Practical aspects, experiences and strategies by using UV/VIS sensors for long-term sewer monitoring

Günter GRUBER [1] and Jean-Luc BERTRAND-KRAJEWSKI [2], Jérôme DE BENEDITIS [2], Martin HOCHEDLINGER [1], Wolfgang LETTL [3]

[1] *Institute of Urban Water Management and Landscape Water Engineering, Graz University of Technology, Stremayrgasse 10/I, A-8010 Graz, Austria*
[2] *URGC, INSA de Lyon, 34 avenue des Arts, 69621 Villeurbanne cedex, France*
[3] *s::can Messtechnik GmbH, Herminengasse 10, A-1020 Vienna, Austria (www.s-can.at)*

ABSTRACT
An explosion-proof UV/VIS sensor has been available even in sewer systems for some years for simultaneous measurement of COD_{eq}, filtered COD_{eq}, TSS_{eq} and $nitrate_{eq}$. This sensor allows in-situ real-time measurements with no sampling, no sample preparation and no reagents. Three case studies are presented in this paper using this UV/VIS sensor for long-term sewer monitoring issues whereby two different installation strategies are applied. The pros and cons of both different installation solutions are compared and different calibration results during dry and wet weather conditions and long-term operational sewer monitoring experiences are given in this paper.

KEYWORDS
sewer process, pollutant transport, on-line monitoring, sewer monitoring, data collection, UV/VIS spectrometer, CSO control

INTRODUCTION
Knowledge of pollutant concentrations and loads transferred in sewer systems is of increasing importance for many purposes: evaluation of their functioning and performance, real time control, the conception and planning of new systems and the rehabilitation of existing sewers, modelling, etc. Traditionally, this type of knowledge is obtained by means of measurement campaigns using automatic samplers. Samples are then analysed according to internationally recognised standards. This approach has provided very valuable information for research and operation in many sewer systems during the last decades (see e.g. Brombach and Fuchs 2003). However it suffers from many limitations and drawbacks: short duration campaigns (typically some days up to some months), limited information obtained at insufficient time intervals which does not allow to evaluate the full dynamics and variability of flow and pollutant concentrations, high proportional costs, heavy maintenance, etc. There are other long-known limitations to this approach such as sampling errors and errors due to sample conservation, transport and preparation (see e.g. Bertrand-Krajewski *et al.*, 2003).

An alternative solution involves using on-line sensors which require less maintenance (at least theoretically over the long term) and are able to deliver a continuous time series of data collected at short time steps ranging from 1 to 5 minutes. Such sensors have been used in wastewater treatment plants for more than a decade but despite their promising possibilities (e.g. dynamic data from sewer systems are necessary to calibrate and validate simulation models and to find and optimize strategies to manage and minimize pollution discharges into receiving waters) their application in sewer systems has, up to now been limited for many reasons: difficult functioning conditions, lack of reliability, fast fouling, difficult access for maintenance, etc. Until recently, turbidimeters were almost the only type of sensor used more or less regularly in sewer systems. However, within the last few years new sensors have become available which are not only potentially applicable in sewer systems, but may also have other important applications in the field of integrated water quality monitoring. Scheer and Schilling (2003) give an overview regarding on-line measurements in sewer systems and describe the possibilities and particular difficulties of measuring combined sewage quality in sewers. Nevertheless, a vast number of boundary conditions (sewer inclination, stormwater flow, duration of dry weather periods, deposition and sediment erosion etc.) have an effect on the concentration of the discharged pollutants and a large number of practical problems still have to be solved before continuous monitoring in sewer networks can be successful under reasonable operational and economic conditions.

