Climate change effects on nitrogen loading to urban lakes: The case of Råcksta Träsk, Stockholm, Sweden

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ABSTRCT

Nutrient loads to aquatic recipients can be expected to change due to climate change. In this work, we focus on nitrogen loads to the lake Råcksta Träsk in Stockholm, Sweden as an example of an urban ecosystem. A substance flow model is developed to describe the sources and pathways of nitrogen at present. A feed-back table approach is applied to indicate potential climate change effects on nitrogen source strengths and processes in pathways, using existing regional climate change scenarios. The tentative results indicate that biological, hydrological, meteorological and biogeochemical effects and change in human behavior as response to climate change may lead to altered nitrogen flows through an urban catchment.

Key words: nitrogen load, urban lake, climate change, substance flow analysis, feed-back table

INTRODUCTION

The eutrophication of urban lakes is threatening urban ecologies and services provided to humans (e.g., Stockholm Vatten, 2006). The amount of nutrients transported is a result of point-source emissions, atmospheric deposition, urban runoff, nutrients leaching from soil and biochemical removal processes in the freshwater system (Arheimer et al., 2005). Except for point-source emissions, all these sources and pathways are strongly influenced by weather and thus the nutrient flow through an urban catchment could be expected to be affected by climate change. In order to manage and avoid potential future eutrophication of urban ecosystems, reliable predictions of the response of nutrient loadings to climate change are thus urgently needed.

Presently, most studies of climate change effects on eutrophication have focused on large scale river basins, arable land, or rural landscapes (De Wit et al., 2000, Mander et al., 2000, Darracq et al., 2005). However, studies of the urbanized area, with its own distinct biogeochemical and hydrological characteristics, affected by complex interactions between society and the environment, are largely lacking in the scientific literature.

In this work, we attempt to understand climate change effects on nitrogen source strengths and the processes in transport pathways in an loading perspective, using an urban-lake catchment in Stockholm, Sweden, as a case study. Therefore, the objectives of this work are:

- To develop a conceptual substance flow model for nitrogen sources and delivery to a selected local lake in an urban catchment;
- To identify factors that influence nitrogen source strengths and pathways, which are sensitive to temperature and precipitation and thus may lead to climate change effects on urban eutrophication.

CASE STUDY

Råcksta Träsk, a small lake in the urban area of Stockholm, northern Sweden, covers about 36000 m^2 and has a maximum depth of 2.3 m and high nitrogen concentrations (StockholmVatten, 2006). Figure 1 shows the land use in the catchment. It is noteworthy that there is a Lamella plant, which receives large parts of the stormwater and discharges the treated stormwater directly to the lake by a ditch. Figure 2 shows a conceptual model of nitrogen biogeochemical cycling and transport in the Råcksta Träsk catchment. A proportion of the nitrogen entering the catchment is transported to the lake, with transformation into alternative forms and potential loss, e.g. denitrification and volatilization, and retention, e.g. sorption and plant uptake, along the transport pathways.

