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USING A PLANNING TOOL AND THE SOFTWARE STORMTAC FOR THE DEVELOPMENT OF STORMWATER MANAGEMENT PLANS

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ABSTRACT

The consultant company Sweco has together with several municipalities implemented and developed a planning-level tool for stormwater and watershed management, suitable to use e.g. within the EU Water Framework Directive. The stormwater and recipient software model StormTac has been used as the operative part of this tool.

The presented tool takes advantage of that only one operative model is needed to address all the system components, including calculations of water and pollutant transport, impacts on receiving waters, recipient criteria concentrations, acceptable load, required reduction and the design of transport, flow detention and pollutant treatment facilities.

Only input data of watershed area (ha) per land use and precipitation data (mm/year) are required for creating the plan, adding the area and volume of the receiving water if acceptable load to the recipient and required load reduction is to be calculated. More site-specific results are obtained by changing default data of e.g measured concentrations in the receiving water body, rain intensities and transport distance.

The model is unique by including more than 70 substances and equal amount of land uses. Results and experiences from implementing the tool and model for the two Swedish municipalities Tyresö and Upplands Väsby are presented.

KEYWORDS

Stormwater; pollutant transport; planning; watershed management; StormTac

INTRODUCTION

Stormwater originates when precipitation and snowmelt runoff does not infiltrate into the ground but instead becomes surface runoff. Stormwater is today generally the main pollutant source in urban areas for loads to the receiving waters resulting in eutrophication and impaired water quality (Gnecco et al., 2004; Kayhanian, 2007; Eriksson et al., 2007a, b).

In 2000 the EU Water Framework Directive was adopted within the European Union with the aim to improve receiving water quality in Europe (EG, 2000). Comparing measured data in Swedish surface waters to Environmental Quality Standard (EQS) values (EG, 2000; Alm et al., 2010) showed that one of the biggest issues in southern and central Sweden is eutrophication, partly due to the load of nutrients in the stormwater. Numerous municipalities in Sweden have recognized the problem and are starting to address how to reach the aims of the directive. To identify measures needed to decrease the effect of stormwater on the receiving waters some municipalities have developed watershed management plans.

There is generally a need for simple-to-use forecasting tools when creating a management plan in order to prioritize measures to achieve the best result for the receiving waters (Ministry of the Environment, Ontario, 2003; The State of New Jersey, 2004;The City of New york, 2008). A requirement is that the model should be able to work using a readily available input data (Ministry of the Environment, Ontario, 2003).

Usually, several complex models are required to include all parts of the watershed system; flow and pollutant transport, receiving waters and water quality criteria, design of treatment and flow detention. The International consultant company Sweco (working with engineering, environmental technology and architecture) has together with several municipalities developed and implemented a planning-level tool for stormwater and watershed management. The presented tool takes advantage of that only one operative model is needed to address all these system components and that only very few input data is needed, even if more can be used. The tool is scientifically reviewed (Larm, 2000) and is also easy to use and can be adapted for different site-specific conditions. It is also unique by including more than 70 substances and equal amount of land uses, and both data and equations are updated continuously and available from a web page (StormTac, 2012).

The objective of this paper is to present a methodology, required input data and obtained results for creating stormwater management plans that could be used elsewhere, to present experiences from developing and employing these plans and what effort are needed in meeting the requirements within the EU Water Framework Directive.

The aim for the two watershed management studies presented here is to answer the following questions with help from the model and working tool:
- How are different land uses (roads, residential areas, agriculture, forests etc.) distributed and which areas contribute with water flows to a specific discharge point or recipients?
- How large are the water flows generated in the sub-watershed areas?
- How large are the pollutant concentrations (mg/l) in the stormwater runoff from different land uses and in the discharge points to the receiving waters?
- What pollutant loads (kg/year) can be expected to the receiving waters from each discharge point and where are the largest points of discharge located?
- What are the conditions of the receiving waters (pollutant concentrations)?
- Where have floods been reported as a problem (capacity problems of the transport system)?
- What are the required detention volumes and places for flow reduction measures?
- Where are stormwater measures to be considered and what kinds and sizes of measures are relevant due to site-specific conditions?
- What are the receiving water quality criteria, e.g. the environmental quality standards

(EQS) according to the EU Water Framework Directive or other criteria, e.g. what are the acceptable loads (kg/year) and the required load reduction?

