WATER RESCUE

Water resources efficiency and conservative use in drinking water supply systems

Interreg
Greece-Bulgaria
WATER RESCUE
European Regional Development Fund

EUROPEAN UNION

WP	**4 Common Methodologies and Tools**
Deliverable *Tool*	**4.3.3 Water Quality joint methodology report** *Joint Deliverable*
Sub-Deliverables integrated	**D.4.4.3**
Project Beneficiary No	**PB3**
Beneficiary Institution	**University of Thessaly-Special Account Funds for Research-Department of Civil Engineering**

The Project is co-funded by the European Regional Development Fund (ERDF) and by national funds of the countries participating in the Cooperation Programme Interreg V-A "Greece-Bulgaria 2014-2020".

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Chapter 1. Introduction: The WATER RESCUE project in brief

1.1 The Project in brief

WATER RESCUE project's concept is based on the common cross-border (CB) water management problems in the two international river basin districts (RBDs) shared between Greece & Bulgaria (Struma-Strymonas; Maritsa-Evros). The common CB problems include water resources quality & quantity being at risk due to natural and human activities and climate change conditions. The consequence is that water bodies fail to meet the good ecological status (GES) (recorded in the river basin management plans-RBMP). In particular, drinking water faces significant risks due to the deteriorated water resources quality while at the same time significant water volume is lost in the water distribution networks (WDNs). The project aims at the sustainable and efficient management of drinking water supply by increasing drinking water use efficiency in WDNs and improving water quality in the whole water supply cycle (from the source and back to the environment). Good Ecological Status can be achieved by improving water quality and reducing water abstraction and can be maintained by taking climate change adaptation measures. The project focuses in drinking water supply management suffering from high Non-Revenue Water (NRW) levels and deteriorated water quality jeopardizing the drinking water consumers' safety and health and their quality of life. Urban water volumes end up to the sewerage networks while wastewater treatment plants are a pressure to water resources quality. Surface water bodies are both used for drinking water abstraction and are the final recipient of treated effluents. Thus, their ecological status is affected by both water quantities abstracted and water quality in the whole water supply cycle (from the resource to the water supply and the wastewater treatment plant and back to the environment).

1.2 Theme of the Project

WATER RESCUE project is expected to achieve Non-Revenue Water/water losses reduction by upgrading and adapting already developed methodologies, technologies and tools including Water Balance assessment and Performance Indicators, hydraulic simulation models, decision support systems and GIS tools. Additionally, WATER RESCUE is expected to achieve water quality improvement across the entire water supply chain (from the water intake point and the raw water treatment plant, back to the environment after the waste water treatment plant) through constant monitoring of water quality parameters in real time, water quality simulation models (including water age) and automatic chlorination systems on line and in line. Climate change impacts will be assessed to finally propose and adopt measures for climate change adaptation. WATER RESCUE has a clear innovative character since the methodologies and tools are integrated and do not tackle individual problems. It is the first time that integrated methodologies will be adapted to include the entire drinking water supply cycle. These methodologies/tools will serve as Early - Warning Systems both for water quantity and quality. WATER RESCUE results will improve drinking water management. At the same time as drinking water is involved, the consumers' safety and health are safeguarded and their quality of life is improved. Non-Revenue Water reduction will increase water resources efficiency, since less water will be abstracted from surface and groundwater bodies and reduce energy consumption as water and energy are interconnected in water supply systems (water-energy nexus). Drinking water quality will be improved through real time monitoring of water quality parameters across the entire water supply chain, from the water intake points, to the water treatment plant and the water distribution network, back to the environment through the wastewater treatment plant. Thus, drinking water quality will be safeguarded from its source up to the consumer's tap. As wastewater effluents return to water resources, their quality monitoring prevents water resources degradation due to this pressure. Water and energy resources efficiency will be promoted and the ability of the cross-border area to adapt to climate change conditions will be improved as all possible natural and man-made pressures will be evaluated, including climate change conditions. Water saving will be accomplished through water losses reduction and increase of the environmental awareness of the public. The quality of life is expected to be upgraded with special emphasis to the protection of the natural environment. Joint policy recommendation guidelines and papers will be developed. Good governance, transparency and participation of all stakeholders in the design, implementation and monitoring of these policies is expected. Know-how and technology transfer will take place not only among the beneficiaries but also in the stakeholders' network that will be developed.

1.3 Project Objectives

The project's main objective is the sustainable cross –border drinking water supply management aiming at water resources efficiency and conservative use through:

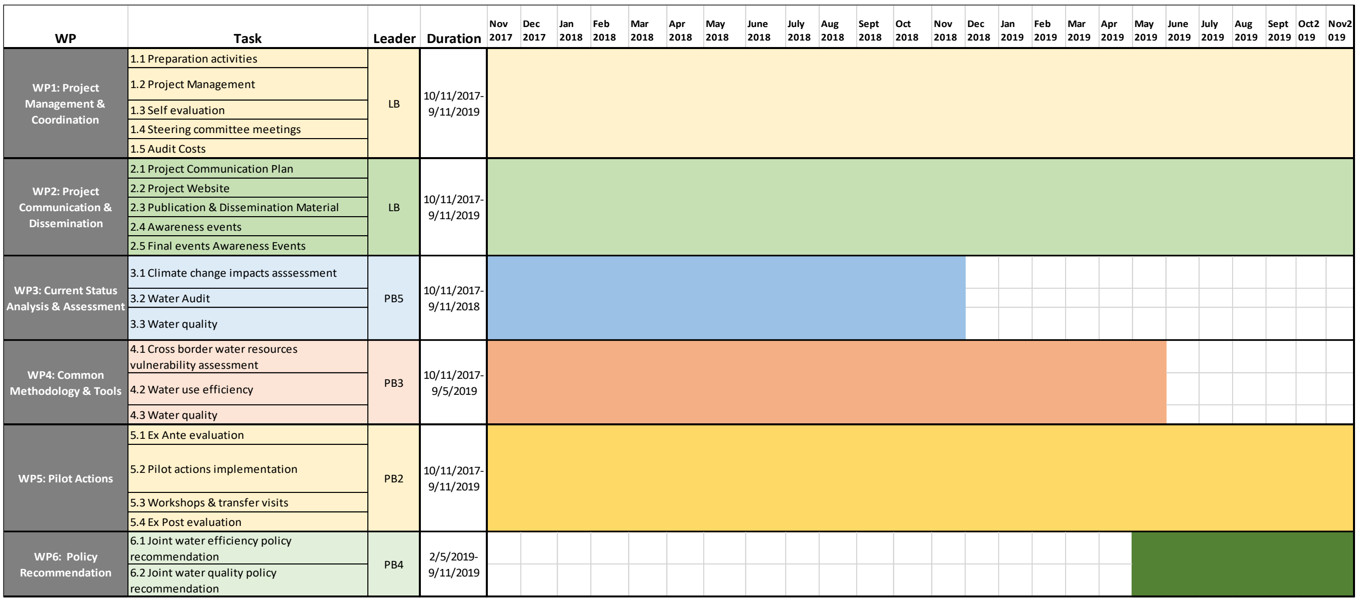
1. Adaptation of a joint methodological framework for water resources management (qualitatively and quantitatively) in relation to the climate change and the natural and human activities and reduction of the water resources vulnerability;

2. Increase water use efficiency through the reduction of Non-Revenue Water and water losses in the water supply networks by implementing measures tackling NRW causes;

3. Improve water quality and safety in the whole drinking water supply cycle, from the water resources to the water distribution network and back to the environment through the continuous monitoring of water quality parameters in real time and the in-line disinfection to reduce the risk of low chlorine residuals and excessive concentrations of THMs (toxic substances causing cancer);

4. Increase innovative technologies use through the integrated management of water resources including GIS-based applications; hydraulic simulation models & decision support systems;

5. Development of "green behavior", increase water saving & reduce water consumption through public awareness campaigns.



WP	Task	Leader	Duration	Nov 2017	Dec 2017	Jan 2018	Feb 2018	Mar 2018	Apr 2018	May 2018	June 2018	July 2018	Aug 2018	Sept 2018	Oct 2018	Nov 2018	Dec 2018	Jan 2019	Feb 2019	Mar 2019	Apr 2019	May 2019	June 2019	July 2019	Aug 2019	Sept 2019	Oct2019	Nov2019
WP1: Project Management & Coordination	1.1 Preparation activities	LB	10/11/2017-9/11/2019	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	1.2 Project Management			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	1.3 Self evaluation			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	1.4 Steering committee meetings			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	1.5 Audit Costs			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
WP2: Project Communication & Dissemination	2.1 Project Communication Plan	LB	10/11/2017-9/11/2019	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	2.2 Project Website			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	2.3 Publication & Dissemination Material			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	2.4 Awareness events			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	2.5 Final events Awareness Events			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
WP3: Current Status Analysis & Assessment	3.1 Climate change impacts asssessment	PB5	10/11/2017-9/11/2018	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨												
	3.2 Water Audit			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨												
	3.3 Water quality			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨												
WP4: Common Methodology & Tools	4.1 Cross border water resources vulnerability assessment	PB3	10/11/2017-9/5/2019	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						
	4.2 Water use efficiency			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						
	4.3 Water quality			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						
WP5: Pilot Actions	5.1 Ex Ante evaluation	PB2	10/11/2017-9/11/2019	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	5.2 Pilot actions implementation			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	5.3 Workshops & transfer visits			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	5.4 Ex Post evaluation			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
WP6: Policy Recommendation	6.1 Joint water efficiency policy recommendation	PB4	2/5/2019-9/11/2019																			▨	▨	▨	▨	▨	▨	▨
	6.2 Joint water quality policy recommendation																					▨	▨	▨	▨	▨	▨	▨

Figure 1. WATER RESCUE timetable

1.4 The Project structure and timetable

The project consists of six work packages:

- WP1: Project Management and Coordination (duration: 24 months)
- WP2: Project Communication and Dissemination (duration: 24 months)
- WP3: Current Status Analysis & Assessment (duration: 12 months)
- WP4: Common Methodology and Tools (duration: 18 months)
- WP5: Pilot Actions (duration: 24 months)
- WP6: Policy Recommendation (duration: 6 months)

The total project duration is 24 months, from 10/11/2017 to 9/11/2019 (Figure 1).

1.5 Project Beneficiaries

Lead Beneficiary is the Municipal Water Supply and Sewerage Company of Komotini (Greece); Beneficiary 2 is the Municipal Water Supply and Sewerage Company of Thermi (Greece); Beneficiary 3 is the University of Thessaly-Special Account Funds for Research-Department of Civil Engineering (Greece); Beneficiary 4 is the Municipality of Kardzhali (Bulgaria); Beneficiary 5 is the Municipality of Gotse Delchev (Bulgaria); and Beneficiary 6 is the Municipal Water Supply and Sewerage Company of Thermaikos (Greece).

Table 1. WATER RESCUE beneficiaries

PB #	PP name	City	Country
PB1	Municipal Water Supply and Sewerage Company of Komotini	Komotini	Greece
PB2	Municipal Water Supply and Sewerage Company of Thermi	Thermi	Greece
PB3	University of Thessaly-Special Account Funds for Research-Department of Civil Engineering	Volos	Greece
PB4	Municipality of Kardzhali	Karddzhali	Bulgaria
PB5	Municipality of Gotse Delchev	Gotse Delchev	Bulgaria
PB6	Municipal Water Supply and Sewerage Company of Thermaikos	Neoi Epivates	Greece

1.4 The present deliverable

1.4.1 The subject of the present deliverable

The present deliverable refers to WP4.3. This deliverable presents a joint methodology on water quality assurance in water intake points (water resources), water distribution system and the wastewater treatment plant (inflow/outflow) serving as an early-warning system (EWS) based on the water quality monitoring and water quality simulation. Water age is part of the methodology as an important factor influencing water quality in water distribution networks.

Chapter 2. Water Resources Quality

2.1 Introduction

Water quality is one of the major concerns nowadays. Water quality degradation has major impacts on all aspects: human, environmental and economic ones. Serious human health problems are associated with the discharge of pathogens in drinking water sources, the eutrophication of lakes, rivers and reservoirs and the discharges of pollutants into water resources. Water resources exploitation is another factor affecting water resources quality.

Water quality refers to the chemical, physical, biological, and radiological characteristics of water. Contaminants that may exist in untreated water include microorganisms such as viruses, protozoa and bacteria; inorganic contaminants such as salts and metals; organic chemical contaminants from industrial processes and petroleum use; pesticides and herbicides; and radioactive contaminants. Water quality depends on the local geology and ecosystem, as well as human uses such as sewage dispersion, industrial pollution, use of water bodies as a heat sink, and overuse.

The term "water quality" describes the physical, chemical, biological and aesthetic properties of water which determine its suitability for different uses, while protecting the health and viability of aquatic ecosystems. Many of these properties are determined or influenced by elements that either solubilize or are suspended in water. "Water quality standards" include numerical parameters that are internationally defined (laws or decrees) to control water quality and further manage it.

The quality of surface and groundwater is affected by several factors. Water moving on the surface or underground can undergo physical or chemical changes, which can be caused by natural factors or human activities. The presence of contaminants adversely affects the quality of water and therefore its end use. Consequently, pollutants are undesirable substances that are either not a component of water or a component contained in abnormally high concentrations.

2.2 Contaminants in water and their effects

Pollutants are generally divided into 4 categories: sediments and natural organic materials, nutrients, bacteria and toxic substances, and can affect water as point sources or diffuse pollution. Point sources interact with water at discrete points, such as when water is drained from a pipe, trench, tunnel, or animal breeding point. Pollution from point sources can be controlled to some extent by appropriate treatment before or just at the point of pollution. Diffuse pollution sources affect water from wider areas, so they cannot be easily identified or controlled. Non-point sources are the atmosphere, rural areas, golf courses, settlements, roads, car parks and groundwater streams that run along long journeys.

Sediments and natural organic materials

The sediments come from soils, rocks or organic matter that have been transported or transported through water or air. Natural organic materials include plant and animal or animal waste. Also, sediments are created by corrosion phenomena on the surface of the earth or on river banks. Corrosion is a natural phenomenon, while human activities such as agriculture, timber, road construction increase the rate of sediment migration into water currents.

Sediment accumulated in rivers can affect vessel movement and also increase the likelihood of flooding because they reduce the capacity of the reservoir. In addition, suspended solids adversely affect the purity and quality of water, while detailed sediments can significantly affect aquatic ecosystems, e.g. when gathered in the gills or fish eggs.

