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REPORT

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Monitoring of Water Quality Parameters in Combined Sewer Overflows

Project acronym: MONITOR-1

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For

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Abstract (English)

MONITOR-1: Simultaneous Monitoring of Combined Sewer Overflows and Receiving Water

Contact: Pascale Rouault, Kompetenzzentrum Wasser Berlin

Sub-study: Monitoring of Water Quality Parameters in Combined Sewer Overflows

The objective of the MONITOR-1 project is to analyse the acute impacts of combined sewer overflows on the Stadtspree, the Berlin segment of the River Spree, in order to develop a model-based tool for recipient/impact based management of combined sewer systems.

To determine the extent of impacts from CSO discharges on water quality of the Stadtspree, water quality parameters will be measured in the sewer system and receiving water during the monitoring campaign. Both water quality and water flow will be assessed.

As acute impacts of combined sewer overflows are the focus of interest, online sensors will be used to obtain high-resolution measurements of various water quality parameters. This approach makes it possible to achieve quasi continuous monitoring. However, online sensor technology is only available for selected water quality parameters such as total organic carbon, ammonia and other "classical" water quality parameters like temperature (T), pH, conductivity and dissolved oxygen.

The two main reasons for the limited use of online water quality sensors in combined sewer overflows so far are:

- The lack of legal requirements making it mandatory to monitor CSO discharges;
- The high maintenance requirements of online water quality monitoring systems, particularly those that generate high-quality data sets. The high maintenance work load is related to the specific composition of the medium (grease, rough waste), the aggressive nature of the monitoring environment, and the frequently poor accessibility of the measuring sites.

This report summarizes the experience gained using online water quality sensors for online water quality monitoring in combined sewer systems in previous monitoring campaigns. These valuable lessons will be used to develop appropriate construction and operation solutions when planning the future monitoring network in Berlin.

We identified nine European projects concerned with online water quality monitoring in combined and sanitary sewer systems. An overview is provided in this report. Most of the experience gained in such monitoring campaigns has been acquired in the fields of research and engineering. This report is the product of our extensive exchange of experiences with experts who have planned and conducted sewer monitoring campaigns. In addition, we toured and evaluated two monitoring stations operated for research purposes. One is located in Graz, Austria (IMW Project) and the other in Lyon, France (OTHU Project).

A standardised reporting format will be used to describe the nine identified projects. The reasons for conducting the sewer monitoring campaigns, the monitoring strategies and the types of online sensors used will be explained. Specific details of online sensor operation, calibration and maintenance and of the transmission and validation of data during the monitoring campaigns will also be provided.

These systematic project descriptions will shed light on the following aspects of the monitoring campaigns:

- Monitoring objectives

  Water quality monitoring in combined sewer overflows is performed for different reasons, which can be grouped into three main categories:

  - Technical questions relating to further sewer system development
  - Operational issues
  - Compliance with regulatory authority rules and regulations

  Projects performed for research applications had a broader scope that included additional issues such as improvement of online sensor operation (sensor calibration and data validation).

- Site selection criteria

  The ideal monitoring site must meet a variety of different criteria such as representativeness of the site and wastewater matrix, safety of the working environment, and ease of access to the site. It is rarely possible to find a site that meets all of the selection criteria. Therefore, compromise solutions are often necessary.

- Installation of sensors in-situ or in a bypass line

  Another core issue during online sewer monitoring site planning is the question of whether to install the sensors directly inside the sewer or in a bypass line outside the sewer. This decision depends mainly on local conditions at the site. Advantages and disadvantages of the two approaches will be discussed.

- Sensor calibration

  The sensor types to be used in the MONITOR project are: 1) optical sensors and 2) ion-selective sensors. These sensors are calibrated by different methods and at different frequencies. The present report provides introductory information on sensor calibration. Further details can be found in a previous project report on the testing of online water quality sensors (Barjenbruch and Rettig 2009).

- Data transmission

  Data sets from the sensors can be transmitted either via a direct cable connection to a local data logger or via a long-distance data transmission line to a remote central server. Local data storage requires intensive support and is therefore best suited for short-term monitoring campaigns. Remote data storage is recommended for long-term sewer monitoring. Concepts for such systems will be described.

- Data validation

  Online water quality sensors generate huge quantities of data. Consequently, automated data validation methods are required because the data load would be too large to handle by manual validation alone. However, automated data validation alone also is not advised because it generally is not possible to define all potential errors and measurement phenomena in advance when programming the software. It is better to perform automated pre-validation screening followed by a manual check of all data classified as questionable during screening. Proposed automated pre-validation screening methods will be discussed in this report.

After reviewing the information from institutes and individuals with previous experience monitoring combined sewer overflows, we found that no standard for the design and operation of online water quality monitoring sites exits. Four key points must be considered when planning the monitoring sites:

- Specific local conditions
- Study objective
- Feasibility of the maintenance workload
- Budget.

Previous monitoring campaigns have generated a knowledge base that can facilitate the planning and design of future monitoring stations. Existing knowledge on the use of sensors for online sewer monitoring, particularly UV-VIS and ion-selective sensors, is summarised in this report. The in-depth experience with online sensor calibration in complex media such as wastewater and combined sewer systems has yielded "standard" sensor calibration methods that can be directly extended to other studies. This knowledge base allows for more efficient planning of online sewer monitoring system operation and maintenance. Certain aspects, however, must be adapted to specific local conditions, particularly the local wastewater matrix. Researchers have already learned valuable lessons on the management of sewer monitoring systems under extremely variable hydraulic conditions, ranging from the very small discharges occurring during dry weather flow (DWF) to very large discharges during wet weather flow (WWF). The data transmission technology currently available for transmission of the collected data is very advanced, reflecting recent developments in the entire field of information technology. Regarding data calibration, new developments for research and operational applications are currently in the pipeline.

As shown in this report, online water quality monitoring has many advantages over the conventional method of sample collection with subsequent laboratory analysis. Online water quality monitoring permits quasi continuous data recording, elucidating highly dynamic processes within the sewer system. Technical requirements for online water quality monitoring systems are high but necessary for the generation of high-quality data sets that can be used with confidence.

Résumé (Français)

MONITOR-1 Surveillance en continu des déversoirs d´orage et des eaux réceptrices

Contact KWB: Pascale Rouault

Sous-étude: Surveillance en continu de la qualité de l'eau des rejets du réseau unitaire

Au sein du projet MONITOR-1, l'effet immédiat des rejets du réseau unitaire en temps de pluie sur les eaux réceptrices est étudié dans le but de développer un outil de gestion des eaux du réseau unitaire se basant sur des critères d'impact sur les eaux réceptrices (critères d'imitions).

Une campagne de surveillance qui se déroulera de façon parallèle au niveau du canal de rejet et au sein de la rivière Spree permettra d'identifier dans quelle mesure les rejets du réseau unitaire affectent la qualité de l'eau de la rivière Spree. Lors de cette campagne de surveillance les débits des rejets et des paramètres de qualité de l'eau seront mesurés.

Etant donné que ce projet se concentre sur les effets immédiats, des sondes en ligne seront utilisées pour mesurer les paramètres de qualité de l'eau. Elles permettent de mesurer ces paramètres avec une très haute résolution temporelle. On parle alors de mesures « quasi-continues ». Il est possible de mesurer avec des sondes en ligne des paramètres choisis tels que la DBO, la DCO, la concentration en ammonium ou les paramètres classiques la température, le pH, la conductivité et la concentration en oxygène dissous. L'utilisation de sondes en lignes pour la mesure de paramètres de qualité de l'eau des rejets du système unitaire est peu répandue, car :

- Il n'existe pas de loi obligeant à mesurer les émissions du système unitaire
- De telles campagnes nécessitent beaucoup d'entretien, surtout si l'on cherche à obtenir des données de bonne qualité. Cet effort de maintenance est justifié par les caractéristiques du milieu (graisses, corps étrangers) ainsi que par la difficulté à accéder au point de mesure.

Ce rapport témoigne des expériences réalisées avec des sondes en ligne pour la mesure de paramètres de qualité de l'eau. Ces expériences seront prises en compte lors de la planification de la campagne de surveillance des rejets du système unitaire prévue sur Berlin afin de définir un design et une exploitation adaptés aux besoins.

Les expériences de neuf projets européens sont considérées, il s'agit de projets au sein desquels des campagnes de surveillance ont été effectuées afin d'obtenir des informations sur les rejets du réseau d'assainissement unitaire, des eaux usées ou eaux mixtes. Ces expériences appartiennent au domaine de la recherche ou sont conduits par des bureaux d'étude. Ce rapport est le fruit d'un échange intensif avec des experts qui ont eux même planifié et conduit des campagnes de surveillance et de la visite de deux sites issus de la recherche, celui de Graz (projet IMW, Autriche) et celui de Lyon (projet OTHU, France).

Les projets sont décrits de façon systématique. Leur but, les méthodes de mesure et les sondes utilisées sont rapportés ainsi que leurs méthodes d'exploitation, c'est à dire d'étalonnage, de maintenance, de transmission des données et leur validation.

La description systématique des projets est ensuite utilisée afin de faire le point sur les aspects suivants des campagnes de surveillance:

- Objectif des campagnes de surveillance

Les motifs pour la conduite d'une campagne de surveillance sont multiples. Les campagnes faisant l'objet de ce rapport peuvent être classées en trois catégories :

  - Questions techniques visant à l'amélioration du système d'assainissement
  - Questions visant à l'amélioration de l'exploitation
  - Respect des réglementations en vigueur

Au niveau de la recherche d'autres aspects sont étudiés tels que l'optimisation de l'exploitation des sondes en lignes (étalonnage, validation des données).

- Critères à prendre en compte pour le choix de la localisation du site de mesures

Un grand nombre de critère doit être pris en compte lors de la recherche de la localisation du point de mesure telles que la représentativité du point de mesures, la sécurité du matériel et du personnel, la facilité d'accès….Il est très difficile de définir un site pour lequel tous les critères soient réunis, il s'agit alors de trouver un bon compromis.

- Capteurs immergés ou en bac de dérivation

La méthode de mesurage (capteurs immergés ou en bac de dérivation) est une question centrale pendant la conception d'une campagne de surveillance. La décision dépend en premier lieu des conditions locales imposées par le site choisi. Les avantages et inconvénients des deux méthodes possibles de mesurage sont expliqués dans ce rapport.

- Etalonnage des sondes

Il est envisagé d'utiliser des spectromètres et des sondes ISE pendant le projet MONITOR. Ces sondes ont leurs propres méthodes et fréquences d'étalonnage, celles-ci sont présentées dans ce rapport. D'avantage de renseignement à ce sujet sont inclus dans le rapport sur le test de sondes de Rettig et al. (2009).

- Transmission des données

L'acquisition des données peut se faire de façon locale ; les données peuvent aussi être transmisses à distance à un serveur central. Une acquisition locale implique un encadrement intensif, elle est plus adaptée à des campagnes de courte durée. Une transmission des données à distance est conseillée pour des campagnes de longue durée. Un concept pour une transmission de données à distance est présenté dans ce rapport.

- Validation des données brutes

Le nombre de données brutes mesurées lors de campagnes avec des sondes en ligne est immense. Une validation manuelle de ces données est une opération fastidieuse, il est conseillé de procéder à une validation automatique des données. En revanche une validation entièrement automatique est déconseillée car il est impossible de prévoir à l'avance tous les phénomènes provoquant des données erronées. Il est donc judicieux de procéder à une validation semi-automatique des données puis de vérifier les données douteuses manuellement. Un protocole de pré-validation est proposé dans ce rapport.

L'échange avec des universitaires ou des personnes ayant acquis de l'expérience dans le domaine des campagnes de surveillances des rejets du système unitaire a montré qu'il n'existe pas de station de mesurage standardisée que cela soit pour ce qui est du design du point du mesure ou de l'exploitation du site. Pour la conception d'un site de mesure les points suivants doivent être pris en considération:

- Les conditions locales,
- L'objectif de la campagne,
- L'intensité de l'encadrement possible à fournir puis en dernier ou premier lieu
- Le budget disponible.

Les campagnes de surveillance qui ont été réalisées jusqu'à présent simplifient la planification et le design de nouvelles stations de mesure avec des sondes en ligne. Un savoir faire sur l'art de manipuler les sondes, notamment les spectromètres et les sondes ISE a été acquis. Les efforts faits afin d'étalonner les sondes dans des milieux difficiles tels que dans des eaux usées ou mixtes ont permis de développer des protocoles d'étalonnage pouvant être utilisés pour de nouvelles applications. L'exploitation et la maintenance peuvent être planifiées de façon plus efficace, même si il faut les adapter aux conditions locales mais surtout au milieu. Les expériences déjà faites en ce qui concerne l'art de procéder avec des conditions hydrauliques très variables, allant de débits très faibles par temps sec jusqu'à des débits importants par temps de pluie, sont précieuses. Les technologies pour la transmission de données sont déjà disponibles grâce aux dernières évolutions faites dans ce domaine. Les techniques et méthodes d'étalonnage évoluent grâce aux expériences venant du domaine de la recherche et des applications diverses.

Ce travail rappelle aussi les avantages qu'a une mesure des paramètres de qualité de l'eau en ligne par rapport à un échantillonnage puis une analyse en laboratoire. Des mesures en continu (quasi-continu) permettent de gagner des informations sur des phénomènes à évolution très rapide. L'effort à fournir pour obtenir des séries de données de bonne qualité et exploitables reste néanmoins non négligeable.

Abstract (German)

MONITOR-1 Monitoring von Mischwasserüberläufen und betroffenen Gewässern

Kontakt im KWB: Pascale Rouault

Teilstudie: Monitoring von Wassergüteparametern an Mischwasserüberläufen

Im Rahmen des Projektes MONITOR-1 wird die akute Auswirkung von Mischwasserüberläufen auf die Stadtspree untersucht, mit dem Ziel, ein modellbasiertes Werkzeug für immissionsorientiertes Mischwassermanagement zu entwickeln.

Inwiefern die Mischwasserüberläufe die Wassergüte des betroffenen Gewässers Stadtspree beeinträchtigen, soll durch ein Monitoring erfasst werden, das parallel im Kanal und im Gewässer stattfinden wird. Bei diesem Monitoring sollen Wassergüteparameter und Durchflüsse überwacht werden.

Da die akuten Auswirkungen im Fokus des Projektes stehen, bietet sich der Einsatz von Onlinesonden zur Messung von Gewässergüteparametern an. Sie ermöglichen die Messung von Gewässergüteparametern mit sehr hoher zeitlicher Auflösung. Solche Messungen werden auch als quasi-kontinuierliche Messungen bezeichnet. Es sind allerdings ausgewählte Wasserqualitätsparameter mit Online Sonden messbar, wie die Kohlenstoffparameter, die Ammonium-Konzentration oder die klassischen Parameter Temperatur, pH-Wert, Leitfähigkeit und Sauerstoffgehalt.

