Improving the Microbiological Quality of Surface Waters in a River Basin in a Densely Populated Area: Scenarios of Costs and Effects

Amélioration de la qualité microbiologique des eaux de surface dans un bassin versant, dans une zone densément peuplée : scénario des coûts et effets

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RÉSUMÉ

Il est indéniable que les municipalités sont intéressées par des solutions rentables permettant d'améliorer la qualité des eaux de surface et permettre la baignade publique. Dans les zones densément peuplées, les stations d'épuration représentent l'une des voies majeures pour l'arrivée de l'*Escherichia coli* dans les eaux de surface réceptrices, lors des jours secs. En outre, après les pluies, les effets sur la santé des surverses d'orage peuvent être graves. La pollution terrestre diffuse, qui est la troisième source importante, augmente les concentrations d'agents pathogènes dans ces eaux de surface. Cette étude présente 20 scénarios pour la désinfection des exutoires des stations d'épuration concernées, de la sortie des surverses d'orage et du ruissellement de surface afin de réduire la quantité de bactéries arrivant dans la Ruhr, dans la zone du projet située dans la ville d'Essen et les villes voisines. Le traitement comprend les options suivantes : irradiation par les UV pour les stations d'épuration, gestion intégrée des systèmes d'assainissement, marais artificiels à écoulement vertical pour surverse d'orage ou traitement à l'acide performique, respectivement. La pollution terrestre diffuse par les eaux de ruissellement est naturellement difficile à localiser. Nous avons donc évalué des mesures organisationnelles. Si le seul traitement des effluents des stations d'épuration grâce à la désinfection par les UV est l'option la plus chère et celle qui a le moins d'impact, la combinaison des trois mesures sur le rejet unitaire de temps de pluie semble la moins coûteuse et celle qui donne les meilleurs résultats.

ABSTRACT

Municipalities are obviously interested in finding cost effective solutions for improving the surface water quality so as to allow public bathing. In densely populated areas, wastewater treatment plants represent one major pathway for *Escherichia coli* in receiving surface waters on dry days. Moreover, after rain events, the health-related effects of combined sewer overflow can be severe. As a third major source, diffuse overland pollution increases concentrations of pathogens in those surface waters. This study presents 20 scenarios for disinfecting the outlet of relevant wastewater treatment plants, discharge from combined sewer overflow and overland flow in order to reduce the load of bacteria into the Ruhr in the project area in the city of Essen and adjacent cities. The treatment includes the following options: UV irradiation for WWTPs; integrated sewer management, vertical flow constructed wetlands for combined sewer overflow and treatment with performic acid. Pollution by diffuse overland flow is, by nature, hard to localize; thus, we evaluated organizational measures. While the sole treatment of WWTPs' effluents via UV disinfection is the most expensive option with the lowest impact in relation to the elimination of *E. coli*, the treatment of diffuse pollution did not show a significant effect after all. Combining all three CSO measures gives the least expensive and most effective results compared to the reduction rates.

KEYWORDS

Disinfection, combined sewer overflow, Bathing Water Directive, integrated sewer management, diffuse pollution

1 INTRODUCTION

Inner-city Rivers are often used for recreational purposes although their water quality does not meet hygiene standards such as those in the EU Bathing Water Directive. In the study area in western Germany in the city of Essen and surrounding areas, the discharge of combined sewer overflows (CSOs) has the most significant impact on the microbiologic quality of the Ruhr on days during and after rainfall events. Under dry weather conditions, the requirements of the EU Bathing Water Directive are already fulfilled today (Tondera et al., 2015). The thresholds are exceeded as a result of CSOs that have been identified as most relevant pathways of pathogens during rainy weather days into the Ruhr River as it passes the project area surrounding Essen and adjacent cities (Tondera et al., 2015), but also diffuse sources have an impact. An overview of the area in question is given in Figure 1.

Of all pathways, the impact of overland flow diffuse pollution is the most complicated to evaluate and to treat (Schreiber et al., 2015). Nevertheless, there are “soft measures” that can help to reduce its impact on the surface water quality (Kay et al., 2007).