Nutrients

Nutrients are the organic or inorganic elements necessary for the sustainable development of life, e.g. carbon, nitrogen, phosphorus and potassium. Nutrients are pumped into the water through the atmosphere, agricultural processes, golf courses, wastewater treatment plants and factories.

However, excess nutrients in water lead to a disproportionate presence of vegetation. The decomposition of this vegetation removes the oxygen contained in the water, causing the death of fish and other life forms. It is reported that high levels of nitrate or ammonia affect the quality of drinking water.

Bacteria

Certain disease-causing bacteria can be transported to surface or underground water from sewage, hazardous tank leakage, or from wastewater from animal breeding sites. Some other species of bacteria are a threat to humans such as coliforms.

Toxic substances

When toxic substances such as solvents, microbicides and certain minerals are found in high water content they can cause diseases, genetic abnormalities or even the death of certain organisms. Toxic chemicals end up in water by direct disposal from industries or by inappropriate disposal of industrial, mining, agricultural and municipal waste. Pollutants in most cases come from cleaning solvents, acids and alkalis.

Even when certain chemicals occur at extremely low concentrations, they are likely to be classified as hazardous to human health as well as to aquatic ecosystems. Toxic substances can also affect the growth, metabolism, reproduction and behavior of organisms (Vandas et al., 2002).

Pollutants effects

The effects of pollutants on water depend on water characteristics as well as on the content and characteristics of each pollutant. In any case, water can be characterized on the basis of its physical, chemical and biological characteristics, which essentially determine its ability to absorb or assimilate certain pollutants without destroying them. For example, larger rivers are absorbing larger amounts of pollutants than small rivers.

Water quality can be affected by various human activities, which increase concentrations in solubilized or suspended pollutants, alter the acidity of the final acceptable water and / or increase the water temperature.

The extent to which human activities change the water quality of a river can be determined by sampling and comparing water and flora and fauna chemistry in the studied area with a reference area where human activities are not taking place.

The amount of pollutants entering the water is determined by various factors such as the various land management practices, the characteristics of the catchment area, the chemical properties of the pollutant and the amounts of pollutants released into the environment.

The presence of pollutants is a more common phenomenon in water courses and small-scale aquifers of unlimited extent. The limited extent aquifers are generally at a greater depth and below the surface of the earth and are protected by layers of relatively impermeable materials which can prevent the movement of the contaminated water.

Groundwater pollution is very difficult to tackle as a result of the slow pace of water movement. For example, some germicides can cause harmful effects on humans, animals and plants if they are exposed to very high levels for long periods of time. Depending on the concentration of pollutants, diseases such as cancer and dysfunction of the nervous system can be caused (Vandas et al., 2002).

2.3 Water Standards

In the international literature, several criteria and guidelines for water quality control are met. For example, some guidelines set maximum values of data concentrations to suit different uses, while other directives are intended to determine the optimal concentration of an element, taking into account some safety factors.

The most commonly used standards for assessing water quality are related to ensuring the quality of drinking water and the health of ecosystems. These standards are determined on the basis of the permitted marginal quantities of various constituents contained in water and laid down by regulatory provisions aimed at protecting human health.

Standards for water quality assurance are usually more stringent than other standards and include parameters that do not fit into specific constraints in other cases. These standards are becoming more stringent as there is better know-how and use of new sophisticated techniques used to determine the concentrations of various elements as well as the effect of these elements on human health.

The ideal method of setting standards includes the following stages:

- scientifically identifying human health risks or benefits;
- quantifying cost estimates to achieve water quality objectives;
- regulatory / policy decisions defining the benefits and before setting standards.

Water quality standards have been set with the aim of making water safe for use in various applications. In the US, the US Environmental Protection Agency (EPA) has adopted guidelines and standards for water quality control on the basis of the following parameters:

Appropriate uses of water, i.e. desirable uses for the water quality in question.

Numerical and practical criteria for proper use. The numerical criteria refer to the minimum physical, chemical and biological parameters required for water to be used appropriately, and the practical criteria refer to conditions and targets to be met to suitably use water.

Legislation and cost

Parameters measured in each case are determined by the legislation of each country on issues such as the chemical composition of drinking water, the disposal of waste, etc. If a substance is considered dangerous under the legislation, it should be traced and recorded. However, hazardous substances contained in water can be determined with precision and low cost by laboratory analytical methods. Sensors are only placed in cases where recording at the point of delivery or outside is required.

In addition, legislation requires the continuous listing of hazardous ingredients only if pragmatic techniques are applied. Although a very large number of chemicals and other ingredients are considered as hazardous by legislation, there are no techniques for measuring or using sensors available to determine these components.

2.4 Water sampling

Water quality characteristics are usually classified into the following three main categories: physical, chemical (organic and inorganic) or organic.

However, proper sampling and use of analytical techniques contribute substantially to the effective determination of water quality. Sampling surveys aim at collecting:

- information on the characteristics of potential and existing water sources
- functional data for the general image in the sampling area
- data used to document the performance of a processing method
- data used for the implementation of new proposed methods
- data that are required to comply with quality standards.

Sampling techniques should ensure that the samples collected are representative, reproducible and useful, as the data resulting from their analysis is used as a basis for the application of appropriate water treatment methods. Before performing a sampling survey, it is necessary to develop a sampling protocol in direct relation to the corresponding quality assurance plan, which includes various parameters for the sampling method.

2.5 Water analyses

The complexity of water quality as a subject is reflected in the many types of measurements of water quality indicators. The most accurate measurements of water quality are made on-site, because water exists in equilibrium with its surroundings. Measurements commonly made on-site and in direct contact with the water source in question include temperature, pH, dissolved oxygen, conductivity, oxygen reduction potential (ORP), turbidity, and Secchi disk depth.

More complex measurements are often made in a laboratory requiring a water sample to be collected, preserved, transported, and analyzed at another location.

Atomic fluorescence spectroscopy is used to measure mercury and other heavy metals. Making these complex measurements can be expensive. Because direct measurements of water quality can be expensive, ongoing monitoring programs are typically conducted by government agencies. However, there are local volunteer programs and resources available for some general assessment. Tools available to the general public include on-site test kits, commonly used for home fish tanks, and biological assessment procedures.

Frequent, predetermined and repetitive sampling frequencies are required for water quality recordings. However, the methodologies used should not be costly and time-consuming (Collin and Quevauviller, 1997).

Sample analysis involves the use of one or more analytical methods to determine the concentration of the data requested.

Instrumental methods of analysis

Sample analysis should take place in the shortest time after sampling so as not to affect their chemical nature. The methods set forth below are suitable for in situ analysis using suitable devices and chemical reagents.

Titration methods

Titration is based on the use of a volumetric pipette containing a standard solution added to the sample to the end point. The endpoint is determined by the color change of the sample or detected by other devices such as e.g. the pH meter.

Photometric methods

Photometers or spectrophotometers are among the most accurate instruments to measure the color of a sample. In field trials, simple filter photometers have been replaced by monochromator spectrophotometers.

Colorimetric methods

The results obtained from colorimetric tests are not as accurate as those obtained from photometric or spectrophotometric assays. Colorimetric methods are popular because of their simple application and low cost. However, this method should not be used individually in cases where very good accuracy is required.

In colorimetric methods, the color produced in the solution is proportional to the concentration of the measured element. This concentration is determined by comparison with standard solutions.

Other instrumental methods of analysis used in the laboratory

Common water analysis methods usually use complex electronic systems that cannot be used in the field, such as:

- Ion chromatography, which is used to measure ions found in traces in water, vapors or concentrates;
- Atomic absorption spectrometry, plasma emission spectrometry, X-ray fluorescence spectrometry and other laboratory techniques, often used to measure trace elements. Some instruments simultaneously provide results for over 40 elements in ppb scale;
- Gas chromatography or gas chromatography / mass chromatography, which quantitatively separate and detect various volatile components (e.g. neutral amines) in concentrates;
- High Pressure Liquid Chromatography, which allows the separation and detection of traces of organic ingredients in antimicrobial applications;
- Total Organic Carbon TOC measurements, which are used to determine the amount of organic ingredients contained in the water following different treatment methods or extractions;
- Nuclear Magnetic Resonance Spectrometry, which is an analytical tool for determining the structure of organic polymers and other organic compounds used for water treatment;
- Infrared Spectroscopy, which allows the qualitative and quantitative determination of organic compounds and the determination of the chemical structure of inorganic compounds.

2.6 Hazard analysis

Risks or various sources of hazard to the local environment must first be identified and assessed. It is necessary to specify the source-pathway-target. For each identified pollutant, the corresponding risk assessment should be made by determining the likelihood that the source of the hazard will reach the target and the severity of the effects caused (Harris and Herbert 1994, DOE 1996, Komnitsas et al., 1998).

The survey of the study area is conducted with the aim of collecting appropriate and reliable data for the assessment of the risk to selected recipients. Therefore, it is necessary to identify the sources of pollution, as well as collect all relevant information on the risk assessment, such as the following (Ferguson et al., 1998):

- Point, extent and type of pollutants;
- Geological and geochemical conditions of the study area and the adjacent area;
- Hydrogeological and hydrological conditions in the wider region;
- Presence and behavior of recipients;
- Ecological and ecotoxicological characteristics of the area.

Geostatistics is used by many researchers to predict pollution in soils and underground waters and to determine the risk of waste disposal (Komnitsas and Modis 2006; 2009, Modis et al., 2008). Risk assessment by comparing experimental results and established standards is not always efficient because the risk cannot be determined if there is no relationship between the source of risk, the transport route and the target. Based on this approach, the study of transport and the degree of pollutants is related to the description of the various transport routes through which a recipient is exposed to risk. The transport routes include soil, surface and groundwater, uptake or absorption by plants, dust, aerosols, etc. In addition, a pollutant may undergo biological, chemical or physical changes likely to affect toxicity, availability and mobility. When pollutants are disposed of in the soil, pollutants (e.g. polyphenols contained in OSHs) are affected by a number of physical, geochemical and biological processes that cause various changes such as attenuation, condensation, immobilization, degradation, etc. Therefore, the exact determination of the hazard depends on both the concentration of the pollutant and the transport route (Deliverable, PROSODOL project, Action 7, 2011).

The risk for each transport route is considered as a combination of the likelihood of a risk reaching the target / recipient (e.g. surface and groundwater contamination due to OSH disposal) and the severity of the damage expected to be caused if the recipient is exposed the risk (e.g. if the polluted water is to be used for irrigation). The probability that a pollutant reaches a recipient in a concentration to cause damage can be assessed qualitatively according to the scale: high (certain or almost certain to happen), medium (likely to occur), low (rare) and negligible (almost impossible to happen). The extent of the damage is assessed as: serious (human loss or irreparable damage to the ecosystem), mild (human illness or injury, negative effects on the functioning of the ecosystem), mild (minor human illness or injury, small ecosystem changes) or negligible annoyance to humans and ecosystems). The quality level of the hazard associated with each transport route followed by a pollutant is attributed to the combination of probability and severity of the effects (Xenidis et al., 2003).

2.7 Protection and restoration

Water pollution is caused by various sources of pollution that affect the waters by various means. Sources of pollution are distinguished in point and diffuse sources.

A point source is a single source of pollution from which pollutants are diffused, e.g. pipes, trenches, boats, factory chimneys etc. Non-point sources are more difficult to locate and consequently the pollution caused is more difficult to deal with. Typically, outflows such as rain water or snow melting water start from non-point sources and, while crossing the surface of the earth, transport fats, dirt, litter, animal waste, micro-organisms and chemical pollutants (e.g. metals, microbicides and fertilizers). Urban non-point sources include roads, car parks, ceilings and construction sites, while rural non-point sources include agricultural and mining areas. Polluted outflows are one of the most serious problems in the world in terms of water quality control.

Drinking water, which meets the needs of more than a quarter of people on earth, comes from groundwater aquifers. When the aquifer is under great underground depths, pollutants that are entrained with rainwater are usually not a hazard. However, larger quantities of water for drinking are found in shallow groundwaters, at risk of being polluted by pollutants on the surface of the earth and moving to groundwater. As long as the groundwater aquifers are polluted, the pollution can also spread to surface waters.

Of course, the opposite phenomenon, i.e. pollution of surface waters, may lead to pollution of groundwater aquifers, which may remain contaminated for long periods of time. In particular, in groundwaters moving at low speed, the residence times of the pollutants are even greater. The most important problems are caused by pollution from oils characterized by low solubility in water. Since the oils are trapped in the soil or in rocks, it is possible to continue to extract them slowly, constantly polluting the groundwater.

With regard to water-soluble surface soils, they are filtered through the ground and end up in the underground waters, while those that are at a shallow depth are polluted in a short period of time. The amount of soil entering the underground aquifers depends on the type of soil, soil characteristics and the distance between the ground and the groundwater.

Pollution sources (Table 2) include outflows from rural and urban areas, chemical extracts and extracts from landfills.

Table 2. Groundwater pollution sources

Source	**Pollutant**
Landfills (inappropriate or poorly managed), unprotected hazardous waste disposal sites, old quarries	Soluble chemical substances included in the waste (metals, salts, organic elements)
Wastewater treatment systems (inappropriate or poorly managed)	Micro-organisms and pathogens
Farms, areas with grass (golf courses)	Fertilizers (nutrients) and microbicides
Animal farms (large scale installations)	Nutrients and micro-organisms extracted from waste
Surface pipelines	Oils, hazardous chemical substances, etc.

Land uses affect groundwater pollution. Strong use in rural areas can result in the extraction of nutrients (active nitrogen from fertilizers), microbicides and microbes that are likely to end up in the underground aquifers. As a result of urban areas, high-pollutant outflows that initially reach the ground can penetrate into the groundwater by transferring some of their pollutant load.

Groundwater aquifers are also contaminated by pathogenic and especially by viruses, which are smaller than most bacteria. For example, microbicides, petrochemicals from tank leaks, impurities from wastewater treatment systems, or extracts from landfills that are inadequately formed or poorly maintained are sources of pollution for groundwater. Pollutants in all the above cases are detectable, but this is not always indicative of a problem. However, there is a need to take appropriate measures to prevent pollution because groundwater remediation is either very difficult or unfeasible (Hill, 2010).

