

An interactive georeferenced water quality model

S. Marsili Libelli, G. Pacini, C. Barresi, E. Petti, F. Sinacori

Department of Systems and Computers, University of Florence, via S. Marta, 3 - 50139 Florence, Italy. Email: marsili@ingfi1.ing.unifi.it

Abstract The geographical positioning of relevant locations along the river reach is of primary importance in water quality studies. This paper proposes an integrated environment where a dynamical water quality model is related to the geographical location of the river reach and produce a georeferenced output in graphic form. This integrated package has been developed in Matlab™ and a smooth integration among the geographical system, water quality model and the graphical user interface has been achieved. After describing the basic feature of the software organisation, the package is applied to two short but environmentally significant river reaches and their water quality simulations are presented in the geographical context.

Keywords Environmental management, Geographical Information Systems, River water quality, Simulation, Systems analysis.

Introduction

Water quality models have reached a considerable degree of flexibility and sophistication (Shanahan *et al.*, 2001), with a large variety of kinetics (Brown and Barnwell, 1987); and sub-models (Chapra, 1997; Jorgensen and Bendoricchio, 2001). For their practical application a flexible interface is required to place the water quality data into their geographical context. This feature is considered of primary importance (Johnston, 1998; Lang, 1998). This paper describes the integration between a water quality model and a georeferencing tool to provide such a link. A previous paper (Marsili-Libelli *et al.*, 2001) described the interfacing of a Matlab™-based quality model to a very popular Geographical Information System (GIS) such as ArcVIEW™. That application was organised with the typical client/server philosophy and defined a communication protocol through which data could be exchanged between the two platforms. This paper, instead, presents an entirely new application, wholly developed in the Matlab™ platform and based on the Mapping Toolbox™. The tight integration of all the package functions results in enhanced interactivity and portability.

The paper presents the features of this integrated application through the case study of two small but environmentally significant river reaches in Tuscany. It will be shown that this solution provides a flexible tool to handle both the water quality and the geographical features of river management problem.

An Integrated Platform

This integrated application has been developed to refer a river water quality model, implemented in Matlab/Simulink™, to its geographical context, processing the geographical data through the Matlab Mapping Toolbox™. The water quality model consists of a number

of dynamical and algebraical equations describing the evolution of river quality along the river length and over time. Figure 1 gives an overview of the interactions among the system modules.

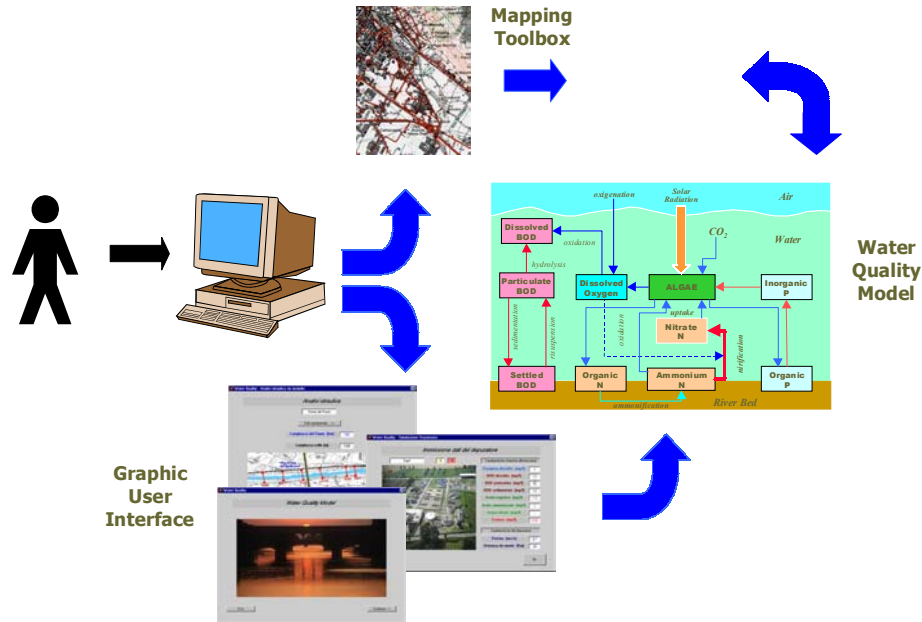


Figure 1 Functional scheme of the interactive quality model with geographical interface.

