SOURCES OF POLLUTANTS DISCHARGING TO LAKE TREKANTEN, STOCKHOLM

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ABSTRACT

Lake Trekanten in Stockholm receives storm water from residential and traffic areas. To improve the lake water quality, storm water measures are being considered. Storm water fluxes and quality has been continuously measured in three successive points. The air-borne deposits have been measured at two points. The sources of the six substances lead, cadmium, copper, zinc, phosphorus and PAH in storm water runoff from the catchment area have been quantified by a source model. It was, e.g., concluded that building materials are dominant sources for copper and important sources for zinc.

Comparisons of model calculations with results from measurements showed reasonable fit for the substances studied. The usefulness of the model for identifying and quantifying the pollutant sources for planning purposes was demonstrated. Four abatement strategies were simulated by the model and the results are here exemplified by copper. Source control measures would reduce production of copper and the outflow with storm water to less than a third. Source control measures include covering copper-plated roofs, decreased traffic and change of vehicle materials.

It is recommended that source control measures are made as a first choice, before considering storm water treatment facilities such as infiltration practises and sedimentation basins.

KEYWORDS

concentrations; flow; mass flux, pollutants; source control; storm water

INTRODUCTION

In the action plan for the lakes and water bodies in Stockholm, Lake Trekanten is described as a highly eutrophicated lake with low transparency and very high contents of heavy metals in the sediments. The lake is important for recreation and has a diversified and valued fauna and flora. To improve the water quality a number of measures in the lake and its catchment (watershed) area have been taken. For example, parts of the storm water from a highway is now diverted into another receiving water. Other parts of the storm water is treated in a lamella oil separator. The water exchange in the lake has been improved by pumping out the bottom water and by replacing it with potable water. But to improve the conditions in the lake in a sustainable way the sources of the pollutions have to be identified, quantified and reduced.

A model for describing and quantifying the storm water pollutant sources and for simulation of the effects of abatement measures has been developed and used for the planned area Hammarby Sjöstad in Stockholm (Malmqvist and Bennerstedt, 1998). The model was considered useful for understanding the processes of generation and spreading of the studied substances, and it was decided that the model would be used for an existing area - the Lake Trekanten catchment area - and verified against measured data. Six substances are included in this study: lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), phosphorus (P) and polycyclic aromatic hydrocarbons (PAH). The study has been financed by the Streets and Real Estate Administration, the Swedish Environmental Protection Agency, the Regional Environmental Foundation and Stockholm Water Company.

DOMESTIC AREA "NYBOHOVSBERGET", STOCKHOLM

The studied area Nybohovsberget is located south of Lake Trekanten (Figure 1) and consists of apartments with attached parking areas and local streets. The domestic area is here divided into three catchment areas; A, B and C. There are measurements that correspond to each area. Area A is smallest (0.6 ha) and is dominated by a domestic house with a copper-plated roof. Area B includes area A, but also other houses with varied roofing, and some streets (total area 4.1 ha). Area C includes both area A and B, but also other buildings and the main street in the area (total area 9.0 ha).

The storm water is conducted in a separate sewer system (i.e. separated from the sewage water) to the lake.

