Compliance with the Urban Waste Water Treatment Directive: European Union City Responses in Relation to Combined Sewer Overflow Discharges

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Abstract

Compliance with the European Union Urban Waste Water Treatment Directive ('the Directive') is a pre-requisite for achieving the primary objective of the Water Framework Directive[1]. 11 EU-27 Member States had to comply with certain requirements of the Directive by 2005. Figures released in 2009 revealed a lack of compliance for wastewater treatment, but 100% compliance for wastewater collection in 8 out of the 11 Member States. This high level of compliance has been facilitated by significant investment in collection and combined sewer overflow (CSO) discharge prevention approaches and technologies. For cities with population equivalent in excess of 1 million, the most common approach to resolving CSO issues was identified to be the addition of extra capacity. Within some cities the use of these

approaches was complemented by the use of real-time control (RTC) and several cities combined both of these approaches with waste water treatment plant (WWTP) expansion and/or sewer separation. Two cities were identified as utilising source control techniques, alongside conventional approaches. Four projects utilised tunnels, in combination with WWTP expansion and RTC. It is apparent that there is not a 'one size fits all' intervention in dealing with problematic CSOs, when trying to comply with the Directive.

Keywords

Combined sewer overflow, compliance, implementation, urban wastewater treatment directive, water management

1. Introduction

A pre-requisite in meeting the primary objective of the Water Framework Directive[1], is achieving implementation of the EU UWWTD ('the Directive'), which addresses the challenge posed by anthropogenic waste water generation as a source of pollution to European waters (Commission of the European Communities, 2009). Negative impacts of waste water discharge include eutrophication, fish kills and impacts on drinking water supplies. By requiring collection and treatment of waste water in all agglomerations in excess of 2000 population-equivalent (p.e.), the Directive aims to eradicate these negative impacts. Two ways of complying with the requirements of the

[1] To ensure that all waters in the EU achieve good ecological status by 2015

Directive are to increase the level of waste water treatment and to increase collection of waste water. The latter assists in the prevention of discharges from combined sewer overflows (CSOs), a major source of pollution to water bodies. This paper focuses on collection for the prevention of CSO discharging, providing a comprehensive review of the approaches being taken by member states in relation to CSO compliance in large cities.

1.1. Compliance by Member States

For EU-15[2] and EU-12[3] Member States, timelines for compliance are slightly different, with the latter having transitional implementation periods for specific agglomerations. Within the full EU-27 there are more than 23,000 agglomerations larger than 2000 p.e., producing 600 million p.e. of waste water (Commission of the European Communities, 2009). In the most recent implementation report (Commission of the European Communities, 2009) only 18 Member States provided required data. Table 1summarises compliance with the Directive in 2009.

Table 1 Compliance with the UWWTD by 18 EU-27 Member States in 2009 (CEC, 20009)

[2] EU-15: Member States prior to 2004 - Austria, Belgium, Denmark, Germany, France, Finland, Greece, Ireland, Italy, Luxemburg, Portugal, Spain, Sweden, The Netherlands, United Kingdom

[3] EU-12: Member States who acceded after 2004 - Bulgaria, Czech Republic, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Romania

Of those 18 Member States, 11 had to comply with certain requirements of the Directive by 2005. Figures revealed a lack of compliance for treatment requirements, but 100% compliance for collection in all countries except Belgium (98%), Portugal (95%) and Slovakia (91%) (Commission of the European Communities, 2009). This high level of compliance has been facilitated by significant investment in a diverse range of collection and CSO discharge prevention approaches and technologies, a review of which is provided in the following sections of this paper.

2. Method

Due to the number of agglomerations to which the Directive applies, cities with a p.e. in excess of 1 million were prioritised for detailed investigation. A comprehensive review of publications from journals, conference proceedings and other sources was undertaken and key experts from across Europe were contacted, in order to provide the most up to date information. Information was gathered using the following methods:

- Internet search to produce a list of the largest cities in the EU, together with their associated water bodies;
- Preliminary internet literature search for documents relating to the UWWTD implementation and CSOs;
- Electronic journal search using EBSCO-EJS to identify relevant academic papers;
- Review of appropriate conference proceedings;
- Identifying and contacting appropriate authors from papers derived from the above journal papers and conference proceedings, as well as the author's peers.

Efforts to obtain Eureau document B4-3040/96/000173/DI, titled ‘Stormwater pollution control in the EU member states’, via contacting Eureau direct and also personal contacts – the document could not be located;

This information was collated and forms the main body of this review.

3. Approaches to Waste Water Collection for CSO Abatement

Although only agglomerations with a p.e. in excess of 1 million were investigated in detail, information is summarised for both large and small cities in Table 2andTable 3, for comprehensiveness. However, the proceeding sections only review in detail a selection of the approaches utilised by the large agglomerations (though these approaches may well be used in smaller agglomerations).

Surprisingly, compliance with the Directive was not the only driver for implementing CSO discharge abatement techniques. Other drivers included the Bathing Water Directive, national guidelines and reducing the impact of urban flooding. The most common approach to resolving CSO issues was identified to be the addition of extra capacity, whether by the construction of detention tanks and/or trunk or interceptor sewers (Athens, Thessaloniki). Within some cities the use of these approaches was complemented by the use of real-time control (RTC) (Barcelona, Lisbon, Marseille, Vienna, Zagreb). Several cities combined both of these approaches with waste water treatment plant (WWTP) expansion (Copenhagen, Lisbon, Paris, Prague) and/or sewer separation (Copenhagen, Hamburg) (Butler and Ward, 2009).

