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Sustainable management of wastewater systems: presentation of an adaptative model based on local dialogue and quality of service assessment

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ABSTRACT
Water resources management is a worldwide challenge for the 21st century. Water resources management in urbanized cities raises the question of cohabitation between the collective wastewater services and the individualized systems. Thus, an objective measure of efficiency is required: this can be done by evaluating the level of provided service instead of evaluating the means available themselves. For several decades, the emergence of new alternative technologies has been raising the question of services efficiency offered by traditional technologies used in drainage management. This question is emphasized by the need for a global management of wastewater systems and the evolution of legislation, from discharges standards ("emission based") to standards in environment acceptance capacities ("immision based"). Integrating these impacts becomes a necessary step in order to plan sustainable drainage decisions. In this context, a methodology, named E_DA_SR[1], is proposed to support wastewater management strategies. This methodology is applied on the SIVOM (Intermunicipal Union with multiple vocations) of the Mulhousian agglomeration (Alsace, France). This study is conducted with a close collaboration of local authorities, of the “Lyonnaise Des Eaux” (Mulhousian manager) and of local stakeholders (associations, Water Agency, etc.).

KEYWORDS
Indicators, assessment, urban drainage, methodology, decision making process, retroaction.

INTRODUCTION
Water resources management is a worldwide challenge for the 21st century. The United Nations’ Commission on Sustainable Development (CSD13) encourages better governance at all levels and promotes regulatory frameworks to protect aquatic and terrestrial environments, requiring an active implication of all stakeholders. In this respect, the Ministerial declarations from the Third and Fourth World Water Forum tend to reinforce the role of local public utilities. These declarations also encourage local authorities to recognize that an effective collaboration with and between all stakeholders is a primary key for reaching water–related challenges and goals (ISO/FDIS 24511, 2007).
The water resources management in urbanized cities raises the question of cohabitation between the collective wastewater services and the individualized systems. Thus an objective measure of efficiency is required: this can be done by evaluating the level of provided service instead of evaluating the means available themselves. For several decades, the emergence of

[1] Evaluation, Decision, Action, Survey and Retroaction

new alternative technologies has been raising the question of services efficiency offered by traditional technologies used in drainage management (Field et al., 1997). This question is emphasized by the need for a global management of wastewater systems and the evolution of legislation, from discharges standards ("emission based") to standards in environment acceptance capacities ("immision based") (Fuchs et al., 1997; Stahre, 2006 ; Villareal, 2005 ; Novotny & Brown, 2007). Integrating these impacts becomes a necessary step in order to plan sustainable drainage decisions (Chocat *et al*., 2007).
In this context, a methodology named E_DA_SR is proposed to support these evolutions. This methodology supports wastewater management by taking into account local characteristics and expectations, and considering logic of performance (results objectives). This approach, derived from methods used in industrial quality management, is based on the continuous monitoring of the gap between provided service and users expectations. The methodology E_DA_SR is composed with five steps, presented in figure 1.

