Hydrological Impacts of Land Use and Land Cover Changes - LUCC in Brazil: current state of the art and scientific challenges

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LUCC impacts in rural and urban areas

1) LUCC are different in urban and rural areas. LUCC in urban areas are quite severe compare to changes in rural area. However, in rural areas, changes affect larger areas.

2) Although changes in urban area are directly related to floods with higher social and economic impacts, most of water management are strongly linked to land use in rural areas.

3) Understanding and predicting the hydrological impacts of LUCC is crucial for water management issues

Questions to be addressed

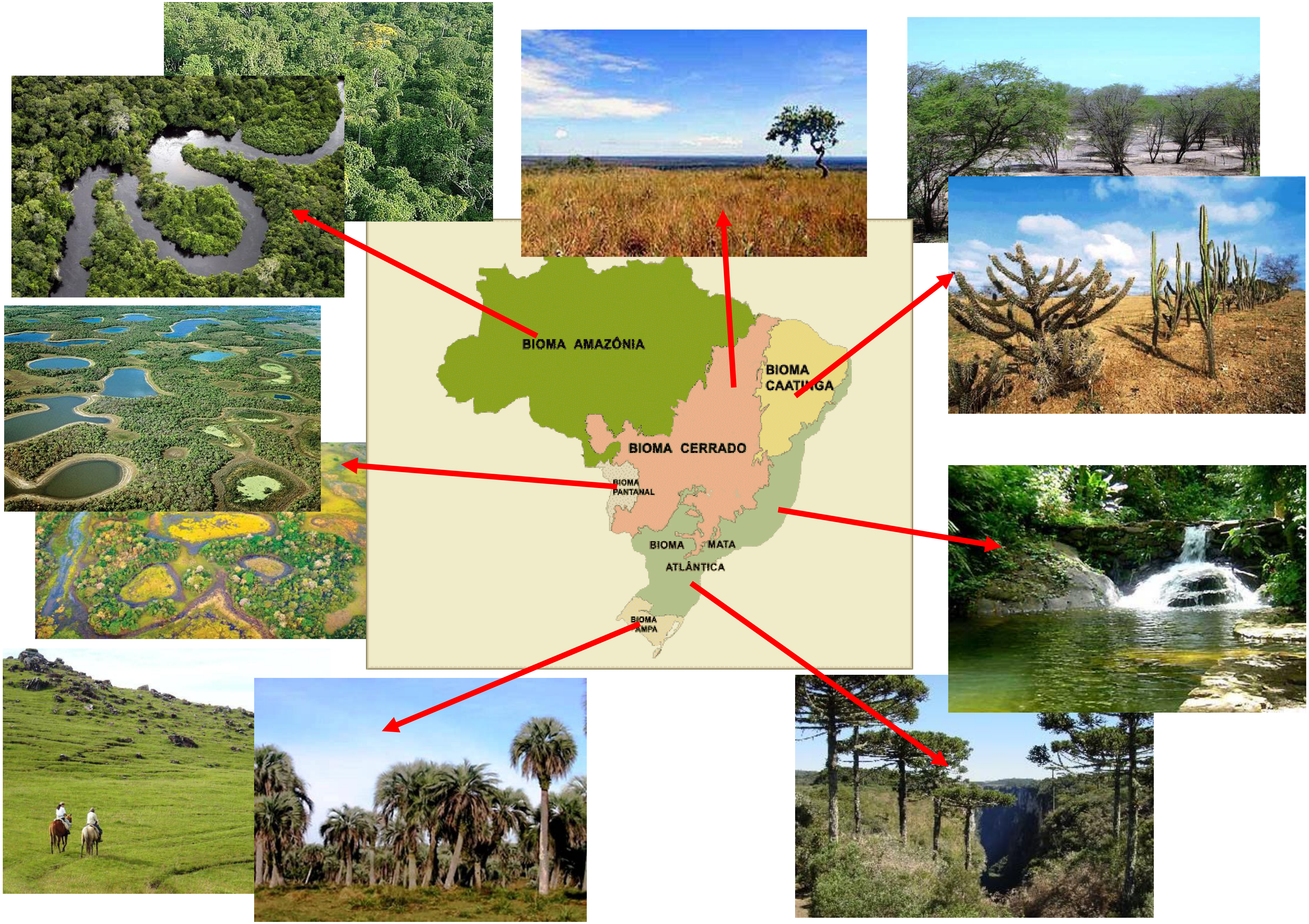
1) What are the evidences of the effects of land use and land cover changes (LUCC) on local-scale to large-scale in the Brazilian tropics?

2) What is the ability of existent models to assess the impacts of LUCC on the hydrological response?

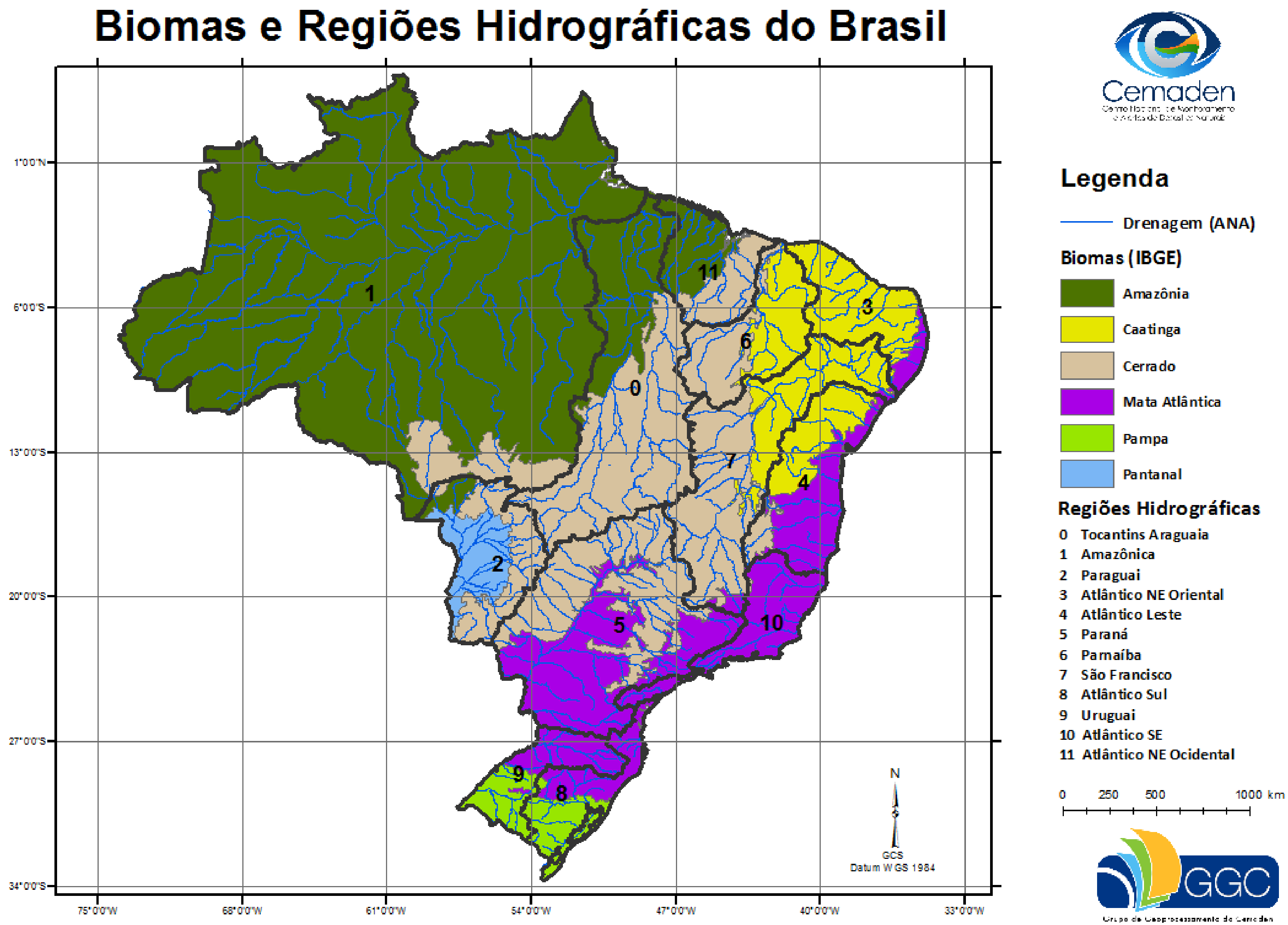
3) What further research is necessary.

A brief lecture of Brazilian´s Geography

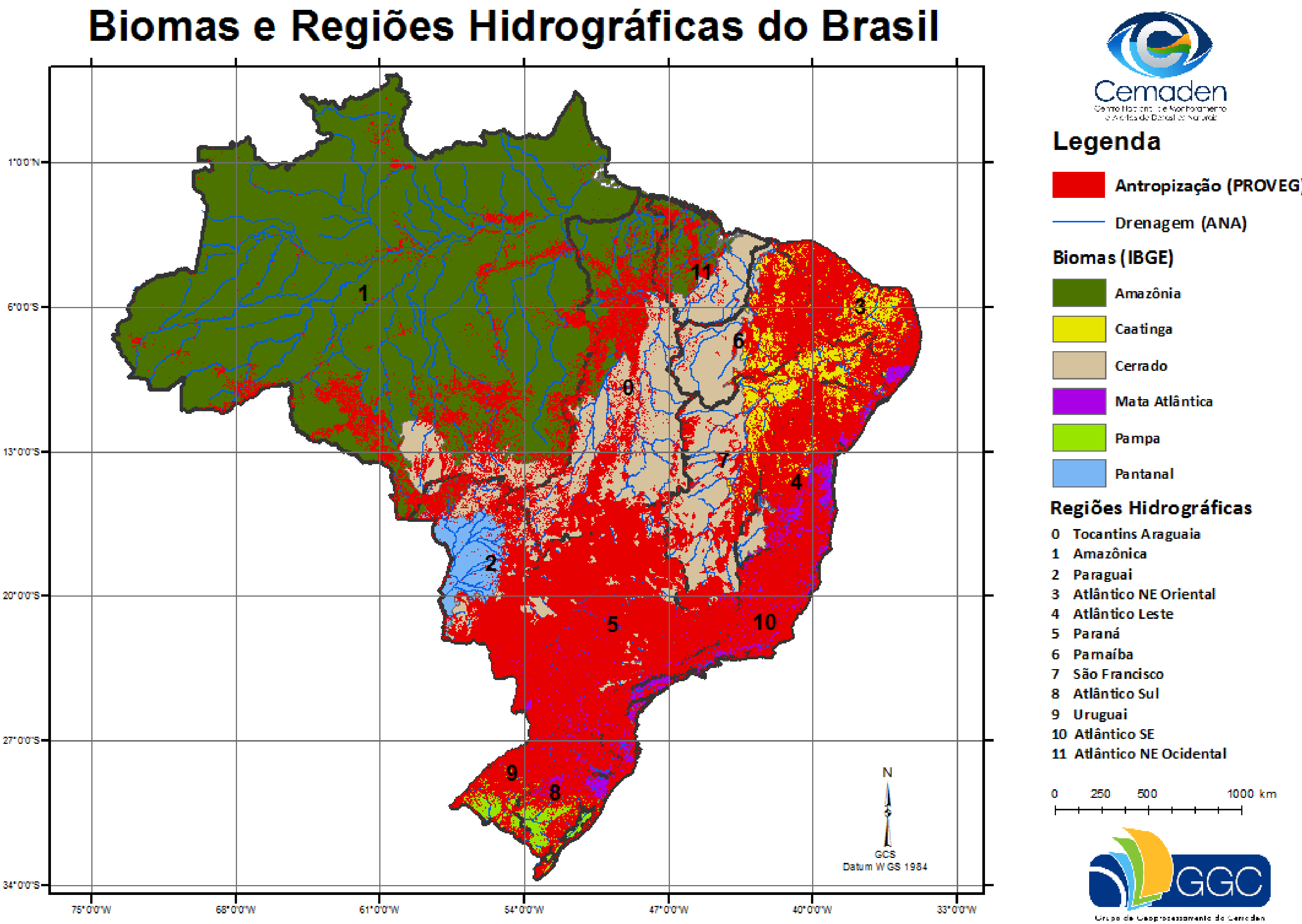
Brazilian main terrestrial biomes



Brazilian natural biomes and hydrographic regions



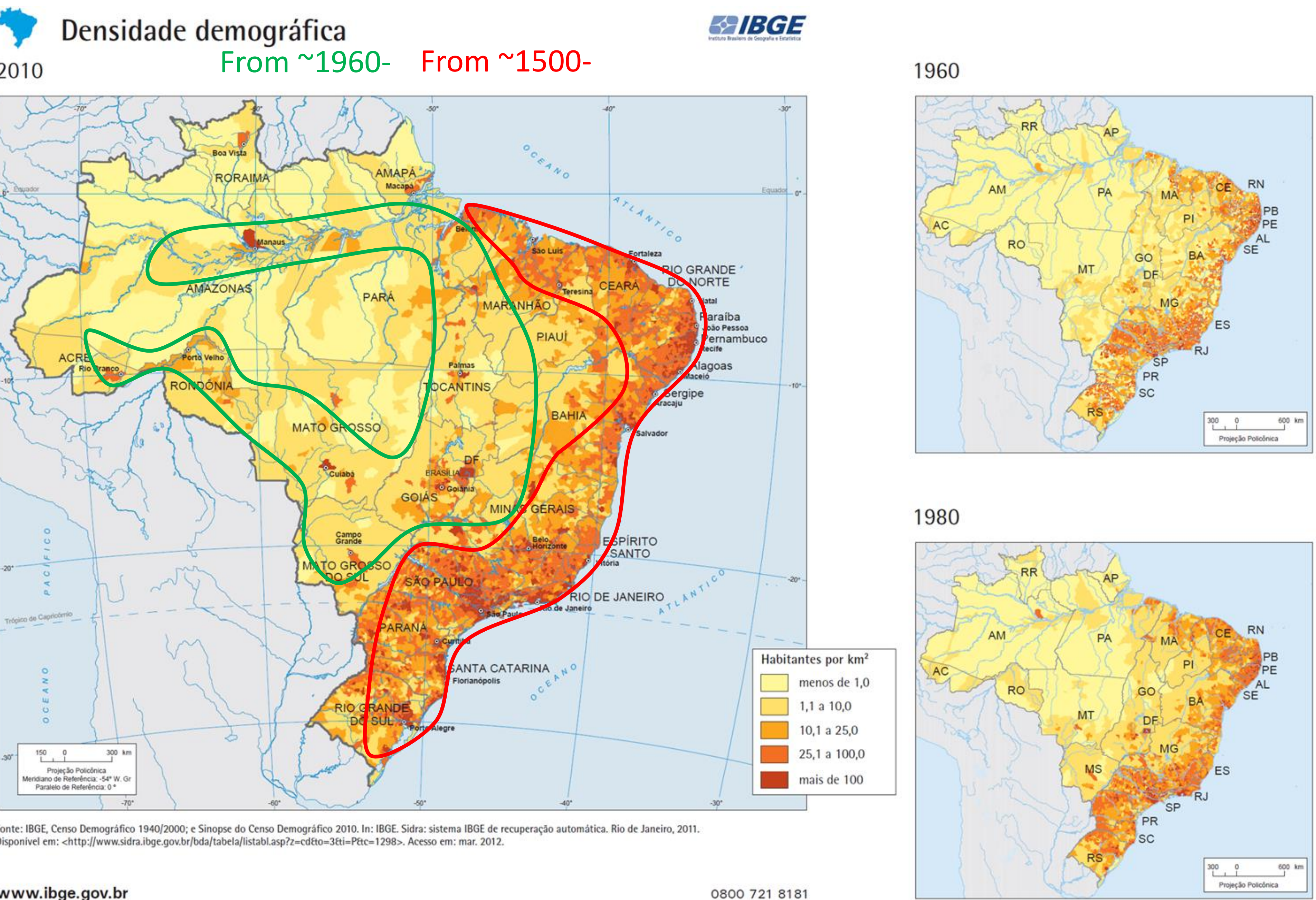
Brazilian natural biomes and hydrographic regions



“Clearing of a Forest”

Defrichement d’une Forêt (c. 1825). Johann Moritz Rugendas (1802-1858)

Historical occupation of Brazil



1) What are the evidences of the effects of land use and land cover changes (LUCC) on local-scale to large scales in the tropics?

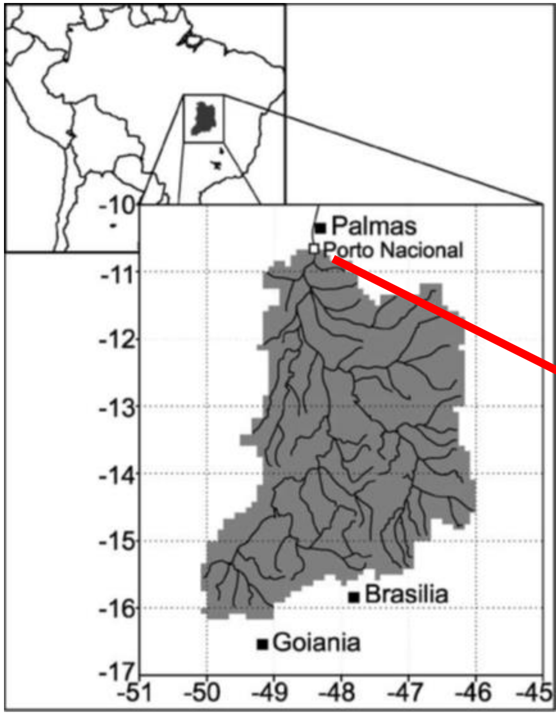
Study case: The replacement of Amazon Forest and *Cerrado* by Pasture

What is the current knowledge?

There is an extensive body of hydrological literature dealing with impacts of land use and land cover change on small (i.e. <1 km2), mainly temperate experimental catchments (Bonell and Bruijnzeel, 2005; Brown et al., 2005; Peel, 2009).

In such controlled conditions, total annual water yield, infiltration and groundwater recharge appeared to increase proportionally to the area of forest removed (e.g. Brown et al., 2005; Van Dijk and Keenan, 2007).

Tocantins River Basin (Costa et al. 2003)



The area of study (upstream of Porto Nacional) has a drainage area of 175 360 km².

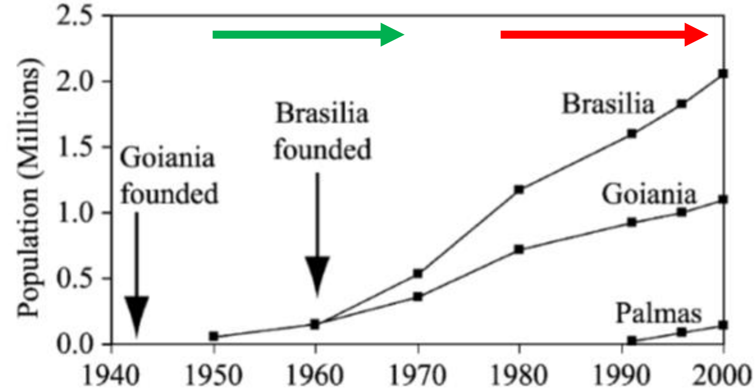


Fig. 2. Population trends in the main cities near the area of study. Goiânia was founded in 1942 to be the new capital of the state of Goiás. Brasília was founded in 1960 to be the new capital of Brazil. Palmas was founded in 1989, to be the capital of the new state of Tocantins. Data are from IBGE (1950, 1960a, 1970, 1980, 1991 and 2000) demographic censuses and one IBGE population count (1996). Data for 1991, 1996 and 2000 were downloaded from http://www.ibge.gov.br.

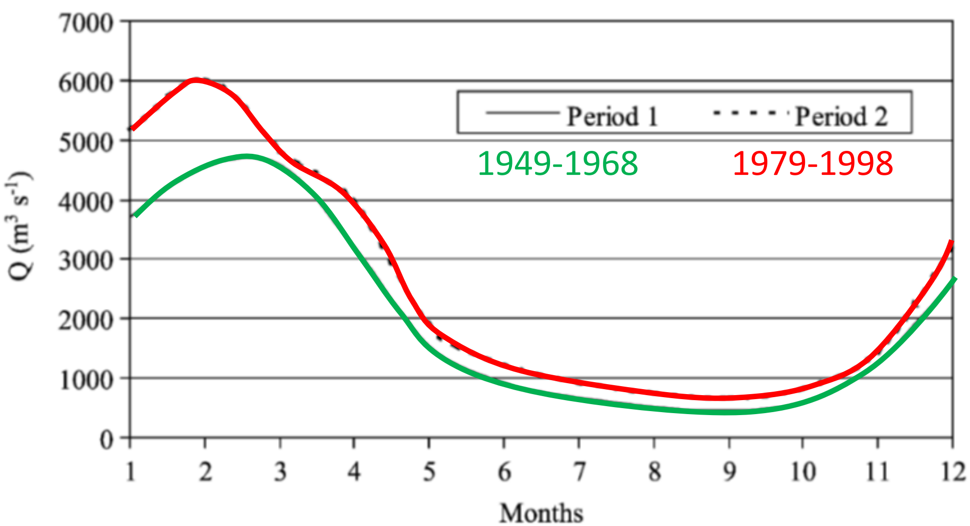


Table 2
Long term mean of hydrological variables in the Tocantins River basin upstream of Porto Nacional

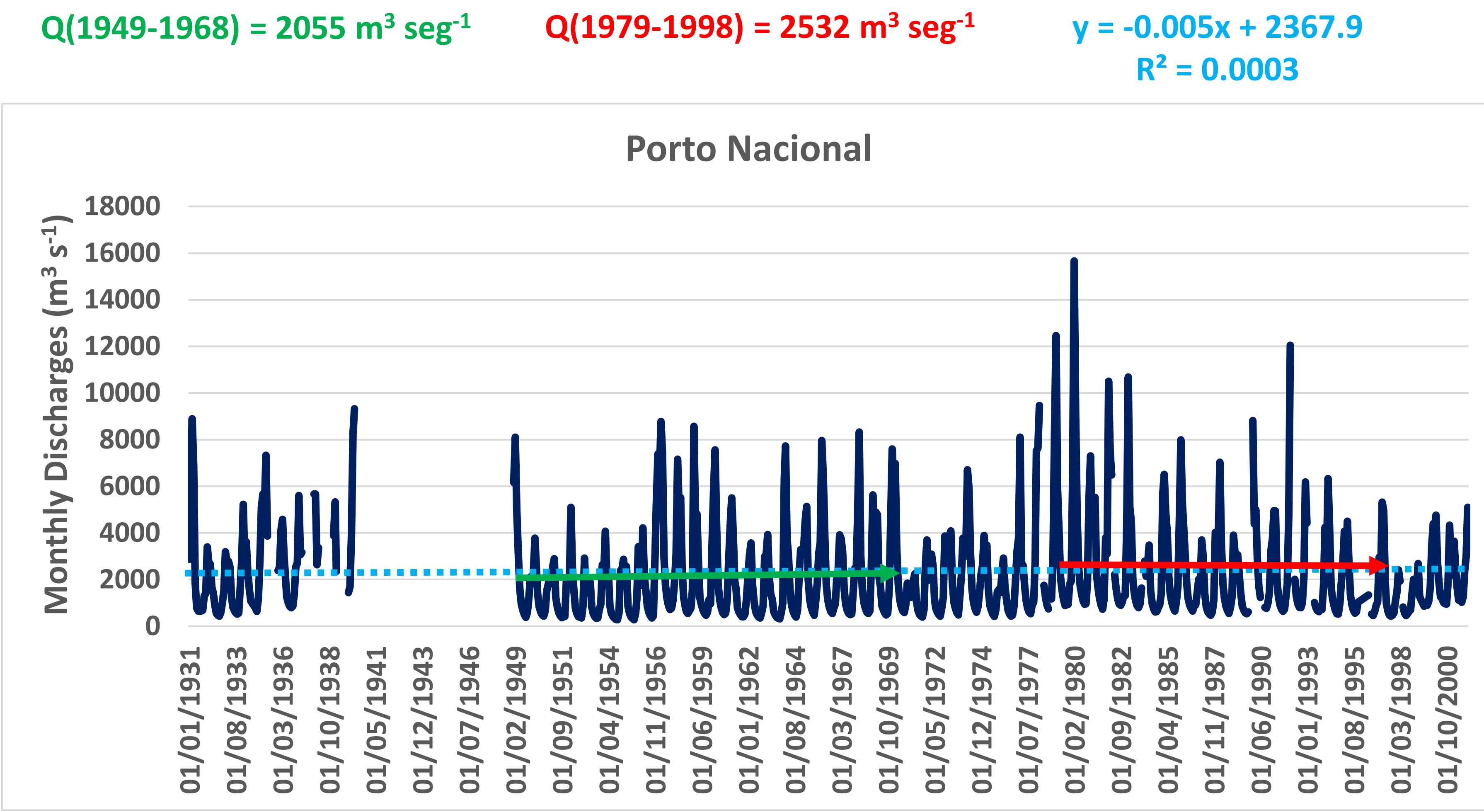
Period	P (mm/day)	Q (m^3/s)	Q (mm/day)	ET (mm/day)	C
1949–1968	4.22	2055.6	1.00	3.22	0.237
1979–1998	4.35	2532.3	1.24	3.11	0.285

P is precipitation (calculated from the CRU dataset), Q is discharge (from the ANEEL records), ET is evapotranspiration ($P - Q$), and C is the runoff coefficient (Q/P).