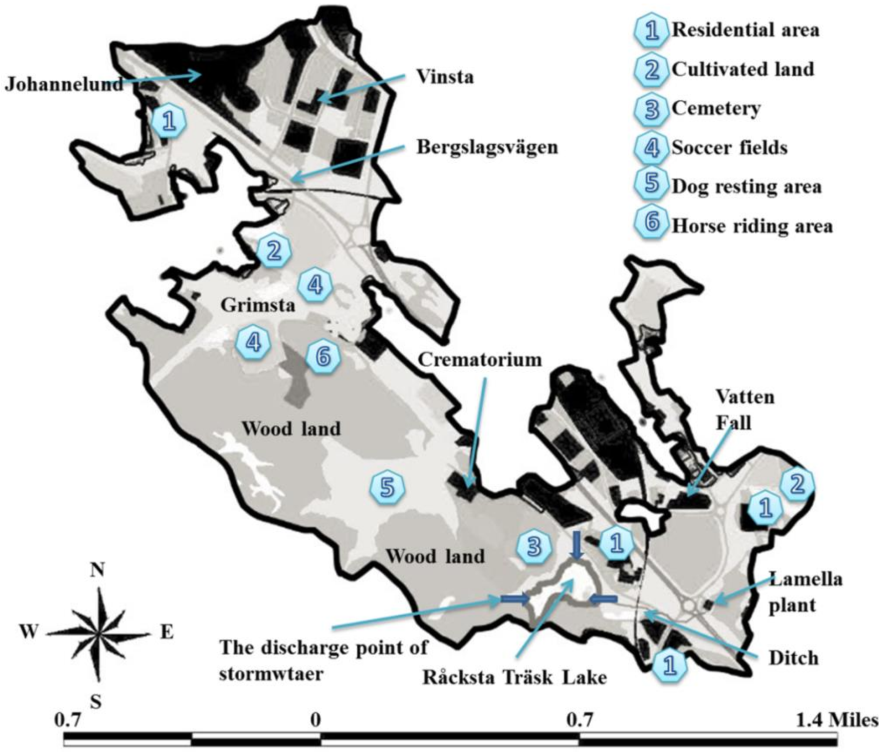

Figure 1. Catchment of Råcksta Träsk (modified from StockholmVatten, 2000).
Green area (Grimsta recreation area including dog resting, horse riding and soccer fields etc., cultivated land, cemetery and wood land), **Construction area** (Johannelund), **Industrial area** (Lamella plant and crematorium), **Business area** (Vattenfall and Vinsta area), **Traffic area** (vehicular roads of Bergslagsvägen, other streets), **Residential area**.

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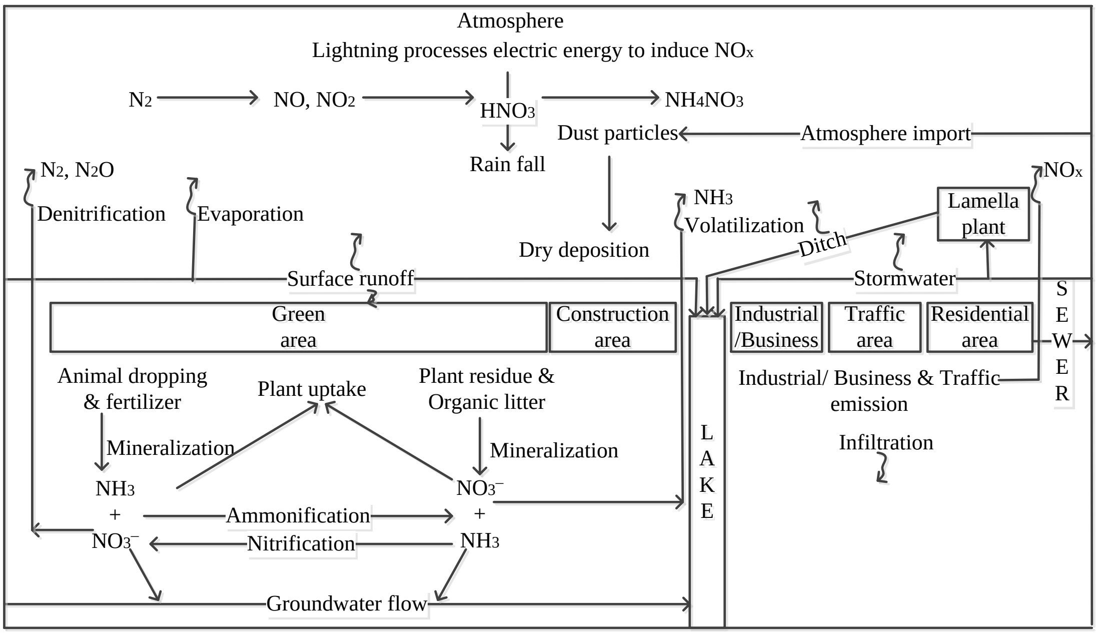

Figure 2. Conceptual model of nitrogen biogeochemical cycling in the catchment of Råcksta Träsk (inspired from Lembi, 2001).

