MODELLING THE IMPORTANCE OF BASEFLOW IN THE RUNOFF AND TRANSPORT OF POLLUTION IN STORMWATER DITCHES AND STORMWATER PIPES.

A dissertation submitted to The University of Manchester for the degree of Master of Science in the faculty of Engineering and Physical Sciences.

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Abstract

Stormwater models, such as StormTac, are very useful in stormwater planning and management. However, although baseflow makes an important contribution to pollutant load, which in turn is dependent upon inputs from various types of land use, the parameters for baseflow and these input in models, such as StormTac, are typically only default values based on a limited number of case studies. In this work, the baseflow module in the stormwater and recipient model StormTac has been revised following review of a more extensive number of case studies. Further work is still required to look at all of the default values to improve the certainty of the StormTac model in particular, and stormwater models in general.

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1. Introduction and background

Stormwater is rainwater or melted snow that either becomes surface runoff on paved surfaces or infiltrates into the ground (Rikstermbanken 2011): it eventually flows into stormwater ditches or stormwater pipes. The water present in stormwater ditches and stormwater pipes before and after a stormwater peak in the flow is termed the **baseflow**.

Stormwater transports many pollutants, such as heavy metals, hydrocarbons, nutrients and pathogens (Elliot and Townsdale 2007). To be able to design treatment facilities and/or take management decisions to meet legislative requirements, predictive stormwater models can be very useful. It is also very important that baseflow is included in stormwater models, because its contribution of pollutants can be substantial: if it is not included there is an important part of the urban hydrological cycle excluded and model outputs may be inaccurate.

There are many stormwater models in use today. This work will focus on the model StormTac (Larm 2005) that is used for management of lake catchments and conceptual design of stormwater treatment facilities. StormTac contains a baseflow module which needs revision as its default values are based on only a few cases studies. This work will focus on revision of the baseflow module of StormTac.

1.1 Pollution

Stormwater is considered to be the main source of pollutants to lakes and watercourses in, or close to, cities (Alm *et al.* 2010). It is well documented that pollution transported with stormwater may cause a lot of damage to the recipients (Robson *et al.* 2007), and stormwater is the second largest contributor of phosphorus and nitrogen to surface waters, after agriculture (King *et al.* 2007). Stormwater transports different kinds of contaminants, both from point sources and diffuse sources, and from dry and wet deposition on the surfaces of a city or land surfaces (Alm *et al.* 2010). There is a range of pollutants present in stormwater, such as heavy metals, PAHs, PCBs, oil, nutrients and bacteria, originating from many different sources such as traffic, buildings and human activities, e.g. car washing (Stockholms stad 2005).

As humans have altered the land surface for different purposes through history, many transport- and physicochemical processes have been impacted, and this has increased the quantity of pollutants. As patterns of flows have changed, the types of pollutants have also changed (Zoppou 1999).

Different land uses result in different compositions and concentrations of contaminants in stormwater, for example stormwater from a road contains higher concentrations of polyaromatic hydrocarbons (PAHs) than stormwater from a residential area (Junestedt *et al.* 2007).

Some important sources of contaminants found in stormwater are buildings and traffic. For buildings the main problem is copper- and zinc roofs, and traffic is the source of rundown surface material (for example asphalt), sand and particles from vehicles (Stockholms stad 2005).

Most substances are adsorbed on to small particles and are so transported with the stormwater (Stockholm stad 2005). When there is a rainfall event, particles on the land surface will be set in motion, and pollutants adhering to the particles and soluble pollutants will be carried by the runoff to a recipient (Zoppou 1999). This diffuse pollution increases due to human activities. What activity that takes place on the land affects the volume of the stormwater, and its composition and concentration of pollutants (Zoppou 1999). Further, the time between precipitation events and its intensity and duration also affect the transport of pollutants. Other sources of pollutants are what Zoppou (1999) calls “failures in the urban infrastructure”, such as leachate from landfills and contamination from sewer infiltration. Due to this diversity in sources and types of pollutants, stormwater management is very complicated (Zoppou 1999).

The contaminants that are present in stormwater can cause harm to humans, plants and animals, and lead to both technical and aesthetic problems. If they appear in high concentration or with high frequency, they can be toxic or highly toxic to humans and have negative biological effects on aquatic animals and plants (Alm *et al.* 2010). The biological effects range from infection of organisms by bacteria and viruses and death from chronic toxicity exposure to alteration of natural habitat cycles and breeding (Zoppou 1999). In addition, if the water gets polluted and the quality degraded, it might not be fit for purposes such as drinking water, irrigation water or recreation (Zoppou 1999). Table 1 summarizes the sources and effects of pollutants in stormwater.

Table 1. Sources and effects of metals and substances that pollute stormwater, adapted from Stockholm Stad (2005) and Zoppou (1999).

Metal/Substance	Effect on animals, humans and water	Main sources to distribution and pollution of stormwater
Mercury	Highly toxic to humans, organisms and aquatic plants. Can cause brain, nerve and kidney damage.	Goods containing mercury, e.g. amalgams and electrical equipment. Diffuse distribution during waste handling.
Cadmium	Very toxic to humans and animals, can lead to chronic kidney and liver disease	Industrial production e.g. plastic stabilisers, electroplating and discarded batteries. Vehicles and as a pollution in zinc.
Lead	Very toxic to humans and animals. Can cause nerve and brain damage in infants, kidney damage and blood disorders in adults.	Combustion of oil and petrol chimneys, vehicles, industrial waster discharge and infrastructure.
Zinc	Depending on water pH and hardness and synergistic interaction with other heavy metals, it can be toxic to water-living animals and plants.	Buildings, vehicles and infrastructure.
Copper	Highly toxic to most aquatic animals and plants. May lead to liver and kidney damage.	Buildings (especially roofs), vehicles, steel production and sewage treatment plant wastes.
Chromium	Negative impact on humans, animals and plants, generally low toxicity but can cause liver, kidney and lung damage.	Vehicles, buildings, waste incineration, electroplating and septic systems.
PAHs	Carcinogen and toxic to humans.	Wood burning. Traffic emissions and tires.
PCBs	Toxic to humans and animals.	Sealants in buildings. Electric capacitor, cables and transformers.
Oil	Harmful to humans and animals. Toxic to animals.	Oil spills, traffic, leakage form vehicles and tanks, and traffic accidents.
Nutrients (nitrogen & phosphorus)	Eutrophication of lakes and oceans leads to algal blooms that result in oxygen deficit.	Combined overflow sewage, animal droppings and manure. Nitrogen comes mainly from atmospheric deposition.
Bacteria	This is a problem where people go swimming, can lead to salmonella infection, dysentery and cholera.	Combined overflow sewage and animal spilling.

1.2 Stormwater models

Predictive models are very useful for planners and engineers to estimate the pollution load for unmonitored watersheds. The behaviour of environmental systems may be predicted quantitatively through modelling, and computer models of urban stormwater flow and quality have been shown to be very useful in assessing the most effective management strategy and the best way to ensure legislative compliance (Zoppou 1999; Brezonik and Stadelmann 2002).

According to Zoppou (1999) there are hundreds of urban stormwater models developed by different institutions, with the first ones that could simulate stormwater quality and quantity written in the early 1970s. Since then many models have been developed: there is everything from very simple to more conceptual and more complex hydraulic models.

There are three basic components of urban stormwater models (Zoppou 1999):

- precipitation
- rainfall-runoff modelling
- transport modelling

The rainfall-runoff modelling simulates both how excess precipitation causes surface runoff and sub-surface flow and how pollutants from impervious surfaces get built-up and washed off. The transport modelling shows how pollutants and flow travels through the stormwater infrastructure, for example pipe networks, ditches and storage volumes.

