Land management scenario modeling for alleviating impacts on water resources

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Contents

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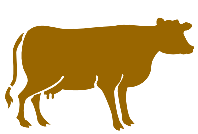
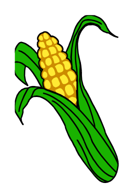
The objectives of **IMAS** *(Integrated Modelling of Agricultural Scenarios)*

Why for the IMAS[1] decision making method ?

- ✓ Supply water managers with an integrated and **collaborative approach**
- ✓ Assess **land-use and farming systems** and agricultural practices

-> Thus, the **impact of land cover and plant cover** on the **nutrients**, **pesticide** and **hydrological transport** in the surface waters has to be defined with **spatialized parametrization** and the SWAT model calibrated on the most sensitive spatialized parameters





[1](Vernier, Leccia-Phelpin et al. 2017)

- ✓ The **agricultural practices** defined by crop * soil types are implemented and spatialized at the HRU level into mgt files though the **Generator of landuse version 2 (GenLU2)**

- ✓ **Sensitivity analysis**, **calibration** and **validation** are lead on a **large number of spatialized parameters**. Two non-intrusive programs are tested for sensitivity analysis and calibration/validation

Parameters to calibrate	Sensitivity analysis, calibration & validation processes	Availibility of obs. data
Hydrological par.	**Stream flow calibration**	4 gauging stations (2006 – 2012) + 2 at the basin upstream (inland)
	Calibrated hydrological parameters ↓	
Nitrate par.	**Nitrate Cc in fresh waters**	57 water quality stations for nitrate monitoring
	Calibrated hydrological parameters Calibrated nitrate parameters ↓	
Plant growth par.	**Crop yields**	Agricultural census refined at the soil type by expertise
	Calibrated hydrological parameters Calibrated nitrate parameters Calibrated plant growth parameters ↓	
Pesticide par.	**Pesticide Cc in fresh waters**	Water quality monitoring st. (#)
	Calibrated hydrological parameters Calibrated nitrate parameters Calibrated plant growth parameters Calibrated pesticide parameters	

Water quality monitoring st. (#)

Glyphosate	32
Metolachlor	42
MCPA	44
Aclonifen	35
Chlorpyriphos-ethyl	44
Isoproturon	44
Mancozeb	15
Methaldehyde	32
Tebuconazole	35

Adapted from Rapport de stage, Santos

Methods of calibration of the SWAT model

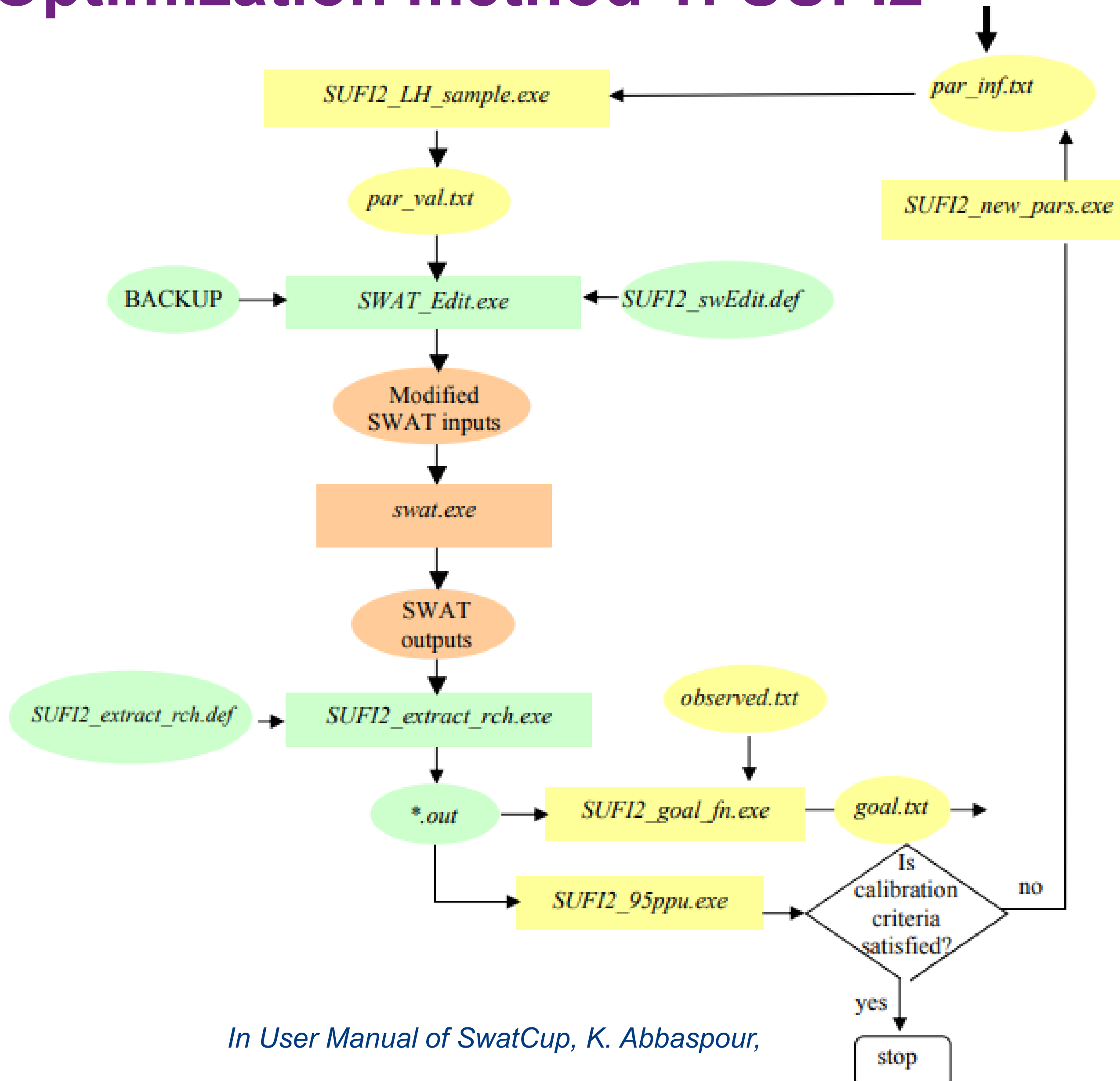
- ✓ **The Sequential Uncertainty Fitting (SUFI2) algorithm part of SWAT-CUP**
  (Abbaspour, 2013)

