SMaRT-OnlineWDN Deliverable 7.1&2: Risk analysis, impact assessment, perception-Methodology

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WP 7 – Risk analysis and impact assessment

D7.1&2 Risk analysis, impacts assessment, perception – Methodology-

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Objectives
The first objective was to develop and to implement a comprehensive risk analysis methodology that deals with intentional contamination of water networks with chemical or microbiological substances by taking into account several risk components: i) the structural vulnerability of the networks to intrusion, ii) the propagation of the contaminant (chemical or biological) in the networks, iii) the sensitivity of the consumers to water quality deterioration, iv) potential internal and external regarding to the water utility comprising human health impacts and loss of economic activities.

The second objective was to realise a survey on consumers from the 3 involved end-users' to analyse their perception of drinking water quality and mobilisation capacity of the consumers in case of deterioration of water quality.

Summary

The SMaRT-Online[WDN] research project aims at developing an online security management toolkit for drinking water distribution systems based on the combination of monitoring/modelling. In the frame of this research project four research goals are defined as 1) Online simulation model considering hydraulic state and water quality, 2) Optimal location of sensors based on the online simulation model, 3) Online source identification of contaminants and 4) Risk analysis, identification and evaluation of impacts (real impacts and perceived ones).

The WP7 addresses this latter objective. The present documents presents the developed **methodology** for risk assessment and an approach to analyse the perception of consumers of drinking water quality and their mobilisation capacity to react in case of contamination.
The current report is divided into 2 main parts.

The first part details the **risk analysis methodology** developed within this project, fitting to the question of intentional contamination (chemical or biological) of a drinking water distribution network, based on one side on the characteristics steps of risk analysis (asset characterisation, threat characterization, vulnerability analysis; consequence analysis) and on the other side on the specificity of a water system build in a network structure and delivering a product used for alimentary devices either for consumers or for industrials. So intrusion and propagation analysis was made based on hydraulic simulation and transport model developed within this project to take into account the network specificity and its serviceability. Concerning water consumers and users, a typology has been build and sensitivity to contamination and consequences on both health and economic activity has been evaluated. Economic consequences on the utility are also taken into account. The risk analysis is achieved according to 4 levels of analysis:

- Consumers and water users sensitivity analysis
- Network vulnerability analysis
- Consequences identification and evaluation
- Risk assessment

The methodology is characterised by the use of Fuzzy logic and multi-decision aggregation methods in the 4 levels. This methodology gives answers to the utility to define the best localisation of sensors in regard with the propagation area and the sensitivity of the consumers and also to adapt its policy for crisis management.

The second part presents the methodology of a sociologic analysis, on water consumers, on the question of **representation of drinking water: from perception on social mobilization**. The study is based on 2 main concepts: The role of trust in the water and risk management and the concept of “alarm raisers”. The first issue is to identify if people do question the water quality in case of a sanitary problem. Secondly, if it is possible to identify potential responsible for population in such crisis and identify what kind of authority people alert? This work was driven after elaboration of a questionnaire and a 20 minutes call phoning interview. The data of the survey data issued from 200 successful calls within consumers of the 3 end users were analysed with Multiple Correspondence Analysis (MCA) and Hierarchical Ascendant Classification (HAC). The analysis achieved a characterisation with 2 axes: trust and involvement of the consumers.

This document ends by a conclusion and perspectives of economic evaluation in the objective of cost benefit analysis of the online security management tool.

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1 Introduction

The main objective of the SMaRT-Online^{WDN} research project is the development of an online security management toolkit for water distribution networks that is based on sensor measurements of water quality as well as water quantity. Its field of application ranges from detection of deliberate contamination (chemical or biological), including source identification and decision support for effective countermeasures, to improved operation and control of a WDN under normal and abnormal conditions (dual benefit). Detailed information regarding contamination sources (localisation and intensity) is explored by means of an online running model, which is automatically calibrated to the measured sensor data. In this project, the technical research work is complemented with sociological, economical and management analysis. Four main research goals are defined, 1) Online simulation model considering hydraulic state and water quality, 2) Optimal location of sensors based on the online simulation model, 3) Online source identification of contaminants and 4) Risk analysis, identification and evaluation of impacts (real impacts and perceived ones). We are focusing in the current document on two aspects: i) risk identification and assessment, ii) sociological analysis of the perception of consumers and their level of confidence regarding to water utility and potential drinking water contamination. We are focusing here on sociological, economical and management aspects within this project completing the hydraulic approach.
Indeed water distribution network (WDN) is not limited to its technical aspects but consists in combination of water resources, the infrastructures (wells, network, pumps, treatment plants) that are both intrusion and propagation vectors, the utility (organisation) owner of the infrastructures who will be responsible to manage the crisis in case of contamination and who is concerned by monitoring infrastructure to allow early warning. The system involves also the consumers who are the clients of the utility and who are besides the resource and the natural environment, the potential victims in case of contamination. A clear distinction is made between domestic consumers who will drink water or use it for toileting or washing and the professional consumers, industrials or handy crafters, using water for their activity: in products preparation (i.e. alimentary products); in the distribution of foods (restaurant), in health or service activities (dentist, hairdresser…). So, one can imagine that the consequences will not be the same depending on the water use and the type of consumer. To give an answer to this question it is necessary to characterise the consumers in front of the threat and in front of the consequences of a contamination. This can be done with sociologic or economic approaches, looking at what they fear or what they will lose in terms of wellbeing, health, revenue … in case of contamination. This will be taken into account in the first part of this report within the risk analysis. One of the objectives of SMaRT-Online^{WDN} research project is the development of an online security management toolkit, relying on sensors and early warning, so analysing the consumers behaviour could help besides hydraulic simulations and transport model to highlight potential links between the intrusion and the impact on consumer's locations.
More directly, concerning the consumers, another issue seemed to be interesting to be investigated within this project by a sociologic approach, it is the perception and behaviour of the consumer as potential reliable sensor. Dealing with such a question needs to interview people and to analyse their answer, looking at: i.e. how they consume tap water? How they know the water system and its management? How they are taking attention to water quality and how much they are able to become acute "alarm raiser" and not only complainer or passive consumers? These questions are investigated in the second part of this report. Finally in the conclusion possible links with further economic evaluations are investigated in order to feed analyse of benefits of early warning for efficient crisis management purposes.

2 Risk analysis for water distribution networks

2.1 The context

The SMaRT-Online^{WDN} research project aims at developing an online security management toolkit for drinking water distribution systems based on the combination of monitoring/modelling. In the frame of this research project four main research goals are defined as 1) Online Simulation Model considering hydraulic state and water quality, 2) Optimal Location of Sensors based on the online simulation model, 3) Online Source Identification of Contaminants and 4) Risk analysis, identification and evaluation of impacts (Piller, 2011). This latter objective constitutes one of the objects of the present document. Thus the proposed approach focuses on a specific event: the intentional contamination of the water distribution network (WDN) related to the intrusion of a biological or chemical contaminant. The following points clarify threats that will be taken into account into the proposed methodology:

- Intentional contamination

We assume that the contamination of the distribution network water is the result of an intentional attack. The motivation of the attacker/terrorist will be a part of the analysis as well as the technical feasibility of the contaminant intrusion.

- Intrusion of contaminant at the level of the distribution network

The contaminant is deliberately introduced into the WDN. The different assets composing the water distribution network will be the objects of a specific analysis in order to determine if it could constitute a potential intrusion point in accordance with the chosen pathways. Production and storage system will not be considered as a potential target of the contamination event. Likewise the vulnerability of the water resource(s) will not be carried out in the risk analysis approach (the efficiency of the water treatment system for the removal of contaminant will not be addressed).

Production and storage will be considered as simple input points from where a certain concentration of contaminant could be introduced within the distribution system. Thus the consequences of contaminant injection at the level of the production system or the storage systems would not be specifically analysed.

- Chemical or microbiological contaminant

The analysis will be restricted to these two types of contaminant. In order to simplify the impacts' evaluation, the radioactive component will be excluded from the analysis.

2.2 Risk analysis definition

The proposed Risk analysis methodology called **WARNING** for "**W**ater **A**nalysis **R**isks for **N**etworks **I**ncidents and u**N**expected events **G**uidance" is an adaptation of the RAMCAP framework (Risk Analysis and management for critical asset Protection) (ASME, 2006). This framework has been used by the U.S. Department of Homeland Security to improve risk analysis among various industry sectors. RAMCAP can be implemented according to 7 steps process as in Figure 1. The steps concern mainly: i) the description of the concerned asset and assess its critical, ii) the types of threats and assessment, iii) consequence analysis) iv) the vulnerability of assets to potential attacks, v) risk assessment and management.

Figure 1. RAMCAP steps process (ASME, 2006 , p 2)

Among a number of definitions of risk the RAMCAP framework selected the following "first-order" definition:

$$Risk = Consequence\ X\ Vulnerability\ X\ Threat \tag{1}$$

Adapted to our context the equation (1) defines the risk generated by the intrusion of contaminant in the WDN as the combination of the three following components:

- Consequences

The potential consequences of the water contamination are evaluated in terms of possible internalities and externalities regarding to the water utilities. Two main of consequences categories are defined: i) consequences on water utility that correspond to potential decrease of serviceability of the WDN and assets contamination (and ii) consequences on third parties that concern possible adverse effects for human health and loss of wellbeing, loss of economic activities or possible pollution of the environment.

- Threat

The RAMCAP framework defines the *Threat* as "the likelihood of a specific attack scenario directed toward a specific asset". It seems hard to estimate the likelihood of particular scenarios. In an initial approach the risk is analysed as a conditional risk with a maximal probability of occurrence (equal to 1). We assume that the occurrence of an attack is very high. This strong assumption leads to the simplification of equation (1). Then the risk assessment only focuses on *consequences* analysis and on the WDN *vulnerability* analysis.

- Vulnerability

The vulnerability concept enables us to estimate the level of success of the WDN contamination. This definition refers to two distinct objects:

- The WDN component as potential intrusion point, considering the analysis at the asset level
- The water consumption point that could be reached by the contaminant, considering the analysis as consumption node level

Hence, assess vulnerability requires taking into consideration both:

- The intrinsic vulnerability of the component of the WDN which could be considered as a potential point of contaminant intrusion (Cf. Part 2 Definition and assessment of WDN asset vulnerability)
- The magnitude of the spread of contaminant from the intrusion point to the water users.

Based on these observations, the equation (1) should be adapted for the WDN intentional contamination context by introducing the notion of *Criticality*.

- Criticality

The Criticality of the WDN components (assets) is the combination of the intrinsic vulnerability of the component with the magnitude of the contaminant spread within the WDN.

$$\textit{Criticality} = \textit{Intrinsic Vulnerability X Contaminant Spread Magnitude} \qquad (2)$$

Where the *Intrinsic Vulnerability* estimates the possibility of introducing contaminant into the WDN from a specific and predetermined point. To assess this possibility of intrusion both technical characteristics and the environment of the intrusion point are taken into consideration. The *Magnitude of the contaminant Spread* describes, from a determined intrusion point, the water flows within the WDN. This Magnitude corresponds at the spatial concentration of contaminant in the system. As the *Contaminant Spread* is dependent on hydraulics, hydraulic transport model is used to simulate the propagation of the contaminant throughout the WDN.

According to the previous assumptions, a specific definition of Risk is adapted to the context of "intentional contamination":

$$\textit{Risk} = \textit{Consequence X Probability of occurrence X Criticality} \qquad (3)$$

Risk = Consequence X Probability of occurrence X Intrinsic Vulnerability X Contaminant Spread Magnitude (4)

As we assume that the probability of occurrence is in the case of a conditional risk equal to 1, the Equation (4) can be simplified as follow:

Risk = Consequence X Intrinsic Vulnerability X Contaminant Spread Magnitude (5)

As the Spread of contaminant is linked to the hydraulics of the WDN the proposed approach gives a central position to the **WDN hydraulic model**.

2.3 Risk analysis methodology

It appears that the assessment of the Risk in case of intentional contamination of the WDN requires the combination of two objects in terms of time and space scales: intrusion point and consumption points. The *spread of contaminant* depends on hydraulics and water demand which are both dynamic. The variation of flows, water demand and consequently the spread of contaminant within the WDN can be described by hydraulic simulations. A WDN detailed hydraulic model combined with a transport model performs these simulations. The simplified flowchart of simulation in Fig. 2 describes the main input and the output data.

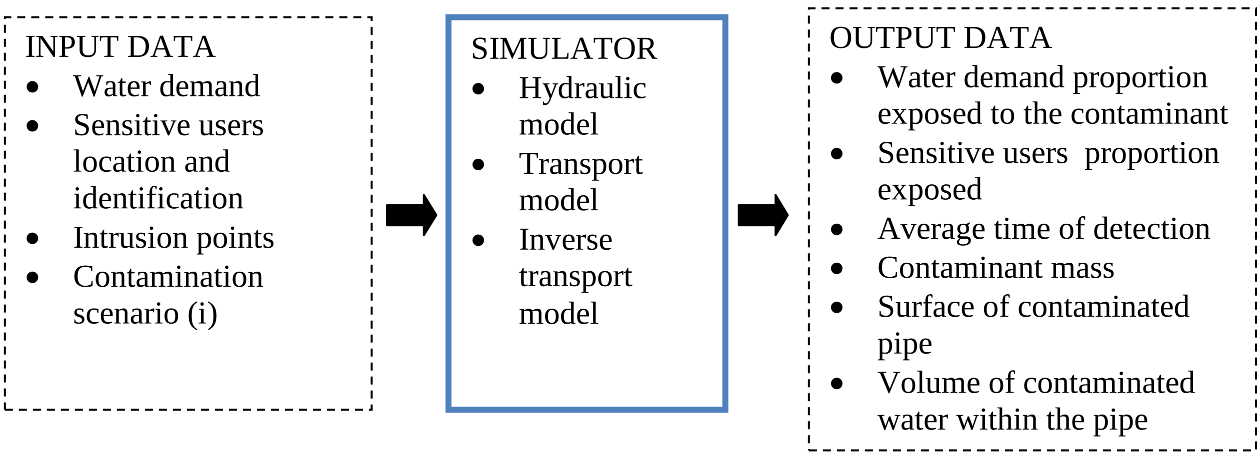


Figure 2. Simplified flowchart of simulation

The proposed approach is based on hydraulic simulations and requires a detailed hydraulic model. It constitutes the tool, which enables us to link the components of the risk: Consequence, Intrinsic vulnerability and Contaminant spread magnitude.

Based on risk components, developed methodology is fulfilled according to 4 main steps: 1) users sensitivity analysis, 2) WDN vulnerability analysis, 3) consequences analysis, and 4) risk assessment and dedicated factors measurement. The calculation of risk factors requires the aggregation of numerous sub-results derived from each enumerated steps.

The Figure 3 proposes a conceptual framework for risk analysis. It consists in 3 levels of aggregation that successively enables estimating of *Contaminant Spread Magnitude*, *Criticality* of the WDN Components and at the end the *Risk* for the intentional intrusion of contaminant.

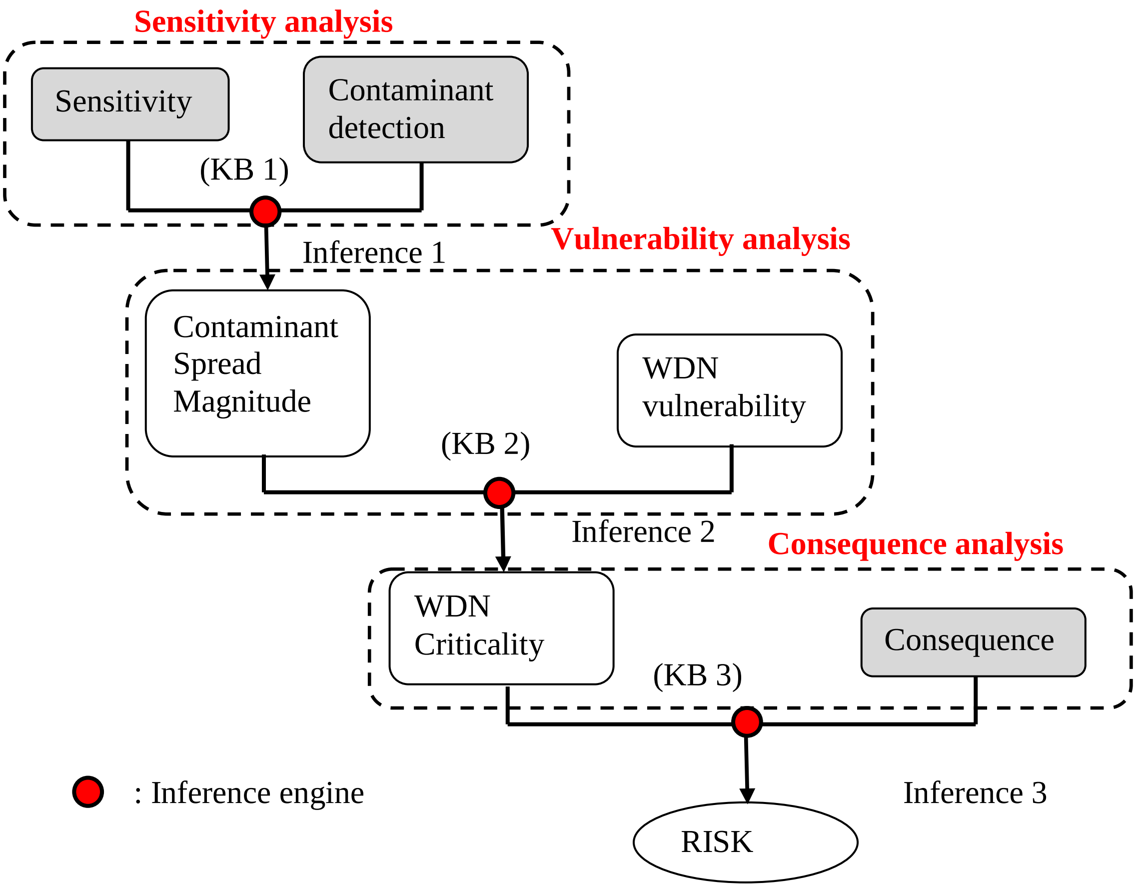


Figure 3. Conceptual framework for risk evaluation based on hydraulic simulation.

The factors in shaded boxes are the direct results of hydraulic simulations. The first level of aggregation, "Inference 1", evaluates the contaminant-spread magnitude. The concept of sensitivity, which concerns the water users, is indirectly used to assess the contaminant spread magnitude. Indeed the results of the simulation process will indicate for each contamination scenario the percentage of sensitive users exposed to the contaminant. In addition the location of existing sensors in the WDN helps to better designate contamination location. We assume that the average time of detection corresponds to the elapsed time between the contaminant intrusion and the detection by sensors. This delay is taken into consideration to assess the contaminant-spread magnitude in combination with the percentage of sensitive users exposed to the contaminant.

The second level, "Inference 2", consists in the assessment of the WDN components criticality as the combination of *Spread Magnitude* and *WDN intrinsic vulnerability*. The third and last level of aggregation is the combination of *Criticality* and *Consequences* in the aim of risk assessment, note that several types of risk can be measured depending on the type of considered consequence. A Fuzzy Inference System (FIS) carries out the three levels of the aggregation process.

It appears that risk analysis aims at estimating of potential risks by computing ad-hoc risk factors.

Factors are derived from intermediate results obtained from successive analysis: 1) sensitivity analysis, 2) vulnerability analysis and 3) consequence analysis.

The following sections highlight specific methodology to conduct each analysis and show the main intermediate results that serves for risk assessment.

2.3.1 Sensitivity analysis of users

The main challenge of the following task is to better understand the sensitivity of the water distribution users against a potential contamination of delivered water. It seems obvious that the sensitivity depends on both the water usages and also the intrinsic characteristics of users. One of the goal of the current task is to highlight the main dimensions of sensitivity in order to build consistent and reliable criteria that are able to sort or rank users. In order to be exhaustive and transparent, a multi-criteria analysis (MCA) approach was developed. Each step of the method was validated and amended by decision makers.

The present task aims at clarifying the following points:

- Define clearly the concept of sensitivity
- Identify all dimensions and aspects of sensitivity
- Define clearly the user and potential categories
- Build criteria according to the identified dimensionalities
- Better understand each considered criteria by defining potential sub-criteria
- Explore approaches and methods able to assess criteria and particularly qualitative ones
- Explore approaches and methods able to aggregate proposed sub-criteria and criteria
- Define a reproducible method that involves all these aspects

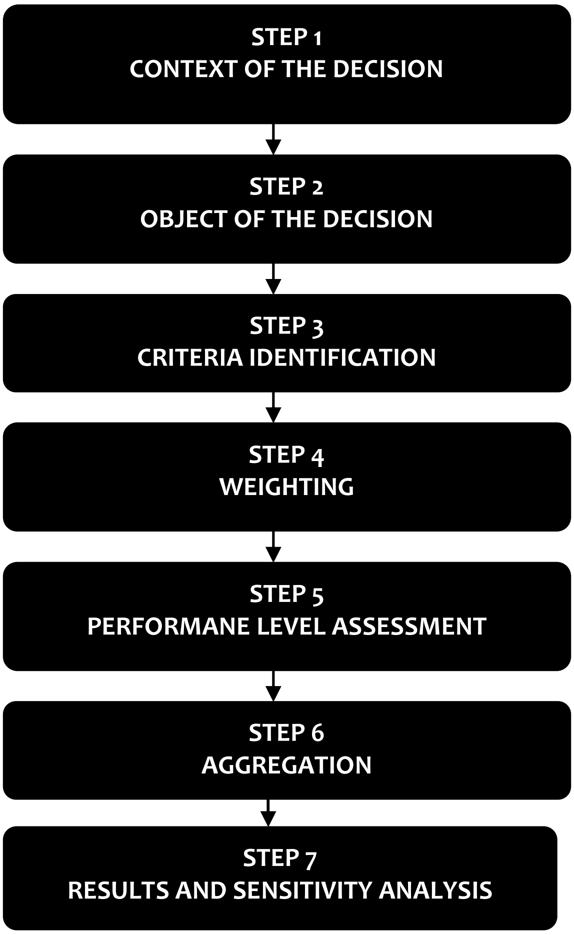


Figure 4. Main steps of sensitivity analysis.

The analysis of sensitive users is based on a multi-criteria decision approach following 7 main steps from the definition of the decision context until the results analysis as illustrated by **Figure 4.**

At the end of the process, all answers and intermediates information will lead to improve the developed method in order to build, to assess and aggregate the sensitivity criteria. The main objective is to elaborate a methodology that will enable the Water Distribution Network (WDN) managers to define the water users that are sensitive to the contamination of the delivered water. As a result, the users will be observed according to their sensitivity to the water distribution network contamination through the evaluation of ad-criteria. The proposed procedure allows ranking of users according to their sensitivity.

2.3.1.1 Context of the decision (Step 1)

In the frame of the SMaRT-Online^{WDN} project the proposed approach focuses on a specific event: the intrusion of a chemical or microbiological contaminant into the water distribution network (WDN) which means that treatment and storage asset are out of the boundary analysis. This event constitutes the frame of the multi-criteria analysis and influences the dimensions to be considered in the definition of sensitivity.

Safety plans and Water distribution network vulnerability studies list systematically the “sensitive users” or the “user in priority”. However the concept of “sensitive user” is addressed intuitively.

In this context, the decision to be highlighted addresses the following question: Is this water user sensitive to the contamination of the water supplied by the WDN? This leads to investigate the following sub-questions:

- How is the water user?
- What are the dimensions of the sensitivity that should be taken into account?

2.3.1.1.1 Sensitivity definition

The WDN managers have to guarantee water supply with desired quality and quantity without prejudice to the principle of uninterrupted public service. It means that the sensitivity of the WDN users can be defined both in terms of water quality and quantity. Service interruption could be one of the consequences of water contamination detection. Most of the time, contamination events have been detected/identified *a posteriori* through water analysis or because of epidemic outbreak or increase of the number of sick persons.

The SMaRT-Online^{WDN} research project aims at developing an online security management toolkit for drinking water distribution systems based on the combination of monitoring/modelling. One of the specific objectives of this project is to optimise the location of water quality sensors, which will permit through the online monitoring of the water quality the detection of contaminant flowing into the water network.

The optimisation of the sensor location for early warning seeks to optimise several objectives as the detection time in order to limit the spread of contaminant into the network. It aims at reducing the elapsed time between the intrusion of contaminant into the system and the water consumption or use. This period of time is prior to the contaminant detection and consequently prior to the interruption of the supplied water (cf. Fig. 5). In the current work, the concept of sensitivity is defined **in light of the water quality deterioration and be limited to the water quality aspects**. The lack of drinking water in terms of quantity deficiency is considered as one of consequences due to the water contamination.

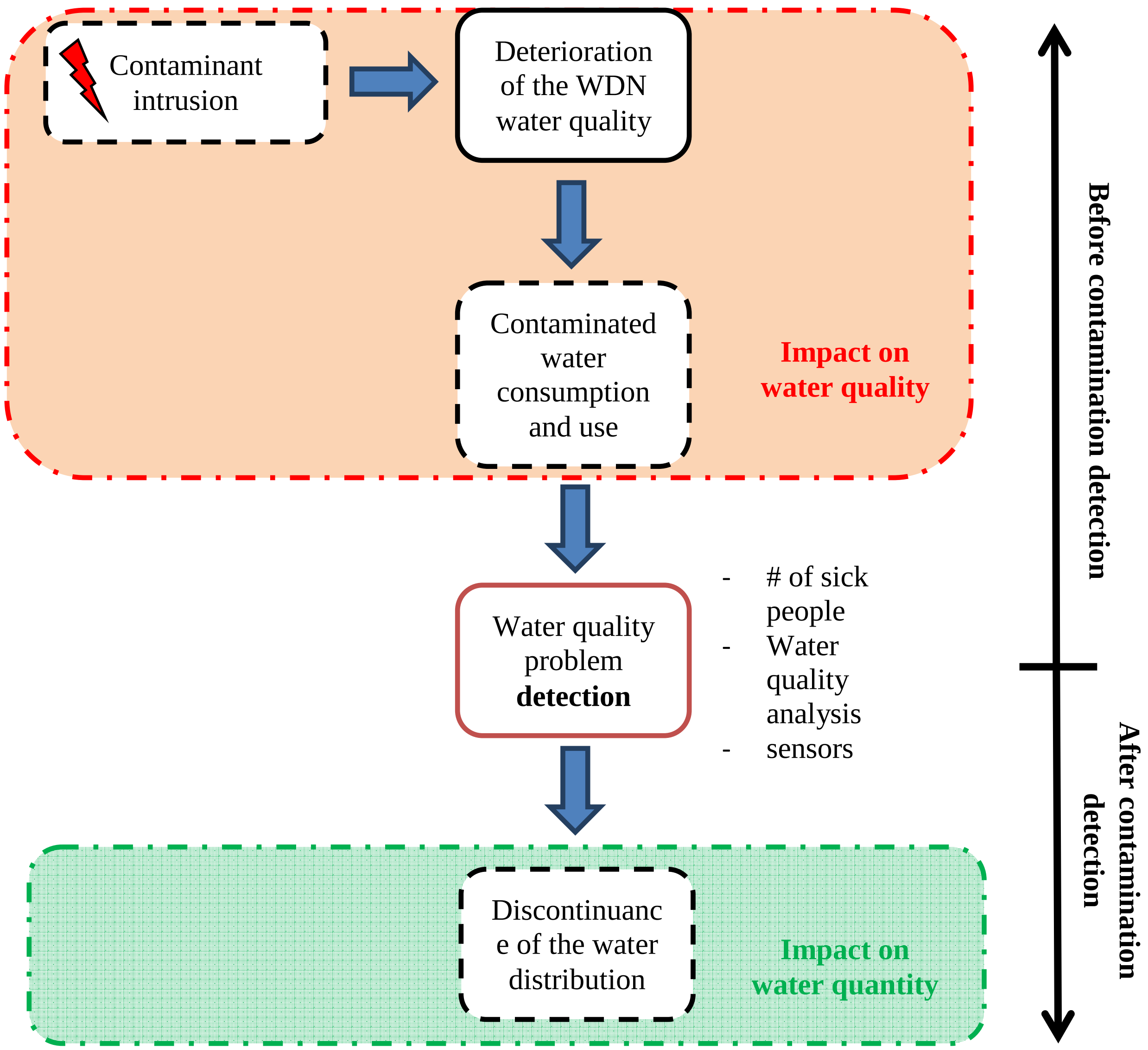


Figure 5. Contamination and impacts

2.3.1.1.2 Water user definition

The notion of sensitivity depends strongly on the **typology of the water use**. Indeed two different types of users can make the same use of water. For instance the patient at the hospital drinks water in the same way that the resident in his accommodation. But water in agro-processing factories is used as the main ingredient in the fabrication process or solvent to wash products and equipment. Thus, it is crucial to observe users according to their water uses. In consequence, the comparison of users will be achieved according to the use of water. This assertion defines the main hypothesis of the developed method. As described in **Erreur ! Source du renvoi introuvable.** four main categories of use can be defined:

- Water for human consumption
- Water for recreational activities
- Water for medical purposes
- Water for professional uses

a. Description of the different types of water use and users

In the following paragraphs different types of water user is discussed, and it is sketch in Figure 6. An exhaustive list of users is established. For each one, it contains the type of water use and the location where water is consumed or used. At the end it is possible, for each type of water use, to identify pair of ‘user/location’.

i. Water for human consumption

It corresponds to the domestic use of water: drinking water, water for food and hygiene. All the users included in this group (domestic users, office employees, schoolboys, hotel client…) are <u>human beings</u> (in opposition with companies, shops, factories…). The location where these users consume the water is materialised by private connection on the distribution network as well as places where people are gathered together for cultural, religious, sport or recreational event whether regular or exceptional.

ii. Water for recreational activities

This use of water concerns all locations where the water is the object or the physical device of recreational activities. This type of use has to be associated with places as aquatic park, swimming pool and municipal bath but also water jets and public fountains. In this case the users are individuals and not organisms.

iii. Water for medical purposes

It corresponds to the water used within the health facilities and the specific case of home-based patients of dialysis. Within the health facilities the water quality is particularly controlled and follows specific procedures. Indeed two main categories of water can be defined according to the level of treatment:

- The water supplied directly from the network and consumed without additional treatment. It corresponds to water for food, drink and standard hygiene, water for basic care for patients without particular risk, water for the cleaning of certain medical devices. We assume further that this use correspond to a <u>domestic use</u>.
- The water subject to additional treatment and enhanced quality monitoring. It corresponds to medical specific uses i.e. water for immune-compromised patients or water for dialysis.

In the case of home-based patients of dialysis the water used for the dialysis is submitted to a complete treatment process from filtration to inverse osmoses.

Both for health facilities and home-based dialysis water quality variations could have strong impacts on health. For this category of use final users of the water supplied are <u>individuals.</u>

iv. Water for professional activities

It concerns water used for industrial or service activities. It includes the industrial sector plus craft, commercial and services activities.

In this case the water user is not individuals but organisms or institutions (firm, company or shop). The location where the activity takes place is considered as the place where the water is used.

Any activities that use the water both in their process of production and for their employee (as a domestic use) are concerned. The process of production may concern agro-industrial or pure industrial activities as well as craft activities (restaurant, butchery, caterer, hairdresser, beautician…).

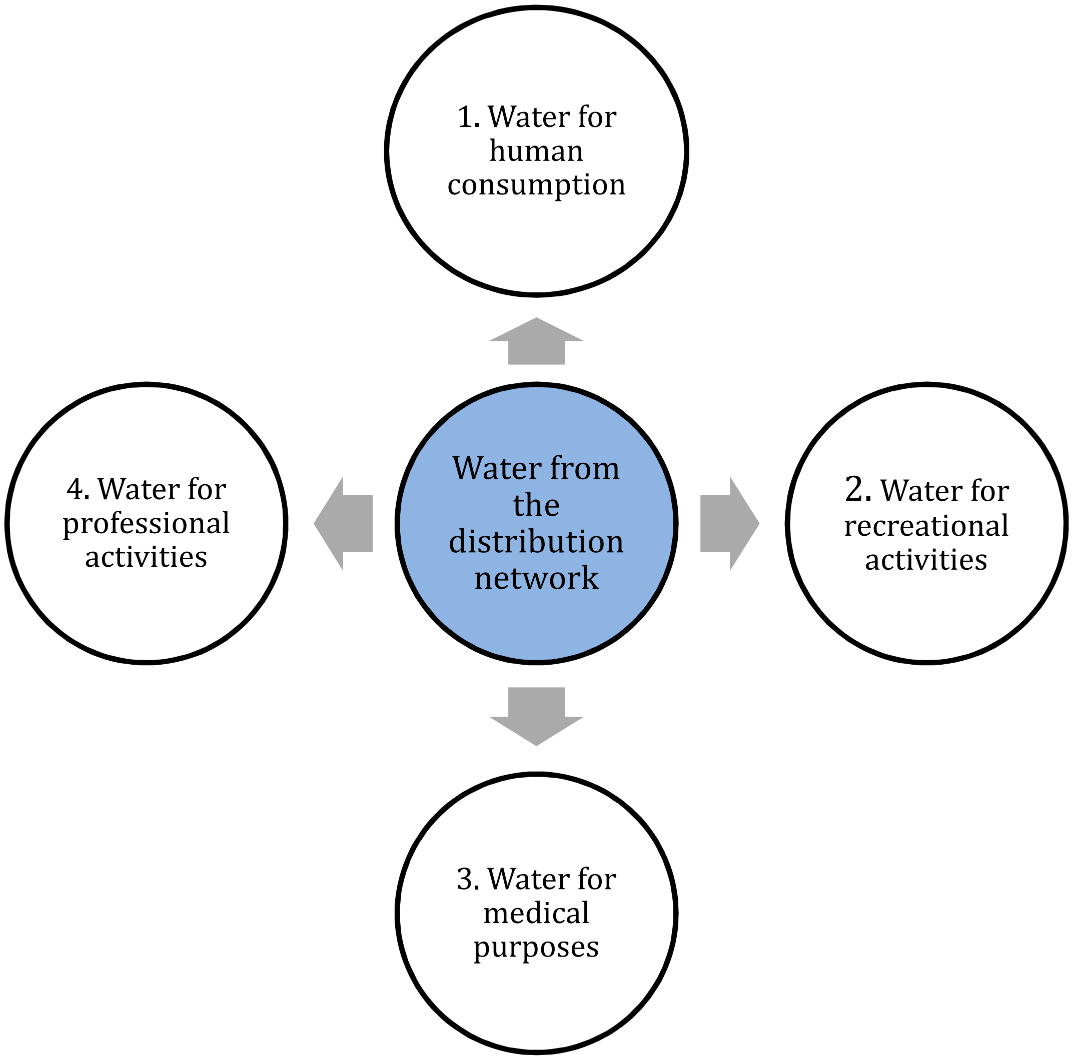


Figure 6. Typology of water uses

2.3.1.2 Object of the decision (Step 2)

Based on water uses, a typology of users could be built. Each user has to be necessarily associated with the location or place where the water is used or consumed for two main reasons:

- The description of the user location will provide information on the type of water use and the potential density of users.
- Thanks to the geographical coordinates of the user location it is possible to project the user on the GIS WDN representation and associate it to the closest node of the water distribution network hydraulic model. In this way the sensitivity of the user is transmitted to the node of the water system model.