Here we describe and present the watershed management process showing the steps from pollutant mapping, presenting examples of existing and proposed measures, finally presenting built measures as results. Tyresö and Upplands Väsby municipality are the two case studies.

Tyresö municipality is located southeast of Stockholm at the coast of the Baltic Sea, populated with around 50 000 persons and has a separate stormwater sewer system, transporting the stormwater to different receiving waters within the municipality. Hence, the sewage is transported separately to a wastewater treatment plant Henriksdal in Stockholm. Upplands Väsby municipality is located north of Stockholm, populated with around 40 000 persons and has also a separate stormwater system within the municipality and sewage transported to Käppalaverket in Lidingö, Stockholm.

METHODS

The calculations of pollutants concentrations and loads as well as the design of flow detention and pollutant treatment facilities in both Tyresö and Upplands Väsby municipalities were carried out with the watershed management model StormTac (Larm T., 2000; StormTac, 2012). The results were presented in a GIS format and in reports (Larm et al., 1998; Larm and Linder, 2001; Larm et al., 2010). The model is best suited for long-term (i.e. not dynamic) predictions and employs a watershed system approach, i.e. the system boundary is natural not administrative. It is a simple model that requires few input data. The only obligatory input data are:

1. Watershed area per land use (ha), see Eq. 1-2
2. The area (ha) and volume (m^3) of the receiving water if acceptable load, Eq. 3-4, and required load reduction (kg/year), Eq. 5, are to be calculated.
3. Yearly precipitation data (mm/year), Eq. 2

There are however many other input data (StormTac, 2012) that are default and can be changed to better reflect site specific conditions, such as:

1. ”Standard concentrations” (mg/l), Eq. 1
2. Runoff coefficients, Eq. 2
3. Rain intensities (l/s/ha) for different rain durations (mm)
4. Design transport distance (m)
5. Temperature (^oC), Eq. 4
6. Measured pollutant concentrations (mg/l)

In Eq. (1) the stormwater pollutant load L_j is calculated (Larm, 2000).

$$L_j = \frac{\sum_{i=1}^{N}(Q_i C_{ij})}{1000} \qquad (1)$$

L	Stormwater pollutant load [kg/year]
j	Pollutant
i	Land uses, *i* = 1,2,…N
Q	Runoff water flow [m^3/year]
C	Land use specific standard concentration for stormwater [mg/l]

The pollutant transport calculations employ default land use specific standard values of pollutant concentrations. The standard concentration data (StormTac, 2012) are compiled as yearly event mean concentrations from long periods of flow proportional sampling. StormTac calculates pollutant concentrations from roads (throughfares and highways) as a function of the traffic intensity (StormTac, 2012).

More than 70 pollutants (Alm et al., 2010; StormTac, 2012) can be chosen for calculation (nutrients, metals, suspended solids, oil, PAHs etc, both in total or dissolved fractions).

The runoff water flow Q is calculated in Eq. (2) (Larm, 2000), using land use specific standard values of runoff coefficients, precipitation data and estimated areas of different land uses within the sub-watershed.

$$Q = 10\,p\sum_{i=1}^{N}(\varphi_i A_i) \qquad (2)$$

p	Corrected precipitation intensity data (rain+snow) [mm/year]
φ	Runoff coefficient
A	Land use area [ha]

It is possible to define a very detailed selection of more than 70 urban and rural land uses (StormTac, 2012), e.g. residential area, terraced house area, multi-family area, industrial area, downtown area, forest, meadow and agricultural property.

Literature studies, consultant projects, personal contacts and participation on conferences are performed to collect data for updating the standard values of concentrations and runoff coefficients, also adding new land uses.

In Sweden the concept of acceptable load has been employed (Larm, 2000; StormTac, 2012), i.e. the maximum total yearly pollutant load (kg/year) that can be transported to a receiving water not to give higher pollutant concentrations in the water body than accepted. The limit concentration values are regulated by receiving water quality criteria concentrations such as Environmental Quality Standards (EQS) in the form of yearly average pollutant concentrations (EG, 2008).