- ✓ **PEST: Parameter Estimation and Uncertainty Analysis (PEST) tool**
  (Doherty, 2005)

Optimization method 1: SUFI2

Written by K. Abbaspour, dedicated to SWAT calibration and uncertainty analysis

- copies and writes into SWAT model input files,
- reads SWAT model output
- executes SWAT and runs it many times (pleasingly parallel)

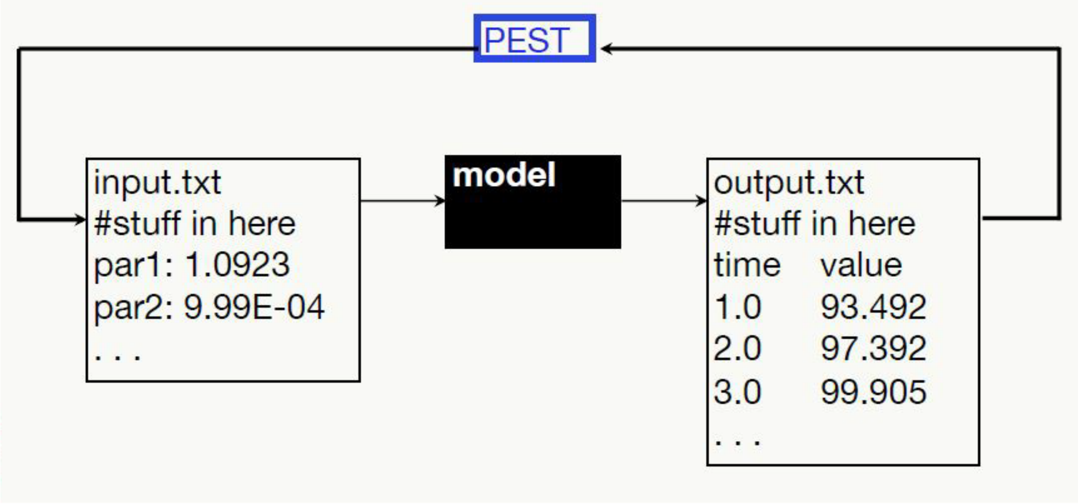


In User Manual of SwatCup, K. Abbaspour,

Optimization method 2 : PEST (Parameter Estimator)