Tocantins River Basin (Costa et al. 2003)

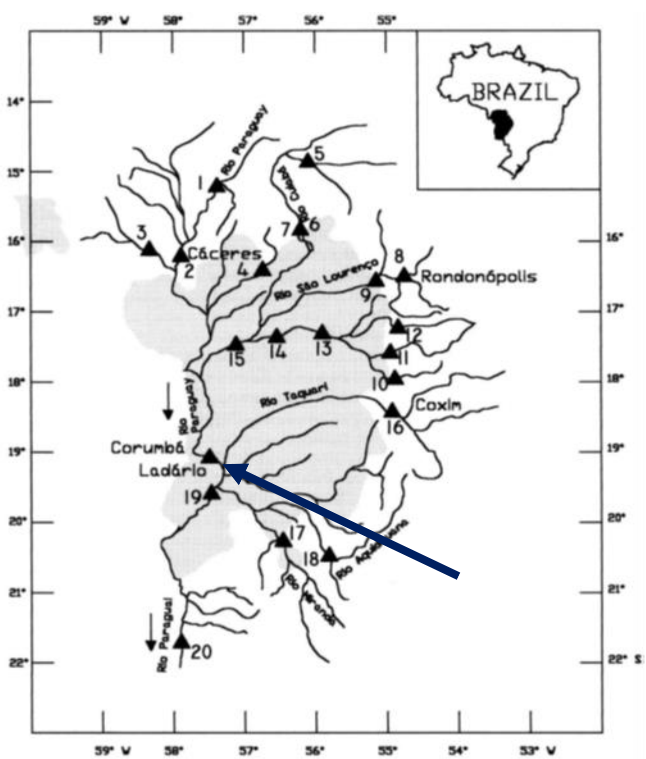
“Our analysis indicates that, while precipitation over the basin is not statistically different between period 1 and period 2; annual mean discharge in period 2 is 24% greater than in period 1; and the high-flow season discharge is greater by 28%.”

However, if we look an "updated streamflow series"…



Looking into rainfall and streamflow trends in the contiguous Upper Paraguay and Southern Amazon Basins

Paraguay River (Collischonn et al. 2001,JH)



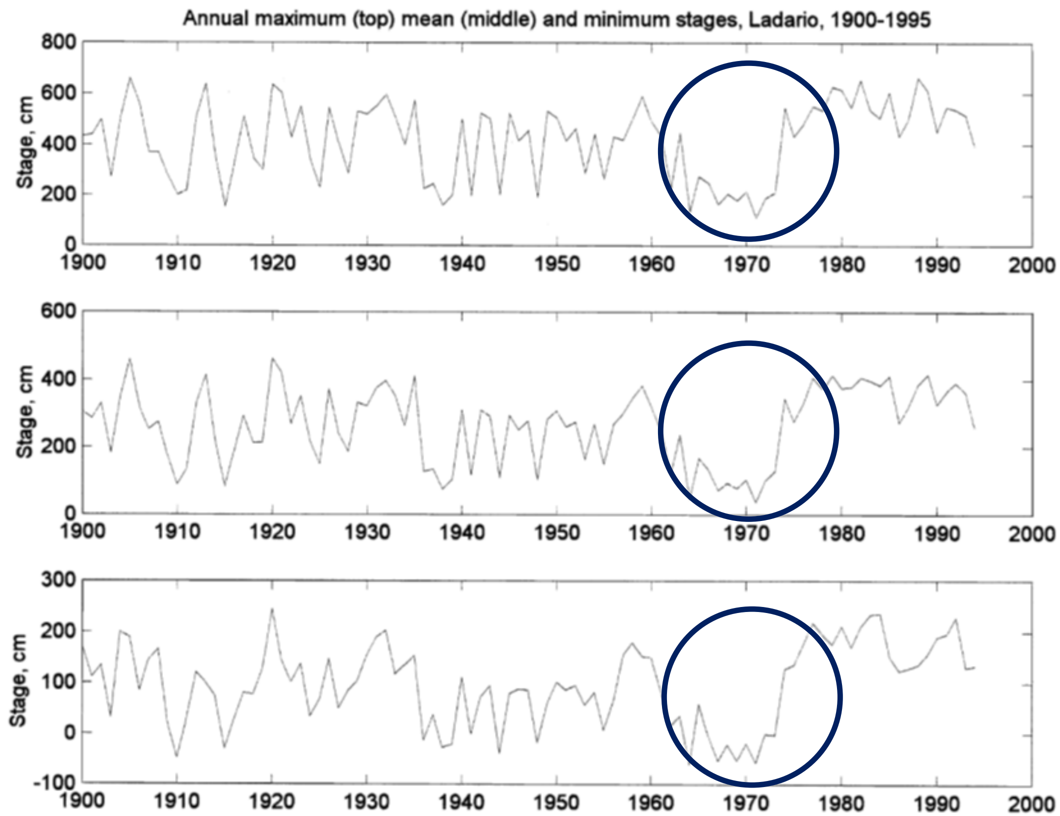
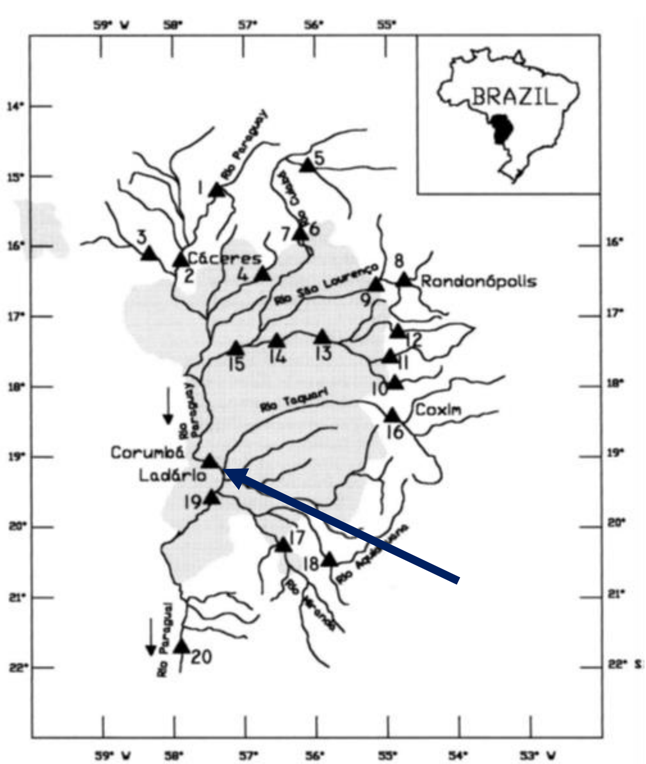


Fig. 3. River Paraguay at Ladario: annual maximum, annual mean, and annual minimum stages for the period 1900–1995.

Paraguay River at Ladário: 253 000 km²

Paraguay River (Collischonn et al. 2001, JH)



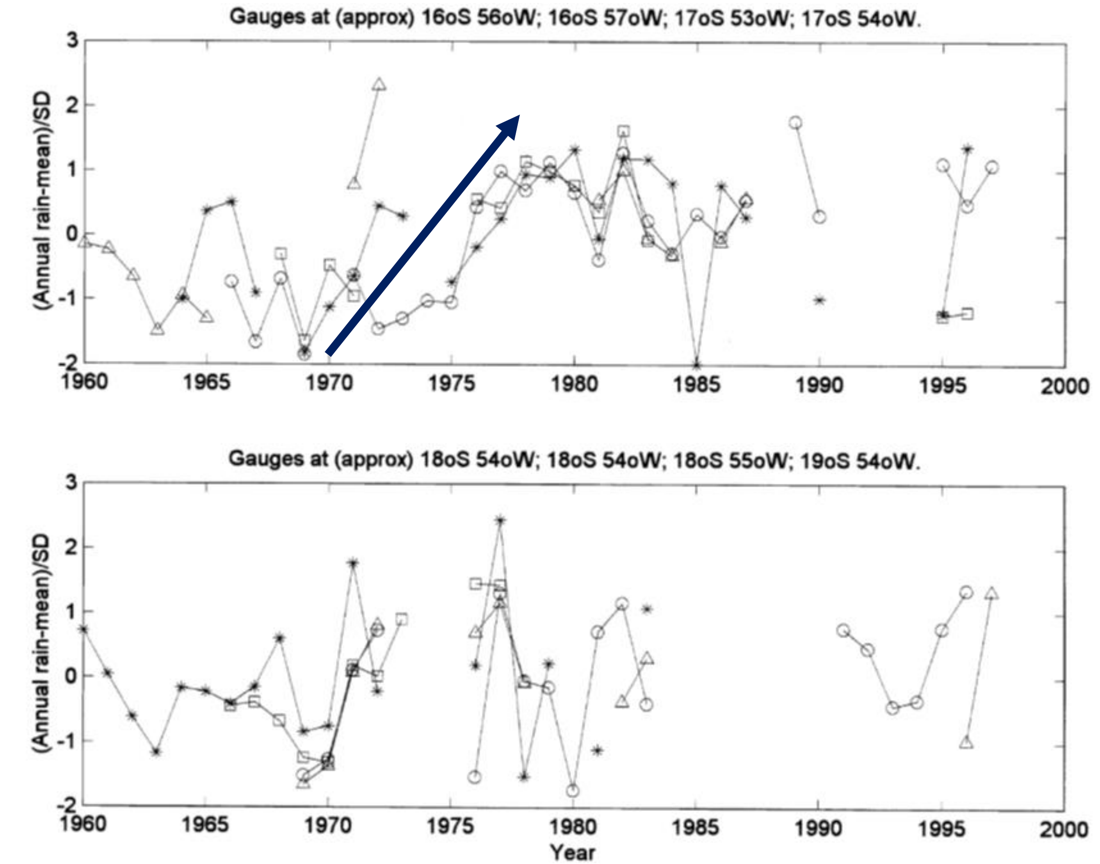
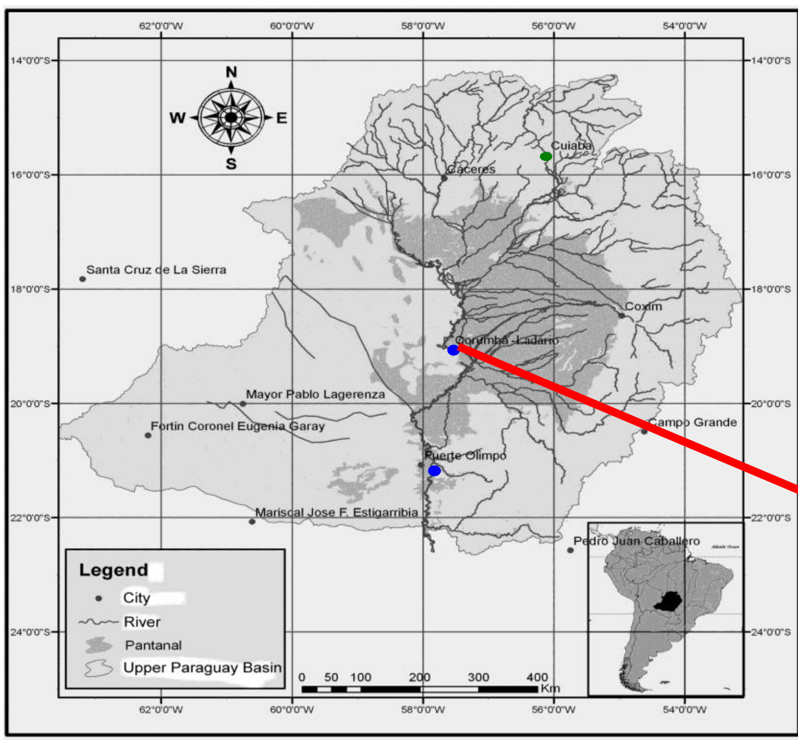


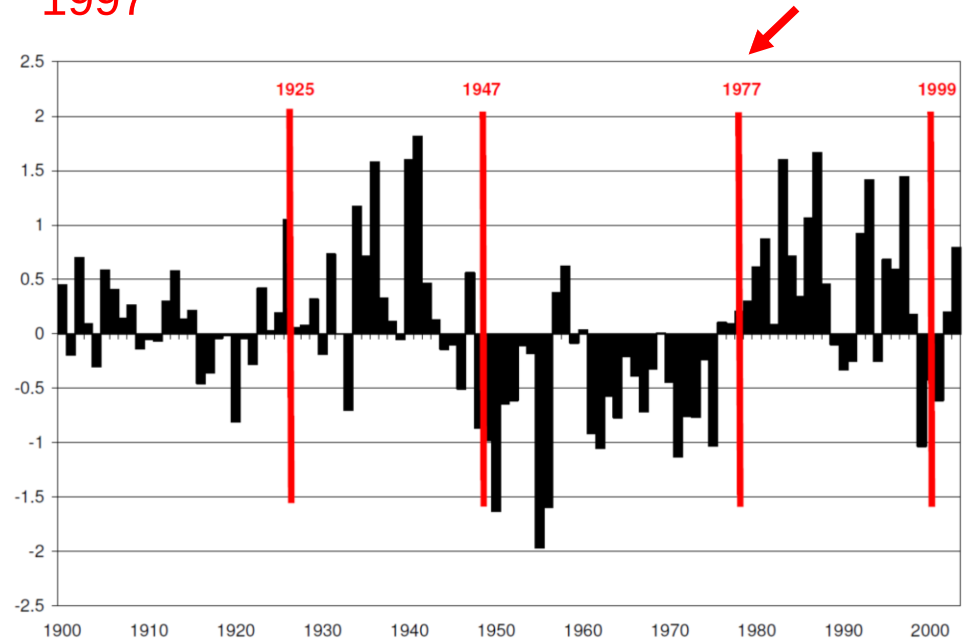
Fig. 9. Standardised mean annual rainfall: upper figure, gauges 16° S 56° W, 16° S 57° W, 17° S 53° W, 17° S 54° W (upper); gauges 18° S 54° W, 18° S 54° W, 18° S 55° W and 19° S 54° W (lower). Symbols for the gauges follow the sequence, triangle, square, star, circle.

"Despite the fragmentary nature in the 36 rainfall records, an explanation for the increase of flow since 1970 was found in the increase of rainfall…. "

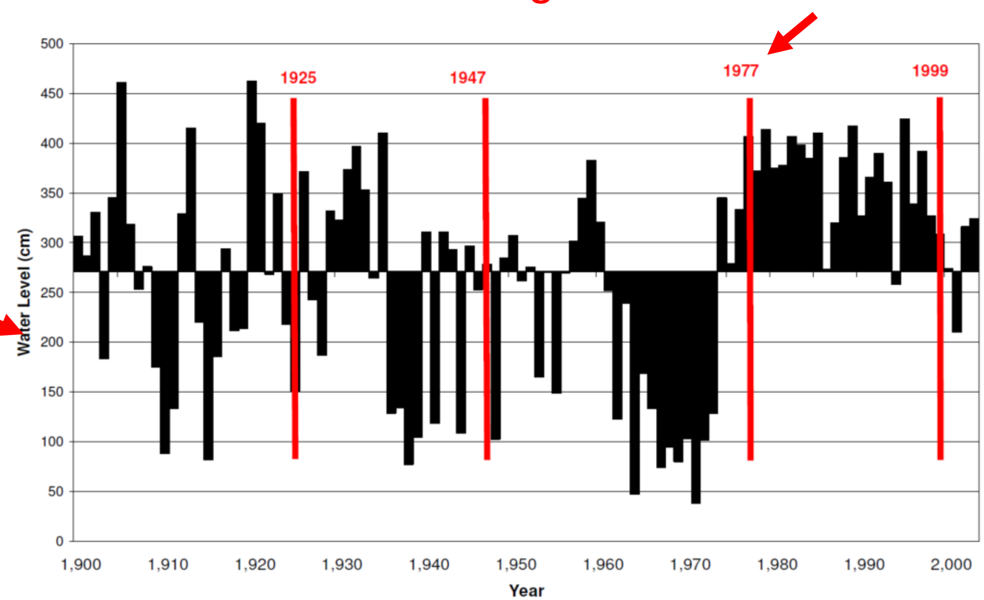
Interdecadal variability in the Upper Paraguay (Allasia, 2008)



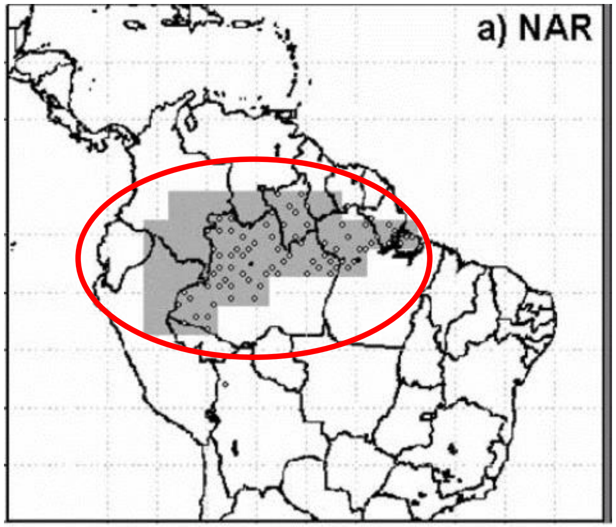
Pacific Decadal Oscillation (Mantua et al. 1997

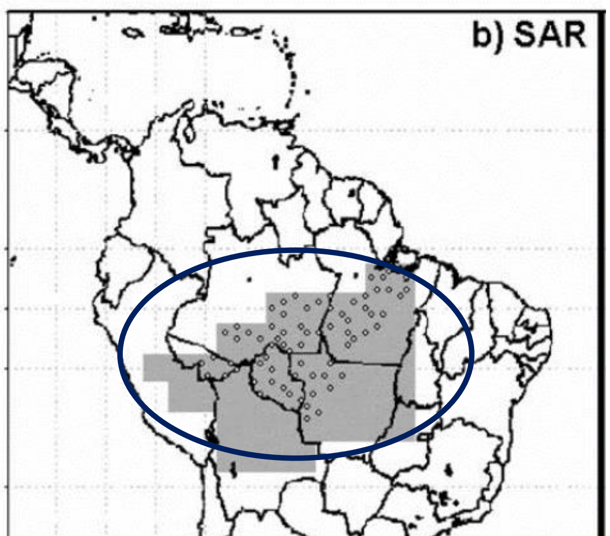


Normalized Water Stage at Ladário



Interdecadal variability in the Amazon (Marengo 2004,IJC)





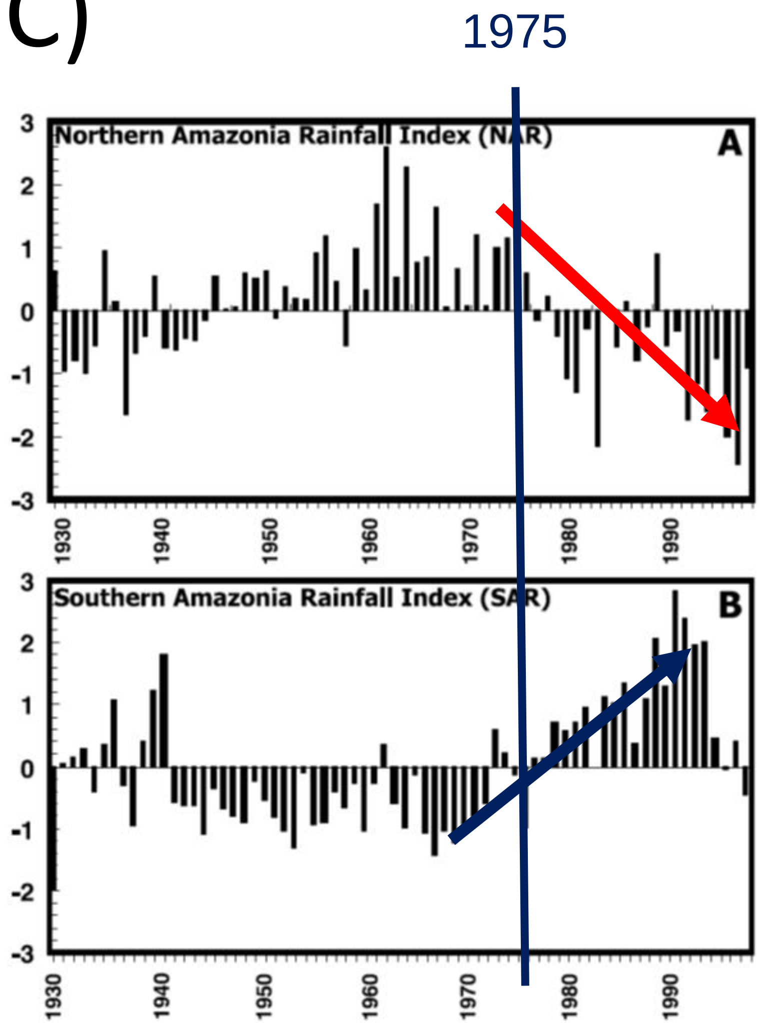


Fig. 3. Rainfall indices in northern (NAR) and southern Amazonia (SAR) from 1929/30 to 1998/99. Indices are expressed as departures normalized by the standard deviation, from the reference period 1949–1998