Two German cities were identified as utilising source control techniques (sustainable drainage systems (SuDS)/disconnection-infiltration, retention basins) alongside conventional approaches (Berlin, North Rhine-Westphalia). Three projects, located in London, Naples and Vienna, utilised tunnels in combination with WWTP expansion and RTC, although the use of tunnels was being assessed in Paris. Helsinki and Stockholm were also identified as utilising tunnels, but this was due to a range of historic reasons, not compliance with the Directive (Butler and Ward, 2009).

Table 2 Summary of CSO abatement approaches in large cities of the EU (Butler and Ward, 2009)

Table 3 Summary of CSO abatement approaches in small cities of the EU (Butler and Ward, 2009)

3.1. Case Studies of Approaches

In order to provide a more in-depth understanding of compliance with the Directive, approaches utilised by the countries summarised in Figure 1are described in the following sections. The agglomerations chosen as case studies are from across all parts of the EU and were selected to represent the diversity of approaches being used to comply with the Directive.

Figure 1 Options for cities in Europe described in detail in this paper (Map from Wikipedia, licensed under the Creative Commons Attribution-Share Alike 2.5 Generic license)

3.1.1. Vienna, Austria

Vienna's RTC activity has become one of the best documented case studies of urban drainage management introduced to comply with water protection regulations. Recent developments within the network include large storage sewers along the river banks of the Danube, Donaukanal, Wein and Liesing (Fuchs and Beeneken, 2005). Additionally, the construction of a detention basin close to the main WWTP of Vienna is planned, with a total volume of approximately 255,000m^3 (Teufel, 2007). These are designed to minimise CSO spills to receiving water bodies during storm water episodes, as well as moderating the inflow to the WWTP.

At the end of 2006, a 3 km long, 30 m deep wastewater tunnel along the River Wien, the 'Weintal-Kanal', was completed. The Wiental-Kanal is capable of storing up to

110,000 m^3 of waste water. In the event of heavy rainfall the Vienna Sewer Network Control sets the rate at which wastewater is discharged to the main WWTP. Additionally RTC is used to control the distribution and pumping systems, which regulate the discharge of water and prevent pollution of the River Wien with diluted wastewater (Wien International, 2006). The Sewer Management System Real Time Control ('SeMaSys RTC') will activate the storage capacity of these relief sewers and detention basin (Nowak, 2007). SeMaSys RTC consists of:

- devices to measure flow (55 points), levels (20 points), point and areal rainfall (25 stations and rainfall radar);
- Local control devices to regulate flow and levels;
- SCADA system to collect and display measured data;
- Central control system to facilitate decision making based on measurements and forecasts.

Within SeMaSys RTC the sewer network is reduced to approximately 2200 pipes, in order to increase computational time. The model was calibrated using measured data and uses Hystem-Extran software to generate rainfall-runoff. The control system is rule-based, but evaluated with the aid of fuzzy logic and the input data. Results from simulations (undertaken using ITWH-CONTTROL software) and real situations are stored in a database for upgrading and self-learning (Fuchs and Beeneken, 2005). The Danube left-bank ('LDS') phase of the RTC became operational in 2005 and the total simulated reduction in accumulated CSO volumes for one year was estimated at around 30% (Nowak, 2007). The second phase comprises the Donaukanal right bank main collector (known as ‘RHSK-E’), which came into operation in 2006. Evaluation results showed the retention volume amounted to slightly over 40% of the previously discharged volumes (Nowak, 2007). The third and final phase, to be realised by 2015, comprises the integration of the Liesing and Wien storage sewers, as well as system optimisation.

3.1.2. Prague, Czech Republic

In 1995 the Municipality of Prague initiated a feasibility study to define a new Urban Drainage Master Plan (UDMP). There were several reasons for a new study, but in particular the previous UDMP ended in 1988 and did not take into account impacts on receiving waters (Gustafsson *et al.*, 2000). The fundamental principle of the UDMP is based on an integrated approach to rainfall-runoff transport and treatment processes in the catchment, sewer, treatment plant and the receiving waters. The conceptual phase of the UDMP began in 1999 with evaluative modelling work to set a final strategy for 2015-2030. Results indicated primarily that the Troja Island WWTP would require expansion, but that the existing structure of the sewer network (combined in the centre and separated in the suburbs) could remain unmodified (Gustafsson *et al.*, 2000). However, in August 2002 serious flooding hit Prague, which challenged this conclusion (Hrabak *et al.*, 2005).

The Prague sewerage network, as well as the main WWTP, was hit by the floods. Rising water in the Vltava River flooded the WWTP and prevented the outflow of wastewater. The system became highly overloaded due to the high water level in the river, the closing of flood defence caps, the overflowing of outlets from the main sewers beneath the city and direct runoff caused by the storm. Measures to remedy this disaster began immediately in autumn 2002. A great deal of attention was focused not only on protective measures against floods caused by rainfall volumes, but also on measures to prevent the 'self-flooding' of the city, caused by the combination of flood and urban waters forced into the sewer system (Hrabak *et al.*, 2005).