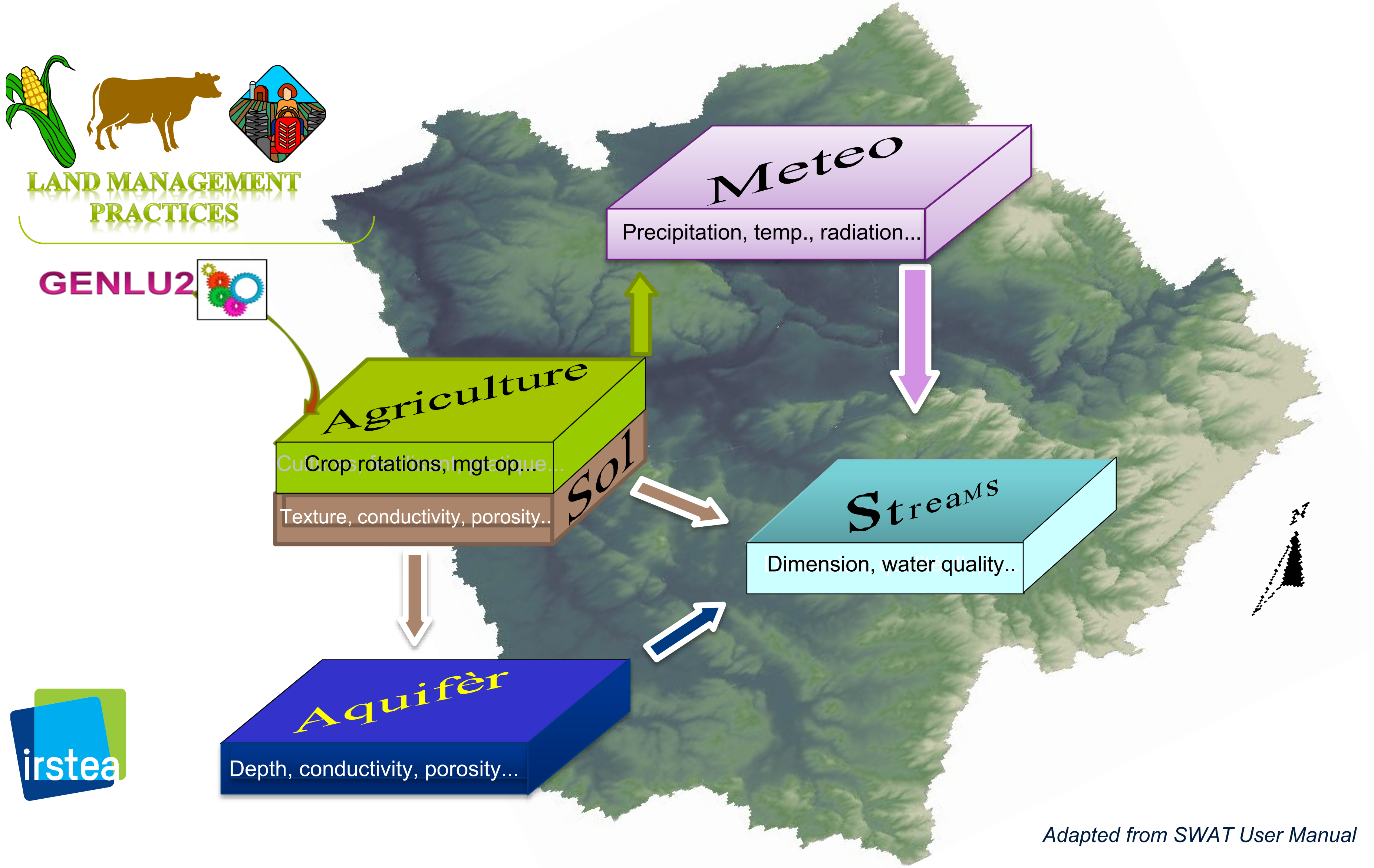
Written by J. Doherty, Model-independent parameter estimation code

- writes ASCII model input,
- reads ASCII model output
- Takes control of a model and runs it many, many times (pleasingly parallel)



