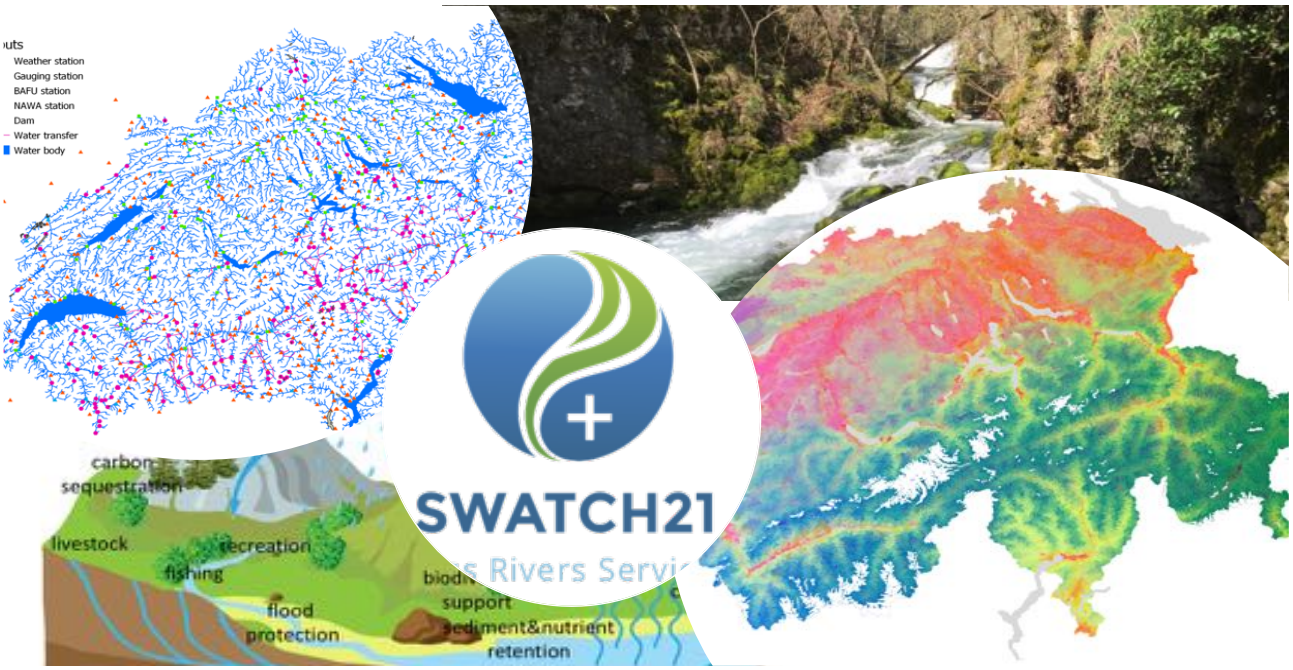


Quels services éco-hydrologiques nous apportent et nous apporterons les rivières de Suisse?

SGHL: Jeudi 4 novembre 2021

Par Anthony Lehmann, Marc Fasel, Pablo Timoner et Saeid Vaghefi

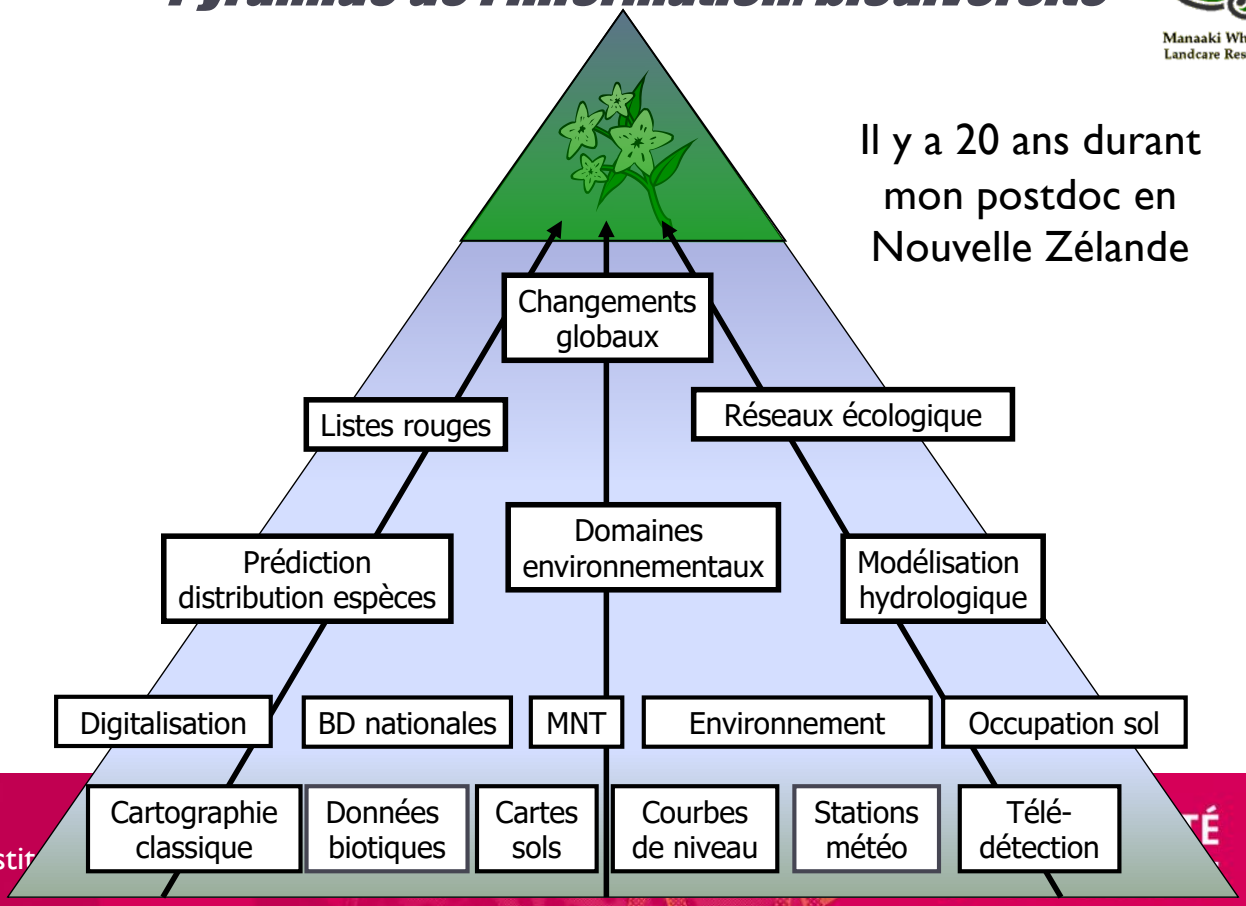
Institute for Environmental Sciences
Dpt. Forel for Aquatic and Environmental Sciences

