Validation of a simplified AQUATOX model to assess quality status of a model river in Sardinia

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Abstract. In the framework of the periodic update of the Sardinian River Basin Management and Water Protection Plans (Italian Law 152/2006, transposition of the 2000/60/EC Directive), we investigated the AQUATOX model feasibility as a tool for assessing the relationships between Driving forces, Pressures, States, Impacts and Responses (DPSIR scheme). To do this, we applied the AQUATOX model to forecast the response of a Sardinian (Italy) river quality status to a set of different environmental perturbations, including nutrient load and water flow variations. The final aim of this work is to study a feasible model, based on a DPSIR scheme, for identifying the necessary and sustainable measures to tackle the criticalities resulting from a set of known environmental perturbations on Sardinian rivers.

1 Introduction

Since Water Framework Directive (2000/60/EC) enactment, River Basin Management Plans have become one of the most important controlling tools for surface water bodies safeguard, and the scientific community started to focus greater attention to the effects of anthropogenic pressures on riverine and marine ecosystems (1). In particular, a lot of scientific interest is addressed on rivers and streams study, in terms of qualitative and quantitative responses to anthropic pressures on the system, applying the Driving forces, Pressures, States, Impacts and Responses (DPSIR) scheme. However, many uncertainties occur when trying to reach such an objective: first of all, rivers and streams, as every environmental system, have to be considered as open systems and present a remarkable sensitivity to many external characteristics, such as water flow rate, temperature, wind intensity. Among available numerical models created to reach such ambitious objective, AQUATOX was chosen in this study, because of its good evaluations in review literature (2) and its simplicity in interfaces.

AQUATOX is an ecological risk model for water bodies, developed by U.S.A. EPA (Environmental Protection Agency) for water quality study and assessment of American streams, lakes, estuaries and lagoons (most recent version available since September 2018). It implements about 450 equations, including a broad set of parameters and variables in its solving process. The model simulates a whole ecosystem, including nitrogen, phosphorus and organic matter cycles, along with the variability of the abundance of plants, invertebrates and fish at different life-cycle. AQUATOX is the last development of a model series which includes CLEAN, CLEANER and PEST (3), and it is different from these because of the additional implementation of the prediction of the effect of nutrients and the toxicants determination (4). It is able to simulate various water body typology, each of them with specific parametrisation and model setting; it usually works with a large amount of data, but not all of them are strictly necessary and can be used to improve model performance, rather than to achieve a rough representation of pressures-response scenarios. This is an important fact in relation to the main task and the central question of this study: the determination of the possibility to use AQUATOX in other contexts apart from the U.S.A. main calibration and validation case studies (5), and in situations of lack of information and data. The relevance of this kind of analysis is due to the shortage of on field monitoring data for the case study investigated, and in general for some Sardinian water bodies. Sardinia is an Italian island which is considered as a single River Basin. As below better described, we tested the model giving only main descriptors values (i.e. the length of a chosen river trait, its maximum and average depth, a rough monthly time series of water flows, and the initial conditions of nutrients), and then compared the results with available field data. The biological component has been described based on other Mediterranean studies, due to the lack of information for Sardinia. Another important fact is that AQUATOX considers each modelled section as a mixed tank: it may sound unusual, but various literature reports show that this assumption is compatible with ecological systems, and AQUATOX is one of the suggested models to analyse the River Basin environmental scale (6).

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Compared to other available models, such as CATS, CASM, Qual2K, WASP7, EFDC-HEM3D, QEAFdChn, BASS and QSim, AQUATOX is declared as the one that involves more processes and variables, so it was identified as the more suitable in the studied context. Because of the particular interest in nutrients fate study, AQUATOX has to be preferred to CATS, even if the latter shows good prediction capability, due to its better representation of eutrophication and anoxia phenomena (7). Even if QEAFdChn shows better representativeness of bioaccumulation, it does not include an eco-toxicologic component, which is important for future model application in Sardinian case studies.

