Project under EU RTD 5th Framework Programme

Contract N° EVK1-CT-2002-00111

Adaptive **D**ecision **S**upport **S**ystem (**ADSS**) for the Integration of Stormwater Source Control into Sustainable Urban Water Management Strategies

Report and Examples for use of the SFM tool

prepared by

Stefan Ahlman

Gilbert Svensson
(Chalmers University of Technology)

Heiko Sieker

(IPS)

www.daywater.org

2002 - 2005

29th December 2005 - FINAL

WP 6/ Task 6.4/ Deliverable N°6.6

Dissemination Level: Restricted (RE)

Document patterns

File name: *D6.6-Report-Examples-Use-SFM-tool-FINAL-2005-12-29.doc*

Sent by: Stefan Ahlman	Examined by: Tomas Metelka, DHI	Revised by: Stefan Ahlman	WP6/T6.4/D6.6 Diss. Level : RE
On: 30/11/05	On: 09/12/05	On: 29/12/05	Version : final

Keywords:

….

Acknowledgement

The results presented in this publication have been obtained within the framework of the EC funded research project DayWater "Adaptive Decision Support System for Stormwater Pollution Control", contract no EVK1-CT-2002-00111, co-ordinated by Cereve at ENPC (F) and including Tauw BV (Tauw) (NL), Department of Water Environment Transport at Chalmers University of Technology (Chalmers) (SE), Environment and Resources DTU at Technical University of Denmark (DTU) (DK), Urban Pollution Research Centre at Middlesex University (MU) (UK), Department of Water Resources Hydraulic and Maritime Works at National Technical University of Athens (NTUA) (GR), DHI Hydroinform, a.s. (DHI HIF) (CZ), Ingenieurgesellschaft Prof. Dr. Sieker GmbH (IPS) (D), Water Pollution Unit at Laboratoire Central des Ponts et Chaussées (LCPC) (F) and Division of Sanitary Engineering at Luleå University of Technology (LTU) (SE).

This project is organised within the "Energy, Environment and Sustainable Development" Programme in the 5th Framework Programme for "Science Research and Technological Development" of the European Commission and is part of the CityNet Cluster, the network of European research projects on integrated urban water management.

Table of contents

1 Introduction

Modelling material fluxes related to stormwater control will make use of hydrological models for providing water balances and simulate material balances (D6.5). The modelling framework will allow for inclusion of knowledge on selected stormwater priority pollutants (SSPP). The integration between the Substance Flow Modelling (SFM) tool and the screening tool developed in WP4 will be ensured. Uncertainty analysis is needed to define model complexity depending on pre-existing information. The beta version of the SFM tool will be incorporated into the adaptive decision support system (ADSS) and tested (WP7).

The main objective of WP6 is to design a software package for stormwater sources and fluxes simulations, i.e. an SFM-tool. This software package will enable an analysis of the sources and fluxes of a selection of the priority pollutants identified in WP4 (D4.3).

1.1 Background and aim

In Europe today, urban water management is highly effected by the implementation of the EU Water Framework Directive (WFD). The most important consequence of the WFD is that water management has to be done on a catchment scale, taking local conditions into account. Sustainable urban water management should therefore include stormwater source control as a method to reduce runoff volumes and peak flows, and at the same time improve the stormwater quality. So far source control has not been widely adopted throughout Europe. This issue is addressed by the research program DayWater, funded by the European Commission under the 5th framework program. The DayWater project aims at building a prototype of an adaptive decision support system (ADSS) related to urban stormwater source control measures (www.daywater.org). The focus in DayWater is on stormwater that is treated locally in urban areas using various structural source control techniques such as detention and re-use, swales and soakaways, catch-basins, wetlands, ponds, porous paving etc., or non-structural methods like public regulations or street sweeping.

One part of the DayWater project deals with the development of a new modelling tool for simulating sources and fluxes in wastewater systems. By combining the modelling approaches in two previously developed models, STORM (IPS, 2003) and SEWSYS (Ahlman and Svensson, 2002), it is possible to use the new sources and flux modelling (SFM) tool to simulate different scenarios of stormwater source control practices. This report presents the new integrated sources and flux model STORM/SEWSYS.

2 Sources and Flux Modelling

A large number of numerical models are available for simulating quantity and quality aspects in stormwater management. The models can be used as design tools, decision support tools or even both. A review of urban stormwater models has been made by Zoppou (2001). The reviewed models vary both in terms of complexity and input data requirements. In terms of mechanisms, the models can be classified as physically deterministic, empirical or conceptual. Combinations of these categories are also possible.

In recent years, more focus has been on developing conceptual stormwater models (Ruan and Wiggers, 1998; Larm, 2000; Calabro, 2001; Wong et al., 2002). Conceptual models are normally based on simple yet sound physical concepts and relatively limited data resources. Compared to deterministic models they are more efficient, i.e. timesaving and less data intensive. Empirical models use systems analysis to analyse the input-output relationship of a dynamic system in a statistical manner. However, empirical models have one major disadvantage: they are usually site-specific. In conceptual models the two mentioned approaches, deterministic and empirical modelling, can be combined. Simple and well-established hydrological and hydraulic principles together with systems analysis form the description of the conceptual model. As such, the models STORM and SEWSYS have been chosen as suitable components for the proposed sources and flux model. The STORM model acts as the platform for the SFM tool. To enhance the stormwater quality part of STORM, the substance flow concept of SEWSYS has been integrated into STORM as a module. The STORM/SEWSYS model is a combination of two tools but they are entirely integrated and are working as one package.