According to SMHI (Swedish Meteorological and Hydrological Institute), the average annual temperature and precipitation in Stockholm in 2007 was 7-8 ℃ and 500-600 mm, respectively. The climate scenarios for Stockholm indicate an increase in mean temperatures of 2.5 - 4.5 ℃ until 2100, and precipitation would be increased, especially in the winter (5-10 % increase in rainfalls is forecasted for 2011-2040, while a 25 % increase is forecasted for 2071- 2100 compared to the reference period of 1961-1990) (Stockholm Stad, 2007).

METHODS

The catchment of Råcksta Träsk is set as the system boundary to identify nitrogen sources and pathways. We developed the conceptual substance flow analysis (SFA) model for nitrogen loading to the lake Råcksta Träsk at present, based on literature data and stakeholder interviews. To consider the climate change effects on the catchment, we follow existing regional climate change model results (see Case Study section). Changes of temperature and precipitation are suggested to present climate scenarios. Conditions directly induced by temperature and precipitation are also taken into account, such as human outdoor activity frequencies and related source types, e.g. traffic volume and amount of pets outside. In order to indicate climate effects on nitrogen loading to a local lake in an urban catchment, we identified factors commonly used in quantitative or qualitative assessments of nitrogen sources and transport assessments in literature. Feed-back tables are used to demonstrate the results.

RESULTS AND DISCUSSION

Conceptual nutrient flow model for Råcksta Träsk, Sweden. Figure 3 shows the developed SFA for nitrogen in the Råcksta Träsk catchment. We categorize the primary sources based on the land type (permeable area or impervious area), and also consider atmospheric import from adjacent catchments and discharge from point sources (StockholmVatten, 2000). For the diffuse primary sources (Sources I-IX in Figure 3), we categorize the type of source and associate it with land use according to Figure 1. Point sources may occur at the industries (Sources X-XI in Figure 3) and sewage from residential and industrial areas is collected and transported to a water treatment plant outside the catchment, and are not considered here, except for potential infiltration to groundwater from leaking pipes. Nitrogen in atmosphere, soil, groundwater, surface runoff, stormwater and the ditch are taken as secondary sources.

