Forest Watershed Services on an Old Frontier in the Brazilian Amazon

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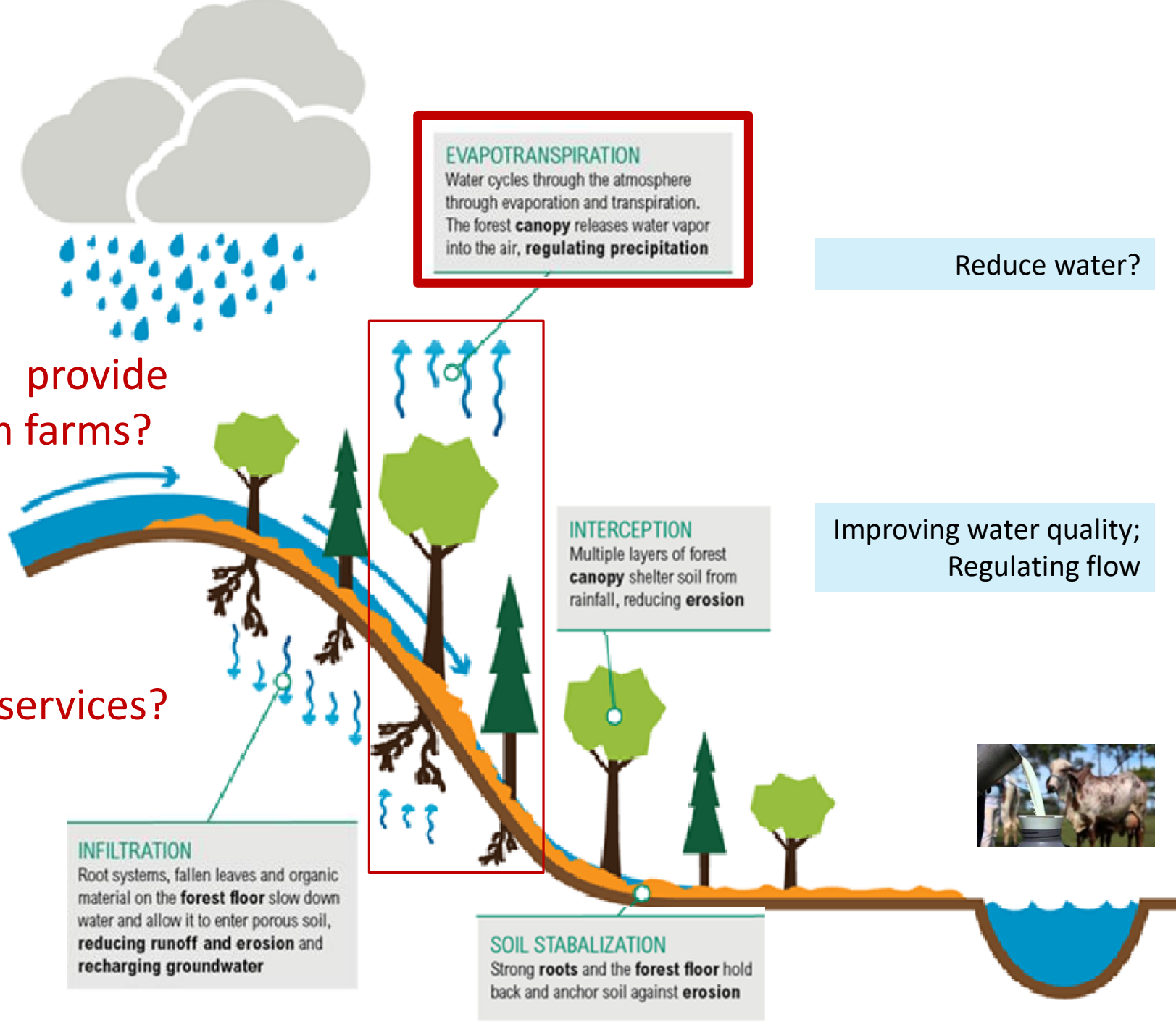
CAMP RESOURCES

AUGUST 7, 2017

Research question

1. Does the Amazon forest provide watershed services to downstream farms?

2. If so, what is the value of those services?

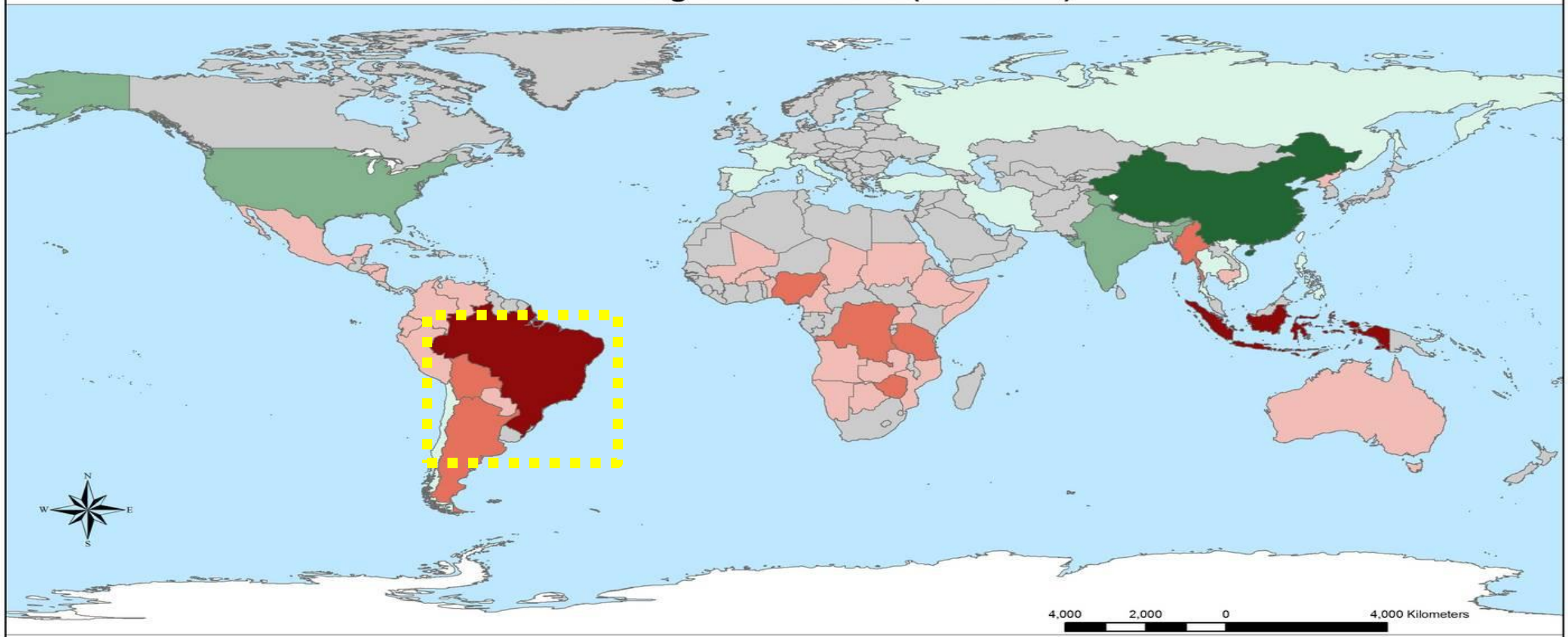


Reduce water?

Improving water quality; Regulating flow

Sources: World Resources Institute

Annual change in forest area (1990-2015)