In User Manual of PEST, J. Doherty

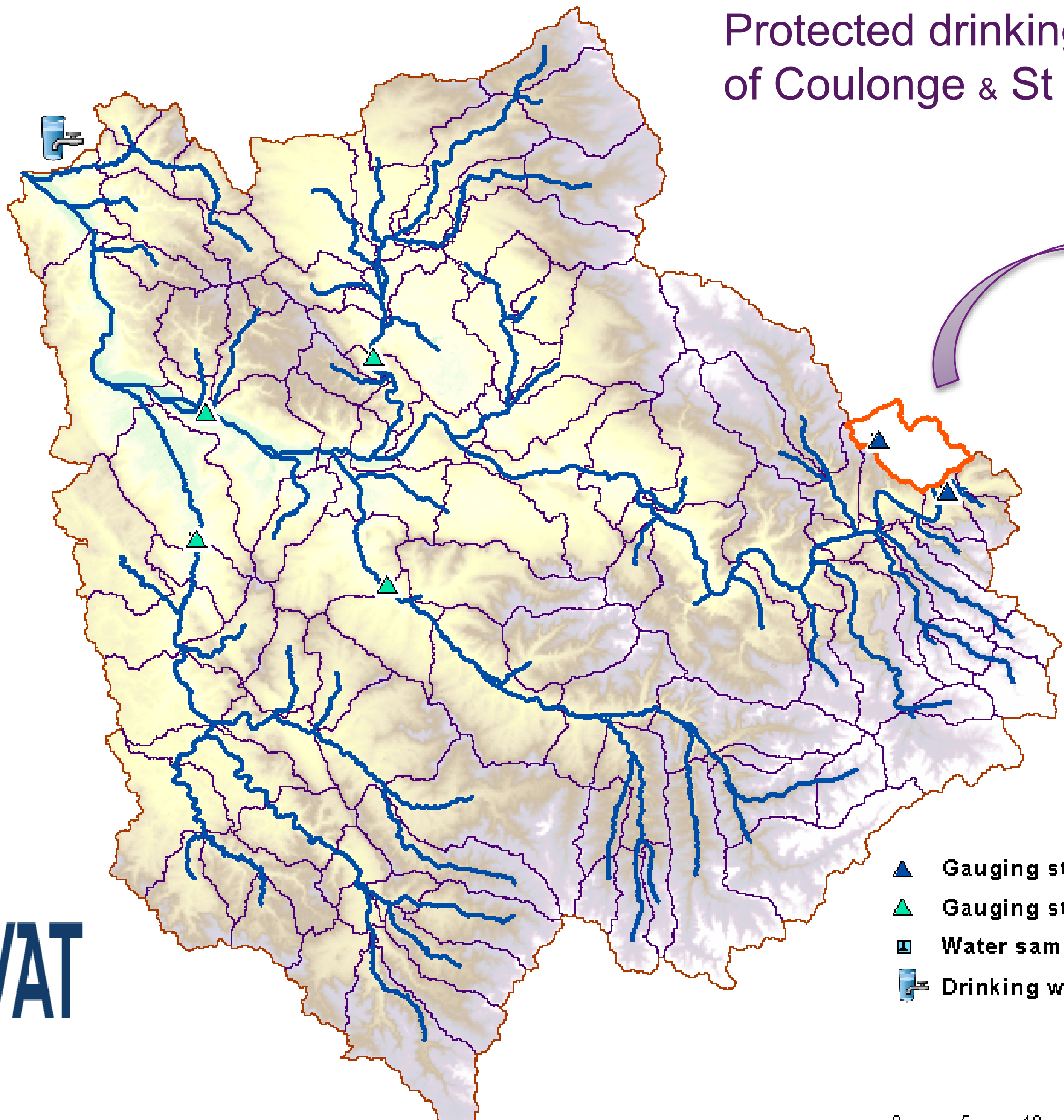
SWAT Implementation on a water supply catchment file

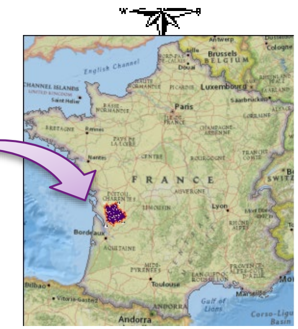


Adapted from SWAT User Manual

Spatialization of the observed data

Protected drinking water supply basin of Coulonge & St Hippolite (S.-W. France)





Reach
Basin
Watershed
Inland

ClipDem
High : 228 m.
Low : -12 m.

Gauging stations for the upstream (inland)
Gauging stations for calibration on streams
Water sampling stations for N, pest. calibration
Drinking water intake on surface waters

