Estimation of transported pollutant load in Ardila catchment using the SWAT model

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Introduction

Ardila is an international stream which rises in Spain and flows to Portugal on the left bank of the Guadiana river, being a tributary of Alqueva reservoir, the largest one in Europe.

In the context of Water Framework this stream was classified with poor quality, representing a critical aspect for Alqueva-Pedrogão System.

Where, often is observed algae blooms due to the excessive presence of nutrients (Phosphorus and Nitrogen).

Thus, it is important to quantify the nutrient load as well as its provenance.

Introduction

Considering WFD requirements the implementation of catchments integrate management is fundamental to achieve good status (chemical and ecological).

The evaluation of water bodies degradation requires modeling studies.

The SWAT (Soil and Water Assessment Tool) model has been widely used to predict stream discharge and nutrient load from catchment of various size.

In this study the SWAT was used to simulate the hydrology and nutrients loads in the Ardila catchment

Objectives

The aims of this study are to estimate:

- the stream flow;

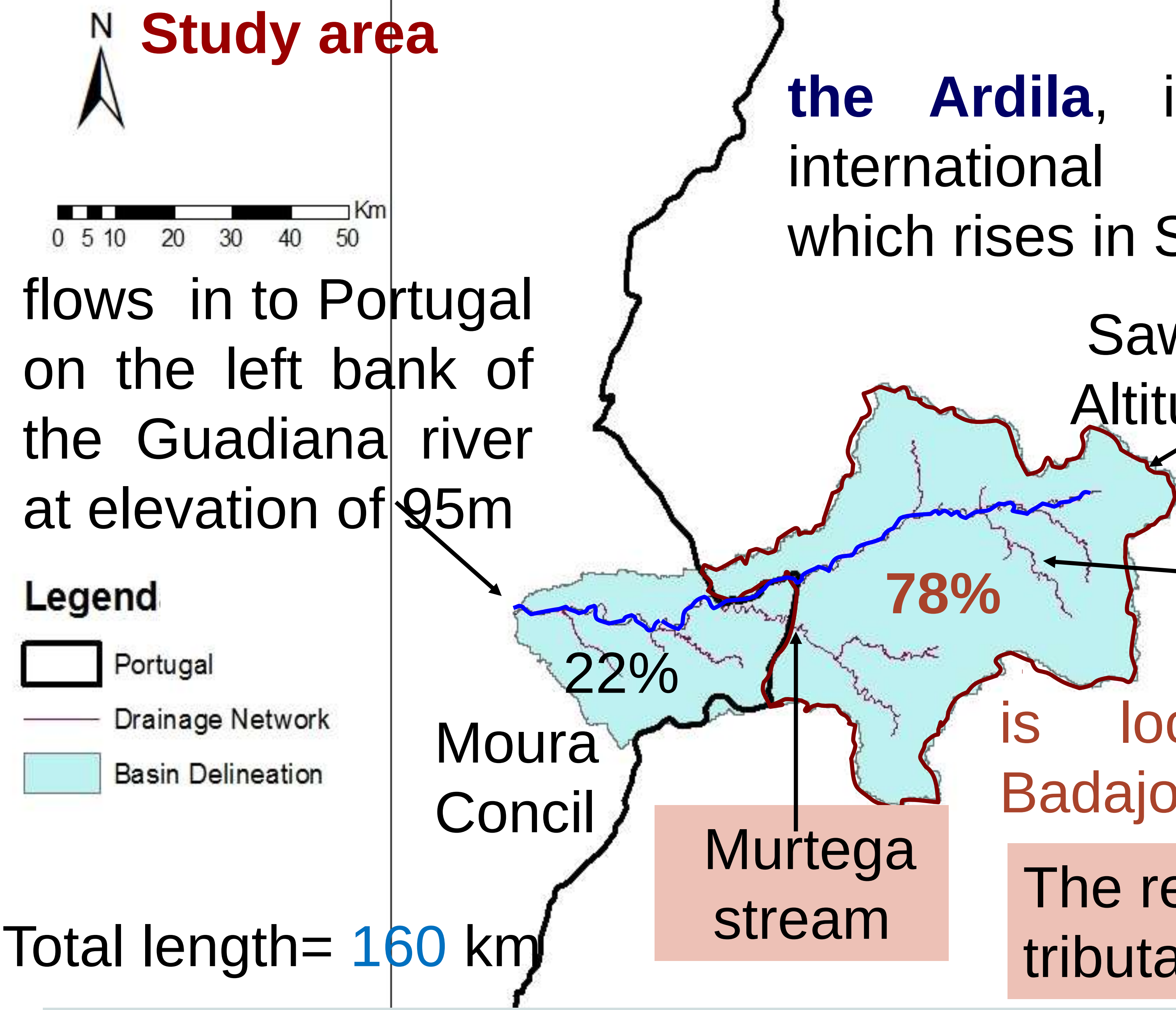
- the transported nutrients load in a transboundary catchment; and

- the nutrients load contributions (in the catchment) in order to understand the provenance.

Study area

the Ardila, is an international river which rises in Spain

flows in to Portugal on the left bank of the Guadiana river at elevation of 95m



Saw Tentudia Altitude:1100m

is localized in Badajoz province

The relevant tributaries are:

Murtega stream

Benferre stream

Total length= 160 km

The study area Ardila catchment is about 3711 Km^2

Methodology

To realize this study, it was used:

ArcView SWAT interface (version 2005) to compile the input files;

SWAT hydrologic model to calibrate and validate the stream flow data;

Statistical parameters, such as Nash-Sutcliffe model efficiency (NSE) and correlation coefficient (R^2) to evaluate the model performance .

Flow data obtained from SWAT (after validated) to estimate the nutrients loads (simulated and observed).

Methodology

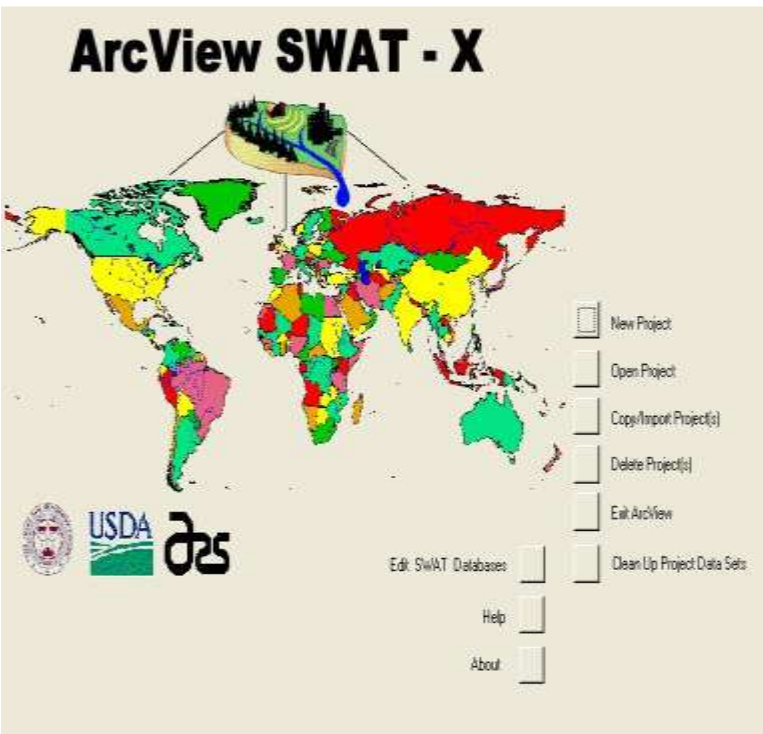
The product of average monthly concentration and simulated flow was performed to estimate the monthly observed loading.

The annual loading (simulated or observed) per hydrologic year was estimated, adding the monthly average loading for the corresponding year.

To evaluate the in came pollution (and to quantify the nutrients load entering at Ardila catchment), nutrients load in-stream water, was simulated at different sub-basins outlets (SB) along the longitudinal Ardila stream.

