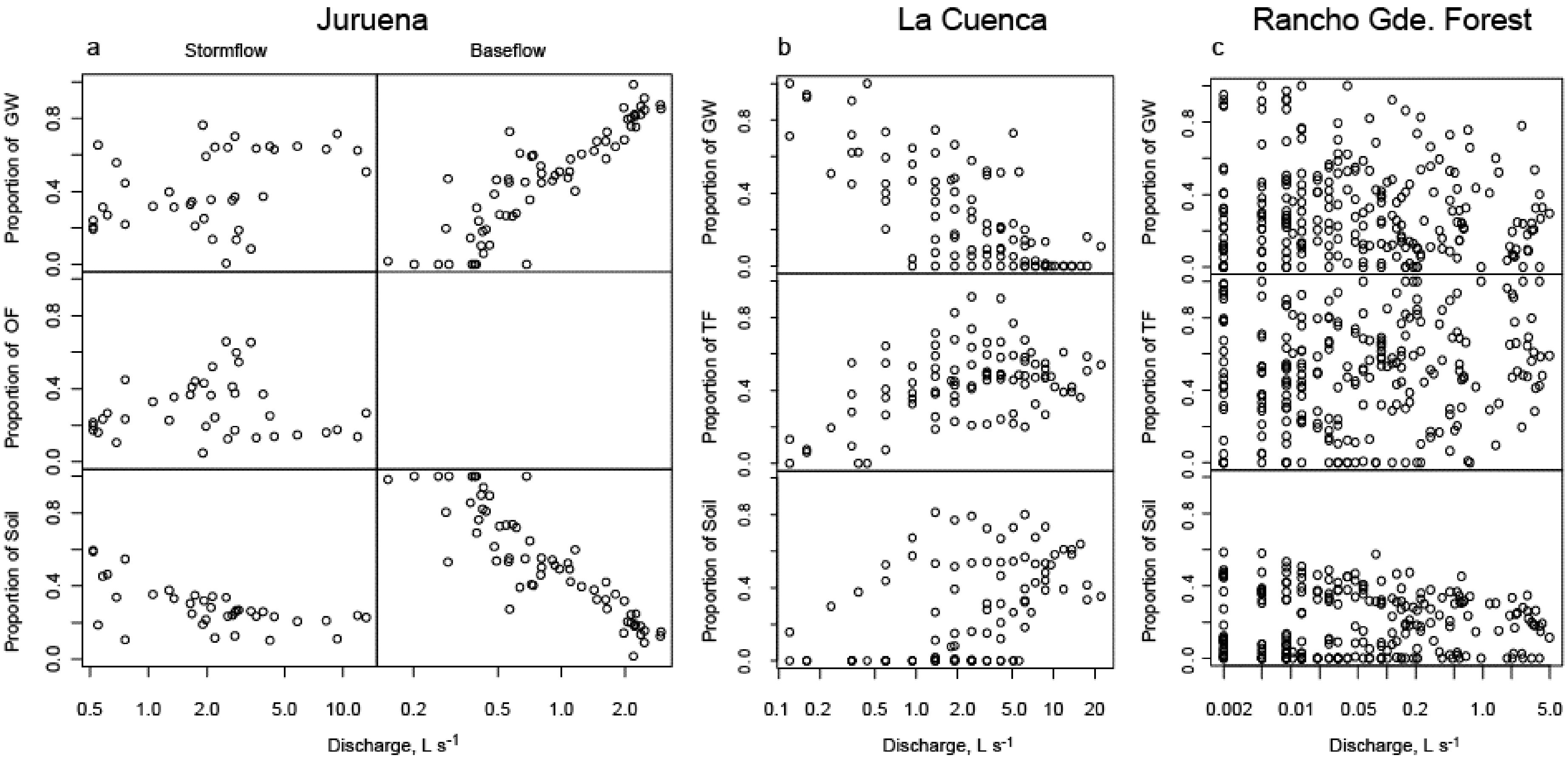



Total Flow Proportions by Source (large catchments)
Nova Vida, Forest
Nova Vida, Pasture
Faz. Vitoria, Mixed
Station 8
a
GW, 5%
Soil 95%
Station 4
b
GW, 87%
Soil, 13.4%
Station 7
c
GW, 13%
OF, 14%
Soil, 73%
Station 12
d
GW, 15%
OF, 23%
Soil, 62%
e
GW, 38%
Soil, 62%