The objective is to sort exhaustively the users into the 4 main predefined types of water use as shown in Tab. 1.

Table 1. Typology of use and water users sorting - summary table

Group 1 Water for human consumption		Group 2 Water for recreational activities		Group 3 Water for medical purposes		Group 4 Water for production process	
User	Location	User	Location	User	Location	User	Location
Resident / Inhabitant	Private house Hotel Collective housing	Swimmer	Swimming pool	Hospital patient	Hospital Clinic	Agro-alimentary industry	Agro-processing factory
Preschool child	nursery	Bather	Municipal baths	Home-based dialysis person	Private house	Electronic industry	Manufacturing firm
School child School boy	School Secondary school High school	Person attending places of worship	Places of worship (mosque, synagogue, church)	Other patients	Dental clinic Medical office Senior nursing home	Pharmaceutics industry	Manufacturing firm
Student	University	Children	Public fountains and water jets			Butchery	Butcher’s shop
Institutional / governmental / office employee	Governmental building Office					Bakery	Baker’s shop
Elderly	Retirement home					Caterer	Caterer’s shop
Persons practicing a sport except swimming	Stadium Sports ground Gymnasium Sport facilities					Hairdresser	Hairdresser’s shop
Cultural, religious, sport event participant	Public places Stadium Places of worship					beautician	Beautician’s shop
						Catering activities	Restaurant Cafeteria Canteen

2.3.1.3 Criteria and Sub-criteria identification (Step 3)

The following paragraph details the definition of criteria for each group. The construction of criteria requires the definition of exhaustive and independent dimensionalities of sensitivity. Each criterion has to describe a share of this dimensionality in consistent and non-redundant manner. The aim is to avoid potential bias into the decision process and make decision reliable according to preferences of stakeholders and the level of available information.

Because the users of the groups 1, 2 and 3 are individuals, it is possible to evaluate the sensitivity of the users of these 3 groups using the same criteria.

Contrariwise companies, factories or firms compose the group 4. Different criteria have to be introduced to assess the sensitivity of the users of this group.

i. Criteria for groups 1, 2 and 3

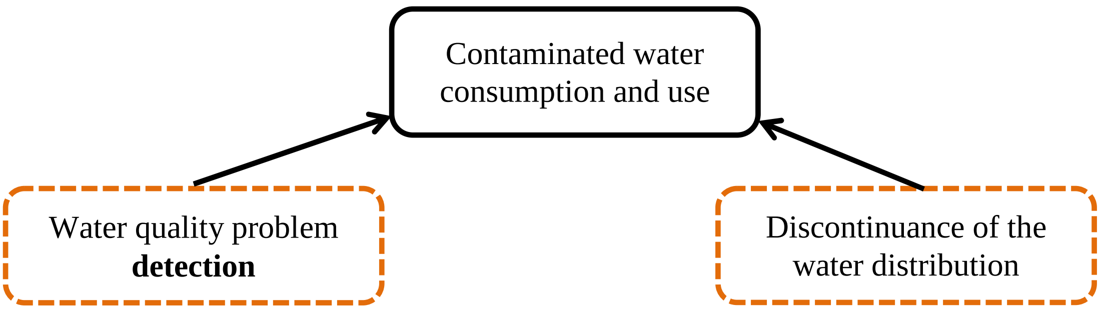
For the users belonging to the groups 1 to 3, the following 3 criteria are proposed to characterise the sensitivity of the users:

- Criterion 1: Attractiveness as attackers target

  By considering that the contamination of the distribution network water is the result of an intentional attack, the attractiveness notion is strongly linked to the motivation of the "attacker". This criterion takes into account the socio-political context and the scenarios established by the decision makers. The attacker seeks to harm specific targets. These targets can be described in terms of:

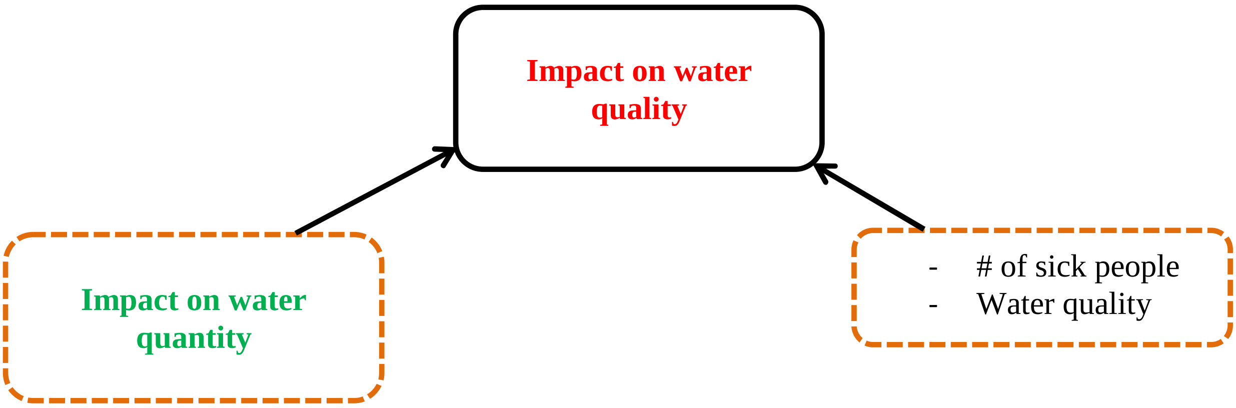
- Image and media attention: whatever the motivations of the attacker (ideological, social, political, personal) the choice of the target is in relation with the symbol represented by the target itself. Through the symbol represented by the target, the aim of the attacker is to focus media attention in order to diffuse a message.
  In consequence and according to the context of the risk analysis categories of users will be more attractive than others. For example embassies as a country diplomatic representation represents an attractive target in the case of an international conflict.

- Attendance rate and density of population: a busy public place represents for the attacker the opportunity to maximise the impact of the attack. Furthermore a higher number of victims are more effective in focusing media and public attention.



- Criterion 2: Level of frailty regarding the health state

In the context of intentional contamination of the WDN, contaminant (microbiological or chemical) could potentially affect the user's health because **the ingestion of contaminated water**. Certain categories of the population are more vulnerable as babies, the children, the pregnant women and the elderly. In the same way patients including immune-compromised persons have to be considered as sensitive users.



The characteristic of the user location gives the information regarding their health state. For example, a hospital welcomes elderly, pregnant human, babies and immune-compromised persons. In order to refine this notion of vulnerability, the age of the user in the given location can be added for evaluating the criteria.

- Criterion 3: Level of exposure

This third criterion deals with the notion of likelihood of ingesting contaminated water. We assume that the likelihood of ingesting contaminated water depends on the frequency of water consumption in a given location where the frequency depends on the type of location.

In fact it is possible to make clear difference between a patient in a dental clinic and patient hospitalised for 3 days. The patient at the hospital is probably more exposed to the contaminated water than the patient in a dental clinic.

According to the assumption that the frequency of ingestion depends on the type of location, the Tab. 2 establishes a link between the type of location and potential frequency of ingestion.

Table 2. Type of location and frequency of water consumption

Type of location	Frequency of water consumption
Hospital	At least 3 opportunities to consume water + water use for specific medical purposes
Residential	At least 3 opportunities to consume water : breakfast, lunch and dinner
School	At least 2 opportunities to consume water
Office (administration, bank, private company…)	7 to 8 hours of attendance per day: At least 2 opportunities to consume water
Sport facilities	Hydration after a physical effort. At least one opportunity to consume water
Accommodation / lodging	At least one opportunity to consume water

Figure 7 gives an overview on the considered criteria for sensitivity assessment of individuals (users) and how they are linked.

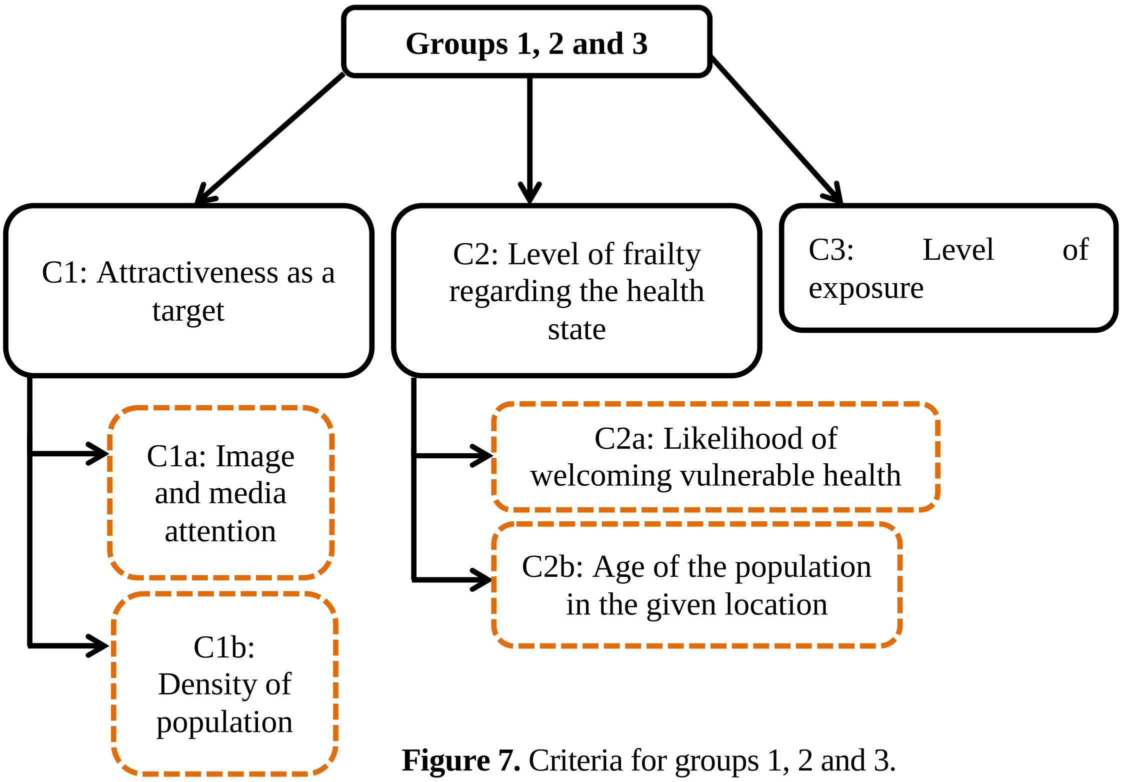


Figure 7. Criteria for groups 1, 2 and 3.

ii. Criteria for group 4

As for individuals we built criterion that enables to characterise the attractiveness of the attacker's target.

Then specific criteria adapted to the typology of the group 4 have to be defined. Indeed this group is not composed by individuals but by companies, firms and shops engaged in economic activities.

The use of the water in this case can be decomposed in 2 sub-types:

- The water used and consumed by employees as drinking water in the workplace;
- The water dedicated for industrial or production purposes.

It is possible to define criteria to characterise the sensitivity of the user for each subtypes of water use. As shown in Fig. 7, the criterion 2 is linked with the water used and consumed by employees in the workplace while criteria 3 and 4 are in relation with the water destined to industrial or production purposes.

- <u>Criterion 1: Attractiveness as attacker's target</u>

This criterion takes into account the political and social context and the scenarios retained by the decision makers. For example in the case of an eco-terrorism scenario the attractiveness of an animal testing laboratory is greater than a bioorganic farm.

- <u>Criterion 2: Number of employees</u>

This criterion concerns the water used and consumed by employees in the workplace.

The highest the number of employees is, the greatest the impact of the water contamination will be.

The number of employees allows making a difference between users within the same activity sector. For example a traditional bakery with 2 employees and an industrial bread factory that employs dozens of employees will not receive the same score for this criterion.

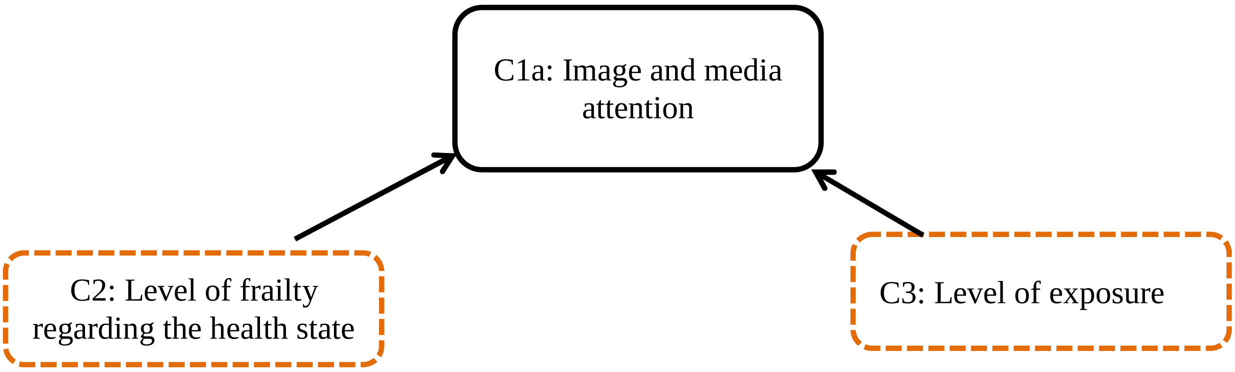
- <u>Criterion 3: Percentage of water bought to public WDN within the activity sector</u>

The Group 4 users are connected to the public water supply network. The water can be used both for the specific activity of the user and for "facility management" (drinking water, water for hygiene…). But certain industries drill private borehole to supply water dedicated to their activity in order to reduce cost or to increase the available quantity of water. Obviously companies equipped with private boreholes are not impacted by the contamination of the public WDN. The consequences of the contamination will be worst for industries fully supplied by the WDN.

In order to make this distinction, we propose to take into consideration the percentage of water bought to public WDN within the activity sector.

- <u>Criterion 4: Vulnerability of the activity regarding the water contamination</u>

The water contamination can disrupt **the orderly functioning of the activity**. We propose to observe the activity of the group 4 users according to the type of water use and the requirement in terms of water quality within the activity sector.



- <u>C4a: Type of preponderant water use within the activity sector</u>

We can identify a wide variety of water uses in the industry sector. Even within a single company it is possible to find such a wide variety of use.

(Petitpain-perrin, 2006) proposed to retain the following three main categories of water uses:

- Water as thermal fluid. In this case, water doesn't participate directly at the production process
- Water used upstream of the production process: raw materials washing and transport operations are concerned by this category
- Water used in the production process. In this case water can:
    - Be added as unique or important component of the end product;
    - Be an essential agent of the fabrication process;
    - Be used to wash products and equipment or to flush end products.

(Mouchet, 2006) proposed to characterise the water uses according to the following categories:

- A: Adding to the product as unique or important component of the end product *i.e.* bottled water, alimentary drinks and foods;
- B: Essential agent of the fabrication process without being in the composition of the end product (*e.g.* textiles, pharmaceutical and chemical industry);
- C: Washing of products and equipment/device (*e.g.* agro-alimentary industry), flushing of end product (*e.g.* electronic component industry);
- D: Thermal application (*e.g.* cooling, boiler feeding, heat transport…);
- E: Material and waste transport (metallurgy, sugar and paper industry…);
- F: Electrolytic process for surface treatment industry;
- G: Air conditioning;
- H: Facility management.

Finally Petitpain-Perrin and Mouchet's characterizations can be compared as presented in the Tab. 3:

Table 3. Water uses classifications

Water uses (by Petitpain-Perrin)	Classification proposed by Mouchet
Water as thermal fluid	D: Thermal application G: Air conditioning
Water used upstream of the production process	E: Material and waster transport
Water used in the production process	A: Adding to the product B: Essential agent of the fabrication process C: Washing of products and equipment F: Electrolytic process

- o <u>C'4b: Requirement in terms of water quality</u>

Water quality requirements are specific to the use of water. We assume these requirements will be higher as the water is in contact with a very sensitive end product.

(Petitpain-Perrin, 2006) proposed to sort the main category of water use as described in the following table:

Table 4. Water quality requirement and water uses.

	Industrial water	Process water Quality	Drinking water quality	Ultrapure water
Type of water use	• Raw material washing and transport • Cooling system	• Equipment washing • Steam production • Product dissolution or dilution	• Adding to the product • Agent of the fabrication process • Washing of products and equipment	• Adding to the product • Washing product • Flushing product
Example of water users	Automotive Mechanical equipment	Sugar refinery Steel and metal industry	Agro-alimentary Cosmetics Fine chemistry	Electronic Pharmaceutics

The agro-alimentary activity requires the use of water that respects the drinking water quality standards. Other sectors use industrial or process water that corresponds to a lower quality level. For its part, electronic and pharmaceutics industry requires the highest level of water quality (ultrapure water). These water quality requirements imply most of the time the treatment of the water before use.

Nevertheless, these water treatment processes can be inefficient or failing. Thus their role as additional protection barriers will not be taken into account.

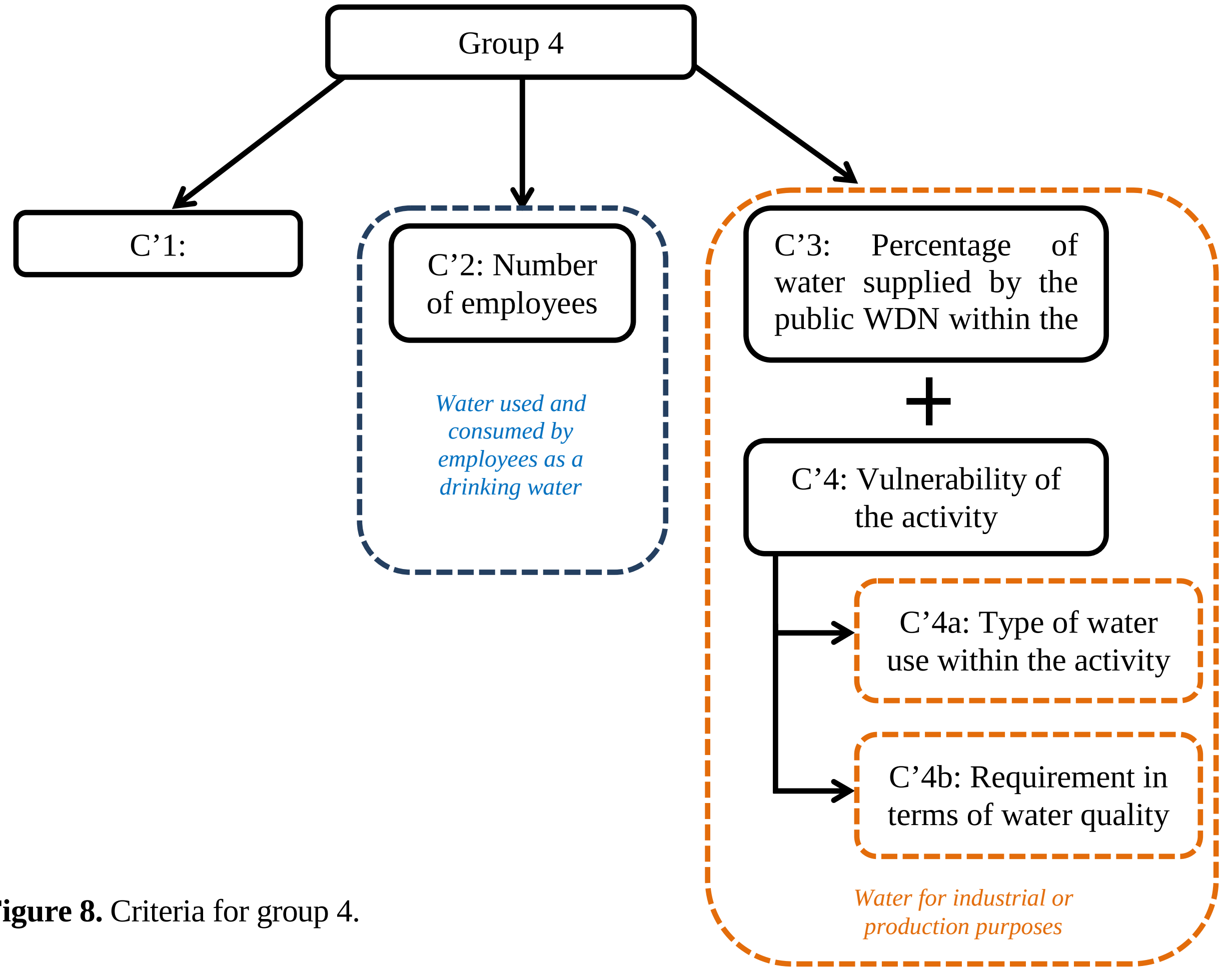


Figure 8. Criteria for group 4.

2.3.1.4 Performance level assessment (Step 4)

This step consists in describing the performance of each criterion. The performance assessment is the result of the decision maker criterion perception. A specific scale has to be built for each considered criterion and ad-hoc utility functions are defined.

These mathematic functions enable an accurate assessment of the criteria performance according to the user characteristics. The normalisation process resulting from the use of this function provides a better distribution of the performance values on the performance scale and facilitates the appreciation of performance variation between users. Furthermore, the use of the utility function constitutes a pre-processing of the data through the definition of thresholds.

b. Criteria for groups 1, 2 and 3

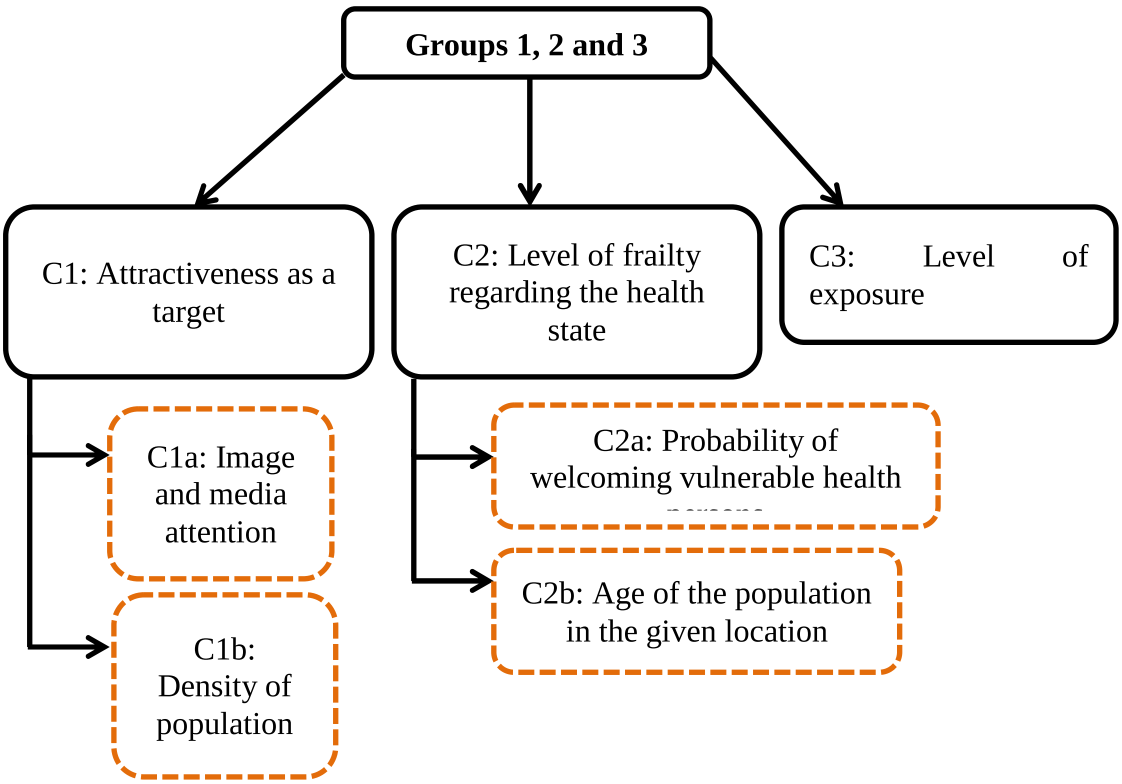


Figure 9. Criteria for groups 1, 2 and 3.

- <u>C1: Attractiveness as a target</u>

As a reminder the criterion 1 is composed by two sub-criteria that are described in the following paragraphs.

- C_{1a}: Image and media attention

The assessment of the criterion C_{1a} is realised from a subjective verbal scale. This verbal scale can be encoded into a numerical scale through a step function P_{C1a} as presented below:

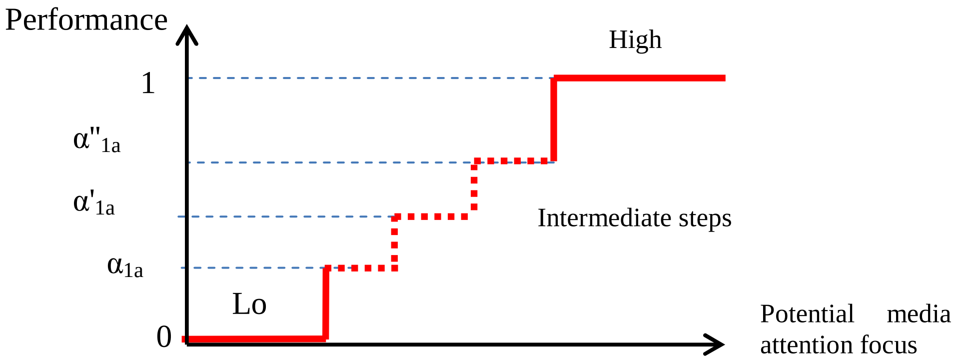


Figure 10. Criterion C1a - performance function

The α_{1a} coefficient value has to be fixed by the decision maker according to the context.

- C1b: Density of population

This sub-criterion deals with the number of potential harmed persons that could be estimated through the density of population around the consumption point.

In the case of the Strasbourg urban area, the demographic data are available at the level of geographical districts, which gather around 2 000 inhabitants. This division enables to describe the inner demographical structure of dense urban area such as the Greater Strasbourg.

The demographic data are divided by the number of water consumption points within the geographical district. This population density value is then affected to the location where the water is used or consumed.

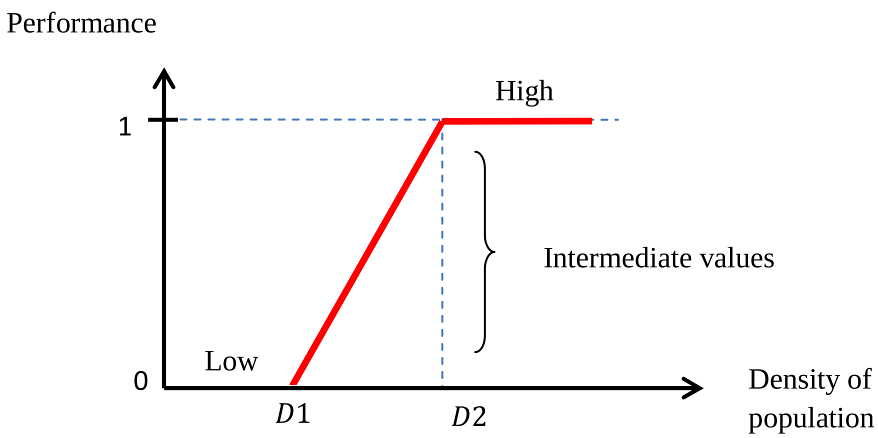


Figure 11. Criterion C1b - Performance function.

The performance P_{C1b} of this criterion is given by the function as described in the above figure and represented by the following equations:

$$\begin{cases} P(d_i) = 0 & \text{if } d_i<D_1 \\ P(d_i) = [1/(D_2-D_1)]*d_i + D_1/(D_1-D_2) & \text{if } D_1\leq d_i\leq D_2 \\ P(d_i) = 1 & \text{if } d_i>D_2 \end{cases} \qquad (6)$$

Where d_i is the number of inhabitants per consumption point.

The D_1 and D_2 coefficient values have to be fixed by the decision maker according to the context.

- C_2: Level of frailty regarding the health status
  - C_{2a}: Likelihood of welcoming vulnerable health persons

We propose to consider the following health vulnerable persons:

- New-born babies
- Children under 12
- Pregnant women
- Elderly
- Patients
- Immune-compromised persons
- Dialysis patients

As mentioned previously the characteristic of the user location gives the information regarding their health state. Each category of health vulnerable persons scores for 1 point. The location, which presents the likelihood of welcoming several categories of vulnerable persons, is assigned of the sum of the points.

The performance P_{C2a} (n) of this criterion is represented by a linear function and is given by the following equation:

$$P\ (n) = \frac{n}{Total\ number\ of\ categories} \qquad (7)$$

Where *n* is the number of vulnerable health people categories.

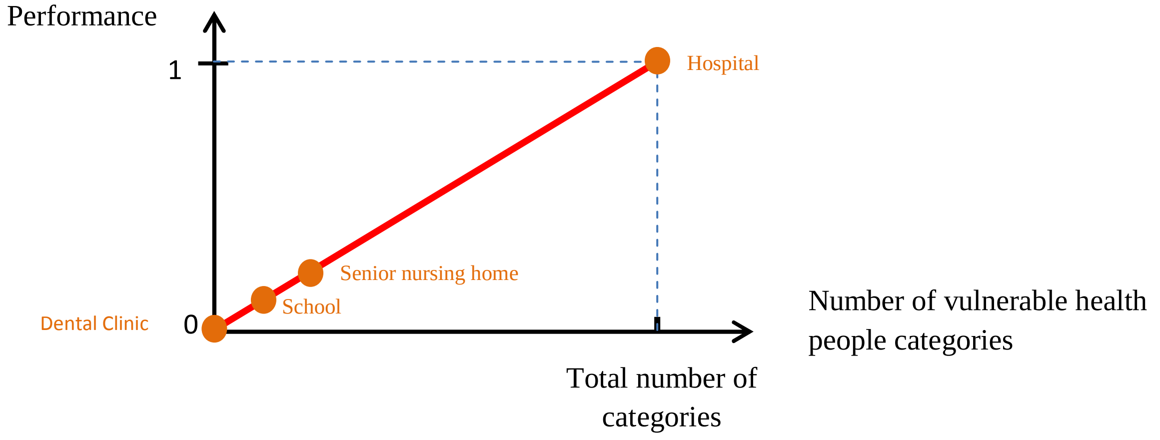


Figure 12. Criterion C2a - Performance function

The Tab. 5 gives for instance the value of P_{C2a} (n) for a few locations. We assume that the total number of vulnerable health person kind is less or equal to 7.

Table 5. Criteria C2a : Performance evaluation examples

Location	Vulnerable health persons	P(N)
Hospital	▪ New-born babies ▪ Children under 12 ▪ Pregnant women ▪ Elderly ▪ Patients ▪ Immune-compromised persons ▪ Dialysis patients	P(7) =1
School	▪ Children under 12	P(1) = 0.14
Retirement home	▪ Elderly	P(1) = 0.14
Senior nursing home	▪ Elderly ▪ Patients	P(2) = 0.28
Private house	Don't welcome specifically vulnerable health persons	P(0) = 0
Dental clinic	Dental clinics don't welcome specifically vulnerable health persons	P(0)= 0

- C_{2b}: Age of the population

We propose to process the age of population data at the level of water demand nodes.

The health vulnerability varies according to age. For a healthy person, the health vulnerability is extreme at birth, then decrease up to a minimum for adults and increase again with age.

These variations are represented by the red line in Figure 13. Then we propose to superimpose the health vulnerability graph over the age pyramid column chart.

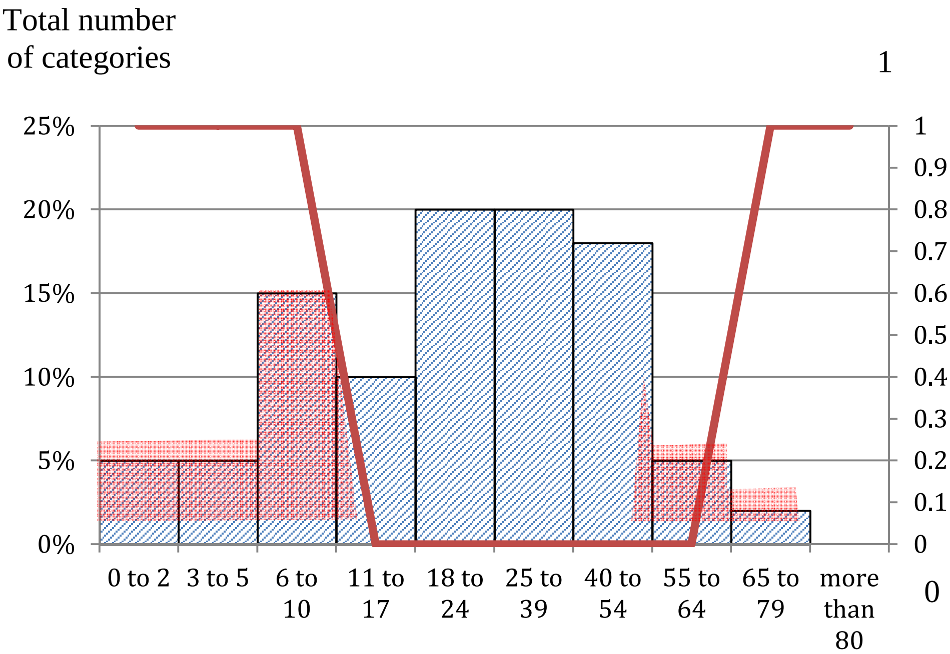


Figure 13. Criteria C2b - Performance evaluation

Finally the percentages of population that is vulnerable according to age are summed (represented on Fig.13 by the red part of the column chart). This sum constitutes the performance P_{C2b} of the criterion “Age of the population”.