2.8 Water treatment methods

Although many methods have been developed and continue to be developed for the purpose of water treatment, in most cases, they need to be combined according to the quality of the water before treatment and the desired water quality after it. Generally, water treatment is a relatively low-cost process, but the ability to directly change its quality in natural systems (sources, lakes and underground water) is limited due to the large volume that needs to be redeveloped. Typically, public water is sanitized prior to dispensing, while liquid waste is sanitized in mechanical systems before being disposed of in the environment.

Hazardous elements are removed from the water or wastewater through specific processes classified into the following categories (Crittenden et al., 2005):

- Natural processes where water treatment takes place through the application of physical forces and involves mixing, transfer of gas, precipitation and filtration;
- Chemical processes where the removal of hazardous elements takes place through the addition of chemicals or through chemical reactions. Two typical examples are chemical precipitation and disinfection;
- Biological processes where the removal of dangerous elements takes place by biological means. The most known processes used so far for the treatment of water are nitrification and denitrification.

Surface and groundwater aquifers are often interconnected, resulting in polluting both hazardous outflows. Pollution prevention strategies contribute to the maintenance of groundwater quality in accordance with regulations requiring that only those microbicides with a low tendency to move to groundwater should be used and in such a way as to limit the production of pollutant effluents.

Other pollution prevention strategies are related to land use and prohibit e.g. the installation of landfills or livestock farms in soils under which underground aquifers end up in water springs.

The remediation of contaminated groundwater requires high cost processes, which are not always available with today's technology. However, pumping and treatment techniques are often used to rehabilitate and control water quality and end use as drinking water. Ground water is pumped to the surface, treated to remove pollutants and then returned to its original position. In particular, in aquifers containing large volumes of water, pumping and treatment can continue for many years without, however, limiting pollution.

In some cases, the treatment is done on the spot without the water being removed from its original position. One of these techniques is the permeable barrier method whereby trenches are opened in which tons of sand-mixed iron fillings are placed. The polluted water flows through this barrier and some organic pollutants, such as trichlorethylene, react with iron and break down to produce non-harmful products. Another technique is the use of anaerobic microorganisms which are able to break down pollutants. The presence of anaerobic organisms is necessary because groundwater contains oxygen.

Water management is related to its intended uses, availability and quality. Water management strategies should take into consideration the hydrological, environmental and social needs of each area. For a rational management of underground aquifers, their characteristics, as well as their possible connection with surface waters, must be determined.

In addition, for the proper management of a hydrological system, its flow direction must be known so that it is possible to easily determine the borehole opening position as well as the amounts of water that can be pumped. Good groundwater quality must be ensured by protecting the aquifer from various sources of pollution.

Water maintenance is a way of solving the water supply problem, also contributing to reducing the effects of short drought periods and limiting the need for new water sources. Water maintenance is the responsibility of everyone (Vandas et al., 2002).

Chapter 3. Drinking Water Quality

3.1 Introduction

High quality drinking water is a basic need for human development, health and well-being. According to the World Health Organization (WHO), methodologies have been identified for risk assessment and standard guidelines for water quality assurance (WHO, 1994; 1999). Consequently, risk management is possible through the development of control and monitoring methodologies as well as national standards for drinking water quality.

However, it is not practical and feasible to develop management practices for each chemical parameter. A more effective approach is to determine the chemical parameters to which humans are expected to be exposed, taking into account that there are likely to be variations from country to country as well as in different regions of a country.

In many countries the development of appropriate risk management practices is not feasible due to a lack of information on the presence and concentration of chemical parameters in drinking water. In order to define specific chemical parameters by the competent services, simple and quick estimation methods can be used. These methods can be applied at national and local level to provide a list of the chemical parameters that are a priority in assessing the risk to human health.

The standard drinking water quality guidelines (WHO 2004; 2006) concern the microbial and chemical contaminants content based on scientific criteria. As a result, they provide a valid guideline for ensuring the quality of drinking water and the development of national standards, also taking into account particular problems as well as the cultural, social, economic and environmental conditions of each country.

The WHO Quality Standards for Quality Assurance of Drinking Water include several parameters according to the following main criteria:

- Presence of a parameter in drinking water, as well as possible toxicity;
- The presence of the parameter is worrying at the international level.

Based on the above criteria, quality standards include about 200 chemical parameters, and this number may change over time. It is important to mention that the chemical parameters for which quality standards have been established are not always contained in drinking water, and others that are not included in the quality standards may be included. However, national or local authorities are under no obligation to develop risk management strategies for each chemical parameter included in quality standards, but it is important to help identify the chemical parameters for managing their hazard.

The quality of drinking water is affected by various parameters. In order to properly assess the risk of drinking water, account should be taken of the whole water system, from supply to consumption. In such an integrated approach, the necessary means are needed to model any interactions between different parameters.

3.2 Legislation

Ensuring the quality of drinking water is a basic need for health and the development of human society. In theory, the health risks with regard to the presence of chemical elements in drinking water can be assessed internationally or locally, depending on the guidelines established. The World Health Organization (WHO) has established risk assessment procedures for certain chemical elements in human health to manage these risks. Control and recording programs and international standards for drinking water quality are used in these procedures.

However, these estimates and the development of management strategies cannot be applied in practice. A more flexible approach is to identify specific chemical elements which are expected to have a significant effect on human health, also taking into account the fact that there are variations from country to country or even across different regions of the same country.

In many countries the development of appropriate risk management strategies becomes difficult due to a lack of information on the presence and concentration of chemical elements in drinking water. However, the authorities responsible for identifying hazardous chemical elements despite the lack of information are guided to a certain extent by simple and rapid assessment methods. These methods can be implemented at national or local level to create lists of chemical elements in a priority order, aiming at a faster assessment of health risks (WHO, 1994; 1999).

The World Health Organization's directives deal with microbial and chemical pollutants in drinking water and describe in detail the scientific procedures for introducing these directives. Therefore, they provide full guidance for ensuring the quality of drinking water and establishing marginal acceptable international prices, taking into account the specific problems and the different social, economic and environmental conditions of each country.

Some of the criteria on the basis of which specific chemical elements are included in the WHO Guidelines for Drinking Water Quality Control are as follows:

- Reliable evidence of the presence of chemical elements in drinking water, combined with the presence of toxicity or potential for the production of toxicity;
- Chemical elements are of particular scientific interest;
- Chemicals are under evaluation or already included in the WHO Pesticide Evaluation Scheme (WHOPES).

Based on the above criteria, guidelines have been established for about 200 chemical elements and compounds. These lists of course do not indicate that these particulars will always be present, or that other items not included in the original list will not appear in the drinking water. However, it is not necessary for local or international authorities to establish a risk management strategy for each chemical element for which limits have been established, but it is important to identify the most dangerous chemical elements (WHO, 2004; 2006).

Each country should have an established policy of drinking water quality control. The nature of the limits set for drinking water is likely to vary from country to country or even region to region. It is possible that practices that produce positive results in one country do not have the same results when applied in another country or region. It is therefore important for each country to assess its needs and the possibilities for applying drinking water limits before defining a legislative framework.

International and national standards should be established in accordance with the scientific criteria as defined by the relevant WHO guidelines on drinking water, also taking into account the national or international environment, socio-cultural and economic conditions. WHO guidelines provide information on the development and application of national standards.

To implement a successful risk management strategy, it is necessary to identify the hazards that can affect the quality of water used by humans. This is because many chemical elements and compounds are likely to pose a threat to human health. The identification of hazards mainly in water intended for human consumption is a slow, complex and high cost process and therefore becomes practically unfeasible. That is, the protection of human health cannot be based solely on the determination of water quality.

Since it is not physically and economically possible to check all quality parameters for drinking water, appropriate recording plans should be developed for the most important features. In order to ensure the quality of drinking water, a water management and protection strategy should be implemented, which also includes water rehabilitation and distribution.

Water management and distribution processes are included in a water quality assurance plan, which essentially involves water rehabilitation so that the concentrations of the contained elements are at acceptable levels and then the water distribution to consumption (Thompson et al. al., 2007).

3.2.1 European Legislation

The Drinking Water Directive (Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption) concerns the quality of water intended for human consumption. Its objective is to protect human health from adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean (http://ec.europa.eu/).

The Drinking Water Directive applies to:

- all distribution systems serving more than 50 people or supplying more than 10 cubic meter per day, but also distribution systems serving less than 50 people/supplying less than 10 cubic meter per day if the water is supplied as part of an economic activity;
- drinking water from tankers;
- drinking water in bottles or containers;
- water used in the food-processing industry, unless the competent national authorities are satisfied that the quality of the water cannot affect the wholesomeness of the foodstuff in its finished form.

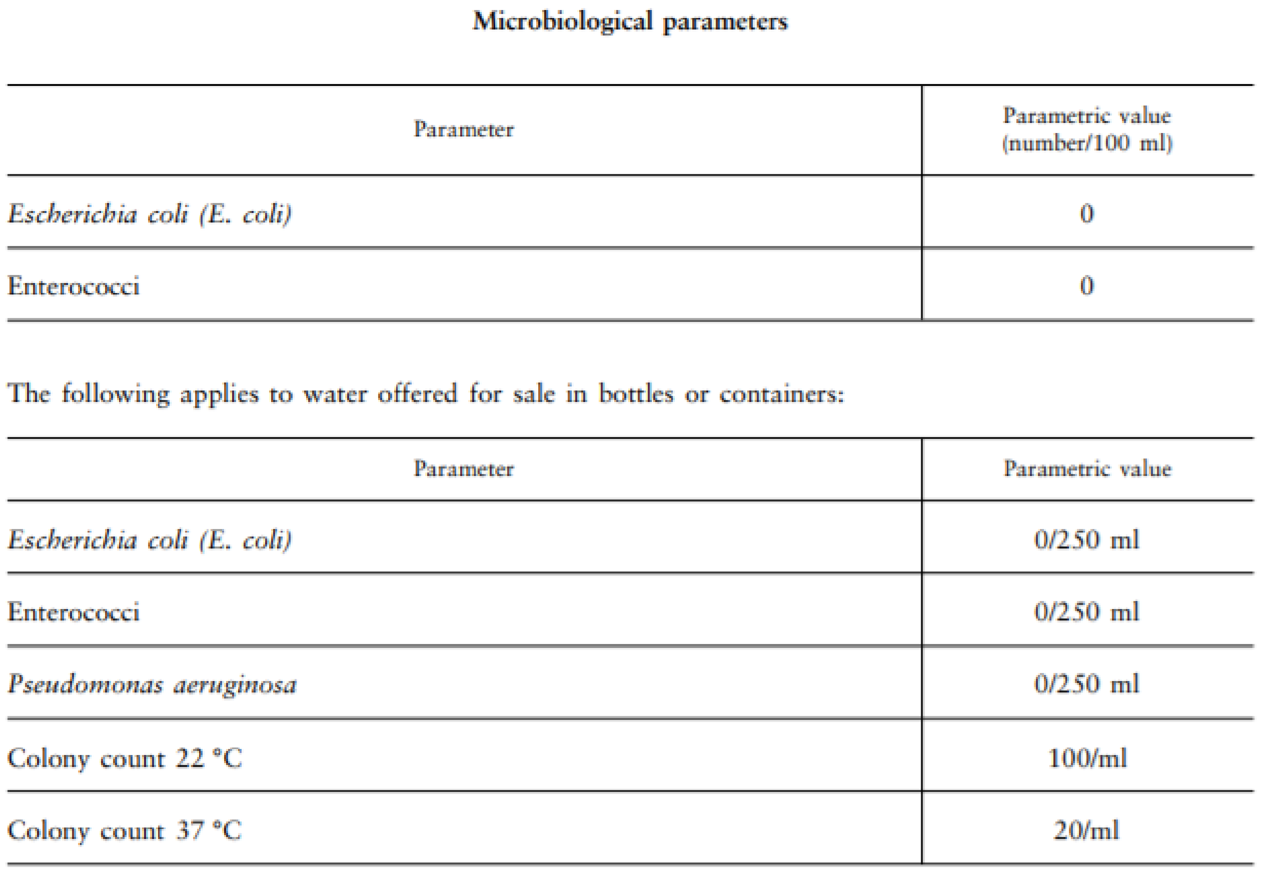
The Directive laid down the essential quality standards at EU level. A total of 48 microbiological, chemical and indicator parameters must be monitored and tested regularly. In general, World Health Organization's guidelines for drinking water and the opinion of the Commission's Scientific Advisory Committee are used as the scientific basis for the quality standards in the drinking water.

When translating the Drinking Water Directive into their own national legislation, Member States of the European Union can include additional requirements e.g. regulate additional substances that are relevant within their territory or set higher standards. Member States are not allowed, nevertheless, to set lower standards as the level of protection of human health should be the same within the whole European Union.

Member States may, for a limited time depart from chemical quality standards specified in the Directive (Annex I). This process is called "derogation". Derogations can be granted, provided it does not constitute a potential danger to human health and provided that the supply of water intended for human consumption in the area concerned cannot be maintained by any other reasonable means.

The Directive also requires providing regular information to consumers. In addition, drinking water quality has to be reported to the European Commission every three years. The scope of reporting is set out in the Directive. The Commission assesses the results of water quality monitoring against the standards in the Drinking Water Directive and after each reporting cycle produces a synthesis report, which summarizes the quality of drinking water and its improvement at a European level.