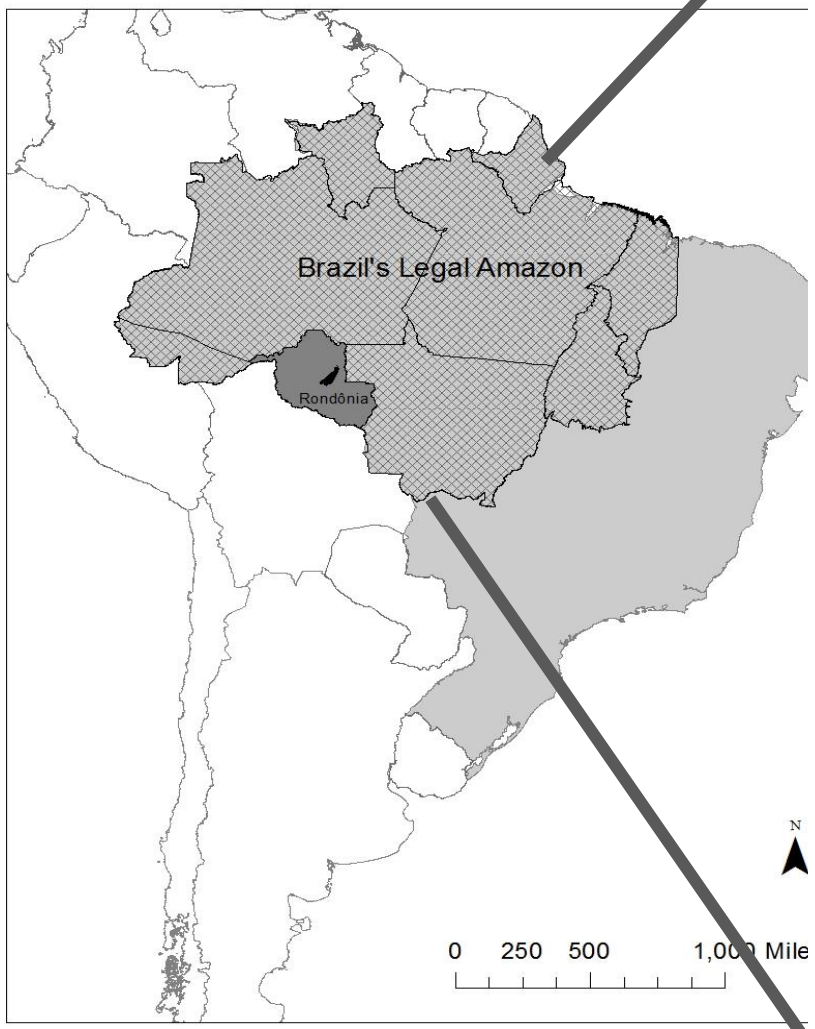


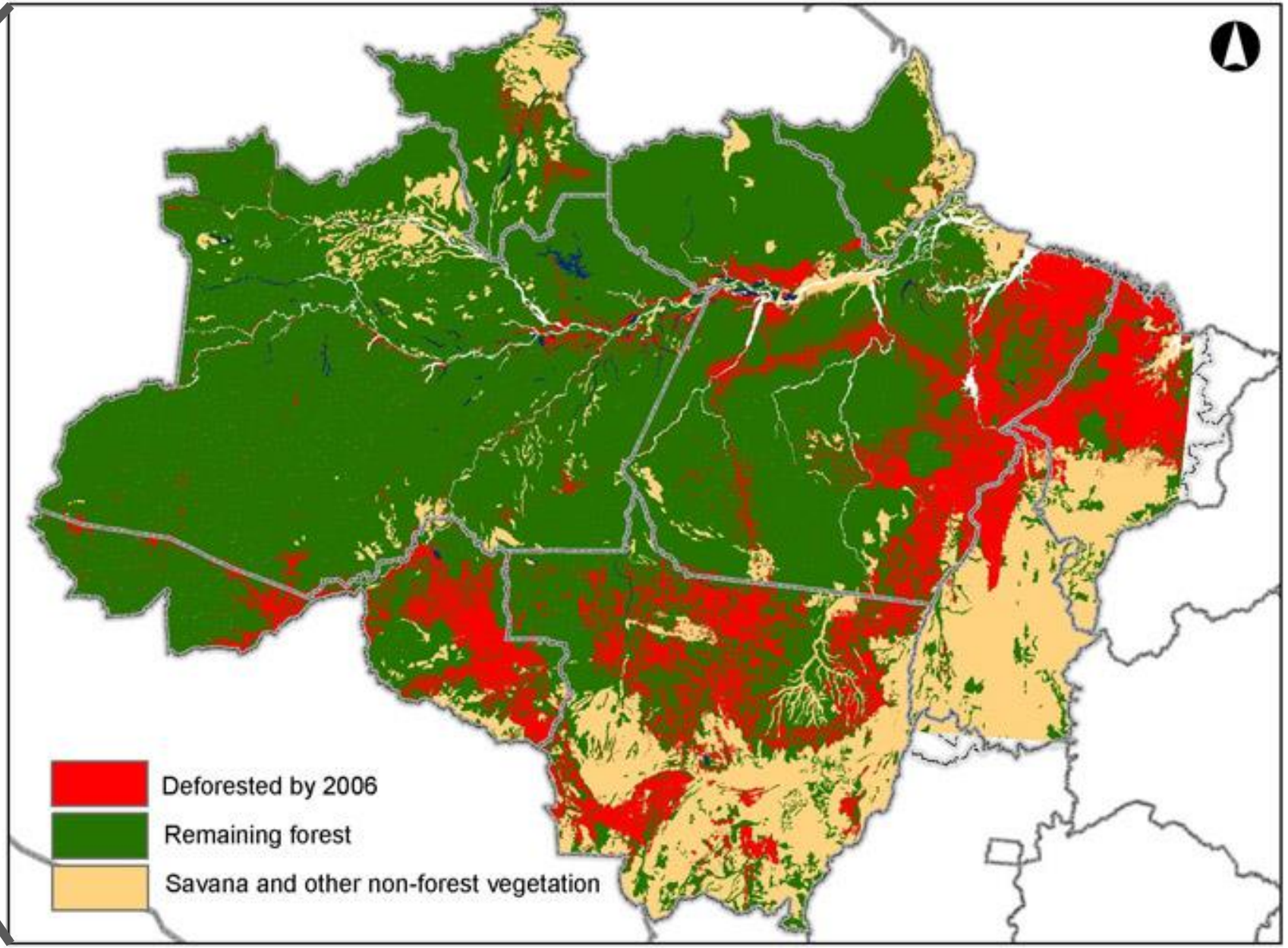
1000 ha

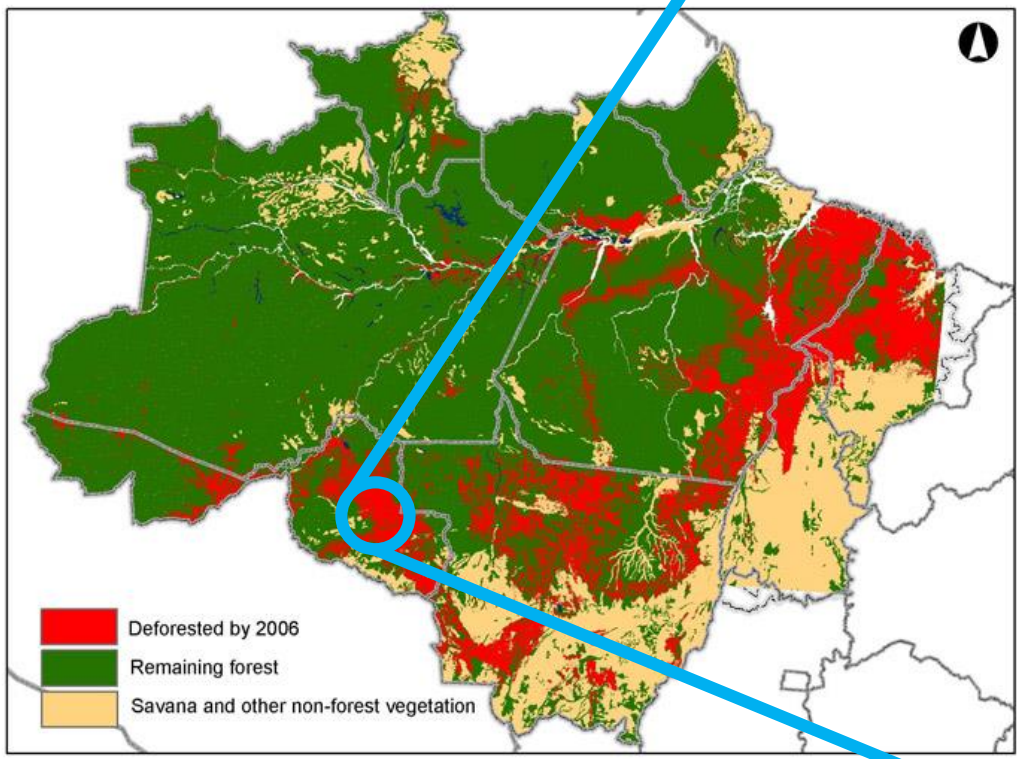
Net gain	Net loss	Small change (gain or loss)
50 - 250	>500	<50
250 - 500	500 - 250	
>500	250 - 50	No data

FAO, 2015. Global Forest Resources Assessment. FAO, Rome

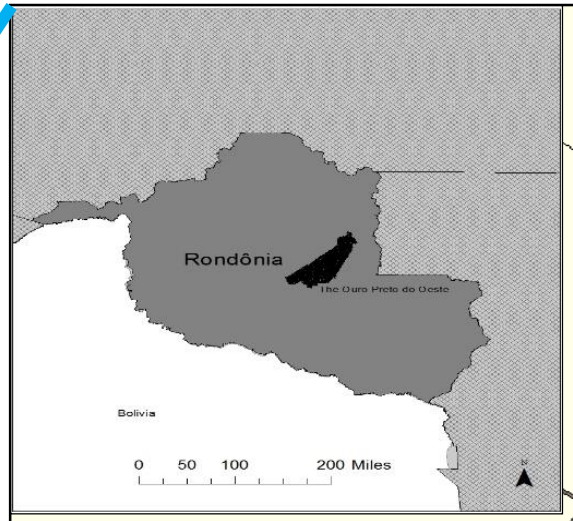
“Arc of Deforestation”







