MODERN APPROACH TO MANAGEMENT OF COMBINED SEWER OWERFLOWS

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Abstract: *Combined Sewer Overflows (CSOs), which are build on combined sewerage network to diminish amount of wastewater carried to wastewater treatment plant (WWTP), loud receiving waters with considerable amount of mixture of sewage and storm water and pollution which they carry. Receiving waters are polluted and their ecological status is affected. The aim of stormwater management in the combined sewerage network during rain event is to keep CSOs overflows in sustainable limits. It is generally necessary to minimize the total emissions from CSOs and WWTP´s. The paper presents basic results of a critical state-of-the-art review on impacts of combined sewer overflows on receiving waters. Paper also describes the potential of technologies for CSOs treatment. Today the conventional measures for reducing CSO pollutant load are well known, however the stochastic behavior of rainfall and the uncertainties in land use development as well as the limited knowledge on efficiency of CSO treatment yield the most difficult conditions for design. Therefore, special attention should be paid to efficiency and cost-effectiveness of applied measures. Paper bring the integrated view of present knowledge on CSO treatment measures especially considering the current demands outgoing from the implementation of EU Framework Directive (WFD).*

Keywords: *combined sewer overflows, urban river, ecological condition,emission limit, imission limit*

1. Introduction

Combined system overflows (CSOs) constructed in the combined sewerage for technical and water management reasons in order to restrict the influent to a wastewater treatment plant (WWTP) during a rain event ensure intermittent discharging of considerable volumes of a mixture of wastewater and storm water, and the pollution contained in the water, into water courses. This strongly overloads the receiving bodies of water and their ecological condition is influenced. The objective of handling the storm water flows in sewage systems is to maintain the shock effects on the receiving bodies of water caused by the CSOs within tolerable limits. At the same time, it is necessary to generally minimise the total emissions from the CSOs and the WWTPs.

The modern approach is built upon the fact that the simulation of rainfall/runoff processes in an urban river catchment area is the current status of knowledge in the field of municipal drainage. Minimum demands on managing rainwater run-off from the combined sewerage are therefore not based on the requirements for the installation of CSOs any more, but they are based on the objective of conveying a certain proportion of pollutants on a yearly average in the flow to the biological stage of the WWTP during rain events.

2. Legislation and methodological approaches in the EU

The legal framework of the European Union in the field of water management and the environment is based on the Framework Directive 2000/60/EC establishing a framework for Community action in the field of water policy, requesting the EC member countries to restrict the pollution of bodies of water caused by diffusion and point sources and to achieve a good chemical and ecological condition of all bodies of water where it is economically and socially feasible by 2015. The framework directive also lists the main pollutants the presence of which must be restricted or fully prevented from. Combined system overflows are a source of a number of these substances (e.g. suspended solids, substances contributing to eutrophication and substances with adverse impacts on oxygen balance). To control the discharges from the point or diffusion sources of pollution into surface water, the Directive requires the so-called „joint approach" using restriction of pollution at the source by determining emission limits and environmental quality standards.

3. Ecological condition of water courses

The overflows of the mixture of wastewater and storm water from the
CSOs cause significant disturbance to the water courses and endanger their ecological condition and compromise demands on their use. The ecological condition of the water courses is put at risk by the mass and physical disturbances that are very complex and act simultaneously. The mass disturbances are caused by a number of substances of various origins as the overflowing water is a mixture of polluted surface runoff, sewage water and industrial wastewater, re-suspended sediments and eroded biofilm in the sewerage. Easily degradable organic substances are decomposed by heterotrophic bacteria consuming oxygen dissolved in water. Oxygen disappears not only from water but also from the bottom sediments in small water courses. Lack of oxygen endangers mainly sensitive fish species. Repeated organic pollution transfer lead to transformation of the trophic conditions of the ecosystem from autotrophic to heterotrophic, resulting in stronger decomposition processes and further oxygen content reduction. The composition of the food chain societies changes from the previously diverse biocenosis into monotonous biocenosis consisting of several destruents tolerant to oxygen concentrations (Krejčí et al., 2004).
Nutrients (nitrogen and phosphorus) transferred to the receiving water of water through the storm water overflows may contribute to eutrophication of the slow flowing reaches of water courses and reservoirs and associated night oxygen deficit. In the total nutrient balance in the river basin, the CSOs are sometimes less important sources than surface sources, diffuse sources and WWTP effluents; however, with the rising number of the WWTPs where nutrients are removed, and with the rising efficiency of these processes and improved agricultural processes, the importance of the combined system overflows as a source of nutrients keeps increasing (in particular, in large agglomerations). Serious problems are caused by the prevailing form of nitrogen in wastewater, being ammonium (NH_4^+) dissociating in the receiving body of water at higher temperatures and pH into toxic ammonia (NH_3) endangering fish species in lower development stages.
The CSOs overflows contain a high share of suspended solids of organic and mineral origin with a number of negative effects on the aquatic biocenosis (Krejci et al., 2004). Suspended solids cause water turbidity, reduce light transmission for plant species and cause physiological stress to fish. The settled substances cause mud silting and silting at the river bed restricting the exchange processes between flowing water and water in the sediment pores, which is negatively reflected in the oxygen supply at the river bed. The decay of the organic share of suspended solids at the river bed causes further oxygen content decrease or even anaerobic conditions. Suspended solids absorb heavy metals and organic pollutants accumulated in slow flowing