2.1 STORM

The STORM software is a hydrological model for simulating stormwater runoff and pollution load (IPS, 2003). STORM is a modern 32-bit software developed in Microsoft® Visual C++, an object-oriented programming language that facilitates further development and also allows for rapid simulations. The main window of STORM is shown in Figure 1. To the left is an “explorer window” where parameters and drainage elements are listed. The drainage structure of the studied catchment(s) is built up in a graphical way in the window to the right using nodes and links. An English and a German version of STORM are available.

STORM is predominately a planning tool for urban water management but also contains features for designing single BMPs (e.g. using design storms to compute necessary storage volumes). Rainfall-runoff transformation is conceptualised using either linear cascade storages or time-surface functions. The model contains conventional drainage elements, both decentralized and centralized, to treat and handle runoff in conventional sewer systems and alternative stormwater management system. The drainage elements include retention tanks, trough-flow tank, retention sewer and overflows as well as infiltration facilities, green roofs or cisterns.

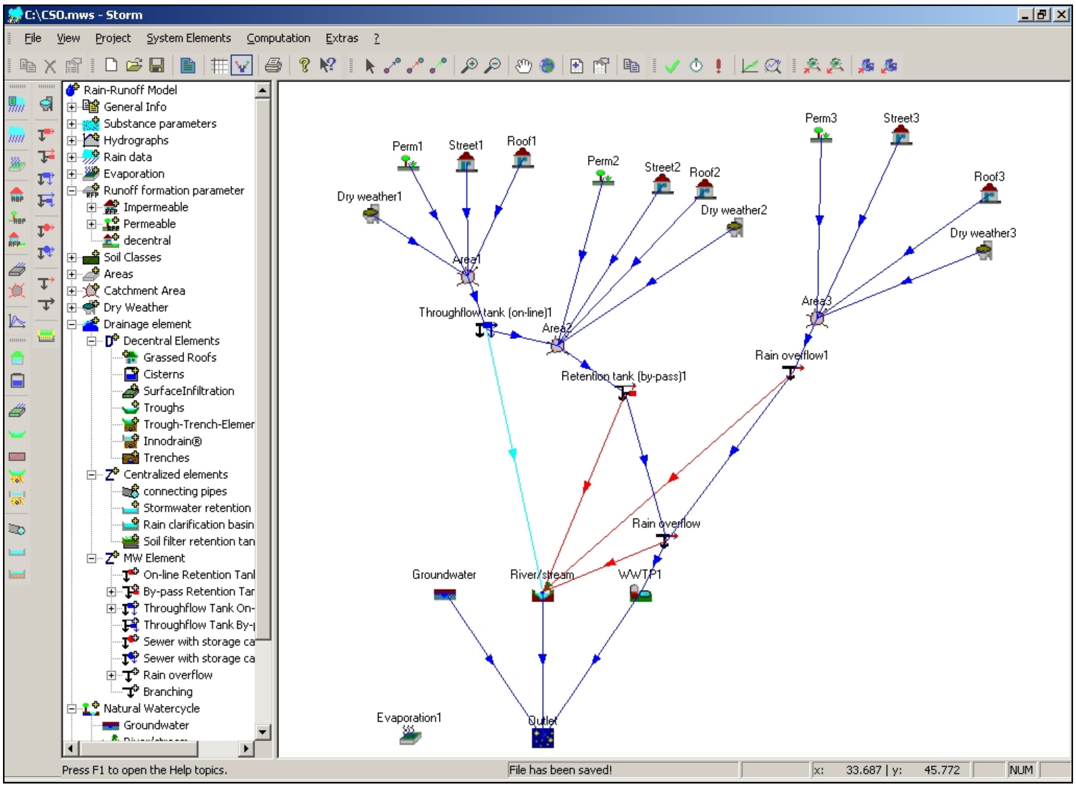

Figure 1. STORM main window.

The results from STORM focus on overall water balances and BMP performance with respect to quantity and pollution transport. Standard concentrations of pollutants are used as input in the model to calculate pollution loads. The runoff processes in the catchments are simulated dynamically using a time-series of rainfall data. The time resolution in a rain file also determines the time-step in the model. Usually a time step of 5 to 15 minutes is used. A prerequisite for the long-term simulation is that the input data consist of actual measured rain gauge readings in their natural chronological progression.

2.2 SEWSYS

The pollutants in stormwater contribute significantly to the total pollutant mass flow in the urban sewer system. To address this issue the new sources and flux model has incorporated a stormwater pollutant generator module from the SEWSYS model. SEWSYS is a model originally developed in MATLAB/Simulink for simulating substance flows in urban sewer systems (Ahlman and Svensson, 2002). The present version of SEWSYS handles both domestic wastewater and stormwater. In the stormwater quality module, the pollutants from sources like dry deposition, traffic and construction materials are generated and accumulated during dry weather until they are washed away during rainfall.