The parametric values set by the Directive are:

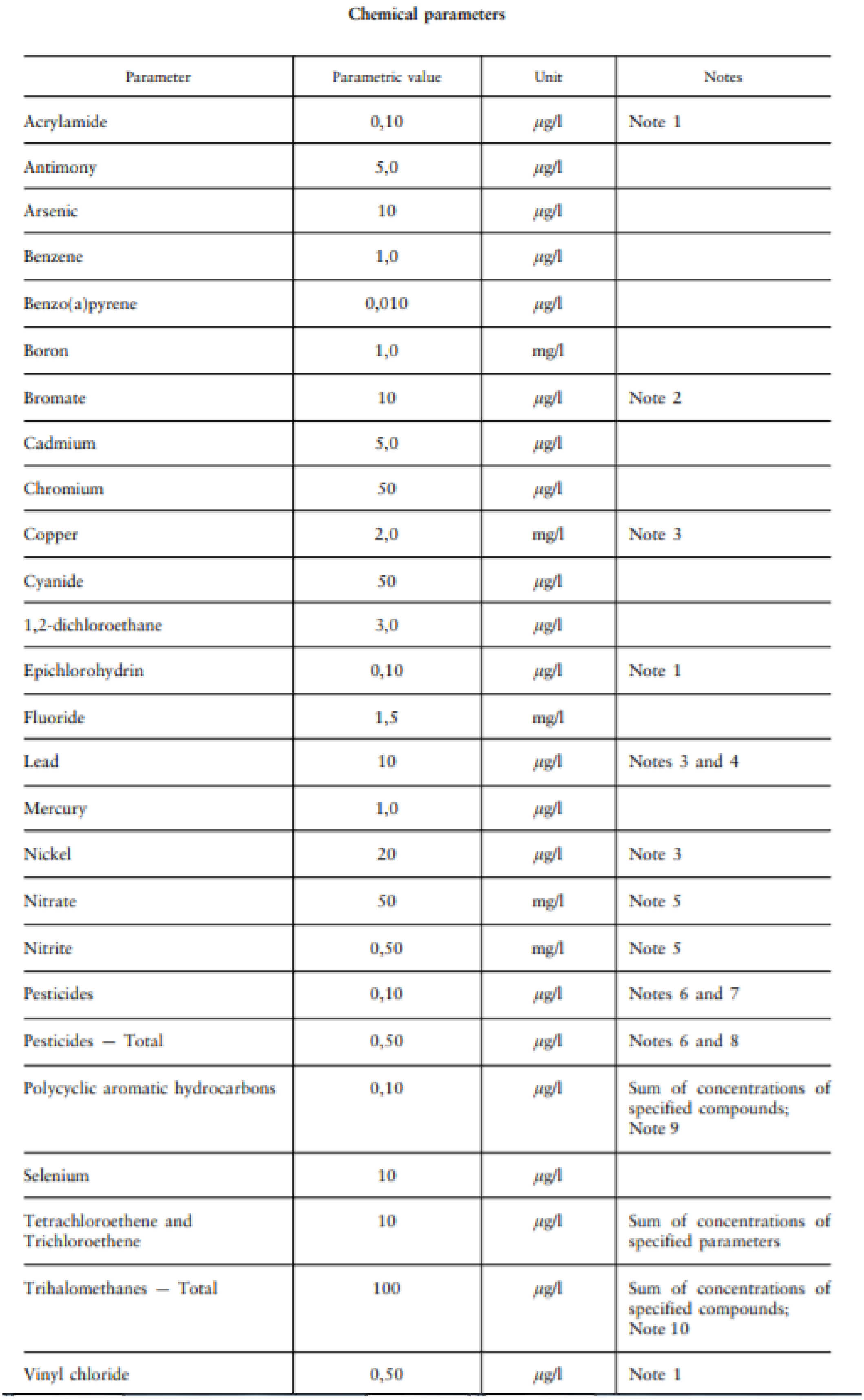


Microbiological parameters

Parameter	Parametric value (number/100 ml)
Escherichia coli (E. coli)	0
Enterococci	0

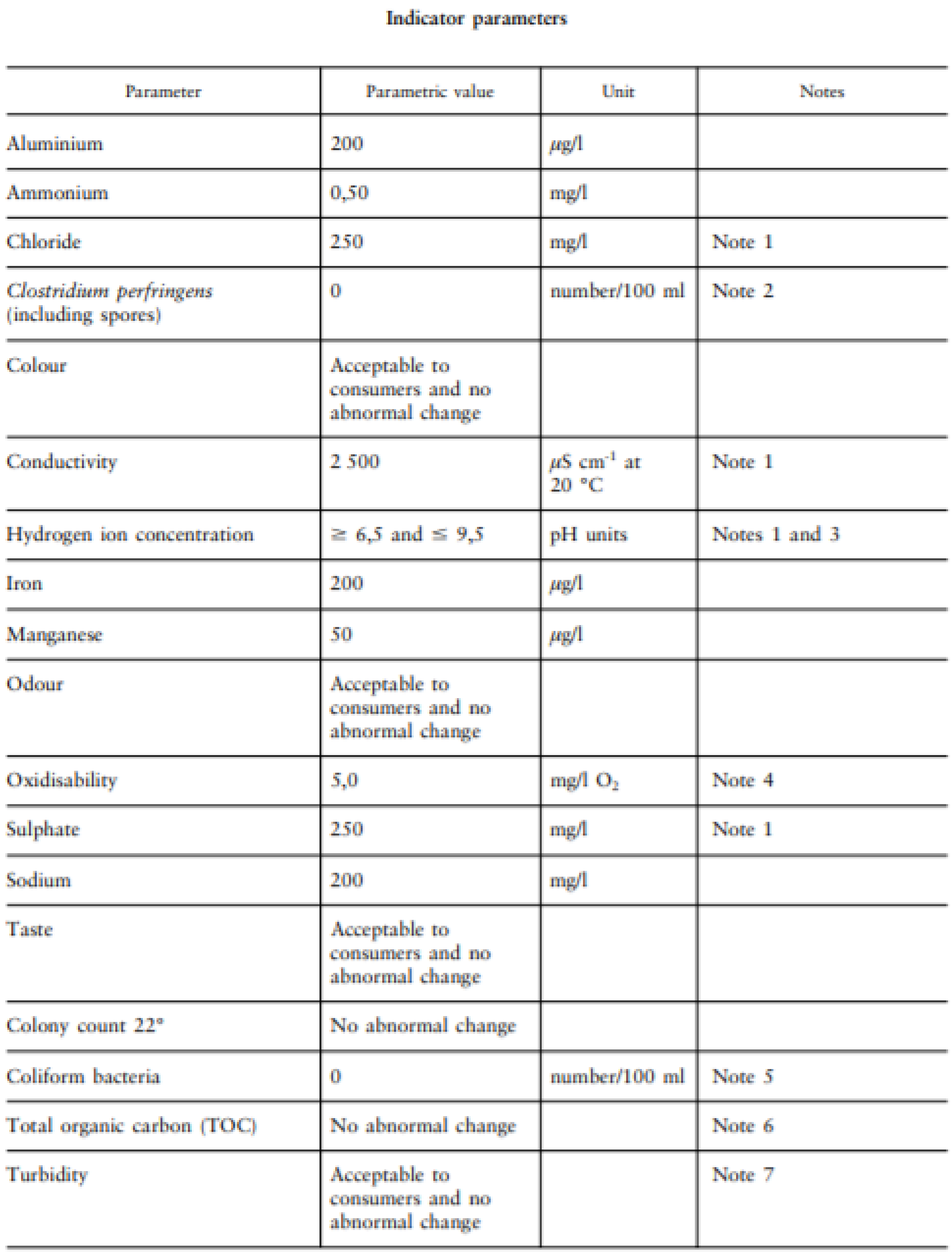
The following applies to water offered for sale in bottles or containers:

Parameter	Parametric value
Escherichia coli (E. coli)	0/250 ml
Enterococci	0/250 ml
Pseudomonas aeruginosa	0/250 ml
Colony count 22 °C	100/ml
Colony count 37 °C	20/ml



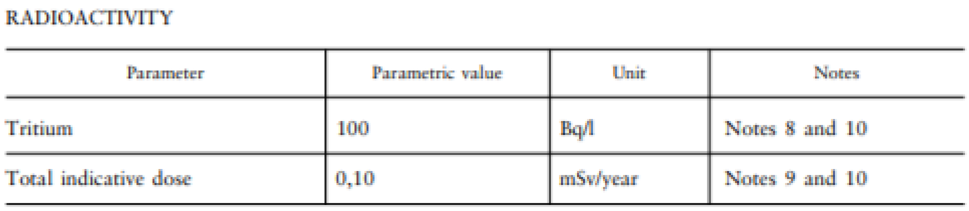
Chemical parameters

Parameter	Parametric value	Unit	Notes
Acrylamide	0,10	μg/l	Note 1
Antimony	5,0	μg/l	
Arsenic	10	μg/l	
Benzene	1,0	μg/l	
Benzo(a)pyrene	0,010	μg/l	
Boron	1,0	mg/l	
Bromate	10	μg/l	Note 2
Cadmium	5,0	μg/l	
Chromium	50	μg/l	
Copper	2,0	mg/l	Note 3
Cyanide	50	μg/l	
1,2-dichloroethane	3,0	μg/l	
Epichlorohydrin	0,10	μg/l	Note 1
Fluoride	1,5	mg/l	
Lead	10	μg/l	Notes 3 and 4
Mercury	1,0	μg/l	
Nickel	20	μg/l	Note 3
Nitrate	50	mg/l	Note 5
Nitrite	0,50	mg/l	Note 5
Pesticides	0,10	μg/l	Notes 6 and 7
Pesticides — Total	0,50	μg/l	Notes 6 and 8
Polycyclic aromatic hydrocarbons	0,10	μg/l	Sum of concentrations of specified compounds; Note 9
Selenium	10	μg/l	
Tetrachloroethene and Trichloroethene	10	μg/l	Sum of concentrations of specified parameters
Trihalomethanes — Total	100	μg/l	Sum of concentrations of specified compounds; Note 10
Vinyl chloride	0,50	μg/l	Note 1



Indicator parameters

Parameter	Parametric value	Unit	Notes
Aluminium	200	µg/l	
Ammonium	0,50	mg/l	
Chloride	250	mg/l	Note 1
Clostridium perfringens (including spores)	0	number/100 ml	Note 2
Colour	Acceptable to consumers and no abnormal change		
Conductivity	2 500	µS cm^{-1} at 20 °C	Note 1
Hydrogen ion concentration	$\geq$ 6,5 and $\leq$ 9,5	pH units	Notes 1 and 3
Iron	200	µg/l	
Manganese	50	µg/l	
Odour	Acceptable to consumers and no abnormal change		
Oxidisability	5,0	mg/l O_2	Note 4
Sulphate	250	mg/l	Note 1
Sodium	200	mg/l	
Taste	Acceptable to consumers and no abnormal change		
Colony count 22°	No abnormal change		
Coliform bacteria	0	number/100 ml	Note 5
Total organic carbon (TOC)	No abnormal change		Note 6
Turbidity	Acceptable to consumers and no abnormal change		Note 7



RADIOACTIVITY

Parameter	Parametric value	Unit	Notes
Tritium	100	Bq/l	Notes 8 and 10
Total indicative dose	0,10	mSv/year	Notes 9 and 10

3.3 Risk Assessment Tools for Drinking Water and Guidelines

3.3.1 Introduction

Fault tree analysis is an important risk assessment tool and provides the ability to model interactions between different parameters. In this analysis, it is possible to model the presence of a parameter based on the presence or otherwise of some other parameters. As a result, an integrated risk assessment for drinking water not only assesses the probability of failure but also the average failure rate of the system.

A fault tree includes the interactions between different parameters using logical gates and shows how certain parameters can lead to system failure, that is to say, the top event. Based on the top event, the tree grows until all the necessary information is gathered. Intermediate features are the events whose causes have been further developed, while basically those events at the edges of the tree are characterized. A leading event leads to system failure, while key events are parameters of failure (Bedford and Cooke 2001; Lindhe et al., 2009).

To ensure the quality of drinking water, each country should use appropriate guidance. The effectiveness of these directives is mainly based on appropriate legislative frameworks based on various national and constitutional factors.

Standards to ensure the quality of drinking water vary from country to country or even region to region. However, for the development and implementation of standards, it is important to take into account current and planned legislation on water, health, local society, etc. as well as to determine the needs of each country to develop standards.

Both national and local standards should be developed in accordance with the WHO (WHO 2004; 2006) scientific criteria, taking into account local or national environmental, socio-political and economic conditions. These guidelines may later provide further information on the development and implementation of national standards.

In order to implement an efficient strategy for risk management, it is necessary to identify any risk related to the quality of water intended for human consumption. However, the identification of chemical parameters which can cause adverse effects on human health, drinking water is a time consuming, complex and high cost process, making it practically difficult to apply. Consequently, determining the quality of water is not sufficient to protect public health.

Since it is not practical and economically feasible to identify all parameters related to water quality, it is proposed to design a monitoring system for the main parameters. The objective of the monitoring system is to prevent pollution, to protect and ensure the quality of drinking water and to control water treatment and distribution methods.

Each water quality assurance plan should provide information on the supply, treatment and distribution of water for consumption. This plan, which determines the acceptable concentrations of chemical parameters in drinking water, is based on the following:

- A complete system of assessing the suitability of existing or future water supplies for the health of recipients;
- Determination of risk control measures. For each measure, appropriate monitoring procedures should be established to identify potential deviations from the acceptable concentrations;
- Develop management plans with the actions required during normal operation (or under other conditions) and record the effectiveness of the system and the monitoring and communication plans.

3.3.2 Water Safety Plans

There is a wide range of both chemical and microbial contaminants that may be found in drinking water, some of which can have adverse health effects on consumers. These can be derived from a number of sources including, the water treatment process. Understanding the nature of sources of contamination and how these may enter the water supply is critical for assuring water safety. An important strategy in providing safe drinking water for the consumer is the multiple barrier approach (Teunis et al. 2004) the application of which is often restricted to the actual water treatment process. As the detection and enumeration of pathogenic microorganisms from microbially contaminated water is both difficult and costly, reliance has traditionally been placed on the examination for microbial indicators of pollution (Dufour et al. 2003). These indicators are usually non-pathogenic bacteria, which are present in faecal material in large amounts. Their enumeration is relatively easy and inexpensive (in comparison with that for individual pathogens). Microbial contaminants, however, are not limited to bacteria and illness may result from exposure to pathogenic viruses or protozoa, both of which have different environmental behaviour and survival characteristics to bacteria. This, coupled with the fact that testing of water immediately prior to, or within, distribution (end product testing) can only highlight a potential health problem after the water has been consumed, has led to the recognition of the need to adopt additional approaches to assuring water quality and safety.

The steps for the development of a Water Safety Plan (WSP) are the following (Water Safety Plan Manual, available at: https://apps.who.int/):

- Assemble the WSP team;
- Describe the water supply system;
- Identify hazards and hazardous events and assess the risks;
- Determine and validate control measures, reassess and prioritize the risks;
- Develop, implement and maintain an improvement/upgrade plan;
- Define monitoring of the control measures;
- Verify the effectiveness of the WSP;
- Prepare management procedures;
- Develop supporting programmes;
- Plan and carry out periodic review of WSP;
- Revise the WSP following an incident.

