Water safety plans: methodologies for risk assessment and risk management in drinking-water systems

JOSÉ MANUEL PEREIRA VIEIRA

Department of Civil Engineering, University of Minho, 4704-553, Braga, Portugal
jvieira@civil.uminho.pt

Abstract Providing good and safe drinking-water is world-wide considered to be a fundamental political issue for public health protection, and must be the primary objective of water supply systems. Drinking-water quality control has currently been based on detection of pathogens and toxic concentrations of chemicals by means of monitoring programs and compliance with national or international guidelines and standards, relying mainly on indicator bacteria and chemicals maximum concentration levels. However, this methodology is often slow, complex and costly. Even for sophisticated and well-operated systems these monitoring schemes have proved to be inefficient in preventing waterborne diseases like, for instance, *Giardia* or *Cryptosporidium* outbreaks. From this evidence we can conclude that end-product testing is a reactive rather than preventive way to demonstrate confidence in good and safe drinking-water. This justifies the need for the formulation of a new approach in drinking-water quality control based on understanding of system vulnerability for contamination and on preventive means and actions necessary to guarantee the safety of the water supplied to the consumer. Water safety plan is a concept for risk assessment and risk management throughout the water cycle from the catchments to the point of consumption. This approach includes the identification of the hazards and introduction of control points that serve to minimize these potential hazards, providing for more effective control of drinking-water quality. This paper presents an overview of the first two years experience in developing and implementing a water safety plan in a Portuguese multi-municipal water company. Since key personnel had contributed to the assessment of hazards and evaluation of corrective actions for control points, a greater understanding of water quality control and improvements on technical operation and performance have been registered, demonstrating good value for the methodology.

Key Words drinking-water quality, multiple barriers, risk management, source water protection

INTRODUCTION

Drinking-water quality control is a key issue in public health policies. Special attention and efforts were taken on surveillance and safety of water supply systems after John Snow established, through epidemiological investigations, water as major route of cholera transmission in London (Snow, 1855), Louis Pasteur (1863) discovered the existence of micro-organisms, and Robert Koch (1863) reported the detection methods of micro-organisms in water. In the late 19th century, many countries in Europe and America started with new approaches of drinking-water quality control, especially in high populated urban public systems, relying mainly on disinfection by chlorine for pathogen micro-organisms inactivation.

From 1950 to 1970 the World Health Organization (WHO) published standards for drinking-water quality that served as a scientific basis for monitoring the quality of the water produced and delivered by water suppliers. Later on, other legislative and regulatory approaches were published by the WHO and the European Union (EU): WHO Guidelines for Drinking-water (1st edition, 1984, and 2nd edition, 1993), and EU Directives 80/778/EC, and 98/83/EC (EC, 1998). This legislation was strongly focused on standards for treated drinking-water and on compliance monitoring. Water quality was guaranteed by the so called end-product testing, based on spot sampling of the water produced. With this procedure it was possible to bring the very widespread water-borne diseases under control, especially those of bacterial origin.

Over the years, several shortcomings and limitations of the end-product testing methodology have been identified. Some of them are related to the following aspects:

a) There is a multitude of water-borne pathogens that cannot be detected or they can be detected insecurely with the classical indicators *E. coli* Coliforms and *Enterococci*, particularly viruses and protozoa. There are examples of water-borne disease outbreaks (*e.g.*, Millwaukee - U.S.A., in 1993) that occurred through water supply systems that met the standard for absence of indicator micro-organisms.
b) Often, monitoring results are available out of time of intervention needed to maintain the safety of a supply system. End-product testing only allows checking if the water delivered was good and safe (or unsafe) after distributed and consumed.
c) End-product testing hardly can be considered a sound method for representative water quality *status*. A very small fraction of the total volume of water produced and delivered is subject to microbiological and chemical analysis. Moreover, the monitoring frequency does not guarantee representative results in time and space, as well.

d) End-product testing does not provide safety in itself. Rather is a mean of verification that all the supply system components and installed control measures are working properly.

In recognition of these limitations, primary reliance on end-product testing is presently considered not to be sufficient to provide confidence in good and safe drinking-water, moving towards to process monitoring by introducing a management framework for safe water (Bartram *et al.*, 2001). The 3rd edition of the WHO Guidelines for Drinking-water Quality, (GDWQ) proposes a more effective risk assessment and risk management approach for drinking-water quality control. The GDWQ emphasize the multi-barrier principle, establishing a systematic process for hazards identification and effective management procedures for their control through the application of a preventive Water Safety Plan (WSP) that comprises all steps in water protection, from catchments to the consumer (2001; WHO, 2004).

