The effects of the short-term Brazilian sugarcane expansion in stream flow: Monte Mor basin case study

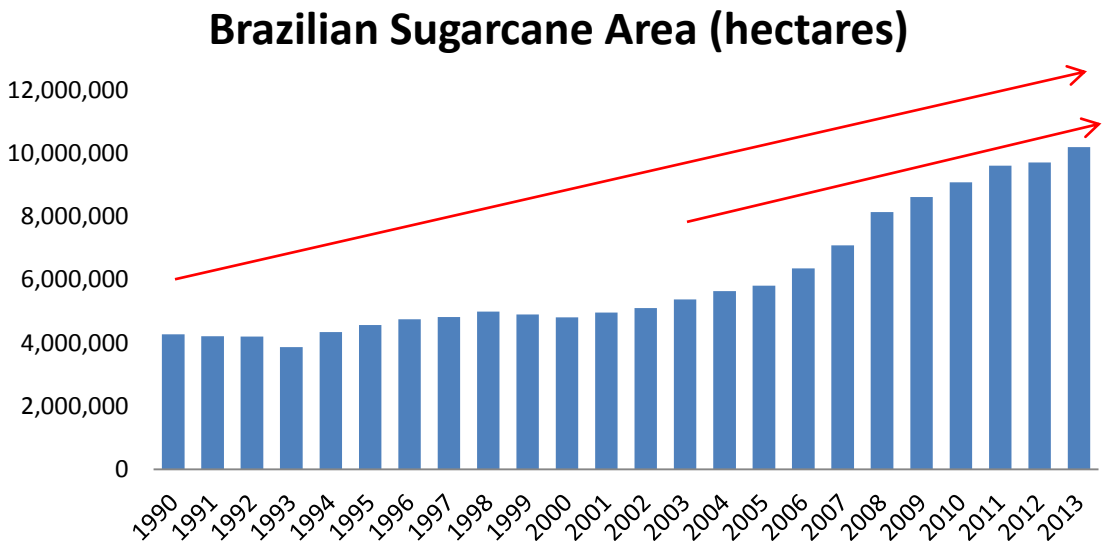
Hernandes, TAD; Scarpare, FV; Seabra, JEA; Duft, DG; Picoli, MCA; Walter, A

BIOEN FAPESP

CTBE Brazilian Bioethanol Science and Technology Laboratory

UNICAMP

Overview



Source: IBGE/PAM, 2015

139% (1990 to 2013)

90% (2003 to 2013)

50% → Sugarcane Ethanol

29 millions of m^3 in 2013

Source: DCAA/SPAE/MAPA

FAPESP Bioenergy Program

↓

Sustainability and Impacts

↓

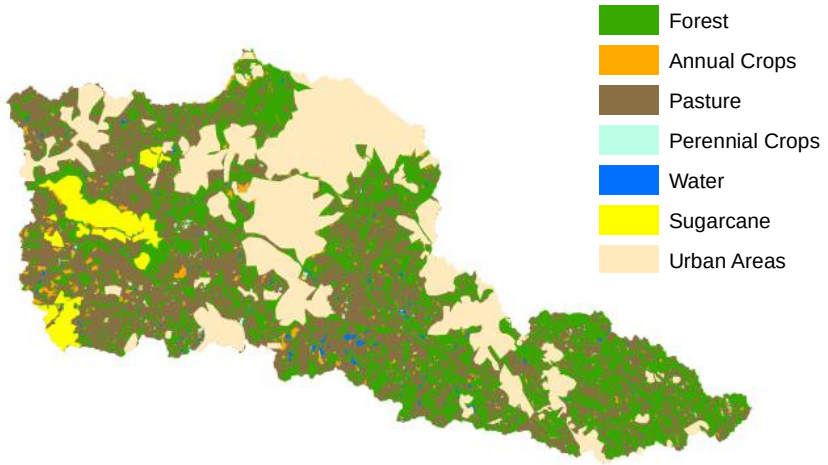
Integrated Analysis of the Sustainability of Sugarcane Bioethanol Production

- Land Use and Land Use Change
- Life Cycle Impact Assessment
- **Water Resources**
- Greenhouse Gas Emissions
- Biodiversity
- Socioeconomic Impacts

Objective

Use the SWAT model to calibrate and validate basin stream flow (in the last years) in three different watersheds →several socioeconomic/geographic/edaphoclimatic conditions and also different sugarcane expansion dynamics