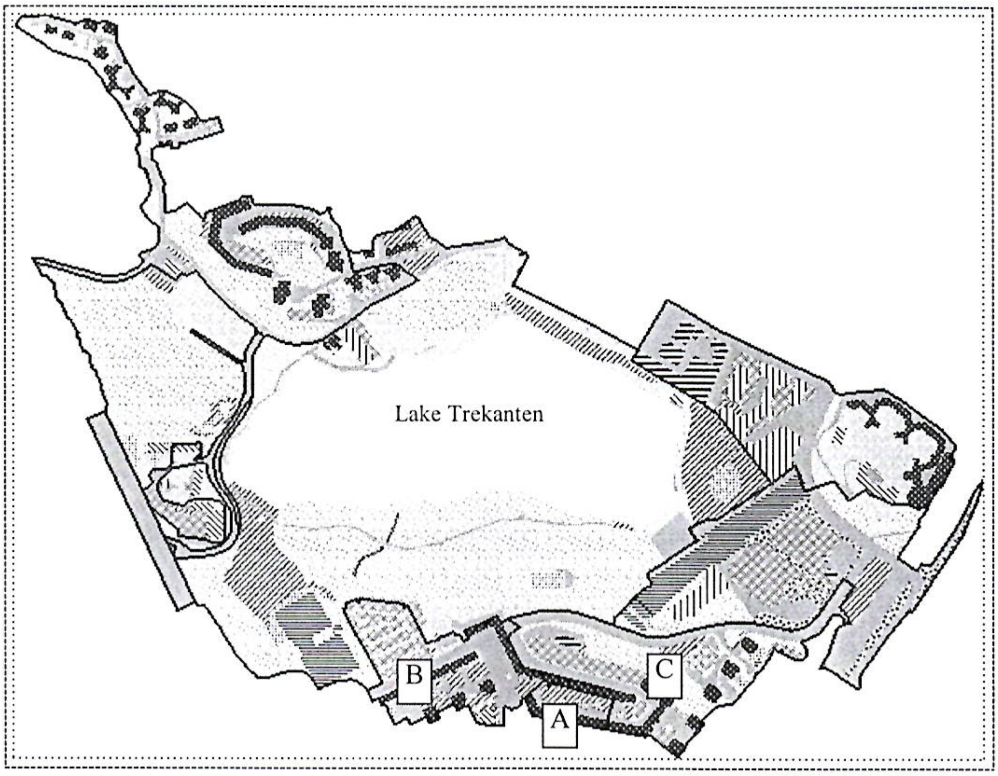

Figure 1. The watershed of Lake Trekanten and the three studied areas (A, B and C) at Nybohovsberget (Picture in GIS-format from Jadelius Å., Environment and health administration in Stockholm).

FIELD MEASUREMENTS

The following 3 points include both flow measurements and sampling:

- In the first manhole in the storm water system after the building with the corrosion study (see below). Besides the building, the sampling area (area A) also includes a backyard.
- Further down in the system (area B) where the runoff from several buildings, backyards and local streets is captured.
- Closer to the lake recipient (area C).

Furthermore, precipitation was measured with a tipping bucket gauge. Wet and dry air deposition was collected in an open bucket type NILU (1 litre deionized water was included). Directly on a roof, measurements mainly dealing with corrosion were performed. Metal emission rates were investigated from surfaces of copper, galvanised steel, impregnated wood, lead surfaces, asphalt surfaces, stainless steel and concrete, and the total runoff from the surfaces have been collected. The corrosion tests will be published (Kucera and Persson, in press).

Continuous flow monitoring was carried out by measuring water level and velocity, and calculating the flow with help of the continuity equation. Equipment from ADS Environmental Services was used. Flow proportional samples were taken by Sigma samplers and collected in one tank per point. The tanks were emptied approximately twice a month. The analyses included SS (suspended solids), tot-P, tot-N, Cd, Ni, Cr, Zn, Cu, and Pb. All metals except Zn and Cu were analysed using an atomic absorption spectrometer with a graphite furnace (SS 028184, 83). The analyses of Cu and Zn were performed using flame atomic absorption spectrometry (SS 028152-2, 50-2). A spectrometer was also used for the analyses of tot-P (SS 028127-2) and tot-N (ASN 62-04/84). SS was analysed in accordance with SS 028112-3.

RESULTS FROM MEASUREMENTS

The measured precipitation values (i.e., both rainfall and snowfall) from the precipitation gauge within the area are around 30% higher than the 1998-values from the SMHI (Swedish Meteorological and Hydrological Institute) precipitation gauge Stockholm, situated 4 kilometres north east of Trekanten. The precipitation exceeds the values from the average year in the SMHI-reference period 1961 to 1990 but is not extreme, see Figure 2 (left).