WATER SAFETY PLANS. A NEW RISK-BASED METHODOLOGY

The methodology proposed in the GDWQ seeks to move away from sole reliance on end-product testing, which will be integrated into a control strategy for consistently ensuring the safety of a drinking-water supply system, applying a comprehensive risk assessment and risk management approach. For most large drinking-water supplies some elements of WSP will often represent routine practice. This may include quality assurance systems (*e.g.*, ISO 9001:2000). Major beneficiaries of this approach will be the small supplies (serving less than 5000 people) where end-product testing is often inadequate. Since a vast majority of the water supplies in Europe are small, monitoring and controlling the water quality of small water supplies is a major issue throughout Europe.

The safety of drinking-water depends on a number of factors, including quality of source water, effectiveness of treatment and integrity of the distribution system. System-tailored hazard identification and risk assessment must be considered as a starting point for system management. A generic flow diagram for risk assessment from catchment to customer is depicted in Fig. 1.

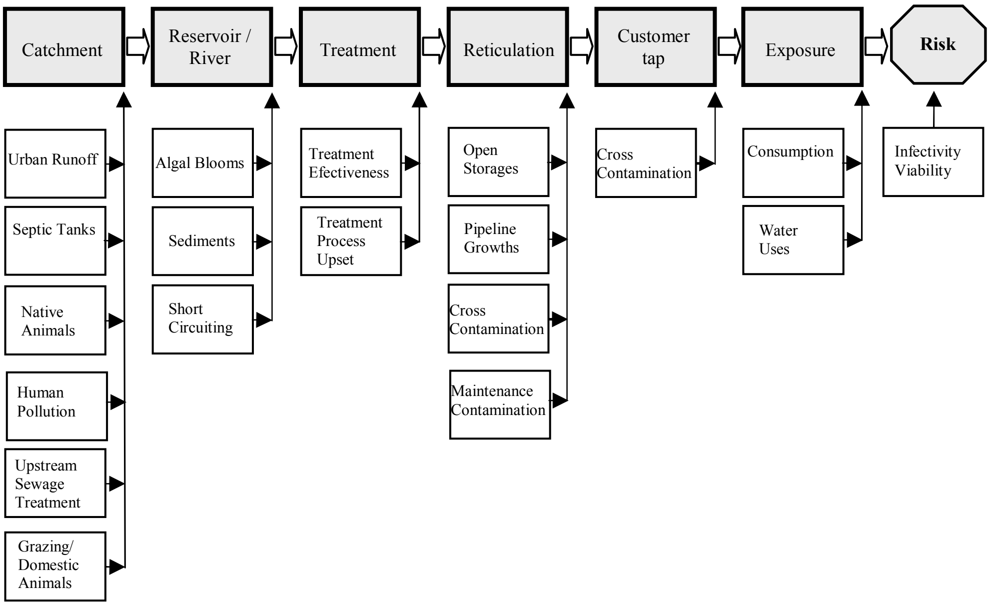

Fig. 1 Generic flow diagram for risk assessment (Adapted from Stevens *et al*., 1995)

The objective of the WSP is to supply water of a quality that will allow health-based targets to be met. The success of the WSP is assessed through drinking-water supply surveillance. The three key components of a WSP are:

a) *system assessment*, which involves assessing the capability of the drinking-water supply chain (from water source to the point of consumption) to deliver water of a quality that meets the identified targets, and assessing design criteria for new systems;

b) identification of control measures in a drinking-water system that will collectively control identified risks and ensure that health-based targets are met. For each control measure identified, an appropriate means of *operational monitoring* should be defined that will ensure that any deviation from required performance is rapidly detected in a timely manner;

c) *management plans* that describe actions to be taken during normal operation or extreme and incident conditions, and that document system assessment (including upgrade and improvement), monitoring, communication plans and supporting programs.

The WSP approach draws on the principles and steps that have been established in Hazard Analysis and Critical Control Point (HACCP) preventive risk management methodology. The application of this approach for drinking-water supplies has been reported in European countries (Germany, France, Switzerland), Australia and New Zealand (Dewettink *et al*., 2001; Nokes & Taylor, 2003). Fig. 2 gives a diagrammatic overview with the key steps for WSP development.