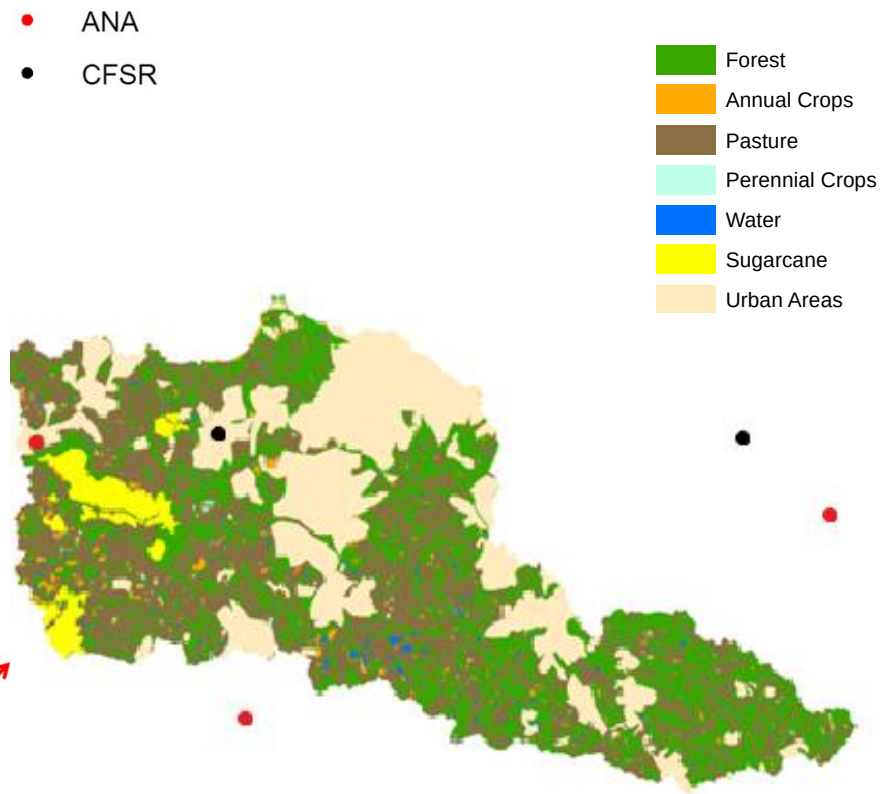
Apply calibrated and validated model in future sugarcane expansion scenarios (2007 to 2028) in order to assess possible impacts on stream flow



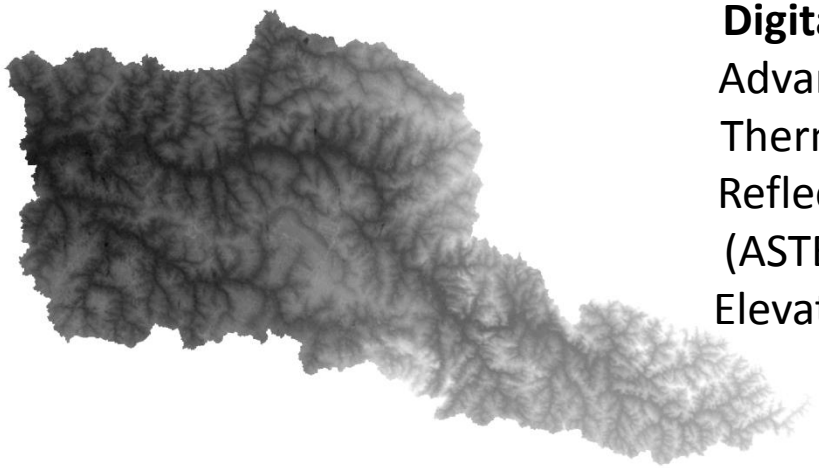
Input Data: Monte Mor Basin

1996 land use base map → ArcGIS supervised classification (Landsat)
Rainfall data →National Water Agency (ANA)

Remaining Weather Data
Global Weather Data for SWAT (CFSR)



Input Data: Monte Mor Basin



Digital Elevation Map
Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (30m)