The acceptable (critical) load is calculated in Eq. (3), derived from the OECD Management model (Vollenweider and Kerekes, 1982), presented in Larm (2005).

$$L_{acc} = \frac{V_{rec}\left(\frac{C_{cr}}{x_j}\right)^{1/y_j}(1 + t_{dr}^{\ 0.5})}{1000 t_{dr}} \tag{3}$$

L_{acc}	Acceptable (critical) pollutant load on the recipient [kg/year]
V_{rec}	Water volume of the recipient [m^3]
C_{cr}	Critical pollutant concentration in the water mass of the recipient for negative effects [mg/l]
x_j, y_j	Empirical coefficients for pollutant j
t_{dr}	Recipient residence time, $t_{dr}=V_{rec}/Q_{out}$ [year]

As an alternative, the simple dilution equation in Eq. (4) can be used when measured recipient data is available (Larm, 2005).

$$L_{acc} = \frac{C_{cr} L_{in}}{C_{rec}^{\ *}} \tag{4}$$

$C_{rec}*$	Measured pollutant concentration in the water body of the receiving water [mg/l]
L_{in}	Total pollutant load on the receiving water [kg/year]

In USA the similar method of Total Maximum Daily Load (TMDL) is used. A TMDL is the ”amount of a pollutant that can be accepted by a water body without causing an exceedence of water quality standards or interfering with the ability to use a water body for one or more of its designated uses” (The State of New Jersey, 2004).

The required reduction for the recipient water quality criteria is calculated in Eq. (5) (Larm, 2005).

$$\Delta L = L_{in} - L_{acc} \tag{5}$$

ΔL	Pollutant load to be reduced for the acceptable load L_{acc} [kg/year]

Modeled system components include stormwater, groundwater, surface water atmospheric deposition, other point sources (e.g. from waste water treatment plants), runoff flow, transport, treatment and detention facilities, see Fig. 1.

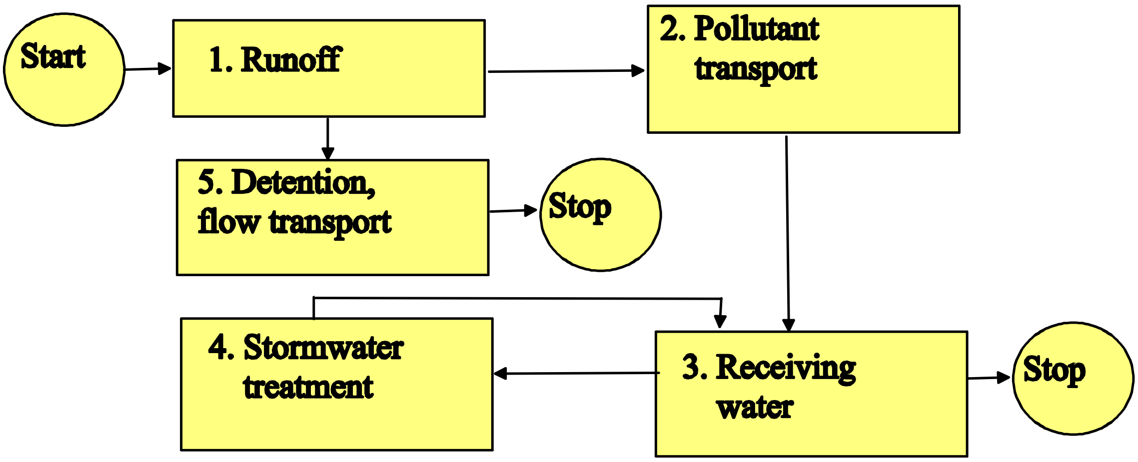

Figure 1 Simplified flowchart of the watershed management model StormTac.

In the process of developing a stormwater management plan the sub-watershed areas are first identified and quantified. These areas are specific for each discharge point and separated into different land uses. Topographical maps and the technical stormwater sewer systems within the areas are studied. The next step is to calculate the runoff water flows, pollutant concentrations and loads for each sub-watershed area. These are compared to estimated limit concentrations and acceptable loads to avoid eco-toxicological effects in the receiving water. Measured data in surface waters were compiled and compared to Environmental Quality Standards (EQS) (Alm et al., 2010), i.e. water quality concentration criteria within the Water Framework Directive (EG, 2008). If the measured volume-weighted mean concentrations in the recipient or calculated concentrations or loads in the outlets exceed the criteria, measures to reduce the pollutant loads are to be taken. Different types of stormwater treatment facilities are proposed. The model is able to quantify needed load reduction and the effects of different measures on the concentration in the surface water. Furthermore the net yearly internal load (net retention to sediments or net release from sediments) within the receiving water is calculated.