UNIVERSITÉ DE GENÈVE

Pyramide de l'information: biodiversité

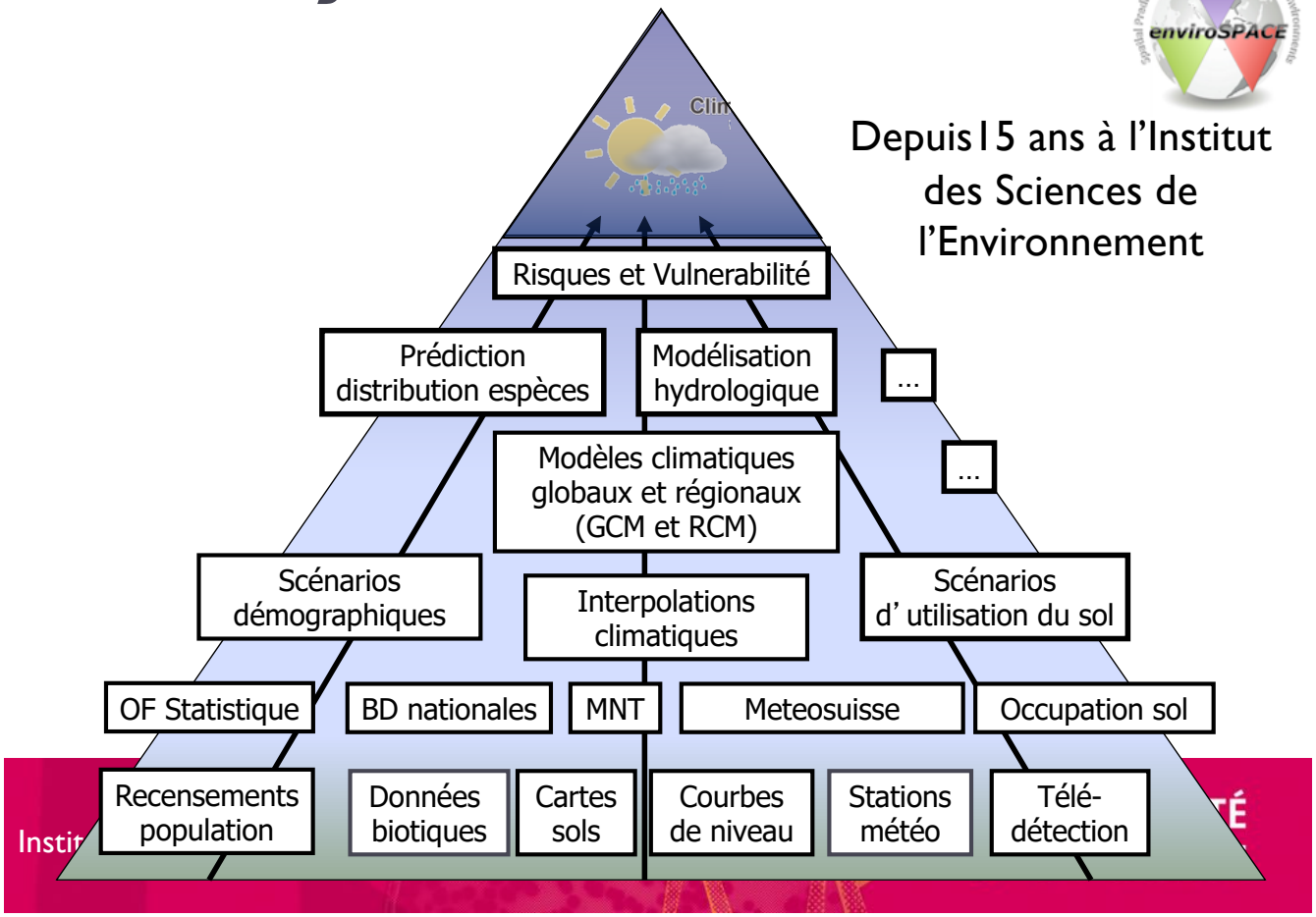
Manaaki Whenua Landcare Research

Il y a 20 ans durant mon postdoc en Nouvelle Zélande



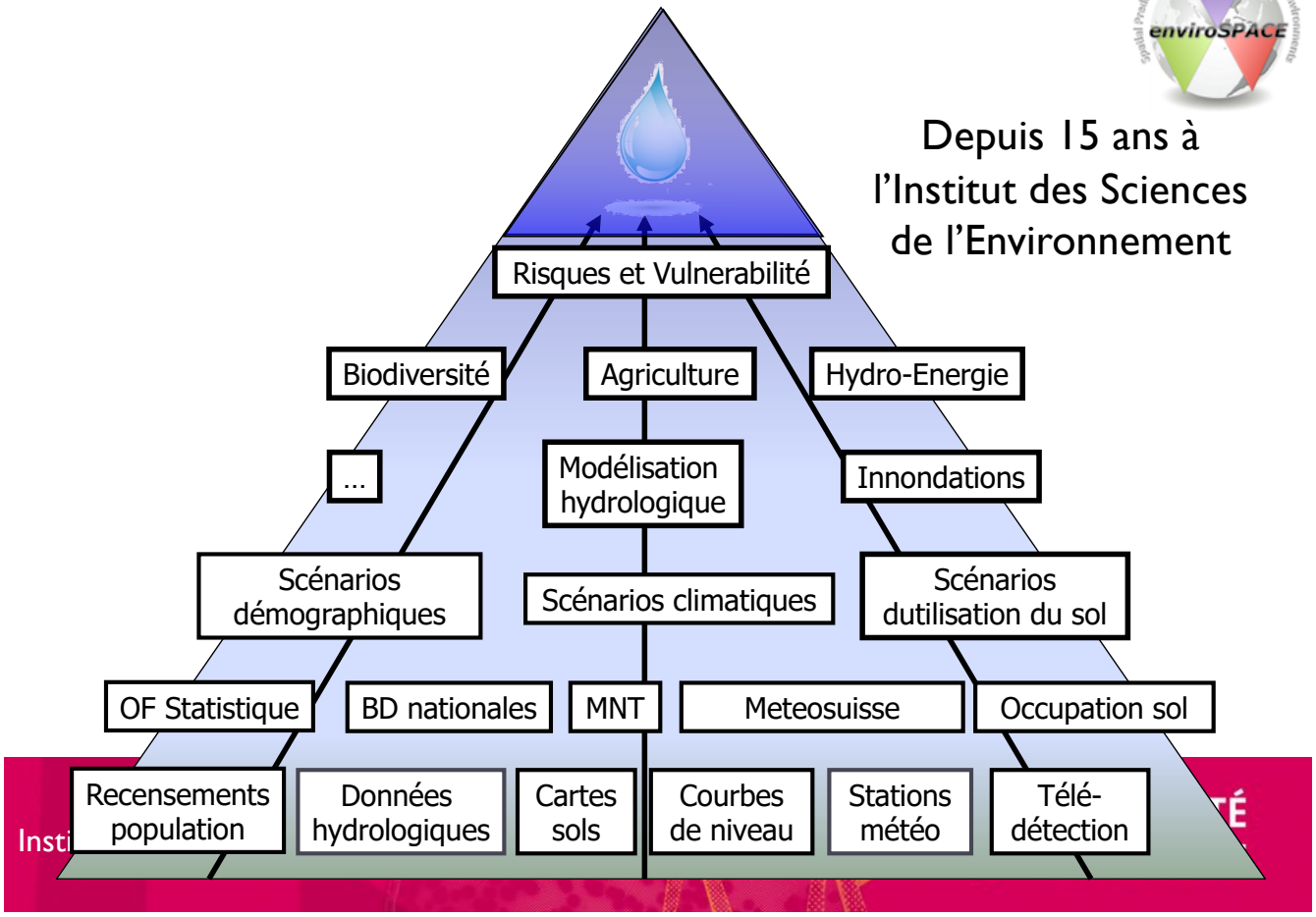
Pyramide de l'information: climat

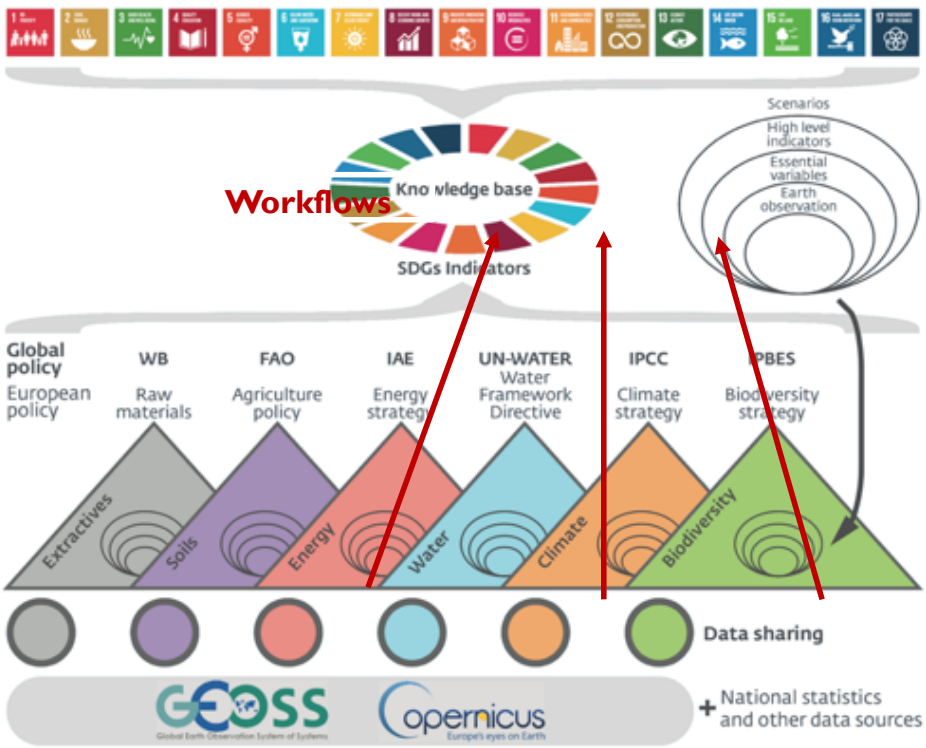
Depuis15 ans à l'Institut des Sciences de l'Environnement