The Ouro Preto do Oeste region, Rondônia, Brazil



VALE DO PARAÍSO

OURO PRETO DO OESTE

NOVA UNIÃO

TEIXEIRÓPOLIS

MIRANTE DA SERRA

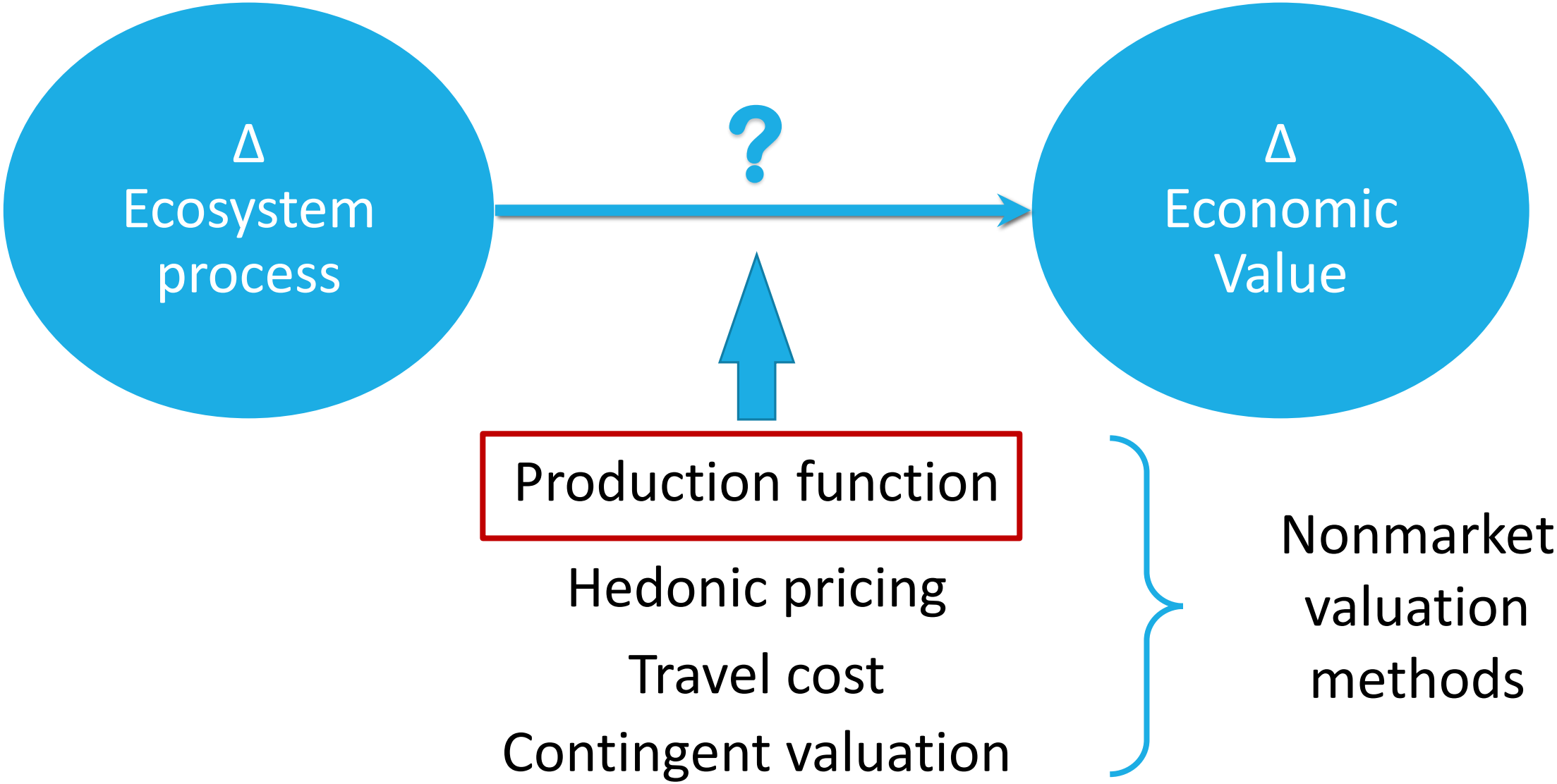
URUPÁ

0 5 10 20 Miles

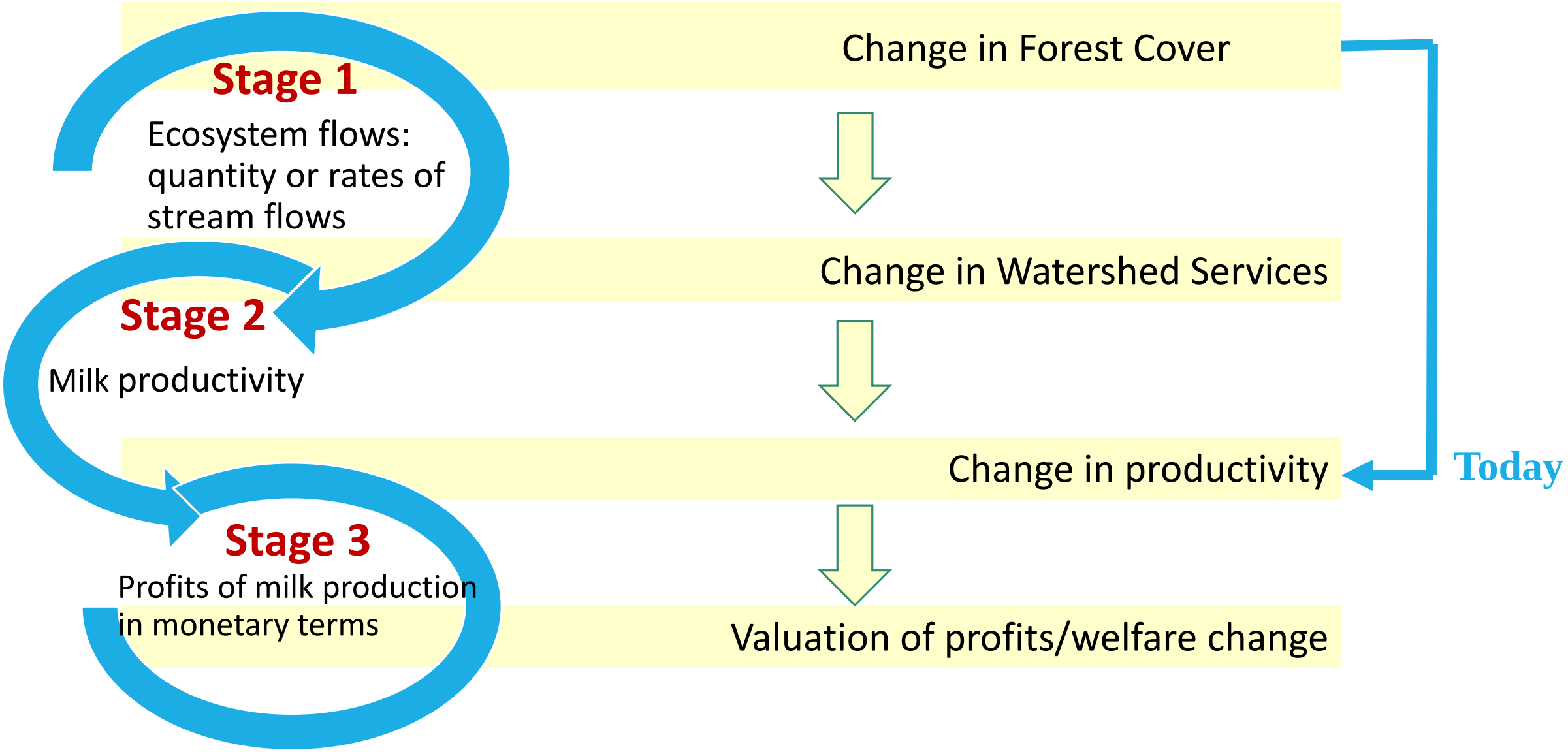
N


CUIDADO
LEITEIRO


Novalar
móveis e eletrodomésticos
HONDA


Δ
Ecosystem process
?
Δ
Economic Value
Production function
Hedonic pricing
Travel cost
Contingent valuation
Nonmarket valuation methods

Three-stage analytical framework (Freeman et al. 1992)



Property-level panel dataset

Support provided by the National Science Foundation SES-0752936, SES-0452852, SES-0076549 and National Socio-Environmental Synthesis Center (SESYNC)

1. Four-waves farm household survey
   - Livestock ownership
   - Agricultural production
   - Household and property characteristics

1996 | 2000 | 2005 | 2009

196, 196, 406, 646 properties

2. Land cover at the lot level
   - Annual LandSat images, 30m pixels
   - Decision tree classifier with spectral mixture analysis