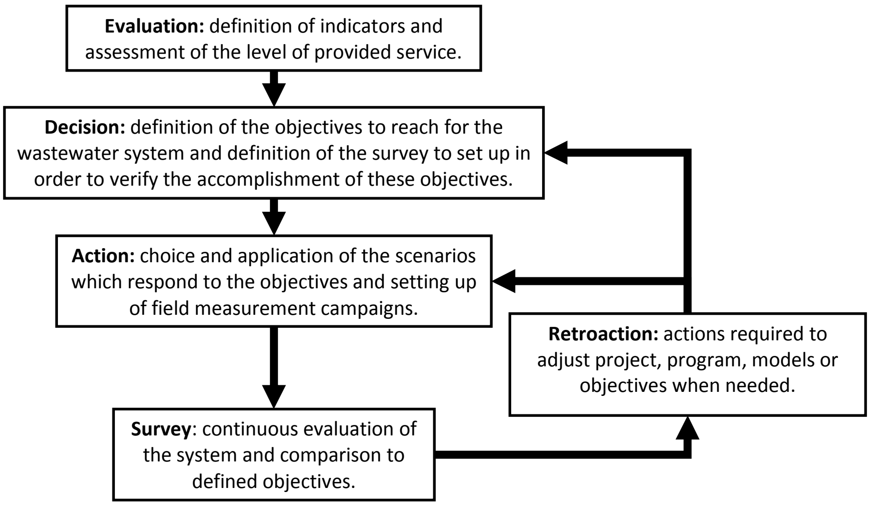

Figure 1 Five steps of the E_DA_SR model: evaluation, decision, action, survey, retroaction.

The originality of this contribution is the development of a methodology aiming at an efficient management, based on a local empirical relationship. This relation can be adjusted by retroaction with the constant monitoring of the quality, and thus, allows an insurance quality of the wastewater management.
In this paper, the E_DA_SR methodology is introduced in the first section, where its construction is explained. The second section illustrates a part of the methodology for the SIVOM (Intermunicipal union with multiple vocations) of the Mulhousian agglomeration (Alsace, France). This illustration focuses on the function “Preserve uses of water bodies” and more especially on river bathing. The methodology and its application are discussed in the third section.

GENERAL PRESENTATION OF THE E_DA_SR METHODOLOGY

The E_DA_SR model aims at meeting the following objectives:
-*To evaluate the wastewater system through all its different functions:* the efficiency of a wastewater system must be considered globally (Calder, 2005). Functions of wastewater systems are presented in Table 1. The E_DA_SR model is based on a holistic approach which integrates water resources management, both the natural and the anthropic systems, and also all possible uses of the system (Mitchell, 1990). This kind of response is required to overcome the typical problems linked to fragmented water management (World Water Council, 2000).

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-*To satisfy expectations of territory's stakeholders:* using local indicators understood by every stakeholders enables them to express their expectations and thus to set up a common language encouraging dialogue.
-*To support the local utilities decisions:* managing a wastewater system requires a participative and negotiation-oriented institutional framework. The methodology E_DA_SR is developed in order to build a local model (representing the local wastewater system). This local model enables the definition of objectives related to local expectations and to the capacities of the wastewater system.
-*To guarantee a sufficient quality of service:* the model E_DA_SR is based on the Deming management method "plan-do-check-act" (Anderson *et al.*, 1994). Integrating quality insurance involves a continuous evaluation of the system in order to detect differences between provided service and quality objectives. These differences must be explained and means to reduce them need to be considered.
To answer these objectives, we propose a five steps methodology, named E_DA_SR (Evaluation, Decision, Actions, Survey and Retroaction); each step (see figure 1) is detailed in the sub-sections below.

Evaluation
To evaluate the level of provided service by the wastewater system, a global vision of the efficiency of the wastewater system is necessary. The assessment of the system's efficiency is based on indicators classified by functions. The different functions of the wastewater system are detailed in the following table:

Table 1. Functions to assess the efficiency of the wastewater system.

Functions	Comments
Protect human health	Evacuating pollution without sanitary risk.
Protect against flooding	Protecting people, structures, goods and infrastructures.
Preserve water bodies quality	Protecting the water bodies from acute and chronic pollution.
Preserve uses of water bodies	Uses include water supply, fishing, bathing, walking, etc.
Avoid the nuisances induced by the wastewater system and other risks	These nuisances include smells, noises, aesthetic pollution, collapses, traffic disruptions, etc. These nuisances may appear during the steps of construction, operation, maintenance or rehabilitation.
Guarantee an acceptable cost for the system	Two costs are distinguished: construction cost (including rehabilitation) and operation cost.
Guarantee a wastewater system easy to operate and to maintain	Drainage system should be easy to rehabilitate or to renovate and operation should be optimized.
Protect the health of the staff	Limiting the risk for the staff during their interventions (inhalation, drowning, disease, explosion, etc.)
Guarantee a social, urban and educational role	Allowing equity of service, informing on the benefits of wastewater system and educating people on the role of water.
Maximize the adaptation capacity of wastewater system	Using technologies allowing the wastewater system to adapt itself to a change of objectives or other changes, such as climate change or local changes.