SEWSYS has previously been used in different research projects where stormwater pollution loads and sources have been analysed. In one project, systems analysis was used to compare different alternatives in wastewater management from several aspects of sustainability (Ahlman et al., 2004a). Another project dealt with the evaluation of the efficiency of a set of non-structural BMPs (Ahlman et al., 2004b).

2.3 STORM/SEWSYS – an SFM tool

The relative importance of different sources for stormwater pollution can vary greatly between catchments. Depending on local conditions, pollution sources can be quite different when looking at catchments of different sizes and in different regions. This variability is included in the SFM tool. The different stormwater pollutant sources and pathways are summarised in Figure 2. This descriptive concept has formed a framework in the development of the pollutant generator in STORM/SEWSYS.

The user of the SFM-tool has the option to employ either standard concentrations or the pollutant generator from SEWSYS to calculate pollution loads. If the user chooses the SEWSYS option, it will be possible to analyse what kinds of substances are present in the catchment, their sources, transport routes and the sinks in which the substances finally reside. At present STORM/SEWSYS handles sources and fluxes of 13 substances and indicators that have been identified in the DayWater project as relevant to stormwater quality management. These selected stormwater priority pollutants (SSPP) include nutrients, heavy metals, PAHs, pesticides and various other organic compounds (Eriksson *et al.*, 2003).

To calculate pollution loads using the pollutant generator, the model requires catchment-specific parameters including traffic load and the percentage of heavy vehicles. The distribution of impervious area between roads, roofs and other areas is also required. The model also needs information about the different roofing materials used in the catchment, such as zinc (galvanised and painted galvanised) and copper surfaces. Table 1 shows the input data necessary for the catchment. The pollutant generator module in STORM/SEWSYS obtains this data from specific values set by the user for each sub-catchment, preferably generated by a GIS. An interface with common GIS-Software (ESRI®, Intergraph®) is available. The GIS-software requires a separate license.

Table 1. Input data for the catchment area

Total impervious area	[m^2]
Roads	[m^2]
Zinc surfaces by roads	[%]
Roofs	[m^2]
Zinc roofs	[%]
Copper roofs	[%]
Other impervious area	[m^2]
Total vehicle km	[km/day]
Heavy vehicles	[%]

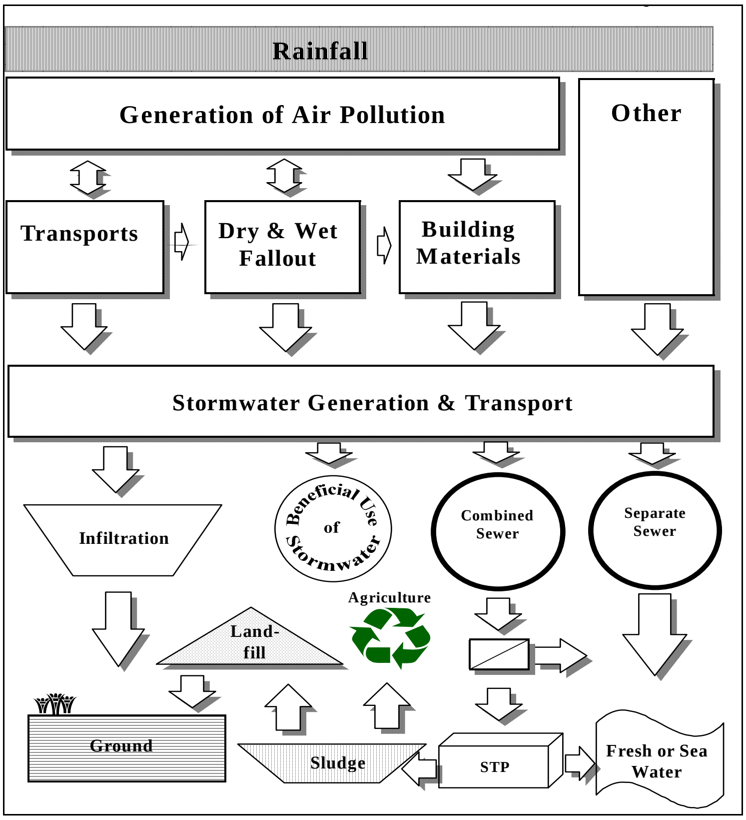

Figure 2. Stormwater pollutant sources and pathways.

2.3.1 Input database on emission factors

In addition to the previously described catchment specific data, the pollutant generator module also requires background data on priority pollutants and their emission factors. This is imported into STORM/SEWSYS from an external Microsoft® Access database and contains general pollution figures, e.g. corrosion rates and emissions for different kinds of material. Each substance is linked to different pollution sources in the database. Data for the pollutant sources have been obtained from literature studies and other existing Swedish models (Ahlman and Svensson, 2002). The adding of new datasets in the database is done in Microsoft® Access. The import interface for pollution data in STORM/SEWSYS is shown in Figure 3. The user chooses an appropriate data set from the database to be used in the simulations. The imported data can be modified afterwards within the STORM/SEWSYS user environment. At present pollution data for catchments in Sweden, Denmark and Germany have been entered into the database. More data are expected to be collected within the DayWater project.