2 Case study

The Cixerri river has been considered for this study case (Fig. 1). Located in the South of Sardinia, near the city of Cagliari, it is a torrential trait, as many of Sardinians rivers, and it represents a typical multi-stressor environment. In fact, the Cixerri river receives urban wastewater treatment plants discharges from cities and villages (Iglesias, Villamassargia-Musei, Siliqua and Uta), at the same time it is an important water source both for civil and for industrial use, furthermore it flows in a vast agricultural area, making diffuse pressures an additional important pressure to be taken into account. We studied the trait that starts from the monitoring station of Siliqua (blue point in Fig. 2), includes the Cixerri lake and ends in Santa Gilla pond (red point in Fig. 2). Geographic data has been sourced from an open-access dataset from Regione Sardegna (Sardegna Geoportale). Cixerri lake is an artificial lake, and its dam is Genna is Abis. Location, water volume and structure characteristics of this element have been taken from the website of Ente Acque della Sardegna (ENAS). Geographic data has been processed through BASINS 4.1 software, which is a Geographic Information System (GIS) that can be directly linked to AQUATOX to provide morphological and general site accurate information for the simulation. A GIS data framing of Cixerri river is shown in Fig. 3.

A lapse of two years has been considered for the Cixerri simulation, which started on 01/02/2012 and ended on 01/01/2014. This period has been chosen taking into account the data need and availability and the limitations of the computation time.

Water flow was modelled according to the most recent Sardinian River Basin Management Plan as described in Table 1.

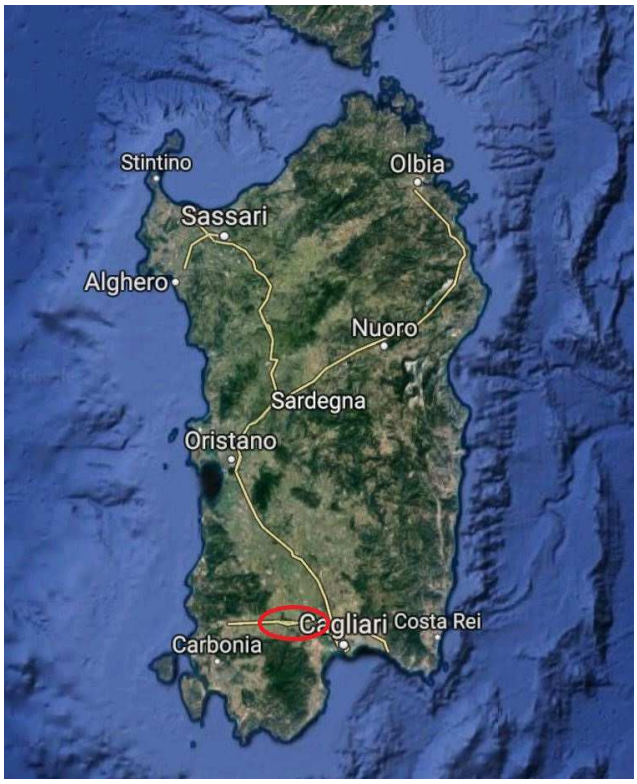

Fig. 1. Satellite framing of the case study.

Fig. 2. Satellite framing of the case study.

Fig. 3. GIS elements framing of the case study.

Table 1. Monthly water flows in the investigated river. Water flows are expressed in m^3/s.

Month	Water flow
January	5.760
February	7.985
March	5.879
April	3.313
May	1.567
June	0.458
July	0.119
August	0.066
September	0.318
October	2.366
November	3.751
December	5.989

3 Results and discussion

For first simulations, vegetal components and concentrations have been carried as those of a pre-existent simulation available in AQUATOX internal dataset, referred to the Blue Earth River case study simulation. In order to better represent a Mediterranean context, invertebrates have been divided as suggested in (8) and summarized in Fig. 4.

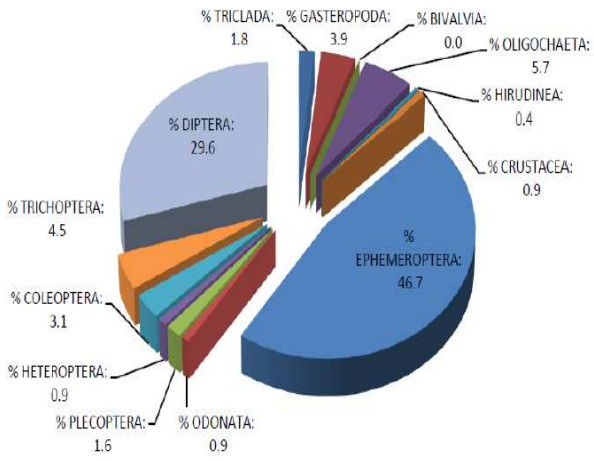

Fig. 4. Pie Chart showing the macrobenthos repartition for Sardinian rivers according to (8).