WATER SAFETY PLAN (WSP)

Preliminary steps

1 Assemble the team to prepare the WSP
2 Document and describe the system
3 Construct and validate system flow diagram

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System assessment

4. Identify and prioritize hazards
5. Characterize risks
6. Identify control measures

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Operational monitoring

7. Establish operational and critical limits
8. Establish monitoring procedures
9. Establish corrective actions

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Management plans

10. Establish management procedures for normal operational conditions
11. Establish management procedures for exceptional conditions
12. Establish documentation and communication procedures

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Validation and verification

13. Water quality assessment, installations, and processes

Fig. 2 Overview of the key steps in the development of water safety plans

ÁGUAS DO CÁVADO SUPPLY SYSTEM. A CASE STUDY

This work outlines the way in which Águas do Cávado S.A. has developed and implemented a WSP in the multi-municipal water supply system for the Metropolitan Area of Oporto – Portugal. It summarises the first two years experience in applying risk assessment using the WSP approach. Águas do Cávado S.A. began preparing the WSP in 2003 with external consultancy by the University of Minho, being a pioneer experience on applying the methodology in Portugal. By June 2004 the plan was established; the preliminary results will be available in 2005.

The Water Supply System

The multi-municipal water supply system produces 230,000 m^3/day from the river Cávado and delivers to 600,000 inhabitants. After treated in Areias de Vilar Water Treatment Plant, drinking water is supplied to eight northern Portuguese towns (Barcelos, Esposende, Maia, Póvoa de Varzim, Santo Tirso, Trofa, Vila do Conde e Vila Nova de Famalicão) who own and operate the reticulation systems (Fig. 3).

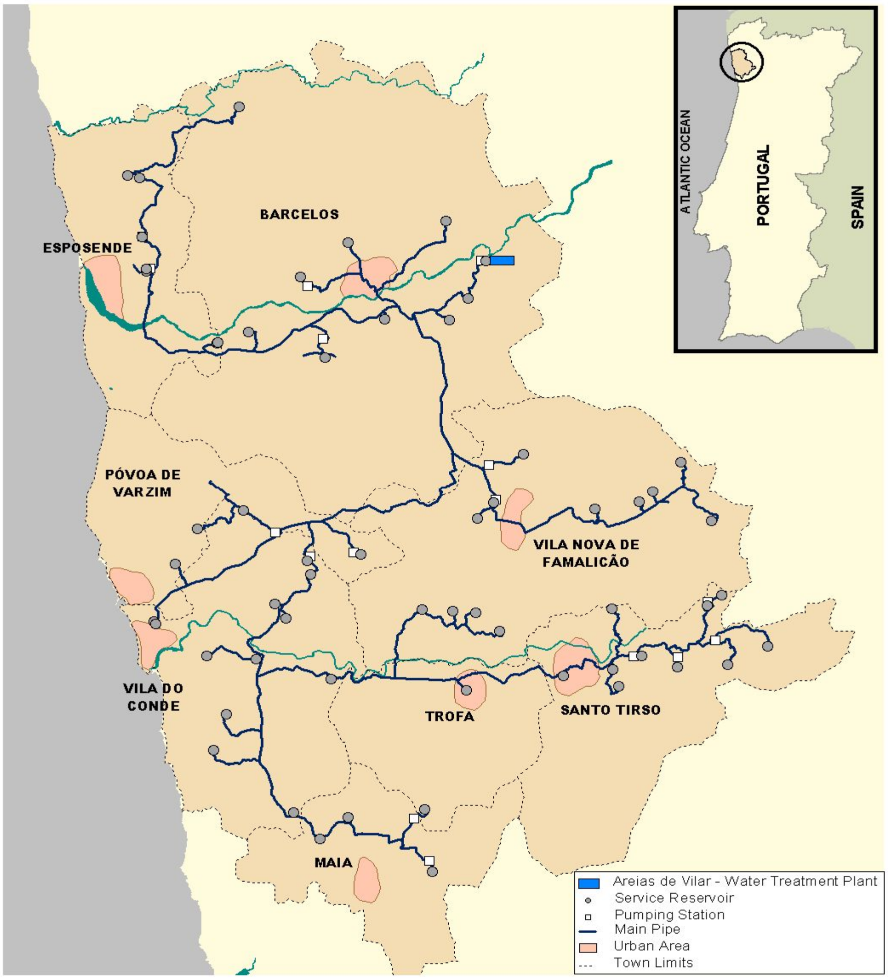

Fig. 3 Survey of the multi-municipal metropolitan area of Oporto water supply system

The infra-structural system constitutes a multiple barrier for water quality protection. Abstracted surface water is stored in a raw water reservoir with a 24 h detention time. The treatment chain comprises pre-ozonation, remineralisation, rapid mixing, flocculation, sedimentation, rapid sand filtration, chlorination, and pH correction. The water is distributed to 56 service reservoirs through a global extension of 237 km cast iron pipes of 1400 and 200 mm diameter. The hydraulic circuit includes 15 pumping stations, valves, and other complementary appurtenances.

