Guidelines for on-line monitoring of wastewater and stormwater quality

A. Llopso-Mascaró1*, A. Gil1, J. Cros2, F. Alarcón3

1 Exploitation and Environmental Control Service, CLABSA, Acer 16, 08038 Barcelona, Spain
2 I+D Department, ADASA Sistemas, José Agustín Goytisolo 30-32, 08908, L’Hospitalet de Llobregat, Spain
3 Telecontrol Department, EMUASA, Plaza Circular 9, 30009, Murcia, Spain

*Corresponding author; e-mail annall@clabsa.es

ABSTRACT
Within the framework of the advanced management of sewer system networks, water quality monitoring is increasingly required. Wastewater and stormwater quality knowledge is a basic requirement for reaching the standards of asset serviceability and assessing the environmental impacts related to drainage systems. In that sense, continuous on-line quality monitoring can be a useful tool to implement pollution load reduction policies, to manage pollution incidents efficiently, to control industrial spills to the network or to protect WWTP (Waste Water Treatment Plants) and network facilities from pollution events.

Nevertheless, the end-users are often at a loss when discussing the available options in the market for continuous quality monitoring in sewer systems. In this context clear and reliable guidelines are presented for real time water quality monitoring in sewerage to assess the design and implementation process of water quality control for standard, affordable, maintainable and technically valid continuous wastewater and stormwater quality stations. This help method is especially oriented to provide with useful solutions to each specific case that can be given. The guidelines are conceived on the development of an easy consultation and user-friendly aid-decision-scheme.

KEYWORDS
Monitoring; on-line; quality sensor; quality station; sewerage

INTRODUCTION
Increasingly restrictive water legislation requires more rigorous and effective controls of water bodies. In this sense, the Water Framework European Directive is a good example. It introduces a new concept of water survey, from a static view represented by discontinuous sampling of biological quality elements, to a dynamic view of water control represented by continuous records of quality variables (Fleichmann, 2007). Even though the directive does not introduce innovative devices for quality control like on-line measurements, automated technologies contribute to improve water monitoring in terms of the new approach on water surveillance.
Tied to the upcoming water legislation, the fact that the wastewater and stormwater impact on the receiving bodies could be very harmful, and that the uncontrolled discharges from ancillaries within the sewer network (pumping stations, WWTP, etc.) could severely damage these facilities, it forces upon sewerage managers a need to perform a strict control of their working field. Water quality monitoring is becoming increasingly important in the advance management of sewer system networks.

Recent developments show that continuous and on-line quality monitoring can be an useful tool to provide valuable information for detecting pollution events (Pouet et al., 2006) that otherwise (conventional samplings) would go unnoticed. Thus the time response in front of that kind of incidents is improved.

Moreover, on-line monitoring allows the implementation of pollution load reduction policies (Fleichmann, 2007) improving the control on industrial discharges to the network (Thomas and Pouet, 2006a) and as a consequence decreasing total polluted load, protecting WWTP and network facilities. It also can prevent the environmental impacts of pollution events.

However, in the meantime to recognise the availability of possibilities in the market in order to undertake a continuous monitoring quality survey of the sewer network, the sewerage managers (end-users) are often at a loss when deciding measurement options (attempt to quality stations modalities), real time measurable quality parameters (sensors or analysers) or even the requirements and considerations to be accounted for in a project of these characteristics. This could be given due to the ignorance or the lack of clear information about the matter and to the technical constraints on the sewerage environment.

Therefore there is a ‘gap’ in the available information for the on-line wastewater and stormwater quality monitoring installations implementation. To fill this lack of information a proposal of clear guidelines in reference to the establishment of a quality monitoring system has been developed. A practical, useful and easy managing help method has been achieved, which can be used by the end-users as a base tool in the first stages of the decision process to implement a wastewater quality monitoring control system.