Der Einsatz von Online Sonden für die Messung von Gewässergüteparametern an Mischwasserüberläufen ist bisher wenig verbreitet, da:

- es keine gesetzlichen Verpflichtungen zur Messung der Mischwasseremissionen gibt und
- der Wartungsaufwand eines solchen Monitorings hoch ist, insbesondere wenn Datensätze mit hoher Qualität aufgenommen werden sollen. Der hohe Aufwand ist durch die Beschaffenheit des Mediums (Fette, Grobstoffe), die aggressive Messumwelt und die häufig begrenzte Zugänglichkeit der Messorte bedingt.

In diesem Bericht sind Erfahrungen zusammengetragen, die mit Online Sonden zur Messung von Gewässergüteparametern in der Mischwasserkanalisation gesammelt wurden. Diese Erfahrungen werden bei der Planung des Kanalmonitorings an der Stadtspree in Berlin berücksichtigt, um eine geeignete Lösung für den Bau und den Betrieb der Anlage zu definieren.

Es wird über neun europäische Projekte informiert, die sich mit der Online Messung von Gewässergüteparametern an Mischwasserüberläufen, in der Mischwasser- oder in der Schmutzwasserkanalisation befassen. Erfahrungen mit solchen Überwachungskampagnen liegen im Forschungs- und teils im Ingenieurbereich vor. Der Bericht ist das Ergebnis eines intensiven Austausches mit Experten, die Monitoringkampagnen geplant und durchgeführt haben, und der Besichtigung von zwei Monitoringstationen aus dem Forschungsbereich. Dabei handelt es sich um die Stationen in Graz (Projekt IMW, Österreich) und in Lyon (Projekt OTHU, Frankreich).

Die identifizierten Projekte sind in einer standardisierten Form beschrieben. Es wird über die Ziele, die Messkonzepte und die verwendeten Online Sonden berichtet. Auch die Merkmale der Kampagnen bezüglich des Betriebes der Online Sonden, das heißt der Kalibrierung und Wartung der Sonden, der Datenübertragung und -validierung werden dargestellt.

Die systematische Beschreibung der Projekte wird dann verwendet, um folgende Aspekte der Überwachungskampagnen zu beleuchten:

- Ziel der Monitoring Projekte

  Die unterschiedlichen Motive für die Durchführung eines Monitorings von Mischwasserüberläufen werden dargestellt. Die in diesem Bericht beschriebenen Kampagnen können in folgende Kategorien zusammengefasst werden:

  - Technische Fragestellungen zur Weiterentwicklung des Abwassersystems
  - Betriebliche Fragestellungen
  - Einhaltung von Regelungen und behördlichen Vorschriften

  Im Forschungsbereich werden zusätzliche Aspekte untersucht, wie die Optimierung des Betriebes von Online Sonden (Kalibrierung, Datenvalidierung).

- Kriterien für die Wahl des Standortes.

  Eine Vielfalt an Kriterien (Repräsentativität des Standortes, der Wassermatrix, Gewährleistung der Arbeitssicherheit, Einfache Zugänglichkeit…) ist bei der Suche nach einer geeigneten Messstelle zu berücksichtigen. Da es selten möglich ist, alle Kriterien zu erfüllen, muss für die ausgewählte Messstelle häufig ein Kompromiss gefunden werden.

- Bypassmessung/ Direktmessung

  Eine Kernfrage bei der Planung einer Messstelle ist die der Messmethode, d.h. ob eine Direktmessung oder eine Bypassmessung gewählt wird. Die Entscheidung hängt im Wesentlichen von den lokalen Randbedingungen ab. Im Bericht erfolgt eine Erläuterung der Vor- und Nachteile der beiden Methoden.

- Sondenkalibrierung

  Die Sonden, die bei der Umsetzung des Projektes MONITOR verwendet werden sollen, sind optische Sonden und ionenselektive Sonden. Diese Sonden müssen mit unterschiedlichen Methoden und Häufigkeiten kalibriert werden. Es werden in diesem Bericht einführende Hinweise gegeben. Ausführlichere Informationen finden sich im Projektbericht über den Test von Online Sonden (Rettig et al. 2009).

- Datenübertragung

  Die Datenspeicherung kann lokal vor Ort vorgenommen werden oder über ein geeignetes Netzwerk (DFÜ) auf einem zentralen Server erfolgen. Eine lokale Datenspeicherung bedeutet eine intensive Betreuung, sie eignet sich eher für kurze Messkampagnen. Für eine lange Messkampagne wird eine Datenfernübertragung empfohlen. Konzepte dafür sind vorgestellt.

- Datenvalidierung

  Durch die große Menge von Daten, die mit Online Sonden erhoben werden können, besteht die Notwendigkeit einer automatischen Validierung der Daten, da eine manuelle Validierung alleine zu viel Zeit in Anspruch nehmen würde. Allerdings wird von einer vollständigen automatischen Validierung der Messdaten abgeraten, da in der Regel nicht alle möglichen Fehler und Messphänomene im Voraus bekannt sind und definiert werden können. Es wird empfohlen, eine automatische Vorvalidierung (Filterung) der Daten durchzuführen und dann nur noch die als unsicher bewerteten Daten manuell zu prüfen. Vorschläge für eine automatische Vorvalidierung werden im Bericht vorgestellt.

Der Austausch mit Instituten und Personen, die mit dem Monitoring von Mischwasserüberläufen Erfahrung gesammelt haben, zeigt, dass es keinen Standard für die Einrichtung und den Betrieb von entsprechenden Messstellen gibt. Bei der Konzeption müssen folgende Punkte berücksichtigt werden:

- die örtlichen Randbedingungen,
- die Zielstellung der Untersuchung,
- der leistbare Betreuungsaufwand und zuletzt oder zuerst
- das Budget.

Die bisher durchgeführten Messkampagnen leisten ihren Beitrag dazu, das Design von weiteren Monitoringstationen zu vereinfachen. Über den Umgang mit Online Sonden, insbesondere mit UV-VIS Spektrometern und ionenselektiven Sonden wurde das vorhandene Know-how zusammengefasst. Die intensive Auseinandersetzung mit der Kalibrierung der Sonden im schwierigen Medium Abwasser bzw. Mischwasser haben dazu geführt, dass „standardisierte Verfahren zur Kalibrierung“ für weitere Untersuchungen direkt übernommen werden können. Auch der Betrieb und die Wartung der Anlagen können jetzt effizienter geplant werden, auch wenn diese an die lokalen Randbedingungen angepasst werden müssen, insbesondere an die Abwassermatrix. Auch für den Umgang mit den sehr unterschiedlichen hydraulischen Bedingungen, von sehr kleinen Abflüssen während Trockenwetter bis zu sehr hohen Abflüssen während Regenwetter, sind die schon gewonnenen Erfahrungen wertvoll. Die verfügbaren Technologien im Bereich der Datenübertragung sind entsprechend der jüngeren Entwicklung im gesamten IT Bereich weit fortgeschritten. Zur Datenkalibrierung laufen derzeit Entwicklungen sowohl im Forschungs-, wie auch im Anwendungsbereich.

Diese Arbeit zeigt auch, dass die Online-Messung von Wasserqualitätsparametern viele Vorteile gegenüber der herkömmlichen Probenahme mit anschließender Laboranalyse hat. Sie ermöglicht durch eine quasi-kontinuierliche Datenaufnahme Informationen über hoch dynamische Prozesse zu gewinnen. Insbesondere der Betriebsaufwand ist jedoch hoch und die Voraussetzung für die Erhebung von Daten hoher Qualität, das heißt von Daten, die verlässlich genutzt werden können.

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Bravo to all of those named above who reported not only their successes and good experiences, but also the difficulties and failures experienced while monitoring sewer networks over the course of the years. This will hopefully enable us to avoid some of these pitfalls.

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1 Introduction

The objective of the MONITOR-1 project is to investigate the acute impacts of combined sewer overflows on the Stadtspree, the Berlin segment of the River Spree, in order to develop a model-based tool for recipient/impact based management of combined sewer systems.

"Water quality oriented analysis of CSO impact on lowland rivers" (Leszinski et al., 2007) describes the results of a preliminary theoretical study conducted by Kompetenzzentrum Wasser Berlin (KWB) in the scope of the Integrated Sewage Management (ISM) Project. The study showed that acute impacts on the slowly flowing waters of the Stadtspree are mainly associated with ammonia toxicity and oxygen deficiency.

To determine the extent of impacts from CSO discharges on water quality of the Stadtspree, water quality parameters will be measured simultaneously in both the sewer system and the receiving waters. Parameters of water quality and quantity will be assessed during the monitoring campaign. This will allow us to determine:

- Which loads are emitted from the combined sewer system at one main discharge point and
- Which impact this has on the water quality of the Stadtspree.

As acute impacts of combined sewer overflows are the focus of the project, online sensors will be used to obtain high-resolution measurements of the various water quality parameters. This approach makes it possible to achieve quasi continuous monitoring. However, online sensor technology is only available for selected water quality parameters such as total organic carbon, ammonia and other "classical" water quality parameters like temperature (T), pH, conductivity and dissolved oxygen.

The two main reasons for the limited use of online water quality sensors in combined sewer overflows so far are:

- The lack of legal requirements making it mandatory to monitor CSO discharges;
- The high maintenance requirements of online water quality monitoring systems, particularly those that generate high-quality data sets. The high maintenance work load is related to the specific composition medium (grease, rough waste), the aggressive nature of the monitoring environment, and the frequently poor accessibility of the monitoring sites.

Although the need for standards for online water quality monitoring using online sensors has been identified (Rieger & Vanrolleghem 2007), no such standards exist. Problems occurring during online water quality monitoring due to a variety of different reasons have created a need for standards. For that reason, the aforementioned authors initiated the *monEAU* project, the goal of which is to develop a system with the following characteristics:

- Flexible (suitable for use at different sites and with different sampling systems, sensors and communication standards)
- Open and modular software design (basic software package that can be upgraded with additional functions in standard software languages in modular fashion)
- Remote control
- Generation of database with high-quality data
- Automated data quality monitoring
- User-friendly
- Proactive and flexible maintenance concept

Monitoring of combined sewer overflows is the focus of the MONITOR-1 project.

The objective of the present report is to summarize previous experiences with the deployment of online water quality sensors for online water quality monitoring in combined sewer systems. We will apply this information to develop appropriate solutions for construction and operation of the sewer monitoring network in Berlin.

We identified nine European projects concerned with online water quality monitoring in combined and sanitary sewer systems. An overview is provided in this report. Most of the experience has been gained in monitoring campaigns conducted in the research and engineering applications. This report is the product of our extensive exchange of experiences with experts who have planned and conducted sewer monitoring campaigns and of our on-site tour and analysis of two existing monitoring stations.

In the second chapter, we will describe the identified sewer monitoring projects using a standardised reporting format including information on the project objectives, monitoring strategies and types of online sensors used in the monitoring campaigns. Specific details of online sensor operation, calibration and maintenance and of data transmission and validation during the monitoring campaigns will also be provided. The third chapter analyses the projects, describes the individual project objectives, and elucidates specific aspects of the different monitoring strategies, including their inherent advantages and disadvantages.

2 Online Monitoring of Combined Sewer Overflows

An overview of the identified online water quality monitoring campaigns in combined sewer overflows/combined sewer systems is presented below (Table 2.1). The individual monitoring campaigns will be described in detail in the following sections. The selected campaigns are long-term sewer monitoring campaigns. Short-term monitoring campaigns were not included in this analysis because of their simpler measurement equipment and facility requirements. The MONITOR-1 project, on the other hand, requires long-term expiriences for planning of a long-term sewer monitoring campaign.

Table 2.1: Overview of projects for online monitoring of combined sewer overflows

Project site / name	Executor	Duration of monitoring
Lyon, France	Field Observatory for Urban Water Management (OTHU)	Since 1999
IMW – *Innovative Messtechnik in der Wasserwirtschaft* / IMW monitoring station in Graz, Austria	Graz University of Technology, Institute of Urban Water Management and Landscape Water Engineering (*TU Graz*)	Since 2002
Homburg-Bröl, Germany	Agger Water Authority (*Aggerverband Gummersbach*) Cologne University of Applied Sciences (*FHS Köln*)	Two years
Tholey-Sotzweiler, Germany	EVS – Entsorgungsverband Saar (Waste Disposal Association of Saarland) Kaiserslautern University of Technology (TU Kaiserslautern)	12/2006 – 06/2008
Dudelange, Germany	CRTE/CRP Henri Tudor NIVUS GmbH	5 Mar 2007 – 12 Apr 2007
Odenthal, Germany	Ruhr University of Bochum, Germany	2000 – 2002 (multiple campaigns)
Bochum, Germany (DFG research project)	Ruhr University of Bochum, Germany	1999-2000

Research projects concerning the deployment of online sensors for monitoring parameters of water quality and quantity in sanitary sewer systems are summarised below (Table 2.2).

Table 2.2: Overview of projects for online monitoring of combined and sanitary sewer systems

Project site / name	Executor	Duration of monitoring
Eindhoven, Netherlands	Delft University of Technology	Since 2007
Discharge monitoring	Dr. Pecher AG WSW Enegie und Wesso AG	Various dates

We toured the monitoring stations in Lyon and Graz (IMW project) in the scope of this study. In addition, we established contact with the designers and executors of other monitoring campaigns in order to compile a systematic list of core data on the campaigns (exception: Homburg-Bröl).

The aforementioned projects will be briefly described in this chapter. These descriptions are based on our information gained from literature searches and intercommunication with persons responsible for the projects. Using a standardised reporting format, this information was summarised in tables (see Appendix) containing the following information:

- Core data on the monitoring campaign
- Description of the monitoring station and site
- Type of online sensors used and operating conditions

Although the reported information focuses on water quality measurement, other parameters were also studied in most of the projects.

Please note that UV-VIS spectrometers cannot be used for direct determination of water quality parameters. UV-VIS spectrometry is based on the principle that every substance absorbs electromagnetic waves of a certain wavelength range. Each substance has a characteristic wavelength, and the concentration of a substance is a function of its absorbance. The absorption spectrum of water is the sum of absorbance of its individual constituents. In UV-VIS spectrometer calibration, measured absorbance spectra are transformed into equivalent concentrations of the concentrations measured during wet chemical analysis. Measurements obtained by spectrometry are therefore referred to as equivalent values (CSB_{eq}, BSB_{eq}, DOC_{eq}, TOC_{eq} TSS_{eq}, NO_3-N_{eq}, etc.). In reference measurement, the correctness of the spectrometer measurements is checked using a water matrix blank as the reference sample.