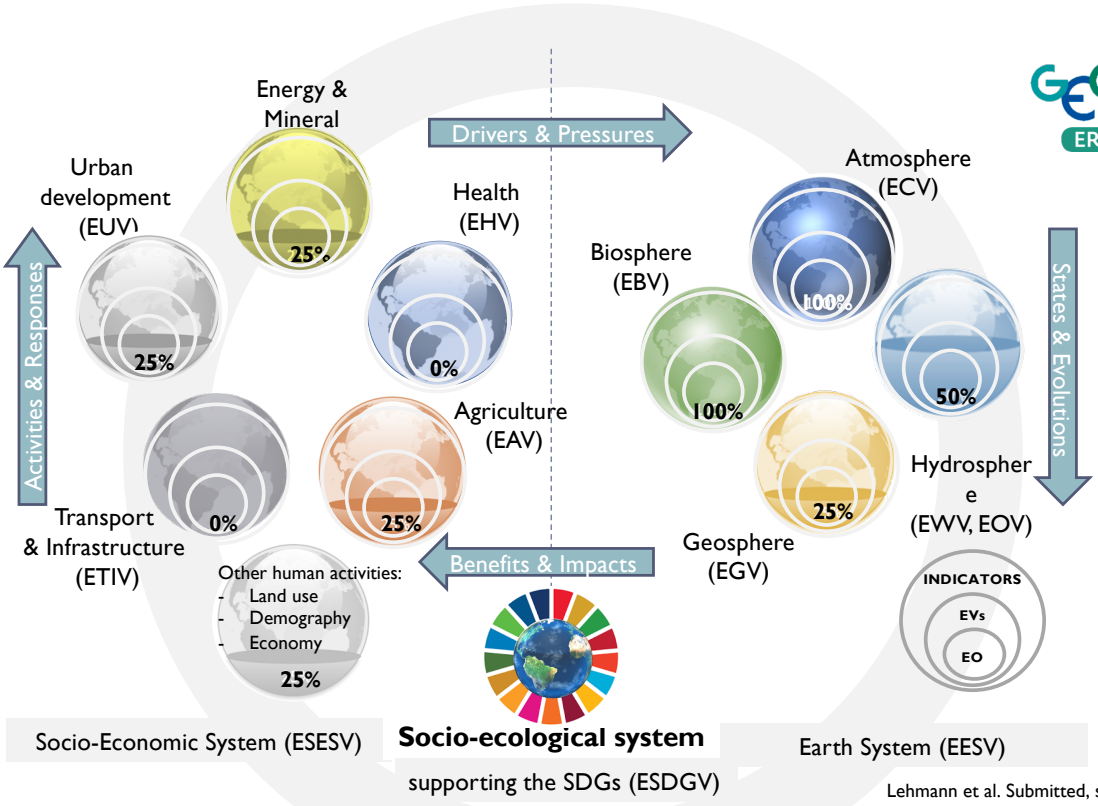
Pyramide de l'information: eau

Depuis 15 ans à l'Institut des Sciences de l'Environnement



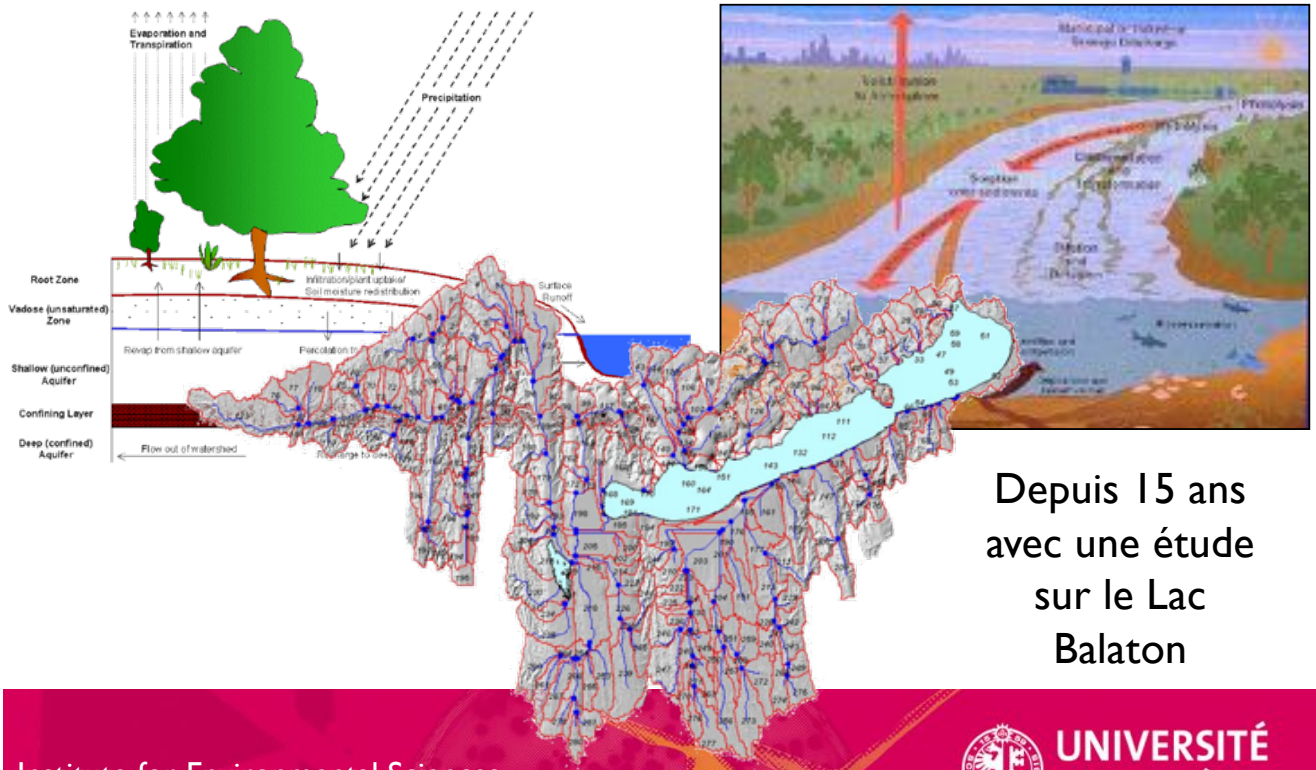


Ces 5 dernières années avec le projet européen GEOEssential



Lehmann et al. Submitted, special issue ESP

SWAT: Soil and Water Assessment Tool



Depuis 15 ans avec une étude sur le Lac Balaton

SWAT: Soil and Water Assessment Tool

Essential Water Variables & SWAT

Areas of application

Primary Essential Water Variables

Supplementary Essential Water Variables

Essential Water Cycle Variables (Structured following the Water SBA analysis as being of approximately high priority when averaged across all user sectors. Some variables/parameters have been combined for simplicity)	Water Cycle Monitoring	Water Cycle Modelling/Prediction	Decision Support - Agriculture	Decision Support - Biodiversity	Decision Support - Climate	Decision Support - Ecosystems	Decision Support - Energy	Decision Support - Groundwater	Decision Support - Health	Decision Support - Land Management	Decision Support/Oceans (Coastal)	Decision Support - Socio-Economic	Decision Support - Water Management	Decision Support - Weather	Cross Ref. - ECVs as per UNFCCC, IPCC)	
Precipitation	X	X	X	X	X	X	X	X	X	X	X		X	X	X	SWAT inputs
Evaporation and evapotranspiration	X	X	X	X	X	X							X			SWAT outputs
Snow cover (SWE, depth, freeze thaw margins)	X	X			X	X	X	X	X	X			X	X	X	SWAT inputs
Soil moisture/temperature	X	X	X	X	X	X		X		X			X		X	SWAT outputs
Groundwater	X	X	X					X	X				X		X	SWAT outputs
Runoff/streamflow/river discharge	X	X	X	X	X	X	X	X	X		X		X		X	SWAT outputs
Lakes/reservoir levels and aquifer volumetric change	X	X			X	X	X		X				X		X	SWAT outputs
Water quality	X	X		X		X			X	X	X	X	X			SWAT outputs
Water use/demand	X	X	X				X		X	X	X	X	X		P	SWAT inputs
Glaciers/ice sheets	X	X			X		X		X				X		X	SWAT inputs
Supplementary Variables																
Surface meteorology	X	X	X		X			X						X	X	SWAT inputs
Surface and atmospheric radiation budget	X	X	X		X										X	SWAT inputs
Cloud and aerosols	X				X									X	X	???
Land Cover and vegetation/land use	X	X	X	X	X	X				X		X	X		X	SWAT inputs
Permafrost	X	X			X										X	???
Elevation/topography and geological stratification		X	X	X				X		X			X			SWAT inputs

Derived from Lawford, R. (ed.), 2014. The GEOSS Water Strategy: From Observations to Decisions.

SWATCH21: project description

Ecohydrology & Hydrobiology 19 (2019) 182–197

Contents lists available at ScienceDirect

Ecohydrology & Hydrobiology

journal homepage: www.elsevier.com/locate/ecohyd

SWATCH21: A project for linking eco-hydrologic processes and services to aquatic biodiversity at river and catchment levels

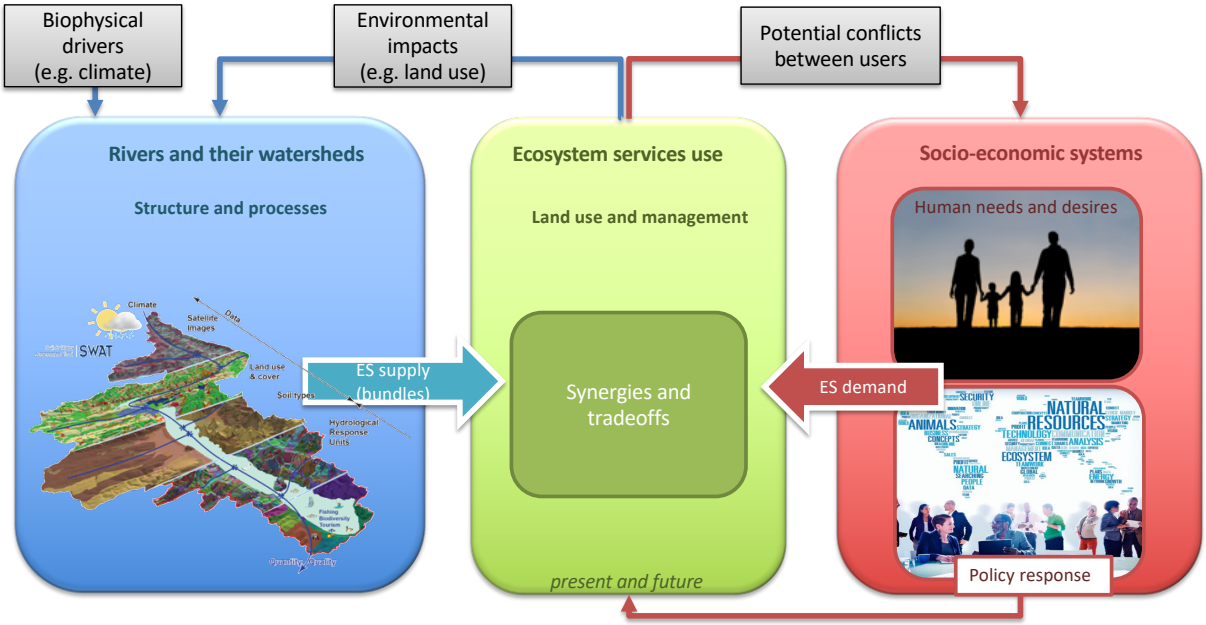
Anthony Lehmann[a,b,*], Pablo Timoner[a,b], Marc Fasel[a,b], Martin Lacayo[a], Saeid Ashraf Vaghefi[b,c], Karim C. Abbaspour[c]

[a] University of Geneva, Institute for Environmental Sciences, enviroSPACE Lab., Bd. Carl-Vogt 66, CH-1205 Geneva, Switzerland
[b] University of Geneva, Department F.-A. Forel of Environmental and Aquatic Sciences, Bd. Carl-Vogt 66, CH-1205 Geneva, Switzerland
[c] Eawag, Swiss Federal Institute of Aquatic Science and Technology, Ueberlandstrasse 133, CH-8600 Duebendorf, Switzerland

Ces 4 dernières années

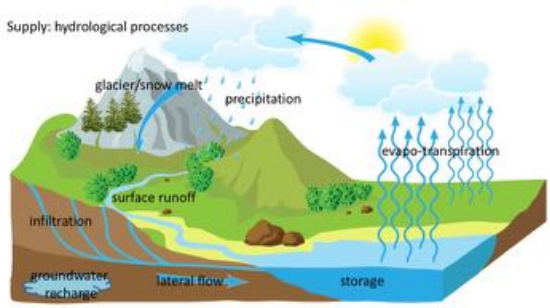
https://doi.org/10.1016/j.ecohyd.2019.01.003

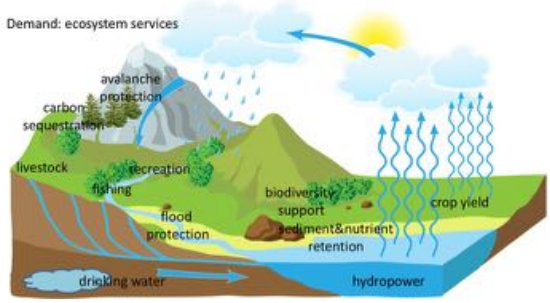
SWATCH21: ecosystem services



Lehmann et al. (2019)

SWATCH21: ES supplies and demands





Provisioning services

§ Agriculture: crop yield will be directly derived from SWAT outputs
§ Drinking water: the amount of blue water used for drinking will be assessed from the population distribution and needs
§ Hydropower: blue water transformed in energy by hydropower will be estimated using the distribution and size of existing dams
§ Water for livestock: blue water available for livestock will be estimated from the distribution of different types of livestocks

Regulating and maintenance services

§ Biodiversity: the ecosystem diversity will be assessed by downscaling existing land use information from 100m (geostat) resolution to 25m (Lehmann et al. unpublished).
§ Flood protection: The Critical Consecutive Days Analyzer (CCDA) has been developed at EAWAG (Vaghefi et al. in prep.).
§ Nutrient and sediment retention will be directly derived from SWAT outputs
§ Carbon sequestration will be calculated with the InVEST package
§ Avalanche protection: this services will be assessed by GIS analyses as in Grêt-Regamey et al. (2008)[97]

Cultural services

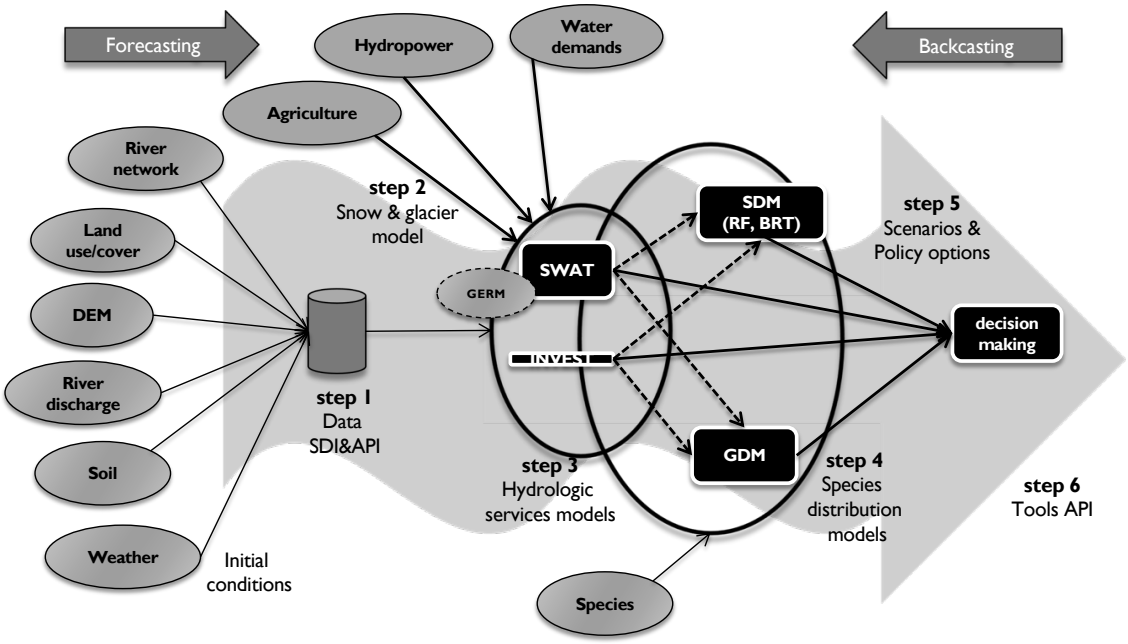
§ Fishing for recreation: this service will be assessed by modelling the species distribution of emblematic fishes species such as trouts using species distribution models (e.g. GRASP[160,161] or MARS[162])
§ Recreation: the recreational value of river beds will be assessed by a combination of GIS analyses of accessibility from roads and walking tracks, and the density of photos made available on Flickr.