In the case of the Strasbourg urban area, the age pyramid, as for the demographic data, is available at the level of geographical districts, which gather around 2 000 inhabitants. The demand nodes included in a given district will be assigned to the previous described sum.

- <u>C3: Level of exposure</u>

As mentioned previously we link the type of location and the frequency of water consumption. The level of exposure is evaluated according to the expected number of opportunities to consume water in a given location. The performance $P_{C3}(f)$ of this criterion is represented by the following equation:

$$P_{C3}(f) = \left(\frac{f}{3}\right)^3 \quad (8)$$

f is the number of opportunities to consume water in a given location.

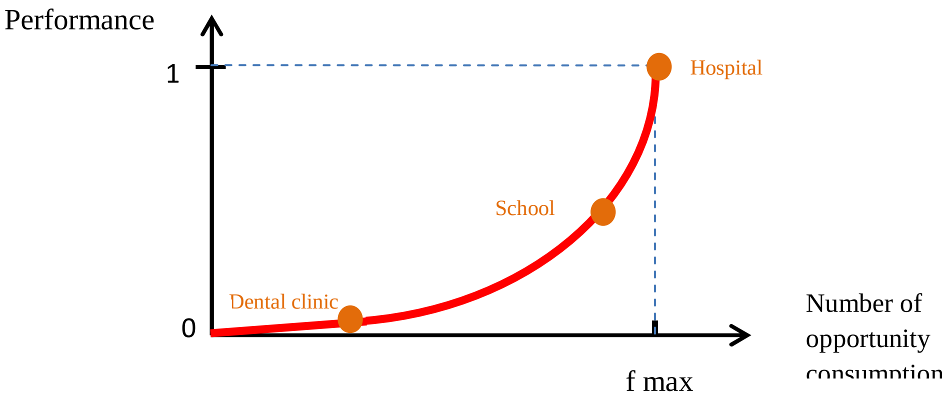


Figure 14. Criterion C3 - Performance function

Number of vulnerable health people categories

Table 6. Criterion C3 – Performance evaluation examples.

Type of location	**Frequency of water consumption**	**P(f)**
Hospital	At least 3 opportunities to consume water	$P_{C3}(3)=1$
Residential	At least 3 opportunities to consume water: breakfast, lunch and dinner	$P_{C3}(3)=1$
School	At least 2 opportunities to consume water	$P_{C3}(2)= 0.44$
Office (administration, bank, private company…)	7 to 8 hours of attendance per day: At least 2 opportunities to consume water	$P_{C3}(2)= 0.44$
Sport facilities	Hydration after a physical effort. At least one opportunity to consume water	$P_{C3}(1) = 0.11$
Accommodation / lodging	At least one opportunity to consume water	$P_{C3}(1) = 0.11$
Dental clinic	Less than one opportunity to consume water during dental care	$P_{C3}(0.5) = 0.028$

c. Criteria for professional users (groups 4)

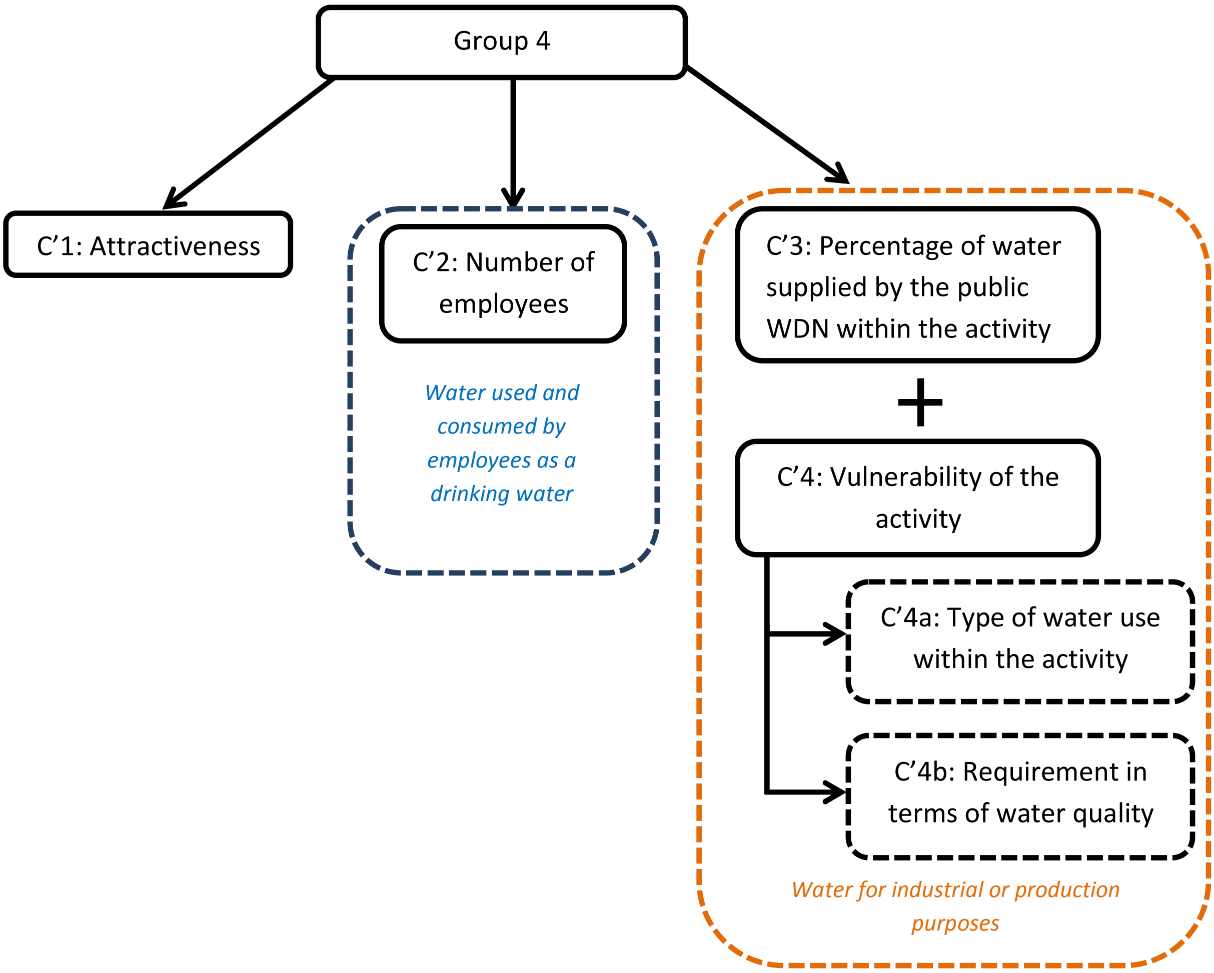


Figure 15. Criteria C1 - Performance function

- <u>C'1: Attractiveness as a target</u>

The assessment of the criterion C1 is realised from a subjective semantic scale and will be encoded into a numerical one through the following step function $P_{C'1}$:

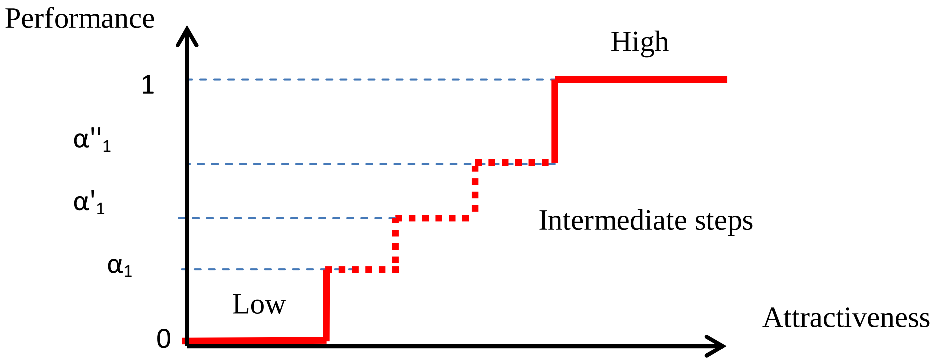


Figure 16. Criteria C1 - Performance function

The α_1 coefficient value has to be fixed by the decision maker according to the context.

- C'$_2$: Number of employees

Group 4 users will be ranked according to the number of employees officially registered.

Nevertheless this criterion will not be directly evaluated as being proportional to the number of employees. Indeed the number of employees officially registered doesn't correspond systemically at the number of employees who are really present at work. For instance industries are used to employ rotating teams, three times per day; in this case the number of employees present at work in lower than the total number of employees officially registered.

For this reason the performance of this criterion could be assessed through a logistic function that defines the threshold from which the criterion performance reaches its maximum value.

$$P_{C'2}(E) = K.\frac{1}{1+ae^{-rE}} \quad (9)$$

Where E is the number of employee registered.

The coordinates of the inflexion point J are$\left(\frac{Ln(a)}{r} \ ; \ \frac{K}{2}\right)$

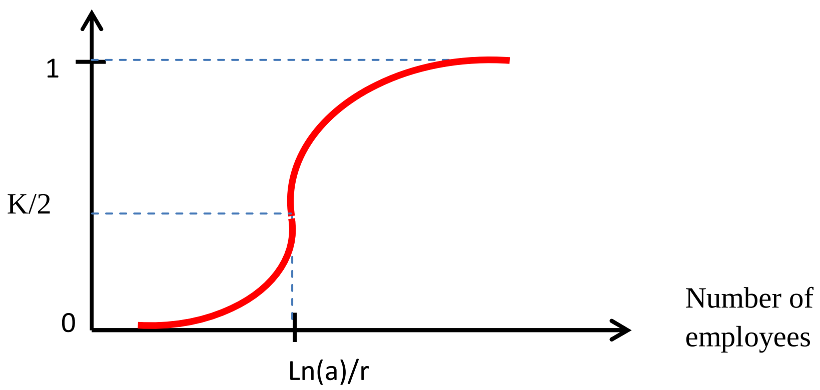


Figure 17. Criteria C1 - Performance function

The values of Ln(a)/r and K have to be fixed by the decision maker according to the context.

- C'3: Percentage of water supplied by the public WDN within the activity sector

The performance of this criterion is directly **proportional** to the percentage of water supplied by the public WDN within the activity sector. In the case of the industrial use of water a statistic study conducted at the request of the French Ministry of ecology and sustainable development provides information on the share of the modes of water supply (Augeraud and Touaty, 2002). The mode of water supply chosen by an industry depends on the needs of the industry (in terms of water quality and quantity) and on the connexion possibilities.

Table 7. Share of the modes of the water supply within industrial activities.

Activity sector	Percentage of public WDN (%)
Meat and dairy	**34.97**
Others agro-industrial activities	13.14
Garment, leather	4.74
Publishing, printing, copying	**88.26**
Pharmaceuticals, perfumery and personal care	13.65
Home furnishing	17.62
Automotive	**36.58**
Shipbuilding, aircraft and rail construction	10.54
Mechanical equipment	17.83
Electric and electronic equipment	18.32
Mineral products	4.28
Textile	12.06
Wood and paper products	0.7
Chemical, rubber and plastics products	7.16
Metallurgy and processing of metals	19.39
Electrical and electronic components	**40.93**
Oil and gas production	0.68
Gas and heat production	6.54

As shown in Table 7 the percentage of the water supplied from a public WDN is relatively low except for the Publishing, printing and copying sector for which this percentage is over 88%. The electrical and electronic components, automotive and meat and dairy sectors buy to a public WDN between 35 and 40% of the water used.

For small companies as butchery or bakery we consider further that the water used for the activity is fully supplied by the public WDN.

- <u>C’$_4$: Vulnerability of the activity according to the type of water use within the activity sector</u>

The assessment of the criterion C’$_4$ performance is based on the aggregation of the sub-criteria C’$_{4a}$ and C’$_{4b}$.

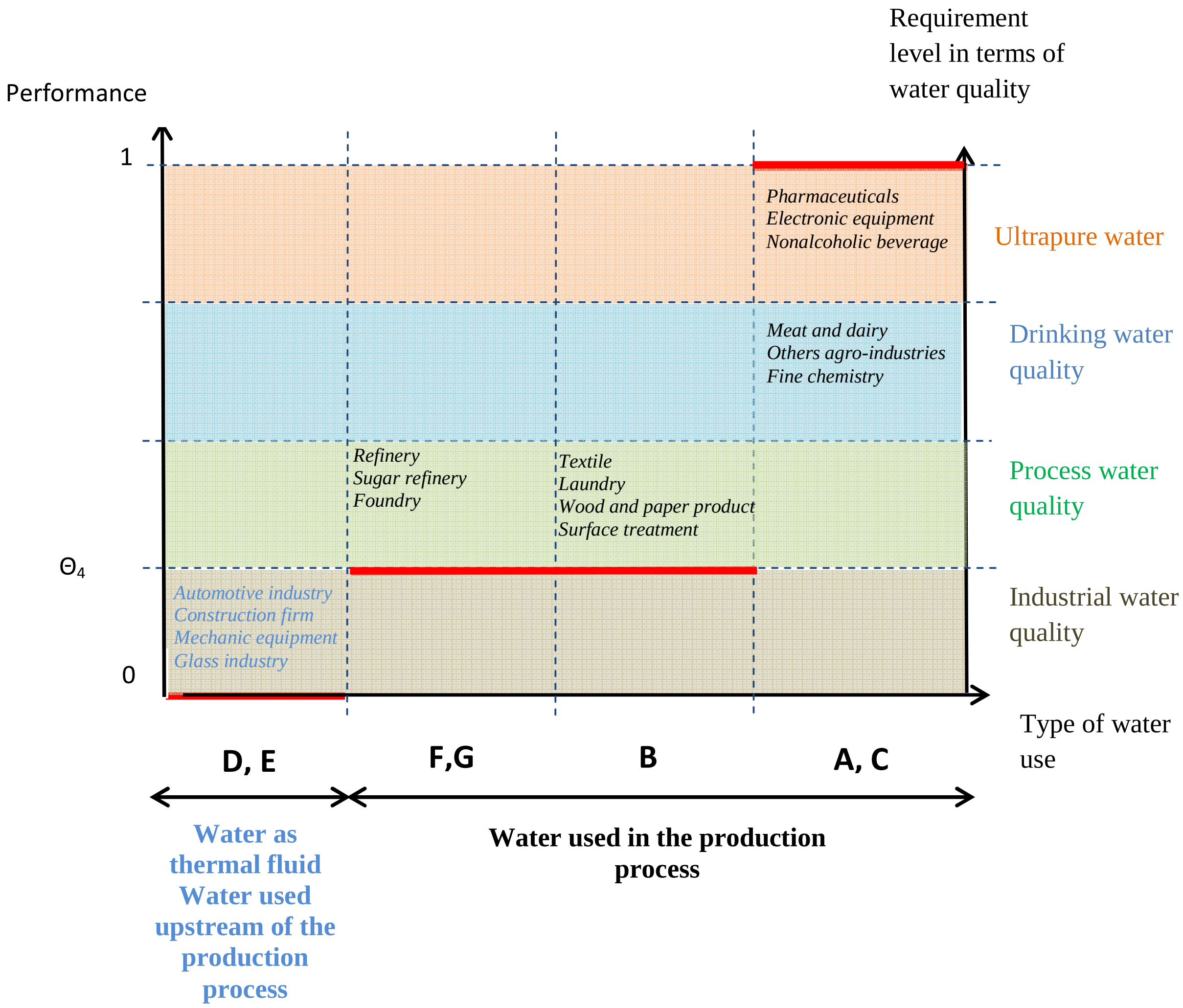


Figure 18. Groups 4 – Vulnerability of the activity according to the type of water use

The performance of the criterion C’$_4$ “Vulnerability of the activity” is given by a step function PC’4 resulting from the aggregation of the sub-criteria C’$_{4a}$ and C’$_{4b}$. The θ coefficient value (first non-zero step in Fig. 18) has to be fixed by the decision maker according to the context. The following table summarises the retained criteria:

Table 8. Group 1, 2 and 3 - Criteria performance evaluation

Group	Criterion		Utility function	Boundary conditions		Intermediate values
				Min	Max	
1,2 and 3	C1: Attractiveness as a target	C1a: Image and media attention	Step function as the translation of a verbal scale	P_{C1a}(low) = 0	P_{C1a}(High) = 1	P_{C1a}(Intermediate) = α_{1a}
		C1b: density of population	Step function according to the density of population	If density $d_i < D_1$ then $P_{C1b} = 0$	If density $d_i > D_2$ then $P_{C1b} = 1$	If $D_1 <$ density $d_i < D_2$ then $P_{C1b} = [1/(D_2-D_1)]*d_i + D_1/(D_1-D_2)$
	C2: Level of frailty regarding the health state	C2a: Probability of welcoming vulnerable health persons	Linear function according to the number of vulnerable health people category	P_{C2a} (0) = 0	P_{C2a} (Total number of categories) = 1	Proportional to the number of categories
		C2b: Age of the population in the given location	Superimposition of the age pyramid column chart with the vulnerability (/age) graph	Minimum percentage of venerable population according to the age	Maximum percentage of venerable population according to the age	Any intermediate value
	C3: Level of exposure		Polynomial function according to the frequency of water consumption in a given location	P_{C3} (f_{min}) = 0	P_{C3} (f_{max}) = 1	According to the polynomial function

Table 9. Group 4 - Criteria performance evaluation

Group	Criterion		Performance evaluation function	Boundary conditions		Intermediate values	Sub-criteria aggregation method
				Min	Max		
4	C’1: Attractiveness as a target		Step function as the translation of a verbal scale	$P_{C'1a}(\text{low}) = 0$	$P_{C'1a}(\text{High}) = 1$	$P_{C'1a}(\text{Intermediate}) = \theta_1$	N/A
	C’2: Number of employees		logistic function according to the number of employees	$P_{C'2a}(0) = 0$	$P_{C'2a}$ (Max number of employees) = 1	Any intermediate value Inflexion point J to be noted	N/A
	C’3: Percentage of water supplied by the public WDN within the activity sector		Affine function according to the percentage of water supplied by WDN	$P_{C'3}(\text{min}) = \%_{min}$	$P_{C'3}(\text{max}) = \%_{max}$	Any intermediate value	N/A
	C’4:Vulnerability of the activity according to the type of water use within the activity sector	C’4a: Type of preponderant water use	Sorting according types of water uses	$P_{C'4}(\text{min}) = 0$ Water used as thermal fluid Or Water used upstream of the production process	$P_{C'4}(\text{max}) = 1$ Water used in the production process and activity that requires drinking water quality or ultrapure water	$P_{C'4}(\text{Intermediate}) = \theta_4$	Step function resulting from the aggregation of the sub-criteria
		C’4b: Requirement level in terms of water quality	Sorting according 4 levels of water quality				

2.3.1.5 Weighting (Step 5)

Determining the weights of criteria describes the preferences of the decision maker (DM), which is not an easy task.

In order to make the weighting process clear and easily reproducible, we use a very simple procedure, based on a set of cards that helps to estimate indirectly weights. This technique have been developed by SIMOS and revised by (Figueira and Roy, 2002).
The advantages of SIMOS procedure are:

- Very easy to implement and understand
- Non focused on the scale of the criterion evaluation
- Accept ex aequo
- Data processing simplified by SRF open-source software coded by LAMSADE (Laboratoire d'Analyse et de Modélisation de Systèmes pour l'Aide à la Décision)

2.3.1.5.1 SIMOS procedure description

The technique used to collect the information consists of the following three steps:

1) Distribute a set of card to the DM. The name of the criterion is written on each card
2) Ask the DM to rank these cards (or criteria) from the least important to the most important.
3) Ask the DM to think about the fact that the importance of 2 successive criteria in the ranking can be more or less close. White cars or blank cards could be introduced between two successive criteria to increase the difference between the criteria.

Once the cards are ranked, it is possible to attribute numerical values to the weights of criteria in 3 steps:

1) Determining the non- normalised weights
2) Determining the normalised weights
3) Determining the ratio z between the weight of the most important criterion and the least important one in the ranking

2.3.1.5.2 Multi-decision makers context

The water department managers can decide to involve several persons in the weighting process. Indeed, it could be interesting to take into account the point of view of person with different backgrounds as technical staff directly involved in the water quality management but although water users or politicians for instance. It means that we deal with a multi-decision maker's context.

Thus the SIMOS procedure mentioned above has to be applied to any decision makers. At the end of the process, we obtain several sets of weights corresponding to the opinions of the decision makers. These sets of weights have to be aggregated properly in order to reflect the opinion of the group. We propose for that to use the Ordered Weighted Average Operators introduced by (Yager, 1988). The OWA-based approach has a number of important benefits:

- The approach doesn't require expert skills and remains easy to implement and to understand
- The weights of the alternatives are associated to the values instead to criteria
- It is possible to define different aggregation policies according to the importance that the decision maker want to associate to high and low performances scores.

i. Ordered Weighted Average (OWA) operators concept

The concept of ordered weighted averaging operators can be defined as follow (Filev and Yager, 1998). An OWA operator of dimension n is a mapping:

$f : \mathrm{R}^n \rightarrow \mathrm{R}$,

That has an associated weighting vector W

$W = [w_1\ w_2\ \ldots\ w_n]^T$

Such that

$\sum_i w_i = 1$; $w_i \in [0,1]$

And where

$$f(\mathrm{a}_1, \ldots, \mathrm{a}_n) = \sum_{j=1}^{n} w_j b_j \tag{10}$$

where $(b_1, \ldots, b_n)$ is simply $(\mathrm{a}_1, \ldots, \mathrm{a}_n)$ reordered from the largest to the smallest.

The function value $f(\mathrm{a}_1, \ldots, \mathrm{a}_n)$ determines the aggregated value of arguments $\mathrm{a}_1, \ldots, \mathrm{a}_n$.

In order to deal with the multi-decision makers' context we propose the Ordered Weighted Average (OWA) operators to aggregate the opinion of several decision makers (Yager, 1988). Indeed the OWA weights generation provides a flexibility to incorporate decision maker's opinion (Sadiq and Tesfamarian, 2006), which can be related to their position in the water service department for instance or their link with the water distribution system.

ii. Implementing Ordered Weighted Average (OWA) operators

The OWA procedure can be implemented in 3 main steps:

1) Reordering of the performance value of the arguments in descending order
2) Determining the weights[1] associated with the OWA operators; in our context we propose to generate the OWA weights using Normal probability density functions as discussed in the following paragraph
3) Aggregation process

iii. Generating OWA weights

Probability function can be used to generate OWA weights (Sadiq and Tesfamarian, 2006). Xu (2005) proposed the probability distribution function which the heights represent OWA weights. Using this function the decision makers can define the ordinal position (once the performance of the arguments have been ranked) to which the maximum value of OWA weights has to be assigned. For n number of arguments to be aggregated, the OWA weight vector W can be computed as

$$W_i^N = \frac{W_i'^N}{\sum_{j=1}^{n} W_i'^N} \tag{11}$$

Where $W_i'^N = \frac{1}{\sigma_n \sqrt{2\pi}} e^{-[\frac{(i-\mu_n)^2}{2\sigma_n{}^2}]}$

[1] We will talk further about OWA weights in order to avoid confusion with the weights assigned to the sensitivity criteria by the decision makers

The mean μ_n and the standard deviation σ_n can be computed as :

$$\mu_n = \frac{1}{n}\frac{n(n+1)}{2} = \lambda\,(1+n) \tag{12}$$

$$\sigma_n = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(i-\mu_n)^2} \tag{13}$$

- *λ parameter*

The λ parameter – i.e. quantile– corresponds to the location of the maximum weights. The Normal probability function which corresponds at $\lambda = 0.5$ provides compromising OWA weight distribution. Performances close to the median ordinal position get the greater values of OWA weights. Performances close to minimum and maximum ordinal positions get the lower values.

In our multi-decision makers context the objective of the aggregation process is to take into account the opinion of the group of persons involved in the SIMOS procedure. The involved persons in the SIMOS game can be sorted in two categories of players:

- Players who proposed a balanced view on the relative importance of the sensitivity criteria: the difference between the weights of the criteria is less than a factor of 5
- Players who hold a strong view on the relative importance of the criteria: the differences between the weights of the criteria is upper than a factor of 10

The latter way of weighting the criteria strongly influences the aggregation result in the case of an arithmetic mean of the value assigned to the criteria. There is a risk that the aggregation result doesn't reflect the opinion of the group.

In order not to give too much importance to the lower and the higher values assigned to the criteria by the decision makers, we consider a Normal probability function which provides a compromising OWA weight distribution.

- *Orness α*

Yager (1988) introduced the concept of orness α, which characterizes the type of aggregation being performed for a particular value of OWA weighting vector. This orness measure is defined as

$$Orness\,(w) = \frac{1}{n-1}\sum_{i=1}^{n}(n-i)w_i \tag{14}$$

Where w_i represents the performance of the i^{th} criterion

- *Dispersion*

In order to differentiate weight distribution at a given orness α Yager proposed a second measure called dispersion Disp (w). This concept can be computed by

$$Disp(w) = -\sum_{i=1}^{n} w_i \ln(w_i) \tag{15}$$

Where $0 \leq Disp(w) \leq \ln(n)$

The maximum dispersion i.e. "ln(n)" corresponds to an uniform distribution of the OWA weights.

iv. Results of the aggregation process

In our multi- decision makers' context it is necessary to clarify the following points:

- The OWA aggregation process is applied to the sensitivity criteria one after the other
- The arguments are represented by the weights assigned to the sensitivity criterion by the decision makers involved in the SIMOS procedure
- At the end of the aggregation process the result to be achieved is an aggregated value of the arguments for each sensitivity criterion

2.3.1.6 Combination of weight / Aggregation (Step 6)

This Step consists in choosing the most appropriate aggregation methods. We face a ranking problem. It means that we have to be able to compare users. But the users are described by the performance of several criteria. We need to combine those data. For that operation, we will compare the results of 3 aggregation methods:

- Weighted sum that is a classic arithmetic sum
- Star plot representation and area comparison: the weighted and normalised performances of the criteria are represented on 5 axis starting from the same point. Then the areas delimited by the designed polygon are compared.
- Electre III is an outranking method of decision-making: Electre III builds outranking relationships based on the performance of the criteria.

The Tab. 10 summarizes the advantages and disadvantages of the different aggregation methods:

Table 10. Aggregation methods – Main advantages and disadvantages

Aggregation methods	Advantages	Disadvantages
Weighted sum	- Easy to understand and implement - Efficient discrimination of data	- Data pre-processing needed (utility function) - Bias in the ranking: the weight values are linked with the standardization scale
Radar	- Graphic representation of the results - Easy to implement and understand	- The radar area calculation is based on a surjective function which cannot provide an efficient discrimination of data
Electre III	- Raw data can be directly processed: No data pre-processing is required - Efficient discrimination of data	- Difficult to understand and implement - The thresholds definition required a specific expertise in the matter - Computational requirement

The use of metric based on radar surface seems not appropriate because it will not enable to discriminate the most sensitive users. This approach has to be excluded too. The Electre III represents an efficient aggregation method, which seems to be well adapted to the context of the decision.

Unfortunately Electre III suffers from two main burdens:

- It requires an important computing capacity
- Its implementation requires specific skills that could represent an operational obstacle

For those two reasons the Electre III has to be eliminated. Finally the **weighted sum** remains the most adapted method even if it there is a bias in the ranking when the utility function is defined in an inappropriate manner.

2.3.1.7 Results and sensitivity analysis (Step 7)

In the frame of the risk analysis methodology analysis, the results of the user's sensitivity assessment will be used at two different levels.

- Firstly the most sensitive users will constitute the starting point of the risk analysis methodology (*cf.* WDN contamination Risk analysis methodology). Indeed the potential contaminant sources are determined using inverse transport method, which is implemented from a selection of the most sensitive users. In that case, the objective of the inverse transport method implementation is to **reduce the computational time** in identifying vulnerable and contaminant intrusion points. In consequence, the numbers of the most sensitive users to be selected depends on the WDN (size, topology) and on the WDN hydraulic model (number of nodes, computation time).
- Secondly the contaminant spread magnitude is evaluated through the combination of the average time of detection of the contaminant and the percentage of sensitive users exposed to the contaminant. In that case the evaluation of the water user's sensitivity has to be exhaustive.

2.3.2 Vulnerability analysis of the WDN

In the present document the concept of intrinsic vulnerability is defined and criteria of vulnerability are introduced in order to evaluate it. Then to quantify the intrinsic vulnerability, we propose a Fuzzy Rule Base (FRB) aggregation scheme. Before describing in details the vulnerability concept we propose to identify the component of the WDN, which could be considered as potential intrusion site location for contaminant.

2.3.2.1 Potential intrusions site

As a reminder, the contaminant is deliberately introduced at the level of the WDN. The different assets of the water distribution network will be the objects of a specific analysis in order to determine if it could constitute an intrusion point in accordance with the chosen pathways.

2.3.2.1.1 Intrusion techniques selection and pathways identification

To start with, we will consider the contaminant to be injected is (1) in a liquid state or contained in a liquid (the contaminant is soluble or in suspension), (2) in a gaseous state, (3) in a solid state. It is also required to identify what are the contaminant intrusion techniques to take into account according to the state of the contaminant. The liquid and gaseous contaminant injection in the WDN requires applying a higher pressure than the water pressure inside the pipe. Regarding the intrusion of a contaminant in solid state the targeted pipe or WDN component must not be filled with pressurized water. To simplify our analysis, the contaminant to be injected is in a liquid state or contained in a liquid.

That being said, four technical configurations of the WDN components constitute realistic pathways:

- WDN component equipped with a by-pass system: the contaminant is injected within the pipe once the valves are closed.
- WDN component equipped with a paddle clamp
- Unburied pipe without specific equipment: this includes, for example, unprotected pipe under bridge or unprotected pipe during works
- Unprotected WDN pipe within technical galleries

Based on these observations, we identify the potential intrusion site according to the following classification: (1) control structures equipped with a by-pass system, (2) WDN components connected to the pipe through a paddle clamp, (3) fire-fighting equipment, (4) unburied pipes.

For the injection device, we consider in our analysis an injection pump and fittings to connect it to existing paddle clamp or socket clamp. The injection pump produces the driving force (i.e., pressure) needed to introduce the contaminant in the pressurized pipe. In some specific configurations under pressure drilling will be required. The following table illustrates the intrusion site classification and proposes a brief description of the injection device to be installed for contaminant injection.

Table 11. Intrusion site classification and injection device description

Intrusion point categories	Intrusion point site	Injection device description
Control structures equipped with a by-pass system	Wash out / Air bleeding / valves boxes	By pass system equipped with 2 valves Install the injection device within the chamber Close the 2 by pass valves Remove the wash out / air bleeding / valve and replace it by the injection device Apply pressure to the system Open the valves to enable the contaminant intrusion
WDN components connected to the pipe through a paddle clamp	Flow rate measuring station	Install the injection device within the concrete chamber Close the valve on the paddle clamp Connect the injection device to the paddle clamp Apply pressure to the system Open the valve to enable the contaminant intrusion
	Sampling point pit	Install the injection device outdoor Close the valve Disconnect the backflow preventer Connect the injection device to the ball valve Apply pressure to the system Open the valve to enable the contaminant intrusion
	Private connexion (BP)	Install the injection pump (indoor) Close the valve located downstream of the water meter Disconnect the backflow preventer Connect the injection device to the valve Apply pressure to the system Open the ball valve to enable the contaminant intrusion
Fire-fighting	PI (Fire hydrant)	Install the injection pump (outdoor)

<table>
<tr><td>equipment</td><td>BI (Underground hydrant)</td><td>Connect the injection system to the hydrant outlet
Apply pressure to the system
Open the hydrant valve to enable the contaminant intrusion</td></tr>
<tr><td rowspan="3">Non-buried pipes without specific equipment</td><td>Unprotected pipe under bridge</td><td rowspan="3">Under pressure drilling equipment:
• Clamp with flange
• Pressure test box
• Valve
• Drilling device
• Plast/joint

Install the clamp
Install the valve
Install the pressure test box
Drill under pressure
Closing the valve and remove drilling device
Install the injection device
Apply pressure to the system
Open the valve to enable the contaminant intrusion</td></tr>
<tr><td>Unprotected pipe during works</td></tr>
<tr><td>Pipes in technical galleries</td></tr>
</table>

2.3.2.2 Intrinsic vulnerability definition

The *Intrinsic Vulnerability* describes the level of protection of device against contaminant intrusion of contaminant into the WDN from a specific and predetermined intrusion point. To assess this susceptibility of contaminant intrusion both the technical characteristics of the intrusion point and its environment are taken into consideration. Indeed technical characteristics and environment are specific to each intrusion point. Thus we propose to define the intrinsic vulnerability as the combination of the *structural vulnerability* and the *vulnerability linked to the environment of the intrusion point*.

2.3.2.2.1 Structural vulnerability

The *structural vulnerability* corresponds to the technical characteristics of the intrusion site. According to these characteristics the contamination of the network is more or less easy. The structural vulnerability could be estimated based on the following criteria:

- *Ease of installation and implementation of the contamination device*

As mentioned previously the intrusion point can be on a non-buried pipe without specific equipment. Some devices installed on the pipe make easier the installation of the injection equipment, for example paddle clamp and by-pass system make this installation easier.
In addition the existence of locations where the contaminant could be stored make easier the contamination operation. Consequently the analysis must track:

- The existence of reinforced concrete pit equipped with a manhole
- The existence of technical gallery
- The possibility of contaminant storage outdoor or indoor

- *Level of protection of the intrusion site*

Anti-intrusion devices constitute a barrier to contamination event: Padlocks, pit bulls, intruder alarm are some of the means used to protect the WDN components.