Due to the nature of stormwater, that it is very dynamic and heterogeneous, reliable measured data are lacking (Junestedt *et al.* 2007). Thus, to be able to describe the relative contribution from different land uses, land use-specific characteristic values are often used for a number of typical pollutants. Those characteristic values are then used in models to show different land uses' stormwater composition (Junestedt *et al.* 2007).

Further, there is the runoff coefficient, which describes the proportion of the precipitation that becomes surface runoff (the other part infiltrates, gets stuck in the pores of the surface, or evaporates from it). The runoff coefficient is given a value between 0 and 1, where 1 means that all of the precipitation turns into surface runoff (Junestedt *et al.* 2007). An impervious surface has a higher runoff coefficient than a pervious one.

It is important to be very careful in the analysis of pollutant concentrations in stormwater as it depends on at what point during a rain event that a sample has been taken, and what kind of rain it was. Therefore it is appropriate to calculate the pollution concentrations on a yearly basis, by using average values multiplied with stormwater volumes that have been measured or calculated locally (Nilsson and Malmquist 1996). Further, the used concentrations should be based on flow proportional sampling during long periods of time, i.e. instantaneous grab sampling should not be used as a basis to characterize stormwater (Larm pers. comm. 2011).

There are both negative and positive aspects of using land use-specific characteristic values. According to Junestedt *et al.* (2007) it is debatable whether characteristic values can describe the stormwater connected to a certain land use. There are many factors that can affect the composition of a certain sample. The intensity of the precipitation can affect the amount of pollutants that are washed off the ground, and the activity that has taken place on the land during the dry periods will also affect the sample. Junestedt *et al.* (2007) concludes that those uncertainties together with many others, such as local conditions, implies the need for real measured data to describe the actual situation for a specific area. On the other hand Larm (2005) claims that land use-specific characteristic values are more relevant to apply than those of single samples during shorter periods, as there is a risk that they might not be representative for the system in question i.e. flow proportional sampling is needed but this can be very expensive. Further, Brezonik and Stadelmann (2002) argue that because it is very expensive to get monitoring data on diffuse source pollution, which has a large impact on recipients, there is now a big interest to compile and analyse existing data to develop predictive models for urban stormwater loads and concentration.

Not all models include the sub-surface flow, and one reason is that in urban areas large areas are impervious and thus do not have any, or very little, sub-surface flow (or at least sub-surface flow that interacts with stormwater). However, to get a correct estimation of runoff and its quality it is very important to have a correct representation of the hydrological cycle (Zoppou 1999). Elliott and Trowsdale (2007) suggest that to include baseflow components and runoff modules in a more comprehensive way is an important way to further develop stormwater models.

There are a number of stormwater models, some include the baseflow in different ways, and some do not. Here follows a few examples.

1.2.1. MIKE SHE

In the stormwater and groundwater model MIKE SHE, the required input parameters to calculate the baseflow are the depth of water in the baseflow reservoir, the depth of water required before baseflow occurs and the time constant for baseflow (DHI Water and Environment 2007).

1.2.2. MUSIC

In the stormwater model MUSIC, the stormwater runoff contains surface runoff and baseflow, and the required input data are rainfall, evapotranspiration and area per land use. For generating baseflow, the following parameters can be used in the model: rainfall threshold (mm), soil capacity (mm), initial storage (%), field capacity, infiltration capacity coefficients, infiltration depth (mm), daily recharge rate (%), daily baseflow rate and deep seepage (%) (McAuley and Knights 2009).

1.2.3. DR$_3$M

Distributed Routing Rainfall-Runoff Model (DR$_3$M) (USGS 2010) is often used to simulate small urban basins. DR$_3$M uses rainfall as an input to simulate stormwater runoff periods that the user selects, showing how the stormwater moves through a system of channels and pipes. Between the stormwater periods, daily soil-moisture is shown. The required input data is daily precipitation, daily evapotranspiration, and short-interval discharge. To define the basin, roughness and hydraulics parameters and sub-catchment areas are required. DR_3M does not simulate the baseflow.

1.2.4. HSPF

Hydrological Simulation Program – Fortran (HSPF) (USGS 2011) is commonly used to calculate the effects of using point or diffuse source pollution treatment alternatives, the effect of land use change and flow diversion among many other things. The required input data for watershed simulation is precipitation and potential evaporation. For water quality simulation, many different kinds of data are needed, such as air temperature, tillage practices, point sources and pesticide application. HSPF does simulate the baseflow.

1.2.5. SWMM

Storm Water Management Model (SWMM) (Rossman 2004) is used throughout the world for many different uses, for example to design control strategies to minimise the risk for combined sewer overflows or to design drainage system components for flood control. The model simulates the quality and quantity of runoff within each subcatchment and there is a lot of input data required for that, such as the land uses, imperviousness, slope, depression storage in both pervious and impervious areas and the percent of impervious area with no depression storage. SWMM simulates the baseflow.

Elliot and Trowsdale (2007) have made a review of a number of different stormwater models, and concluded that most of the models are limited in their abilities to predict baseflow in different ways. For example, the models MUSIC, SWMM and MOUSE do not include infiltration from infiltration ditches and therefore do not contain all the factors that affect the baseflow. All the models in the review are missing one factor or another that has an impact on the baseflow, for example leakage from the water supply network, what effect the type of vegetation has on the evapotranspiration, or the regional groundwater flows. This means that if those models were to be used for prediction of the effects on baseflow of e.g. urbanisation, the results could be unreliable.

1.3 StormTac

One model that does include baseflow in the calculation of flow and pollution load is StormTac, a watershed based hydrological model with the purpose to quantify water flows and pollutant loads, design of stormwater treatment facilities and the quantification of acceptable loads and reduction needs for receiving waters e.g. lakes, among other things.

StormTac has several modules, and this work will focus on the baseflow module, which is part of the runoff module in Figure 1.

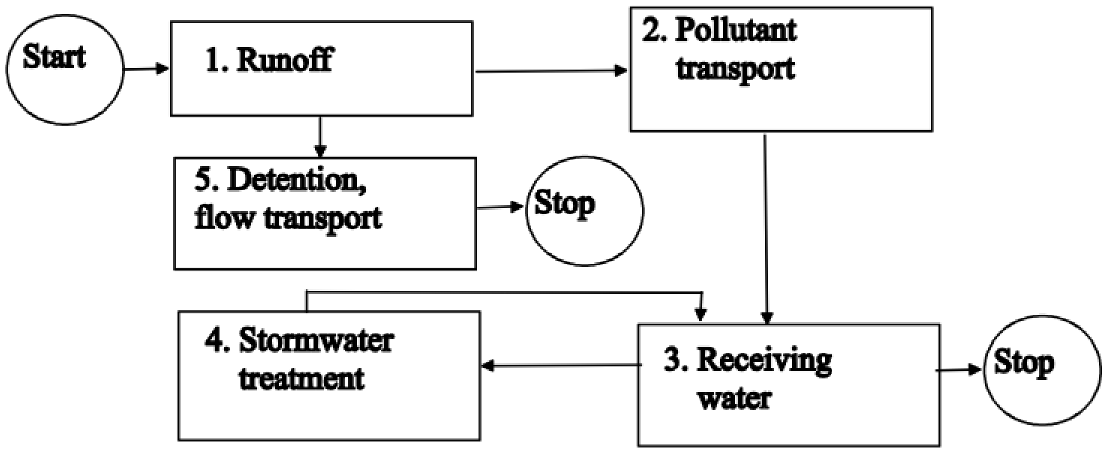

Figure 1. Simplified flowchart of the model StormTac (Larm 2005).