Lehmann et al. (2019)

SWATCH21: Expected outputs

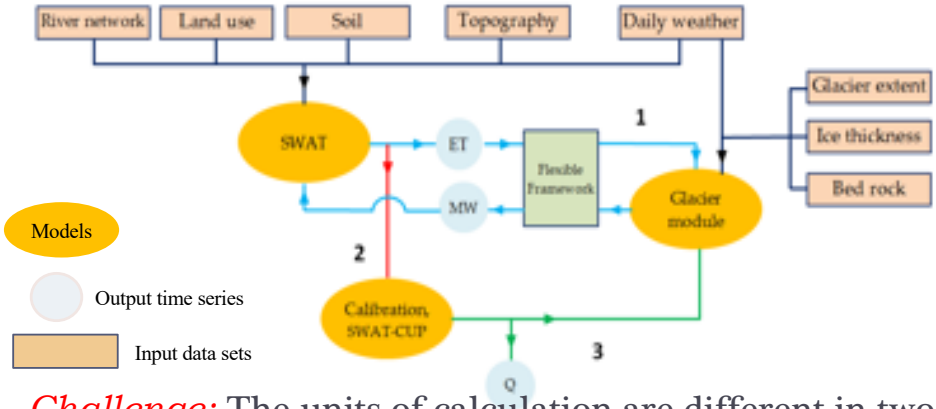
Data Type	Description
SWAT outputs	Daily, monthly and yearly water flow, nutrient and sediment loads
INVEST outputs	Yearly ES: water yield, sediment and nutrient retention
SDM outputs	Species distribution predictions for FEPT groups
Ecosystem Services	Provisioning services: - water for hydropower - water for domestic use - water for agriculture and livestock - water for power generation Regulating services: - sediment retention - nutrient retention - flood water retention Cultural services: - recreational value - recreational fishing value Supporting services: - nutrient recycling - species diversity - environment flow requirements - transportation
Scenarios impacts	Impacts of climate and landuse scenarios on SWAT, INVEST, SDM, ES outputs

SWATCH21 workflow



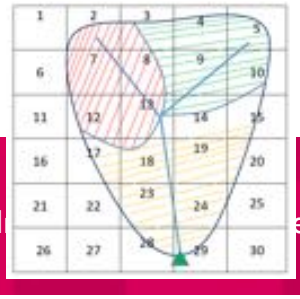
Lehmann et al. (2019)

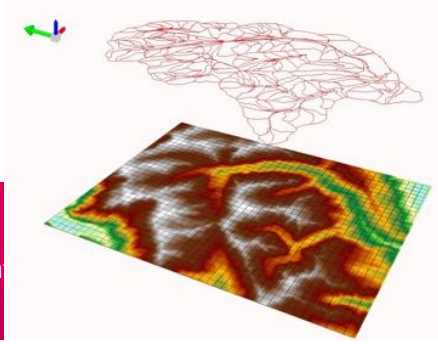
#SWATCH21: Glacier and snow melt

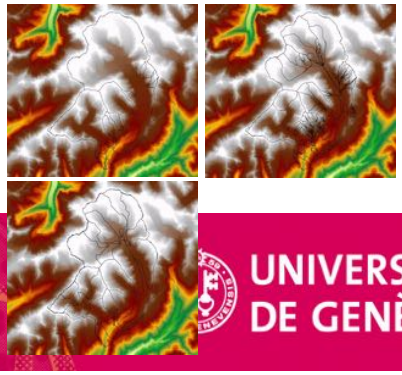


Vaghefi et al. (submitted)

Challenge: The units of calculation are different in two models?
Solution: Overlaying SWAT Sub-basins map with glacier module grids







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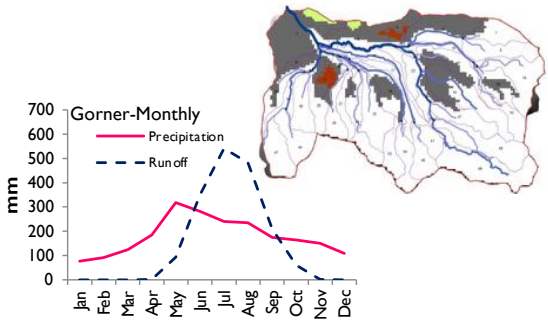
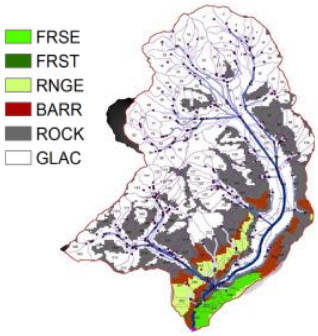
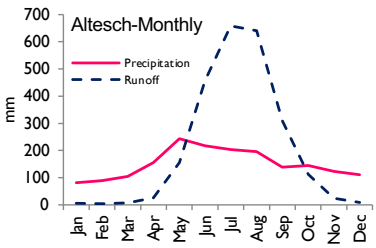
#SWATCH21: Glacier and snow melt

- Aletsch Catchment
  Total Area: 196 km^2, Glacier area: 82 km^2, 15 km^3 ice (20% of Swiss ice, 2014)

- Gorner Catchment
  50m grids







#SWATCH21: Glacier and snow melt

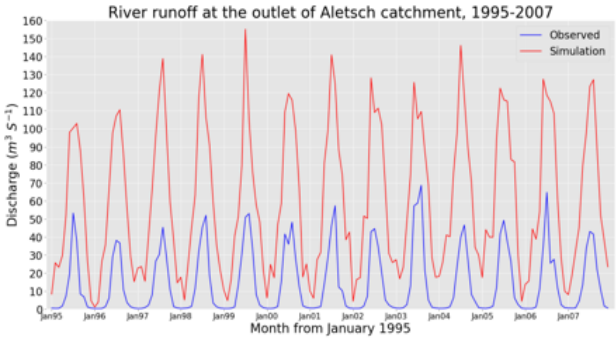
1- Original run of the SWAT - without elevation band and - with SWAT default snow-melt parameters
- with ice-melt added as point source calculated with initial glacier parameters taken from the literature.
SFTMP = 1.0
SMTMP = 0.5
SMFMX = 4.5
SMFMN = 4.5
TIMP = 1

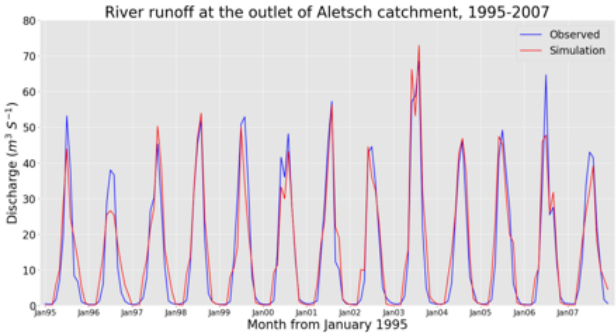
NSE = -7.5
R2 = 0.79

3- Final SWAT run after addition and calibration of TLPAS and PLAPS as snow parameters

SFTMP = 1.1
SMTMP = -3.3
SMFMX = 2.9
SMFMN = 3.3
TIMP = 0.12

PLAPS = 0.45 mm/km
TLAPS = 5.4 oC/km
NSE = 0.89
R2 = 0.89

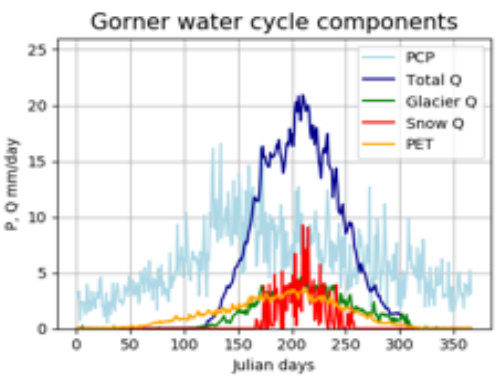


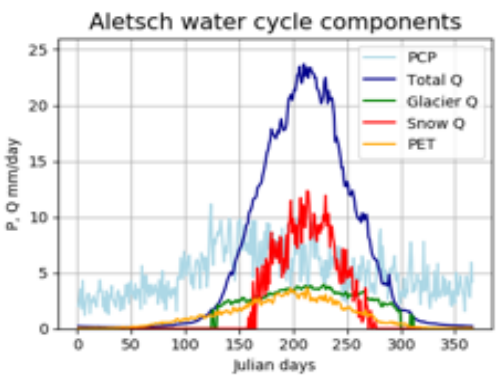


Vaghefi et al. (submitted)

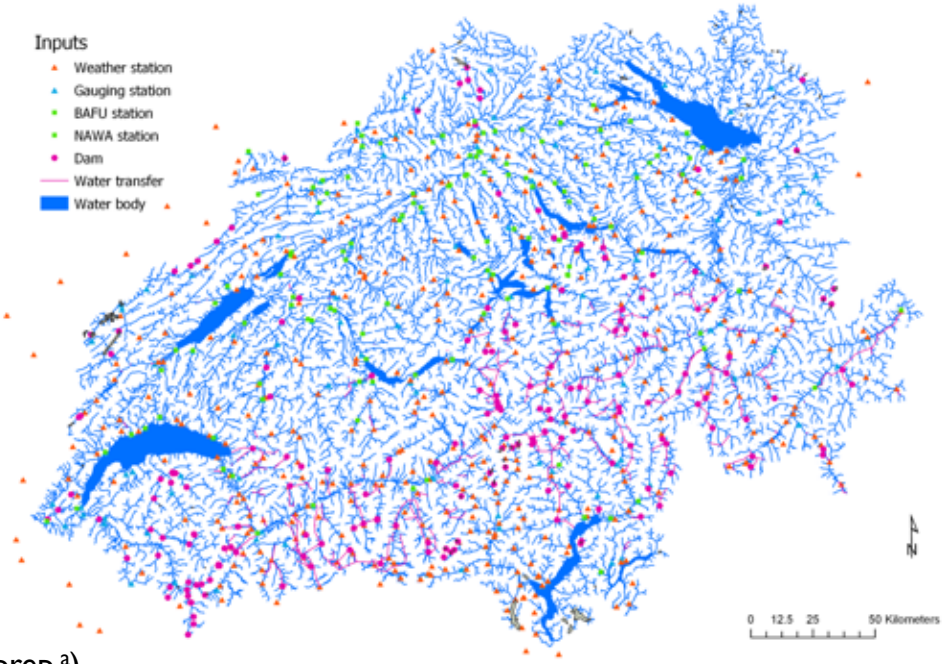
#SWATCH21: Glacier and snow melt

Average temporal distribution of simulated Total runoff (Total Q), simulated Glacier-melt runoff (Glacier Q), simulated Snow-melt runoff (Total Q), potential evapotranspiration (PET), and precipitation (P)