Since the values of the Bathing Water Directive were only exceeded during and within 48 hours after rainfall events, we chose to consider treatment scenarios for rainy weather days. For each pathway, we estimated different treatment options and their effect on the discharge of *E. coli* into the Ruhr River.

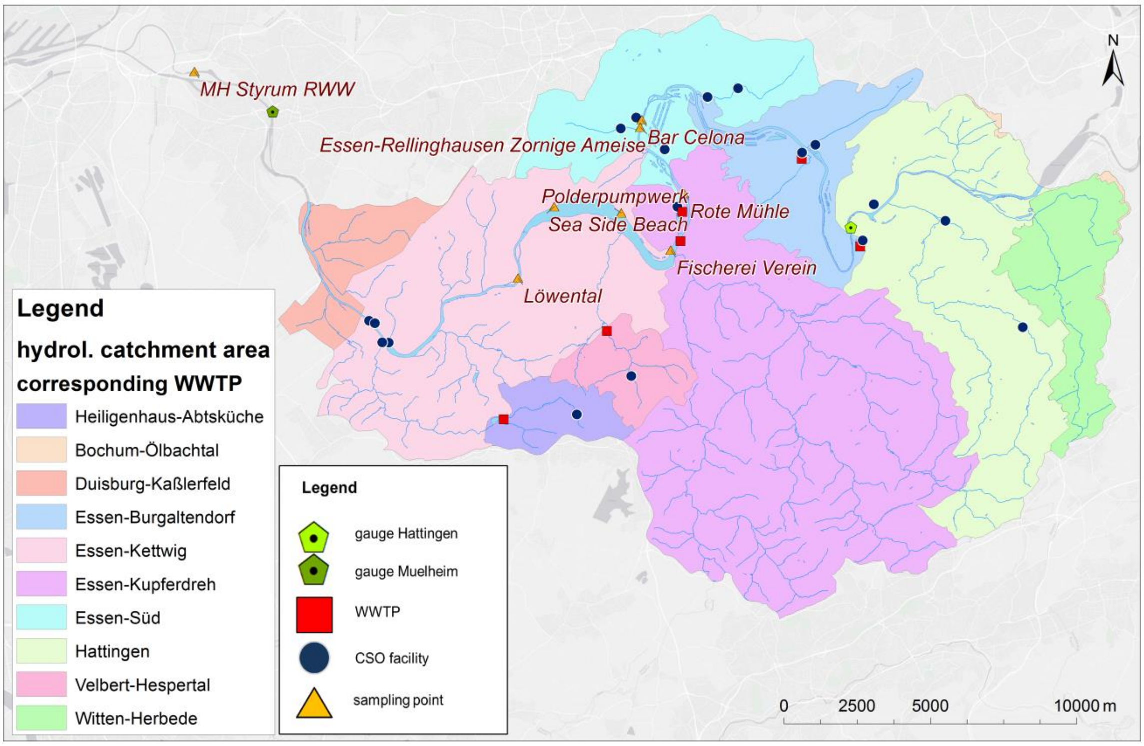

Figure 1: Project area: overview of catchment areas, WWTPs, largest CSO facilities and sampling points (results described in Tondera et al., 2015)

2 METHODS

2.1 Efficacy scenarios on total microbial loads

In a recently published pathway model, microbial loads into the Ruhr River within the project area were calculated using a Monte Carlo approach and set into proportion (Tondera et al., 2015). This model calculates distributions from 10^6 normal distributions for both microbial concentrations and possible flow volumes for each pathway. In order to evaluate the effect of potential measures, we altered the relevant parameters using a mean scenario from the Monte Carlo simulation (basic scenario, presented in Table 2). Hydraulic efficiencies were considered as well as treatment efficiencies. For the basic scenario, total loads for each pathway were calculated. For the treatment scenarios, the altered loads were simulated and the total $\log_{10}$ reduction over all pathways calculated in comparison to the basic scenario. In total, 20 scenarios were simulated, including the basic scenario. Table 1 gives detailed information on the treatment scenarios which are described in the sections following the table.