Principles of the SWAT model

SWAT is a semi distributed hydrological **model** with ArcView GIS 3.2 interface called AVSWAT, which **delimits** the river watershed and network using the digital elevation model (DEM)



and calculates the daily water balance based on:

- soil and land use,
- slope and
- weather data.

Principles of the SWAT model

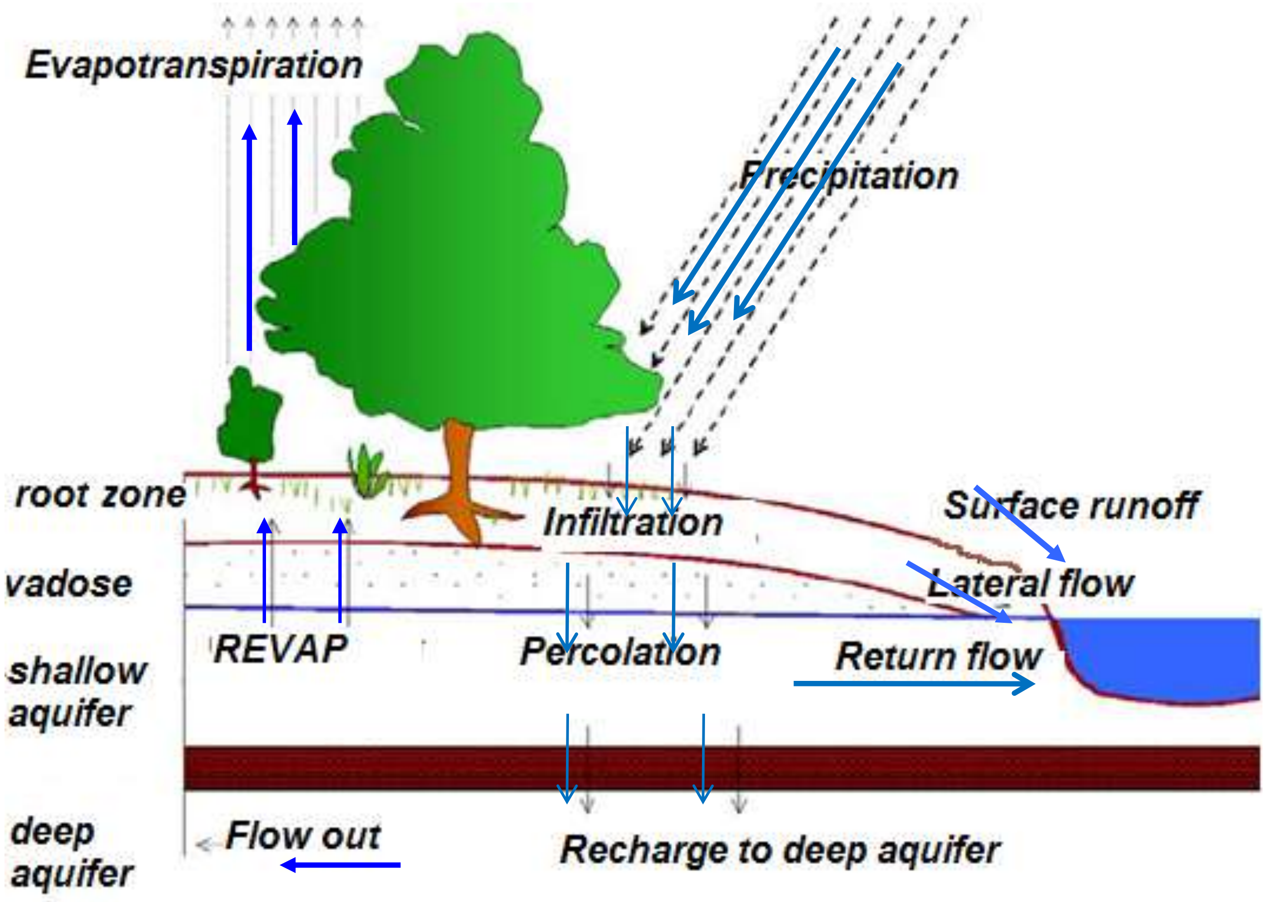
The model is based on the water balance general equation:

$$SW_t = SW_o + \sum_{i=1}^{t}\left(R_{day} - Q_{suf} - E_a - w_{seep} - Q_{gw}\right)$$

where:

SWt	- Final soil water content (mm H_2O);
SW0	- Initial soil water content;
t	- Time;
R_{day}	- Rainfall;
Q_{suf}	- Surface runoff;
E_a	- Amount of evapotranspiration;
W_{seep}	- Amount of water entering in the vadose zone from the soil profile;
Q_{gw}	- Amount of water returning to the rivers as base flow.

The hydrology simulation is split into divisions:



Hydrologic cycle, adapted from Neitsch *et al*., 2005

(1) Land phase

Which controls the **amount** of water, sediment, nutrient and pesticide loading in to the main channel, in each subbasin .

(2) Water phase

Defined as the **movement** of water, sediment, nutrients, etc. through the channel network (of the watershed) to the outlet.

Principles of the SWAT model

The SWAT model

Represents the spatial heterogeneity of the study area by dividing the watershed into multiple sub-watershed.

Each sub-watershed is subdivided into several hydrologic response unit (HRU), with homogeneous land use and soil type.

The HRU represents percentages of the sub-watershed area and are not identified spatially in the simulation.

The combination of daily rainfall and the Soil Conservation Service curve number procedure was used to estimate surface runoff from HRU.

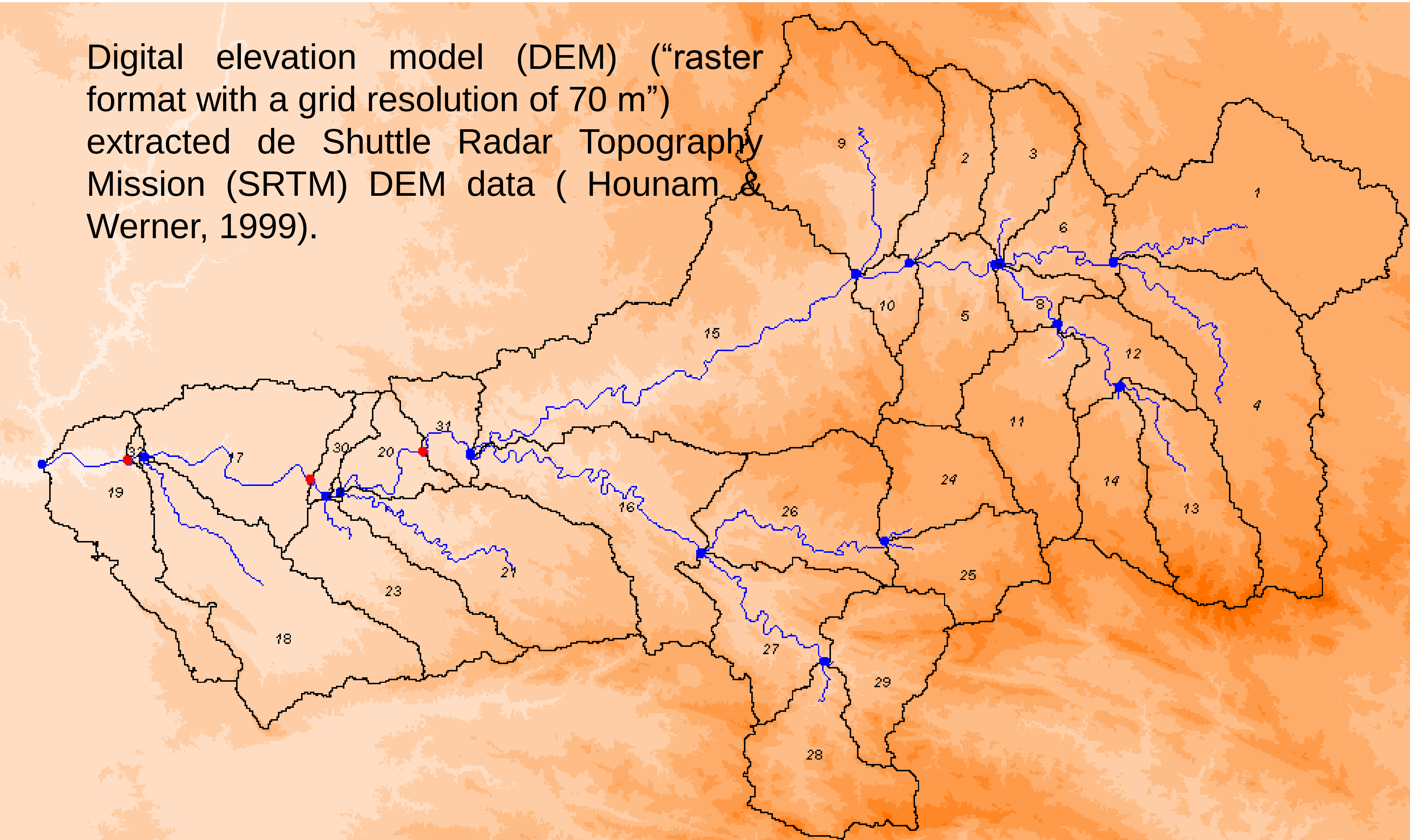
The movement and the transformation of nitrogen and phosphorus within an HRU are simulated as a function of nutrient cycles, consisting of several inorganic and organic pools.

