SWAT Soil & Water Assessment Tool

SWAT+ application to simulate and evaluate water management actions impacts on model performance and streamflow regime

Alejandro Sánchez-Gómez,
Aruca Pedrero-Redondo,
Eugenio Molina-Navarro

SWAT Conference

October 2025

Fort Collins, Colorado (US)

UCDAVIS
CIVIL AND ENVIRONMENTAL ENGINEERING

Universidad de Alcalá

Hydrological and Water management models

Hydrological models (SWAT, MIKE SHE, TOP Model, etc.).

- ✓ Focused on the simulation of **hydro-environmental processes.**
- ✓ Evaluation of water resources availability under climate change).
- agement actions.

- Common procedure → Coupling models (Hydrological models outputs used as inputs in Water management models)
- **Including the simulation of water management actions in hydrological models**

Water manageme
BASIN, WEAP, AC

ment actions.

valuate scenarios (e.g., demand increase).

× Most lack hydrological processes simulation (**require hydrological inputs**).

Water management simulation with SWAT+

SWAT+
SOIL & WATER ASSESSMENT TOOL

Decision tables

Water allocation module

Example res_rel.dtl file
1

CONDITIONS
ACTIONS CONFIGURATION
ALTERNATIVES
ACTIONS EXECUTION

name	conds	alts	acts
ex_rel_table	4	5	4

var	obj	obj_num	lim_var	lim_op	lim_const	alt1	alt2	alt3	alt4	alt5
month	null	0	null	-	6.00000	>=	<	-	-	-
month	null	0	null	-	8.00000	<=	-	>	-	-
vol	res	0	pvol	*	1.00000	<	<	<	>	-
vol	res	0	evol	*	0.95000	-	-	-	-	>

act_typ	obj	obj_num	name	option	const	const2	fp	outcome
release	res	0	summer_rate	rate	0.10000	0.00000	null	y n n n n
release	res	0	winter_rlse	inflo_frac	0.15000	0.00000	null	n y y n n
release	res	0	full_rlse	days	5.00000	0.00000	pvol	n n n y n
release	res	0	emerg_rlse	ab_emer	0.00000	0.00000	null	n n n n y

.DTL FILES IN SWAT+

lum.dtl file → **Land use management** (irrigation, harvest, etc.)
res_rel.dtl file → **Reservoir release**
flo_con.dtl file → **Water movements** (water transfers, irrigation, etc.)

Water management simulation with SWAT+

Decision tables

Water allocation module

- Allow to configure **water movements between SWAT+ objects** (irrigation, water transfers, diversions)

ugh decision tables

SWAT

SOIL & WATER ASSESSMENT TO

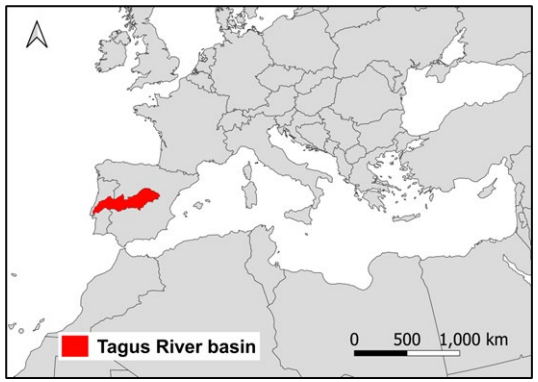
These novelties

- **Enhance the reliability** of the model when simulating regulated basins ✓
- Enhance the **capabilities and usefulness** of the model
  → Simulation of water management scenarios

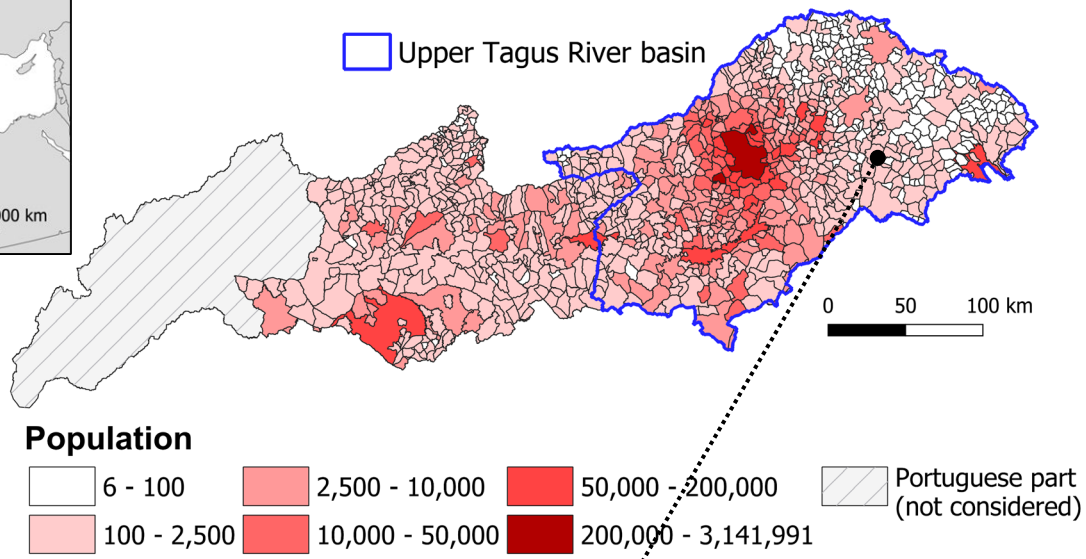
											IN OCT_MIN	NOV_MIN	DEC_MIN	
											0.01	0.01	0.01	
											SCRC1		FRAC1	COMP1
										1	1	1	1	n
										1	1	1	1	n
										1	1	1	1	n
										1	1	1	1	n
										1	1	1	1	n
										1	1	1	1	n
										1	1	1	1	n
										1	1	1	1	n
										1	1	1	1	n
10	hru	341	irr_crt	15	sr	null	null	null	0	null	1	1	1	n
11	hru	342	irr_crt	15	sr	null	null	null	0	null	1	1	1	n
12	hru	343	irr_crt	15	sr	null	null	null	0	null	1	1	1	n

SOURCES | MINIMUN WATER AVAILABILITY | DEMAND OBJECTS | DEMAND CONDITIONS

The Tagus River basin (TRB)



- International basin
- Most populated in the Iberian Peninsula (10 million inhabitants)

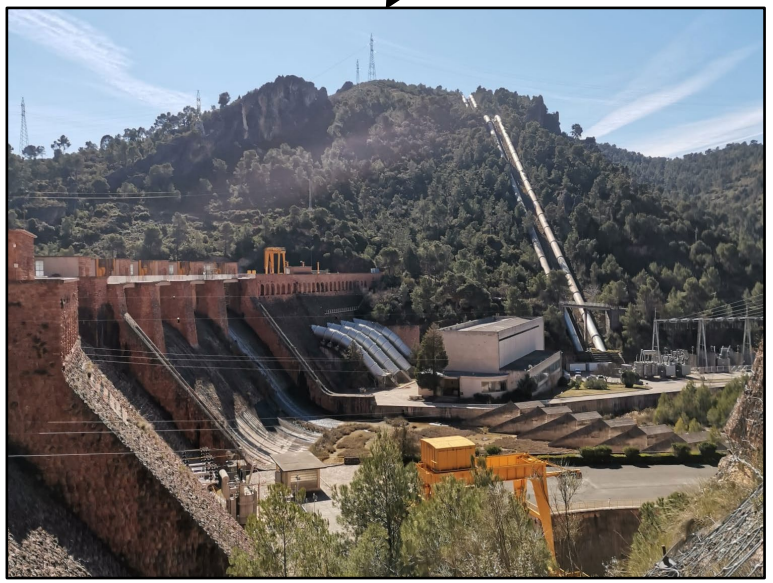


Upper Tagus River basin (UTRB)

41% of the TRB (34,000 km²)

Most populated part (7.5 million inhabitants)

Source of the Tagus Segura Water Transfer (TSWT, diverts 330 hm³/year)



The UTRB supplies most of the water demand in the TRB → **Priority region to assess water resources availability**

OBJECTIVES

Objectives

- Improving the simulation of water management in the UTRB using SWAT+

- Design, simulate and compare management scenarios impact on
  i) model performance and
  ii) streamflow regime

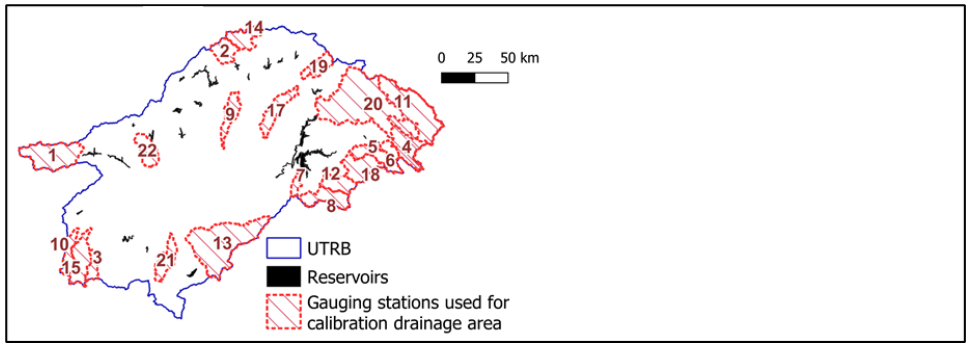
PREVIOUS WORK: DEVELOPING A REALISTIC MODEL

REALISTIC SIMULATION OF HYDROLOGICAL PROCESSES

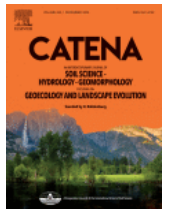
IMPLEMENTING THE SIMULATION OF WATER MANAGEMENT

Model calibration

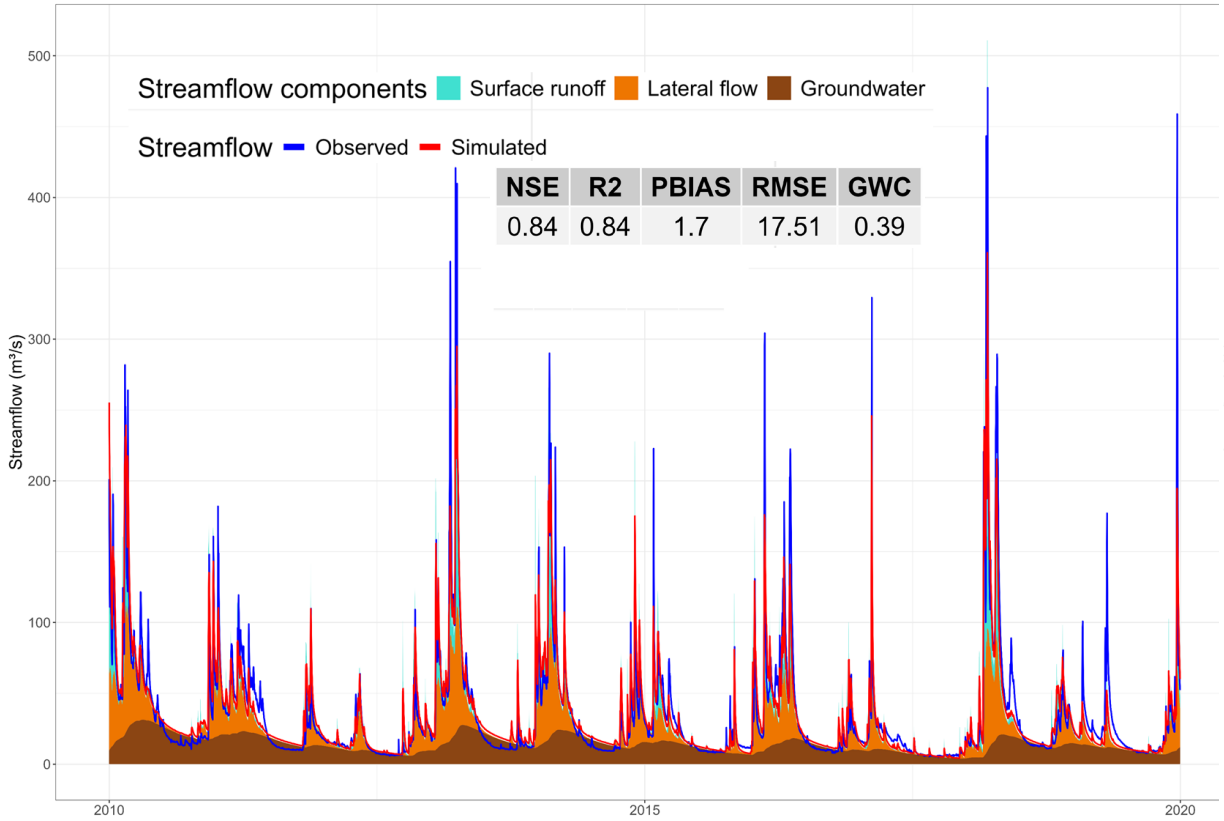
Model calibration → Zonal calibration (geological regions) and in natural regime areas



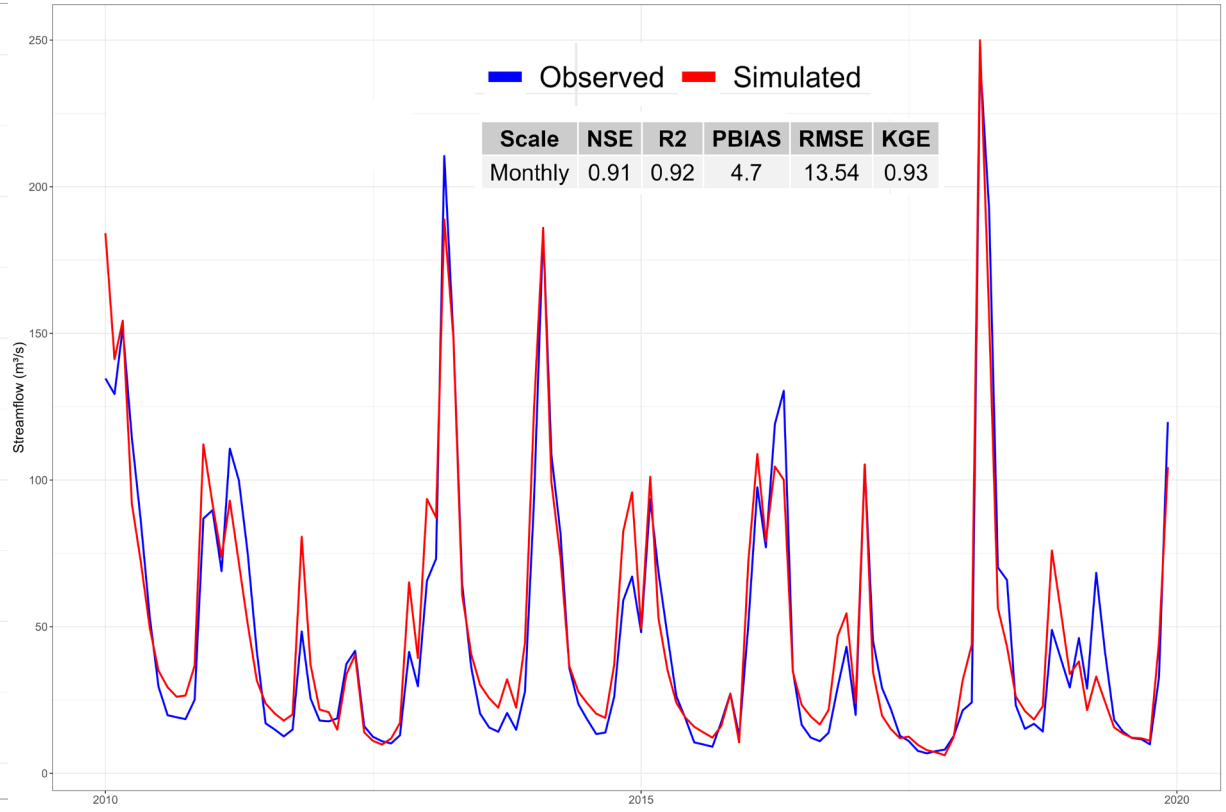
Sánchez-Gómez, A., et al. (2025). Multi-spatial and multi-criteria calibration to guarantee a robust SWAT+ hydrological model in a large and heterogeneous catchment. CATENA, 261, 109508.



