Enhancing Water Resource Sustainability in a Coastal River Basin through Integrated SWAT Modeling

SWAT International Conference - Strasbourg

2024 July 12nd.

Odile Phelpin

Odile Phelpin for SWAT modeling
Benoît Othoniel for SD modeling

A **water-dependant** territory facing water **shortages** and water **conflicts**

<u>Agriculture</u>: Highly agricultural land with mainly **intensive** agriculture (70%): **irrigated cereals** and **cognac vines** for **export** abroad.

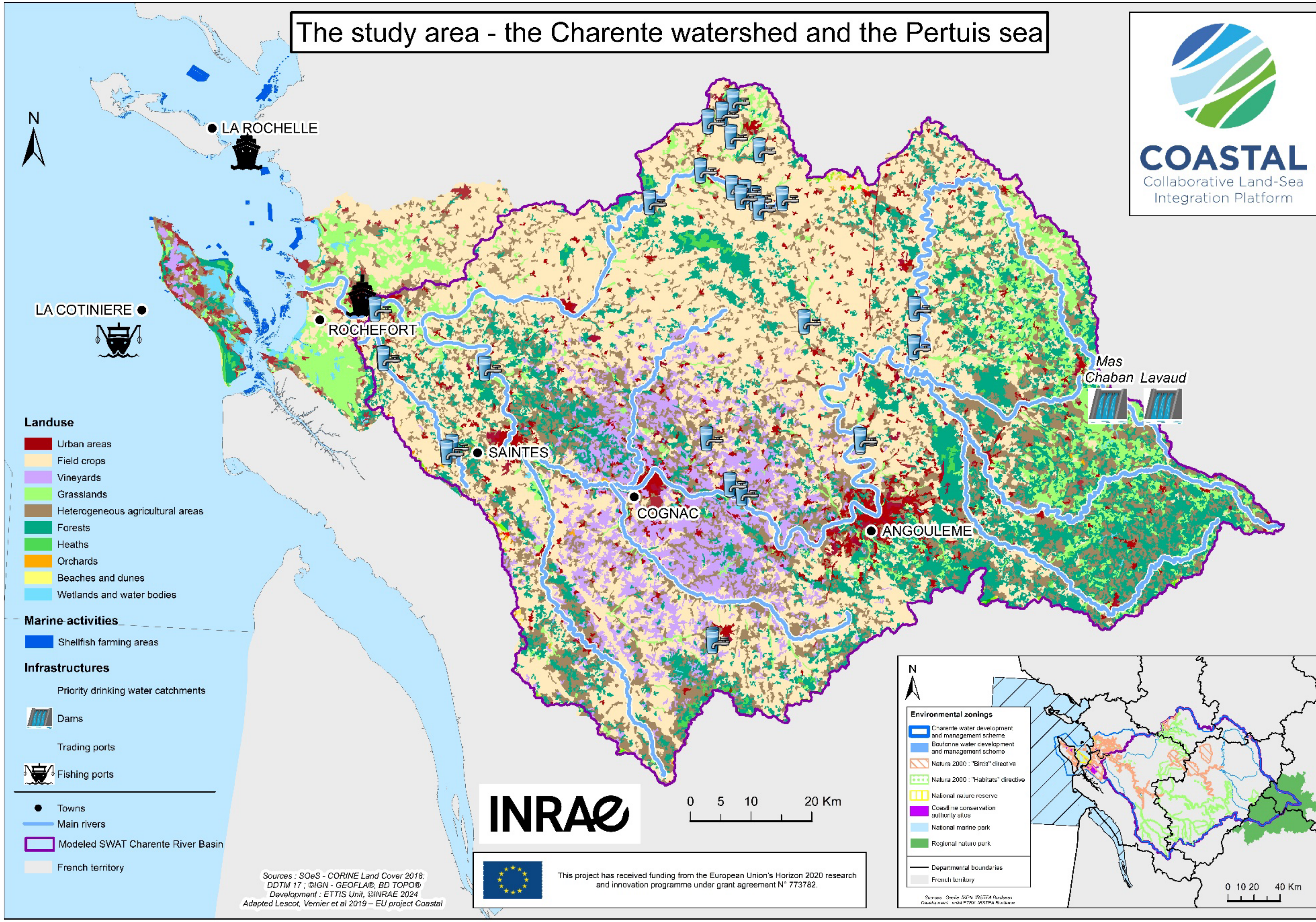
<u>Environment</u>: One **tributary structurally** in **high water shortage**

<u>Water management</u>: Despite upstream **reservoir dams** (14Mm^3 of capacity), issues in maintaining **low-water target flow**.

<u>Population</u>: **Drinking** water under (**tourism**, creeping **coastline urbanization**, drinking water sources closing due to **NPS pollution**)

<u>Oyster</u> <u>production</u>: depending on water quality (**pesticides**) and availability (**salt**)

<u>Climate change</u>: marine **inundation** (**marshes** and **coastal flats**) -> Possible land **salinization**



Land-sea complex issues and sustainable territorial development

<u>How</u> <u>to :</u>

- Save **50 Mm³** (=25%) of water by **2050**?
  Facing NPS **pollution**, **irrigation needs**, structurally highly **deficitaire rivers**, and **climate change**?
- Establish **common strategies** along the **land-sea continuum** for water quality and availibility for global **health**, **ecosystems** and **activities**?
- Maintaining the local (water-dependant) **activities?**

In **compliance** with:

- **Sustainibility**
  - SDGs
  - Agenda 2030
  - One Health
- **Regulations**
  - The European Green Deal
  - National Environmental Code

Photos : Multi-Actor Lab 4 – The Charente River basin and its coastal zone -Final review meeting

Figure 9. Main topic structure of the European Green Deal.