Total Flow Proportions by Source Across Scale



Proportion vs. Flow Relationships (small catchments)

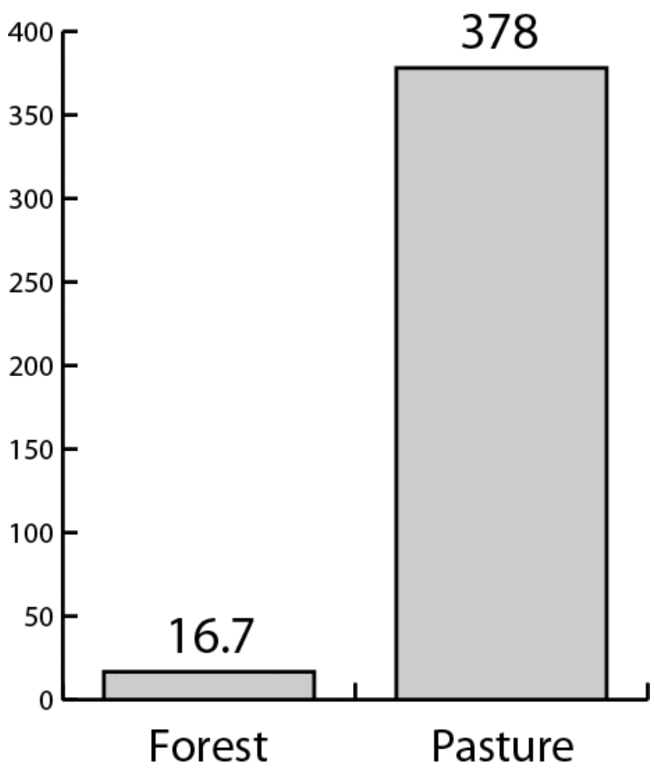


Some (transient) conclusions…and thoughts:

- A consistent pattern across sites in which groundwater and soil solution end members emerged as the main sources to stream flow on most sites

- “Fast” flowpaths dominated small watersheds

- “Slow” flowpaths increase predominance in large watersheds



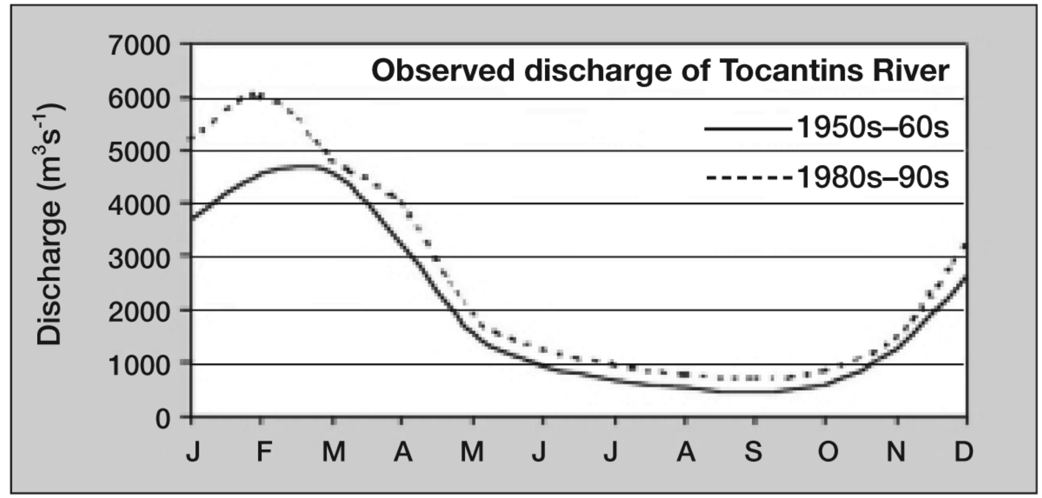


Figure 4. *Effects of land cover change on river flow. Here we illustrate the observed changes in river discharge in the Tocantins river basin that resulted from land-cover change and agricultural clearing in the mid-20th century. The solid line is the mean monthly discharge for the period 1950–60s, when crops and pasture covered about 30% of the land area of the 176 000 km² basin. The dotted line is the river discharge during the 1980s and 1990s, when crops and pasture had increased to cover more than 50% of the basin (adapted from Costa* et al. *2003).*

Costa et al 2003, adapted by Foley et al. 2007

•Can this approach help us understand the links between the changes in water yields at the <1 ha and the changes (or lack of) at the river basin scale?