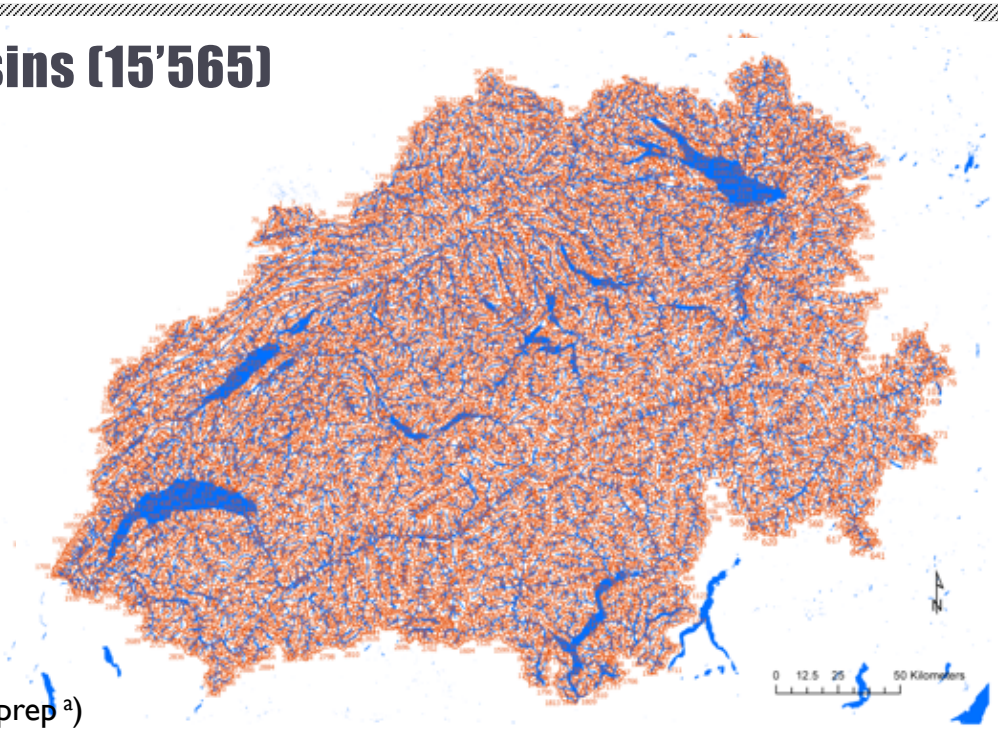
SWATCH21: weather and gaging stations



Fasel et al. (in prep [a])

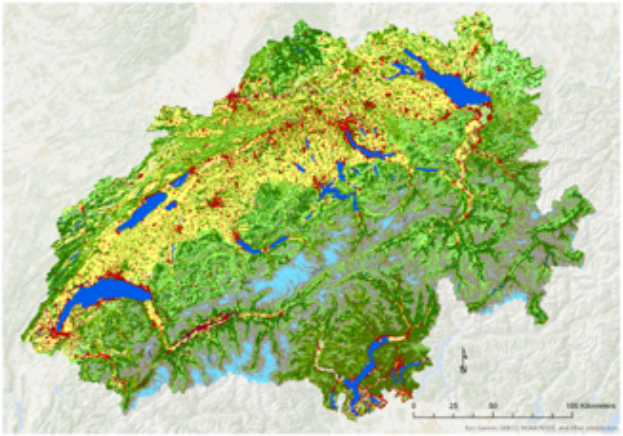
SWATCH21: SWAT model

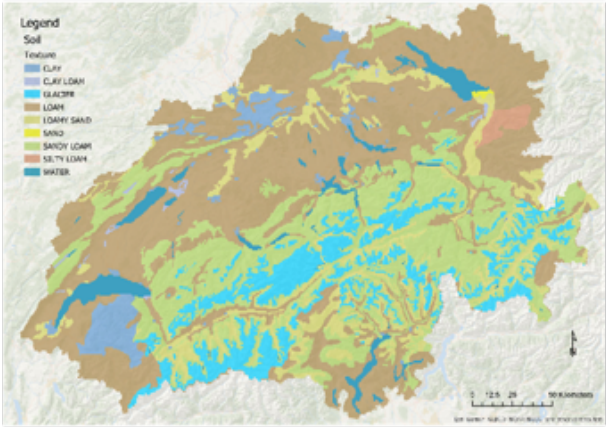
Subbasins (15'565)



Fasel et al. (in prep [a])

SWATCH21: Land use and soils categories





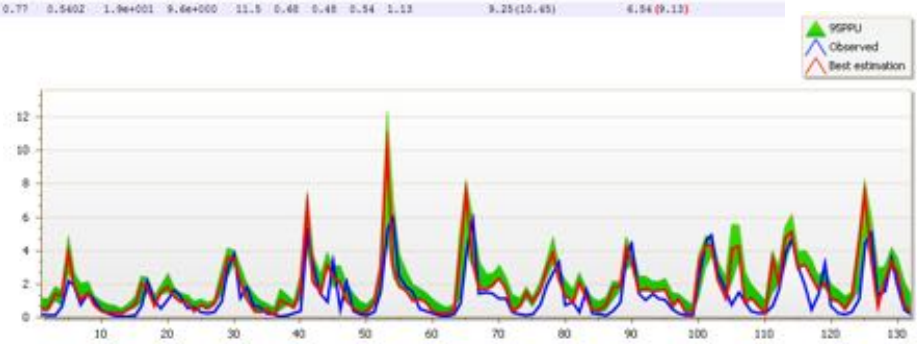
Fasel et al. (in prep [a])

#SWATCH21: Calibration avec SWAT CUP

SWATCH21
Swiss Rivers Services

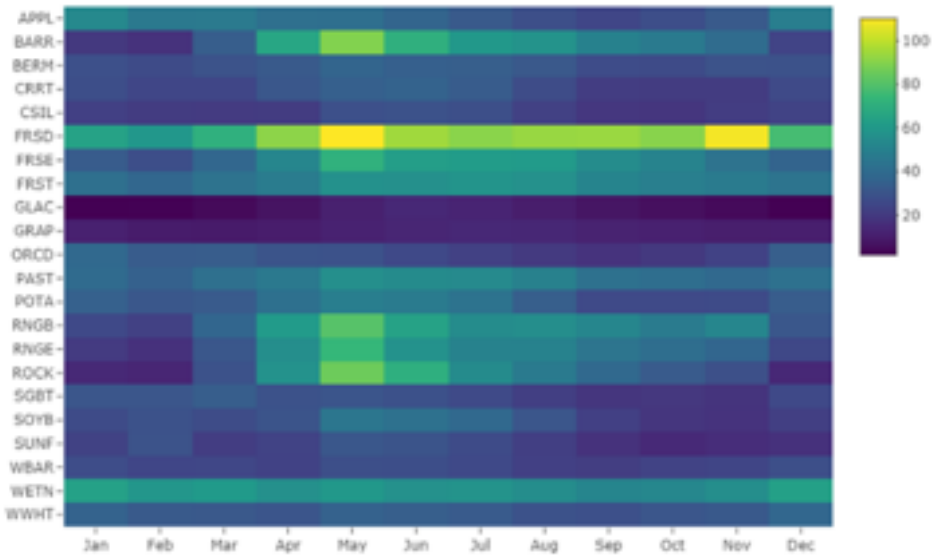
Goal_type= Nash_Sutcliff No_sims= 200 Best_sim_no= 21 Best_goal = 6.890698e-002

Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	KGE	RSR	MNS	VOL_FR	---	Mean_sim(Mean_obs)	StdDev_sim(StdDev_obs)
FLOW_OUT_357	0.45	0.84	0.56	0.27	0.4845	1.5e+000	4.4e-001	-33.1	0.55	0.85	0.24	0.75		1.94(1.46)	1.70(1.46)
FLOW_OUT_371	0.83	1.29	0.59	0.45	0.5247	5.3e+001	4.6e+000	1.7	0.73	0.74	0.33	1.02		18.84(19.17)	11.25(9.81)
FLOW_OUT_538	0.37	1.24	0.52	0.20	0.3647	1.1e+001	3.6e+000	-43.8	0.48	0.89	0.11	0.70		6.00(4.17)	3.76(3.71)
FLOW_OUT_643	0.48	0.80	0.33	0.26	0.1504	6.0e+001	6.7e+000	9.8	0.52	0.86	0.29	1.11		9.58(10.62)	7.25(9.00)
FLOW_OUT_715	0.39	0.92	0.68	0.66	0.2309	1.1e+002	2.9e+001	-10.5	0.55	0.73	0.29	0.91		21.09(19.09)	9.83(14.22)
FLOW_OUT_763	0.69	1.28	0.74	0.73	0.5853	3.4e+002	3.5e+001	-4.9	0.83	0.52	0.55	0.95		66.19(63.09)	32.59(35.69)
FLOW_OUT_886	0.73	1.22	0.77	0.76	0.5815	3.5e+002	6.1e+001	1.3	0.80	0.49	0.58	1.01		69.72(70.66)	33.52(39.97)
FLOW_OUT_1033	0.80	0.84	0.53	0.52	0.2477	2.9e+000	1.0e+000	-3.0	0.55	0.69	0.33	0.97		2.96(2.87)	1.56(2.47)
FLOW_OUT_1295	0.36	0.89	0.46	0.36	0.2190	2.4e+000	7.6e-001	-25.1	0.50	0.80	0.12	0.83		2.95(2.36)	1.39(1.95)
FLOW_OUT_1341	0.55	1.09	0.60	0.53	0.3906	3.7e+000	8.5e-001	-19.0	0.67	0.69	0.24	0.84		4.45(3.74)	2.41(2.81)
FLOW_OUT_1441	0.51	1.07	0.62	0.57	0.3251	1.1e+002	4.4e+001	-12.9	0.59	0.65	0.30	0.89		24.04(21.30)	10.78(14.09)
FLOW_OUT_1447	0.68	1.30	0.79	0.77	0.5397	4.0e+002	1.5e+002	-6.0	0.73	0.48	0.50	0.94		69.30(65.39)	31.57(41.22)
FLOW_OUT_1521	0.34	0.77	0.84	0.77	0.6006	8.9e+000	4.5e+000	-27.5	0.64	0.48	0.43	0.78		6.67(5.23)	4.04(6.18)
FLOW_OUT_1543	0.79	1.19	0.81	0.79	0.5985	7.3e-001	3.5e-001	-9.4	0.77	0.46	0.55	0.91		2.35(2.60)	1.51(1.84)
FLOW_OUT_1619	0.79	0.95	0.83	0.77	0.5402	1.9e+001	9.6e+000	11.5	0.68	0.48	0.54	1.13		9.25(10.65)	6.54(9.13)



Fasel et al. (in prep [a])

#SWATCH21:
eau par catégorie d'utilisation sol et mois de l'année

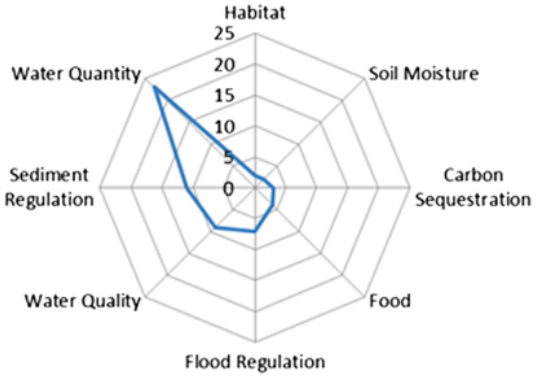


Fasel et al. (in prep [a])

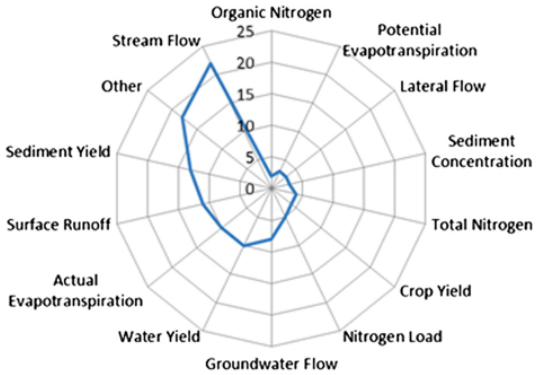
#SWATCH21: échange d'eau entre pays

Fasel et al. (in prep [a])

#SWATCH21: Review on SWAT & Ecosystem services



Radar chart shows the ES topics most frequently address by SWAT publications.

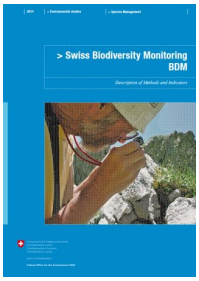


Most common SWAT output variables used for interpretation of ES.

