



Modelling Different Types of Stormwater Treatment Facilities Considering Irreducible Concentrations

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Abstract. To design Stormwater Treatment Facilities (STFs) properly, we recommend the use of an urban drainage model that should include the calculation of runoff quality, to be based on a detailed land use specification, include site-specific design parameters, calculated outflow concentrations and loads of specified pollutants of relevance for the receiving water. This study compiles minimum outflow concentrations from stormwater databases of different types of STFs (wet ponds, wetlands, biofilters and underground retention basins with filters). These concentration data are used for the suggested values of specific “irreducible concentrations” (C_{irr}). Suggested C_{irr} for phosphorus (P) varies from 20–40 $\mu\text{g/l}$ depending on facility type, for copper (Cu) 1.8–4.0 $\mu\text{g/l}$, for zinc (Zn) 2.0–15 $\mu\text{g/l}$ and for total suspended solids (TSS) 2 900–5 000 $\mu\text{g/l}$. Corresponding data for 70 substances are compiled in the StormTac database and employed in the urban drainage model StormTac Web. C_{irr} have significant impact regarding the choice of facility type and its calculated dimensions. This design parameter and the calculated outflow concentrations can be used to investigate the need for combined serial facilities or complemented design elements with more planted vegetation or installed filters. Such elements can be required to decrease C_{irr} and thereby reach project specific limit outflow concentrations and loads. The suggested data will be further evaluated and updated with respect to more data from different facility types and more substances.

Keywords: Irreducible concentration · Stormwater · Treatment

1 Introduction

Stormwater management are required to meet specific objectives considering site-specific as well as receiving water conditions, instead of using general percent removal rates (Clark and Pitt 2012). Effluent (outflow) concentrations and loads need to be calculated. In urban drainage modelling, designers therefore need to apply design methods that includes parameters such as areal or volumetric relations to the reduced watershed area (area \times runoff coefficient), inflow concentrations, vegetated area, flow detention and the minimum outflow concentrations (Larm and Hallberg 2008). These parameters have great impact on the design and resulted outflow quality.

The minimum outflow concentrations or “irreducible concentrations” (C_{irr}) refer to a Stormwater Treatment Facility’s (STF’s) inability to reduce pollutant concentrations

below a certain level. Consequently, if the inflow concentrations are close to C_{irr} , no further reduction is likely. If they are equal to or falls below C_{irr} there could even be a negative removal (Schueler 1996). This important design parameter is further studied here for different types of STFs. C_{irr} is affected by incoming content and internal processes in facilities. Examples are decomposition of plants, leakage from the bottom due to lack of oxygen, the exchange with sediment, stirring sediment because benthic animals, background content of materials in filter materials and vegetation beds (Center of Watershed Protection 2007; Schueler and Holland 2000).

The findings of Randall et al. (1982) and Urbonas and Stahre (1993) suggest a lowest reachable outflow concentration for TSS around 10 000–20 000 $\mu\text{g/l}$, for facilities relying primary in sedimentation. There is a limit to sedimentation basins efficiency for smaller particles. Since metals are associated with smaller particles, filtration may be required to meet potentially very low discharge limits. Organic media such as filtration media has a background contamination but increased removal and reduced C_{irr} can be reached with e.g. adapted materials for certain pollutants, increased contact time etc. (Clark and Pitt 2012). Normally it is not possible to reach C_{irr} -values with only sedimentation, so to reach lower values one can use other or combine facilities in a “treatment train” (Pitt 2010), plant more vegetation, add a filter or improve the maintenance of the facility etc. A stormwater management model is required to include site-specific parameters to design STFs to meet these objectives, e.g. StormTac Web (Larm 2000). Irreducible concentrations are here presented for phosphorus (P), copper (Cu), zinc (Zn) and suspended solids (SS). These 4 substances are selected since there are much available data and they are generally of priority in different countries, used in water quality criteria and as basis for designing STFs (Larm and Hallberg 2008). C_{irr} are suggested to be estimated from outflow data from different types of STFs.

2 Materials and Methods

2.1 StormTac Web

Runoff quality in the stormwater and recipient model StormTac Web (Larm 2000) is estimated based on land use from e.g. the National Stormwater Quality Database (NSQD) (Clark and Pitt 2012) and the StormTac Database (Larm 2018). Estimated reduction efficiencies and outflow concentrations are simulated based on site-specific parameters such as inflow concentrations and C_{irr} . The simulations are performed for > 100 land uses and 70 substances.