**METHODOLOGY**

In order to ensure reliable guidelines a sequential process has been taken into account. First of all a rigorous state of the art monitoring implementation has been carried out, followed by the definition of the general specifications about all the components and aspects of a quality station installation. And finally a thorough cost-benefit analysis about the different options of implementation is achieved. The information collected, analysed and developed, leads to the easy to use and useful guidelines for on-line water quality monitoring.
Figure 1. Methodological diagram

State of the art
In the state of the art process, elaborate questionnaires are fulfilled by wastewater managers, consulting companies and suppliers. The purpose of these questionnaires is to obtain a real and first-hand knowledge of the implementation degree of wastewater quality monitoring and of the requirements and real interests of the end-users. Moreover additional information is collected by technical visits.

Once all the information available is compiled, a general view about the current and future needs is achieved and a first approach to best practice in continuous and real time wastewater monitoring is made. The general concepts regarding to wastewater quality characterisation and on-line monitoring have been supported and defined through a bibliographic consultation (Rieger and Vanrolleghem, 2007; Batlle, 2006, Thomas and Pouet, 2006b; Serramia, 2004; Bertrand-Krajewski et al., 2000; Harmancioglu et al., 1994; for example).

Through the survey course a broad agreement from all the participants about the need of wastewater quality monitoring is reached. Similar level of interest in the different goals are pursued in a real time control point; WWTP protection and process control, network discharges control, industrial spills control and finally, received bodies waters control.

A profile of a wastewater and stormwater quality point of control has been built based on the information provided by the questionnaires compiled. The profile has been reached through a
detailed analysis of the quality stations characteristics that covers more than 250 control points. The general considerations are summarized as:

- Several pursued objectives at the same time at the same quality station.
- Several locations, mainly WWTP and sewers (90% of sewers requested are combined), followed, in a distance, by industrial manholes, detention tanks, pumping stations and receiving waters.
- Mobile stations are commonly used.
- Sensors are usually installed inside the pipe (in-flow measurements) than pumping collection systems.
- On-line measured quality parameters by sensors or analysers in order of importance:
  - First group: pH, conductivity, temperature and turbidity, with a noticeable satisfaction level.
  - Second group: SAK, as a measure of organic matter.
  - Third group: ORP, DO, nutrients and others.
- High presence of automatic samplers, sometimes even replacing the sensors.
- Maintenance requirements: half of the answers declare that the frequency of maintenance is carried out once or more in a week. Only 10% of answers can do the maintenance monthly. Wastewater managers are concerned about the maintenance costs (low satisfaction degree).
- Data acquisition and management: full agreement about the main point: reliability. The data acquisition is defined by periods of time with high heterogeneity in the communication systems and the software involved. Data management usually follows simple procedures with a lack of thorough data analysis methodology.

The main needs detected through all the state of the art process are first of all clear and reliable design specifications (the gap is again confirmed), secondly, investment and maintenance costs decrease, thirdly, improvement of reliability measures and finally elaborate information management procedures.

Once the needs are detected the present work tries to determine the specifications to guide on the design of the quality stations, to minimize the tasks of maintenance and to obtain valid data for the achievement of a water quality control system directly related to offer modern environmental control services.

**General specifications**

The following methodology is based on the critical points to take into account when implementing a monitoring quality station.

*General concepts in water sewerage monitoring.* Water quality characterisation from the sewer system is an essential requirement for achieving a good knowledge of the operation network. The point of measure choice in a basin is important to be considered with attention in terms of the mobilized pollution that characterized it (in dry periods or raining periods, deepening on the measurement purpose). Therefore, the most common contaminants in the basin might be kept in mind according to their origin (domestic, industrial, agriculture and surface run-off) to approach the sewer network monitoring and the quality parameters to be measured.

Moreover, the measured quality parameters and how they should be sampled depend on the objective of the collection (supposed usefulness of data collected). The installation of the proper water quality devices depend on the survey requirements. Basically the equipment should at least
register flow and pollution data (to obtain pollutograph and hidrograph or to attain mass balance studies). In addition, the rain data can be useful in the case of analysing stormwater and combined networks.