1996 2009

~ 9000 properties

3. Spatial data
   - farm boundaries
   - road networks, market locations
   - biophysical conditions

1996 2009

~ 9000 properties

4. Hydrological data

1996 2009

~ 9000 properties

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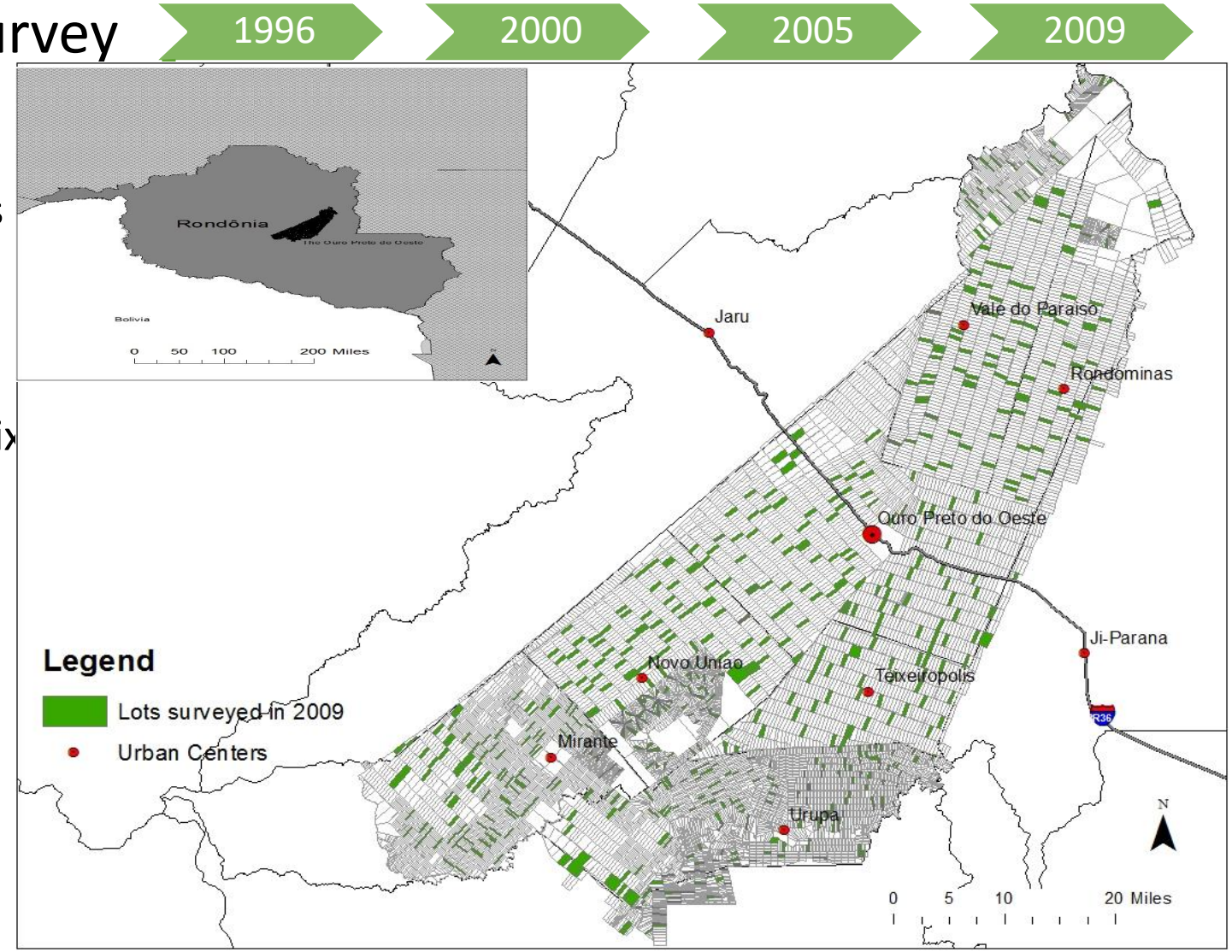


Hydrological data

- Size of watershed corresponding to the lot

Proxy for flow on the lot

  Land cover on the watershed identified

- Precipitation (monthly)

  Maximum and Minimum Temperature (monthly)

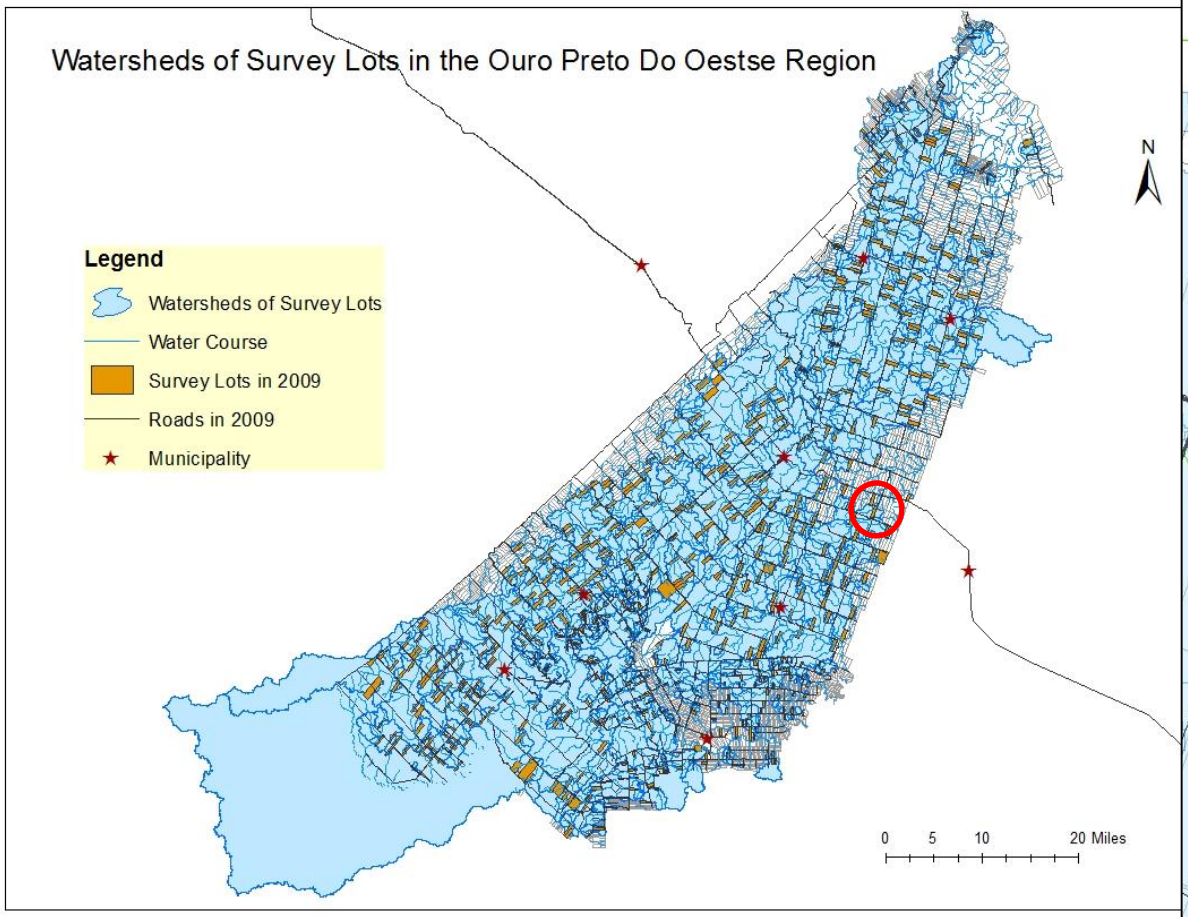
- Low flow runoff

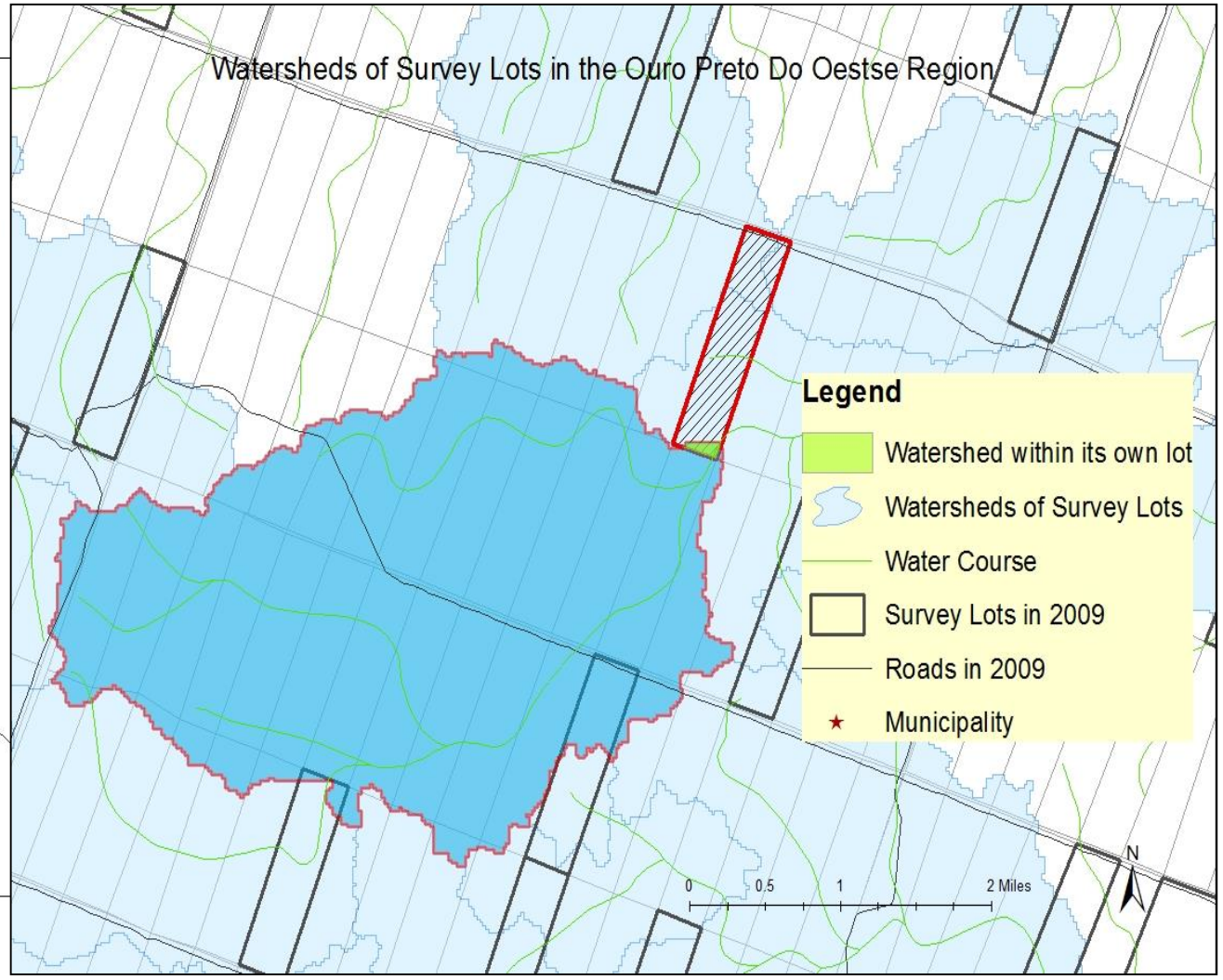
mean of the 10% lowest flows (m3/day) calculated for each survey year at two watersheds in the study area (Jaru river and Jamari river).

