Stormwater management strategies: source control versus end of pipe

Stratégies de gestion de l'eau : contrôle à la source versus le "tout-tuyau"

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RÉSUMÉ

Les égouts pluviaux sont connus pour apporter une contribution significative aux charges annuelles de polluants dans les plans d’eau où ils se déversent. Les égouts pluviaux de la ville d’Almere rejettent les eaux pluviales de 1384 ha de zone imperméable à travers 700 exutoires d’égouts pluviaux dans le milieu aquatique récepteur local. Ce milieu aquatique souffre d’eutrophisation et d’une accumulation à long terme des niveaux de polluants dans le lit de sédiments. Afin d’être en mesure de choisir la stratégie la plus efficace de gestion des eaux pluviales, la municipalité d’Almere et le service des eaux Zuiderzeeland ont lancé un important projet de surveillance sur 2 ans afin de mesurer la qualité des eaux pluviales et l’impact potentiel du contrôle à la source et des mesures en bout de ligne pour diminuer les émissions à travers les exutoires d’égouts pluviaux. Les mesures de contrôle à la source, telles que l’élimination des branchements illicites et une fréquence accrue du nettoyage des bouches d’égout, se sont avéré les actions les plus efficaces. L’impact potentiel des solutions "tout-tuyau" grâce à la décantation s’est révélé très limité, en raison du faible potentiel de décantation des solides dans les eaux pluviales d’Almere, aux exutoires d’égouts pluviaux.

ABSTRACT

Storm sewers are known to significantly contribute to annual pollutant loads to receiving water bodies. The storm sewers of the city of Almere discharge the stormwater of 1384 ha of impervious area via 700 storm sewer outfalls (SSOs) to the local receiving water system. This water system suffers from eutrophication and long term build-up of pollutant levels in the sediment bed. In order to be able to select the most effective stormwater management strategy, the municipality of Almere and Water Authority Zuiderzeeland have launched a 2 year extensive monitoring project to measure the storm water quality and the potential impact of source control and end of pipe measures to decrease the emission via SSOs. Source control measures, such as removal of illicit connections and increasing the cleaning frequency of gully pots showed to be most effective. The potential impact of end of pipe solutions based on settling showed to be very limited due to the low settleability of solids in the storm water of Almere at the SSOs.

KEYWORDS

Gully pots, illicit connections, lamella settler, monitoring, storm water quality

1 INTRODUCTION

Separate sewer systems are widely applied in economically developed countries. Storm sewers are known to contribute significantly to the annual pollutant loads into the receiving waters and many cause severe degradation of urban receiving waters (House et al. 1993). In the United States, stormwater runoff is a major contributor to pollution of receiving waters (Lee et al. 2007). This requires knowledge of local stormwater characteristics to assess the relative contribution of the stormwater pollution to the overall load to the receiving waters as well as knowledge of the impact of storm water strategies. As storm water characteristics may vary significantly between locations and events (see e.g. Langeveld et al., 2012 for a range of values from literature), local knowledge on the stormwater quality is required to select the appropriate storm water management strategy.

In Almere, The Netherlands (as presented during the NOVATECH 2013 and published by Langeveld et al., 2014) a very extensive monitoring project has been performed to obtain information on the storm water quality and the impact of source control and end of pipe measures to reduce emissions from storm sewer outfalls (SSOs).

This paper shortly describes the set up of the two year monitoring project, the monitoring results and a comparison of the effectivity of two source control measures (removal of illicit connections and cleaning of gully pots) versus two end of pipe solutions (a lamella settler and a SSO sediment basin).

2 MATERIAL AND METHODS

2.1 System description

Almere (194.500 inhabitants) is a city founded in 1975 after the realisation of the Flevopolder in order to accommodate for the increase of population in Amsterdam. In 1995, the municipality counted nearly 75.000 inhabitants, which had doubled by the year 2000. The main type of sewer system applied in Almere is the separate system, with foul sewers discharging to the waste water treatment plant and storm sewers discharging via storm sewer outfalls (SSOs) to the receiving waters. Earlier studies showed that the quality of the receiving waters is to a large extent determined by nutrient rich seepage (Almere is situated 4 m below mean sea level) and the outflow from the SSOs.

The sewer system of Almere comprises 680 km of storm sewer, 625 km of foul sewer, 700 SSOs and 1384 ha contributing area. The municipality has divided the catchment into three categories:

- I. Storm sewers dating before 1985, a period associated with the use of traditional building materials;
- II. Storm sewers dating from 1985, a period associated with the use of more sustainable building material;
- III. Special areas with a high risk of pollution, i.e. industrial zones.