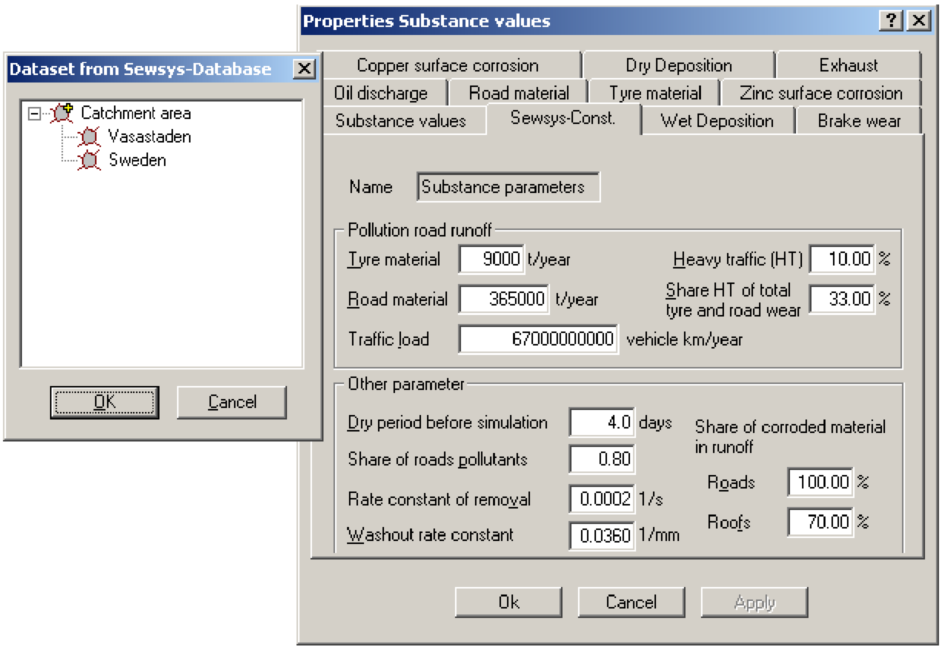

Figure 3. Input data for the pollutant generator module.

2.4 MODEL OUTPUTS AND APPLICATIONS

The new STORM/SEWSYS model provides simulation techniques to evaluate hydrological cycle changes and hydrological risks in urban catchments. These changes can be caused by the non-existence or application of stormwater source control measures. The model matches the spatial scale and integration level that govern the implementation of stormwater source control. From a stormwater quantity aspect, the focus is on the functional behaviour of structural BMPs, interactions with changing groundwater levels, increased runoff via building drainage and implications for existing downstream wastewater systems. The hydrological part also includes runoff from snowmelt.

Traditionally in stormwater quality models, including the present version of STORM, the water quality part in the model incorporates standard concentrations as input for user-defined pollutants. Using standard pollutant concentrations for different land uses is useful because it makes the model easier to work with and requires less input data. However, in terms of pollutant load from stormwater runoff, the appropriate long-term strategy would be to avoid, replace or reduce the sources of stormwater pollution. To be able to achieve quality source control, i.e. to reduce the pollutants at the source, it is necessary to have a more detailed pollutant generation and transport model. The sources for pollutants from different activities in the urban area have to be separated in their respective origin, i.e. material corrosion, brake wear, tyre wear etc. The pollutant generator module in STORM/SEWSYS makes this possible. A selection of model outputs have been summarised in Table 2. In addition, results from long-term STORM/SEWSYS simulations enable statistical analysis and the calculation of hydrological data such as hydrographs and runoff volumes.

Table 2: Selected model outputs from STORM/SEWSYS.

Hydrology		Runoff hydrograph	time; m^3/s
		Runoff volume	m^3/year
		Snowpack depth	time; mm water equivalent
Pollution Loads	Wet deposition	A number of substances	g/year
	Roads	A number of substances	g/year
	Roofs	A number of substances	g/year
	Other	A number of substances	g/year
Pollution Sources	Roads	A number of sources	%
	Roofs	A number of sources	%
	Other	A number of sources	%

3 Example – SFM in Vasastaden

In year 1999 the Swedish Parliament agreed on 15 environmental quality objectives (EQOs), which form the basis for all ongoing and future environmental work in Sweden (SEPA, 2004). The overall goal is to solve the major environmental problems we currently face, and to achieve this goal within one generation. Stormwater has previously been reported as a large contributor to the pollution and degradation of receiving waters in the urban environment (Schiff *et al.*, 2002; Tsihrintzis and Hamid, 1997). To remedy the negative effects of stormwater discharges, many best management practises (BMPs) have been suggested and implemented worldwide. BMPs can be divided into: (1) structural (such as engineered and constructed systems) and (2) non-structural (institutional, education or pollution prevention practices) (Clary *et al.*, 2002). Both types of BMPs have the ultimate purpose of improving the quality and/or controlling the quantity of stormwater runoff.

A systems analysis was performed for the sewer system in the catchment Vasastaden in the city of Göteborg, Sweden. SEWSYS was used in this study for the substance flow analysis (Ahlman *et al.*, 2004a), and in simulating different non-structural BMPs and the resulting reduction in pollution that would be achieved (Ahlman *et al.*, 2004b).

3.1 Modelling approach

The modelling approach chosen for this study uses the SEWSYS model from the viewpoint of two cases:

1. For management by objectives, *i.e.* aiming towards specific environmental quality criteria (EQC).
2. For the evaluation of source reduction practices, *i.e.* a source control scenario with different non-structural BMPs.

