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RIVER WATER QUALITY MODELLING IN DEVELOPING A CATCHMENT WATER SAFETY PLAN

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ABSTRACT

The primary aim of a catchment water safety plan is to reduce risks within the catchment to protect the quality of drinking water sources at the intake point. Even where effective arrangements for catchment management and control have been implemented, unexpected deterioration in raw water quality can pose a risk to treated drinking water quality. Thus potential sources of pollution impacting the area of influence of the intake should be identified and monitored. An important part of any catchment management strategy includes implementation of raw water monitoring programmes, targeted at the most likely microbiological threats to water treatment. When combined with good monitoring datasets, properly calibrated, tested and verified surface water models can be used to forecast or estimate risks under various scenarios. This allows a good insight into impacts associated with known and anticipated land use activities within the catchment. In this work a hybrid methodology based on river water quality data analysis and hydrodynamic and water quality modelling was developed to assess the surface water quality in the Portuguese river Cávado. This component constitutes the base for developing a catchment water safety plan at this river basin.

Key words: catchment water safety plan, safe drinking water, river water quality modelling

INTRODUCTION

Supplying good and safe drinking water is a key issue in public health protection policies. Usually, national and international legislative and regulatory procedures adopted for water quality control are based in the so-called end-product testing methodology which means that the application of monitoring programmes are based on spot sampling of the water distributed to the consumers in order to verify the compliance of the results against the pre-established standards for treated drinking water.

Recognizing that this methodology has several shortcomings and limitations in drinking water supply systems in both developed and developing countries, the World Health Organization propose the novel concept of Water Safety Plan (WSP) consisting of a management framework for safe drinking water based on effective risk assessment and risk management approach that comprises all steps in water protection, from catchments to the consumer [1], [2].

Based on this concept of preventive WSP, significant efforts have been registered worldwide in developing and implementing this systematic process for hazards identification, risk assessment, and effective management procedures [3], [4], [5], [6], [7], [8]. Strategic frameworks establishing comprehensive methodologies for a systematic and organic scaling-up of WSP at a national or regional basis have also been reported [9].

In this context, the protection of raw water sources quality is of paramount interest for guaranteeing safe water in the drinking water supply system. Anthropogenic activities in the catchment area have significant impacts on surface and groundwater, and can highly influence the technological treatment scheme required to ensure that the water entering the water distribution system is safe for human consumption. In this way integrated water resources management is a critical task for adequate identification of pressures acting in the catchment water cycle and for defining the preventive measures and early warning systems required for implementing effective water sources protection strategies.

The objective of this work is to discuss the applicability of river water quality models in predicting the impacts of domestic pollutant loads in the quality of drinking water sources, allowing the implementation of early warning system at a river basin scale. The Portuguese river Cávado basin case study presented in this work illustrates the methodology proposed and its duplicability at a wider scale. Time series of water quality data have been collected at twelve monitoring stations within the river catchment. The river model was implemented applying the Sobek [11] software and includes reservoirs, hydraulic structures and main tributaries, as well as the most significant point sources pollutant loads discharged by waste water treatment plants, industrial and livestock within the river basin.

CATCHMENT WATER SAFETY PLANS

Principles for establishing a framework

Drinking water sources protection strategy should be based on catchment management plans, which include monitoring requirements, corrective actions for dealing with routine and unexpected incident conditions, and communication strategies [10]. Contingency procedures can be effective in preventing and overcoming a number of natural disasters (e.g. floods, droughts, extreme meteorological conditions) as well as in man-induced actions (e.g. accidents, vandalism). Figure 1 depicts a simple diagrammatic representation of typical links that can be established in preparing a catchment management plan.

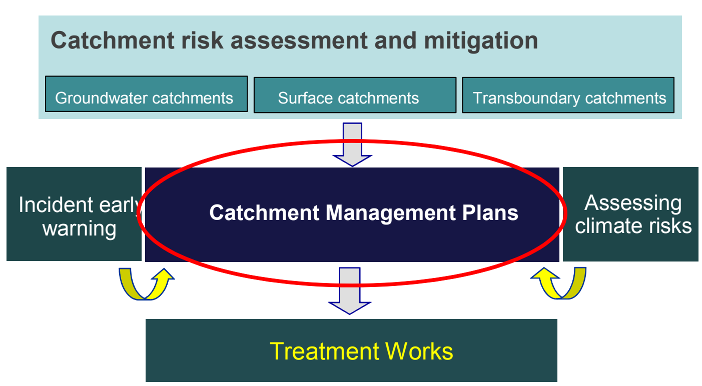


Figure 1. Framework for preparing a catchment management plan.