reaches and are harmful to organisms that are in contact and penetrate to the supply chain.

Physical disturbance results in changes of the living space in the water course which may lead to the disappearance of some of the aquatic societies. The most important physical disturbance is hydraulic stress, and, to a lesser extent, short-term temperature changes.

The shock storm water discharges from sewerage change, especially in small water courses, the hydraulic conditions over in a very short time. High flow velocities result in the removal of the aquatic organisms from their living space. In extreme cases, there occurs a large-scale movement of the bed and transport of sediments and extensive washing out, damage or death loss of a major part of the population. Flood waves volumes caused by runoffs from urban areas and their flow rate maxima and frequencies are much higher compared to previous runoffs from the natural environment to which the aquatic organisms are adopted. Too frequent population losses then result in major unspecified impoverished of the aquatic fauna. On the other hand, high flow rates carry away fine sediments and the river bed gets silted, which is accompanied by the decrease in the chronic effects of substances adsorbed on the sediment (Krejčí et al., 2004).

A short-term temperature increase as a result of hot storm water discharges in the summer has an influence on minor water courses where this can cause reduced dissolvability of oxygen in water and accelerated microbial processes resulting in further oxygen losses. Increased temperature also boosts toxicity of some substances (Krejčí et al., 2004).

The disturbance of some demands on using the water courses is related to its disturbed ecological condition as this is conditioned by it (e.g. fishing). The aesthetic condition is often disturbed, too, by objects in wastewater (e.g. toilette paper, sanitary napkins) and hygienic disturbance by pathogenic organisms endangering the use of the water course as a source of potable water and a bathing place (Krejčí et al., 2002).

The disturbances of the water courses by CSO overflows have various duration (Krejčí et al., 2002). Short-term (acute) effects of the increased concentration of toxic substances (in particular, ammonia), oxygen deficit, turbidity, increased temperature and hydraulic stress lasts for up to several hours after the overflow and they usually intensify each other. Delayed effects occur for several days up to weeks after the overflows and include, in particular, oxygen deficit in water and river bed sediments and disturbance of the hygienic condition by pathogenic organisms. Long-term effects of CSO overflows are a result of cumulative effects of a series of events. This includes river bed silting by suspended solids, oxygen deficit in the sediment, chronic toxicity of heavy metals and organic pollutants, eutrophication by nutrients and changed morphological structure of the water stream as a result of erosion.

The potential endangering of the water courses differs in relation to the size of the river basin and type of the water course. Generally speaking, the most endangered streams are minor water courses where the ratio of water discharged from sewerage during rain events to the flow rate in the river is substantially higher than in the streams with sufficiently high water content. As regards minor water courses in middle highlands, the hydraulic disturbance is more serious than mass disturbance, as given the high gradient of the river beds, even a relatively small increase in the flow rate may result in the removal of organisms and erosion. Compared to this, water streams in lowlands and bloated streams have a low velocity and therefore the hydraulic effects