Francesconi et al. 2016: http://dx.doi.org/10.1016/j.jhydrol.2016.01.034

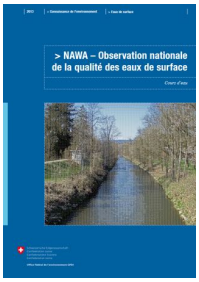
SWATCH21: Community distribution modeling

Swiss Biodiversity Monitoring Program (BDM)



BDM Coordination Office (2014). Swiss Biodiversity Monitoring BDM. Description of Methods and Indicators. Federal Office for the Environment, Bern. Environmental studies no. 1410. 103 pp

National Surface Water Quality Monitoring Program (NAWA)



OFEV 2013. NAWA – Observation nationale de la qualité des eaux de surface. Cours d'eau. Office fédéral de l'environnement, Berne. Connaissance de l'environnement n° 1327: 72 p.

info fauna CSCF

Timoner et al. 2020

Comparing possible policy outcomes

SWATCH21: Community distribution modeling

- Assemblages and β-diversity

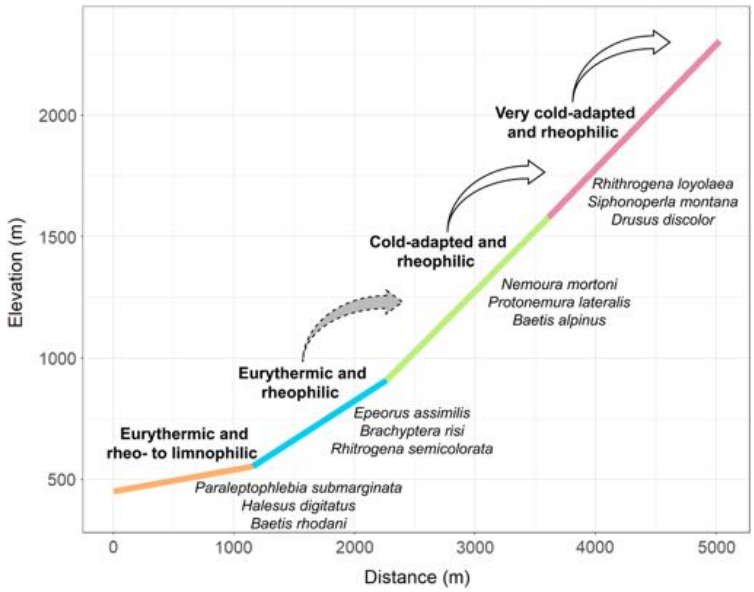
Current situation

2060 - RCP8.5

Timoner et al. 2020

SWATCH21: Community distribution modeling

- Assemblages and β-diversity



Timoner et al. 2020

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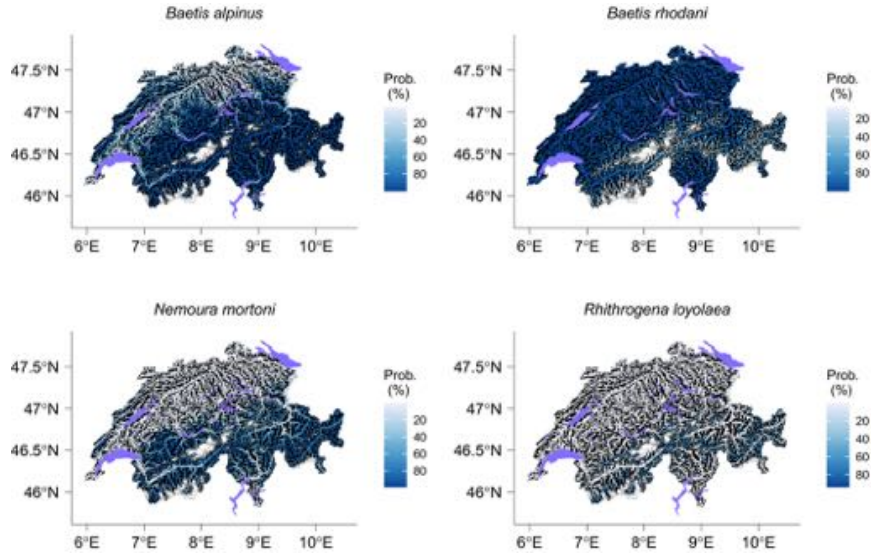
SWATCH21: Species distribution modeling

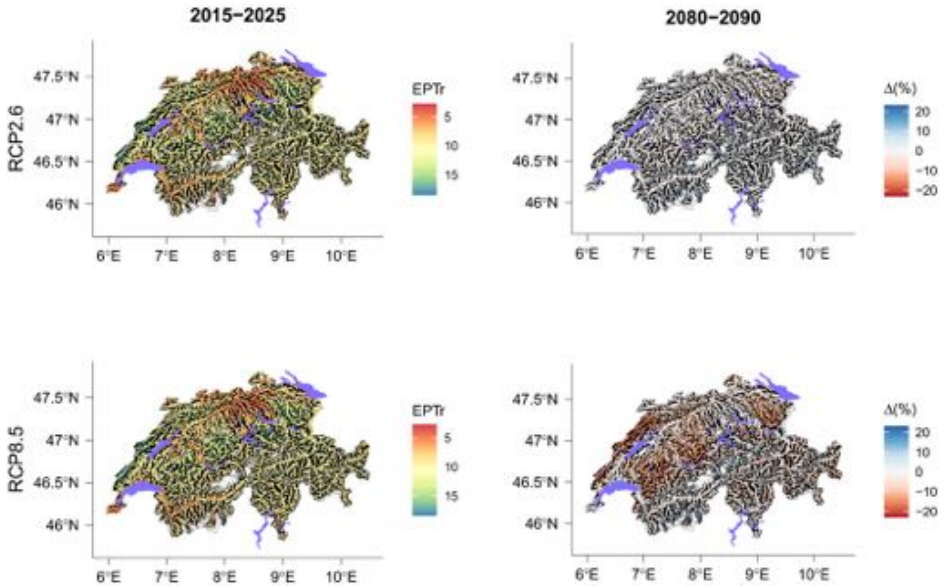
- Species distribution



Timoner et al. 2021

SWATCH21: Species distribution modeling

- Species richness (α-diversity)



Timoner et al. 2021

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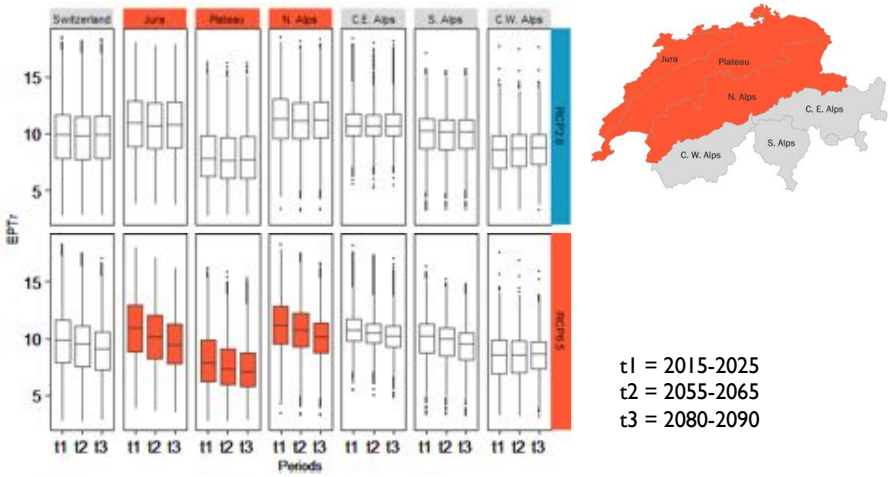
SWATCH21: Species distribution modeling

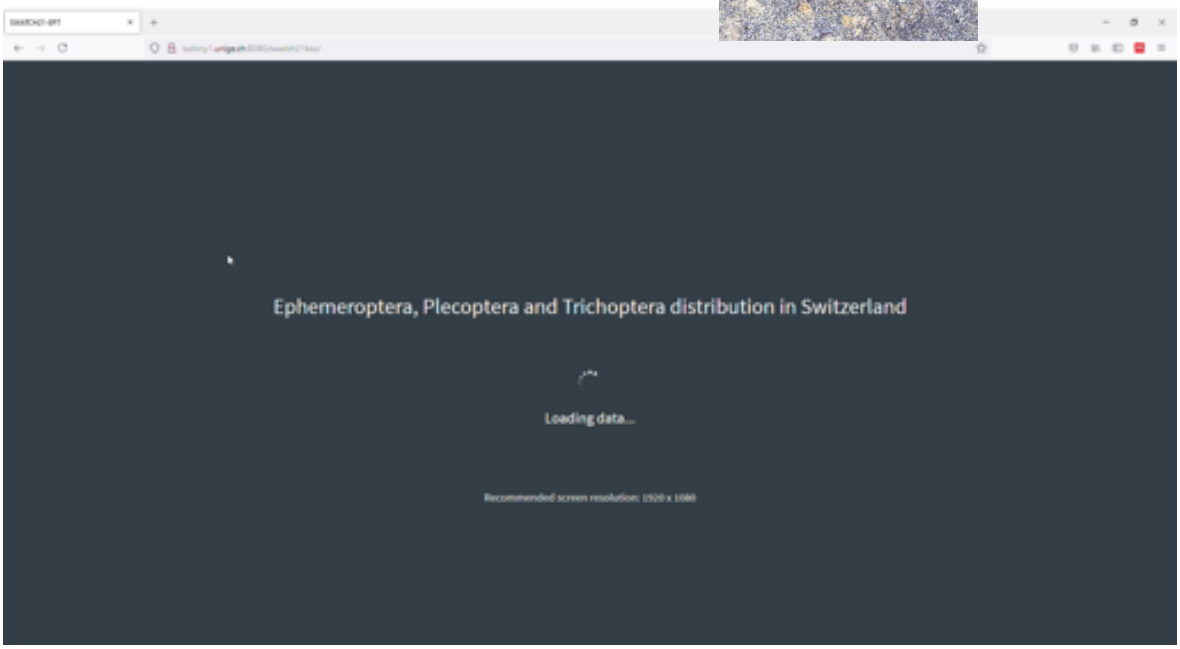
- Species richness (α-diversity)