The river system can be defined through the user interface, positioning relevant features (e.g. tributaries, abstraction points, wastewater treatment plants, non-point sources, etc.) in their geographical context, through dedicated interfaces. Hydrodynamic data should also be entered. In the case of time-space models they will serve as the velocity field over which the diffusion equations are integrated. In the case of stationary models, the flow velocity is used to compute the *flow-time*, so that the model results can be geographically positioned on the map.

The georeferencing module

Geographical data can be entered either through a digitizer or using GPS data. Starting from these data, the core of the georeferencing algorithm is the creation of a co-ordinate vector, representing the river course, which is then transformed into a collection of co-ordinate cells with the resolution of the digitiser or GPS fixes. Each cell contains an array of pointers, one for each river parameter, e.g. stream velocity, BOD, DO, N-NH₄, etc., which need not to be sampled at the same locations. Figure 2 shows the organisation of the geographical data. The top row is the cell array containing the digitised co-ordinates. The second row is the array of the sampling sites co-ordinates $\mathbf{S} = (S_1, S_2, \dots, S_n)$. Given the possible positioning errors between river cells and sampling cells, \mathbf{S} is not required to be a subset of the top row, because an approximating procedure of *river referencing*, shown in Figure 3, will reconcile their geographical discrepancy and align them along the cell-defined river course. This procedure determines the nearest river cell by minimising the euclidean distance between the sampling

location and the cells. The sampling point is then assigned the co-ordinates of the nearest cell. The last two rows contain the arrays of co-ordinates of the quality parameters, to which the same *river referencing* procedure has been applied.

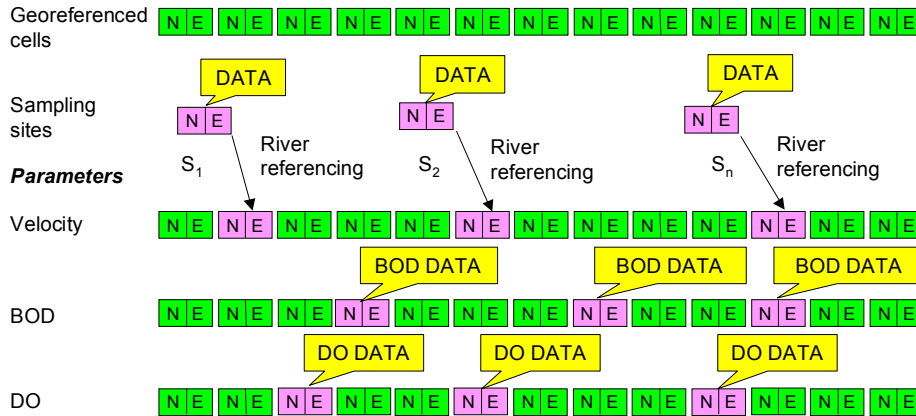
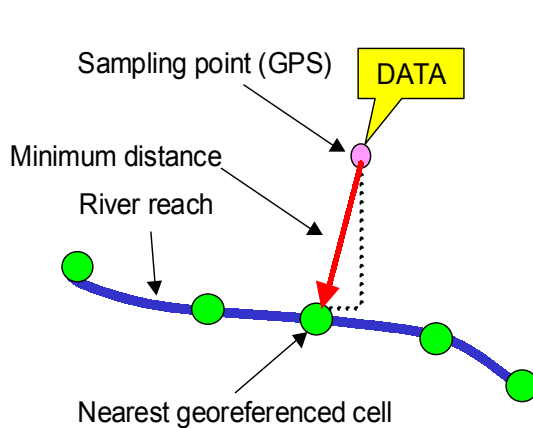


Figure 2 Defining the river as a collection of cells and referring their content into a geographical context.



In many cases both data entries may coexist, because often the river course is first digitised and then the GSP-related sampling points are added at a later time. This may cause a discrepancy due to the differing accuracy. Therefore, in positioning the sampling points a reconciling algorithm is used, computing the minimum distance from the GPS point and the nearest digitised cell in the geographical co-ordinate system. The sampling is then referred to this cell. This algorithm is shown in Figure 3.

Figure 3 Reconciling digitised river cells with GPS sampling locations.