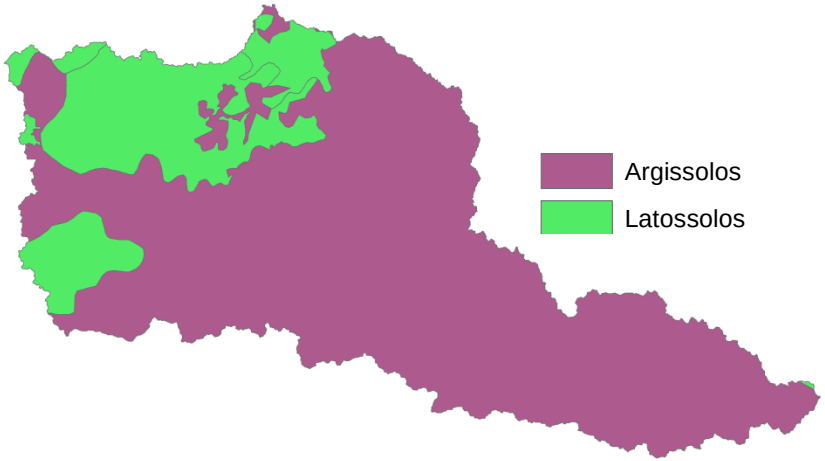
Simulation

- Monthly time step
- 1995 to 2007
- 2 years of model warm up

Stream flow time series
National Water Agency (ANA)
1997 to 2007

LAT	LON	Name	Code	Basin	Responsible	River	State	Area (km^2)
-22.96	-47.30	MONTE MOR	62420000	RIO PARANÁ	ANA	RIO CAPIVARI	SP	697

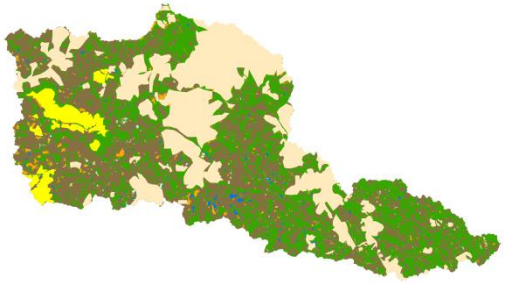
Input Data: Monte Mor Basin



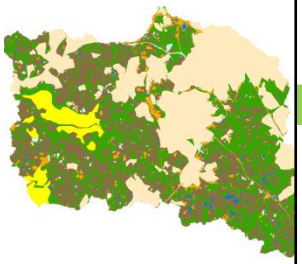
Pedological Map
Campinas Agronomic Institute (IAC)
1:500000 scale
Soil parameters → Brazilian Agricultural Research Corporation (EMBRAPA) Soil Public Database

SNAM	S5ID	CMPPCT	NLAYERS	HYDGRP	SOL_ZMX	ANION_EXCL	SOL_CRK	TEXTURE	SOL_Z1	SOL_BD1	SOL_AWC1
TEEL	NY0076	1	3	V	1828.800049	0.5	0.5	SIL-VFSL-FSL	254	1.27	0.
KEARSARGE	NH0031	8	3	V	457.2000122	0.5	0.5	STV-SIL-SIL-UW	101.6	1.1	0.
CARDIGAN	NH0033	8	4	V	787.4000244	0.5	0.5	STV-SIL-SIL-SIL-	101.6	1.1	0.
DUTCHESS	VT0052	5	3	V	1651	0.5	0.5	SIL-SIL-CNV-FS	101.6	1.1	0.
STISSING	MA0050	5	3	V	1524	0.5	0.5	STV-SIL-CN--SI	228.6	1.05	0.
WARWICK	MA0059	5	3	V	1651	0.5	0.5	FSL-SY--FSL-LS	203.2	1.15	0.
BERNARDSTON	MA0010	3	3	V	1651	0.5	0.5	STV-SIL-CN--SI	152.4	1.1	0.
SKERRY	NH0004	9	3	V	1651	0.5	0.5	STV-FSL-GR--FS	101.6	0.95	0.
SUCCESS	NH0052	9	4	V	1651	0.5	0.5	STV-SL-LS-S-S	177.8	0.8	0.
PERU	NH0014	5	3	V	1651	0.5	0.5	STV-FSL-FSL-FS	152.4	0.9	0.
WAUMBEK	NH0016	3	3	V	1651	0.5	0.5	STV-FSL-GRV-L	254	0.95	0.
PILLSBURY	NH0038	5	3	V	1651	0.5	0.5	STV-L-FSL-FSL	127	1.15	0.
ROCK OUTCROP	DC0015	5	1	V	1524	0.5	0.5	UWB	1524	2.5	0.
BECKET	NH0002	5	3	V	1651	0.5	0.5	STV-FSL-FSL-SL	50.8	0.95	0.
WATER	DC0038	3	1	V	400	0.5	0.5		400	1.1	0.
PITS	NY0029	4	1	V	1524	0.5	0.5	GR--LS-GRV-S-(	1524	1.5	(
CAMBISSOLOGO	CX0022	5	5	V	1050	0.5	0.5	media	220	1.493	0.1
LATOSSOLOGO	LE0022	5	5	V	1600	0.5	0.5	media	100	1.309	0.0
ARGISSOLOPP	PV022	4	4	V	1700	0.5	0.5	mediaarenosa	100	1.44	0.0
LATOSSOLOPP	LV022	4	4	V	2750	0.5	0.5	media	230	1.309	0.0
NITOSSOLOPP	NV022	5	5	V	1500	0.5	0.5	argilosa	200	1.28	0.0
LATOSSOLOAMM	LA022	5	5	V	2750	0.5	0.5	argilosa	300	1.1	0.1
LATOSSOLOVMM	LV022	5	5	V	1130	0.5	0.5	argilosaa	200	1.19	0.1
ARGISSOLOMM	PA022	4	4	V	1000	0.5	0.5	arenosamedia	250	1.28	0.