Major implementation steps

Development of a catchment WSP includes five main steps: (i) map and characterise the catchment, (ii) identify hazards and hazardous activities, (iii) assess risks, promote mitigation measures and verify their effectiveness, (iv) implement risk based raw water monitoring, and (v) implement catchment warning and response procedures [10].

Geographic information systems are adequate and efficient solutions that can be used for electronically interpreting and manipulating the large amount of data necessary for catchment WSP implementation.

Identification of hazards and hazardous activities consist on the identification of potential point and diffuse sources of pollution impacting the abstraction points.

Hazards and hazardous activities identified in the catchment should be prioritised in terms of likelihood and severity of consequences. In doing so it will be particularly important to consider not just of those potential pollutants which could have a rapid impact on the waterworks but those which could deteriorate over a long time period if mitigation measures are not implemented.

Implementing raw water monitoring programmes targeted at the most likely parameters of concern based on the catchment characterisation/ risk assessment, is a crucial component of any catchment management strategy, and include implementation. The frequency and timing of sampling must take into account the potential variability of raw water pollution load, for example due to weather conditions.

Pollution incidents potentially impacting water supply abstractions will occur from time to time, even where effective arrangements for catchment management and control have been implemented. The early warning procedures that need to be put in place will vary depending on the local situation and available communication systems. Whatever procedure is developed will need to be simple, agreed by all parties and clearly documented. Once implemented the procedures should be regularly reviewed to identify areas for improvement.

RIVER CÁVADO CATCHMENT WSP

Catchment characterisation

River Cávado catchment (Figure 2), located in the north-western region of Portugal, is used intensively for water supply, agricultural irrigation and hydropower generation. With a drainage area of 1589 km^2 and a mean width of 16 km, river Cávado catchment has a mean elevation of 564 m with several peaks above 1500 m, and an average population density of 200 inhabitants/km^2 (minimum of 22 at Montalegre municipality and maximum of 1770 at Braga municipality). River network includes the rivers Cávado and Homem and the following main tributaries: Beredo, Borralha, Cabreira, Cabril, Cavadas, Caveiro, Covo, Febras, Gerês, Milhazes, Pontes, Rabagão, Toco, and Tojal.

The annual mean rainfall is 2200 mm, 42 % of which is concentrated in the months of December, January and February. The water is intensively used for hydropower generation, domestic and industrial water supply and agricultural irrigation. Main tributaries are river Rabagão (left side, with a drainage area of 257 km^2) and river Homem (right side, with a drainage area of 246 km^2).

Due to the river basin characteristics, six large hydropower plants (apart from several other small units) are in operation with an installed power of 377.6 MW and a mean annual energy production of 1535 GWh. A total reservoir volume of 1170 hm^3 is possible with these dams, which represents a high regulatory capacity for river flows. For this reason, this water use constitutes a key factor to be considered in any water management policy adopted for the basin.

The study area occupies the lower level part of the basin, where the main residential and industrial areas are located, and distributed over five municipalities: Amares, Vila Verde, Braga, Barcelos and Esposende. All of these municipalities are served by water treatment plants (WTP) and wastewater treatment plants (WWTP).