First, management by objectives is introduced to meet EQC given by the Swedish Environmental Protection Agency (SEPA) with respect to environmental effects in recycling sewage sludge (SEPA, 2002) and surface water discharges (SEPA, 1999). In detail this implies measures to achieve: (a) acceptable sewage sludge quality for agricultural use according to SEPA's proposed action plan for the year 2020 and (b) acceptable stormwater quality for direct discharge of stormwater to the local water body. Copper, zinc and lead were found to be the critical substances in stormwater discharges directly to the local water body, taking the dilution effect into account. The reductions required for copper, zinc and lead were 90 %, 55 % and 50 %, respectively. Also, the characteristics of the sewage sludge from the local wastewater treatment plant were taken into consideration for this calculation. Copper and lead must be reduced by about 10 %, but this reduction is assumed to be achieved without any specific prevention measures. Cadmium poses the greatest challenge and must be reduced by 62 % to comply with the EQC associated with the use of sewage sludge as fertilizer.

Second, the SEWSYS model is used to simulate a scenario with different non-structural BMPs. The scenario is based on a hypothetical control program that includes prevention, education and regulations and that would be fully adopted by the year 2020. The effects of the control program are simulated using the following assumptions on pollution reduction from:

- copper roofs by 80 %, using material replacement, painting and copper filters in down-pipes.
- painted roofs by 20 %, by using paint with a lower zinc content.
- brake wear by 80 %, by banning the use of copper in brake linings within seven years.
- galvanised areas (*e.g.* street furniture) by 20 %, through painting and replacement.
- tyre wear by 80 %, by using more environmentally friendly tyres.
- road wear by 60 %, by different studs in tyres and a change in driving patterns.
- Atmospheric deposition (wet and dry) by 1 percentage unit per year, *i.e.* in total 17 %.

In addition, the traffic load in the catchment is assumed to decrease 10 % by the year 2020 by the introduction of tolls in the inner city.

3.2 Study site

The study was carried out for the sewer system in Vasastaden, a district in the city centre of Göteborg. The area is densely populated and consists of residential and commercial buildings, built mainly in the late 19th century and beginning of the 20th century. Figure 4 shows the catchment divided into six sub-catchments and the surface distribution. The catchment has a total area of 75 ha; the impervious area has been calculated to be 51 ha. There are two different kinds of sewer systems in the catchment today: a separate system and a combined system. In the separate system, sanitary wastewater is diverted directly to the WWTP. Stormwater is transported to the nearest combined network system and hence influencing the combined sewer overflow (CSO) volume. The reason for having this system is that the stormwater is considered too polluted to be diverted directly to the local water body Vallgraven.

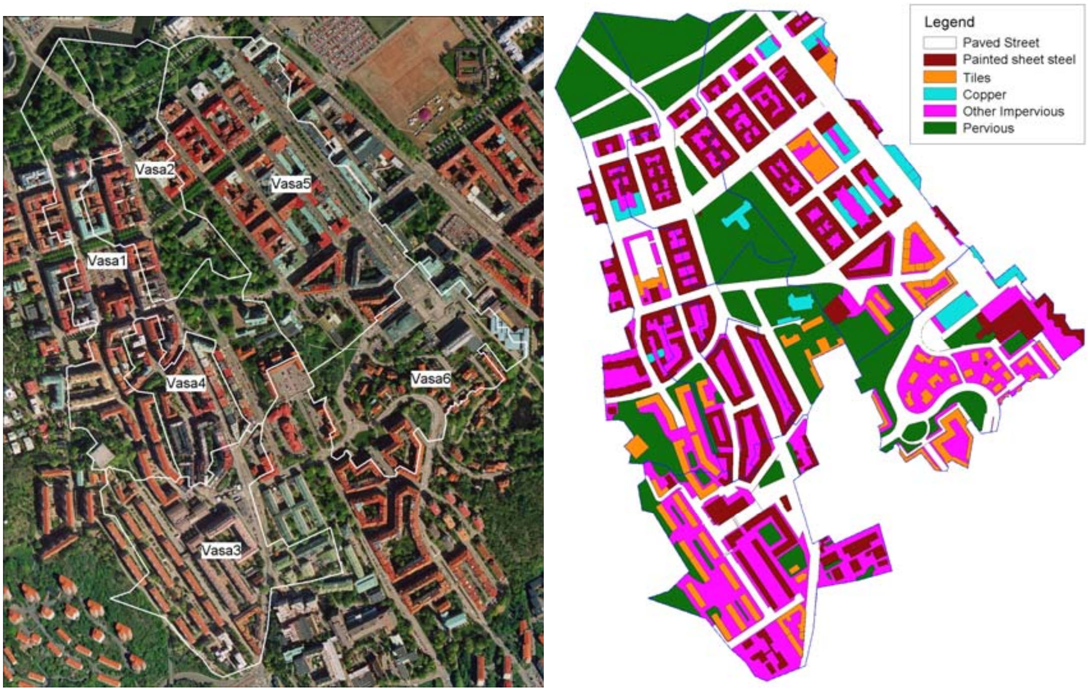

Figure 4. The Vasastaden catchment (divided into sub-catchments) and the distribution of surfaces.