Input Data: Monte Mor Basin



1999



2001

ArcGIS supervised classification

Land use change updates

ArcGIS Intersect

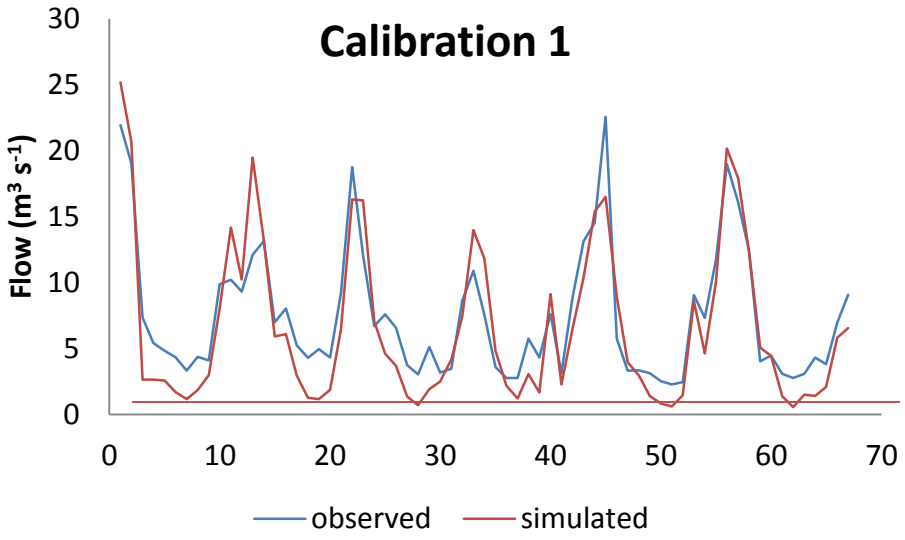
1996/1999	Sugarcane	Forest	Annual	Pasture	Perennial	Urban
Sugarcane	75%	6%	0%	18%	0%	0%
Forest	1%	68%	2%	28%	0%	0%
Annual	7%	38%	10%	43%	0%	2%
Pasture	2%	30%	2%	64%	1%	1%
Perennial	1%	26%	7%	61%	2%	3%
Urban	0%	0%	0%	0%	0%	99%
1996/2001	Sugarcane	Forest	Annual	Pasture	Perennial	Urban
Sugarcane	68%	5%	0%	25%	1%	2%
Forest	1%	71%	3%	17%	1%	5%
Annual	8%	20%	20%	35%	5%	9%
Pasture	2%	29%	3%	58%	2%	7%
Perennial	2%	10%	10%	48%	16%	12%
Urban	0%	1%	1%	2%	1%	96%
1996/2004	Sugarcane	Forest	Annual	Pasture	Perennial	Urban
Sugarcane	60%	18%	1%	19%	1%	2%
Forest	1%	81%	1%	10%	1%	6%
Annual	10%	40%	5%	26%	8%	11%
Pasture	2%	41%	1%	46%	2%	7%
Perennial	6%	23%	3%	42%	11%	15%
Urban	0%	2%	0%	2%	0%	96%
1996/2007	Sugarcane	Forest	Annual	Pasture	Perennial	Urban
Sugarcane	59%	4%	0%	34%	0%	2%
Forest	1%	64%	1%	26%	0%	6%
Annual	7%	21%	0%	53%	3%	9%
Pasture	3%	25%	1%	64%	1%	7%
Perennial	4%	17%	1%	60%	4%	11%
Urban	0%	1%	0%	3%	0%	96%