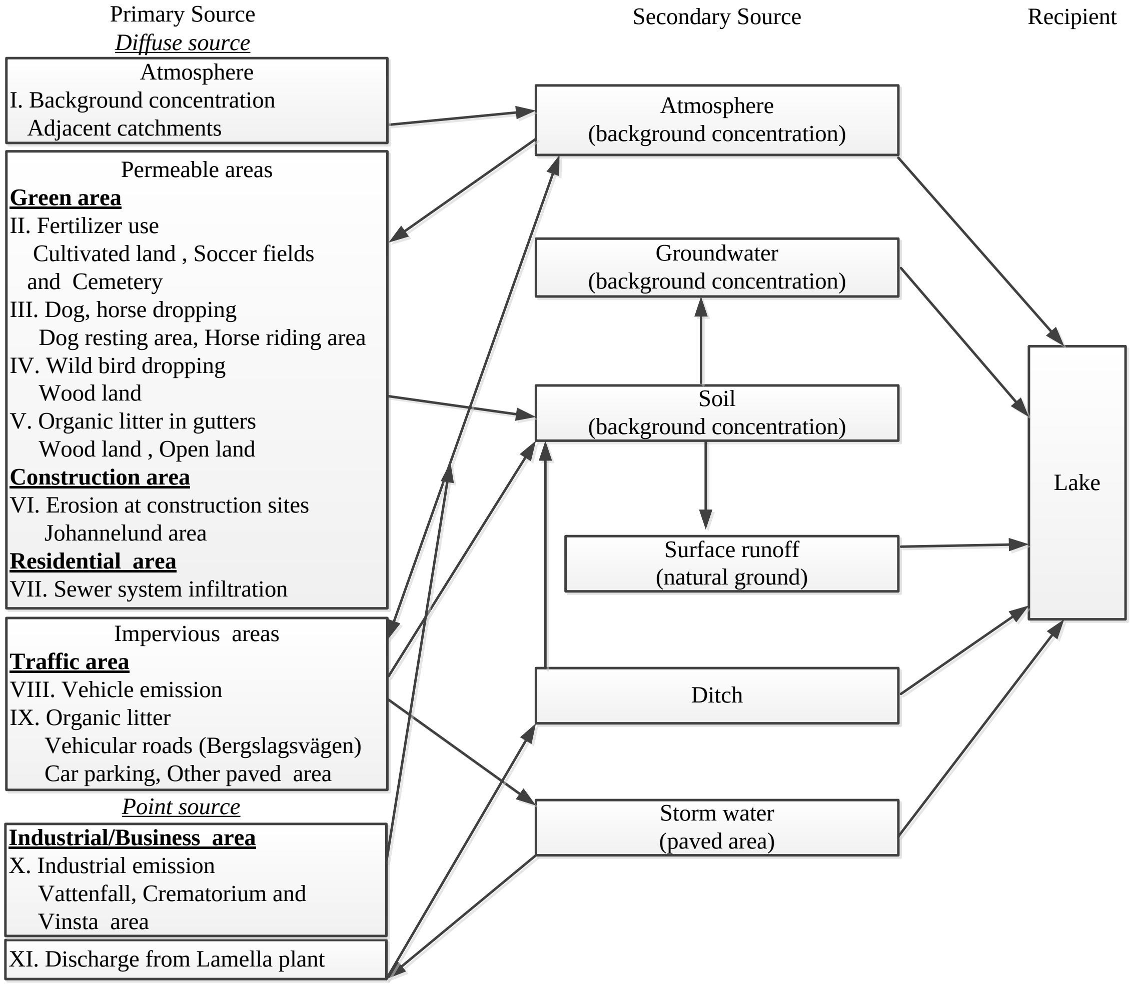

Figure 3. Tentative model for nitrogen flow in the Råcksta Träsk catchment.

Feed-back from climate change on nitrogen primary sources. Table 1 shows identified factors involved in the primary source strengths and tentative relationships with changes of temperature and precipitation. In Table 1, notation "1" and "0" stands for potentially "impacted" and "not impacted" by climate changes of temperature (T) and precipitation (P), respectively. Out of the eleven primary sources of nitrogen, climate change was identified to affect several, through either biological (Sources II, IV and V), hydrological (Sources VII and XI), and meteorological (Source I) effects or change in human behavior (Sources III, VI, VII). Note that here the human behavior relates to human outdoor activities. No effect is expected for industrial emissions, which is well controlled and managed. It is also noteworthy that factors that involve technology and human morality have little dependency on climate change (such as street cleaning, sewage treatment efficiency, etc.).

Table 1. Feed-back table for climate change effects on primary sources (as portrayed in change of temperature (T) and precipitation (P)).

Source #	Factors in source strengths	Condition*		Supporting literature (if any)
		T	P	
I	removal in adjacent catchments	N/A	N/A	
	lightening in adjacent catchments	1	1	(Price, 2008)
II	plants nitrogen requirement	1	1	(Arheimer et al., 2005)
	plants nitrogen leaching	1	1	(Arheimer et al., 2005)
	maintaining grass in soccer fields	N/A	N/A	
III	per dog/horse	0	0	
	amount of dogs, horses	1	1	(Baghli and Verhagen, 2005)
	cleaning up	0	0	
IV	biodiversity	1	1	(Crick, 2004)
	per wild bird	N/A	N/A	
	number of birds	1	1	(Crick, 2004)
V	leaf-litter accumulation	1	1	(Nilsson et al., 1999)
	portion near around gutters	0	0	
VI	site characteristics	0	0	
	area	0	0	
	construction process	1	1	
VII	volume of sewage	0	0	
	infiltration rate	0	1	(Semadeni-Davies et al., 2008)
VIII	traffic volume	1	1	(Keay and Simmonds, 2005)
	per vehicle emission	0	0	
IX	leaf-litter accumulation	1	1	(Nilsson et al., 1999)
	street cleaning	0	0	
	public littering	1	1	(Nicholls, 2006)
X	emission from Vattenfall	0	0	
	emission from Vinsta area	0	0	
	emission from crematorium	0	0	
XI	received stormwater	1	1	(Bergstrom et al., 2001)
	discharge by plant itself	0	0	
	treatment efficiency	0	0	

source number according to Figure 3.
* N/A = not available; 1 = climate change affected; 0 = not climate change affected; T = temperature; P = precipitation.