The evaluation step of this methodology is similar to the methodologies suggested by Ellis *et al.* (2004) and Kennedy *et al.* (2007); however our methodology concerns the whole wastewater system, integrating the scale of the city itself instead of the scale of a specific

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urban operation. The wastewater system is characterized by the 10 functions introduced above. Each function is defined by several indicators representing the different aspects of a function. Two categories of indicators have been defined:
- A *final indicator* is an indicator which must be understood by every stakeholder in order to develop local negotiation. The *final indicators* are based on interviews with territory's stakeholders;
- An *expert indicator* is required to complete information given by *final indicator*s; for example if a *final indicator* has a long response time or needs a long period to be calibrated or monitored, an expert indicator will be considered in the mean time. This kind of indicator is also used to connect final indicators to possible actions on wastewater system.

Once indicators have been identified, the methodology allows, based on expert relations named "effect-cause relationships", to connect the various actions on the wastewater system to indicators which are representative of the results objectives. A second expertise allows to build empirical relations, named "relationships of co-evolution", estimating the efficiency of these various actions. Because it is an impossible task to locally and precisely model all phenomena, these relationships are intended to define general trends as the best available representations of the local phenomena. They are established by joining several sources of information: literature review (including standards), local expertise and field measurement campaigns. Local expertise depends on available knowledge: expertise may come from the wastewater system manager, from the services of control and surveillance, from scientists…. Field campaigns of measurements may be existing or should be planed. In fact, the methodology is mostly based on local expertise and field campaigns, and consequently the proposed indicators are not intended to be standardized or used in another location; this global approach differs from those proposed by Guérin-Schneider and Brunet (2002) or Matos *et al*. (2002).
Thus, the evaluation step includes more than a simple evaluation; it involves the realization of an empirical and simplified modelling of the wastewater system itself. An illustration related to the function "Preserve uses of water bodies", and more especially of the bathing uses, is proposed in the next section (application on the Mulhousian territory).

Decision and Action

The next steps, *decision* and *action*, can be divided as follows:
- First of all, local authorities define the objectives based on local dialogue with all stakeholders. Objectives concern the *minima* to reach for final indicators and the weights attributed to each final indicator. Based on relationships of co-evolution, values for final indicators can be translated into operational expectations for the wastewater system.
- In parallel to the definition of the objectives, means to monitor these indicators must be defined. In fact, in the scope of quality insurance management an objective cannot be use if no monitoring is possible. Monitoring is required to verify quality objectives and to calibrate/validate the empirical model, which is the major difficulty (Brelot-Wolff *et al.*, 1993). The definition of monitoring also means the establishment of expectations for measured variables, measurements protocols, measurements location, etc.
- It is then necessary to define the projects or scenarios which correspond to the required *minima*. Projects which do not fulfil these expectations are adapted, or even eliminated if no adaptation is possible.
- Between the selected projects, the project to implement is chosen using a multicriteria method based on weights and values of each function. Multicriteria analysis enables to choose the project which offers the best consistence with the overall priorities of decision-makers.

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- Finally, the chosen scenario and the associated field monitoring are set up. Scenario setup includes a calendar of actions to apply to the wastewater system, and field monitoring includes measurements locations and expected values. It is implied that both the system and the expected values to reach for are in a permanent evolution.

Survey and Retroaction

The two last steps of the E_DA_SR model aim at ensuring the quality of wastewater services. This quality of service requires a continuous link between needs and provided services. A provided service is qualified as sufficient when the needs are satisfied. For example, considering river bathing uses, the provided service corresponds to the water quality. In this case, a co-evolution relationship must be established between water quality and for example the number of days per year where bathing is possible. *Final indicators* are meant to represent these needs and are regularily measured and compared to objectives. Figure 2 shows the permanent survey of the gap between the provided service and the objectives to reach.