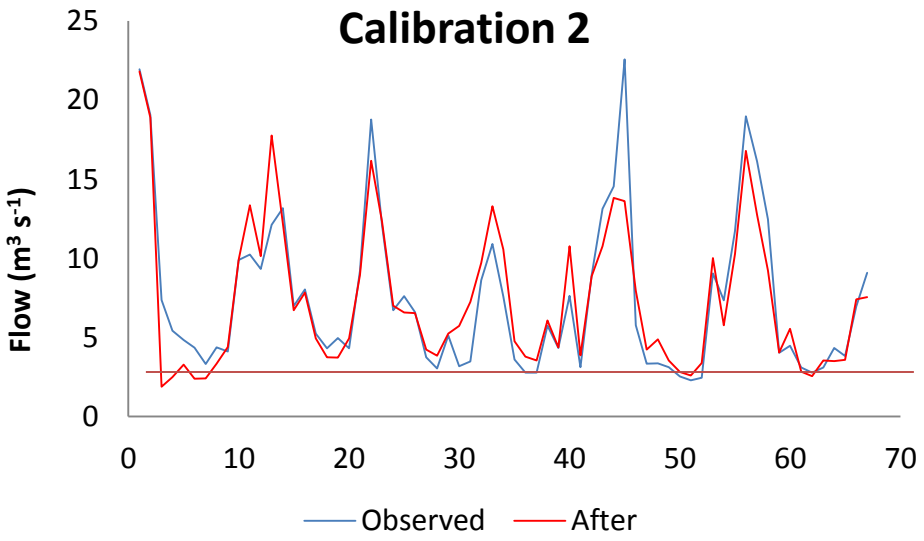
Monte Mor Basin Modelling Results

Global Sensitivity → SWAT-CUP
2000 simulations

Parameter/Source	Min	Max	t-stat	p-value
CN2	1	98	-21.99	0.00
SOL_K	0	1000	-20.42	0.00
SLSUBBSN	10	150	19.27	0.00
SOL_AWC	0	1	12.89	0.00
ESCO	0	1	-5.26	0.00
Alpha_Bf	0	1	-3.09	0.00
EPCO	0	1	2.95	0.00
GWQMN	0	5000	1.99	0.05
CH_N2	0	1	-1.15	0.25
GW_DELAY	0	500	-1.06	0.29
SOL_ALB	0	0.25	-0.79	0.43
Canmx	0	10	0.49	0.63
GW_REVAP	0.02	0.2	-0.46	0.64
SURLAG	0	10	-0.41	0.68
CH_K2	0	150	-0.35	0.73
REVAPMN	0	500	0.30	0.76

Using all 16 parameters changing default values





Monte Mor Basin Modelling Results

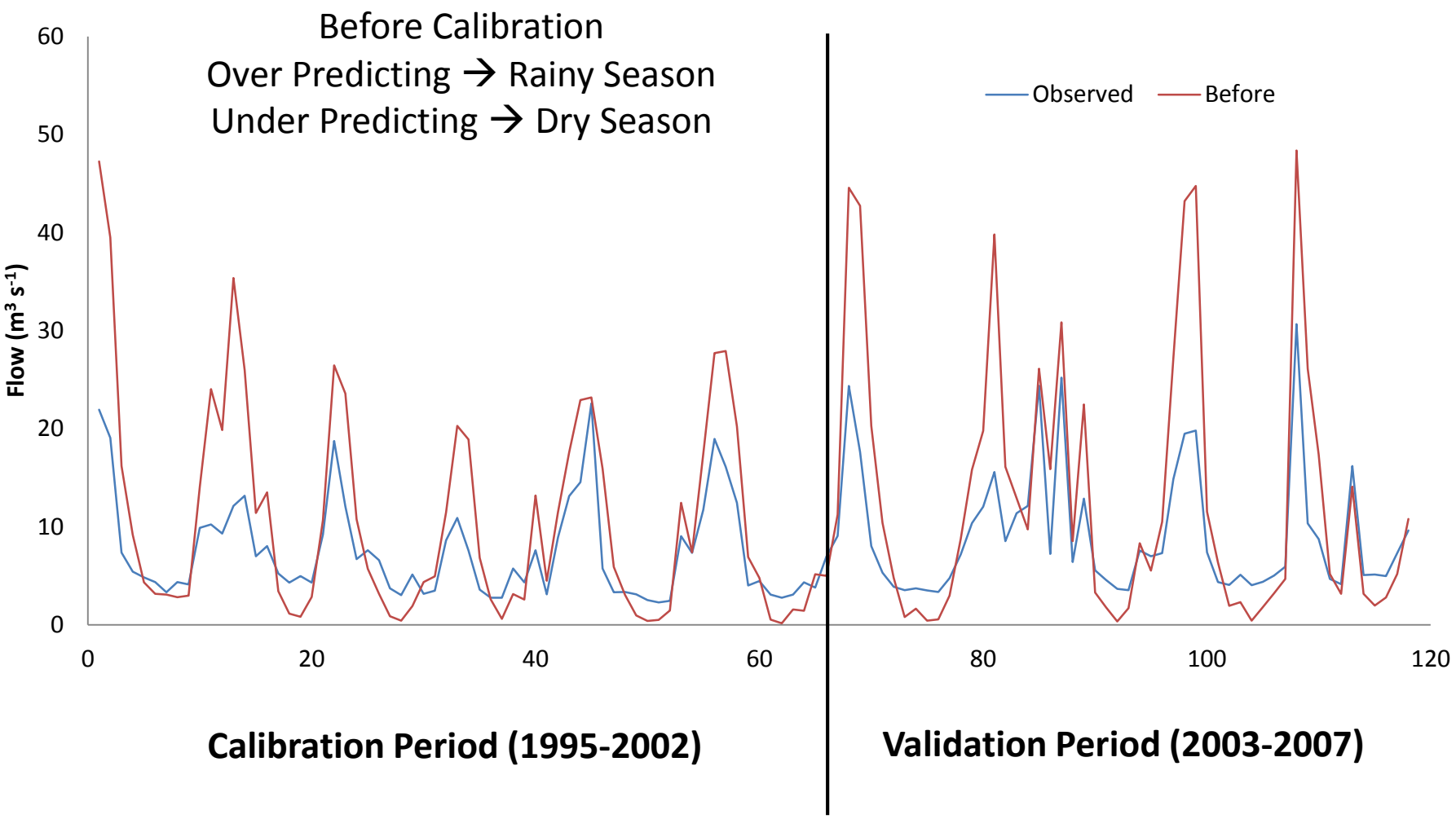
Values after SWAT-CUP SUFI2 calibration with 2000 simulations