For fertilizer use (Source II), wild bird dropping (Source IV) and organic litter (Sources V and IX), all factors chosen to represent the source strength could potentially be influenced by changes of temperature and precipitation. These sources are suggested to be given priority in further studies. As the Råcksta Träsk catchment has large green areas, including the Grimsta recreation area and large woodland areas, potential change in activities from both human and wild life in green areas as result of climate change would also need to be further investigated.

Feed-back from climate change on nitrogen secondary sources and pathways. Figure 4 gives the identified processes that regulate nitrogen transport through different pathways to the lake based on Figures 2 and 3. For surface runoff, groundwater, stormwater and ditch, transport occurs in water and the loading is determined by the nitrogen concentration and volumetric water flow. This is in agreement with Mander et al (2000) and Darracq et al (2005) who found waterways to be dominant pathways for taking nitrogen to the water recipient. Water flow, rainfall, snowmelt and groundwater balance are considered as important for the nitrogen loading, which is also in agreement with previous literature (e.g., De Wit et al., 2000). For the nitrogen concentration, nitrogen loss and retention are considered for all the pathways, as detailed in Figure 2, which is in agreement with recent nitrogen loading modeling (e.g., Venohr et al., 2011).

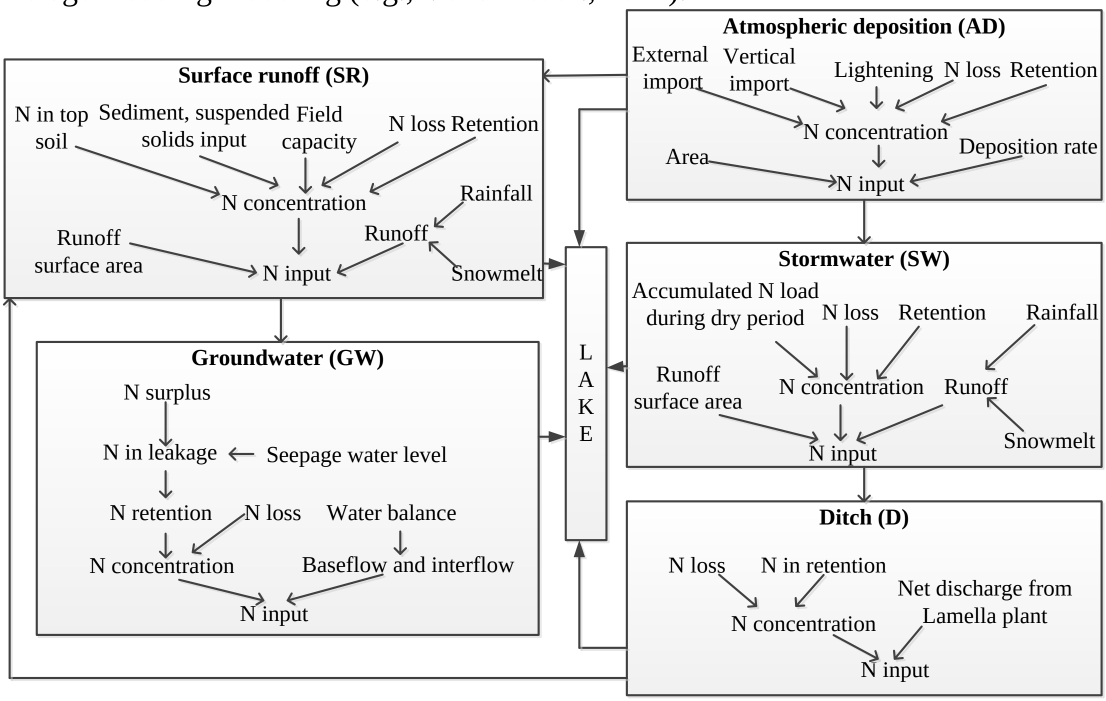

Figure 4 Pathways and processes for nitrogen (N) emission into Råcksta Träsk (inspired by Venohr et al., 2011; compare Figures 2 and 3).