Table 1. Considered treatment scenarios

No.	Measures	Estimated efficiency of treatment option	
1a	Integrated sewer management	5 % volume reduction of CSOs	
1b		10 % volume reduction of CSOs	
1c		15 % volume reduction of CSOs	
1d	Integrated sewer management (scenario 1b) + CSO-CWs	10 % volume reduction of CSOs + 1.5 $\log_{10}$ *E. coli* reduction via CSO-CWs	CSO-CW: 50 % hydraulic efficiency
1e			CSO-CW: 65 % hydraulic efficiency
1f			CSO-CW: 80 % hydraulic efficiency
1g	Integrated sewer management + CSO-CWs (scenario 1e) + PFA treatment	10 % volume reduction of CSOs + 1.5 $\log_{10}$ *E. coli* reduction and 65 % hydraulic efficiency via CSO-CW + 3 $\log_{10}$ via PFA disinfection	50 % hydraulic efficiency PFA disinfection
1h			75 % hydraulic efficiency PFA disinfection
1i			100 % hydraulic efficiency PFA disinfection
2a	Integrated sewer management (scenario 1b) + WWTP effluent UV disinfection	scenario 1b + 1.5 $\log_{10}$ *E. coli* reduction via UV disinfection of WWTP effluent	
2b		scenario 1b + 2.5 $\log_{10}$ *E. coli* reduction via UV disinfection of WWTP effluent	
2c	Integrated sewer management + CSO-CWs (scenario 1e) + WWTP effluent UV disinfection	scenario 1e + 1.5 $\log_{10}$ *E. coli* reduction via UV disinfection of WWTP effluent	
2d		scenario 1e + 2.5 $\log_{10}$ *E. coli* reduction via UV disinfection of WWTP effluent	
2e	Integrated sewer management + CSO-CWs (scenario 1h) + PFA treatment + WWTP effluent UV disinfection	scenario 1h + 1.5 $\log_{10}$ *E. coli* reduction via UV disinfection of WWTP effluent	
2f		scenario 1h + 2.5 $\log_{10}$ *E. coli* reduction via UV disinfection of WWTP effluent	
3a	WWTP effluent UV disinfection	1.5 $\log_{10}$ *E. coli* reduction via UV disinfection of WWTP effluent	
3b		2.5 $\log_{10}$ *E. coli* reduction via UV disinfection of WWTP effluent	
4a	Measures to reduce discharges by diffuse pollution	Estimated reduction 5 %	
4b		Estimated reduction 10 %	
4c		Estimated reduction 15 %	

2.2 Overland flow (diffuse pollution)

To reduce the discharge of pathogens into the Ruhr, cooperation partners could organize voluntary agreements with agriculturalists as they are already hired nowadays with the focus to minimize the use of pesticide, nitrate and phosphates. Consultations contain, for example, advice on the use of manure as fertilizer, or the installation of riparian strips.

Microorganisms can also be reduced by improving the storage of liquid manure. Investigations by Güde et al. (2001) showed a significant decrease in pathogen loads after storing liquid manure for three months, which lead to a total reduction of *E. coli* in the manure. For the scenarios 4a to 4c, we assumed that reasonable measures could reduce the total *E. coli* load discharged into the river by 5, 10 or 15 %, respectively.

2.3 Wastewater treatment plants

Three wastewater treatment plants (WWTPs) discharge into the Ruhr River upstream a popular, however illegal beach in the so-called river arm Baldeneysee. Disinfection via UV irradiation was chosen as measure here. Scenarios 2a to 3b imply a mean reduction of 1.5 / 2.5 $\log_{10}$ in the effluent of a WWTP due to disinfection with UV irradiation.

2.4 Combined Sewer Overflows

For this scenario, the most relevant storage tanks and sewers were identified according to their yearly discharge into the Ruhr. Only storage tanks were chosen that discharge into the Ruhr after the level gauge Hattingen (Figure 1; offset) and before the Ruhr River enters Baldeneysee.