2.1 OTHU Project – Lyon, France

The *Observatoire de Terrain en Hydrologie Urbaine* (OTHU), or Field Observatory for Urban Water Management, is the longest running online sewer monitoring campaign to date. We visited one of the OTHU monitoring stations in the course of planning the Berlin online monitoring facility.

OTHU is an observatory for the study of urban drainages, particularly stormwater runoff, and their environmental impacts. Eight institutional partners including the INSA de Lyon (Jean-Luc Bertrand-Krajewski) and four operational partners participate in the OTHU research consortium.

Their diverse research activities centre around the analysis of rainfall distribution, water and pollutant loads from catchment areas during wet and dry weather flow, the impact of these inputs on the soil, ground water and surface waters, interactions between urban and rural catchments, and the development of strategies for sustainable urban water management.

Five locations in Lyon and the surrounding area were selected as the sites for construction of water quality monitoring stations. Measurement of additional parameters (e.g. flow metering) was also performed. The impact of combined sewer overflows is being investigated at the monitoring station in the Ecully catchment. The combined sewer overflow at the Ecully site is the main CSO for that catchment area.

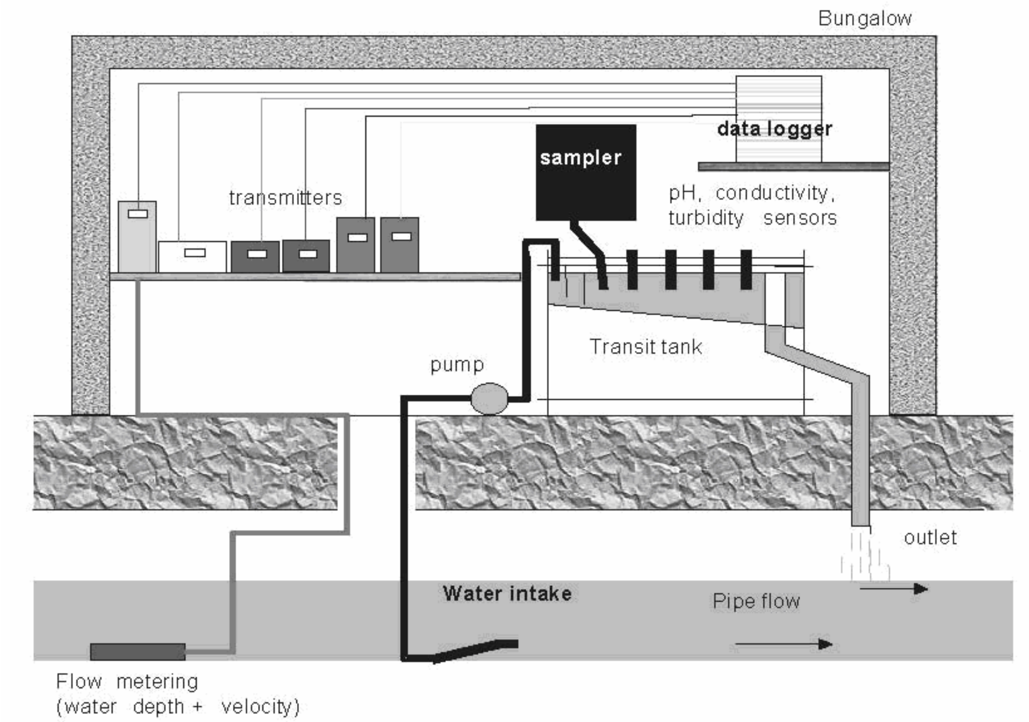

Figure 2.1: Schematic diagram of bypass installation set-up used for online monitoring in the OTHU project (Barraud et al. 2001)

The sensors for online water quality monitoring are installed in a bypass line at all monitoring stations in Lyon. A schematic diagram of the bypass installation set-up is presented in Figure 2.1. System configuration and operation were optimised and standardised in the scope of the measurement technology work package, which was based on the results of extensive tests, e.g. for calibration of the online sensors.

A UV-VIS spectrometer is used for measurement of COD_{eq} and TSS_{eq}. The spectrometer is calibrated once over the course of a day. Measurements are recorded once every 2 minutes. In addition to automatic compressed air cleaning, manual cleaning followed by reference measurement is performed as often as necessary but at least once a week. Temperature (T), conductivity, turbidity and pH measurements are obtained using online sensors. Full details on the features and operation of the sensors are provided in the Appendix.

In a publication covering topics ranging from urban drainage system modelling and monitoring to sewer system design and operation, Bertrand-Krajewski et al. (2000) compiled recommendations based on lessons learned in the OTHU project.

Data management is also carefully organised in this project. When standard monitoring is performed, the acquired data are pre-validated in a series of seven tests (Mourad & Bertrand-Krajewski 2002). The pre-validation screening process is described in Section 3.6. Final validation is performed manually.

2.2 IMW Project / Graz Monitoring Station – Graz, Austria

In the IMW project, several monitoring stations were set up in order to monitor water quality parameters in the urban water cycle. The Graz monitoring station (Figure 2.2) is located in a combined sewer overflow. It was designed and subsequently operated by the Technical University of Graz Institute of Urban Water Management and Landscape Water Engineering (Günther Gruber). During the planning stages of the Berlin monitoring station, we toured the Graz monitoring station and had an extensive exchange of information with the investigators there.

In Graz, COD_{eq}, TSS_{eq}, temperature and NO_3-N_{eq} measurements are obtained using a pontoon-mounted submersible UV-VIS spectrometer for direct in-situ real-time measurement. The pontoon is installed in the wastewater channel of the sewer inlet (Figure 2.3).

Local calibration of the UV-VIS spectrometer is carried out based on the results of a 24-hour dry weather monitoring campaign. Measurements are recorded once every 3 minutes during dry weather flow (DWF) and once per minute during wet weather flow (WWF). In addition to automatic compressed air cleaning, manual cleaning followed by reference measurement is performed as often as needed.

Direct measurement, as in Graz, is possible only when using sensors with ATEX certification (in accordance with ATEX Directive 94/9/EC), that is, sensors approved for use in sewer systems. At the Graz monitoring station, an additional measuring cell with an ion-selective sensor is installed in a bypass line and used for NH_4-N, NO_3-N and pH measurement. The membranes of the ion-selective sensor must be changed regularly. Further details regarding sensor features and operation are provided in the Appendix.

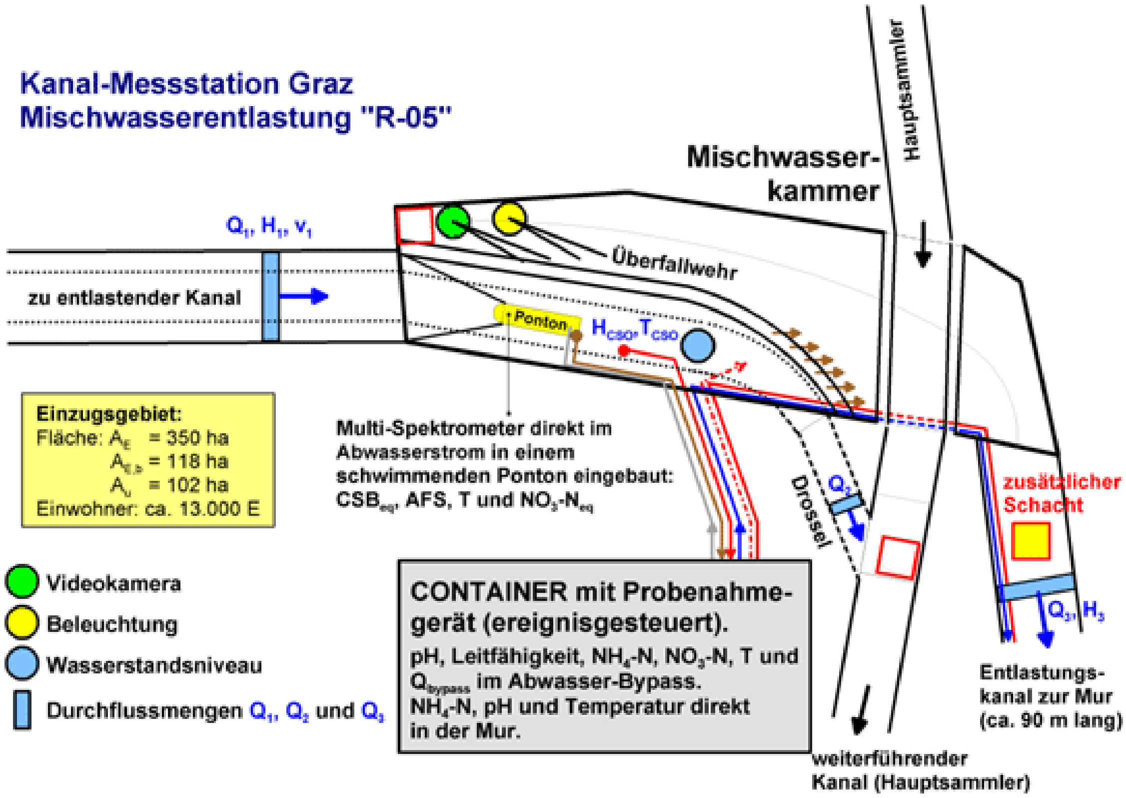

Figure 2.2: Overview of the measurement systems installed at the Graz monitoring station (Gruber et al. 2003)

Data transmission is accomplished via a central monitoring network control centre. Whenever possible, all sensors are digitally connected via a local interface to a local computer. Sensors that produce analogue signals only because they lack a digital interface are connected to the local computer via an analogue-digital module. The data sets are transferred at regular intervals from the local computer to the monitoring network control centre, where it is stored in a database in structured format. The transfer memory of Graz monitoring station's local computer is generally transmitted once an hour to the monitoring network control centre, where the plausibility of the received raw data is tested. If certain predefined system conditions are not met, a warning is sent to the monitoring station operator.

Automated data validation procedures are not used at Graz monitoring station present, but will be implemented during the next project phase.

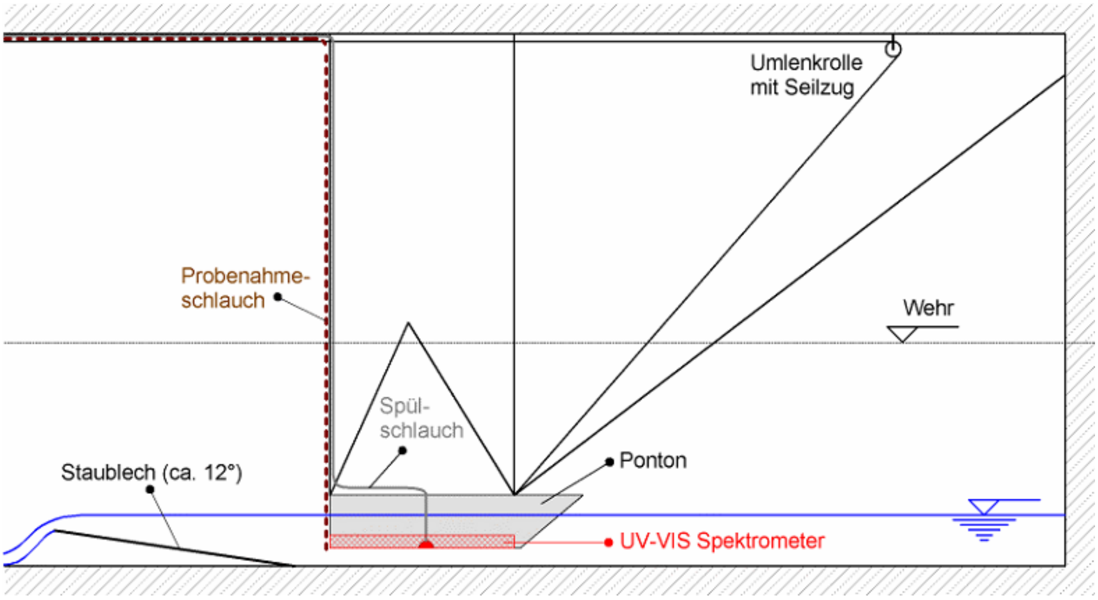

Figure 2.3: View through the pontoon showing the sampling tube and cable hoist set-up (Gruber et al. 2003)

2.3 Homburg-Bröl, Germany

The objective of Homburg-Bröl project, conducted by the Agger Water Authority (*Aggerverband Gummersbach*) and the Cologne University of Applied Sciences (*FHH Köln*), is to develop a strategy for real-time control of the sewer system and wastewater treatment plant. The performance of online sensors used for ammonia, COD_{eq}, pH and temperature measurement was therefore tested in the scope of the project.

Ion-selective sensors were used for NH_4-N measurement. The practicability of the sensors i.e. their measurement performance under real conditions and the expected maintenance workloads were assessed as the key performance indicators. An estimate of operating costs during continuous operation was also generated. Sensors from four different manufacturers were tested.

Due to space limitations, a bypass line was installed at the level of the discharge channel of the CSO tank (Figures 2.4 and 2.5).

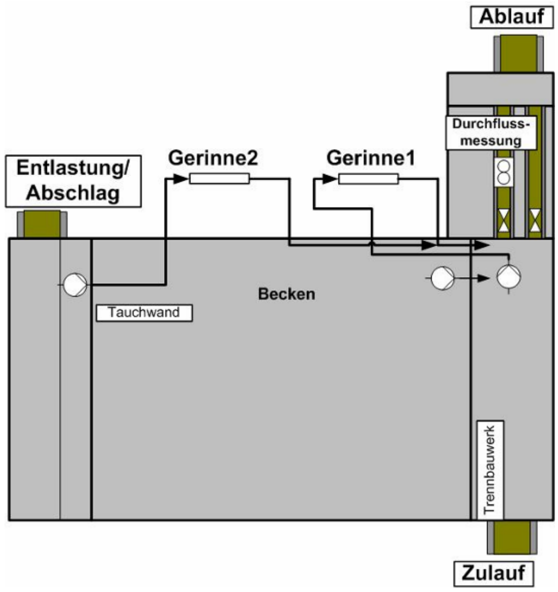

Figure 2.4: Layout of sampling points in the combined sewer overflow tank (Graner et al. 2007)

According to the investigators, the membranes of the ion-selective sensors had to be replaced frequently (every 7 to 10 days). The Homburg-Bröl experience shows that, after various improvements, it is possible to achieve a high data availability rate (85% of the annual online monitoring measurements). System failure susceptibility and maintenance intensity are greater in summer than in winter because the pump (shredder pump) has to cut up larger quantities of solids and has smaller volumes of fluids available for cooling during the summer. The number of working hours required to get the system to achieve a measurement accuracy of ± 10 % (approximately ± 1mg/l of measurement) is 50 to 70 hours/year.