StormTac utilizes static equations to calculate water and mass balances, and to estimate yearly acceptable pollution loads on receiving waters (Larm 2005). The simplified (in respect to normally available input data) equation proposed for calculating the base flow is:

$$Q_b = 10 p K_x \sum_{i=1}^{N} (K_{\inf,i} A_i) \qquad (01)$$

Where

Q_b = base flow or ground water flow to the recipient [l/s]

p= corrected precipitation intensity data (rain+snow) [mm/year]

K_{inf} = fraction of the yearly precipitation that is infiltrated

K_x= share of K_{inf} that reaches the base flow

i = land use categories, *i* = 1,2,…..N

A = land use area [ha]

Hence, the calculation of baseflow is based on precipitation, fraction of infiltrated precipitation, share of infiltrated precipitation that reaches the base flow, and the areas of different land uses. The precipitation (p) intensity data needs to be corrected for systematic errors, and the land area per land use (A) has to be mapped. The fraction of the yearly precipitation that is infiltrated (K_{inf}) is calculated through the following simplified equation:

$$K_{\inf} = \frac{p - (p\varphi) - E}{p} \qquad (02)$$

Where

p = corrected precipitation intensity data (rain+snow) [mm/year]

φ = runoff coefficient

E = potential evapotranspiration intensity [mm/year]

E is calculated as follows:

For all land uses except forests and recipients or lakes:

for $\varphi \leq 0.90$ $E = 1000(0.50 - 0.55\varphi)$ (03)

For $\varphi > 0.90$ E = 0

For forests:

E_{forest} = 445 (input data)

For recipients:

$E_{recipient}$ = 590 (input data)

The equations above are stated as preliminary and will likely change in the light of new data. For example, E cannot be a function of φ alone.

Figure 2 illustrates the parameters evaporation (E), precipitation (p), runoff coefficient (φ), fraction of the yearly precipitation that is infiltrated (K_{inf}) and share of K_{inf} that reaches the base flow (Kx) in a ditch. Figure 3 illustrates evaporation (E), precipitation (p), runoff coefficient (φ), fraction of the yearly precipitation that is infiltrated (K_{inf}) and share of K_{inf} that reaches the base flow (Kx) in a stormwater sewer.

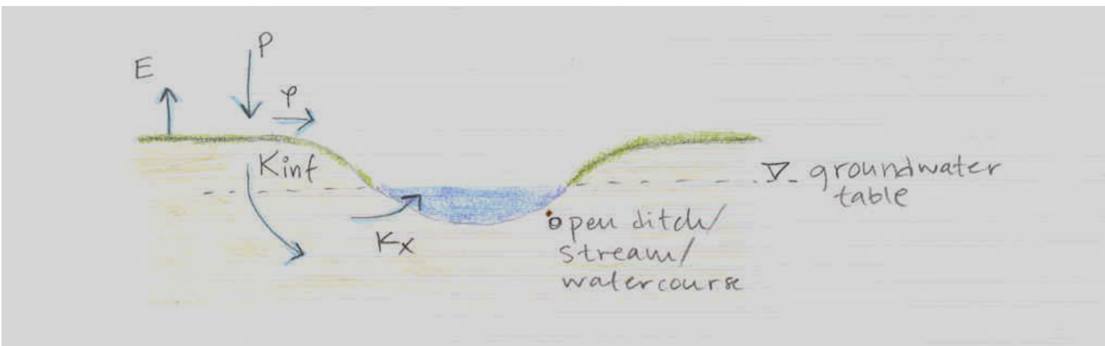

Figure 2. Schematic of E, p, K_{inf} , K_x and φ (see equations 01 and 02) for stormwater ditches.

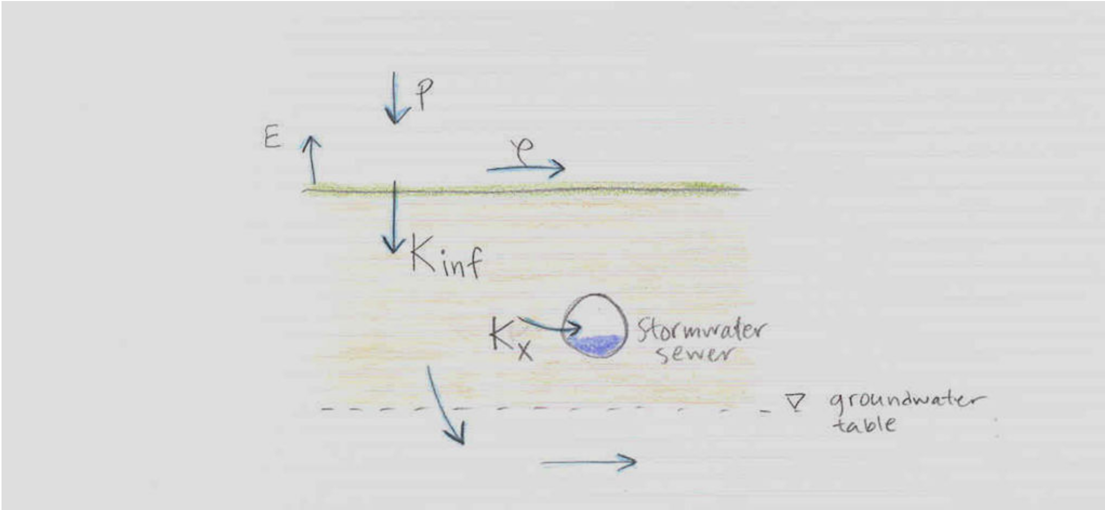

Figure 3. Schematic of E, p, K_{inf} , K_x and φ (see equations 01 and 02) for stormwater sewers.

The K_x-value is a constant in the baseflow equation that shows how large a fraction of K_{inf} that reaches the baseflow. The default K_x-value (0.7), that can be changed in the model, is based on data from only a few case studies. Due to this lack of data, the baseflow module in StormTac is contributes to overall model uncertainty. An uncertainty analysis conducted by Stenvall in 2004 showed that the baseflow (Q_b) is sensitive to the K_x-value, and further calibration against new case studies was recommended. Consequently, the K_x-value needs to be calibrated against more case studies to establish if a revision is necessary, and to be able to make more reliable baseflow calculations.

The land use-specific characteristic values for the baseflow in StormTac are also based only on a few case studies, so more case studies are needed to get more certain and more reliable values.

StormTac does not aim to be a comprehensive baseflow model, but nevertheless a robust baseflow module is required for accurate calculations of flows and pollutant concentrations in the overall stormwater model.

1.4 Aim

The aim of this work is to complement and revise the baseflow module in the stormwater and recipient model StormTac.

1.5. Objectives

1. To generate calibration data for the K_x-value through a literature study.
2. To revise the K_x-value of the baseflow based on the data collected in the literature study.
3. To revise the land use-specific characteristic values of pollutants in the baseflow module.

2. Method

The principle is to use cases where the all the parameters (except the K_x-value) of equation 01 are known, which means that also the baseflow is known. For every case, the parameters are put into the model, and then different Kx-values are tested until the baseflow calculated by the model is the same as the actual measured baseflow. The case studies will be found through a literature study and by personal communication with Sweco's Thomas Larm at (the developer of the model), who has identified a number of case studies and provided original data from these. Table 2 shows details about the case studies.