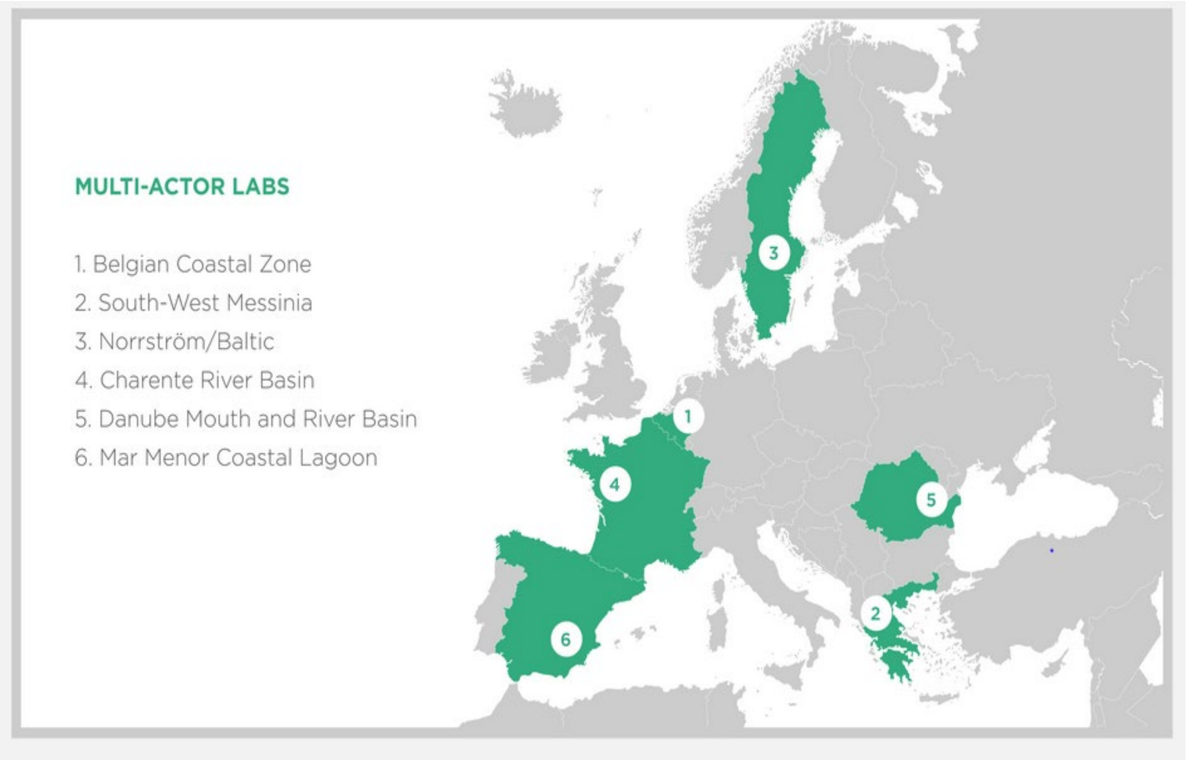
Overview of the H2020 COASTAL project

HORIZON 2020

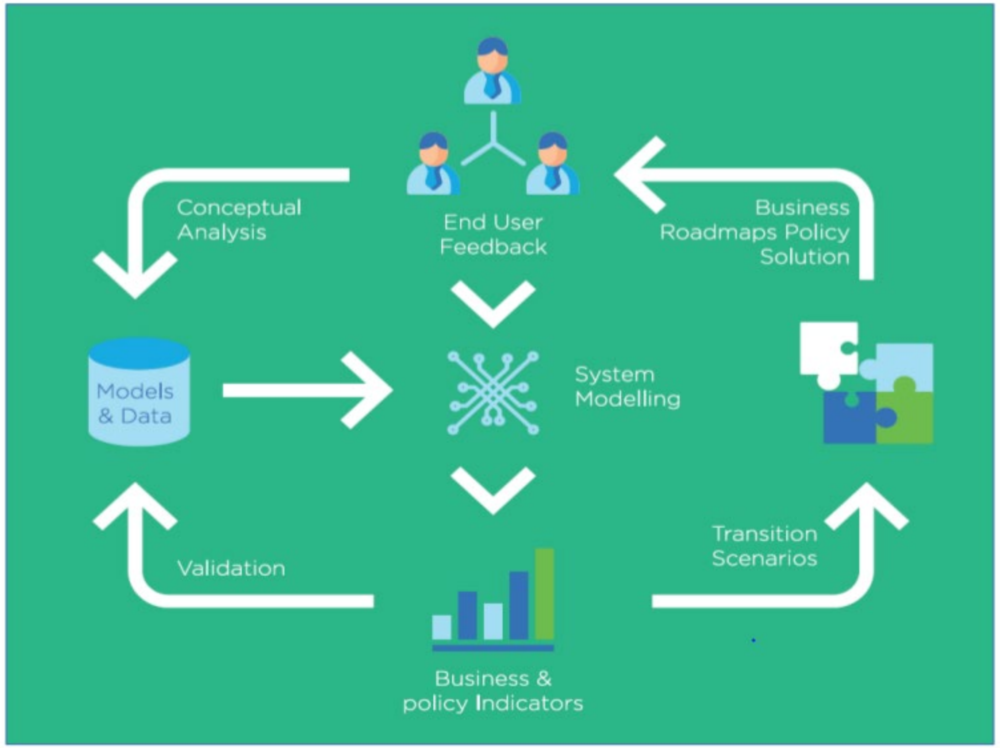
COASTAL
Collaborative Land-Sea Integration Platform

https://h2020-coastal.eu/

Objective: "Co-creating evidence-based business roadmaps and policy solutions for enhancing *coastal*-rural collaboration and synergies"



Map of countries participating in the COASTAL project. Coordinator: VITO.



General workflow in the COASTAL project (https://h2020-coastal.eu).

General workflow in the COASTAL projet (Deliverable D7)

Holistic approach to complex problems in the Charente River basin: general methodology with the **SWAT model**

Stakeholder engagement

Multi-actor labs

- Mind maps
- Scenarios

Scenarios -> Models

- System Dynamics (SD)

Vensim
VENTANA

- Ecohydrological model

SWAT Soil & Water Assessment Tool

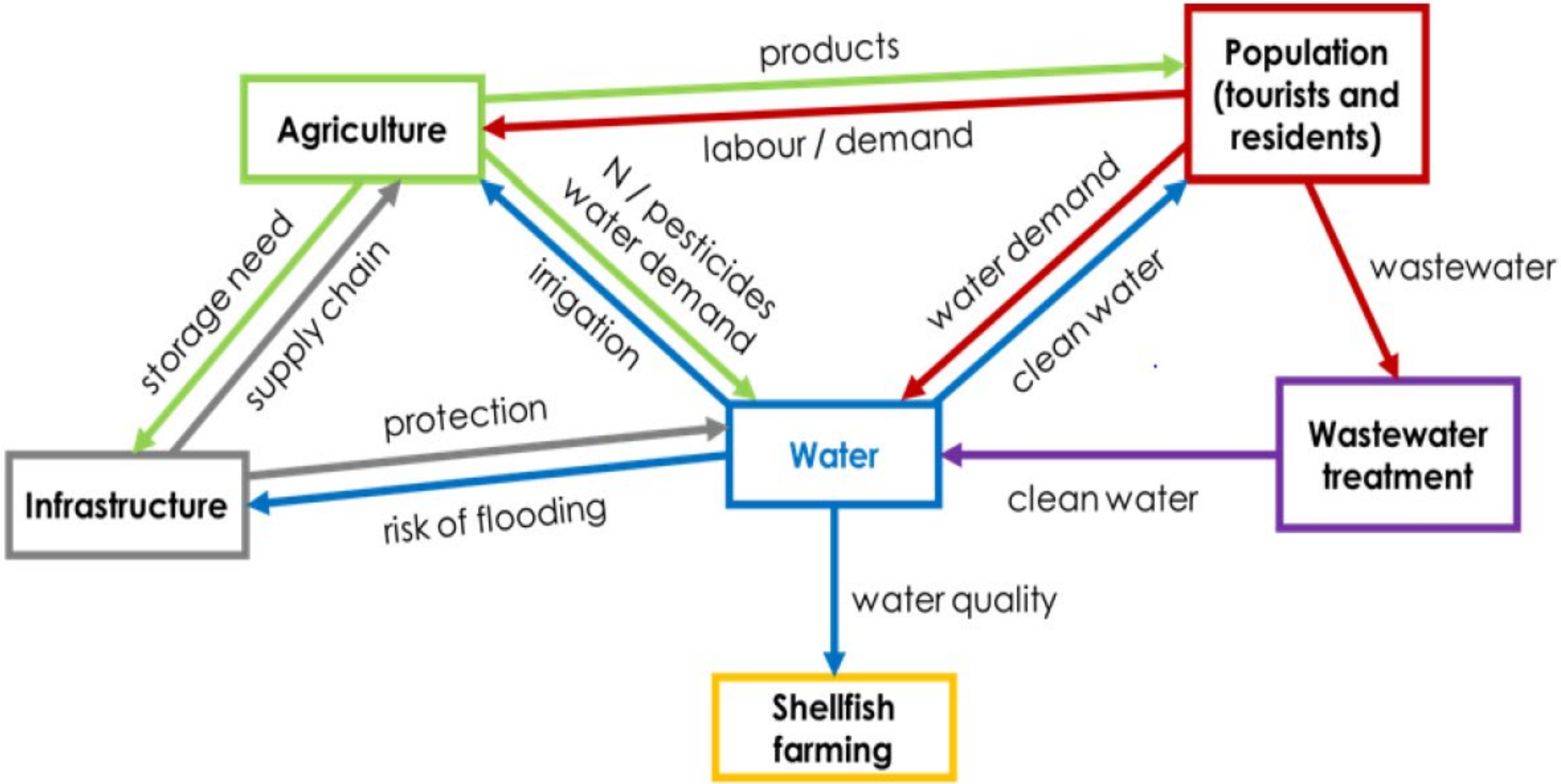
Knowledge management

- Multi-actor labs: feed-backs
- Collaborative Platform
- Roadmaps for territorial development

This current presentation

Hydrologic variables	Water quality (N, pesticides) & Plant growth
↓	↓
Water SD sub model	Agriculture SD sub model

Drivers of the **land-sea system** identified during the **sectorial workshops**



Structure of the integrated system dynamics (SD) model for the Charente river basin and adjecent coastal zone.(Deliverable D06 COASTAL Project)

Water lays is at the center of the system

Site-specific methological adaptation: The SWAT contribution

The **10,000 km²** study area involves **complex hereogeneous biophysical** and **hydrological** issues (karst, resurgence, dam releases, etc.)

Precipitation and **evapotranspiration** are a source of system external **uncertainties** that affect the **SD** model. It operates at a **monthly time step** -> Results in zero flow at low flow rates

While **SWAT** provides **continuous daily time** step, **spatially explicit** simulations of **hydrologic processes**, SD provides a complementary approach to explore broader system behavior and policy implications over time. Together, these tools can provide a more comprehensive understanding of watershed dynamics and inform better decision making for sustainable water management.

SWAT model outputs are used for providing ranges of magnitude, for calibrating, validating, verifying variables in the **coarser non spatialized SD model**, such as hydrological balance – in particular the **streamflows** –, as well as **evapotranspiration** and **climate** variabilities (for the baseline and climate change scenarios)

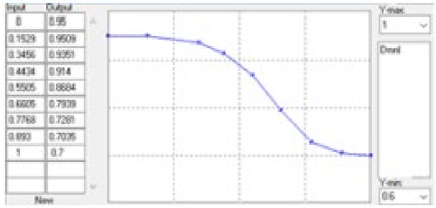
For **further** information on **the SD model**: https://h2020-coastal.eu/resources/773782-COASTAL-WP4-D14.pdf, pp. 112-113

S.V. = scenario variable. Type: S = stock, C = constant, T = time-series, L = lookup.