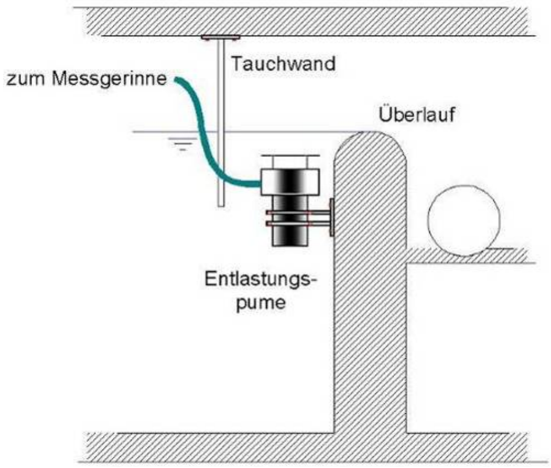

Figure 2.5: Measurement flume for sewer and discharge channel (left) and sampling equipment set-up (right) (Graner et al. 2007)

This group concluded that ion-selective sensors are suitable for rugged practical applications because they consistently provide measurements of sufficient accuracy for real-time control of sewer systems and require no sample preparation.

2.4 Tholey-Sotzweiler, Germany

Investigators at waste water system of Tholey-Sotzweiler studied possibilities of controlling combined sewer overflows into the local wastewater treatment plant in order to assess the potentials for integrated operation of the sewer system and wastewater treatment plant. Water quality was monitored in the plant influent and in a combined sewer overflow. Simulation models were calibrated based on these data. This joint project conducted by Entsorgungsverband Saar (EVS - Waste Disposal Association of Saarland), Kaiserslautern University of Technology's Department of Urban Water Management and NIVUS GmbH extended over a period of two years. A UV-VIS spectrometer was used for measurement of COD_{eq} und TSS_{eq}. The spectrometer was calibrated using a wide range of composite samples. In addition to automatic compressed air cleaning, manual cleaning followed by reference measurement was performed as often as needed. An ion-selective sensor equipped with an automatic compressed air cleaning unit was used for NH_4-N measurement. It was manually cleaned and calibrated at the same intervals as the UV-VIS spectrometer. A two-point calibration procedure was performed. In this campaign, the sensors were installed in situ for direct measurement. Sensors without ATEX certificates were also used. However, a gas alarm was used to switch off the sensors immediately if explosive gases were detected. The sensors used for measurement of stormwater overflow were installed directly in front of the weir crest. To protect them from drying, the sensors were stored in a piece of pipe sealed at the bottom and open at the top during dry weather. A float lifted the sensors out of the pipe during overflow events. However, this dry weather strategy did not protect the sensors adequately from drying.

2.5 Dudelange, Luxembourg

This monitoring campaign by the Resource Centre for Environmental Technologies of the Henri Tudor Public Research Centre (CRTE/CRP Henri Tudor) and NIVUS GmbH in Dudelange focused on storage capacity utilisation within large sewer systems. Extensive online flow and water quality monitoring was carried out in a combined sewer overflow.

One UV-VIS spectrometer was used for COD_{eq} and TSS_{eq} measurement; it was mounted to the bottom of a float in order to obtain direct (in situ) measurements (Figure 2.6). A second UV-VIS spectrometer, which was used to measure the spectral absorption coefficient (SAC), was installed in a bypass line. Details on the features and operation of the sensors used in this campaign are provided in the Appendix.

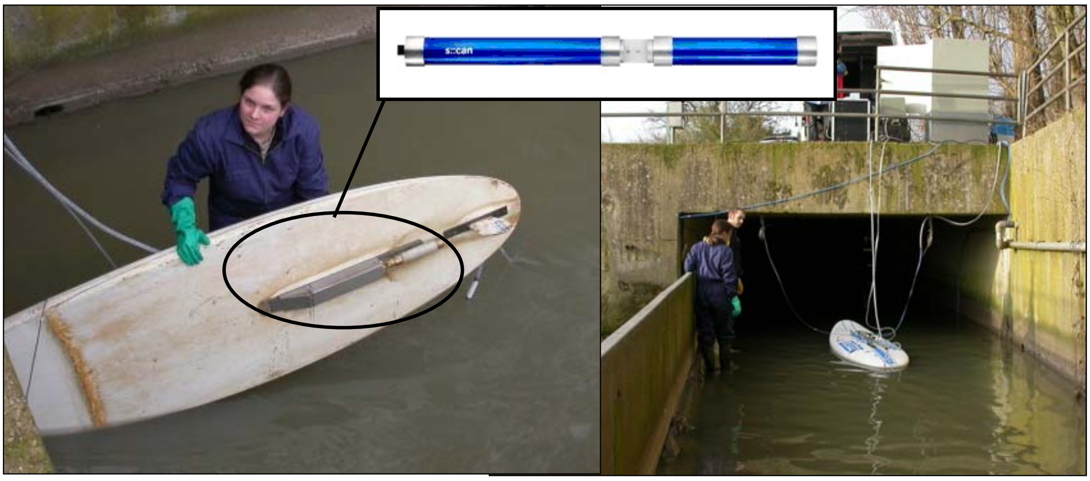

Figure 2.6: View of the UV-VIS spectrometer mounted on the bottom of a float (surfboard) and monitoring site in Dudelange (http://www.crte.lu/mmp/online/website/function/327/238_EN.html)

Data sets were logged once per minute. The sensors were calibrated by means of comparison with laboratory analysis samples. The researchers' local calibration procedures achieved much better correlation than the global calibration results obtained using the manufacturer's standard software package. In addition to automatic cleaning with compressed air, the sensors were manually cleaned twice during the one-month sampling campaign.

Remote water level (H) and rainfall measurement data were acquired via a GSM modem. Local readout from the flow meters and UV-VIS spectrometers was also used.

Validation of flow data was accomplished by comparing the measured flow data with dry weather flow data from other municipalities in Luxembourg and by comparing the dry weather flow with water consumption (hourly consumption rate). Validation of UV-VIS spectrometry data was performed by comparing the measurements from the two UV-VIS sensors with each other.

2.6 Odenthal, Germany

The objective of the monitoring campaign in Odenthal was to develop a comprehensive strategy for discharge-based assessment of the impact of combined sewer overflows on sensitive salmon spawning areas and integrated real-time control of sewer system and wastewater treatment plant. This two-year monitoring campaign was a joint project of the Department of Urban Water Management and Environmental Engineering of the Ruhr-Universität Bochum and the Wupper Water Association (*Wupperverband*).

During the campaign, numerous parameters were assessed in different parts of the urban drainage system, including the sewer system, the wastewater treatment plant, the discharge channel of the CSO tank and the receiving water. Here, we will report only on the sensors used in the discharge channel of the combined sewer overflow tank (Figure 2.7). All sensors were installed inline for direct measurement.

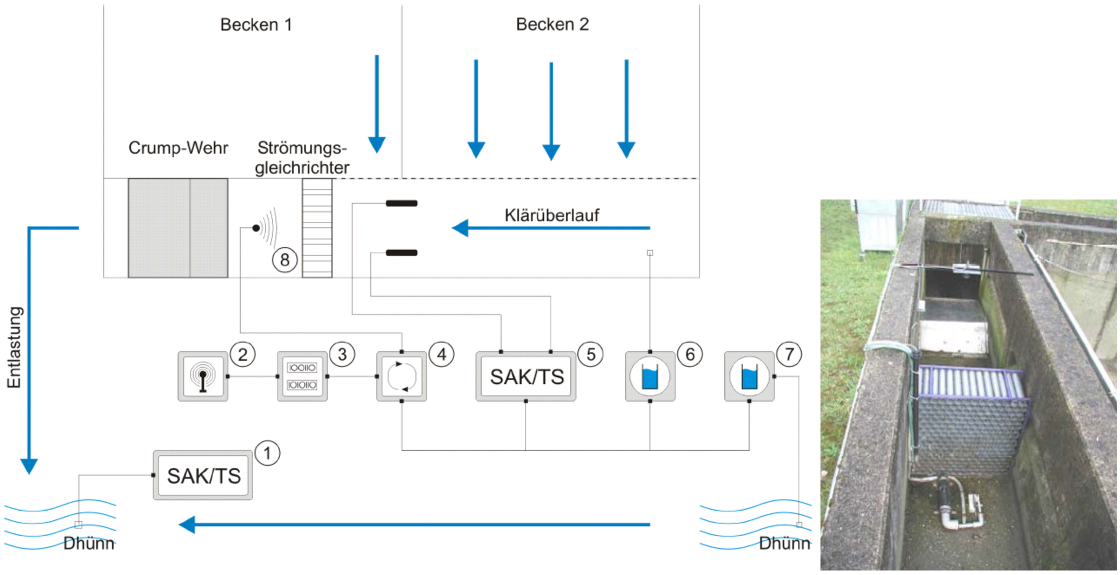

Figure 2.7: Left: Schematic diagram of monitoring site in the discharge channel of the CSO tank showing the following equipment: 1) SAC/TS sensor, 2) modem, 3) data logger, 4) measurement converter, 5) SAC/TS sensor, 6) sampler, 7) sampler with YSI sensor and 8) ultrasonic sensor. Right: Photograph of monitoring equipment installed in the discharge channel of the CSO tank. Source: Hoppe and Weilandt (2003).

Data sets were logged once per minute. A procedure for sensor operation was developed, including cleaning and calibration. In the foreground stand Cleaning when necessary.

2.7 DFG Project – Bochum, Germany

The monitoring campaign in Bochum was conducted as part of a research project sponsored by the German Research Foundation (DFG) and carried out by the Department of Urban Water Management and Environmental Engineering of Ruhr-Universität Bochum. The objective of the project was to develop an integrated real-time sewer system control strategy based on the discharge behaviour of a sewer with storage capacity and overflow. The campaign extended over a period of two years, and twenty events were analysed.

Direct measurements were taken inside the combined sewer. SAC measurements were obtained using sensors mounted directly on the base of the sewer (Figure 2.8). Data sets were logged once every five minutes. Details regarding the monitoring campaign can be found in the Appendix.

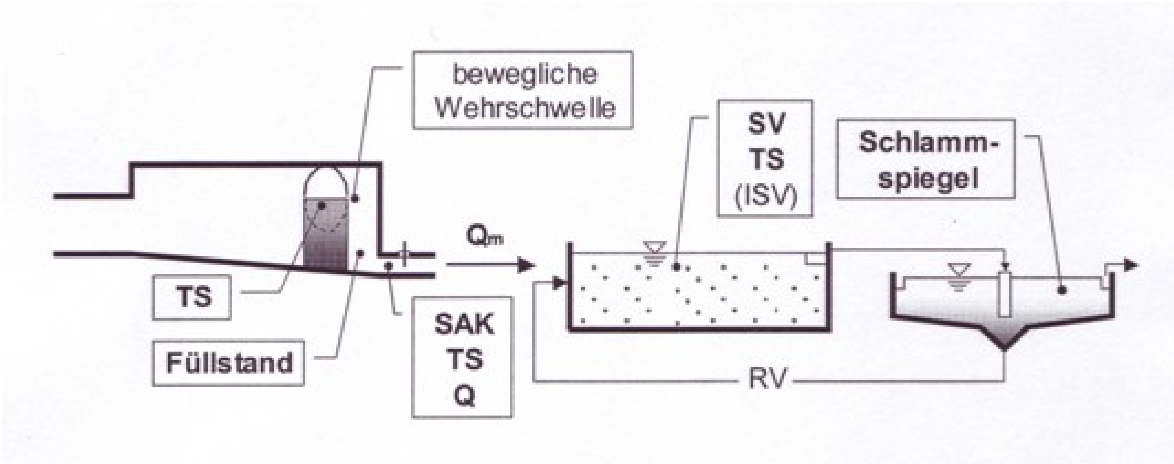

Figure 2.8: Principle of the investigated method of discharge-based real-time control of combined sewer systems (Grüning and Orth 2004)

2.8 Eindhoven, Netherlands

The objective of the Eindhoven project was to reduce river pollution due to discharges from the local wastewater treatment plant and combined sewer overflow. The work was conducted as a joint project of the local water authority (Waterschap de Dommel) and Delft University of Technology (TU Delft).

Six water quality monitoring sites within the combined sewer system are operated as part of an extensive and ongoing monitoring campaign started in 2006. The researchers monitored the quality of water from and within three catchments. All water quality measurements were performed in bypass lines. A UV-VIS spectrometer was used for COD_{eq} and TSS_{eq} measurement. Sensor measurements were recorded once per minute.

Overviews of the drainage system (Figure 2.9) and of the monitoring stations and target parameters (Figure 2.10) are presented on the following page. Details regarding the monitoring campaign and measurement operations can be found in the Appendix.