Table 2. The case studies used in this study

Case study number	Details	Reference
1	Streams, Sätraån and Skärholmsbäcken, Sweden	(Larm *et al.* 2000)
2	Stockby, Lidingö, Sweden	(Larm *et al.* 2002)
3	Lake, Kyrkviken, Lidingö , Sweden	(Larm *et al.* 2002)
4	Dams, Bäckaslövsdammen/ Krubban/ Järnbrottsdammen, Sweden	(Wikström *et al.* 2004)
5	Lake, Säbysjön, Järfälla, Sweden	(Larm 2004)
6	23 agricultural watershed areas in Sweden	(Stjernman 2009)
7	Dam, Kolardammen, Tyresö, Sweden	(Rydberg and Hammarström 2003)
8	Streams, Sätraån and Skärholmsbäcken, Sweden	(Larm *et al.* 2000)
9	Dam, Tibbledammen, Upplands Bro, Sweden	(Alm *et al*. 2010)
10	Southeast near the outlet of Lake Flaten, Sweden	(Larm *et al.* 2001)
11	West of Lake Flaten, east of natural wetland area, Sweden	(Larm *et al.* 2001)
12	Northwest of Lake Flaten, north of Herrängsparken, Sweden	(Larm *et al.* 2001)
13	Tyresö C, Sweden	(Jansson 2005)
14	Ursvik, Sweden	(Persson and Yman 2010)
15	Trap Pond Outlet ,Nanticoke river watershed, Delaware, USA	(Andres *et al.* 2007)
16	Mifflin Ditch, Nanticoke river watershed, Delaware, USA	(Andres *et al.* 2007)
17	Nanticoke river, Nanticoke river watershed, Delaware, USA	(Andres *et al.* 2007)
18	Herring Run Tributary, Nanticoke river watershed, Delaware, USA	(Andres *et al.* 2007)
19	Dukes and Jobs ditch, Nanticoke river watershed, Delaware, USA	(Andres *et al.* 2007)

The case studies used to calibrate the K_x-value need to include (all or some of) the following information:

- Area per land use
- The baseflow
- Concentration of substances

In some case studies, the baseflow is given because it has been measured, although in many reports only the stormwater flow is measured. Then the baseflow must be estimated manually through studying the stormwater flow, the baseflow and the precipitation. When the flow data is available, it is plotted in a diagram where it is clear where there is high and low flow. What is sought for is the yearly average of the baseflow, so not the lowest flow, but what seems to be the average lowest flow (i.e. disregarding stormwater flow during precipitation events). From the diagram, a baseflow is estimated. It is also important to know the precipitation so that it is clear which of the peaks in the stormwater flow depend on rainfall, and which ones that do not as these are part of the baseflow.

Usually, pollutant concentration is not directly measured in the baseflow but only in the stormwater flow. In those cases a period without precipitation and consequently low flow has to be found in the flow diagram, and concentration measurements must have been taken during the same period in order to estimate concentrations in the baseflow.

This process of estimating the average, minimum and maximum values of baseflow (l/s) together with baseflow concentrations from laboratory reports was a major part of the work, together with finding data from added case studies from the literature studies (that should include land use areas).

2.1. K_x-value

To get data for calibration of the Kx-value, the first step was to extract the area per land use and to estimate the baseflow from every case study.

Table 3 shows the area per land use for all the case studies, and Table 4 shows the baseflows from the case studies.

Table 3. Area per land use in the case studies (see table 2 for details of case studies).

Land use (ha)	Case study 1	Case study 2	Case study 3	Case study 5	Case study 7	Case study 9	Case study 10	Case study 11	Case study 12	Case study 13	Case study 14	Case study 15	Case study 16	Case study 17	Case study 18	Case study 19
Roads (ADT)	0.70		2.2	16	4.9	9.0				1.1	1.9					
Parking	1.0			9.1		3.4										
Detached houses	2.1	1.8	47	42	135	88	24.9	52	10	5.0	9.1					
Terraced houses	6.5	6.8	39		66	65		3.6	0.80	31						
Apartments	1.3		21	15	218	63	0.50		0.30	110		315	13	1502	21	68
Garden plots					4.6											
Commercial				4.2	16					7.0						
Industry		12	0.70	1.7	21	9.6										
Park	4.2				51											
Golf courses										0.56						
Forests	11	25	9.3	148	334	233	7.9	68	31	30		1231	89	2613	2.1	131
Farmland		4.3		12								1983	10	11037	10	461
Meadows		6.4	21	41		178		3		6						
Wetlands		1.7		5.0				8.8				557	265	3374	1.2	133
Green area												207	12	858		36
Other												26	0.39	117	0.24	5.5
Total	27	58	140	293	850	649	33.3	135	42	190	11	4320	389	19500	34	835

Table 4. Baseflow in the different case studies.

Type of baseflow	Case Study 1	Case Study 2	Case Study 3	Case study 5	Case study 7	Case study 9	Case study 10	Case study 11	Case study 12	Case study 13	Case study 14	Case study 15	Case study 16	Case study 17	Case study 18	Case study 19
Average flow (l/s)	0.3	1.1	1.8	0.87	25	30	0.80	5.2	1.4	3.0	0.30	506	5.7	3953	1.1	179
Minimum flow (l/s)	0.0			0.10		15	0.42	5.0	1.0	0.080						
Maximum flow (l/s)	4.0			2.0		40	1.0	20	3.0	6.0						

As mentioned above, the formula to calculate the baseflow is:

$$Q_b = 10pK_x \sum_{i=1}^{N} (K_{\inf,i} A_i) \qquad (01)$$

The K_{inf} and the precipitation (p) were assumed to be correct in the model, so the area per land use was put into the model and then different K_x-values were tested until the correct (measured) baseflow was calculated by StormTac. See figure 4, figure 5 and figure 6.

2.2. Pollutant concentrations

The goal was to calculate the concentration of each pollutant in the baseflow from each type of land use, and it was done in a number of steps.

The median value of the concentration of a number of pollutants from the case studies were calculated, see table 5. The median value was chosen instead of the average value because the mean concentration would have been too affected by the extreme values. Median values have been used throughout the study.

There were other substances present in a few of the case studies, and the data has been put into the model, but it will not be presented in this report, due to the small amount of data for each substance. The substances are Al, As, Ba, Ca, Co, Fe, K, Mg, Mn, Na, S, Sb, W, CODCr, DOC, TOC, Cl, NH4, NO3, DEHP, monobutyltin, dibutyltin and Si.

The concentration of pollutants from rural areas was estimated by comparing the lowest value (min) and the second lowest value (min-1) from the current study, the original rural concentration (default value in the model), the concentration for stormwater in forests, and the minimum and median concentrations in groundwater. No equation was used here as there are no data to make an equation from. A coarse analysis was done, extreme values were taken away and a reasonable value was estimated. See table 6. The minimum and maximum values of concentrations are also shown.

For each case study the proportion of urban land uses, and the proportion of rural land uses were calculated. The rural land uses are forests, farmland, meadows, wetlands, green area and grave yard, and urban land uses are all of the rest. From the result a median value for the share of rural and the share of urban land use was calculated.

The following model formula was developed (assumed) to calculate the concentration of pollutants from urban land uses:

$$C_{urban} = (C_{median} – C_{rural}*share_{rural})/share_{urban} \quad (04)$$

Table 7 shows the values used to calculate the urban concentration.

When the urban and rural characteristic values were established for each pollutant, the urban concentration was assumed to be that for the land use “apartment” and the rural concentration assumed to be that for the land use “forest”. As the characteristic concentration for each pollutant from each land use is already established for stormwater in StormTac (based on flow proportional data from land uses), the same relationship as between different land use-specific concentrations for stormwater was used for the baseflow. Hence, the calculated concentration for rural land use was set as “forest” and then the same relationship as between the forest concentration and the other rural land uses in stormwater was used for the baseflow. The same principle was used for the urban land uses where the urban concentration was set as the land use “apartments”, and the other urban land uses got their concentrations according to the allocation in stormwater, see table 8.

To estimate the uncertainties associated with this method and data, the land use-specific characteristic values were also calculated based on the minimum rural and urban concentration, and the maximum rural and urban concentration, see table 9 and table 10 respectively. The minimum and maximum concentrations of different pollutants were also calculated, see table 11.

The following equation was developed (assumed) to calculate the land use-specific characteristic values for baseflow based on stormwater:

If $C_{x,b} > C_{min,\ b}$ and if $C_{x,\ b} < C_{max,\ b}$ then:

$$C_{x,b} = {C_{x,s} \cdot C_{a,b}}/{C_{a,s}} \quad (05)$$

else $C_{x,b} = C_{max\ b}$ if urban area

else $C_{x,b} = C_{min\ b}$ if rural area

Where

C = concentration

x = land use

b = baseflow

s = stormwater

a = apartment

It is an assumption to use the same allocation between land uses for baseflow as for stormwater. This is due to the lack of land use-specific data for calibration, i.e. there was no case study with one single land use, and so it would have been too complex to calibrate the model based on many different land uses. If a review of this method would result in an alternative better method, it can easily be changed in the model, as the model is continuously updated with new data and updated methods.