Soil & Water Assessment Tool | SWAT

0 5 10

Sources: IGN, DB Carthage

Odile Leccia - 2018
ETBX, IRSTEA Bordeaux

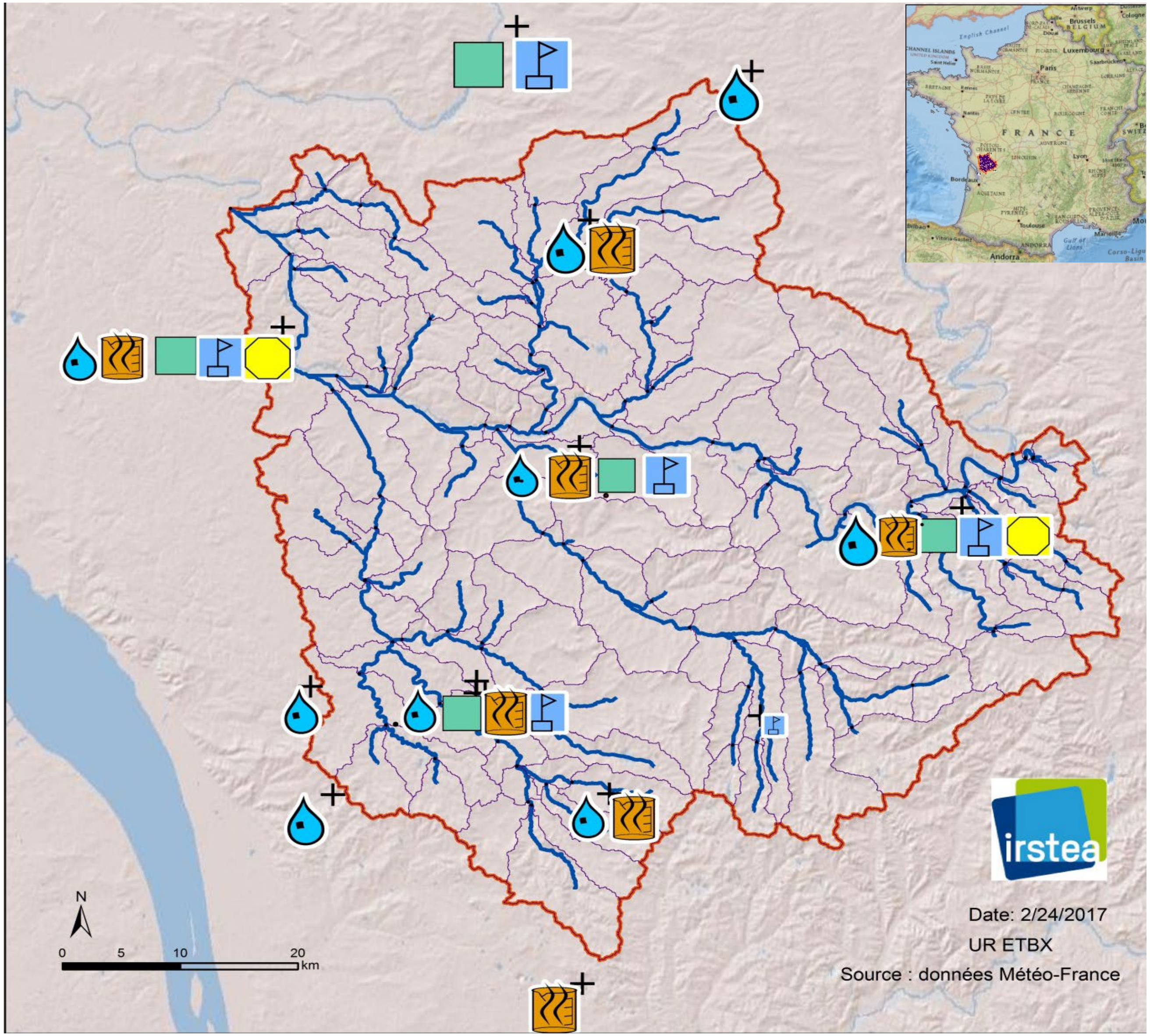
Weather parameter spatialization

Spatialization of daily time serie climate parameters

- Precipitation
- Temperatures (min/max)
- Humidity
- Solar radiation
- Wind speed

Water streams

Subbasins



Soil & Water Assessment Tool SWAT

Calibration on hydrological parameters

Parameter	Physical explanation	Spatialisation	Number of par.
CN2	Initial SCS runoff curve number for soil moisture condition II	By soil type	9
CNOP	Updated Curve Number (CN2) in plant, tillage and harvest/ kill operations	By soil type for each crop growing on the HRU	100
CH_N1	Manning’s value for the tributary channels	Uniform	1
GW_DELAY	Delay time for aquifer recharge	By contributory area at each station	4
ALPHA_BF	Baseflow alpha factor (1/days)	By contributory area at each station	4
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	By contributory area at each station	4
CHW2	Average width of main channel	Uniform	1
CHD	Depth of main channel	Uniform	1
CH_N2	Manning’s value for the main channel	Uniform	1
ESCO	Soil evaporation compensation factor	By soil type	9
EPCO	Plant uptake compensation factor	Different for each crop rotation	37
MSK_X	Weighting factor to control impact of the storage time constant for low flow	Uniform	1
SURLAG	Surface runoff lag coefficient	Uniform	1
CANMX	Maximum canopy storage	Different for each crop rotation	37
OV_N	Manning’s value for overland flow	Different for each crop rotation	37
SOL_KSAT	Saturatead hydraulic conductivity	By soil type	9
SOL_AWC	Available water capacity of the soil layer	By soil type	9
SOL_BD	Moist bulk densty	By soil type	9
SOL_Z	Depth from siol to bottom of layer	By soil type	9
BLAI	Maximum potenetial leaf area index	By crop	16
GW_REVAP	Groudwater « revap » coefficient	By contributory area at each station	4