In addition non-return systems are installed on the WDN component in order to avoid back siphoning and prevent water contamination. Anti-intrusion and non-return devices must be taken into account in the vulnerability analysis. The *structural vulnerability* will be the result of the combination of the *ease of installation of the contamination device* and *the physical protection of the intrusion site.*

2.3.2.2.2 Vulnerability linked with the environment of the intrusion site

The vulnerability linked with the environment could be assessed based on the following criteria:

- *Ease of physical access to the intrusion site*

The immediate environment of the intrusion site constrains the access to the WDN pipe. For instance it is easier to get access to a WDN component located on the sidewalk than the same component located on the roadway. Consequently the immediate environment of the intrusion site is checked in order to assess the ease of access to the site. Three cases seem to be relevant: (1) private area, (2) public place as square or garden, (3) roadway.

- *Level of surveillance of the intrusion site*

Intrusion site located in public spaces or on public roads can be subject to certain surveillance from the citizen as observers or sentinels. In consequence distinction is done between: (1) private area without surveillance and (2) public places with normal citizen oversight.

The *vulnerability linked to the environment of the intrusion site* will be the result of the combination of the *Ease of physical access to the intrusion site* and *the level of surveillance of the site.*

2.3.2.3 Intrinsic vulnerability evaluation using Fuzzy inferecne system

2.3.2.3.1 Introduction to Fuzzy Inference Systems

Fuzzy logic deals with problems in which vagueness is involved (Zadeh, 1965). For instance Fuzzy is particularly useful in systems that use semantic assessment as input. It is the case for intrinsic vulnerability, which is evaluated from criteria without sharp boundaries. Furthermore the combination of the different criteria must be equivalent to linguistic rules based on operator opinion, which are characterized by a strong non-linearity. Fuzzy Inference Systems (FIS) are based on specific rules, which seem suitable for this type of application.

Fuzzy Inference system can be implemented in 3 steps: (1) Inputs fuzzification, (2) Inference using an engine, which contains a rule base algorithm, (3) output defuzzification.

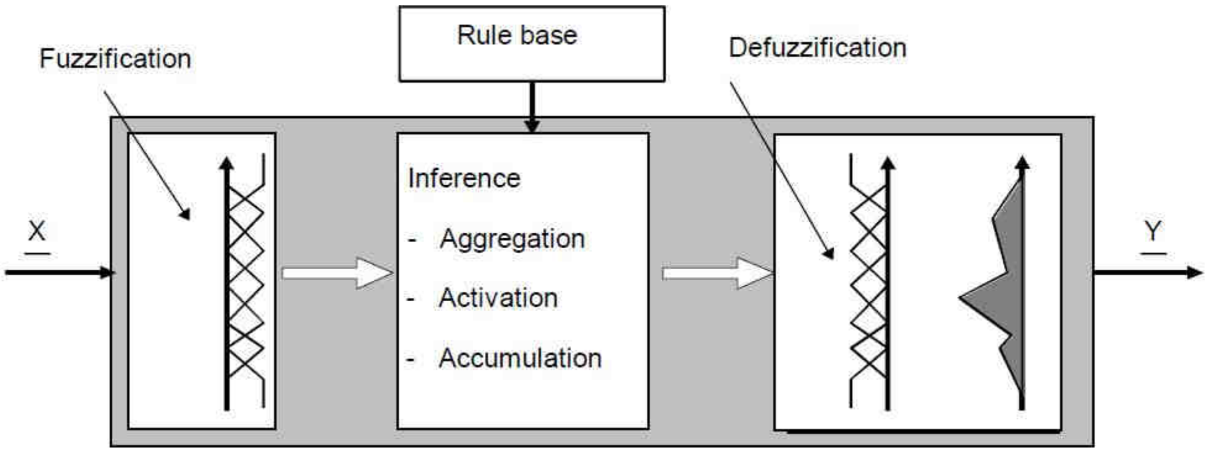


Figure 19. Structure and functional element of fuzzy control (source IEC 61131-Part 7).

The functional elements of Fuzzy Control, mentioned above and illustrated in Figure 19, are explained below (IEC 61131 – part 7):

- The fuzzification comprises the process of transforming crisp values into grades of membership for semantic evaluation in fuzzy sets. The membership function is used to associate a grade to each evaluation.
- The rule base algorithm contains the linguistic rules which describes specific process under consideration
- Mamdani's fuzzy inference scheme, which uses 'min-max' operations, is implemented. The Inference combines the fuzzified inputs with the rule base and conducts the fuzzy reasoning process. It consists in the 3 sub-functions of aggregation (determining the degree of accomplishment of the condition from the degree of membership of the subconditions), activation (activation of the IF-THEN conclusions) and accumulation (combination of results of linguistic rules in a final result using the maximum algorithm).
- The defuzzification consists in the conversion of the fuzzy result of inference into a crisp output variable using the Center of Gravity (CoG) method

2.3.2.3.2 Inputs fuzzification

Fuzzy logic starts with the concept of a fuzzy set. A fuzzy set is a set without crisp boundaries which describes vague concepts; that is, semantic assessment. As mentioned by Kleiner *et al*. (2006), a fuzzy set describes the relationship between an uncertain quantity x and a membership function μ, which ranges between 0 and 1. Many shapes of membership function are possible but triangular shape is more suitable for the current application. In case of triangular shape, the fuzzy sets can be defined by three points representing the three vertices of the respective triangle.

In our case, the vulnerability criteria correspond to the input data of the FIS. Associated with triangular membership functions it constitutes the Data Base (DB) for the fuzzy rule based modelling Cingolani and Alcada-Fdez (2012).

2.3.2.3.3 Inference engine

Once the DB have been defined the fuzzy inference engine will combine the fuzzy set values using a collection of fuzzy control rules – the Rule Base (RB) – which represents the relationships between variables of the DB. Finally the Data Base (DB) and the Rule Base (RB) are the components of the Knowledge Base (KB).

Using Mamdani's fuzzy inference method, the output of the inference engine is a fuzzy set. The amount of output fuzzy sets is equal to the number of rules collected in the KB. These output fuzzy sets are then combined into a single output fuzzy set. Indeed decisions are based on the testing of all the KB rules.

2.3.2.3.4 Defuzzification process

The last step of the FIS is the defuzzification. The input for the defuzzification process is a fuzzy set and the output is a single number. This single output value makes easier the decision making process as ranking or sorting.

The most popular defuzzification method is the centroid calculation, which returns the centre of area under the curve. Other metrics can be used as the centre of gravity, mean max, rightmost max, and leftmost max.

2.3.2.4 Application to intrinsic vulnerability evaluation

The proposed approach requires an aggregation of several non-commensurate criteria to estimate the intrinsic vulnerability. To deal with such an uncertainty, an index-based approach, which uses the Fuzzy Inference System, was developed by Francisque *et al.* (2009). The proposed Fuzzy Inference System combines 3 inference engines as described in the following framework structure.

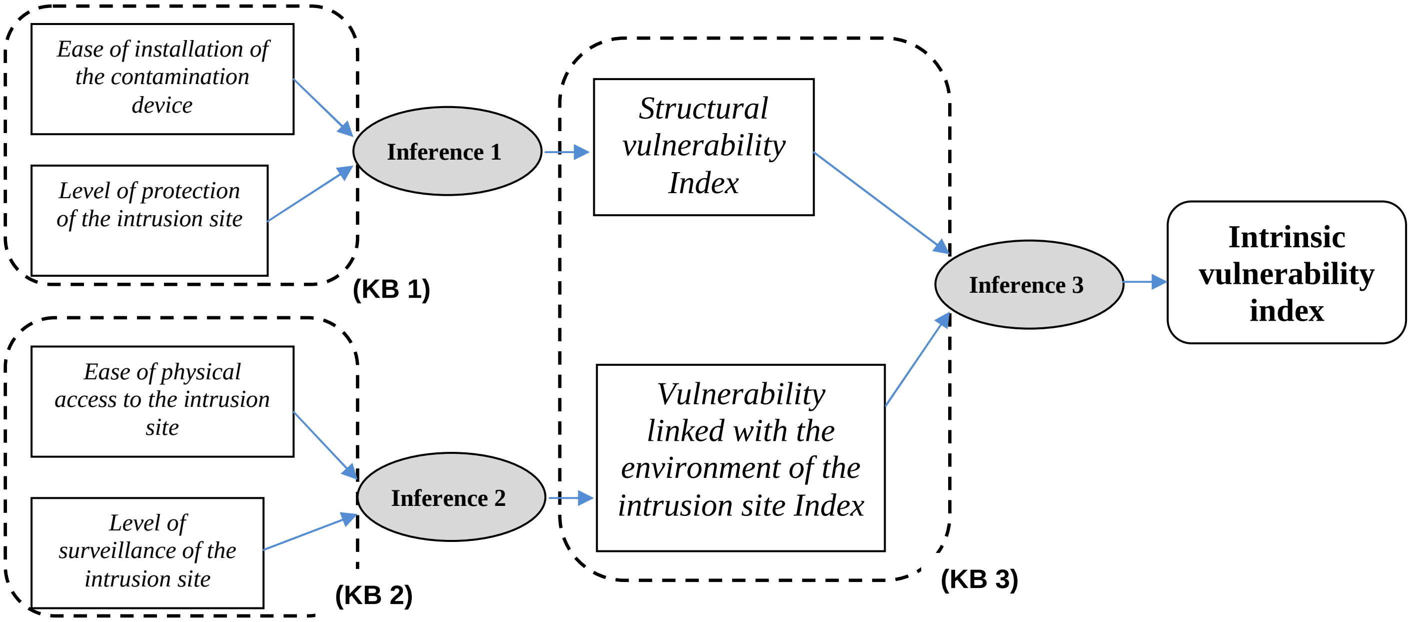
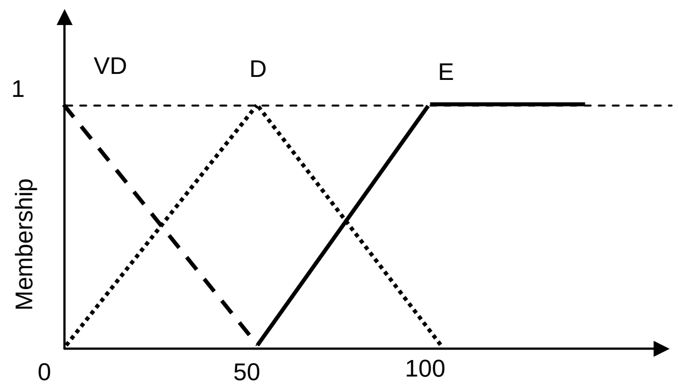


Figure 20. Fuzzy hierarchical structure for the evaluation of the intrinsic vulnerability

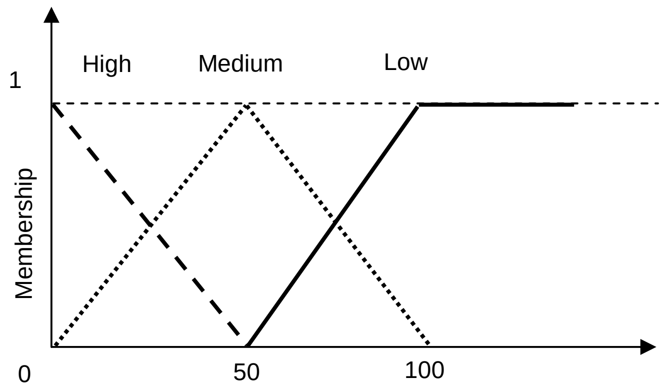
The three Inference Engines will be supplied respectively by three knowledge bases (KB) as defined in the following figures:

Data Base 1

Ease of installation of the injection device	$\mu_{i,1}$	$\mu_{i,2}$	$\mu_{i,3}$
Easy (E)	50	100	100
Difficult (D)	0	50	100
Very Difficult (VD)	0	0	50



Level of protection of the intrusion site	$\mu_{i,1}$	$\mu_{i,2}$	$\mu_{i,3}$
Low	50	100	100
Medium	0	50	100
High	0	0	50



Rule Base 1

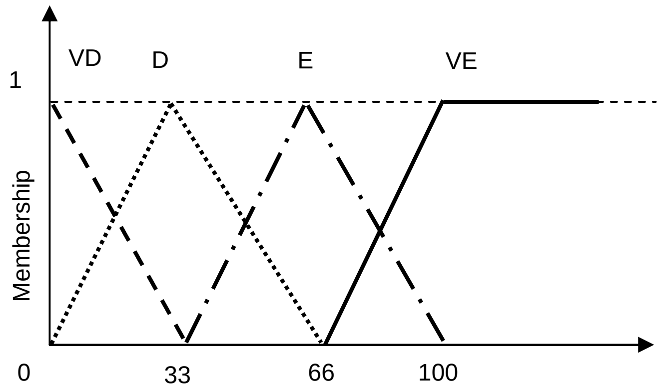
Structural vulnerability (SV)		Ease of installation of the injection device (I)		
		Easy	Difficult	Very Difficult
Level of protection of the intrusion site (P)	Low	*High*	*High*	*Medium*
	Medium	*High*	*Medium*	*Medium*
	High	*High*	*Medium*	*Low*

IF *Level of protection* is "P" **AND** *Ease of installation of the injection device* is "I" **THEN** Structural vulnerability is "SV"

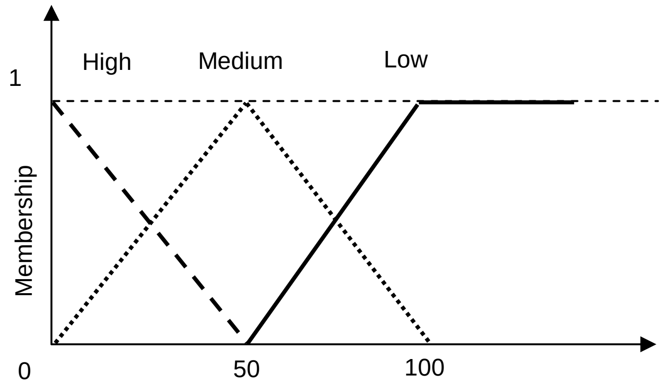
Figure 21. Knowledge Database 1- Database and Rule Base for the “Structural Vulnerability” model.

Data Base 2

Ease of physical access to the intrusion site	$\mu_{i,1}$	$\mu_{i,2}$	$\mu_{i,3}$
Very Easy (VE)	66	100	100
Easy (E)	33	66	100
Difficult (D)	0	33	66
Very Difficult (VD)	0	0	33



Level of surveillance of the intrusion site	$\mu_{i,1}$	$\mu_{i,2}$	$\mu_{i,3}$
Low	50	100	100
Medium	0	50	100
High	0	0	50



Rule Base 2

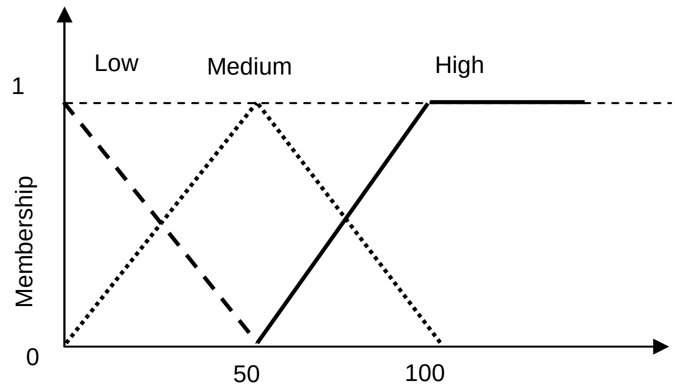
Vulnerability linked with the environment of the intrusion site (VE)		Ease of physical access to the intrusion site (A)			
		Very easy	Easy	Difficult	Very difficult
Level of surveillance of the intrusion site (S)	Low	*High*	*High*	*Medium*	*Medium*
	Medium	*High*	*High*	*Medium*	*Low*
	High	*High*	*Medium*	*Low*	*Low*

IF *Level of surveillance* is "S" **AND** *Ease of physical access* is "A" **THEN** Vulnerability linked with the environment is "VE"

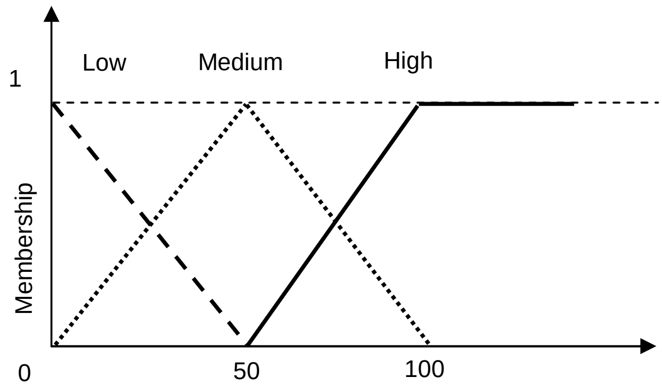
Figure 22. Knowledge Database and Rule Base for the “Vulnerability linked with the environment of the intrusion site” model.

Data Base 3

Structural Vulnerability	$\mu_{i,1}$	$\mu_{i,2}$	$\mu_{i,3}$
High	50	100	100
Medium	0	50	100
Low	0	0	50



Vulnerability linked with the environment of the intrusion site	$\mu_{i,1}$	$\mu_{i,2}$	$\mu_{i,3}$
High	50	100	100
medium	0	50	100
low	0	0	50



Rule Base 3

<table>
<tr><td colspan="2" rowspan="2">Intrinsic vulnerability (IV)</td><td colspan="3">Structural Vulnerability (SV)</td></tr>
<tr><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td rowspan="3">Vulnerability linked with the environment of the intrusion site (SE)</td><td>Low</td><td>Low</td><td>Medium</td><td>Medium</td></tr>
<tr><td>Medium</td><td>Medium</td><td>Medium</td><td>High</td></tr>
<tr><td>High</td><td>Medium</td><td>High</td><td>High</td></tr>
</table>

IF *Vulnerability linked with the environment of the intrusion site (VE)* is "SE" **AND** *Structural Vulnerability* is SV" **THEN** Intrinsic Vulnerability is "IV".

Figure 23. Database and Rule base for the "Intrinsic Vulnerability" model.

2.3.2.5 Creating inference engines using jFuzzyLogic

In order to design and implement the Fuzzy Inference Systems, an open source library for fuzzy systems called jFuzzyLogic and developed by Alcala-Fdez and Cingolani (2012) was used. The jFuzzyLogic library permits to: (1) standardization reduces computer programming by using Fuzzy Control Language, (2) functional and complete implementation of FIS providing a programming interface and an Eclipse plugin, (3) independent software platform fully implemented in Java.

The Fuzzy Control applications programmed in Fuzzy Control Language are encapsulated into Function Blocks, which specify the input and output parameters, the membership functions for each input variable, the Fuzzy Control specific rules and operators, the defuzzification method.

For criteria mentioned in the KB 1 and 2 the numbers of partition level have been limited to 3 or 4 (Low / Medium / High or Very Easy/Easy/Difficult/Very Difficult) in order to distinguish the different assets without introducing too many levels. The fuzzy numbers thus obtained are represented by triangular fuzzy sets and mapped onto non-dimensional relative scale that ranges from 0 to 100 as illustrated in Figure 24.

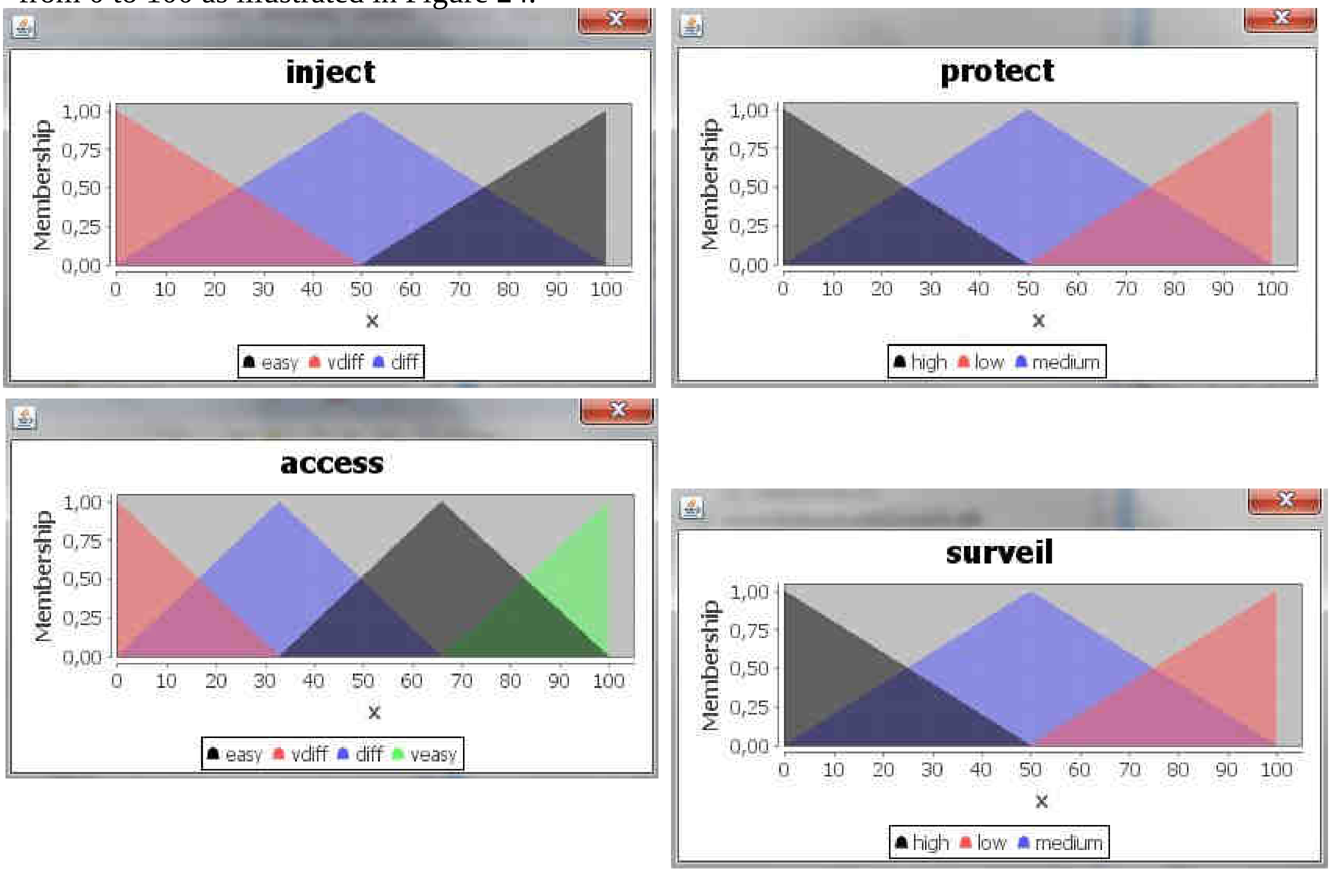


Figure 24. Criteria for KB 1 and KB 2 – jFuzzylogic graphic interface

The outputs of the inference engines 1 and 2 – outputs which are crisp values - are then partitioned into 3 levels (Low / Medium / High) and represented by triangular fuzzy set mapped onto a relative scale as described for the inputs. These outputs correspond to the input fuzzy sets used by the inference engine 3.

The results of this third inference engine are represented by a triangular fuzzy set partitioned and mapped in the same way than the outputs of the inference engine 1 and 2 (Cf. Fig.25). This last triangular fuzzy set is then defuzzified into a single crisp value: **the intrinsic vulnerability index**.

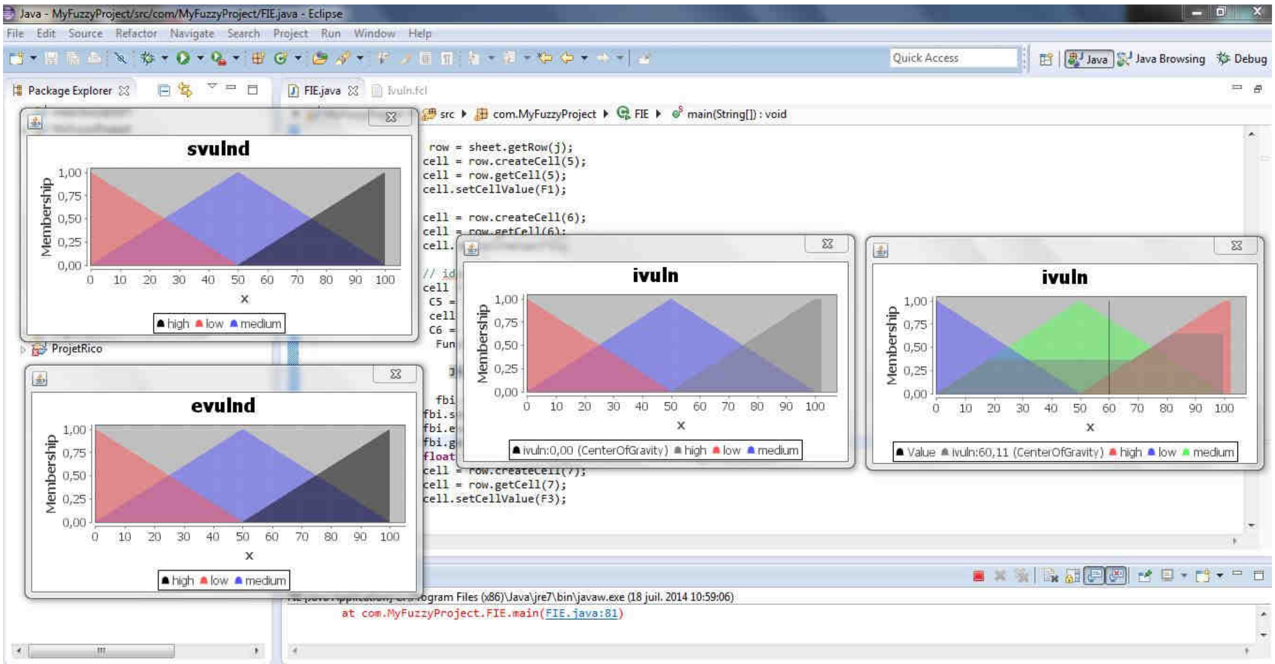


Figure 25. Inference engine n° 3- jFuzzylogic graphic interface.

In order to combine the 3 inference engines the programming interface proposed by Cingolani and Alcada-Fdez (2012) has been adapted in order to provide an automatic calculation tool. The list of WDN asset defined by 4 criteria as mentioned previously represents the inputs data of the inference engine 1 and 2. This list is recorded into an excel file. This file is automatically scanned by a specific java program, which injects the input data values within the right inference engine. This automated calculation tool makes the inference task easier and reduces computational time.

2.3.3 Consequences identification and evaluation

The consequence analysis completes the vulnerability analysis that assesses the likelihood to harm the network and its assets. Risk analysis requires the identification of potential consequences, which in our case are due to intentional contamination of drinking water. As mentioned before, the analysis focuses on the water distribution network (WDN) in other word, potential consequences for users, water utility and assets of WDN. Many types of consequences or impacts can be enumerated. They can be gathered into families as economic, technical, environmental, human health, psychological, sociologic, etc.

This section aims at establishing a comprehensive methodology for assessment and evaluation of some potential consequences that could be monetised or assessed by specific impacts models. Impacts of water contamination could be measured in direct and indirect way.

For more readability and understanding, potential consequences are gathered into two main groups: i) consequences on water utility and ii) consequences on third parties. We assume that monetisation of some impacts is suitable to have commensurable indicators. Concepts of externalities and internalities seem relevant to highlight consequences supported by the water utility and those supported by third parties. When contamination occurs, several potential consequences are possible that could harm consumers and technical devices. Even if responsibility of water utility is engaged regarding to water consumers, the community will support illness due to contamination, so it’s the health system that takes in charge sick persons.

Costs due to hospitalisation, health care and medicines will be partially or completely supported by the community. They represent an externality for water utility and constitute an indirect cost for it. In the same domain, loss of autonomy as temporary or permanent disability constitutes externality that could be estimated by the induced cost of social and psychological care and possible allowance for harmed persons.
Adverse effect to technical system or to its serviceability is considered as internality and supported by utility; in this case all rehabilitation, renewal or cleaning (flushing) operations are supported by the utility.

Costs inherent from these actions are considered as direct cost and imputed to the water service. Water utility has also to support the cost of emergency water delivery for population by providing consumer with water by substitution way: vehicle with water tank, bottles of water, etc. Costs inherent from these operations are considered as direct costs supported by the utility and constitute internality. The contamination induces a partial or total service interruption that constitutes a direct loss of economic activity for water utility; a direct cost of unsealed water can be estimated for the period of service interruption.

The detection of contamination in a specific network zone or the entire network induces generally an interruption of water delivery. Consequence for consumer in term of illness, loose of economic activity or wellbeing is considered as externality for water utility. This impact depends on the water use that could be domestic or non-domestic. A way to estimate this consequence is to characterise the value that consumer gives to water, in other word what is his willingness to pay (WTP) to maintain the service level and water quality.
Contamination will harm its way of life and wellbeing, so the value of the contamination’s impact corresponds to the decrease of his life condition at least on short term time period.
Another type of prejudice concerns psychological adverse effect to consumer that could lead to lose of confidence into water utility and harm brand image of it.
This type of prejudice could engender a decrease of water consumption and lose of economic activity for water utility especially in context of concurrence with other utility or with other water resources, self-resource “drilling” especially for industrials.

The Table 12 resumes some internalities and externalities from water utility point of view due to water contamination. The monetisation of these impacts allows estimating of the value of the water or the service provided both for domestic and non-domestic use. The obtained monetised assessment don’t correspond necessarily to a real expenditure, be aware to the fact that all valuations could not be summed up. In other hand, the interpretation of each impact should be done independently when the aggregation is not allowed.

Table 12. Impacts of water contamination

Type of consequence	Impacted party	Economic	Human Health	Psychological	wellbeing
Externalities	Domestic-user	Hospitalisation and medicine Water purchase	Illness, loss of autonomy and disability permanent or temporary	Loss of confidence and brand image	Loss of life condition and wellbeing
	Non-domestic	Loss of economic activity		loss of confidence and brand image	
		Cleaning , rehabilitation, renewal operations			
	Other utilities: wastewater, etc.	Treatment problem			
		Cleaning , rehabilitation, renewal operations			
	Environment	Loss of recreational activities			
	Community	Hospitalisation and medicine	Hospitalisation and medicine		
		Allowances/indemnities	Allowances/indemnities		
Internalities	Water utility	Cleaning, rehabilitation, renewal operations			
		Unsealed water due to service interruption			
		Water deliver by substitution ways			

It appears that one way to assess some of the illustrated impacts is the monetisation that could be achieved by several approaches. In order to assess impacts, it's required to choose an adequate method among existing one: Travel cost method, Contingent Valuation Method, Avoided cost, Substitution cost.

For practical reasons, the assessment of impacts should be done at the scale of the hydraulic nodes that aggregates several consumers with mainly two water uses: domestic and non-domestic. The proposed approach should tackle this operational dimension to provide an accurate estimation at the required level. In the following section each impact is analysed according to its adversity to the consumer and how it can be assessed by selecting an appropriate monetisation approach.

2.3.3.1 Human health consequences analysis

The following section deals with the assessment of potential non-cancer effects on human health observed on short-term period due to acute exposure to chemical or microbiological contaminants. One of possible way to achieve this type of analysis for drinking water is to adapt existing approach as Quantitative Microbiological Risk Analysis (QMRA) Petterson *et al.*, 2006). The proposed methodology is an adaptation of QMRA by an enlargement of the approach to acute microbiological and chemical contaminants exposure and the consideration of a sub-system corresponding to the water distribution network (WDN) where no investigation is done about potential pathways or source of contamination. The monitoring of the concentration of contaminants is operated by specific sensors disseminated all over the WDN that allows detecting possible contamination, this aspect of risk mitigation and management is not addressed. In the current work, pathway corresponds to intentional introduction of contaminant into the network; accidental events for example are not considered.

2.3.3.1.1 Hazard identification

This step consists in determining the effects of potential contaminants on human health and on anthropic activities. Considering WDN, the main studied hazard concerns the exposure of water consumers to intentional (voluntary) contaminations of drinking water. This deliberate act consists in the introduction of microbiological or chemical contaminant into the network, which potentially harms user's health or their activities. In the current work, we assume that only two types of contaminants can be used: i) microbiological contaminants and ii) chemical contaminants. Only oral route of contamination is addressed. It's clear that risk management policy depends on the type of contaminant and requires the description of exposure models in one hand and requires the description of potential adverse effects in other hand by analysing the dose-response models or other derived models depending on the nature of contaminant.

2.3.3.1.2 Exposure model

The exposure model defines the level of exposition of water consumers to contaminants spread into drinking water. The assessment of exposition depends on three main dimensions: i) potential pathways, ii) possible routes and iii) the characteristics of the contaminant at the consumer place (node). In our case pathways seem to be focused on the drinking water delivered by the network, even if other types could exist, they are not handled.

Routes concern the way that the consumer is in contact with contaminant. For both types many routes exist as oral ingestion, inhalation or skin contact. In the current work, only direct oral ingestion of contaminants is considered as a potential contamination route. The analysis of the ingestion is based on: the volume of consumed water per time period (day, week, month, etc.), the concentration of the contaminant at the moment of ingestion and the intake dose. So, consumption pattern is needed to measure the potential ingested volume.

It's also required to assess the concentration of contaminant in order to measure potential ingested quantity of contaminant. So, the problematic of exposure model requires the investigation of two main aspects: i) understand water allocation and estimate water consumption with an accurate consumption model and ii) identify potential contaminant types and describe the behaviour of contaminant mixed to water, for simplification reason we assume that chemical contaminant is completely mixed to water and constitutes a homogenous mixture.

a. Water allocation and demand estimation

The availability of hydraulic simulation model allows estimating of the demand at node level, the water volume delivered to several consumers and potentially variety of water uses. A real challenge consists in proposing a way to allocate the water consumption to consumers.
Possible way to ensure a repartition is to consider an average consumption per user in order to calculate the number of potential consumers connected to the considered node. The allocation permits assessing the quantity of contaminant ingested by the consumer based on the ingested volume and concentration. It's also possible to estimate the concentration that could harm the consumer health by using retrospective exposure model. Let's consider a node with an estimated demand that corresponds to the consumption of several consumers. The consequence analysis should be able to measure effects of contamination on all users. One way to deal with this is to fit a probability function that describes: i) according to a mean consumption value, define the potential number of consumers and or ii) describe the mean consumption value per consumer.
It's clear that the proposed approach consists in a way to deal with the lack of accuracy of demand description in the hydraulic model based because it aggregates several consumers with different uses into the same consumption node.