The new land use-specific characteristic values were compared to the original ones to calculate the difference and see how much they have changed, see table 12.

3. Results

StormTac now has 16 case studies with flow data for the base flow, and 9 Swedish and 5 American case studies with pollutant concentrations in the baseflow. When the current study started there were 6 case studies in StormTac's database for baseflow, number 1-6 in table 2.

3.1. K_x-value

Figure 4 shows the K_x-value during average baseflow. The median K_x-value is 0.7.

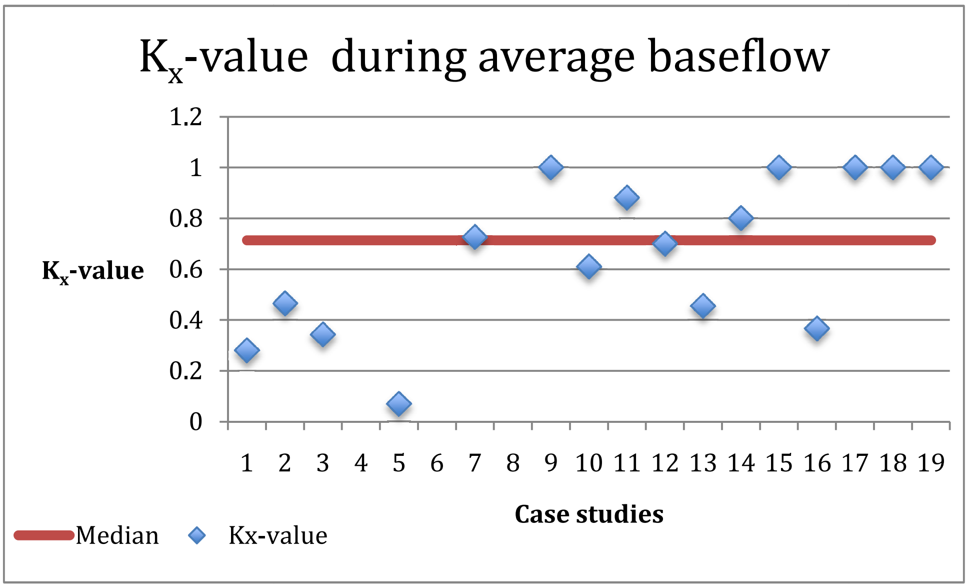

Figure 4. K_x -values during average flow

Figure 5 shows the Kx-value during minimal baseflow. The median Kx-value is 0.3.

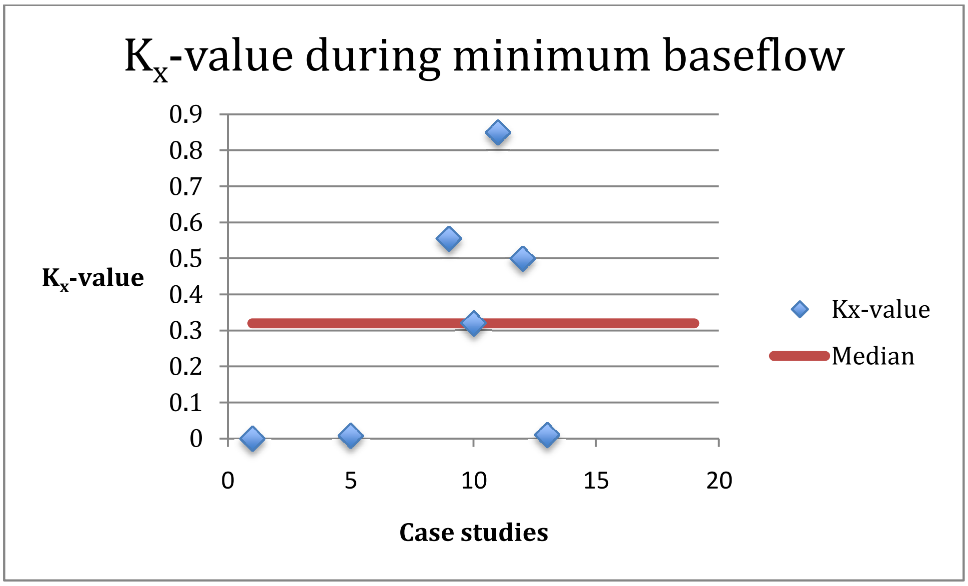

Figure 5. K_x -values during minimal baseflow.

Figure 6 shows the Kx-value during maximum baseflow. The median Kx-value is 1.

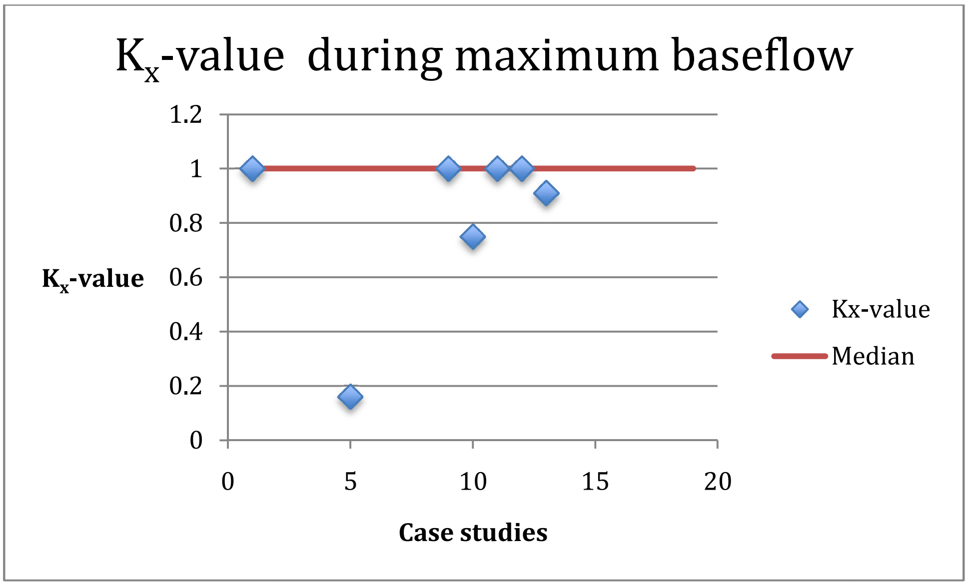

Figure 6. K_x -values during maximum baseflow.

Based on these results, the proposed best default K_x-value is 0.7. However, the K_x-value varies with land use, type and condition of sewer, share of sewers versus open ditches, area and other site-specific conditions. The median value for minimum flow (see figure 5) is 0.3, whilst the median value for maximum flow (excluding values of K_x = 1 for which the model did not reach the correct baseflow) was 0.8 (see figure 6) – thus a range of default values from 0.3 to 0.8 might reasonably be used. When there is extreme variation, from paved surfaces (no infiltration) to lakes (everything infiltrates), K_x can vary between 0 and 1. The result of K_x is a range where the median is 0.7, but it can often vary between 0.3 and 0.8, and in extreme cases it can vary between 0 and 1.

This added information of K_x-data was added to the model StormTac, as a result of the work. Further, the used areas per land use and base flow data from each case study was added to the data base of the model.

3.2. Pollutant concentrations

The compiled land use-specific base flow concentrations were replacing the old data in the model StormTac as a result of this work.