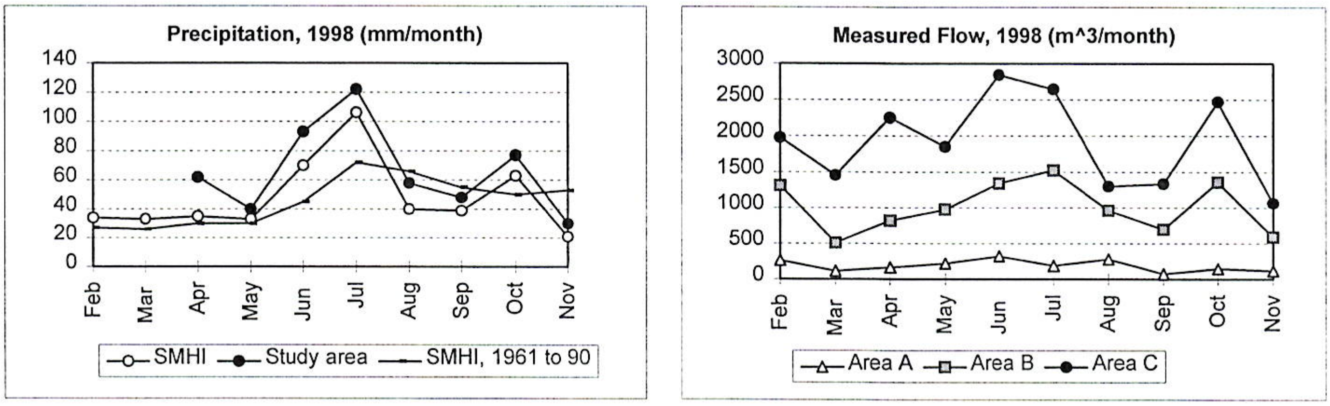

Figure 2. Measured precipitation and measured storm water flow, February to November 1998. Data from December 1998 and January 1999 are yet to come.

The storm water flow from the three studied areas is presented in Figure 2 (right). Since area C includes areas A and B, the flow that comes from area C consequently is the largest. The "measured" (the data from the two months to come have been estimated using average precipitation values and estimated runoff coefficients from the adjacent months) flow for the annual study period is around 0.26 x 10^6 m^3/km^2/year, which is a normal value for this part of Sweden if considering the urban land use of the site (Larm, 1996).

Figure 3 presents flow-proportional total concentrations of lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), and phosphorus (P) in the storm water system of the areas. Concentrations of PAH are to be analysed (only calculated values are presented in Figure 3). Limit discharge concentrations in storm water are also included in Figure 3. These show at which concentrations storm water may be discharged to recipients without any need of treatment and have been preliminary estimated in an adjacent study (Larm, 1998). The limit discharge concentrations are different for different sensible recipients and can be used for helping to decide when measures are to be taken. The proposed limit discharge concentrations correspond to yearly median values.

The measured concentrations of Pb in Figure 3 shows values around 26 μg/l (estimated yearly average value for area C) which is "normal" for this type of land use (mainly apartments). A rather comprehensive literature study of land use specific pollutant concentrations show normal values between 10-50 μg/l from domestic areas (Larm, 1997). The limit discharge concentration of Pb, 20 μg/l, is exceeded.