The input data required are:

SWAT model input data

Digital elevation model (DEM)

Digital elevation model (DEM) ("raster format with a grid resolution of 70 m") extracted de Shuttle Radar Topography Mission (SRTM) DEM data (Hounam & Werner, 1999).

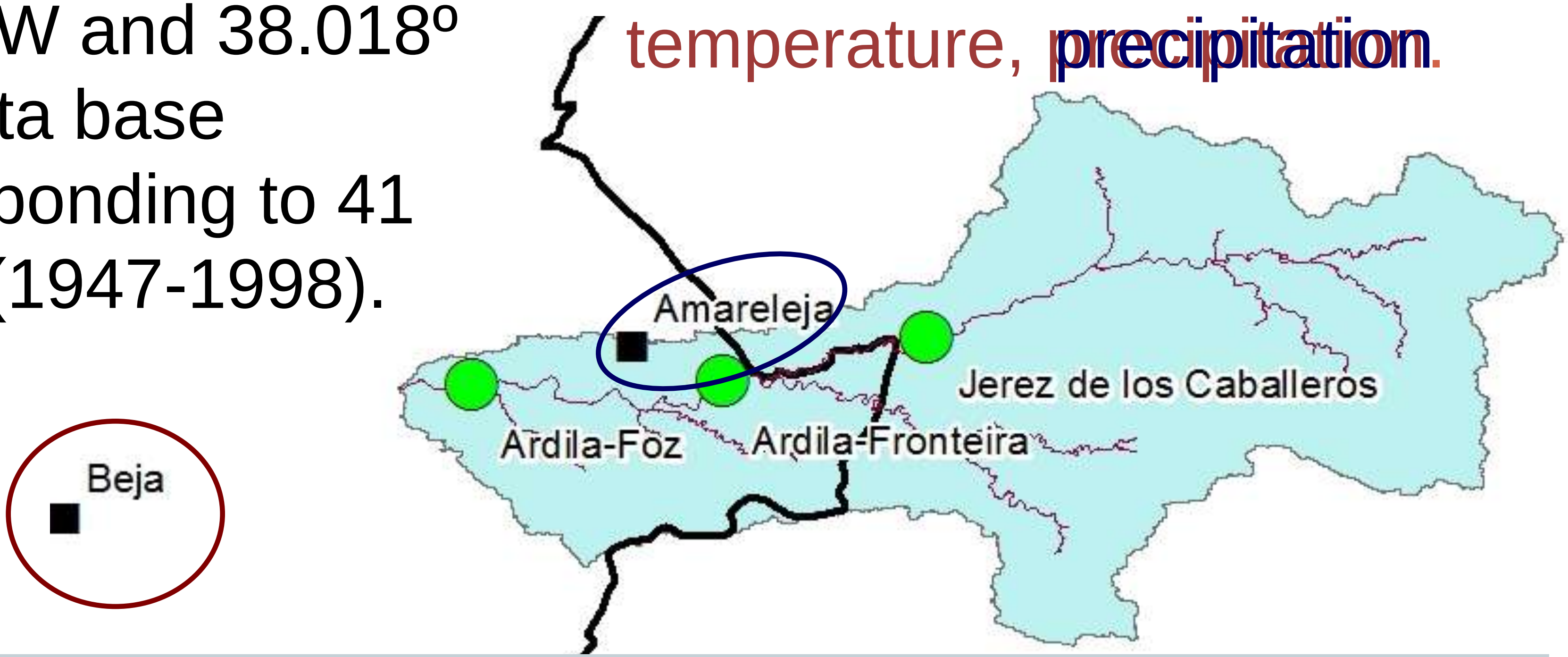


Ardila watershed delineation (32 sub-basin and 174 HRU)

Meteorological data

Solar radiation; relative humidity; wind speed; maximum and minimum temperature, precipitation.

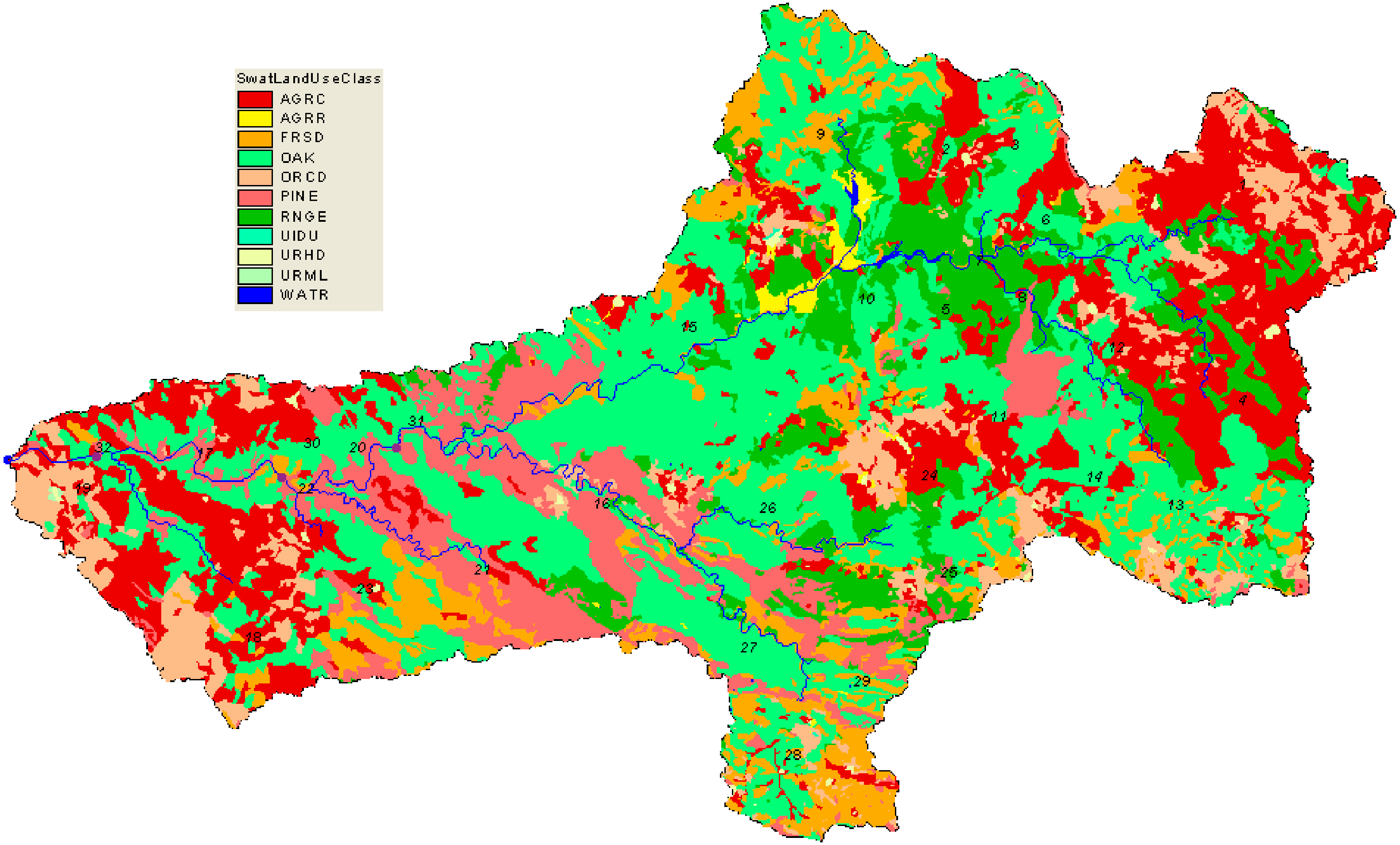
Meteorology **Beja** station (localized at 7.868ºW and 38.018º N). Data base corresponding to 41 years (1947-1998).