Parameter	Method	Fit Value	Description	Units
CN2	Relative	-0.397	SCS runoff curve number for moisture condition 2	na
SOL_AWC	Relative	0.611	Available water capacity of the soil layer	mm mm^{-1}
SOL_K	Relative	0.946	Saturated hydraulic conductivity	mm h^{-1}
SOL_ALB	Relative	0.261	Moist soil albedo	na
SLSUBBSN	Relative	0.090	Average slope length	m
ESCO	Replace	0.787	Soil evaporation compensation factor	na
EPCO	Replace	0.112	Plant uptake compensation factor	na
CANMX	Replace	0.835	Maximum canopy storage	mm
CH_N2	Replace	0.825	Manning's "n" value for the main channel	na
CH_K2	Replace	90.905	Effective hydraulic conductivity in main channel alluvium	mm h^{-1}
SURLAG	Replace	5.676	Surface runoff lag time (day)	day
GW_DELAY	Replace	403.936	Groundwater delay	day
GW_REVAP	Replace	0.044	Groundwater "revap" coefficient	na
GWQMN	Replace	1723.817	Threshold depth of water in the shallow aquifer required for return flow to occur.	mm
ALPHA_BF	Replace	0.878	Baseflow alpha factor	day
REVAPMN	Replace	118.151	Threshold depth of water in the shallow aquifer for "revap" to occur.	mm