In Table 2, the complete set of initial conditions for the case study simulation have been reported. It results from the combination of pre-defined data in AQUATOX for Blue Earth River simulation, the implementation of more specific data, as above described, and available monitoring information about examined site. Parameters not included are meant overlooked or were assumed to be zero.

Table 2. Initial conditions for Cixerri simulation.

State Variable Name	Initial Conditions	Units
NH3 & NH4+	0	mg/L
NO3	4	mg/L
Tot. Sol. P	0.2	mg/L
CO2	0	mg/L
Oxygen	9,00	mg/L
Peri Low-Nut Diatom	0.00328494	g/m2 dry
Phyt High-Nut Diatom	0.001009124	mg/L dry
Phyt Low-Nut Diatom	0.000829888	mg/L dry
Phyto, Navicula	0.000842673	mg/L dry
Peri, Green	0.0022381	g/m^2 dry
Phyto, Green	0.000788045	mg/L dry
Cryptomonas	0.000943996	mg/L dry
Tubifex	0.7	g/m^2 dry
Caddisfly, Trichopter	0.58	g/m^2 dry
Mayfly (Baetis)	5	g/m^2 dry
Stonefly	0.23	g/m^2 dry
Gastropod	0.46	g/m^2 dry
Odonata	0.11	g/m^2 dry
Water Vol	9500	m^3
Temp	25	Deg. C
pH	7.5	-

The simulation started with the given configuration. In Table 3, the main results are shown: every pollutant concentration is expressed in mg/l, N indicates total nitrogen as the sum of all its forms and TSS indicates Total Suspended Solids. The values are meant averaged on all simulation period. The comparison between AQUATOX predictions and monitored concentrations shows good results for ammonia and oxygen (respectively, 14,5% and -9,04% of difference), but not so good for the other parameters, where differences are remarkable. In general, trends are not captured by the model, so are not reported.

It has to been noticed that vegetal species and concentrations were assumed as those given by AQUATOX by default for this simulation. Surely, this affects the model capability to represent both of phosphorus and nitrogen (total and its forms) cycles, as a consequence of the uncertain determination of algae concentration.

Table 3. Comparison between AQUATOX results and monitored values for concentrations of some pollutants (every concentration is expressed in mg/l).

	NH_4	N	P	O_2	TSS
AQUATOX	0.03	3.49	0.69	8.43	2.30
Monitoring	0.03	0.78	0.10	9.27	18.21
Difference	0.00	2.71	0.59	-0.84	-15.91

Starting from the above described setting, some response simulations has been conducted, varying different parameters one at the time. Considered animals were *Tubifex tubifex*, Caddisfly, Mayfly (Ephemeroptera), Stonefly (Plecoptera). For plants Diatoms has been chosen. As first, an increment of 20% in nutrients and detritus has been considered. For the whole animal components, percentage variations were found between -10% and +50%; Diatoms duplicate their abundance in average, with peaks of triplication in several periods.

Opposite effects were found decreasing by 20% nutrients and detritus: Mayfly decrease about -100%, and similarly plants. It is worth highlighting that the model was found to be sensitive to initial conditions of nutrients: for both of the aforementioned conditions variations, strong effects were registered in terms of final output of nutrient concentrations (an increment of about 4 times of the output as a consequence of an increment of 20% of the input value for some periods). A variation of 20% of the water flow did not significantly affect final results.

4 Conclusions

As highlighted by the results section, the study of pollutants trends with AQUATOX in conditions of lack of data could be a difficult task. However for some investigated parameters (namely ammonia and dissolved oxygen) a long-term forecast seems to be possible. The importance of this conclusion is related with the aim of this AQUATOX usability study: the need of tools to forecast the water bodies ecosystems response to pressure goes along with the need of the same forecast capability in terms of what-if analysis applied to measurements which are supposed to be taken to improve water quality. These are phenomena which take place in long time horizons, so in this sense a good forecasting model gives an additional support for measures decision and planning management measure.
Another important aspect highlighted by the results of this study is the importance of considering ecosystem vegetation for simulations, and hence guide further studies, where a more intensive attention is paid to this aspect.

The consistency of model response to input variations, even with a rough configuration of some parameters, due to limitations in available data, leads to consider this preliminary results on AQUATOX suitability to study water quality in Sardinian context good enough to carry further investigations.

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