Amareleja station (located at 7.229º W and 138.210º N).

Data base was related to 72 years (1931- 2003) [http://snirh.pt].

The land use and soil associated with meteorological data have a significant influence on the water balance.



Land use at Ardila watershed.

Source:[http://dataservice.eea.europa.eu/dataservice/]

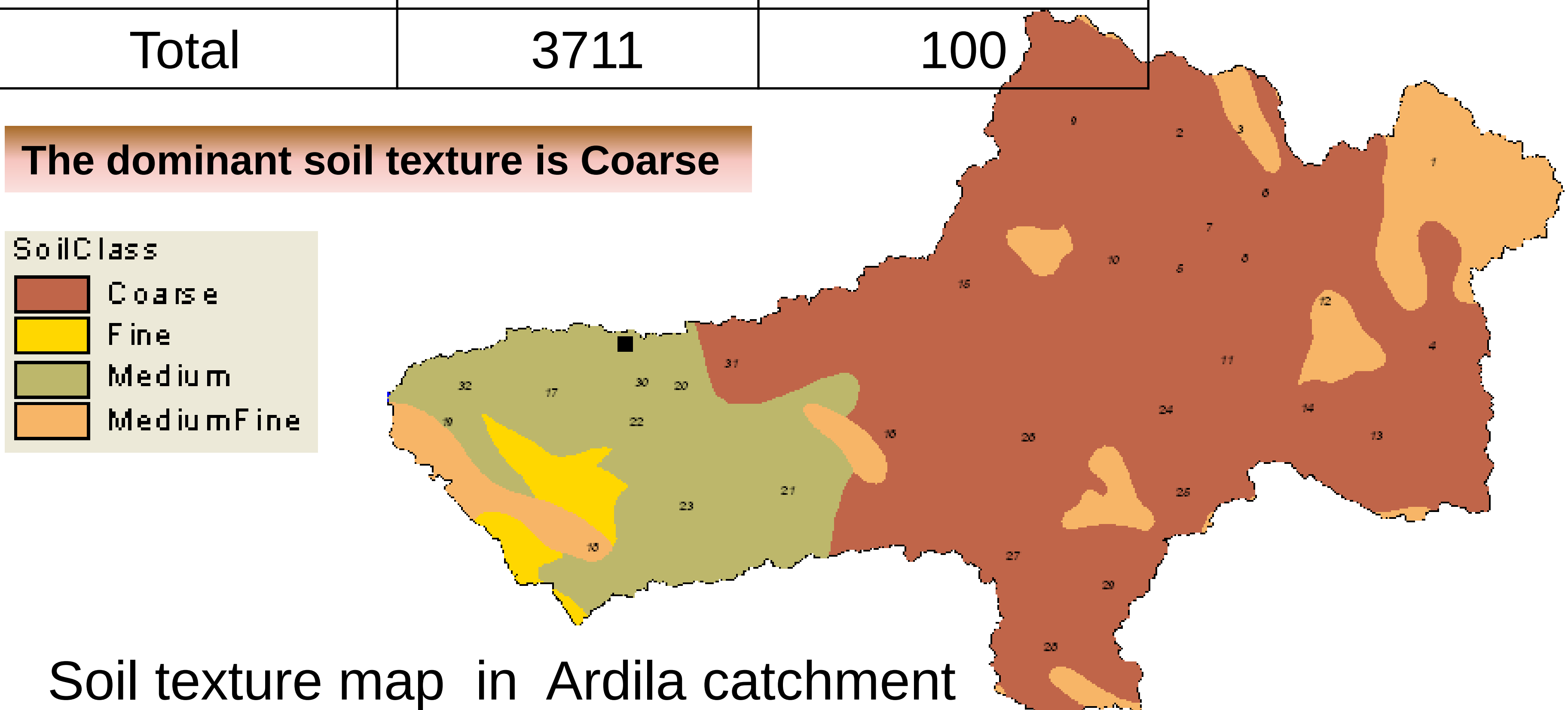
Land use at Ardila catchment

Land use class	Area [km²]	Area [%]
The land use is dominated by Oak	1321	35.6
Pine	444	12.0
Forest-deciduos (FRSD)	375	10.1
Range-grasses (RNGE)	436	11.8
and agricultural land-close-grown	792	21.3
Agricultural land-row crops (AGRR)	25	0.7
Industrial (UIDU)	1.6	0.04
Residential- med/low density (URML)	14	0.4
Orchard (ORCD)	295	8.0
Water	7	0.2
Total	**3711**	**100.0**

Soil classification at Ardila catchment

Soil texture	Area [Km²]	Area [%]
Fine	96	2.6
Medium	672	18.1
Medium fine	499	13.4
Coarse	2444	65.9
Total	3711	100

The dominant soil texture is Coarse



Soil texture map in Ardila catchment

Flow data

To calibrate and validate the model flow results, the flow station chosen was:

Ardila Foz, located at 7.142ºW and 38.167ºN.

The daily flow data are relative to 50 years (1950 to 2000) [http://snirh.pt].

Because it was the only that had long flow data series.

Water quality data

Water quality data are needed to determine the load transported by the (Ardila) stream.

The station chosen was:

Ardila Capt, located at 7.237ºW and 38.152ºN.

The water quality data are relative to 18 years (1981 to 1999). [http://snirh.pt].

Results and discussion

Simulation of flow

The application of the model in the first simulation showed differences between simulated and observed flows mainly because the groundwater default values established by the model, do not reflect the watershed reality;

The variables of groundwater with more influence in the calibration process, which need to be adjusted, are: baseflow recession coefficient (ALFA_BF), groundwater Revap (GW_REVAP) and groundwater delay time.

Results and discussion

Simulation of flow

Table 1- Initial and final values for the calibrated variables

Variable name	Allowable range	Initial value Simulation1	Final value Simulation 2
Alfa_BF	0.1-1.0	0.048	**1.0**