give way to the mass effects (BWK-Materialien 1, 2003).
The flow velocity in the water course has a major impact on the duration of pollution and settling of suspended solids. The slower the water flows, the longer the duration of the adverse effects of pollution transfer on biocenosis. Fast flowing and cold streams in middle highlands are not so much affected by the organic pollution as the lowland water courses, as the substances are transported faster, and aeration and oxygen transfer through the water table is faster thanks to increased turbulence. The critical oxygen deficit does not occur immediately downstream the CSO, but further downstream, especially in reaches with low reaeration. In minor water streams the suspended solids are transported faster downstream but the river bed may be locally silted. In slow flowing reaches there occurs significant settling of fine particles and organic suspended solids from the CSO, which may lead to anaerobic conditions at the river bed associated with nutrient release and eutrophication, or, as the case may be, heavy metal re-mobilisation. Ammonia toxicity endangers river courses with limy subsoil or reaches with a higher temperature as a result of missing shading or slow flowing eutrophicated river reaches in lowlands with increased pH (BWK-Materialien 1, 2003).
Morphological quality of the CSOs has a high potential for ensuring re-settling of disturbed reaches by organisms from the undisturbed river reaches upstream or from protected spaces in the area of disturbance and therefore it is able to compensate for the CSO overflow effects relatively fast. If the interconnection with undisturbed river sections or other water streams is not provided and heterogenic habitats serving as protective spaces are lost, the re-settlement potential decreases (Krejčí et al., 2002).

4. Protection of the receiving body of water from the emission point of view

The objective of protecting the receiving body of water from the emission point of view is to make sure that a certain share of pollution contained in the mixture of wastewater and storm water conveyed through the combined sewerage is conveyed to the biological stage of a WWTP in the average yearly balance. This protects the receiving body of water mainly from the built-up pollution and its long-term effects. Emission criteria are defined both for the whole urban river catchment area drained by a combined sewage system as well as for the individual combined system overflows. Whereas the emission criteria for the whole urbanised catchment areas are directive, the criteria for the individual structures are only recommendatory. This approach makes it possible not to have to construct individual structures if the river catchment area meets the prescribed pollutant removal proportion and if it also meets the pollution criteria. As regards the average yearly balance, a minimum proportion of storm water flows and the relevant dissolved pollution and suspended solids carried by the combined sewerage must be conveyed during rain events to the biological stage of the WWTP. Dissolved pollution is understood as, for example, N-NH_4 and a major proportion of COD, BOD_5, N_t and Pt. These so-called „minimum efficiencies“ of removal do not concern the specific structures but the whole catchment area of the combined sewerage irrespective of whether the emissions are discharges into one or several receiving bodies of water. Differentiation of the emission criteria for various size categories of WWTPs reflects the efficiency of pollutant removal at the WWTP, and the density of sewerage connection rate in urbanised catchment areas. As regards larger size WWTP, the government regulation No.

61/2003 Sb. as amended, provides a higher pollutant removal efficiency and therefore it makes sense to convey stronger pollutions to the plants. A higher density of inhabitants is usually in the catchment areas of large WWTPs rather than small WWTPs. A lower required efficiency of conveying substances to small WWTPs prevents from the disproportionally high specific retention volumes in scarcely populated areas and lower wastewater treatment efficiency.

The calculation of the actual efficiency of storm water flows and pollutants in sewerage conveyed to the WWTP is conducted by means of a simulation of rainfall/run-off processes in the catchment areas using calibrated hydrological or hydrodynamical models of a multi-year rain series (preferably a minimum of 10 years). The efficiency of conveying substances during rainfalls to the WWTP may be increased by a number of diverse measures that allow for substantial flexibility in the planning process. This includes, for example, storm water infiltration, retention, increased influent to the WWTP, real time sewerage flow control and mechanical pre-treatment of water flowing through storm water overflows into the receiving body of water. The most efficient method of reducing the total emissions in sewerage using one or multiple measures and ensuring an optimal cost/benefit ratio in a specific case must be searched for by using long-term simulation of the rainfall/run-off processes in the urban catchment areas (Kabelkova et al, 2010).

5. Protection of the receiving body of water from the pollution point of view

In specific cases it is necessary to tighten up the emission criteria based on the actual effects of overflows from the CSOs in the receiving body of water , i.e. pollution. The pollution protection of the receiving body of water respects the parameters of the specific water course and concentrates on the hydraulic disturbance of the receiving body of water, acute ammonia toxicity, oxygen deficit and suspended solids. For these key indicators, the target values of the receiving body of water are defined during wet flows (pollution criteria). The pollution protection also includes hygienic pollution and aesthetic disturbance of the receiving body of water as a result of CSO overflows, for which, however, the key indicators have no target values for rain events.

