Introducing River Modelling in the Implementation of the DPSIR Scheme of the Water Framework Directive

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Abstract: In Italy the National Environmental Protection Agency (ANPA) is about to adopt the Drivers-Pressures-States-Impacts-Responses (DPSIR) model introduced by the EC Water Framework Directive (WFD). This paper reassess the current definitions of *Indicators* in the light of the WFD, proposes the design of modular procedures and computational practices to determine the most significant *State* indicators, integrates the QUAL2E water quality model for the generation of quality data to assess differing DPSIR scenarios, with the final aim to produce an integrated software, partly based on Excel and partly on QUAL2E, whereby current quality data can be used to generate quality scenarios and apply the DPSIR model. The proposed method is applied the Arno river catchment.

Keywords*:* Water Framework Directive; DPSIR; water quality models; decision support systems; catchment planning

1. INTRODUCTION

The central concept of the Water Framework Directive (WFD, EC 60/2000) is the *integration* among the various expertise and disciplines aiming at a better management of water (EC 2002a; E.C. 2002b; E.C. 2002c). This paper presents an attempt to such integration to relate Pressures and Impacts in the *Drivers-Pressures* - States - Impacts - Responses (DPSIR) model, as required by Article 5 and along the guidelines of Annex II of the Water Framework Directive. However, its use is not straightforward given the differing nature of the data on which it operates. Normally information about *Drivers* are supplied by the statistical or socio-economic departments, whereas the data from which *Impacts* are computed from data directly collected by the authority in charge local monitoring. Normally the communication and data integration among these structures is weak. Moreover, in the practical application of the DPSIR model several obstacles are encountered:

1) Statistical data are related to administrative boundaries which almost always do not coincide with the physical boundaries delimiting the model domain.
2) The distinction between *States* and *Impacts* is not fully clear, because often *Impacts* are regarded as a further processing of the *States*.

For river systems, proposals for the standardisation of their ecological status have already been forwarded (Hering and Strackbein, 2001) and several *States* have been proposed on a biological basis, such as the Extended Biotic Index (EBI), to portray the ecological condition of the river system, but no practical *Impact* definition has been proposed so far.

In the light of these considerations the present research attempts to:

a) Introduce the use of water quality models, QUAL2E in particular, for the generation of quality data to be used in the DPSIR model and produce quality scenarios, both actual and projected;
b) Introduce a practical definition of *Impacts* in the light of the WFD;
c) Design modular procedures and computa-tional practices to determine the most significant *State* indicators and produce *Impact* information from them.

The final product of the study is an integrated software, partly based on Excel and partly on QUAL2E, through which current hydraulic and river quality data can be used to generate quality scenarios to be assessed in the DPSIR context. The procedure is first described in general terms and then illustrated in details with an application to the Arno river system, in central Italy.

2. INTEGRATION OF THE DPSIR SCHEME

The integration between the DPSIR scheme and the water quality model consists of a number of cascaded operations, which are linked as shown in Figure 1.

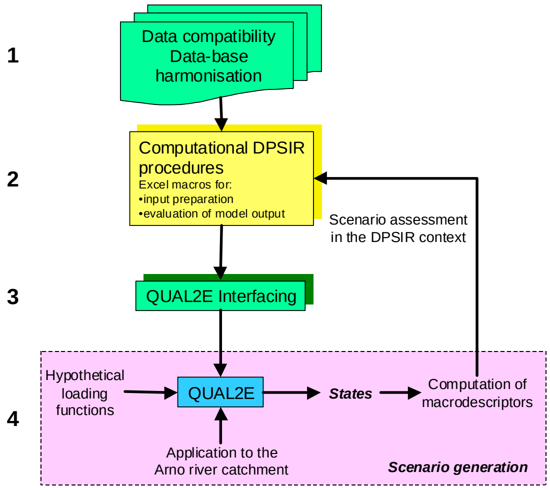

Fig. 1. Collection of procedures required for the integrated DPSIR scheme.