A research project conducted in Austria focused on the development, installation and operation of an integrated water quality network applicable for sewer networks to surface water. As one part of this network, two online sewer monitoring stations were installed at combined sewer overflow structures (CSO) – one in Graz and another one in Vienna – to quantify pollution concentrations (COD_{eq}, TSS_{eq}, NH4-N, pH, temperature) and loads in the combined sewers and into the receiving water. The monitoring station in Graz has now been operating continuously since October 2002 (Gruber *et al.*, 2004) and the one in Vienna began working in November 2004. Five sewer systems monitoring stations have been installed since 2001 in four different catchments in the city of Lyon, France, within the long-term OTHU (Field Observatory for Urban Drainage) research project, equipped with on-line sensors to measure pH, conductivity, temperature and turbidity (Bertrand-Krajewski *et al.* 2000). In the Ecully catchment, an additional on-line COD analyser and a single wavelength UV sensor has been installed.

MATERIALS AND METHODS

UV-VIS submersible spectrometer

A submersible UV/VIS s::can® spectrometer for in-situ real-time measurements is used in Graz, Ecully and Vienna. It is a spectrometric probe 44 mm in diameter and about 0.6 m length which can be installed directly in the process. It requires no sampling, no sample preparation and no reagents. This 2-beam 256 pixel UV/VIS spectrometer functions in the UV/VIS range (200–750 nm), with a xenon lamp as a light source for simultaneous measurement of COD_{eq}, filtered COD_{eq}, TSS_{eq} and $nitrate_{eq}$. A single measurement typically takes about 15 seconds. The measurement path length can be adjusted from 2 – 100 mm. This opens a wide range of applications from ultra pure waters (DOC < 10 µg/L) up to concentrated wastewaters with a COD of several 1,000 mg/L. A path length of 5 mm is usually used for wastewater applications. The instrument is equipped with an auto cleaning system using pressurised air (3 – 5 bar).

Installation requirements

Sensor installation can be considered as part of the measurement method, since if is of utmost importance that the sensor is located at a representative sampling spot under all conditions occurring at the measurement location. For measurements in sewer networks this means that the issue of highly varying water level and flow velocity has to be addressed. As e.g. for the intake of automatic samplers, this question is crucial but very difficult to answer in a fully satisfactory way. This topic is not part of this paper but should be analysed with great care for any monitoring project.

In the case studies presented in this paper, two solutions have been adopted for sensor installation. The first solution consists of locating the sensor within the sewer structure itself, such as floating under a pontoon attached to the chamber walls and to the ceiling by steel ropes. With such an installation in the CSO structure in Graz, the sensor is always located in the top water layer and subsequently measures the water quality which is discharged at the overflow weir during storm flow conditions (see Figure 1).

The second solution, used in Ecully and Vienna, consists of installing the sensor in a by-pass measuring flume located in a shelter outside the sewer system in Lyon and in a large pumping station hall in Vienna. A pump (a 1 L/s and 1 m/s peristaltic pump in Ecully, a 2 L/s and 1 m/s submersible shredding pump in Vienna) is used to pump the wastewater from the sewer into the measuring flume (see Figure 2). The peristaltic pump has two advantages: i) the wastewater matrix is to a large extent unaffected whereas the samples provided with a shredding pump are changed by using shredding knives to pump the wastewater blockage free, and ii) the pump is used periodically in the reverse direction to cleanse the sampling tube, thus avoiding blockages. However, peristaltic pumps are limited to a maximum suction head of approximately 8-9 m while shredding pumps can provide samples to higher levels only depending on their Q/H curves. Other aspects about installation alternatives are summarised in Table 1.

Table 1 Pros and cons of different sensor installation alternatives for sewer monitoring