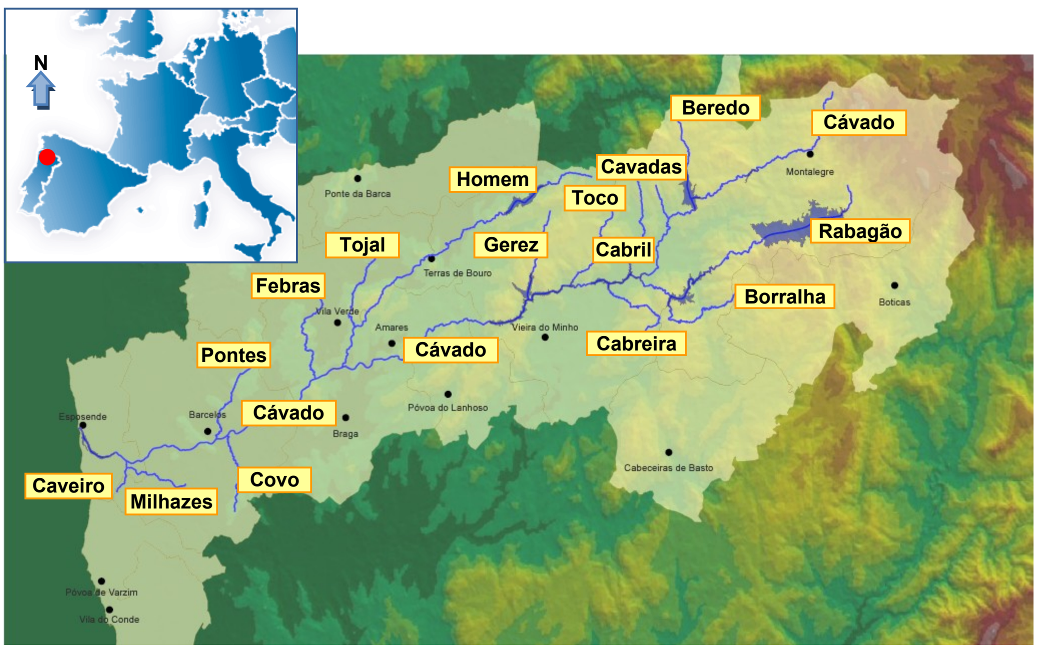


Figure 2. River Cávado catchment.

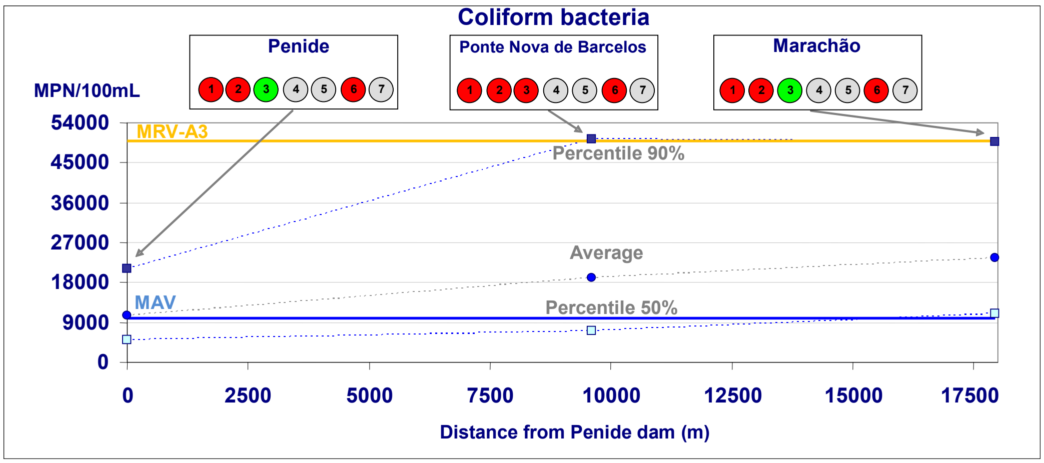
Catchment information system

Geographical information available for the catchment was organized according to the information structure defined by the INSPIRE Directive [12]. The relevant information is readily available via web interfaces, using an application developed for that specific purpose.

Meteorological, hydrometric and water quality data are also available on the catchment information system. This database contains historical records of parameters registered at monitoring stations. These data are the basis for water quality diagnostics assessment, and to the definition of modelling scenarios to predict the water quality dynamics.

A web application to access monitoring data was developed. The service provided by this application includes the following functionalities: graphical selection of the monitoring station from the map or from a list of available monitoring stations; graphic visualization of the data series for the selected parameter at a given station, data presentation in tabular layout and the possibility of exporting to an external file. It also allows the calculation of statistical parameters of the active data series and the automatic generation of a synthetic report about the pair monitoring station/parameter.

Historical data was analysed for all gauge stations. Figure 3 presents an example of that analysis, representing the comparison between statistical measures of coliform bacteria concentration and the standards (maximum allowable values – MAV, and maximum recommended values – MRV) for different water uses at three different stations (Penide, Ponte Nova de Barcelos and Marachão) located along the downstream river Cávado reach.



USES		STANDARD
1	Public supply - Class A1	MRV=50 MPN/100mL
2	Public supply – Class A2	MRV=5000 MPN/100mL
3	Public supply - Class A3	MRV=50000 MPN/100mL
4	Aquatic life - Salmonids	—
5	Aquatic life - Cyprinids	—
6	Bathing water	MRV=500 MPN/100mL MAV=10000 MPN/100mL
7	Irrigation	—

LEGEND
- Percentile 90% less than the standard
- Percentile90% greater than the standard
- Not applicable

Figure 3. Coliform bacteria concentrations at Penide, Ponte Nova de Barcelos and Marachão water quality monitoring stations.