Calibration on nitrate parameters after spatialization

Parameter name	Physical explanation	Spatialization	Number of parameters
ANION_EXCL	Fraction of soil porosity from which anions are excluded	By soil type	9
CDN	Denitrification exponential rate coefficient	Uniform	1
CMN	Rate factor for humus mineralization of active organic nutrients	Uniform	1
ERORGN	Oragnic N enrichment ratio for loading with sediment	Uniform	1
HLIFE_NGW	Half-life of itrate in the shallow aquifer (days)	By contributive area at each gauging station	4
NPERCO	Nitrate percolation coefficient	Uniform	1
N_UPDIS	Nitrate uptake distribution parameter	Uniform	1
RSDCO_PL	Residue décomposition coefficient	By crop type	16
SDNCO	Denitrification threshold water content	Uniform	1
SOL_CBN	Organic carbon content (% soil weight)	By soil type	9

Sensitivity analysis

On 240 spatialized parameters

- 62 parameters with t-stat > 1
- 33 out of the 62 are CNOP [(1)] for each couple of crops*soils

Parameter Name	t-Stat	P-Value
CNOP{..}.mgt	4.09	0.00
CANMX.hru	3.86	0.00
CNOP{..}.mgt	3.67	0.01
SOL_K(..).sol	3.41	0.01
CNOP{..}.mgt	3.26	0.01
BLAI{..}.crop.dat	3.09	0.01
SOL_BD(..).sol	3.05	0.01
CANMX.hru	2.95	0.02
CNOP{..}.mgt	2.90	0.02
SOL_AWC(..).sol	2.86	0.02
CH_N2.rte	2.82	0.02
CNOP{..}.mgt	2.82	0.02
CANMX.hru	2.73	0.02
CNOP{..}.mgt	2.71	0.02
CNOP{..}.mgt	2.63	0.03
SOL_Z(..).sol	2.57	0.03
CANMX.hru	2.56	0.03
CH_D.rte	2.37	0.04
CNOP{..}.mgt	2.25	0.05
CNOP{..}.mgt	2.20	0.06
SOL_AWC(..).sol	2.18	0.06
SOL_Z(..).sol	2.16	0.06
CNOP{..}.mgt	2.00	0.08
SOL_K(..).sol	1.95	0.08
BLAI{..}.crop.dat	1.95	0.08
CNOP{..}.mgt	1.82	0.10
CNOP{..}.mgt	1.81	0.10
CNOP{..}.mgt	1.80	0.10
CNOP{..}.mgt	1.79	0.11
CNOP{..}.mgt	1.79	0.11

Parameter Name	t-Stat	P-Value
MSK_X.bsn	1.78	0.11
BLAI{..}.crop.dat	1.76	0.11
CNOP{..}.mgt	1.74	0.12
SOL_BD(..).sol	1.71	0.12
CANMX.hru	1.69	0.13
GWQMN.gw	1.68	0.13
CNOP{..}.mgt	1.67	0.13
SURLAG.bsn	1.64	0.13
CNOP{..}.mgt	1.62	0.14
CNOP{..}.mgt	1.60	0.14
CNOP{..}.mgt	1.60	0.14
CANMX.hru	1.59	0.15
CNOP{..}.mgt	1.55	0.15
BLAI{..}.crop.dat	1.54	0.16
SOL_BD(..).sol	1.49	0.17
CNOP{..}.mgt	1.41	0.19
CNOP{..}.mgt	1.40	0.19
CNOP{..}.mgt	1.32	0.22
CNOP{..}.mgt	1.32	0.22
CNOP{..}.mgt	1.31	0.22
CNOP{..}.mgt	1.31	0.22
CNOP{..}.mgt	1.26	0.24
CNOP{..}.mgt	1.26	0.24
CNOP{..}.mgt	1.20	0.26
CANMX.hru	1.18	0.27
CN2.mgt	1.12	0.29
CNOP{..}.mgt	1.11	0.30
CNOP{..}.mgt	1.09	0.30
CNOP{..}.mgt	1.06	0.32
CANMX.hru	1.06	0.32
CN2.mgt	1.01	0.34
CNOP{..}.mgt	1.01	0.34

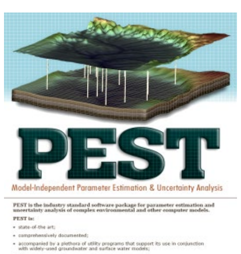
[(1)] CNOP: updated Curve Number (CN2) in plant, tillage and harvest/ kill operations