Variable	Type	Description	S.V.	Source
initial *water in soil*	S	The initial amount of water in soil is estimated at 900 Mm^3.		Calibrated*
initial *groundwater*	S	The initial amount of water in aquifers is estimated at 1000 Mm^3 (full capacity).		Calibrated*
initial *dam storage*	S	The assumption is that dams are full when the model starts in January.		cf. *dam capacity*
initial *surface water*	S	The initial amount of surface water is estimated at 600 Mm^3.		Calibrated*
initial *water streams*	S	The initial amount of water in streams is estimated at 400 Mm^3.		Calibrated*
initial *water in marshes*	S	The initial amount of water marshes is estimated at 300 Mm^3.		Calibrated*
rainfall	T	Possible future rainfall patterns are retrieved from a climate model based on the IPPC scenarios while monitoring data are used in the past.	X	SWAT simulation (cf. Box 1 in Sub model 1)
basin area	C	The area of the basin is 10550 ha.		Etablissement Public Territorial de Bassin Charente, 2020b
average soil depth	C	The soil is on average 1 m deep in the region.		Bichot & Gennat, 2018
volume of soil in the basin	C	It is calculated in the model as the product of the *basin area* and the *average soil depth*.		Endogenous
soil saturation limit	C	The maximum capacity of the soils is estimated to 0.24 m^3 of water per m^3 of soil.		Bichot & Gennat, 2018
infiltration coefficient according to soil saturation	L	cf. Lookup in Figure 56		Calibrated*
evaporated share of irrigation	C	10% of the water spread for irrigation directly evaporates.		Ruelle et al., 2004
evapotranspiration by other covers than agriculture	T	It is approximately 1.3 times higher than the evapotranspiration by the agricultural covers.		SWAT simulation (cf. Box 1 in Sub model 1)
groundwater capacity	C	The aquifers can stock around 1000 Mm^3 of water.		Calibrated*
seepage rate according to soil saturation	L	cf. Lookup in Figure 56		Calibrated*

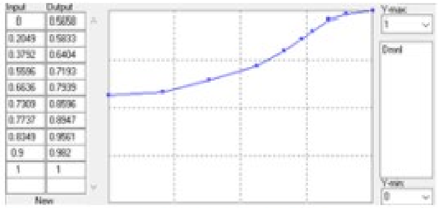
* Calibrated based on SWAT simulation

infiltration coefficient according to soil saturation



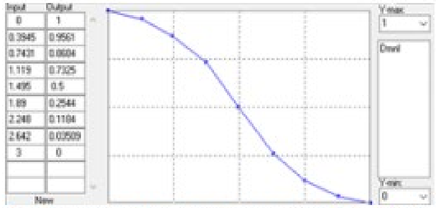
The *infiltration* of rain water in the soil diminishes as the soil becomes more saturated.

seepage rate according to soil saturation



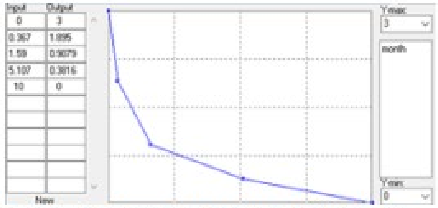
The more saturated is the soil, the faster water goes to the aquifers.

virus frequency according to time reflowing



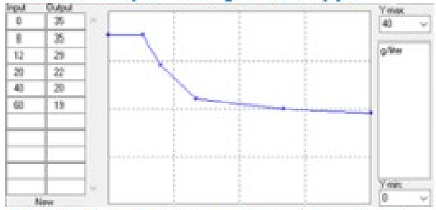
The *occurrence of viruses* increases with the *WWTPs overload*.

WWTP treatment duration according to overload



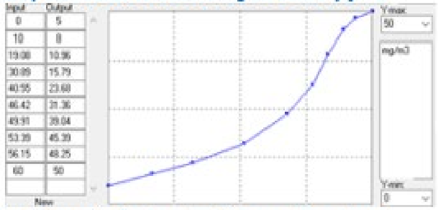
The more overloaded are the WWTPs, the faster water is treated. It can be 0 month (water just goes through) during extreme events.

coastal salinity according to estuary flow



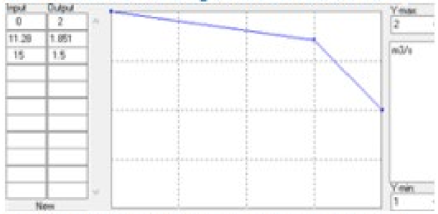
Coastal salinity diminishes with the inflow of fresh water. It never goes above 35g/L because of the ocean's inertia.

trophic resource according to estuary flow



The incoming freshwater brings nutriments and organic matter to the estuary, increasing the *concentration in trophic resources* in the estuary.

dam release according to low water stream

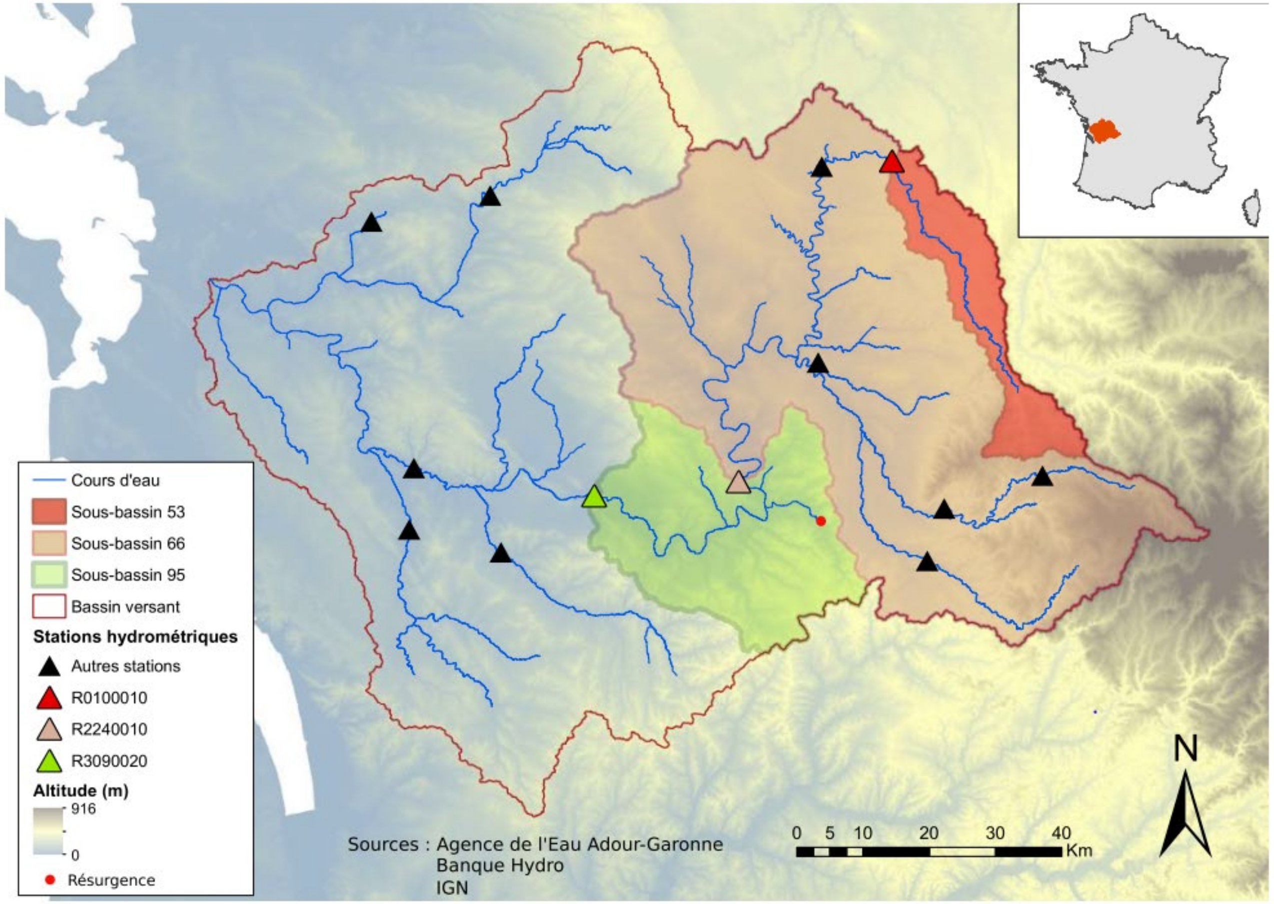


In period of drought, the dams release water at a rate that increases as the *water streams flow* decreases.