In case of absence of an accurate hydraulic model with specific consumption pattern for each water use, we propose an alternative approach to estimate water allocation and exposure to contaminant. Let's consider two potential water allocations: i) domestic uses and ii) non-domestic uses. We assume that the hydraulic model computes the water consumption Q_i of a given node n_i during the simulation period (observation window) [t_a, t_b]. We note α the allocation rate of water demand dedicated to domestic use and β the allocation rate of water demand dedicated to non-domestic use with $\alpha = 1 - \beta$. The value of α *and* β could be estimated according to data and information that concern the water uses into the concerned node, for nodes where the water uses are unknown, values are generated randomly according to Monte Carlo simulation for example. We focus in the following section on domestic use. Let's consider that the domestic consumption per consumer q is given by the following pattern, which depends on both the day period and level of consumption c per unit time:

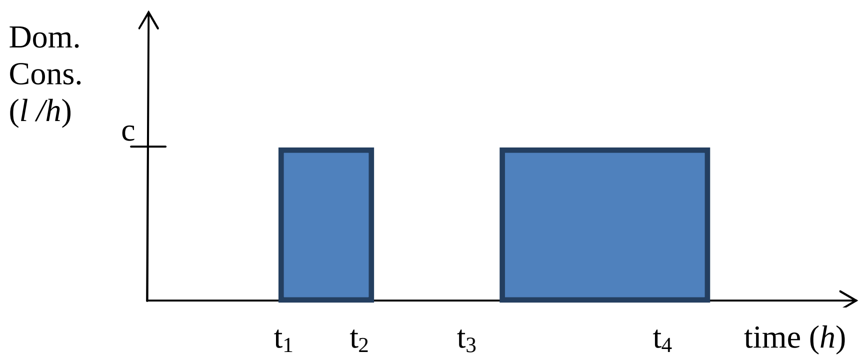


Figure 26. Pattern for average daily domestic consumption.

Because the consumption behaviour of each consumer is different, we assume that the value of c is not constant but could vary from consumer to another. The variation of this parameter could be described by a probability function in order to take into account the uncertainty concerning the estimation of consumption. Let's consider a normal distribution of the c parameter value.

The average daily consumption is around 150 L (French context) and considering a confidence interval of [120; 180] at 99% estimations of μ_q (the theoretical mean) and δ_q (the theoretical standard deviation) could be obtained as follow:

$\mu_V+3\ \delta_V=180$
$\mu_V-3\ \delta_V=120$

The resolution of equations leads to obtain $\mu_{V=}150$ L and $\delta_V=10$ L. The unit consumption q at time t is calculated by the following equation (for the step function of Figure 26):

$q(t) = 0 \quad if\ t < t_1$
$q(t) = c \quad if\ t_1 \le t < t_2$
$q(t) = 0 \quad if\ t_2 < t < t_3$
$q(t) = c \quad if\ t_3 < t < t_4$
$\mathbf{q(t) = 0 \quad if\ t_4 < t}$

$$\mathbf{V_k = \int_0^{24} q(t)dt = Kc \rightarrow \mu_V = K\mu_c} \qquad (16)$$

Where K is the consumption daily period in h, c is the consumption in L/h and V_k is the domestic daily volume in L associated to the pattern k.
This implies that $\mu_c = \frac{\mu_V}{K}\ and\ \delta_c = \frac{\delta_V}{K}$. Considering a consumption daily period of 8 hours (K=8), we obtain the following values: $\mu_{c=}18.75$ L/h and $\delta_C=1.25$ L/h.

Finally we get: $c \sim N(\mu_c = 18.75, \delta_c = 1.25)$.

We note $V_{dom}(i)$ the part of node consumption dedicated to domestic use for node i so :

$$\mathbf{V_{dom}(i) = \alpha_i V(i)} \qquad (17)$$

In other hand the domestic consumption is equal to the sum up of all the individual nodal consumption or it can be obtained by multiplying the daily consumption by the number of consumers of the node i, nc(i) as follow :

$$V_{dom}(i) = nc(i)V_k \qquad (18)$$

$$nc(i) = \frac{\alpha_i V(i)}{V_k} \qquad (19)$$

In order to validate the obtained values of nc(i), α, V(i) and V_p a comparison between the apparent and real number of consumers at “Iris” level is achieved (Ilots regroupés pour l’information statistiques) is achieved. Iris corresponds to a geographical unit zone gathering about 2 000 inhabitant for who several statistics are available (Insee, 2008). Let’s consider n inhabitants into a given Iris area delivered by k nodes, so:

$$\sum_{i=1}^{k} nc(i) = n \qquad (20)$$

$$\sum_{i=1}^{k} \frac{\alpha_i V(i)}{V_k} = n \qquad (21)$$

In case of lack of information about the water use at the nodes, the allocation share to domestic use α could be sampled between 0 and 1.

The water allocation at the scale of sub-network gathering k nodes, where water consumption is known, can be estimated by the vector $\alpha = (\alpha_1, \alpha_2, \ldots., \alpha_k)$ that indicates the water allocation for domestic uses at each node i of the analysed sub-network. The allocation of non-domestic use can be easily obtained by the vector $\beta = (1 - \alpha_1, 1 - \alpha_2, \ldots., 1 - \alpha_k)$.

The ingested dose per consumer is proportional to the rate of ingested water among the total domestic use. The parameter *p* indicates this rate, so the ingested dose $d_j(t)$ of a contaminant depends on concentration C_i (*t*) in (*mg/L* or ppm). $C_i(t)$ is provided by the transport hydraulic model for any node i; the temporal evolution of the concentration is sketched in Fig.27

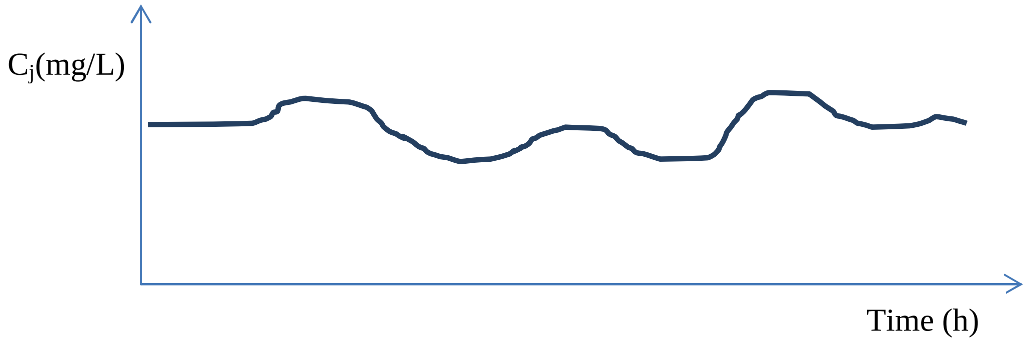


Figure 27. The variation of concentration over time.

The intake dose at time t depends on the ingested water volume and the concentration of contaminant at time t into water, so the instant intake dose for consumer *j* at node *i* and following pattern k at time t is equal:

$$d_j(t) = q_k(t)C_i(t)p \tag{22}$$

The total intake dose over time period $[t_a;t_b]$ is obtained by all ingested dose over the simulation period of time:

$$d_j = \int_{t_a}^{t_b} q_k(t)C_i(t)p dt \tag{23}$$

Another way to deal with the intake dose is to estimate the **average** intake dose over a certain period of time based on the average consumed volume and the average concentration of the analysed contaminant during the considered simulation period. The average intake dose is calculated by the following equation:

$$(\overline{d_j}) = \overline{q}\,\overline{C}\,p \tag{24}$$

The average intake dose should be compared to Acute Reference Dose (*ARfD*) in case of chemical contamination or used as input parameter into dose-response model in case of microbiological contamination.

b. Type of contaminant

The exposure model is sensitive to the type of introduced contaminant and if multiple contaminants are injected simultaneously or not. The definition of the behaviour of contaminant into the network and with water is not an easy task. So, for the current study we assume that only one type of contaminant is introduced to the network, the mixing of contaminants is not addressed. Another assumption concerns the type of contaminant by clearly distinguishing between chemical contaminant and microbiological contaminant. The main distinction concerns the mixing with water. For chemical contaminant, we assume a homogenous mixing with water that leads to consider that consumers connected to the same node are in contact with the same quantity of contaminant, in other word their exposure to contamination is quietly the same. For microbiological contaminant the mixing is not complete, so microorganisms still separated from water and are randomly spread into water, in that case the exposure of consumers connected to the same source is not the same. Due to the random variation of the location of microbial particles, microbiological counts may be expected to follow a **Poisson distribution** Haas *et al.* (1999). The Poisson distribution could be used as a way to deal with uncertainty of the estimation of the concentration of contaminant at the node level. We assume that the value of concentration estimated by the hydraulic model corresponds to the mean value of the number of organisms per unit volume, noted λ. The probability to have k microorganisms at the node j is given by the following equation:

$$P(X = k) = \lambda^k . \frac{e^{-\lambda}}{k!} \qquad (25)$$

The estimation of the intake dose depends on the presence of microorganisms into ingested water; this step seems quite different for microbiological rather than chemical contamination.

2.3.3.1.3 Dose-Response model for microbiological contamination

Several dose-response models had been developed for average contaminant dose. The main purpose of models is to establish relationship between the dose of contaminant and its consequence in terms of infection or illness. A clear distinction is underlined in literature between models concerning microbiological contaminants and those dedicated to chemical contaminants. The following section addresses both models, by defining the more cited models in the literature. Microbiological contamination concerns the presence of pathogens or microorganisms into drinking water that potentially harms human health. The infection process needs that a consumer ingests a certain number of pathogens, depending on the intake dose and the type of pathogens, infections could proceed to illness. Infection and illness can be described by specific probability distribution. For microbiological contamination, contaminants correspond to microorganisms or colony forming units (CFU).

2.3.3.1.3.1 Exponential model

The exponential dose-response model is recommended when the intake likelihood of a dose of pathogens is Poisson-distributed and all of the ingested pathogens have the same probability of causing infection, the probability of infection per person per day is obtained by the following equation:

$$P_{(inf/day)} = 1 - e^{-rd} \qquad (26)$$

Where r is the survival probability of each pathogen or the probability of infection per pathogen, considered as constant and similar for each pathogen, d is the average intake dose that corresponds to the number of ingested pathogens. The ingested dose by itself can be considered as discrete variable with a certain probability distribution (Poisson or multinomial for example) in case of uncertainty to estimate the intake dose.

2.3.3.1.3.2 Beta-Poisson model

When the survival probability r is not constant and assumed to be distributed with Beta function, the dose-response relationship is described by a Beta-Poisson Model. Because the complexity of calculation of the probability of infection inherent from this model, a derived simple dose-response model based on some approximations is commonly used as follow:

$$P_{(inf/day)} = 1 - \left(1 + \frac{d}{\beta}\right)^{-\alpha} \tag{27}$$

Where d is the intake dose, α and β the parameters of the Gamma function. The values of parameters differ from pathogen to another. The Table 13 defines some recommended values according to the type of pathogen:

Table 13. Impacts of water contamination

Model	Exponential	Beta-Poisson		Reference
Pathogen(s)	R	α	Β	
Cryptospoidium parvum	0.018			(Messner et al,2001)
Giardia Lambia	0.01982			(Rose et al, 1991)
Rota virus		0.265	0.4415	(Haas et al, 1993)
Campilobacter jenunis		0.024	0.011	(Teunis el,2005)
E.Coli O157:H7		0.0571	2.2183	(Strachan et al, 2005)

When consumers are exposed to contaminant for more than one day, the probability of infection is derived from the following equation that indicated the probability of infection for n days of exposition to a pathogen:

$$P_{(inf/n\ days)} = 1 - (1 - P_{(inf/day)})^{n} \tag{28}$$

The process of infection depends on the ingested dose and intrinsic resistant to infection of each consumer. In this case the infection process is independent from individual to another one. In the case of a similar probability of infection for a similar dose, the number of infected persons per day can be described by binomial distribution with parameter P corresponding to the probability of infection. The probability to have k infected persons among m persons is obtained by the following equation:

$$P(K = k)_{day} = C_m^k . P_{(inf/day)}^k . (1 - P_{(inf/day)})^{m-k} \tag{29}$$

The infection by itself is not enough to assess the adversity of a pathogen for human health. It is required to describe the progression of infection to illness. Two types of models exist: i) a constant rate model and ii) a dose-dependent model.
The constant rate model is the most common used; it considers a constant conditional probability of individual to be illness if it is infected. This probability corresponds to a fixed proportion of individuals with infection progressing to illness. The table 14 resumes some conditional probabilities for some pathogens:

Table 14. Conditional probabilities for some pathogens (Example)

Pathogens	$P_{(illness/infection)}$
Cryptospoidium parvum	0.70
Giardia Lambia	0.24
Rota virus	0.88
Campilobacter jenunis	1
E.Coli O157:H7	1

In case of a dose dependent model, the conditional probability of illness given infection is given by the following equation:

$$P_{(illness/infection)} = 1 - (1 + \gamma f(d))^{-\theta} \tag{30}$$

Where γ, θ are parameters issued from epidemiology study for concerned pathogens and f(d) is function that depends on the ingested dose of contaminant that leads to progress from infection to illness. (US EPA, p. 33, 2010). The conditional probability can be described by many probability distributions (Beta, Gamma, Lognormal,) with regard to statistical data analysis; the shape of the distribution depends on the type of contaminant and the dose dependent relationship.

2.3.3.1.4 Risk characterization for human health consequences

A way to assess consequences of the contamination is to identify outcomes and end-points of illness due to infection by ingested contaminant. Consequences of illness outcomes can be evaluated in several points of view: health, economic, social. It exists for human health risk assessment a metric developed by WHO (World Health Organization), DALY for Disability Adjusted Life Years that estimates the years of life lost (YLL) and number of years lived with disability (YLD) as consequence of illness outcomes. The term risk is used because the metric crosses between potential outcomes (consequences) and likelihood of outcomes in case of illness regarding to the exposure to contaminant. Evaluating the contaminant burden requires estimating of illness outcomes likelihood, severity and duration.

The DALY, for *j* outcomes is obtained by the following equation derived from Petterson *et al.* (2006, p19):

$$DALY = \sum_{j=1}^{J} YLL_j + YLD_j \tag{31}$$

$$DALY = \sum_{j=1}^{J} P_{(illness/infection)}\, P_{(infection)} P_{(j/illness)} DW_j D_j \tag{32}$$

$P_{(illness/infection)}$: probability that infection progresses to illness
$P_{(j/illness)}$: probability of outcome *j* in case of illness
$P_{(infection)}$: probability of infection per person
DW: disability weight or severity
D_j: duration of outcome *j*

It appears that consequences on human health depend on the severity of outcomes and disability caused by the ingestion of microbiological contaminants. Combination between consequences and their probability of occurrence is computed into human health risk assessment that could be carried out on yearly or daily basis per person or on a group of persons.

In absence of availability of outcomes with accurate evaluation of duration and severity for all potential contaminants, the calculation of DALY seems difficult. So the number of ill persons will measure the adverse effect on human health without specifying the nature of outcomes and their severity.

A definition of "acceptable risk level" or a "reference risk level" is required for risk mitigation. The estimation of a reference level in relation to water is specific to health outcomes in terms of frequency, severity and duration. A partial indicator that does not involve outcomes can be measured based on the hypothesis that even if a person is infected, illness not necessary occurs. So the risk of diseased (*RD*) measures the likelihood to be infected and to be ill over a time period. It can also be interpreted as the proportion of ill persons among a group of persons. The RD is calculated by the following equations:

$$RD(year) = P_{(illness/infection)}P_{(inf/year)} \tag{33}$$

$$RD\ (365\ days) = P_{(illness/infection)}\left[1-(1-P_{inf/day})^{365}\right] \tag{34}$$

$$RD\ (n\ days) = P_{(illness/infection)}\left[1-(1-P_{inf/day})^{n}\right] \tag{35}$$

According to (WHO, 2008, p. 45) the reference level of risk on health due to waterborne diseases is equal to 10^{-6} DALYs per person per year, it corresponds of a tolerable loss of healthy life of one year in a population of a million over a year (more details on the calculation are available in (WHO, 2008, p. 130). For pathogen causing outcome with low case of fatality rate (diarrhea), the reference level of risk of diseases could be equivalent to 10^{-3} per person per year that means that 1 person is ill for 1000 contaminated persons over a year.

2.3.3.2 Consequences on water utility

The assessment of internalities based on direct costs that will be potentially supported by the utility in case of contamination are derived from potential consequences and the emergency procedures that will be implemented. Some of costs are directly generated by the implementation of procedures that should be clearly established and known.
The cost assessment requires emergency procedures analysis and dedicated information system that inventories assets and their characteristics.

2.3.3.2.1 Asset cleaning and reparation (ACR)

It corresponds to direct cost supported by the utility to clean, to disinfect or to repair asset harmed by the contamination for a given scenario of contamination. It can be estimated by the flushing cost for example which is generally expressed per unit of pipe length or per cleaned surface. Notice that this cost does not include the cost of treatment of water used for cleaning.
We assume that in case of contamination, flushing cost increases depending on the type of contaminant because it implies specific and more expensive treatment for cleaning water. For limited contamination, this cost could be estimated based on the type of harmed asset or the length of contaminated pipes. This direct cost is considered as an operating expenditure. The estimation of cost can be calculated based on the volume of water required for cleaning, the cost of immobilised machines and personal costs. The table 15 summarises required data for cost assessment. Impacts on asset can be assessed by calculating the cost of cleaning and reparation

per unit of asset or per surface of contaminated inner pipe wall, let's consider unit cost per surface or length, the total amount of cost is obtained by the following equation:

$$ACR = C_{cleaning} \times n_{asset} + C_{cleaning} \times S_{pipe} \quad (36)$$

Table 15. Required data for cleaning cost assessment

Type of contaminant	Harmed asset	Emergency procedure	Type of cleaning/flushing method	Cost of cleaning
Nature and concentration of contaminant	Type of asset and size of contamination: area of pipe wall, number of pipes, number of asset, length of pipe, others	Procedure to be implemented	The appropriate technic for cleaning and for cleaning water treatment	Unit cost of cleaning per asset or length + unit cost per m^3 of contaminated water cleaning.

2.3.3.2.2 Asset renewal or rehabilitation (ARR)

It corresponds to expenditures of renewal or rehabilitation of contaminated asset for a given scenario of contamination. It is unplanned expenditure that corresponds to capital expenditure. The decision of renewal depends on the gravity of the contamination and type of contaminant, the emergency procedure can indicate if the renewal is required. In general, cost depends on material and diameter or on asset's size; it is expressed per unit of length. The direct cost is calculated based on the cost of providing the asset and roadwork that includes materials, machines and personnel costs.

Table 16. Required data for renewal or rehabilitation cost assessment.

Type of contaminant	Harmed asset	Emergency procedure	Type of action	Cost of action
Nature and concentration of contaminant	Type of asset and size of contamination: area of pipe wall, number of pipes, number of asset, length of pipe, others	Procedure to be implemented	Renewal or rehabilitation	Unit cost of renewal or rehabilitation per length or per asset including excavation (removal), providing of pipe roadwork and decontamination of removal asset

The total cost of rehabilitation or renewal depends on the length of impacted pipes or asset; ARR can be estimated by:

$$ARR = C_{RR} \times l + C_{RR} \times n_{asset} \quad (37)$$

2.3.3.2.3 Daily loss of income (DLI)

It corresponds to the cost of unsold water due to the service interruption. The cost can be estimated by the average undelivered water during the period of interruption.

Table 17. Required data for daily loss of economic activity assessment

Duration of interruption	Harmed consumers	Volume estimation	Daily loss of economic activity	Cost of action
Period and duration of interruption	Type and number of undelivered consumers	Undelivered water volume	Loss of income due to interruption =undelivered volume x price of m^3 of drinking water	Unit cost of renewal or rehabilitation per length or per asset including excavation (removal), providing of pipe roadwork and decontamination of removal asset

The unsold water corresponds to the potential consumption of impacted consumers over the service interruption or contamination period. The daily loss of income corresponds to the average unsold water per day of service interruption.

$$DLI = V_w \times n_c \times \mathrm{W_p} \tag{38}$$

2.3.3.2.4 Water delivery by substitution (WS)

It corresponds to the cost of bottled or conditioned water provided to consumer instead potable water and the cost of water in tanks delivered by special trucks. This cost can be estimated based on an average volume of substituted water, let consider 2 bottles of spring water and 50 L per person delivered by tank. Average cost estimation can be done according to this scenario.

Table 18. Required data for water delivery cost assessment

Duration of interruption	Harmed consumers	Volume estimation	Required logistic	Cost
Period and duration of interruption	Type and number of undelivered consumers	Estimation of required volume to deliver, for example 2 bottles of mineral water and 50 l per person	Number of tanks, number of trucks and number of employees	Cost of water for tanks+ Cost of bottled or conditioned water + logistic cost (rent of trucks and tanks) + personnel costs

2.3.3.3 Loss of confidence and brand image (LCBI)

The cost of confidence can be estimated by the changing in consumer's behaviour especially for primary needs, for drinking for example. The loss of confidence can be estimated by the unsold water due to the substitution of tap water by spring water for drinking and/or cooking or by the decrease of proportion of consumers that drink tap water due to contamination events or any events that harm the brand image of the water utility. The volume of daily volume per person is ranged between 2 to 10 L per person per day, which can constitute a severe loss of exploitation income for water utility at the level of the entire network.

Table 19. Required data for loss of confidence cost assessment

Behaviour of consumer	Volume estimation	Cost
Proportion of consumer drinking bottled water	Estimation of decrease of water consumption due to substitution of tap water by bottled water for drinking and cooking for example per person	Loss of income due to substitution =volume of substitution x price of m^3 x Duration of substitution

We assume that persons impacted by contamination could change their consumption behavior and avoid using delivered potable water for drinking and cooking uses. The loss of confidence is estimated indirectly by the loss of income for water utility due to water substitution during D days, substitution could be temporary or permanent. By considering n_c impacted consumers and V_w volume of daily water and p_{dc} the proportion for cooking and drinking uses and W_p is the water price per liter or m^3.

$$LCBI = n_c \times V_w \times W_p \times p_{dc} \quad (39)$$

2.3.3.4 Consequences on third parties

2.3.3.4.1 Ad-hoc indicator for human health consequences

This section deals with human health consequences of exposure to microbiological and chemical contaminants. Based on existing indicators for consequences and risk characterization of microbiological contamination, we define a specific indicator that measures the number of ill persons at the scale of the consumption node and for a minimum dose d_{min} corresponding to the dose over which the risk of diseases is considered as critical. The equation of d_{min} depends on the type of pathogen and its dose response model. We substitute in equation (33), $P_{(inf/day)}$ by its expression for each type of pathogen. In case of Poisson model, equation (33) becomes:

$$RD\ (n\ days) = P_{(illness/infection)}[1-(1-e^{-rd})^n] \quad (40)$$

For a reference level of risk, RD_{ref} the value of d_{min} is obtained as follow:

$$d_{min} = \frac{-ln\left[1-\left(\frac{RD_{ref(n)}}{P_{(illness/infection)}}\right)^{1/n}\right]}{r} \quad (41)$$

In case of Beta-Poisson model, the value of d_{min} is obtained as follow:

$$d_{min} = \beta\left[\left(1-\frac{RD_{ref(n)}}{P_{(illness/infection)}}\right)^{(-1/n\alpha)} - 1\right] \quad (42)$$

As mentioned above, the repartition of pathogens is not homogenous into water; the probability for ingesting a number of pathogen (X=k) per person is defined by equation (25). In order to measure the number of ill persons at a given node for at least dose d_{min}, we calculate the following probability:

$$P(X \geq d_{min})_= 1 - \sum_{k=0}^{d_{min}-1} \lambda^k . \frac{e^{-\lambda}}{k!} \quad (43)$$

Let's consider n_c consumers delivered by a node, the number of minimum potential ill persons exposed to at least a dose d_{min} can be obtained as follow:

$$n_{ill\ person} \geq \alpha n_c P(X \geq d_{min})\ RD(n) \quad (44)$$

Where α represents the proportion of domestic consumers connected to the node or the share of domestic water use. The estimation of ill persons is a possible way to assess the consequence of contamination on human health. Note that types of outcomes are not considered, adverse due to illness are not considered by the proposed indicator because the unavailability of reliable data establishing causes-effects links between contaminants, outcomes and their duration. In absence of knowledge, we assume that the estimation of ill persons constitute a comprehensive and interesting indicator for scenarios comparison for the same contaminant.
Dose response models for chemical contaminants are based on toxicity studies. The goal of toxicity assessment is to quantify the mathematical response between the intensity of the contaminant and its adverse effects.

Toxicity analyses are conducted on animals, which may be imperfect for humans. Running tests on animals could lead to assess the following thresholds:

- LD50: Median lethal dose (LD50) of a toxic substance is the dose required to kill half the members of a tested population
- NOAEL: No Observed Adverse Effect Level is defined as the highest dose or concentration of a chemical in a single study found by experiment or observation that causes no adverse effect health (WHO, 2008, p 150)
- LOAEL: Lowest Observed Adverse Effect Level is the lowest observed dose or concentration of a substance at which there is a detectable adverse effect (WHO, 2008, p 150), LOAEL is commonly used when NOAEL is not available.

Dose-response estimation for a single chemical by an oral route of exposure may lead in the calculation of a reference dose (*RfD*) for chronic effects, defined by (U.S. EPA, 2000) as: "The *RfD* is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime."

The *RfD* refers to a certain dose level under which no adverse effect is observed or expected to occur. The calculation of a reference dose is based on listed thresholds by considering an uncertainty factors (UF) or safety factor to transpose the adverse level from animals to human:

$$RfD = \frac{NOAEL\ or\ LOAEL}{UF} \quad (45)$$

The human range of UF derives from 10 to 0.1 depending on the type of contaminant and its human health adverse; some substances are less adverse for human than animals. *RfD* is generally expressed by dose of substance per body weight per time unit of exposure (daily, monthly, yearly). The level of dose is considered for chronic exposure and long-term adverse effects.

In the current work, we focus on acute exposure and short-term adverse effects. Many concepts deals with the this kind of acute effects; for EPA acute exposure can be derived from RfD by modifying the value of UF; the Acute Reference Dose (*ARfD*) can be assessed based on variation of NOAEL, LOAEL or UF to take into account acute and short term adverse effects. In the same way the office of water (OW) developed health advisories (HAs) assessment approach for several short and long term exposure durations (1 day, 10 days, longer-term, and lifetime) the calculation of HAs is derived from NOAL/UF. The Agency for Toxic Substances and Disease Registry (ATSDR) defines Minimal Risk Levels for Hazardous Substances (MRLs) as " *... an estimate of daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified route and duration of exposure*." The estimation of MRLs is quite similar to RfD assessment for non-cancer health effects but includes both route of contamination (oral or inhalation) and duration. For MRLs duration is addressed by providing for the designation of MRLs in three different duration categories: acute (<=14 days), intermediate (15-364 days) and chronic (> 365 days).
It appears that several thresholds exists but seems derived from *RfD* estimation. We consider in the current work a threshold noted Acute Reference Dose (*ARfD*) corresponding the minimum intake dose per liter and per body weight causing acute adverse effects on short term (<=14 days).
The consequences on human health can be measured by the number of ill persons connected to a consumption node. We assume that if intake dose (d_{intake}) is above ARfD, acute outcomes are observed on all connected persons to the node. Let's consider n_c persons connected to a node, number of ill persons $n_{ill\ persons}$ is obtained by the following equation:

$$n_{ill\ persons} = n_c.(1 - Y) \tag{46}$$

With:

$$Y = \begin{cases} 1 \ \ if \ \ d_{intake} < ARfD \\ 0 \ if \ d_{intake} \geq ARfD \end{cases} \tag{47}$$

It appears that a reference level or threshold level of risk (RLR) is required for risk mitigation, which can be expressed in terms of RD, RLR_{RD} or DALY, RLR_{DALY}. It could be fitted based on experience feedback or determined with the use of inference approach with the help of decision maker or an expert. Let's define diseases quotient (DQ) that indicates if the level of risk is tolerable or not based on a predefined threshold, DQ could be defined based on risk of diseases or DALY value as follow:

$$DQ = \frac{RD}{RLR_{RD}} \text{ or } DQ = \frac{RD}{RLR_{DALY}} \tag{48}$$

The risk analysis at the node level could be achieved based on the value of *DQ*. If *DQ* is greater than 1, the node is considered as critical. The human health risk assessment for chemical contamination could be done for cancer and non-cancer endpoints. In the current study, only non-cancer consequences on human health are considered because the aim of the proposed methodology is to assess the acute response over short-term effects on health after exposure.

EPA develops a data base on the Integrated Risk Information (IRIS) (US EPA, 2015) as follows containing several types of chemical contaminants and their characteristics and their potential outcomes in case of ingestion. Most of risk characterization model are based on toxicity studies and experiments on animals.

The risk characterization of chemical contamination is achieved by the calculation of a hazard quotient or hazard index which compares the average intake of a dose (*AID*) of substance over the exposure period with the acute reference dose (*ARfD*) as follow:

$$HQ = \frac{AID}{ARfD} \tag{49}$$

Remember that ingested contaminant dose per consumer *j* at node i is obtained by equation (22), the hazard equation becomes:

$$HQ = \frac{\alpha V(i) C_i(t) p}{nc(i) ARfD} \tag{50}$$

The value of *HQ* can be constant or oscillates among range of values depending on the uncertainties of variables used for the calculation. The proposed approach allows estimating of the potential health risk on individuals, which is valuable, but not enough.

In fact, in practical point of view, risk assessment should be achieved at the node level defined by the hydraulic model because it refers to the consumption point. Each node contains several consumers with different water uses. The level risk depends on the number of harmed consumers and their sensitivity.

Illustration:
The current example shows how human health risk assessment can be achieved for chemical contamination exposure based on intake dose calculation and hazard quotient (HQ) estimation. The hydraulic simulation during a day period indicates a water consumption for the node "*i*" , V (i) equal to 2 m^3 . The concentration of toluene (chemical contaminant) in tap water is equal to 1mg/L, and p=1%.

Case 1: Domestic use is known, 80 % of water is used for domestic purposes.
In this case $\alpha = 0.80$ and V(i)=2 000 L (V_{dom} = 1600 L).

The determination of ingested dose is obtained by Monte Carlo simulation as follow:

Run	$c \sim N(18.75, 1.25)$ in [L/h]	V_k=Kc in [L]	nc(i) (#)	d_j in [mg/day]
1	15.24	121.9	13	1.22
2	18.75	150.0	11	1.50
3	19.54	156.3	10	1.56
4	19.14	153.1	10	1.53
5	18.31	146.5	11	1.46
6	20.49	163.9	10	1.64
7	18.72	149.8	11	1.50
8	19.91	159.3	10	1.59

9	20.16	161.3	10	1.61
10	18.73	149.8	11	1.50
Mean value	18.90	151.2	11	1.51

The number of delivered consumers was found between 10 and 13, with a mean ingested dose of 1.51 mg of toluene per day. The A*RfD* value for this contaminant is 0.029 mg/kg/day so for an adult of 70 kg the contamination threshold per day is equal to 2 mg. It seems that in that case the ingested dose is not adverse for health. In other way to deal with this situation is to estimate the average concentration of contaminant that corresponds to the *ARfD* value (threshold for adverse for health if we consider an adult with weight of W) based on a retrospective exposure approach:

$$C_{max} = \frac{ARfD \times W \times nc(i)}{\alpha \times \mathrm{V}(i) \times p} \tag{51}$$

For the considered example, the maximum tolerated concentration is C_{max}= 1.35 mg/L of toluene.

<u>Case 2:</u> The domestic use is unknown so the α value is generated randomly drawing a uniform distribution.

Run	α	$c \sim N(18.75, 1.25)$ in [L/h]	V_k=Kc in [L/h]	nc(i) (#)	dj [mg/day]	HQ	C_{max} [mg/L]
1	0.29	15.24	121.9	5	1.22	0.60	1.67
2	0.92	18.75	150.0	**12**	1.50	0.74	1.35
3	0.35	19.54	156.3	4	1.56	0.77	1.30
4	0.72	19.14	153.1	9	1.53	0.75	1.33
5	0.91	18.31	146.5	12	1.46	0.72	1.39
6	0.24	20.49	163.9	**3**	1.64	0.81	1.24
7	0.38	18.72	149.8	5	1.50	0.74	1.36
8	0.52	19.91	159.3	7	1.59	0.78	1.27
9	0.40	20.16	161.3	5	1.61	0.79	1.26
10	0.37	18.73	149.8	5	1.50	0.74	1.35
Mean value		18.90	151.2	7	1.51	0.74	1.35

We observe a range of values for the ingested dose between 1.22 and 1.51 mg/day, the variation of hazard quotient is between 0.60 and 0.74, which still less than 1. This corresponds to an absence of adverse effect for the considered intake dose. The range of max concentration of contaminant into water is between 1.24 to 1.67 mg/L.

2.3.3.4.2 Loss of economic activity from non-domestic user (LEA)

It corresponds to the potential interruption or diminution of economic activity due to contamination that leads to a total or partial loss of income. The potential impact depends on the sensitivity of the activity to drinking water and the existence of alternative sources of water (self-drilling or other suppliers). Two type of sensitivity can be measured: i) sensitivity of the activity to water, S_w and the level of dependence of the consumer to the water utility (main supplier or not), S_u. Let's consider S_w and S_u as normalised weight indicating the level of dependence where 1 is the highest level and 0 the lowest level. By assuming a linear correlation between the annual operating income (OI_{annual}) and water availability, the daily operating income (OI_{daily}) for a non-domestic user i having an economic activity is calculated by the following equation:

$$OI_{daily}(i) = S_w \times S_u \times \frac{OI_{annual}}{n_{days}} \tag{52}$$

The measure of daily consequences on several non-domestic consumers due to contaminant scenario can be obtained by summing up individual values of operating income.