Hydraulic disturbance

The CSO must not have significant adverse hydraulic effects on the biocenosis of the water stream. Their effects depend on the water course morphology, in particular the volume of protective spaces and the river bed stability. Negative ecological effects can be expected when the number of the river bed erosion events as a result of increased storm water flows is more than double compared to the natural condition; as regards water courses with disturbed morphology, the disturbance may be caused by a series of minor events.

Suitable measures to reduce the hydraulic disturbance of the water courses by CSO and storm water discharges from separate sewerage are represented by reducing storm water discharges from urban river basin by reducing the size of impermeable surfaces or their disconnection from the sewerage and retention tanks and storm water infiltration preferably in the area of the storm water discharge retention in the sewerage or storm water tanks, potentially equipped with runoff control in the sewer system in order to optimise the use of retention spaces and ensure even utilisation of the WWTP capacity and reduction in the tangential tension directly in the water course. Broadening of the river bed must be defined with respect to the depth so as not to disturb the ecological condition of the water stream. It is necessary to examine potential negative effects of the changed morphology of the water course.

Acute ammonia toxicity

Sewage water contains high concentration of ammoniated nitrogen which passes through the CSOs to the receiving bodies of water. Non-dissociated ammonia NH_3 is formed from the NH_4^+ ions at higher pH and temperature values and it is toxic mainly to fish at lower development stages. The longer the effect of ammonia, the lower the concentration the fish can handle. To exclude acute toxicity of ammonia, the $N\text{-}NH_3$ concentration in the water stream may not be exceeded even for as short time (for a period of 1 hour) over 0.1 mg/l in salmon water and 0.2 mg/l in carp water (max. permissible recurrence of 1 year).

What can be considered as a measure to reduce acute ammonia toxicity in the water course is sewage water retention and controlled discharges into the sewerage, increased throttled flow to the WWTP (lower $N\text{-}NH_4$ concentrations in separated water) and increased retention volume in the sewer, separated water pre-treatment, e.g. outlet to an earth filter. However, given the considerable space demands, this measure is usually confined to little urbanised areas. Natural vegetation shading results in reduced temperatures and pH fluctuation in the water course. This affects the dissociation balance of ammoniated nitrogen and reduces the proportion of toxic non-dissociated ammonia to the total ammoniated nitrogen.

Oxygen deficit

The organic substances transfer through the CSOs and their subsequent decomposition may result in considerable oxygen deficit in the water course or its sediments. Salmon fish is the most sensitive to the lack of oxygen. In order to ensure sufficient protection of biocenosis, the oxygen concentration in the river water as a result of the CSOs may not drop below 5 mg/l. At this concentration it is expected that there will not be anaerobic conditions even at the uppermost sediment level. The calculation of oxygen concentration in the receiving body of water after the separation is subject to considerable uncertainties even if the simulation programmes are used. Oxygen deficit in the water course is usually caused by a combination of organic dry weather loading, eutrophication, and CSO overflows. It is therefore recommended that the water course should be examined and dissolved oxygen concentrations should be measured. The lowest values occur at night and early morning when there is still no photosynthetic oxygen production.

Improvement of the situation usually calls for a combination of measures enhancing their efficiency. Potential measures to reduce the oxygen deficit include a reduction of other sources of mass loading in the water courses than the CSOs, reduction in the number of overflows and pollution transfers from the CSOs by means of measures taken in the river basin and the sewerage. It also includes the reduction in impermeable surfaces in the catchment areas connected to the sewerage, increased influent to the WWTP, more frequent sediment removal from the sewer system.