Table 5. Pollutant concentrations in the baseflow from different sites and their median value

Substance	Median	Case study 1	Case study 2	Case study 3	Case study 4	Case study 5	Case study 6	Case study 7	Case study 8	Case study 9	Case study 15**	Case study 16**	Case study 17 **	Case study 18**	Case study 19**
P (mg/l)	0.064	0.021	0.065	0.064		0.060	0.13	0.56	0.032		0.43	0.15	0.28	0.12	0.33
N (mg/l)	1.1	1.0	0.85	1.2	0.20	1.2	5.2				9.2	3.4	21	4.0	53
Pb (mg/l)	1.4	0.80	0.50	0.50		2.4		18		2					
Cu (mg/l)	6.6	16	6.4	6.6	5.0	6.0		32	6.5	8.4					
Zn (mg/l)	24	10	35	24	10	10		154		29					
Cd (mg/l)	0.050	0.050	0.050	0.050	0.050	0.10		3.2		0.025					
Cr (mg/l)	1.4	0.50	1.7	1.0		1.0		8.8		7.3					
Ni (mg/l)	3.1	4.5	3.0	1.0		2.0		11		3.2					
Hg (mg/l)	0.016*							0.14		0.047					
SS (mg/l)	11	23	3.4	1.2	5.0	17	19		4.5	36	43	48	89	43	44
Oil (mg/l)	0.10		0.15	0.050											

*There was too little data to get a reliable median, so values from stormwater and groundwater were also included.

** The Delaware values were much higher than the other values and the nitrogen (N) concentration was even higher than in stormwater, the values did not seem reasonable, so they are not included in the median.

Table 6. Pollutant concentrations in baseflow from rural land uses

Substance	Minimum concentration	Second lowest concentration	Original rural concentration	Concentration forest stormwater	Concentration groundwater minimum	Concentration groundwater median	**Estimated rural concentration**	Minimum rural concentration	Maximum Rural concentration
P (mg/l)	0.021	0.032	0.060	0.035	0.0090		**0.030**	0.0090	0.060
N (mg/l)	0.20	0.85	1.1	0.75	0.39		**0.70**	0.20	1.1
Pb (µg/l)	0.50	0.80	0.70	6.0	0.10	0.18	**0.80**	0.10	6.0
Cu (µg/l)	5.0	6.0	3.0	6.5	0.20	0.80	**4.0**	0.20	6.5
Zn (µg/l)	10	10	6.0	15	1.1	17	**10**	1.1	17
Cd (µg/l)	0.025	0.050	0.020	0.20	0.020	0.027	**0.030**	0.020	0.20
Cr (µg/l)	0.50	1.0	0.20	0.50	0.20	0.22	**0.40**	0.20	1.0
Ni (µg/l)	1.0	2.0	1.1	0.50	1.1	2.2	**0.50**	0.50	2.2
Hg (µg/l)	0.0020	0.016	0.0030	0.0050	0.00026	0.0020	**0.0040**	0.0026	0.016
SS (mg/l)	1.2	3.4	1.0	34			**1.5**	1.0	34
Oil (mg/l)	0.050	0.15	0.0	0.10	0.010		**0.070**	0	0.15
PAH (µg/l)			0.010	0.0		0.10	**0.010**	0	0.10
BaP (µg/l)			0.0083	0.0			**0.0083**	0	0.0083

Table 7. The values used to calculate the concentration of pollutants from urban land uses

Substance	Concentration median	Concentration rural	Proportion rural	Proportion urban	**Concentration urban**	Minimum urban concentration	Maximum urban concentration
P (mg/l)	0.064	0.030	0.40	0.60	**0.087**	-0.0050	0.080
N (mg/l)	1.1	0.70	0.40	0.60	**1.4**	-0.13	1.4
Pb (µg/l)	1.4	0.80	0.40	0.60	**1.8**	-0.37	9.5
Cu (µg/l)	6.6	4.0	0.40	0.60	**8.3**	-2.3	8.2
Zn (µg/l)	24	10	0.40	0.60	**33**	-4.9	22
Cd (µg/l)	0.050	0.030	0.40	0.60	**0.064**	0.013	0.31
Cr (µg/l)	1.4	0.40	0.40	0.60	**2.0**	0.067	1.4
Ni (µg/l)	3.1	0.50	0.40	0.60	**4.9**	0.50	3.3
Hg (µg/l)	0.0076*	0.0040	0.40	0.60	**0.010**	-0.0022	0.024
SS (mg/l)	11	1.5	0.40	0.60	**17**	0.67	56
Oil (mg/l)	0.10	0.070	0.40	0.60	**0.12**	-0.047	0.20

*Adapted value to get C urban = 0.01, estimated maximum in respect to normal stormwater data; 0.015 – 0.08 µg/l.

Table 8. The land use-specific characteristic values based on the estimated average rural and urban concentration.

Land use	P (mg/l)	N (mg/l)	Pb (µg/l)	Cu (µg/l)	Zn (µg/l)	Cd (µg/l)	Cr (µg/l)	Ni (µg/l)	Hg (µg/l)	SS (mg/l)	oil (mg/l)	PAH (µg/l)	BaP (µg/l)
Roads (ADT)	0.052	2.1	2.0	13	77	0.034	7.0	5.4	0.032	25	0.14	0.10	0.0021
Airports	0.029	1.5	0.084	1.9	14	0.014	0.56	1.9	0.020	32	0.026	0.050	0.0036
Railway area	0.015	0.84	3.1	13	56	0.029	0.37	0.85	0.020	14	0.10	0.050	0.0031
Harbour area	0.078	1.6	1.6	11	64	0.034	0.86	2.7	0.020	25	0.13	0.050	0.0036
Parking	0.029	0.96	3.6	11	47	0.041	2.5	2.2	0.020	35	0.14	0.050	0.0018
Petrol stations	0.029	1.0	6.0	8.3	37	0.18	0.50	2.2	0.020	15	0.15	0.050	0.0018
Detached houses	0.058	1.2	1.2	5.5	27	0.045	0.66	3.2	0.0060	11	0.069	0.050	0.0083
Terraced houses	0.073	1.3	1.4	6.9	28	0.054	1.0	3.8	0.0080	11	0.10	0.050	0.0083
Apartments	0.087	1.4	1.8	8.3	33	0.064	2.0	4.9	0.010	17	0.12	0.050	0.0083
School area	0.087	1.4	1.8	8.3	33	0.064	2.0	4.9	0.012	17	0.12	0.050	0.0083
Leisure houses	0.13	2.9	0.60	5.5	27	0.045	0.33	2.7	0.0060	12	0.017	0.050	0.0083
Garden plots	0.058	4.4	0.60	4.1	17	0.018	0.33	0.54	0.0048	9.5	0.017	0.050	0.0083
Commercial, less dense	0.072	1.4	2.0	5.5	36	0.073	0.76	3.8	0.020	19	0.15	0.050	0.0083
Commercial, more dense	0.13	1.8	4.8	10	82	0.13	1.8	7.1	0.020	89	0.15	0.050	0.083
Commercial	0.081	1.6	2.4	6.1	47	0.091	0.83	4.6	0.020	25	0.15	0.050	0.0083
Industry	0.087	1.6	3.6	12	90	0.14	2.3	8.7	0.028	25	0.15	0.050	0.0075
Park	0.035	1.1	0.72	4.1	8.4	0.027	0.50	1.1	0.0080	12	0.034	0.010	0.0083
Golf courses	0.10	1.8	0.60	4.1	6.0	0.027	0.12	1.1	0.0040	14	0.034	0.050	0.0083
Highway ditches	0.073	2.3	1.8	8.3	30	0.038	0.60	1.0	0.0040	27	0.093	0.050	0.0028
Industry, less dense	0.085	1.4	3.0	9.7	72	0.10	1.6	6.3	0.024	20	0.15	0.050	0.0083
Industry, more dense	0.12	1.9	6.0	22	135	0.19	2.7	11	0.032	55	0.15	0.050	0.0083
Office and commercial	0.073	1.3	3.6	8.3	47	0.082	2.2	3.8	0.040	25	0.15	0.050	0.0
Forests	0.030	0.70	0.80	4.0	10	0.030	0.40	0.50	0.0040	1.5	0.070	0.050	0.0083
Farmland	0.22	5.3	9.0	14	20	0.10	1.0	0.50	0.0050	100	0.15	0.010	0.0083
Meadows	0.17	0.93	0.80	9.2	20	0.045	1.6	1.0	0.0040	2.0	0.14	0.010	0.0083
Wetlands	0.043	0.84	0.80	5.0	10	0.025	0.50	1.0	0.0040	1.2	0.070	0.010	0.0083
Green area (mixed meadows & forests)	0.056	0.84	0.60	6.6	13	0.038	0.50	1.0	0.0040	1.8	0.11	0.010	0.0083
Grave yard	0.043	0.93	0.80	12	17	0.045	1.6	1.0	0.0040	3.5	0.14	0.010	0.0083