As Figure 1 shows, there are four main steps involved:

1) In the preliminary part, the data availability, consistency and compatibility are assessed and the required data-bases are either harmonised if already existing or constructed if only raw data are available. It should be realised that several databases are required to set up the DPSIR scheme and these data are presently maintained by differing adminis-trations, hence the need for a preliminary harmonisation of the available data regarding river catchment and related water quality into a coherent framework. The result has been a comprehensive *Driver* definition;

2) A number of numerical procedures have been developed to obtain a consistent *Pressure* generator from the existing *Drivers* or from their hypothetical values assumed in new scenarios. Other related procedures have been set-up for the assessment of quality model output

3) An interface has been developed between the previous procedures, mainly coded as Excel macros, and the river quality model;

4) QUAL2E was selected as the river quality model and used as a *States* generator starting with the input data originating from the DPSIR context. A downstream processing section determines the *Impacts* from the QUAL2E outputs and makes them available for the scenario assessment procedures in step 2. It also provides the interface for geographical information system (GIS) presenting the computation results as colour codes on the catchment thematic map. More studies on the interfacing between river quality models and GIS can be found in Marsili-Libelli et al. (2001).

2.1 Data assessment in view of the DPSIR scheme

Setting up a DPSIR scheme implies the availability of a large number of data regarding the river catchment, which are usually not gathered and maintained by the same agency. Therefore, a preliminary task has been the harmonisation and validation of the data: three main *Drivers* have been considered: *population*, *agriculture* and *industry*. The first is defined as the number of people consistently living in the area, though in resort areas seasonal fluctuations have been accounted for. The agriculture driver was defined as a combination of the extension of agricultural land and livestock, whereas industry was accounted for in terms of number of employees, energy bill and water consumption. These *Drivers* generate pressures in terms of pollution discharges into the river systems. Population and industry tend to generate point-source pollution, whose wastewater is generally collected through a sewage system and delivered to a centralised wastewater treatment plant. The agricultural pressure is more difficult to quantify since a large part of it generates diffuse pollution. This can be estimated with specific software (CRITERIA) which yields the synthetic pollution load given the agricultural activity and the terrain characteristics. At the end of this preliminary data harmonisation, drivers and pressures were defined in coherent terms.

2.2 Integration of a water quality model in the DSPIR scheme

Having defined *Drivers* and *Pressures*, the next problem is the integrating the latter in a water quality model context. For this, it is required that *Pressures* generate inputs compatible with the water quality model. Under these boundary conditions the model produces a quality scenario from which the *States* are extracted and the

Impacts computed. This augmented DPSIR scheme is shown in Figure 2, with the insertion of the selected water quality model, QUAL2E (Brown and Barnwell, 1985) buffered by a pre- and post-processing sections as interfaces to the conventional DPSIR scheme. In this context QUAL2E represents a bridge between *Pressures* and *States.*

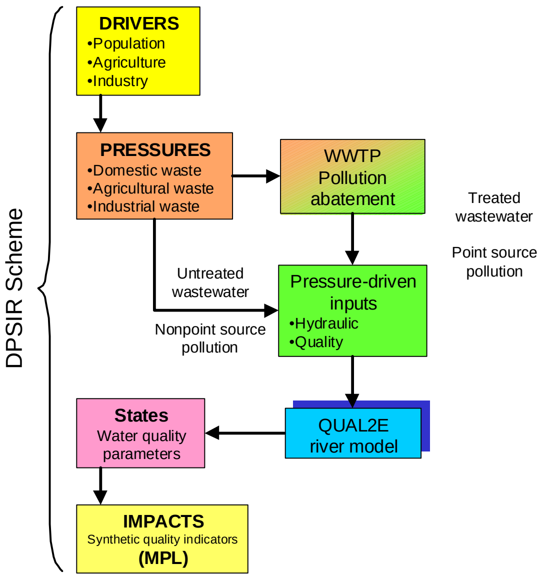

Fig. 2. Integration of water quality modelling in the DPSIR scheme.

2.3 Scenario generation

Providing the water quality model with the correct inputs requires a pre-processing stage which, starting with the *Drivers*, defines the resulting *Pressures* in terms of treated and untreated waste, introduces the abatement of the point- sources considering the average efficiency of the WWTP, as shown in Figure 2. All these data must be formatted in order to be compatible with the QUAL2E input data format. This procedure can also be used to assess hypothetical scenarios, generated by *Drivers* perturbations around the current values.

2.4 Water quality modelling

QUAL2E was selected as the water quality model being the most widely used by environmental agencies around the world and having achieved a high degree of acceptance and credibility. Setting up the input data for a QUAL2E model is not an easy task, because the river must be partitioned into reaches of appropriate length, each subdivided in cells, and for each unit both hydraulic and quality parameters must be specified. An automated procedure was coded to generate the QUAL2E input files from the Excel spreadsheets containing the *Drivers* and *Pressures* data of the whole river catchment.