t1 = 2015-2025
t2 = 2055-2065
t3 = 2080-2090

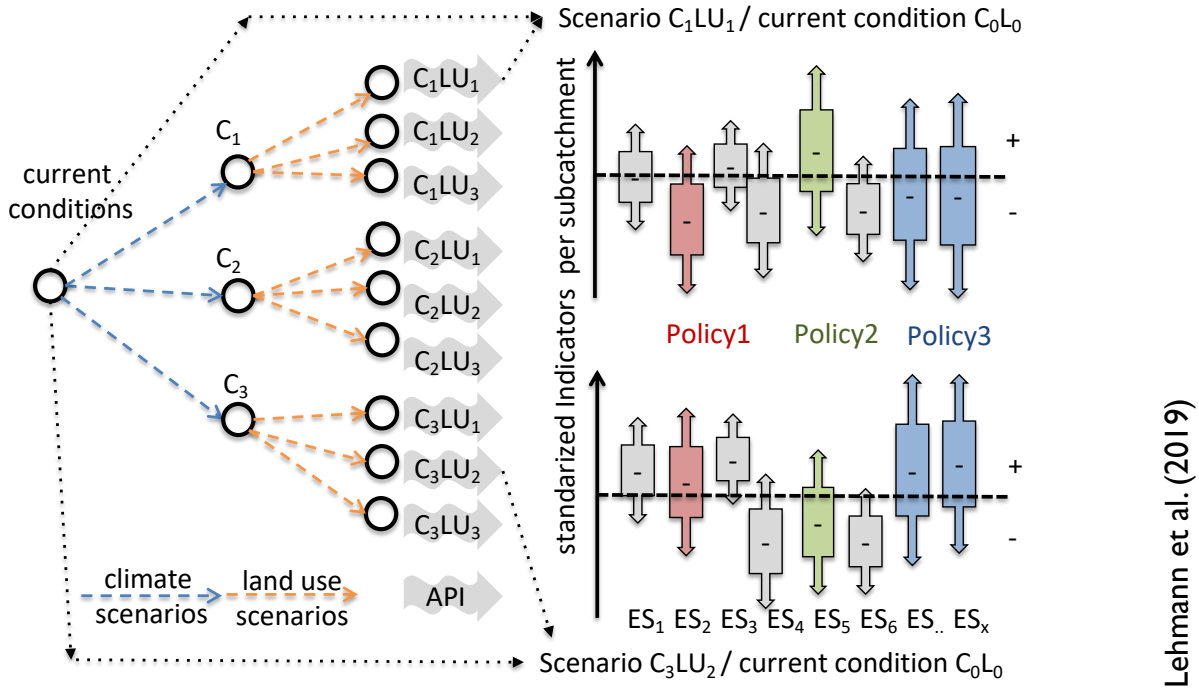
Timoner et al. 2021

SWATCH21: web interface



http://lsshiny1.unige.ch:8080/swatch21bio/

SWATCH21: tradeoffs and synergies



Lehmann et al. (2019)

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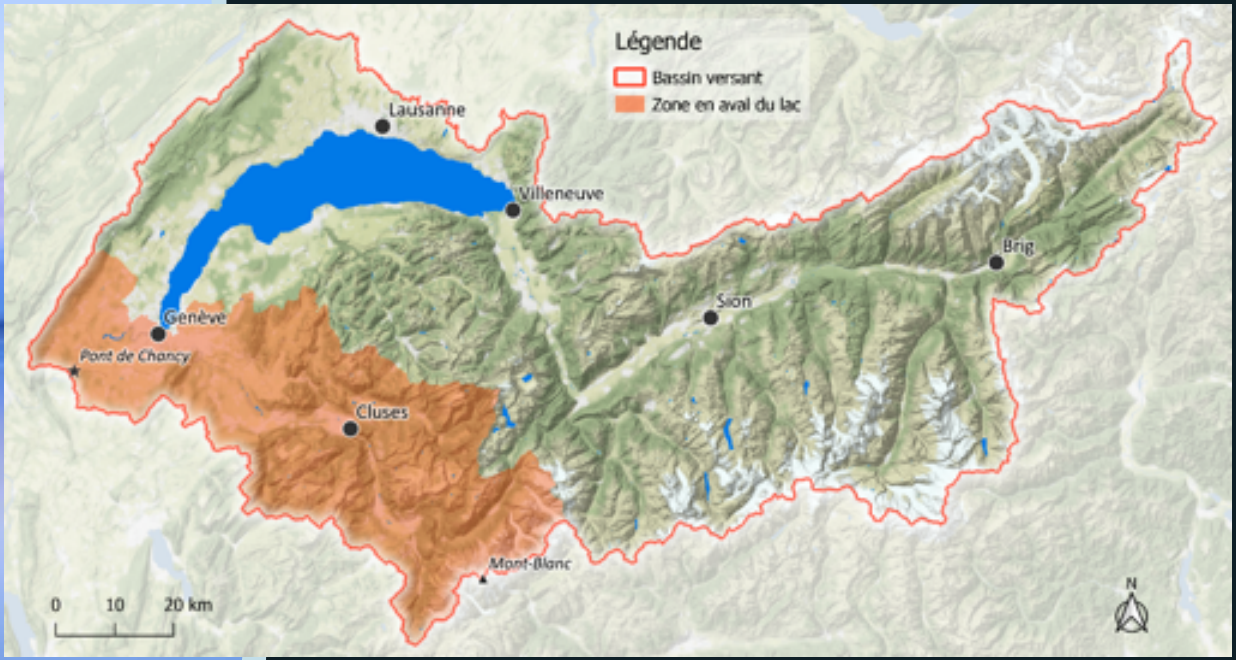
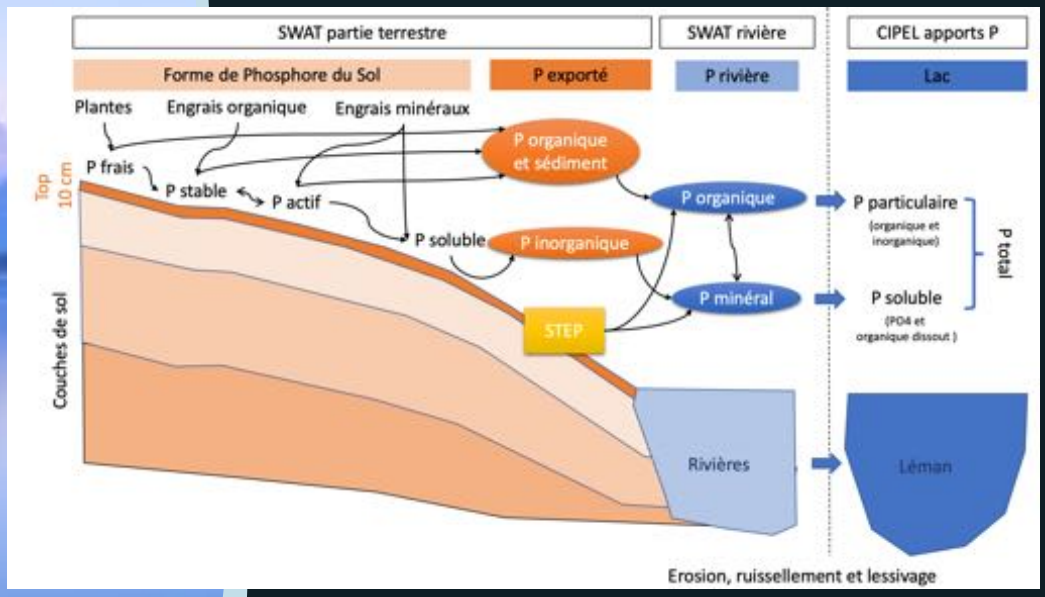
Zone d'étude

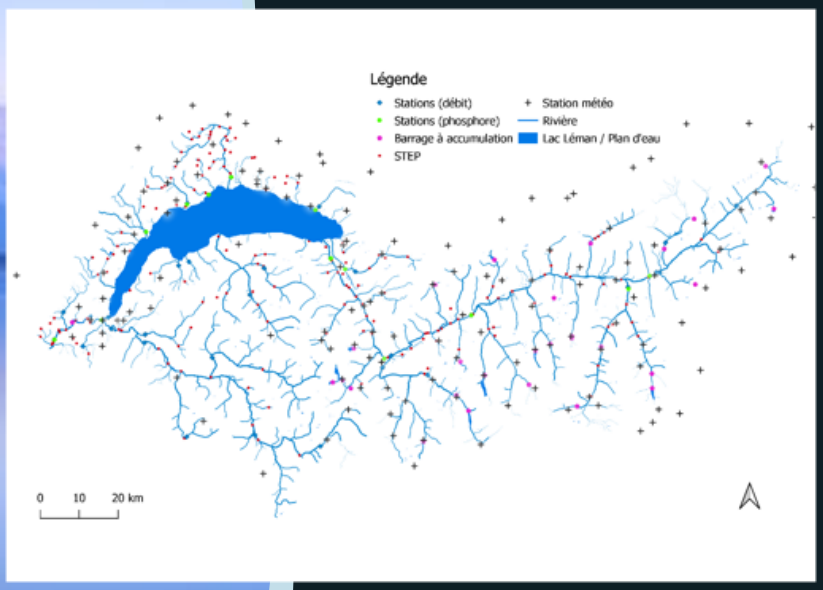


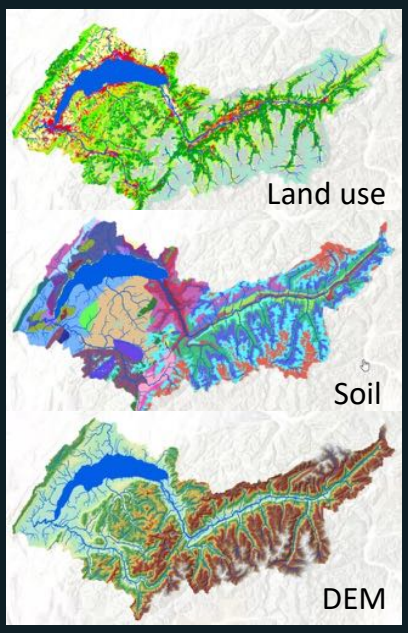
Fasel et al. (in prep[b])

SWAT: formes du Phosphore



Données de calibration disponibles





Fasel et al. (in prep[b])

Calibration débits des affluents

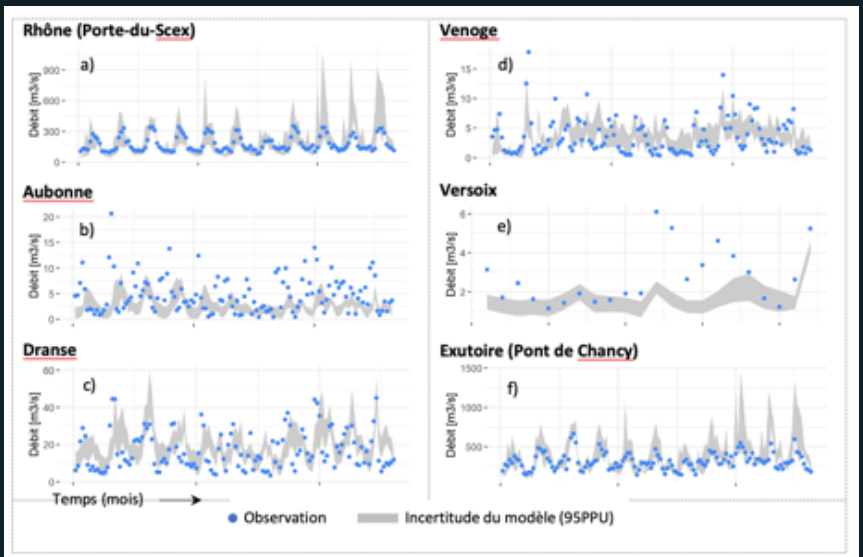


Figure 13a-f: Graphiques de calibration de débit des affluents principaux.