The rain series used for the scenario simulations was from 1926 and is used as it describes well a normal hydrological year in Göteborg, which gives an annual precipitation of 685 mm. There is however a trend in the recent years that the annual rain volume increases but the higher rain intensities stay fairly constant. Figure 5 shows the rain series with intensities in μm/s distributed over 30 minutes.

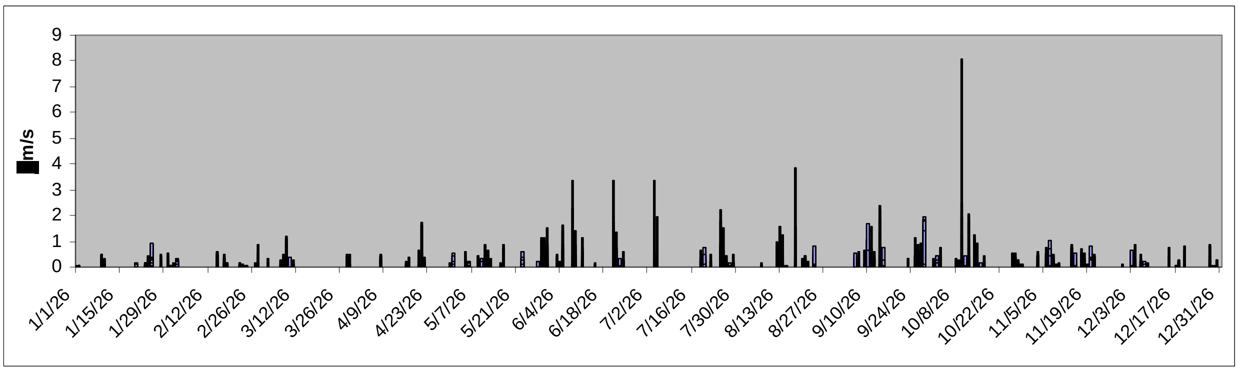

Figure 5. Rain series (1926) used for the scenario simulations

3.3 Results and discussion

The simulation results from SEWSYS for the present situation as compared with the hypothetical control program comprising different non-structural BMPs, are shown in Table 3 and Figure 6. The pollution load in kg per year is chosen as the comparative output parameter since the annual stormwater volume is the same in both simulations. SEWSYS yields an annual stormwater volume of 262,000 m^3. The simulations show relatively high reductions in copper and PAH, 77 % and 50 % respectively, whereas the reductions for the other substances range from about 15 to 30 %.

Table 3. Pollution loads for the present situation and with non-structural BMPs [kg y^{-1}]

	Cu	Zn	Pb	Cd	P	N	PAH	BOD
Present	42	66	3.1	0.10	25	381	0.30	2176
After source control	9.6	49	2.3	0.08	21	316	0.15	1826
Reduction	77%	26%	28%	23%	14%	17%	50%	16%

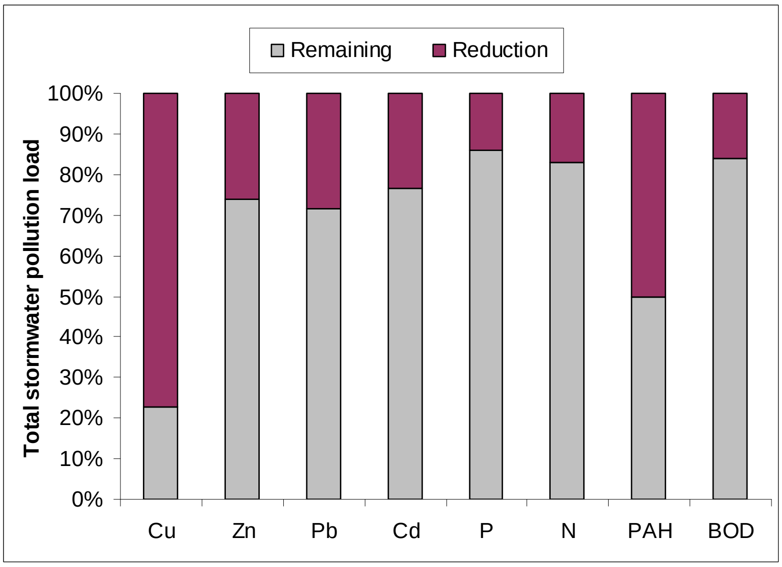

Figure 6. Simulated reductions by source control measures

In SEWSYS, it is also possible to distinguish how the total reduction is distributed among the different sources of stormwater pollution incorporated in the model. As seen in Figure 7, the reduction in copper corrosion and brake wear contribute most (about 98 %) to the total reduction of copper, and a reduction in road wear is the greatest contributor to lower PAH levels. Nitrogen and BOD are not shown in Figure 7 because the major source of these substances is atmospheric deposition and the simulated reduction will consequently only be dependent on that source.