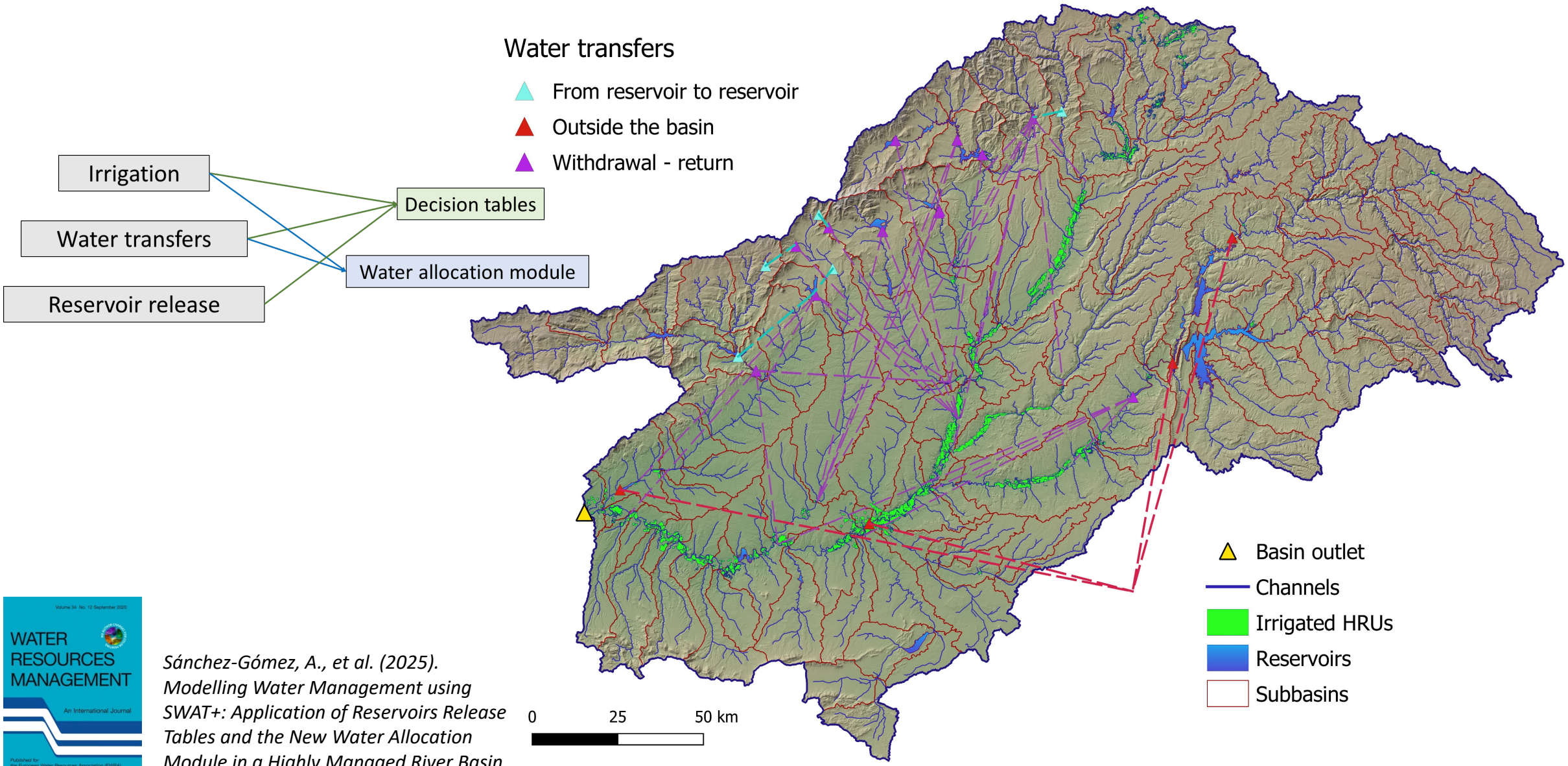
Aggregation of streamflow (daily) of calibrated sub-catchments



Aggregation of reservoirs inflow (monthly)



Water management in the UTRB



Sánchez-Gómez, A., et al. (2025). Modelling Water Management using SWAT+: Application of Reservoirs Release Tables and the New Water Allocation Module in a Highly Managed River Basin. Water Resources Management, 1-43.

IMPROVING MANAGEMENT IMPLEMENTATION

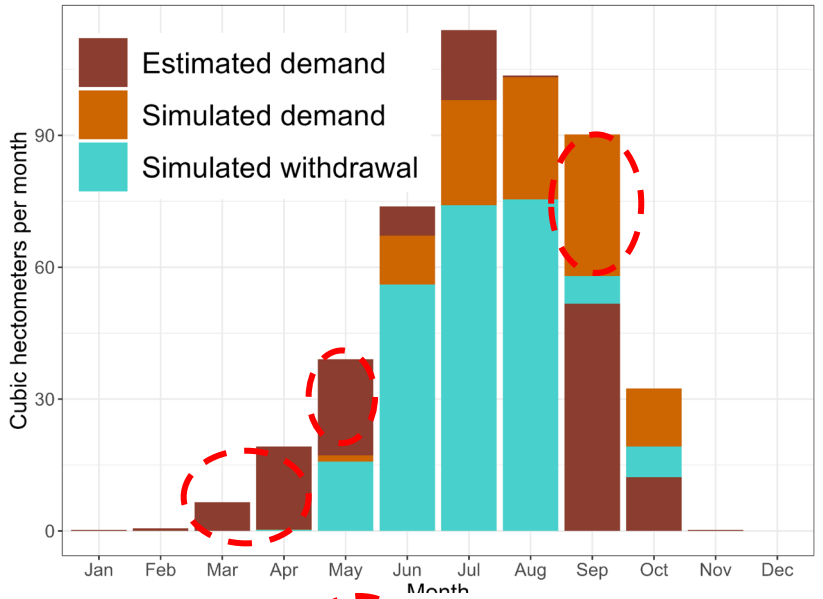
IRRIGATION

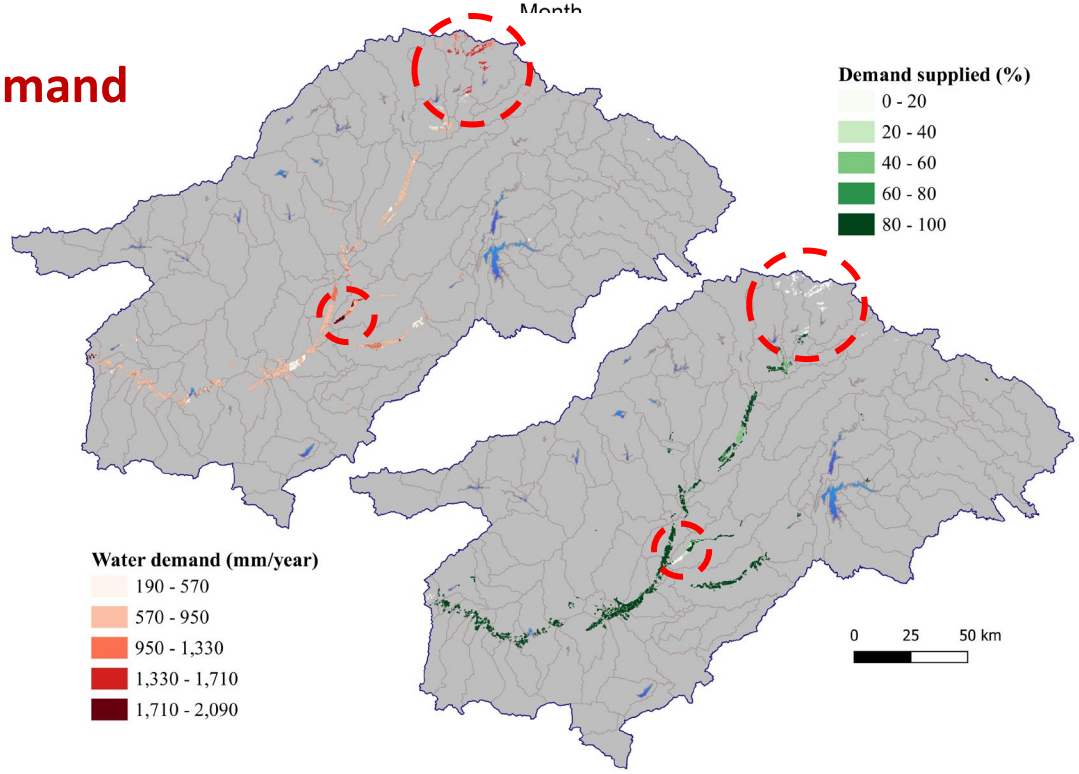
WATER TRANSFERS

Water management implementation: Room for improvement

Irrigation

- Simulated demand → **97% of the estimated**
- Simulated irrigation → **71% of the estimated demand**
- Simulated demand **timing** can be improved





Irrigation

Changes in irrigated HRUs

Irrigated HRUs were compared with different land-use datasets (CLC + SIOSE + Satellite image) →

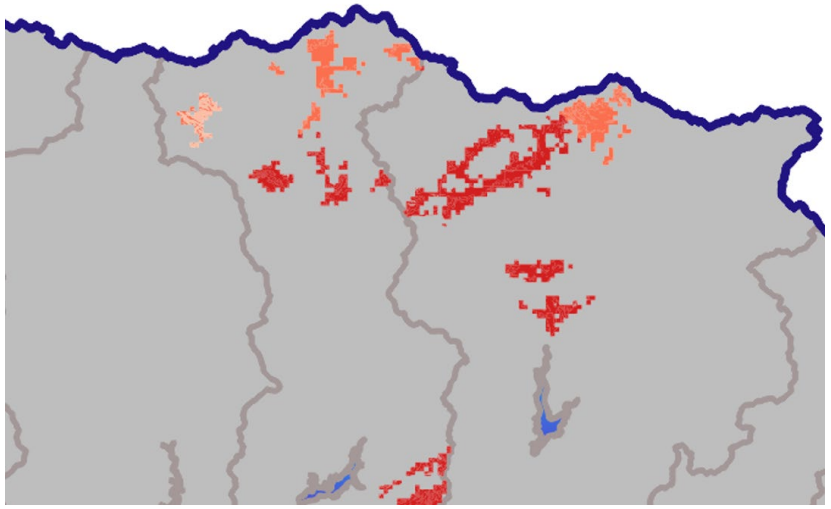
Some of the HRUs that were poorly irrigated were actually not irrigated crops →

Converted to rainfed cereals

Changes in plant management and parameters

Days to mature parameter reduced (from 150 to 120 days) to favour a **quicker development of the plant** (corn)

Plant cycle was **brought forward** by 15 days



Irrigation

Changes in water allocation file:

Previous water allocation tables → Closest channel was the only source

NAME	RULE_TYP	SRC_OBS	DMD_OBS	CHA_DB
channel_163_irrig	high_right_first_serve	1	4	y

SRC_NUM	OB_TYP	OB_NUM	JAN_MIN	FEB_MIN	MAR_MIN	APR_MIN	MAY_MIN	JUN_MIN	JUL_MIN	AUG_MIN	SEP_MIN	OCT_MIN	NOV_MIN	DEC_MIN
1	cha	163	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

NUMB	OB_TYP	OB_NUM	WITHDR	AMOUNT	W_RT	TR_TYP	TREAT	RCV_OB	RCV_NUM	RCV_DTL	SRCS	SRC1	FRAC1	COMP1	SCRC2	FRAC2	COMP2
1	hru	3674	irr_crt	12	sr	null	null	null	0	null	1	1	1	n			
2	hru	3675	irr_crt	12	sr	null	null	null	0	null	1	1	1	n			
3	hru	3676	irr_crt	12	sr	null	null	null	0	null	1	1	1	n			
4	hru	3677	irr_crt	12	sr	null	null	null	0	null	1	1	1	n			

Now → **Closest aquifers are used as secondary source** that compensate if demand is not fully supplied

Irrigation amount slightly modified

NAME	RULE_TYP	SRC_OBS	DMD_OBS	CHA_DB
channel_146_irrig	high_right_first_serve	2	4	y

SRC_NUM	OB_TYP	OB_NUM	JAN_MIN	FEB_MIN	MAR_MIN	APR_MIN	MAY_MIN	JUN_MIN	JUL_MIN	AUG_MIN	SEP_MIN	OCT_MIN	NOV_MIN	DEC_MIN
1	cha	163	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2	aqu	13	15	15	15	15	15	15	15	15	15	15	15	15

NUMB	OB_TYP	OB_NUM	WITHDR	AMOUNT	W_RT	TR_TYP	TREAT	RCV_OB	RCV_NUM	RCV_DTL	SRCS	SRC1	FRAC1	COMP1	SCRC2	FRAC2	COMP2
1	hru	3674	irr_crt	13	sr	null	null	null	0	null	2	1	1	y	2	0	y
2	hru	3675	irr_crt	13	sr	null	null	null	0	null	2	1	1	y	2	0	y
3	hru	3676	irr_crt	13	sr	null	null	null	0	null	2	1	1	y	2	0	y
4	hru	3677	irr_crt	13	sr	null	null	null	0	null	2	1	1	y	2	0	y

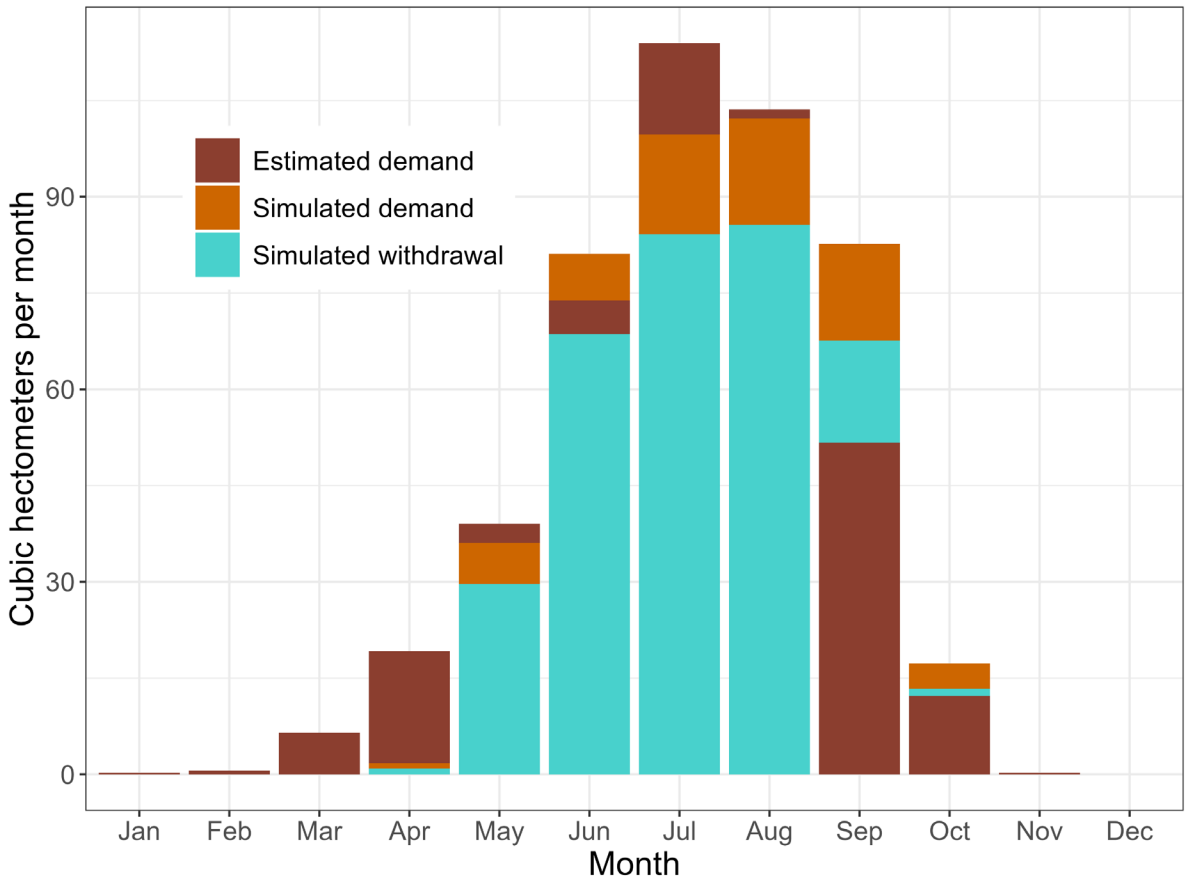
Irrigation improvement

Basin scale (average annual)

Variable	Model		Improvement (hm³)
	Previous	New	
Observed demand (hm³)	421	421	-
Simulated demand (hm³)	409	421	12
Simulated demand (%)	97.1	100	-
Simulated withdrawal (hm³)	299	350	51
Observed demand met (%)	71.0	83.1	-

- ✓ Improved demand simulation
- ✓ Noticeable improvement in the amount supplied
- ✓ Seasonality better reproduced

Basin scale (average monthly)



Water management implementation: Room for improvement

Water transfers

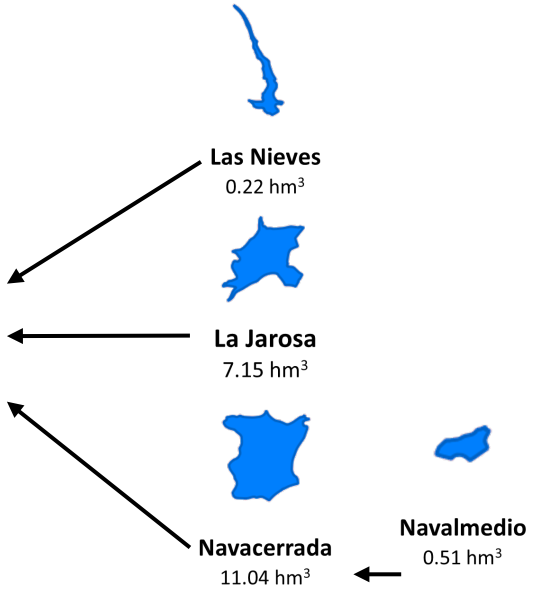
- Simulated demand → **100% of the estimated**
- Demand supplied → **90% of the demand (1,050 hm³/y)**
- **TSWT simulated at 80%**
- Some transfers had a **channel as source (small reservoirs not included in the model) → Poorly supplied**
- **No simulation of consumptive use →** All **water for human consumption** returned

Water transfer	Observed amount (hm³/year)	Simulated demand (hm³/year, % of observed)	Simulated water transfer (hm³/year)	Demand met (%)
TSWT	358.10	357.85 (100)	283.46	79.21
Atazar Canal	167.73	167.7 (100)	167.70	100.00
Valmayor Canal	100.33	100.26 (100)	88.21	87.98
Jarama Canal	88.82	88.82 (100)	86.08	96.91
Cazalegas irrigation Canal	78.80	78.82 (100)	77.64	98.50
Picadas and AMSO canals	69.00	68.54 (99)	67.28	98.16
San Juan Canal	64.26	64.31 (100)	64.31	100.00
Santillana Canal	51.94	51.97 (100)	51.97	100.00
El Vellón and Guadalix canals	32.79	32.72 (100)	32.72	100.00
El Villar Canal	30.02	30.02 (100)	30.02	100.00
Almoguera Canal	30.00	30.06 (100)	29.93	99.55
Las Nieves Canal	28.38	28.44 (100)	14.55	51.15
Trillo nuclear plant	18.00	18.74 (104)	18.74	100.00
La Jarosa Canal	14.79	14.78 (100)	5.86	39.67
Sorbe Canal	12.55	12.47 (99)	12.47	100.00
Navacerrada Canal	10.00	10.01 (100)	3.99	39.88
La Aceña Canal	9.81	9.78 (100)	9.78	100.00
Navalmedio Canal	4.65	4.66 (100)	4.36	93.62
La Pinilla Canal	3.72	3.64 (98)	3.64	100.00
Aceca power plant	0.80	0.79 (99)	0.79	100.00