3.3.2.1 Assemble the WSP team

Establishment of a qualified, dedicated team is a prerequisite to securing the technical expertise needed to develop a WSP. This step involves assembling a team of individuals from the utility, and also in some cases, from a wider group of stakeholders, with the collective responsibility for understanding the water supply system and identifying hazards that can affect water quality and safety throughout the water supply chain. The team will be responsible for developing, implementing and maintaining the WSP as a core part of their day-to-day roles. It is essential that all involved play an active role in the development of the WSP and support the WSP approach. It is important that the WSP team has adequate experience and expertise to understand water abstraction, treatment and distribution and the hazards that can affect safety through the supply system from the catchment to the point of consumption. For small utilities, additional external expertise may be helpful. The team is vital to getting the WSP approach understood and accepted by everyone connected with water safety within and outside the utility. Therefore, an inclusive team that works with everyone within a utility and outside is likely to be far more effective than an exclusive team who impose their WSP approach on the utility. A vital early task of the team is to set out how the WSP approach is to be implemented and the methodology that will be used, particularly in assessing risk.

3.3.2.2 Describe the water supply system

The first task of the WSP team is to fully describe the water supply. Where utilities do not already have documentation of the water system, it is essential that field investigations are conducted. The objective is to ensure that subsequent documentation of the nature of the raw, interim, and finished water quality, and of the system used to produce water of that quality is accurate to allow risks to be adequately assessed and managed. While it is accepted that there may be some room for a generic approach to be taken where works are very similar, or where liaison with outside bodies remains the same for a number of water supplies, each supply must be assessed in detail on its own. Data should be gathered specifically for that supply, and all other steps taken leading to a WSP should be exclusive to that particular supply. Many utilities will already have extensive experience of their water system and hold relevant documentation. In this case, the WSP will simply require this to be systematically reviewed to ensure it is up to date and complete and checked for accuracy by a site visit.

The following should be included in the description, but it is not an exhaustive list, nor is every point relevant for each water supply system:

- Relevant water quality standards;
- The source(s) of water including the runoff and/or recharge processes, and if applicable, alternative sources in case of incident;
- Known or suspected changes in source water quality relating to weather or other conditions;
- Any interconnectivity of sources and conditions;
- Details of the land use in the catchment;
- The abstraction point;
- Information relating to the storage of water;
- Information relating to the treatment of the water, including the processes and chemicals or materials that are added to the water;
- Details of how the water is distributed including network, storage and tankers;
- Description of the materials in contact with water;
- Identification of the users and uses of the water;
- Availability of trained staff;
- How well existing procedures are documented.

3.3.2.3 Identify hazards and hazardous events and risk assessment (tool)

This step constitutes the system assessment which identifies the potential hazards and hazardous events in each part of the water supply chain, the level of risk presented by each hazard and hazardous event, the appropriate measures to control the identified risks, and confirmation that standards and targets are met.

In this step:

- Identify all potential biological, physical and chemical hazards associated with each step in the drinking water supply that can affect the safety of the water;
- Identify all hazards and hazardous events that could result in the water supply being, or becoming contaminated, compromised or interrupted;
- Evaluate the risks identified at each point in the flow diagram previously prepared.

Risk assessment takes place using a quantitative or a semi-quantitative approach. The likelihood/frequency of the hazardous event and the severity/consequence of the hazard must be estimated. The are also qualitative approaches based on expert judgements. Following the quantitative / semi-quantitative approach, the likelihood/frequency of the hazardous event takes the following values (WSP manual, WHO, at https://apps.who.int/):

- Rare likelihood or frequency (value equal to 1): once every 5 years
- Unlikely (value equal to 2): once a year
- Moderate likelihood or frequency (value equal to 3): once a month
- Likely (value equal to 4): once a week
- Almost certain (value equal to 5): once a day.

Then, the severity or consequence of the hazard is assessed:

- Insignificant or no impact (value equal to 1)
- Minor compliance impact (value equal to 2)
- Moderate aesthetic impact (value equal to 3)
- Major regulatory impact (value equal to 4)
- Catastrophic public health impact (value equal to 5).

The risk is calculated using the following equation:

Risk = Likelihood X Severity

- When risk takes values lower than 6, then the risk is low.
- When risk takes values between 6 and 9, the risk is medium.
- When the risk takes values between 10 to 15, the risk is assessed as high.
- When risk values exceed 15, the risk is very high.

		Severity or consequence				
		Insignificant or no impact (1)	Minor compliance impact (2)	Moderate aesthetic impact (3)	Major regulatory impact (4)	Catastrophic public health impact (5)
Likelihood or Frequency	Almost certain (5)	5	10	15	20	25
	Likely (4)	4	8	12	16	20
	Moderate (3)	3	6	9	12	15
	Unlikely (2)	2	4	6	8	10
	Rare (1)	1	2	3	4	5
Risk score		<6	6-9	10-15		>15
Risk rating		Low	Medium	High		Very high

Figure 2. Risk assessment based on the suggestion of WHO for the WSPs (https://apps.who.int/)

3.3.2.4 Determine and validate control measures, reassess and prioritize the risks

Concurrently with identifying the hazards and evaluating the risks, the WSP team should document existing and potential control measures. In this regard, the team should consider whether the existing controls are effective. Depending on the type of control, this could be done by site inspection, manufacturer’s specification, or monitoring data. The risks should then be recalculated in terms of likelihood and consequence, taking into account all existing control measures. The reduction in risk achieved by each control measure will be an indication of its effectiveness. If the effectiveness of the control is not known at the time of the initial risk assessment, the risk should be calculated as though the control was not working. Any remaining risks after all the control measures have been taken into account, and which the WSP team consider unacceptable, should be investigated in terms of additional corrective actions. Control measures (also referred to as ‘barriers’ or ‘mitigation measures’) are steps in the drinking-water supply that directly affect drinking-water quality and ensure the water consistently meets water quality targets. They are activities and processes applied to reduce or mitigate risks

3.3.2.5 Develop, implement and maintain an improvement/upgrade plan

If the previous step identifies significant risks to the safety of water and demonstrates that existing controls are not effective or are absent, then an improvement/upgrade plan should be drawn up. Each identified improvement needs an 'owner' to take responsibility for implementation and a target implementation date. The assessment may not automatically result in the need for new capital investment. In some instances, all that may be needed is to review, document and formalize the practices that are not working and address any areas where improvements are needed. In other cases, new or improved controls or a major infrastructure change may be needed. Improvement/upgrade plans can include short-, medium- or long-term programmes. Significant resources may be needed and therefore a detailed analysis and careful prioritization should be made in accordance with the system assessment. It may be that improvements need to be prioritized and phased in. Implementation of improvement/upgrade plans should be monitored to confirm improvements have been made and are effective and that the WSP has been updated accordingly. It should be taken into consideration that the introduction of new controls could introduce new risks to the system.

3.3.2.6 Define monitoring of the control measures

Operational monitoring includes defining and validating the monitoring of control measures and establishing procedures to demonstrate that the controls continue to work. These actions should be documented in the management procedures. Defining the monitoring of the control measures also requires inclusion of the corrective actions necessary when operational targets are not met.

3.3.2.7 Verify the effectiveness of the WSP

Having a formal process for verification and auditing of the WSP ensures that it is working properly. Verification involves three activities which are undertaken together to provide evidence that the WSP is working effectively. These are:

- Compliance monitoring;
- Internal and external auditing of operational activities;
- Consumer satisfaction.

Verification should provide the evidence that the overall system design and operation is capable of consistently delivering water of the specified quality to meet the health-based targets. If it does not, the upgrade/improvement plan should be revised and implemented.

3.3.2.8 Prepare management procedures

Clear management procedures documenting actions to be taken when the system is operating under normal conditions and when the system is operating in 'incident' situations (corrective actions) are an integral part of the WSP. The procedures should be written by experienced staff and should be updated as necessary, particularly in light of implementation of the improvement/upgrade plan and reviews of incidents, emergencies and near misses. It is preferable to interview staff and ensure their activities are captured in the documentation. This also helps to foster ownership and eventual implementation of the procedures.

3.3.2.9 Develop supporting programmes

Supporting programmes are activities that support the development of people's skills and knowledge, commitment to the WSP approach, and capacity to manage systems to deliver safe water. Programmes frequently relate to training, research and development. Supporting programmes may also entail activities that indirectly support water safety, for example those that lead to the optimization of processes, like improving quality control in a laboratory. Programmes may already be in place, but are often forgotten or overlooked as important elements of the WSP. Examples of other activities include continuing education courses, calibration of equipment, preventive maintenance, hygiene and sanitation, as well as legal aspects such as a programme for understanding the organization's compliance obligations. It is essential that organizations understand their liabilities and have programmes in place to deal with these issues.

3.3.2.10 Plan and carry out periodic review of the WSP

The WSP team should periodically meet and review the overall plan and learn from experiences and new procedures (in addition to regularly reviewing the WSP through analysis of the data collected as part of the monitoring process). The review process is critical to the overall implementation of the WSP and provides the basis from which future assessments can be made. Following an emergency, incident or near miss, risk should be reassessed and may need to be fed into the improvement/upgrade plan

3.3.2.11 Revise the WSP following an incident

To ensure that a WSP covers emerging hazards and issues, it should be reviewed periodically by the WSP team. A particular benefit of implementing the WSP framework is a likely reduction in the number and severity of incidents, emergencies or near misses affecting or potentially affecting drinking-water quality. However, such events may still occur. In addition to the periodic review, it is important that the WSP is reviewed following every emergency, incident or unforeseen event irrespective of whether new hazards were identified to ensure that, if possible, the situation does not recur and determine whether the response was sufficient or could have been handled better. A post-incident review is always likely to identify areas for improvement whether it is a new hazard or revised risk for the risk assessment, a revision for an operating procedure, a training issue or a communication issue, and the WSP must be revised to reflect the changes. In many cases, it will be necessary to include other stakeholders in the review. It is important that water suppliers, within their WSP, have procedures in place to ensure that the WSP team is made aware of the circumstances and details of all incidents, emergencies, and near misses.

3.3.3 HACCP

The Hazard Analysis Critical Control Point (HACCP) system is a systematic and scientifically documented system designed to identify specific risks as well as identify preventive and corrective actions for their control aimed at managing the safety of the products produced. It is essentially an effective tool for both the food industry and the health authorities to prevent food-borne illness (Vela & Fernandez, 2003). HACCP is not a system that validates the safety of food and beverages. Instead, it is a precautionary food safety management system that prevents risks through the recognition of critical control points (CCPs) and their ongoing monitoring (National Advisory Committee on Microbiological Criteria for Foods, 1994). This system is applied to identify natural, chemical and biological hazards that could potentially cause adverse health effects for consumers (Codex Alimentarius, 1997). The main feature of the HACCP system is that it can be applied to every food and beverage production line and can be adapted to the particular conditions of production of any product. For this reason, HACCP is among the risk assessment tools specifically designed for drinking water.

The basic seven (7) steps of HACCP are:

- hazard analysis,
- CCP identification,
- establishing critical limits,
- monitoring procedures,
- corrective actions,
- verification procedures, and
- record-keeping and documentation

The implementation and development of an ISO22000 system is a particularly complex process and is differentiated according to the specific features of each line of potable water pumping, treatment and distribution. The basic steps to be taken when implementing a HACCP in water supply systems are the following:

- Team formation;
- Description of the product and its use;
- Flow diagram;
- Hazards analysis;
- Critical control points determination;
- Determination of critical thresholds, monitoring system and corrective actions;
- Confirmation and verification system.

3.3.3.1 Team formation

The members of the HACCP team are responsible for the design, development, validation and implementation of the HACCP system. For this reason, the HACCP team should be made up of people with wide knowledge, experience and abilities in the whole range of drinking water treatment and distribution activities (Cook et al., 2015; Swierc et al., 2005).

Therefore, the members of the team should come from all departments of water companies such as strategic planning, potable water production and processing, quality control department, etc. Sometimes it is necessary to provide know-how from outside bodies with a view to covering any gap of knowledge or experience in specific areas of activity (Martel et al., 2006). The theoretical background and experience of the HACCP team should be combined with technical capabilities (Martel et al., 2006). Therefore, in order to enable a HACCP team to carry out its work, it should consist of both scientists and production workers and technical staff. Of course, knowledgeable and experienced experts in assessing and addressing physical, chemical and biological hazards in drinking water treatment and distribution networks as well as control measures are an integral part of the HACCP team.

In summary, a HACCP team should be composed of members of all parts of a drinking water treatment and distribution company such as quality control, production, equipment maintenance, pumping sources management, distribution network, damage repair, etc. The appropriate combination of HACCP experience and knowledge can both avoid the possibility of ignoring possible risks and avoid the definition of a large number of critical control points without real significance.

In addition, the team leader plays a catalytic role in the proper functioning of the HACCP team. Within his / her competencies is the selection of team members, problem solving, guidance, implementation and monitoring of support programs, the combination of HACCP with other quality management systems, the definition of responsibilities of each member of the team, planning and organizing HACCP meetings, facilitating internal and external communication between both company departments and stakeholders, auditing, reviewing and reviewing the HACCP plan, set up education and training programs for employees, etc. (Cook et al., 2015; Swierc et al., 2005).

3.3.3.2 Description of the product and its use

Unlike potable water production, the description of the product and the determination of its intended use is imperative for food production companies because of the great heterogeneity of the products produced (Havelaar, 1994). With regard to product description, a set of information that may affect the original quality of the pumped water, its subsequent treatment and the likelihood of occurrence of risks should be included. First of all, the drinking water abstraction source (surface, basement, seawater) and then the characteristics of the area where the product originates, i.e. geological features, flora, fauna, land use, etc., should be mentioned. This information, in conjunction with the source of water, provides us with useful data on the estimated initial quality of drinking water as well as on the treatment necessary to make it safe for human consumption (Martel et al., 2006; Swierc et al., 2005).

In addition, some process steps such as disinfection or filtering which are considered critical to ensure the safety of drinking water could also be included in the product description. Of course, it is equally important to refer to the drinking water supply time in collection and storage tanks, tank construction and distribution network, the way water is stored in household consumption points, and any particular characteristics of people consuming it (pregnant women , patients, hospitals, the general public).

With regard to its intended use, from the moment we refer to drinking water treatment and distribution companies, it goes without saying that we are referring to the possibility of water being usable for consumption by the consumer. Therefore, it should meet all the requirements of Directive 98/83 / EC.