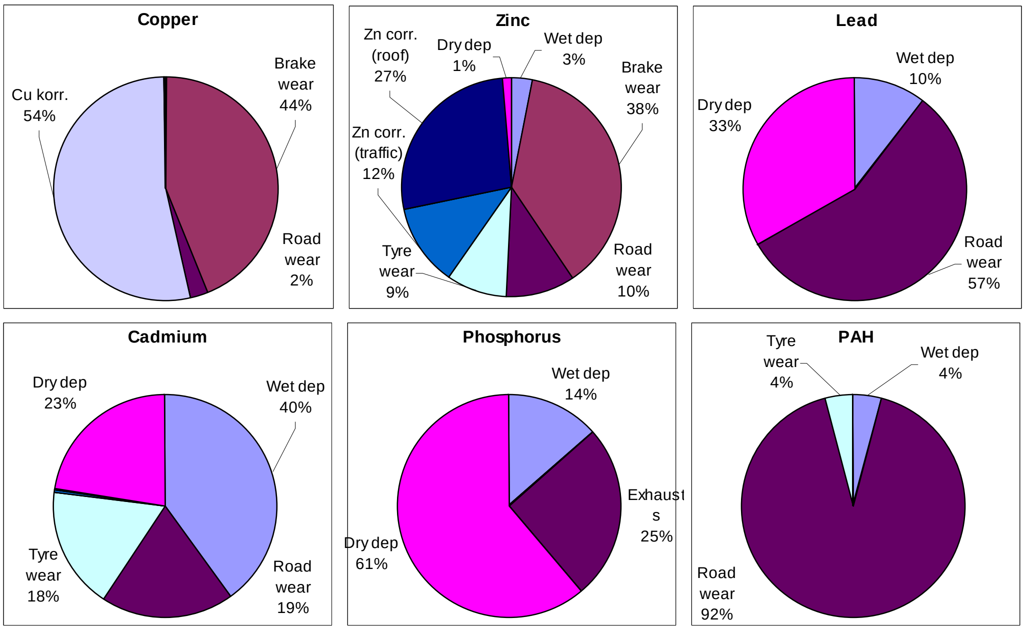

Figure 7. The respective source and its relative contribution to the total pollution reduction

In the first case (management by objectives), SEWSYS is found to be useful in providing catchment-specific pollution data, and identifying the important sources and how large the reduction in pollution must be to meet the desired EQC. In the second case (source control), SEWSYS makes it possible to study the effects of the measures taken, *i.e.* what reduction in pollution the measures actually give. SEWSYS also makes it possible to identity which sources have the greatest effect on reductions in pollution.

In a comparison between the pollution reductions required by the EQC and the simulated reductions achieved using the control program it is observed that a simulated cadmium reduction of 23 % falls very short of the required of 62 %. Furthermore, the simulated reductions in copper (77 %), zinc (26 %) and lead (28 %) do not measure up to the required reductions in surface water discharge of 90 %, 55 % and 50 %, respectively. There is a clear need to further reduce the pollution load for the critical heavy metals.

Figure 8 shows the distribution of the sources that contribute to the remaining pollution in the system. From this figure it can be seen that the greatest sources to copper pollution is still copper corrosion and brake wear, for zinc it is zinc corrosion and tyre wear. Since the road wear has been reduced dry deposition is now the greatest contribution to lead pollution. Cadmium from road and tyre wear is greatly reduced why the remaining pollution is mainly added through wet and dry deposition. To be able to achieve a significantly higher reduction in pollution, there is a need to implement structural BMPs. Such measures may be stormwater retention ponds, filters and infiltration devices.

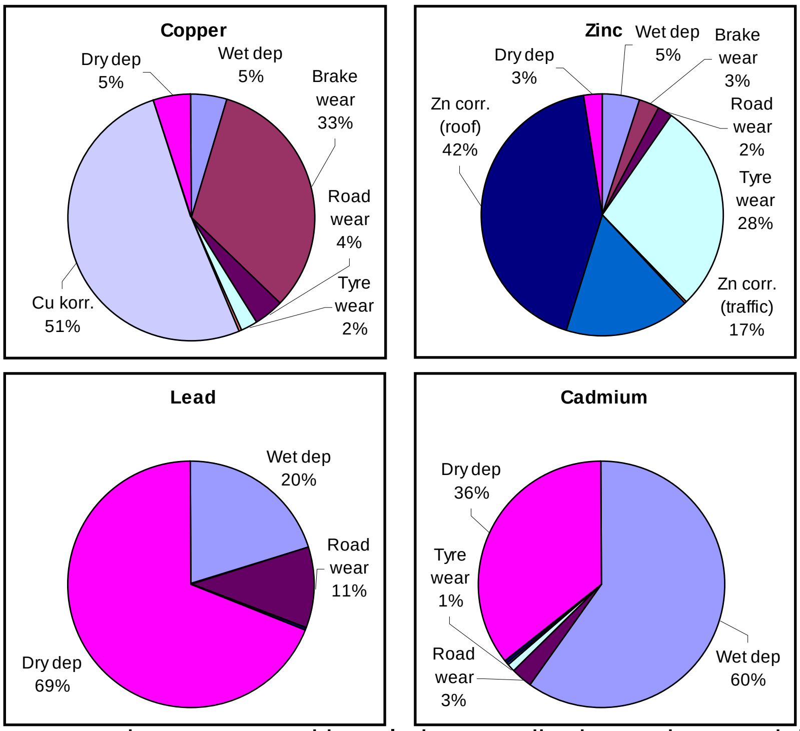

Figure 8: The respective source and its relative contribution to the remaining pollutants.