Correlation matrix for 100 selected parameters

Nom param		BLAlvine	CNOPvineC	CNOPvineD	CNOPvineD	CNOPvineG	CNOPvineG	CNOPvineT	CNOPpratG	CNOPpratT	CNOPrngeG
	Code PEST	113	1131	1133	1134	1135	1136	1137	1505	1507	155
BLAlvine	113	1.0E+00	-2.0E-01	4.4E-03	7.9E-03	1.4E-01	3.2E-03	-3.6E-02	4.4E-02	-7.6E-03	1.0E-01
CNOPvineChamP	1131	-2.0E-01	1.0E+00	-1.1E-01	1.1E-02	-5.4E-02	9.2E-03	-2.9E-02	-7.6E-02	-2.5E-02	3.0E-02
CNOPvineDHyLi	1133	4.4E-03	-1.1E-01	1.0E+00	-6.3E-04	-2.2E-02	1.9E-02	4.1E-02	-1.9E-02	-3.7E-02	4.3E-02
CNOPvineDsab	1134	7.9E-03	1.1E-02	-6.3E-04	1.0E+00	-8.5E-03	-1.3E-01	1.1E-02	5.4E-02	-7.0E-04	3.2E-02
CNOPvineGrMar	1135	1.4E-01	-5.4E-02	-2.2E-02	-8.5E-03	1.0E+00	-5.3E-02	-1.9E-01	3.2E-02	3.9E-02	-2.2E-02
CNOPvineGrSup	1136	3.2E-03	9.2E-03	1.9E-02	-1.3E-01	-5.3E-02	1.0E+00	5.7E-02	-1.8E-01	5.2E-02	-3.3E-02
CNOPvineTPBas	1137	-3.6E-02	-2.9E-02	4.1E-02	1.1E-02	-1.9E-01	5.7E-02	1.0E+00	-9.5E-02	5.0E-02	3.1E-02
CNOPpratGrMar	1505	4.4E-02	-7.6E-02	-1.9E-02	5.4E-02	3.2E-02	-1.8E-01	-9.5E-02	1.0E+00	-5.0E-01	1.3E-01
CNOPpratTPBas	1507	-7.6E-03	-2.5E-02	-3.7E-02	-7.0E-04	3.9E-02	5.2E-02	5.0E-02	-5.0E-01	1.0E+00	9.8E-02
CNOPrngeGrMar	155	1.0E-01	3.0E-02	4.3E-02	3.2E-02	-2.2E-02	-3.3E-02	3.1E-02	1.3E-01	9.8E-02	1.0E+00

*Extraction of 10 * 10 parameters out of 100 * 100*

In Rapport de stage, L. Santos



- 33 out of the 62 are CNOP for each couple of crops*soils

Sensitivity analysis with PEST

→ With min. sensitivity 10^{-3}

→ Correlated parameters (Absolute coefficient > 0.5)

Parameter_1	Parameter_2	Coeff	Abs Coef.
SOL_BD GrSup	SOL_AWC DHyLi	0.99	0.99
CHW2	SOL_KSAT ChamS	-0.88	0.88
SOL_BD ChamP	SOL_KSAT ChamP	-0.82	0.82
SOL_AWC GrMar	SOL_Z GrMar	0.82	0.82
ALPHA_BF Reste	GW_DELAY Reste	0.73	0.73
OV_Nrngb	OV_Nvine	0.72	0.72
EPCOpppf	OV_Ncbot	0.71	0.71
SOL_AWC VaMaT	SOL_Z VaMaT	-0.65	0.65
OV_Nfrst	CNOPrngbDHyLi	0.65	0.65
BLAIvine	CANMXvine	-0.61	0.61
CNOPrngbChamP	CNOPsunfChamP	-0.61	0.61
CANMXprap	EPCOrngb	0.6	0.6
EPCOvine	EPCOrngb	-0.59	0.59
ALPHA_BF Né	SOL_Z ChamS	0.59	0.59
CNOPrngeGrMar	ESCO GrMar	-0.58	0.58
CNOPfrstTPBas	CNOPsunfTPBas	-0.56	0.56
ALPHA_BF Né	SOL_AWC VaMaT	0.55	0.55
SOL_AWC ChamS	CNOPsunfChamS	0.52	0.52
CNOPvineDHyLi	CNOPrngeVaMaT	-0.51	0.51
CNOPwcanChamP	CNOPsunfVaMaT	-0.51	0.51
CNOPpratGrMar	CNOPpratTPBas	-0.5	0.5
SOL_Z TPBas	SOL_BD TPBas	0.5	0.5

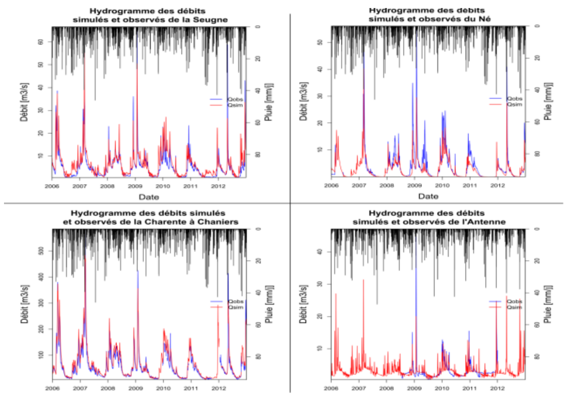
SUFI2 vs PEST: Calibration & validation results

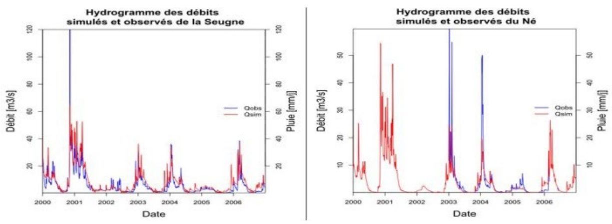
→ Both methods produced acceptable fit at two stations with certain measures.