Once the hydraulic and quality data were specified, calibration runs were made in order to select the kinetic parameters which gave the best agreement between model response and observed quality data. Given the seasonal variability of several *Drivers* and related *Pressures*, the data were grouped into seasonal matrices and the same was done with QUAL2E parameters. The result was the availability of four seasonal scenarios for the whole procedure.

2.5 Impact generation

From the QUAL2E outputs, consisting of a large number of chemical and biological pollution indicators, some synthetic quality indicators are now extracted in accordance to Table 1.2 in Annex II of the WFD defining the_ecological status classifications. The most coherent with the model output is certainly the Macrodescriptors Pollution Level (MPL) introduced by the Italian legislation (D.L. 152/99) in accordance with the WFD, which can be obtained from the scores of the seven main pollution indicators shown in Table 1.

Table 1
Definition of Macrodescriptors Pollution Level

	MPL Level				
Parameter	1	2	3	4	5
100-DO (% sat.)	≤ |10|	≤ |20|	≤ |30|	≤ |50|	>|50|
BOD_5 (mgO_2/L)	<2,5	≤4	≤8	≤15	>15
COD (mgO_2/L)	<5	≤10	≤15	≤25	>25
NH_4 (mgN/L)	<0,03	≤0,10	≤0,50	≤1,50	>1,50
NO_3 (mgN/L)	<0,3	≤1,5	≤5,0	≤10,0	>10,0
P_{tot} (mgP/L)	<0,07	≤0,15	≤0,30	≤0,60	>0,60
E. coli (UFC/100 mL)	<100	≤1000	≤5000	≤20000	>20000
Score	**80**	**40**	**20**	**10**	**5**

Summing the scores for each variable yields the MPL value, which is then translated into a five-zone colour code, according to the ranges of Table 2. If one of the variables could not be measured, a reduced, 6-variable, MPL can be computed with scaled ranges.

Table 2
MPL ranges

Quality	MPL	Score	
		7 variables	*6 variables*
High	1	560-**480**	480-**440**
Good	2	475-**240**	420-**220**
Moderate	3	235-**120**	215-**110**
Poor	4	115-**60**	105-**55**
Bad	5	< 60	< 55

A collection of Excel macros provide the required post-processing procedures to computes the MPL from the QUAL2E model outputs and present it on the cartography using the pertinent colour codes.

3. APPLICATION TO THE ARNO CATCHMENT

The above procedure was implemented in the database system of ARPAT, the regional environmental protection agency in Tuscany, and applied to the river Arno catchment, shown in Figure 3, together with the main tributaries, wastewater treatment plants, flow gauges with a rating curve and the water quality monitoring stations.

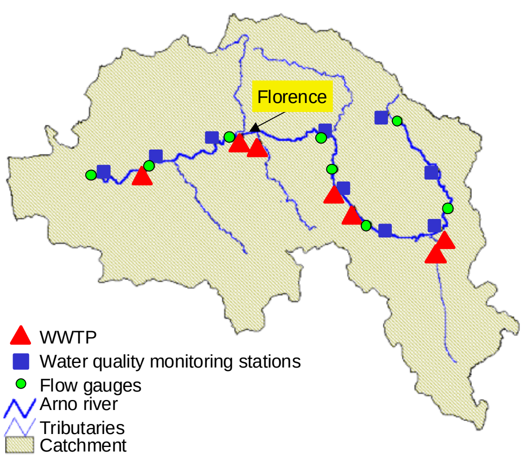

Fig. 3. Arno river catchment.

The first step was to analyse the *Drivers* and generate the *Pressures*. From the three main *Drivers* the pressures were derived introducing the concept of Population Equivalent (PE) for domestic pollution, Employee Equivalent (EE) for industrial pollution and Fertiliser Consumption (FC) for agriculture. The numerical values of these correspondence were obtained from demographic and socio-economic studies regarding the human and economic activities in Tuscany. The first two of these data represent the input to the wastewater treatment compartment, whereas the third represents the diffuse pollution, which should be estimated with specific tools, e.g. Criteria. From the WWTP operating records, the average removal efficiency is obtained and this represents the transfer function between *Pressures* and actual quality inputs to the river model, whose outputs define the *States* of the system, globally referred to as river quality. The last stage is the computation of the synthetic quality index MPL, representing the *Impact* resulting from the application of the known *Pressures*.

Given the seasonal variability of two of the three Drivers, population and agriculture, together with the climatic changes and ensuing variation in river self-purification dynamics (Brown and Barnwell, 1987; Chapra, 1997), it was decided to generate four pressure matrices, one for each season.

