Approach to Support Water Quality Watershed Project.

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Abstract: Current European water law inspires research, within which it is necessary to investigate numerous phenomena, with the aim to place responsible authorities in the conditions for the correct application of the norm. The attention is addressed mainly to the attainment of good water quality status, according to Water Framework Directive (WFD). This paper briefly presents a methodology used for implementation of watershed approach, with an aim of defining water quality in the lake's immissary as a result of all different pollution-generating activities within the watershed. This paper describes therefore research lines of monitoring and modelling efforts to characterize nutrient loads in watershed scale. Following this integrated approach, it has been possible to identify satisfactory solutions to develop watershed project.

Key-Words: WFD, integrated approach, watershed, water quality.

1 Introduction

Rivers and streams are an important component of the natural environment, and need to be protected from all sources of pollution because man's own survival depends on their sustainable use. Rivers, however, are increasingly under threat from different pollutants, despite the fact that the river water quality can be influenced by natural phenomena such as climate and geology, the main sources of pollution are related to anthropogenic activities: mining, agriculture, forestry cutting, cattle farming and urbanisation [1]. As a result, both point and diffuse sources of pollution affect water quality. Currently, both sources of pollution have resulted in two important water quality problems in surface waters: eutrophication (nutrient enrichment) and contamination by hazardous organic compounds. To tackle these typical water quality problems, and for the sake of both ecological and human welfare, rivers (all water resources in general) must be protected, restored and sustained. This needs appropriate nationwide environmental regulations and assessment tools. The most widely applied environmental regulation is European Water Framework Directive (WFD)[2]. Directive requires reaching a good ecological status for all surface water. Following its implementations, river water quality models are an integral part of environmental assessment tools, as they assist the environmental regulators to reach water quality objectives. However in order to implement models usually large set of data is needed. As such, the monitoring becomes an important issue in a watershed holistic approach. The benefits of the synergy between modelling and monitoring are often mentioned by number of authors and the linkage of both, monitoring and modelling makes possible to apply the cost-benefit measures [3], [4]. Such integrated project approach is suitable to investigate nutrients sources and theirs effect on receiving water.

One of the long-term project of this type is carried out at IRSA-CNR (Water Research Institute of the Italian National Research Council), Brugherio in co-operation with number of institution and universities. The project involves a wide spectrum of water resources management and its methodology, once proven, could be accepted as a keystone in the planning process for lake water recovery strategies in the future. Project final goal is to obtain an integrated model for the Lake Pusiano watershed. Models can be implemented to develop support to the restoration plan of lake ecosystem, in agreement with the recent European Water Framework Directive, and to contribute to the application of *Piani di Tutela* (Regione Lombardia; provided by Italian national law) [5].

Purpose of this paper is to present developed research line and implemented methodology for this kind of watershed study. Paper presents integrated monitoring and modelling implementation. Both tools are here considered an appropriate approach to jointly study the entire watershed. Developed methodology can be used for implementation in others case studies.

2 Problem Formulation

2.1 Study context and problem statement

In developing an integrated water quality program that can be used as a tool in water quality regulations, the main (*first)* problem comes from the difficulty of research about aquatic system functioning, because of multiple and complex interactions between physical, chemical and biological factors. In particular, nutrient are important factors playing a role in the eutrophication processes. Furthermore, the importance of hydrology in ecological studies on nutrients has been emphasised since 1959 by Orghidan cited by Brunke and Gonser [6] and many recent works [7], [8]. In particular, quantitative data of water discharges are needed, as well as information about pathways. Then the use of a suitable model is necessary. According to the state-of-the-art, watershed models are typically used for hydrological simulations, although a conceptual model can be used for rivers [9]. A lot of watershed models are too complex to be used in water quality modelling. In order to evaluate river water quality, in-stream models ought to be used. The traditional effect assessment is based on a steady-state approach, in which concentration does not vary in time. In reality, however, the stream is exposed to a time-varying concentration. To take into account temporal variability, long time scale models need to be applied. As separate models do not address all interactions, integration of watershed and river models is essential.

And finally *problem* is related to the lack of appropriate data for input. In traditional basic water quality modelling (QUAl2), both quantity and quality processes must be calibrated. Thus, to take into account regional condition monitoring data should be collected. This problem is due to the lack of attention given to the interaction between monitoring and modelling in traditional water quality assessments programs. Monitoring and modelling may interact by many aspects. For example, monitoring data may be the input to modelling to improve accuracy and thereby reduces uncertainty. Modelling on the other hand, may have a direct effect (data needs) or indirect effect (decrease or increase of) on monitoring program development. Such effect in turn will affect the time and cost of project [10].