3.3.3.3 Flow diagram

One of the most important and important responsibilities of the HACCP team is the development of flow diagrams which should clearly capture the exact process of treating drinking water from the pumping source to the final consumption point. A thorough inventory of all stages and procedures followed will be the basis for a successful evaluation of all potential risks. In the flow diagram, apart from the basic processes, points in the distribution network that could affect the safety of drinking water should also be highlighted. Such points could be storage tanks, pumping stations, control valves, chemical additive feed points, and so on. Of course, it is often necessary to construct secondary flow charts to further analyze all activities.

3.3.3.4 Hazards analysis

The possibility of thoroughly recording all potential risks is essential for the successful implementation of the HACCP system. The source of water origin can determine both its original quality and its further processing. Although groundwater is considered to be of higher quality than surface water, it does not cease to be dangerous for the occurrence of biological, chemical and physical hazards. Surface and groundwater may carry or be contaminated with pathogenic micro-organisms and chemical residues due to chemical and solid waste disposal close to underground aquifers or surface water abstraction sources as well as inappropriate land use (Fick et al. 2009; Lenrner & Harris, 2009; WHO, 2011). It is also common for water to contain a series of foreign bodies (wood, stones, insects) that can endanger the health of the consumer. Some of the control measures that can be applied to prevent this physical hazard are visual water control. The transfer of drinking water from pumping sources to the storage tank of untreated water can be a source of contamination with pathogenic microorganisms, chemical residues and with metallic or non-foreign bodies (Martel et al., 2006; Nadebaum et al., 2004; National Water Quality Management Strategy, 2004). Many times the formation of bio-elements inside the transport pipelines, the corrosion of conduits, the presence of cleansing and disinfectant residues, as well as any loosening and leakage of pipelines can adversely affect the physico-chemical and microbiological safety of water. To prevent the emergence of specific risks, rehabilitation, staff training and maintenance of the transport network can be established. Possible contamination with pathogenic microorganisms and residues of cleansing and disinfecting agents can also occur when storing water in collection tanks prior to its main treatment. Similarly, equivalent training, sanitation and maintenance programs for storage tanks play a catalytic role in the safety of drinking water. The treatment of groundwater differs in relation to surface water both in nature and in the type of treatment steps.

3.3.3.5 Risk assessment tool and Critical control points determination

The definition of Critical Control Points is based on the results of reputable scientific research papers (Damikouka et al., 2007; Havelaar, 1994; Khaniki et al., 2009; Martel et al., 2006; Nadebaum et al., 2004; Tavasolifar et al ., 2017). At each stage, the probability of occurrence of the risk as well as its severity has been taken into account. First of all, the source of drinking water for both biological and chemical hazards is considered a critical control point. The presence of a high number of pathogenic micro-organisms as well as high concentrations of chemicals of household, industrial and agricultural origin can increase the risk to unacceptable levels, thus not being able to reduce or eliminate it in later stages.

Risk assessment is used to determine the critical control points in a water supply system. To do so, the water supply system is examined in stages, for example water supply, water treatment, water distribution, etc. For every stage the probability of occurrence of the hazard as well as its severity are examined. One of the known methodologies is a semi-quantitative risk evaluation procedure, based on the implementation of food safety management systems (COMMISSION NOTICE 2016/C 278/01) covering prerequisite programs and procedures based on HACCP principles. The risk level is defined based on the probability of the hazard occurrence and the hazard's effect. As probability (P), the hazard's probability to occur in the end product is defined, if the specific control measures are not present or failing, taking into consideration the next process steps where hazard's elimination of reduction to an acceptable level is possible and taking into consideration the already implemented prerequisite programs. Probability takes values from 1 (very small) to 4 (high) (COMMISSION NOTICE 2016/C 278/01):

- Very small probability (P=1) means that: (a) the hazard has never occurred before; (b) there is a next step in the process that eliminates or reduces the hazard; (c) when the control measure fails, the production process is not possible; and (d) there is limited or local contamination.
- Small probability (P=2) when: (a) the prerequisite program fails or is not existing, the probability of the hazard to occur is limited; and (b) the control measures are general and well implemented.
- Real probability (P=3): when the control measure fails is not existing, the hazard is present at the end-product.
- High probability (p=4): when the control measure fails or is not existing, then the hazard is present.

The effect (E) or severity of the hazard related to human health takes values from 1 (limited effect) to 4 (very serious effect) (COMMISSION NOTICE 2016/C 278/01):

- Limited effect (E=1): when there is no problem for the consumer related to food safety or the hazard does not reach a dangerous concentration.
- Moderate effect (E=2): when exposition to a high concentration for a long period of time results in no serious injuries or the effect on health is temporary but clear.
- Serious effect (E=3): (a) there is a clear effect on health with short-term or long-term symptoms resulting rarely in mortality; and (b) the hazard has a long-term effect but the maximal dose is unknown.
- Very serious effect (E=4): (a) the consumer group belongs to a risk category and the hazard can result in mortality; (b) the hazard results in serious symptoms and mortality can result; and (c) there are permanent injuries.

The risk level (R) is estimated as follows: R = P*E, with a scale from 1 to 7, as shown in Figure 3 ((COMMISSION NOTICE 2016/C 278/01).

- Risk values are 1 and 2: no specific actions are necessary, and control is covered by prerequisite programs elaborated.
- Risk values are 3 and 4: it must be examined if the prerequisite programs monitor and control the identified risk.
- Risk values are5, 6 and 7: a critical control point is identified.

High (4)	4	5	6	7
Real (3)	3	4	5	6
Small (2)	2	3	4	5
Very small (1)	1	2	3	4
	Limited (1)	Moderate (2)	Serious (3)	Very serious (4)

Figure 3. Determination of R based on P and E ((COMMISSION NOTICE 2016/C 278/01)

3.3.3.6 Determination of critical thresholds, monitoring system and corrective actions

Once the Critical Control Points have been determined, we can move on to the implementation of the other principles of the HACCP Plan. To avoid the occurrence of biological and chemical hazards in both surface and groundwater, the mandatory and indicative parameters of Directive 98/83 / EC should be checked. This directive sets out the critical limits for each parameter and any inaccurate deviation from the parametric reference values may lead to the emergence of biological and chemical hazards. For this reason, the quality control department of water companies should carry out periodic chemical and microbiological analyzes of water samples from the pumping sources. In case of divergences, some indicative corrective actions could be considered to find and remove the source of contamination, create buffer zones around the source of the source, determine land use, choose a different source of pumping, and block its unhindered access common and unauthorized people around the sources of water abstraction.

3.3.3.7 Determination of the confirmation and verification system

The definition of a HACCP plan verification system is usually divided into two sections. The first part includes the confirmation of the technical basis of the HACCP project, while the second part includes the verification of the correct design and implementation of the HACCP plan (Swierc et al., 2005; Martel et al., 2006). An example that could be used for the necessity of a technical basis when implementing a HACCP plan is to determine the critical control limits. These limits should be based on specific technical data demonstrating and ensuring the possibility of producing safe drinking water. Such data can be found in scientific journals, user manuals, the requirements of specific Community and national guidelines, historical data, experimental tests, mathematical models, etc. (Scott, 2005). In addition, the verification procedure could include confirmation of the correct identification of all possible hazards and critical control points as well as the relevance and effectiveness of the critical limits, the monitoring system and the corrective actions. The verification system is required to identify all of the objective evidence that contributes to efficient treatment and production of safe drinking water, which can be collected through internal and external inspections (Mayes, 1999; Sperber, 1998).

3.4 Water age

Water age is a major factor in water quality deterioration within the distribution system. The two main mechanisms for water quality deterioration are interactions between the pipe wall and the water, and reactions within the bulk water itself (USEPA). As the bulk water travels through the distribution system, it undergoes various chemical, physical and aesthetic transformations, impacting water quality. Depending on the water flow rate, water quality, pipe materials and deposited materials (i.e., sand, iron, manganese), these transformations will proceed to a greater or lesser extent. The factors influencing water age are water demand, system operation and system design. Water demand varies within the day and also changes with time. Water supply networks are designed for long time periods and cover sudden water demand such as firefighting or population increase. Water demand also differs according to its kind e.g. residential, commercial, etc.

Water age varies between a system retention time of 1.3 days and a maximum retention time of 3.0 days. The literature cites examples of both “short” (i.e., less than 3 days) and “long” (i.e., greater than 3 days) water ages (USEPA). Water demand is related to land use patterns, types of commercial-industrial activity present in a community, the weather (i.e., lawn watering), and water use habits of the consumers (i.e., conservation practices, reuse practices). Conservation, particularly use of reclaimed water on-site or through separate distribution systems, will tend to lead toward greater water age when all other factors are held constant.

Water quality problems are strongly related to water age (Table 3).

Table 3. Water quality problems related to water age

Chemical issues	**Biological issues**	**Physical issues**
Disinfection by-product formation	Disinfection by-product biodegradation	Temperature increases
Disinfectant decay	Nitrification	Sediment deposition
Corrosion control effectiveness	Microbial regrowth	Color
Taste and odor	Taste and odor	

The formation potential of disinfection by-products (DBP) depends on several chemical and physical characteristics including type and level of organic matter, type and level of specific inorganic parameters, pH, temperature, type and level of disinfectant residual, and contact time (USEPA). As water ages, there is a greater potential for DBP formation. Higher water temperatures during summer seasons can increase DBPs as the chemical reactions proceed faster and go further at higher temperatures. Also, higher water temperatures often cause a higher chlorine demand, requiring an increased disinfectant dose and resulting in higher DBP formation potential. Corrosion control effectiveness can be related to water age. With increased detention time there are impacts on the effectiveness of phosphate inhibitors and pH management in poorly-buffered waters.

Tracer studies have been performed to calculate water age throughout a distribution system, calibrate water quality and hydraulic models, and to enhance the study of water age in relation to water quality parameters such as chlorine residual or trihalomethanes (USEPA). Tracer studies can utilize injected chemicals such as fluoride, or calcium chloride. Alternatively, in systems with multiple sources with varying water quality characteristics (such as differences in water hardness or conductivity); these natural constituents can be used as the tracer. Finally, during transitional periods in system operation, such as changeovers from chlorination to chloramination, the resulting constituents can be traced. Other utilities have taken advantage of a fluoride system shut down, use of alternative water sources, or a switch in coagulant to trace water through the distribution system. Mathematical models that represent the hydraulic behavior of the movement of water have been used to estimate water age in distribution systems (Clark and Grayman, 1998). Water quality models can be used in conjunction with hydraulic models to predict concentrations of chlorine, DBPs, and other constituents in a distribution system (Vasconcelos et al., 1996).

There are several indicators that may suggest high water age. These include aesthetic considerations that may be identified by consumers (odor, taste), as well as the results of distribution system monitoring efforts. It should be noted that indicators can be triggered by factors other than water age, such as insufficient source water treatment, pipe materials, and condition/age of distribution system.

Chapter 4. Drinking Water Treatment

Drinking water sources can be surface water (springs, wells, lakes, reservoirs) or groundwater. Accordingly, depending on the source of origin and its particular physicochemical and microbiological characteristics, water should be appropriately processed to comply with the requirements of the existing legislation on "water for human consumption" (Directive 98/83/EC).

In general, groundwater meets the requirements of the Drinking Water Directive 80/778/EEC, resulting to the fact that groundwater does not need to be further processed or undergo slight treatment. However, there are cases where complicated and extremely expensive treatments are required, such as cases of particularly "hard" waters and waters containing high sulphate concentrations (SO_4^{2-}).

On the contrary, surface water never meets the quality standards laid down by the legislation on "water for human consumption". For this reason, surface water must undergo light to extensive treatment to remove undesirable ingredients, haze, odors / flavors, pathogenic microorganisms, hardness, etc.

Directive 75/440 / EEC defines the required quality of surface water intended for the production of drinking water. Based on this directive, "fresh" surface waters for the production of drinking water are classified into three categories according to the standards they meet:

- **class A1 surface waters** are characterized by comparatively low pollution expressed in terms of suspended solids, organic load, nitrogen and other pollutants. These waters undergo simple physical treatment and disinfection (eg rapid infiltration and disinfection).
- **Category A2 surface water** is suitable for water supply after smooth physical and chemical treatment as well as disinfection. They are usually subject to pre-chlorination, agglomeration, flocculation, sedimentation, filtration and disinfection (final chlorination).
- With regard to **A3 surface water**, it should be stressed that they are characterized by increased concentrations of organic matter, nitrogen, pesticides, hydrocarbons, phenols and some other pollutants, making them suitable for water after advanced physical and chemical treatment (e.g. pre--chlorination, agglomeration, flocculation, precipitation, filtration, adsorption, ion exchange and disinfection).

There are also alternative water sources, such as desalination and others.

4.1 Surface Water treatment

Surface water sources may be easily contaminated by animal and human wastes, and chemicals from runoff. Surface water may also be at risk of algal blooms. Due to the potential for contamination, surface water is not recommended as a source of drinking water unless treated appropriately.

The surface water treatment plants could be divided into three phases (Mitrakas, 2001; Darakas, 2010; Tsonis, 2003). The first phase is called pretreatment and includes scraping, pre-polishing and mixing. The second phase refers to the primary treatment comprising the steps of flocculation, coagulation, refining, ozonization and adsorption. In the last phase called secondary treatment, water is disinfected by applying various methodologies such as chlorination, ozonization and ultraviolet radiation (Figure 4 & 5). During pre-treatment, the surface water passes from the scattering stage. If surface water is classified in categories A2 and A3, it is considered necessary to proceed to disinfection. This is necessary to prevent the growth of pathogenic microorganisms and algae and to contribute to the oxidation of substances that cause undesirable odors and flavors. The most commonly used disinfectants are chlorine (Cl_2) and potassium permanganate ($KMnO_4$). However, chlorine dioxide (ClO_2) and ozone (O_3) can often be used. Chlorine can be introduced into the water in the form of solid, liquid or gas while potassium permanganate is usually added as a granular solid which is completely water soluble. On the other hand, ozone is a gas generated on the spot with the introduction of pure oxygen or air. Of course, the choice of the most suitable pre-conditioning method depends on a number of factors such as application costs, mechanical equipment, etc.