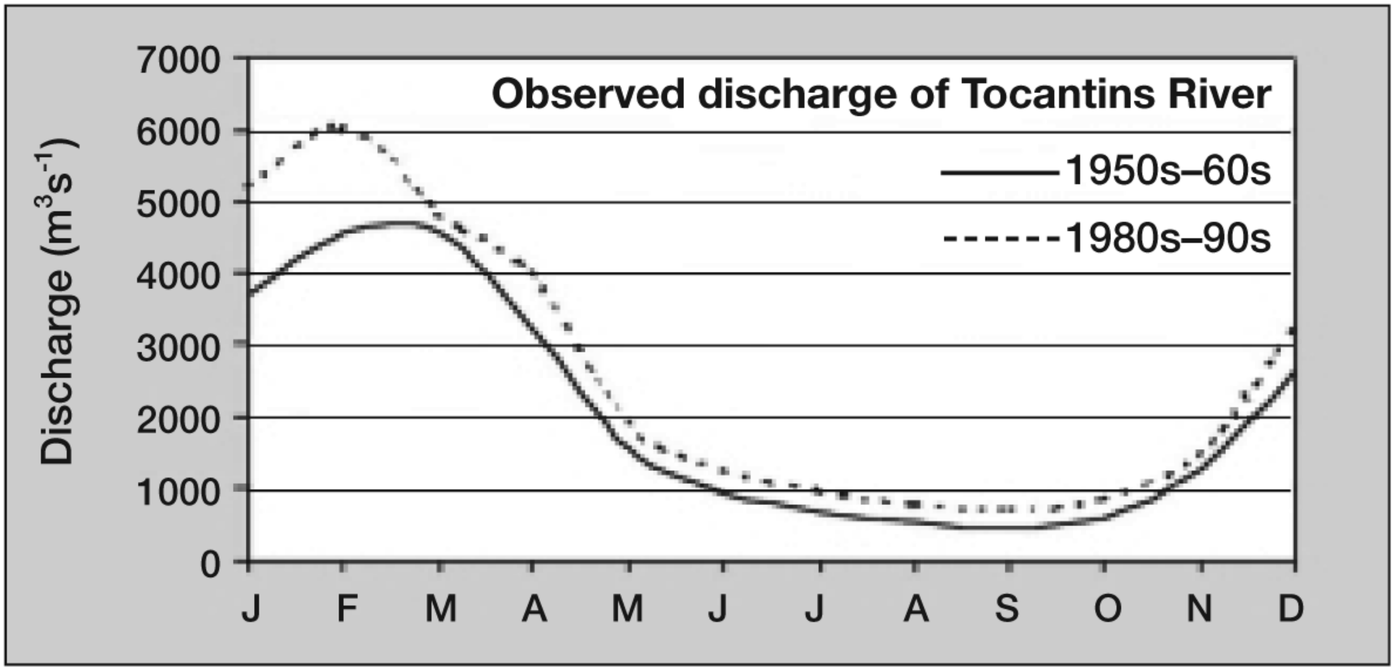


Figure 4. *Effects of land cover change on river flow. Here we illustrate the observed changes in river discharge in the Tocantins river basin that resulted from land-cover change and agricultural clearing in the mid-20th century. The solid line is the mean monthly discharge for the period 1950–60s, when crops and pasture covered about 30% of the land area of the 176 000 km² basin. The dotted line is the river discharge during the 1980s and 1990s, when crops and pasture had increased to cover more than 50% of the basin (adapted from Costa* et al. *2003).*

Costa et al 2003, adapted by Foley et al. 2007