So that problem definition cover *three objectives.*. The *first goal* is to contribute to construction of a water quality database of the selected region with the development of an appropriate monitoring program (definition of the requirements and development of field measurement for water quality). The monitoring should be suitable to assess water quality in watershed and prepare the input for modelling framework. The *second goal* is to develop an integrated modelling framework that can be used as a tool in water quality assessment. The goal of an integrated modelling framework is not only valid in view of the applicability of the model, but also of its suitability in integrated water quality studies, highlighting its linkage to the monitoring data (and vice versa). The *third goal* is to use integrated monitoring and modelling to give insight into the sources of nutrient pollutants in watershed, in which the effect of CSO's is also investigated in presented case study. Such knowledge can then be explored to analyse the eutrophication (stressors like nutrients) in the studied aquatic ecosystems. In the long term, the final aim is to contribute to develop recovering plan to reach good ecological status as required by WFD.

2.2 Case study description

The observed watershed is Lake Pusiano watershed situated on the southern edge of the Alps (Northern Italy). Lake Pusiano is one of the main inter-morenic sub-alpine lakes in this region. It is located in the North of Italy in Lombardy, in the middle of the two branches of Como Lake, in the so-called Triangolo Lariano. The watershed area is 96.4 km^2.

The main river is Lambro, a relatively small water body significantly affected by seasonal changes (the river base flow is ~2.0 m^3/s), that mainly flows through calcareous soils. Large part of the catchment is natural, covered by forests (~70 %), meadows and pastures (~7 %), agricultural lands (~4 %) and urban areas (12 %) with a population of about 60000, mainly located in downstream portions of the watershed. Climate conditions are characterized by warm dry periods and by shorter periods of heavy rains, this being a very important aspect to take into account while hydrological characterizing the system. Chemical compounds primarily affecting water quality in studied watershed are nutrients (nitrogen and phosphorus). Until the mid-80's, direct discharges of urban and industrial wastewaters into the River Lambro led to elevate levels of hypertrophy with total phosphorus concentrations up 200 µgP/ l. In these years a sewer network was built (it covered 70 - 80% drainage of river watershed and regulations to reduce phosphorus were implemented. Both factors determined a sensible reduction of nutrient loads to the lake. This caused a progressive improvement of the trophic quality of lacustrine waters evidenced by reduction of the total phosphorus concentrations by approximately 70 % in winter circulation. This obviously appeared some time after the construction of the sewer network; however in the past decade stability conditions were reached. Currently, the lake still shows eutrophication conditions with total phosphorus concentrations of 69 µgP/ l during winter circulation, reduced water transparency and deep layer anoxia during summery stratification. Therefore, the lake is still far from ecological objective indicated by Legislative Decree 152/99 and the WFD [11].

The attention is therefore focalised on the estimation of nutrient contribution and an analysis of pollution sources, not allowing an improvement of lake ecological status. The present situation is due to nutrient loads, than still come from the river watershed, through its direct imissaries, as well as through the direct drainage area of the lake. As also several CSOs (Combined sewer overflows) presented in the watershed, their importance increases with the increase of general precipitation. It must be considered that the runoff from urban impervious areas represents a diffuse source that can be of relevant intensity, when concerning the urbanised area of Lake Pusiano watershed.

3 Problem Solution

3.1 Development of methodology for watershed project

The research methodology of this kind of projects can be distributed in the following areas: Pre-field work, field work and post-field work. The research method for watershed project proposed based on developed project is presented in a flow chart below in figure 1.