Water transfers

Small source reservoirs introduced

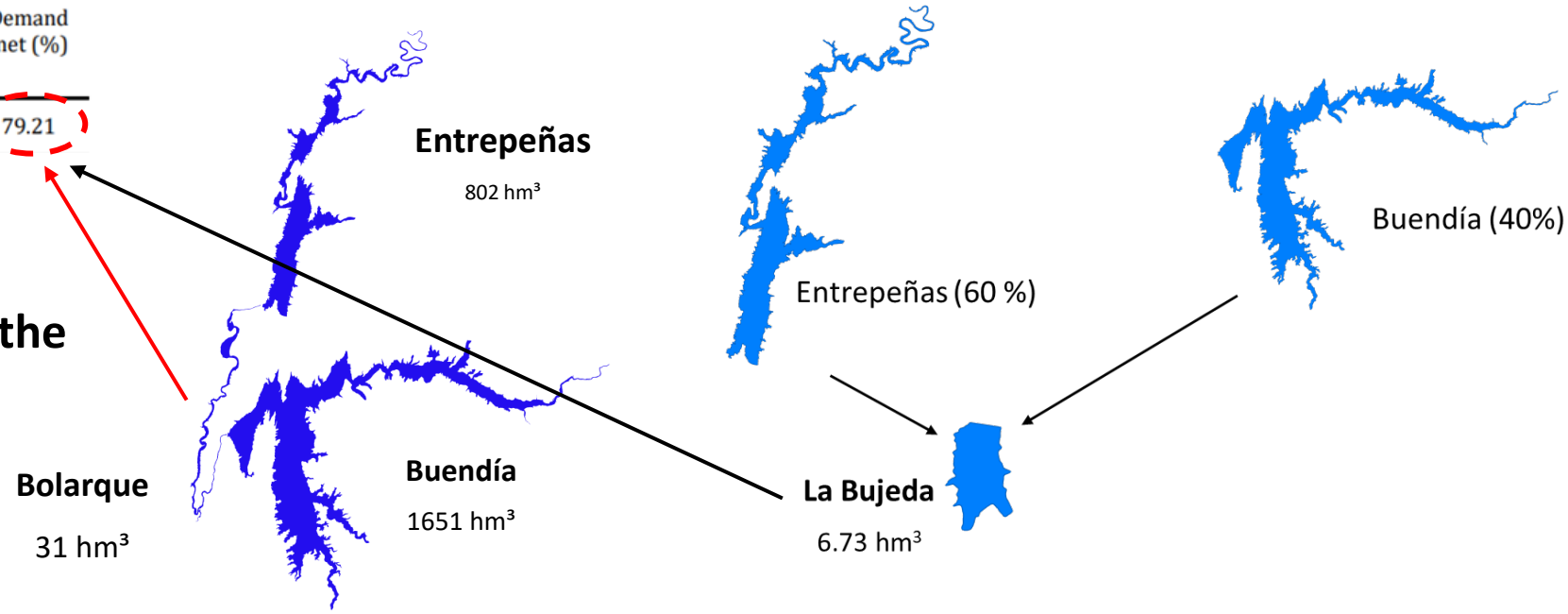
Water transfer	Observed amount (hm^3/year)	Simulated demand (hm^3/year, % of observed)	Simulated water transfer (hm^3/year)	Demand met (%)
Las Nieves Çanal	28.38	28.44 (100)	14.55	51.15
La Jarosa Canal	14.79	14.78 (100)	5.86	39.67
Navacerrada Canal	10.00	10.01 (100)	3.99	39.88



New configuration for the TSWT

Water transfer	Observed amount (hm^3/year)	Simulated demand (hm^3/year, % of observed)	Simulated water transfer (hm^3/year)	Demand met (%)
TSWT	358.10	357.85 (100)	283.46	79.21

- **New connections adapted in the water allocation file**



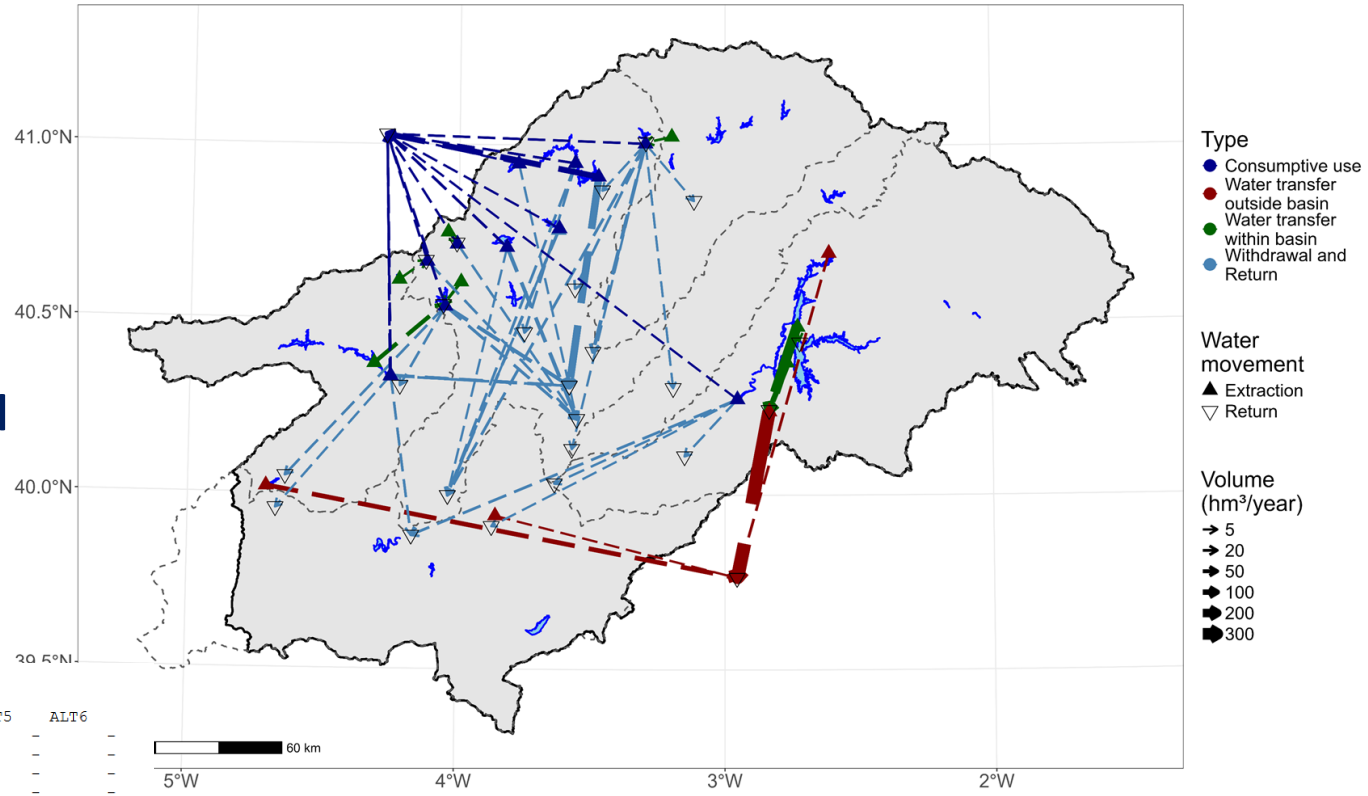
Water transfers

Including water consumption fraction

Before → **All water** for human consumption (~600 hm³) **returned** to the rivers

Now → Only 70 % return, and **30 % is removed (180 hm³)**

***flo_con* tables** duplicated →
To configure the **70-30 proportion**




```
NAME            CONDS   ALTS    ACTS
wr_jarama_1_ret     10   6   6
VAR             OBJ  OB_NUM LIM_VAR     LIM_OP      LIM_CONST              ALT1    ALT2   ALT3   ALT4    ALT5    ALT6
month           null      0    null         -       2.00000                  -       >      -      -       -       -
month           null      0    null         -       3.00000                  <       -      -      -       -       -
month           null      0    null         -       4.00000                  -       -      >      -       -       -
month           null      0    null         -       5.00000                  -       <      -      -       -       -
month           null      0    null         -       6.00000                  -       -      -      >       -       -
month           null      0    null         -       7.00000                  -       -      <      -       -       -
month           null      0    null         -       8.00000                  -       -      -      -       >       -
month           null      0    null         -       9.00000                  -       -      -      <       -       -
month           null      0    null         -      10.00000                  -       -      -      -       -       >
month           null      0    null         -      11.00000                  -       -      -      -       <       -
ACT_TYP         OBJ    OBJ_NUM   NAME           OPTION    CONST    CONST2     FP          OUTCOMES
divert          null      0  jm1_dvrt_1  flo_cms   0.012       0         null       y   n   n   n   n   n
divert          null      0  jm1_dvrt_2  flo_cms   0.022       0         null       n   y   n   n   n   n
divert          null      0  jm1_dvrt_3  flo_cms   0.024       0         null       n   n   y   n   n   n
divert          null      0  jm1_dvrt_4  flo_cms   0.013       0         null       n   n   n   y   n   n
divert          null      0  jm1_dvrt_5  flo_cms   0.003       0         null       n   n   n   n   y   n
divert          null      0  jm1_dvrt_6  flo_cms   0.006       0         null       n   n   n   n   n   y
```

Water allocation tables duplicated → Same source, but now 2 receiver objects (***consumptive*** and ***return***)

```
9    divert    1    wr_jarama_1_ret     0.0    sr    null    null    cha     155    null    1    3    1.0    n
9    divert    1    wr_jarama_1_cons    0.0    sr    null    null    cons    1      null    1    3    1.0    n
```

Water transfers improvement

Out
Withdrawal-return
Between reservoirs

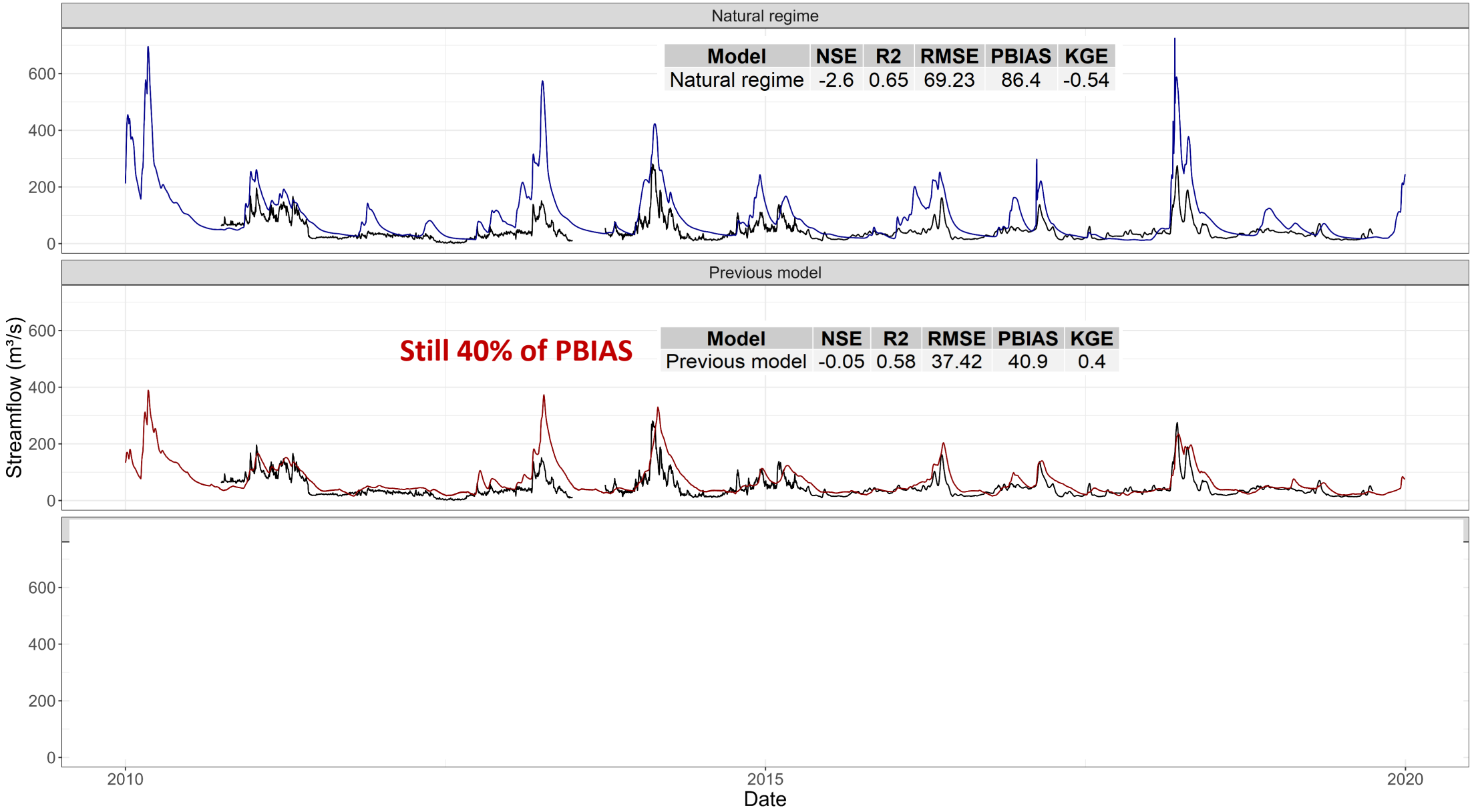
Individual water transfers

Water tranfer	Observed demand (hm^3/year)	Simulated demand (%)	Simulated transfer (% of observed)		Change	
			Previous model	New model	%	hm^3/year
TSWT	357.9	99.5	79.2			
Valmayor canal	100.3	99.5	88.0			
Las Nieves canal	28.4	99.8	51.3			
La Jarosa canal	14.8	99.5	39.6			
Navacerrada canal	10.0	99.7	39.9			

Basin scale

Model	Observed demand (hm^3/year)	Simulated demand (%)	Simulated transfer	
			(% of observed)	hm^3/y
Previous	1168.9	100	90.1	1053.5
New			97.5	1139.5
		Improvement	**7.4**	**86.0**

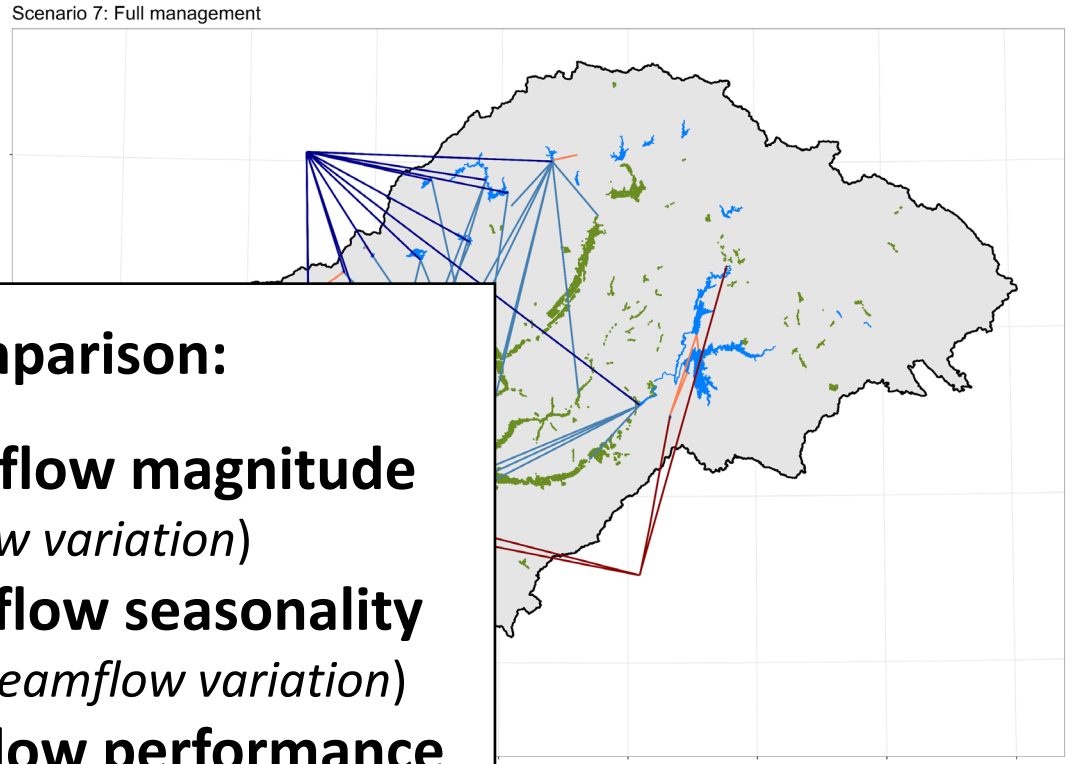
Basin outlet performance improvement



DESIGN AND SIMULATION OF WATER MANAGEMENT SCENARIOS

Management scenarios

Scenario	Reservoirs	Irrigation	Water transfers	
			Outside	Inside
7: Full management				



Scenarios comparison:

- Impact on **streamflow magnitude** (*aa streamflow variation*)
- Impact on **streamflow seasonality** (*average monthly streamflow variation*)
- Impact on **streamflow performance** (*UTRB outlet*)