The municipality of Almere and regional water authority Zuiderzeeland have launched a comprehensive research project OSAL (Optimisation Study Almere). The objective of the OSAL project is to quantify the emission from SSOs as well as the impact of the SSOs on the receiving water quality. The project also looks into strategies/measures to improve the receiving water quality to comply with the water quality standards.

The OSAL project comprises in total 7 pilot projects, figure 1 shows the 5 pilots described in this paper. Pilot 1 involves long term monitoring of the storm water quality at 3 SSOs. Pilot 2 analyses the impact of the frequency of gully pot cleaning on the storm water quality at the SSOs. Pilot 3 quantifies the impact of illicit connections on the storm water quality at the SSOs. Pilot 4 studies the impact of cleaning of the outflow structure of the SSOs on storm water quality. Pilot 5 monitors the efficiency of a lamella settler for storm water treatment purposes. In the project, also the quality of ground water in the drains connected to the storm sewers and the impact of SSOs on the receiving water quality have been studied. However, the latter two are considered beyond the scope of this paper.

The pilots have been performed at 3 selected locations, see table 1.

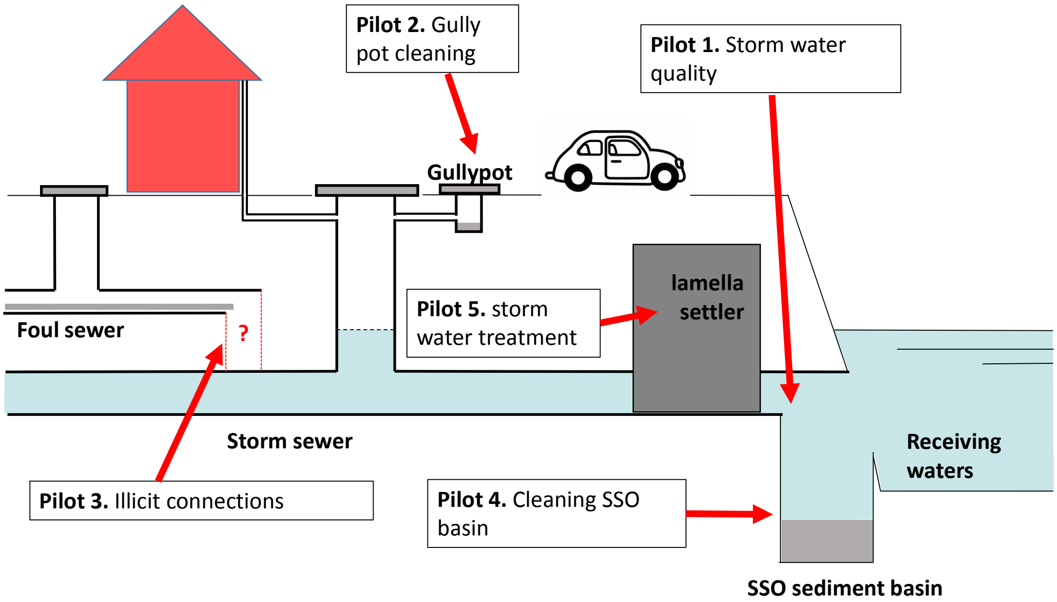

Figure 1. Pilots in OSAL research project

Table 1. Site characteristics

Location	Land use	Ha impervious area connected	Period of development	Comment
Baljuwstraat	City center	7.7	Before 1985	Category III catchment, research location for pilots 1, 2, 3 and 5
Sluis	Medium density residential	7.0	Before 1985	Category I catchment, research location for pilots 1 and 3
Palembang weg	Medium density residential	5.2	After 1985	Category II catchment, research location for pilots 1, 3 and 4

2.2 Monitoring set up and monitoring data

The monitoring set up at each location comprised a flow sensor, a water level sensor, a rain gauge, a automatic sampler and turbidity and electric conductivity sensors just upstream of the SSO. The storm water quality has been analysed in the lab per storm event, resulting in an event mean concentration (EMC) per event for the parameters listed in table 2. Based on the EMCs, volume weighed Site mean concentrations (SMC) have been derived. This paper only discusses the results for zinc and total phosphate, being the parameters related to the main water quality issues.