Pollutant sources and raw water sources at risk

Pollutant point sources resulting from domestic and industrial WWTP discharges together with livestock farms discharges were identified as important hazardous events in the catchment (Figure 4). They were located and their potential pollutant loads were estimated. Also two major raw water sources at risk are identified: Areias de Vilar WTP and Ponte do Bico WTP.

River network water quality modelling

A model of the rivers network to simulate river water flows and levels (hydrodynamics) and the transport of substances that are used as water quality indicators is available for this river catchment. River hydrodynamics is simulated based on the one-dimensional mathematical formulations of the equations of mass and momentum conservation for free surface flows. Water quality modelling is based on the one-dimensional mass transport equation.

Sources are considered as point sources using lateral discharges into the main rivers. River water quality parameters are: dissolved oxygen, biochemical oxygen demand and three bacteria indicators (total coliform, faecal coliform and streptococci). First order decay reactions were assumed in modelling microbial and chemical transformation mechanisms. Mechanisms include river water deoxygenation and reaeration and bacteria mortality.

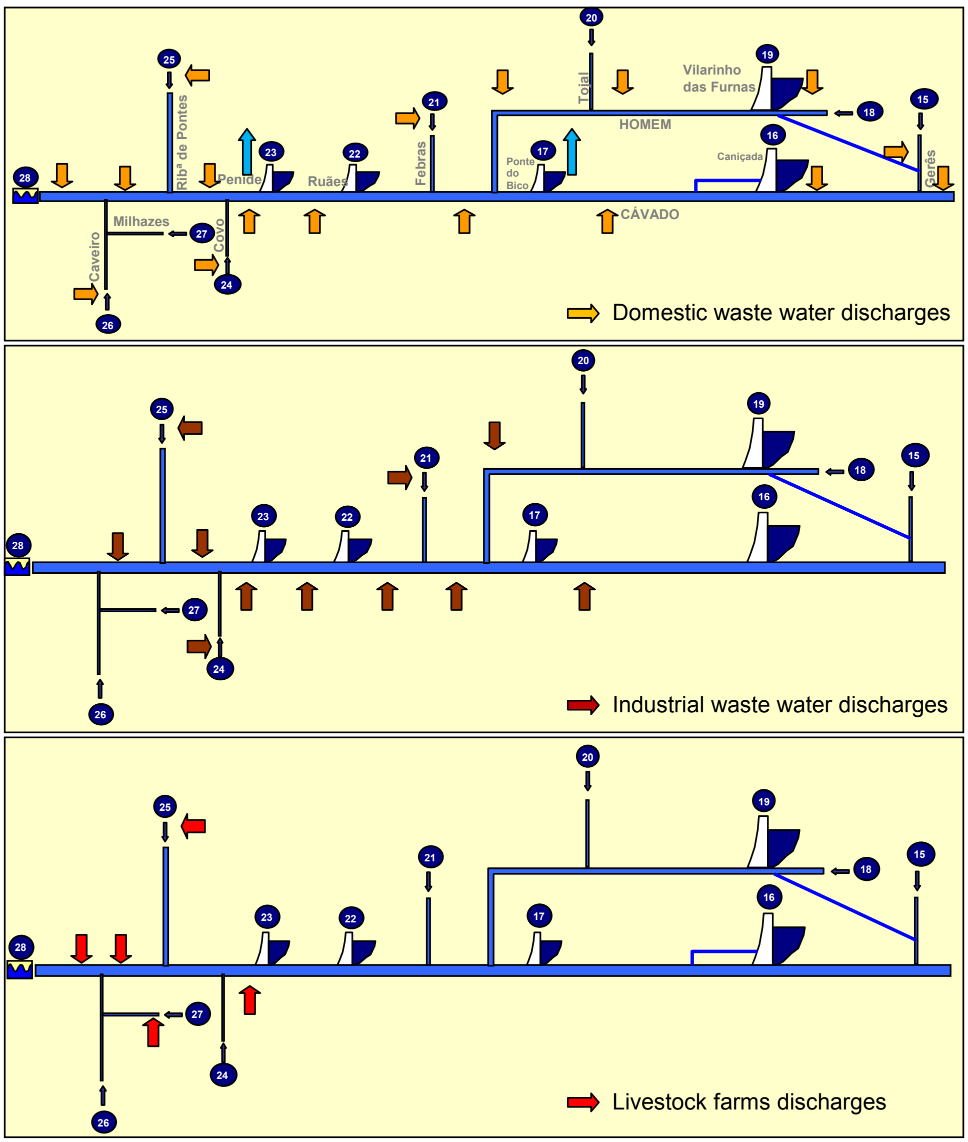


Figure 4. Pollutant point sources at river Cávado catchment.