Fasel et al. (in prep[b])

Statistiques de calibration Q

Affluent	Débit moyen simulé [m³/s]	Débit moyen observé [m³/s]	PBIAS	NS	p-factor	r-factor	Période
Rhône	167.1	179.2	6.7	0.33	0.83	2.15	2005-2015
Aubonne	3.3	4.8	31.3	-0.10	0.30	0.38	2005-2015
Dranse	20.3	16.7	-21.6	0.06	0.40	0.68	2005-2015
Venoge	3.2	3.5	10.0	0.24	0.56	1.11	2005-2015
Versoix	2.0	2.7	25.8	0.05	0.55	0.60	2011-2015
Exutoire	337.5	318.3	-6.1	0.03	0.74	2.16	2005-2015

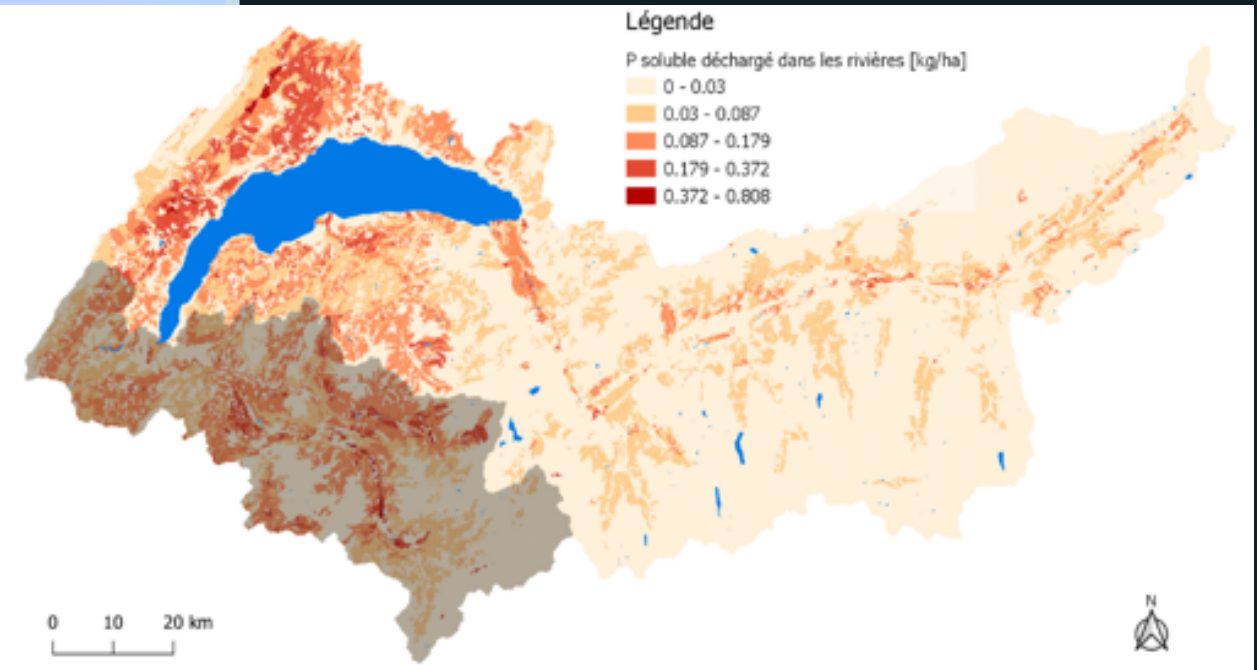
Fasel et al. (in prep[b])

Statistiques de calibration P

Affluent	P_i mensuel moyen simulé [kg]	P_i mensuel moyen observé [kg]	PBIAS	p-factor	r-factor	Période
Rhône	2579.5	2711.2	4.9	0.32	1.06	2005-2015
Aubonne	70.7	134.6	47.5	0.61	0.89	2005-2015
Dranse	252.0	326.6	22.9	0.59	0.84	2005-2015
Venoge	154.2	239.9	35.8	0.80	1.83	2005-2015
Versoix	84.7	177.7	52.3	0.74	0.85	2011-2015
Exutoire	13972.8	12398.5	-12.7	0.49	0.61	2005-2015

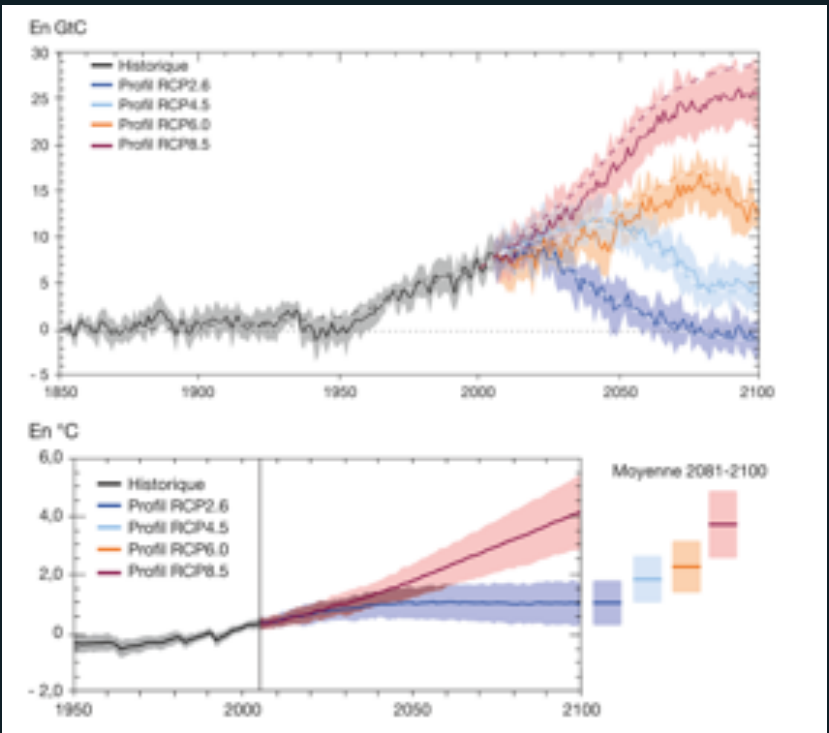
Fasel et al. (in prep[b])

Cartes de potentiel diffus en kg/ha par HRU



Fasel et al. (in prep[b])

Scénarios climatiques



https://www.statistiques.developpement-durable.gouv.fr/edition-numerique/chiffres-cles-du-climat/3-scenarios-et-projections-climatiques

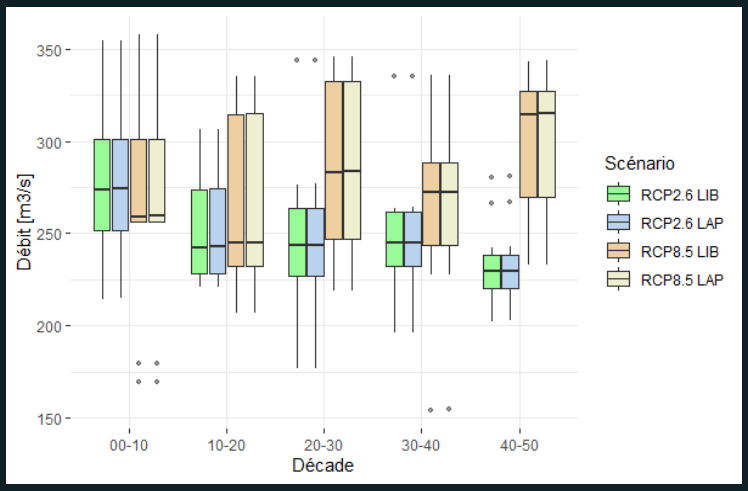
Scénarios de changement d'utilisation du sol

	De	Forêt (mixte)	Terre arbustive	Agriculture	Scénario
< 900 m	Forêt	100%	0	0	LAP - 50% engrais
	Terre arbustive	2%	98%	0	
	Agriculture	10%	10%	80%	
> 900 m	Forêt	95%	5%	0	
	Terre arbustive	2%	98%	0	
	Agriculture	20%	20%	60%	
< 900 m	Forêt	100%	0	0	LIB 100% engrais
	Terre arbustive	0	100%	0	
	Agriculture	0	2%	98%	
> 900 m	Forêt	100%	0	0	
	Terre arbustive	90%	10%	0	
	Agriculture	60%	30%	10%	

Dérivé de Silva 2017

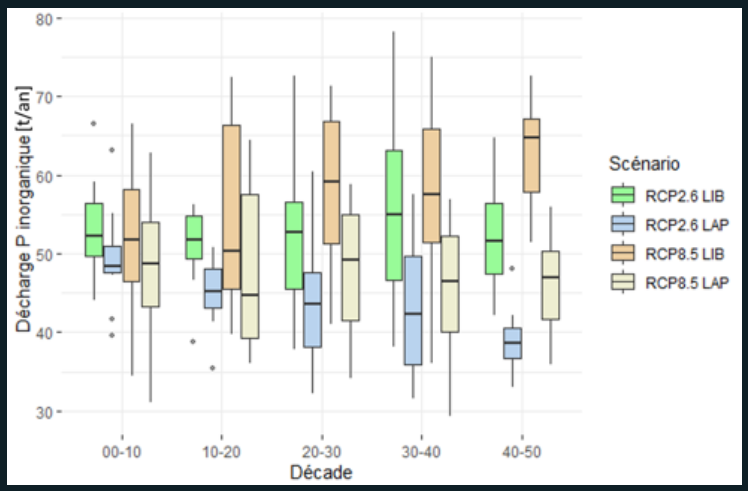
Fasel et al. (in prep[b])

Débit annuel moyen par décade entrant dans le lac (m^3/s)



Fasel et al. (in prep[b])

Décharge annuelle moyenne de P inorganique entrant dans le lac (t/an)



Fasel et al. (in prep[b])

CONCLUSIONS

Ecosystem services (ES): key concept for integration of domains

Essential Water Variables (EWVs): either inputs or outputs of SWAT

SWAT: very good integration tool for ES and Nexus approaches

SDM: predictions of changes in river biodiversity according to climate changes

CIPEL : Modeling of water quality in changing Land use and climate (ES = nutrient retention)

SWATCH21: first SWAT modeling of Switzerland that is bringing new information on river ES and biodiversity

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Project Publications

Fasel, M., Vaghefi, S., Abbaspour, K, Lehmann, A. (in prep[a].) A High-Resolution Hydrological Model for Switzerland – Linking Essential Water Variables to Ecosystem Services with SWAT

Fasel, M., Loizeau, J.-L., Lehmann, A. (in prep[b].). Modelling of diffuse phosphorus in Lake Geneva with the SWAT model.

Lacayo-Emery, M.A., Rodila, D.-D., Giuliani, G., and Lehmann, A., 2021, A framework for ecosystem service assessment using GIS interoperability standards: Computers & Geosciences, no. 104821.

Lehmann, A., Timoner, P., Fasel, M., Lacayo-Emery, M.A., Ashraf Vaghefi, S.S., and Abbaspour, K.C., 2019, SWATCH21: a project for linking eco-hydrologic processes and services to aquatic biodiversity at river and catchment levels: Ecohydrology and Hydrobiology, v. 19, no. 2, p. 182-197.

Timoner, P., Fasel, M., Ashraf Vaghefi, S.S., Marle, P., Castella, E., Moser, F., and Lehmann, A., 2021, Impacts of climate change on aquatic insects in temperate alpine regions: Complementary modeling approaches applied to Swiss rivers: Global Change Biology, v. 27, no. 15, p. 3565-3581.

Timoner, P., Marle, P., Castella, E., and Lehmann, A., 2020, Spatial patterns of mayfly, stonefly and caddisfly assemblages in Swiss running waters in the face of global warming: Ecography.

Vaghefi, S.A., Abbaspour, K. Farinotti, D., Fasel, M.; Huggel;, C., Lehmann, A. (submitted), Impact of climate change on of glacier meltwater and river discharge: The case of the Aletsch and Gorner catchments, Switzerland, under review, Science of Total Environment

Vaghefi, S.A., Muccione, V.; Huggel, C.; Salzmann, N., Lehmann, A. (in prep), Large cities in Switzerland are acclimatizing to hot days and nights, Under preparation