Table 2. Water quality parameters

Parameter group	Parameter
General	Suspended solids, COD, chloride
Nutrients	Kjeldahl nitrogen, ammonium, nitrate, phosphate (total P and ortho-P)
Micro pollutants	PAH10, mineral oil
Metals	As, Cd, Cr, Cu, Hg, Ni, Pb, Zn
Hygienic quality	E-Coli 37°C and 44°C
Treatability	Settling velocity

The monitoring project started in January 2013 and lasted until July 2015. The number of events with a good data availability and quality adds to 50 for Baljuwstraat, 38 for Sluis to 31 for Palembangweg.

3 RESULTS AND DISCUSSION

3.1 Pilot 1. Storm water quality

Table 3 shows the storm water quality measured at the 3 locations, compared to literature data. The storm water in Almere is, like in Arnhem (Langeveld et al., 2012), relatively clean compared to international data. For the parameter zinc, location Palembangweg, shows significantly lower concentration levels than the other locations. This confirms the earlier results in Almere, where locations build after 1985 showed significantly lower zinc concentrations than locations dating before 1985 (Langeveld et al., 2014). Based on the average storm quality of the three locations and a nett precipitation of 500 mm/a, the total load discharged via all the SSOs of Almere amounts to 680 kg zinc and 1.640 kg phosphate per year.

Table 3. Storm water quality, site mean concentration

Parameter	unit	Almere Baljuwstraat	Almere Sluis	Almere Palembangweg	Range 3 locations Arnhem*	Range international literature**
Zn	µg/l	82	77	25	76 – 152	146 - 3330
P-tot	mg/l	0,18	0,31	0,42	0,20 – 0,26	0,35 – 3,0

* Langeveld et al., 2012, ** International data from Bratieres et al. (2008), Salvia-Castellvi et al. (2005), Fuchs et al. (2004) and Daligault et al. (1999)

3.2 Pilot 2. The frequency of gully pot cleaning

The effect of gully pot cleaning has been analysed comparing two cleaning frequencies: 1 times per year and 6 times per year. Each time before cleaning, the sediment bed depth was measured in 20 gully pots and samples have been taken from the sediment for analyses. Cleaning gully pots every 2 months increases the amount of sediment removed by cleaning the gully pots with nearly a factor 3 compared to the normal cleaning frequency of 1 times per year. Extrapolating this result for the entire city would mean an extra annual removal of 190 tons of sediment or (using the measured concentrations of 337 mg Zn/kg solids and 1900 mg P/kg solids) 64 kg zinc and 360 kg phosphate.

Strikingly, the additional load removed in the gully pots due to an increased frequency of cleaning gully pots does not result in cleaner stormwater at the SSO. The stormwater quality monitoring from pilot 1 has been continued for the second year during which the gully pots have been cleaned once every two months. These monitoring results show that the storm water quality did not differ significantly for both periods. The SMC calculated for zinc is 5% higher in the year with intensive cleaning and for phosphate 10 % lower. This might be due to the monitoring set up, which is designed to take a representative sample of the storm water flow, i.e. at a height of 30% of the diameter of the completely filled pipe and which does not take rolling bed load into account. Another reason could be the influence of the in sewer stocks, which has not been quantified in the monitoring period.

3.3 Pilot 3. Illicit connections

Before the start of the monitoring period for pilot 1, the three catchments have been analysed for illicit connections using distributed temperature sensing (DTS). Only in the Sluis catchment, 8 illicit connections have been found and repaired, in the other two catchments no illicit connections have been found. Based on the average wastewater production and composition per household, the annual load discharged via the 8 illicit connections in Sluis has been calculated. This load has been compared to the annual pollutant load discharged via the SSO based on the measured storm water quality in pilot 1. The additional load due to illicit connections amounts to +100% of the annual phosphate load and to +21% for the annual zinc load for Sluis. Assuming that the results for the three catchments with respect to illicit connections are representative for the entire city, removal of all illicit connections would reduce the phosphate load with 50 kg zinc and 580 kg phosphate.

3.4 Pilot 4. Cleaning of SSO sediment basins

Nearly 60% of the SSOs in Almere have been provided with a SSO sediment basin. These basins are located directly downstream of the SSO and collect the sediment discharged via the SSO. In the project, the basins have been cleaned 4 times a year. Before cleaning, the sediment bed height has been measured and samples have been taken from the sediment bed. The results show that intensive cleaning of all the SSO basins, could result in a removal of 42 tons of sediment annually. With an average concentration in the sediment of 150 mg Zn/kg solids and 2000 mg P/kg solids, 6 kg zinc and 84 kg phosphate can be yearly removed.