Water transfers inside: Consumptive use

Water transfers inside: Return

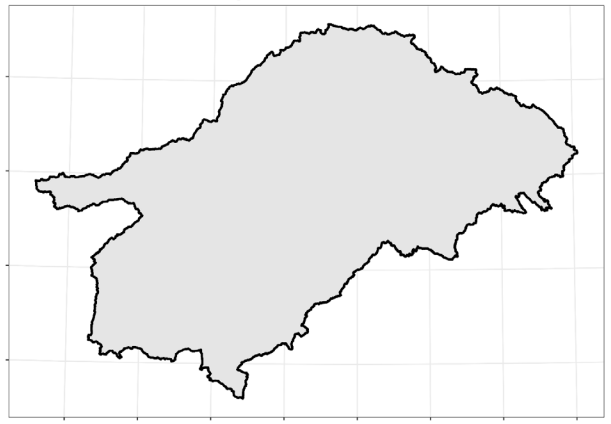
Water transfers between reservoirs

Water transfers outside

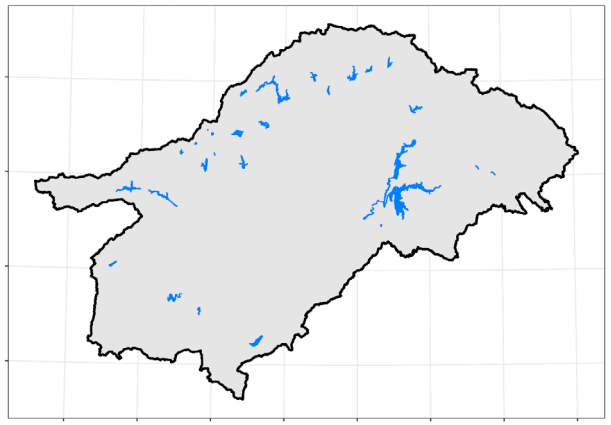
Impact on streamflow magnitude

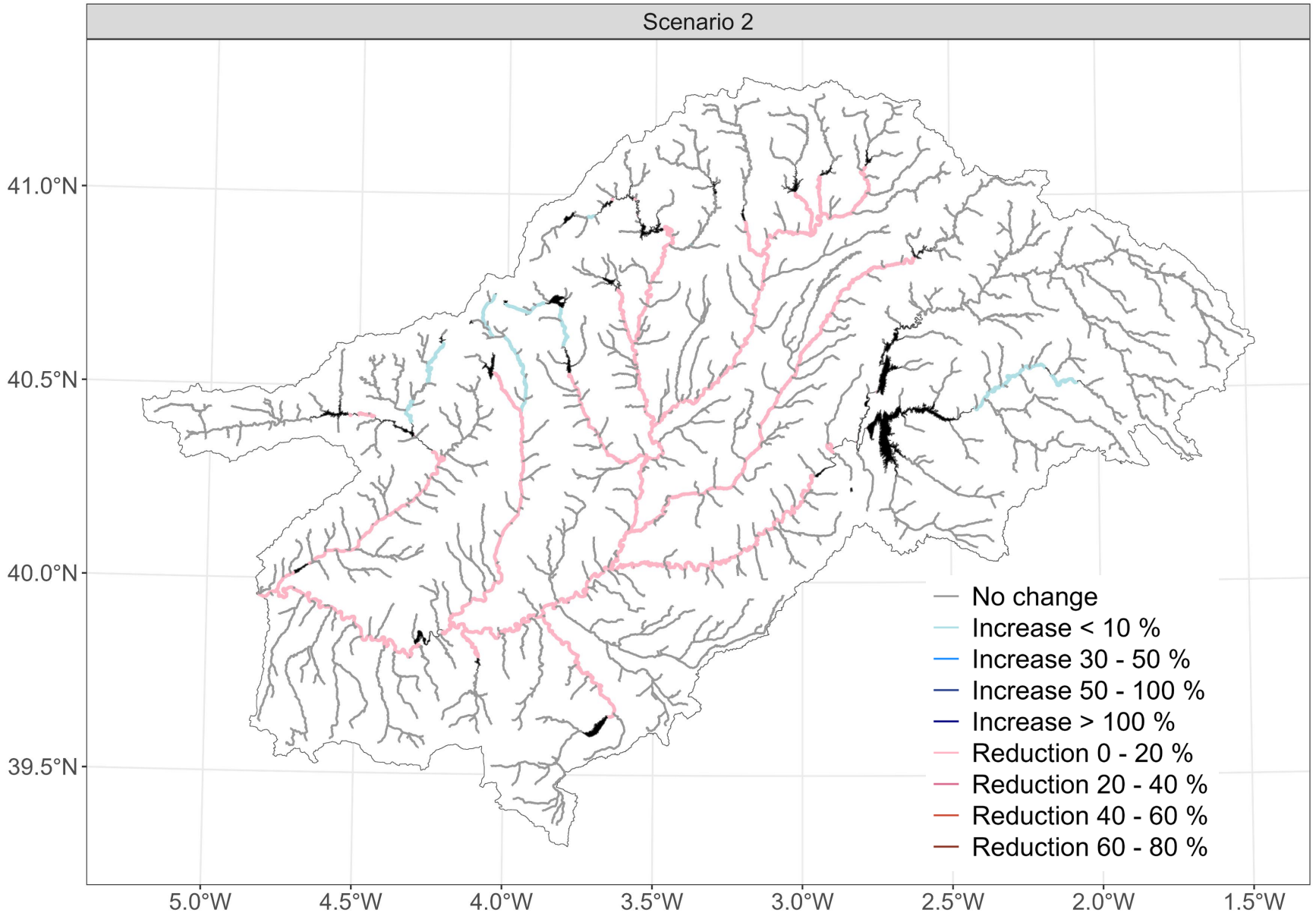
Reservoirs vs. Natural regime

Scenario 1: Natural regime



Scenario 2: Only reservoirs

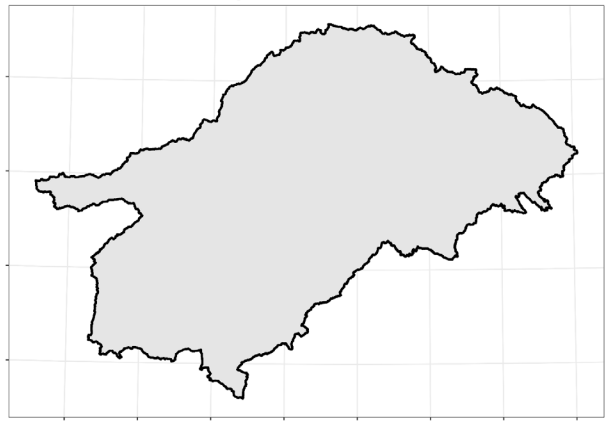




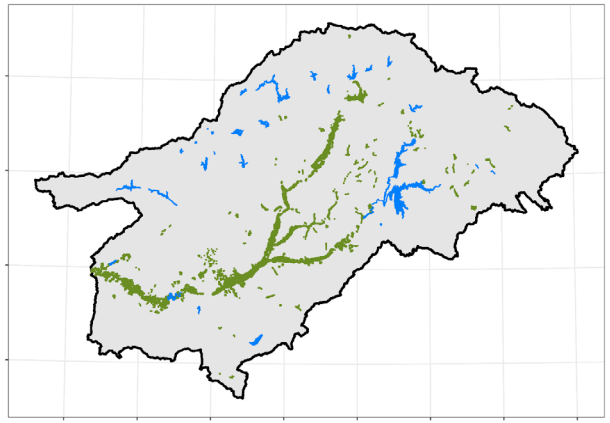
Impact on streamflow magnitude

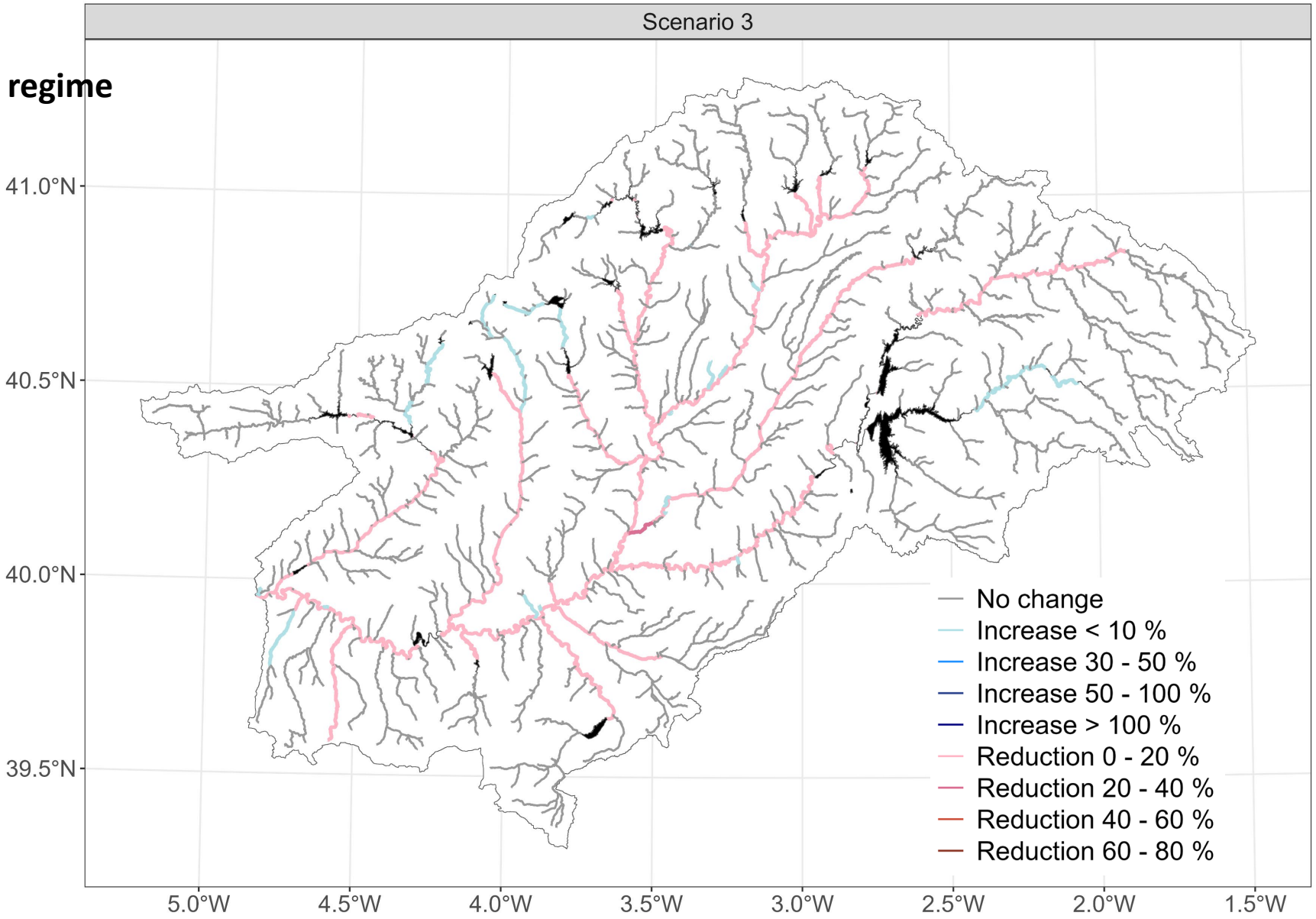
Reservoirs+Irrigation vs. Natural regime