Interdecadal variability in the Amazon (Marengo 2004,IJC)

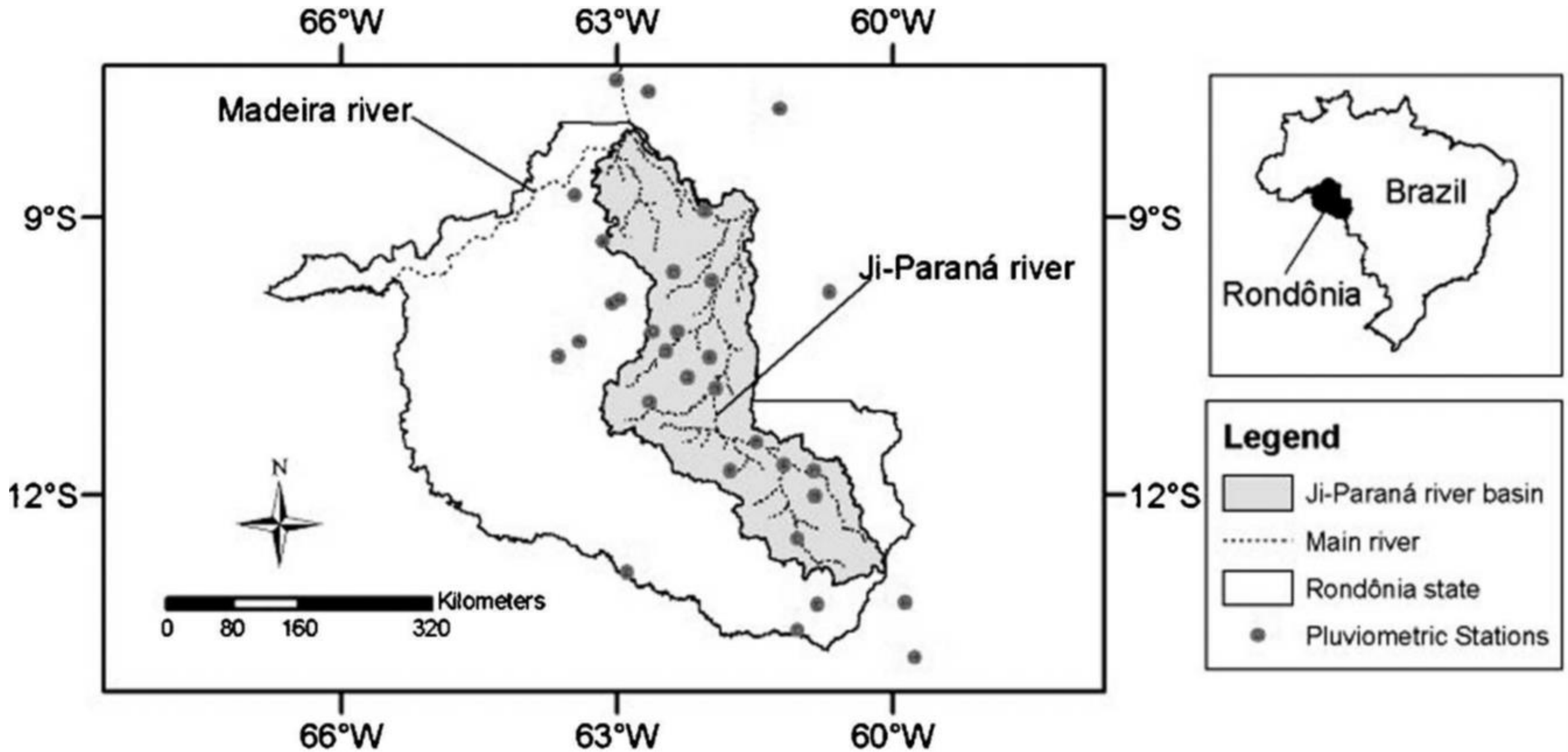
“The decadal analysis suggests shifts in Amazonian rainfall regime in the mid-1940s and the mid-1970s, where northern Amazonia had relatively wetter conditions during the 1945 to 1975, and relatively drier conditions between 1975 and 1998.”

“Variability in the SSTs of the tropical Pacific and Atlantic is likely to play an important role in driving the interdecadal variability in Amazonia’s rainfall.”

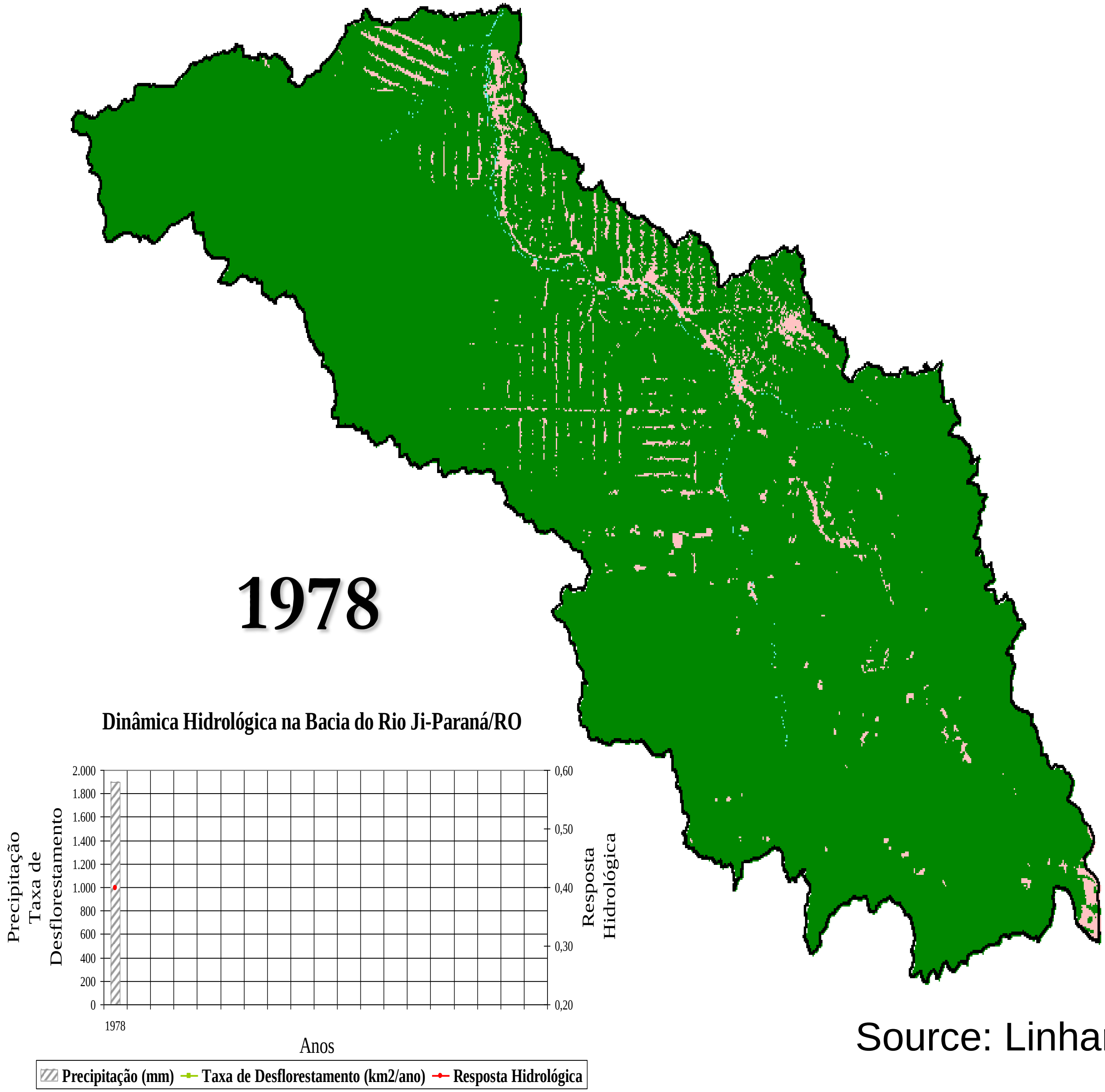
It is clear that basins contiguous to the Tocantins show indication of a shift in the interdecadal variability between 1975-1977 which resulted in an increased of rainfall

Therefore, it is likely to assume that most (perhaps all) of the trend observed in the Tocantins basins are associated to decadal variability rather than LUCC