3.5 Pilot 5. Storm water treatment with lamella settler

The efficiency of a lamella settler has been calculated based on the monitoring data of the influent and the effluent of the settler. A removal rate of 18% has been found for suspended solids. This low value is mainly due to the low settleability of the solids in the storm water in Almere, with only 30% of the solids having a higher settling velocity than 1 m/h, which is the design surface loading for the lamella settler. Equipping all 700 SSOs with a lamella settler, would result in an annual removal of 49 tons of sediment, or 29 kg zinc and 90 kg phosphate.

3.6 Discussion

Table 4 gives an overview of the results of the 5 pilots, expressed in kg phosphate and zinc per year. It is clear that the removal of illicit connections would have the largest influence on the annual emission via SSOs, followed by more frequent cleaning of gully pots. More frequent cleaning of SSO sediment basins or the application of lamella settlers would only have small influence on the annual emission.

Table 4. Annual load and potential annual load reductions based on results pilots (kg/a)

Parameter	Annual emission SSOs Almere (incl. illicit connections) 'Normal situation'	Pilot 1. Annual emission SSOs Almere (excl. illicit connections)	Pilot 2. Reduction via gully pot cleaning (6x/year)	Pilot 3. Reduction via illicit connection removal	Pilot 4. Reduction via SSO basin cleaning (4x/year)	Pilot 5. Reduction via lamella settler
Zn (kg/a)	730	680	64	50	6	29
P_{tot} (kg/a)	2.220	1.640	360	580	84	90

4 CONCLUSIONS

The two year extensive monitoring campaign in Almere has resulted in an extensive dataset. This extended abstract shows a small proportion of the results. The presented results show that storm water in the Netherlands is relatively clean compared to international literature. This might be due to the low gradient of the catchments and storm sewers discharging below the water table of the receiving waters, typically resulting in low flow velocities.

Based on the results for zinc and phospate it is concluded that:

- Illicit connections are the most influencing factor with respect to the annual pollutant load
- Additional cleaning of gully pots results in a significant removal of pollutants, however, this did not result in measurable improved storm water quality within one year.
- End of pipe solutions, such as sediment basins and lamella settlers can only have a limited influence on the annual pollutant load
- The researched source control options are more effective than the end of pipe solutions

LIST OF REFERENCES

2000/60/EC. Directive of the European Parliament and of the Council establishing a framework for Community action in the field of water policy (2000/60/EC). 23 October 2000; http://europa.eu.int/eur-lex/.

Bratieres, K., Fletcher, T. D., Deletic, A., & Zinger, Y. 2008. Nutrient and sediment removal by stormwater biofilters: A large-scale design optimisation study. Water Research, 42(14), 3930-3940.

Daligault, A., Meaudre, D., Arnault, D and Duc, V. 1999. Stormwater and lamella settlers: efficiency and reality. Water Science and Technology 39(2) 93-101

Fuchs, S., Brombach, H. and Weiß, G. 2004. New database on urban runoff pollution. Proceedings of NOVATECH 2004, Lyon, France, pp. 145-152.

House, M.A., Ellis, J.B., Herricks, E.E., Hvitved-Jacobsen, Seager, J., Lijklema, L., Aalderink, H. and Clifforde, I.T. 1993. Urban drainage – Impacts on receiving water quality. Water Science and Technology, 27(12), 117-158.

Langeveld, J.G, Boogaard, F., Liefting, H.J., Schilperoort, R.P.S., Hof, A. , Nijhof, H., de Ridder, A.C. and Kuiper, M.W. 2014. Selection of monitoring locations for storm water quality assessment. Water Science and Technology 69 (12), pp. 2397-2406

Langeveld, J.G., Liefting, H.J., Boogaard, F.C. 2012. Uncertainties of stormwater characteristics and removal rates of stormwater treatment facilities: Implications for stormwater handling. Water Research 46 (2012) 6868 – 6880

Lee, H., Swamikannu, X., Radulescu, D., Kim, S.-j., Stenstrom, M.K. 2007. Design of stormwater monitoring programs Water Research 41 (18), 4186-4196

Salvia-Castellvi, M., Iffly, J.F., Guignard, C. and Pfister, L. 2005. Characterisation of urban stormwater runoff from separated sewer overflows in Luxembourg. 10th Int. Conf. on Urban Drainage, Copenhagen/Denmark, 21-26 August 2005