Scenario 1: Natural regime



Scenario 3: Reservoirs and irrigation

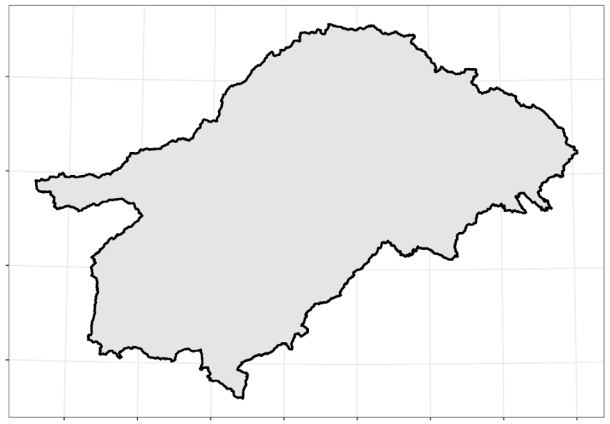




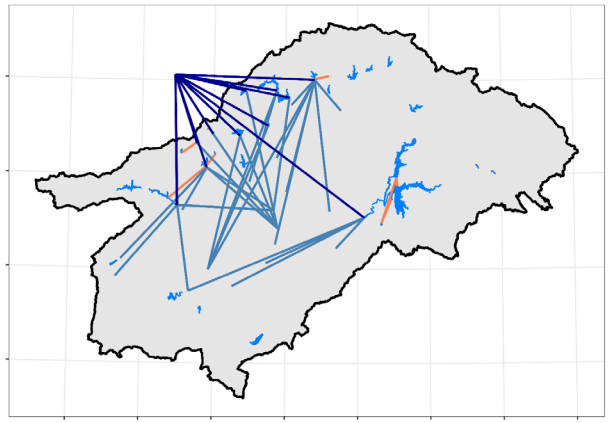
Impact on streamflow magnitude

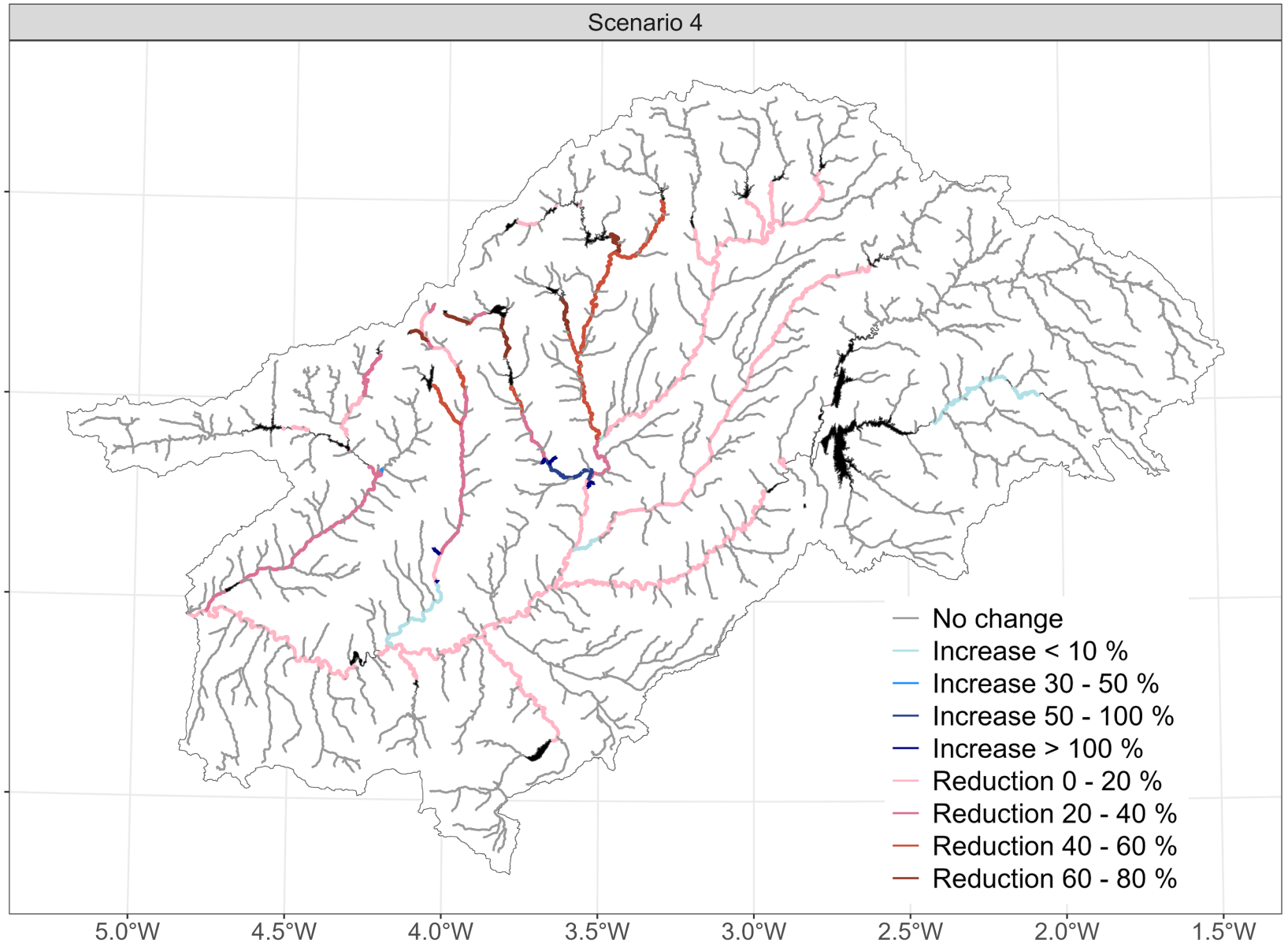
Reservoirs+WTI vs. Natural regime

Scenario 1: Natural regime



Scenario 4: Reservoirs and transfers inside the basin

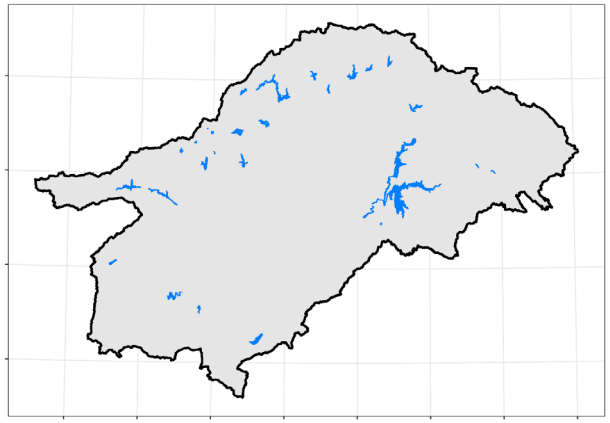




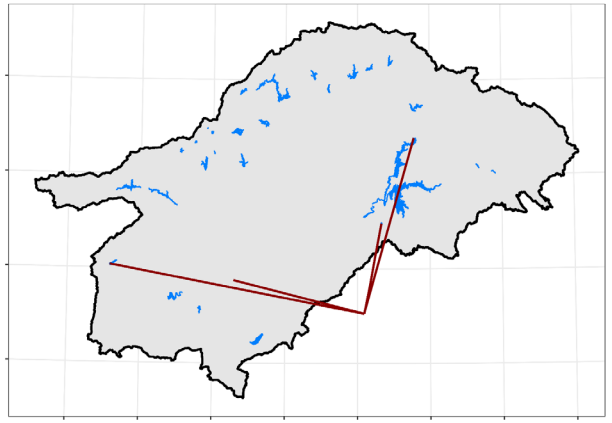
Impact on streamflow magnitude

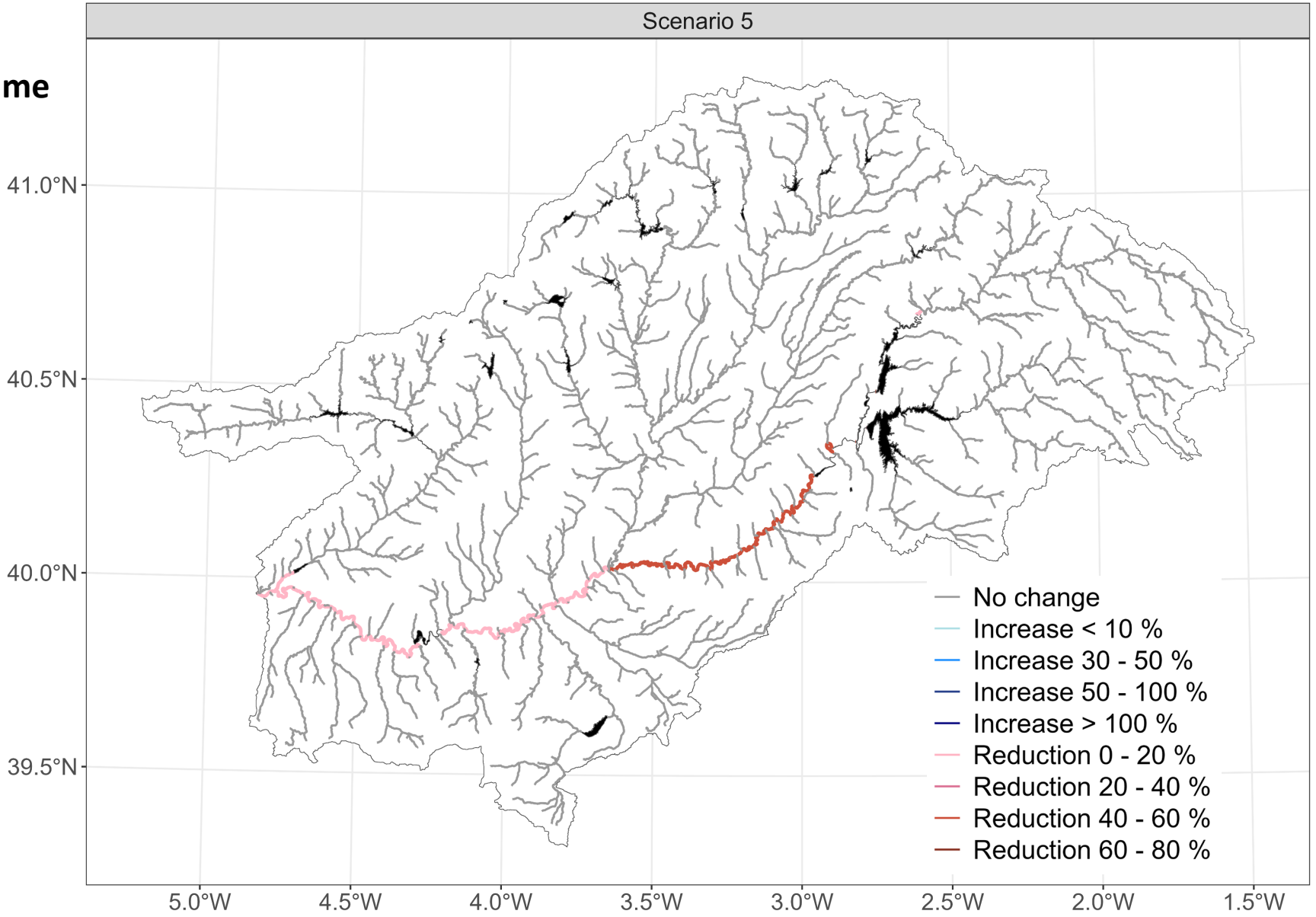
Reservoirs+WTO vs. Natural regime

Scenario 2: Only reservoirs



Scenario 5: Reservoirs and transfers outside the basin

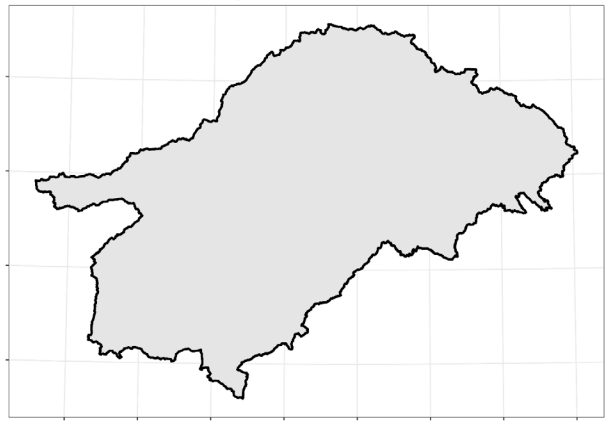




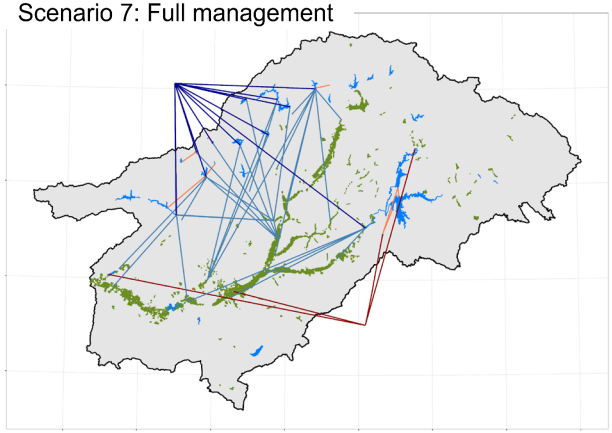
Impact on streamflow magnitude

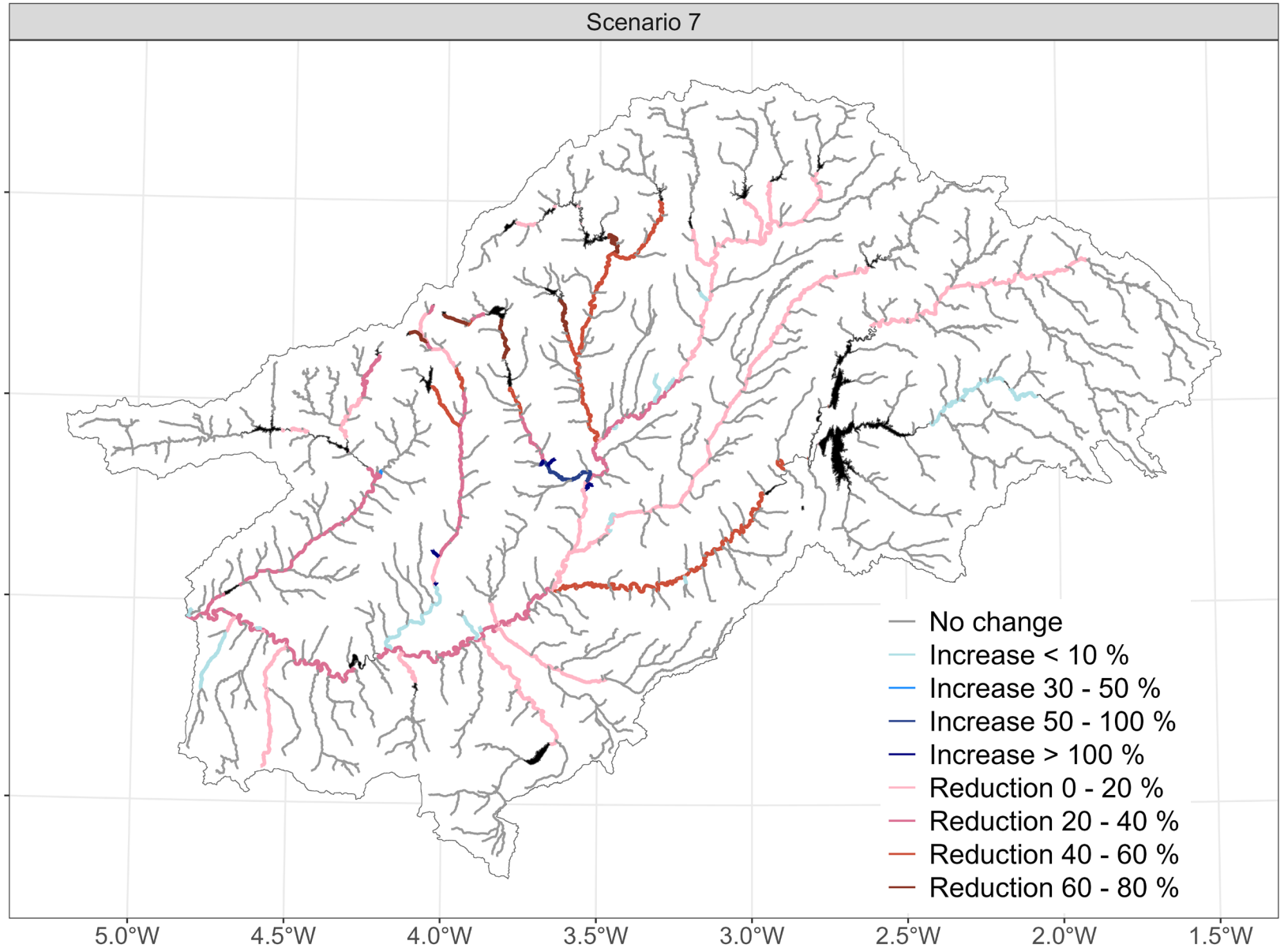
Full management vs. Natural regime

Scenario 1: Natural regime



Scenario 7: Full management





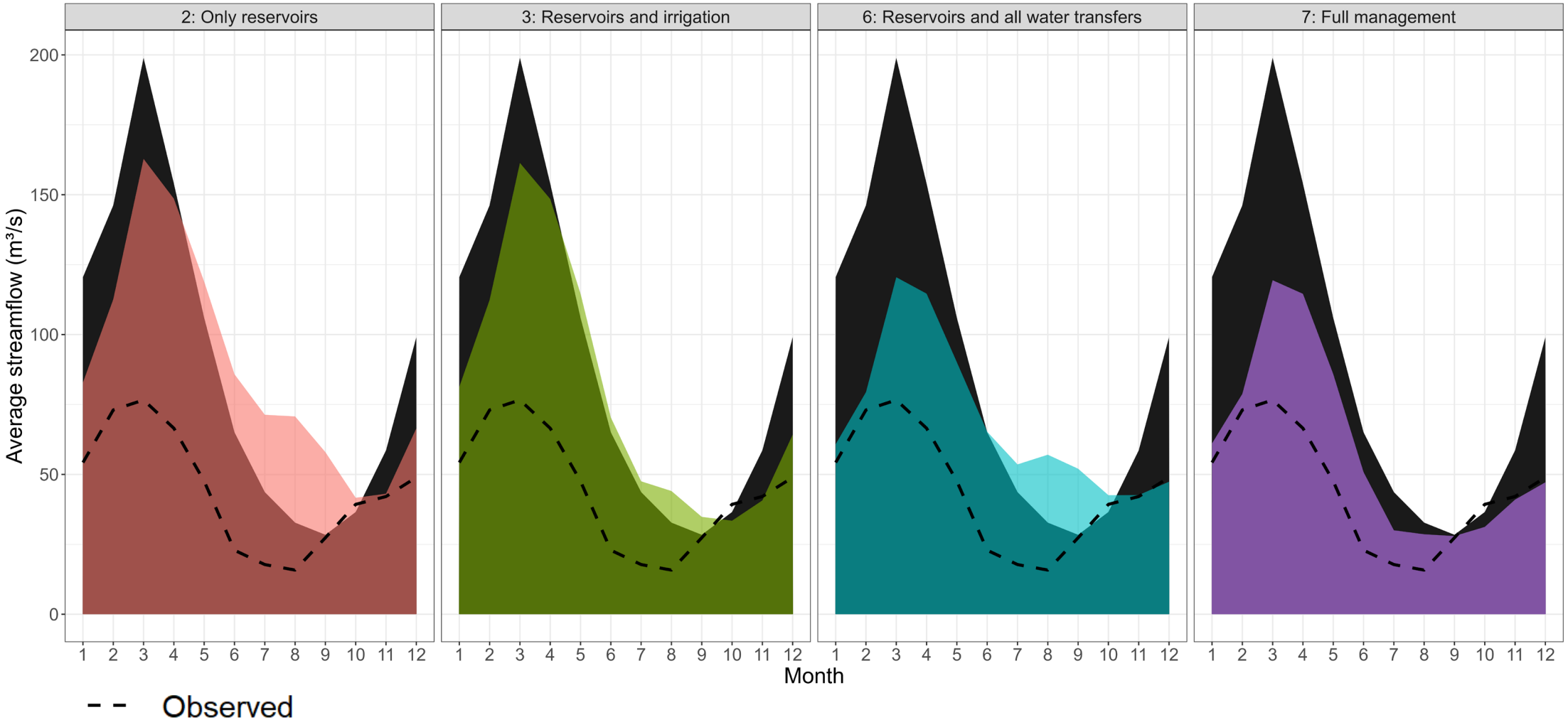
Impact on streamflow magnitude

Average streamflow at basin outlet:

Scenario	Basin discharge (hm^3/y)	Change regarding natural regime (%)
1: Natural regime	2843	-
2: Only reservoirs	2776	-2
3: Reservoirs and irrigation	2488	-12 Irrigation
4: Reservoirs and transfers inside the basin	2600	-9 Consumptive use
5: Reservoirs and transfers outside the basin	2331	-18 WT Outside (TSWT)
6: Reservoirs and all water transfers	2158	-24
7: Full management	1871	-34