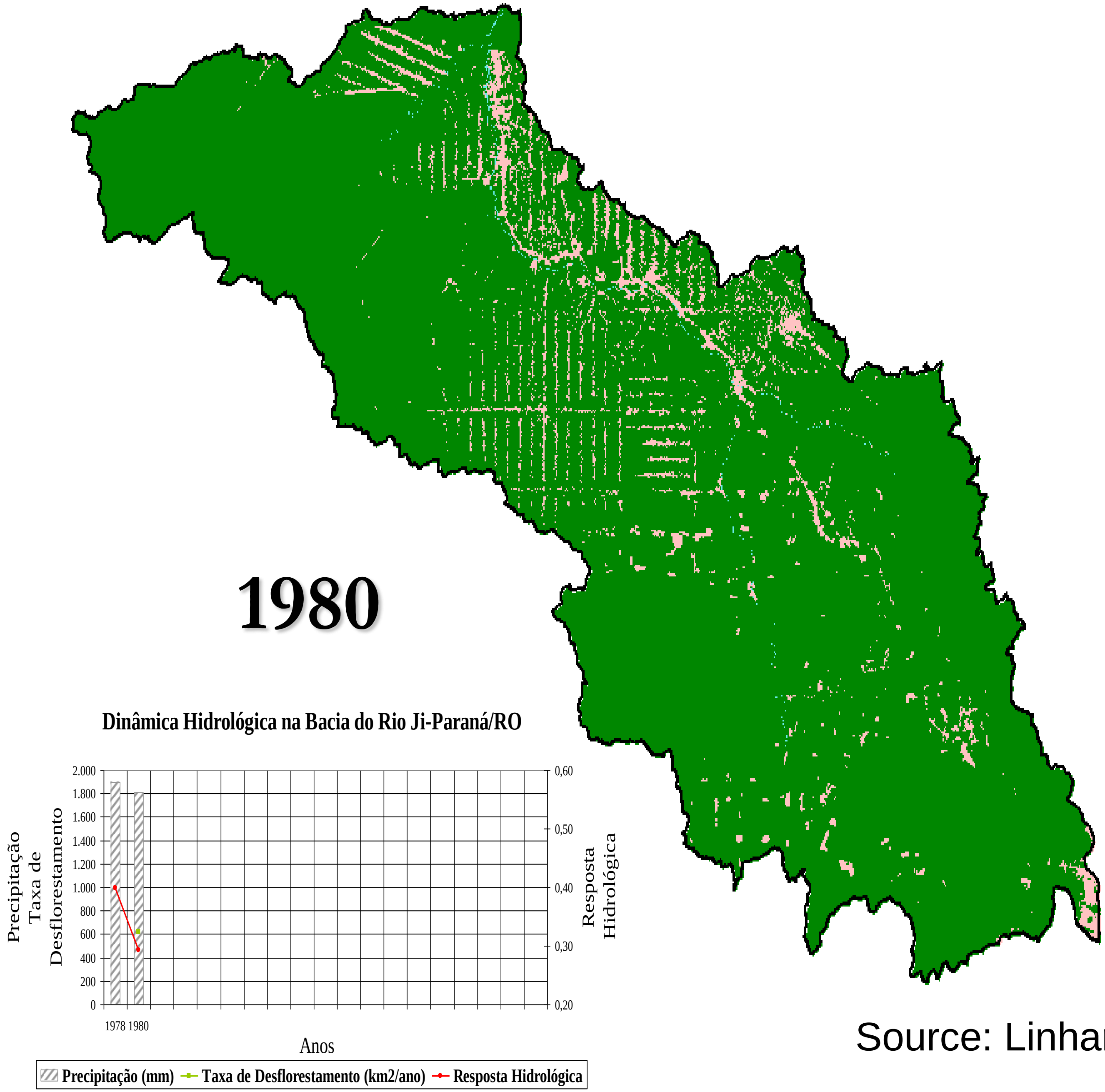
The Ji-Paraná River Basin



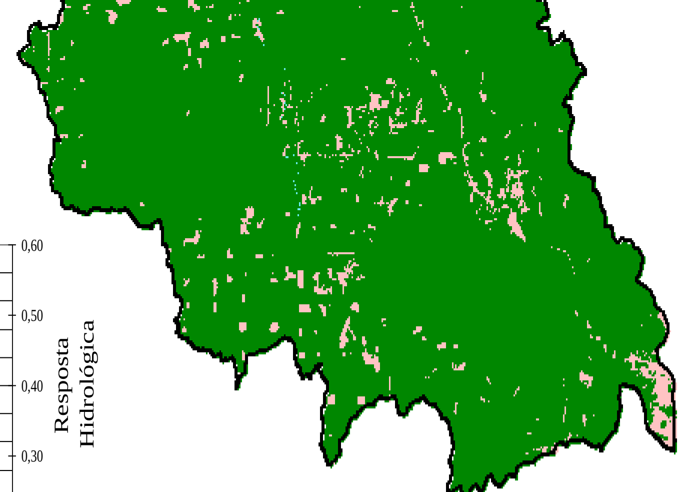
Ji-Paraná



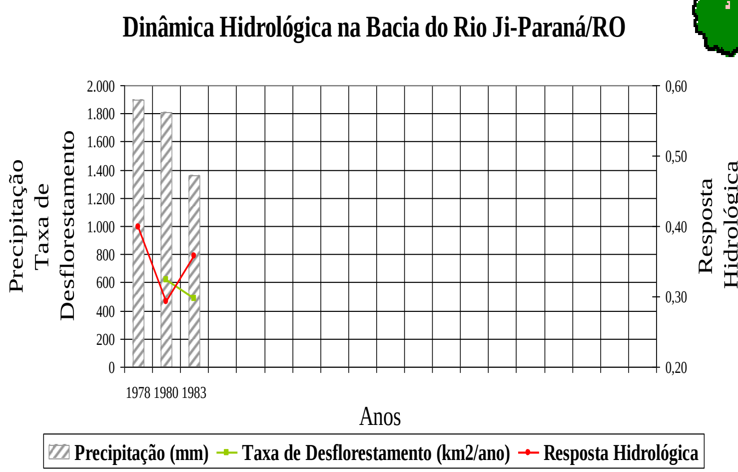
Source: Linhares, 2005



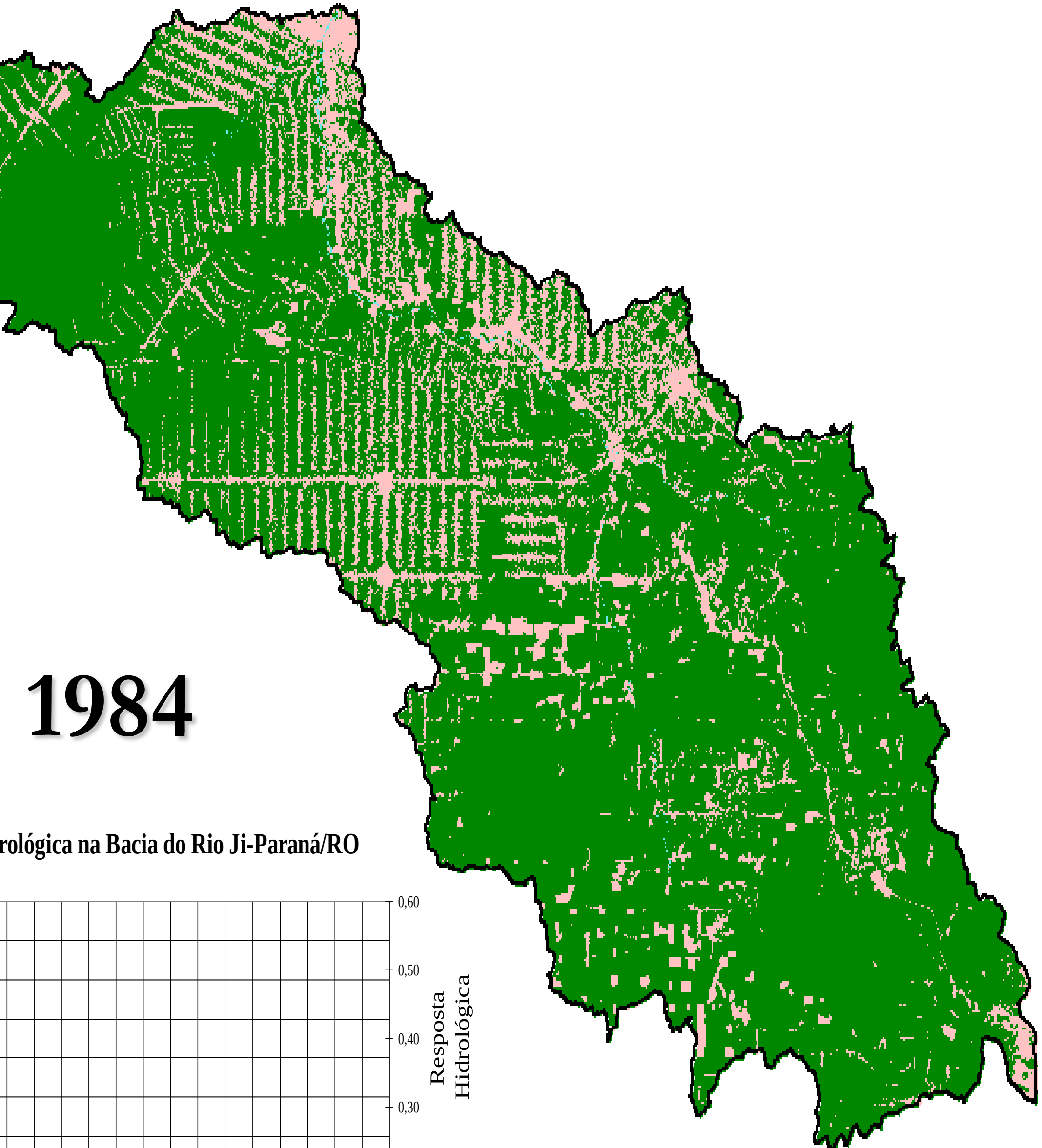
Source: Linhares, 2005

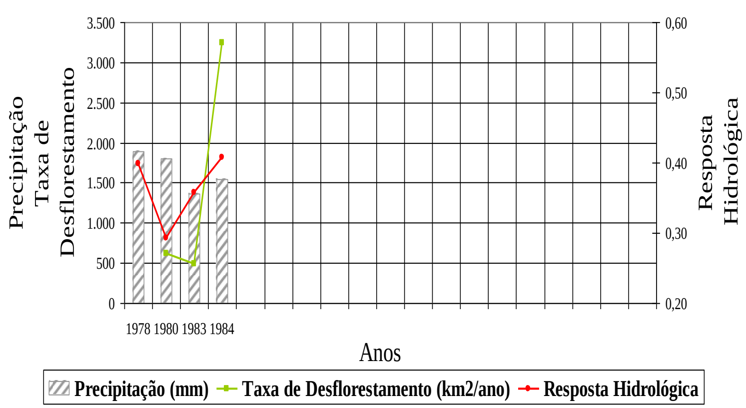
1983



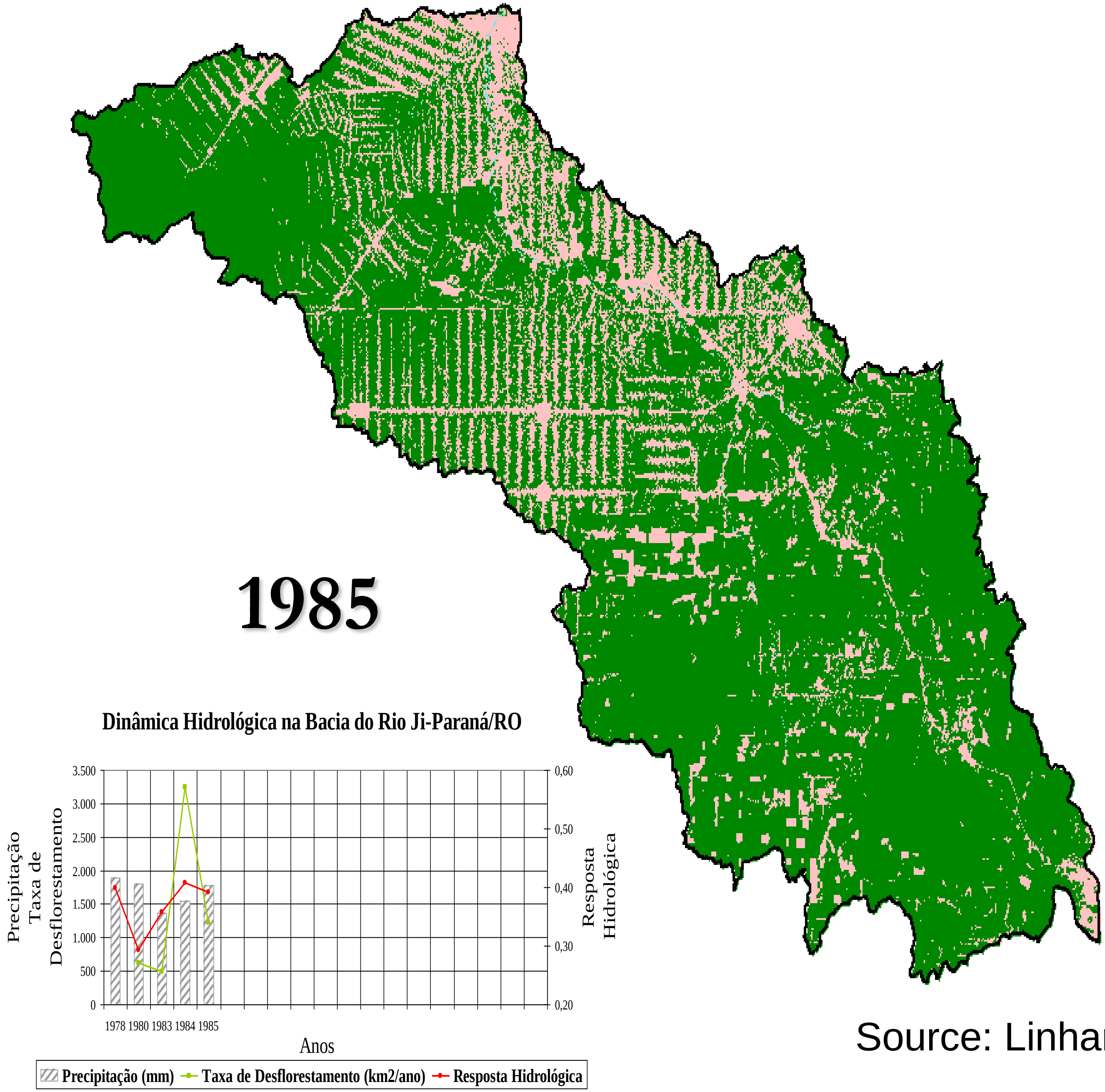
Source: Linhares, 2005



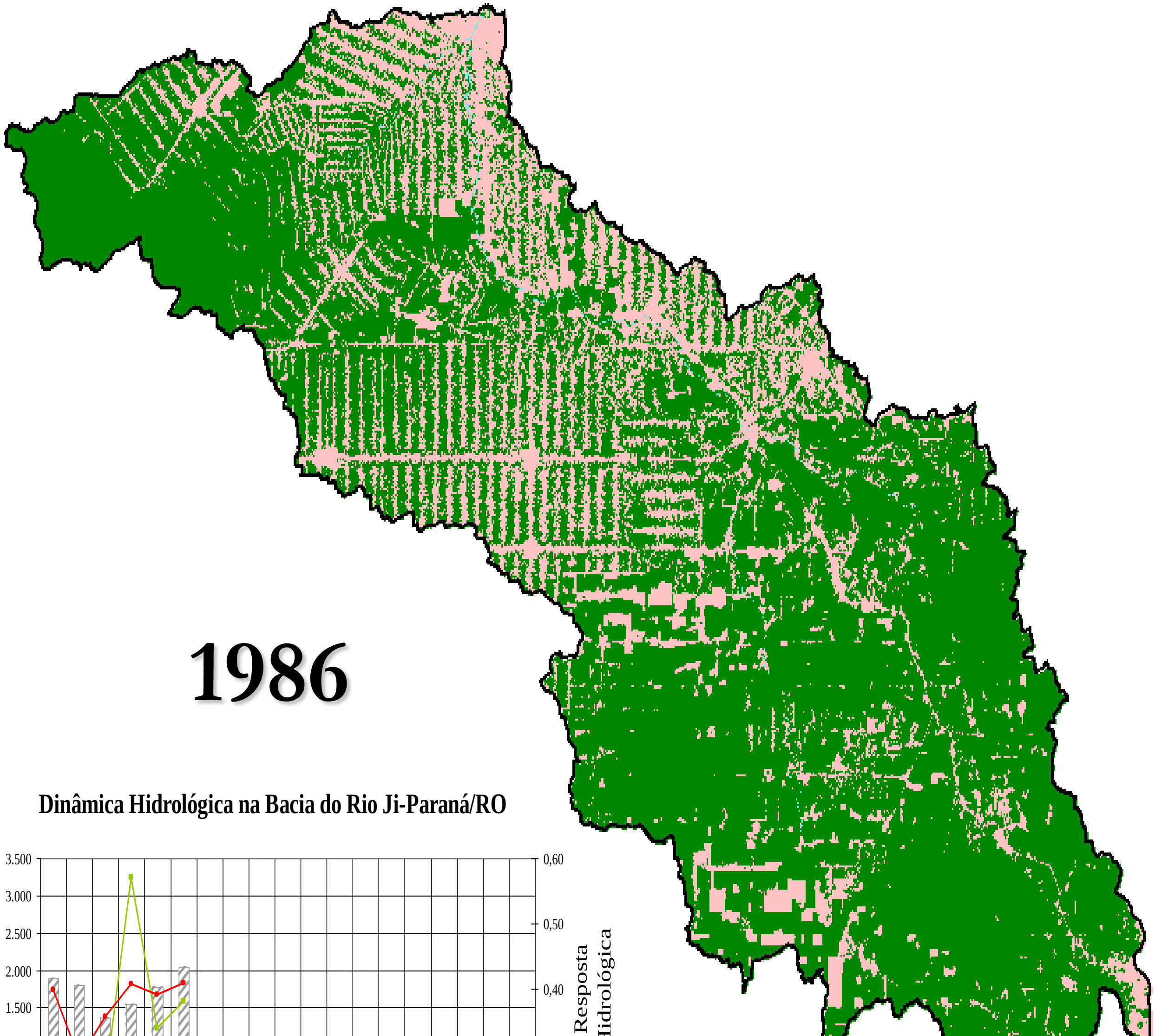
Dinâmica Hidrológica na Bacia do Rio Ji-Paraná/RO



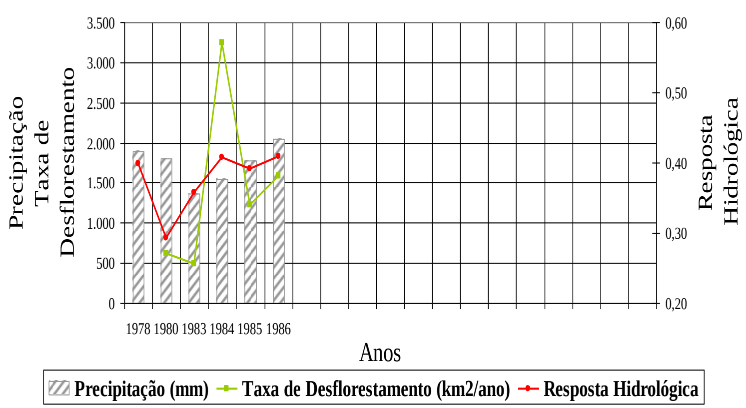
Source: Linhares, 2005



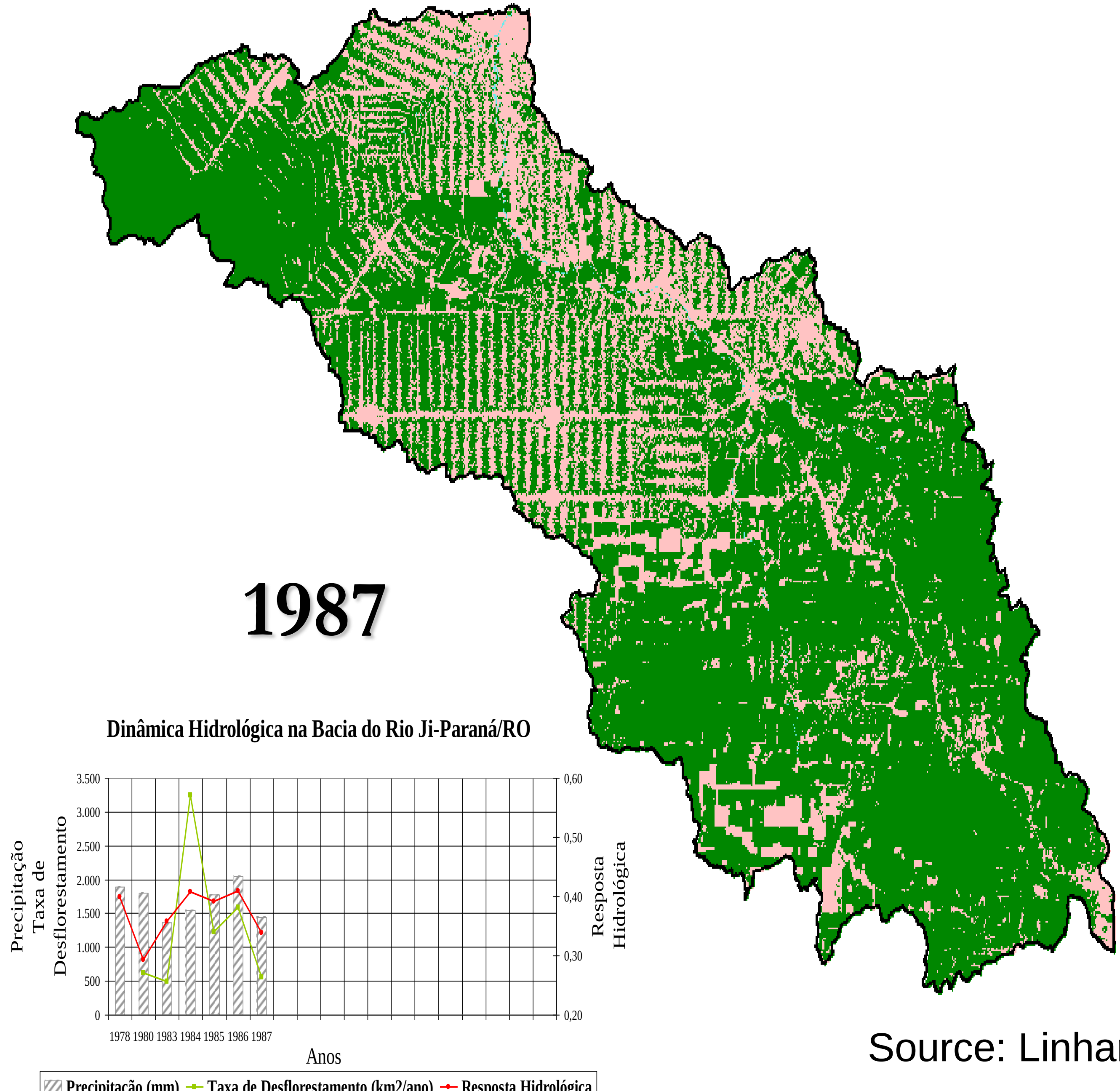
Source: Linhares, 2005



Dinâmica Hidrológica na Bacia do Rio Ji-Paraná/RO



Source: Linhares, 2005



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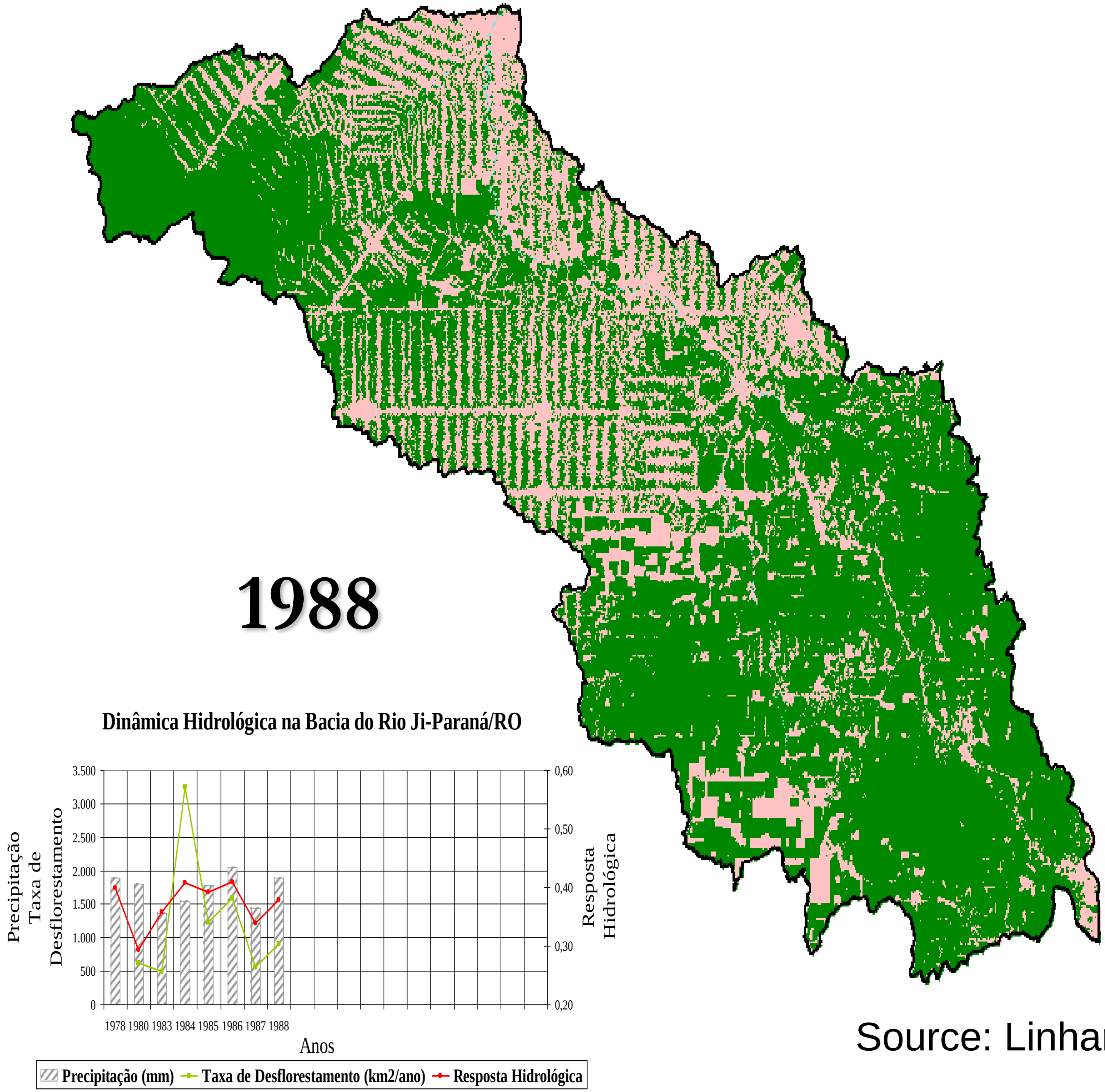
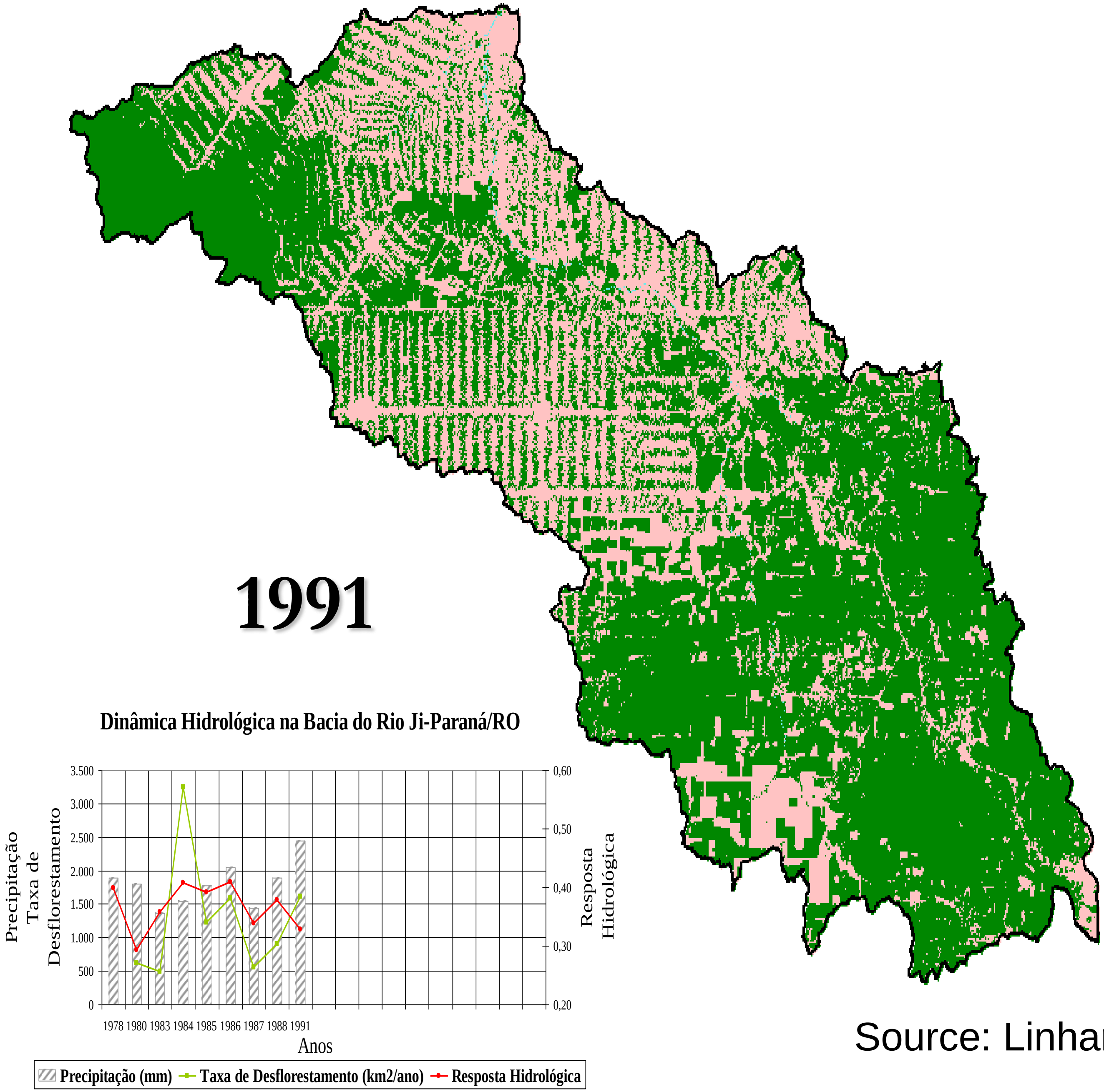
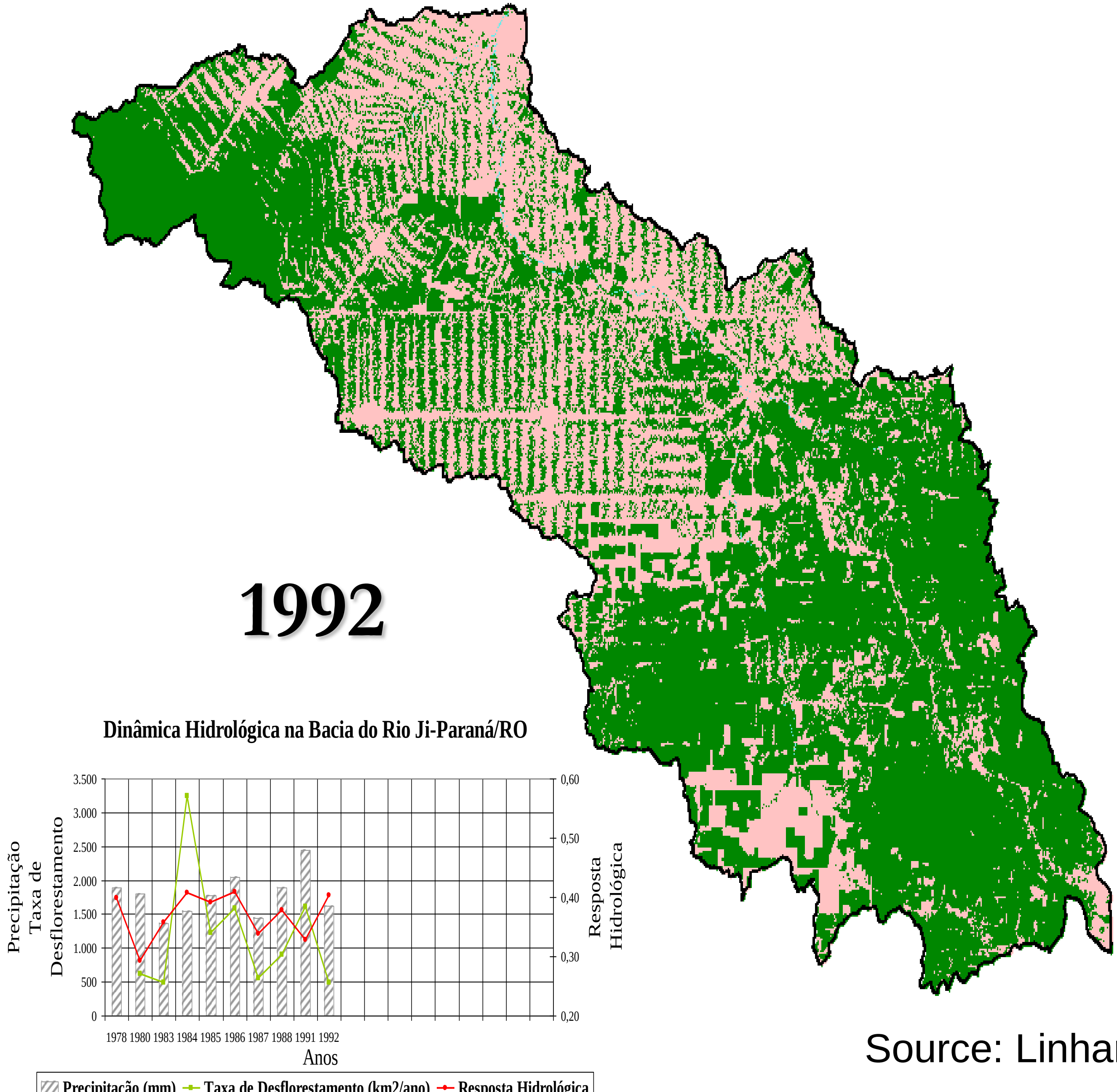