2.2 Irreducible Concentration

Schueler (1996) suggested a preliminary estimate of C_{irr} of pollutants in general stormwater practice outflows as 150–200 $\mu\text{g/l}$ (P) and 20 000–40 000 $\mu\text{g/l}$ for TSS. Outflow concentration data from different STFs has been compiled from the International BMP Database 2016 summary statistics (Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2017) and the StormTac database (Larm 2018). Updated C_{irr} -

values has been suggested from these data, compiled in Table 1. The reduction efficiency RE (%) of a stormwater treatment facility can be expressed as a function of pollutant inflow and outflow loads or concentrations. Furthermore, RE depends on site-specific parameters. Higher inflow concentration and more vegetation can e.g. result in higher RE, and C_{irr} can stop further treatment (Larm and Alm 2014). To consider C_{irr} in the design processes we present simply the general functions of RE as a function of inflow concentration C_{in} and outflow concentration C_{out} , (Eq. 1), from which C_{out} is calculated in Eq. (2). The condition of C_{irr} in Eq. (3) is used to calculate the maximum achievable RE, $RE_{achievable}$ (Eq. 4) (Minton 1998):

$$RE = 100(C_{in} - C_{out})/C_{in} \quad (1)$$

$$C_{out} = C_{in} - C_{in}RE/100 \quad (2)$$

$$C_{irr} \leq C_{out} \quad (3)$$

$$RE_{achievable} = 100(C_{in} - C_{irr})/C_{in} \quad (4)$$

To evaluating data, the “BMP-weighted” and “storm-weighted” approaches can be used (Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2017). The BMP-weighted approach represents each BMP with one value representing the central tendency and variability of each individual BMP study. The storm-weighted approach combines all the storm events for the BMPs in each category and analyses the overall storm-based data set. When implementing the concept of C_{irr} the hypothesis is that the BMP-weighted should be used, since it considers periods with releases of pollutants from the facility materials or sediments to the water phase; else too small C_{out} -values

Table 1. Minimum total outflow concentration ($\mu\text{g/l}$), excluding outliers. Compiled data from StormTac database represents suggested irreducible concentration (C_{irr}) for each facility.

		P [$\mu\text{g/l}$]	Cu [$\mu\text{g/l}$]	Zn [$\mu\text{g/l}$]	TSS [$\mu\text{g/l}$]
Wet pond	StormTac database, BMP-weighted (C_{irr})	20	1.8	14	2 900
	<i>BMP database, Storm-weighted</i>	5.0	0.70	2.0	300
Wetland	StormTac database, BMP-weighted (C_{irr})	30	3.0	15	5 000
	<i>BMP database, Storm-weighted</i>	8.0	0.40	2.5	300
Biofilter	StormTac database, BMP-weighted (C_{irr})	40	4.0	7.0	3 000
	<i>BMP database, Storm-weighted</i>	6.0	0.80	0.70	400
Smaller underground retention filter basin	StormTac database, BMP-weighted (C_{irr})	30	2.0	2.0	5 000

would be used, not considering the effects of longer time periods. To further show how C_{irr} can have great impacts on the choice of type and size of treatment facilities, StormTac Web was used in an example case study designing stormwater treatment for a 20 ha residential area.

3 Results and Discussion

3.1 Results

In Table 1, minimum outflow concentrations from the International BMP Database and the StormTac database are compiled for different facility types. The compiled data from the BMP database are storm-weighted, the approach was selected for the referred report because it provides a much larger data set for analysis (Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2017). The BMP data shows that it occasionally, without taking to account the long-time effects, can give very low outlet concentrations. StormTacs database shows BMP-weighted data. They represent long-term performance data from each case study whereby they are suggested as irreducible concentrations, C_{irr} .