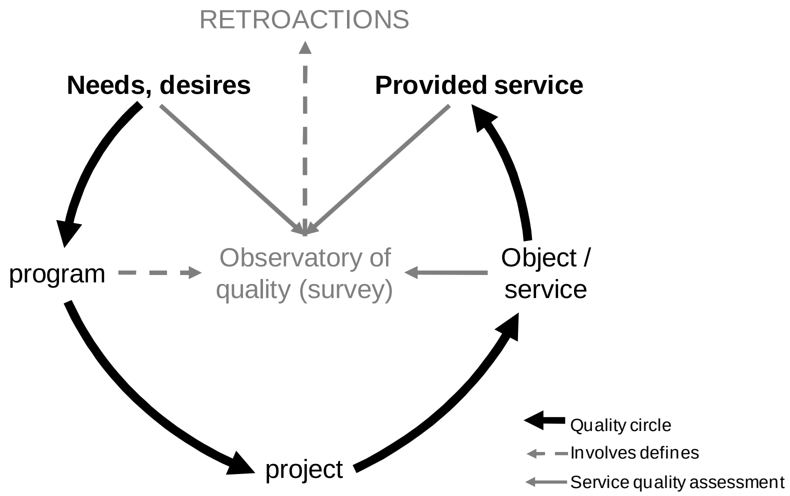

Figure 2 Survey and retroaction of the E_DA_SR model are based on the continuous improvement of the quality adapt from (Brelot, 1994).

The continuous improvement of the quality can be described as follows:

- *The needs and desires* concern all stakeholders involved in the wastewater system. A general typology was established in accordance with Jacquet-Lagrèze's works (1981), depending on each stakeholder's position and membership (association, firm, lobby, etc.). This functional typology is presented in the case study (figure 5). Stakeholders' needs may change over time, due to an external event (flooding, peak of pollution, etc) or a personal evolution of sensitivity, implicating a change in the wastewater services.
- *The program* aims at representing the specifications for the wastewater system in order to meet the needs. The program is highly related to the *Decision and Action* phase of E_DA_SR (definition of *minima* to reach and weights).
- *The project* is the answer to the program selected (considered as best available), including actions and measurement campaigns. It is also related to the *Decision and Action* phase of E_DA_SR (project selection).
- *The object or service* is the operating wastewater system itself, in constant evolution due to the implementation of new objects or new actions.
- *The provided service* is the impact of the operating of the wastewater system. Impacts concern all stakeholders and the natural environment. The gap between the needs and the service provided by the system corresponds to the quality.
- *The monitoring of quality* is defined in the program and must assess continuously if the wastewater system respects the program and moreover that the provided service responds to

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stakeholders' needs. In case of an increasing negative gap – a negative derive - , retroactions are required.

- *The Retroaction* step concerns all the possible correction actions:
    - First of all, if an exceptional stakeholder (natural or human) appeared, the time estimated to reach the objective could be reviewed; or if the exceptional stakeholder has been given irreversible damages, program must be reviewed;
    - Secondly, if necessary effect-cause relationships are analyzed and corrected or modified. Corrections may concern modification of trends or modification of actions related to the wastewater system (for example, a source of suspended solid which has been underestimated or omitted);
    - Thirdly, final indicators are checked: if they appear not to be relevant to assess the provided service, a new negotiation with all stakeholders will be proposed;
    - Finally, whether previous actions have been applied or not, program must be reviewed and then the project, including actions and measurement campaigns, must be adapted. This will be facilitated if chosen technologies have sufficient adaptation capacities. Sustainable management involves that local authorities promote the function "Guarantee a capacity of adaptation of the wastewater system".

In the case of a positive derive (service provided exceed the needs), if no exceptional stakeholder appeared, final indicators and effect-cause relationships may be improved if necessary.

The E_DA_SR model is therefore a complete methodological support allowing the respect of quality insurance in the field of wastewater system management. The following section illustrates an application of the *Evaluation* step of the model for the Mulhousian territory.