Installation Type	Floating Installation	By-pass Installation
long term investigations	**suitable** • spot sample direct in the sewer system • no sample delay • no sample supply and no pump necessary • measurement condition unstable and subject to large range variations • lower energy consumption • only pontoon has to be maintained • optical path must be cleaned regularly (in the sewer) • accessibility to sewer system necessary • drilling holes to sewer necessary (cable, hose, cleaning water) • compressor for automatic cleaning appliance recommended • automatic cleaning appliance has to be controlled regularly (difficult in the sewer) • shelter recommended • danger of damage existing • no biofouling	**suitable** • spot intake direct in the sewer system • sample delay (some seconds, which can be accounted for e.g. in the data logger) • sample supply and pump necessary • measurement condition very stable if the sample supply is working reliably (pump reliability is crucial) • higher energy consumption • intake tube spot and measuring flow through flume have to be maintained • optical path must be cleaned regularly (in the shelter) • accessibility to sewer system necessary (but less frequently) • drilling holes to sewer necessary (only for pumping hose) • compressor for automatic cleaning appliance recommended • automatic cleaning appliance has to be controlled regularly (easy in the shelter) • shelter necessary • danger of damage low • biofouling in the pumping hose
short term investigations	**suitable** • no pump and no shelter necessary • automatic cleaning appliance by compressed-air bottles	**not recommended** • shelter, pump and automatic cleaning appliance necessary

Figure 1 Behaviour of the swimming pontoon under varying flow conditions (dry weather flow, storm water flow with overflow and extreme overflow)

Figure 2 Bypass installations in Ecully with a peristaltic pump (two left photos) and in Vienna with a submersible shredding pump (two right photos) for wastewater supply to measurement flumes containing the sensors

RESULTS AND OPERATIONAL EXPERIENCES

Spectrometer calibration

A so-called global calibration for typical municipal wastewater is provided by the manufacturer as the default configuration for the UV/VIS spectrometer (Langergraber *et al.*, 2003). Due to the different composition of wastewaters, e.g. with significant industrial contributions, a second calibration step (local calibration) is recommended to enhance the measurement quality. For this purpose, laboratory analyses are correlated with in-situ measurements for the actual wastewater. The local calibration is able to account for specific wastewater compositions and possible matrix effects. Spectra of measured absorbencies are transformed in equivalent concentrations (C_{eq}) of various substances (TSS, COD, etc.) using statistical regression models expressed by:

$$C_{eq} = \sum_{i=1}^{n} (\lambda_i \cdot a_i) + K$$

with n the number n of used wavelength λ_i depending on the measuring system and the specific local wastewater matrix. The weighing factors a_i are determined after fitting to laboratory analyses. The constant offset K can be used for the specific wastewater matrix adjustment over all single wavelengths. Every calibration model results from a compromise between generality and robustness. Usually, particularities in calibration data can be better reproduced by increasing the value of n. Therefore, minor deviations between calculated equivalence values and laboratory values can be determined. On the other hand, with a large number n, the probability of a major changing of the weighing factor for a different wastewater matrix increases.

Initially, both spectrometers in Graz and in Ecully were operated using the manufacturer's default calibration parameters, which only gives a rough correlation between the measured absorption and the parameters of interest. This global calibration resulted in underestimations of the spectrometer values during the daylight hours and in overestimations during the night hours during dry weather flow at both measurement sites. Local calibration was then carried out. An example of the results for TSS_{eq} in Ecully is given in Figure 3: the equivalent concentration is correctly estimated by the sensor. Successive calibrations (not shown here) appeared as stable in time. Figure 4 shows, for a 24-hour sampling campaign in Graz for the COD_{eq} parameter, the comparison between the manufacturer global calibration curve named "influentV01t" and a better local calibration curve named "gruber02V010".

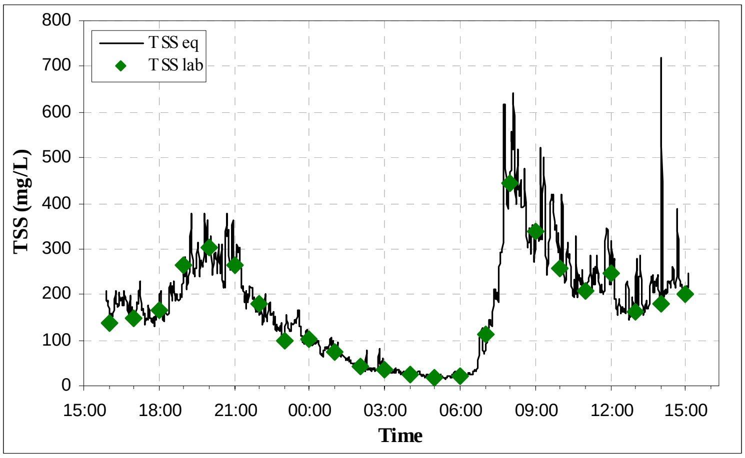

Figure 3 Equivalent TSS concentration and laboratory TSS concentration after local calibration in Ecully (dry weather 24h period in July 2004).