Hydrological data

- Size of watershed corresponding to the lot

Proxy for flow on the lot





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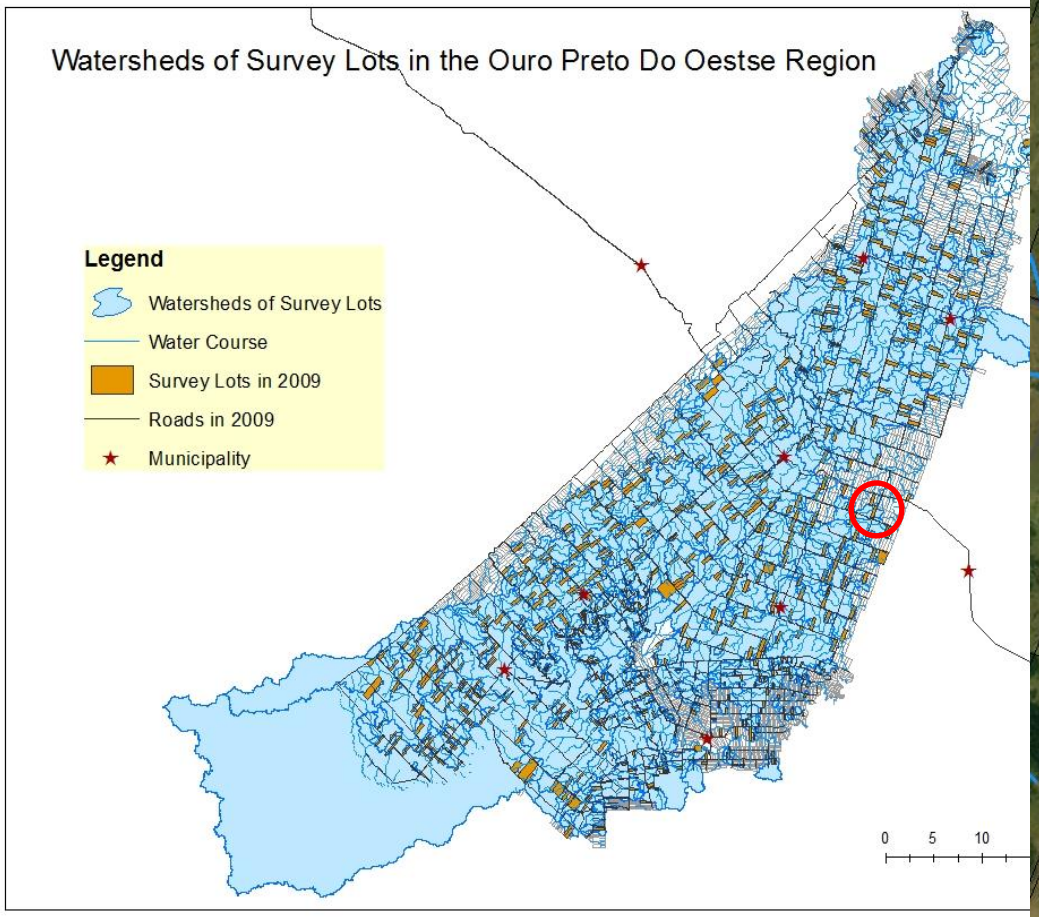
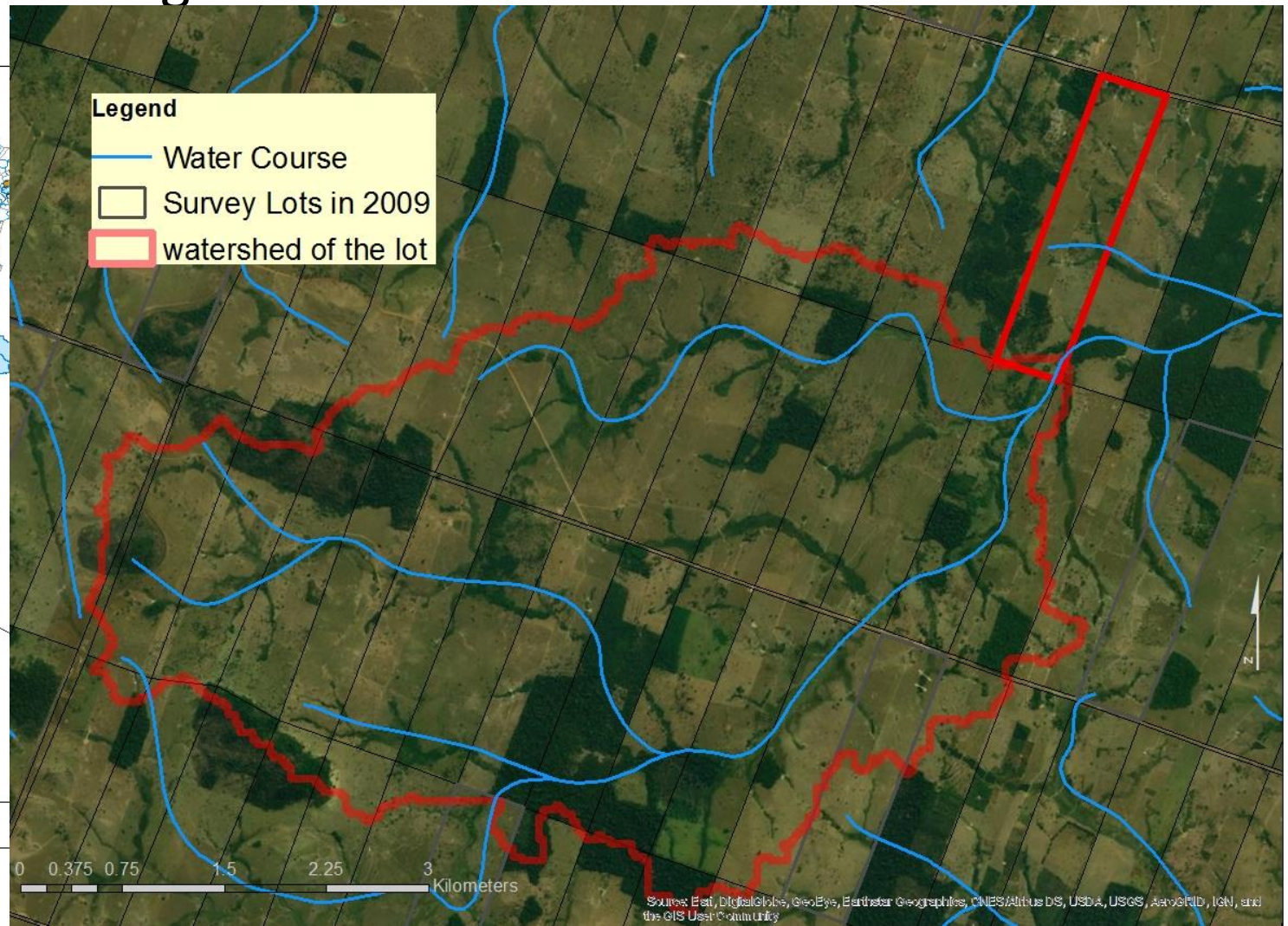
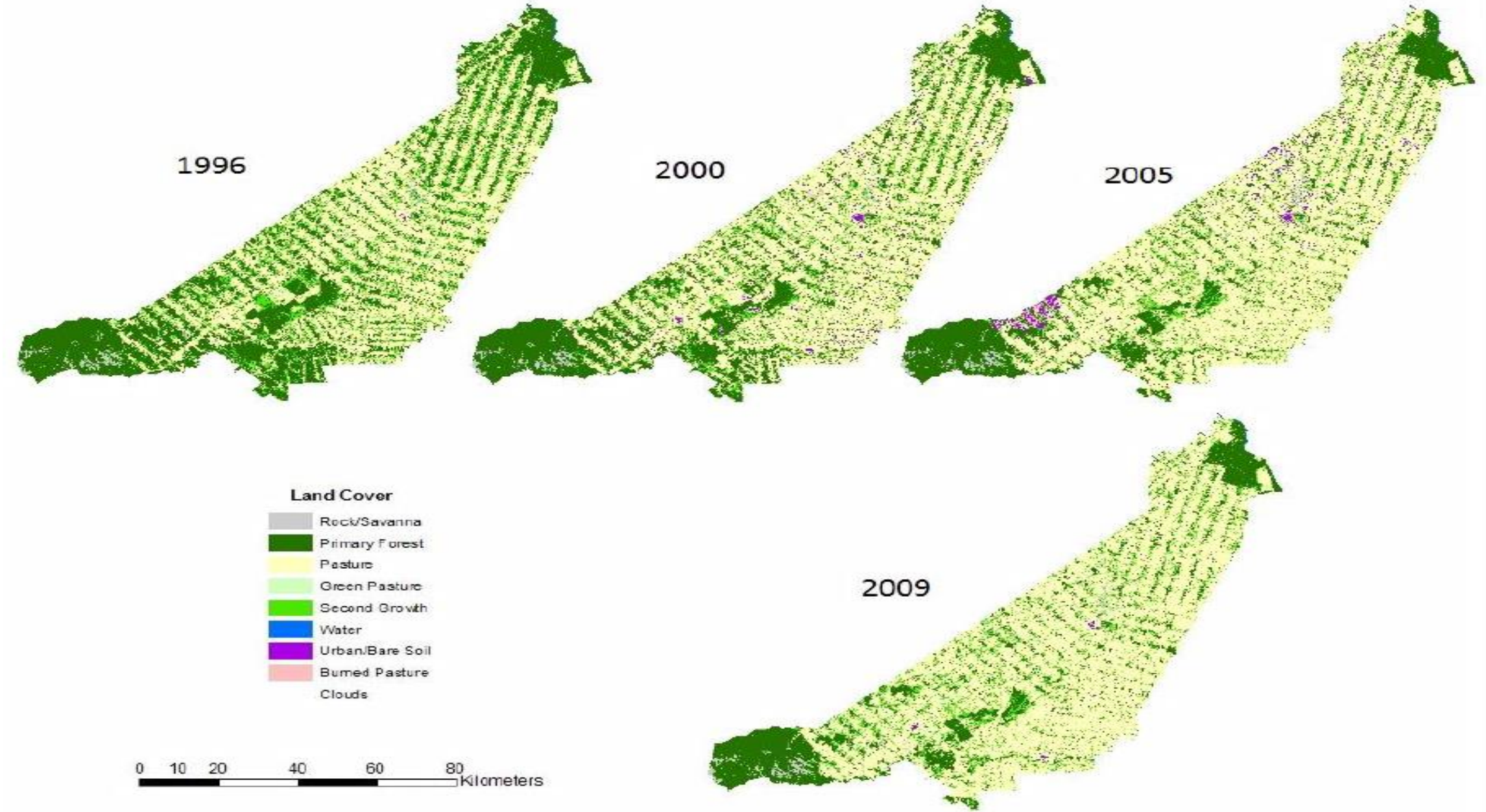