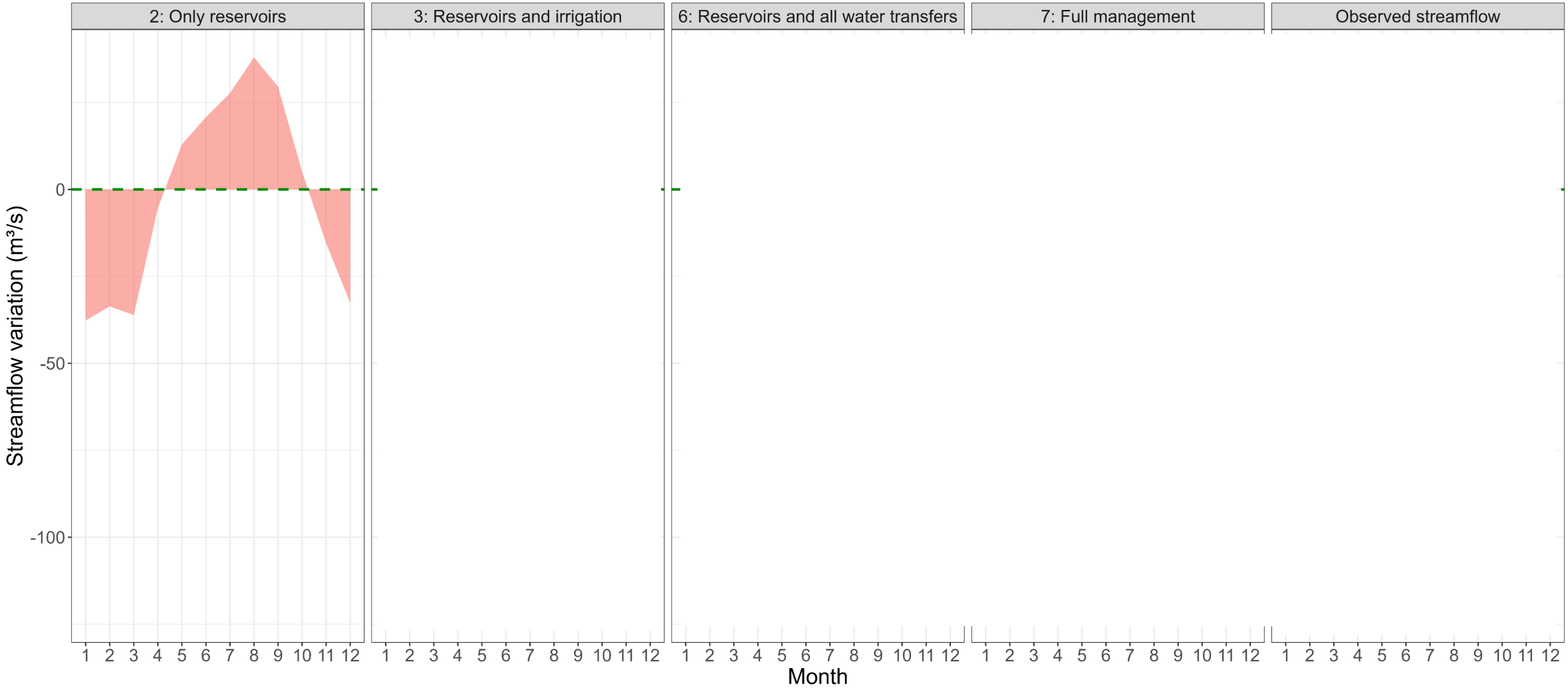
Impact on streamflow regime

Average monthly streamflow: Natural regime vs. Scenarios and observed



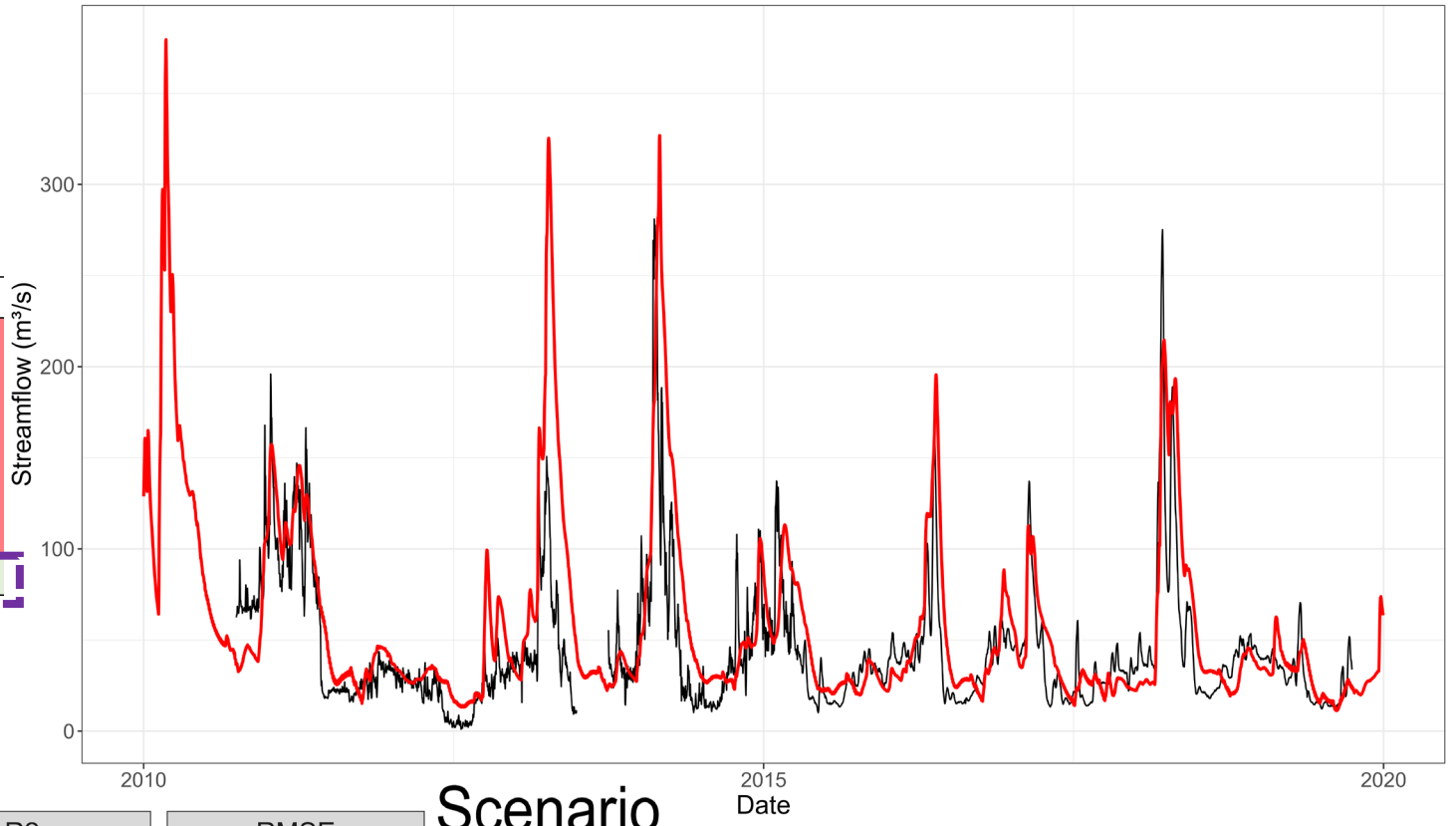
Impact on streamflow regime

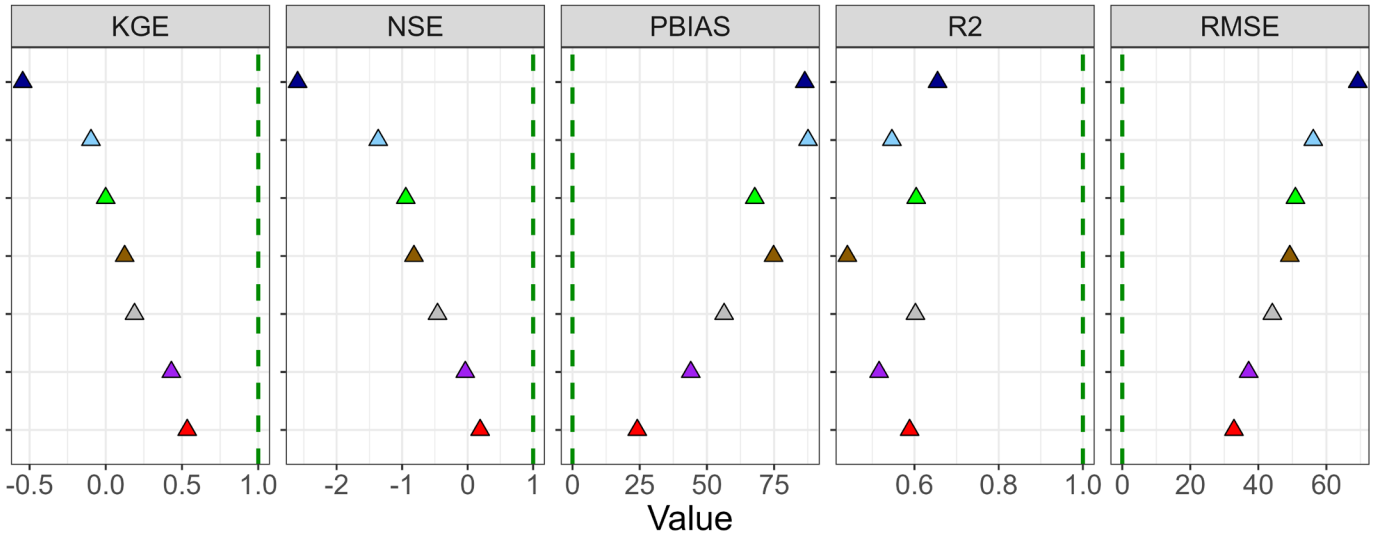
Variation of monthly streamflow: Scenarios and observed vs. Natural regime scenario

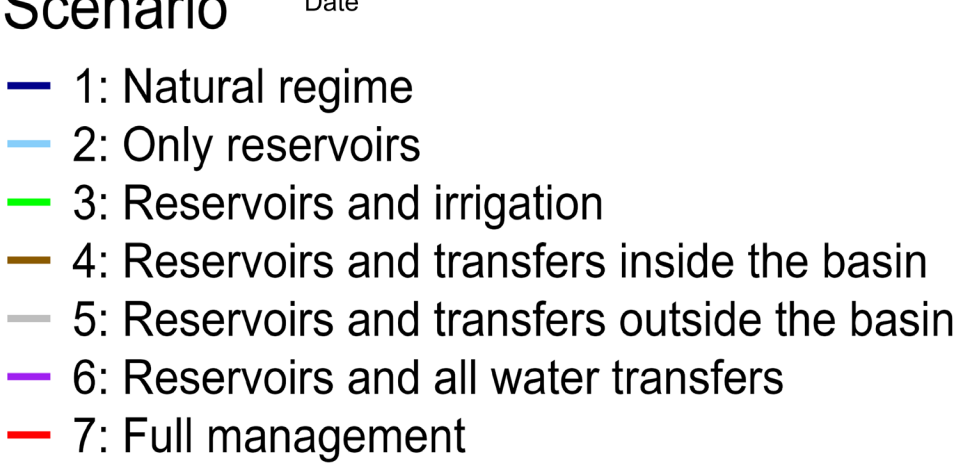


Impact on model performance

Scenario	NSE	R^2	RMSE	PBIAS	KGE
1: Natural regime	-2.6	0.65	69.2	86.4	-0.54
2: Only reservoirs	-1.36	0.55	56.1	87.6	-0.1
3: Reservoirs and irrigation	-0.94	0.6	50.9	67.8	0
4: Reservoirs and transfers inside	-0.82	0.44	49.2	74.8	0.12
5: Reservoirs and transfers outside	-0.46	0.6	44.1	56.4	0.19
6: Reservoirs and all water transfers	-0.04	0.52	37.2	44	0.43
7: Full management	0.19	0.59	32.8	24.1	0.53







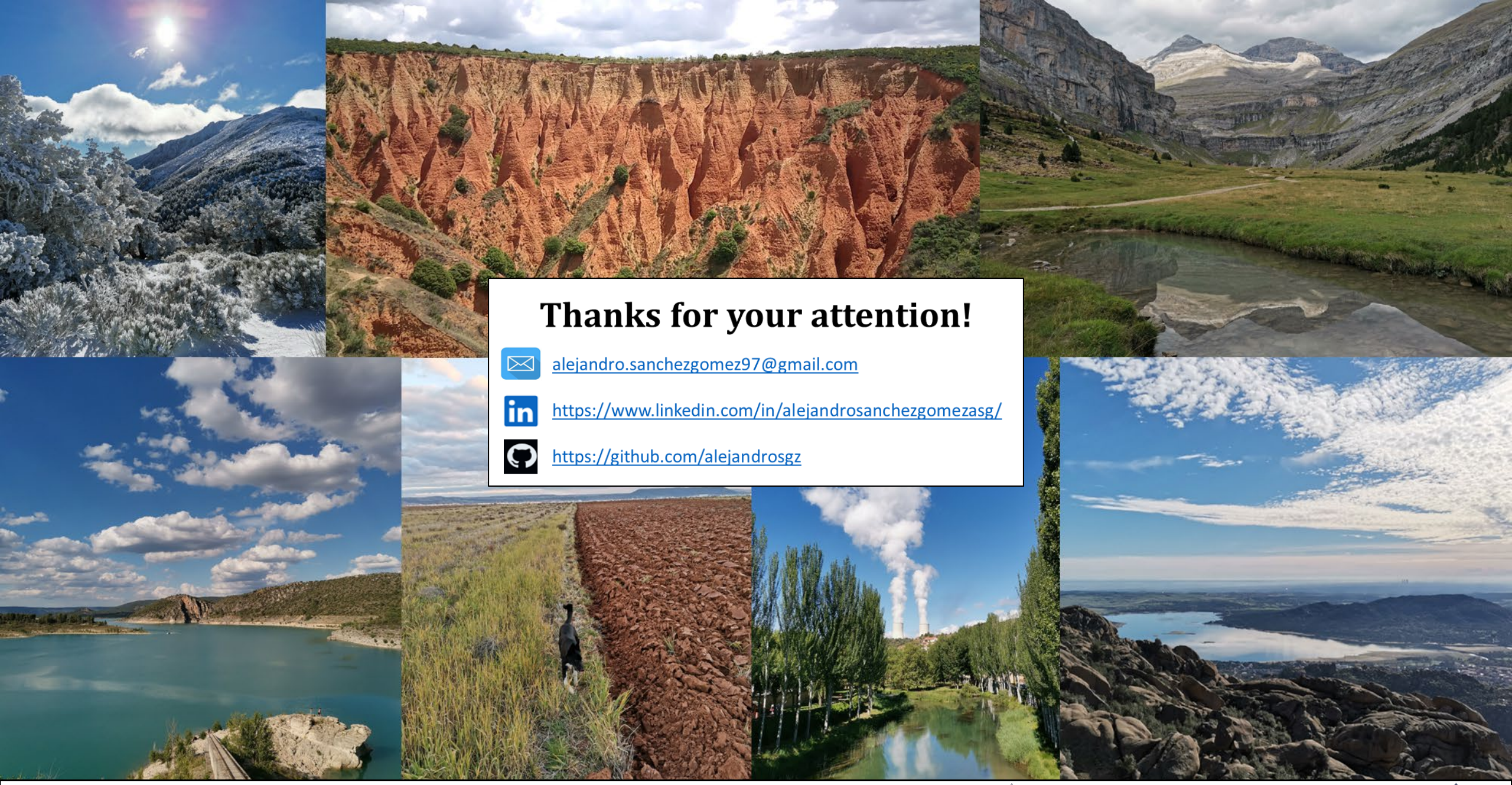
CONCLUSIONS

The implementation of management actions was improved compared to the previous model.

- **Irrigation demand** (+12 hm^3/y) and **water supply** (+51 hm^3), as their **timing,** were better simulated.
- **Water transfers simulation was increased** by 86 hm^3 (7 % of total demand), enhancing the simulation of **some key transfers such as the TSWT**.
- Despite some room for improvement (further work), the **streamflow simulation** at the end of the catchment **was noticeably improved** (PBIAS reduced to satisfactory values).

Six water management scenarios were compared with a natural regime one.

- Water management **impacted streamflow** in a large extent, **both in magnitude and seasonality**. The **impact of water transfers outside the basin** was found the largest (-18 % of streamflow at the outlet compared to natural regime), followed by irrigation (-12 %) and water consumption (9 %).
- The **impact on the seasonality** clearly **differs among scenarios**.
- The **simulated impact is still lower than the observed** (bias in simulated streamflow + bias in simulated management).



Thanks for your attention!

alejandro.sanchezgomez97@gmail.com

https://www.linkedin.com/in/alejandrosanchezgomezasg/

https://github.com/alejandrosgz

SWAT Soil & Water Assessment Tool

Universidad de Alcalá

UCDAVIS CIVIL AND ENVIRONMENTAL ENGINEERING

Cofinanciado por la Unión Europea

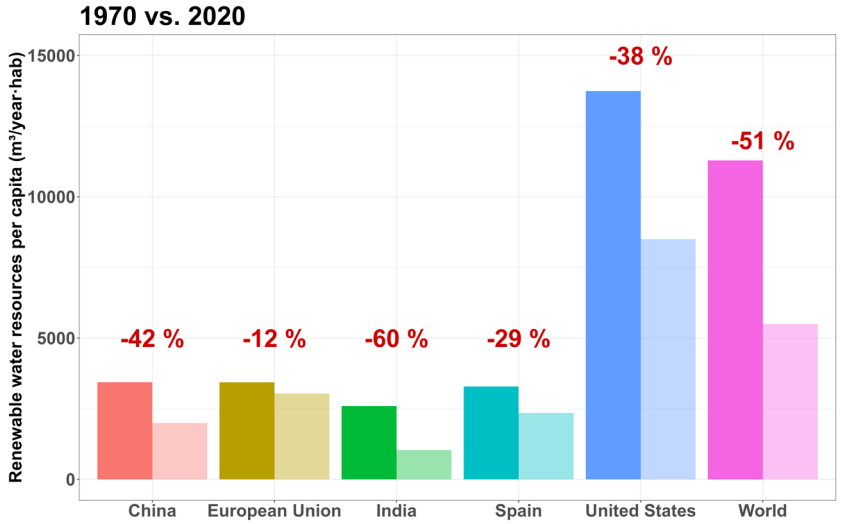
MINISTERIO DE HACIENDA Y FUNCIÓN PÚBLICA

Fondos Europeos

Castilla-La Mancha

Water resources and their management

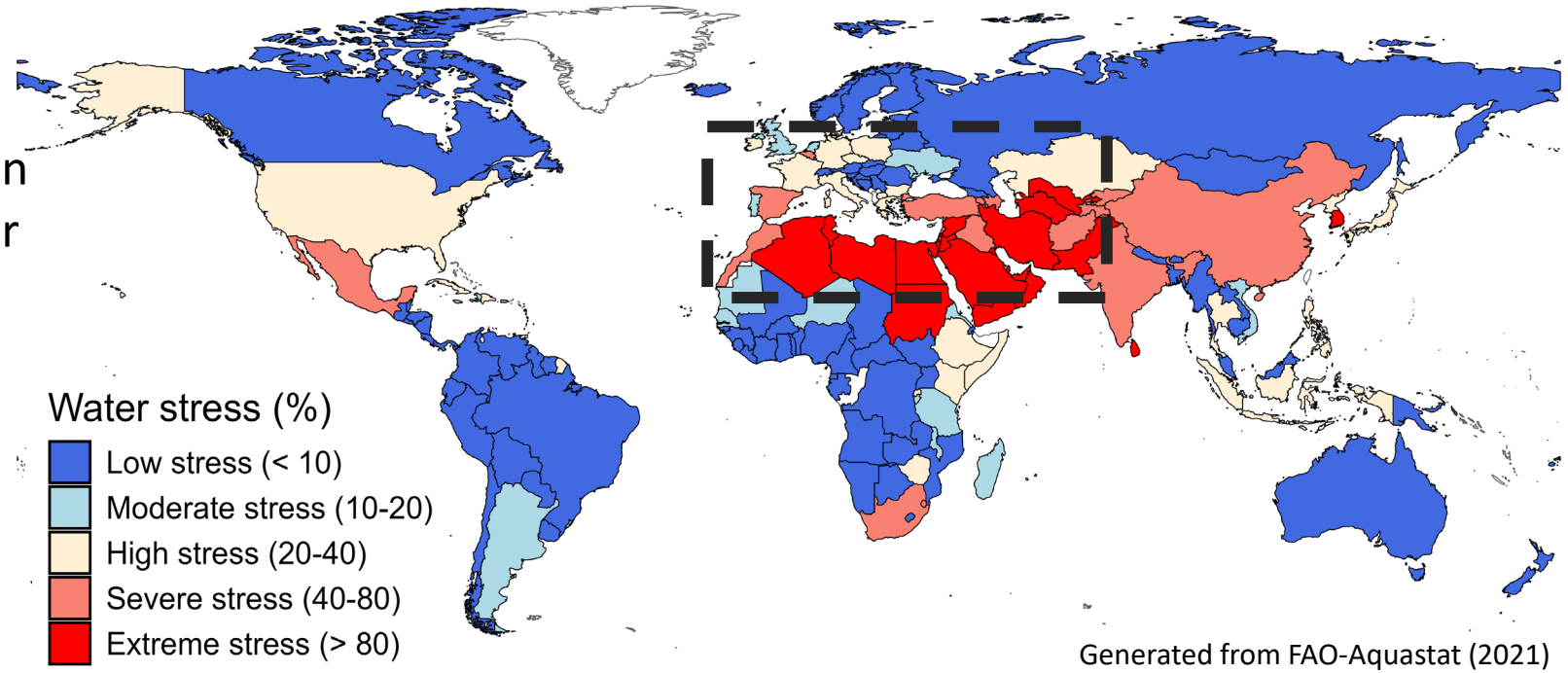
Water resources per capita →
Halved in the last 50 years
(FAO-Aquastat, 2021)



Generated from FAO-Aquastat (2021)

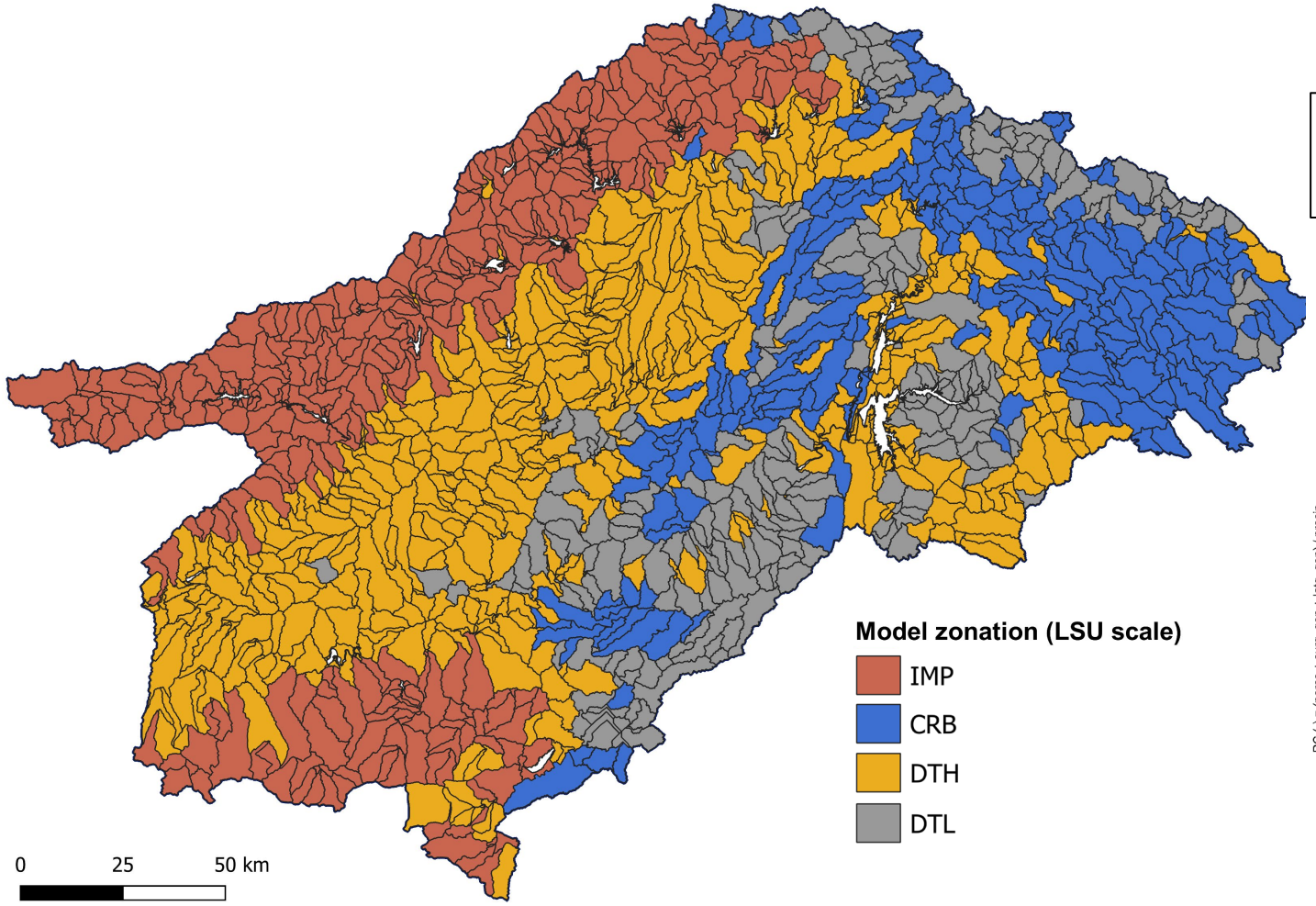
Severe water stress →
Affects 2/3 of the world population
at least during one month per year
(Mekonnen & Hoekstra, 2016)

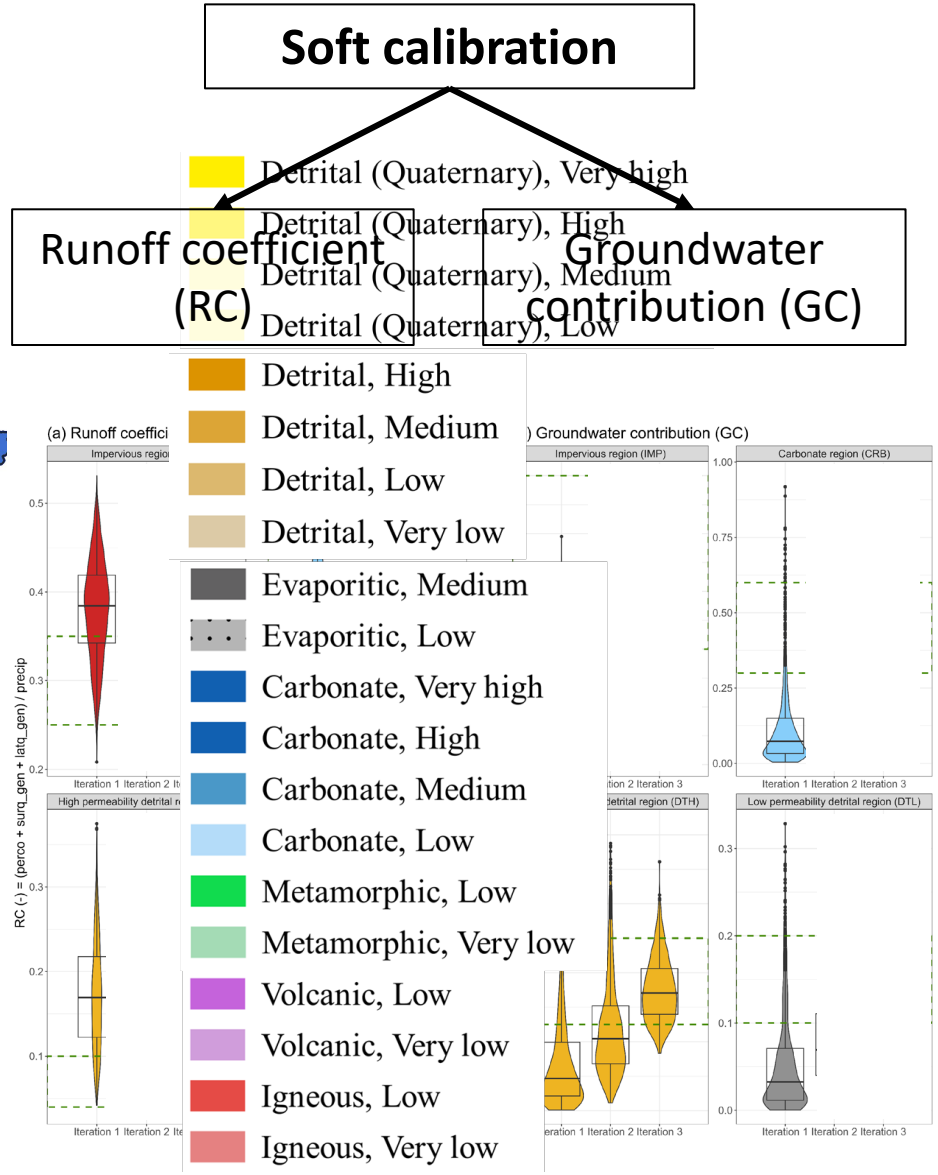
$$Water\ stress = \frac{Water\ demand}{Renewable\ water\ resources}$$



Generated from FAO-Aquastat (2021)

Geological zonation and soft calibration





Sánchez-Gómez, A., et al. (2025). Using sensitivity analysis and soft calibration of geological regions to improve the representation of hydrological processes in a SWAT+ model. Hydrological Sciences Journal, 1-18. https://doi.org/10.1080/02626667.2024.2446268

Hard calibration

Natural regime areas

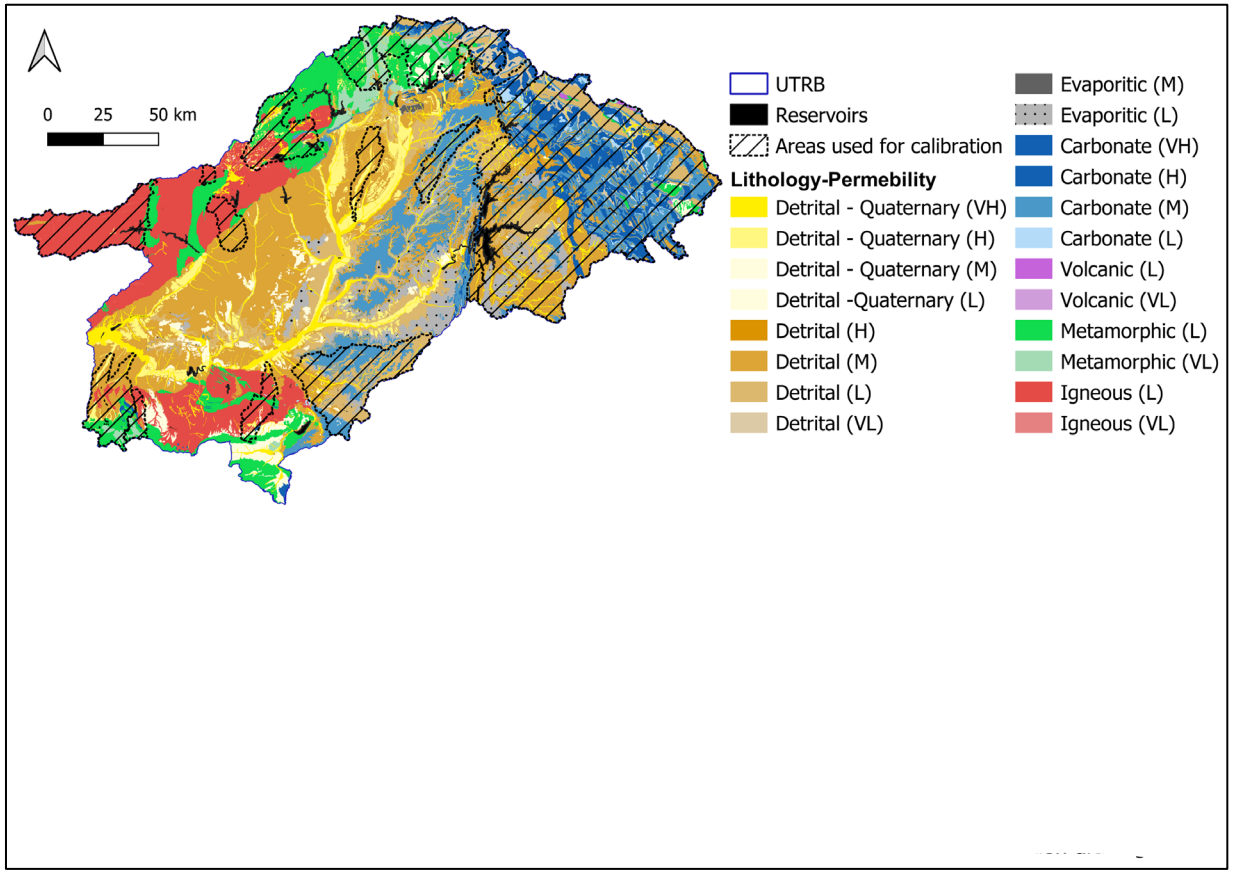
22 sub-catchments

Daily streamflow performance
Groundwater contribution (-)
Streamflow components simulation

12 headwaters reservoirs

Monthly inflow performance

44% of the UTRB



Initial parameterization: Crops distribution and management

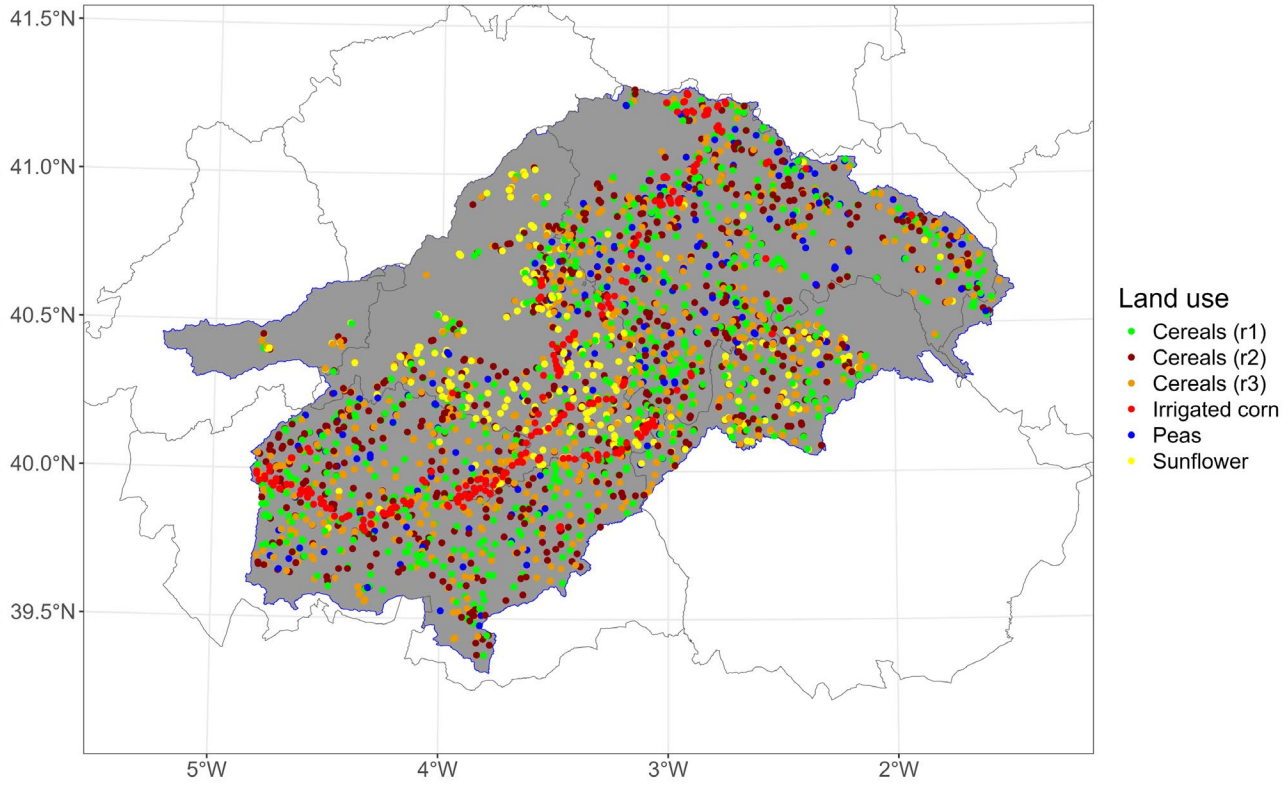
Rainfed arable crops →
Different SWAT land use for each main province

Land use split into **dominant crops** →
Different proportions (MAPA, 2020)

Cereals split to allow **different states** of the rotation **Wheat**/**Barley**/**Fallow**

Province	*Agricultural land use split*				
	Group 1	*Group 2*	*Group 3*	*SUNF*	*FPEA*
Ávila	23%	22%	22%	32%	1%
Madrid	22%	21%	21%	31%	5%
Cuenca	26%	26%	26%	18%	4%
Guadalajara	30%	29%	30%	1%	10%
Toledo	31%	30%	31%	1%	7%

Irrigated crops → Individual land use

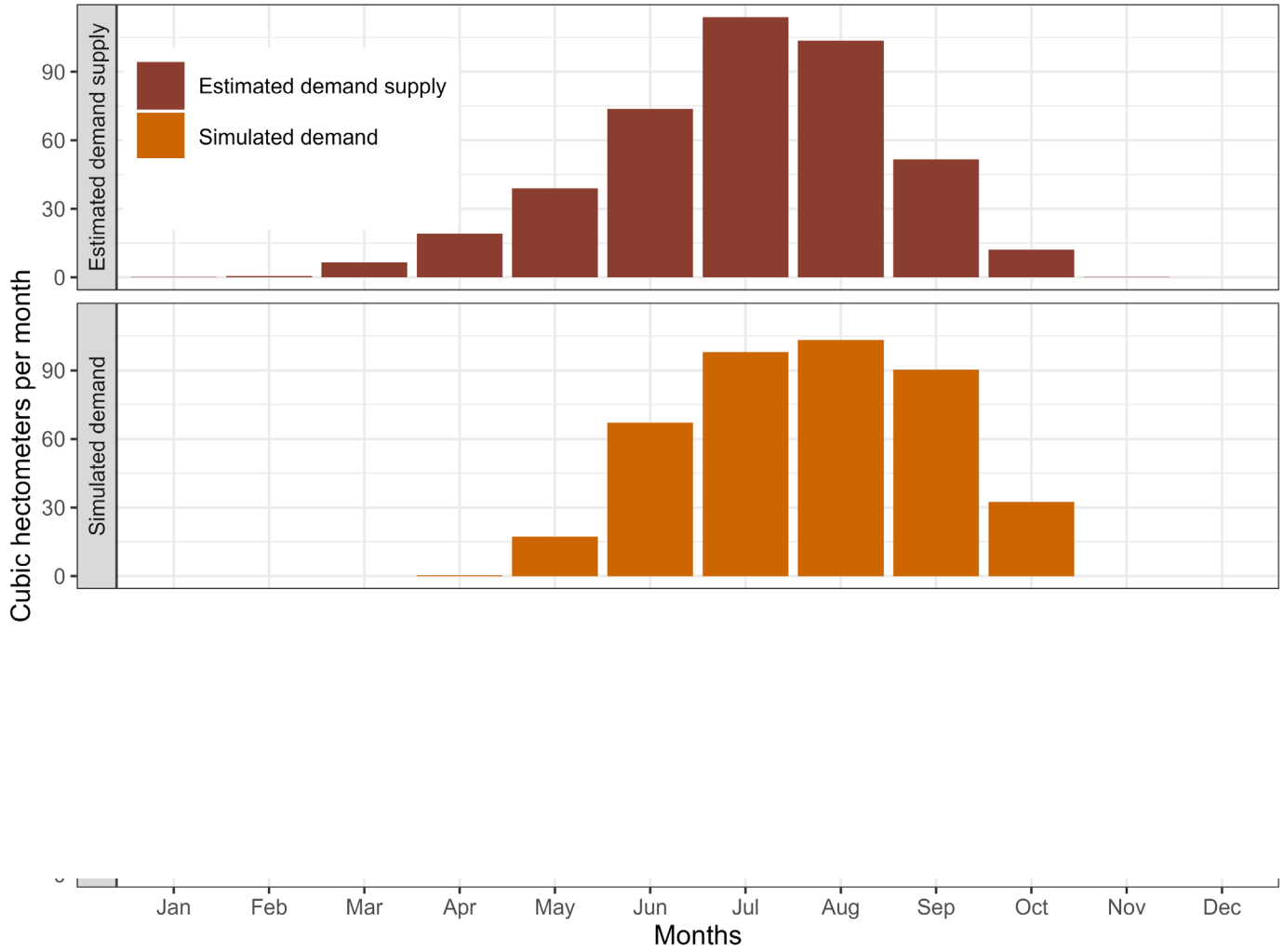


Rainfed arable HRUs configuration

Water management implementation

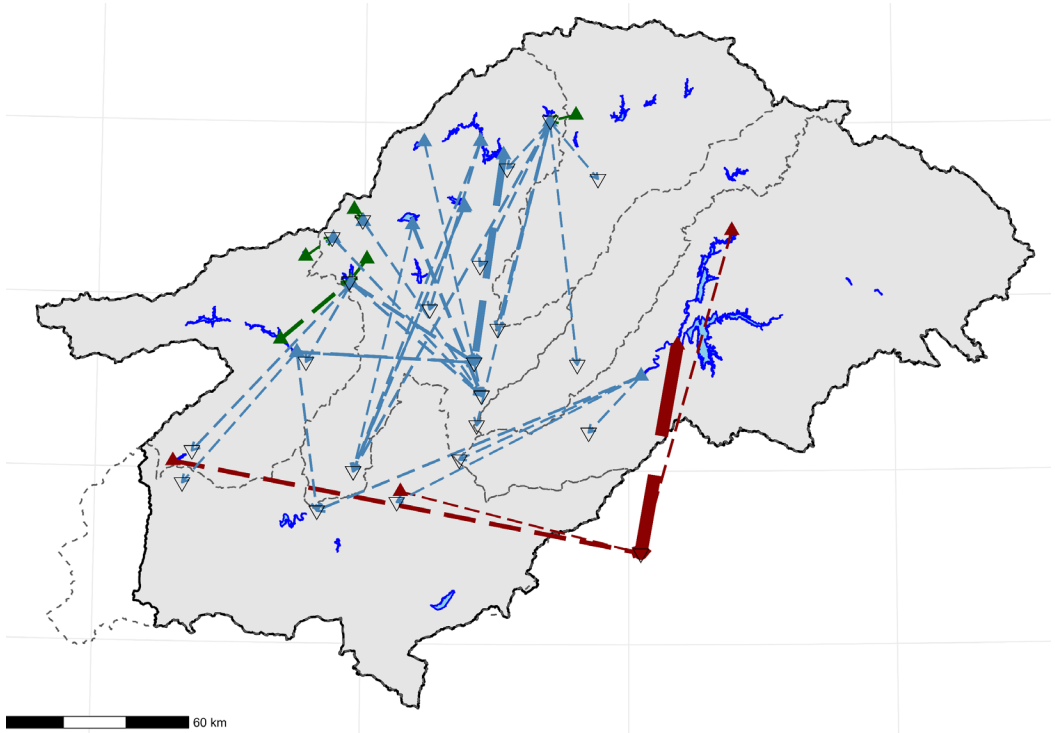
Irrigation implementation

- **97%** of the estimated demand was simulated
- The seasonal pattern was reproduced
- 73% of the simulated demand was met → 299 hm³/year



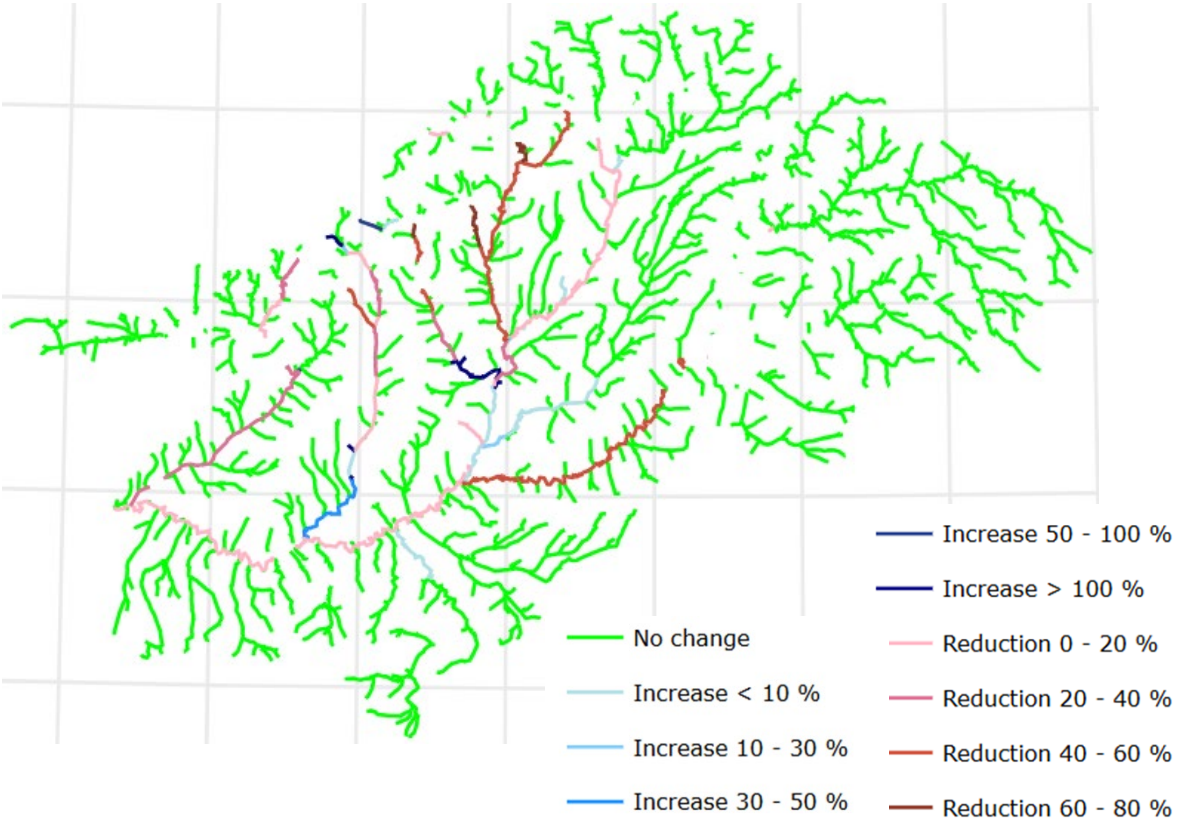
Water management implementation

Water transfers implementation



	Observed demand (hm³/year)	Simulated demand (hm³/year, % of observed)	Simulated water transfer (hm³/year)	Demand met (%)
Total UTRB	1,174.49	1,174.39 (100)	1,053.49	90.0

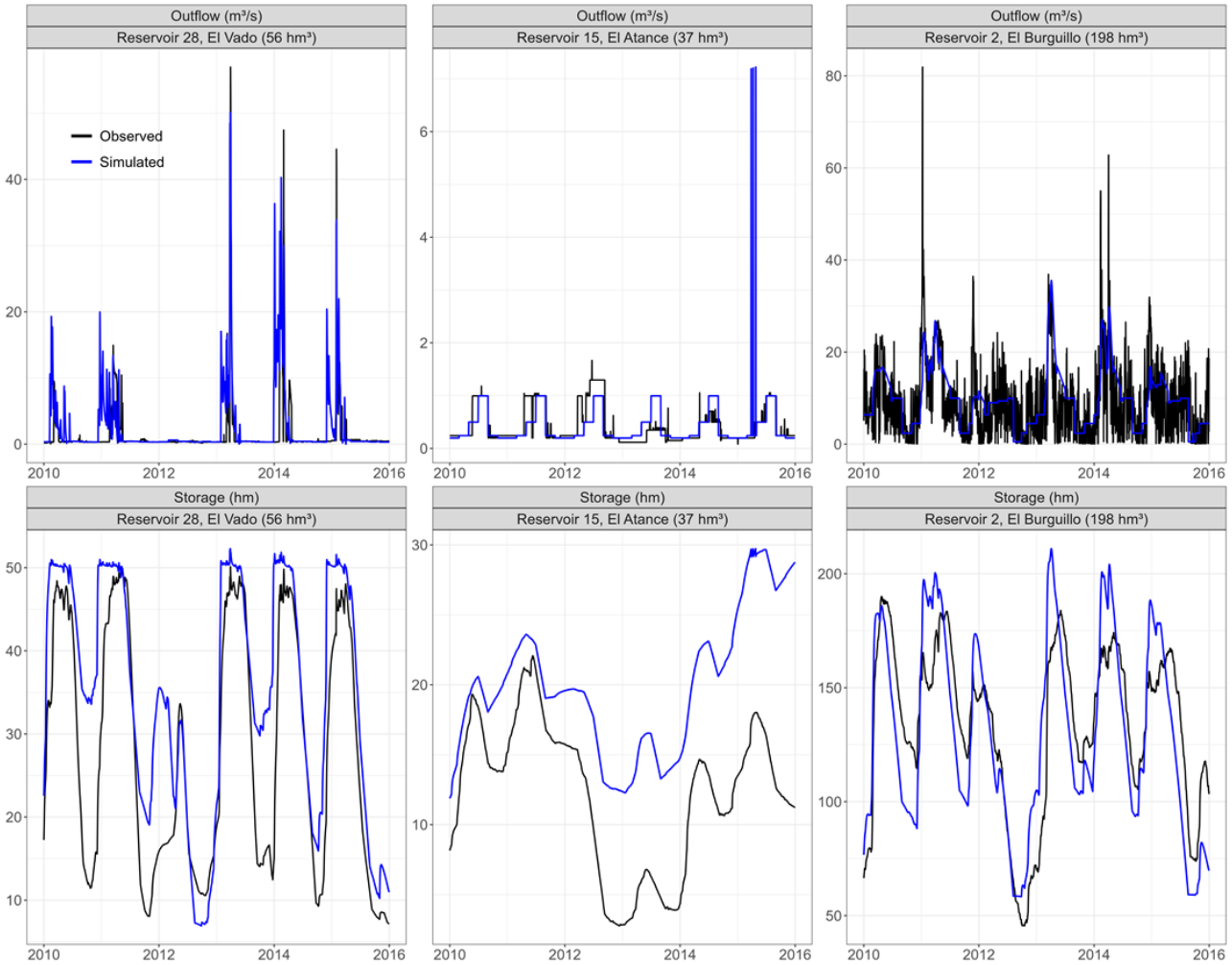
Streamflow comparison: Water transfers vs. no water transfers



Water management implementation: Room for improvement

Reservoirs

- **Satisfactory** simulation of many, but room for improvement in others
- **Improving reservoirs is work in progress**
  - New reservoirs introduced
  - Edits in some decision tables



Variable	NSE	R^2	PBIAS	RMSE
Storage	0.44	0.72	25.1	10.40
Outflow	0.22	0.52	37.5	2.70
Inflow	0.82	0.82	6.1	2.24

Variable	NSE	R^2	PBIAS	RMSE
Storage	-4.01	0.46	72.0	10.44
Outflow	0.19	0.25	-7.0	0.36
Inflow	0.36	0.42	6.4	0.46

Variable	NSE	R^2	PBIAS	RMSE
Storage	0.72	0.75	-0.6	22.51
Outflow	0.47	0.60	4.6	4.23
Inflow	0.92	0.93	5.3	3.03

Water management implementation

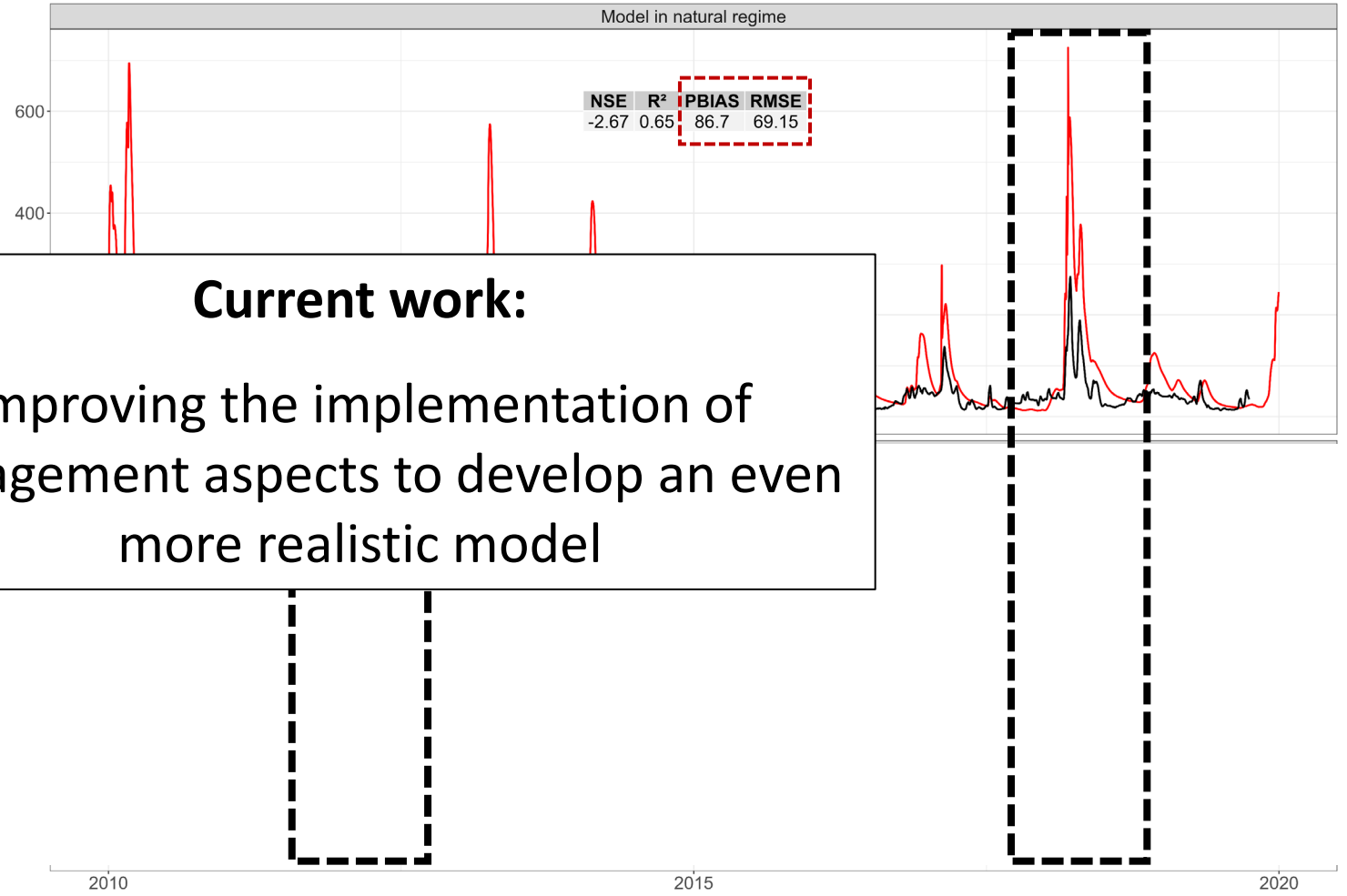
How does implementing management actions affect the UTRB outlet?

Improved low flows and high flows simulation

NSE improved, but still very low
R^2 slightly worse

PBIAS and RMSE →
Error reduced by 50%

Still 40% of PBIAS



Current work:

Improving the implementation of management aspects to develop an even more realistic model