The direct index of groundwater flow responds to changes in recharge

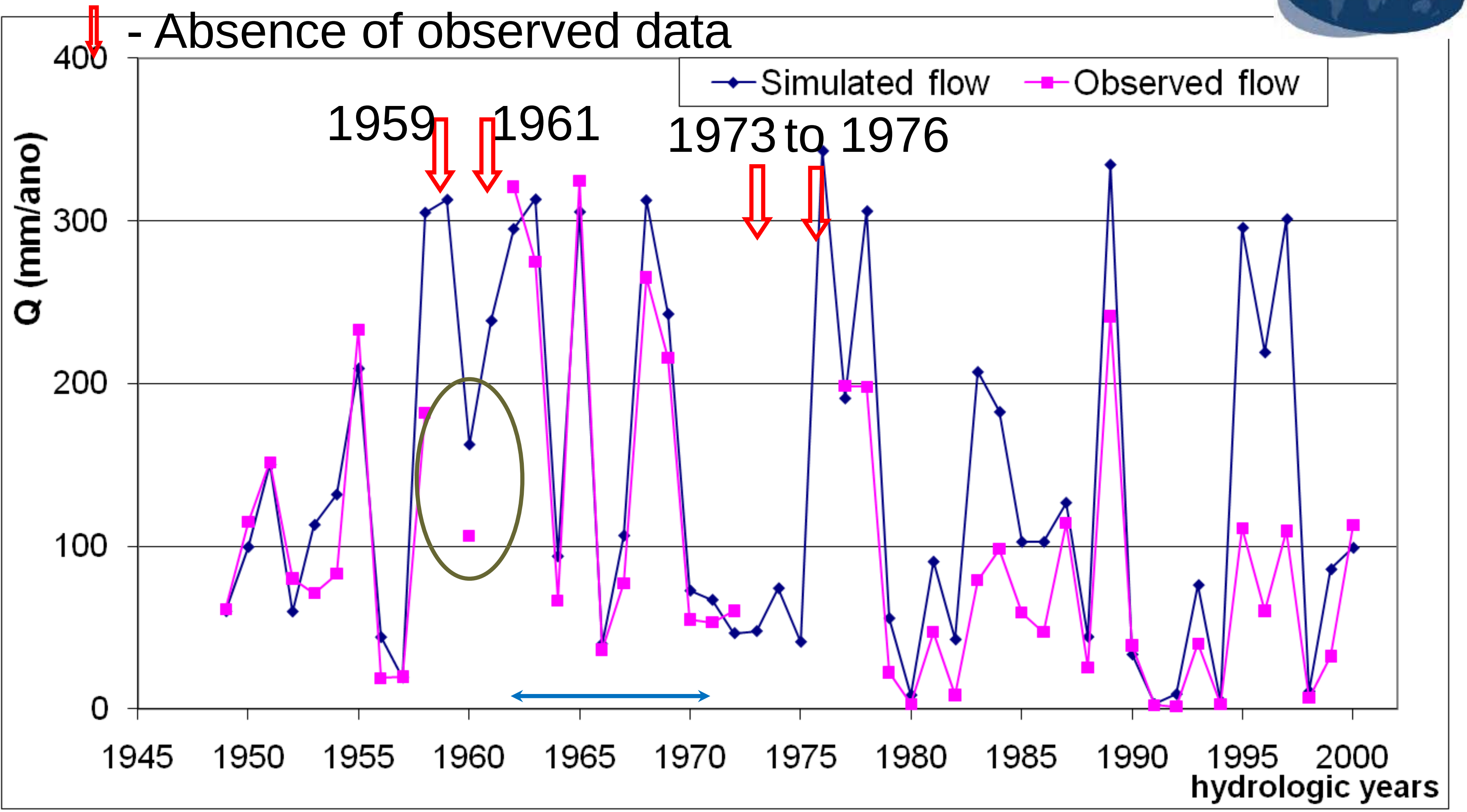
GW_Delay	0 – 500 d	200 d	**3 d**

The time that the water released by the soil bottom layer travels until reaching the shallow aquifer.

USLE_K	0.01-0.65	0.1	**0.3**

The soil erodibility (K) factor is reflected by the conditions of soil reaction to the erosion process of hydrological nature

Results and discussion



Comparison of the observed and the simulated flow data at Ardila Foz gauge.

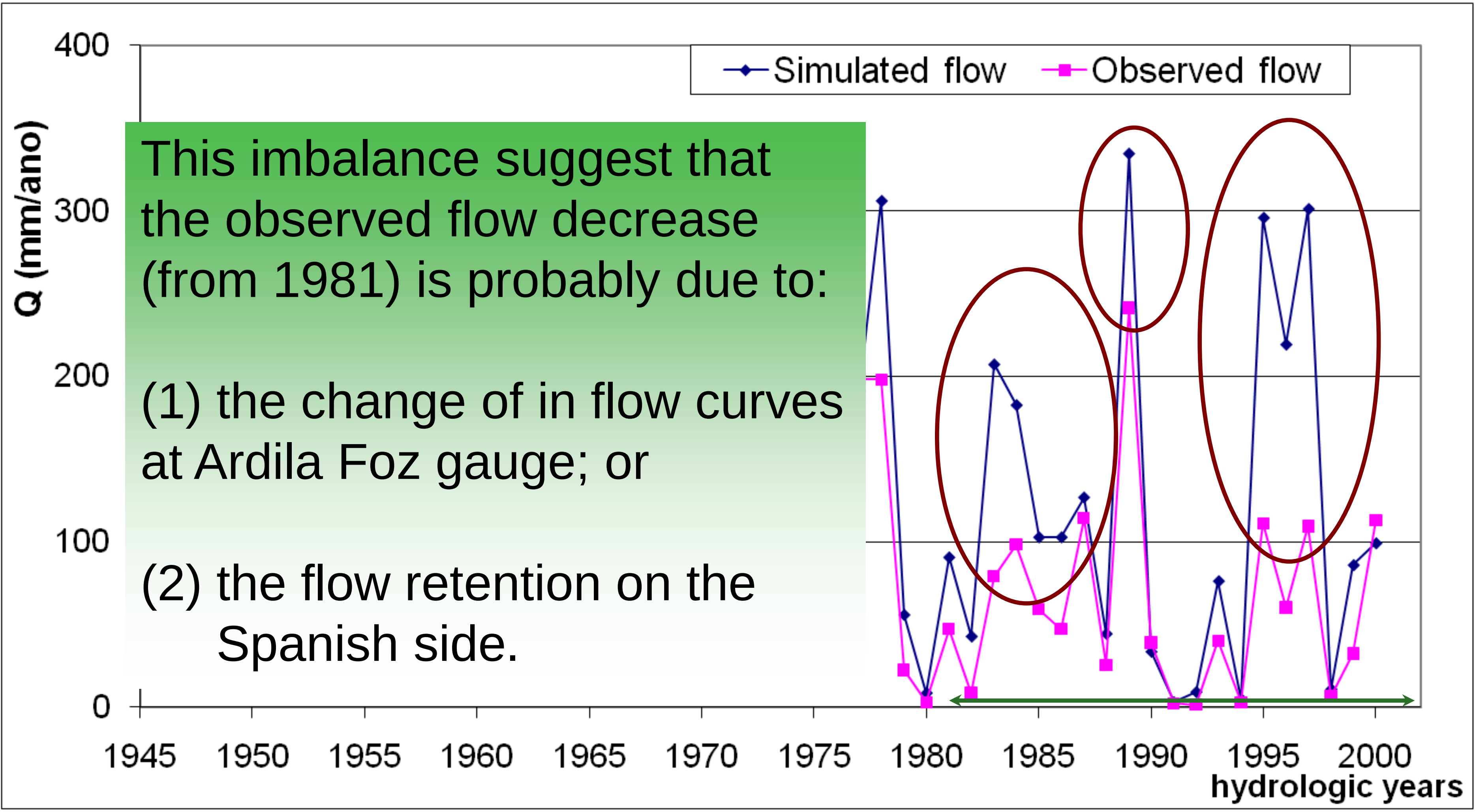
From 1962-1972 the model output and observed results are similar.

From 1981 the simulated flow is greater than the observed flow, although the progress curve is similar.

This imbalance suggest that the observed flow decrease (from 1981) is probably due to:

(1) the change of in flow curves at Ardila Foz gauge; or

(2) the flow retention on the Spanish side.



Comparison of the observed and the simulated flow at the Ardila gauge.

Results and discussion

The correlation coefficient (R^2) measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1.

A value of 0 indicating that no correlation;

A value of 1 representing that the predicted equals the measured dispersion.

The NSE ranges from $-\infty$ to 1

NSE $\leq$ 0 indicates that the mean of the observed data is a better predictor than the model output.