2.3.3.4.3 Loss of life condition and wellbeing (LLCW)

The literature review shows that the economic value of water can be estimated based on the use and non-use value of water as illustrated by table 20.

Table 20. The economic value of water (Adapted from (Kulshreshtha, 1994, p23)

Total economic value				
Water use value			Value of non-use	
Values for direct uses	Values for indirect uses	Option value	Intrinsic value	Patrimony value
Irrigation/Agriculture Industrial Domestic Commercial	Recreational Ecosystem	Further /future use		Intergenerational Solidarity

All these dimensions seem relevant for natural water resources. For drinking water, we focus on the direct use of water and specifically on direct domestic and non-domestic use. The water delivery of water with certain quality improve life condition and make easy economic activities, service interruption due to contamination creates service perturbation or interruption that harms wellbeing and consumer behaviour. A way to deal with the decrease of life condition due to water interruption is to assess the value of water use. In case of domestic use, the value of the access to service can be estimated by the ability of the utility to maintain the service or a certain water quality.

The value is obtained in indirect manner based on the use of monetisation approaches as Valuation Contingent Method. The concept of consumer surplus (CS) or compensating surplus can be used to assess the value of domestic use. We assume that the CS corresponding to the advantage for consumer between two level of water prices, it indicates the amount that consumer is ready to pay for a given service or quality level. The water contamination influences consumer behaviour, with reference to standard situation, it means before contamination. The average daily water consumption is around 150 L in France. In the situation of contamination water, the sensitivity of consumer will not be the same for the entire volume, we assume that it's WTP depends on the required volume, it means that in specific condition, consumer will focuses on its primary needs which are water for cooking and drinking estimated between 5 and 10 L per day per person (at least 3 bottles of 1.5 L). We assume that a threshold of uncompressed volume of 50 L corresponds to the required volume for other domestic needs. The WTP depends on the demand of consumers, it means that consumer is ready to pay more for small volume that corresponds to elementary needs, his WTP decreases until threshold corresponding to the actual average price per m^3, the WTP decreases over volume of 150 L because consumer is not interested to pay more for more water. The curve of consumer demand is characterised by 3 thresholds: 1) Q_p, volume for primary needs; 2) Q_u, uncompressed water for other domestic use and 3) the average daily consumption in normal condition, Q_m.

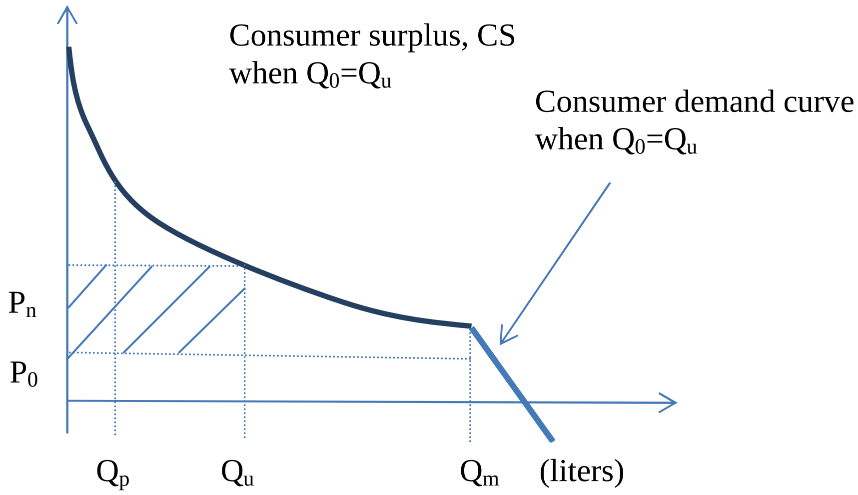


Figure 28. Example of domestic daily water demand

According to the Figure 28, the value of domestic use can be estimated by the surplus cost (SC) that corresponds to the area comprised between the demand curve and two levels of price, actual price P_0 and the new price P_n, according to (Muller, 1985) the surface "$P_nQ_uP_0$" corresponds to the total net willingness to pay for drinking water. Average net willingness to pay is the area divided by the total water consumption. In order to estimate the net WTP by considering elasticity demand-price $\varepsilon<0$, (Muller, 1985) proposed the following equation:

$$\begin{cases} NWTP = SC \\ SC = P_0Q_0\frac{[\frac{P_n}{P_0}]^{\varepsilon+1}-1}{\varepsilon+1} \end{cases} \tag{53}$$

The average willingness to pay per unit of volume ANWTP is obtained by dividing NWTP by the volume Q_0.
In practical, the value of P_n can be estimated based on the price of spring water for example that can be used as substitution to the delivered water. The consequences of microbiological or chemical contamination in terms of loss of wellbeing and loss of service level can be indirectly measured by the NWTP (n_c) for all impacted consumers of a given node (undelivered consumers or delivered with contaminated water) and for a given consumed volume Q_0:

$$NWTP(n_c) = \sum_{i=1}^{n_c} SC(i) \tag{54}$$

2.3.3.4.4 Water pollution (WP)

The introduction of a contaminant into WDN impacts human health, WDN assets and can potentially harm wastewater network at least until contamination is detected. In fact, water consumption engenders a release of wastewater, if drinking water is contaminated; water dedicated to sanitation use is also contaminated. When it is released into wastewater network, it can also harm natural environment because treatment plants are not equipped with required decontamination processes. So a way to assess this consequence is to estimate the volume of water dedicated to sanitation use of impacted consumers until the time detection, since introduction of contaminant until the detection and service interruption.
The time detection is random and depends on several variables, so we advise to estimate an average daily volume of released water. Let's consider n_c number of harmed consumers, V_w the

average consumption per consumer per day, p_s: portion of sanitation use, the average released daily water volume is obtained by the following equation:

$$WP_{daily} = n_c \times V_w \times p_s \tag{55}$$

2.3.3.4.5 Summary of potential consequences assessment

Remember that proposed indicators are a way to estimate potential consequences of microbiological or chemical contaminant on WDN. For more readability and understanding, consequences that can be considered as internalities or externalities are gathered into two main groups: i) consequences on water utility and ii) consequences on third parties. The following table resumes potential type of consequences and how they are calculated in the scope of the developed methodology according to ad-hoc comprehensive indicators. The methodology addresses midpoints impacts and does not address potential damages due to potential consequences.

Table 21. Potential consequences

Type of consequence		Way to asses it (indicator)	Scale	Acronym	Unit
Consequences on water utility	Asset contamination	Cost of cleaning, repairing or renewal	Node or scenario of contamination	ACR ARR	€
	Loss of income	Unsold water per day or during contamination period	Node or scenario of contamination	DLI	€
	Water delivery by substitution	Cost of elementary volume of water delivered by alternative way (bottles, tank, etc.)	Node or scenario of contamination	*WS*	€
	Loss of confidence and brand image	Consumer behaviour changing	Scenario of contamination	*LCBI*	€
Consequences on third parties	Human health	Number of ill persons	Node or scenario of contamination	$n_{ill\ person}$	#
	Loss of wellbeing	Willingness to pay	Node or scenario of contamination	$NWTP$	€
	Water pollution	Released contaminated water	Scenario of contamination	*WP*	m^3
	Loss of income for non-domestic users	Loss of daily operating income due to partial or total interruption or perturbation of water delivery	Node or scenario of contamination	OI_{daily}	€

2.3.4 Risk assessment

The risk assessment is based on the combination of potential consequences and WDN criticality as explained in previous sections. The methodology proposes the evaluation of specific factors derived from successive analysis of consumer sensitivity, asset vulnerability and potential consequences on water utility and on third parties. The Fig. 29 resumes main steps of the developed methodology.

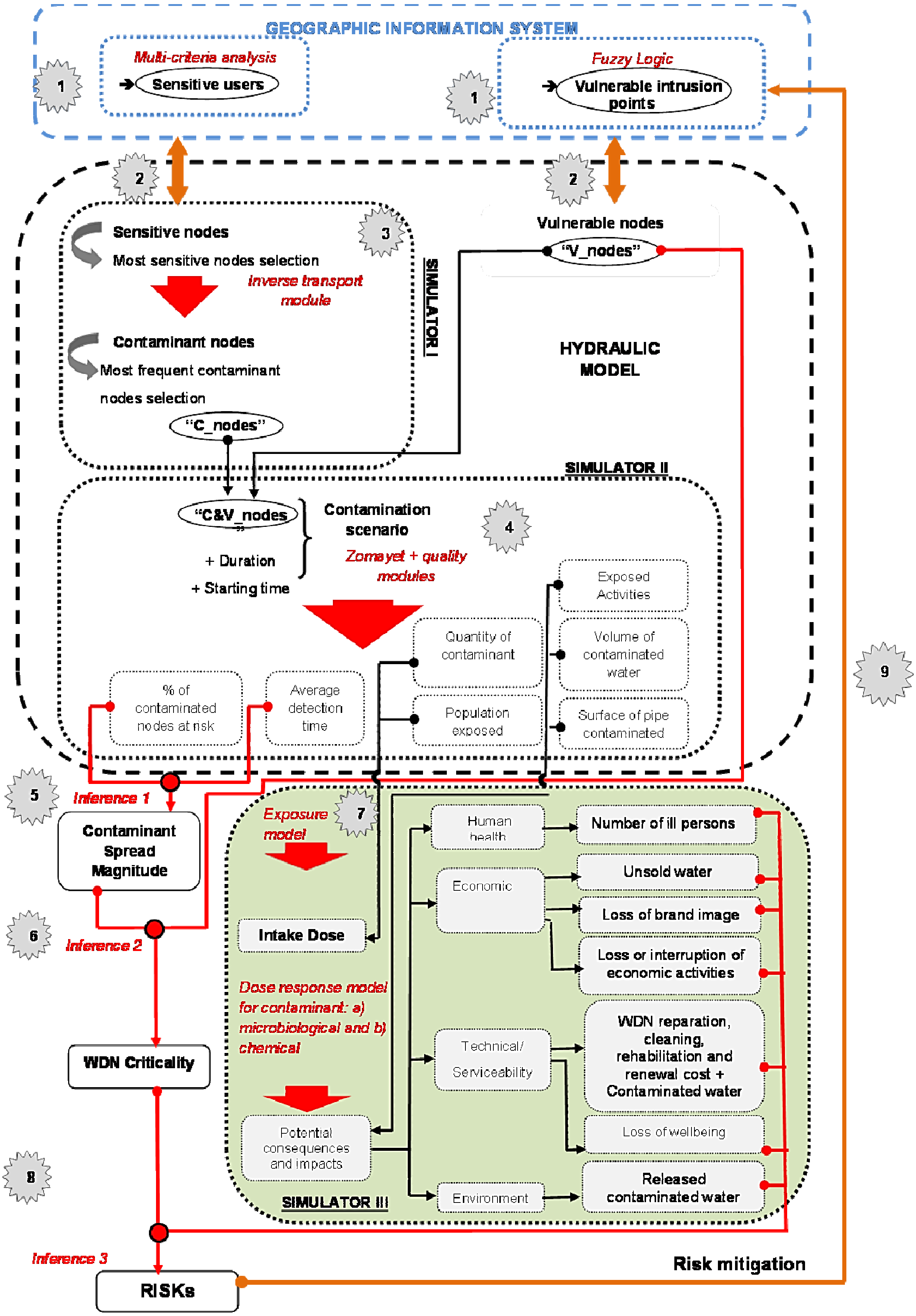


Figure 29. Main steps of risk assessment methodology

The construction of factors assumes the use of specific fuzzy functions that fit measured indicators and gather them for a given scenario into normalised factors between 0 to 100 as illustrated by Fig. 30. Because contamination induces several potential consequences, risk assessment covers several aspects. 6 factors can be computed to assess risk on water utility: Risk of asset contamination (*RACR* & *RARR*), Risk of water utility income loss (*RWUI*), Risk of water delivery by substitution ways (*RWD*), Risk of loss of confidence and brand image (*RLCBI*). 4 factors can be computed to assess potential risk on third parties: Risk on human health (*RHH*), Risk of wellbeing loss (*RLWB*), Risk of pollution (*RP*) and Risk on economic activities.

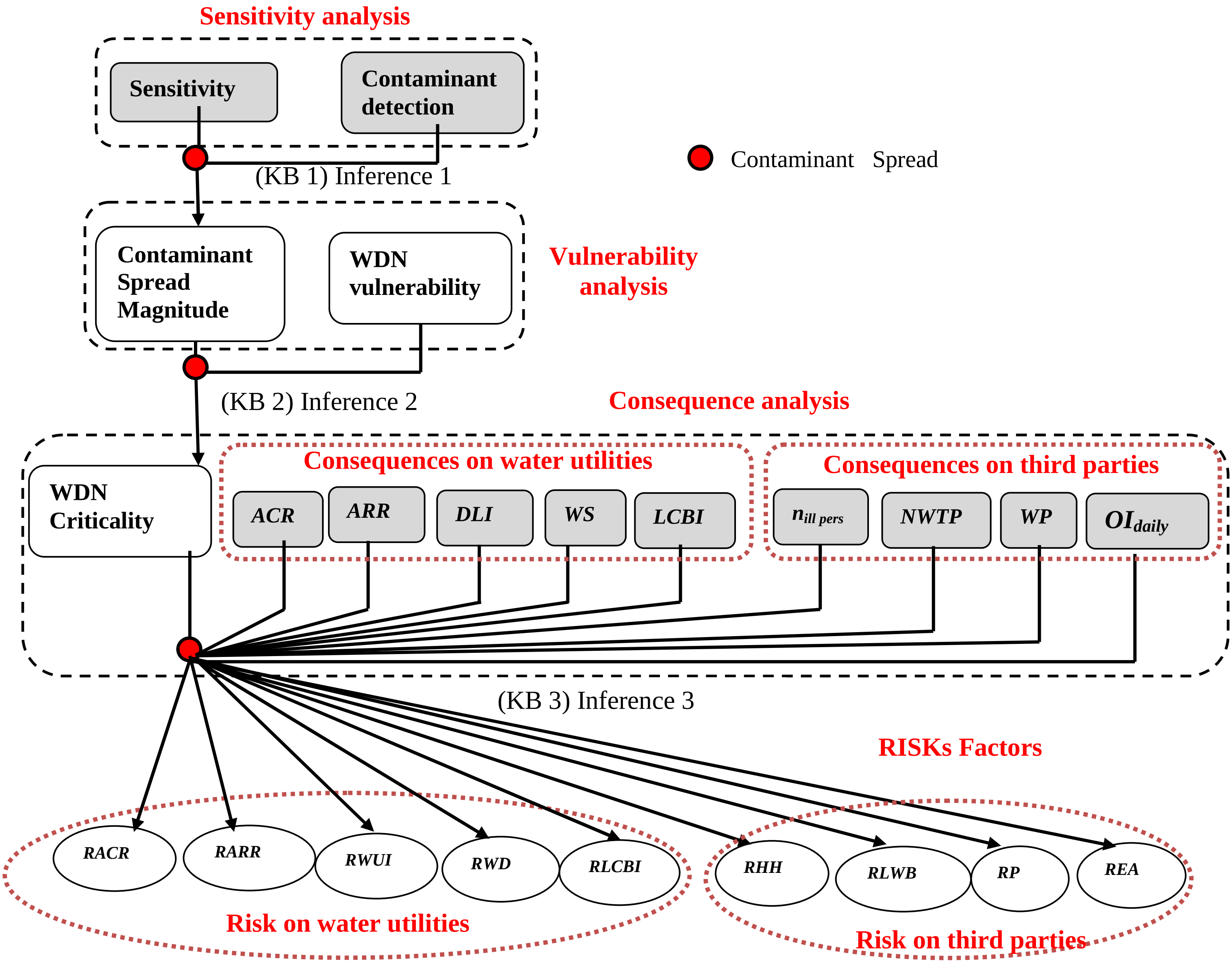


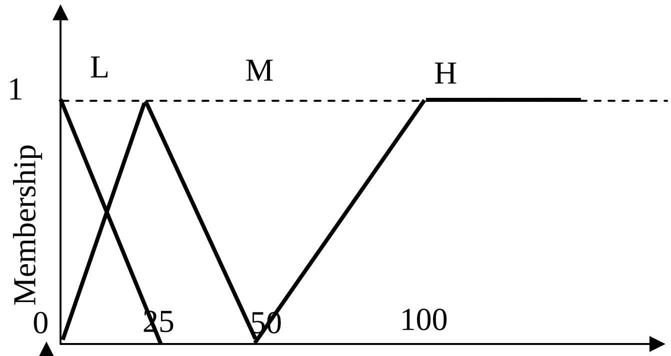
Figure 30. Risk factors assessment.

2.3.4.1 Scheme for aggregation

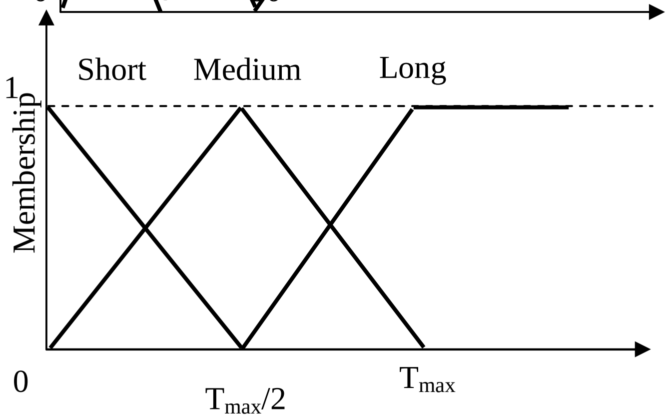
We propose to implement a cascading approach for risk assessment as described in Fig. 31. The system is composed by three cascading inference engines. Indeed the outputs of the first inference engine is combined with the inputs of the second inference engines; in the same manner the outputs of the second inference engine is aggregated with the input of the third inference engine. The results to be achieved – the output of the third inference engine – is a single number, which represents the **Risk Index.** The three Inference Engines will be supplied respectively by three knowledge bases (KB) as defined in the following figures:

Data Base 1

Percentage of sensitive users exposed (S)	$\mu_{i,1}$	$\mu_{i,2}$	$\mu_{i,3}$
Low (L)	0	0	25
Medium (M)	0	25	50
High (H)	50	100	100



Average detection time (T)	$\mu_{i,1}$	$\mu_{i,2}$	$\mu_{i,3}$
short	0	0	$T_{max}/2$
medium	0	$T_{max}/2$	T_{max}
Long	$T_{max}/2$	T_{max}	T_{max}



Rule Base 1

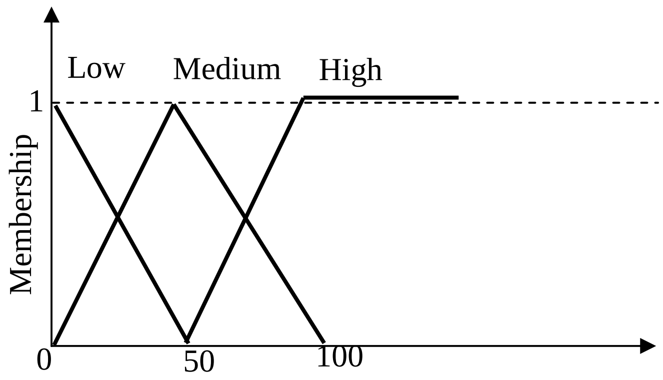
<table>
<tr><td colspan="2" rowspan="2">Magnitude of the contaminant Spread (MS)</td><td colspan="3">Percentage of sensitive users exposed (S)</td></tr>
<tr><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td rowspan="3">Average detection time (T)</td><td>Short</td><td>Low</td><td>Medium</td><td>Medium</td></tr>
<tr><td>Medium</td><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td>Long</td><td>Medium</td><td>High</td><td>High</td></tr>
</table>

IF *Percentage of sensitive users exposed* is "S" **AND** *Average detection time device* is "T" **THEN** Magnitude of the contaminant Spread is "MS"

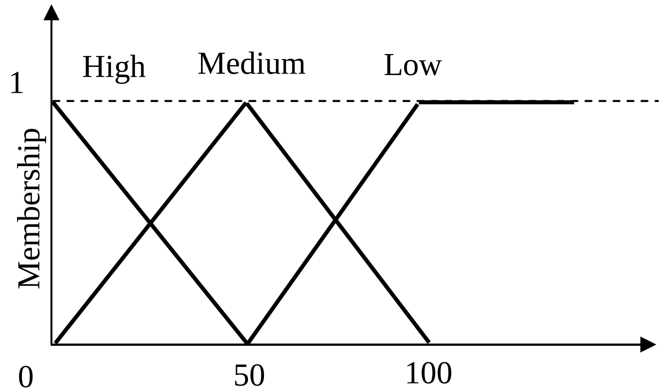
Figure 31. Knowledge Database 1 – Data Base and Rule Base for the “Magnitude of the contaminant spread” model.

Data Base 2

Magnitude of the contaminant Spread (MS)	$\mu_{i,1}$	$\mu_{i,2}$	$\mu_{i,3}$
Low (L)	0	0	50
Medium (M)	0	50	100
High (H)	50	100	100



Intrinsic vulnerability (IV)	$\mu_{i,1}$	$\mu_{i,2}$	$\mu_{i,3}$
Low	0	0	50
Medium	0	50	100
High	50	100	100



Rule Base 2

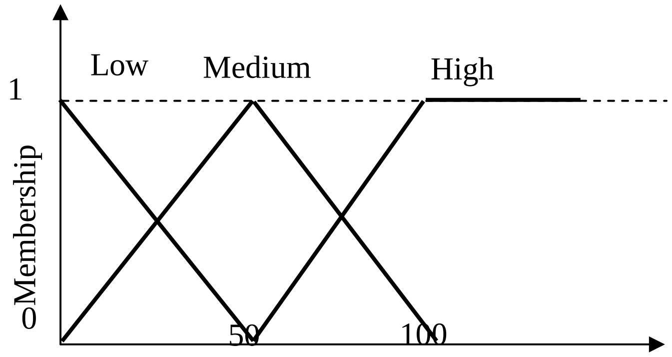
Criticality (C)		Magnitude of the contaminant spread (MS)		
		Low	Medium	High
Intrinsic vulnerability (IV)	Low	Low	Medium	Medium
	Medium	Low	Medium	High
	High	Medium	Medium	High

IF Magnitude of the contaminant spread is "MS" **AND** intrinsic vulnerability is "IV" **THEN** Criticality is "C"

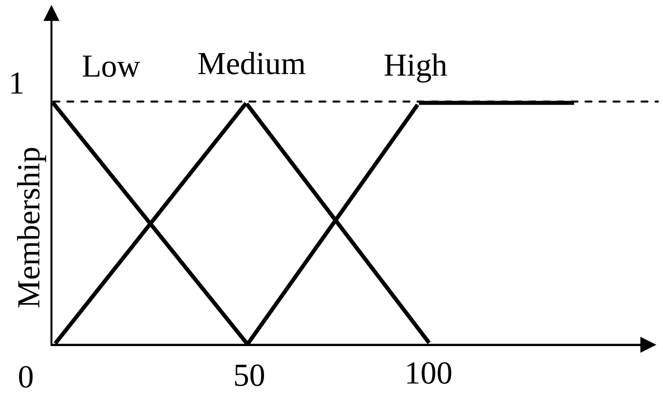
Figure 32. Knowledge Database 2 – Data Base and Rule Base for the “Criticality” mo**del**

Data Base 3

Criticality (C)	$\mu_{i,1}$	$\mu_{i,2}$	$\mu_{i,3}$
Low	0	0	50
Medium	0	50	100
High	0	100	100



Consequences (Co)	$\mu_{i,1}$	$\mu_{i,2}$	$\mu_{i,3}$
Low	0	0	50
Medium	0	50	100
High	0	100	100



Rule Base 3

Risk (R)		Criticality (C)		
		Low	Medium	High
Consequences (Co)	Low	Low	Low	Medium
	Medium	Medium	Medium	High
	High	Medium	High	High

IF Vulnerability linked with the environment of the intrusion site (VE) is "SE" **AND** Structural Vulnerability is SV" **THEN** Intrinsic Vulnerability is "IV"

Figure 33. Knowledge Database 3 – Data Base and Rule Base for the "Intrinsic Vulnerability" model

For any factors mentioned in the KB 1, 2 and 3 the numbers of partition level have been limited to 3 (Low / Medium / High or Short/Medium/Long) in order to distinguish the different assets without introducing too many levels. The fuzzy numbers thus obtained are represented by triangular fuzzy sets and mapped onto non-dimensional relative scale that ranges from 0 to 100 except for the average time of detection scale, which ranges from 0 to T_{max}.

The result of this third inference engine is represented by a triangular fuzzy set partitioned and mapped in the same way than the outputs of the inference engine 1 and 2. This last triangular fuzzy set is then defuzzified into a single crisp value: **the Risk index**. In order to combine the 3 cascading inference engines the programming interface proposed by Cingolani and Alcada-Fdez (2012) has been adapted in order to provide an automatic calculation tool. The list of WDN asset defined by the following 4 factors – (1) percentage if sensitive users exposed, (2) average time of detection, (3) Intrinsic vulnerability, (4) Consequences - represents the inputs of the inference engines which are not produced by the inference system; these inputs are successively complemented by the results of the inference engine 1 and 2. This list is recorded into an excel file. A specific tool was programmed in java to enter input data values within the right inference engine. This automatic calculation tool makes the inference task easier and reduces computational time.

2.3.4.2 Computation time problem and solution approach

The hydraulic model is supported by a simplified representation of the WDN extracted from Water department GIS database in order to limit computation time. Even this simplification, computation time is still a serious constraint. Indeed the WDN contamination scenario to be performed is defined by a set of variable attributes including intrusion point, contaminant event time and duration. The combination of these variables leads to generation of huge number of potential contaminant scenarios representing prohibitive computation time. To deal with this constraint, a specific computationally acceptable procedure has been developed.

It is based on the combination of the following aspects: (1) hydraulic simulation, (2) contaminant transport using quality model, (3) Potential contaminant sources determination using Inverse transport method. The framework presented in Figure 2 illustrates this combination of techniques. The Porteau® software – developed by Irstea[2] – calculates the WDN hydraulic behaviour (Zomayet Module) and it simulates the contaminant transport within the system (Quality module) as explained in the next section.

2.3.4.3 Hydraulic simulation using Porteau software

Porteau® is a tool to model the behaviour of looped water distribution network under pressure. The input data includes the complete topography of the network as well as the most precise spatial distribution of the consumers on the different consumption nodes or along pipes. The network may include water tanks, pumps and its operation rules, valves (motorised or not) as well as consumption described by consumption models (Porteau, 2015).

Nodes, links and devices form the hydraulic model. A node can be a *Resource* node, *Tank* node or *Ordinary* node with consumption or/a simple junction node.

Pipe links ensure the connexion between nodes. The flow within the pipes generates head losses, which are calculated by the software according pipe roughness factors. An extended period simulation model is used to calculate the pipe flow rates according to the mass and energy conservation. The results are the variations in the different values for each node and pipe over the simulation period: water level in the tanks, incoming and outgoing volumes, head level of the

[2] IRSTEA : Institut national de Recherche en Sciences et Technologies pour l'Environnement et l'Agriculture

consumption points, flow rates in the pipes, pumps schedule time and tank thresholds, operation of the various components in the network.

The Porteau® software is based on a demand-driven model that means that the nodal demand is beforehand fixed and does not depend on the available pressure. Consumption time-patterns are built according to the water users' behaviour. Patterns could be different from node depending on its characteristics. However, the water consumption representation in the hydraulic model is based on strong assumptions and requires several level of simplification.

2.3.4.4 Improved Contaminant transport model

The quality model to simulate the propagation of contaminant throughout the WDN uses the outputs of hydraulic simulation.

2.3.4.5 Inverse transport method

As explained by Ung *et al*. (2013), a novel backtracking algorithm is used to look for all the potential sources of contamination across a defined past time period or window. Using reverse time method and complemented with probabilistic approaches the system gives out the different potential sources. The reverse time method uses the results of the hydraulic calculation realized by the "Zomayet" module and the quality model developed by "Irstea" for Porteau® Software.
As an illustration of the reverse time method the Figure 34 shows the results of the backtracking approach that matches potential sources of contamination of one specific targeted nod

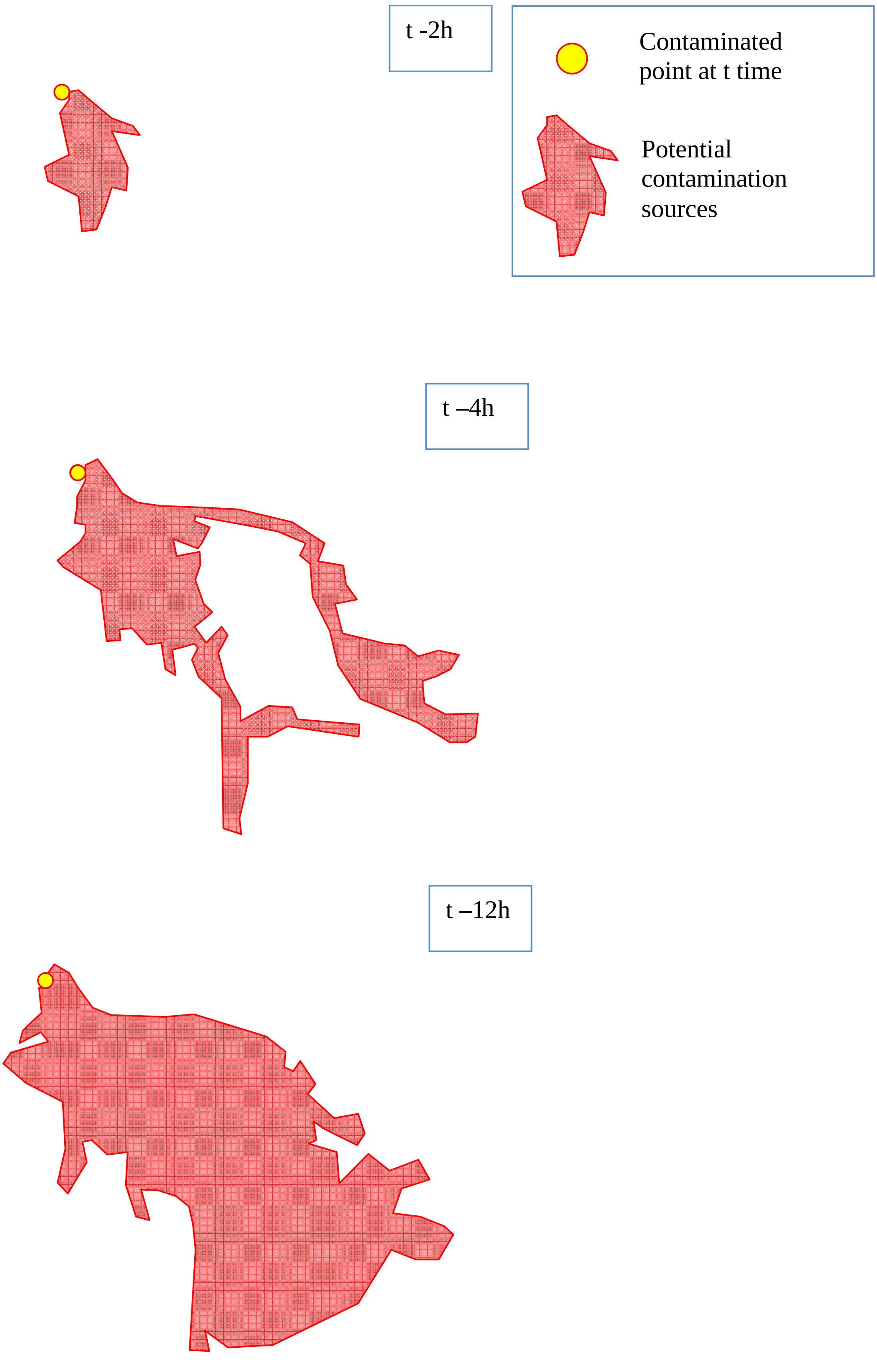


Figure 34. Illustration of the potential source enumeration with three levels of reverse time

2.3.4.6 Combined simulation procedure

The proposed simulation procedure is a combination of "normal" transport analysis method (from the intrusion site to the water consumers) and "inverse" transport method (from selected water demand nodes to the source of the contamination). As mentioned previously the purpose of such a complex combination is to decrease the computational time which would require a 'one-way' approach. An overview of the proposed "combined simulation procedure" is described in the following section. It focuses more on the simulation procedure description than on how to assess the vulnerability and sensitivity concepts. All the different steps described further are illustrated in Figure 35 from the transfer of information to the final Risk evaluation.

2.3.4.7 Information transfer between GIS to Hydraulic model

Water users and WDN assets must be described accurately in order to identify and evaluate the risk dimensions. The proposed approach requires the use of GIS tools in order to include geographic information concerning users and also the propagation of contamination. Thus a detailed GIS of analysed WDN must be available and should describe the system and locates its components: pipes, connections and other devices (valves, fire devices, wash out, air bleed, flow meters...). However, this detailed representation is composed by tens of thousands of nodes. Keeping such detailed information to create the hydraulic model is not only unnecessary but would generate prohibitive computational time when simulating. In consequence simplified hydraulic model was proposed to perform the risk analysis. The information contained in the GIS WDN representation is transferred to the hydraulic model as shown in Figure 34. More specifically GIS information regarding users and asset characteristics are assigned to the hydraulic model nodes.