Consequently, a number of projects were undertaken to improve the performance of the sewer system. Flood gates were installed within the sewers and CSOs received modification, as well as slight changes in tank geometry and the installation of pre-treatment devices. As far as could be identified, there is also a large retention tank being constructed in the Karlin area (Pryl, 2009). Further work was undertaken to fully understand the impacts of CSO remodelling on receiving water bodies in Prague, from a water quality perspective. In order to assess benefits of the individual CSO reconstruction phases, pollution and hydraulic impacts of overflow were simulated by a computer model ('REBEKA') using a 70 year rainfall time series for Prague. Simulation results for the reconstruction phases revealed a gradual decrease in the average number of overflows per year, overflow volume and duration and the amount of suspended solids discharged in the individual reconstruction phases. The average number of overflows possibly causing ammonia toxicity was reduced by half (from 9 to 4.9) in phase II and nearly eliminated in phase IV (0.4). However, the overflow volume, amount of suspended solids correlating to heavy metals and hydraulic stress were not significantly reduced until phase V in 2005. In addition to this, research on new types of CSO was being undertaken (Pollert *et al.*, 2008).

3.1.3. Copenhagen, Denmark

In Copenhagen there are 43 overflow structures in action between 0-33 times a year – the average discharge being approximately 14 times annually. However, this varies between CSOs near the harbour, where interventions have been implemented, and those areas awaiting development (Sorensen *et al*, 2005). A number of new retention basin facilities have been built since 1994 in order to avoid or reduce wastewater discharge to marine and freshwater areas during high intensity rainfall events. The plants were dimensioned according to the specific requirements of individual receiving waters set out by the environmental authority. The Sydhavnen facility (15,000 m^3) utilises comprehensive online management of gates and meters, which has improved conditions in the inner harbour. The Utterslev Marsh facility (limited to the northern neighbouring municipalities) was supplemented with a constructed wetland system in 1998 allowing the mixture of wastewater and rainwater to be treated before discharge to the nearby marsh. The East Amager facility (40,000 m^3) ensures the requirement for bathing water quality can be met. It is the first time that this has been made a primary requirement. During this period, attention was increasingly directed to the sewer system's impact on ground water and on conditions in lakes and streams.

Consequently, the water quality has increased in the harbour, permitting the reopening of several public swimming baths, 50 years after the last one was closed due to the levels of pollution reaching the harbour. As some areas are still to be improved, a SCADA-based alarm system was implemented within the harbour, to warn of CSO incidences likely to cause high *E. coli* concentrations. The limit was established at less than 1000 *E. coli* per 100 ml for less than 5% of the bathing season. This was estimated to correspond to 2-3 overflow events during the bathing season, which is of 92 days. Figure 2illustrates the reduction in CSO volumes released to the harbour since 1995 (Sorensen and Kofod-Andersen, 2005).

Figure2 Measured and predicted reductions in CSO volumes released to the Copenhagen harbour areas (Sorensen and Kofod-Andersen, 2005)

The next phase of intervention is rehabilitation to the sewer system of the new Ørestad district of Copenhagen and involves implementation of a separate sewer system. The water will be divided into three streams: wastewater, rainwater from contaminated surfaces (roads, parking areas, etc.) and rainwater from clean surfaces (roofs, parks, etc.). The wastewater will be led to the treatment plant, while the rainwater from clean surfaces will be used recreationally in the established canals. The contaminated rainwater will be treated in a specially designed rainwater treatment plant, which will utilise dual porosity filtration (a pilot was undertaken in 2005), before being released into the canals. The future townscape of this district will include open drains containing the uncontaminated rainwater from roofs (Sorensen *et al*., 2005).

Additionally, in 2008, an investigation was made as to whether to treat surface runoff and discharge directly into the harbour or convey the surface run-off with the wastewater to a centralised wastewater treatment plant and discharge into the sea, outside Copenhagen (Clauson –Kaas *et al*., 2008). A 0.6 km² area of the harbour area which is being completely renewed was selected for conducting the modelling of three scenarios:

1) Interception of all surface runoff with the centralised wastewater system;

2) Interception of poor quality surface runoff to the centralised wastewater system and local discharge of good quality surface runoff;

3) Local discharge of all surface runoff.

For each scenario, the investment, operation and maintenance costs were calculated and are given in Table 4andTable 5.

Table 4 Investment costs (€) for the three scenarios (Clauson –Kaas *et al.*, 2008)

Table 5 Operation and maintenance costs (€) for the three scenarios (Clauson –Kaas *et al.*, 2008)

Combining investment, operation and maintenance costs, the interception of poor quality surface runoff alone is, financially, comparable to discharging all surface runoff locally. Environmentally, it was estimated that for scenario 2 more than ten times the number of *E.Coli* would be potentially discharged compared to scenario 3. For scenario 1 the discharge is about ten times higher than for scenario 2. In terms of bathing water quality, scenario 3 (local discharge of all runoff) is the best solution.

Considering the economic and environmental assessment, it was decided to implement scenario 2 (local discharge of good quality surface run-off and intercepting of poor quality surface run-off) for the whole harbour area. Presently, all new urban developments in the area will have to comply with this system. In future, the issue will have to be approached comprehensively, for example by reducing this diffuse pollution from vehicles and improving the removal of ecotoxic compounds. At the same time, building permits will only be given if the roof materials do not include ecotoxic compounds such as Zn, Pb, Cr, Cu and PAH. This solution also supports the policy of the management of Copenhagen who want to disconnect as much rainwater as possible from its wastewater system to reduce operational costs on pumping stations and wastewater treatment plants and also to prepare for a change in rainfall pattern as a consequence of climate change (Clauson –Kaas *et al*, 2008).