APPLICATION ON THE MULHOUSIAN TERRITORY

Presentation of the case study

This methodology is applied on the SIVOM (Intermunicipal Union with multiple vocations) of the Mulhousian agglomeration (Alsace, France) where a close collaboration exists between the SIVOM, the "Lyonnaise Des Eaux" (Mulhousian manager) and 23 local stakeholders. The Mulhousian SIVOM consists in the association of 16 administrative districts, and manages 750 kilometres of wastewater networks (Figure 3).

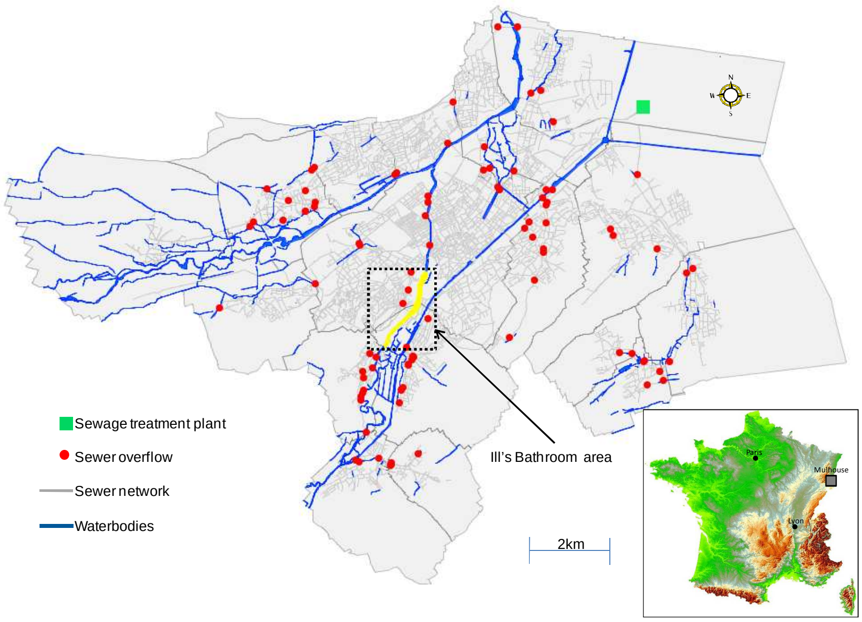

Figure 3 SIVOM of the mulhousian agglomeration: localisation (Alsace, France) and description of the watewater system.

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This case study only concerns the function "Preserve uses of water bodies" as defined by the Rhone-Mediterranean-Corsica Water Agency (1998) and deals with the river bathing uses in a specific area called "Ill's Bathroom area" (see figure 3).

Setting up the function "Preserve uses of water bodies"
Effect-cause relationships connect the *final indicator* to possible actions on the wastewater system, as shown in Figure 4. These actions aim at reducing the *limiting factors*, which are the local origins limiting the river bathing uses.