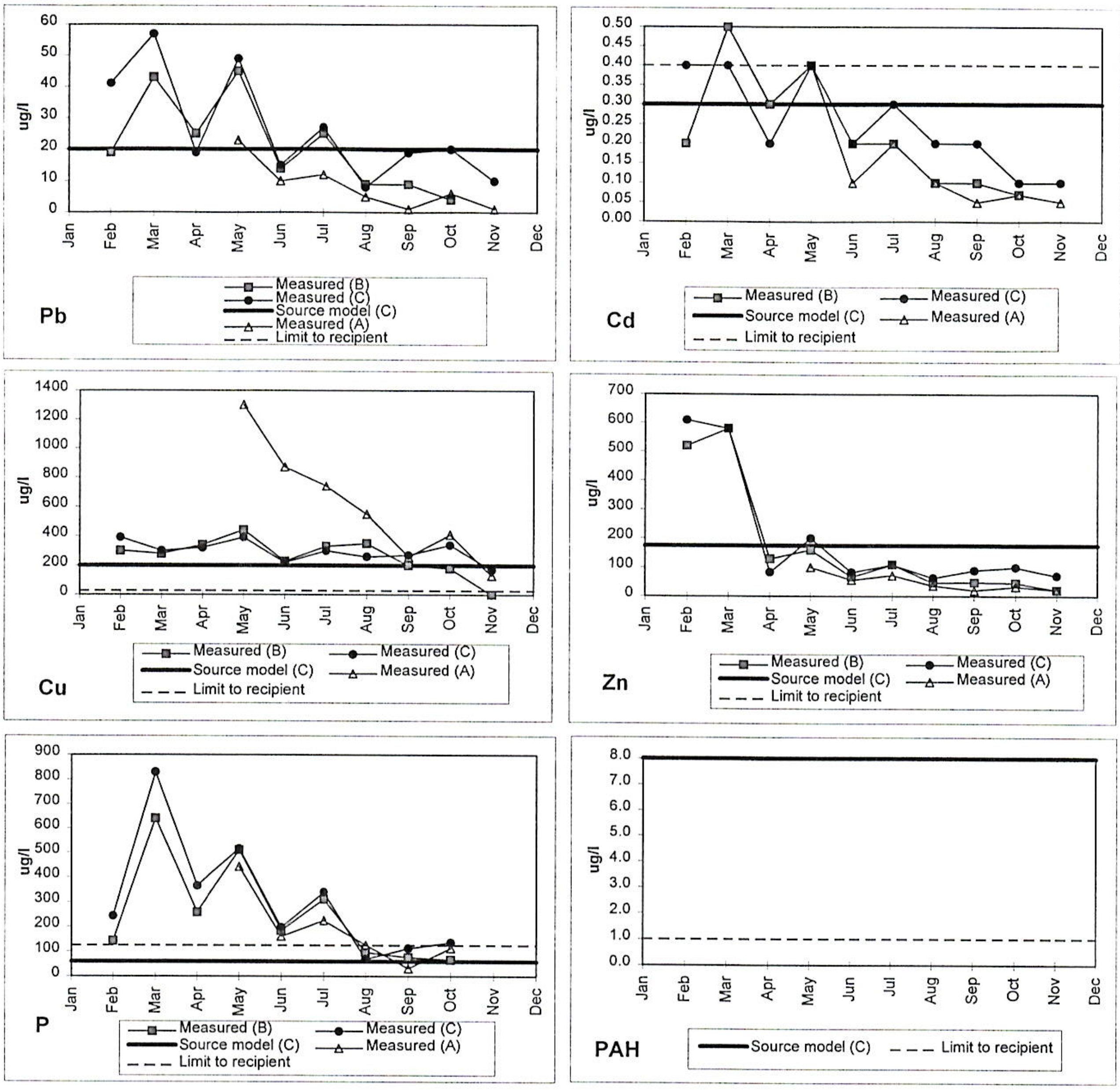

Figure 3. Measured (from area A, B and C) versus model calculated concentrations of Pb, Cd, Cu, Zn, P and PAH in storm water. Comparisons to estimated limit concentrations for discharge to the lake recipient.

The measured Cd-concentrations are relatively low; around 0.25 μg/l. Normal Cd-values are between 0.3-2 μg/l. The limit discharge concentration, which is set to 0.4 μg/l, is not exceeded. The measured Cu-concentrations, in average 300 μg/l, are very high compared to normal values between 15-150 μg/l and compared to the limit discharge concentration 25 μg/l. The Cu-concentrations in the storm water from area A are particularly high, as expected due to the copper roofs. The measured Zn-concentrations are around 200 μg/l and relatively normal (normal values are between 50-500 μg/l). However, they are above the limit discharge concentration 175 μg/l. The measured P-concentrations are in average 300 μg/l compared to normal values between 50-450 μg/l and compared to the limit discharge concentration 125 μg/l. The comparisons of measured pollutant concentrations to limit discharge concentrations generally indicate that measures for reducing the pollutant concentrations in storm water is recommended. The comparisons of measurements to model calculations (Figure 3) are discussed in the section of verification to measurements.

MODEL LAYOUT AND DESCRIPTION

The model is a simple Excel model. Four categories of sources are included: traffic, building materials, atmospheric deposition, and human beings and animals. Runoff and mass flows are calculated from four types of areas: traffic areas, residential areas, parks, and commercial and industrial areas. All areas include all four categories of sources. Separate files contain data on all surfaces in the catchment area, properties of the building materials used, traffic intensities, number of inhabitants and general data on activities in the area. Other files contain data on precipitation and atmospheric fallout. The files are all linked into a computation file, in which annual flows of the chosen six substances from the area are calculated. For this study, all surfaces have been carefully investigated, both concerning areas and materials. A GIS map of this part of Stockholm has been used in combination with detailed mapping in situ. The GIS application on this case study was developed by the Environment and health protection administration in Stockholm. Some of the other data needed has been measured, as traffic intensities, others have been obtained from general demographic registers in Stockholm, as the number of inhabitants. A general layout of the model is given in Figure 4.