3.1.4. North Rhine-Westphalia, Germany

The Rhine-Ruhr metropolitan area (RRMA) is the largest metropolitan area of Germany with about 11,800,000 inhabitants. It is the only megacity in Germany. In 1990 the decision was made to reconstruct the Emscher hydrological system with restored watercourses - the 'Emscher project'. An entire river with a total length of 85 km within a huge metropolitan region is undergoing rehabilitation (Frehmann *et al.*, 2008). After reconstruction, the maximum inflow during heavy rainfall events will be 16.5 m^3/s instead of the 30 m^3/s at present (Frehmann *et al.*, 2008).

Along the 'rainwater route' (Figure 3), rainwater is disconnected from the sewer and infiltrated to enrich the groundwater and to re-establish the water cycle. Additionally, the restoration of watercourses is being undertaken and several industrial enterprises are constructing their own pre-treatment plants. Additionally, in October, 2005 the Emscher Association ('Emschergenossenschaft'), the local authorities in the Emscher region and the Environmental Ministry of the Federal Land of North Rhine-Westphalia signed the ‘Agreement for the Future Management of Stormwater’. The target of this agreement is that within the next 15 years 15% of the stormwater generated in the Emscher catchment will be decoupled from the sewer system, with a new sewer network ready by 2014/15 (Geretshauser and Wessels, 2007). This will substantially reduce the number and frequency of CSOs required. Future plans for the area also include:

- Improvement of rainwater treatment (for example, infiltration of rainwater at source, where possible);

- Reduction of municipal, industrial, trade, mining and polluted rainwater discharges. (Herbke *et al*., 2006)

In terms of charging, a membership fee is paid, which is dependent on the quantity and quality of sewage and rainwater being discharged. For example direct dischargers pay directly to the Emscher Association, whereas households are represented through municipalities (‘*democratic legitimisation*’). As such the charging system already incorporates the polluter-pays principle and cost recovery in the Emscher River Basin ranges from 96.9% to 107.2% (Herbke *et al.*, 2006).

It is estimated that the overall wastewater management restructuring of the 865 km² Emscher catchment area will cost around €4.5 billion (Frehmann *et al.*, 2008). Subsidies of €4.5 million were provided for the Emscher region for the implementation of rainwater harvesting and infiltration projects up to 1999. The subsidies amounted to €5/m² of impervious area disconnected from the drainage system. Since 1994, 18 towns have participated with a total of 82 different projects and 47 projects have been or are being implemented. These pilot disconnection programmes are centralised into a GIS known as the Stormwater Management Information System, 'SMIS', based on the Open Geospatial Consortium (OGC) standard. SMIS allows local authorities to easily identify feasible disconnection measures to implement in other areas, as well as calculating the percentage of an area with potential for disconnection (Geretshauser and Wessels, 2007).

Figure 3 The 'Rainwater Route' of the Emscher Region (Becker and Raasch, 2001)

As well as these disconnection activities, the main component of the restoration scheme is the large underground trunk sewer, which has been under construction since 2001. The sewer will have a total length of 51 km and runs alongside the Emscher from Dortmund to Dinslaken. The wastewater which had previously been discharged to the Emscher will be collected and subsequently fed to the WWTPs in Bottrop and Dinslaken (also known as 'KLEM'), (Frehmann *et al.*, 2008).

Operation of such a critical infrastructure, serving several millions of people poses particular challenges. As such, Frehmann *et al.* (2008) undertook an integrated simulation of the entire system. Treatment plants were implemented using the 'SIMBA' simulation for wastewater systems, rainfall-runoff modelling was provided by 'MOMENT' (previously established by the Emscher Association) and the trunk sewer was modelled using the US EPA 'SWMM5'. The integration of these models permitted a range of automated operational control scenarios to be investigated across the entire Emscher wastewater system.

3.1.5. Naples, Italy

The Directive was transposed into Italian law through the National Directive 152/1999, which was published on May 11th, 1999. However, its complete fulfilment is still far from being achieved, particularly in Southern Italy. However, there are a number of features of the Neapolitan sewer network designed to deal with CSO spills (Gisonni, 2009). Most of the main sewer system is comprised of tunnels, due to the particular urban context (steep slopes, dense urbanization and a large underground infrastructure). The principles of 'sustainable drainage' are not heavily utilised by the Neapolitan City Council. Within the tunnels, drop structures are quite frequent with drop heights as large as 80 m. For this reason most of the structures are vortex drop shafts. One of the latest installations on the sewer network in Naples is the Impianto di Coroglio. Its main features include preliminary wastewater treatment, such as screens, sand traps, roto-sieves (illustrated inFigure 4), which then pump the effluent to the main WWTP via a 12 km long tunnel (Gisonni, 2009). The design discharge is 22,000 m^3/per hour (approximately 500,000 p.e.) and the plant is equipped with noise and odour control. CSO structures (such as side weirs, bottom openings and baffled weirs) are generally designed so that the sewer flow is directed to the WWTP for up to five times the average dry weather flow. Discharges exceeding this may then be conveyed directly towards the receiving water bodies (Gisonni, 2009).

Figure 4 Sand removal and roto sieving at Impianto di Coroglio, Naples (Gisonni, 2009)

RTC is not currently being applied extensively. A few pumping stations are equipped with automatic systems aimed at managing emergency conditions. Additionally, debris screens and sediment traps are often built, but they suffer from a systematic lack of maintenance. Furthermore, no flushing systems are in operation due to: (i) steep slopes that guarantee adequate self-cleaning velocities; and (ii) water shortages, meaning there is little spare capacity to flush the sewer channels (Gisonni, 2009).