NSE value of 1, reflects a perfect fit between the simulated and measured data;

Correlation coefficient (R^2) and Nash-Sutcliffe model efficiency coefficient (1949 to 1959) stream flow

Period	1949-1958			1958-1959		
	All	monthly	daily	All	monthly	daily
$Qm_{observed}$ (mm/year)	94	95	94	181	181	182
$Qm_{simulated}$ (mm/year)	113	114	113	316	314	317
R^2	0.595	0.745	0.596	0.869	0.972	0.869
NSE	0.443	0.594	0.445	0.119	-0.514	0.119

Correlation coefficient (R^2) and Nash-Sutcliffe model efficiency (NSE) coefficient (1959 to 1972) stream flow

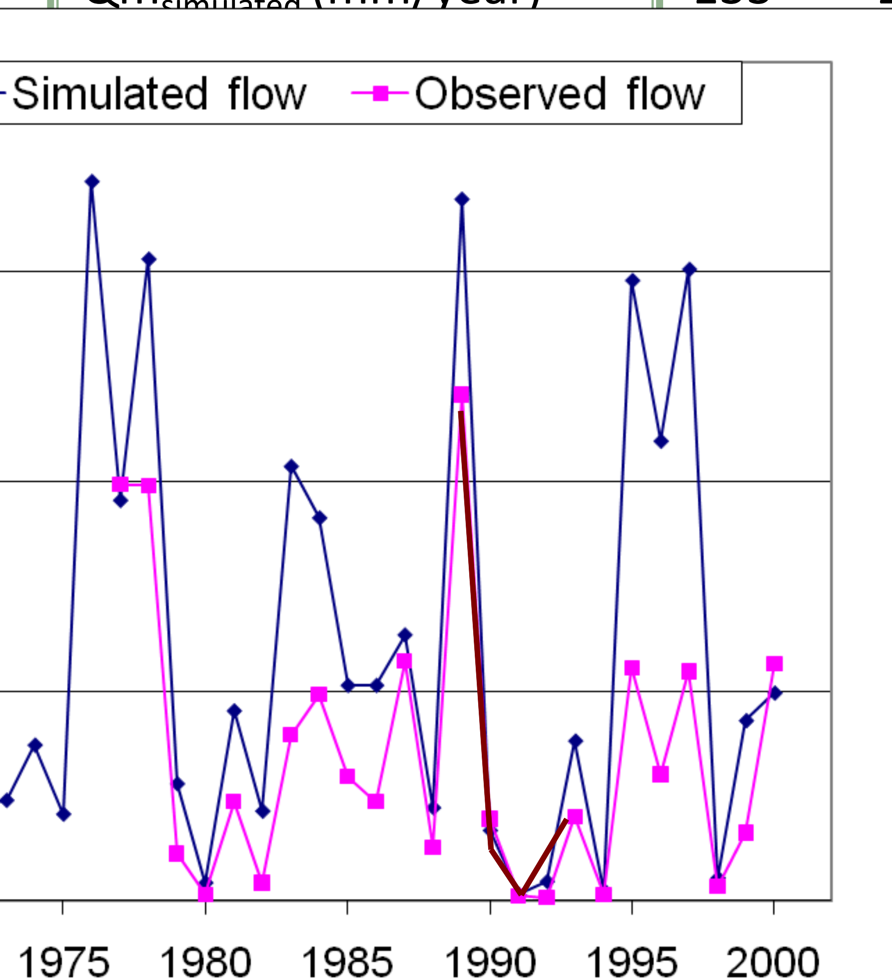
Period	1959-1960			1962-1972		
	All	monthly	daily	All	monthly	daily
$Qm_{observed}$ (mm/year)	151	141	151	168	170	168
$Qm_{simulated}$ (mm/year)	242	231	242	192	197	192
R^2	0.708	0.848	0.708	0.706	0.892	0.706
NSE	-0.631	-0.129	-0.630	0.644	0.840	0.644

R^2: 0- bad res.; 1- perfect results. **NSE**:(-) bad; >0.5- good; 1- perfect results

Results and discussion

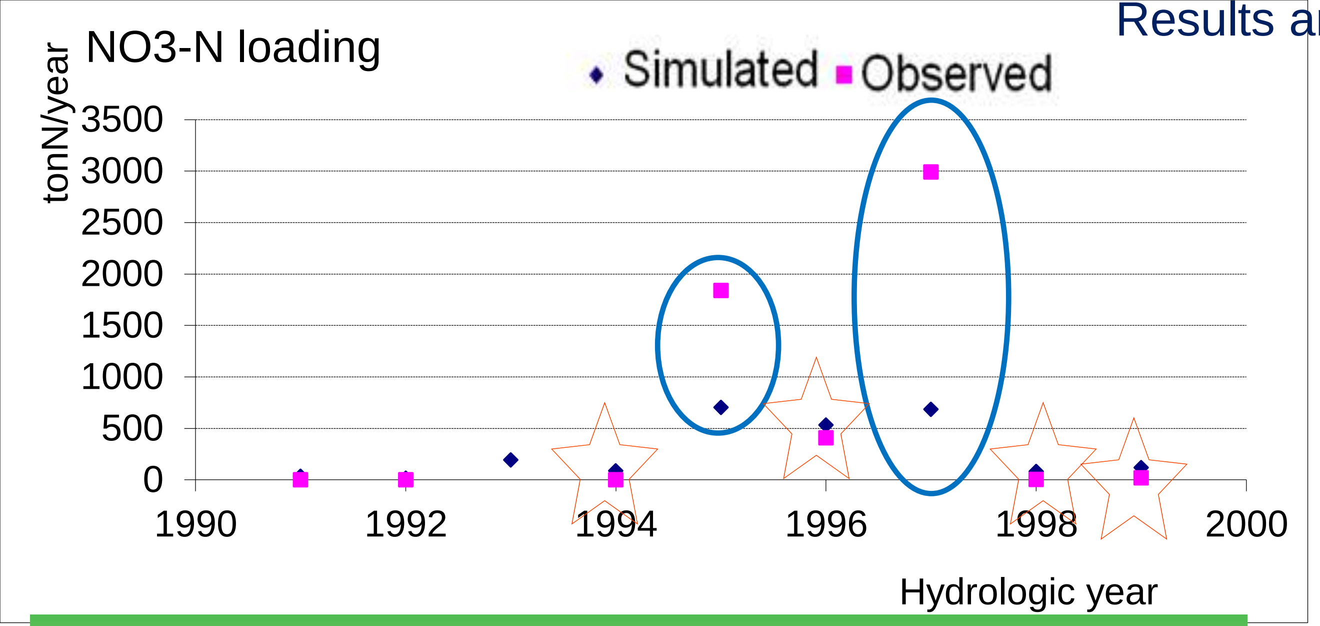
Correlation coefficient (R^2) and Nash-Sutcliffe model efficiency (NSE) coefficient from 1949 to 1959 stream flow

Period	1977-1988			1988-1993		
	All	monthly	daily	All	monthly	daily
$Qm_{observed}$ (mm/year)	79	84	79	58	58	58
$Qm_{simulated}$ (mm/year)	133	139	133	89	90	89
R^2				0.687	0.906	0.677
NSE				0.463	0.739	0.434