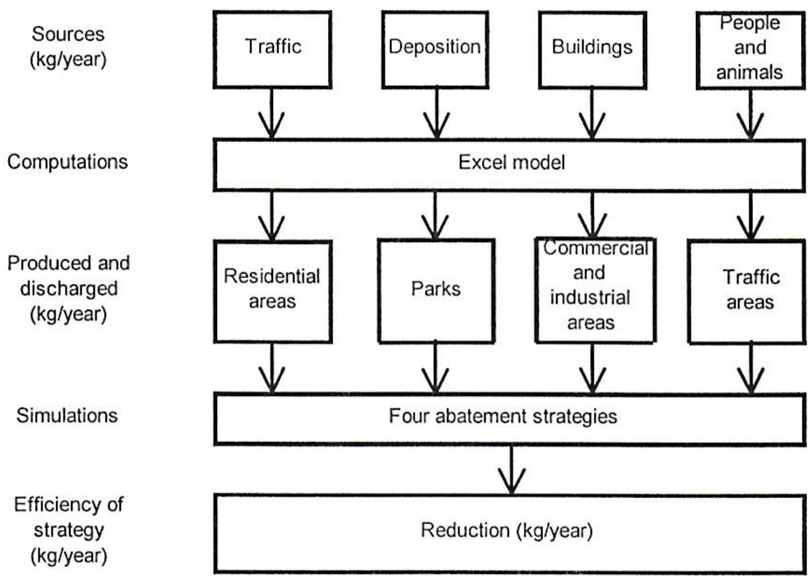

Figure 4. General layout of the source model.

RESULTS FROM MODELLING

For each of the sub-catchments, totally produced amounts of the studied substances and yearly mass fluxes have been calculated. In Figure 5 the distribution of sources in the catchment area C (Nybohovsbergen) is shown. The results give a good base for understanding where the most important sources are to be found, and which kinds of abatement measures that might be most efficient. Building material is the dominant source for copper and an important source for zinc (roofs and fittings). Traffic is an important source for all the studied substances except phosphorus. Atmospheric fallout is the dominant source for cadmium and PAH. The sources for phosphorus are people and animals and, to some extent, atmospheric fallout.