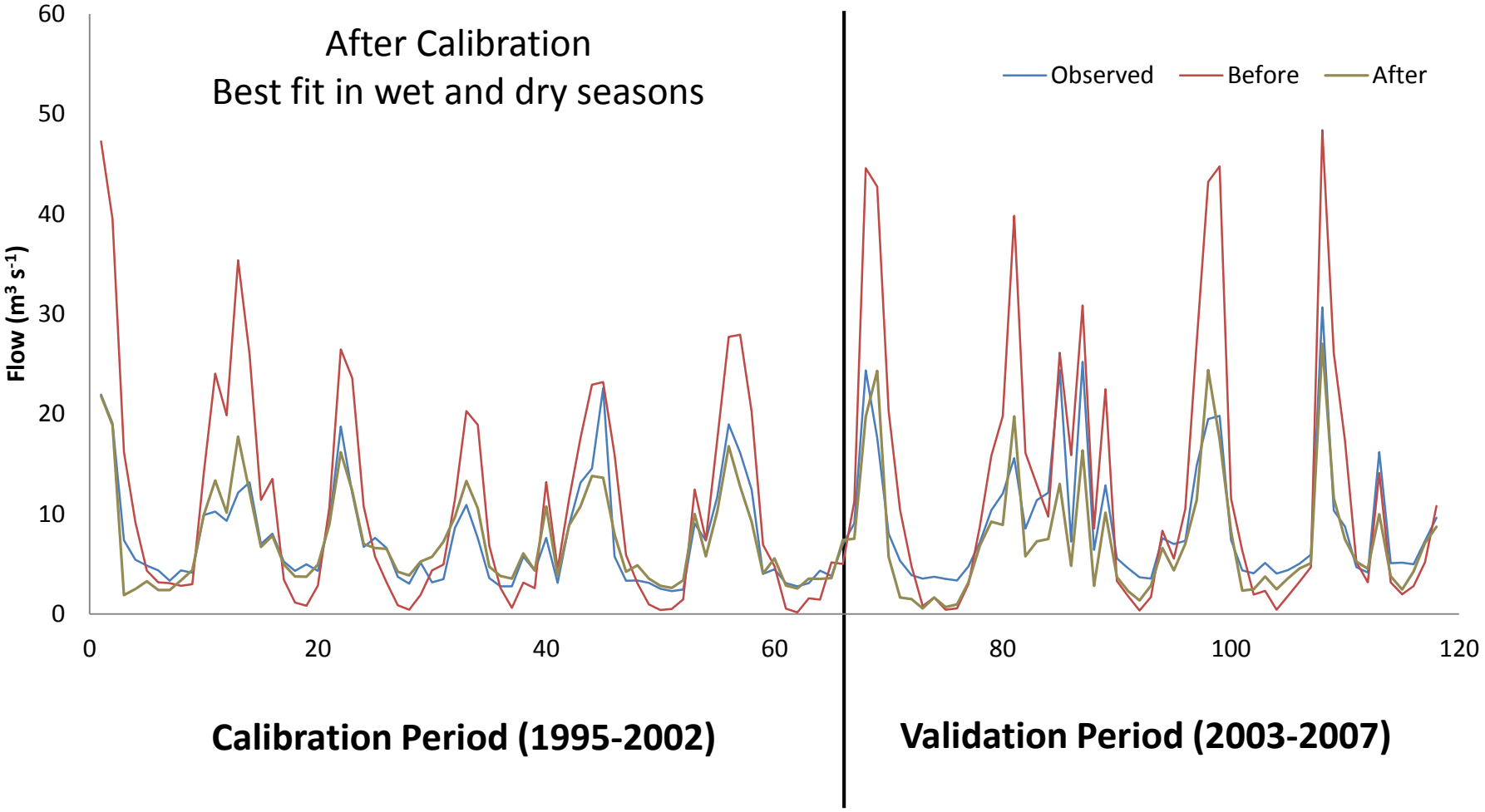
CN2 (-0.5 – 0.2); Soil Parameters (-0.1 – 1); SLSUBBSN (-0.2 – 1)

Replace changes → same max and min as global sensitivity

Monte Mor Basin Modelling Results



Monte Mor Basin Modelling Results



Monte Mor Basin Modelling Results

Calibration and validation results

Statistical Parameters	Calibration 1997-2002		Validation 2003-2007		Calibration + Validation 1997-2007	
R2	0.83	Satisfactory[(b)]	0.82	Satisfactory[(b)]	0.83	Satisfactory[(b)]
NS	0.83	Very Good[(a)]	0.74	Good[(a)]	0.78	Very Good[(a)]
RSR	0.42	Very Good[(a)]	0.51	Good[(a)]	0.47	Very Good[(a)]
PBIAS	1.4	Very Good[(a)]	19.8	Satisfactory[(a)]	10.3	Good[(a)]

[(a)] Moriasi et al., 2007
[(b)] Santhi et al., 2001

Monte Mor Basin Future Scenarios

Short-term Brazilian sugarcane expansion scenario (FS1)

Variable/parameter	Source
World GDP	World Bank
Brazilian GDP	World Bank
Oil prices	International Energy Agency - World Energy Outlook 2012
Brazilian population	IBGE - Brazilian Institute of Geography and Statistics
Sugarcane yield	Based on historical data - PAM (IBGE) - Municipal Agricultural Production
Total ethanol production	EPE - Energy Research Company
Total gasoline production	EPE - Energy Research Company

Predictions → BLUM
Brazilian Land Use Model

Sugarcane Expansion in 6 Macro Regions

Sugarcane expansion in Piracicaba Micro Region

Year	Sugarcane Area (ha)
2012	156,161
2013	163,894
2014	164,698
2015	167,930
2016	176,683
2017	184,440
2018	186,071
2019	186,071
2020	186,071
2021	186,071
2022	186,071
2023	186,071
2024	186,071
2025	186,071
2026	186,071
2027	186,071
2028	186,071
2029	186,071
2030	186,071