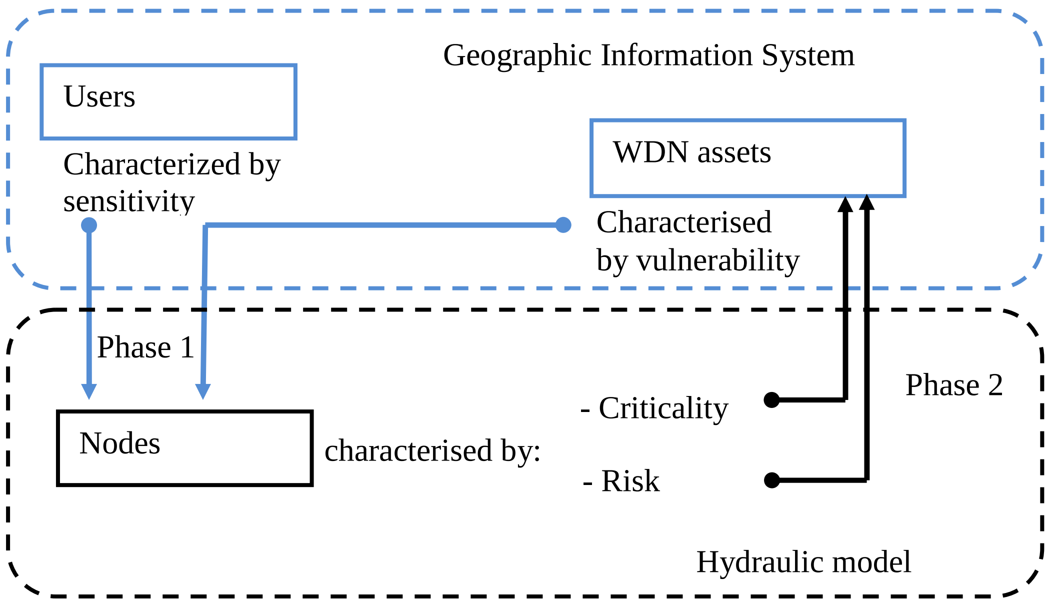


Figure 35. Information transfer framework from GIS to Hydraulic model.

The different concepts used in the information transfer between objects from two different systems have to be clarified. This transfer requires the definition of matrix of transfer and transfer rules' sets as described in Fig. 36.

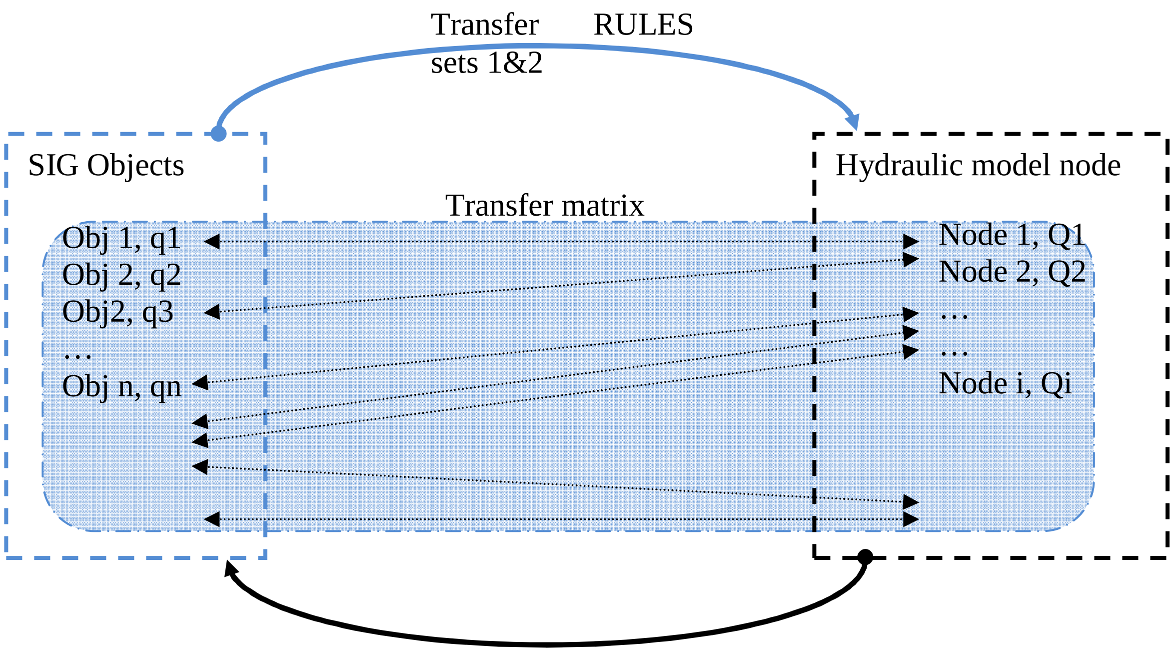


Figure 36. Transfer of information between GIS and Hydraulic model – Aggregation process, Matrix of transfer and rules

In a first phase, the information contained in the GIS WDN representation is transferred to the hydraulic model. More specifically GIS information regarding user sensitivity and WDN asset vulnerability is transferred to the hydraulic model nodes as illustrated in Fig. 36. This first phase constitutes an aggregation process (from the GIS object to the model nodes), which is defined by sets of transfer rules (sets 1 and 2 in Fig. 36)
In a second phase, the hydraulic model produces the data, which are used to assess the criticality and risk at the level of the nodes. This information is then transferred to the WDN assets represented in the WDN GIS.

The previous two phases requires the adequate recording of the connecting links between GIS objects (users and WDN assets) and the hydraulic model nodes into a specific matrix called **transfer matrix** (Cf. Figure 36).

- Transfer matrix construction

The transfer matrix construction consists of 3 main steps. The first step is the export of the model nodes and pipe links into the GIS system that contains the GIS objects (water users and WDN assets). The second step, illustrated in **Figure 37**, is based on orthogonal projection. Once pipe links, nodes and GIS objects have been gathered under the same system of coordinates, the GIS objects are projected orthogonally into the closest pipe link. As each pipe segment is defined by two end-nodes, it is possible to assign the name or reference of one of the ends node which defined the pipe link to the GIS object. With this last step, all the GIS objects (WDN assets or water users) are referenced: the transfer matrix is created.

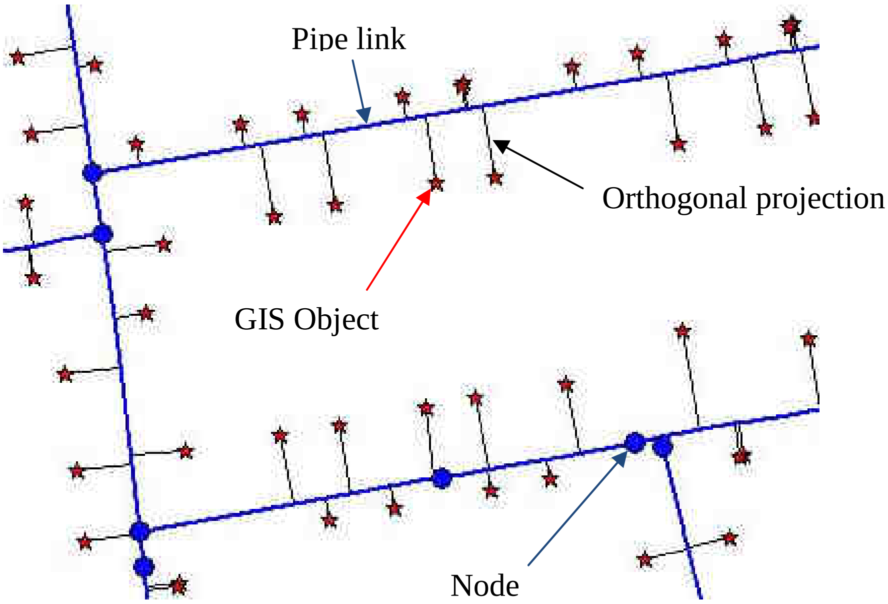


Figure 37. Orthogonal projection of GIS object on the WDN pipe links

The next step is related to the definition of rules on which the aggregation process is based.

- Transfer rules sets definition

In the transfer matrix generated, one node model can be connected to several GIS objects. In consequence several values of the parameters, which characterised the GIS object, are assigned to a unique model node. To complete the aggregation process, it is necessary to compile the value of that parameter into a crisp value. For that, transfer rules are defined according to each specific parameter to be aggregated.

  - Sensitivity rules set (set 1)

The assessment of the user sensitivity results in producing sensitivity values, which range between 0 and S_{max} where S_{max} is the maximum value of sensitivity. An aggregation process based on an ordinary sum of the values of sensitivity is not appropriated. On one side, such a sum would give more weight in terms of sensitivity to a node with dozens of very low sensitive users than to a node connected with a single highly sensitive user. On the other side, it could be interesting to be able to consider that hundreds of sensitive users could be as sensitive as a single highly sensitive user. In consequence and in order to take into account not only the sensitivity value but also the number of users at node level, specific transfer rules have to be designed.

Let consider:

- n number of water users to be aggregated at the level of one model node
- S_{max} maximum value of sensitivity among all the water users of the WDN
- ΣS sum of the sensitivity value at the level of the node i

- $MAX_i(S)$ maximum value of the sensitivity at the level of the node i among the users connected to this node.
    - λ ratio which is defined by the decision maker according to the context
- S_i the final value of the sensitivity to be assigned to the node i

then the aggregation process is defined by the following transfer rules:

IF $\Sigma S / S_{max} < \lambda$ AND $MAX_i(S) = S_{max}$
THEN $S_i = S_{max}$

ELSE IF $\Sigma S / S_{max} < \lambda$ AND $MAX_i(S) \neq S_{max}$
THEN $S_i = MAX_i(S)$

ELSE IF $\Sigma S / S_{max} \geq \lambda$
THEN $S_i = S_{max}$

- Vulnerability rules set (set 2)

The assessment of the WDN asset vulnerability results in producing vulnerability values, which range between 0 and V_{max} where V_{max} is the maximum value of vulnerability. For each node i, the final vulnerability value V_i to be assigned to the node is the maximum value of the vulnerability among the WDN assets connected to the node i.e. $MAX_i(V)$.

- Criticality and Risk rules set (set 3)

Once the criticality and risk have been assessed at the level of the hydraulic model nodes these characteristics are transferred back to the WDN assets contained in the GIS. This operation is possible thanks to the transfer matrix as defined in Figure 35 and Figure 36.

2.3.4.8 Contamination pathways selection

As mentioned previously WDN contamination scenarios can be defined by the following attributes: 1) intrusion pathway, (2) type of contaminant, (3) mass of contaminant, (4) contaminant event time, (5) contaminant event duration.
The identification of the intrusion sites (=pathways) as the first attribute of WDN contamination scenario requires a specific pre-treatment in order to limit the number of simulation runs and consequently the computation time. This pre-treatment takes place in 4 steps:

1. *Water user's sensitivity evaluation*: the sensitivity of the water users against the water contamination is defined and evaluated from available GIS databases. The sensitivity of water users is then assigned to the water demand nodes of the hydraulic model. The most sensitive nodes are listed and constitute the critical starting points of the inverse transport method protocol.
2. *Contaminant nodes for the most sensitive users:* Using the *inverse transport method* (Simulator I in Figure 29) the hydraulic model nodes that are contaminant for the most sensitive users are identified and sorted in descending order according to their frequency of occurrence; the resulting list indicates the most frequent contaminant nodes for the most sensitive users (called 'C_node').

3. *Intrusion pathways Intrinsic Vulnerability evaluation*: The intrinsic vulnerability of the potential intrusion pathways is defined and evaluated from the WDN GIS database.
4. The vulnerability of the intrusion points – called 'V_node'- is then transferred to the hydraulic model nodes. The most vulnerable intrusion points are then listed.
5. *Contaminant and vulnerable nodes*: The list of V_node is mashed with the list of C_nodes. The resulting list indicates the vulnerable intrusion pathways that are contaminant (called C&V_nodes).

The C&V_nodes list represents the starting point of the main simulation process as described in the following section.

2.3.4.9 Contamination scenario definition

Once the pathways have been defined 4 remaining attributes have to be defined for the contamination scenario: (1) type of contaminant, (2) mass of contaminant, (3) timing of the contamination event, (4) contamination event duration. *The type of contaminant and mass of contaminant* are primordial parameters in human health risk assessment. Indeed the response model linked to the contaminant ingestion is correlated with these 2 parameters. Regarding the simulation of the contaminant propagation throughout the WDN, the contaminant transport is simulated as **a perfect tracer**. Complex mechanisms as density effects, chemical or biological decay, reaction with other existing molecules or with inner wall of pipe materials are not considered. Based on that observation, *type and mass of contaminant* are not considered for the definition of the contamination scenario.

Through the simulation process the results to be achieved is the representation of the spatial and temporal concentration of contaminant in the system. As the simulations are time dependant, timing and duration of the contamination event are parameters, which are relevant to take into consideration in the contamination scenario definition.
Regarding the contamination occurrence time, we assume the worst-case scenario corresponds to the intrusion of contaminant a short period of time before the daily water consumption peaks. Generally it could have two different values: in the morning and in the evening to be fixed according to the water demand pattern.

Regarding the duration event, the contaminant nodes, which are relevant to consider for the definition of the scenarios, are those identified by the backtracking approach. Moreover the duration event is technically limited by the reverse time method which can generate a huge volume of data if the past time window is too long. Consequently the duration event is set equal to the past time period which has been defined for the inverse transport method.
In summary, the definition of contamination scenario is based on preselected intrusion pathways, predefined contamination event timing and duration event. Further we address hydraulic simulation based on pre-defined contamination scenario. The benefits that are actually being sought by this approach are reducing the simulation runs number and consequently limiting the computational time. This approach evaluates the Magnitude of the contaminant spread as detailed in the next section.

2.3.4.10 Contaminant spread magnitude evaluation

The objective of the simulation process is the evaluation of the *Contaminant Spread Magnitude* (Simulator II in Figure 29). The transport model outputs estimate the spatial and temporal concentration of contaminant in the system. At the end of the simulation process the available results are the following: (1) the percentage of water demand exposed to the contaminant, (2) the percentage of sensitive users exposed; (3) the average detection time, (4) the volume of

contaminated water within the pipe, (5) the surface of contaminated pipe. We propose to characterize the *Spread Magnitude* by the combination of the percentage of Sensitive users exposed to the contaminant and the average elapsed time of contaminant detection (if sensors have been installed to monitor water quality). The percentage of sensitive users exposed to the contaminant indicates the severity of the contamination event. Indeed the adverse effects likely to occur due to exposure will be higher for sensitive consumers. The percentage of contaminated nodes will be taken into account through the sensitivity of the water users. Indeed density of population is part of the criteria that contributes to the water users' sensitivity evaluation.
On the other hand the average time detection enables the consideration of the water quality monitoring system set up on the WDN. Indeed if the contamination is rapidly detected, the potential exposure to contaminant is low.

2.3.4.11 WDN component criticality evaluation

Once the simulations have been achieved the Criticality of the WDN component – as the combination of the intrinsic vulnerability of the component and the magnitude of the contaminant spread – can be evaluated.
To complete the equation of Risk assessment (Equation 5) Consequences of the contamination event have to be evaluated.

The obtained values should be well interpreted in order to offer a way for risk mitigation. Concerning water network management, the definition of practical and operational indicator is a challenge. So why hydraulic simulation model is involved into the methodology in order to take into account WDN operation? How the obtained values could be used into decision process? The proposed indicators can be calculated at the scale of consumer node or for a given scenario of contamination. It is clear that computed factors serves to estimate a risk levels covering several types of risk, the interpretation of obtained values should be done in global way in order to have a large overview of all potential risks.

2.3.5 Summary of addressed potential risks

The aggregation of risk factors is not addressed in the current work because we assume that it leads to a loss of knowledge about potential risks. The existence of risk factors both on water utility and third parties seems more helpful for decision maker and for risk mitigation because it offers more and accurate information about potential risks.
A way to make interpretation easier is the use of graphical method for representation as spider network that provides a synthetic and overview on potential risks for a given contamination scenario. The comparison of spider plots can help decision maker to sort contamination scenarios and establish priorities in terms of risk level.

The Tab. 22 summarises potential risks due to voluntary contamination and possible assessment factors.

Table 22. Potential risks

Type of risk		Way to assess it (indicator)	Scale	Acronym
Risks on water utility	Risk of Asset contamination	Cross ACR and ARR with WDN criticality	Node or scenario of contamination	RACR RARR
	Risk of water utility income loss	Cross DLI with WDN criticality	Node or scenario of contamination	RWUI
	Risk of Water delivery by substitution	Cross WS with WDN criticality	Node or scenario of contamination	*RWD*
	Risk of Loss of confidence and brand image	Consumer behaviour changing	Scenario of contamination	*RLCBI*
Risks on third parties	Risk on human health	Number of ill persons	Node or scenario of contamination	*RHH*
	Risk of loss of wellbeing	Willingness to pay	Node or scenario of contamination	RLWB
	Risk of pollution	Released contaminated water	Scenario of contamination	*RP*
	Risk on economic activities	Loss of daily operating income due to partial or total interruption or perturbation of water delivery	Node or scenario of contamination	REA

3 Representation of drinking water: from perception to social mobilization

3.1 Why is it usefull to question the representation of drinking water?: Research questions and hypothesis

In this project, the analysis of the risk perception will not be implemented (the main issues of the project are not suitable for this kind of research). Our study will follow two main issues dealing with the risk management in the drinking water supplies. Our analysis takes place in a well-developed literature dealing with the analysis of risk management procedures and their influence on the individual behaviors in case of a disaster. The whole system takes into account the precautionary principles, the crisis management and the recovery procedures (or "coping capacity" - figure. 38). The feedbacks are also important to understand how individuals ("laypersons") and stakeholders ("experts") have been involved in the management of the crisis and what kind of key elements in such management have to be modified or strengthened.

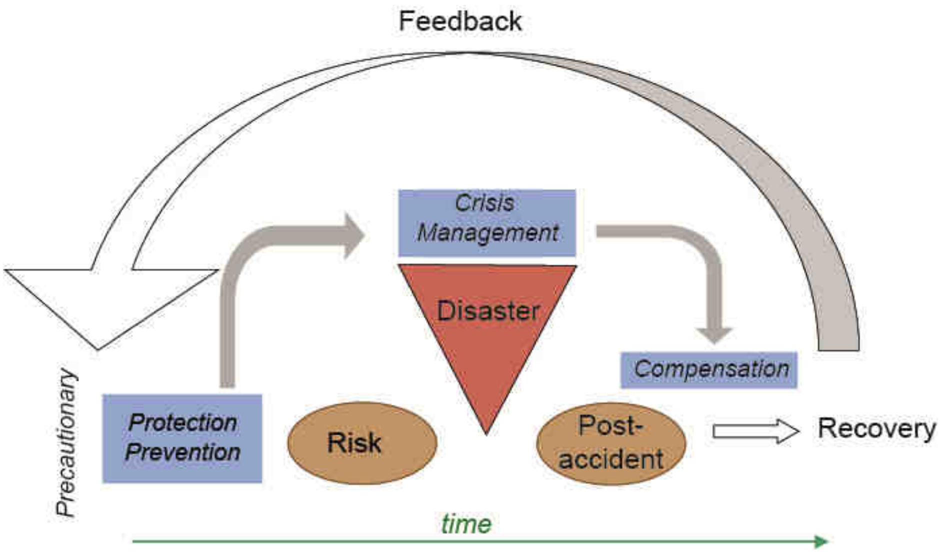


Figure 38. The risk management system (Heitz, 2013)

The main issues that will be questioned in this project are:

1) The **role of trust** in establishing and maintaining political legitimacy in hazard management (Cvetkovich 1999). What is trust? Lewis and Weigert (1985) define trust with 3 dimensions: cognition, affective component, behavioral component. They distinguish trust from confidence and legitimacy and define some indicators that allow us to assess the level of trust in a risk management policy (also see (Peters, Covello, and McCallum 1997):

- honesty,
- fairness,
- neutrality,
- impartiality of the trustee

In our case study, knowing the level of trust can decrease the complexity of a situation (*cf.* Luhmann, Earle et Cvetkovich) and trust is important to foster collaborations (Misztal 1996). (Alesina and La Ferrara 2002; Baxter and Greenlaw 2005; Bradbury, Branch, and Focht 1999; Cox 2004) also establish a strong relation between trust and perception. Moreover, trust and public participation are also related: when people trust in their stakeholders' decisions, they accept to collaborate to implement risk management policies. The communication and information campaigns are then more efficient.

The concept of trust is frequently used in geography and we will adapt it for the project: the issues are not the same in case of a hazard management and a contamination analysis, but 4 main issues (that could be useful for the study of the vulnerability of water networks) are identified. These issues are:

- To identify the trustee (from the individual point of view) involved in drinking water supply;
- To understand the level of trust / distrust of the trustee;
- To identify, in case of distrust, what are the main issues revealed by the individuals?;
- To question the role of responsibility / legitimacy of some stakeholders in trust.

2) The concept of "alarm raisers" (Chateauraynaud and Torny, 2005). Why is it interesting to question the concept of « alarm raisers »? The first issue is that we can identify if people do question the water quality in case of a sanitary problem. Secondly, we can identify potential responsible for population in such crisis and identify what kind of authority people alert. That is to say, by questioning individuals we can identify the authorities, which are considered as legitimate by the individuals *(cf. trust and distrust in risk management – Cvetkovich et al) and also* define the whistleblower (and to question on its perceived status for the society). This analysis will allow us to implement common actions by increasing the mobilization of actors. We can also assess the importance of "time" in the management of a risk related to drinking water.
Chateauraynaud and Torny (2005) identify 3 parameters to understand the alarm time and the mobilization time (i) the level of predictability of the disaster, (ii) the degree of intentionality and (iii) the degree of reversibility. These 3 parameters will be assessed using our surveys and then we will be able to define the alert management system perceived by both the stakeholders and the population (Figure 39).

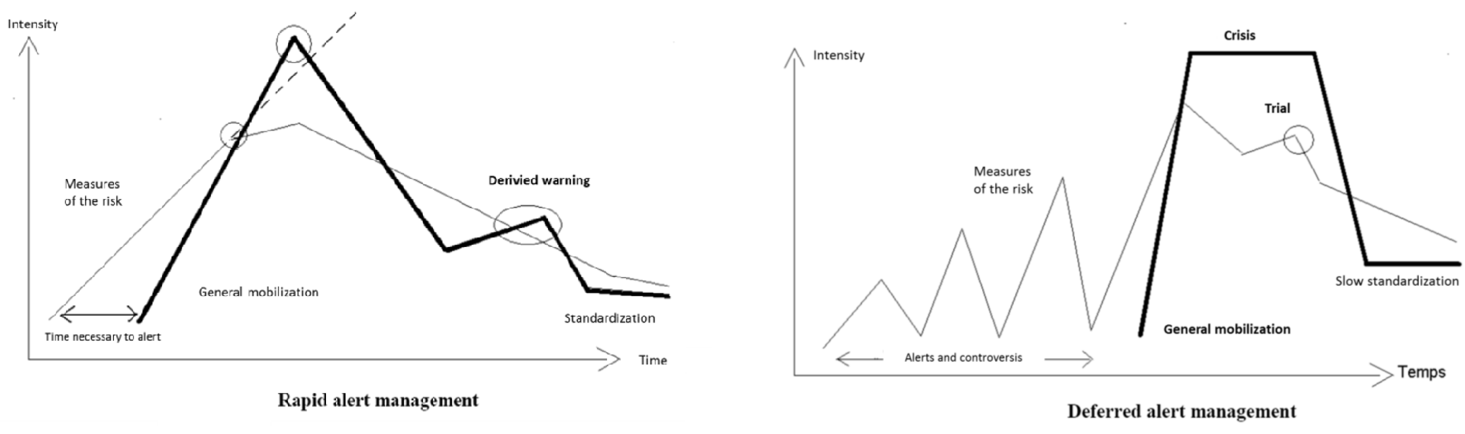


Figure 39. The alert management in case of a crisis or a long term risk (Chateauraynaud and Torny, 2005).

The question is: why do people rise and alarm and when? Using this concept, some issues can be raised up and useful in « SMaRT-Online^{WDN} ». These issues are declined in 5 objectives:

- To understand the way people perceive a specific good: drinking water;
- To question the way they could become « whistle-blower »;
- To know what kind of precursory signs could be significant for people;
- To understand what kind of perceptual faculties are mobilized by people before they alert public authorities;
- To identify authorities people as legitimate to protect them / prevent terrorist attacks. This last point is directly linked with the first issue questioned in the project.

Main research question: Is the consumer able to have a key-role in the monitoring of the water quality?
Two main hypotheses have to be controlled:

- H1 The consumers are able to identify a threat on the water quality
    - What kind of representation of the quality? What kind of knowledge?
    - What is a good water quality?
- H2 The consumers are able to inform other consumers or the stakeholders in case of a threat
    - Can they communicate about water quality?
    - Which stakeholders are identify as legitimate?

3.2 Methodology of the surveys: from qualitative pre-study to the construction of the database

3.2.1 Passation and structuration of the survey

The number of surveys was shared per site, amounting to 200 surveys per site (Berlin, Strasbourg and Paris):

- For Strasbourg, the survey focused on inhabitants of the major town exclusively.
- For Paris, three towns with different socio-economic profiles were chosen in order to be representative of the very important number of sites for which our partner is responsible.
- For site Berlin, the entirety of the large city was chosen.

In terms of sampling, the "quota method" was employed in respects to age, sex and socio-economical group. The objective was then to achieve a representative sample in respects to these three criteria.

To prepare and write the questionnaires for the survey among the population of the three sites, we lead qualitative interviews with inhabitants. The aim was to perfect the survey by challenging the assumptions and preconceptions on which the first drafts of the questionnaire were built.

Interviews were obtained using personal and professional networks, with a conscious effort to obtain diversity in terms of gender, age and socio-economic group. The interviews were mostly lead in person and otherwise lead over the telephone or using online telephone services. A total of 15 interviews were lead, recorded and fully transcribed: 5 per area, with average length varying between 15 and 40 minutes.

3.2.1.1 Structuring the survey: main themes and questions

The survey was built using results from the qualitative pre-study, literature and discussions with the concerned end-users. From this emerged a structure on which the survey was built:

- Description of the individual
- General behaviour and attitude towards the environment and water
- Knowledge of drinking water management
- Knowledge and trust in stakeholders of drinking water management
- Perception of drinking water security
- Beliefs and values concerning the future of drinking water security

Because this was a cross-national study, the three surveys could not be entirely the same. Certain questions had to be adjusted to the national as well as local contexts, notably those concerning specific stakeholders.

3.2.1.2 Passing the survey: Tests and final adjustments

Once the survey was finalised, it was submitted to testing by the French call centre in charge of passing the survey. During a meeting, the team in charge (four individuals) were presented the survey, were briefed about its main objectives and were given the opportunity to ask questions about its content. Discussions were held about the formulation of the questions (simplicity and clarity were of the essence) and some first minor adjustments were made accordingly.
The survey was then submitted to a first testing phase where each telephone interviewer made two calls: thus 8 tests. The calls were recorded and could be listened to. Discussion took place over the following days and new adjustments were suggested for the survey.

Afterwards, a second set of 12 recorded interviews was led. This second test phase served mostly to confirm the relevance of the first adjustments, to give final instructions to the phone interviewers, and to make the last changes to the survey with respects to the formulation of questions.

Once the French survey was finalised, it was translated into German and sent to the German call centre. As most of the testing had already been done in French, the German side needed only to suggest minor adjustments with the formulation of the questions. The calls could begin nearly immediately.

3.2.2 Structuration of the database

3.2.2.1 Recoding holes in the database

For reasons about to be explained, the database was received with various gaps in information. Three types of "holes" were identified and were (re-)coded accordingly.

Missing data: Certain questions (although very few) were concerned by an absence of answer where they should have been one. For financial and practical reasons, data from the first 8 test surveys was kept and added to the database. Although not ideal, such a choice seemed acceptable because the tests led very few important changes to the survey in the end. The missing data concerns therefore the 8 individuals from Strasbourg who were not asked the five questions which were added after the first test phase (see above).

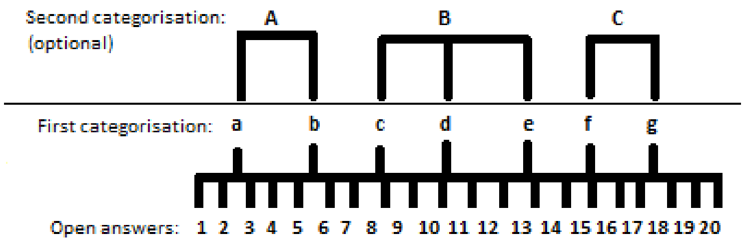
Unasked questions: In this survey, many questions were only asked to the respondent if a certain answer was given to a previous question. As a result there was a need to identify sections which were left unanswered because the question was not asked.
Unmentioned answers: Within certain questions, several answers were possible. As a result in the database the participants' answers were coded according to whether they mentioned a pre-coded answer or did not. A specific code was therefore used in order to differentiate unmentioned answers from missing data or the questions not being asked.

3.2.2.2 *Re-coding open answers: General method*

Re-coding answers to open questions followed an iterative process consisting of three key steps:

1 All noted answers were firstly entirely read and thoroughly scrutinised

2 Thematic categories were then suggested based on patterns emerging from the answers. When there were many answers, this phase was sometimes split into two: a first step consisted in identifying as many categories as necessary to accurately describe the answer (first categorisation); secondly close categories were grouped together to form larger but less numerous groups (second categorisation).



Each answer was then individually reviewed and coded according to categories it could belong to. This means that certain long or complex answers could belong to several categories.

Table 23. Encoding for potential answers

Open answer:	**Coded as:**	***(optional) Re-coded as:***
Answer 1	a, d	*A, B*
Answer 2	d, e , g	*B, C*
Answer 3	F	*C*
Etc…	…	…

This process of course required interpretation of the answers by the researcher. Although most answers left little to no ambiguity in terms of intended meaning, a very small number of these were still subject to discussion and consequently a slightly higher level of interpretation was required on behalf of the researcher: in such situations, as a rule of thumb, the most literal interpretation of the answer was privileged. However, particularly ambiguous answers were noted with a question mark, coded as "other" or "various", and if necessary separated from the mean analysis.

Two types of open answers had to be coded in order to "close" the database: firstly when precisions given by respondent who answered "other" to a closed-ended question; and secondly all the answers given to open-ended questions.

3.2.2.3 Creating new variables

In order to obtain more relevant variables in the database, data from certain questions was used in order to create new variables. The methods and assumptions used to create these new variables are described in this section.

3.2.2.3.1 Scoring the general levels of sensibility towards the environment

In order to assess the participants' general level of sensitivity towards environmental issues, an index was created by attributing a score to each participant based on their answers to some questions. This index aimed to assess whether a participant did or did not do certain environmentally friendly behaviours. Scoring follows as such:

Table 24. Possible scoring

Participant states doing environmentally friendly behaviour	2 points
Participant states not doing behaviour	0 points
Participant states not knowing if behaviour is done	1 point

In this scoring system, it is assumed that is "better" not knowing than explicitly stating that an environmentally motivated behaviour is not done. Indeed undecided individuals were considered as potential candidates for adopting either behaviour in the future.

3.2.2.3.2 Being able to name water supplier

Respondents were asked if they knew whom their water supplier was and if so to name him. A new variable was consequently created in order to separate those who knew the name of their water supplier from those who did not.

3.2.2.3.3 Scoring the general level of knowledge of the water distribution system

Just like for environmental sensibility, a scoring system was created based on whether a respondent was able or not to cite the mean steps of what becomes of water as it leaves an individual's household.
The respondents were asked to explain what happened to water after it left their house, and were instructed to continue giving steps until they did not know anymore or felt satisfied with their answer. The maximum amount of points was awarded if three key steps were mentioned in the right order:

- 1. Water is sent to a treatment plant
- 2. Water returns into the natural water circuits
- 3. Water evaporates and returns to the ground and rivers in the form of rain

The scoring system goes as follows:

- The respondent was awarded 2 point for each correct step named in the right order
- 1 point was given if a key step was mentioned but in the wrong order.
- Intermediate steps were not awarded any points, even if correct, but did not penalise the respondent either. For example, an individual who would name all three steps correctly in the right order, but also mentioned intermediate steps (for example:

“Water goes in the sewers”, “Water is stored in tanks or basins”) would still be awarded all the points for mentioning the key steps correctly.

- A lack of answers also gave 0 points.
- -1 point was taken off the final score if the individual mentioned that water was sent directly back into the city after being cleaned (or is “recycled”). This decision is based on reports of common misconceptions of the drinking water cycle, where according to CREDOC a significant proportion of French water consumers believed that drinking water was not released into natural water streams after having been cleaned, but instead was sent directly back to the cities for new consumption (this was coined by some as a “toilet to tap” configuration).

In the end a score between -1 and +6 was awarded to each individual. It was bumped up to a score between 0 and 7 for better legibility.

3.2.2.3.4 Determining the potential for being an alarm raiser

Respondents were at a certain point of the survey to imagine and describe their reaction immediately following a noticeable sudden loss of tap water quality at their house. Later in the survey, individuals having experienced problems or individuals having experienced doubts with tap water quality were asked to describe their immediate reaction to these problems or doubts.
These questions had for purpose to firstly get a general impression of the types of reactions possible, but even more importantly were secondly aimed at testing whether citizens were more likely to communicate or keep to themselves in situation of crisis concerning tap water quality.
As a result, each identified type of reaction was categorised according to whether it translated to the communication of the noticed problem, the lack of its communication, or the impossibility to determine this based on the available information. Each answer could then be coded according to one the three new categories. When the individual stated several actions which each belonged to different categories, a hierarchy was applied placing “communicating” at the top, and “not communicating” at the bottom. For example, an individual stating both “communicative” and “non-communicative” behaviour would have his answer coded as “communicates”, following the logic that ultimately the individual would have communicated the problem despite also adopting non-communicative behaviours

3.3 Methodology used for establishing dependency between variables: chi-square test, cross-tabulation, and PMD method

3.3.1 The PMD method

Through the example of crossing age with being able to name the water supplier, this section offers the reader a detailed illustration of the methodology used to examine the relationship between variables and their corresponding classifications. We will present it as a three-step process:

1- Understanding the relation between age and knowledge of the water supplier’s name firstly consists in verifying whether both classifications are statistically dependent or not within the sample. In order to do so, the chi-square test can be applied.

Our data processing software (Tanagra) indicates that for these two classifications, the value of chi-square (referred to as p) is equal to 0,0001. In order to reject the null hypothesis (referred to as H0) within a 5% marge of uncertainty, the value of p must be inferior to 0.5. If the null hypothesis is verified, both classifications should thereby be considered statistically independent one from another and any variation from within should not be considered statistically significant. In our situation H0 can be rejected, meaning that a statistical dependency between the two classifications can be established.