1988

Source: Linhares, 2005

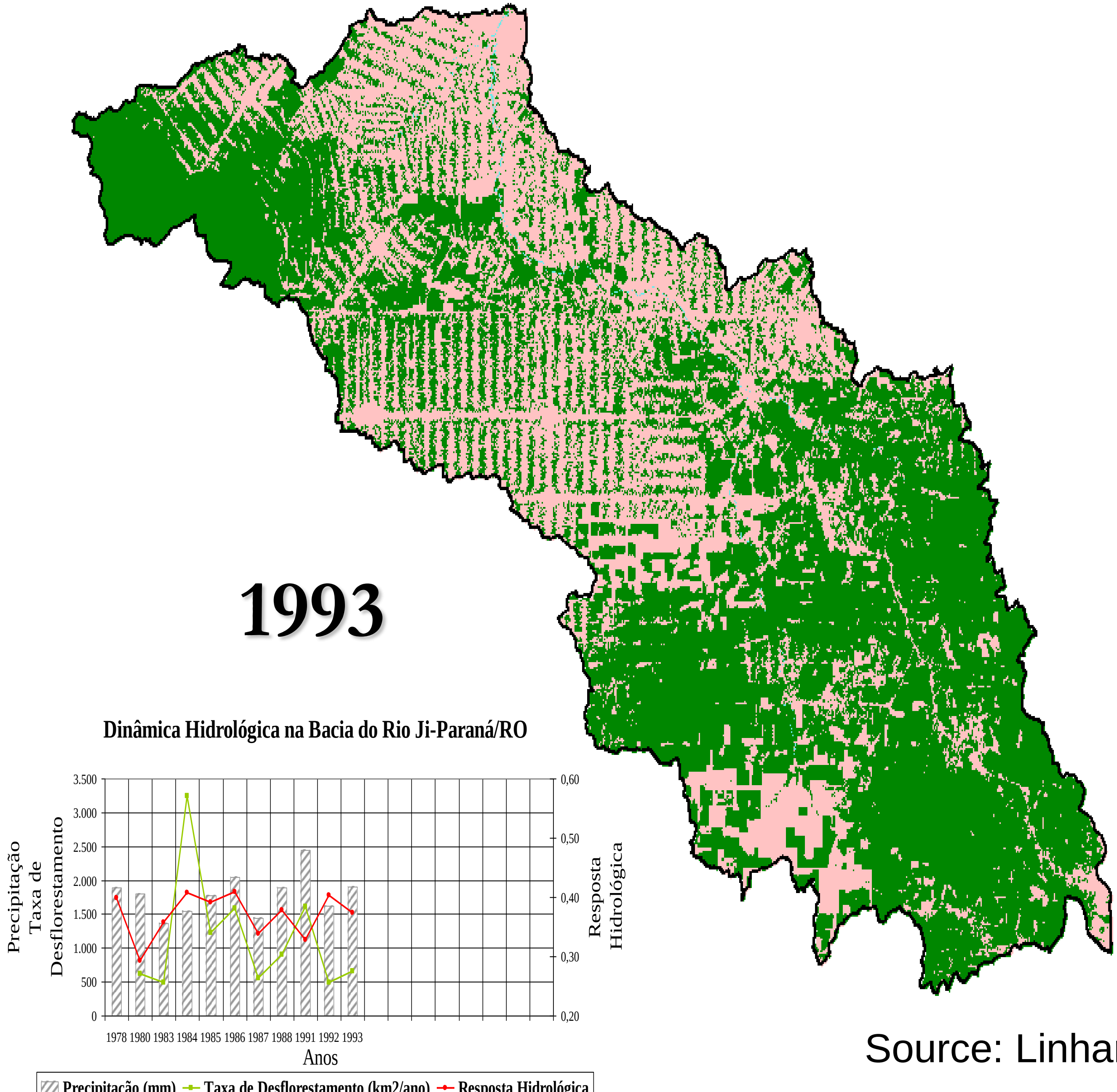


Source: Linhares, 2005

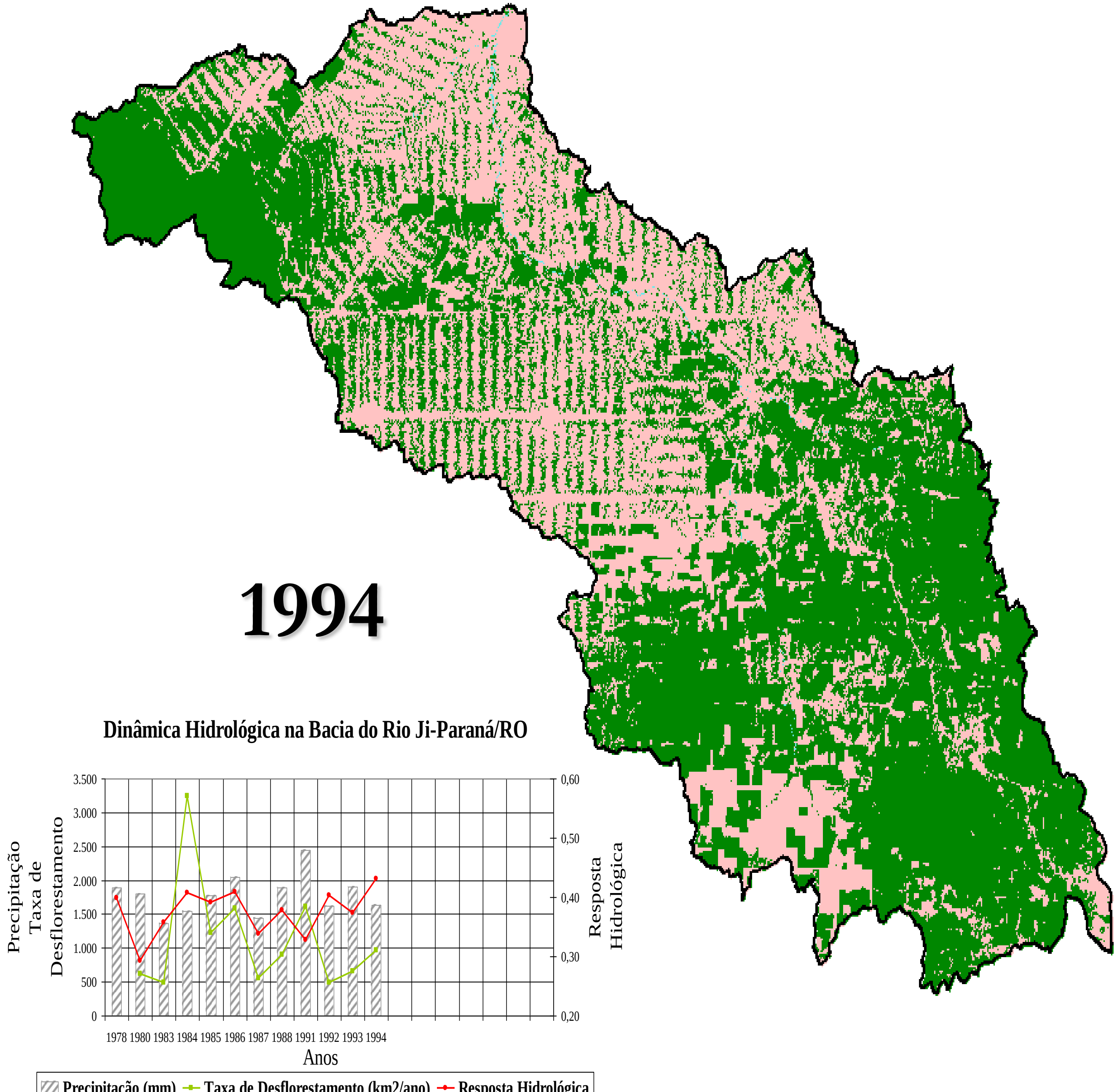


Source: Linhares, 2005

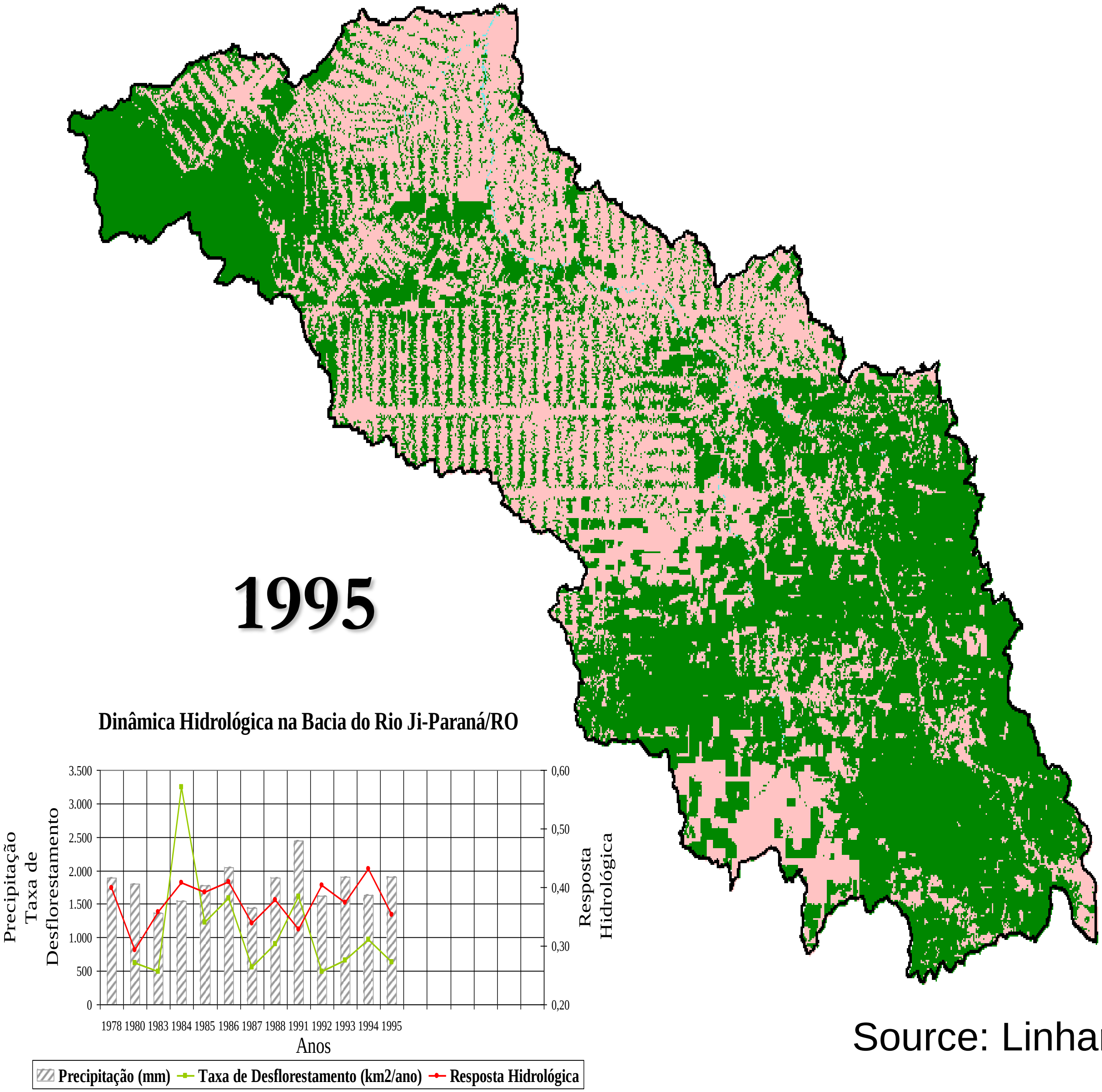
1993



Source: Linhares, 2005



1994
Dinâmica Hidrológica na Bacia do Rio Ji-Paraná/RO
Precipitação
Taxa de
Desflorestamento
3.500
3.000
2.500
2.000
1.500
1.000
500
0
0,60
0,50
0,40
0,30
0,20
Resposta
Hidrológica
1978 1980 1983 1984 1985 1986 1987 1988 1991 1992 1993 1994
Anos
Precipitação (mm)
Taxa de Desflorestamento (km2/ano)
Resposta Hidrológica

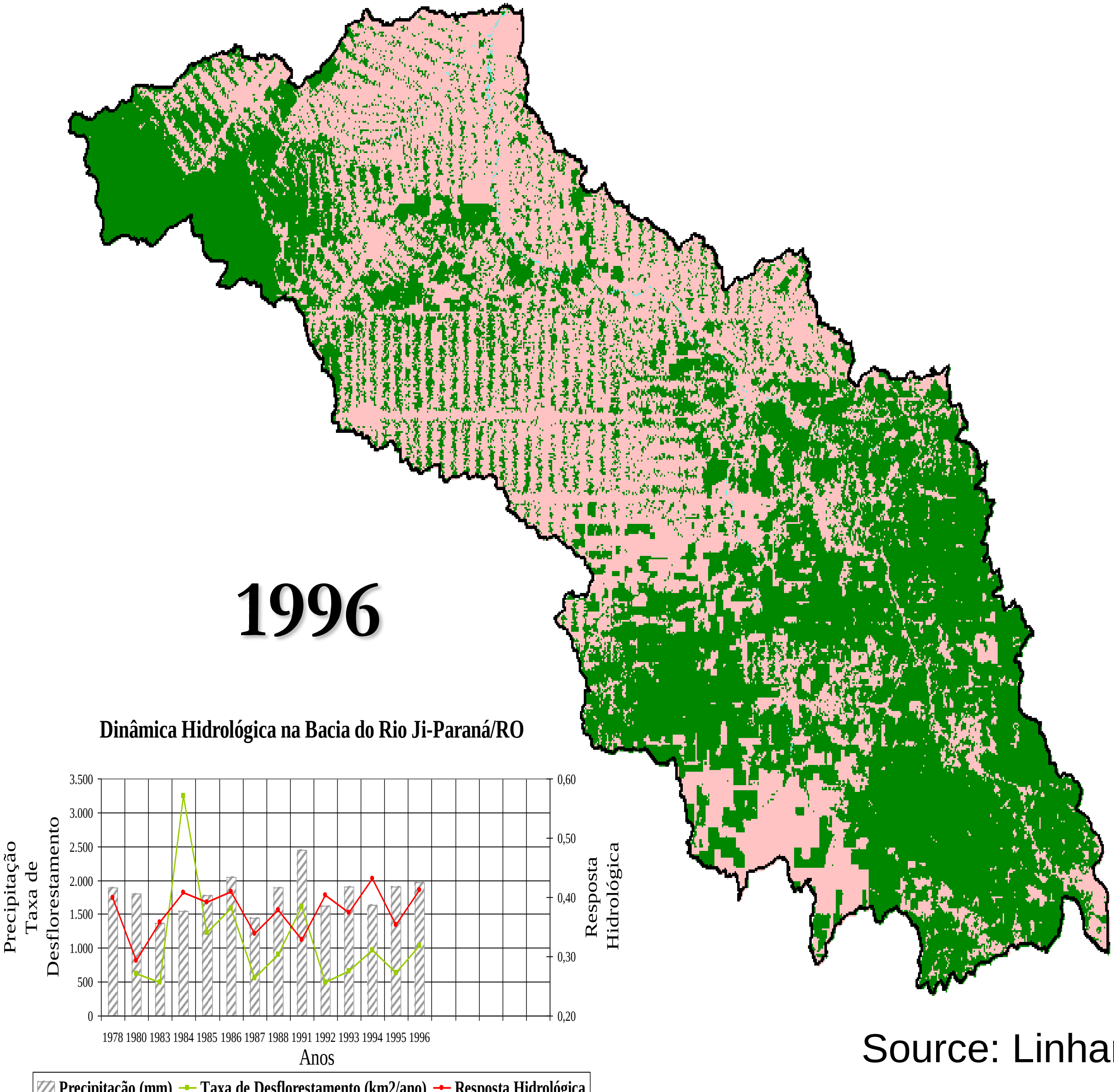


1995

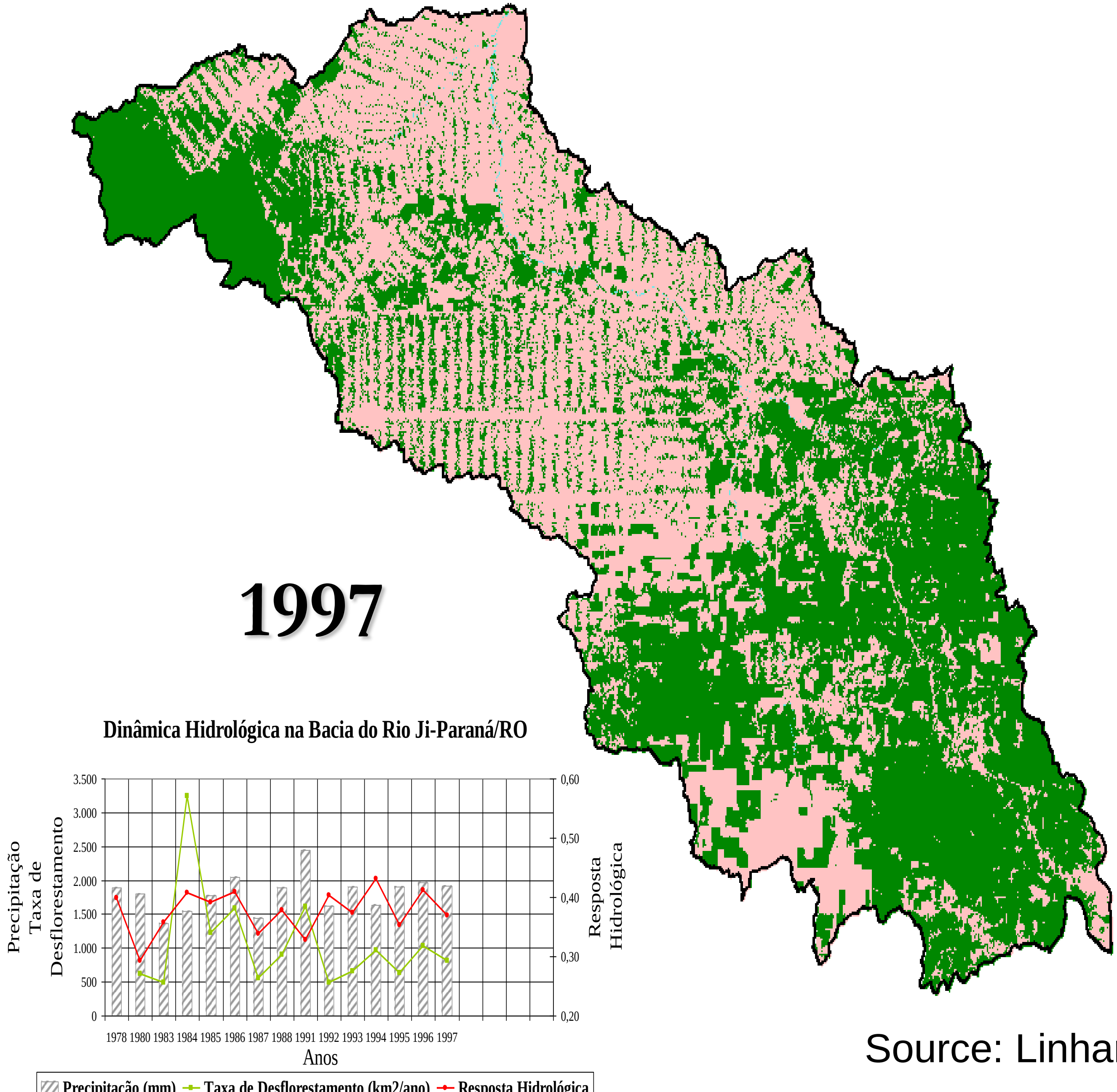
Dinâmica Hidrológica na Bacia do Rio Ji-Paraná/RO