Water Safety Plan development and implementation

The methodology adopted in developing and implementing the WSP was structured in three parts: Part I – Fundamentals, corresponding to the development phase, in which the basic aspects needed for risk assessment and risk management are described; Part II – Operational Aspects, where, for each element of the water supply step (source, treatment, and distribution), a synthesis of risk management, control measures and corrective actions in critical control points are established; and Part III – WSP Practical Application, where the *modus faciendi* for operational monitoring and reporting is stated.

Part I – Fundamentals

The risk assessment and risk management, from catchment to the customer, constitute the key issues for the whole process. This was made identifying risks and assessing their significance, and stating systematic management of the control measures and corrective actions needed for their control. Three working phases were defined: preliminary tasks (technical inventory of the system); hazards identification and risk assessment; and performance reporting. For each of the working phases, auxiliary forms were designed in order to help organising the information to be included, as depicted in Fig. 4.

The information given by the water supply flow diagram (Fig. 5) and the deep knowledge of the system performance are the basic conditions for hazards identification and risk assessment. Occurrences of biological, physical and chemical hazards linked with the different steps of the system were investigated. In each of them, questions like "what is happening here?" and "what can run wrongly here?" were asked.

For each hazard identified, a risk prioritization was then established by means of a calculated risk factor, which was obtained multiplying the likelihood of its occurrence (ranging from unlikely to almost certain) by the severity of the consequences (ranging from insignificant to catastrophic). Further details of this methodology can be obtained in (Vieira, 2004). A typical HACCP decision tree was applied to determine the points where it is absolutely necessary to prevent, eliminate or reduce hazards for acceptable limits, establishing critical control points (CCP). Identification of CCPs was finally set up when and where it was considered that a process must be controlled to reduce the hazard to an acceptable level.

Working phase	Auxiliary Form	Contents
Preliminary Tasks	**Auxiliary Form 1** – Water company general organization.	**Flowchart with a summary description of the hierarchical structure and functioning. Includes a brief description of manager tasks and responsibilities for each functional area.**
	Auxiliary Form 2 – **Overview of the water supply system.**	**List and brief description of the main water supply system steps.**
	Auxiliary Form 3 – **Team constitution for WSP development.**	**Identification of the WSP team: contacts, functions and responsibilities.**
	Auxiliary Form 4 – **Flux diagram construction and validation.**	**Construction and validation of the flux diagram from catchment to service reservoirs.**
Hazards Identification and Risk Assessment	Auxiliary Form 5 – **Hazards identification and critical control points (CCP) definition.**	**Assessment of hazards that can occur in the water supply system. Establishment of CCP.**
	Auxiliary Form 6 – **Critical limits (CL) definition and monitoring procedures.**	**Definition of CL. Establishing of monitoring procedures to confirm if CLs are respected.**
	Auxiliary Form 7 – **Corrective actions establishing.**	Hazards removal or reduction. For each CCP corrective actions and related procedures have been defined.
	Auxiliary Form 8 – **Definition of instructions for CCP control.**	Working instructions for CCP control. Upgrade existing or establish new instructions.
Performance Reporting	Auxiliary Form 9 – **WSP compliance.**	Instructions for the daily functioning of the WSP (instructions for maintenance and control of CCP). Reports on daily activities and data collected.
	Auxiliary Form 10 – WSP validation and verification.	Assessment of WSP in an annual basis. Analysis of external and internal factors and their influence on system performance.

Fig. 4 Procedure synthesis for WSP development in Águas do Cávado S.A.

After CCPs identification, critical limits (CL) are established based on scientific or operational information. In this case, CLs have been set according to Águas do Cávado internal standards, operating procedures, and performance targets of the Quality Management System. Some of the CLs were taken on the safety side of legal standards parameters, in order to guarantee the overall water quality of the system.

The compliance of CLs is verified through a wide range of parameters that are monitored with on-line sensors and on-site determinations. A sampling and laboratory analysis program at different points of the system has also been included. It is expected that the control measures and monitoring activities are effective enough to smoothly control the routine functioning of the system. However, if and when a CL violation is detected, corrective actions must be considered.