Table 9. Land use-specific characteristic values based on the minimum rural and minimum urban concentration

Land use	P (mg/l)	N (mg/l)	Pb (µg/l)	Cu (µg/l)	Zn (µg/l)	Cd (µg/l)	Cr (µg/l)	Ni (µg/l)	Hg (µg/l)	SS (mg/l)	oil (mg/l)
Roads (ADT)	-0.0030	-0.20	-0.40	-3.6	-11	0.0032	0.0088	0.011	-0.0071	0.94	-0.056
Airports	-0.0017	-0.15	-0.017	-0.54	-2.1	0.0029	0.0088	0.011	-0.0045	1.2	-0.010
Railway area	-0.0009	-0.08	-0.64	-3.8	-8.2	0.0032	0.0088	0.011	-0.0045	0.5	-0.040
Harbour area	-0.0045	-0.15	-0.32	-3.1	-9.3	0.0032	0.0088	0.011	-0.0045	0.94	-0.051
Parking	-0.0017	-0.092	-0.73	-3.1	-6.8	0.0032	0.0088	0.011	-0.0045	1.3	-0.053
Petrol stations	-0.0017	-0.092	-1.2	-2.3	-5.4	0.0032	0.0088	0.011	-0.0045	0.6	-0.067
Detached houses	-0.0033	-0.12	-0.24	-1.6	-3.9	0.0032	0.0088	0.011	-0.0013	0.4	-0.027
Terraced houses	-0.0042	-0.12	-0.29	-1.9	-4.2	0.0032	0.0088	0.011	-0.0018	0.4	-0.040
Apartments	-0.0050	-0.13	-0.37	-2.3	-4.9	0.013	0.067	0.50	-0.0022	0.7	-0.047
School area	-0.0050	-0.13	-0.37	-2.3	-4.9	0.0032	0.0088	0.011	-0.0027	0.7	-0.047
Leisure houses	-0.0077	-0.27	-0.12	-1.6	-3.9	0.0032	0.0088	0.011	-0.0013	0.5	-0.0067
Garden plots	-0.0033	-0.42	-0.12	-1.2	-2.4	0.0032	0.0088	0.011	-0.0011	0.4	-0.0067
Commercial, less dense	-0.0041	-0.13	-0.42	-1.6	-5.3	0.0032	0.0088	0.011	-0.0045	0.7	-0.068
Commercial, more dense	-0.0075	-0.18	-0.98	-2.9	-12	0.0032	0.0088	0.011	-0.0045	3.8	-0.11
Commercial	-0.0047	-0.15	-0.49	-1.7	-6.8	0.0032	0.0088	0.011	-0.0045	1.0	-0.10
Industry	-0.0050	-0.15	-0.73	-3.5	-13	0.0032	0.0088	0.011	-0.0063	1.0	-0.17
Park	-0.0020	-0.10	-0.15	-1.2	-1.2	0.0032	0.0088	0.011	-0.0018	0.47	-0.013
Golf courses	-0.0058	-0.18	-0.12	-1.2	-0.88	0.0032	0.0039	0.011	-0.00089	0.52	-0.013
Highway ditches	-0.0042	-0.22	-0.37	-2.3	-4.4	0.0032	0.0088	0.011	-0.00089	1.0	-0.036
Industry, less dense	-0.0049	-0.14	-0.61	-2.7	-10	0.0032	0.0088	0.011	-0.0054	0.76	-0.113
Industry, more dense	-0.0070	-0.18	-1.2	-6.1	-20	0.0032	0.0088	0.011	-0.0071	2.1	-0.21
Office and commercial	-0.0042	-0.13	-0.73	-2.3	-6.8	0.0032	0.0088	0.011	-0.0089	1.0	-0.087
Forests	0.0090	0.20	0.10	0.2	1.1	0.020	0.2000	0.50	0.00026	1.0	0.0
Farmland	0.22	5.3	0.01	0.014	0.020	0.00010	0.0010	0.0005	0.00001	100	0.15
Meadows	0.051	0.27	0.10	0.46	2.1	0.030	0.80	0.50	0.00026	1.3	0.050
Wetlands	0.021	0.24	0.10	0.23	0.89	0.015	0.06	0.50	0.00026	1.2	0.050
Green area (mixed meadows & forests)	0.021	0.24	0.08	0.33	1.4	0.025	0.10	0.50	0.00026	1.2	0.050
Grave yard	0.021	0.27	0.10	0.62	1.8	0.030	0.80	0.50	0.00026	2.4	0.050

Table 10. Land use-specific characteristic values based on the maximum rural and urban concentration

Land use	P (mg/l)	N (mg/l)	Pb (µg/l)	Cu (µg/l)	Zn (µg/l)	Cd (µg/l)	Cr (µg/l)	Ni (µg/l)	Hg (µg/l)	SS (mg/l)	oil (mg/l)
Roads (ADT)	0.048	2.1	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	78	0.15
Airports	0.027	1.5	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	89	0.044
Railway area	0.014	0.8	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	44	0.15
Harbour area	0.072	1.5	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	79	0.15
Parking	0.027	0.9	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	89	0.15
Petrol stations	0.027	0.9	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	48	0.15
Detached houses	0.053	1.2	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	36	0.12
Terraced houses	0.067	1.2	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	36	0.15
Apartments	0.080	1.4	9.5	8.2	22	0.31	1.4	3.3	0.024	56	0.20
School area	0.080	1.4	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	56	0.15
Leisure houses	0.123	2.8	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	40	0.029
Garden plots	0.053	4.3	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	30	0.029
Commercial, less dense	0.066	1.4	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	61	0.15
Commercial, more dense	0.119	1.8	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	89	0.15
Commercial	0.075	1.6	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	80	0.15
Industry	0.080	1.5	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	80	0.15
Park	0.032	1.0	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	39	0.058
Golf courses	0.093	1.8	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	44	0.058
Highway ditches	0.067	2.2	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	85	0.15
Industry, less dense	0.078	1.4	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	64	0.15
Industry, more dense	0.11	1.8	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	89	0.15
Office and commercial	0.067	1.3	0.018	0.032	0.15	0.0032	0.0088	0.011	0.00014	80	0.15
Forests	0.060	1.1	6.0	6.5	17	0.20	1.0	2.2	0.016	34	0.15
Farmland	0.22	5.3	0.0090	0.014	0.020	0.00010	0.0010	0.00050	0.0000050	100	0.15
Meadows	0.34	1.5	6.0	15	34	0.30	4.0	2.2	0.016	45	0.30
Wetlands	0.086	1.3	6.0	7.5	14	0.15	0.30	2.2	0.016	16	0.15
Green area (mixed meadows & forests)	0.11	1.3	4.5	11	23	0.25	0.50	2.2	0.016	40	0.23
Grave yard	0.086	1.5	6.0	20	28	0.30	4.0	2.2	0.016	80	0.30

Table 11. The maximum and minimum concentration of different pollutants in the baseflow.