→ They differ at two other stations with more doubts on the measures: SUFI performed better than PEST and vice versa.

	PEST		SUFI2	
Gauging station	**NSE of log Q**	**NSE of natural Q**	**NSE of natural Q**	**R^2**
Antenne_SBV_23	0.33	0.43	0.50	0.64
Charente_SBV_ 26	0.85	0.67	0.83	0.85
Né_SBV_59	0.84	0.73	0.57	0.71
Seugne_SBV_54 lembeyre	0.70	0.74	0.65	0.70

SWAT-CUP





Calibrated parameters	Calibration and validation process	Results (ex.)

Hydrological parameters

Stream flow calibration

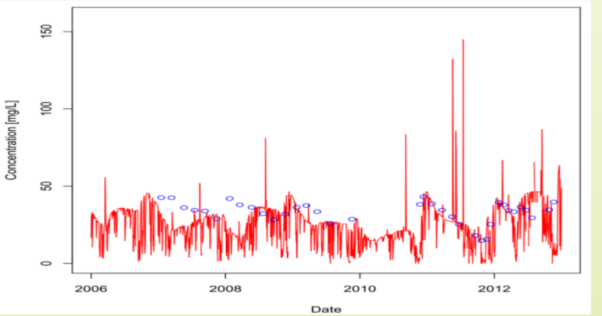
Calibrated hydrological parameters

Gauging stations	Calibration (1995 – 2005) NSE	Validation (2006-2012) NSE
Antenne	0.34	0.43
Charente	0.85	0.67
Né	0.84	0.73
Seugne	0.70	0.74

Nitrate parameters

Nitrate Cc in fresh waters

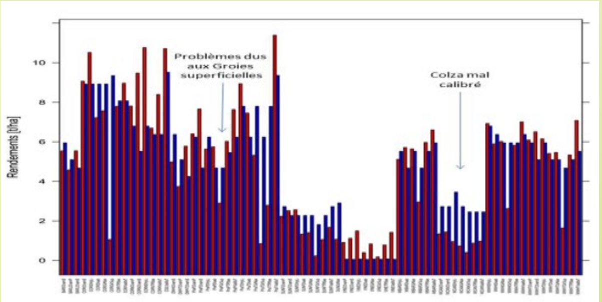
Calibrated hydrological parameters
Calibrated nitrate parameters



Plant growth parameters

Crop yields

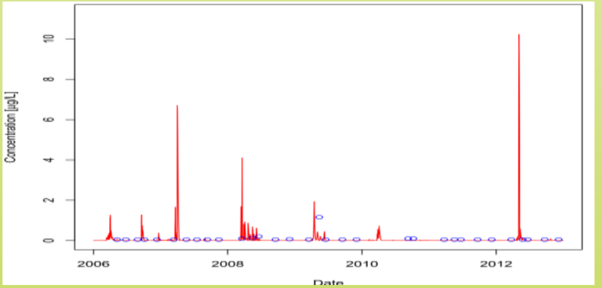
Calibrated hydrological parameters
Calibrated nitrate parameters
Calibrated plant growth parameters



Pesticide parameters

Pesticide Cc in fresh waters

Calibrated hydrological parameters
Calibrated nitrate parameters
Calibrated plant growth parameters
Calibrated pesticide parameters



Main features PEST vs SUFI2

From this work, we found out that both are able to handle large number of parameters for calibration, validation and sensitivity analysis.

In tems of implementation time, PEST needs time of data computing so as to get it adapted to the SWAT model

SUFI2 has en ergonomic interface and enables to get visualization (hydrographs and dotty plots)

SWAT-CUP

In tems of computation time SUFI2 was faster than PEST

Some options are avaible in PEST : Stream calibration on neperian logarithms

PEST

In conclusion, a few learnings

This soil*crop discretization has generated a high number parameters used for calibration validation.

→ Risk of equifinality, of over-fitting and the need for soft data

- ❖ Strong parameter interdependence

  => Numerical optimization but also expert knowledge

→ The importance of sampling, of parametrization when calibrating

→ The necessary role of sensitivity analysis

Thank you !

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- Françoise Vernier, agronomist
- Jean-Marie Lescot, agro-economist