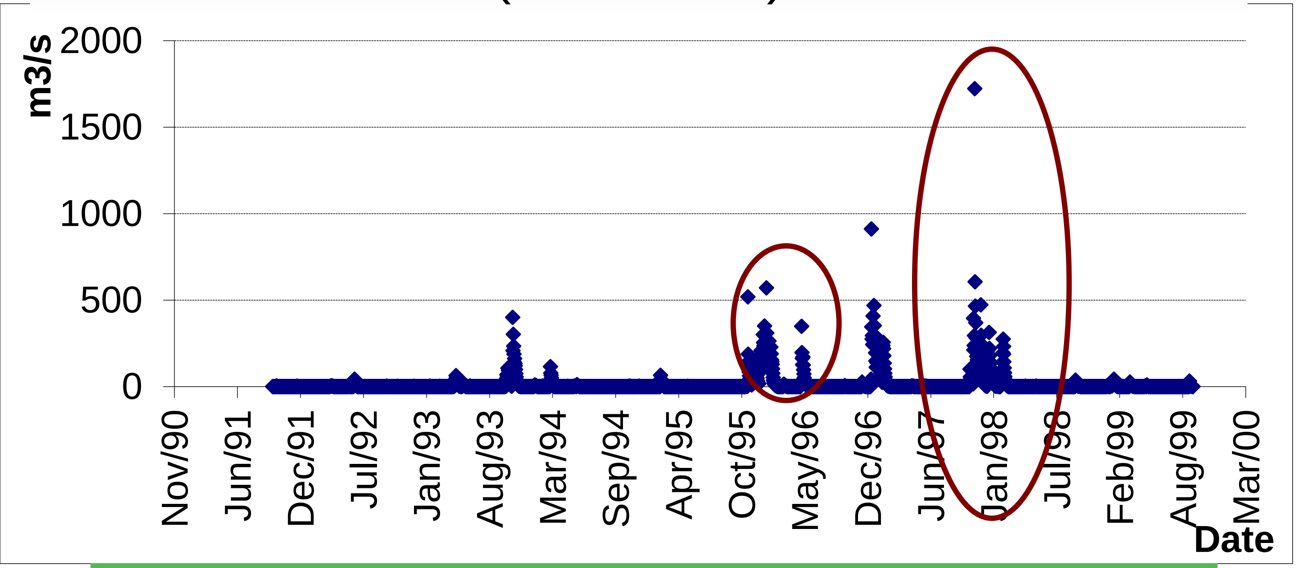


R^2: 0- bad res.; 1- perfect results

NSE:(-) bad; >0.5- good; 1- perfect



Simulated and observed annual nitrate loading (1991-1999)



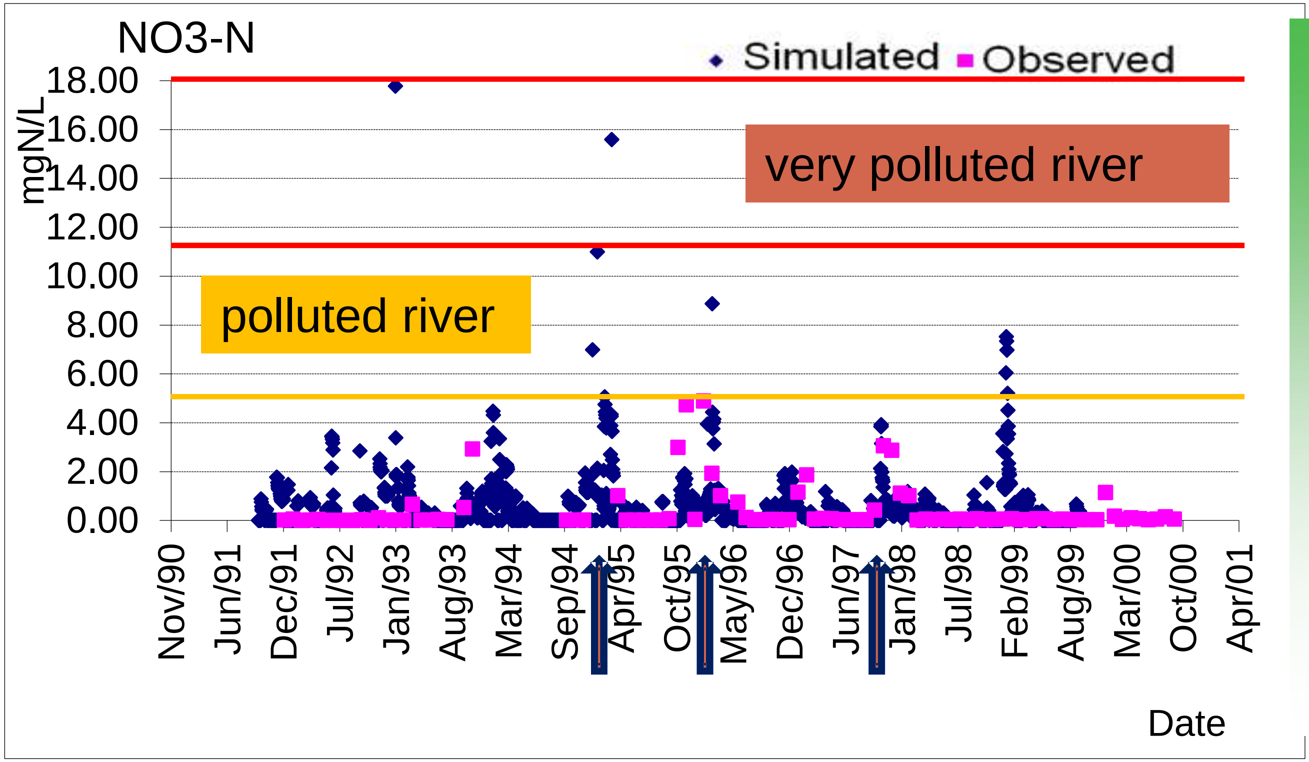
Monthly evolution of simulated stream flow (1991-1999)

The annual nitrate load simulated is higher than the observed, except in wet years 1995/1996 and 1997/1998;

when the flow was higher.

Nitrate concentration

In those years: the SWAT shows high concentrations at the beginning of winter but after that it reduces with dilution effect;



Simulated and observed nitrate concentration (1991-1999).

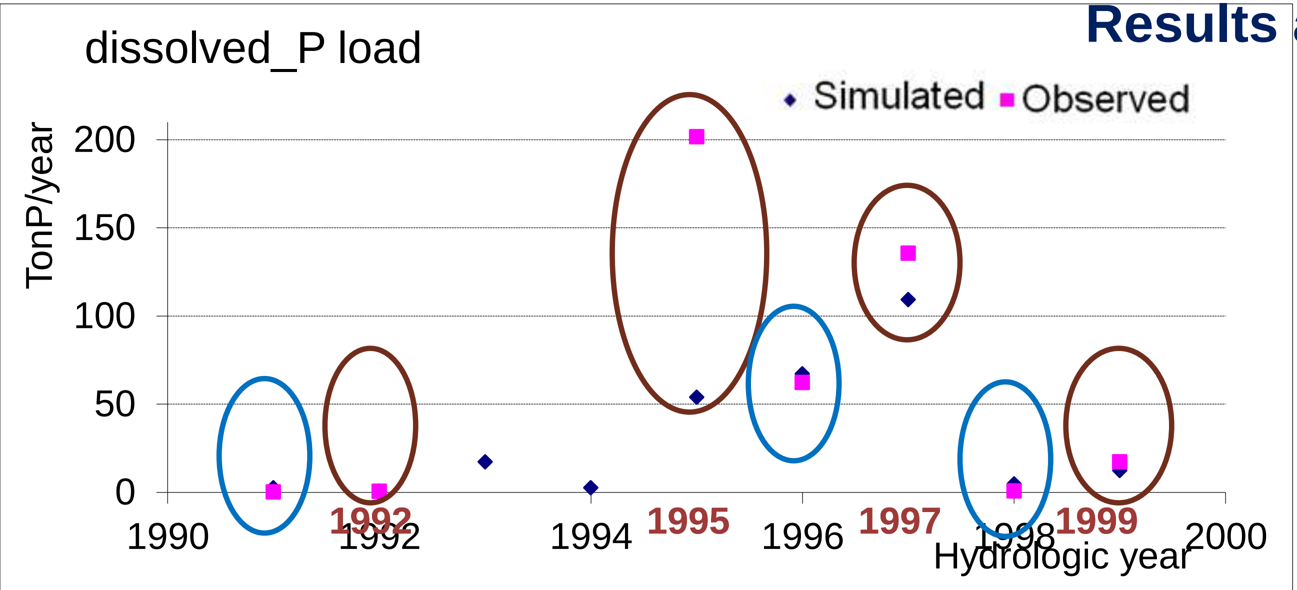
In accordance with stream classification for multiple uses (DSRH, 1998) the nitrate results show that the Ardila stream can be classified as:

Polluted river 5.67<NO_3-N <11.30 mgN/L)

tending to very polluted (11.32<NO_3-N <18.07 mgN/L) in wet years.