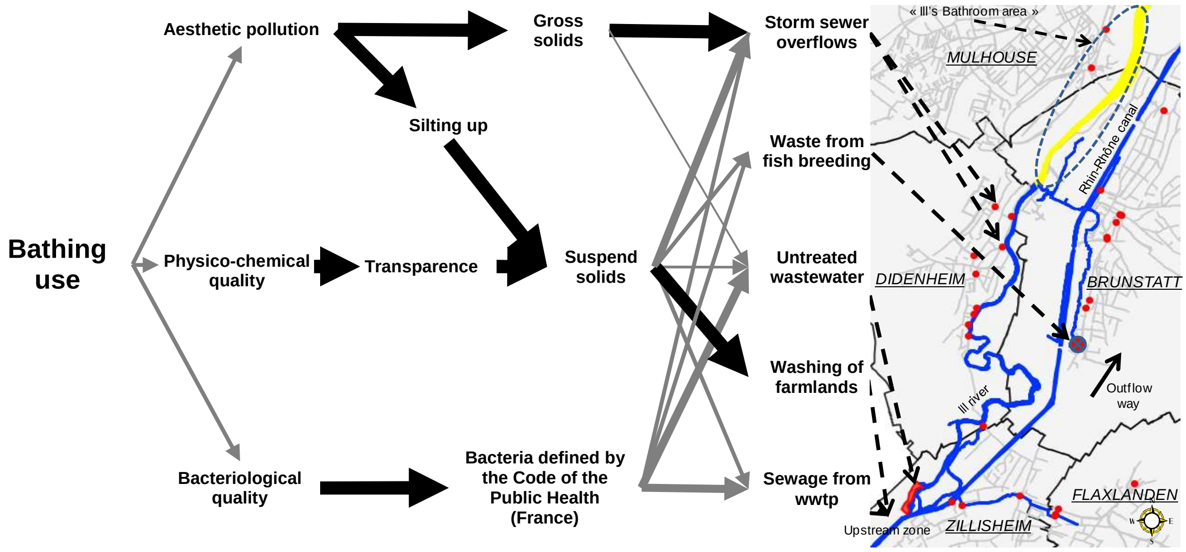

Figure 4 Effect-cause relationships for the bathing use on the "Ill's Bathroom area" on the SIVOM on the mulhousian agglomeration (Alsace, France).

According to our local survey, bathing use appears to be directly dependent on aesthetic pollution, physico-chemical quality and bacteriological quality of water. These three aspects must be fulfilled in order to guarantee bathing use. Three kinds of arrows are being considered: the size of the arrow represents the importance of the source and the influence of the limiting factor on the final indicator. Concerning the studied area, bathing use is limited by five upstream sources: the storm sewer overflows, the organic waste rejected by the fish breeding farms, untreated wastewater directly rejected into the river, washing of farmlands and sewage rejected by the wastewater treatment plant.
Each arrow defines empirical relationships of co-evolution, based on experts opinion, literature review and field measurements. For instance, Figure 5 presents the relation between gross solids pollution (one of the final indicators selected to measure aesthetic pollution in the Ill's bathroom area), and the number of combined sewer overflows equipped with a screen (which is one possible action on the wastewater system).

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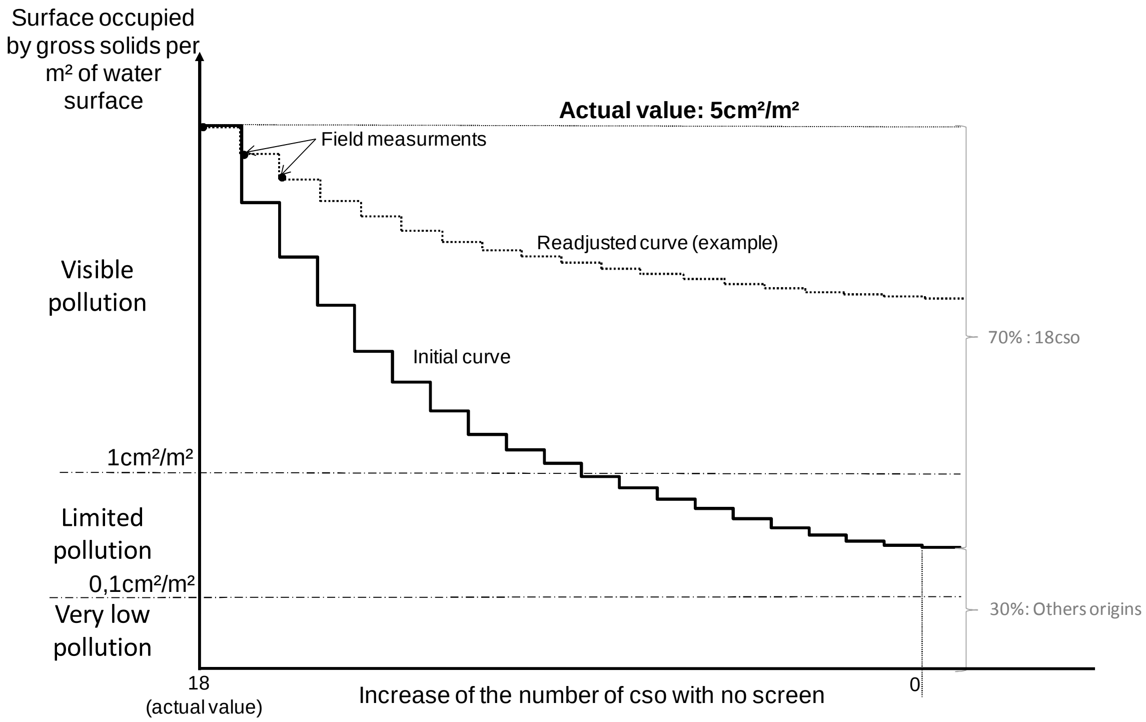