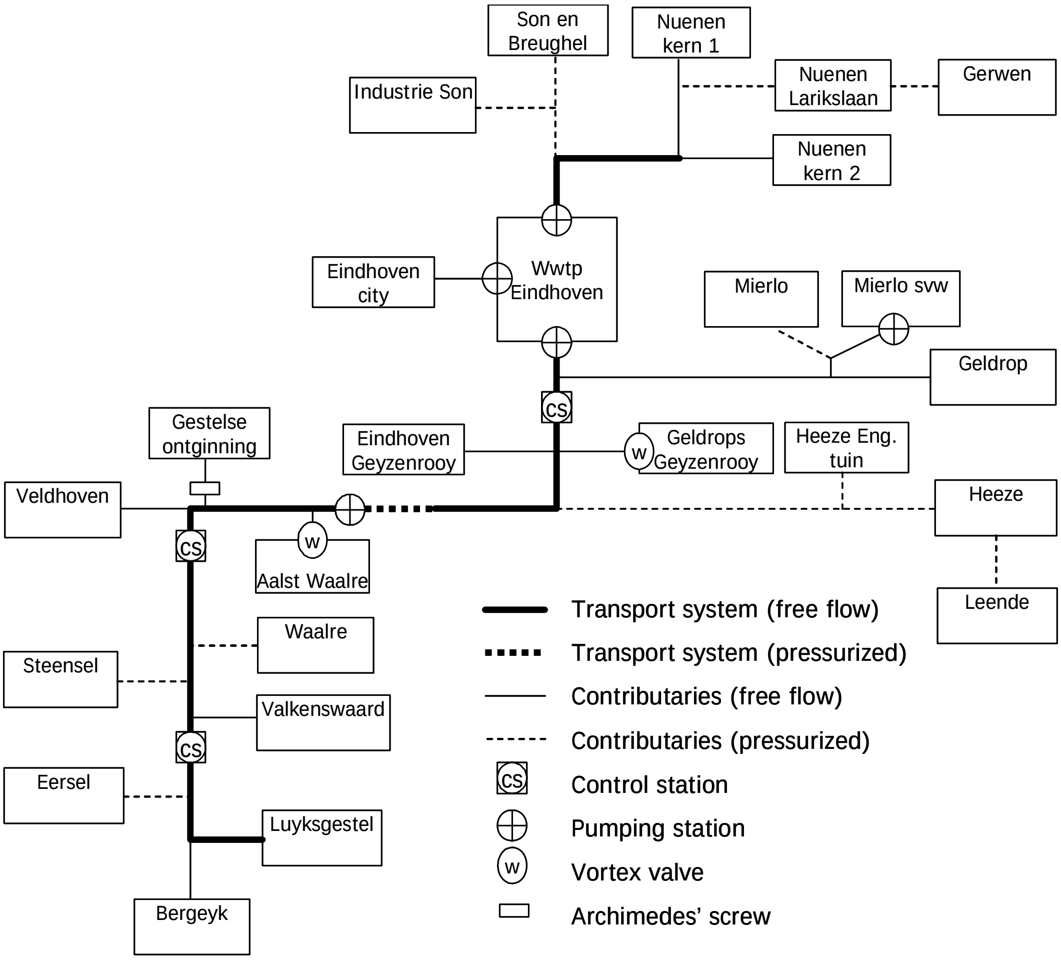

Figure 2.9: Urban drainage system in Eindhoven (Schilperoort et al. 2006)

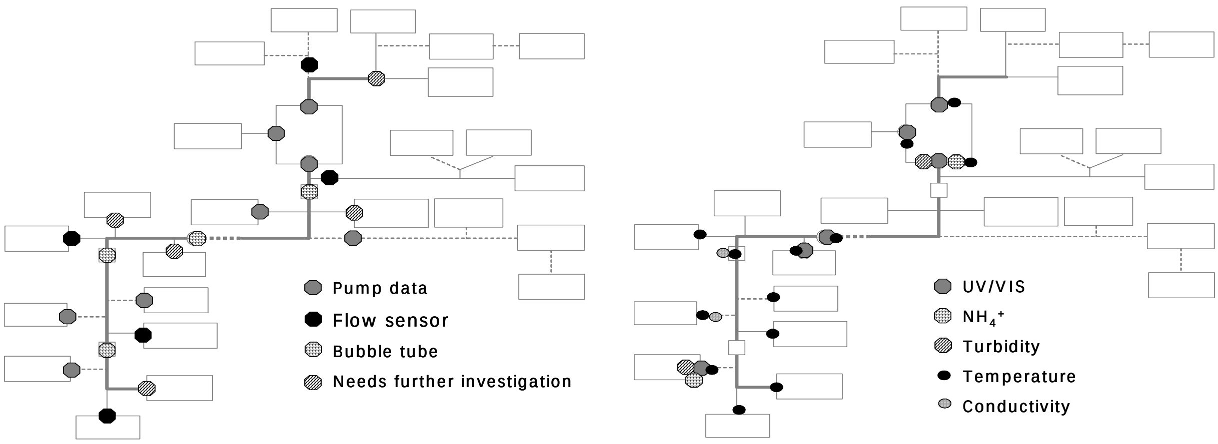

Figure 2.10: Overview of online water quality monitoring sites and target parameters monitored in Eindhoven (Schilperoort et al. 2006).

2.9 Wuppertal Monitoring Campaign, Germany

Within this monitoring campaign, water quality in the sewer system is currently being monitored. The objective of the campaign is to monitor the discharges from a development site into the adjacent sewer system. With this solution the construction of a new sewer system for the development site could be avoided. This ongoing monitoring campaign has been jointly conducted by the local power and water authority "*WSW Energie and Wasser AG*" and the consulting firm "*Dr. Pecher AG*" since 2008.

The UV-VIS spectrometer used to measure concentrations of pollutants in the industrial sewer influent was mounted directly in the pump station. A multi-point calibration procedure was performed. In addition to automatic compressed air cleaning, manual cleaning followed by reference measurement is performed once every four weeks.

2.10 Monitoring of water quality parameters, Wuppertal, Germany

Additional studies of the deployment of online sensors for continuous measurement of substances in wastewater in the sewer system have been in progress in Wuppertal since 2007. The Wuppertal public utility company "*Wuppertaler Stadtwerke AG*" (WSW) and the "*Dr. Pecher AG*" consulting firm have placed UV-VIS spectrometers at various points within the sewer system. Applications range from discharge monitoring and evaluation of the effects of treatment measures to regulation and control of wastewater disposal systems (Grüning and Hoppe 2007).

In these monitoring campaigns, the installations are not temporary but permanent operative monitoring points. When conducting such long-term sewer monitoring, it is important to use high-precision, low-maintenance sensors. The sensors were installed within the sewer for direct measurement. The calibration procedure consists of two thorough calibration steps with 40 reference measurements each. When the sensors are in operation, manual cleaning followed by reference measurement is performed once a week up to every four weeks depending on the site. Figure 2.11 shows an example of the an installed measurement system. Sensor data are recorded once every 5 minutes.

Figure 2.11: Water quality parameter and flow measurement in the sewer system (temporarily measuring point) (Hoppe et al. 2008)

3 Project Analyses

After completing the project overview, intercommunication with experts who planned and operated the monitoring stations, and the literature search, we were able to summarize the important features of the projects and detail the advantages and disadvantages of the respective solutions. Our objective was to identify solutions that seem appropriate for the planned combined sewer overflow monitoring project in Berlin. The objectives of the monitoring campaigns, reasons for installing the sensors directly within the sewer or in a bypass line, and characteristics of regular system operation as well as details regarding data calibration, data transmission, and data validation procedures will be discussed.

3.1 Objectives of Monitoring Combined Sewer Overflows

Water quality monitoring campaigns in combined sewer overflows or combined sewers are performed for different reasons, which can be grouped in three main categories (Bertrand-Krajewski et al. 2000):

- Technical questions relating to further sewer system development
- Operational issues
- Compliance with regulatory authority rules and regulations

Combined sewer overflow monitoring is also a topic of interest in the research field. The ultimate goal is to improve the operation of online sensors used to monitor pollutant discharges. A special need for improvement of calibration procedures (Graz, Lyon and Dudelange), sensor operation and data validation procedures has been identified.

3.1.1 Technical Questions Relating to Further Sewer System Development

Data derived from sewer monitoring campaigns can be used to better understand and analyse sewer system processes and performance. Furthermore, monitoring data can serve as an aid to decision-making and as a tool to evaluate the efficacy of implemented system improvement measures. Based on our information exchange and literature search of monitoring campaigns in combined sewer overflows, the following applications were identified:

- For future urban drainage system investment planning support. In Utrecht, for example, the investigators are using the monitoring data to calibrate a numerical model of the sewer system and simulate scenarios; planned measures will then be assessed and implemented according to the results of the analysis.
- For acquisition of data on discharges from sewer systems (OTHU, Lyon and Graz). Data on pollutant discharges into receiving waters can be used to identify effective strategies for urban water management.
- For enhancement of process understanding (this applies to most projects).

3.1.2 Operational Issues

Monitoring can be used for the surveillance and management of operational processes such as the filling and emptying of storage structures (e.g. stormwater tanks), monitoring of the sewer system at critical or representative sites within the system, identification of operational anomalies, preparation of annual balance sheets, analysis of system malfunctions and their consequences, operational adjustment, and identification of system maintenance needs. In our information exchange between experts and review of the literature, the following applications were identified:

- Operational improvement of the existing urban drainage system in Eindhoven, Homburg-Bröl, Tholey-Sotzweiler, Odenthal, Bochum and Dudelange. The objective of monitoring is to reduce pollutant loads spilled into the receiving waters. This operational improvement was achieved in part by integrated real-time control of the sewer system and wastewater treatment plant and in part through analysis of sewer storage capacity utilisation during wet weather flow.
- Improvement of operational processes such as overflow control (real-time control) for more optimal use of in-sewer storage capacity.

3.1.3 Compliance with Regulatory Authority Rules and Regulations

Regulatory authority rules and regulations for the operation of urban drainage systems vary from one country to another. Monitoring of discharges from combined sewer systems is mandatory in some countries. Industrial discharge must be monitored according to size and origin. Online monitoring generally makes it possible to check compliance with regulatory requirements. Based on our information exchange and research, we identified the following case in which this applies:

- Discharge monitoring: In Wuppertal, discharge from a new development must first be monitored before is allowed to drain into a privately owned industrial sewer.

3.2 Site Selection Criteria

When attempting to identify a suitable monitoring site, a variety of different criteria must be considered. It is rarely possible to find a site that meets all of the selection criteria. Therefore, compromise solutions are often necessary. The ideal monitoring site should meet the following criteria:

- Representativeness of the

  - Site: The frequency and intensity of measured events should be comparable to those at other sites.

  - Water matrix: Thorough mixing is essential.
- Safe working environment
- Ease of access
- Adequate space to install a container on the site if necessary

- Access to essential infrastructure:

  - Electricity

  - Water

  - Internet/broadband connections

- Adequate protection from vandalism; the use of inconspicuous sampling equipment is recommended
- Ability to obtain permission to install monitoring equipment in the sewer and set up a container if necessary
- Spatial proximity to the institution performing the study (this is not an excluding factor but is very helpful because these are high-maintenance systems)

These can be classified as general criteria. Depending on the objective of the study, additional criteria may also apply.

3.3 Installation of Sensors In-situ or in a Bypass Line

Certain core questions must be answered before planning a monitoring campaign:

- Which target parameters will be monitored (flow, pollutants, etc.)?
- Where will monitoring be performed?
- When, for how along and at which temporal resolution should monitoring be performed?
- Which uncertainty factors can be expected and/or tolerated?

These questions are basically determined by the objective of monitoring and must be decided on a case-by-case basis. The site of sensor installation (i.e. directly inline as in Graz and Dudelange or in a bypass line as in Lyon and Eindhoven) is another key issue. The question of where to best install the sensor is mainly determined by the specific local conditions. Discussion of the advantages and disadvantages of the two sensor installation approaches can facilitate this decision.

The main advantage of using a direct inline measurement set-up (sensor mounted directly on the sewer pipe or on a pontoon within the sewer) is that measurements can be obtained directly within the medium without time delay and in situ. The disadvantage is that the relative difficulty of access to monitoring sites inside the sewer system, which makes installation and maintenance of the sensor equipment more difficult. Incrustation is another problem that can affect sensors installed in sections of the sewer subject to periodic drying (Weilandt et al. 2001). Sensors used for direct inline measurement inside a sewer system must be ATEX-certified (ATEX Directive 94/9/EC). Bypass line installation may be the best solution at sites where space restrictions and low water volumes are critical factors (e.g. in Homburg-Bröl).

Table 3.1: Advantages and disadvantages of installing sensors directly inline or in a bypass line (adapted from Gruber et al. 2006).

Direct (inline) installation	**Bypass installation**
▪ Sensor is located directly inside the sewer (on a pontoon)	▪ Sensor is located in a bypass line/flume located outside the sewer
▪ No need to transport samples out of the sewer	▪ Continuous transport of samples from the sewer to the bypass is required
▪ No time delay or transport-related unmixing of samples	▪ Time delay and possible transport-related unmixing of samples
▪ Measurement conditions are very unstable, particularly during CSO discharges, posing a constant risk of sensor damage	▪ Measurements conditions for the sensors are very stable and constant provided that the sample conveyor is working properly
▪ High risk of sensor damage	▪ Low risk of sensor damage
▪ Low energy consumption	▪ High energy consumption due to conveyor
▪ Only the pontoon requires maintenance or drain cleaning and can be accessed relatively easily using the cable hoist	▪ Intake opening of the bypass line/flume requires regular maintenance plus drain cleaning and sediment removal as needed
▪ Optical path of the sensor must be cleaned within the sewer	▪ Optical path of the sensor can be cleaned relatively easily within the bypass line/flume
▪ Measurements are obtained in wastewater near the base of the sewer during dry weather flow and near the surface during combine sewer overflows	▪ In continuous bypass line operation, wastewater near the base of the sewer is always conveyed and analysed except in cases where a flexible pump hose with a float is used
▪ Regular access to the pontoon inside the sewer is necessary	▪ Access to the pump intake opening inside the sewer is required (infrequently)
▪ If no access shaft is available, boreholes must be made for the data cable, air line and clean water line.	▪ If no access shaft is available, boreholes must be made for the pump hose from the measurement container to the sewer
▪ An air compressor is needed for automatic sensor cleaning	▪ An air compressor is needed for automatic sensor cleaning
▪ Pressure rinsing is harder to control inside a sewer pipe or pontoon.	▪ Pressure rinsing is relatively easy to control inside the bypass line/flume
▪ Measurement container use is recommended	▪ Measurement container use is mandatory
▪ No biofouling problems	▪ Pump hose subject to biofouling
	▪ Q measurement should be performed in a bypass line

Table 3.1 provides an overview of the advantages and disadvantages of direct inline sensor installation as opposed to sensor installation in a bypass line (adapted from Gruber and Kainz 2006). Although direct inline measurement was achieved by mounting the sensor on the bottom of a pontoon in this specific case, most of the rationales apply to sensors directly mounted to sewer structures. As the table shows, there is no ideal solution. One must be aware of the advantages and disadvantages of each sensor installation method.

Bertrand-Krajewski et al. (2000) propose a solution consisting of installation of the sensor in a bypass line/flume located in a container outside the sewer system. The full details of their bypass solution are discussed, including dimensions, materials and methods.

Gruber et al. (2004) provide practical information on the design of a direct measurement system.

3.4 Sensor Calibration

Optical sensors and ion-selective sensors are calibrated by different methods and at different frequencies. Extensive information is provided in an online sensor test report (Barjenbruch and Rettig 2009).

Weilandt et al. (2001) stressed that it is necessary to perform additional tests of the quality of measurements during sensor calibration and to check for synchronisation of all sensor clocks in the network. These checks must be performed before and after cleaning. This is mandatory in order to ensure plausible correlation of the results of qualitative and quantitative water measurements.