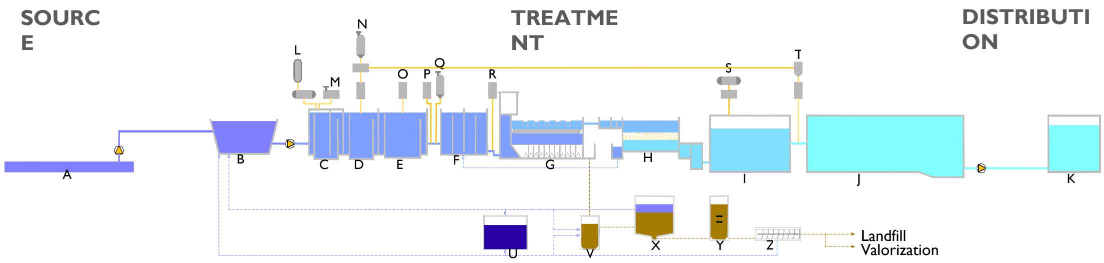

Fig. 5 Flow diagram of the water supply system

Performance reporting has been established by setting instructions for the daily functioning of the WSP (instructions for maintenance and control of CCP) as well as for the assessment of WSP in an annual basis. Analysis of external and internal factors and their influence on system performance, with special focus on communication, were also included.

The multiple barrier concept was applied in structuring a procedure for hazard identification and for establishing control measures, CCPs, LCs and corrective actions, as presented in Fig. 6.

In the development of the WSP there were 23 CCPs identified but it is realized that many of the controls initially identified as CCP will not be further considered if the risks are adequately managed with “good management practices” or if effective subsequent control exists. This will be an obligatory point of revision after one year of WSP implementation.

