UDM 2018
11th International Conference on Urban Drainage Modelling
23-26 Sep | Palermo - Italy

# Modelling different types of stormwater treatment facilities considering irreducible concentrations

**Thomas Larm and Anna Wahlsten**
StormTac corporation, Stockholm, Sweden

**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 µg/l depending on facility type, for copper (Cu) 1.8-4.0 µg/l, for zinc (Zn) 2.0-15 µg/l and for total suspended solids (TSS) 2 900-5 000 µg/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 x 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 µg/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 µg/l (P) and 20 000 – 40 000 µg/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):

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

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

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

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

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 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, $C_{irr}$.

**Table 1.** Minimum total outflow concentration (µg/l), excluding outliners. Compiled data from StormTac database represents suggested irreducible concentration ($C_{irr}$) for each facility.

| | | **P** [µg/l] | **Cu** [µg/l] | **Zn** [µg/l] | **TSS** [µg/l] |
|---|---|---|---|---|---|
| **Wet pond** | StormTac database, BMP-weighted ($C_{irr}$) | 20 | 1.8 | 14 | 2 900 |
| | *BMP database, Storm-weighted* | *5.0* | *0.70* | *2.0* | *300* |
| **Wetland** | StormTac database, BMP-weighted ($C_{irr}$) | 30 | 3.0 | 15 | 5 000 |
| | *BMP database, Storm-weighted* | *8.0* | *0.40* | *2.5* | *300* |
| **Biofilter** | StormTac database, BMP-weighted ($C_{irr}$) | 40 | 4.0 | 7.0 | 3 000 |
| | *BMP database, Storm-weighted* | *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 |

**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 µg/l. The total Zn concentration from the residential area to the wet pond was $C_{in}$= 62 µg/l. The permanent pool area of the wet pond was 2 500 $m^2$ and gave reduction efficiency (RE) = 77% and $C_{out}$= 14 µg/l, see the left picture in Figure 1. $C_{irr}$ (Zn) for a wet pond is 14 µg/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 $C_{irr}$.


**Figure 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 µg/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 µg/l < $C_{crit}$, i.e. sufficient treatment, see the right picture in Figure 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.

**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 µg/l depending on facility. For copper (Cu) $C_{irr}$ varies between 1.8-4.0 µg/l. For zinc (Zn), $C_{irr}$ varies between 2.0-15 µg/l and for total suspended solids (TSS) between 2 900-5 000 µg/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.

## References

ASCE (2000). Data Evaluation Report, Task 3.4. National Stormwater Best Management Practices Database Project, October 2000.

Center for Watershed Protection (2007). National Pollutant Removal Database. Appendix C: Updated BMP Removal Efficiencies from the National Pollutant Removal Database & Acceptable BMP Table for Virginia. Center for watershed Protection, Ellicott City, Maryland, USA.

Clark S.E. and Pitt R. (2012) Targeting treatment technologies to address specific stormwater pollutants and numeric discharge limits*. Water research 46*, 6715-6730.

Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. (2009). Urban stormwater BMP Performance monitoring. October 2009.

Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. (2017). International Stormwater BMP Database 2016 summary statistics, 2017.

Larm T. (2000). Watershed-based design of stormwater treatment facilities: model development and applications. *PhD thesis*, Royal Institute of Technology, Stockholm, Sweden.

Larm T. (2018). StormTac database, www.stormtac.com.

Larm T. and Alm H. (2014). Revised design criteria for stormwater facilities to meet pollution reduction and flow control requirements, also considering predicted climate effects. *Water practice and Technology.*

Larm T. and Hallberg M. (2008) Design methods for stormwater treatment – site specific parameters. *11th International Conference on Urban Drainage, ICUD,* Edinburgh, Scotland, UK, 2008.

Minton G.R. (1998). Stormwater Treatment Northwest, Vol. 4, August.

Pitt R. (2010). Evaluation of Biofiltration Media for Engineered Natural Treatment Systems. *Report from University of Alabama to Geosyntec Consultants*, CA. May 10, 2010.

Randall W.C., Ellis K., Grizzard J.T., Knocke W.R. (1982) Urban Runoff Pollutant Removal by Sedimentation, Stormwater Detention Facilities. *Proceeding from Conference on Stormwater Facilities, ASCE.*

Schueler T.R. (1996). Irreducible pollutant concentrations discharged from stormwater practices. *Article 65. Technical note #75 from watershed protection techniques*. 2(2): 369-372.

Schueler T.R. and Holland H.K. (2000). The Practice of Watershed Protection. Article 65 Irreducible Pollutant Concentrations Discharged from Stormwater Practices. In *Watershed Protection Techniques*. 2(2): 369-372. Center for watershed Protection. www.cwp.org.

Urbonas B.R. and Stahre P. (1993). Stormwater Best Management Practices Including Detention. USA.