Examples of measures that may be simulated in StormTac are changed land use, stormwater treatment and detention facilities (e.g. wet and dry ponds, wetlands, filter strips, swales and detention basins). The types of facilities to be used will depend on the site-specific conditions such as soil, groundwater level and topography. Performance depends on e.g. water quality, climate, maintenance, design and size.

StormTac (StormTac, 2012) includes optimized tools for the design of treatment facilities for stormwater. They are based on empirical data and are continuously being updated. In Eq. (6) the permanent pool area for a wet pond and a constructed wetland is calculated (Eq. 7).

$$A_p = \varphi A K_{A\varphi} \tag{6}$$

A_p	Area of permanent pool [m^2]
$K_{A\varphi}$	Regression constant, normally 150 (70-400) for wet ponds and 300 (100-800) for wetlands (StormTac, 2012)

One of the most commonly used methods for calculating the required reduction efficiencies and area of stormwater wet ponds and constructed wetlands is based on empirical functions derived from Eq. 6. However, these methods need to be revised and complemented in order to consider site specific conditions, by also including parameters such as inlet concentrations (C_{in}), share of vegetation (veg), share of bypass (bypass), detention volume (V_d), irreducable concentration (C_{irr}) and temperature (temp) (Larm and Hallberg, 2008; Persson and Pettersson, 2009).

Because data are limited and the complexity of natural systems are high, the uncertainty is difficult to quantify for calculated loads and concentrations of pollutants, stormwater runoff design flow and corresponding required dimensions of facilities for flow detention and pollutant load reduction. The amount and quality of input data are very different for e.g. different substances and land uses (Alm et al., 2010; StormTac, 2012). In StormTac each concentration for each substance have been categorized in three levels of uncertainty, based on the number and variance of input data. Only flow proportional data has been used. Sensitivity and uncertainty analyses can be modeled by using maximum and minimum values from the included database of the model.

When the types of measures have been identified, cost-benefit analyses is performed in the model by calculating facility costs and reduced loads. The included default cost data are derived from calculated and resulted costs from a large number of projects designing transport, detention end treatment facilities. This data can be changed by the user. The results of the calculations are used to prioritize different measures.

The first versions of the watershed management plans were performed in 1998 in Tyresö municipality (Larm et al, 1998) and in 2001 in Upplands Väsby (Larm and Linder, 2001). These plans have been updated with new development areas and with updated concentrations of pollutants in the runoff from different land uses. The second reported versions of the plans are also adapted to comply with the criteria for the receiving waters within the Water Framework Directive and to new requirements and regulations within the municipality (Larm et al., 2010; Pirard et al., 2012). This paper is reporting on the whole process from the first to second iterations of the plans.

Figure 2 presents a map of phosphorus load from sub-watershed areas in Tyresö municipality. There are maps of other pollutants that give an overview of the pollutant situation and a basis for pollutant treatment measures. The figure also presents all sub-watershed areas (bold lines) within the municipality, the surrounding lakes and the Baltic Sea (to the right).