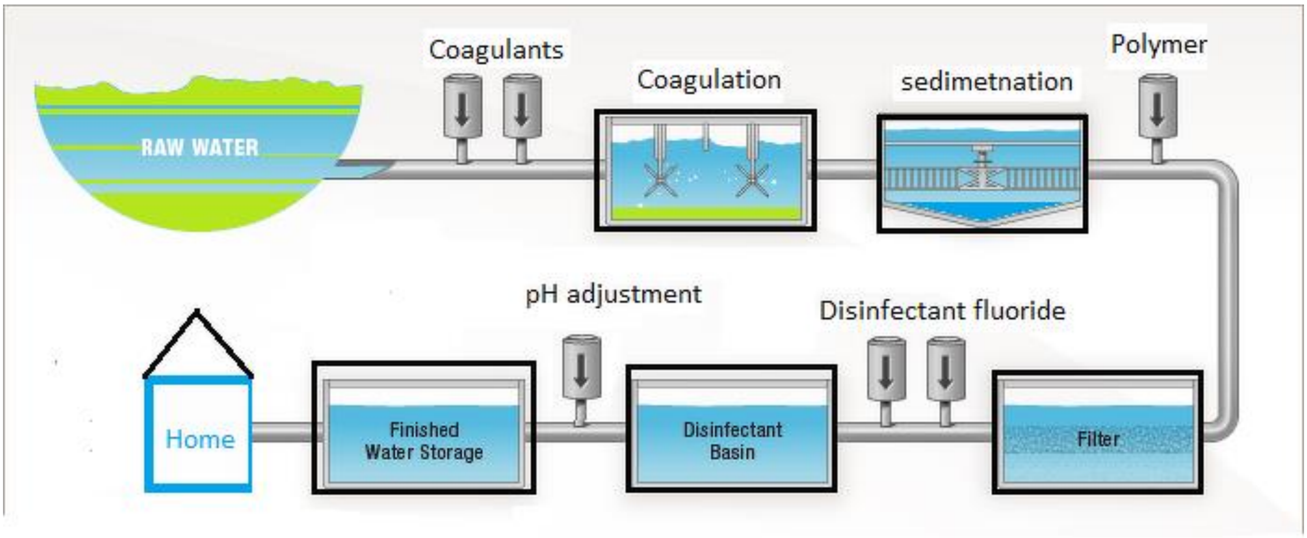


Figure 4. Indicative schematic representation of surface water treatment

Primary treatment begins with the flocculation step. Most organic and inorganic compounds that are dissolved in water can settle down within a reasonable amount of time. However, the settling time of the colloidal particles whose diameter is less than 0.001 m is very large and therefore it is necessary to remove them with specially designed processes. The high sedimentation time is due to the fact that the influence of their surface load compensates for the effect of gravity. The colloidal particles are divided into hydrophobic and hydrophilic. Hydrophobic colloidal particles are usually inorganic particles and have a negative surface charge. On the other hand, hydrophilic colloids are mainly derived from organic materials but also have a negative surface load due to the attachment of water molecules to their surface. The stability of these particles is due more to their affinity with water, as they are easily dispersed in the mass and less on the electrical charges they have. There are various mechanisms and chemical means by which flocculation of colloidal particles can be achieved. The most commonly used flocculants are aluminum sulphate or Alum, sodium aluminate ($NaAlO_2$), ferrous sulphate heptahydrate and calcium hydroxide. Also, sulfuric acid (H_2SO_4), sulfur dioxide (SO_2) and various polyelectrolytes are used as coagulating aids. When Alum is added to water, a chemical reaction that produces positively charged aluminum ions takes place. Then these ions adhere to the surface of the negatively charged colloidal particles, thereby neutralizing their negative charge and destabilizing them. Then coagulation follows where the destabilized colloidal particles are joined together to form agglomerates. Depending on the flocculant that has been used, there is a different coagulation mechanism. Thereafter, the refining step follows. Refining aims to remove particles by filtration through a porous medium. It includes many variations such as space filtration, surface filtration, etc. based on water filtration, gravity or pressure, with various combinations of filter media such as sand, anthracite and various synthetic fibers and films. Most water refineries usually consist of many twin sand beds depending on the size of the plant and the volume of water to be treated. The last two stages of primary processing of an indicator potable water treatment plant are completed with ozone and adsorption. At this stage, the main objective of ozonation is the oxidation of organic load and the removal of undesirable odors and flavors. Regarding the stage of adsorption, it should be emphasized that it is intended to remove organic and inorganic impurities. At this stage, the adsorption of the components in the adsorbent is effected through the electrostatic forces that draw the adsorbed component from the solution on the solid surface of the adsorbent. The forces or mechanism by which the adsorbed component is attracted to the surface of the adsorbent material may be physical or chemical without a clear identification between the physical and chemical electrostatic forces being developed. The most commonly used adsorbents are activated carbon and synthetic polymers. Activated carbon can be used to remove hundreds of organic impurities. It is usually added to the water in the form of powder, but sometimes activated carbon beds are formed in granular form from which the water passes to remove its organic impurities.

The first stage of the secondary process is the disinfection of drinking water aimed at destroying or inactivating pathogenic micro-organisms. Disinfection can be achieved by chemical and physical means. Disinfection is analyzed later in section 4.3 of the present deliverable.

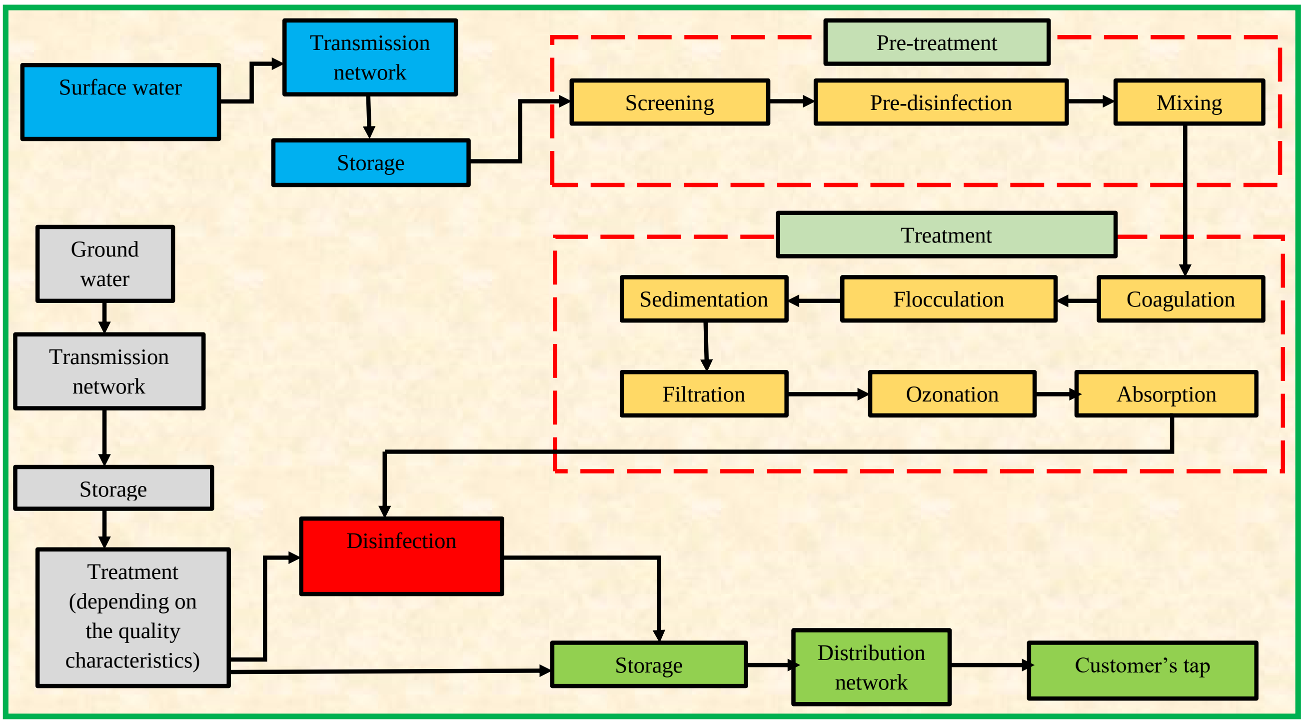


Figure 5. Surface and groundwater treatment phases

4.2 Groundwater treatment

Iron, manganese, hydrogen sulfide, calcium and magnesium are impurities that often occur in groundwater, leading to the application of methodologies to remove them. Under the influence of physicochemical and microbiological processes, the iron and manganese contained in the soil is converted from an insoluble form into a soluble form and released into groundwater. The main problem they create is the erosion of water treatment and storage equipment. Additionally, by the action of ferro-reducing bacteria undesirable by-products are produced which give the water a metallic taste (Barloková & Ilanský, 2010).

There are many ways to remove iron and manganese from underground water (Barloková & Ilanský, 2010). Some of these are air oxidation, the use of oxidizing agents (O_2, Cl_2, O_3, $KMnO_4$), and removal by alkalization, ion exchange, biological filtration and membrane utilization. The most commonly used methodology is air oxidation. Accordingly, soluble iron (Fe2 +) and manganese (Mn2 +) salts are converted into the sparingly soluble iron and manganese dioxide (MnO_2) salts. Thereafter, these sparingly soluble salts are removed by the use of filters. Of course, it should be noted that the rate of oxidation is significantly influenced by pH. For removal of iron, the pH should be equal to or greater than 7 while the corresponding value for the removal of manganese should be equal to or more than 8 (Ilanský et al., 2008). For this reason, it is sometimes preferred to convert $Mn_2{}^{+}$ to MnO_2 by using bacteria.

Groundwater may also contain hydrogen sulfide. Degraded organic materials, rocks and soil contain sulphate and sulphate compounds. Under anaerobic conditions, sulfur-reducing bacteria in their attempt to convert organic compounds into energy use sulphate and sulfate compounds to produce undesirable hydrogen sulfide (Faust & Osman, 1983; Lloyd, 2006). Hydrogen sulphide dissolves in the underground water and gives the water a smell of damaged egg. People have the ability to perceive the presence of hydrogen sulphide even at very high concentrations (0.003-0.2 ppm), making it necessary to apply techniques to remove it (EPA, 2003). Of course, it should be stressed that the presence of high concentration of hydrogen sulfide in drinking water can cause gastrointestinal disturbances, anorexia, nausea, drowsiness, vomiting, etc. (Health Canada, 1992). Several techniques are used to remove hydrogen sulfide, including aeration, ozone, ion exchanger, reverse osmosis and chemical oxidation (Einarsen et al., 2000; Janssen et al., 1999). Calcium and magnesium are often present at high concentrations in groundwater and are responsible for the hardness of the water. Generally, water is considered "hard" when it contains more than 100 mg / l $CaCO_3$. Extensive hardness can cause many problems, most notably salt deposition in processing equipment, storage tanks, transport piping, and household equipment. Some methods used to soften groundwater are "lime soda process", ion exchange and nanofiltration (Van der Bruggen & Vandecasteele, 2003).

4.3 Disinfection

4.3.1 Disinfection methods

Disinfection is a crucial water treatment method as it ensures that water is free of pathogenic micro-organisms causing water borne diseases. It is worth noting that in the U.S. cholera incidence was reduced by 90%, typhoid by 80% and amoebic dysentery by 50% after introducing disinfection in water treatment (Richardson et al., 2017; Ohanian et al., 1989). It is known that disinfection is affected by many parameters such as water temperature, water pH, type of existing bacteria, type of disinfection, disinfectant dose, contact time and inorganic and organic material existing in water. Although disinfection is the method for the removal (or inactivation) of pathogens, disinfection itself can result in the formation of inorganic and organic disinfection by-products (DBPs). DBPs are usually trihalomethanes (THMs) and haloacetic acids (HAAs).

Chemicals used as disinfectants include the use of chlorine and its derivatives, as well as the use of ozone, while the use of ultraviolet radiation is included in physical means. Chlorine gas, sodium hypochlorite, calcium hypochlorite and chlorine dioxide can be added to the drinking water to achieve chlorination. Chlorine has the ability to react with various compounds present in water. The amount of chlorine that reacts with these substances before starting its purely disinfecting action is called the required chlorine. For this reason, the amount of chlorine to be added to the water should be such as to cover the amount of chlorine required and additionally ensure that the residual chlorine content is at least 0.1 mg / l at the end of the distribution network (EPA, 2011).

In recent years ozone is used to decontaminate water. Ozone is produced with the aid of ozonizers from either pure oxygen or atmospheric air. The application of ozone has several advantages. It has rapid and strong disinfecting action, it does not produce trihalomethanes and it does not alter the odor and taste of water. Ozone is a powerful disinfectant able to inactivate Giardia or Cryptosporidium, not inactivated easily with other methods. However, it does not have residual action, breaks down quickly, requires high capital and operating costs and requires careful use and continuous power supply (Table 4).

Ultraviolet radiation can be used to decontaminate drinking water. The application of 250-265nm wavelength radiation is particularly effective for the inactivation of pathogenic microorganisms since at this wavelength the maximum radiation absorption is obtained from the genetic material of the microorganisms.

Of course, all microorganisms do not have the same sensitivity due to factors such as chemical composition and cell wall thickness. This method does not require the expense of a large sum of money and does not lead to the production of undesirable by-products. On the other hand, the devices have the drawback of decreasing performance over time. There is also the possibility of repaired cells damaged by UV radiation.

Although there are many methods used for disinfection purposes, chlorination is the most widely used. Liquefied chlorine gas or sodium hypochlorite solution (sometimes the term "chlorine" is used) is added in water (EPA, 2011). Alternatively, chloramination is used. This process involves the formation of monochloramine from ammonia and chlorine dosed in water. Chloramination requires a good process control as there are implications in taste and the formation of by-products (Table 4). Comparing the capability to ensure water without pathogens, chlorine is better than monochloramine, as chlorine is capable of maintaining a residual in distribution, able to react with other pathogens met in the distribution network. However, while chlorination may result in the formation of trihalomethanes (THMs), chloramination does not form THMs (Table 4).

Chlorine dioxide is also used for disinfection purposes. Although it is more powerful than chlorine and does not form THMs when reacting with humic substances, chlorine dioxide is generated on demand and it is substantially more expensive (Table 4).

Other chemical disinfectants include copper silver ionization and hydrogen peroxide. However, it is not scientifically verified that copper silver ionization is an effective disinfectant. Hydrogen peroxide is not used for drinking water disinfection as it is unstable in storage and its effectiveness in bacteria and viruses is questioned.

The disinfection processes and their key advantages and limitations are given in Table 4 (Tsitsifli & Kanakoudis, 2018).

Table 4. Basic disinfection processes, their advantages and limitations (Tsitsifli & Kanakoudis, 2018).