The SWAT Model set-sup

- Modeled SWAT Charente includes the whole Charente river basin, except the estuary : the natural hydrological regime strongly disturbed by the flatness and the marine inflows and canals.
- Focus on the heavily agricultural hinterland, main source of freshwater quality degradation due to diffuse pollution and regular freshwater shortages for irrigation
- Input data:
  - DEM 25m*25m (IGN)
  - Water daily discharge: BANQUE HYDRO. WQ: SIE AEAG
  - Weather data and RCPs: Météo-France, DRIAS
  - Soils: INRAE-Chambre d'Agriculture
  - Landuse: RPG (agricultural census), Corine Land Cover 2018, Chambre d'Agriculture

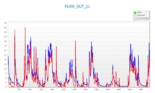
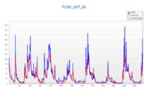
Delineation: 107 sub-basins, 3,659 HRUs

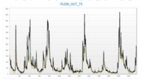
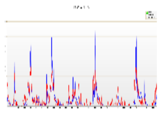
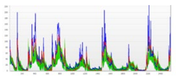
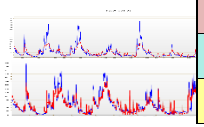


Streamflow Calibration & Validation from upstream to downstream using SUFI2 after SA

Calibration: 1998-2008

Sub-basin	Average monthly flow observed (m3.s^{-1})	Average monthly flow simulated (m3.s^{-1})	Percentage difference (%)	NSE	R^2
53	4.10	3.8	**7**	0.60	0.61
67	2.05	1.87	**8**	0.64	0.66
101	3.10	2.67	**13**	0.69	0.71
7	5.89	4.82	**18**	0.60	0.62
55	1.75	1.67	**4**	0.67	0.67
88	6.25	6.19	**0.9**	0.71	0.71
66	28.74	28.23	**1.8**	0.83	0.83
95	43.16	43.15	**0.008**	0.72	0.73
96	-	-	-	-	-
73	-	-	-	-	-
91	6.27	5.71	**8**	0.68	0.70
11	5.11	5.21	**1**	0.71	0.73

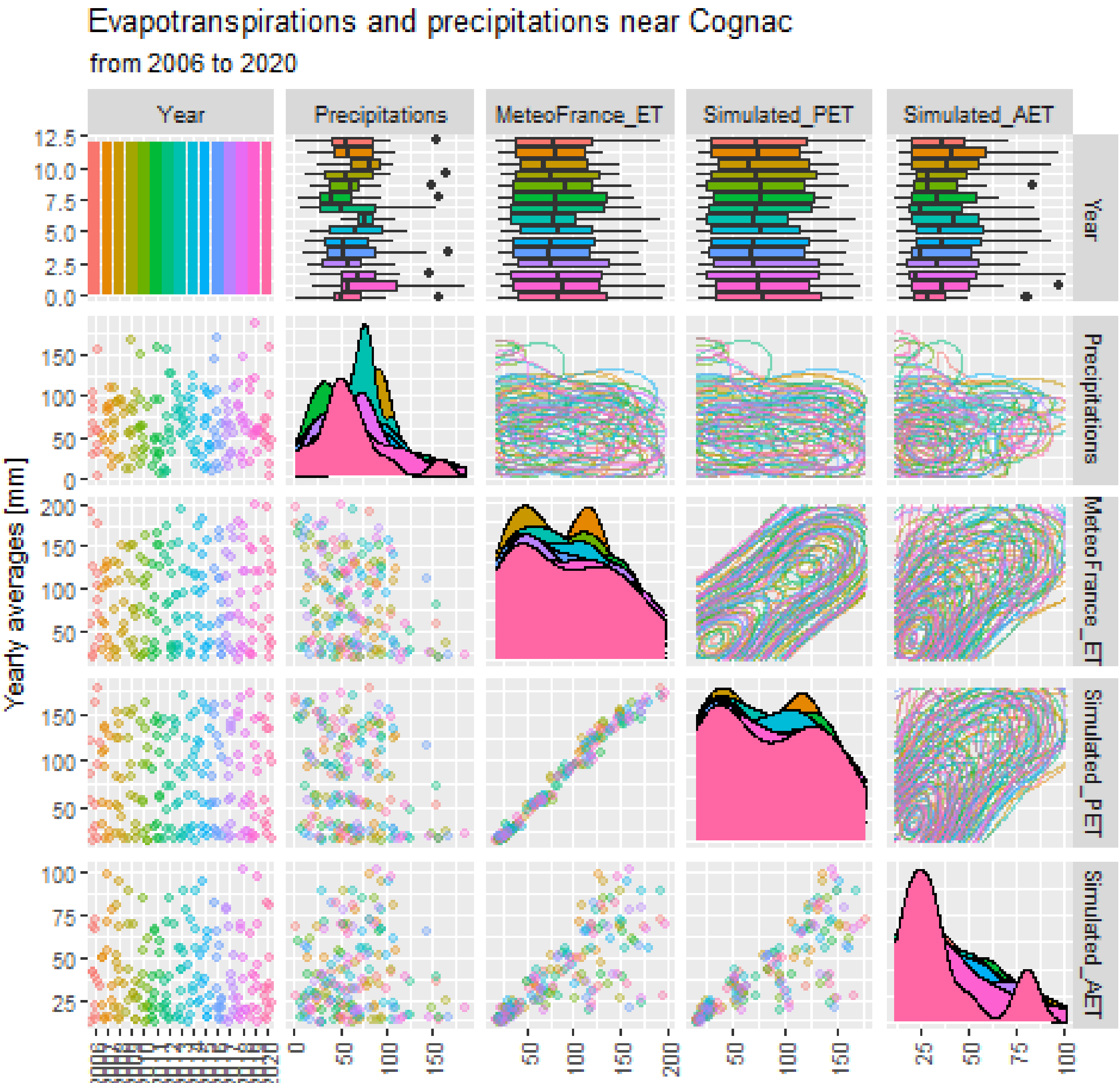





Validation: 2009-2018

Sub-basin	Average monthly flow observed (m3.s^{-1})	Average monthly flow simulated (m3.s^{-1})	Percentage difference (%)	NSE	R^2
53	-	-	-	-	-
67	-	-	-	-	-
101	-	-	-	-	-
7	-	-	-	-	-
55	-	-	-	-	-
88	-	-	-	-	-
66	29.31	25.30	**13**	0.79	0.8
95	51.64	51.08	**1**	0.76	0.77
96	3.59	3.85	**7**	0.70	0.7
73	75.98	63.56	**16**	0.68	0.78
91	7.43	5.90	**20**	0.76	0.79
11	6.30	4.76	**24**	0.78	0.83

Satisfactory to overall good calibrations at the monitored sub-basin according to Moriasi's criteria.

ET and PCP SWAT simulations



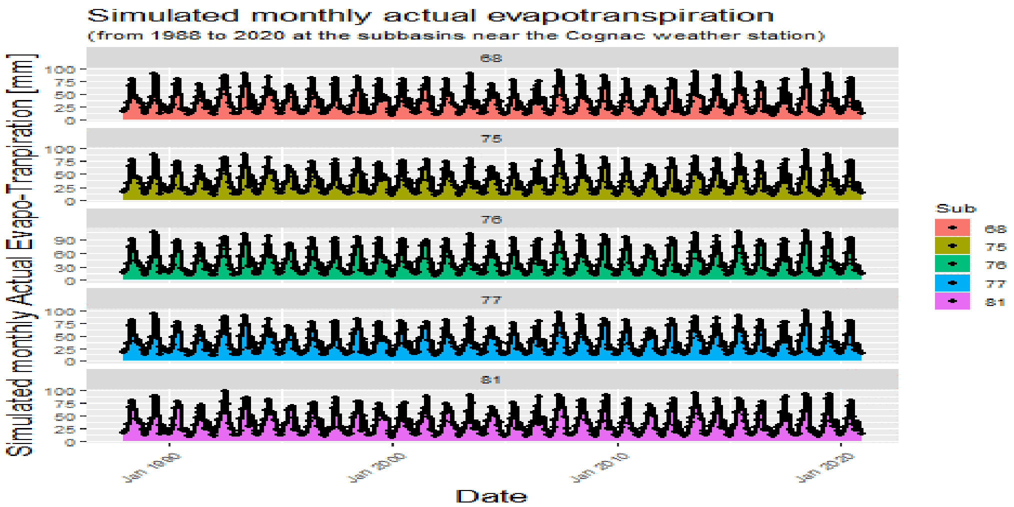
Inter-annual heterogeneity is strong.
Simulated PET reflects these less.

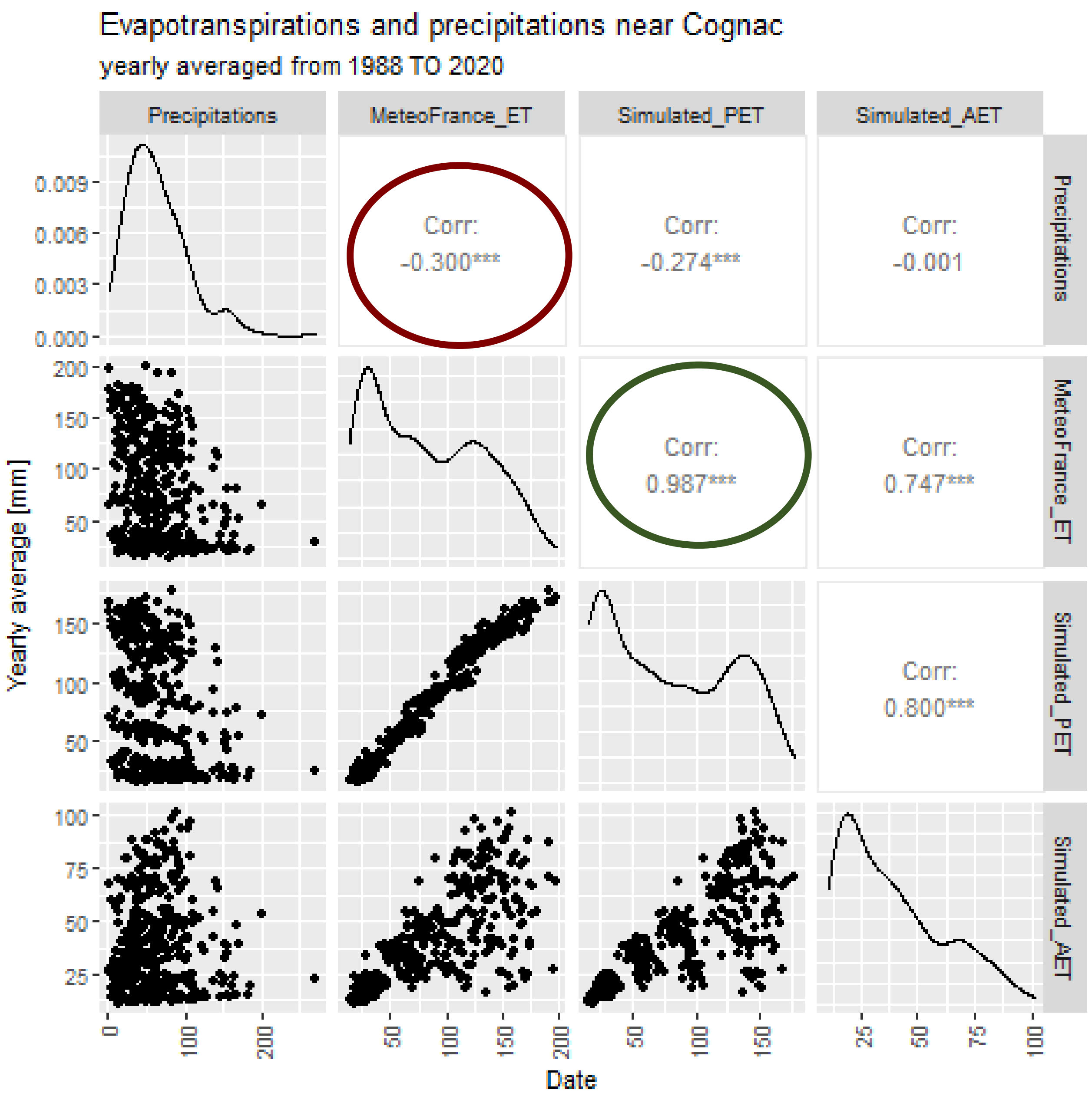
Good agreement between simulated ET and institutional PET for the nearest SAFRAN point in the vicinity of ground-based weather stations.

ETs and PCP

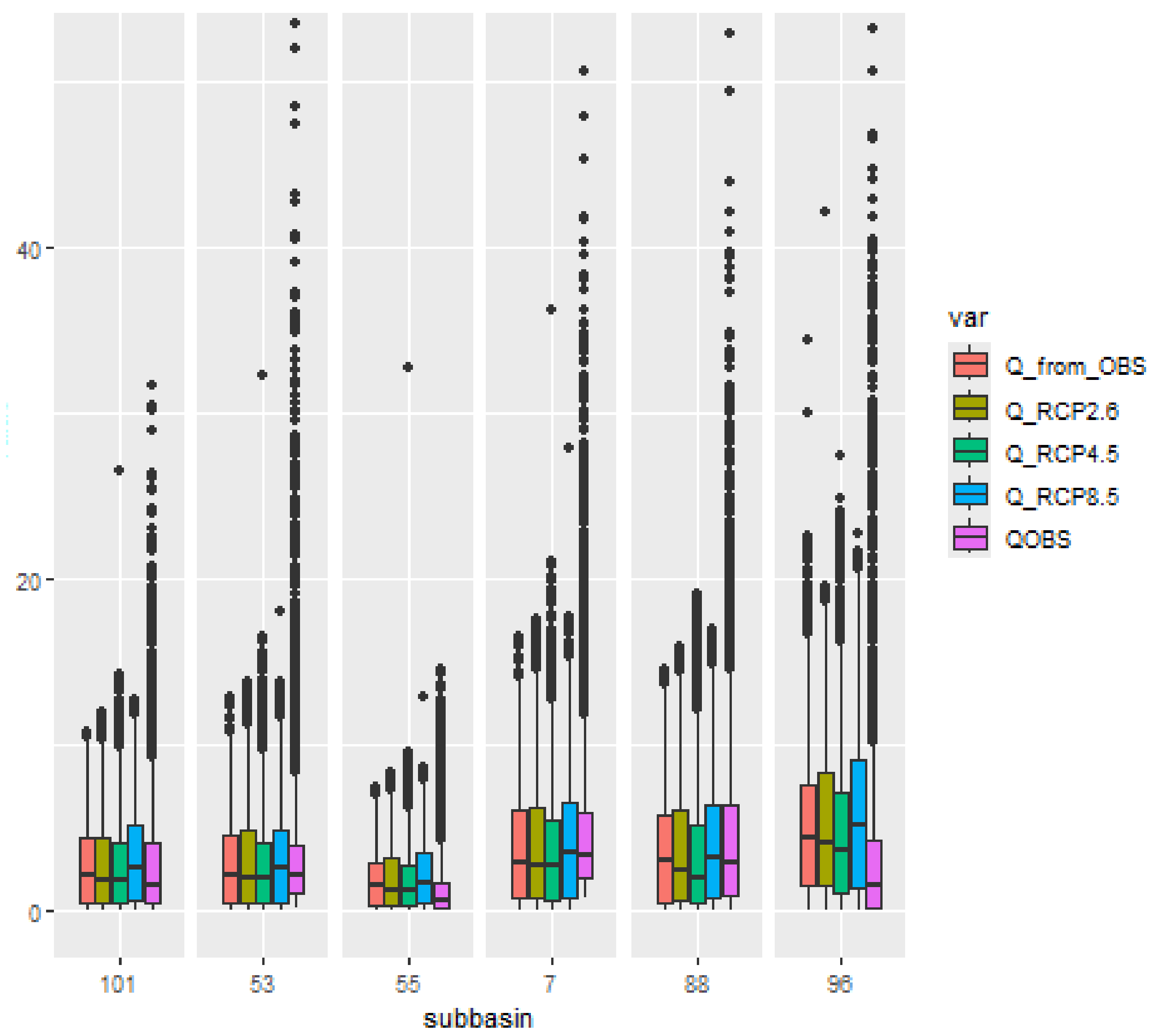
Slight tendency for evaporation to decrease as precipitation increases.
(<-> Mostly oceanic climate, wind may increase ET.
In these area, the limestone soils tend to dry out more quickly, especially as they are more exposed in the rows of the vines).

Very good correlation between SWAT simulated PET and PET calculated by Météo-France at Cognac weather station.





Streamflow distribution



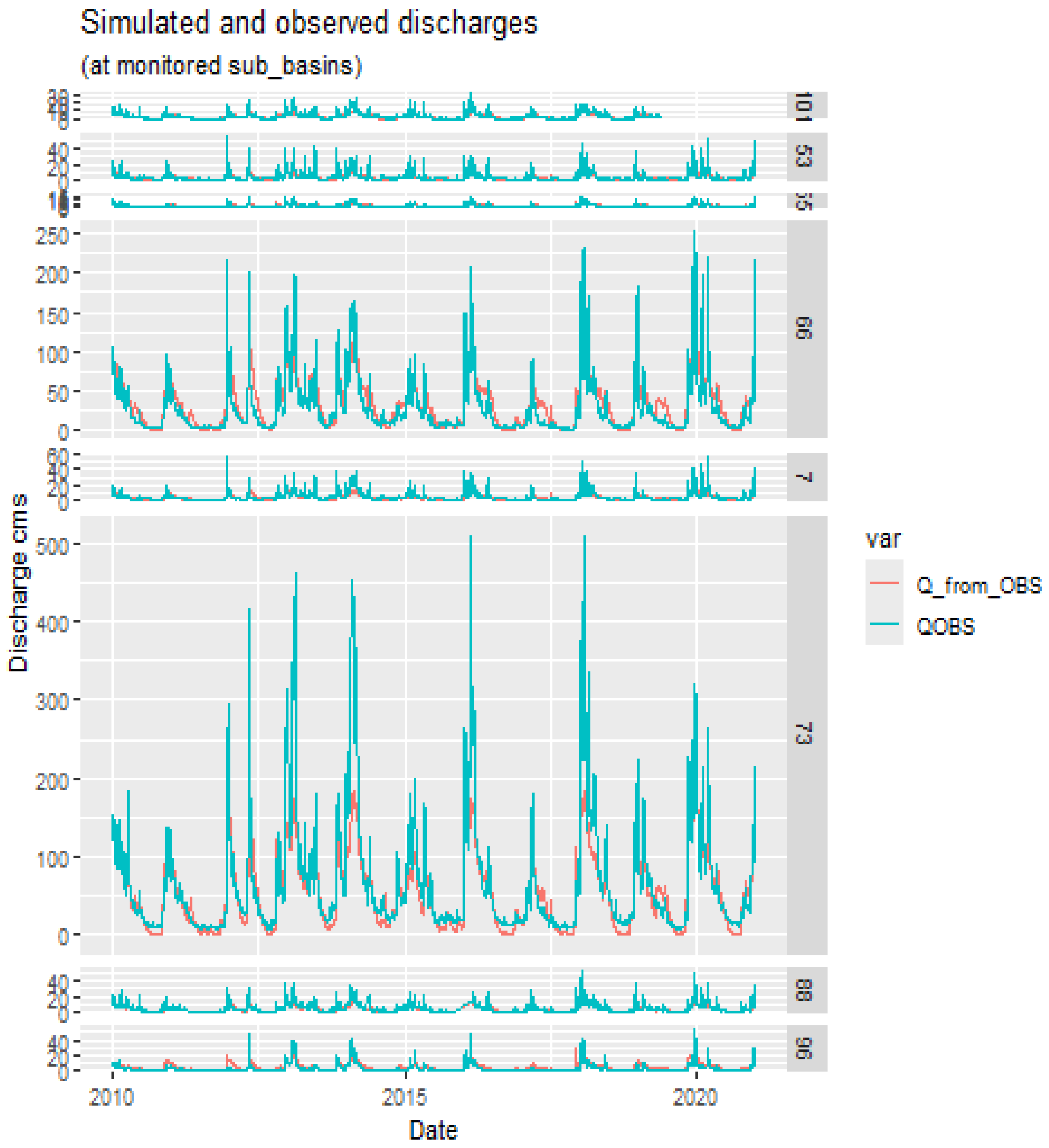
Spatial varaibilities in streamflows trends

Overall, RCP 8.5 would generate more rainfall, in intensity and quantity.

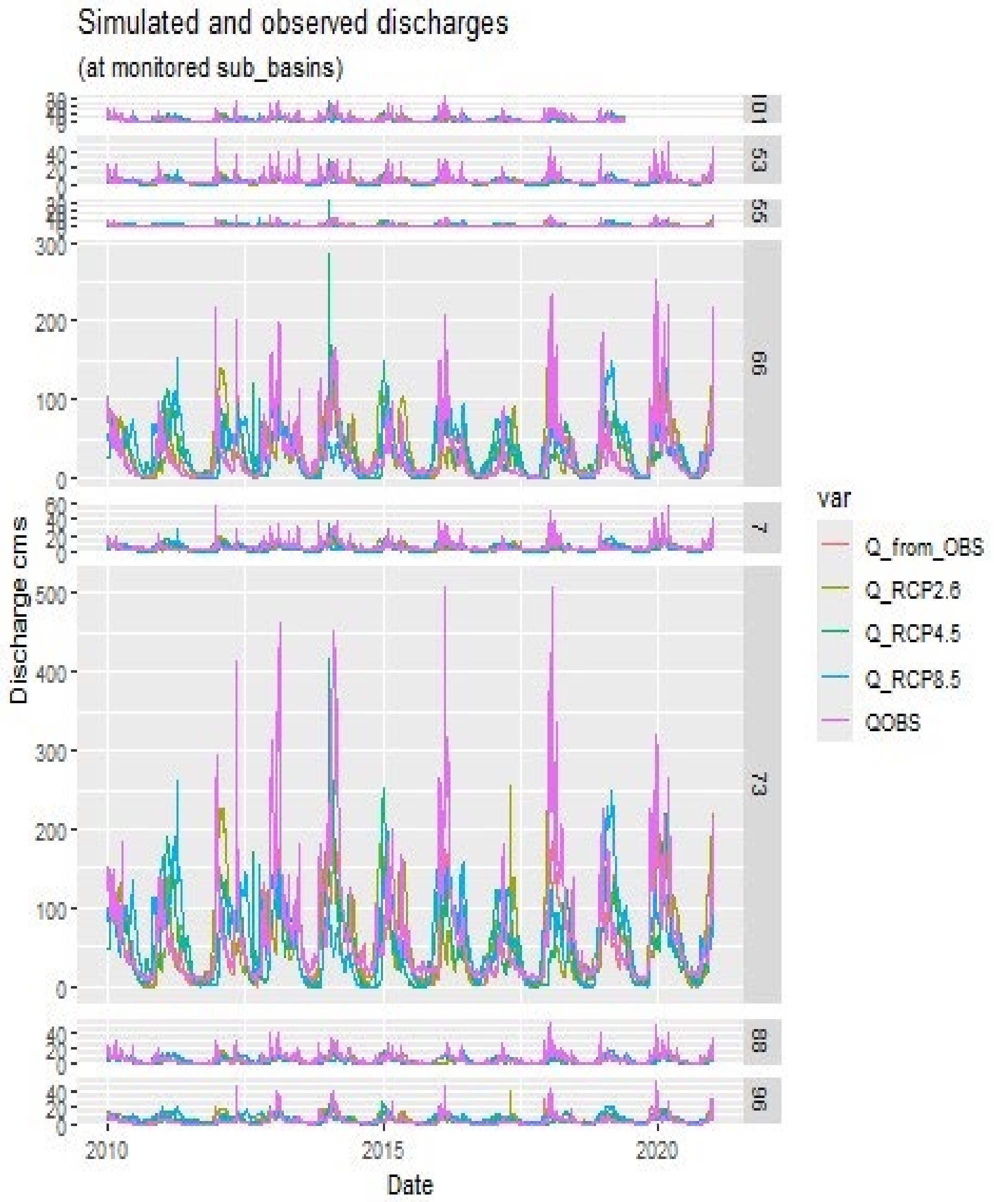
-> Raises the issue to keep the fresh rainwater