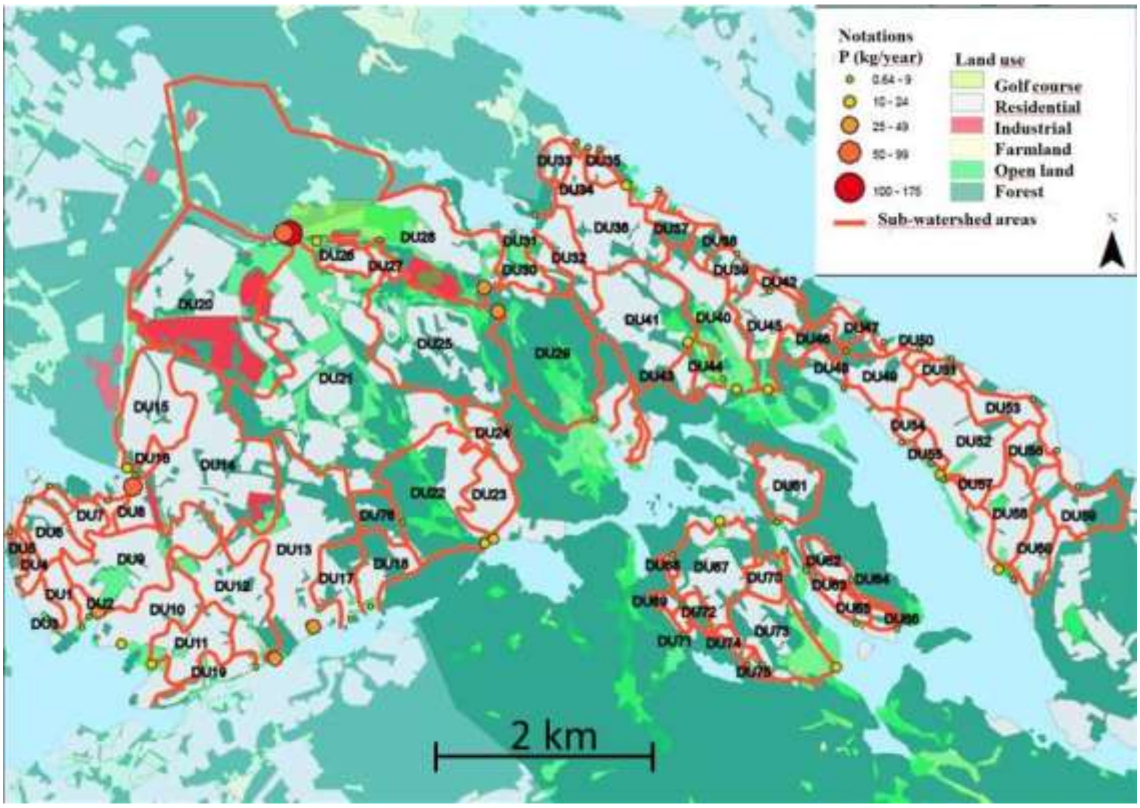

Figure 2 GIS map of the municipality of Tyresö with an overview of the phosphorus loads from different areas in the municipality.

RESULTS AND DISCUSSION

With the use of the planning tool, the largest pollutant discharges and general pollution sources (from each land use within each sub-watershed area) in the municipalities are identified and presented, see Fig. (2). This information, together with data on the conditions in the receiving waters, gathered experience from the municipalities and in-situ studies, serves as a basis for suggesting possible measures to be taken for reducing the flow and pollutant pressure on the receiving waters, see Fig. 3. The suggested measures and sites are a result of model simulations of required areas and volumes that have been compared to available areas and volumes. This provides the user with an overview of the stormwater management and a plan to study where and what kind of measures needed to be taken to get the best result and to comply with e.g. the Water Framework directive.