**On-line water quality sensors and analysers.** The water quality monitoring systems in urban drainage is growing up. This aggressive environment involves higher difficulties of implementation than other environments like drinking or surface waters. Due to the fact that quality measurement in wastewater requires the installation of rough and maintainable devices, the sensors and analyzers in the market are limited. In this context, complete requirements are developed regarding the quality parameters to control through continuous and real time monitoring (Bertrand-Krajewski *et al.*, 2000; Thomas and Pouet, 2006b), keeping in mind the general specifications of each quality parameter (measurement principle, usefulness, controllable process, etc.), as well as the available measurement technologies in wastewater.

It is important to remark that the main function of continuous monitoring quality devices is not to offer an exhaustive characterization of water, but show tendencies or behaviour standards (Fleichmann, 2007). This is due to the limited number of wastewater on-line monitoring quality sensors, high interferences and variability in the measurement in an environment as aggressive as the sewerage one.

Some quality parameters measurable by on-line sensors that until now have produced acceptable results in direct measure in sewer system, without the necessity of installing a complicated hydraulic track, are the following ones: temperature, pH, electrical conductance, redox potential (ORP), turbidity, dissolved oxygen (DO) and organic matter (SAK: Spectral Absorption Coefficient for the estimation of BOD, COD and TOC).

There are also appealing automatic analyser equipments for a good characterisation of the water but which complexity, investment cost and maintenance, only justifies their implantation in very determined cases. Some of the most commonly used ones are nitrogen analysers like ammonium (NH₄⁺), nitrate (NO₃⁻) and nitrite (NO₂⁻), phosphorus analysers like phosphates (PO₄³⁻) or hydrocarbons and oils analysers.

![Figure 2](image.png)

*Figure 2.* Technical forms. Quality parameter sensor form (conductivity) on the left; auxiliary device form (automatic sampler) in the middle; and quality station typology form (out flow measuring channel station - high flow pumping in flow measuring station) on the right.
Auxiliary facilities. Taking into consideration that the number of feasible on-line quality sensors in wastewater and stormwater is limited, and that their main function is to show tendencies, not to obtain an exhaustive water quality characterization, automatic samplers are usually installed (Thomas, 2006). Thus, in the case of an unusual detection in the behaviour patterns, an automatic sample could be taken to the laboratory complementing the on-line data monitoring devices.

Locations. Another key point in the quality stations installation in sewer system is the control point locations (Strobl et al., 2006), which depend on the network configuration, the availability of sites to install the equipments, the purpose of the measurement, etc. In that sense, some possible sites of wastewater and stormwater quality control stations would be located in:
- Main sewer network (non-entry sewer, entry sewer or interceptor)
- Sewer network facilities (detention tanks, pumping stations, sewer overflows to the receiving bodies)
- WWTP (entrance and exit)
- Industries (sewer manhole at the end of the industrial process or in sewer junction point of industrial parks, in both cases upstream to the connection to the municipal network).

Quality stations typologies. The general specifications culminate in the wastewater on-line quality control station type definition. Considering that standard models of automatic and monitored quality stations do not exist, and depending on the objectives and requirements of the particular cases (quality parameters to monitor, location, flow characteristics, etc.) the design of the quality station and the devices to be installed must significantly vary. In these terms, requirements and considerations are detailed for the different types of quality stations existing nowadays (task supported by pilot tests).