3.1.6. Barcelona, Spain

The drainage system within Barcelona experiences a rainfall regime with high intensity events. In addition the catchment contains both high mountains and flat coastal areas with a high population density and a high percentage of impervious land. This combination has resulted in historic floods and fluvial and coastal pollution during rainfall events. The Great Olympic sewerage works was completed in 1992, but the sewer network was still insufficient, inflexible and under conventional management. At this time the municipality became aware of the need for a new approach towards the sewer system and its management. This resulted in the council creating a new company, CLABSA, which is a public-private partnership tasked with transforming the drainage system. CLABSA is focused on the planning, control and exploitation of technology to be more effective against flooding and pollution (Salamero *et al.*, 2002).

The main drivers for improvement have been fulfilment of *EU directives*, increased demand on the system, increased environmental awareness and coordination problems with wastewater treatment plants (WWTP). With this in mind a new ‘Advanced

Management of Urban Drainage' (GADU) approach has been utilised. A Master Drainage Plan and decision support systems (DSS), such as the territorial information system (SITE), a modelling system (SIMO) and a RTC system (SITCO), have been developed with an emphasis on data quality and reliability to facilitate full sewerage management. As such, the sewer network now comprises: 1,650 km of sewers, 41,000 manholes, 60,000 inlets, 69,000 connections, 500 control instruments, 405 km of fibre optics, a 150km vacuum waste collection network, 146 flow control points, 24 rain gauges, 9 CSO control points and 2 water quality control points (some of these are illustrated in Figure 5). Actuators allow automatic local/global control of 10 tanks, 19 pumping stations and 36 gates (Figure 6). The system is strictly maintained and uses appropriate control algorithms and the extensive SITCO database within SIMO to simulate levels and flows in the network, as well as CSO spills and their effect on receiving waters.

The Master Drainage Plan also identified a need for a 70% reduction in CSOs. Therefore between 1997 and 2005 a range of interventions were implemented, including:

- 10 x 500,000 m^3 tanks (Figure 6);
- 1 storage gate and 5 diverting gates (Figure 6);
- 25 km of sewers with large dimensions.

In 2002, a pilot RTC scheme was conducted in the Bac the Roda catchment to develop a methodology for Barcelona-wide implementation (Barro *et al.*, 2002), which was then fully implemented. During a rainfall event the infrastructure is managed using RTC across a range of emergency levels. RTC of the detention tanks has permitted the regulation of 2,700,000 m^3 of discharges per year (including industrial discharges), preventing 470 tonne of suspended solids being spilled. This has led to an improvement in the quality of the receiving water evidenced by a reduction in faecal coliform numbers and a decrease in anoxia zones in the harbour bottom. The infrastructure interventions and control techniques undertaken have been heavily publicised within Spain, both at national conferences and in local media. Education and awareness raising activities were undertaken, including tours of the control rooms and underground tours of the detention tanks (Escaler Puigoriol, 2009).

Figure 5 Real Time Control of the sewer network of Barcelona (Escaler Puigoriol, 2009)

Figure 6 Detention tank and gates in the sewer network of Barcelona (Escaler Puigoriol, 2009)

3.1.7. London, United Kingdom

Designed in the 19th century and built as a combined system, London's sewer system is no longer able to cope with the volumes of sewage and runoff generated by its continually expanding population and increase in impervious areas, respectively (Thames Water, 2011a). To tackle increasing CSO discharges, Thames Water in conjunction with the Environment Agency began investigating possible solutions in 2001 (Thames Water, 2011b). A total of 34 unsatisfactory CSOs were identified – 22 of which required direct interception and 12 of which could be dealt with indirectly, through local improvements. The independent Thames Tideway Strategic Study considered and rejected the following options for reducing discharges from the unsatisfactory CSOs, for the following reasons:

- Widespread implementation of SuDS – logistically and financially prohibitive;

- Separation of the combined sewer system into separate surface and foul water sewers - logistically and financially prohibitive;

- Addition of in-line or off-line storage in the form of detention/retention tanks – disruption, land availability and cost of fragmented storage;

- Extend use of existing bubbling and skimming boats (to reduce the impact of discharges of untreated sewage) – viewed as merely tackling symptoms and not a viable long-term solution.

Consequently, the selected solution was an integrated programme of works (London Tideway Improvement Programme) consisting of improvements at 5 sewage treatment works (STW) and construction of the Lee Tunnel and the Thames Tunnel. The tunnels will intercept excessive flows before they reach CSOs, acting as a storage device from which the flows will be conveyed to Beckton STW in east London (Thames Water, 2011a). At present, investigative studies are being undertaken at sites selected for the tunnel drive shafts, with construction utilising tunnel boring machines (TBMS) due to commence in 2013 and completion estimated to be in 2023. The main tunnel will be 23km long and 7.2m in diameter at depths of 33m to 65m depth in a west to east direction (Figure 7), with additional connection tunnels with diameters from 2.2m to 5m (Thames Water, 2011d). Estimated costs at the time of publication were €807M, €760M and €4.8M, for the STW improvements, Lee Tunnel and Thames Tunnel, respectively.