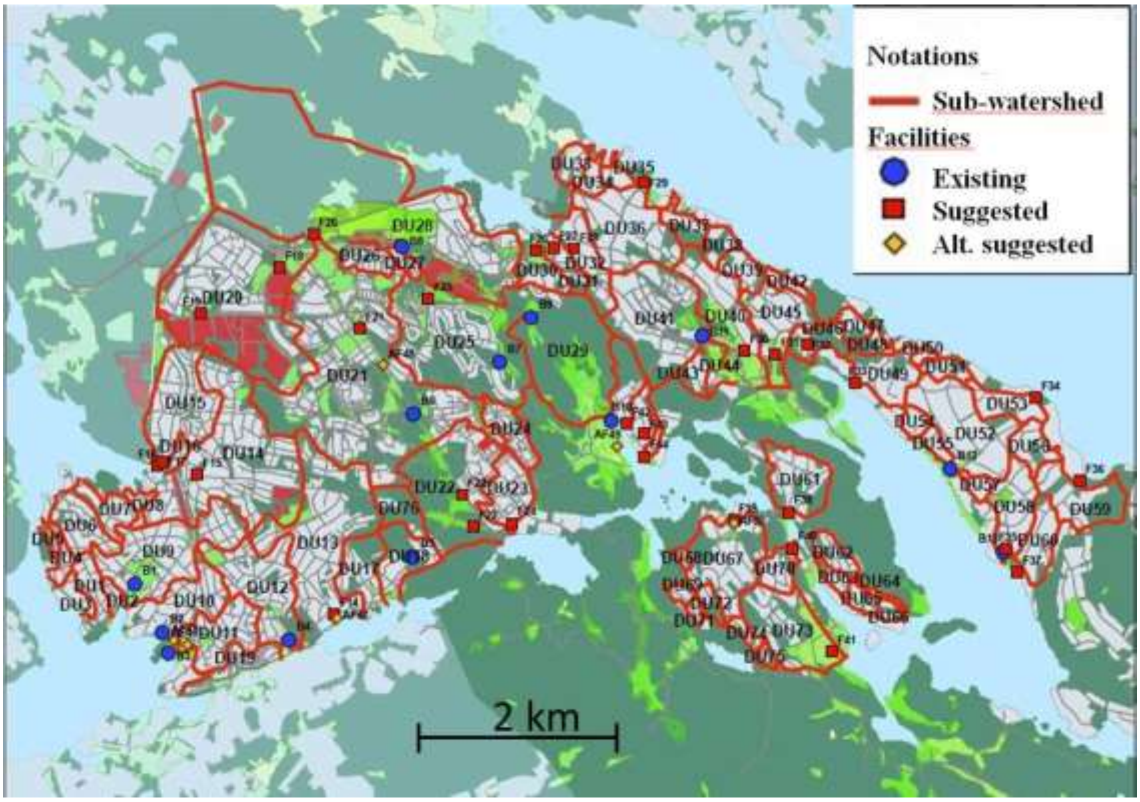

Figure 3 Map of existing and proposed (suggested and alternatively suggested) detention and treatment measures in Tyresö municipality.

The proposed measures are then prioritized using different criteria:

- The location, size and type of the recipient in the lake system.
- Reduced pollutant load.
- Cost-benefit, e.g. facility cost per reduced load.
- Floods and their resulted problems and frequency.

The list of priority is a help for the municipality for implementing the measures.

Below we present the watershed management plan for Upplands Väsby, showing the watersheds of the lakes Oxundasjön, Fysingen, Edssjön and Fjäturen and proposed places for stormwater treatment facilities, see Figure 4. The map also presents where the acceptable load of different pollutants in the lake is exceeding the lake water quality criteria. Different pollutants in the runoff are important to reduce in different lakes depending on the conditions in the lake and the required load reduction (Eq. 3-4). For instance, phosphorus (P) and nitrogen (N) requires reduced loads to Lake Oxundasjön, and N, lead (Pb), copper (Cu) and P requires reduced loads to Lake Fjäturen. This is a basis for deciding the type of facilities that are to be proposed at different locations.