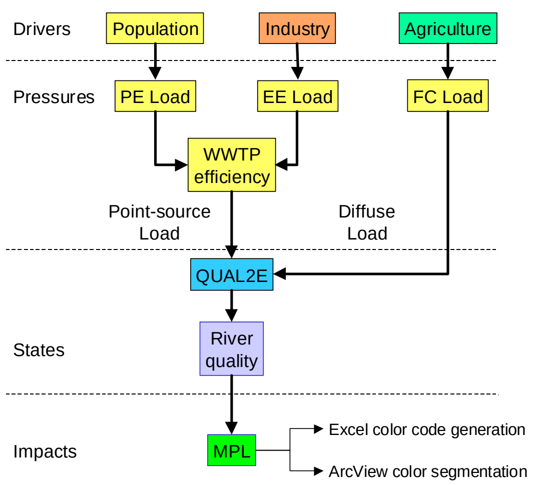

Fig. 4. Computational scheme relating *Drivers*, *Pressures*, *States* and *Impacts* in the proposed model.

3.1 Water quality model calibration

The data from the water quality monitoring stations, indicated with squares in Figure 3 were used to perform a rough calibration of QUAL2E. At this stage a precise calibration was not possible, nor advisable, because:

1) No fully validated quality model for the Arno river system exists to date. Several aspects of the Arno river systems are not yet fully understood, let alone modelled;

2) Quality data, either from the river monitoring stations or from the WWTPs, need further validation and are not always closely linked to hydraulic data;

3) Diffuse pollution data and projections are still incomplete.

Even with these sources of uncertainty a water quality model such as QUAL2E can still be used in this context as an enhancement to the existing data-bases in a more comprehensive scheme with the final aim of *Impact* computation. This is currently expressed as the MPL, divided in five ranges rather than sharp numerical values. Hence the use of a preliminary calibrated QUAL2E model can be justified for indicating a new approach and applying the method previously outlined.

Figures 5 - 9 show the effect of perturbing the Population Driver with a 20% increase of the domestic pollution over its current value. The results shown were obtained for the summer scenario, but similar results were produced for the other seasonal settings.

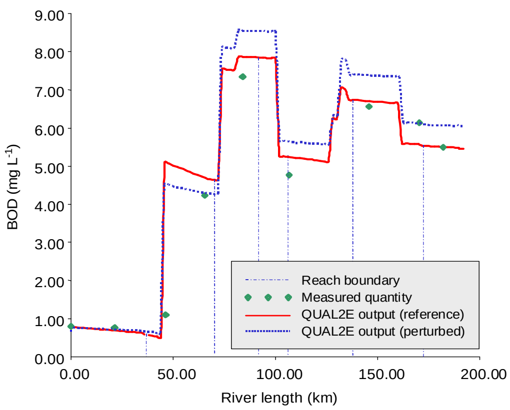

Fig. 5. BOD model output in the reference and perturbed Summer scenario, together with the calibration data.

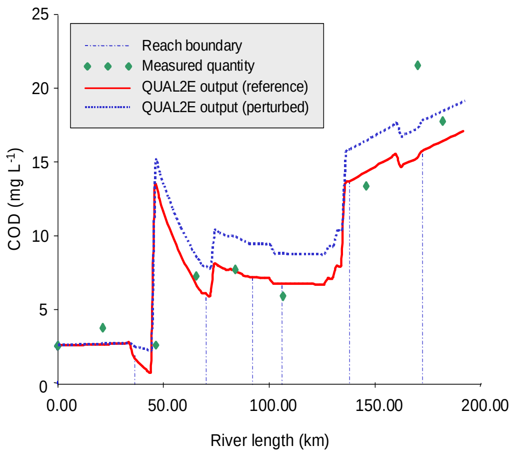

Fig. 6. COD model output in the reference and perturbed summer scenario, together with the calibration data.

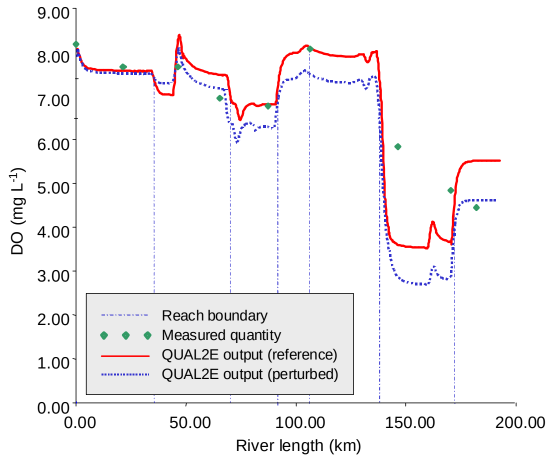

Fig. 7. DO model output in the reference and perturbed summer scenario, together with the calibration data.