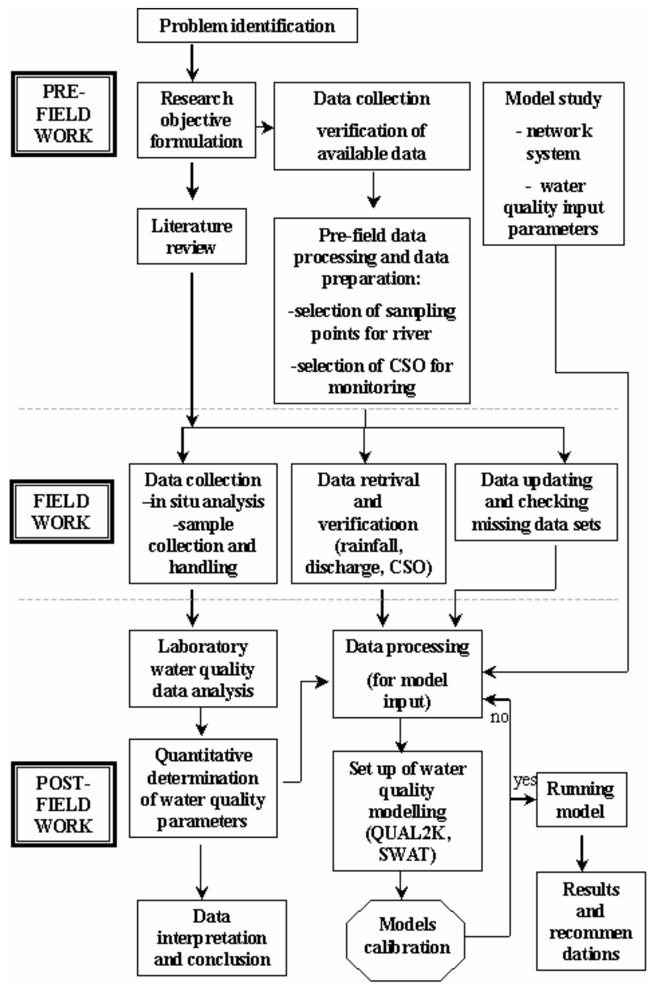

Fig.1. Developed methodology flow chart for presented case study.

As can be seen in figure 1 this study contributes to the development of a water-related database in the region. Data available on the territory and those that are acquired through project work are presented. One of the major goals of the *Pre-field work* was to define the requirements and develop field measurement survey for water quality monitoring program. This study proposed and tested a methodology for locating the optimal position of monitoring points within a watershed. These problems are important to be faced.

In developing a monitoring and modelling plan, it was considered up front whether to use modelling, since the use of a model and its level of complexity affect the need for monitoring data. In this study, modelling is indeed needed. Modelling may in fact be relevant to reviewing and revising water quality state and help to fulfil gaps between data. Modelling can also assists in formulating and testing the cause-effect relationships between pollutants sources and receiving water impacts. Further this knowledge can help to evaluate management alternatives and formulate an acceptable water quality standard. Model selection was done according to a number of factors including: type and physical characteristics of the receiving water body, water quality parameters to be modelled, and time scale over which the receiving water is modelled.

Samples for water quality in selected monitoring sides was collected (*Field work)*. Samples from 11 measurement points, for more then 20 events were collected. CSO's discharge data were collected during rainfall events (5 events) for 5 selected structures. In *post-field work*, integrated monitoring and modelling of nutrient contaminants in watershed is explored. Its highlight consists of linking monitoring to simulation models, and vice versa. Around the modelling framework, elements exist that are required for the investigation in order to prepare inputs from monitoring data. Moreover, algorithms used to represent processes affecting the modelled determinants include empirical terms and coefficients that must be set by calibration. These terms and coefficients have been derived from literature review, as well as by calibration against observed data (field results). On the basis of both simulation and measured values, pollutant loads were estimated and investigation of seasonal variation in nutrient concentration were done.

Post field - work was done to explain and quantify the nutrient inputs that affect lake water quality and to determine cause effect relationship between land use and pollution sources.

This way, nutrient sources in the watershed are evaluated using a modelling tool for predicting loads and asses of the importance of monitoring programmes.

3.2 General outcomes from implemented monitoring programme

One of principal objectives of case study was to analyse nutrient pollutants in Lake Pusiano watershed. For obtaining this, characteristic of water quality was conducted in different point of watershed. This was done by developing proper monitoring plan to provide essential and accurate information. It was considered that monitoring plan elements were designed in way to support modelling efforts.

The monitoring program has been adapted to allow measuring changes in river since 2002. Extensive quality characterisation has been conducted at five CSO sites, which are distributed throughout watershed area. Those are representative for area of monitored river sub-basins and in consequently in different land use characteristic. The water quality variables for river stations and CSO sites included in the basic physical, chemical and biological component, however with focus on phosphorus, nitrogen and sediments. In the monitoring program it was impossible to measure the concentration of pollutants over the complete duration of storm event (no automatic sampler). Therefore collection of wet weather data is the most critical element of the data collection programme.

Summarising, there were four components of water quality monitoring programs in the presented project undertaken:

- Lake monitoring program;
- Sources monitoring program
- River monitoring program (since January 2004 expanded); and the
- CSO monitoring program (since January 2004).

Data from monitoring program were analysed by different ways. Then characteristic values of concentration were evaluated.

Studies show that variations in concentration levels between individual monitoring stations may be explained in part by differences in:

- precipitation pattern
- size of the drainage area upstream from the monitoring station
- type of drainage area (e.g. population density, type of land use, etc.)
- design and condition of the sewer system (for CSO)

3.3 Integrated modelling approach

The use of mathematical models as a tool in water quality management is largely driven by legislation, and their practices also vary from country to country. In a country where the water quality is based on the WFD, the mathematical models can be required to assist the water quality regulator to achieve the water quality objective (as described previously).