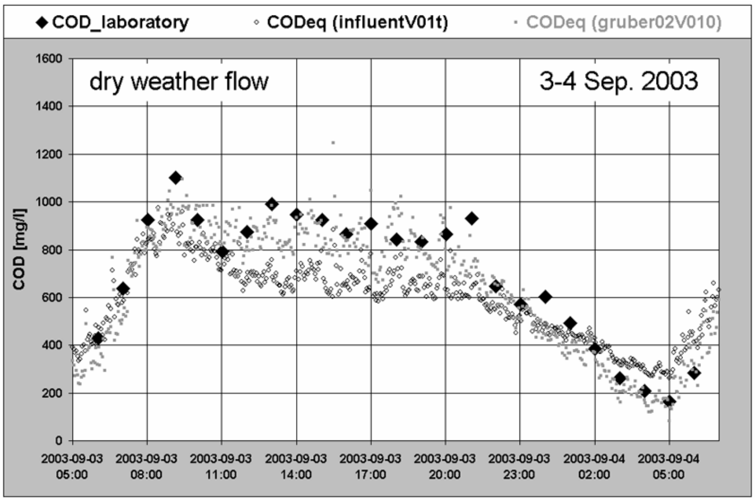

Figure 4 Comparison between the global calibration of the manufacturer (influentV01t) and a new calibration set locally adjusted to the wastewater matrix in Graz (gruber02V010) for COD

However, the "on-line" local calibration features included in the sensor software may sometimes be insufficient to reach the required level of accuracy, especially in the case of a strong matrix effect leading to both an underestimation of high concentration during daily peaks and an overestimation of low concentrations during night periods. Therefore an adapted "off-line" local calibration has been developed in Ecully as a linear combination of two independent calibrations: one for peaks values and one for low values. The results are illustrated in Figure 5.