Construction will involve coordination with 14 local authorities, an extensive list of other consultees and bodies under the Infrastructure Planning Regulations and compliance with a range of recommendations outlined in the extensive Environmental Impact Assessment conducted. Considerable pre, during and post-construction monitoring is planned, to ensure that all operations are conducted in the most environmentally sustainable manner. Real time control aspects are embodied in the coordinated operation of the existing sewer system, expanded treatment works and the tunnel system. It is estimated that implementation of the Thames Tunnel will reduce CSO discharges from over 50, to four or less in a typical year with capture of about 96% of the CSO volume, fulfilling compliance with the Directive (Thames Water, 2011d).

Figure 7 Preferred Route for the Thames Tunnel, London (Thames Water, 2011c)

4. Discussion and Conclusion

The ways in which cities in several EU Member States aim to achieve or are achieving compliance with the collection/CSO component of the Directive have been identified. The main drivers for dealing with problematic CSOs are not restricted to compliance with the Directive; they also include complying with the Bathing Water Directive and reducing urban flooding. Additionally, approaches to compliance either with the Directive or National Laws transposed from the Directive vary widely between Member States, depending on the region or water/waste water management structure/organisation. Several cities have established a ‘Master Plan for Urban Drainage’ as a vehicle by which to review and address the existing and future issues associated with parts of their sewer networks (Barcelona, Hamburg, Prague, Zagreb).

The most common approach to resolving CSO issues was identified to be the addition of extra capacity, whether by the construction of detention tanks and/or trunk or interceptor sewers (Athens, Thessaloniki). Within some cities the use of these approaches was complemented by the use of RTC (Barcelona, Lisbon, Marseille, Vienna, Zagreb). Several cities also combined both of these approaches with WWTP expansion (Copenhagen, Lisbon, Paris, Prague) and/or sewer separation (Copenhagen, Hamburg). Two German cities were identified as utilising source control techniques (SUDS/disconnection-infiltration, retention basins) alongside some of the more ‘traditional’ approaches (Berlin, North Rhine-Westphalia). Four recent projects, located in Paris, London, Naples and Vienna, utilised tunnels with all utilising them in combination with WWTP expansion and RTC. The use of tunnels is also currently being assessed in Paris. Helsinki and Stockholm were also identified as utilising tunnels, but this was due to a range of historic reasons, not compliance with the Directive.

Within smaller cities, a range of approaches was also identified, ranging from interceptor sewers (Granollers, Spain and Steinkjer, Norway) and off-line storage basins (Cosenza, Italy), through to source control and SuDS (Baerum and Bergen, Norway and Lund and Malmo, Sweden) and local or pre-treatment techniques (Oeiras, Portugal). RTC was also popular at this scale, especially in Germany (Bochum, Dresden, Leipzig, Obere Iller). Within all approaches identified, data collection and modelling were key components of design and comparisons of several options using feasibility assessments were common.

Operationally, Scandinavian and Western European cities were identified as being further ahead with implementation than Eastern European cities. These tended to be in the data collection and modelling phase, rather than the construction phase. Vienna was the most advanced in utilising RTC, but even so was not 100% operational. In conclusion, it is apparent that there is not a ‘one size fits all’ intervention in dealing with problematic CSOs, when trying to comply with the UWWTD or other drivers.

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Table 1 Compliance with the UWWTD by 18 EU-27 Member States in 2009 (CEC, 20009)

Infrastructure	% Provision of the total pollution load
Collecting Systems	98%
Secondary Treatment	87%
More Stringent Treatment[4]	72%

[4] Required in sensitive areas

Table 2 Summary of CSO abatement approaches in large cities of the EU (Butler and Ward, 2009)

Country	City	Driver	Approach/es	Cost	Status
Austria	Vienna	National guidelines	RTC, detention tunnel/basins.	€123 M (RTC only)	Mostly operational
Croatia	Zagreb	Water quality Environment	RTC, expand collectors	-	Data collection/modelling
Czech Rep.	Prague	Flooding Water quality	Pre-treatment, expand interceptor, add retention tanks, expand WWTP	-	Part implemented, part planned
Denmark	Copenhagen	Bathing water quality	RTC, retention basins, WWTP expansion, sewer separation	-	Operational
Finland	Helsinki	Bathing water quality Environment	RTC, WWTP, sewer tunnels, separate sewers	-	Operational
France	Lyon	WFD Flooding	RTC, data collection, modelling	-	Operational
	Marseille	Bathing water quality	RTC, trunk sewers	-	Operational
	Paris	WFD	RTC, new/expanded WWTP, storage (reservoirs/tunnels)	€4000 M	Mostly operational
Germany	Berlin	National guidelines (via UWWTD)	RTC (local), SuDS, heightening CSO crests, storm tanks	-	Operational
	Hamburg	National guidelines (+ flooding)	Sewer separation, retention basins, interceptors, WWTP expansion	€767 M €7.7/m^3	Operational
	North Rhine-Westphalia	Environment	Trunk sewer, disconnection of impervious areas, infiltration	€4500 M	Part operational, part ongoing construction
Greece	Athens	Flood and pollution control	Interceptor sewer diversion/expansion	-	Planned
	Thessaloniki	Flood and pollution control	Additional interceptor	-	Under construction
Italy	Naples	UWWTD	Tunnel, new WWTP, RTC, odour control	-	Operational
Netherlands	Rotterdam	Flood and pollution control	RTC, detention tanks and small scale SuDS	€11 M (tanks & RTC)	Operational
Portugal	Lisbon	Water quality (pollution)	RTC, on/off-line storage, interceptor sewer, WWTP upgrade	€160 M (to 2012)	Part operational, part ongoing construction
Spain	Barcelona	Flood and pollution control	RTC, detention tanks	-	Operational
Sweden	Stockholm	Various	Tunnels, WWTP	-	Operational
UK	London	UWWTD	Tunnels	€4000 M	Public Consultation