Source: Linhares, 2005

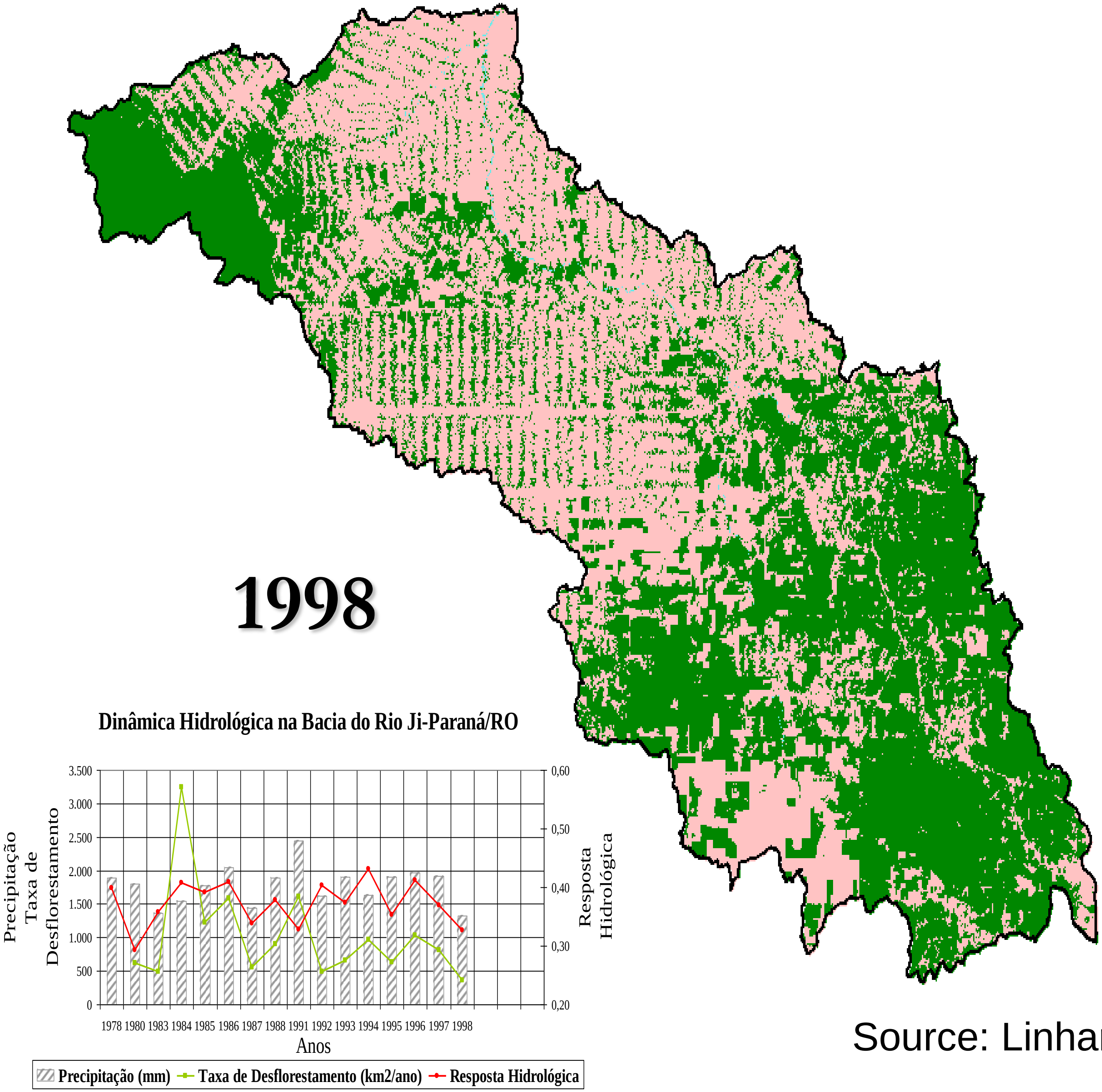
1996



Source: Linhares, 2005



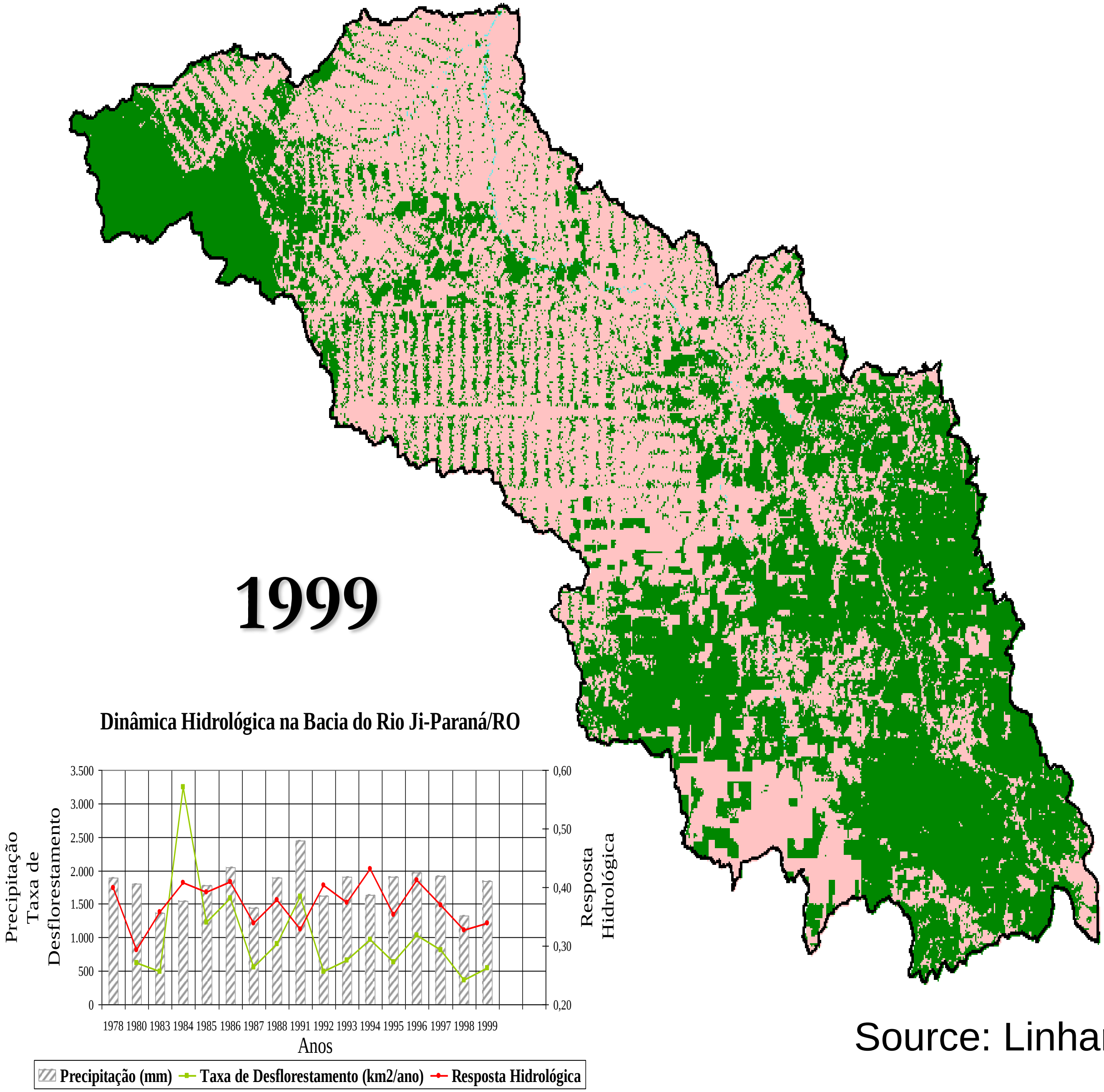
Source: Linhares, 2005



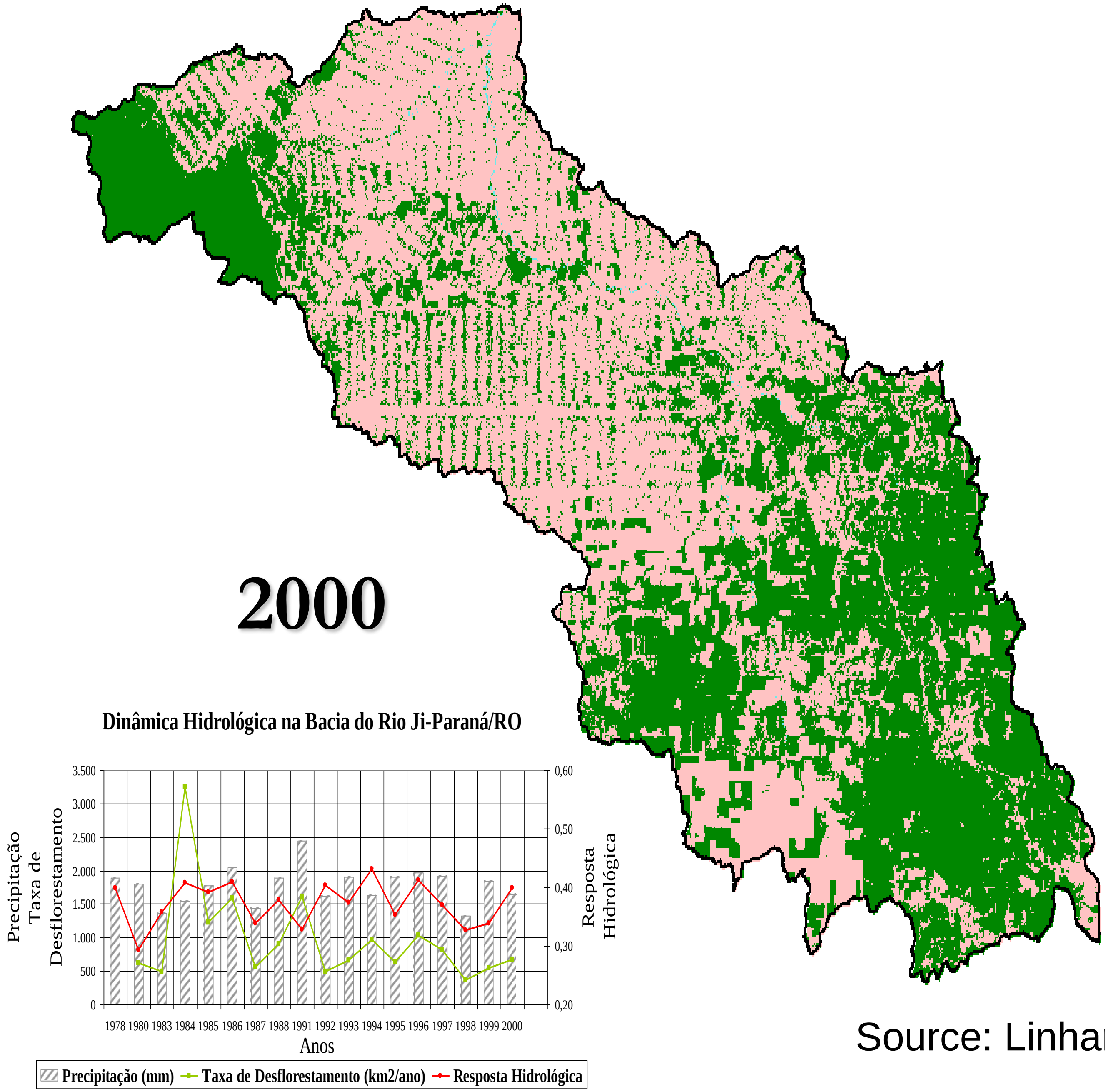
1998

Dinâmica Hidrológica na Bacia do Rio Ji-Paraná/RO

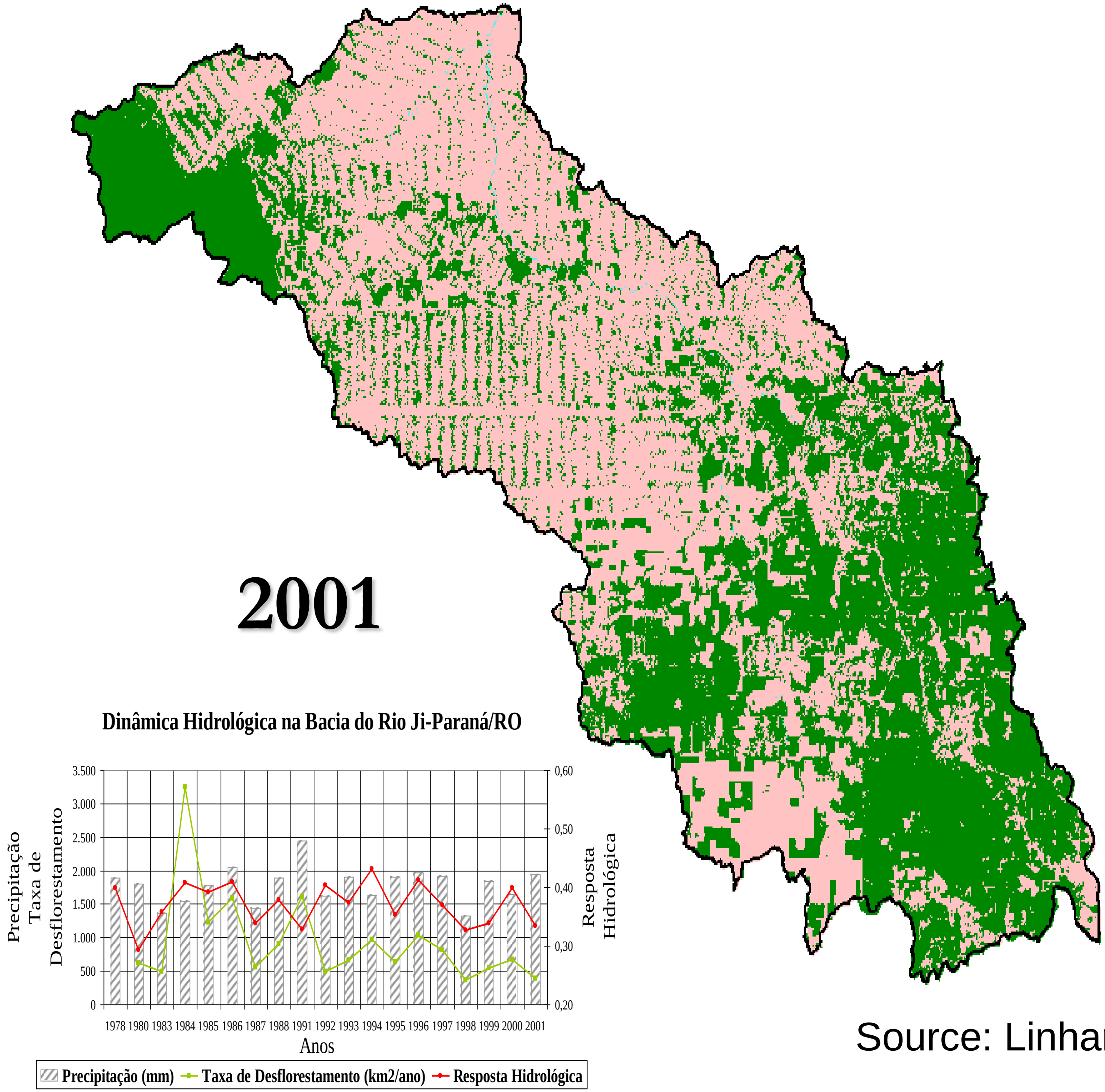
Source: Linhares, 2005



Source: Linhares, 2005

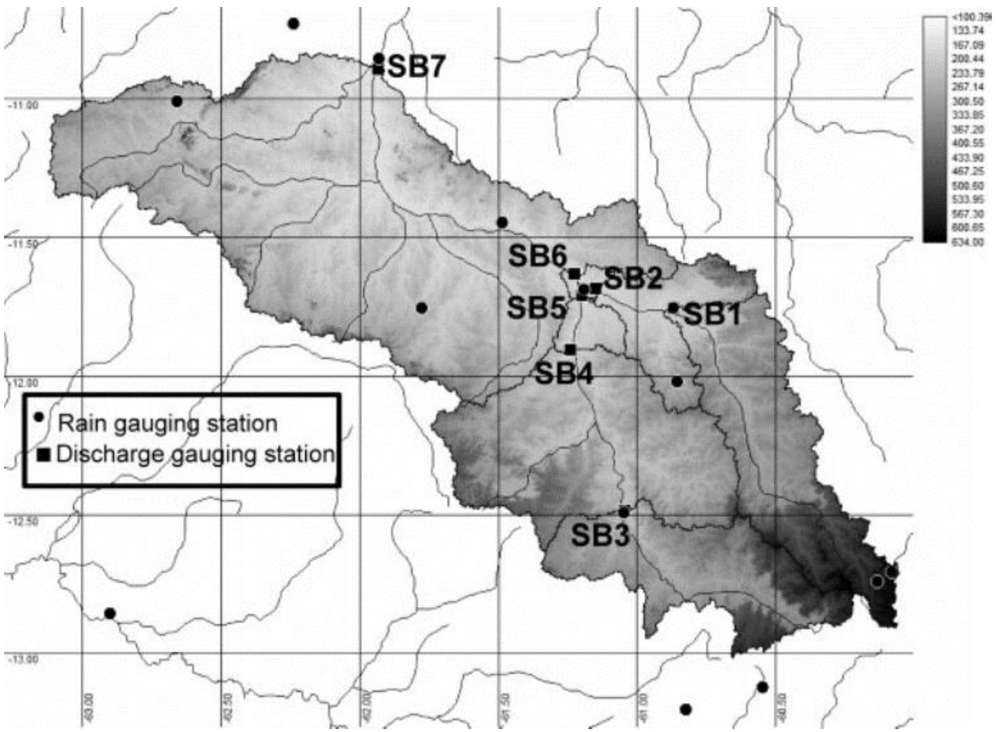


Source: Linhares, 2005



Source: Linhares, 2005

Ji-Paraná Basin (Rodriguez et al. 2010,HP)



Increased deforestation with the scale

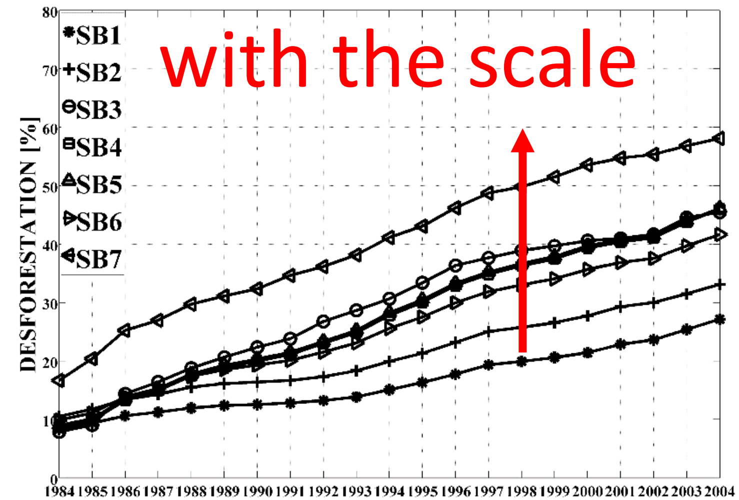
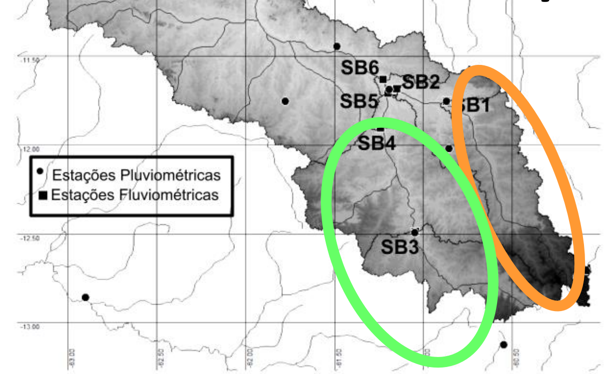


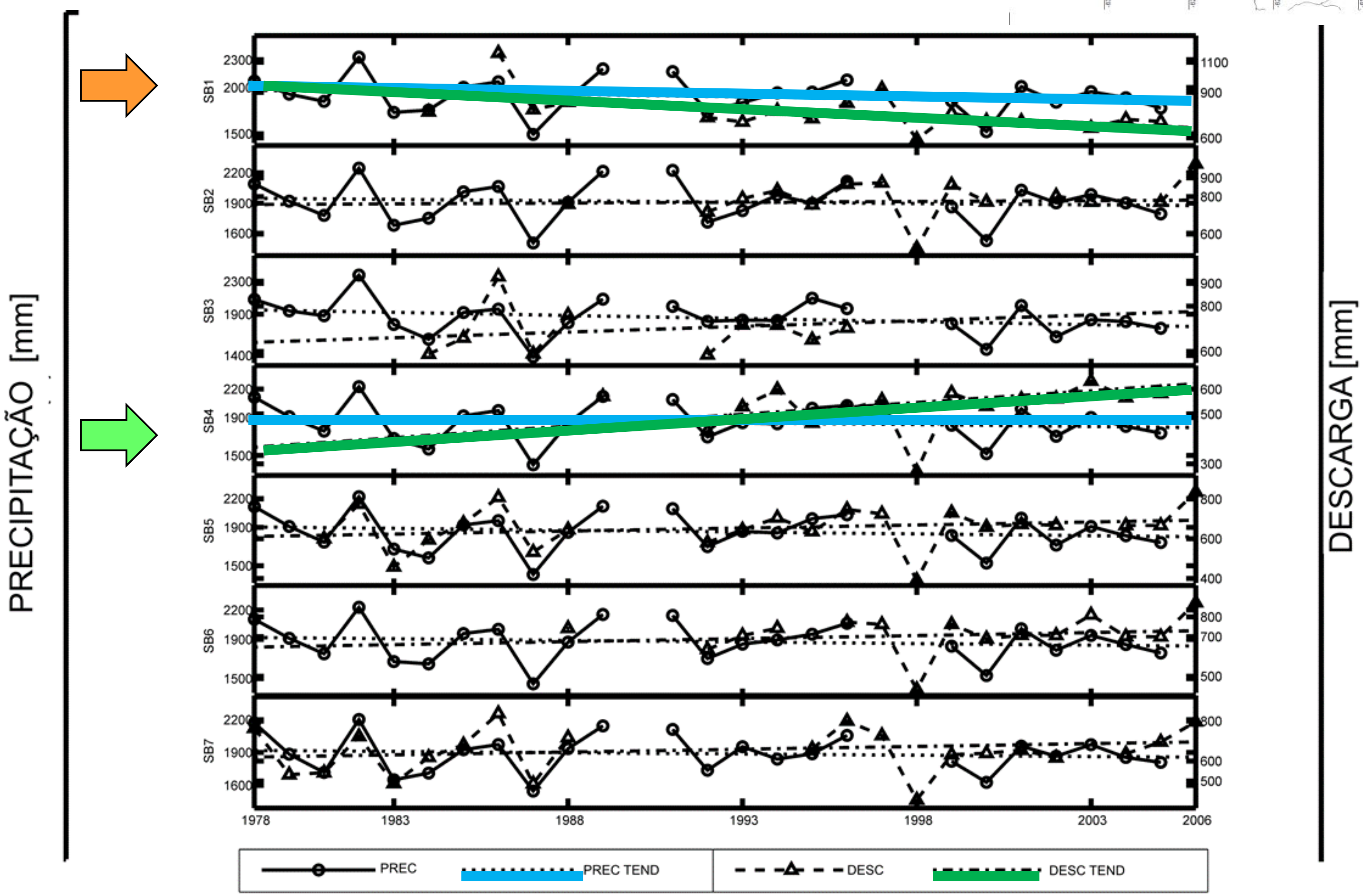
Table I. Streamflow gauge series: temporal coverage

BASIN	SB1	SB 2	SB 3	SB 4	SB 5	SB 6	SB 7
ST	Flor do Campo	Comemoração	Fazenda Expansão	PCH Primavera	Pimenta Bueno	Bela Vista	Ji-Paraná
LAT	−11·74	−11·67	−12·48	−11·9	−11·68	−11·62	−10·87
LON	−60·86	−61·18	−61·05	−61·24	−61·19	−61·22	−61·94
AREA [km^2]	4230	5940	3686	9705	10 114	16 092	33 012

Ji-Paraná Basin (Rodriguez et al. 2010,HP)

No significant trend in rainfall series





Analysis of the trends in dicharges

- Trends detected only in the small sub-basins
- Increase in the peak discharges and decrease in minimum flows
- Decreasing lag-times
- The response depends on the catchment topography

THE IMPACT DEPENDS ON THE SCALE

Basin	SB 1	SB 2	SB 3	SB 4	SB 5	SB 6	SB 7
Period	1991-2004	1990-1999	1991-1995	1991-2004	1990-2005	1995-2005	1993-2001
P02							
VMX	+						
P10				+			
UPQ							
AVG				+			
SLP							
MDN	-						
VAR				+			
SKW	+		-				
KUR	+						
LWQ	-	-			-		
VMN	-						
P90	-	-					
T07				-	-	-	
T15	-				-		
DEF	+	+	+	+	+	+	+
PD	+	+		+	+	+	+
ED	+	+		+	+	+	-

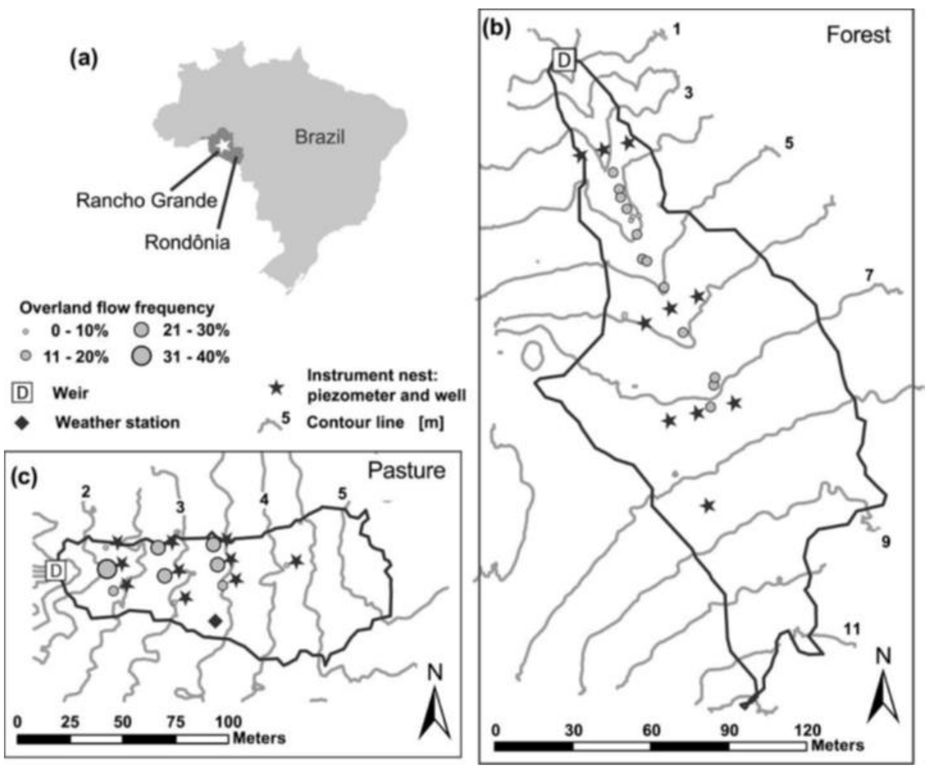
Are there thresholds?

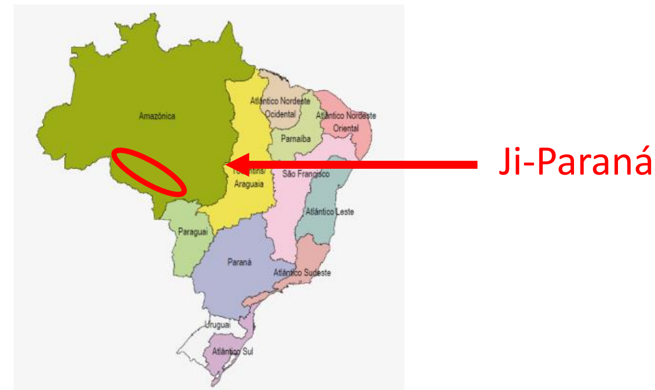
Blosch et al., 2007

Hamilton, 1990 Wilk et al., 2001

Consistently with these results, signals of LUCC can also be detected in micro-scale catchment studies

Rancho Grande paired catchment study (Germer et al. 2010,JH)





Adjacent forest (1.37 ha) and pasture (0.73 ha) catchments approximately 400 m apart.