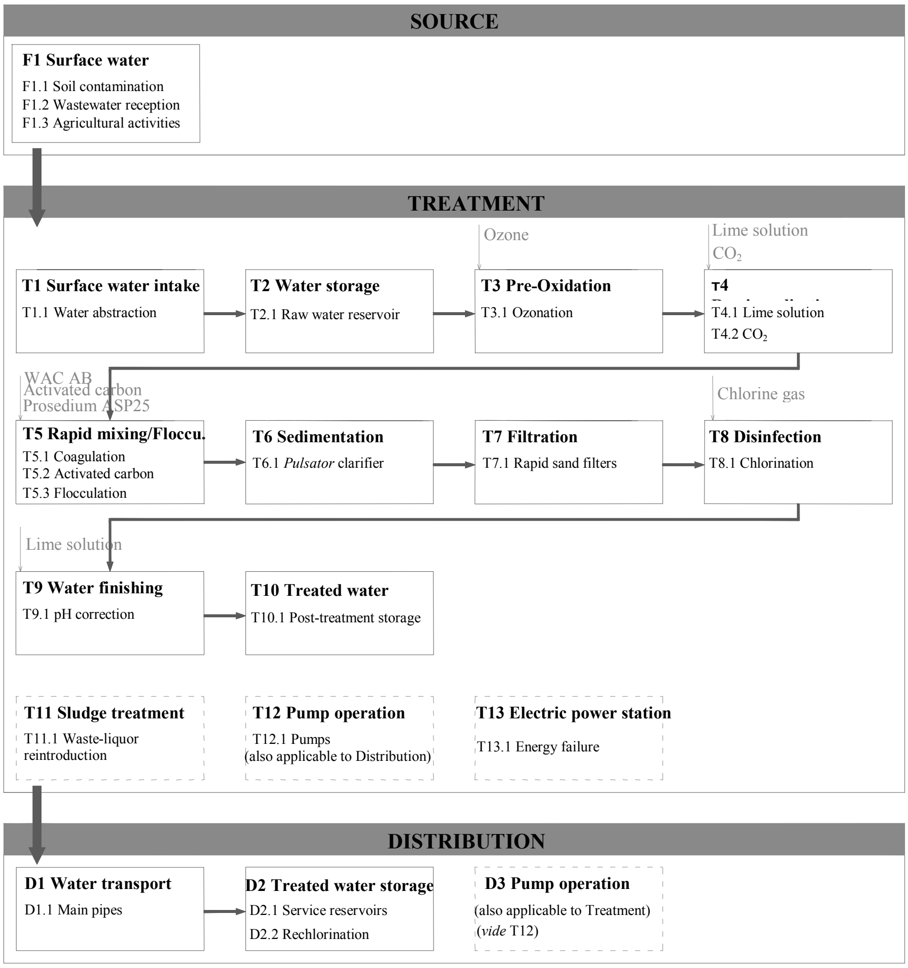

Fig. 6 Water supply elements for WSP development

Operational Aspects

For each of the CCPs identified, a synthesis of risk management, control measures and corrective actions was established. An example of the designed operational tables is given in Fig. 7, where the case of rapid sand filtration is considered. It shows an easy way to understand the major facts associated to this CCP: particles and organic matter passing through the porous filter media are considered physical and biological hazards; control measures are implemented in order to guarantee the quality of filtered water; corrective actions consist of operational adjustments in previous treatment steps or higher dosing of chlorine at the disinfection step.

Event T7.1.1 Filter bed supernatant water out of control					
CCP 14	**Hazard:** physical and microbiological **Level of risk:** high				
HAZARD *T7.1.1.1* Organic matter and turbidity not removed					
Control measures					
Develop a filter maintenance plan. Adjust the number of filters according to the flow rate to treat. Control backwash water recirculation. Establish an equipment calibration procedure.					
Operational monitoring					
What?	**CL**	**Unity**	**When?**	**Who?**	**Corrective actions**
Turbidity of treated water	> 0.7	NTU	On-line	DOP	Adjust previous steps in order to optimise filtration efficiency. Higher disinfectant dosing
Colour	> 20	mg/L Pt-Co	Weekly	SLB	
Clogging optimal point	> 2500	mm	Whenever a criterium is reached	DOP	
Fitration time	> 80	hour			
Residual Aluminium	> 0.2	mg/L Al	Daily	SLB	
Amonia-N	> 0.6	mg/L NH_4			
Cryptosporidium	> 0	n.º/100 mL	Weekly	SLB	
Giardia	> 0	n.º/100 mL			

Fig. 7 Management of CCPs. Example for rapid sand filtration

WSP Practical Application

After one year of WSP practical application, a series of monthly reports are already available. From them it is possible to have the first understandings of capabilities, vulnerabilities and difficulties for an efficient system management. In Fig. 8 the example of turbidity removal efficiency in the system (July 2004) is presented.

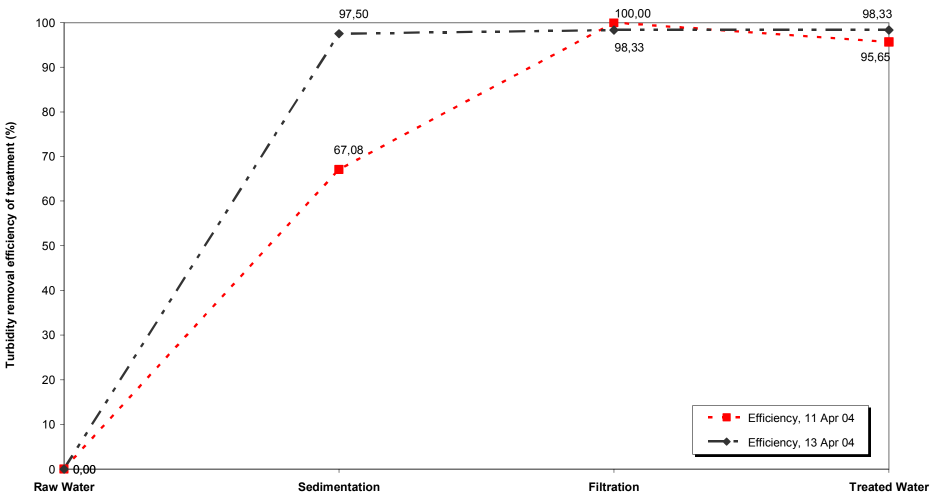

Fig. 8 Turbidity removal efficiency through the water supply system

CONCLUSIONS

WSP is a process control oriented management system that can help water suppliers to produce and deliver good and safe drinking-water, contributing in this way to improve public health protection.

Development and implementation of a WSP in Águas do Cávado S.A. have also demonstrated that water suppliers can successfully adopt methodologies for risk assessment and risk management in drinking-water systems. This water company has already quality management systems according to ISO standards (for water quality monitoring, and for preventive maintenance of the water system). The systematic operational controls introduced by the WSP have allowed better understandings of negative and positive performances, which appear to be very interesting for internal inspections and maintenance services.

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