Table 1. Water quality stations typologies taken into account

<table>
<thead>
<tr>
<th>Water quality stations typologies</th>
<th>In flow</th>
<th>Type 1.-In flow measuring station</th>
<th>a. No energy autonomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td></td>
<td></td>
<td>b. Energy autonomy</td>
</tr>
<tr>
<td>Out flow</td>
<td>Type 2.-Out flow measuring channel station - high flow pumping</td>
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<td></td>
<td>Type 3.-Out flow measuring compact station - low flow pumping</td>
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<tr>
<td>Mobile</td>
<td>Type 4.- Out flow measuring modular station</td>
<td>a. Low flow pumping</td>
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<td></td>
<td>Type 5.-Mobile station (energy autonomy)</td>
<td>b. High flow pumping</td>
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</tbody>
</table>
Figure 3. Wastewater and stormwater quality monitoring stations. ‘Type 3 - Out flow measuring compact station - low flow pumping’ on the left; ‘Type 1- In flow measuring station’ in the middle; and ‘Type 5 - Mobile station (energy autonomy)’ on the right.

Cost-benefit analysis
An exhaustive cost analysis is conceived for each quality station modality defined, based in all the different elements that compose the station. To achieve this purpose, real quality stations are analyzed and suppliers are consulted to determine costs averages for each of the different elements that compose a quality station. In this way, the indicative costs of the different options of quality station typologies are stipulated: the more complex a quality station is, the higher are the associated costs.

With all the information collected and developed (throughout state of the art, specifications and cost analysis) a comparative evaluation of the different quality station modalities is provided, looking at attentively the budget, technical requirements and determining factors such as maintenance, resulting in an elaborated cost-benefit analysis.

RESULTS AND DISCUSSION: GUIDELINES
It has been developed an aid-decision-scheme. This scheme is conceived as guidelines specifically focused to facilitate the decision-making when is required the implementation of a continuous wastewater and stormwater quality monitoring system in sewer network.

The scheme pretends to be an useful tool for those managers of sewer networks, as well as for engineers or advisers which focus their work in the wastewater and stormwater area, who try to install quality monitoring stations in sewers or in some of sewer networks facilities associated.

These guidelines provides help mainly to tackle the following aspects:
- Recommendation on which typology of quality station to install according to a set of criteria.
- Determination on which elements to take into account to approach a project of wastewater quality station.
- Approximation on the costs associated to a reliable wastewater quality station.

The aid-decision-scheme is configured in three interactive consultant forms:
The form 1, ‘Quality station implementation’ according on the selection by the user of a few pre-established criteria that define its particular case, will provide, as a result, the recommendation of the most suitable quality station typology option, as well as the first approximation to the global cost of the suggested quality station. Those criteria taken into account are distinguishing and defining elements of the control point with the goal to determine objectively the quality station modality. These criteria are: the purpose of measurement, station site requirements, site availability for the installation of the equipment that composes the station, available auxiliary services, flow sampling point and devices of measure to be installed.

The form 2, ‘Quality station construction’, allows to set up a quality station with different elements depending on the needs of the end-user. Afterwards shows an specific approximation budget of the choice of the whole elements selected that conform the particular quality station.

And finally the form 3, ‘Specifications’, allows quick queries of different specifications forms (quality stations typologies forms, quality parameters sensors and analysers forms, and automatic samplers forms).

CONCLUSIONS
Quality stations are increasingly required to achieve an advanced management of urban drainage, however the lack of clear information about continuous wastewater and stormwater quality monitoring puts the managers (end-users) at a loss when discussing the available options.

The presented guidelines fill this need by means of the development of a simple aid-decision-scheme in the process of implantation of wastewater quality monitoring stations. Specifically it provides help to tackle the recommendation on the typology of quality station available to be installed according to a set of criteria, the determination on the elements to take into account to approach a project of wastewater quality station and the approximation on the costs associated to a reliable wastewater quality station.
Furthermore, it solves most of the technical constraints on sewerage quality devices. In this way, it allows an easy consultation of technical forms about quality parameters (automatic sensors and analysers), auxiliary devices and quality stations typologies, thus becoming a reference for the assembly of an affordable, maintainable and technically valid wastewater and stormwater on-line quality station, to every given case.

Therefore a practical, useful and easy managing help method has been achieved, which can be used by the sewerage managers as a base tool in the first stages in the decision process to implement a wastewater quality monitoring control system.

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