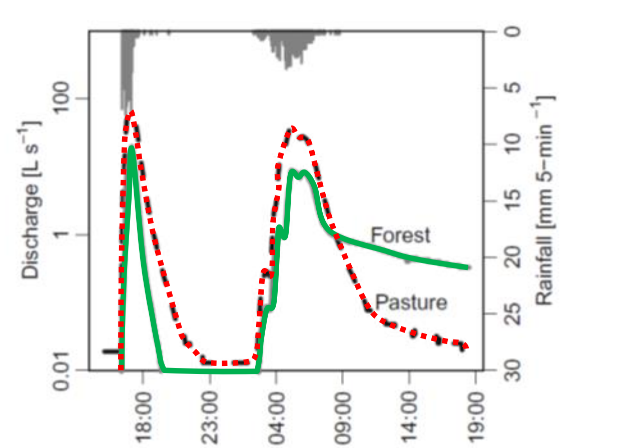


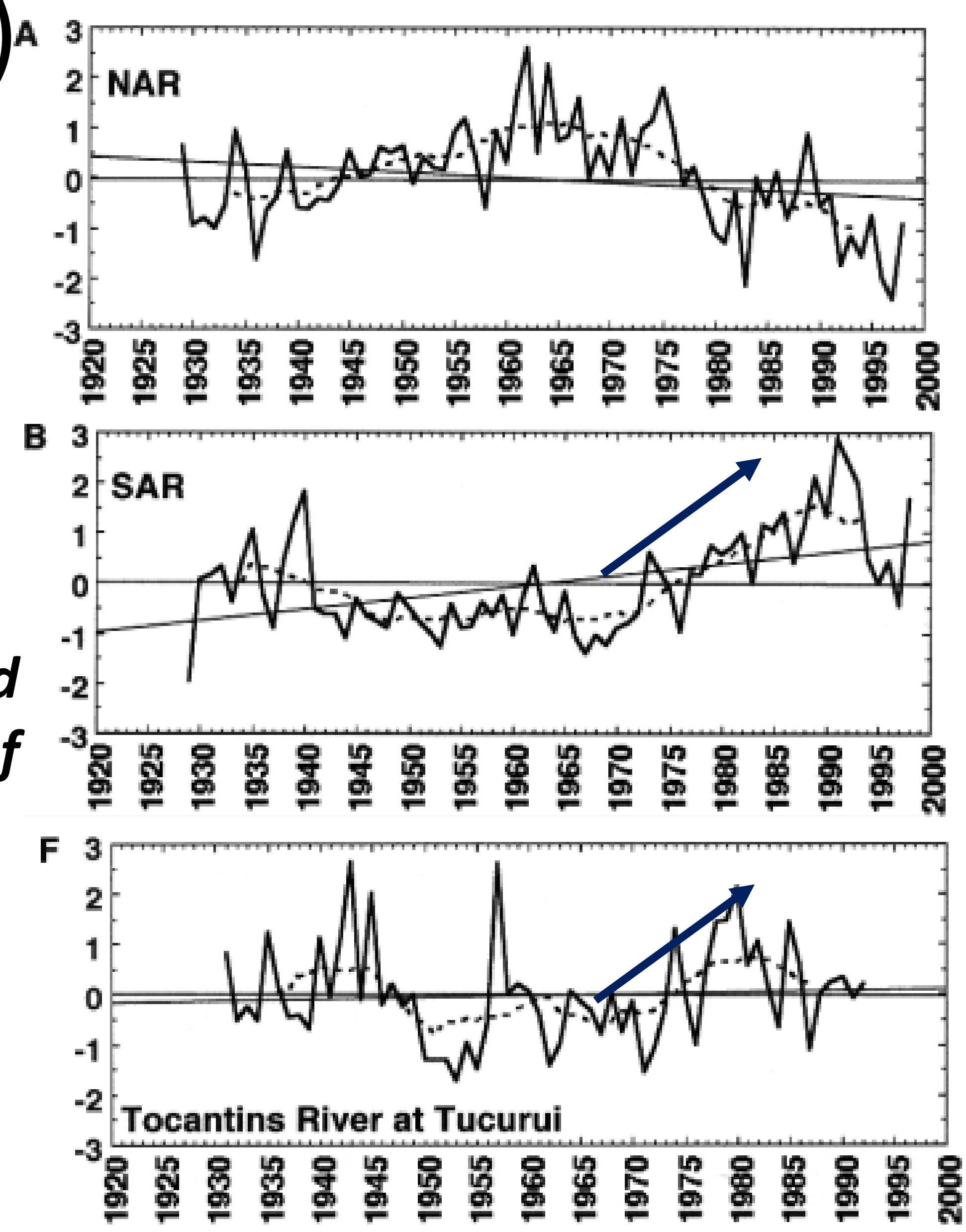
Fig. 7. Comparison of forest (grey solid line) and pasture (black dashed line) stormflow hydrographs for a rainfall event on March 5–6, 2005. Discharge is plotted on a logarithmic scale to show small flow differences more clearly. Bars in the top of the figure indicate 5-min rainfall sums.

And what happen at the Amazon wide scale?

Whole Amazon Basin, for instance Marengo. (2009, HP)

"Since 1929, long-term tendencies and trends have been detected in a set of regional-average rainfall time series in the Amazon basin and supported by the analysis of some river streamflow time series.

These long-term variations are more characteristic of decadal and multi-decadal modes, indicators of natural climate variability, rather than any unidirectional trend towards drier conditions(as one would expect, due to increased deforestation or to global warming)"



How unique are those results found in the Ji-Paraná basin?

Detecting changes in streamflow after partial woodland clearing in two large catchments in the seasonal tropics

Jorge L. Peña-Arancibia [a,b,c,*], Albert I.J.M. van Dijk [a], Juan P. Guerschman [a], Mark Mulligan [b], L. Adrian (Sampurno) Bruijnzeel [c], Tim R. McVicar [a]

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In the Comet catchment, findings from a simple coupled water–energy balance framework suggested that most of the observed changes in annual streamflow were related to climate variability. However, the period immediately after clearing showed an increase in interannual streamflow that suggested a decrease in interannual evapotranspiration associated with LUCC. An overall increase in annual streamflow in the post-LUCC period (1971–2007) was mainly attributed to higher than average rainfall linked to La Niña conditions in the wet 1970s. Results from applying a Budyko-type model to assess changes in evapotranspiration efficiency for pre- (1920–1953) and a climatically similar post-LUCC (1979–2007) showed a slight decrease in evapotranspiration of 3.1–3.8% with negligible (i.e. 1%) increase in streamflow. Likely causes for

However, this is not the case for all meso-scale basins in the tropics

Studies and methodologies implemented to investigate the effects of land use/land cover change (LUCC) on streamflow in large (>10,000 km^2) tropical catchments. Methods refer to: TSA, time-series analysis; MOD, modelling.

Catchment (Country)	Area (km^2)	Forest cover change (%)	Period pre- and post-LUCC	Method(s)	Effects on streamflow (% change)	Reference
Pasak River (northern Thailand)	14,500	−50	1955–1980[a]	TSA	No change	Dyhr-Nielsen (1986)
Citarum River (west Java, Indonesia)	4133	−50	1922–1929 1979–1986	TSA, MOD	Increase (11%)	Van der Weert (1994)
Tocantins River (central Brazil)	767,000	−19	1949–1968 1979–1998	TSA, MOD	Increase (24%)	Costa et al. (2003)
Nam Pong River (north-eastern Thailand)	12,100	−63	1957–1965 1969–1995	TSA, MOD	No change	Wilk et al. (2001)
Comet River (central Queensland, Australia)	16,440	−45	1920–1949 1970–2000	TSA, MOD	Increase (40%)	Siriwardena et al. (2006)
Ji-Paraná (southwestern Amazonia, Brazil)	33,012	−50	1978–2000[b]	TSA	No change	Linhares (2005) and Rodriguez et al. (2010)
Pearl river and East, North and West Rivers (Guandong Province, China)	179,752	+37	1965–1986 1993–2006	TSA	No change	Zhou et al. (2010)

[a] No distinctive pre- and post-LUCC periods.
[b] No distinctive pre- and post-LUCC periods but transitory changes of LUCC and streamflow.

Peña-Aranciaba et al. (2012)

In conclusion:

At small scales (< ~500 km^2), signals of LUCC can be clearly detected

At the meso scale (~10 Thousand km^2), the detection of signal is sometimes contradictory, mainly because of the interdecadal varibility

At the large scales (millions of km^2) signals of LUCC are not detectable

However…….

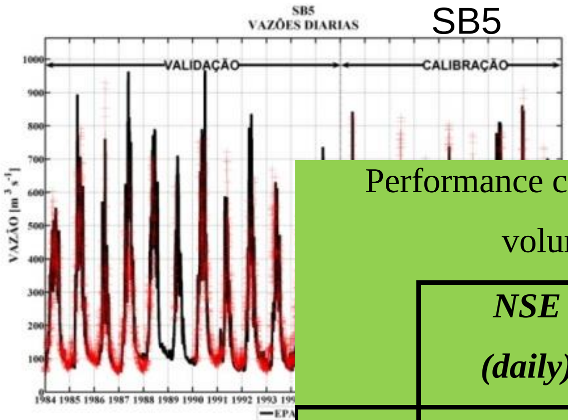
Although the impacts of LUCC at local-scale appear to be “diluted” at larger scales, it is likely to assume that there are “threshold values” of disturbance (or “tipping points”) when the local-scale signals become significant at large scales.

Probably, the basin capacity to attenuate the effect of local disturbance depends on a unique combination of natural climate variability and soil, vegetation, geology, etc, heterogeneity.

2) What is the ability of existent models to assess the impacts of LUCC on the hydrological response?

Ji-Paraná Basin (Rodriguez et al, submitted to HSJ)

SB5



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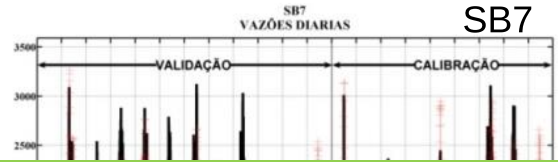

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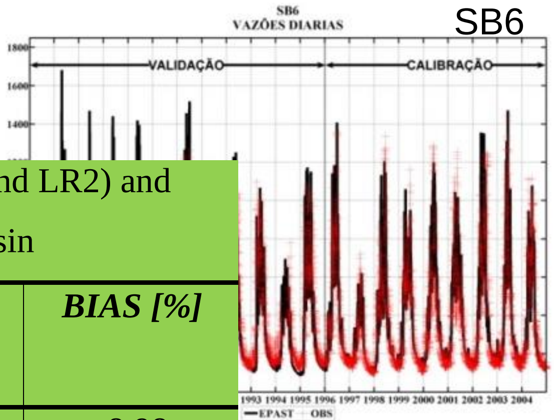

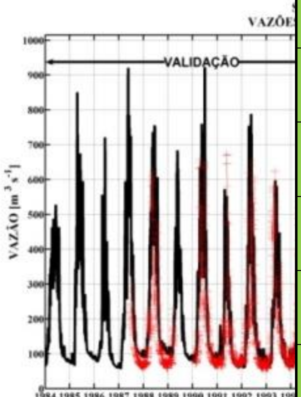

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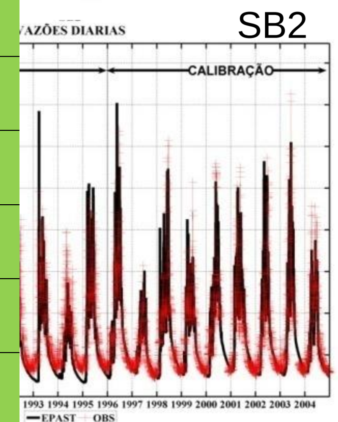
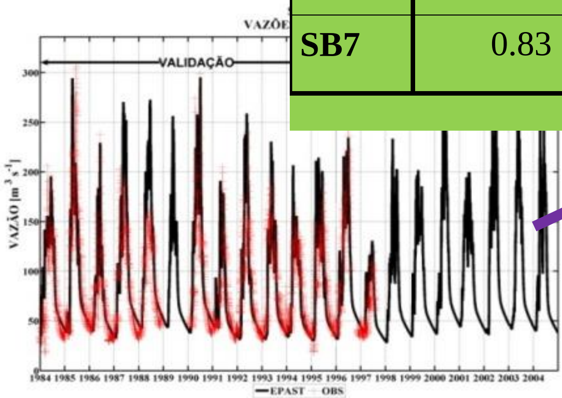
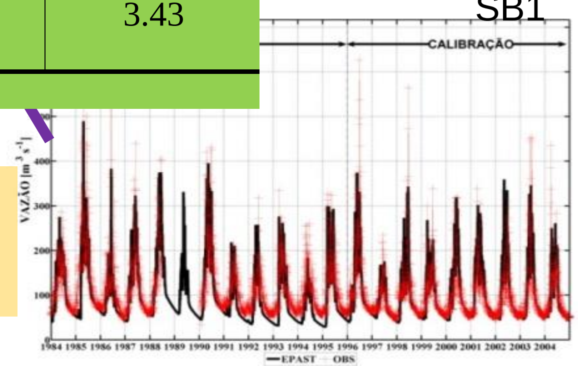




SB1



Performance coefficients for daily discharges (NSE, KGE, R2 and LR2) and volumes (BIAS) for six sub-basins of the Ji-Parana basin

	NSE (daily)	*KGE (daily)*	*R2 (daily)*	*LR2 (daily)*	*BIAS [%]*
SB1	0.63	0.80	0.71	0.73	-8.98
SB2	0.73	0.85	0.87	0.78	-10.75
SB3	0.54	0.76	0.66	0.72	1.24
SB4	0.67	0.78	0.78	0.78	-7.75
SB5	0.77	0.88	0.85	0.85	-3.48
SB6	0.80	0.89	0.86	0.86	-2.74
SB7	0.83	0.89	0.80	0.90	3.43

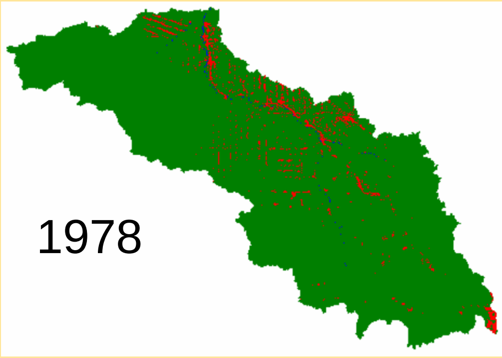
Hydrological model MHD-INPE calibration

Experiments of LUCC with a hydrological model

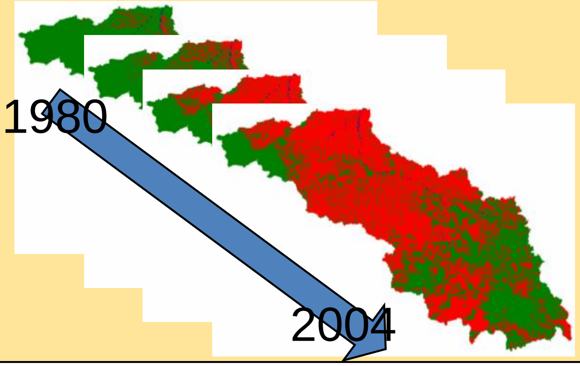
Three experiments

- **EFLOR** LUCC equivalent to the 1978 vegetation map
- **EPAST** all deforestation turned into pasture and remained as such
- **ECAPO** a fraction of deforested areas turned into a secondary regrowth (*capoeira*)

- Vegetation maps



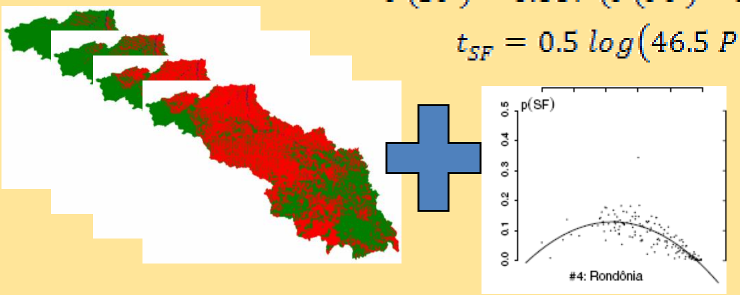
- EFLOR



- EPAST
  - Controle
  - Calibração

$$P(SF) = 0.687\ (P(PF) - P(PF)^2)$$

$$t_{SF} = 0.5\ log\big(46.5\ P(PF)\big)$$



Neef et al., 2006

- ECAPO

The effect of secondary regrowth (*capoeira*):

Higher albedo at the beginning of the regrowth

Evaporation rates higher than a primary forest

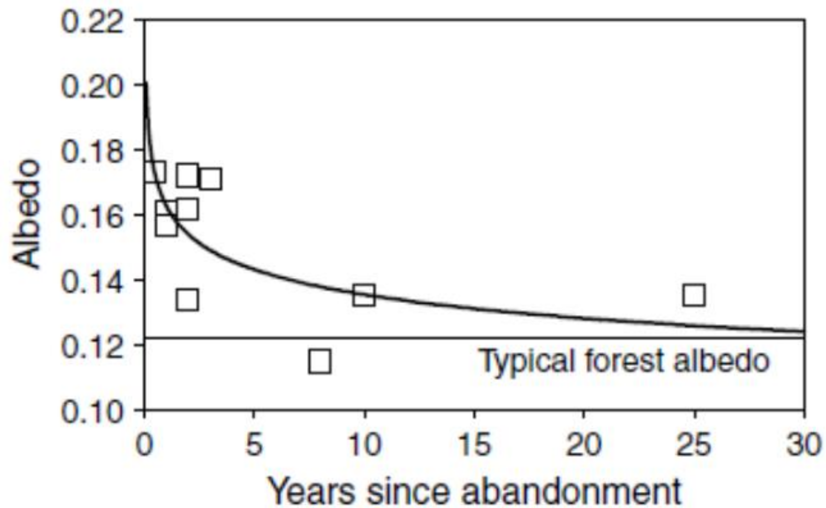


Figure 1. Albedo of secondary vegetation as a function of years since abandonment of clearing for sites in eastern Amazon Basin and northern Thailand; based on data from Giambelluca *et al.* (1997, 1999)

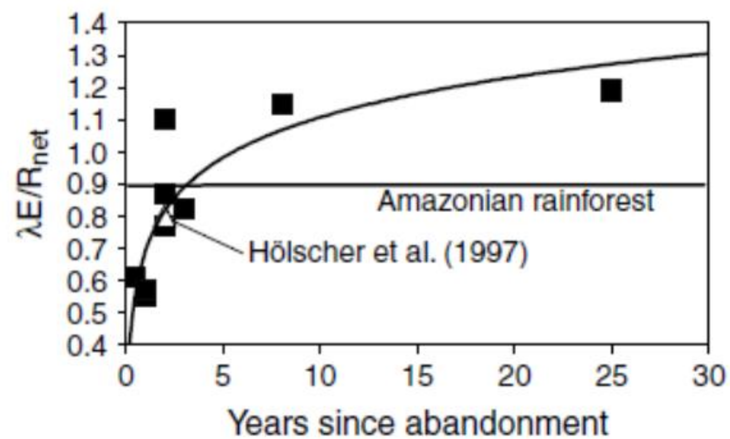
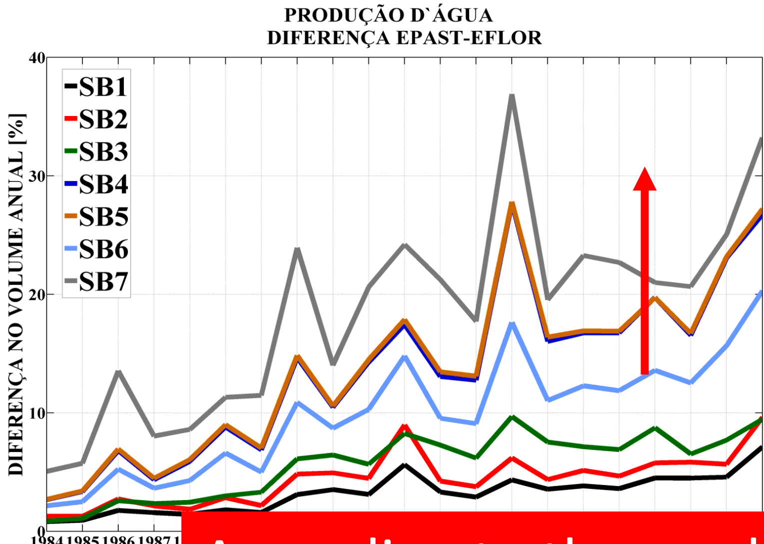
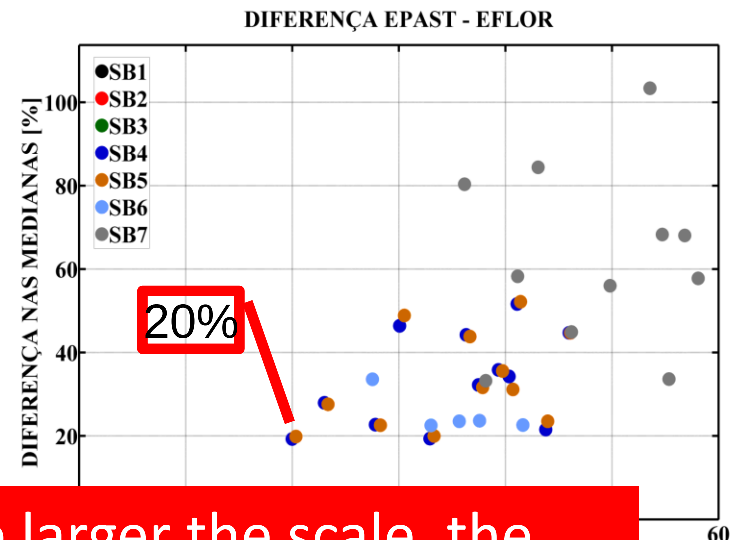


Figure 3. Evaporative fraction (ratio of energy used for evapotranspiration to net radiation) of secondary vegetation as a function of years since abandonment of clearing for sites in eastern Amazon Basin and northern Thailand; based on data from Hölscher *et al.* (1997) and Giambelluca *et al.* (2000)

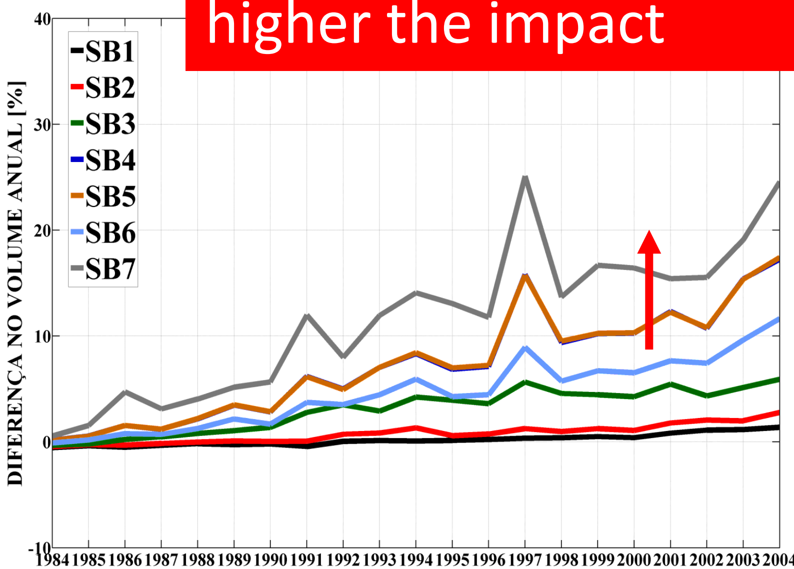
Giambelluca 2001.