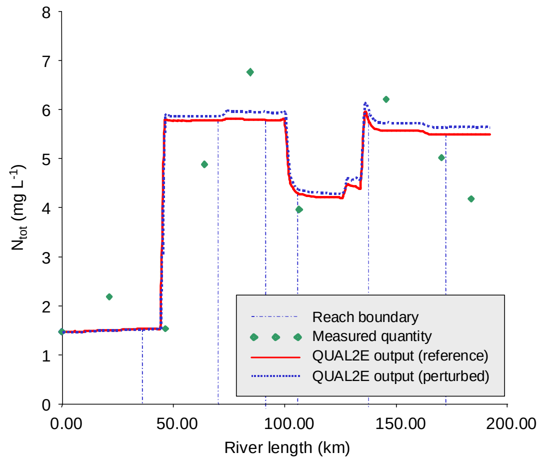

Fig. 8. Total N model output in the reference and perturbed summer scenario, together with the calibration data.

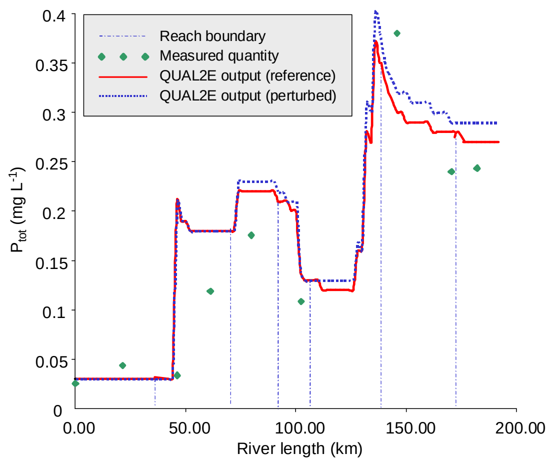

Fig. 9. Total P model output in the reference and perturbed summer scenario, together with the calibration data.

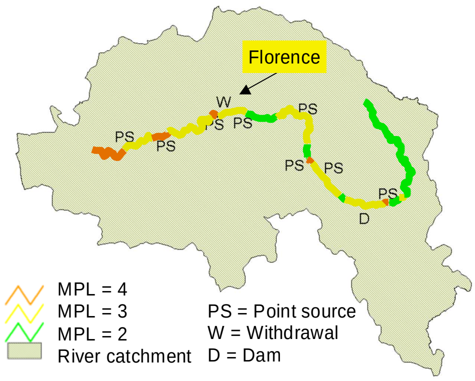

Fig. 10. Colour segmentation of the reference scenario.

In addition to producing stationary values along the river course, the software computes the MPL bands and places the corresponding colours on the river reaches in the GIS catchment map. The resulting quality scenarios are compared in Figure 10, showing the reference scenario, and Figure 11 showing the perturbed situation. It can be seen that the river quality is decreased by one level, particularly in the middle and lower reaches, downstream of the dam, where the quality was already critical.

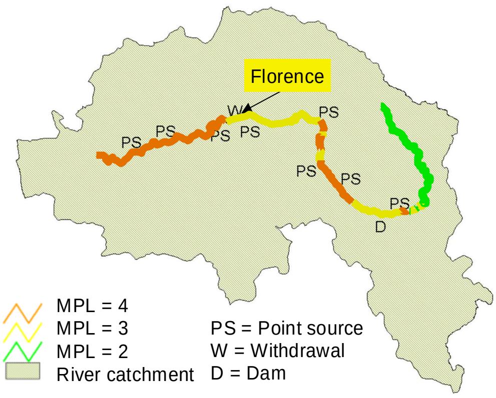

Fig. 11. Colour segmentation of the perturbed scenario.

4. CONCLUSIONS

This paper has presented a computational procedure for the integration of a widely used river water quality model, QUAL2E, into the DPSIR scheme for the assessment of water quality in the guidelines of the Water Framework Directive of the European Community. The benefits of the integration consist of a better integration of the many databases required to prepare the input data to QUAL2E. It also provides a set of automated procedures to launch model simulations directly from the quality data spreadsheets. Another set of Excel macros was developed to compute the *Impact* from the QUAL2E model output in terms of the Macrodescriptors Pollution Level, used to qualify the water quality in the WFD context and provide the corresponding colour codes to the GIS environment depicting the catchment situation.

5. ACKNOWLEDGEMENTS

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