In order to reduce the amount of CSOs, we investigated potential reduction through integrated sewer management: a reduction of 5, 10 or 15 % of discharge volume for integrated sewer management was assumed and further treatment with vertical flow constructed wetlands for combined sewer overflow (CSO-CWs) and with performic acid (PFA).

Due to the stochastic occurrence of CSOs, the treatment is always divided into hydraulic and removal efficiency. Hydraulic efficiency describes the flow volume that could be treated and would not have to be discharged untreated on a by-pass; removal efficiency describes to which extent *E. coli* might be removed. Since hydraulic efficiency differs from event to event, we calculated different options: 50, 65 and 80 % for CSO-CWs and 50, 75 and 100 % for disinfection with PFA. As removal efficiency, we chose 1.5 $\log_{10}$ for CSO-CWs and 3 $\log_{10}$ for treatment with PFA based on literature values.

2.5 Cost estimations

All cost calculations were made based on the dynamic cost comparison method as presented in DWA (2012) for wastewater treatment. It helps to compare all accumulating costs during the time span of a technical construction, including investments, re-investments, maintenance and operation as well as interest and inflation. For the following scenarios, we chose the standard interest given in DWA (2012) of 3 % and neglected the effect of inflation. The investment costs were calculated by deducting the current German VAT of 19 %.

3 RESULTS AND DISCUSSION

3.1 Impact on the microbiological water quality

The total loads for the basic scenario (mean scenario from Monte Carlo simulation) are given in Table 2. In comparison to these values, the estimated reduction for diffuse pollution did not show any result on a log scale (accuracy of two digits after decimal point). Thus, cost calculations were limited to WWTP effluent treatment and CSO reduction and treatment.

Table 2. Basic scenario : Simulated total mean *E. coli* loads (based on Tondera et al., 2015)

Pathway	**Total mean *E. coli* load per average bathing season [MPN]**
Ruhr River base flow	1.63E+10
tributary streams	7.69E+09
WWTPs	7.11E+10
CSOs	4.40E+11
Diffuse pollution	7.78E+09
Sum	**5.43E+11**

On rainy weather days, the amount of discharged water is estimated to be reduced by 5 % to 15 % on average due to integrated sewer management. 15 % reduction of CSO discharge is equivalent to the extra amount of surface runoff that would have to be treated if precipitation of up to 4 mm did not lead to CSOs. Yet comparing it to the available data of 2000 to 2012 in the bathing season, without integrated sewer management, 104 days on average are considered as rain days with precipitation of more than 1 mm on the current day or on one of the two days before, which might lead to values exceeding the threshold value of the Bathing Water Directive (Tondera et al., 2015). On the chosen

13-year average, only 72 days would then be considered as rain days and the other days as possible bathing days in terms of the Bathing Water Directive. In addition, on days with only low CSO discharge volumes, the microbial quality of the Ruhr River would not be compromised as much as today if CSO-CWs and treatment with PFA were implemented.

3.2 Costs

Total costs for the treatment of the three WWTPs' effluents added up approximately € 900,000 a^{-1}, including € 536,000 a^{-1} for operation, repairs and maintenance. In this scenario, integrated sewer management required € 200,000 € a^{-1}, CSO treatment via CSO-CWs € 400,000 a^{-1} and PFA disinfection € 90,000 a^{-1}. Costs e.g. for energy supply were not considered.

Figure 2 shows the total effects as log reduction related to relative treatment costs. It shows that disinfection of WWTP effluent only (scenarios 3a, 3b) leads to high relative costs and low overall reduction; while the most effective option in terms of treatment efficiency and costs are the combined measured for CSO treatment (scenarios 1g to 1i).