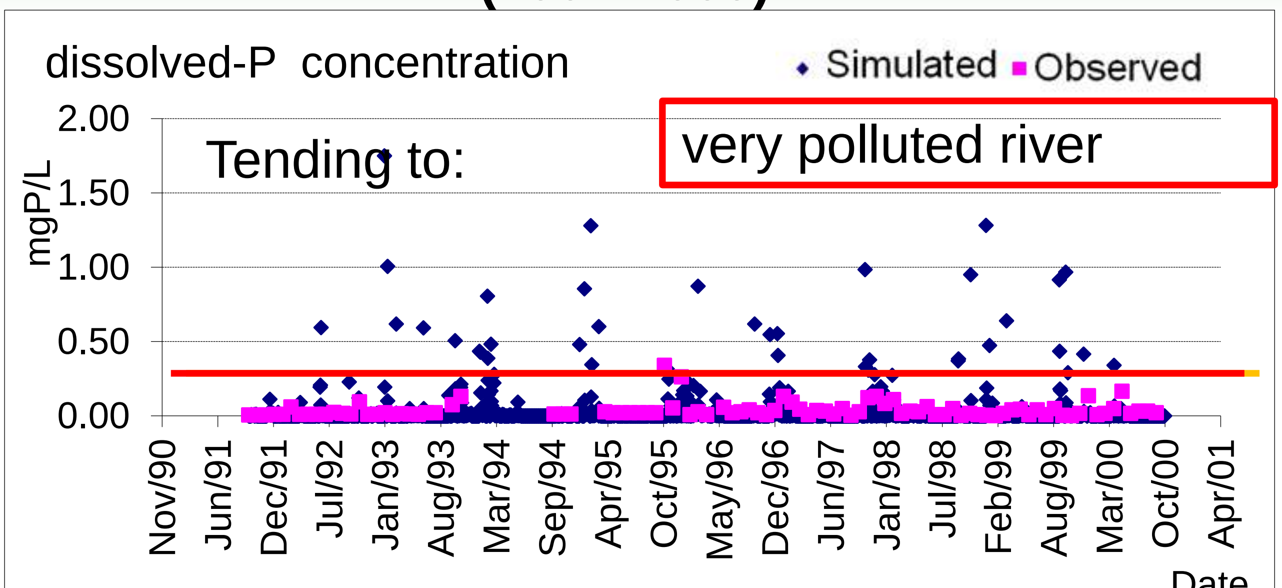
Results and discussion

SWAT Soil & Water Assessment Tool



Simulated and observed annual dissolved P loading (1991-1999).

During dry years, the observed annual dissolved Phosphorus load was above simulated results, contrasting with wet years.



in wet yeas

Phosphate>0.41 mgP/L)

Phosphate<0.41 mgP/L)

Polluted river

Simulated and observed dissolved P concentration (1991-1999)

Average monthly Nitrate and Dissolved P load

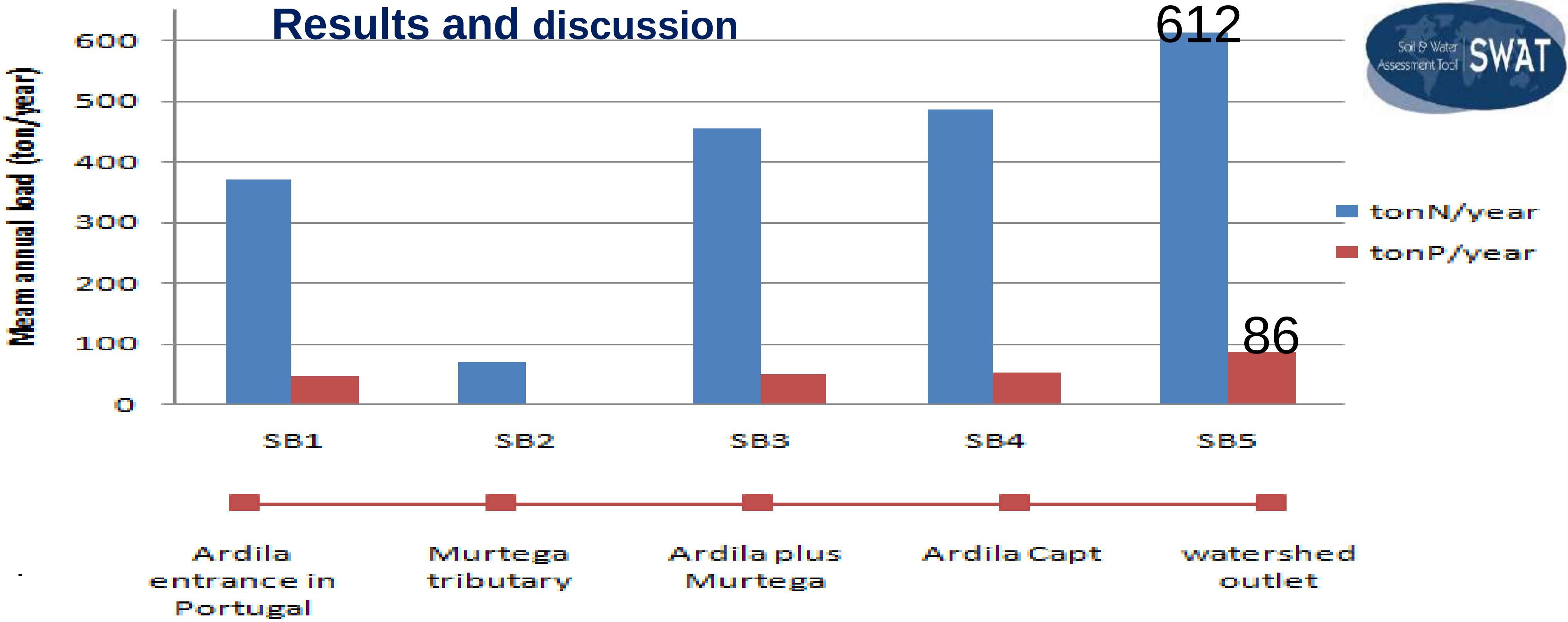
correlation coefficient (R^2) and Nash-Sutcliffe model efficiency (NSE) coefficient (1991- 1999)

	NO3-N (tonN/month)		Dissolved P (tonP/month)	
	simulated	observed	simulated	observed
Average monthly	25.4	65.9	2.8	4.8
R^2	0.42		0.47	
NSE	0.25		0.45	

Similar findings of statistical parameters, for nitrate were reported by Chu et al. (2004), who obtained R^2= 0.27 and NSE=0.16 for calibration period and R^2= 0.38 and NSE=0.36 for validation period.

Results can be considered reasonable for dissolved P because the NSE (0.45) is within the range (0.39 to 0.93) found in the literature for monthly validation.

Results and discussion



Average annual loads contribution of nutrients at subbasin (SB) outlets along the longitudinal Ardila river.

The estimated average nutrient loads per year coming from Spain is about 72% of the total nitrogen load and 50% of the total phosphorus load;
from Portugal is about 28% and 41% respectively.

Conclusion

The results showed a good agreement between simulated and observed Ardila stream flow (for monthly time step) for 1962 to 1972 (NSE= 0.8; R^2 = 0.91).

The statistical coefficients of the average:

- dissolved phosphorous load model performance were relatively reasonable (NSE= 0.45 ; R^2= 0.47).

- nitrate load model performance were poor (NSE=0.25; R^2= 0.42). However, characteristic nitrate behavior with high concentrations and load in winter months, and low nitrate loads in drier summer months were observed.

The contribution of nitrogen and phosphorous load from Spain is about 72% and 59% respectively. From Portugal it is about 28% and 41% of nitrogen and phosphorous load.

Conclusion

The SWAT model application reveals an useful tool to reproduce historical records and simulate results whenever gauging data are unavailable.

To calibrate and validate simulated results, inputs data were related to Portuguese part of the watershed.

However, further studies using additional data (precipitation, water quality, etc.) from Spain are recommended.

An evaluative analysis of the influence of point sources and different land use cover types should be made.

Acknowledgements

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Thank you for your attention !