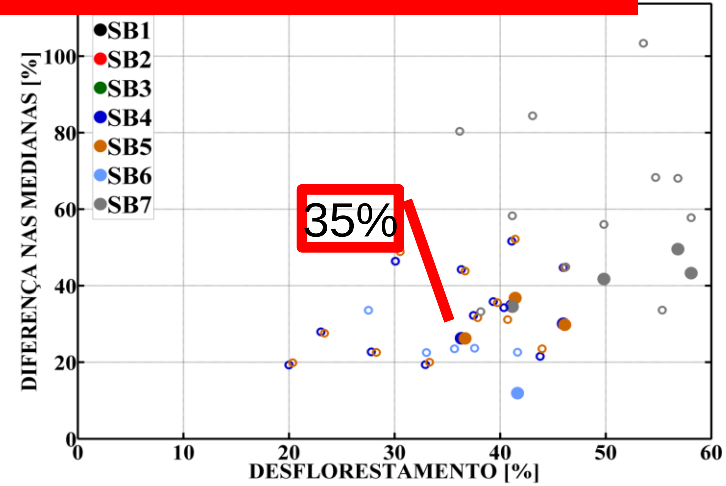
Hydrological Model Simulations: water yield impacts





According to the model, the larger the scale, the higher the impact





Qualitative similar results have been obtained using several other models

“ *The simulations with IBIS and THMB offline indicate that the local ET decrease and subsequent discharge increase* ***can be a significant fraction of the water balance when greater than 50% of a watershed is deforested***” (Coe et al 2009, JH).

Results with the VIC model suggests that “*the replacement of forests by annual crops such as soybeans* ***might result in an increase of Ji-Paraná river discharges up to 37% during the wet season and 90% during the dry season***” (Santiago, 2005, thesis).

“*We analysed impacts of deforestation on streamflow of the river Ji-Paraná (southern Amazon) using the MGB-IPH hydrological model. Three forest cover scenarios were simulated: pristine condition with predominant (~100%) forest cover; current condition with about 57% deforestation; and a hypothetical 100% deforestation scenario.* ***Results suggest that average annual discharge of the river Ji-Paraná increases by about 31 mm for each 10% of the basin drainage area that is deforested. These results are consistent with worldwide experimental studies, but are not verified in observed streamflow records of the Ji-Paraná River***“ Bayer and Collischonn, 2013)

“*The semi-distributed hydrological model SLURP was applied in the Jamari River basin, Brazil, to investigate the impacts on hydrological processes caused by changes in surface land cover and land use, as well as climate change. Realistic and extreme scenarios of deforestation were analyzed.* ***An increase was found of runoff when deforestation occurred***“ (Nobrega et al., 2010)

“*The model SWAT was calibrated for the Ji-Paraná river basin using sediment and flow discharge data provided by ANA. ..The model produced satisfactory r2 values in most of the sub-basins for flow calibration. However, the values of r2 for sediment concentrations were not significant*.“ (Dinato, 2013)

In conclusion:

Almost (if not all) models predict that the effects of LUCC will amplify across scales, while observations suggest the opposite: signals are diluted at larger scales.

Because the effect of LUCC can be modelled at small scales, the most likely explanation for the amplification of signals is related to the inability of models to upscale nonlinear processes at larger scales due to spatial heterogeneity.

In conclusion:

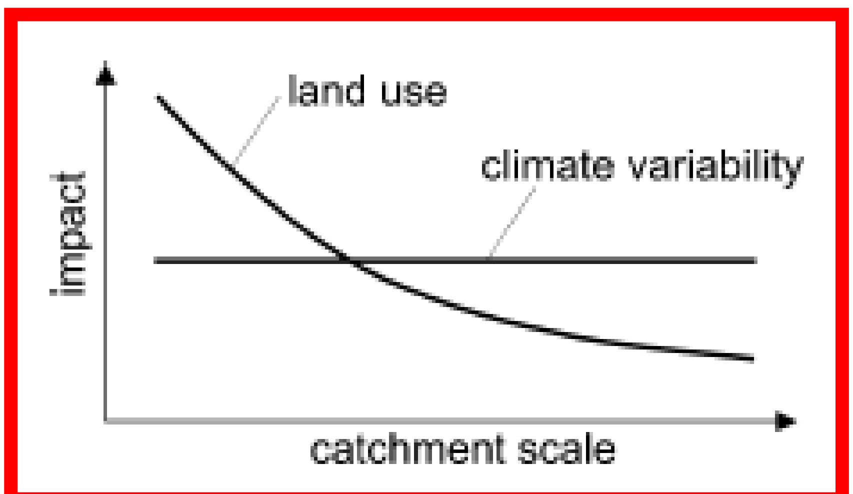
Besides this, models assumed a quasi-dynamic state of equilibrium, while observations of rainfall-runoff responses due to LUCC are time-lagged.

That creates uncertainties for the determination of **threshold values** of disturbance for which the large-scale hydrological response becomes clear.

3 What further research is necessary.

There are several scale related differences that may preclude the direct verification of the results in small experimental catchments at larger scales. Among then (Blöschl et al., 2007; Donohue et al., 2010):

(i) climate gradients;
(ii) the mosaic of land uses;
(iii) vegetation types and
(iv) spatially variable soils and geology across the catchment



Besides this, in-stream processes also affect the impacts at larger scales (Mc Intyre, 2010)

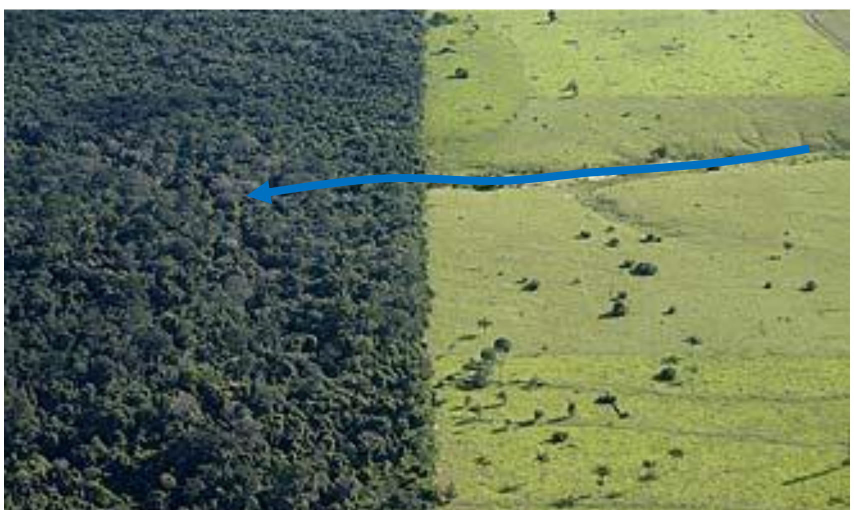
Geomorphological dispersion: the configuration of the drainage network controls the arrival times of impacts downstream

Hydrodynamic dispersion: channel friction attenuate the impacts

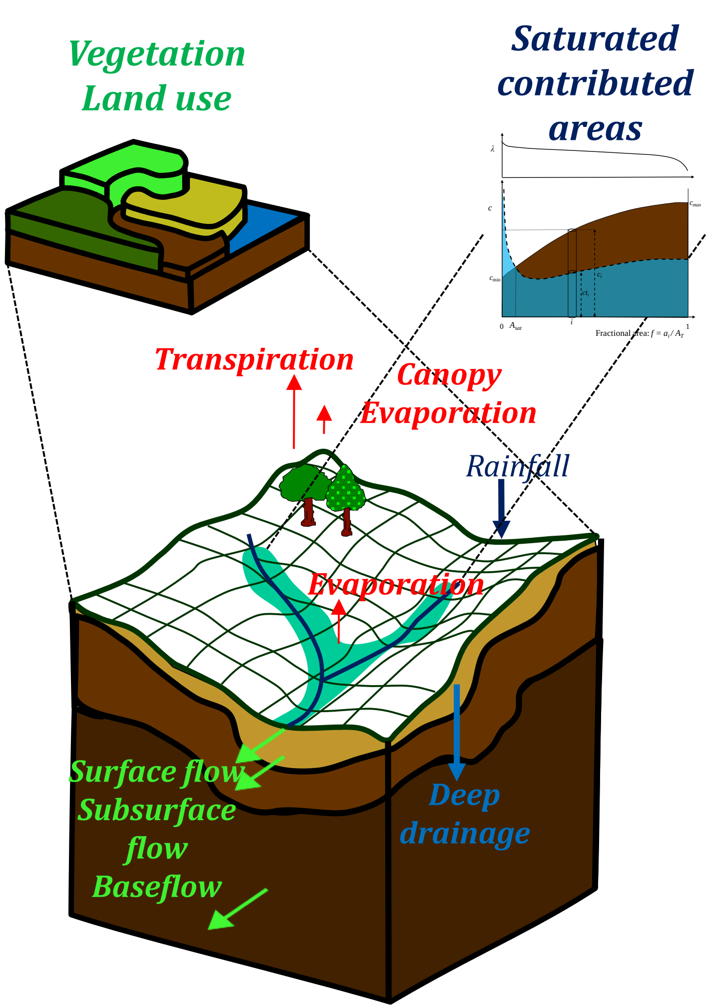
In addition, the effects of fragmentation

On surface runoff

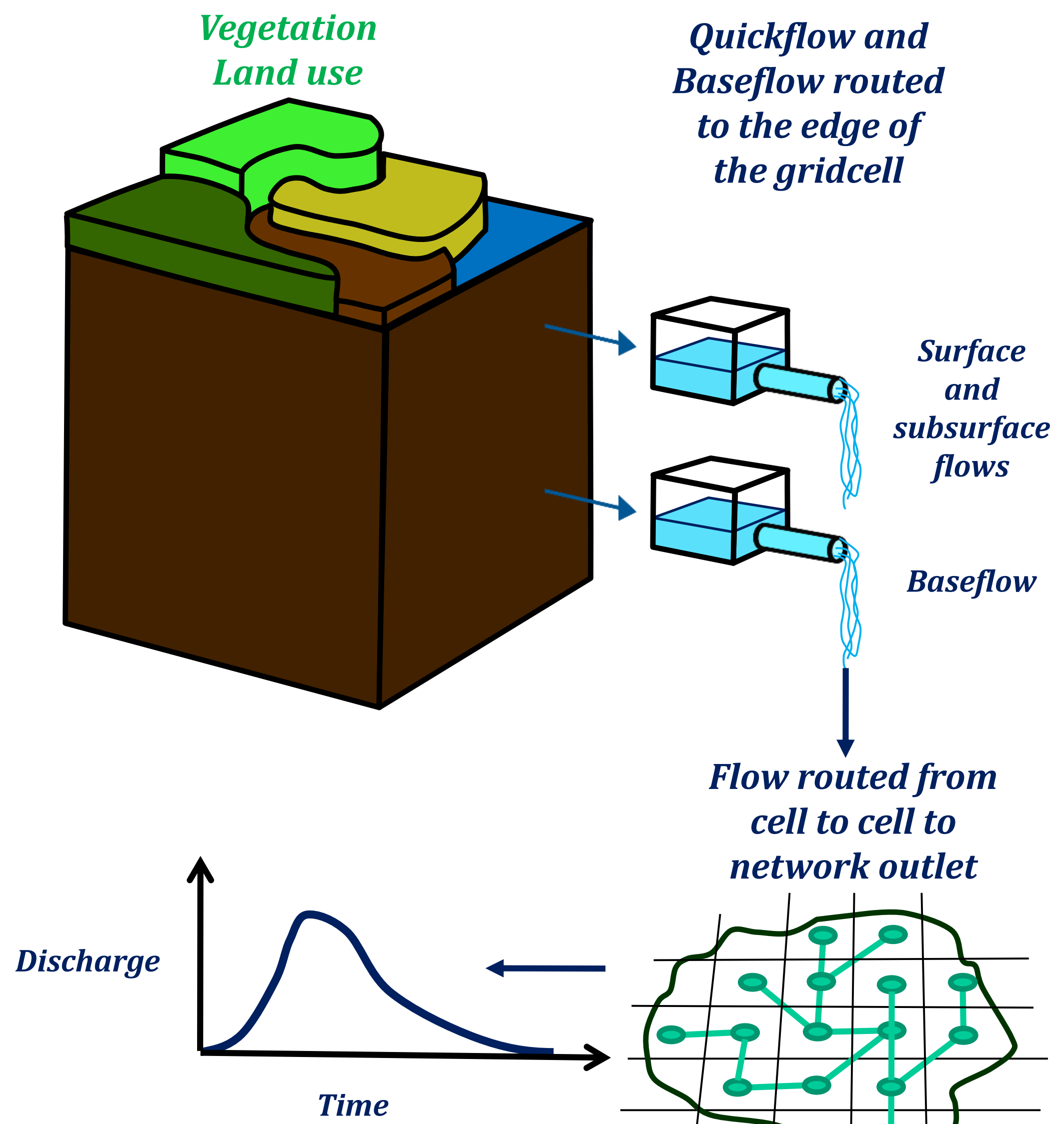
In stream propagation



Conceptual design of a hydrological model

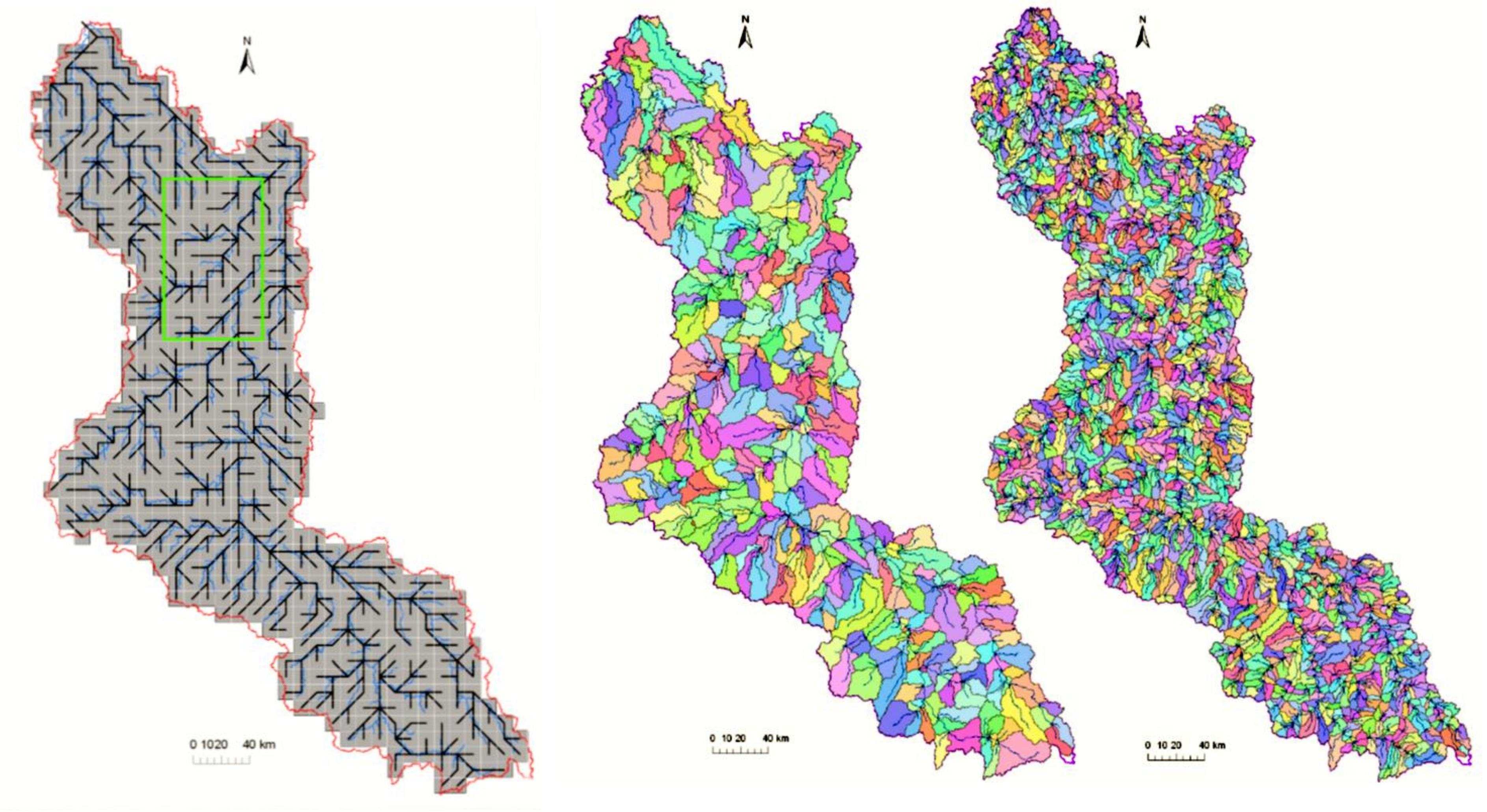


Runoff separation



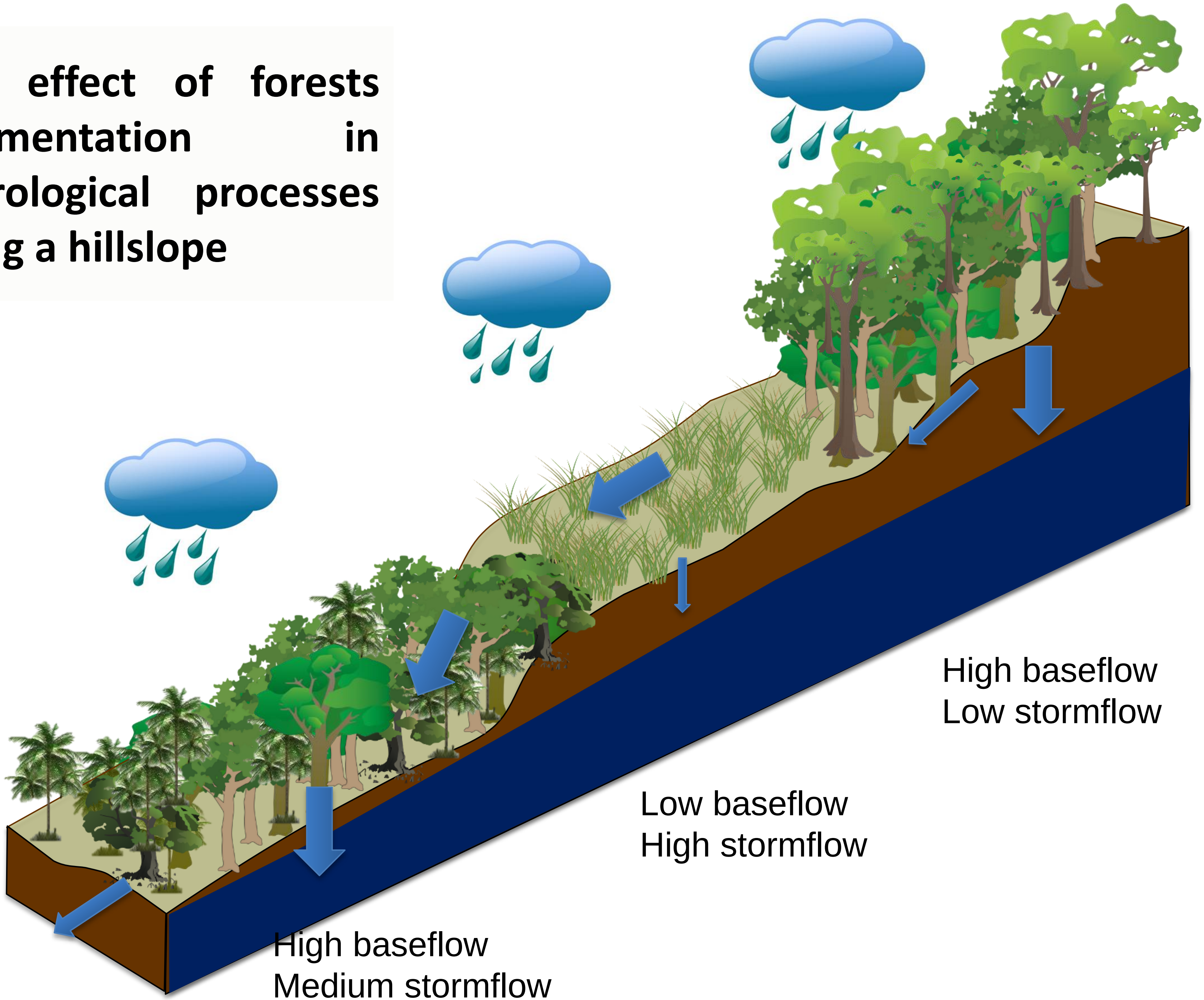
River Routing

Conceptual design of a hydrological model



Paz et al. 2011.

The effect of forests fragmentation in hydrological processes along a hillslope



In conclusion:

LUCC are clearly scale dependent. While most models predict that LUCC amplify across scales, observations suggest the opposite: signals seems to disappear across scales, at least in several catchments.

The most likely explanation for these contradictory results could be attribute to the increase of heterogeneity across scales, including geology, soil types, climate, and land uses fragmentation, which local-scale interactions are not (or poorly) represented in hydrological models.

That creates uncertainties for the assessment of impacts.

In temperate catchments…

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Modelling the hydrological impacts of rural land use change

Neil McIntyre, Caroline Ballard, Michael Bruen, Nataliya Bulygina, Wouter Buytaert, Ian Cluckie, Sarah Dunn, Uwe Ehret, John Ewen, Alexander Gelfan, Tim Hess, Denis Hughes, Bethanna Jackson, Thomas Kjeldsen, Ralf Merz, Jong-Sook Park, Enda O'Connell, Greg O'Donnell, Ludovic Oudin, Ezio Todini, Thorsten Wagener and Howard Wheater

"*The ability of hydrologists to quantify the impact of rural land use change on the water cycle is however limited and **we are not able to provide consistently reliable evidence to support planning and policy decisions.***

This shortcoming stems mainly from lack of data, but also from lack of modelling methods and tools."

Thank you!

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