Results

Figure 5 presents illustrative results obtained with the water quality model for some scenarios that are being worked out in order to support the risk analysis tasks at this phase of the development of the catchment WSP. The impact of the rupture of one of the most important WWTP (Frossos) was simulated and results at two different locations (Areias de Vilar WTP and Barcelos city) for coliform bacteria (CB) concentrations are presented at the upper graph of Figure 5. The lower graph presents the seasonal expected variation in CB concentrations for one of those locations considering constant pollutant average discharges and monthly averages of river discharges.

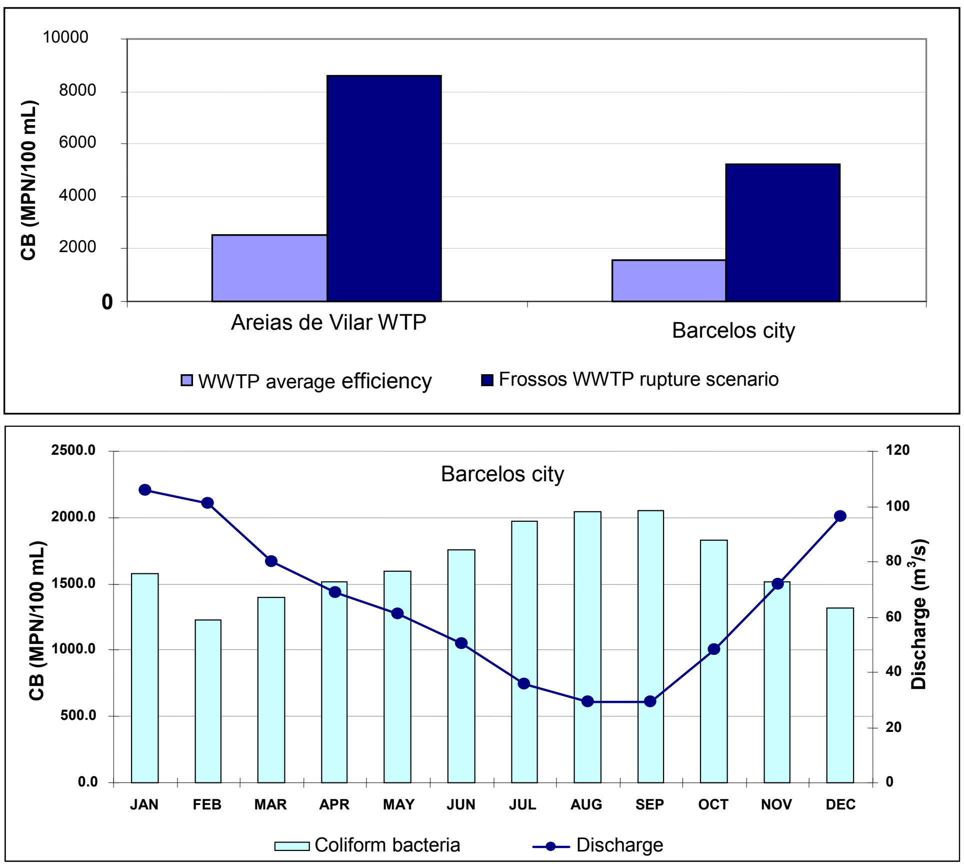


Figure 5. Illustrative results obtained with the water quality model for scenarios that are being worked out in order to support the risk analysis for catchment WSP implementation.

CONCLUSION

Catchment WSP is a new concept for guarantee safe drinking water sources at a basin scale. Currently two major components concerning the implementation of a catchment WSP for river Cávado are implemented: risks assessment, and promoting mitigation measures and verifying their effectiveness. Further steps include implementing of risk based raw water monitoring, and implementation of catchment warning and response procedures. Application of the developed modelling tools demonstrated to be a major component for a sound evaluation of the risks and to prepare adequate response procedures.

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