Mature forest cover in the Ouro Preto do Oeste region



Econometric model

Milk supply
= f(watershed services, output prices, prices of variable inputs, quality of fixed inputs)

Specification:

Milk supply

= f(watershed size, water availability, mature forest cover in the watershed,

milk price, distance to market, household and lot characteristics)

Econometric model

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Specification:

Milk supply
= f(watershed size, water availability, mature forest cover in the watershed,
milk price, distance to market, household and lot characteristics)

Model specification: full set of interaction terms between forest cover and other determinants of watershed services

$$ln(Milk\ productivity)_{it} = \beta_0 + \beta_1(\boldsymbol{year \times ln(forest\ cover_{it})}) + \beta_2 watershed\ size\ grp_i + \beta_3 ln(forest\ cover_{it}) + \beta_4 year + \beta_5 milk\ price_{it} + \beta_6 ln(dist\ to\ market_i) + \beta_j lot\ charact._{it} + \beta_j HH.charact._{it} + \varepsilon_{it}$$

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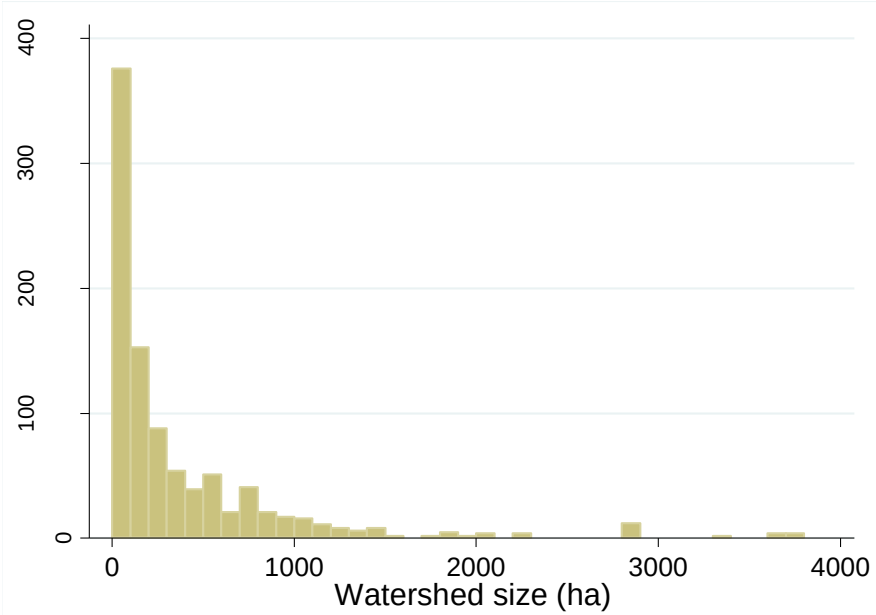
Classify watershed size (small, medium, large)

Small ($<$ 100 ha): 123 lots

Medium (100 ha ~1000 ha): 148 lots

Large ($\geqslant$ 1000 ha): 33 lots

Total: 304 lots (year 2009)



Descriptive Statistics

	Variable	Obs.	Mean	Std. Dev.	Min	Max
Dependent Variables	Milk per cow, dry (liters)	967	2.42	2.62	0	33.33
	Milk per cow, wet (liters)	967	3.85	4.77	0	70
	Milk per hectare, dry (liters)	966	1.17	1.66	0	20.88
	Milk per hectare, wet (liters)	966	1.84	2.76	0	47.85
Determinants of watershed services	Area of watershed (ha)	967	466.19	848.82	0.19	6224
	Area of forest in the watershed (ha)	909	97.68	192.28	0.01	1590
	Rainfall in dry season (mm)	967	151.23	62.68	37.00	254.30
	Rainfall in wet season (mm)	967	1154.32	290.74	870.30	1673.70
	Year	967			1996	2009
Prices	Milk price, dry (R$/liter)	967	0.19	0.12	0	0.53
	Milk price, wet (R$/liter)	967	0.18	0.1	0	0.53
	Distance to market (km)	967	15.11	6.98	1.19	35.05

Other proxies for fixed inputs (human and natural capital): household head age and education, household size, soil suitability, slope, lot age, lot size, municipality fixed effects, and temperature.

Marginal effects of ln(forest) by year

(Four-year unbalanced panel, n=307)

	ln (Milk per cow)				ln (Milk per ha)			
	Dry		Wet		Dry		Wet	
	FE	RE	FE	RE	FE	RE	FE	RE
Year 1996 *ln(forest)	-0.061	-0.011	-0.134**	-0.043	-0.032	-0.015	-0.0879*	-0.053**
	(0.055)	(0.028)	(0.066)	(0.033)	(0.038)	(0.023)	(0.027)	(0.047)
Year 2000 *ln(forest)	0.005	0.049*	0.008	0.082***	-0.013	0.008	-0.017	0.019
	(0.049)	(0.026)	(0.059)	(0.030)	(0.034)	(0.021)	(0.024)	(0.042)
Year 2005 *ln(forest)	-0.073	-0.007	-0.102*	-0.011	-0.068**	-0.033*	-0.100***	-0.048**
	(0.044)	(0.020)	(0.053)	(0.023)	(0.031)	(0.017)	(0.019)	(0.038)
Year 2009 *ln(forest)	-0.071	-0.009	-0.073	0.011	-0.070**	-0.039**	-0.083**	-0.037*
	(0.043)	(0.020)	(0.052)	(0.023)	(0.030)	(0.017)	(0.019)	(0.037)