2- Now that the dependency is established, one can begin qualifying the nature of this dependency. Cross-tabulation of both classifications gives us the following distribution:

	18-29 y o	30-44 y o	45-59 y o	+60 y o	Sum
Does not know name	**106** *84,85*	**102** *107,74*	**95** *101,01*	**97** *106,4*	400
Knows correct name	**20** *41,15*	**58** *52,26*	**55** *48,99*	**61** *51,6*	194
Sum	126	160	150	158	594

We can see that two values are given per variables crossed:
The value above, shown in bold, corresponds to the actual number of individuals, which belong to both categories. We can see for example that 106 individuals are aged between 18-29 years of age and that do not know the name of their water supplier.

The value beneath the previous one, shown in italic, indicates the theoretical value required in order to obtain perfect independence between the crossed classifications. This means for example that in order for knowing or not knowing the name of the supplier to be perfectly independent from age, there would need to 84.85 individuals aged between 18-29 years of age who do not know the name of the supplier. This value is of course theoretical. It is calculated by applying the proportions of a variable belonging one classification in respects to the total population, to the total of a variable within the other classification.

By comparing the actual number of individuals belonging to two groups to the theoretical value for independence, we can begin qualifying the nature of the relation between the two classifications. If the actual number observed is higher than the theoretical value, we can talk about an "attraction" between the two variables. We can see for example that there are 106-84.85=21.15 more individuals who are aged between 18 and 29 years of age and who do not know the name of their supplier, than the value required for independency. This means that there is an attraction between being aged between 18 and 29 and not knowing the name of the supplier. Consequently, we can also see that there is 20-41.15=-21.15 more, or in other words 21.15 fewer individuals aged between 18 and 29 years than the value required for independency with knowing the correct name of the supplier. In this situation we can talk about "repulsion" between the two variables.

This first observation enables us to state that within our sample: 18 to 29 years olds tend to know less often the correct name of their water supplier.

3- By using the method of percentage of maximum deviation (PMD) described by Philippe Cibois[3], we can go one step further in qualifying the degree of attraction and repulsion between two given variables. The method consists in qualifying through percentages, how close or how far two variables are from complete (i.e. 100%) attraction or repulsion.

The PMD is calculated differently depending on if we are in a situation of attraction or repulsion. In the case of attraction, like in the example of 18 to 29 year olds not knowing the supplier's name, our aim is to assess how close this attraction is to its maximum capacity. In order to do so, one must first identify the maximum number of individual possible for group considered. In this example we can see that there are maximum 400 individuals who do not know the name of the supplier, but there are only 126 individuals who are aged between 18 and 29. The maximum number of 18 to 29 year olds who do not know the supplier's name is therefore limited to 126 individuals.

Once this maximum is identified, one can calculate how far the observed value is from the potential maximum. We calculate the PMD by dividing the distance between the observed value and theoretical value for independence, by the distance between the maximum possible value and the theoretical value for independence. In our case, we get:

PMD (18-29 yo / DK supplier name) = (106-84.85) / (126-84.85) = 51.34%

This result means that in the case of 18 to 29 year olds who do not know their water supplier's name, the maximum distance between theoretical independence and maximum attraction reaches 51%.

In cases of repulsion, the PMD is calculated by dividing the distance between the observed value and the theoretical value for independence (this negative in value), by the distance between the minimum possible value (therefore always 0) and the theoretical value for independence. In our case, we get:

This result means that in the case of 18 to 29 year olds who know the name of their water supplier, the maximum distance between theoretical independence and maximum repulsion (i.e. 0 individuals belonging to this group) reaches 51%. In order to separate cases of attraction and repulsion, the PMD in case of repulsion is presented with a negative sign; thus multiplying the total by -1.

Considered alone, the information offered by the PMD can be useful for qualifying of the intensity of the attraction or repulsion between both variables. It can also be useful for comparing degrees of attraction and repulsion between different sets of variables. Nonetheless, one must keep in mind certain limitations when using the PDM. Like for any percentage-based analysis, keeping in mind the size of the basis (i.e. Distance to maximum attraction or repulsion) is essential for a critical understanding of the results given. Indeed, this Distance to independence might vary quite considerably from one set of variables to another, which means that in situations where this distance is small, percentages might show a very important PMD, when in fact deviance in terms of population is actually quite low.

3.3.2 Links between sociological traits

Cross-tabulation reveals that certain links can be made between the various sociological traits of the sample. We will first mention the logically expected ones, and then present some less expected ones, as these should be considered during interpretation.

[3] CIBOIS Philippe; *Les écarts à l'indépendance, techniques simples pour analyser les données d'enquête* ; Editions Sciences Humaines ; 2003

It is important to note that from now the significance of the links presented between variables have been tested using the khi-square test and rejection of the null hypothesis was only accepted within a 5% level of error. Also the PMD here presented follows specific rules in order to be considered statistically significant: if the maximum deviancy is below 60, then difference between expected and observed value must be superior to 4; if the maximum deviancy is between 60 and 100, then difference between expected and observed value must be superior to 5, if the maximum deviancy is superior to 100, then difference between expected and observed value must be superior to 5% of the maximum deviancy.

The first and most logical existing link is the high correlation existing between old age (belonging to the +60 year old group) and being retired. This relation requires very little explanation as the logical link between both variables is self-explanatory and allows very few exceptions. One should also note that this relation was hypothesised and used in order to separate students from retired in the German socio-economic classification "Students + retired" (see methodology section), so this relation was all the more to be expected.
And as should also be expected, being of a younger age (18-29) is linked more strongly with having no occupation or being a student, whereas having an occupation is linked more strongly with being aged between 30 and 59.

Finally in terms of expected links, old age and being retired is also quite logically linked to less often having children under 15 in the household.
In terms of existing links which are more complex to explain, age and gender appear to be somewhat linked in our sample, as 18 to 29 year olds tends be more masculine (PMD [Men / 18-29 yo] = +22%, max=67.67), whereas the other age groups tend to consequently hold slightly higher proportions of women. This distribution is coherent with general demographics in western countries which show that men are more numerous at a younger age, and women at later stages in life.

Significant relations should also be noted between gender and socio-economic groups in our sample. Men tend to hold a stronger ground in groups such as independents (PMD=+26%, max =8), high executives, liberal and intellectual professionals (PMD =+24%, max=52.63) and workers (PMD=+44%, max=21.48), whereas women tend to have a stronger presence as employees or state officials (PMD=+23%, max=83.33), and being retired (PMD=+6%, max=79.63).

One might also note that a link exists between gender and owning or renting the household one lives in. A slightly higher share of women tend to rent the household they are living in (PMD [Women / Tenant] = +9%, max =135.63) and consequently men tend be more often proprietors of their household (PMD [Men / Owner] = +9%, max =135.63].

Finally, one can establish a link between socio-economic groups and owning and renting the household one lives in. Independents (PMD=+ 43%, max=8.71), high executives, liberal and intellectual professionals (PMD =+28%, max=56.92) and the retired (PMD=+ 12%, max=99.9) tend to be owners of the household, whereas employees and state officials (PMD=+20%, max=75.45), workers (PMD=+76%; max=16.77) and students or people with no occupations (PMD=+12%, max=36.45) tend to rent their household.

Although it is of course considerably more complex than what about to be stated, the three last observed trends point towards the general inequalities which still exist between different socio-economic groups, as well as between men and women in today's society. Men still tend to occupy higher or more influential professions than women generally speaking, and wealthier socio-economic groups will dispose of more means with which to buy the household they are living in. Age also plays a role in the acquisition of a household as older individuals will have had more time to acquire the funds necessary for acquisition.

3.3.3 Factorial Analysis and Clustering

In order to obtain legibility of the data as a whole, two methods known as Multiple Correspondence Analysis (MCA) and Hierarchical Ascendant Classification (HAC) were applied to our data. MCA enables us to generate a small number of dichotomised axes out of a larger selection of key variables. The individuals in our sample can then be positioned according to their coordinates on the selected axes (in our case two axes). The new coordinates of the MCA will be used as a starting point for the next step. HAC is a clustering method, which consists in grouping two by two the closest individuals and then groups in a sample, until homogenous groups are created. The final number of groups considered is consequently chosen by the researcher. Using group characterisation, the groups generated can be described according to the positioning of the group on the axes and the characteristics, which are the strongest in each group.

3.3.3.1 Multiple correspondence analysis

After several trials with different combinations, 10 variables were finally selected in order to get the strongest statistical significance of the axes. These are as follows:

Input
Environmental sensitivity
Belief in difficulties to come with water in the future
Belief that tap water is polluted
Knows water supplier name
Feeling of having enough information on tap water.
Has already searched for information on tap water
Belief that making information available is important
Belief that a sudden loss of water quality is likely
Agreement that surveillance systems are efficient and require no improvement
Agreement with developing systems of communication between citizens for water vigilance

3.3.3.2 Clustering and group characterisation

Once that the two main axes have been created and defined, CAH was done using the coordinates of the individuals on both axes.

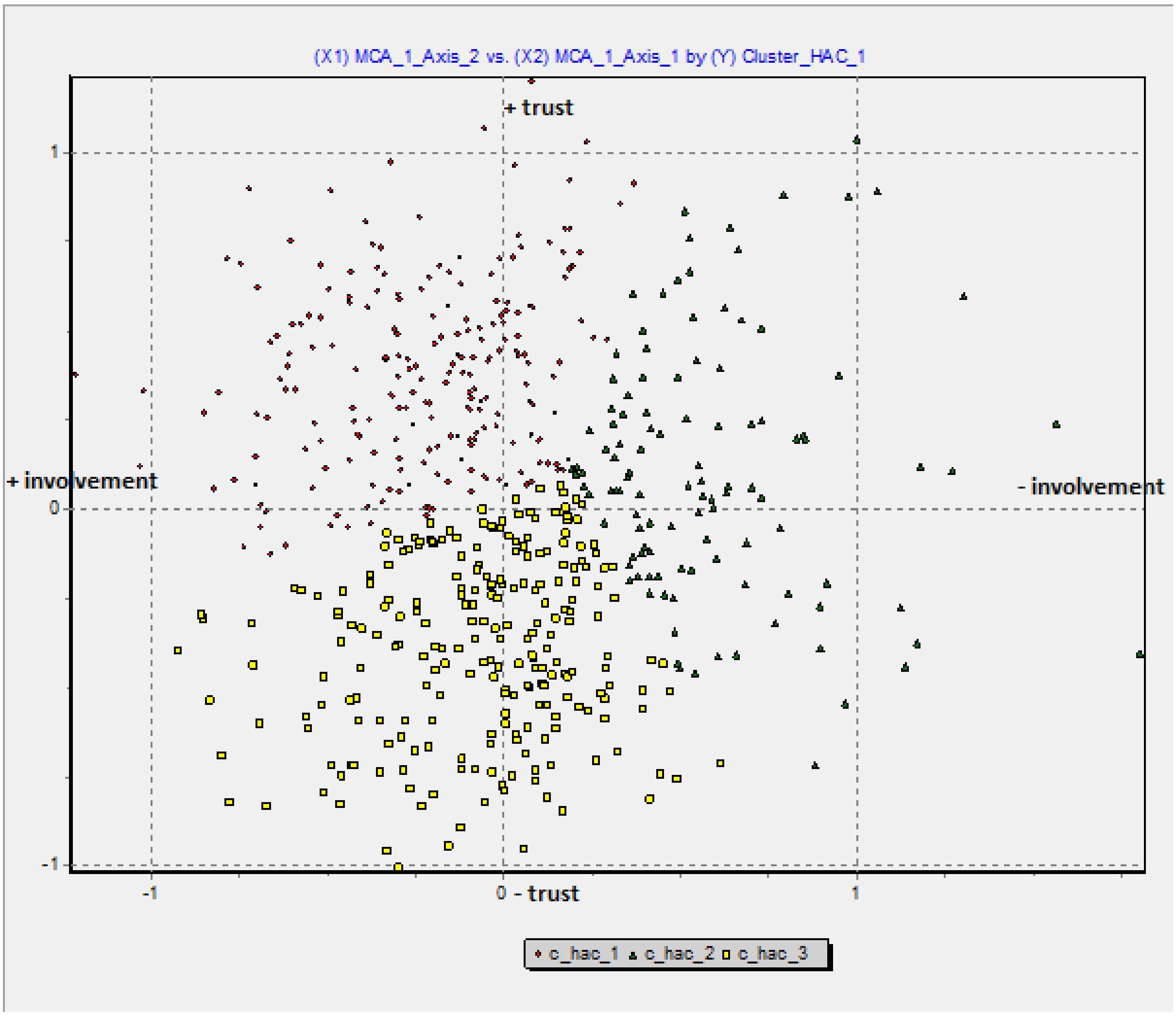


Figure 40. Plot of individual responses

The graph above firstly displays each individual according their positioning on the graph. The Y axis corresponds to axis 1: it opposes individuals with high trust in water in the positive end to individuals with low trust in water. The X axis correspond to axis 2: it opposes individuals with high involvement/ concern on the negative end to individuals with little or no involvement / concern on the positive end.

The graph above secondly displays each individual according to the CAH group they belong to. We have chosen to display the CAH results according to three groups, as was also recommended by our data treatment software.

4 Conclusion and perspectives

This report presents the methodology of the risk analysis methodology and of the social analysis of consumers' perception of water quality, which were adopted within SMaRT-Online^{WDN} project.

4.1 Perception analysis

The perception analysis, which was made by interviewing consumers belonging to the 3 end users territory clearly, established the fact that the customer has in general a good opinion of tap water quality and trust in the managers and operators of the utility and is not systematically in position to identify and to communicate on the question of the water quality change except to the water utility in some cases.
Our hypothesis to consider the consumer as a potential alarm raiser is not confirmed up to now. In the investigation the question of “deliberate contamination” was not clearly expressed to the people, people had to explain water quality troubles they already undergo or heard about and which elements could deteriorate water with their own words: only 2 people on 600 answers spoke from “contamination”.
Consumers maybe will relate to the water utility but maybe not to their neighbour for instance to make sure he is also concerned and there is a problem linked with water. So communication and education would be necessary to change this situation but maybe the risk to generate fear to the consumers and divert them from tap water drinking is too high.
Of course, for the utility, giving alert when several complaints arrive in a short time or analysis consumers’ complaints data is a way to get information directly from the consumers but this has to be taken with precaution, water managers consider that “some people will easily complain where are other ones trust in the water management and do not react: this district will complaint, this other one not”. So in case of a contamination event information may be incomplete…
But developing consumers’ vigilance could be a way to complete the information in case of water quality deterioration and could be used to confirm an alarm given by one or several sensors. Of course that means, for the utility, going further within communication with consumers and promoting their participation.

This analysis of the consumers’ perception confirms the necessity to put in place procedures and tools to be used for raising alarm in case on contamination based on monitoring and modelling the network as it is investigated within the Smart-Online^{WDN} project in order to develop an online security management toolkit for drinking water distribution systems. In this procedure, is the risk analysis one of the important steps.

4.2 Risk analysis

The methodology developed within the risk analysis, integrates the results of 4 steps:

- Hydraulic modelling of the network;
- Definition and evaluation of the intrinsic vulnerability of the system to contamination intrusion;
- Definition and evaluation of user’s sensitivity to water quality and water use;
- Analysis of the consequences (internalities/externalities) of a contamination event.

The developed methodology provides to utility managers, the link between intrusion points and impact in terms of contaminated sensitive consumers by using hydraulic modelling, intrinsic vulnerability of the network. The use of the transport model (deliverable 4.3) to predict the ingested volume and dose-response estimations give different answers for chemical or biological contaminants. The consumption nodes affecting the most sensitive consumers to water quality for domestic or industrial use are identified and represented as hotspots on the GIS.

So the risk analysis provides two relevant responses, on one hand it helps for the optimal placement of sensors in order to protect in priority the most vulnerable intrusion points and the intrusion points delivering to many sensitive consumers, on the other hand, the identification of these hotspots gives information to the utility for its crisis management: priority information areas, priority water cuts, or its prevention/protection policy.

Concerning the analysis of consequences, the two domains concerned by contaminations are the impacts on health for the water consumers and the economic consequences on the utility (internalities) and on trade or industrial activities using water in their activity or fabrication process (*e.g.* dentist, food production, etc.). These dimensions have been taken into account in the developed risk analysis in order to give an operational tool giving a quick answer in case of contamination with a rapid effect contaminant, so priority is given to alarm raising and identification of sensitive sectors regarding chemical and biological contaminants. The health impacts are considered within the characterisation of the sensitivity of the consumers taking into account the vulnerability of the persons (age, ill people…), the contaminant concentration and the number of consumers concerned by a given contamination event.

4.3 Discussion and perspectives

A further investigation on public health impacts could be to look at pathologies and heath costs. These could bring further information to the utility managers to be aware of all the consequences of a given contamination and give them elements to quantify the efficiency of their early warning system within a cost-benefit analysis. It is also a way of relating the effects more widely on the households, firms and government (WHO[4], 2009). Making such evaluation needs to be able to make a good link between the dose of contaminant that a given consumers can ingest and the effective pathology this person will or not develop. Such answers need illness data investigation and epidemiologic approaches and precise cost evaluation driven illness by illness. Thus the study of cost of illness analysis driven after the cryptosporidium outbreak in Milwaukee, USA in 1993, with diarrheal illness considers direct medical costs and productivity losses, using a phone call survey of 613 households and analysing three levels of illness - the mild one only needing medication and the severe illness level conducting to hospitalisation - to estimate the cost of illness (Corso *et al.*, 2003). Another example is given by Frost and ali (2002) who realised a cost benefit analysis of a lower arsenic MCL (maximum contaminant level) going from 50 to 10 µg/L, looking at cancer diseases reduction. An interesting cost analysis of several disease can be mentioned (US EPA, 2007) looking at different cancers, adverse development effects, respiratory illnesses but giving no information on rapid effects contaminations and no link with the contaminant and the dose giving a given pathology.
The link between a contaminant and the characterisation of the individual pathologies within a contaminated population is one difficulty, the second one is to evaluated the precise illness costs and to be able to do it for each illness with real data or to use macro analysis data and loose part of information.

Looking at the literature of health costs, typology of medico-economic cost is given by several authors such as Launois (1999) giving in each case who is impacted by the cost in France cases (hospital, illness insurance reimbursement, state and local collectivises, individuals, society) or Lassagne *et al.* (2012) dividing indirect costs for tangible and intangibles effects (*e.g.* moral prejudice). The following table gathers these several points of view:

Table 25. Health cost topology

[4] WHO: World Health Organization

Direct costs
Medical cost (medicine and hospitalisation)
Familial cost (transport of the ill person, loss of work hours to take care of the ill person)
Social costs (work interruption, invalidity, death, allocation for handicap…)
Institutional costs Research, formation…
Indirect costs
Tangible effects (Work hours lost due to the illness, lost of leisure time…)
Intangible effects (moral prejudice, pain and suffering…)

Several methods are proposed in the literature (Lassagne and ali., 2012) (WHO, 2010) (Unsworth *et al.* 1993) to evaluate health costs:

- Contingent valuation approach: uses a survey to estimate the willingness-to-pay to avoid a given illness. Directs costs, indirect costs and cost associated to pain and suffering can be taken into account (US EPA, 2007)
- Cost of illness approach: valuates medical costs and sometimes cost to society from lost earnings. Pain and suffering, value of leisure time, costs of benefits for preventive measures are not taken into account. Data at France national level on hospitalization costs are given by the technical agency of hospitalization information (ATIH) using the international scale of homogenous ills.
- Hedonic valuation approach: estimates the relationship between environmental improvement or reduced worker risk and other variables , it is difficult to separate illness from other independent variables
- Averting behavior approach: looks at preventive measures to avoid or mitigate the illness effects

4.4 An interesting exemple

To illustrate our discussion we present as an example the Cincinnnati Contamination Warning System Pilot (CWS). This CWS has been evaluated by the US EPA[5] Water Security Initiative from January 2008 to June 2010 (EPA, 2014a) using a cost benefit analysis.
The general frame of this CSW involves the following steps:

[5] US EPA: United States Environmental Protection Agency

Monitoring an Surveillance

Water quality monitoring

Enhanced Security Monitoring

Customer Complaint surveillance

Public health surveillance

↓

POSSIBLE CONTAMINATION

↓

Consequence Management

Sampling and Analysis

↓

RESPONSE

Figure 41: Cincinnati Contamination Warning System Pilot (EPA 2014a)

During the evaluation, because there were no contamination events, to fill the gap, a ensemble of 2015 contamination were simulated representing a large range of contaminants and injection locations. The contamination scenarios were worked out using hydraulic simulation linked to an exposure module and a Health Impacts and Human Behavior model (HI/HB) simulating actions of individuals who either detect a problem with drinking water or experience symptoms after being exposed to harmful contaminant. For the individual behavior tracking, call to the utility provides inputs in the Customer Security Surveillance (CCS) Model, and health seeking behaviors provide inputs in the Public Health surveillance (PHS) model. This HI/HB model determinates also the overall public health consequences (illness, fatalities and healthcare burden) for each scenario regarding for instance contamination during one showering event in the morning (for the inhalation exposure route), or during five consumption events spread throughout the day (for the ingestion exposure route). The threshold doses were derived from expert judgment of medical specialists and toxicologists. The percentage of symptomatic individuals in each demographic group issued from literature review (Bertakis *et al.*, 2000 and Schappert and Bert, 2006).

The Customer Security Surveillance CCS Model considers that all customers have the potential to detect contaminants that change the aesthetic characteristics of the drinking water and so that they may detect the contaminant if his concentration is above the contaminant specific detection threshold and then call the utility. Two outputs: WUERM notification time and CCS confidence index (link between consumers ‘complaint and water quality).
The Public Health surveillance PHS model (EPA, 2014e) analyses health-seeking behaviors and identifies unusual trends coming from CCS model (911 simulation calls) in order to detect unusual clusters of illness and disease. PHS model monitors also 3 other data streams (Emergency Medical Services, Epicenter surveillance tool, and the Cincinnati drug and Poison Information center). If an alert is given by one data base, the local health partners work collaboratively with the Greater Cincinnati Water Works GCWW utility personnel (Water Utility Emergency Response Manager WUERM) to determinate if the contamination has a link with drinking water, this time is also taken into account resulting from exercises performed during the

evaluation time. Two outputs: WUERM notification time and PHS confidence index (link between reliability of information and suspicion of water contamination).

To evaluate the Cincinnati CWS a cost benefit analysis has been driven taking into account implementation and operation direct costs and the benefits due to early warning concerning revenue (lost water and lost of business revenue for water quality depending industries and leisure time for consumers), remediation and Public health. For Public health, were considered fatalities cost and medical treatment costs using international classification of diseases or the clinical classification category for treatment of the specific contaminant and the estimated length of hospital stay required for that contaminant (Rotter *et al*., 2010).

This example that we investigated more specifically on the Health impacts and costs and the individual behavior shows on one hand the difficulty to make the link with pathologies'data coming from epidemiologic studies or global classifications and the specific pathologies linked with water network contamination and individual impact estimations and to make the link with a given contaminant dose. On the other hand heavy hypothesis have be taken concerning the capacity of judgment ability of consumers, within the CCS model, according to our survey results.
So taking into both of these dimensions needs further research.
Cost benefit analysis is a method that can help to evaluate the benefits of early warning in case of contamination, but that means that all costs concerning health impacts concerning care and medicine but also intangible costs should be taken into account, making this exercise is difficult and need many simplifications but at the end it is fruitful: in Cincinnati simulation the highest benefits of early warning were observed for public health concern.

5 ANNEXE Survey questionnaire

Management of drinking water: beliefs, legitimacy and citizen alerts

Information at disposal of telephone interviewer to convince respondent to accept to participate (only as much information as necessary to convince will be given):

- Survey on the management of drinking water
- French/German project named Smart On Line
- The project is funded by the French and German Ministries of Research & Education
- Project partners involved are University of Strasbourg, IRSTEA, ENGEES, VEDIF/SEDIF, BWB, KIT…
- Information can be consulted on http://www.smart-onlinewdn.eu/
- Your answers will be anonymous / No intention of selling or collecting personal information
- We will need between 15 and 20 minutes

Part A: Participant's sociological traits

0. Area (for Strasbourg and Berlin): ____________

1. What is your year of birth? _________

2. Sex/gender:
   M
   F

3. What is your occupation? ____
(If retired ask previous occupation, for unemployed ask field of expertise, for students ask for course).
   - 8 categories for France
   - 11 categories for Germany

If the person meets the requirement, continue the survey. Otherwise thank participant and end conversation

4.1. Do you live in…
   Individual
   Collective housing

4.2. Are you …
   The owner
   Renting your accommodation

5. How many people live in your home, including yourself? __________

6. And how many children under 15 live in your home? ______________

Part B. Awareness and sensitivity towards environmental issues and water

7. Could you please tell me if environmental considerations have motivated or currently motivate you to:

7.1. Regularly buy cleaning products which are labelled respectful of the environment?
- Yes
- No
- NA

7.2. Regularly buy organic or/and locally produced foods?
- Yes
- No
- NA

7.3. When possible, try to avoid using transport systems considered more polluting (such as car, or plane)?
- Yes
- No
- NA

7.4. Separate your waste before collection?
- Yes
- No
- NA

7.5. Own any of the following: compost bin, rain water collector, energy meter?
- Yes
- No
- NA

7.6. Make efforts to limit your daily energy consumption (gas or electricity)?
- Yes
- No
- NA

7.7. Regularly buy second hand objects such as clothes or home equipment?
- Yes
- No
- NA

7.8 Invest time or money into supporting environmental groups or NGOs?
- Yes
- No
- NA

8. What do you consider is/are your main source(s) of information concerning your current understanding of environmental issues? (Do not read options. Multiple answers possible)
- National or local newspapers
- Internet
- TV reports or documentaries
- Discussions with my surroundings
- From my education and/or professional training
- Specialised or scientific journals
- I have little or no knowledge of the environment Other_________________________________
- NA

9. Have you ever asked yourself questions concerning the general quality of water in France/Germany?

Yes
No
NA

10.0. Do you believe that there are going to be problems/challenges related to drinking water in France/Germany in the next 20 years?

Yes
No
NA

10.1. (If answer is Yes) What kind of problems? (Donotreadanswers.)

Problems with quantity of available drinking water
Problems with quality of available drinking water
Quality and quantity
NA

Part C. Knowledge of water distribution system and legitimacy of stakeholders to inform

11.0. How important is it for you to know where your tap water comes from?

Very important
Important
Not very important
Not important at all
Don't know

11.1. Why so? (Do not read answers. Multiple answers possible)

Important	Not important
I want to know what water I am using I can get information on the quality of the water I am using No particular reason in mind, but it seems important Now that you ask me, yes it seems important (ask to explain reason) Other :______________	I have no control over where my water comes from It is not my responsibility to know I never asked myself the question I am not interested in knowing Other : ____________

NA

12.0. Is it important for you to know the chemical and mineral composition of tap water?

Very important
Important
Not very important
Not important at all
Don't know

12.1. Why so? (Do not read answers. Multiple answers possible)

Important	Not important
I want to know what's in my water I want to make sure my water is safe / of good quality No particular reason in mind, but it seems important Now that you ask me, yes it seems important (ask to explain reason) Other :______________	Too complicated to understand It is not my responsibility to know I never asked myself the question I am not interested in knowing Other : ____________

NA

13.0. Do you know who is in charge of the water distribution in your home?

Yes

No

13.1. (If answer is Yes) Who? (Do not read answers)

CUS, VEDIF, SEDIF, BWB…

…

I don't remember the name right this second I don't know Other________________________

14. What do you think becomes of used water, meaning once it leaves your home? (Do not read answers. Encourage participant to describe circuit until a circle is complete or participant is satisfied with answer or is unsure. Tick steps accordingly).

It goes into the sewer system
It is sent to a treatment plant for cleaning
It is sent back to the cities for consumption
It is evacuated into the rivers/nature
It eventually ends up in the sea
It is collected by other cities
Through evaporation and rain it ends back in the ground, rivers and sources
I never thought about it
I don't know
Other :____

15. Do you feel like you know everything you need to know about your tap water?

Yes
No
NA

16.0. Do you think this information is available?

Yes
No
NA

(if no skip to 16.3.)

16.1. (if yes) Have you ever consulted the information?

Yes
No
NA

16.2. (if yes) How would you rate the quality of the information?

Very good
Good
Medium
Poor
Very poor
Don't know

16.3. Do you think having such information available is important?

Very important
Important

Not really important
Not important at all
Don't know

17.0. Do you think information concerning your tap water should…
… come to you…
… or that is sufficient to make it available should you wish to consult it ?
NA:_______________

17.1. How should this information be made available? (Do not read answers. Multiple answers possible)
On a website
By organising meetings with water suppliers
By request at water supplier or town hall
Sent by email
Regularly sent to me by postal mail (bulletin)
Along with my water bill
Other : ______________________
NA

18. I am going to give you a list of sources of information. Please tell me how much you trust them to inform you of the quality of your tap water:

	No trust at all	Somewhat trust	Trust	Fully trust	Don't know
Your water supplier					
The City					
Scientists					
Medical authorities					
State services/ authorities					
Citizen committees or environmental groups					
Discussions with surroundings					
Other:_____					

Part C. Behaviour and perception of risk linked to daily use of water

19.0. At home do you drink mostly:

Non-filtered tap water
Bottled water
Filtered tap water
Both in similar amounts
I practically never drink water
NA

19.1. What reasons? (Do not read answers. Multiple answers possible)

Reasons to prefer bottled water	Reasons to prefer tap water
Tap water is of bad quality Tap water is potentially dangerous for my health Tap water tastes bad or smells strange The water is too hard (too much calcium) Bottled water is better for my health I like sparkling water Out of habit, I have always drunk bottled water Other : ________	Tap water seems fine It is cheaper It is practical (for ex. no need to carry bottled water) It is better for the environment Out of habit, I have always drunk tap water I add the gas myself Other : _______

NA

20. Please tell me how important the following characteristics are for assessing water's quality.

	Not important at all	Not very important	Important	Very important	NA
Taste					
Smell (for bottled water users)					
Colour					
Hardness of water					
The presence of Chlorine					
(For bottled water drinkers) Brand of water (egs. Nestlé, Carola…)					
Other: ___________					

21. What's the first thing you would do if very suddenly the quality of your tap water changes and no longer meets your expectations? (Do not read answers. Tick first answer only. If respondent gives several answers at same time: note order)

I call my water supplier to mention the problem

I ask my neighbours if they are experiencing the same problems
I warn my neighbours
I ask my family and close friends if they are experiencing the same problems
I warn my family and close friends
I wait and see if the situation improves
I don't do anything
(if tap water drinker) I switch to only drinking bottled water
I don't know
Other :____
____

22. In your option, the occurrence an unexpected change to the quality of your tap water seems to be:

Very likely
Likely
Unlikely
Very unlikely
Don't know

23. What types of problems seem the most realistic? (Do not read answers. Multiple answers possible)

Dangerous concentration of heavy metals
Bacteria
Intentional contamination
Contamination following works on the pipe systems
Water source polluted
Technical error at the water purification plant
Contamination following bad weather and/or natural disaster
Other ____
Don't know
None

24.0. Do you think there might be a risk that your tap water is polluted?

Yes
No
Don't know

24.1. (If yes) What kinds of pollutions? (Do not read. Multiple answers possible)

Nitrates or other products related to intensive agriculture
Natural radioactivity
Products rejected by Man into the ecosystem (hormones, toxins…)
Presence of heavy metals due to the passage of water through the city pipes
Presence of heavy metals or bacteria due to the passage of water through the pipes of my house
Treating water actually pollutes it (adding chemicals)
Other : ____
Don't know

Part D. Feedback from experience of unexpected quality change

25.0. Have you experienced in the past problems related to the quality of tap water in your home?

Yes
No
Don't remember

25.1. (if yes) More than once?

Yes
No
Don't remember

(only if no to 25.0.)

26. Do you remember it occurring to somebody you know in your area? (max distance: region)

Yes
No
Don't remember

(If No skip to 29)

27. (If yes to 25 or 26) What were the problems? (Do not read answers)

Bacteria
Too much chlorine
Dirty water (sand, earth…)
I don't really know but people were ill in my neighbourhood
I don't know/ I don't remember
Other : ____

28.0. Did these problems change your behaviour in respects to tap water consumption?

Yes
No
Don't know

28.1. (if yes) Indefinitely?

Yes
No, I went back to my hold habits eventually
Don't know

(Skip to 33)

29. In the past, have you ever experienced doubts concerning the quality of your tap water?

Yes
No
Don't know

(If No skip to 33)

30. What happened? (Do not read answers. Multiple answers possible)

The water smelt bad when it came out of the tap

The water had an usual colour
The water tasted strange
I felt ill after drinking the water
No particular reason, I just questioned it
I heard worrying information
I generally distrust tap water
I don't remember/ I don't know
Other :____

31. What did you do as soon as you noticed? (Do not read answers. Multiple answers possible)
I called the water suppliers
(if not same as water supplier) I called the city administration/ town hall
I called State/Regional services
I didn't do anything and it eventually sorted itself out
I didn't do anything and it is still a problem
I spoke to my neighbours
I looked for information on internet
I looked for any announcement on TV or radio
I don't remember

32.0. Did these doubts encourage you to change your behaviour concerning water consumption?
Yes
No
Don't know

32.1. (if yes) Indefinitely?
Yes
No, I went back to my hold habits eventually
Don't know

Part E. The future of water management

33. I am now going to read you different proposals for a vision of the management of drinking water. Please tell me to what extent you agree or disagree to each one.

	Strongly disagree	Disagree	Agree	Strongly agree	No opinion
We must trust our water suppliers to supply us with water of good quality					
The current systems in place to control water quality are effective and require therefore no (or very little) improvement					
We should develop communication systems between citizens so we can keep each other informed of water quality, and to alert one another in case of problems					
As well as frequent testing, we should install electronic sensors in the water distribution systems in order to guaranty an optimal surveillance of water quality					
I am willing to pay a moderate extra cost in my water bill in order to finance the installation and maintenance of such sensors					

34. We have finished the survey. Thank you! Do you have any things you wish to add concerning drinking water in your city?

Thank you and have a nice day!

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