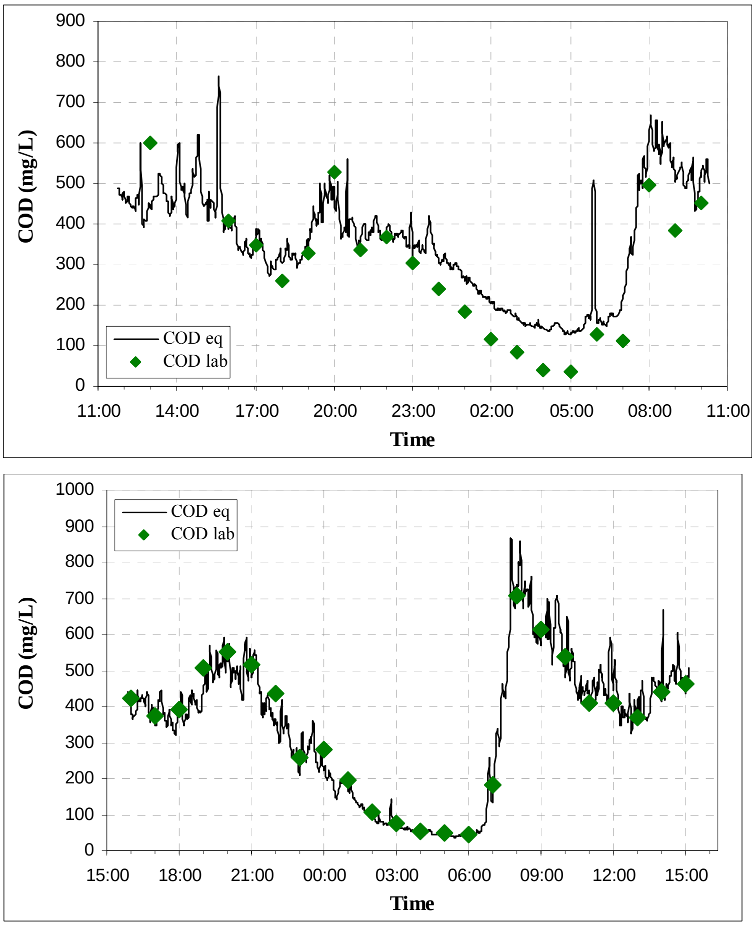

Figure 5 Best possible “on-line” calibration in July 2004 (top) and adapted “off-line” local calibration in September 2004 (bottom), both during dry weather in Ecully.

Other aspects should also be accounted for during wet weather. The global calibration always resulted in underestimations of the spectrometer values at both measurement sites during dry weather flow conditions for the low concentration range. However, this was not generally observed during wet weather flow for similar low concentration ranges where the global calibration accorded quite well with taken lab samples.

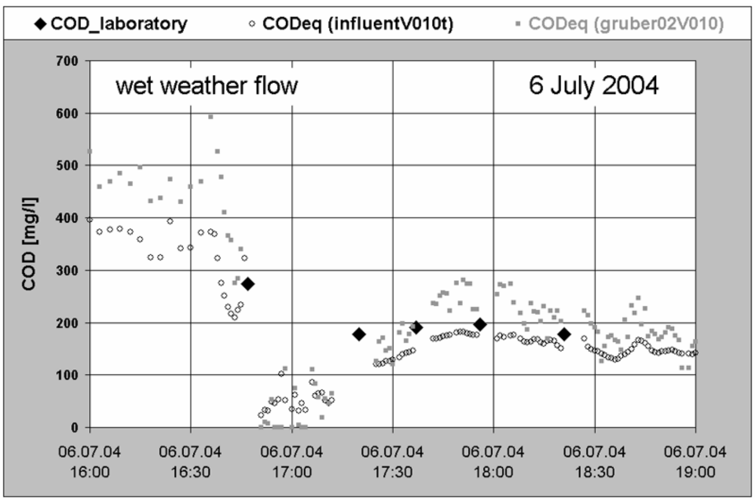

Figure 6 Comparison between the global calibration of the manufacturer (influentV01t), a new local calibration (gruber02V010) and spot lab samples during wet weather condition in Graz

Figure 6 shows the comparison between the global calibration (named influentV01t) and the dry weather locally adjusted calibration (named gruber02V010) applied during wet weather conditions in Graz. As the stormwater composition varies significantly depending on the "history" of the storm event, it is very likely that the description of one particular event may lead to erroneous results (Stumwöhrer *et al*., 2003). E.g., a stormwater flow after a longer dry weather period with a large amount of deposits which are suddenly scoured will likely have a higher pollutant load than a stormwater flow after a long rainy period.

Operational Experiences
The monitoring station in Graz has now been operating continuously since October 2002. Initial clogging problems have been solved by an appropriate use of moveable steel ropes, deflection pulleys and steel baffles. The spectrometer and the bottom of the sewer are cleaned manually by means of high pressure cleaner every 1-2 weeks. In the future, a motor driven cable winch will be installed: it will be remotely activated through Internet to help reduce on site maintenance work. Both sites in Graz and Vienna are equipped with video camera surveillance systems permanently accessible via the Internet, which greatly facilitates the maintenance work (e.g. with permanent control of the pontoon position, and early detection of any clogging problems).
In comparison with the floating installation in Graz, the maintenance needed in Ecully and Vienna is more intensive, to avoid sedimentation and clogging problems in the measurement flumes. In Ecully and in Graz, a fraction of the pressurized air used to clean the sensor optical chamber is diverted and used just around the sensor itself: this change solved the sedimentation problems. Reliable air cleaning systems are a very important requirement for all used submersible spectrometers as they facilitate reliable spectrometer values. Figure 7 shows all COD_{eq} values measured in 2004 in Graz. Due to a broken air cleaning system at the beginning of July, the spectrometer values started to increase. This damage was not detected. After repair, the activation of the cleaning system was forgotten for three further weeks which resulted in the same COD_{eq} drift as in July.