3.4.1 UV-VIS Sensor Calibration

Two types of calibration procedures are used for UV-VIS sensors:

- Local calibration: In situ measurements by the spectrometer are transformed in equivalent concentrations of the target parameters (TSS, COD, etc.). This is done by comparing the spectrometer measurements with the corresponding laboratory measurements for samples collected from the same medium at the same time. Before monitoring water quality in a sewer system, for example, samples are first collected once hourly over the course of a 24-hour period. The sensor is calibrated using these samples covering the daily range of concentration over time. When monitoring water quality parameters in a combined sewer in which wet weather flow is of interest, calibration should ideally be performed using samples collected during and after a rain event. The sampling method and analytical method require special attention (Bertrand-Krajewski et al. 2007, Hoppe et al. 2008). In the monitoring campaigns described here, the calibration procedure consists of a single adjustment to the wastewater matrix of interest at the start of monitoring.
- Reference measurement: Using distilled water as the blank/reference sample, the correctness of sensor measurement is checked and adjusted as needed. Reference measurement is performed at regular intervals as a test of

measurement quality. The frequency of reference measurement using distilled water as the blank varies from twice a year with additional reference measurement as needed (e.g. in Graz) to once a month (in most of the other monitoring campaigns). Additional reference measurements are performed if the spectrometer readings appear questionable due, for example, to signal drift.

3.4.2 Ion Selective Sensor Calibration

A two-point calibration procedure is recommended for ion-selective sensors. The sensors are immersed in solutions and the measured values are recorded. The sensors are then calibrated by comparing the sensor measurements to the known concentrations of the test solutions. Locally, the calibration set is adjusted to the wastewater matrix (offset or one-point calibration). In Graz, one-point calibration was performed every 2 weeks and two-point calibration every 8 weeks. In Homburg-Bröl, one-point calibration was performed at weekly intervals.

3.5 Data Transmission

Data sets from the sensors can be transmitted either via a direct cable connection to a local computer or via a long-distance data transmission line to a remote central server.

When local data storage is used, data readout must be performed at regular intervals. As sensor data sets must be checked each day of a monitoring campaign, local data storage is better suited for short-term sewer monitoring. The advantage is that data problems can be identified quickly. However, the corresponding work load is proportionately high.

Remote data storage (transmission of data sets via a long-distance data transmission line to a remote central server) is recommended for long-term sewer monitoring. Data sets from the online sensors are first transmitted to the local data logger, which then sends the data at regular intervals to the remote central server. With long-distance data transmission, the data are sent either via cable (normal telephone line, digital subscriber line, etc.) or via radio (GSM, GPRS, UMTS, etc.). Data received by the central server are then stored in a database. The database allows simple and rapid access to the data (via Internet) and thus permits direct assessment of the data by the project team. Synchronisation of all clocks in the sensor network is crucial for assurance of data quality. A plan for transmission of data sets to a central server is shown in Figure 3.1.

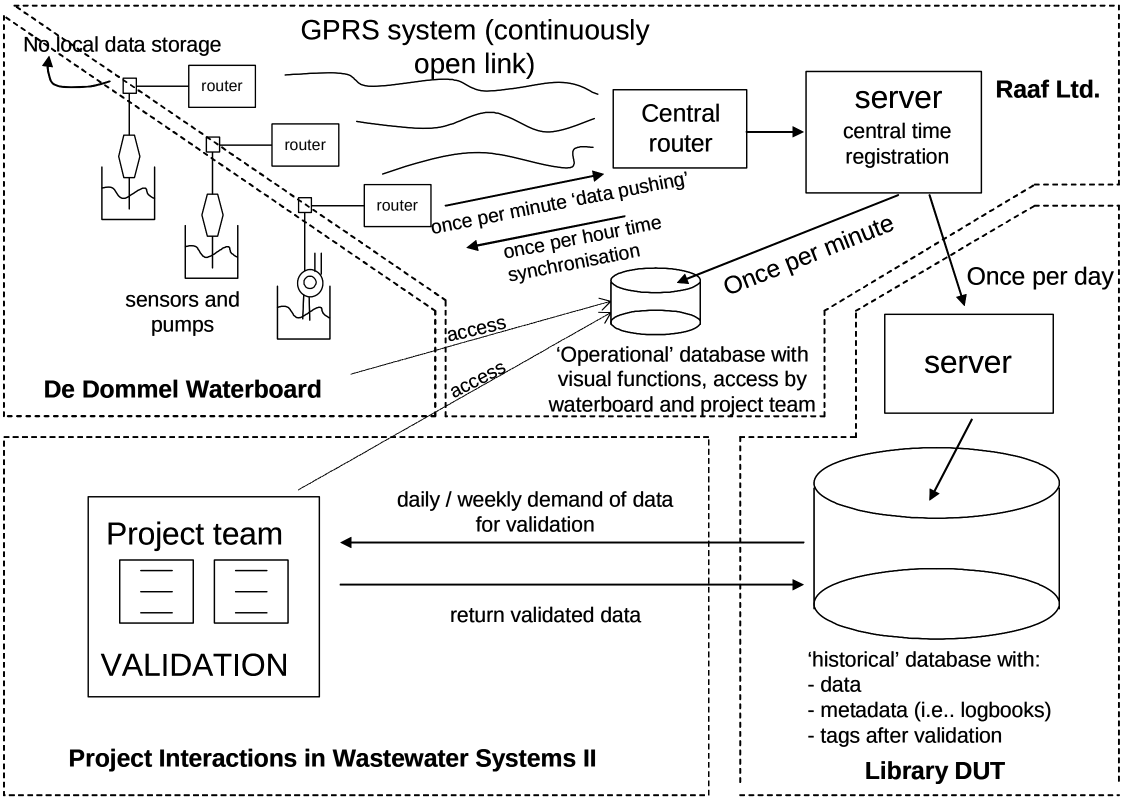

Figure 3.1: Data transmission and validation scheme used in Eindhoven (Schilperoort et al. 2006)

Gruber et al. (2004) discussed the potential causes of data gaps during online water quality monitoring in receiving waters in Vienna. Many data gaps were attributed to data transmission errors. Consequently, careful planning and execution of data transmission are crucial. Potential causes identified:

- Failure of sensor software: The software programme either failed to open or was not in the external trigger mode (resulting in failure to transmit data to the central station software)
- Sensor cable error (sensor not plugged in): Failure of one or more sensors to transmit data to the local computer
- Local computer failure: The local computer failed to store and thus to transmit data via a GSM connection.
- Down time for maintenance
- Sensor transmitter down
- GSM network down: Data sets are stored in the local computer but cannot be transferred to the central server.
- Power outage: A USV power supply unit provides backup power for an interruption-free electricity supply; during a power outage, the station's computer can continue to operate on backup power for one hour; after that, the computer performs a controlled shutdown and does not record any further data until normal power is restored.

3.6 Data Validation

The use of questionable or incorrect data can result in false conclusions. This can have a considerable impact on system operation or planning, depending on which purpose the monitoring data are used. Careful monitoring site planning and operation as well as thorough and extensive validation of the collected data are essential for the production of high-quality data.

Online water quality sensors generate huge quantities of data due to their high temporal resolution and the large number of signals recorded per unit time. Consequently, automated pre-validation screening is necessary because the data load would be too large to handle by manual validation alone.

Manual validation is often performed based on graphic visualisation. This is an unrealistic method of dealing with long-term data sets. However, a considerable amount of time must be invested in the development and adaptation of automatic validation systems. Therefore, manual validation is the preferred method for short-term monitoring campaigns. In Dudelange, manual data validation was achieved by comparing the sensor readings with other measurements or by comparing the measurements recorded by two UV-VIS spectrometers (dual sensor measurement).

In automated pre-validation screening, data sets from the sensor are classified as "correct", "questionable" or "incorrect". Manual validation is then performed only for data classified as questionable. Because a large amount of time must be invested in the development and adjustment of automated data validation systems, they generally are not used except in long-term sewer monitoring projects. Because of the multitude of potential applications for these systems, there is no standard validation protocol for all conceivable monitoring sites and sensors. The validation procedure must always be locally adapted to the specific wastewater matrix and local conditions.

However, fully automated data validation is not advised because it generally is not possible to define all potential errors and measurement phenomena in advance when programming the software. Therefore, automated data validation does not entirely dispense with the need for critical visual inspection.

In Tholey-Sotzweiler, semi-automated routines based on regression analysis were developed for plausibility testing and for detection and correction of outliers and drift. Investigators (e.g. in Graz) have identified the need for automated data validation during long-term sewer monitoring campaigns and will implement such procedures during the next project phase. Investigators in Utrecht developed an automatic data validation tool (Van Bijnen and Korving 2008). 55,000 data objects are stored each day. The validation procedure consists of a group of different tests for identification of missing data, detection of readings outside the expected measurement range, etc. Regression models are used for recognition of trends. The pre-validation procedure used in Lyon consists of a series of seven tests (Mourad and Bertrand-Krajewski 2002). In each test, the sensor reading is assigned the value "A" (correct), "B" (questionable) or "C" (incorrect). The final rating is derived from the worst scores of the seven individual tests. This method must be adjusted for each sensor. Data classified in pre-validation screening as questionable or incorrect is subject to final manual validation. In the end, only two classifications are possible—correct or incorrect.

The seven tests are:

1- Sensor operation test: Is the sensor in the on or off mode?

2- Outlier check: Is the sensor reading within the plausible physical measurement range?

3- Is the local reading realistic?

4- Assessment of measurement quality based on time between measurement and last maintenance date. Measurements obtained shortly after the last maintenance date are classified as "correct", and those obtained long after the last maintenance date are classified as "questionable".

5- Is the gradient of the sensor reading in a realistic range?

6- Redundancy between readings from two sensors measuring the same parameter at (approximately) the same site, if possible

7- Analytical redundancy (between two measurement parameters that correlate with each other)

4 Summary

After reviewing the available information from institutes and individuals with previous experience monitoring combined sewer overflows, we found that no standard procedure for the design and operation of such monitoring stations exits. Four key points must be considered when planning CSO monitoring stations:

- The specific local conditions,
- The objective of the study,
- The feasibility of the maintenance workload and
- The size of the budget.

The past sewer monitoring campaigns performed help to simplify the design of future monitoring stations, for example, by uncovering the advantages and disadvantages of installing the sensors directly within the sewer or in a bypass line outside the sewer. In this report, we have summarised the existing knowledge on the use of sensors for online sewer monitoring, particularly UV-VIS and ion-selective sensors. In-depth past experience with the calibration of online sensors for monitoring of wastewater and combined sewer systems has led to the development of "standardised" sensor calibration procedures that can be directly applied in other studies. This knowledge base allows for more efficient planning of online sewer monitoring system operation and maintenance. Certain aspects, however, must be adapted to specific local conditions, particularly the local wastewater matrix. Researchers have already learned valuable lessons on the management of monitoring systems under extremely variable hydraulic conditions, ranging from the very small discharges occurring during dry weather flow (DWF) to very large discharges during wet weather flow (WWF). The data transmission technology currently available for transmission of the collected data sets is very advanced, reflecting recent developments in the entire field of information technology. Regarding data calibration, new developments for research and operational applications are currently in the pipeline.

As shown in this report, online water quality monitoring has many advantages over the conventional method of sample collection with subsequent laboratory analysis. Online water quality monitoring permits quasi continuous data recording, providing valuable information on highly dynamic processes. Technical requirements for online water quality monitoring systems are high but necessary for the generation of high-quality data sets that can be used with confidence.

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Appendix A

Table A-1: General information on sewer monitoring in Lyon, France (OTHU project)

Location	Lyon and surrounding area
Motivation	The *Observatoire de Terrain en Hydrologie Urbaine* (OTHU) is an observatory for the study of urban drainages, particularly stormwater runoff, and their environmental impacts. The objective of monitoring is to find solutions for better management of wastewater treatment. Main areas of research interest: ▪ Rainfall distribution ▪ Water and pollutant discharges from catchment areas during wet and dry weather flow ▪ Effects of discharges on soil, aquifers and receiving waters ▪ Interaction between urban and rural catchment areas ▪ Sustained strategy development in urban water management Five representative sites in Lyon and surrounding areas were selected for study of: ▪ Different urbanisation types ▪ Combined and separate sewer systems ▪ Combined sewer overflows, percolation tanks and stormwater retention tanks ▪ Effects on receiving water and aquifer
Objective of monitoring	To study the effects of combined sewer overflows on the receiving water (rapidly flowing stream) in Ecully (the other sites had a different focus and were not included in this analysis).
Project executors	▪ Eight research partners: BRGM, Cemagref, Ecole centrale de Lyon, ENTPE, INSA de Lyon, Université Lyon I, Université Lyon II, Université Lyon III (13 of its institutes) ▪ Operational partners: Grand Lyon, Agence de l'Eau, Ministères de l'Equipement, de l'Ecologie et de la Recherche, Région Rhône-Alpes
Contact	Jean-Luc Bertrand-Krajewski, Laboratoire de Génie-Civil et d'Ingénierie Environnemental, INSA de Lyon

Duration of campaign	Since 1999
Site selection criteria	Ecully: Small urban catchment area with moderate population density
Catchment area	Mainly combined sewer drainage; overflows spill into a small catchment with fast flowing water. Monitoring performed at the *du Valvert* overflow. Size: 245 ha
Type/site of sensor installation	Bypass installation: Water quality sensors at all stations are installed in structurally identical bypass lines. Flow metering is performed inside the sewer up- and downstream of the combined sewer overflow. Water supplied by peristaltic pump in flume. Flow rate: 1l/s. Maximum water level: 7 m (internal hose replaced every 3 weeks due to wearing). Flow metering: In bypass line via the pump. Pump flow is reversed every 12 minutes to clean the bypass inlet (immediately after a measurement).