Example Case Study

A wet pond was simulated for Zn reduction from a 20 ha residential area with StormTac Web, with an assumed critical outlet concentration (C_{crit}) of 10 $\mu\text{g/l}$. The total Zn concentration from the residential area to the wet pond was $C_{in} = 62 \mu\text{g/l}$. The permanent pool area of the wet pond was 2 500 m^2 and gave reduction efficiency (RE) = 77% and $C_{out} = 14 \mu\text{g/l}$, see the left picture in Fig. 1. C_{irr} (Zn) for a wet pond is 14 $\mu\text{g/l}$ (Table 1), the simulation has stopped further treatment due to e.g. leakage from the sediments and the decomposition of plants. To reduce C_{out} further, a larger pond would not give any effect in this case, using the concept of C_{irr} .



Fig. 1. To the left a wet pond treating the stormwater and to the right a wet pond combined with a smaller underground retention filter basin.

To get further reduced C_{out} we simulated a smaller underground retention filter basin downstream the wet pond. This type of facility has the potential to reduce C_{out} to 2.0 $\mu\text{g/l}$ (Table 1), if simulated site-specific conditions so permit. An underground retention filter basin with a treatment volume of 25 m^3 were simulated in series with the wet pond which resulted in an overall RE = 94% and $C_{out} = 3.7 \mu\text{g/l} < C_{crit}$, i.e. sufficient treatment, see the right picture in Fig. 1. The very high RE of Zn in this example case study can be explained by a large wet pond in a series with an underground retention filter basin. Furthermore, the results assume good maintenance of the sediments and the in- and outlets of the facilities, and that the selected filter can perform high Zn removal.

3.2 Discussion

The data in Table 1 are all compiled in the StormTac database, together with data for many more substances and facility types. The aim is that C_{irr} shall represent minimum values of sites with a certain facility type, but minimum of mean outflow concentrations during annual periods from each site. C_{irr} should not be based on short term minimum concentrations since there e.g. could be release processes during events of high flow or decomposition processes from plants, if not harvested. This will be further evaluated after planned studies of complementary data from more facility types and more substances. In StormTac Web, the reduction efficiency is adjusted so that not less than C_{irr} is obtained at the outlet (Larm and Alm 2014). However, it is possible to unlock this restriction if it is believed possible to achieve lower levels by adapting the choice of plants or add filters or the like.

4 Conclusions

Stormwater treatment facilities need to be designed based not on general percent removals, but instead based on site-specific conditions for different treatment components, considering irreducible concentrations (C_{irr}). The compiled results indicate that there is no general irreducible barrier and that much lower C_{irr} than preliminary suggested by Schueler (1996) may be achieved. Irreducible concentration is a relative concept as opposed to using the concept as an absolute delimiter. It is possible to get concentrations as low as desired, but it is often not practical to design facilities to achieve extremely low concentrations since that would require e.g. treatment trains and/or chemical addition (Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2009). Earlier research (ASCE 2000) and the compiled minimum effluent data in Table 1 indicate large variations between different BMP types. There is a C_{irr} that normally can be achieved for a certain type of facility, which can affect the choice and dimension of the chosen type of facility. In many cases, a treatment train incorporating different processes that target different pollutant characteristics can be needed to achieve strict discharge limits. It can be composed of sedimentation (e.g. in wet ponds) followed by filtration unit processes (e.g. in biofilters) (Pitt 2010). If it is required to lower the calculated outflow concentration of a certain substance, then it is possible to complement the facility with more plants or to add an outlet filter with materials adapted for better reduction. Based on presented results, C_{irr} for phosphorus (P) varies from 20–40 $\mu\text{g/l}$ depending on facility. For copper (Cu) C_{irr} varies between 1.8–4.0 $\mu\text{g/l}$. For zinc (Zn), C_{irr} varies between 2.0–15 $\mu\text{g/l}$ and for total suspended solids (TSS) between 2 900–5 000 $\mu\text{g/l}$ depending on facility. This outflow concentration and load data can be simulated with e.g. StormTac Web or the like, beginning with calculating inflow quality from land use data. Also, other site-specific parameters are to be considered in the design.

Continued studies will focus on compiling updated BMP-weighted effluent concentrations from the BMP database (www.bmpdatabase.org) in Access format, by weighting each event effluent concentration by the event flow, and then calculating minimum concentrations per facility type. These minimum data will be compiled in the

StormTac database (www.stormtac.com), used to update the suggested irreducible concentrations in Table 1 for several more BMP types and substances. These are to be further implemented in StormTac Web.

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