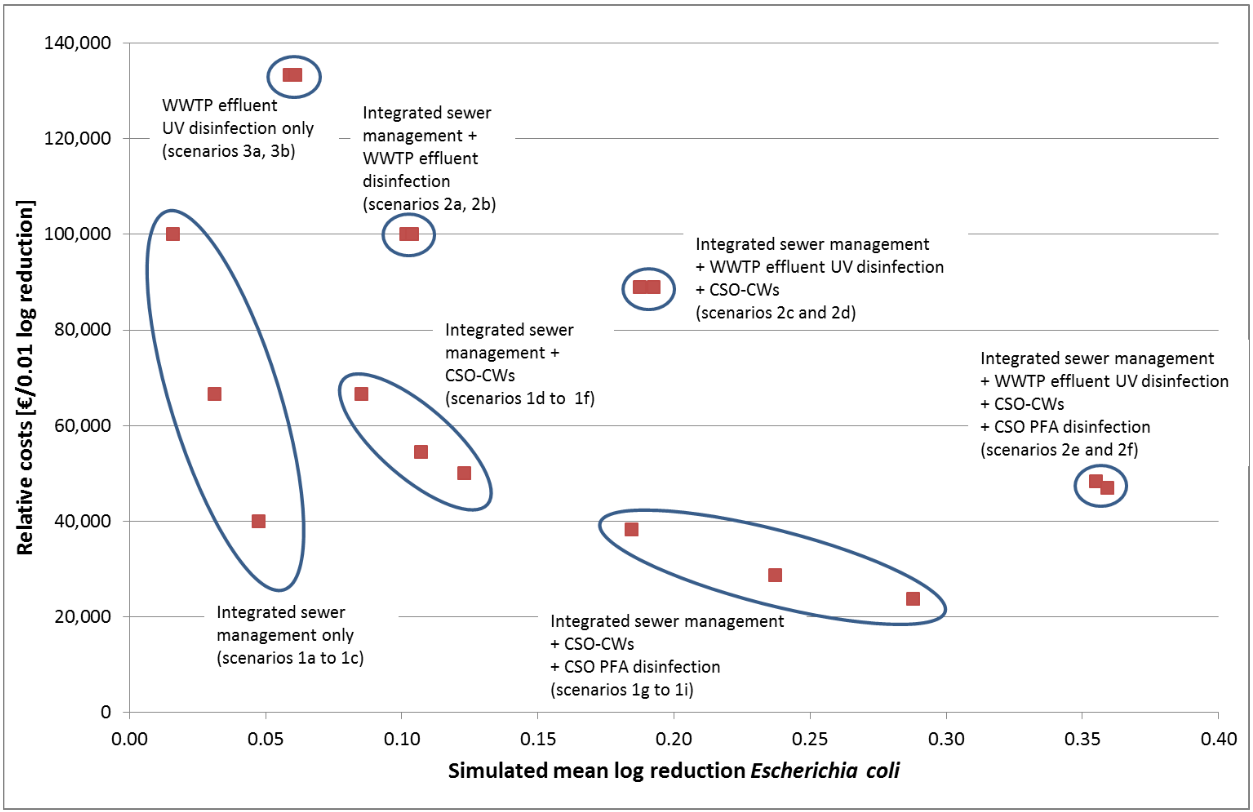

Figure 2: Simulated mean log reduction for E. coli and relative costs during bathing season

These results show which pathways can be treated in the most cost-efficient way; however, one cannot conclude resulting concentrations in the Ruhr River. It serves helping decide which pathway to investigate more closely in order to fulfil the requirements of the Bathing Water Directive in the future.

4 CONCLUSIONS

Combined sewer overflows contribute most significantly to the *E. coli* load in the Ruhr River near Essen in western Germany. Thus, reducing the discharge volumes and treating the remaining discharge to a certain extent should be considered.

We simulated 20 treatment scenarios and compared them to a basic scenario. While the treatment of diffuse pollution did not reveal a significant effect, the most cost-effective treatment compared to the reduction rates can be achieved by treating the CSO discharge. However, it is not possible to evaluate whether such a reduction in the real catchment area might lead to the simulated reduction; nonetheless, it shows possibilities to approach these problems in more detailed investigations.

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