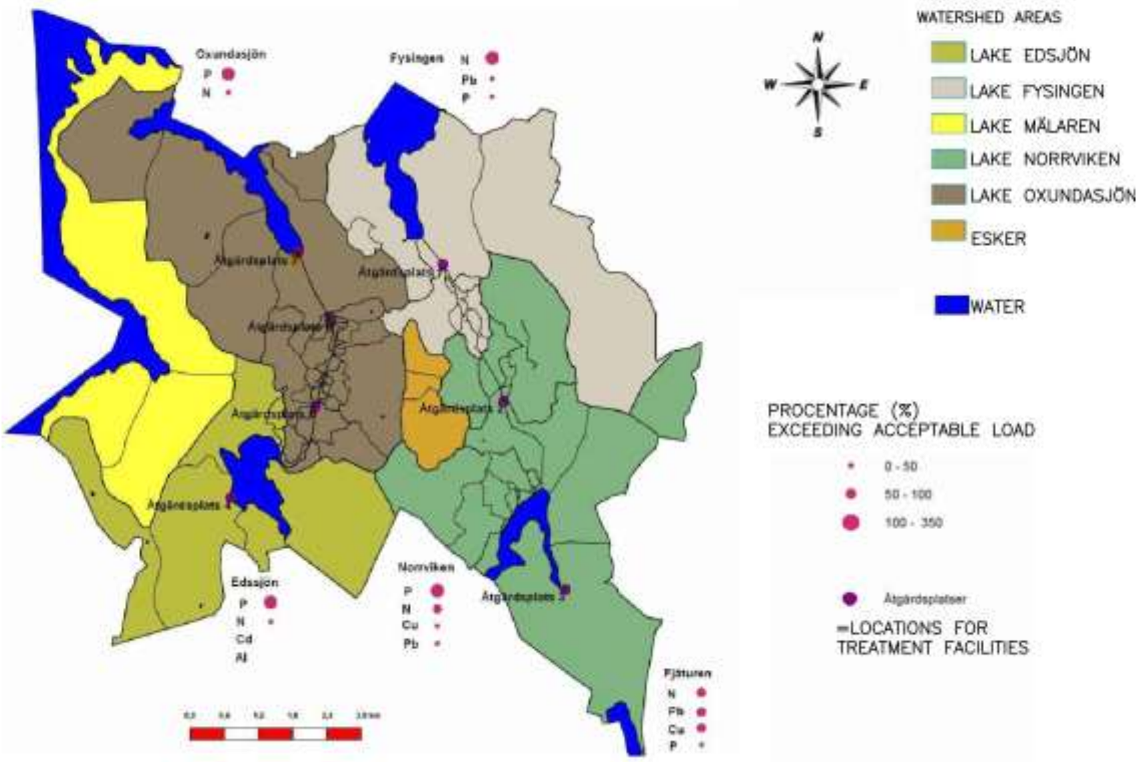

Figure 4 An overview map of lake watersheds in Upplands väsby, places of proposed stormwater treatment facilities and which pollutant acceptable loads are exceeded.

Figure 5 presents, as an example from the report, proposed detention measures for reducing floods in one of the sub-watershed areas in Lindalen, Tyresö, and shows a proposed place for one of the suggested detention dry ponds.

Figure 5 To the left proposed detention measures for reducing floods in one of the sub-watershed areas in Lindalen, Tyresö. To the right the proposed place for a dry detention pond, adjacent to the road Bollmoravägen in Tyresö.

Figure 6 presents, as another example, a map of the part of the eutrophied Lake Oxundasjön that is situated in Upplands Väsby municipality and the sub-watershed areas. It also presents the proposed location of a stormwater treatment facility both in the map and at sight before and after a treatment facility including a wet pond with a wetland zone that was built during 2001. The pond treats the stormwater from the central areas of Upplands Väsby, i.e. it receives a large part of the pollutant load from the municipality. This was a direct result of the management plan.

Figure 6 To the left a map of the part of Lake Oxundasjön that is situated in Upplands Väsby municipality and the sub-watershed areas. A proposed location for a stormwater treatment facility is marked in the map. The middle picture shows a proposed area for a treatment facility at Ladbro, before the wet pond in the right picture was constructed.

After more than ten years of experience from the first to the present versions of the stormwater management plans in the municipalities we believe that the success factors when implementing stormwater management plans is communication and an open discussion between experts and people with good local knowledge. The municipalities now have the knowledge of, reports and maps showing for instance:

1. Where the largest pollutant sources are located (Fig. 2).
2. Where pollutant treatment are of most priority (Fig. 3)
3. Where there are largest risks for floods (Fig. 3)
4. Which receiving waters that require measures to improve water quality (Fig. 4)
5. What pollutants are of most concern in the different watersheds and to focus treatment on (Fig. 4)
6. What areas and volumes that are needed for flow detention and pollutant treatment.

The management plan of Tyresö presents data for 13 pollutants, they are phosphorus (P), nitrogen (N), lead (Pb), copper (Cu), cadmium (Cd), chromium (Cr), nickel (Ni), mercury (Hg), suspended solids (SS), oil, the sum of 16 polycyclic aromatic hydrocarbons (PAH) and benso(a)pyrhene (BaP). The plan for Upplands Väsby includes data for 11 pollutants, excluding the two latter mentioned above for Tyresö. As a comparison, the report of the New Jersey management plan presents and focus on SS, P and N (The State of New Jersey, 2008). The plan of New Jersey furthermore express the load per land use in a unit that corresponds to the metric unit kg/ha/year to calculate loads (kg/year), compared to the Swedish plans that are using concentrations (mg/l) and flow calculations (m^3/year) to calculate loads (kg/year), see Eq. 1-2. One advantage of using concentrations and flow is that these can be directly compared to measured data.