Table A-2: Deployment of online sensors for sewer monitoring in Lyon, France (OTHU project)

Device type	Manu-fac-turer	ATEX certifi-cate	Target parameters	Additional measurement equipment	Data logging frequency	Calibration	Reference measurement	Automatic cleaning		Manual cleaning	
								Type	Frequency	Type	Frequency
UV-VIS spectrometer	s::can	Yes	CODeq TSSeq T	Automatic sampler Compressor for automatic cleaning	Every 2 min	Once over 24-hour period	Monthly	Compressed air	Every few minutes	Mechanical, with water	1-2 times a week; as needed
Turbidimeter (dual sensor measurement)		No	Turbidity		Every 2 min					Mechanical, with water	1-2 times a week; as needed
			pH Conductivity								
Piezometer Ultrasound (Doppler)		Yes	Flow (dual sensor measurement)		Every 2 min					Mechanical	Monthly and after large events

Table A-3: General information on sewer monitoring in Graz, Austria (IMW project)

Location	Graz, Austria
Motivation	Long-term online sewer monitoring for analysis of pollutant transport processes in sewers
Objective of monitoring	Online monitoring of annual pollutant loads discharged from a combined sewer overflow in the city of Graz to the receiving water (River Mur).
Project executors	IMW research group: ▪ Institute of Water Protection, Freshwater Ecology and Waste Management, University of Natural Resources and Applied Life Sciences, Vienna, Austria ▪ Institute of Urban Water Management, Graz University of Technology ▪ Institute for Water Quality, Resources and Waste Management, Vienna University of Technology ▪ DDI Dieter Depisch und Silvia Kerschbaumer-Depisch ZT GmbH engineering firm
Contact	Günter Gruber, Institute of Urban Water Management and Landscape Water Engineering, Graz University of Technology
Duration of campaign	Since 2002
Site selection criteria	▪ Potential to measure full-volume CSO discharges ▪ Accessibility ▪ Space to set up a measurement container for storage of non-explosion-proof electronic devices ▪ Access to essential infrastructure (electricity, water and internet/broadband): ▪ Proximity to the Institute of Urban Water Management and Landscape Water Engineering, Graz University of Technology ▪ Adequate protection from vandalism / inconspicuous design
Catchment area	Size: 350 ha Population: 13,000 inhabitants

Type/site of sensor installation	**Direct measurement**: Explosion-proof UV-VIS sensors mounted on a pontoon placed inside the sewer. Pontoon attached by steel cables to the ceiling (permits measurement during minimal water flow conditions at night) and to the back and side walls of the combined sewer overflow (for return of pontoon to the wastewater channel after rain events). Baffle underneath the pontoon achieves pooling of water below the pontoon at minimum flow during the night periods and reduces the risk of clogging. **Bypass installation**: Non-explosion-proof sensors installed in a flume outside the sewer. Water supplied by peristaltic pump in closed bypass line with flow-through flume. Flow rate: 3 l/s. Maximum water level: 6 metres Magnetic inductive flowmeter used in bypass line. Bypass flow pump activated only during rain events (triggered by measured water depth in CSO chamber). The bypass line is cleaned by reversing the direction of pump flow while rinsing the bypass with clean water at the same time.

Table A-4: Deployment of online sensors for sewer monitoring in Graz, Austria

Device type	Manu-facturer	ATEX certifi-cate	Target parameters	Additional equipment	Data logging frequency	Calibration	Reference measurement	Automatic cleaning		Manual cleaning	
								Type	Frequency	Type	Fre-quency
UV-VIS spectrometer	s::can	Yes	CODeq TSSeq NO3-Neq Temp	Video camera for surveillance Floodlights Compressor for compressed air cleaning	Wet weather flow: Every 3 minutes Dry weather flow: once/minute	Local calibra-tion based on 24-hour monitoring campaign with hourly sampling; control based on analysis of combined sewer samples from auto-mated sampler	If a non-removable coating forms, use distilled water as zero reference (twice a year)	Air pressure: 5 bar	Every 5 measurements or every 15 min during wet weather flow; every 5 min during dry weather flow	Mechan-ical	As needed
Ion-selective sensor	Nadler	No	NH_4 N pH NO_3-N		Same s::can sensor	One-point: every 2 weeks Two-point: every 8 weeks		Cleaned with pure water or compressed air			As needed
Flo Dar® Doppler radar flowmeter	Marsh McBurney	Yes	Q, v and H in inflow channel								As needed
Ultrasonic flow-meter OCM flowmeter		Yes	Q, v and H in discharge channel								As needed
Conductance sensor			Conductivity								
Pt100			T								

Table A-5: General information on sewer monitoring in Homburg-Bröl, Germany

Location	Homburg-Bröl, Germany
Motivation	Development of strategy for integrated real-time control of sewer system and wastewater treatment plant
Objective of monitoring	Evaluation of online ammonia, COD, pH and temperature monitoring using sensors installed in WWTP influent and CSO effluent
Project executors	Aggerverband Gummersbach (Agger Water Authority) Cologne University of Applied Sciences (FHS Köln)
Duration of campaign	Two years
Site/type of sensor installation	Two sites: One bypass system suited for different CSO structure types. Impeller pump positioned between scumboard and weir crest; design ensures adequate sampling material even during small events. Second bypass system for sewer network monitoring. Space restrictions and low water volume prevent use of pontoon-mounted sensor (direct measurement). Shredder pump used for wastewater pumping was mostly clog-free

Table A-6: Deployment of online sensors for sewer monitoring in Homburg Bröl, Germany

Device type	Manufacturer	ATEX certificate	Target parameters	Calibration	Reference measurement	Automatic cleaning		Manual cleaning	
						Type	Fre-quency	Type	Frequency
Ion-selective electrodes	Four manufacturers	No	NH_4	Multiple laboratory analyses for calibration purposes (once a month, a daily curve was generated using composite samples collected every 2 hours) yields 12 curves for 3 event types (DWF, WWF and short events), 24 x 10 min composite samples	Every 10 days with use of new membranes	Com pressed air			Every 7 days (with reference measurement)

Table A-7: General information on sewer monitoring in Tholey-Sotzweiler, Germany

Location	Waste water system Tholey-Sotzweiler, Germany
Motivation	To study possibilities of improving control of combined sewer overflows into the wastewater treatment plant in order to assess the potentials for integrated operation of the sewer system and WWTP. Calibration of sewer network model.
Objective of monitoring	Monitoring in sewer network and inflow channel of WWTP to generate data for simulation model calibration
Project executors	EVS – Entsorgungsverband Saar (Waste Disposal Association of Saarland) Kaiserslautern University of Technology, Department of Urban Water Management NIVUS GmbH
Contact	Ralf Hasselbach, Entsorgungsverband Saar (EVS)
Duration of campaign	12/2006 to 06/2008
Site selection criteria	In three sewers with storage capacity and overflow so that 70% of the pollutant loads could be analysed.
Catchment area	Size: 400 ha Population: 12332 inhabitants
Site/type of sensor installation	Direct measurement (in situ), also using non-explosion-proof sensors that were switched off when explosive gases were detected. Sensors are installed directly in front of the weir crest. During dry weather flow, the sensors were stored in a piece of pipe sealed at the bottom and open at the top. A float lifted the sensors out of the pipe during overflow events. According to the investigators, this did not protect the sensors adequately from drying.

Table A-8: Deployment of online sensors for sewer monitoring in Tholey-Sotzweiler, Germany

Device type	Manufacturer	ATEX certificate	Target parameters	Calibration	Reference measurement	Automatic cleaning		Manual cleaning	
						Type	Fre-quency	Type	Frequency
UV-VIS spectrometer	s::can	Yes	CODeq TSSeq	Extensive calibration; daily curve from 2-hour composite sample	Once a month with distilled water^	Compressed air			Once a month and as needed
Ion-selective electrodes	WTW® VARIO conductivity meter, N, with potassium compensation	No	NH_4		Two-point calibration	Compressed air			Once a month and as needed
OCM Pro ultrasonic sensor with cross-correlation	NIVUS		V for Q calculation			Almost maintenance-free			
Air ultrasonic transducer			V for Q calculation						
Ultrasonic sensor			H in front of and behind the weir crest						

Table A-9: General information on sewer monitoring in Dudelange, Luxembourg

Location	Dudelange, Luxembourg
Motivation	Study on utilisation of storage capacity of large sewer systems for CSO discharge storage during wet weather flow.
Objective of monitoring	▪ Online monitoring of water quantity (l/s, m²/d) and quality (COD, TSS, NO_3) during dry weather flow (hydrographs) and combined sewer overflows (external target) ▪ Determination of infiltration water discharge rate (external target) ▪ To perform tracer test for flow-through measurement assessment (internal target) ▪ UV-VIS absorption measurement calibration by means of multiple local calibrations (COD) (internal target) ▪ Comparison of UV-VIS measurements with those obtained using s::can spectrolyser and U-VAS/ SOLITAX sensor (HACH LANGE) (internal target)
Project executors	CRTE/CRP Henri Tudor NIVUS GmbH
Contact	Kai Klepiszewski, CRTE Emmanuel Henry, CRTE
Duration of campaign	5 March 2007 to 12 April 2007
Site selection criteria	Inlet of stormwater overflow downstream of Dudelange. Future site of a stormwater tank in bypass
Site/type of sensor installation	Direct measurement (inline) ▪ Three OCM Pro flow meters distributed throughout cross-section of flow ▪ s::can spectrolyser mounted on the bottom of a float ▪ HACH LANGE sampler equipped with UVAS sensor (SAC) and SOLITAX sensor (turbidity) (bypass installation) ▪ ISCO 4250 sensor for water level (H) measurement (for control of sampler) ▪ ISCO Avalanche (refrigerated sampler) ▪ ISCO 674 (rain gauge)

Table A-10: Deployment of online sensors for sewer monitoring in Dudelange, Luxembourg

Device type	Manufacturer	ATEX certificate	Target parameters	Additional equipment	Data logging frequency	Calibration	Reference measurement	Automatic cleaning		Manual cleaning	
								Type	Fre-quency	Type	Frequency
UV-VIS spectro-meter	s::can	Yes	CODeq TSSeq	ISCO automatic sampler	1 min	Based on comparison of sampling comparison and HACH LANGE cuvette test results (37 comparison samples)	Reference measurement with distilled water	Com-pressed air	5 min	Brush and cleaning solutions	Twice during monitoring campaign
OCM Pro ultrasonic sensor with cross-correlation	NIVUS	Yes	V H		1 min	Water level (H) measured using metre stick			Brush	Weekly	
UV-VIS spectro-meter	HACH LANGE	No	SAC Turbidity		2 min			Wiper	5 min		
Water level (Pressure)	ISCO	No	mm		1 min						
Rainfall	ISCO	No	min								

Table A-11: General information on sewer monitoring in Odenthal, Germany

Location	Odenthal, Germany
Motivation	Monitoring campaign for discharge-oriented assessment of combined sewer overflows into sensitive salmon breeding sites in the scope of the Odenthal research project and as a basis for sewer network control planning (sewer network/WWTP).
Objective of monitoring	Online monitoring of combined sewer overflows and WWTP inflows and outflows. Monitoring data will be used to develop the following models: ▪ Pollutant load simulation model ▪ Hydrodynamic drainage model ▪ Water quality simulation model Dynamic simulation programme for the WWTP Description of hydraulic stress and water pollution
Project executors	Department of Urban Water Management and Environmental Engineering, Ruhr-Universität Bochum Wupper Water Association (Wupperverband)
Contact	Dr. Holger Hoppe, Ruhr-Universität Bochum (now at Dr. Pecher AG in Erkrath)
Duration of campaign	Various campaigns during the 2000 to 2002 period
Site selection criteria	▪ Combined sewer overflows at relevant structures ▪ Accessibility and safe working environment ▪ Representativeness
Catchment area	Size: 318 ha Paved area: 62.86 ha Population: ca. 12,500 inhabitants
Site/type of sensor installation	Direct (inline) UV measurements (Dr. Lange company) in inlet (behind screen) and outlet of WWTP and discharge channel of a combined sewer overflow (in front of crump weir) Sensor mounted on base of sewer or flume Direct (in situ) UV measurement (comparison with s::can UV-VIS spectrometer measurements) in the wastewater treatment plant inlet Direct in-situ measurements in receiving water (conductivity, temperature, O_2 content)

Table A-12: Deployment of online sensors for sewer monitoring in Odenthal, Germany

Device type	Manufacturer	ATEX certificate	Target parameters	Additional equipment	Data logging frequency	Calibration	Reference measurement	Automatic cleaning		Manual cleaning	
								Type	Fre-quency	Type	Frequency
SAC sensor	Dr. Lange	No	SAC	Bühler automated refrigerated sampler	1 min		As needed				Event-dependent
TS sensor	Dr. Lange	No	TS		1 min		As needed				Event-dependent
	WTW	No	Temperature Conductivity		1 min		As needed				< 4 weeks
FDU 80 ultrasonic sensor	Endress & Hauser		H V				As needed				< 4 weeks

Table A-13: General information on sewer monitoring in Bochum, Germany

Location	Bochum, Germany
Motivation	Monitoring campaign to generate data on the discharge behaviour of a sewer with storage capacity and overflow as the basis for development of an integrated real-time sewer system control strategy.
Objective of monitoring	Online monitoring of combined sewer overflows and outflow discharge to the wastewater treatment plant
Project executors	Department of Urban Water Management and Environmental Engineering, Ruhr-Universität Bochum
Contact	Dr. Helmut Grüning, now at Dr. Pecher AG, Erkrath
Duration of campaign	1999-2000 (12 months; detailed analysis of 20 individual events)
Site selection criteria	Potential for monitoring of pollutant concentrations in combined sewer overflows and throttle drainage at a stormwater tank Accessible and safe working environment Representativeness
Catchment area	Size: 360 ha Paved area: 165 ha Population:15000 inhabitants
Site/type of sensor installation	UV measurements (Dr. Lange company) directly in the discharge channel and throttle line Sensor mounted on base of sewer or flume Additional sampler Sewer storage V= 1680 m³ Throttle line – DN 800 Discharge channel – DN 2500

Table A-14: Deployment of online sensors for sewer monitoring in Bochum, Germany

Device type	Manufacturer	ATEX certificate	Target parameters	Additional equipment	Data logging frequency	Calibration	Automatic cleaning		Manual cleaning	
							Type	Fre-quency	Type	Frequency
SAC sensor	Dr. Lange	No	CODeq BOD5eq		5 min					
TS sensor	Dr. Lange	No	TS		5 min					

Table A-15: General information on sewer monitoring in Eindhoven, Netherlands

Location	Eindhoven, Netherlands
Motivation	Optimatisation of urban drainage system: To reduce pollution of river by introducing clean water from wastewater treatment plant and combined sewer overflows
Objective of monitoring	To evaluate the impact of sewer network control on pollutant discharges, monitoring in combined sewer
Project executors	▪ Delft University of Technology ▪ Waterschap de Dommel
Contact	Remy Schilperoort, Delft University of Technology
Duration of campaign	Since 2006
Site selection criteria	Site allowing temporal and spatial analysis of dynamic changes in water quality ▪ Monitoring in sewer main pipes in which the entire wastewater from a district is collected ▪ Accessibility ▪ Flow measurement: Minimum distance of measuring equipment behind shaft or change in hydraulic conditions must be 25 times the sewer pipe diameter
Catchment area	10 municipalities Size: 60,000 ha Population: 425,000 inhabitants
Site/type of sensor installation	Six measurement sites (3 stationary sites in the inlets to the WWTP and 3 mobile sites within the sewer system) Bypass installation because of frequent difficulty of access to the measuring sites. Pumping by non-shredding pump in a container. Flow rate: 8 l/s. Maximum water level: 7 metres.