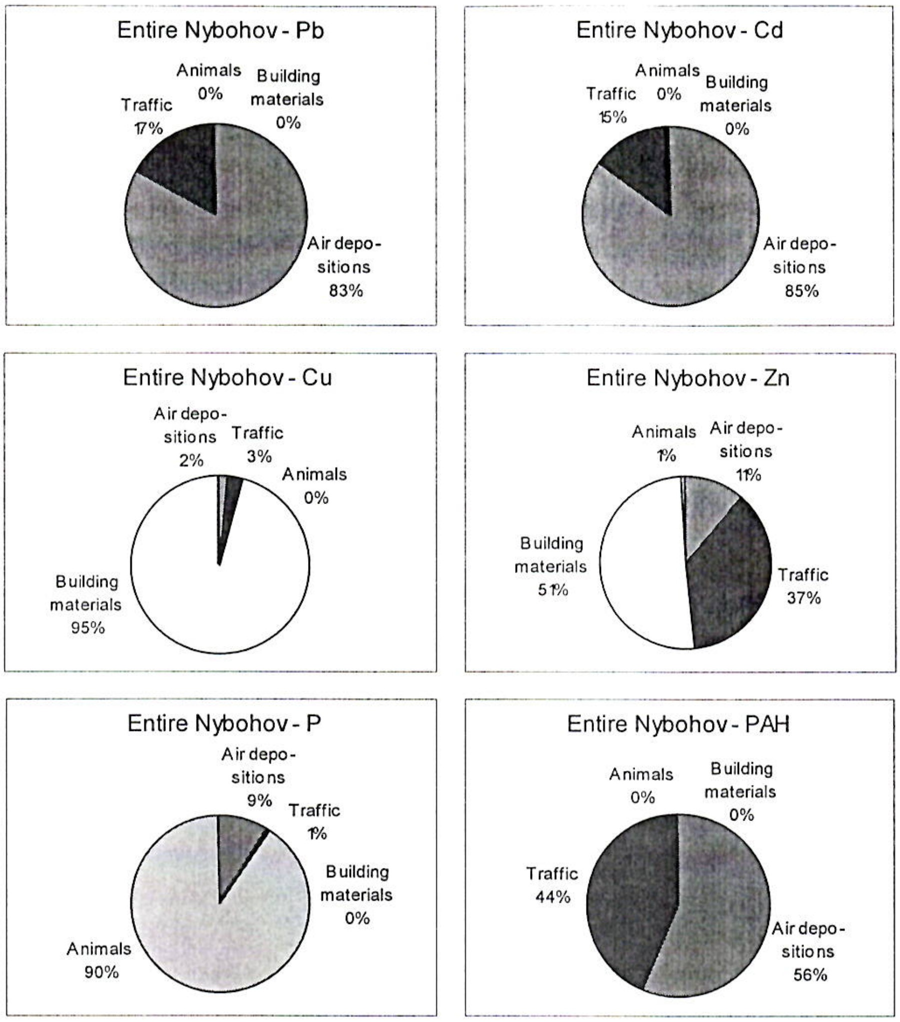

Figure 5. Sources of lead, cadmium, copper, zinc, phosphorus and PAH in Nybohovsbergen C.

A comparison of the mass flows of copper from the three catchment areas (A, B and C) and the calculated concentrations of copper in the storm water runoff is given in Figure 6. Although area A is small compared to the entire area, the copper runoff from the area is very high. Note that the concentration in storm water is nearly 1g/l as yearly average.

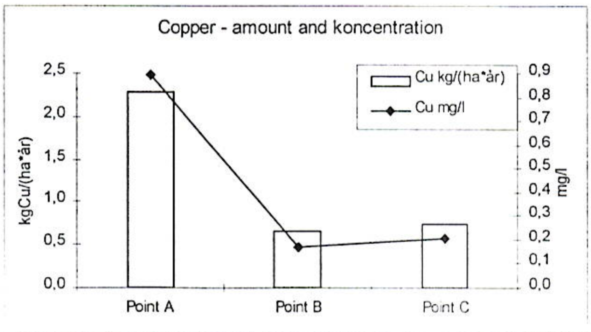

Figure 6. Comparison of amounts and concentrations of copper from the three catchment areas.

VERIFICATION OF MODEL RESULTS WITH MEASURED VALUES

The results of the source model, which has not yet been calibrated, show lower flow values than the measured data (Table 1). According to Figure 3, the calculated yearly average concentrations of Pb, Cd and Zn show a good fit to the measured concentrations. The calculated concentration of Cu is lower than the measured concentrations and the calculated P-concentration is much lower. The match of storm water flow and concentrations (especially concerning copper and phosphorus) is expected to improve when the model has been calibrated. Table 1 also presents the difference between the measured and the model calculated amounts. The metal loadings show a good fit between measurements and source model calculations. The phosphorus loading from measurements is higher than the loading calculated from the source model.

Table 1. Storm water flow (m^3/year) and pollutant loadings (kg/year) from area C (the total studied area). Results from measurements and model calculations.

Area C	Flow m^3/year	Pb kg/year	Cd kg/year	Cu kg/year	Zn kg/year	P kg/year	PAH kg/year
Measurements	23700	0.6	0.006	7.1	5.2	7.1	-
Source model	33200	0.7	0.006	6.6	5.8	1.9	0.3

ALTERNATIVE ABATEMENT MEASURES

Eight alternatives for improving the storm water quality and decreasing the discharges of polluted storm water have been used for simulations, and combined into four scenarios:

Scenario 1 - Source control) comprises measures for the reduction of the pollutant sources, e.g., the use of tile roofs instead of copper plated or galvanised and painted steel sheets, painting of all galvanised objects like lampposts and railings, more frequent street cleaning, decreased traffic within the area and/or changes of construction materials in the vehicles and concrete or natural paving stones instead of asphalt pavements.

Scenario 2 - Source control and treatment) involves, in addition to the measures under scenario 1), measures taken within the storm water system, mainly infiltration of all storm water from the housing areas, and treatment of all storm water from the traffic areas in floating sedimentation ponds.

Scenario 3 - Best possible and long term improvements) also accounts (in addition to scenario 1 and 2) for the future effects of reduced discharges to water and air according to international agreements, i.e., long term or best possible strategies.