RTC = Real-Time Control; WWTP = Wastewater Treatment Plant; WFD = Water Framework Directive; UWWTD = Urban Wastewater Treatment Directive; SuDS = Sustainable Drainage Systems; CSO = combined sewer overflow

Table 3 Summary of CSO abatement approaches in small cities of the EU (Butler and Ward, 2009)

Country	City	Approach/es
Denmark	Albertslund (Copenhagen)	Source control (retention ponds), oil separators
	Various	Enhanced clarification technologies (local treatment)
Estonia	Tallinn	Water quality monitoring/modelling
France	Rosheim	Simulated RTC of storm basin and WWTP
	Selestat	Modelling for instrumentation
	St Malo	Interceptor sewer/RTC
Germany	Bochum	RTC
	Dresden	RTC of sewers and retention ponds
	Leipzig	RTC/WWTP rehabilitation
	Obere Iller	RTC of sewer and WWTP
Germany/ Norway	Various	Simulated RTC
Italy	Cosenza	Off-line storage basin; Constituent-Index Relationships
	N/A	Application of RTC to theoretical sewer network
Kosova	Prishtina	Sewer separation
Norway	Baerum	‘*Distributed Stormwater Management Practices*’
	Bergen	‘*Stormwater solutions without pipes*’ and the ‘*Blue–Green concept*’ - planning ‘*flood ways*’ within urban areas
	Steinkjer	Interceptor sewer
Portugal	Oeiras	Pre-treatment of CSOs
Scotland	Various cities	Disconnection/source control
Spain	Granollers, Besos Basin	Interceptors, source control, detention basins
Sweden	Helsingborg	RTC, sewer system rehabilitation, retention pond construction, WWTP expansion
	Lund	SuDS
	Malmo	SuDS
	Vasastaden	Source control (modelled)
UK	Liverpool	Optimal Pollution Control (OPC – simulated RTC)

Table 4 Investment costs (€) for the three scenarios (Clauson –Kaas *et al.*, 2008)

	Scenario 1 Size	**Cost (M €)**	**Scenario 2 Size**	**Cost (M €)**	**Scenario 3 Size**	**Cost (M €)**
Retention basin (m^3)	16,500	21.5	5,300	4.0	0	0.0
Pumping station (#)	14	0.2	14	0.2	23	0.3
Pipeline (m)	8,200	0.5	8,200	0.5	15,600	1.3
Local runoff treatment (#)	0	0.0	0	0.0	12	0.1

Table 5 Operation and maintenance costs (€) for the three scenarios (Clauson – Kaas *et al.*, 2008)

	Scenario 1 Size	**Cost (M €)**	**Scenario 2 Size**	**Cost (M €)**	**Scenario 3 Size**	**Cost (M €)**
Retention basin (m^3)	16,500	0.02	5,300	0.01	0	0.00
Pumping station (#)	14	0.05	14	0.05	23	0.07
Pipeline (m)	8,200	0.02	8,200	0.02	15,600	0.04
Local runoff treatment (#)	0	0.00	0	0.00	12	0.04

Figure 1 Options for cities in Europe described in detail in this paper (Map from Wikipedia, licensed under the Creative Commons Attribution-Share Alike 2.5 Generic license)

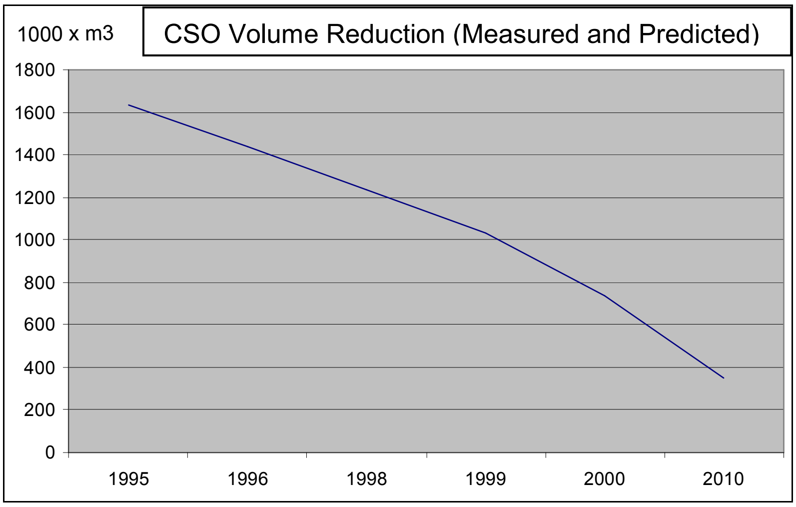

Figure 2 Measured and predicted reductions in CSO volumes released to the Copenhagen harbour areas (Sorensen and Kofod-Andersen, 2005)