Concentration	P (mg/l)	N (mg/l)	Pb (µg/l)	Cu (µg/l)	Zn (µg/l)	Cd (µg/l)	Cr (µg/l)	Ni (µg/l)	Hg (µg/l)	SS (mg/l)	oil (mg/l)	PAH (µg/l)	BaP (µg/l)
Minimum	0.021	0.20	0.50	5.0	10	0.025	0.50	1.0	0.0020	1.2	0.050	0.010	0.0018
Maximum	0.56	53	18	32	154	3.2	8.8	11	0.14	89	0.15	0.10	0.083

Table 12. The difference in percentage between the original land use-specific characteristic values and the land use-specific values obtained in this study.

	P (mg/l)	N (mg/l)	Pb (µg/l)	Cu (µg/l)	Zn (µg/l)	Cd (µg/l)	Cr (µg/l)	Ni (µg/l)	Hg (µg/l)	SS (mg/l)	Oil (mg/l)	PAH	BaP
Original median concentration urban	0.060	1.1	0.8	6.0	10	0.050	0.80	3.0	0.0050	5.0	0.050	0.050	0.0083
New median concentration urban	0.073	1.5	1.9	8.3	36	0.050	0.85	3.5	0.020	20	0.13	0.050	0.0083
Percentage difference	21%	35%	137%	38%	265%	-0.14%	5.9%	17%	300%	291%	151%	0.0%*	0.0%*

Old median concentration rural	0.060	1.1	0.70	3.0	6.0	0.020	0.20	1.1	0.0030	1.0	0.0050	0.010	0.0083
New median concentration rural	0.049	0.89	0.80	7.9	15	0.041	0.75	1.0	0.0040	1.9	0.12	0.010	0.0083
Percentage difference	-18%	-19%	14%	164%	150%	106%	275%	-5.7%	33%	88%	2350%	0.0%*	0.0%*

*There were no new values for PAH and BaP, so the difference is 0.

4. Discussion

The data for the K_x-value (the share of infiltrated water that reaches the baseflow) was added to StormTac, and StormTac's database was complemented with data on area per land use and estimated baseflows for every case study. The previous baseflow concentrations, based on considerably fewer case studies were replaced with the baseflow concentrations resulting from this study.

4.1 K_x-value

Since the result shows that the median K_x-value is 0.7 during average baseflow conditions, this confirms that the original value 0.7 is a good default value for K_x. This study also showed the variance that the K_x-value could have; it has a normal range from 0.3 to 0.8. This is very useful as the K_x-value can be adapted to the case where it is used. If it is known, for example, that a large proportion of the land uses is impervious, then the K_x-value can be set to lower than 0.7, and if there are mainly pervious land uses, K_x can be set to higher than 0.7. Further, the results show that the extreme values 0 and 1 are possible as well, $K_x = 0$ could be set if the land use is a road-area that does not result in any baseflow at all, and 1 can be where there is a lake and everything that infiltrates becomes part of the baseflow (or in that case also groundwater inflow to the lake).

It might appear that the range for K_x is very wide, but this likely reflects reality, because of the highly variable contributions of baseflow to stormwater. There are also large differences in pollutant concentrations between different land uses, again reflecting time-dependent variations.

Usually data on the amount of leakage is not available, because it depends on the age of the pipes, local circumstances and site-specific flows, so a default value must be used for K_x. However, if it would be known that e.g. the pipes are newly constructed then a lower K_x-value could be used, so it is possible to test to vary the K_x-value between a minimum and maximum value. It would be very useful to conduct sensitivity and uncertainty analysis to see how much K_x and other included parameters (precipitation, evaporation, and runoff coefficients) affect the outcome.

By using equation 01 it is assumed that K_{inf} is correct, and thereby that the precipitation, the runoff coefficient and the evapotranspiration are correct as well. But what has been used here is the default precipitation 636 mm/year for all case studies due to lack of precipitation data. 636 mm/year is the estimated real yearly precipitation for Stockholm. A very simple sensitivity analysis was conducted through testing different values for precipitation, and this lead to relatively large differences in the K_x-value. Therefore it is proposed that a further study should make an inventory of the precipitation data for these case studies in this work so that data could be used, instead of the yearly average precipitation, to continue the calibration or investigation of the K_x-value. In addition, it is proposed to analyse the impact of the other parameters through sensitivity analysis of the runoff coefficient and evapotranspiration.

The recommendations for further studies, such as sensitivity analyses, will be used by Thomas Larm, developer of StormTac, to further analyse the K_x-values, and to inform revisions of methodology etc.

4.2. Pollutant concentrations

The number of case studies that gives the basis for both Kx-values and for the land use-specific characteristic values has increased from 6 to 19 as a result of this study. There are 8 new Swedish cases, and 5 new cases from Delaware, USA. Therefore the new default values are seen as more reliable than the previous ones.

The new and the old land use-specific characteristic values were compared and assessed. For most of the substances the result shows reasonable values for the land use-specific characteristic values. They are pretty similar to the previous ones and values from groundwater and not higher than values from urban stormwater. Although the values for nitrogen (N), phosphorus (P) and suspended solids (SS) from the American study, Delaware, were extremely high, and therefore they were not included in the calculation of the median value (and the following land use-specific characteristic values), as that would have resulted in unrealistic values. Further, there was little data on mercury (Hg) and concentrations were higher than in stormwater (which seemed unreasonable), so a special method was used to calculate the median value where mercury concentrations from groundwater and stormwater were included as well. That resulted in lower more reasonable concentrations.

It is always a risk to reject data, it might show something interesting, but in this case it is probably showing that this method might not apply outside of Scandinavia (which is where it has been used). It can also be because the precipitation data is something completely different in Delaware than the default value from Stockholm that has been used in this work.

What has been touched upon several times is the importance of yearly average values due to spatial and temporal heterogeneity of stormwater, and this is one of the reasons why it is difficult to get data. For example, there might be different concentrations even within a land use. One way to test StormTac would be to use it on a new case study that has not been incorporated in the model, and to see how close to the measured value the model output is.

The estimation that was done for the rural concentration (table 6) was done as objectively as possible. From experience data for comparison was chosen and then the most likely value was estimated. The assessment is different for different substances, for some it is known that the concentrations are higher in stormwater than in baseflow, for other that the baseflow concentration is closer to the groundwater concentration. This is a problem for stormwater, for example there are not measured data from all kinds of land uses and in those cases the only way to get a value is to compare to other values and make an estimate. To get an idea about the uncertainty of theses values, the minimum and maximum rural and urban concentrations were also calculated (see table 6 and table 7), and used to calculate the land use specific characteristic values with minimum and maximum concentrations (see table 9 and table 10). The result gets a bit odd because of the way the formula is built up, but it illustrates that there are uncertainties associated with this method and this data.

The land use-specific characteristic values will continuously be reviewed and revised with new data and assessments as the model is being used, new comparisons with measured data etc. This is already the case with the values for stormwater, and this project is the start of that process for the baseflow concentrations.

If the model is used in a case where the actual concentrations are measured, then it is possible to put those values into the model. The default values may be used when there are no measurements.

StormTac is a fairly simple model, but it is common that all the data required by other models is not available. StormTac only needs area per land use as input data, as there are land use-specific characteristic values for baseflow pollutant concentrations and the runoff coefficients, as previously mentioned yearly precipitation data can either be added or default values can be used. The concentrations, the coefficients and the precipitation can be changed, and the only obligatory input data is area per land use. To continue this study, it is proposed a comparison with other models regarding what input data they require, and what equations they use to calculate the baseflow (l/s). Thereafter maybe the methodology of StormTac will be revised, still taking into account the required input data and what normally is available.

Finally, StormTac is mainly a stormwater model and recipient model, but baseflow can play a rather important role for the total calculated mass and water fluxes. This baseflow part was previously more uncertain based on fewer case studies. This study resulted in more reliable data and gives recommendations for and discussion of continued studies.

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