The river structure, represented by the cell array in the geographical co-ordinate system and related quality vectors, can be used to compute geometrical quantities such as length between any couple of cells and the *flow-time* between them. This information forms the basis on which the quality model can be run.

The water quality module

The river quality dynamics presently in use is limited to the fundamental pollutants, such as BOD, Dissolved Oxygen, Nutrients (N and P), and algae, but can be extended to include any relevant parameter. Their kinetics are derived from the QUAL2E model (Brown and Bamwell, 1987) and incorporate more recent results (e.g. Chapra, 1997; Jørgensen and

Bendricchio, 2001; Shanahan *et al.*, 2001), which in some instances have been adapted to the local context, e.g. for the re-aeration and de-oxygenation rate constants. Depending on river dimensions and problem requirements, the model can be either plug-flow stationary, as in QUAL2E, or a more complex space-time model, capable of describing the full time-varying behaviour along the reach. Figure 4 shows the various capabilities of the quality module.

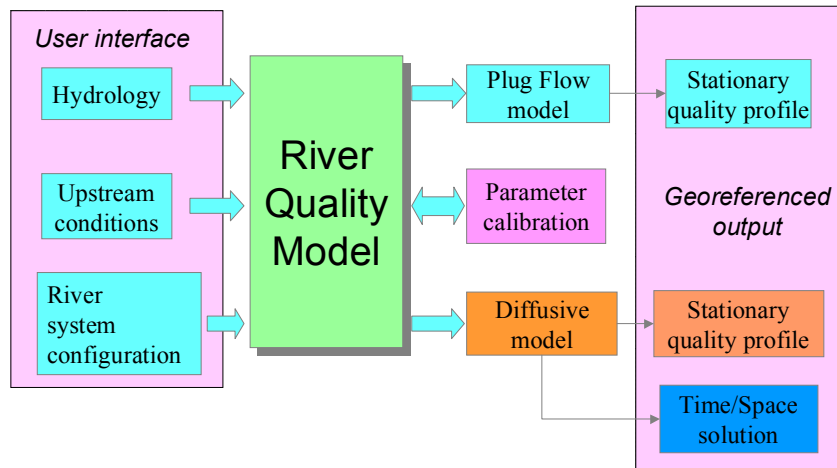


Figure 4 Features and software engineering of the water quality model.

Application to case studies

The development of this application was instigated by the regional environmental protection agency (ARPAT) in view of an intensive monitoring program of short but environmentally sensitive river reaches. In fact, data sampling programs can be planned with this tool, because the model can indicate the most sensitive spots along the river, where quality data are most significant. Another use of the package is the reconciliation between "official" discharge data and the evidence coming from river surveys. In many cases unknown (or unauthorised) discharge points can be inferred from the discrepancies between model response and observed quality data. The same applies for non-point source pollution, which being distributed along a river reach, is very difficult to observe but its effect becomes apparent when the model response diverges from the observed quality data. To demonstrate the procedure, parts of two tributaries of the river Arno, named Bisenzio and Sieve, are considered.

The reaches considered in the study included the upper course of the Bisenzio river, 37 km long and the river Sieve, for a length of 47 km, from a major reservoir down to the confluence into the Arno. The two rivers are very different: the Bisenzio flows through a heavily industrialised valley, with a high concentration of textile industries which once were powered by the river flow. Now the river has become the recipient of all the discharges from dyeing and weaving industries. Though wastewater treatment facilities are now widespread, still occasional spillages remain.

On the contrary, the Sieve runs through a valley (the Mugello) where agricultural activities prevail and environmental quality is satisfactory, with several high-quality dairy

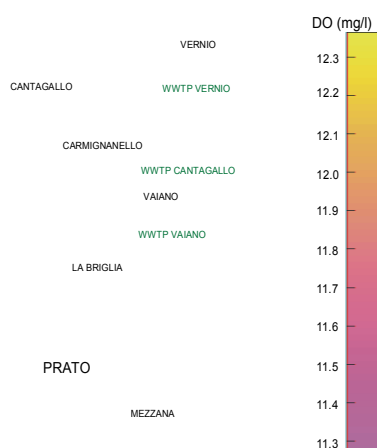
factories and health farms. Therefore, the Sieve quality is rather high and the set-up of a quality model is regarded as a tool in a comprehensive effort to conserve and improve the present environmental standards.