3.4 Conclusions from example Vasastaden

SEWSYS is found to be useful in providing catchment-specific pollution data, and identifying the important sources and how great the reduction in pollution must be to meet the desired EQC. SEWSYS also makes it possible to study the effects of the measures taken, *i.e.* what reduction in pollution the measures actually give as well as it makes it possible to identity which sources have the greatest effect on reductions in pollution.

The non-structural BMPs applied did not achieve a sufficient reduction in pollution to meet the desired environmental quality criteria. To do so requires the implementation of additional BMPs, both non-structural and structural.

4 Overall conclusions

In the scope of the EU research project Daywater, SEWSYS was combined with the pollution load model STORM. At the same time, the SEWSYS algorithms were integrated into the comfortable user interface of STORM. With the combined model STORM-SEWSYS, a water and substance flow model is available that is especially suitable for conceptional planning (e.g. in the scope of drainage master planning). Further information about STORM/SEWSYS can be found in DayWater deliverable D6.8 and in the tools section of the website www.daywater.cz.

Development of a sources and flux model (SFM) for analysing substance flows in stormwater systems increases the need of knowledge on material uses in urban areas. Some of the information needed for modelling can be found in databases at municipalities, but in general there is a lack of important data on surface materials. Available methods for obtaining the needed data are to compile information in existing databases and complement with field inventories. Field investigations in larger catchments are time consuming and it can be problems to reach roofs and private properties to determine the material uses. Another approach reported by German (2004) is to use remote sensing for mapping of the catchment.

5 References

Ahlman, S. and Svensson, G. (2002). Modelling substance flows in urban sewer systems using MATLAB/Simulink. In: *Proceedings of the Ninth International Conference on: Urban Drainage*, E. W. Strecker & W. C. Huber (Eds.), September 8-13 2002, Portland, OR, USA.

Ahlman, S., Svensson, G., Malm, A., Kant, H. and Karlsson, P. (2004a). Methodology for systems analysis of sustainable wastewater management - assessment for an urban catchment in Vasastaden, Göteborg. In: *Proceedings of the 5th International Conference on Sustainable Techniques and Strategies in Urban Water Management (NOVATECH'2004)*, June 6-10 2004, Lyon, France.

Ahlman, S., Malm, A., Kant, H., Svensson, G. and Karlsson, P. (2004b). Modelling non-structural Best Management Practices - focus on reductions in stormwater pollution. *Water Science and Technology,* **52**(5), 9-16.

Calabro, P. S. (2001). Cosmoss: conceptual simplified model for sewer system simulation; A new model for urban runoff quality. *Urban Water,* **3**(1-2), 33-42.

Clary, J., Urbonas, B., Jones, J., Strecker, E. W., Quigley, M. and O'Brien, J. (2002). Developing, evaluating and maintaining a standardized stormwater BMP effectiveness database. *Water Science and Technology,* **45**(7), 65-73.

Eriksson, E., Baun, A., Mikkelsen, P.S. and Ledin A. (2003). Proposed justified list of potential stormwater priority pollutants. Research project DayWater. Deliverable N° D4.3.

German, J. (2004). Surveying of urban surface materials and impervious areas using remote sensing. DayWater Research Project. Deliverable 6.2.

IPS. (2003). STORM Manual *Ingenieurgesellschaft Prof. Dr. Sieker mbH*. Berlin.

Larm, T. (2000). *Watershed-based design of stormwater treatment facilities: model development and applications.* PhD Thesis, Dept. of Civil and Environmental Engineering, Royal Institute of Technology, Stockholm.

Ruan, M. and Wiggers, J. B. M. (1998). A conceptual CSO emission model: SEWSIM. *Water Science and Technology,* **37**(1), 259-267.

Schiff, K., Bay, S. and Stransky, C. (2002). Characterization of stormwater toxicants from an urban watershed to freshwater and marine organisms. *Urban Water,* **4**(3), 215-227.

SEPA. (1999). *Bedömningsgrunder för miljökvalitet: Sjöar och vattendrag [Environmental Quality Criteria: Lakes and watercourses]* (Rapport 4913). Swedish Environmental Protection Agency, (in Swedish, summary in English). Available: http://www.naturvardsverket.se/.

SEPA. (2002). *Aktionsplan för återföring av fosfor ur avlopp [Action plan for recycling of phosphorus from wastewater]* (Rapport 5214). Swedish Environmental Protection Agency, (in Swedish, summary in English). Available: http://www.naturvardsverket.se/.

SEPA. (2004). *Sweden's environmental objectives*, [Internet]. Available: http://miljomal.nu/english/english.php [2004-05-04].

Tsihrintzis, V. A. and Hamid, R. (1997). Modeling and management of urban stormwater runoff quality: A review. *Water Resources Management,* **11**(2), 137-164.

Wong, T. H. F., Fletcher, T. D., Duncan, H. P., Coleman, J. R. and Jenkins, G. A. (2002). A model for urban stormwater improvement conceptualisation. In: *Proceedings of the Ninth International Conference on: Urban Drainage*, September 8-13 2002, Portland, OR, USA.

Zoppou, C. (2001). Review of urban storm water models. *Environmental Modelling and Software,* **16**(3), 195-231.