Streamflows

Baseline



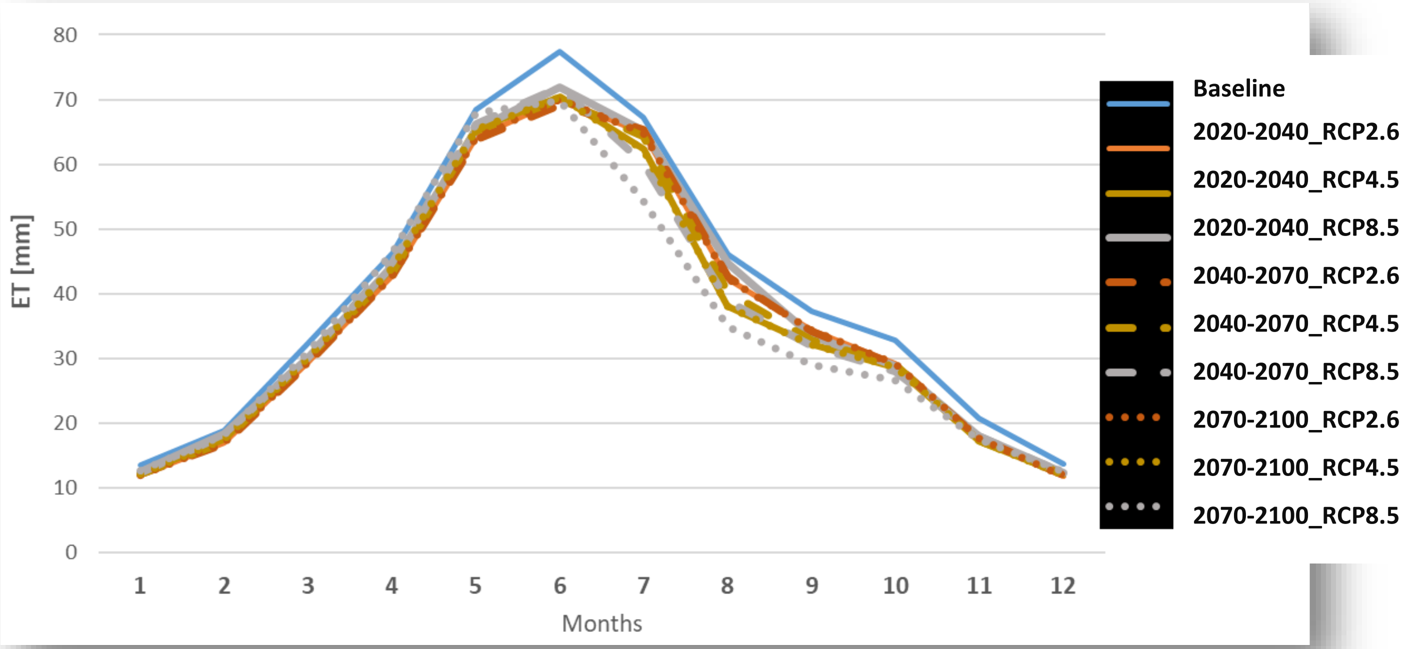
RCPs and baseline

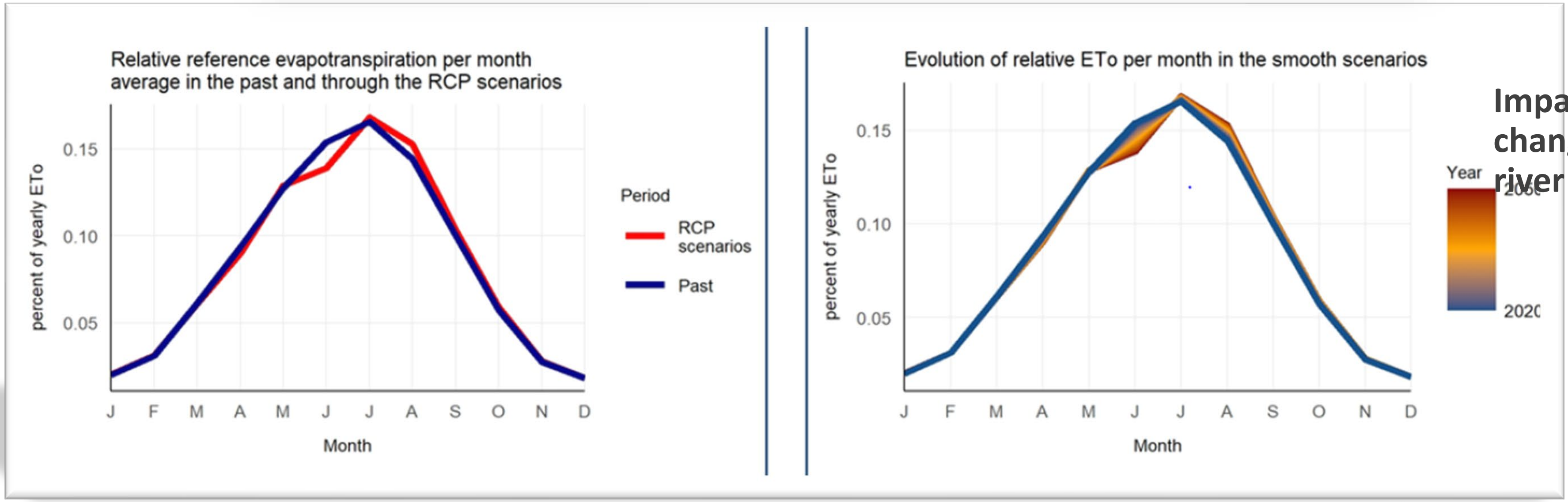


Results : **Evapo-Transpiration**

SWAT

VENSIM



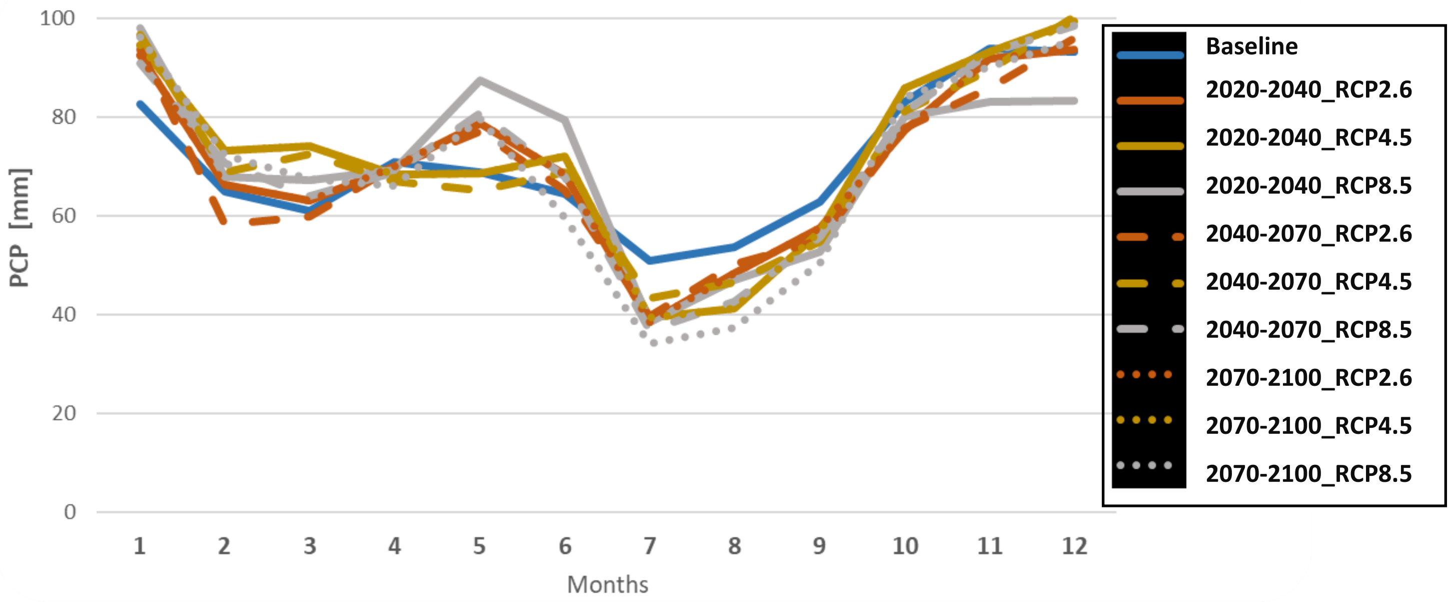


Impacts of climate change on the Charente river watershed in 2050

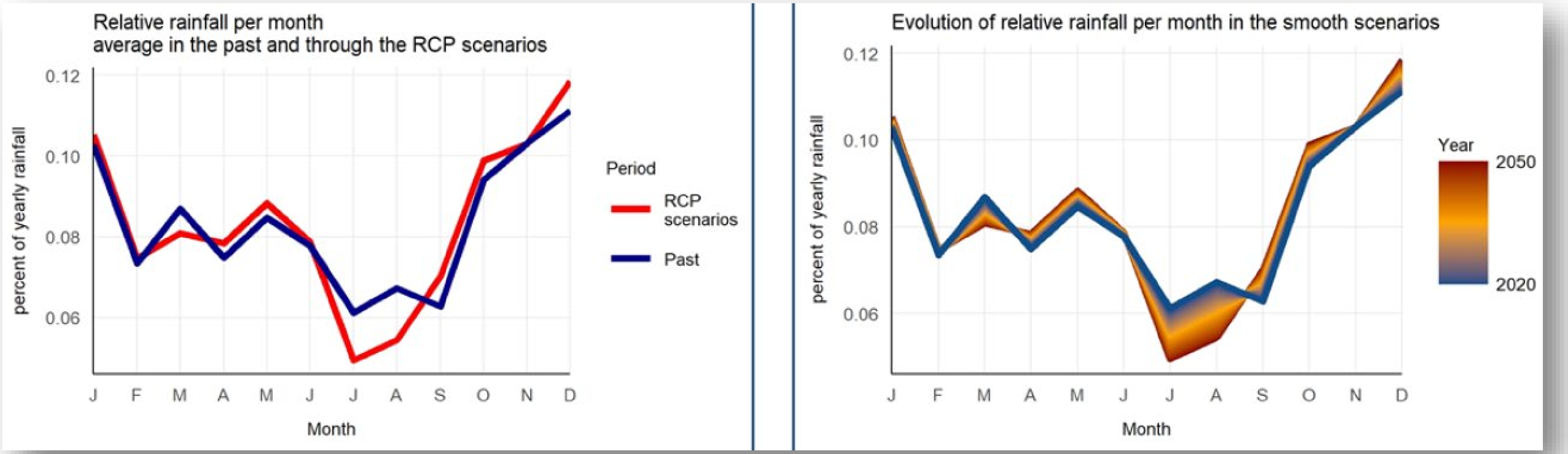
Precipitation

SWAT

VENSIM

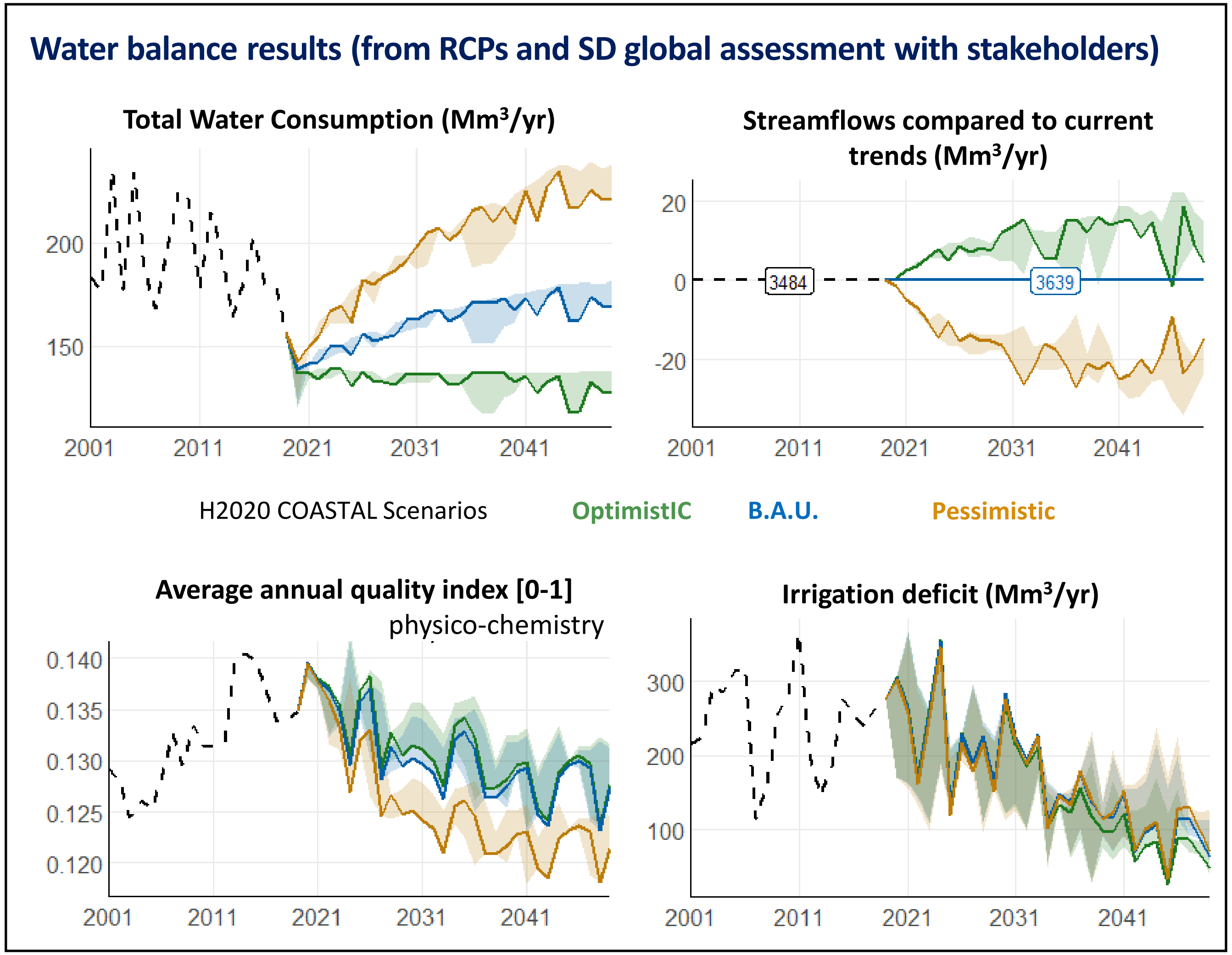


More cumulative precipitation and intensity with stronger gradient through RCP2.6, RCP4.5 & RCP8.5.



COASTAL
Collaborative Land-Sea Integration Platform
https://h2020-coastal.eu/

Final results: Impacts of climate change on the Charente river watershed in 2050



https://h2020-coastal.eu/resources/

RÉPUBLIQUE FRANÇAISE · INRAE · ETTIS · AGENCE DE L'EAU ADOUR-GARONNE · EPTB Charente · Comité Régional de la Conchyliculture Charente-Maritime · Agricultures & Territoires Chambre d'Agriculture Nouvelle-Aquitaine · Bio Nouvelle-Aquitaine · Conservatoire du littoral · CAPENA · Port Charente Atlantique · Port Atlantique La Rochelle ... et autres.

Discussion

Limits

1- Uncertainty due to RCP scenarios that vary greatly from one model to another (is using a multi-climate model the right decision?)

2- ‘dubious flows in low and high water’ -> Need to improve streamflow monitoring mention in observed data sets

3- Improve the SWAT modelling of the very low flows and the peaks

Benefits

1- RCPs scenarios, despite their uncertainty, provide trends: depletion, decrease in availability of water resources.

2- Awareness raising with stakeholders, promotion of integrated management instead of sectoral management, taking into account the land-sea continuum towards more resilience and sustainability

3- Strengthens synergies with hydrosystems

Conclusion

Applied to a coastal river basin, combining established and open source models: SWAT (Soil and Water Assessment Tool) and System Dynamics (SD) VENSIM.

The simulated runoff data closely match the observed values, showing good agreement during both calibration and validation phases, with NSE values of 0.83 and 0.75 during calibration and validation, respectively, and R2 values of 0.85 and 0.78, respectively; the simulated potential evapotranspiration is also in agreement with the observed PET.

Overall, the contribution of SWAT to the calibration of the SD model facilitated the identification of management strategies to mitigate water use conflicts and promote territorial development, and facilitated decision support for public policy and water managers.

This methodology offers flexible solutions without the need for specific model development, thus supporting decision-making processes and promising for application in different contexts.

… et autres.

‘ Thank You ! ’

Andro L. SWAT Hydrological Modeling of the Charente river basin: From Data Processing to Model Calibration. Modélisation hydrologique SWAT du bassin versant de la Charente : du traitement des données au calage du modèle. MASTER2 Sciences de l'eau - Hydro3, 2019, pp. 30., https://hal.inrae.fr/hal-02609674, OA.

Carter C., Lescot J.-M., Petit K., Phelpin-Leccia O., Piller O., Sabatié S., Terreaux J.-P., Vernier F. (2019). *Improving synergies between rural and coastal areas to tackle the water quality issues: the COASTAL project.* Presented at: LUWQ2019 - International Conference on LAND USE and WATER QUALITY: Agricultural and the Environment, Aarhus (Danemark), Danemark (2019-06-03 - 2019-06-06), https://hal.inrae.fr/hal-04358008, OA