In both cases, the short length of the courses (37 Km for the Bisenzio and 47 Km for the Sieve) and the large number of point-sources together with several unknown distributed inputs, would not justify a time-space complex model. It was therefore decided to opt for a steady-state *flow-time* model, to be allocated through the georeferencing part of the package.

The water quality variables included in the model are BOD, often obtained as the readily biodegradable fraction of COD, Dissolved Oxygen (DO), Ammonium-Nitrogen (N-NH₄) and Nitrate-Nitrogen (N-NO₃). Phytoplankton play an important role in the oxygen balance, often contributing to over-saturation. This is also due to the fact that oxygen consumption is often lower than expected because the readily biodegradable fraction of COD has been taken up by the wastewater treatment plants before discharge. This greatly diminishes the oxygen demand in the river, where only the slowly biodegradable fraction of COD remains and justifies the high values of DO found in almost all the sampling locations.

For each applications, the parameters of the quality model are estimated by minimising the sum of squared differences between simulations and experimental data, using a modified form of the Simplex search method (Marsili-Libelli, 1992). A preliminary study, included in the package, ranks model parameters in terms of sensitivity, indicating those which should be estimated on a case-by-case basis.

The Bisenzio water quality model



The quality in the upper Bisenzio is mainly controlled by the three major wastewater treatment plants operating along the reach. On the other hand, the self-purification dynamics is rather limited as a consequence of inhibiting factors from the discharges of the dyeing factories and the tendency of wastewater treatment of taking up almost all the readily degradable COD.

Calibrating the quality model with data sampled from the upper reach of the Bisenzio, the georeferenced out-put of Figure 5 is obtained. For the reasons already explained and the presence of the three WWTP, the DO level is almost always above saturation.

Figure 5 DO profile along the Bisenzio upper course in the georeferenced system. The DO sag downstream of the three WWTP can be noticed.

The Sieve water quality model

Given the variability of the river morphology and the stream velocity along the reach, several rate constants were found to be space-dependent. Therefore they were modelled as a function of water velocity and other morphological factors. In this sense, the river model used for the Bisenzio would be unsuitable in this case. Several distributed BOD and N-NO₃ sources had to be introduced in order to explain the observed quality behaviour. Also, in the

upper reaches, photosynthesis played a major role in producing over-saturated DO conditions. Figure 6 shows the model response in the georeferenced system, with contribution from point and non-point sources.

Figure 6 Georeferenced water quality in the Sieve river.

Conclusion

The georeferencing of a river water quality model has been solved by proposing a simple algorithm to partition the river into a number of cells and relate their content to the geographical context. The cell system is also used to compute related quantities such as *flow-time* and the input-output mass balance including WWTPs, tributaries, abstractions, etc. After the quality module has performed its computation, the geo-referencing module is again invoked to place the results again in the geographical context using colour codes. Of course quality vs. distance or three dimensional time-space plots are also available.

Acknowledgement

This research was partly supported by the Regional Agency for Environmental Protection of Tuscany (ARPAT).

References

- Brown L.C. and Barnwell T.O. (1987). *The enhanced stream water quality models QUAL2E and QUAL2E-UNCAS: Documentation and user manual*. US - EPA Environmental Research Laboratory, EPA/600/3 - 87/007, Athens, GA.
- Chapra S.C. (1997). *Surface Water Quality Modelling*. McGraw-Hill, New York, NY.
- Johnston C.A. (1998). *Geographic Information System in Ecology*. Blackwell Science, Oxford.
- Jørgensen S.E. and G. Bendricchio (2001). *Fundamentals of Ecological Modelling*, 3rd ed., Elsevier, Amsterdam.
- Lang L. (1998). *Managing Natural resources with GIS*. Environmental Systems Research Institute Inc., New York, NY.
- Marsili-Libelli, S. (1992). Parameter estimation of ecological systems. *Ecological Modelling*, **62**: 233 - 258.
- Marsili-Libelli S., Caporali E., Arrighi S., Becattelli C. (2001). A Georeferenced Water Quality Model. *Water Sci. Tech.* **43** (7): 223 – 230.
- Shanahan P., Borchart D., Henze M., Koncsos L., Rauch W., Reichert P., Somlyódy L. and Vanrolleghem P. (2001), River Water Quality Model No.1: I: Modelling approach. *IWA Series of Scientific and Technical Reports n. 11*.