Scenario 4 - Short-sighted measures) comprises measures that can be taken on a short sight and at reasonable cost, including exchange or painting of metal surfaces, infiltration of storm water from housing areas and treatment of storm water from traffic areas in sedimentation basins.

The results from the simulated four scenarios are presented in Figure 7, exemplified by copper for area A and for the entire catchment area C.

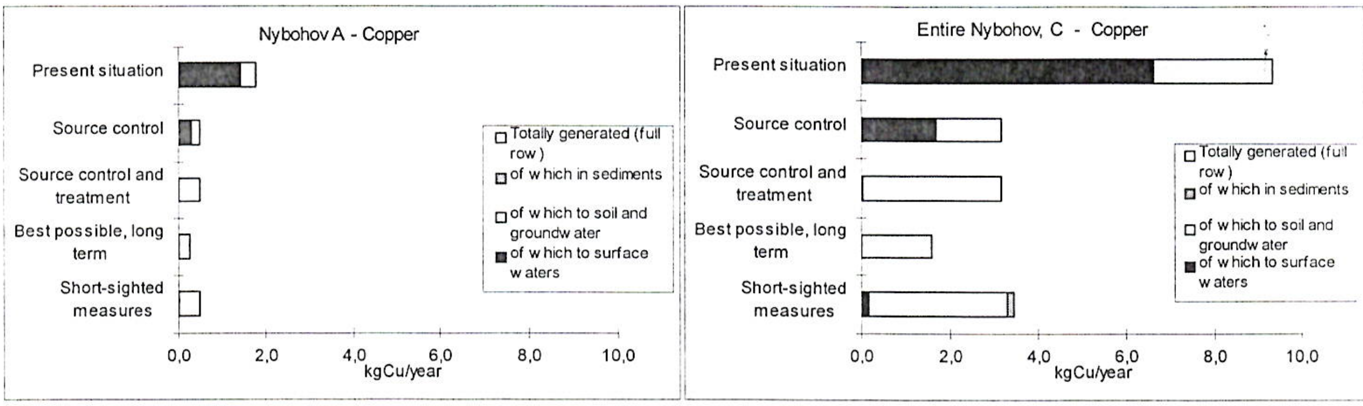

Figure 7. Copper flows in catchment area A and the entire area C in Nybohovsbergen. Results from simulations for four abatement strategies.

CONCLUSIONS AND DISCUSSION

It was concluded that building material is the dominant source for copper and an important source for zinc (roofs and fittings). Traffic is an important source for all the studied substances except phosphorus. Atmospheric fallout is the dominant source for cadmium and PAH. The sources for phosphorus are people and animals and, to some extent, atmospheric fallout.

The results of the model calculations have been compared with results from measurements in the three catchment areas, showing that the results produced by the model were good for lead, cadmium and zinc, and reasonable for copper and phosphorus. An exact agreement between calculated and measured values was not found and was neither anticipated, since the calculations were made on a yearly basis for an average year and since the model is not yet calibrated. However, the usefulness of the model for identifying and quantifying the pollutant sources for planning purposes was demonstrated.

Four abatement strategies were developed and simulated by the model: source control (scenario 1), source control and treatment (scenario 2), best possible and long term improvements (scenario 3) and short-sighted measures (scenario 4). The results of the simulations are here exemplified by the results from copper. For the entire catchment area Nybohovsbergen C, source control would reduce the production of copper and the copper outflow with storm water from the area to less than a third. In the small catchment area A, where copper-covered roof is a dominating surface, source control measures are even more effective. The production of copper in area A would be reduced to 25%. Source control measures include the covering of copper-plated roofs by, e.g., tiles and bitumen, decreased traffic and/or change of construction materials in the vehicles, especially the brake linings.

Further reductions of the amount of copper transported to the lake by storm water would be achieved if the storm water was either infiltrated to the groundwater (from the residential areas) or treated in sedimentation basins (from the traffic areas). Drawbacks from an environmental point of view would be that the soil and groundwater becomes polluted at the infiltration. Furthermore, sediments from the sedimentation basin must sooner or later be taken care of, and, regardless of method, it will involve a potential environmental risk.

It is recommended that source control measures are made as a first choice and that stormwater treatment facilities are chosen only when the pollutant sources have been reduced as much as is practically possible.

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