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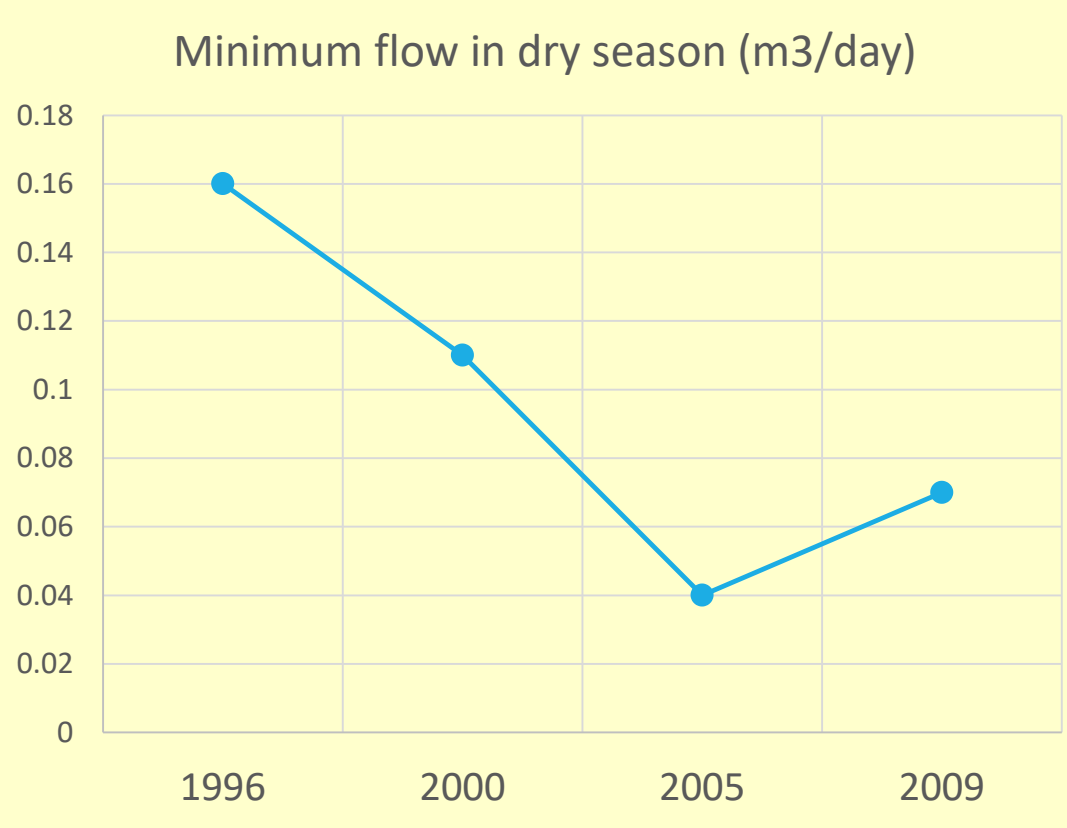

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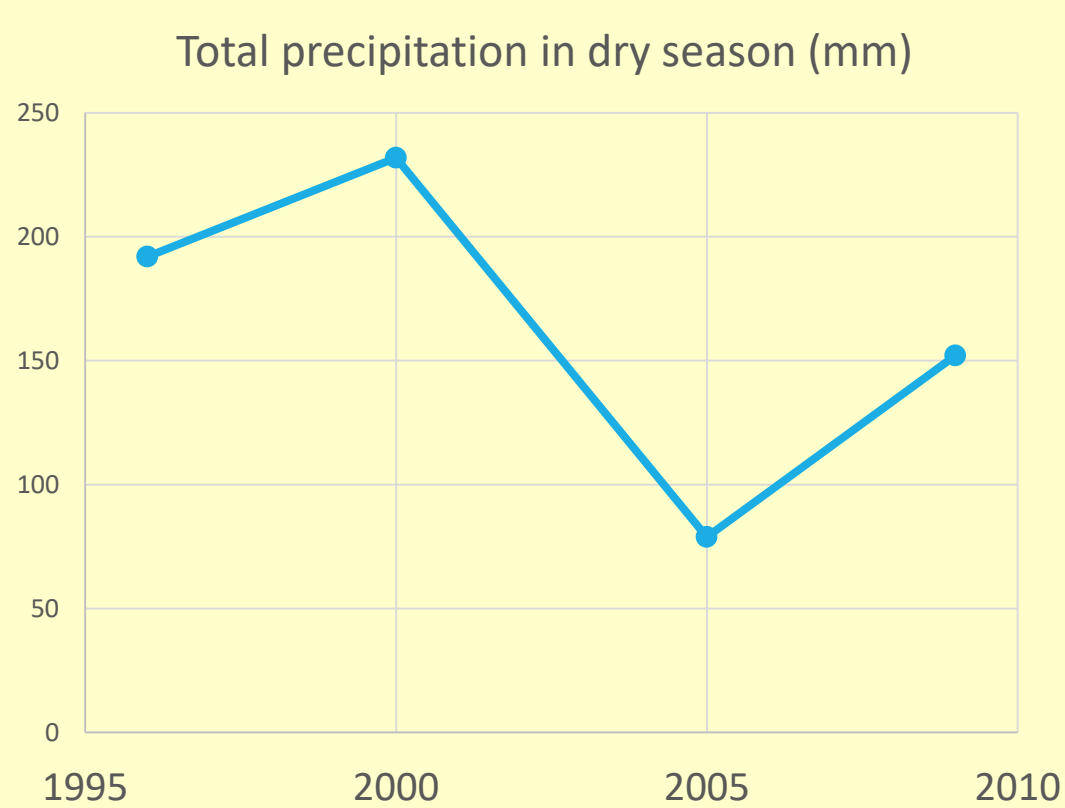


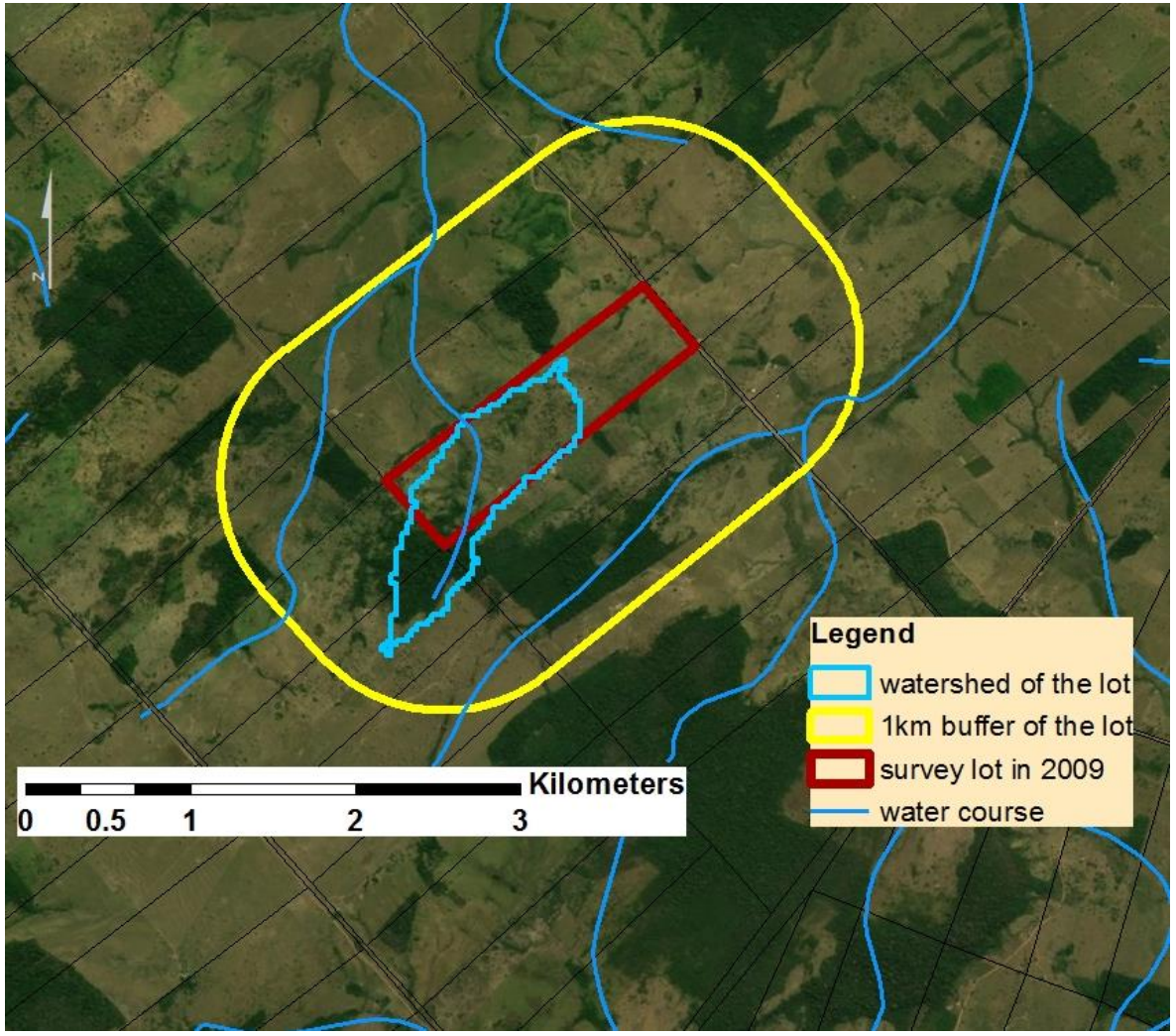
Marginal effects of ln(forest) by watershed size