Suspended solids

Suspended solids transfer from the CSOs to the water course may result in short-term and long-term disturbance (turbidity, river bed silting, oxygen deficit at the bottom etc.). The determination of the pollution criteria for separated water is not possible given the current status of knowledge. The informative value of the pollution criteria to determine the critical cases is the concentration of suspended solids in the water course downstream the overflow amounting to 50 mg/l. A guideline when exceeding this value is the ratio between the number of inhabitants in the river catchment area (PE) and Q 347 in the water course. The exceeding is likely at PE/Q347 > 25 PE/(l/s), potentially at PE Q 347 > 15 PE/(l/s), if there are sediments in the sewers. If the recommended ratios are exceeded, it is necessary to make an on-site examination and, potentially, propose measures to retain suspended solids. Suitable measures to reduce the load caused by suspended solids are partly identical with measures to reduce oxygen deficit, i.e. a reduction in the number of overflows and pollution transfer from the CSOs in the catchment area and the sewer system, in particular regular cleaning of the sewerage in sections with low gradients and separated water pre-treatment (e.g., earth filter).

Hygienic pollution

The overflows contain a significant volume of pathogenic microorganisms (bacteria, viruses) causing hygienic pollution to the receiving body of water endangering its recreational use. Indicative organisms of faecal pollution are usually Escherichia coli and intestinal enterococca. In the separated water, concentrations of 104-107 KTJ/100 ml of Escherichia coli are expected. Although the pathogenic microorganisms in water do not propagate and, on the contrary, die relatively fast, several days after the overflow the target values of bathing water quality set out by Directive 2006/7/EC may be exceeded. Bathing water should not receive water from the CSOs or the overflow frequency should at least be reduced as much as possible. A potential solution might be a temporary ban on bathing.

Aesthetic disturbance

Waste and objects coming from the sewerage (e.g. sanitary protection trapped by the vegetation) are visible for a long time even after overflowing through the CSOs. They normally do not affect the water quality. There is no limit defined for the aesthetic disturbance. Experience shows that CSOs with the maximum frequency of overflows of 5-10x/rCSOs usually cause only small aesthetic problems. As regards river courses with increased requirements for protection against aesthetic disturbance, the following is recommended to capture the floating objects: installation of screens and sieves in the combined system overflows and scum boards. However, to trap the drifted objects, these are more efficient in respect of front overflows than side overflows. Construction of plug flow tanks is suitable for short distances in the catchment areas. In this case, the plug flow tanks are more suitable than otherwise generally recommended retention tanks retaining the first flush. Once filled up, the mixture of dry weather and wet weather flows through the combined sewerage is diverted upstream the tank directly into the receiving body of water. On the contrary, the plug flow tank carries the whole overflow which is mechanically pre-treated and gross impurities are trapped. Another possibility is to install vortex separators with a special protection of the spillway with sieves that can trap floating and drifted objects and, after a rain event, they can also ensure automatic cleaning. Along with the technical measures it is also necessary to address the method of cleaning and removing the entrapped objects while respecting all related regulations.(Kabelkova et al, 2010)

5. Checking the measures efficiency

The efficiency of the adopted measures must be checked in terms of emissions in the sewer system and pollution and its effect on the receiving body of water. Once the measures are taken, measurements should be conducted to recalibrate the simulation model and to perform numerical evaluation of fulfilling the emission and pollution criteria. Checking is also performed by field examination. Once the measures are put in practice,

detailed information should be gathered, regular checks may be performed using more simple methods.
To document the function and operation of the overflows to the water courses (tanks, CSOs, vortex separators etc.) and to verify the calculation assumptions it is appropriate to ensure continuous measurement of the most important structures or to calculate the frequency of filling up the tank, overflow duration,

outflow through the throttling route downstream the CSO or the vortex separator and running time of the mechanical equipment.
During the pollution check it is necessary to carry out a physical-chemical and biological-ecological survey of the water course in the reaches upstream and downstream the CSOs outlets. Priority is given to a simple check of visible signs of disturbance. As regards large outlets, the ecological condition of the water course is assessed based on the structure of the macrozoobenthos society, potentially diatom. The survey is performed at the minimum flow rate and usually indicates long-term effects of the discharge. To determine the immediate effects, it is necessary to measure chemical and hygienic indicators. Given the high demands, this is usually carried out only for potable water and bathing water.
(Kabelkova et al, 2010)