The management plan of Tyresö employ 17 urban and rural land uses, the plan of Upplands Väsby 37 land uses. For comparison, around 12 land uses are reported in the plan of New Jersey and around 20 in the plan of New York (The State of New Jersey, 2004; The City of New york, 2008). The land uses are not the same in the two US plans and the two Swedish plans also employ other categories of land uses, even if some are equal or very similar in all 4 plans. These are the residential, commercial and industrial areas. The Swedish plans include, as opposite to the US plans, different categories of roads with different traffic intensities.

Since the first plans both Upplands Väsby and Tyresö municipality have built most of the facilities proposed. The plans have served a basis to prioritize different kinds of measures, such as facilities for flow detention and pollutant treatment. The plans have also been a good basis to gain the support from politicians since they present where and what type actions are needed, and the costs and priority of each action. The plans have been presented in the web pages of the municipalities and maps and report have been printed, available for citizens within the municipalities. This is a way to increase the awareness and understanding of urban water management within the municipality.

The two Swedish management plans consist more of measures downstream or in the separate stormwater system, more local measures are mentioned as recommended measures in new areas of development. As a comparison, New York City is largely serviced by a combined sewer system, i.e. stormwater and wastewater are transported through a single pipe so more local treatment facilities such as green roofs and green streets are in focus (The City of New york, 2008). It is not appropriate to use open facilities such as wet ponds in or after a wastewater sewer due to higher amounts of bacteria. It is being discussed to add more local measures to the Swedish management plans, as examples for different types of development areas. Furthermore, the plan of New Jersey gives the developer a maximum allowable percent of imperviousness (The State of New Jersey, 2004), also something to discuss with the Swedish municipalities. The plan of New York includes a map of areas that have been flooded (The City of New york, 2008); a third possible complement for the Swedish plans.

New urban areas have been developed in both Tyresö and Upplands Väsby since the first plans and as the urbanization increases, the runoff to the receiving waters change and therefore the demand for new treatment and flow detention facilities increase. With time new rules and regulations are also formed to which the plan must be adapted, such as the Water Framework Directive implemented in the second versions of the plans. There are also more updated data of pollutant concentrations, how to design different facilities etc. The different system components in the stormwater management plans are based on empirical data that still is relatively uncertain so there is much to gain by letting the plans to be living documents and continually being updated. In that way, uncertainty will decrease by time and the access of more data and updated models. Furthermore, new technology and updated design methods will give more reliable information on what type and size of facilities are best at different locations, taking consideration to site-specific conditions. This has a large significance. If these management plans would not have been developed, it would be very difficult to know what actions are most cost-effective, where they are needed most and what sizes and number of facilities that are needed to cope with the conditions in the receiving waters as well as the floods.

CONCLUSIONS

The developed planning tool and work method has been successfully implemented for the two municipalities Tyresö and Upplands Väsby, outside Stockholm; Sweden. It can also be used for specific receiving waters. The tool can together with the operative model StormTac be used elsewhere by collecting and employing the same type of input data.

The paper presents required and optional input data used for these case studies. The required input data are area per land use (ha), and the area (ha) and volume (m^3) of the receiving water if acceptable load (kg/year) and required load reduction (kg/year) is to be calculated. By employing default data all other necessary calculations for creating the plan can be performed. More site-specific results are obtained by changing the default values. Examples of optional input data are precipitation data (mm/year and rain intensities (l/s/ha) for different rain durations (min)), design transport distance (m) and measured pollutant concentrations in the receiving water body.

A stormwater management plan is a valuable tool when motivating measures needed to be taken, e.g. by presenting loads and measures on maps and described in a report. The plan include information to prioritize different kinds of measures, such as facilities for flow detention and pollutant treatment. These are designed, their effects on pollutant load and flow reduction calculated, including estimated costs.

The model StormTac was able to quantify pollutant loads and concentrations for each land use and for each outlet from all sub-watershed areas, to calculate receiving water quality before and after treatment, calculate acceptable loads and to design treatment measures to reduce the loads to reach the acceptable loads for each receiving water. It is possible to calculate more than 70 pollutants and land uses respectively.

The working method and model have shown to match the available amount of input data, give the needed results for making cost-effective measures according to the Water Framework Directive. They are continuously being improved and complemented with new data and revised methods.

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