Table A-16: Deployment of online sensors for sewer monitoring in Eindhoven, Netherlands

Device type	Manu-facturer	ATEX certificate	Target parameters	Data logging frequency
UV-VIS spectrometer	s::can	Yes	CODeq Soluble CODeq TSSeq	Once per minute
			Conductivity Temperature	Once per minute
			NH_4-N	
			Turbidity	
Flo-Tote-3™ electromagnetic flowmeter	Marsh McBirney		Q	Once per minute
Ultrasonic sensor (for method comparison)			Q	Once per minute
Bubble tube level			H	Once per minute

Table A-17: General information on sewer monitoring in Kulloch – Wuppertal, Germany

Location	Wuppertal, Germany
Motivation	Discharge monitoring
Objective of monitoring	Online monitoring to generate discharge monitoring data (at connection between the sewer system of a development area to an industrial site)
Project executors	▪ WSW Energie und Wasser AG ▪ Dr. Pecher AG
Contact	Dr. Helmut Grüning, Dr. Pecher AG, Erkrath Dr. Holger Hoppe, Dr. Pecher AG, Erkrath
Duration of campaign	Since 2008
Site selection criteria	Monitoring of pollutant loads in adjacent sewer system Accessible and safe working environment Representativeness (good mixing of wastewater)
Site/type of sensor installation	Direct measurement: UV-VIS spectrometer (s::can) installed directly in pump well. Shaft cleaned regularly (suction cleaning) to prevent clogging by routine maintenance of pump well.

Table A-18: Deployment of online sensors for sewer monitoring in Kulloch – Wuppertal, Germany

Device type	Manufacturer	ATEX certificate	Target parameters	Additional equipment	Calibration	Reference measurement	Automatic cleaning		Manual cleaning	
							Type	Frequency	Type	Frequency
UV-VIS spectrometer	s::can	Yes	CODeq TSSeq	Laboratory analyses	Two-point calibration (minimum)	Every 2 weeks	Compressed air			Every 2 weeks

Table A-19: General information on industrial discharge monitoring in Wuppertal, Germany

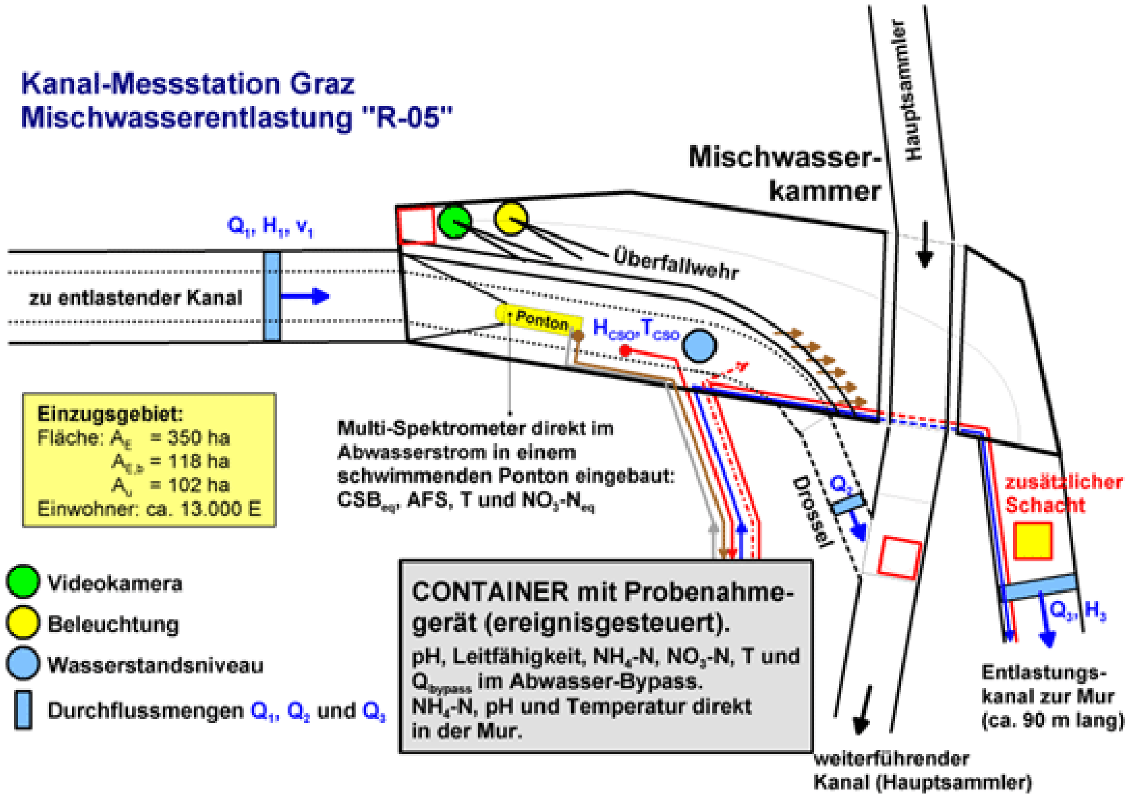
Location	Wuppertal
Objective of monitoring	Rtc Evaluation of rain water discharge treatment system
Project executors	▪ WSW Energie und Wasser AG ▪ Dr. Pecher AG
Contact	Dr. Helmut Grüning, Dr. Holger Hoppe, Dr. Pecher AG, Erkrath
Duration of campaign	Since 2007
Site selection criteria	Determination of pollutant Accessible and safe working environment Representativeness
Site/type of sensor installation	UV-VIS spectrometer (s::can) Direct measurement (in situ)

Table A-20: Deployment of sensors for industrial discharge monitoring in Wuppertal, Germany

Device type	Manu-facturer	ATEX certificate	Target parameters (amongst others)	Additional equipment	Data logging frequency	Calibration	Reference measurement	Automatic cleaning		Manual cleaning	
								Type	Fre-quency	Type	Frequency
UV-VIS spectrometer	s::can	Yes	CODeq TSSeq	Laboratory analyses	Every1 to 5 min	Two reference measurements including 43 control measurements	Weekly	Com-pressed air			Weekly up to every 4 weeks
Magnetic inductive flowmeter					Every 1 to 5 min						

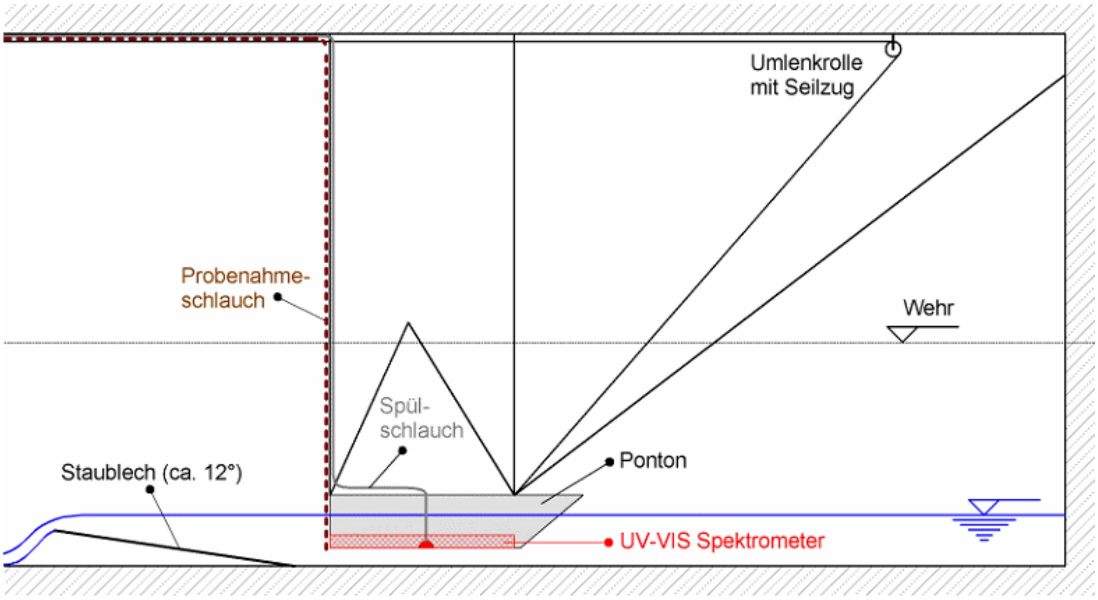
Translation of text in figures:

Figure 2.2



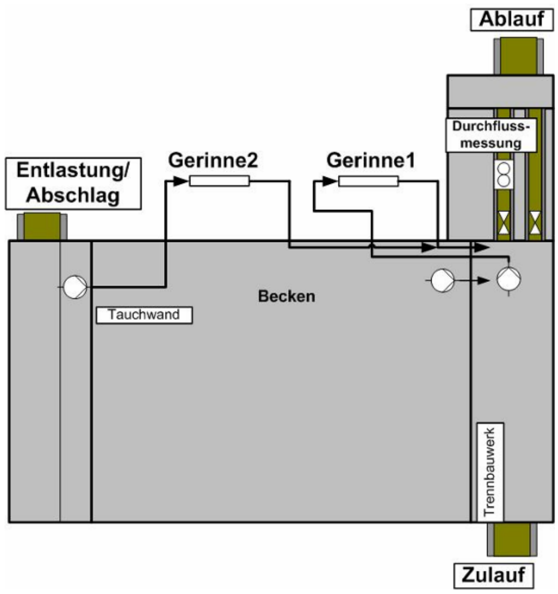
Graz Monitoring Station Combined Sewer Overflow R-05		CSO chamber	
Inflow channel	Overfall weir		
Catchment area: Area: Approx. 13,000 inhabitants	Pontoon		
	Multi-spectrometer installed on pontoon located directly in medium: COD_{eq}, TSS, T and NO_3-N_{eq}	Outflow	Additional manhole
Video camera Lighting Water level sensor Flow rates Q1, Q2 and Q3	Container with sampler (event-controlled): pH, conductivity, NH_4-N, NO_3-N, T and Q_{bypass} in the wastewater bypass NH_4-N, pH and T directly in the River Mur		Overflow channel to River Mur (approx. 90 m)
		Receiving sewer	

Figure 2.3



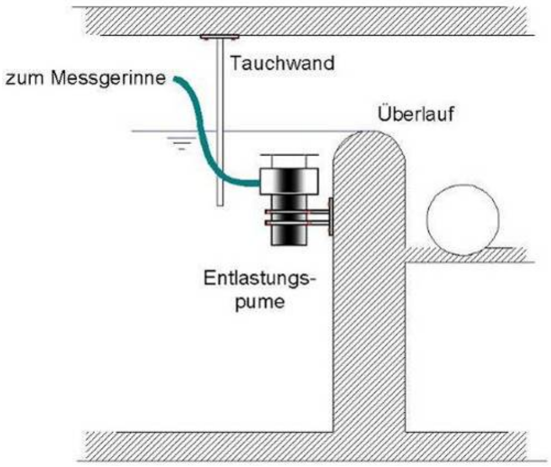
			Cable hoist with deflection roller
Sampling tube			Weir
Baffle (approx. 12°)	Rinsing tube	Pontoon	
		UV-VIS spectrometer	

Figure 2.4



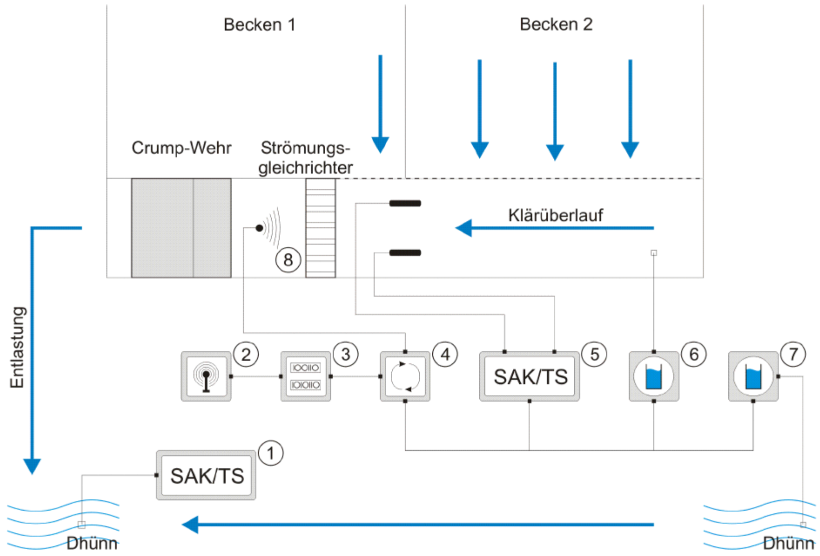
			Outlet
Overflow	Channel 2	Channel 1	Flowmetry
	Scumboard	Basin	Flow divider
			Inlet

Figure 2.5



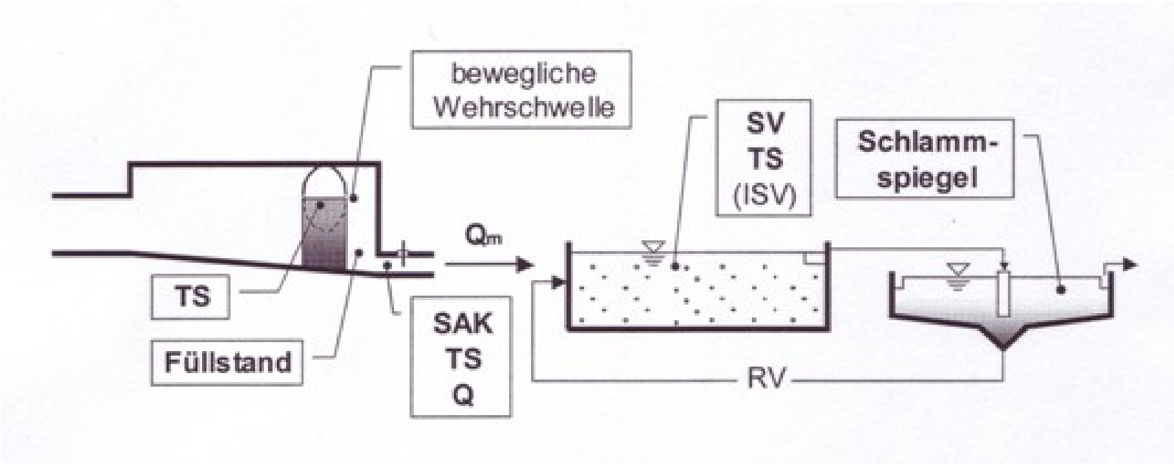
To flume	Scumboard	Overflow
	Pump	

Figure 2.7



		Basin 1	Basin 2	
	Crump weir	Flow regulator	Overflow structure for settled combined water	
Discharge channel			SAC/TS	
	SAC/TS			
River Dhünn				River Dhünn

Figure 2.8



	Floating weir		
TS	SAC TS Q	SV TS (ISV)	**Sludge level**
Filling level		RV	