Karageorgis A., Panagopoulos Y., Kastanidi E., Destouni G., Kalantari Z., Seifollahi-Aghmiuni S., Maneas G., Othoniel B., Lescot J.-M., Leccia-Phelpin O. et al. (2021). H2020 Project COASTAL - Deliverable D14 Operational SD Models for Coastal-Rural Interactions -Case Study Level. https://hal.inrae.fr/hal-03549159, OA

Lescot J.-M., Petit K., Sabatié S., Vernier F., Leccia-Phelpin O., Kastanidi E., Panagopoulos I., Karageorgis A., Destouni G., Seifollahi-Aghmiuni S. et al. (2020). H2020 Project COASTAL - Deliverable D6-revised v7 - Model and Data Inventory. https://hal.inrae.fr/hal-03549221, OA

Othoniel B., Lescot J.-M., Vernier F., Phelpin O., Sabatié S. (2022). MAL04 System dynamics model for the Charente River basin and its coastal zone (France). Zenodo, https://dx.doi.org/10.5281/zenodo.7075123, https://hal.inrae.fr/hal-04580066

Phelpin O., Vernier F., Petit K., Carayon D. (2024). Restoring surface water quality: quantitative assessment of the performance of agrienvironmental trajectories for mitigating pesticide concentrations. https://hal.inrae.fr/hal-04580036, OA

Phelpin O., Vernier F., Petit K. (2022). *Restauration de la qualité des eaux de surface : évaluation quantitative de la performance des trajectoires agroécologiques d'atténuation des concentrations de pesticides avec SWAT.* Presented at: 50e congrès du Groupe Français des Pesticides, 18-20 mai 2022, Namur, Belgique (2022-05-18 - 2022-05-20), https://hal.inrae.fr/hal-03789077

Phelpin O., Andro L. (2019). *Assessing SWAT model performance using gridded SAFRAN/ CFSR and conventional weather station datasets at different hydrometeorological spatial and temporal resolutions: A case study on the 10,000 km² Charente river basin S-W France.* Presented at: 2019 Vienna SWAT Conference, Vienna, Austria (2019-07-17 - 2019-07-19), https://hal.inrae.fr/hal-02609671.

Vernier F., Leccia-Phelpin O., Lescot J.-M., Brajterman O., Verstraeten Y., Papoutsis S. (2018). *Climate mitigation at the national level*, https://hal.inrae.fr/hal-02607380

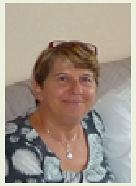
Vernier F., Leccia-Phelpin O., Lescot J.-M., Minette S., Miralles A., Barberis D., Scordia C., Kuentz Simonet V., Tonneau J.P. (2017). Integrated modeling of agricultural scenarios (IMAS) to support pesticide action plans: the case of the Coulonge drinking water catchment area (SW France). *Environmental Science and Pollution Research,* 24 (8), 6923-6950, https://dx.doi.org/10.1007/s11356-016-7657-2, https://hal.inrae.fr/hal-02604761.

For further information on the SWAT modeling part, please contact:

Odile Phelpin Odile.phelpin@inrae.fr

COASTAL Collaborative Land-Sea Integration Platform — PROJECT TEAM, MAL4 Charente Pertuis, France

Coordination MAL4



Dr Françoise Vernier, Agro-geographer

Jean-Marie Lescot, Economist

Scientific team

Dr Catriona Carter, Political science

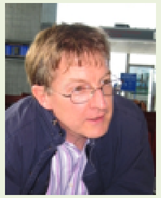
Kevin Petit, Geomatician

Odile Phelpin-Leccia, Eco-hydrological modeling

Benoît Othoniel, System Dynamics modeling

Dr Olivier Piller, Mathematics/ Modeling

Sandrine Sabatié, Data management, IT



Dr Jean-Philippe Terreaux, Economist

HORIZON 2020

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773782.

https://h2020-coastal.eu/ COASTAL Collaborative Land-Sea Integration Platform

RÉPUBLIQUE FRANÇAISE · INRAE · ETTIS · AGENCE DE L'EAU ADOUR-GARONNE · EPTB Charente · Comité Régional de la Conchyliculture Charente-Maritime · AGRICULTURES & TERRITOIRES CHAMBRE D'AGRICULTURE NOUVELLE-AQUITAINE · BIO NOUVELLE-AQUITAINE · Conservatoire du littoral · CAPENA · PORT CHARENTE ATLANTIQUE · Port Atlantique La Rochelle ... & others.