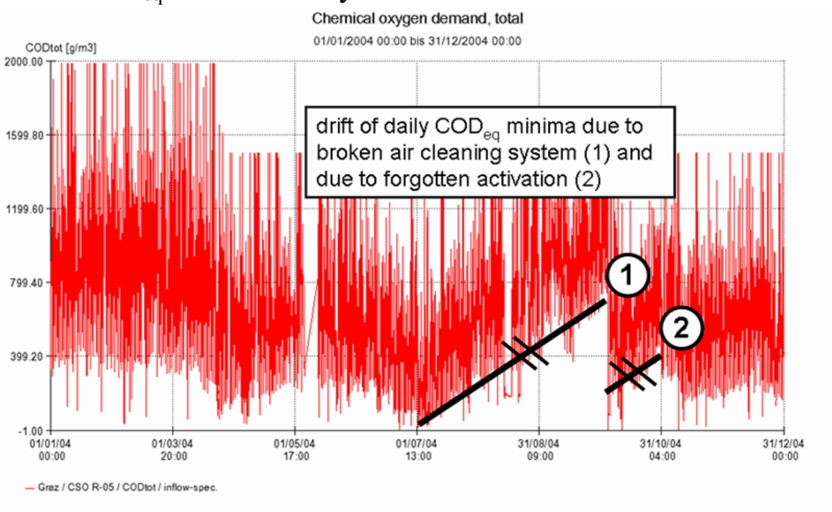

Figure 7 (1): Same drift of daily CODeq minima due to a broken air cleaning system and (2) due to a forgotten activation of the compressor of the air cleaning system

CONCLUSIONS
Even today there is a general lack of knowledge about the complex sewer processes concerning the transfer of pollution loads in and from sewer networks. Previous knowledge was mostly obtained by means of measurement campaigns using automatic samplers and following lab analyses which were not able to record the highly variability in sewer systems.

An explosion-proof UV/VIS sensor has been available for some years for simultaneous measurement of COD_{eq}, filtered COD_{eq}, TSS_{eq} and $nitrate_{eq}$ even in sewer systems which allows in-situ real-time measurements with no sampling, no sample preparation and no reagents. This sensor is operating at three sewer on-line monitoring measurement sites in Austria (Graz and Vienna) and France (Lyon) for long–term issues. Depending on the surrounding conditions at the measurement sites, two principal different installation strategies are possible – floating installation in a swimming pontoon directly installed in the sewer system or by-pass installation in flow through flumes outside the sewer system with wastewater supply by peristaltic or submersible shredding pumps.
Up to now, and during dry weather conditions, validation experiences of the spectrometer values have resulted in general underestimations of high concentrations during daily peaks and in overestimations of low concentrations during night periods using the global calibration set of the manufacturer. After local calibration and adjustment work based on taken reference lab samples, the deviations could be reduced at all sites. This additional adjustment work is therefore, generally recommended if high trueness of the spectrometer equivalent values is important. However, the dry wastewater matrix adjusted local calibrations does not inevitably deliver reliable data during wet weather conditions due to the different composition of stormwater runoff depending on the "history" of each storm event. Further and more detailed research work is still needed in these fields.
For long-term operation, reliable air cleaning systems are mandatory for both the spectrometer itself to prevent signal drift due to plague creation at the measurement windows of the spectrometer and for the used flow through flumes to prevent sedimentation processes. Besides this consideration, permanent video camera surveillance is nowadays quite cheap and greatly facilitates maintenance work. Their application is strongly recommended to achieve reliable non-stop time series.

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