(Four-year unbalanced panel, n=307)

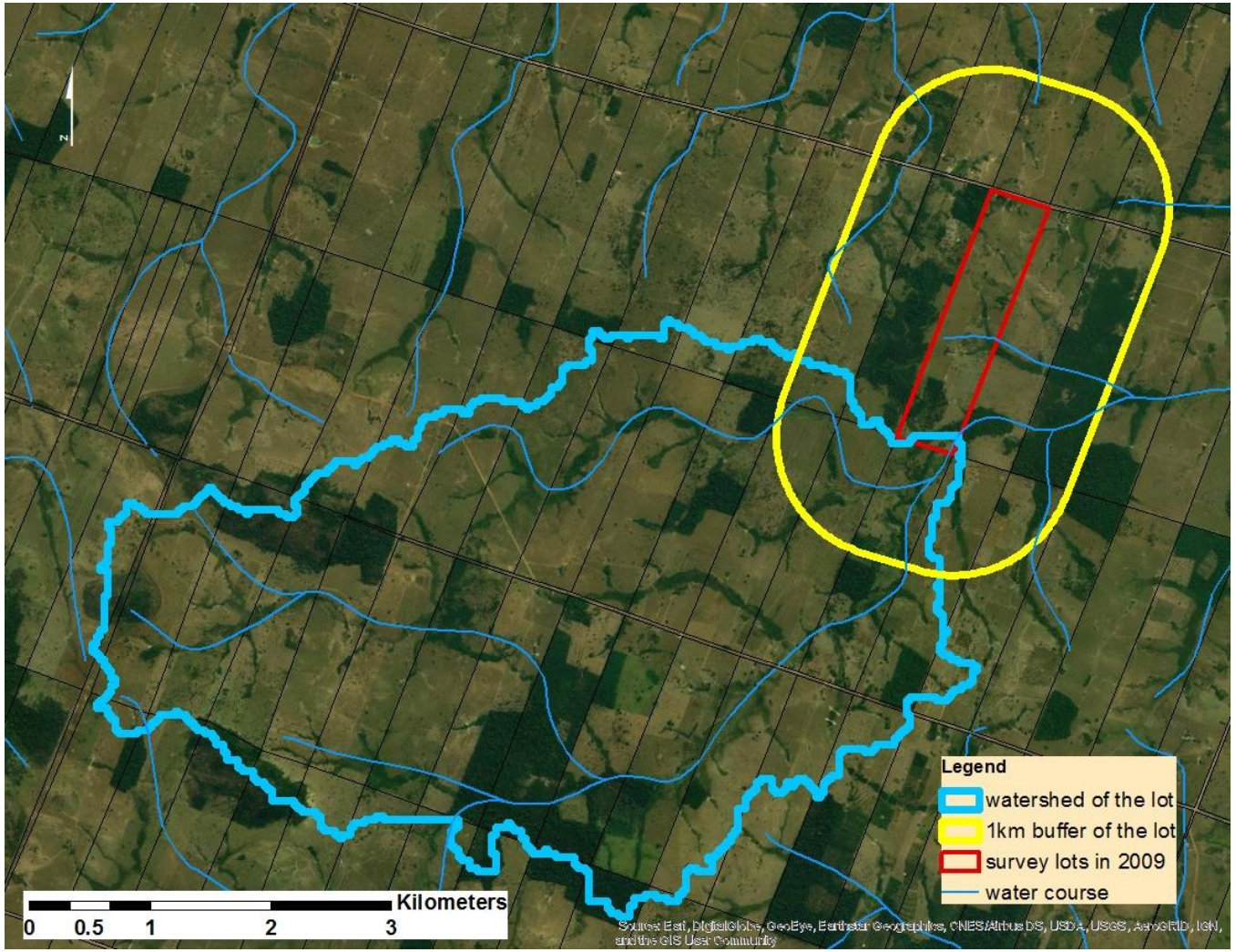
	ln (Milk per cow)				ln (Milk per ha)			
	Dry		Wet		Dry		Wet	
	FE	RE	FE	RE	FE	RE	FE	RE
Small *ln(forest)	-0.027	0.018	-0.036	0.013	-0.056**	-0.025*	-0.081***	-0.033**
	(0.036)	(0.016)	(0.045)	(0.019)	(0.024)	(0.014)	(0.031)	(0.016)
Medium *ln(forest)	-0.088*	0.003	-0.144**	0.004	-0.027	-0.011	-0.053	-0.024
	(0.052)	(0.017)	(0.064)	(0.020)	(0.035)	(0.016)	(0.044)	(0.018)
Large *ln(forest)	0.089	0.011	-0.010	-0.081	0.008	0.035	-0.095	-0.020
	(0.169)	(0.058)	(0.211)	(0.066)	(0.114)	(0.054)	(0.146)	(0.059)

Note: "*", "**", "***" , "****" indicate significance at the 10%, 5%, 1%, and 0.1% levels

Small watershed (<100 HA)



Large watershed (>1000 HA)



Robustness Test

Marginal effects of ln(forest in 1km buffer of the lot)

(Four-year unbalanced panel, n=319)

	ln (Milk per cow)				ln (Milk per ha)			
	Dry		Wet		Dry		Wet	
	FE	RE	FE	RE	FE	RE	FE	RE
ln(forest 1km buffer)	-0.072	0.005	-0.117*	-0.034	-0.077**	-0.029	-0.114**	-0.056**
	(0.058)	(0.025)	(0.070)	(0.029)	(0.039)	(0.021)	(0.049)	(0.025)

Robustness Test

Marginal effects of ln(secondary forest in the watershed) watershed size

(Four-year unbalanced panel, n=308)

	ln (Milk per cow)				ln (Milk per ha)			
	Dry		Wet		Dry		Wet	
	FE	RE	FE	RE	FE	RE	FE	RE
Small *ln(forest)	-0.026	-0.007	0.017	0.036	-0.021	-0.028*	0.013	-0.002
	(0.029)	(0.020)	(0.035)	(0.024)	(0.019)	(0.016)	(0.025)	(0.019)
Medium *ln(forest)	-0.001	0.013	0.001	0.024	0.015	0.009	0.021	0.012
	(0.025)	(0.017)	(0.031)	(0.019)	(0.017)	(0.013)	(0.022)	(0.016)
Large *ln(forest)	-0.021	-0.043	0.003	-0.052	0.036	0.029	0.067	0.048
	(0.062)	(0.046)	(0.075)	(0.054)	(0.041)	(0.035)	(0.052)	(0.043)

Robustness Test

Marginal effects of ln(secondary forest in the watershed) by year

(Four-year unbalanced panel, n=308)

	ln (Milk per cow)				ln (Milk per ha)			
	Dry		Wet		Dry		Wet	
	FE	RE	FE	RE	FE	RE	FE	RE
Year 1996 *ln(forest)	0.009	0.013	-0.004	0.005	0.019	0.009	0.013	0.001
	(0.029)	(0.023)	(0.035)	(0.027)	(0.019)	(0.017)	(0.024)	(0.021)
Year 2000 *ln(forest)	0.036	0.047**	0.068*	0.080***	0.041*	0.030*	0.072**	0.054**
	(0.029)	(0.024)	(0.035)	(0.028)	(0.020)	(0.017)	(0.024)	(0.021)
Year 2005 *ln(forest)	-0.017	0.002	0.000	0.017	-0.004	-0.009	0.011	0.0004
	(0.022)	(0.017)	(0.027)	(0.020)	(0.015)	(0.013)	(0.018)	(0.015)
Year 2009 *ln(forest)	-0.039	-0.023	-0.002	0.010	-0.018	-0.022*	0.004	-0.006
	(0.024)	(0.018)	(0.029)	(0.021)	(0.016)	(0.013)	(0.020)	(0.016)

Findings based on the above model

► **Upstream deforestation (mature forest) associated with an increase in milk production per hectare**

Consistent with forest science — forests can reduce surface runoff both because trees use water and because they allow more infiltration.

Consistent with animal science — milk cattle needs a large amount of water to produce milk.

► **The effect is the same in wet and dry seasons;**
The effect is largest in small watersheds and dry years.

Evapotranspiration, i.e. trees are acting as pumps rather than sponges.

► **Effect of secondary forest on milk productivity is positive when water abundant**

Secondary forest on any one pixel lasts an average of 5 years and is not left to be converted into forest in the future. Instead the areas are re-burned within 5 years to create pasture.

Findings based on the above model

►**Upstream deforestation (mature forest) associated with an increase in milk production per hectare**

Caveats:

- Forest may have a positive effect **regionally** by contributing to precipitation**.**
- As forests become scarcer, they may matter more for **water quality**.

Next steps

- Dynamic effects
  - with lagged forest cover
  - lagged investments in milk production
- Location of forest in the watershed
- Distinguish watershed inside and outside the property
- Monetary valuation of productivity impacts

Thank you !