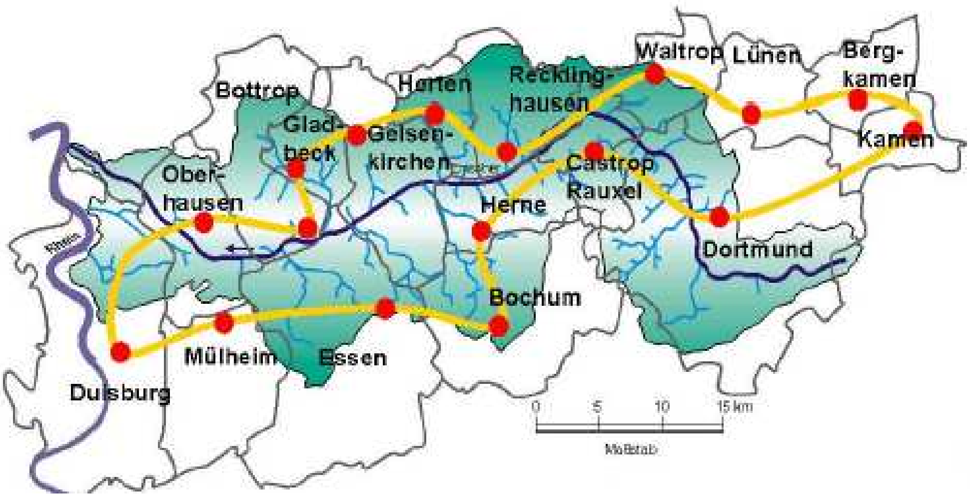

Figure 3 The 'Rainwater Route' of the Emscher Region (Becker and Raasch, 2001)

Figure 4 Sand removal and roto sieving at Impianto di Coroglio, Naples (Gisonni, 2009)

Figure 5 Real Time Control of the sewer network of Barcelona (Escaler Puigoriol, 2009)

Figure 6 Detention tank and gates in the sewer network of Barcelona (Escaler Puigoriol, 2009)

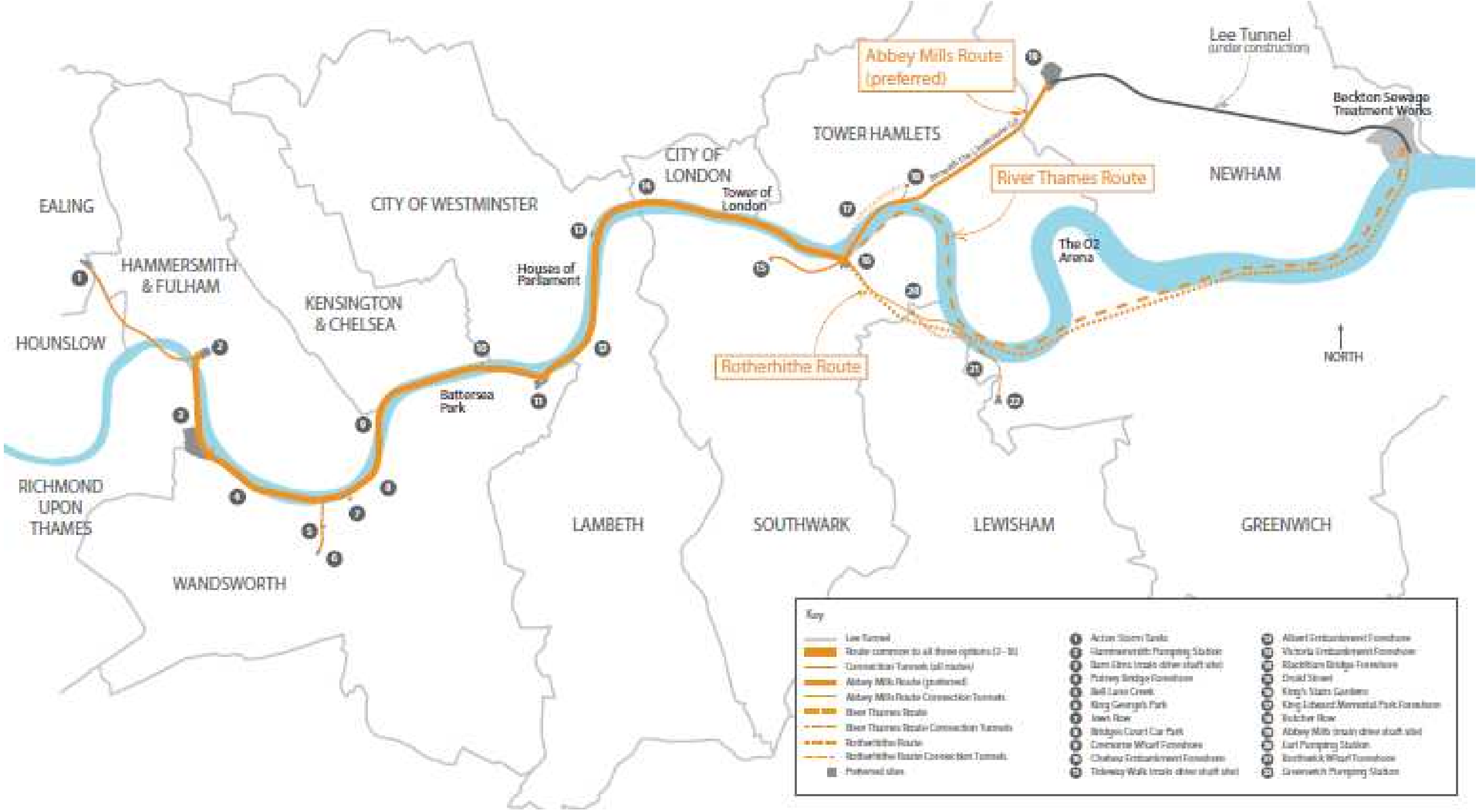

Figure 7 Preferred Route for the Thames Tunnel, London (Thames Water, 2011c)