Reviewing literature, it can be noted that there is a wide array of available models developed within the scientific community during recent years [12, 13, 14].

SWAT and QUAL2K were selected for this project, because those meet the model selection criteria specified by technical approach and address the project objectives. Approach includes models that have the relevant physical, chemical, and biological processes, and have been successfully used throughout the United States and Europe. QUAL2K (or Q2K) [13] be used in this study is a river and stream water quality model that is intended to represent a modernised version of the QUAL2E model by EPA [14]. The Soil and Water Assessment Tool (SWAT) is model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service [15]. SWAT is a spatially distributed, physically based watershed scale model. The SWAT physio-graphic data, monitoring data, and associated assessment tools are integrated in a customised GIS (Geographic Information System) environment. In this study the AVSWAT version of model is used, which is a full-integrated version within ArcView 3.2.

Given that, AVSWAT and QUAL2K were applied to Lake Pusiano watershed to determine existing nutrient loads, link nutrient sources to in-stream indicators, and calculate the load assessment reductions necessary to achieve the numeric target value for the selected indicator.

Overall the SWAT proved very capable of being able to predict, with reasonable accuracy, the nitrogen and phosphorous levels of the major sub-basins in the Lake Pusiano Watershed.

In the in-stream nutrient calibration process, since data collection for water quality was focused on an intensive field survey for nutrients, the simulated values were compared with the measured values, which were collected during fieldwork. Experience with the QUAL2K model has proven the importance of site-specific data to model predictions.

In developing loads assessment, one must take into account the "critical condition" for stream flow, loading, and water quality parameters. The "critical condition" is generally defined as the condition when the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or characteristic water uses. The critical condition for Lake Pusiano watershed is during high flow (defined in part of Q2K model development), when nutrient contributions are dominated by non-point sources or CSO discharges. Literature searching gives example from Pittsburgh, where CSOs and urban streams receiving CSO discharges, were tested for nutrients. Data suggested that CSO are a significant source in small streams [16].

Generally, the results strongly suggest that i) the presence of polluted CSO discharges might have a significant effect, and ii) nutrients enter during high flow events that should be considered as critical conditions.

4 Conclusions

Diffuse pollution is a complex environmental issue due to the multitude of possible pathways existing to reach the surface water system. However, to meet the current requirements of the UE legislation [5], diffuse sources of water pollution need to be identified, quantified and controlled. In the same way development and validation of a proper methodology is needed in accordance with the WFD to achieve a "good" surface water status in year 2015. Probably the only approach that can guarantee an adequate estimate of the diffuse pollution is a water quality model calibrated with direct in stream measures of quality parameters. The presented example of watershed project's aim was the analysis of the causes determining current Lake Pusiano trophic condition through an integrated monitoring and modelling approach. The complexity of this kind of study, including the analysis and integration of multitude natural aspects, therefore is best accomplished by means of GIS support allowing a relational comparison of territorial information. For this reason, the methodological approach chosen in this study is a GIS-linked hydrology and water quality model, Soil and Water Assessment Tool – SWAT, used in combination with a steady-state simulation model QUAL2K. This allows hydrological analysis and determination of the sediment and nutrients loads to the main channel. It allows to evaluate sediment movement and nutrient transport following different management options, with simulations concerning past, present and future. This will allow to help to identify actions needful to mitigate water quality problems within the lake.

This study shows that developed methodology can be used as an effective tool to predict the effects of watershed activities on surface water bodies. Father, it can also be used to analyse the effects of alternative management strategies and aid regulatory agencies in decision making.

An integrated monitoring and modelling approach can be introduced to capture the complex watershed processes, so that it can be applied to investigate future situations, especially in developing loads reductions plans, to meet required water quality standards.

Proposed integrated approach is suitable to investigate the combined effects of both point and non-point pollutants on the aquatic system. As such, the proposed modelling approach addressed an important issue in water resource management. Under the watershed approach, monitoring programs in connection with modelling, address watershed problems in an effective and cooperative fashion. The application of the watershed approach is particularly timely and appropriate since required since 2000 by the Water Framework Directive. In general principle of the WFD suggests that countries should prepare national water action plants to operational strategies for action at the river basin. An example of the management value of models can be seen in Lake Pusiano modelling efforts. The models explained that the current rate of nutrients reduction, so that lake eutrophication is being controlled by watershed surface runoff rather than internal or atmospheric load.

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