Figure 5 Relationship of co-evolution between gross solids (aesthetic pollution) and the number of combined sewer overflows equipped with a screen. Only gross solids superior to 1 cm² are taken into account.

Gross solids pollution is quantified by measuring the surface occupied by gross solids (superior to 1 cm²) per m² of water surface. This unit has been proposed by (Krejci *et al.*, 2005) and corresponds to a visual disturbing effect. The present level of gross solids pollution is 5 cm²/m² of water surface, which is unacceptable to guarantee bathing use. The bathing use is authorised when the gross solids pollution is under 1cm²/m² (limited pollution). Experts estimated that 70% of the gross solids accumulated in Ill's bathing area come from combined sewer overflows and 30 % come from other sources. The initial curve is an estimation of the actual effect-cause relationship: it implies that if all combined sewer overflows are equipped with screens, aesthetic pollution (due to CSO) should be between 1 cm²/m² and 0.1 cm²/m² of water surface. The readjusted curve corresponds to a possible correction depending on measurement campaigns (*Survey* and *Retroaction* phases).

Other effect-cause relationships are not represented in this paper. They also may evolve with measurement campaigns. Co-evolution models allow the determination of actions that are the most efficient. For example, adding screens to the first 3 CSO (16 % of all CSO) will eliminate 40 % of gross solids pollution. Also, if the 10 first CSO are equipped with a screen, visible pollution should be below 1 cm²/m². As said before, this forecast is based on an estimation trend (figure 5): measurement campaigns and quality of service monitoring will improve this estimation.

The most difficult part of this work is the establishment of empirical relationships of co-evolution. Indeed, only few stakeholders have a general vision, and there is also general lack of information. The most important difficulty of our system lies on our ability to manage information (Shuping *et al.*, 2006). The E_DA_SR methodology completes this objective by accompanying the decision making process during the continuous assessment of quality of service. The *Retroaction* step is of major importance when dealing with incomplete information.

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CONCLUSIONS

The E_DA_SR methodology aims at supporting decision makers. It implicates five steps: Evaluation, Decision, Actions, Survey and Retroaction. The local utilities decision process should respond to the monitoring objectives:

- evaluate the wastewater system through all its different functions
- integrate and satisfy expectations of territory's stakeholders
- guarantee a sufficient quality of service
- consider local specificities
- include reactivity in the decisional process.

The main elements of this methodology are the effect-cause relationships construction and the *retroaction* phase. Effect-cause relationships offer a consistent trend based on local expertise: there are the best representations of the local phenomena. By regularly monitoring service quality, it will be possible to correct or adapt these trends.
In the case of the Mulhouse study, the *evaluation* step for the functions "Protect the uses on the water bodies" and "Preserve waterbodies quality" are nearly finished. The evaluation of others functions is in progress. The next step in the E_DA_SR model, the *decision* phase, will be beginning soon.
This methodology is reproducible in other locations: local specificities will conduct to choose other final indicators and to construct different effect-cause relationships. Furthermore, this methodology can be adapted to other domains, where decision making is required and where the system to manage is complex to understand and represent.

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