5. Tools and methods

The evaluation of the effects of CSOs on the receiving body of water should be a standard part of projects focusing on drainage master plans. Therefore, before commencing the work, a decision should be made on the applied simulation tools given the specific tasks, extent of schematic presentation of the urbanised catchment area and available data. The assessment of fulfilling the emission criteria may be performed using the outputs of the long-term simulation of the rainfall/run-off process using an urbanised catchment area model usually developed as part of the drainage master plan. By using the same simulation it is possible to make an assessment of the hydraulic disturbance of the receiving body of water. The assessment of the ammonia toxicity must be based on a model containing particle transport. To speed up the calculations and to ensure flexibility when assessing the alternatives it is advisable to use a hydrological model with gross schematising of the urbanised catchment area. The assessment of other pollution criteria does not require the simulation of the rainfall/run-off process in the urbanised catchment area. The models must be calibrated and verified and a sensitivity analysis of the results of the calculation focusing on the most uncertain input data is recommended.
The most accurate information in the current disturbance of the water course ecosystem caused by an urban drainage system can be obtained based on a biological-ecological survey. The assessment using the biological-ecological survey is meaningful in the existing outlets or as a check of the efficiency of the measures taken. The survey encompasses the assessment of the visible signs of disturbing the water courses and societies of benthic invertebrates. Its integral part is represented by assessing the water quality and the hydromorphological condition of the water course, which affects its biological condition. The assessment of the visible signs of disturbing the water courses can be used separately for a fast indicative assessment of the status of the water course and it also provides a series of additional information when evaluating the overall ecological condition. It is carried out along with the assessment of the morphological condition of the water course in the reaches upstream and

downstream the outlets. The data of the long-term water quality in the water stream is used as additional information to assess its biological condition and to assess the fulfilment of the pollution criteria of the combined system overflows.
The assessment of the morphological condition of the water course and the potential of re-settlement in the disturbed reaches provide for important supporting information to assess the structure of the macrozoobenthos societies as it enables differentiation between the effects of degraded water course morphology on the biological condition of the water course and the effects of storm water separators. It is also used to differentiate the hydraulic loadibility of the water course. The objective of assessing the morphological condition is to determine the deviation from the natural condition. What is assessed is the changeability of the depth and width of the river channel including the flow characteristics, character and diversity of the river bed and its structure, character of the banks, width and structure of the bank zone and longitudinal passability of the stream defined by the presence of obstacles in the stream. To assess and classify the morphological condition of the water courses, a number of methodologies are available assessing the main aspects with various levels of detail.
(Kabelkova et al, 2010)

3. Conclusions and recommendations

In the first place, it is necessary to evaluate the fulfilment of the emission criteria. However, the measures needed in the event of a potential failure to ensure the prescribed minimum efficiency of dissolved and suspended pollution at the WWTP are taken only after assessing the pollution in the water course so as to enable potential coordination of the measures. Measures proposed to fulfil the pollution criteria only on the basis of a numerical evaluation may not be economically feasible given the inherent safety of the evaluation even if more detailed levels of calculation are applied, and therefore, biological-ecological assessment of the water course is recommended as it enables better target orientation. The biological-ecological survey and continuous measurements of structures identified as critical is recommended to commence after determining the actual condition prior to the implementation of the proposed measures. The biological-ecological survey determines both the ecological condition of the water course in the reference profile upstream the assessed urbanised catchment area or the municipal drainage discharge point, and it identifies causes, extent and distance of the disturbance. If the ecological condition of the water course downstream the CSO is good (Directive 2000/60/EC), no measures need to be taken at a slight disturbance compared to the reference.

The specific proposed measures must be taken to determine the causes of the problem and while respecting the local conditions. The measures may be taken in the urbanised catchment area, in the sewer system or in the natural catchment area and in the water course. Priority is given to measures at the source, i.e. the urbanised catchment area aimed at eliminating the cause of the problem before taking remedial measures.

As regards morphologically degraded water courses, it is also necessary to consider the possibility of their revitalisation which may be more efficient for improving their biological condition than measures taken in the municipal drainage system (Krejčí et al., 2002). Similarly, with respect to rivers with a very low water quality in the urban catchment areas it is necessary to take measures in the urban drainage system and reduce the pollution transfer at more elevated localities. The procedure when selecting the measures includes first the selection of suitable measures for a more detail survey, determination of costs and subsequent consideration of further criteria such as uncertainties, operating reliability etc. The measures are ranked according to the priorities in relation to measures in the catchment areas upstream and according to the severity of the water course disturbance by the urban drainage. A good ecological condition of the water course or a good ecological potential (with respect to strongly affected bodies of water) (Directive 2000/60/EC) in the evaluated urban catchment areas is envisaged in the near future.

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