Table 2 shows all the identified factors that we tentatively considered for the secondary sources and processes in the transport pathways (based on Figures 3 and 4) and their relationships with change in temperature and precipitation. The results indicate that climate change potentially could influence a large fraction of the factors chosen to represent the secondary source strengths and pathways by hydrological, biogeochemical and meteorological effects. Moreover, there are more factors that contribute to N concentration than to volumetric water flow that may be affected by climate change.

Table 2. Feed-back table for climate change effects on secondary sources and pathways (as portrayed in change of temperature (T) and precipitation (P)).

Pathway#					Factors (as shown in Figure 4) in the pathways	Condition*		Supporting literature (if any)
AD	SR	SW	GW	D		T	P	
					N concentration			
	√				N in top soil (Soil)	F	F	
			√		N surplus (Soil)	F	F	
	√				sediments, solids input (Soil)	1	1	(Asselman et al., 2003)
		√			accumulated N load	1	1	(Arheimer et al., 2005)
√	√	√	√	√	N loss	1	1	(Swift et al., 1998)
√	√	√	√	√	N retention	1	1	(Arheimer et al., 2005)
√					lightening	1	1	(Price, 2008)
√					atmospheric vertical import	1	1	(Ganeshram et al., 2002)
√					atmospheric external import	N/A	N/A	
	√				field capacity	1	1	(Eckhardt and Ulbrich, 2003)
					Volumetric water flow			
	√	√			rainfall	0	1	(Bergstrom et al., 2001)
	√	√			snowmelt	1	0	(Bergstrom et al., 2001)
			√		water balance	0	1	(Porporato et al., 2004)
			√		seepage water level	0	1	(Van Roosmalen et al., 2007)
				√	net discharge from Lamella plant	0	0	
					Atmospheric fallout			
√					deposition rate	1	1	(Arheimer et al., 2005)
√	√	√			area (permeable, impervious, lake)	0	0	

The "√" refers to the factor being involved in the pathways.
pathway as indicated in Figure 4.
* N/A = not available; 1 = climate change affected; 0 = not climate change affected; F = needs further study.

In Figure 3, soil is indicated as a secondary source, while we exclude it in Figure 4. The nitrogen loading from soil to surface runoff and groundwater (Figure 4) is governed by a complex interplay between biogeochemistry and transport (compare Figure 2) that calls for detailed studies (marked by "F" in Table 2). Moreover, due to particularly change in precipitation events, there is a likely change in nitrogen distribution between pathways (not explicitly indicated in Table 2) that needs to be considered in future studies.

CONCLUSIONS

Based on literature data and stakeholder interviews, we established a SFA conceptual model for nitrogen for the selected case (the catchment of Råcksta Träsk in Stockholm, Sweden). Eleven primary sources, six secondary sources and five pathways were identified, categorized (Figure 3) and connected to land use (Figure 1) in the urban catchment.

Using existing literature and climate change model results, we found that climate change, as reflected in an increased annual mean temperature and precipitation, could affect primary source strengths due to change in human behavior, hydrology, biology and meteorology (Table 1). In particular, tentative results showed all factors used to indicate source strengths connected to fertilizer use, wild bird dropping and organic litter on the streets and adjacent land could be affected by climate change and these should thus be given priority in future studies.

Our results also indicate that climate change potentially may alter the secondary source strengths and pathways by hydrological, biogeochemical and meteorological effects (Table 2). In particular, change in the complex interaction between biogeochemistry and water flow influencing the soil as a secondary source or sink of nitrogen and potential redistribution of nitrogen between different pathways as consequence of climate change calls for further studies.

ACKNOWLEGEMENTS

We are grateful to Ph.D. Stina Thörnelöf and Ph.D. Tonie Wickman, Environment and Health Administration, Stockholm, Sweden, for providing case study data and for helpful discussions of the project. China Scholarship Council (中国国家留学基金委) provided a scholarship for Jiechen Wu.

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