Stabilized Area

19.2%
Growth
(2012 – 2030)

Basin Physical Parameters

Monte Mor Basin Future Scenarios

Sugarcane expansion in Micro Region = Sugarcane Expansion in Monte Mor Basin

29210 hectares 554 hectares

Year	Sugarcane Area (ha)	Expansion	Source
1996	2114	0%	Land Use Map
2007	2430	15%	Land Use Map
2012	2889	37%	CANASAT
2018	3443	63%	BLUM

FS1

- (2012 – 2028) predicted increase of 42% → 2% of Monte Mor basin area
- Over pasture lands → 10% of pasture area replaced by sugarcane
- Only in subbasins with sugarcane

PBIAS -0.23

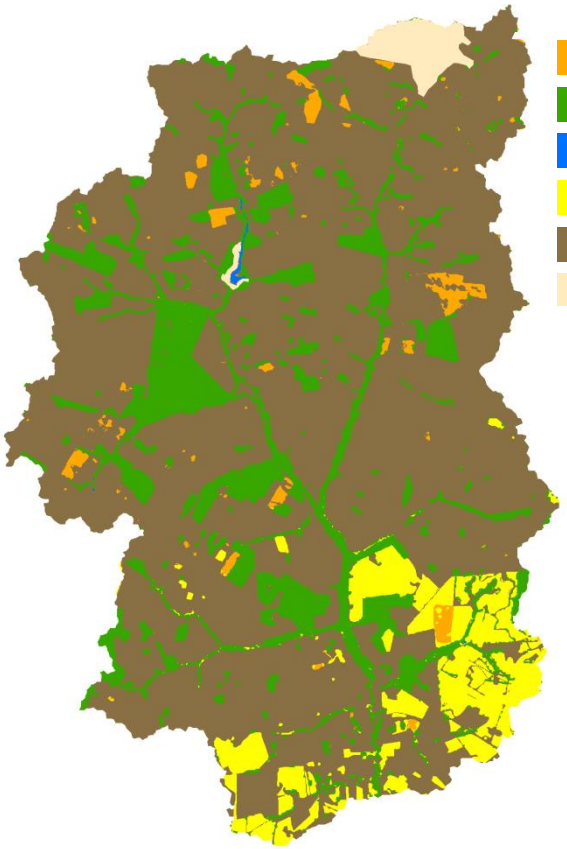
FS2

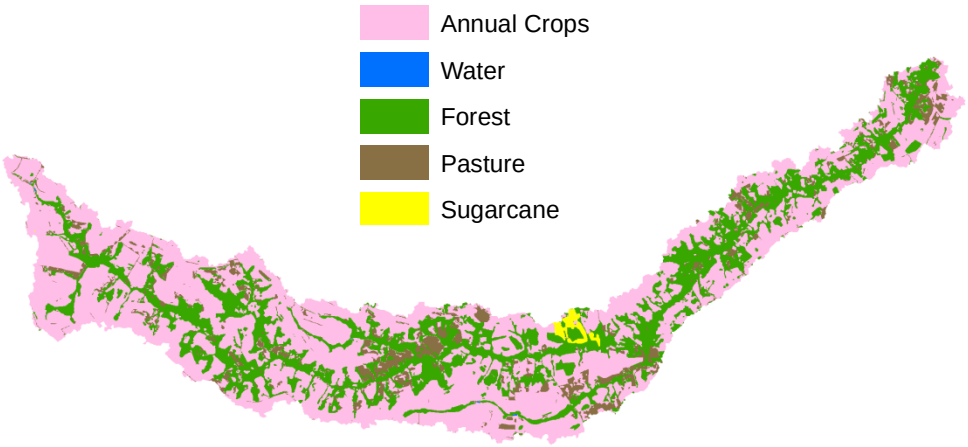
- Pasture area in subbasins with sugarcane were converted to sugarcane
- 12706 hectares
- 18% of the total basin area

PBIAS -3.69

Basins Future Scenarios

Ajice (São Paulo Expansion Area) & Fazenda Monte Alegre (Goiás Expansion Area)





Expected Expansion 2012-2030

Ajice → 136,550 hectares

Faz. Monte Alegre → 140,403 hectares

Thank You!

thayse.hernandes@bioetanol.org.br
thaysedourado@gmail.com

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