Disinfection process	Advantages	Limitations
Chlorination	Effective disinfectant; residual in distribution	By-products formation; loss of residual when water age is increased
Chloramination	Stable residual; less odour and taste issues	Less effective disinfectant; needs good process control to avoid taste and odour issues
Chlorine dioxide	More effective than chlorine at higher pH; less by-product issues	Inorganic by-product formation
Ozone	Effective disinfectant	Residual inefficiency; difficult to process; expensive technology
UV	Insignificant by-product implications	Less effective than chlorine; no residual

4.3.2 Disinfection effects

One of the major concerns about disinfection processes is the formation of by-products that can be dangerous for the human health. DBPs are formed due to the disinfectant overdose or inappropriate use. Organic and inorganic compounds react with the disinfectant and form by-products, organochlorine ones and inorganic ones. Organic compounds include trihalomethane (THM) and haloacetic acids (HAAs). The first researches on DBPs appeared in the 1970s, when Rook and others identified chloroform and other THMs in drinking water (Richardson et al., 2007; Rook, 1974; Bellar et al., 1974). The formation of these DBPs are related to the existence of organic matter in water, water pH and temperature and the type of disinfectant used. Except of organic by-products, inorganic by-products are also formed such as chlorate and bromate related to the type of disinfectant. The problem is even bigger as DBPs are formed along the water distribution network depending on the retention time in storage tanks and pipelines, as well as the disinfectant dose being able to maintain a residual along the distribution network (and especially its dead-ends). Regarding chlorination, chlorine residual is considered as the most accepted and reliable indicator for real time control of bacteria. Research has not revealed any micro-organism that meets all criteria to become a reliable indicator for disinfection efficacy.

DBPs may have adverse effects on human health. Extended research on the topic showed that DBPs are blamed for cancer and reproductive / developmental effects (Richardson et al., 2007). Sadiq and Rodriguez (2004) reported on the THMs effects in human health, impacting negatively to human organs such as liver, kidney and the nervous system, have negative reproductive effects and potentially cause cancer (Sadiq & Rodriguez, 2004). Today, THM side effects on humans' health are being studied in-depth, such as infertility, teratogenicity, kidney and liver inefficiency, effects on the nervous and hematopoietic system (King & Marrett, 1996). Several epidemiological studies focus on the harmful effects of chlorine by-products and link their increased concentrations with an increased risk of various forms of cancer growth (King & Marrett, 1996).

Although it is believed that only surface waters, due to their organic load, react with disinfectants forming DBPs, they can also be formed in groundwaters where anthropogenic contaminants are found. More than 600 DBPs are reported in the literature (Richardson et al., 2007; Boorman et al., 1999). Some of the DBPs are regulated and others are considered as emerging DBPs as they have lower occurrence levels and toxicological effects. Richardson et al. (2007) studied the quantitative occurrence and the health effects of 85 DBPs concluding that drinking water is a complex mixture and thus there are synergistic effects. People are exposed not only to water through drinking but also through other activities such as bathing, cleaning, washing (dermal and inhalation exposure) etc. Additionally, studying the effects of individual DBPs does not reveal the actual situation as groups of DBPs exist in water at different concentrations, having different synergistic effects. THMs include chloroform, bromodichloromethane, dibromochloromethane, and bromoform (Richardson et al., 2007).

Regulations or guidelines to control DBPs and minimize consumers' exposure to potentially hazardous chemicals maintaining adequate disinfection are set by many organizations, such as U.S. EPA, the World Health Organization (WHO) and the European Union. U.S. EPA has set 100mg/L as the maximum contaminant level for total THMs (total concentration of four THMs), while WHO guidelines set chloroform concentration to 0.2mg/L, chlorodibromomethane and bromoform to 0.1mg/L each and bromodichloromethane concentration 0.06 mg/L. European Union guidelines set total THMs concentration to 0.1mg/L. Even the new guidelines that will be included in the updated drinking water directive set the same value of total THMs but encourage water utilities to pursue lower concentrations without affecting disinfection. Many water utilities trying to comply with the new regulations changed their disinfection practices using other disinfectants such as ozone, chlorine dioxide or chloramines in primary treatment and chlorine as a secondary disinfectant. However, the alterations in disinfectant methods may raise new issues and problems. In Greece the maximum acceptable level of total THMs is set by the Joint Ministerial Decision (Y2/2600/2001) to 0.1mg/L, complying with the EU Drinking Water Directive 98/83/EC.

To evaluate the risk posed by multiple contaminants in water, the Relative Health Indicator (RHI) was developed by Seidel et al. (2014). RHI is a semi-quantitative indicator that takes into consideration both cancer and non-cancer health outcomes from the exposure of various contaminants (chemical and microbial) found in water. DBPs are listed as one of the top ten risks at national level in the U.S.

4.3.3 Predictive models

DBP concentrations differ at the storage tanks and within the water distribution network (WDNs) and especially in their dead-ends. Reaction time is the key factor, as longer reaction time leads to higher consumption of residual disinfectant and results in more formation of DBPs (Chen & Weisel, 1998; Rodriguez et al., 2000). Chen and Weisel (1998) and Rossman et al. (2001) showed that HAAs degrade in WDN's dead-ends. pH and temperature are proportional to THMs formation, but pH effects vary for different DBPs (Sadiq & Rodriguez, 2004).

Many predictive models have been developed for the DBPs formation. Sadiq and Rodriguez (2004) reviewed models based on laboratory studies and/or real field data. The first models for chlorinated DBPs appeared in 1983 (Minear & Morrow, 1983) predicting the formation of total THMs, while the first models for other DBPs appeared in 1994 (Ozekin, 1994). Many models followed, some of them based on laboratory data and others on field data. Field studies compared to laboratory ones take into consideration the effects of the distribution system on residual disinfectant concentration and DBP formation as they measure or observe human exposure (Sadiq & Rodriguez, 2004). Another difference is the contact time, that can be easily estimated in laboratory studies, needs tracer studies or hydraulic simulation models in field studies. Prediction models are based on empirical relationships or kinetics involved during chlorination.

DBPs formation depends on the water quality and several operational parameters related to disinfection. It is accepted that DBPs formation varies from one place to the other. The developed predictive models are based on many parameters such as temperature, pH, reaction time, dissolved organic carbon, chlorine dose, initial residual chlorine etc. The study of Sadiq and Rodriguez (2004) presents the predictive models developed and their parameters (Table 5). Several studies showed that DBPs formation is proportional to temperature. Micro-organisms increase as temperatures increases, thus higher disinfectant dose is applied during the summer period, resulting in high DBPs concentrations. The conditions affecting the disinfection efficiency and the requirements to maintain disinfectant residuals simultaneously affect DBPs formation (vicious cycle). Several studies [16] showed that THMs concentrations are higher within the WDN compared to the storage tank. This is also due to the existence of organic matter in the biofilms located in the water pipes walls. Organic matter in water is another parameter affecting proportionally DBPs formation.

Table 5. DBPs predictive models' parameters (based on Sadiq & Rodriguez, 2004)

Parameter		**Units**
Br-	Bromide ion	mg/L
Cl2	Initial chlorine concentration	
pH	pH	
T	temperature	o C
NVTOC	Non-volatile organic carbon	mg/L
TOC	Total organic carbon	mg/L
D	Chlorine dose	mg/L
t	Reaction time	hrs
UV	UV absorbance at 254nm	cm-1
TTHMo	Initial total THM concentration	
Flu	fluorescence	%
Co	Residual chlorine at the treatment plant after chlorination	mg/L
α	Parameter depending on location which chloroform is predicted	
ε	Random error	
Ch-a	Chlorophyll-a	mg/m3

DOC	Dissolved organic carbon	mg/L

Predictive models are very helpful to the water utility managers, as they can help them during decision making, for example setting disinfectant dose, the contact time, adjustment of pH, etc. in order to reduce the DBPs formation and at the same time maintain the required disinfectant residual. These models can be also used to identify the locations for boosters in order to maintain the required levels of disinfectant residuals and reducing the DBPs formation. Water sampling points can be identified for water quality control using such models. This is why modelling and optimization tools are very helpful.

Chapter 5. Conclusions

The present deliverable presents a joint methodology on water quality assurance in water intake points (water resources) and the water distribution system serving as an early-warning system (EWS) based on the water quality monitoring and water quality simulation. The methodology takes into consideration both predictive and corrective actions. Predictive methods are risk assessment tools such as the Water Safety Plans and the implementation of HACCP and ISO 22000. Corrective actions are the well-known methods used for water treatment. These methods are described in this deliverable.

Also, the deliverable includes an assessment of the factors affective drinking water quality, both physico-chemical and microbiological. Water age is part of the methodology as an important factor influencing water quality in water distribution networks. Water sampling and the analytical methods used for water analyses are also included in this deliverable.

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APPENDIX A. Water Quality data from Bulgaria

A1 Water Quality Institutional Framework in Bulgaria

According to the Water Act and the Health Act, a competent authority in the Republic of Bulgaria in the field of drinking water, bathing water and mineral water intended for drinking or used for prophylactic, therapeutic and hygienic purposes, incl. and bottled mineral waters is the Ministry of Health and its regional structures - 28 Regional Health Inspections (RIs).

Responsible for the implementation of the requirements of the legislation on drinking water, including the monitoring of the quality of drinking water in its entirety, are water supply organizations, in their capacity as structures carrying out the activity of water supply for drinking and domestic purposes.

National drinking water legislation is fully harmonized with the EU Directives and is in the process of implementation. The main regulations governing this area are:

- Ordinance No. 9 on the quality of water intended for drinking and domestic purposes (SG, issue 30 of 2001) (Directive 98/83 / EU);
- Ordinance No. 12 on the quality requirements for surface water intended for drinking water supply (SG, issue 63 of 2002) (Directives 75/440 / EEC and 79/869 / EEC);
- Ordinance No. 3 on the Conditions and Procedures for Investigation, Design, Approval and Operation of Sanitary and Protective Zones around Water Sources and Drinking Water Supplies and Mineral Water Sources Used for Medical, Prophylactic, Drinking and Hygienic Needs. 88 of 2000).

According to the above, as well as other legal acts, the Ministry of Health, respectively. RHIs carry out state health control of drinking water, bathing water, mineral water, water sources and water supply facilities and facilities, sanitary protection zones, bathing places in open water areas, etc.

The activities of the RHI in the field of drinking and bathing water include the following main areas:

- ✓ Monitoring (sampling and laboratory analysis) of drinking water quality - in all settlements in the country at the point of its leakage from the crane with the consumer, as well as raw water from drinking water sources, water at different stages of treatment and its delivery to the "final consumer", water from self-supplied water supply, water from "public local water sources". RHIs are obliged to carry out at least 50% of the full volume of surveys to be carried out by water companies. The information below about drinking water quality in the country is based on data from the Health Insurance Institute.
- ✓ Control (inspection) of the sanitary and hygienic condition of the facilities and facilities for central drinking and domestic water supply - water sources, water intake facilities, sanitary protection zones (POPs), drinking water treatment plants (PSWs), chloratorine and other water stations , reservoirs, self-watering facilities, “public local water sources”, etc., as well as bathing areas; coordination of project documentation for sanitary protection zones of water sources for drinking and household purposes and project documentation of water supply facilities and networks, participation in admissions committees for such sites.
- ✓ Undertaking administrative penalties (prescriptions, acts, penal decrees, suspension orders, property sanctions, removal from work, etc.) and other measures to identify non-compliance with drinking water quality and violations of sanitary and hygiene requirements for water sources , water supply facilities and facilities, sanitary protection areas, bathing areas, etc.
- ✓ Study and analysis of the problems with drinking water and bathing water, participation in the preparation of projects and programs for solving them.

- ✓ Performing paid analyzes of drinking water at the request of individuals and legal entities.

A2 Water Quality Testing Methods

With respect to the monitoring and requirements for drinking water quality, it is necessary that the laboratory equipment used by the operator operating the water supply system be able to carry out as many analyses as required by the relevant regulations (Ordinance 9 on drinking water quality) and be accurate as a research method. Current laboratory equipment limits the number of indicators tested and requires much of the research to be outsourced, which involves a long time for sample analysis and high costs. The laboratory equipment provided in the project will enable the investigation of a large number of indicators required by the relevant drinking water quality regulations, will enable the rapid and timely analysis of the samples, as well as the measurement with high accuracy and correctness.

APPENDIX B. Beneficiaries’ reports

The Project is co-funded by the European Regional Development Fund (ERDF) and by national funds of the countries participating in the Cooperation Programme Interreg V-A "Greece-Bulgaria 2014-2020".

WATER RESCUE

Water resources efficiency and conservative use in drinking water supply systems

Interreg
Greece-Bulgaria
WATER RESCUE
European Regional Development Fund

EUROPEAN UNION

WP	**4 Common Methodology & Tools**
Deliverable *Tool*	**4.4.3 Water Quality joint methodology** *Questionnaire*
Project Beneficiary No	**PB4**
Beneficiary Institution	**Municipality of Kardzhali**

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The contents of this report are sole responsibility of the Municipality of Kardzhali and can in no way be taken to reflect the views of the European Union, the participating countries the Managing Authority and the Joint Secretariat.

Table of Contents

Name of the organization/institution: Municipality of Kardzhali
Beneficiary number: PB4

1 Water Quality Institutional Framework

Please present briefly the legislation (in Bulgaria) regarding water and in particular drinking water.

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Study and analysis of the problems with drinking water and bathing water, participation in the preparation of projects and programs for solving them.

Performing paid analyzes of drinking water at the request of individuals and legal entities.

2 Water Quality Testing Methods

- Please describe how water quality is examined (what are the methods, etc.) according to your experience
- Please describe the water quality problems you are facing and how the pilot action (supply of the ….) will resolve the problem
- Please describe how you plan to use the equipment

- The flowmeters included in the project will help to locate sections of the water supply system where there is a suspected loss or theft of water, and after their installation very accurately and quickly it will be possible to identify possible accidents in those sections.
- With respect to the monitoring and requirements for drinking water quality, it is necessary that the laboratory equipment used by the operator operating the water supply system be able to carry out as many analyzes as required by the relevant regulations (Ordinance 9 on drinking water quality) and be accurate as a research method. Current laboratory equipment limits the number of indicators tested and requires much of the research to be outsourced, which involves a long time for sample analysis and high costs. The laboratory equipment provided in the project will enable the investigation of a large number of indicators required by the relevant drinking water quality regulations, will enable the rapid and timely analysis of the samples, as well as the measurement with high accuracy and correctness.

3 Comments

Please provide any comments.

Appendix A: