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Hydrological and Environmental Effects of Agricultural and Urban Activities in a Small Swedish River Basin

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The environmental influence of forestry, agriculture and urban activities on the hydrological conditions in a small river basin in southern Sweden and the effects on the river water quality are analyzed and quantified on different time scales. The emphasis is on the river flow fluctuations and the transport of nitrogen to the sea. Different measures for decreasing the load of nutrients are discussed. It is shown that if wetlands are re-established in rural areas and techniques for water treatment are introduced, it is possible to reduce the nitrogen transport to the sea by 60%. However, this reduction would have little influence on improving the nutrient status of coastal waters.

Introduction

Many studies have been devoted to point pollution on river water quality, but studies on the overall environmental conditions in a river basin including diffuse sources are few, especially if variations of the runoff and the pollutant load over periods shorter than a year are considered. In small river basins the runoff from urban areas may constitute a significant part of the river discharge during certain periods. The influence of cities on river water has been studied on annual bases (Wanielista 1979; Welch 1980, Hogland and Niemczynowicz 1980; Enell 1989; Berndtsson 1990). However, the influence of a city on a river depends on upstream conditions and is different for different periods of the year. To determine the environmental status of the river and to find means of improving the conditions, pollutant sources must be identified and the environmental effects of these sources estimated for different river flow conditions.

In this paper the flow regime and the pollutant conditions in the small Höje river basin in southern Sweden are investigated. The discrete influences of agricultural activities, forested areas and urban areas on the river flow and on the nutrient and heavy metal load is quantified, so that the effect of different means for nutrient removal can be estimated. The time distribution of river discharge and pollutant load is shown, and the effect of extreme situations is discussed. Finally, the nitrogen contribution from all small rivers discharging into the Sound between Sweden and Denmark is related to other nitrogen sources, and the overall effects of nitrogen removal in Höje river specifically, and in all the rivers, are quantified. The Höje river basin is dominated by agricultural land. The calculations made in this paper based on a 10-year time series of measurements from an agricultural experimental basin, Värpinge (Lindh 1983), a 1.5 year long continuous time series of all discharges from the city of Lund at 50 stations (Hogland 1986) and discrete measurements in the forested areas (Enell and Henriksson 1988), were used for analysis of the varying hydrological and water quality conditions.

The Höje River Basin

Basin Characteristics

The Höje river basin is situated near the city of Malmö in the south of Sweden. The total basin area is 310 km^2 and consists of 59% (183 km^2) agricultural land, 29% (88.5 km^2) forest and meadow, less than 1% (1.5 km^2) lakes and 12% (37 km^2) urbanized area, as shown in Fig. 1. The city of Lund with 80,000 inhabitants, and 5 towns, 5,000 each, are situated within the basin. The difference in altitude, from the highest point on the water divide to the river mouth, is 180 m. The main stream of the Höje river is 47 km long with a difference in altitude of 60 m. The soil types within the basin are moraine and boulder clay, with spots of fine and coarse sand. Forests and meadows can be regarded as relatively undisturbed land. The agricultural land is used for modern cropping practices.

The quantity and quality of water in the river is mainly affected by municipal wastewater, agricultural tile and ditch drainage and groundwater contribution from agricultural and forested areas. There are no industrial discharges into the river.

The mean annual precipitation varies within the river basin from 650 mm/yr in the higher elevated eastern part of the catchment to 550 mm/yr at the river mouth in the western part. The annual average evaporation has been estimated to be 500-450 mm/year. (Gustafsson and De Geer 1976; Lindh *et al.* 1983).

River flow characteristics from the Swedish Meteorological and Hydrological Institute's gauging station located downstream from the city of Lund, drainage area 258.8 km^2, for the periods 1971-1977, 1978-1979 and 1985-1991 are given in Table 1

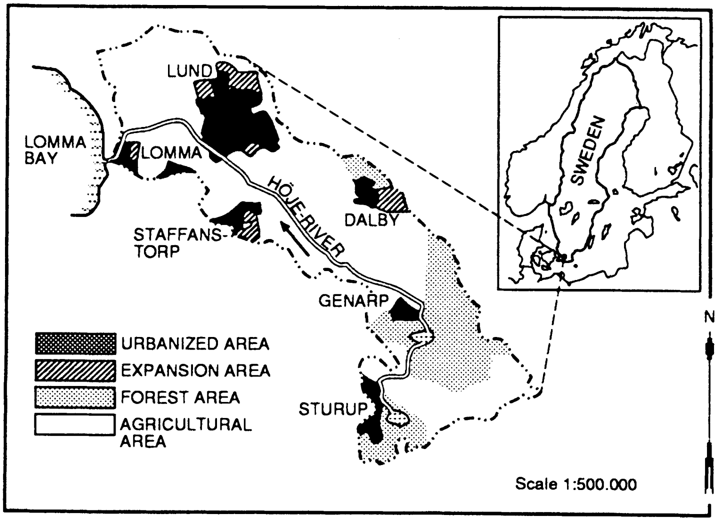


Fig. 1.
Land use in the Höje river basin.

Table 1 – Flow characteristics (m^3/s) for the Höje river, downstream from the city of Lund, drainage area 258.8 km^2

HHQ	MHQ	MQ	MLQ	LLQ
35	14	1.9	0.17	0.04

HHQ = Highest ever flow, MHQ = Mean annual high-water flow, MQ = Long-term average flow, MLQ = Mean annual low-water flow, LLQ = Lowest recorded low-water flow. Unit: m^3/s (VIAK 1979)

(VIAK 1979; Hogland and Niemczynowicz 1980; Länsstyrelsen 1992). The mean flow corresponds to 200 mm annual runoff.

The city of Lund constitutes the main urban part of the basin. The central part (6.5 km^2), of which 50% is impervious area, is drained by a combined sewer system. The suburban parts (12.9 km^2) of the city are drained by separate wastewater and storm water systems. The fraction of impervious area of the suburban parts is about 30%. The wastewater from the city of Lund is treated effectively with respect to BOD and phosphorous, as is the waste water from the towns within the basin.

During the last two centuries the cultivated farmland has increased fourfold. Wetlands have been drained, the Höje river and its tributaries straightened, so the extent of wetland areas has decreased from 3% to 0.2% of the catchment area. The length of the main river has been shortened from 192 km to 95 km (Ekologgruppen 1990). Until the early 1950s, systems of small shallow canals were used for irrigation of meadows with river water, thereby introducing nutrients to the grass. From the beginning of the century fertilizers have been used, but were not used extensively until the 1960s. The changes of the agricultural landscape and the use of new agricultural methods should have resulted in less water storage capacity within the agricultured parts of the basin, faster rainfall-runoff response and decreased travel times of water particles through the river system, reduced river flows during summer and leaching of nutrients to the river, as shown in studies by for example Savini and Kemmerer (1961), Chow (1964), Sopper and Lull (1967), Sangvaree and Yevjevich (1977).

Urban Runoff and Pollutant Transport

The contribution to the river flow from urban areas is from storm water, treated wastewater, combined sewer overflow (CSO), and groundwater flow discharging into ditches. The annual storm water runoff for the city of Lund is 0.3 m^3/s, which corresponds to 270 mm/yr (Hogland 1986), but occurs during rather short intervals (hrs) of time. On an annual basis the discharge of treated wastewater dominates the urban river flow contribution, being 893 mm or 0.5 m^3/s; 0.06 m^3/s is storm water in the combined wastewater-stormwater system and 0.20 m^3/s is subsurface water that leaches into the sewerage system. The total amount of leaching into the drainage and sewerage system of the city of Lund is 0.24 m^3/s. The contribution from sewer overflow is 0.006 m^3/s. For short periods, 3 hrs, the highest storm water discharge in the 1.5 year measuring period was 8.3 m^3/s, which is 0.8 mm/h, and the highest CSO-discharge was 3.5 m^3/s, or 0.3 mm/h.

The monthly water balance for the city of Lund is shown in Table 2. Drinking water is transferred from outside the basin. The evaporation was calculated as a residual term from water balance calculations for pervious areas by adding the potential evaporation for depression storage on impervious areas (Hogland *et al.* 1980). Snowmelt occurred in March, when the monthly wastewater discharge doubled because of meltwater in the combined sewer system. The amount of water leaching into the storm water sewer system in the city of Lund was estimated as the base flow after separation of the effective runoff. Also the drainage to the wastewater sewer system was calculated as being the base flow transport through the wastewater treatment plant, subtracting clean-water supply and runoff from the combined sewer system treatment plant.

Combined sewer overflow (CSO) is the water discharged directly to receiving waters from an overloaded combined sewer system. The problems of combined sewer overflows have been studied since the early 70s (Mattei *et al.* 1970; Driscoll 1981; Field 1991 and Hogland *et al.* 1986). CSO discharge occurs mainly during heavy convective rainfall, but may also occur during frontal rains and snowmelt, and when electricity supply to pumping stations is interrupted. CSO occurs in Lund 30-40 times a year and lasts for some minutes up to 3-6 hours. During snowmelt overflow for 50-60 hours has been observed (Hogland 1986).

Table 2 – Water budget for the city of Lund in the Höje basin (after Hogland and Niemczynowicz 1979)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	15.6	11.1	32.3	9.3	4.5	23.0	24.0	12.2	43.8	15.6	14.4	28.1	19.5
Ei	1.8	7.1	10.7	8.0	11.9	19.3	17.1	15.7	13.7	7.7	6.3	9.1	10.9
Mm	0	−1.9	+4.1	−4.7	−8.8	−3.1	−0.2	−6.2	+14.7	+3.7	+3.1	+3.0	+0.3
Ms	+10.3	+5.5	−23.2	0	0	0	0	0	0	0	0	+10.3	+0.2
Qw	24.1	23.1	50.4	30.3	23.0	22.9	20.9	19.8	27.7	24.2	24.4	25.1	26.4
Qs	2.4	1.9	32.3	7.8	2.5	5.4	4.4	1.9	10.4	3.3	4.3	4.7	6.8
Qc	0	0	1.1	0.1	0.4	1.1	0.4	0	0.9	0	0.1	0	0.4
Dw	12.7	13.9	14.1	13.0	13.9	13.1	10.4	11.8	13.0	15.0	12.3	11.7	12.8
Lw	12.8	10.8	28.0	18.6	10.2	8.7	7.7	7.3	9.9	10.8	11.6	12.4	12.4

Unit:l/s km^2

P = precipitation, Ei = evaporation and losses, Mm = changes in soil moisture storage, Ms = changes in snow storage, Qw = waste-water (includes Lw), Qs = stormwater (includes Lw), Qc = CSO, Dw = drinking water, Lw = leaching to sewer system supply

The pollutant load from wastewater leaving the wastewater treatment plants is known in detail. The concentration of total nitrogen in the ongoing water from the treatment plant in Lund is 19 mg/l, and the concentration of phosphorous 0.28 mg/l. The concentration of incoming water is also known, 28 mg/l nitrogen, 5.5 mg/l phosphorous, which means that the total load of combined sewer overflow can be computed.

The contaminants in the stormwater originate from atmospheric fallout, traffic, corrosion of building materials, litter and animal droppings (Lazaro 1979; Hogland *et al.* 1982; Malmquist 1983; Hall 1984; Hogland 1986; Svensson 1987). The concentrations in the runoff water vary with land use and population density. The mass transport from the urban part of the Höje basin was determined by multiplying measured runoff from different surfaces and discharges of different waters by the concentrations measured in the city of Lund. The results are shown in Table 3. In the calculation, thinly populated areas are also included. Treated wastewater dominates the urban discharge on an annual basis for all constituents but zinc.

Table 3 – Urban pollutant discharges in annual runoff and load per unit area, mm and kg/km^2 yr

	Treated wastewater	CSO	Stormwater
Runoff	46	0.4	12
N_{tot}	11.3	0.05	0.35
P_{tot}	0.16	0.01	0.05
Cu	0.10	0.0008	0.03
Zn	0.06	0.0005	0.07
Pb	0.06	0.0005	0.02

Table 4 – Water budget for the agricultural area. Measured, 10-year mean values in l/s km^2 (after Lindh 1983)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	20.1	15.2	16.4	13.9	12	16.6	23.9	16.8	20.4	19	26.2	23.1	18.6
E	3	3.7	6.3	14.3	25.8	29.7	26.9	24.3	15	8.6	5.4	4.1	13.9
Mm	+6.3	+0.4	+1.9	−4.6	−14.9	−13.5	−3.0	−7.5	+5.4	+8.2	+15.8	+8.2	+0.2
Ms	+1.1	+0.8	−3.4	0	0	0	0	0	0	0	0	+1.5	0
R	3.0	3.7	0	0	0	0	0	0	0	1.5	1.5	1.1	0.8
Q	6.7	6.6	11.6	4.2	1.1	0.4	0	0	0	0.7	3.5	8.2	3.6

P = precipitation, E = evaporation, Mm = changes in soil moisture storage, Ms = changes in snow storage, R = rest term (percolation and/or errors in measurements and calculations)

Runoff and Pollutant Transport from Agricultural Land

Hydrological data from the experimental basin in Värpinge was used for calculating both the runoff contribution to the river from the agricultural part of the Höje basin and the nutrient contribution. For the 10-year measurement series, 1971-80, the average annual runoff was 113 mm (3.6 l/s.km^2), ranging from 17 to 226 mm/yr. The annual evaporation was 441 mm. The water budget for the agricultural basin is given on a monthly basis in Table 4.

About 3 km^2 of arable land in the river Höje basin is irrigated. The maximum volume of water used for irrigation is 2,000 m^3/day or 0.14 m^3/s (4 mm/day irrigated area), Ekologgruppen (1990). As an average, the quantity of water used for irrigation during the vegetation period is 0.070 m^3/s (VIAK 1979), of which 0.025 m^3/s is taken as groundwater or from marl ponds and the remainder from surface water.

The lowest observed flow in the river since 1971 is 0.26 m^3/s at the SMHI gauging station downstream from Lund (VIAK 1979 and Länsstyrelsen 1992). The lowest observed flow corresponds closely to the estimated minimum discharge from the wastewater treatment plants, 0.23 m^3/s.

The mass transport of different constituents has been calculated for the Värpinge area (see Table 5). Atmospheric deposition and fertilization contribute to the

Table 5 – Runoff and mass transport, on a monthly basis, from the Värpinge agricultural area (after Lindh 1983; Hogland 1986). Unit: l/s km^2 and kg/km^2 month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q	6.7	6.6	11.6	4.2	1.1	0.4	0	0	0	0.7	3.5	8.2
N_{tot}	193	184	431	156	34	8	0	0	0	29	138	280
P_{tot}	3.0	4.0	2.8	0.9	0.4	0.2	0	0	0	0.7	2.0	3.7
Cu	2.3	1.3	1.9	0.9	0.1	0.04	0	0	0	0.15	1.2	1.37
Zn	0.4	0.2	0.6	0.2	0.1	0.03	0	0	0	0.06	0.3	0.4
Pb	0.7	1.4	1.9	0.4	0.3	0.09	0	0	0	0.4	1.0	1.3

pollutant load. When calculating the mass transport, the 10-year average runoff (1971-1980) series has been multiplied by a shorter (1.5 year) series of monthly concentration measurements (1978/79) from Värpinge. The pollutant load to the river is highest in the winter, when the runoff is high.

Runoff and Pollutant Transport from Natural Areas

Data from 12 sub-basins within the Höje basin taken from a study carried out by Enell (1987) were used for determining the runoff and pollutant contribution from forested areas to the Höje river. Since the forested areas are situated high up in the river system, where the annual precipitation is 650 mm as compared to 550 mm at the river mouth, runoff from forested areas is higher (240 mm) than the agricultural runoff (150 mm). However, there are no continuous discharge measurements for the 12 sub-basins.

The leaching of total nitrogen was reported by Enell (1987) to vary between 1.8-2.4 ton/km^2 yr, and phosphorous between 30-55 kg/km^2 yr, which is almost 10 times higher than the values given as being representative for southern Sweden, Monitor (1983). The monthly mean phosphorous concentrations varied in the range 40-219 μg/l and the nitrogen concentrations of the stream water in the range 2.1-6.6 mg/l. Average concentrations for heavy metals were for Cu 75 μg/l, Zn 25 μg/l and Pb 60 μg/l, which is, especially for lead, extremely high. The mass transport for each month was calculated by multiplying the estimated monthly runoff by the measured concentration in the forest runoff, see Table 6. There is almost no leaching from July to November. The leaching of nutrients is highest during the winter, as is true for the agricultural parts of the Höje river basin.

Table 6 – Mass transport on a monthly basis from forested parts of the Höje river basin, in kg/km^2 month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N_{tot}	69	105	943	354	92	13	3	~0	~0	~0	46	271
P_{tot}	2	1	19	11	2	0.5	~0	~0	~0	~0	1	6

Water Balance

The annual contribution to the basin runoff from different areas is summarized in Table 7. About 30% of the runoff is from urban areas, 55% from agricultural and 14% from forest and meadow areas. The discharge of treated wastewater is 22% of total runoff to the river.

The measurement period was divided into two 6-month periods; May-October,

Table 7 – Runoff contribution for different types of water, relative to flow and absolute contribution

	Runoff	Runoff	Runoff
Type of runoff water	mm/yr	% of total runoff	m^3/s
Wastewater	46	22.3	0.60
CSO	0.4	0.2	0.01
Stormwater	12	7.2	0.20
Agriculture	258	55.3	1.50
Forest/meadow	133	15	0.40
Total (Q_{tot})	~275	100	~2.7

P=213 mm and November-April, P=314 mm, respectively. In Fig. 2, calculations based on runoff measurements in 1978/79 are shown. The most extreme runoff events for different time scales (6 months, 1 month, 1 week, 1 day and 3 hours mean) are given.

The highest relative rate of the urban discharge (90% or more) occurs as a consequence of showers in a dry summer (time base week, day and hours). If a heavy rainfall occurs during this period, the stormwater discharge can be 55-60% of the total runoff and CSO up to 20%. The three-hour discharge values, presented in Fig. 2, represent a rainfall of 20 mm in September, and snowmelt combined with precipitation of 12 mm during March. In September the urban discharge was more than 80% (wastewater discharge was 60%) of total discharge to the river, in month values on the May-October graph.

Annual mass transport from different types of water to the Höje river is shown in Fig. 3. It is seen that the dominant source for phosphorous is by far treated wastewater. The only two significant nitrogen contributors are wastewater and

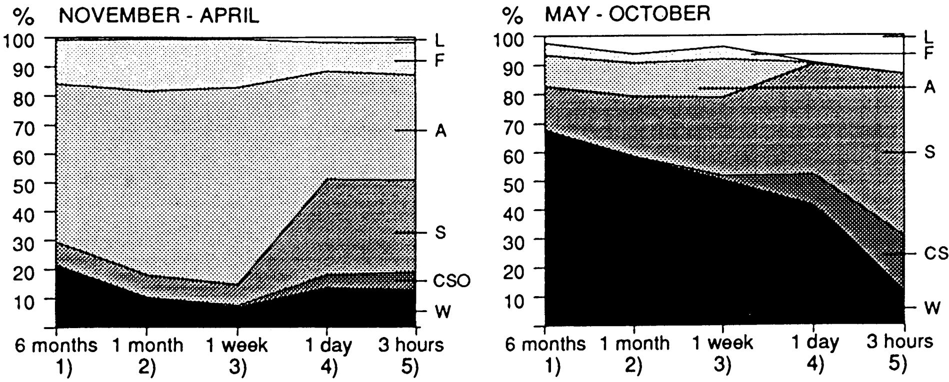


Fig. 2. Percentage of the various types of runoff for different time scales, during the periods November-April and May-October, 1978/79.

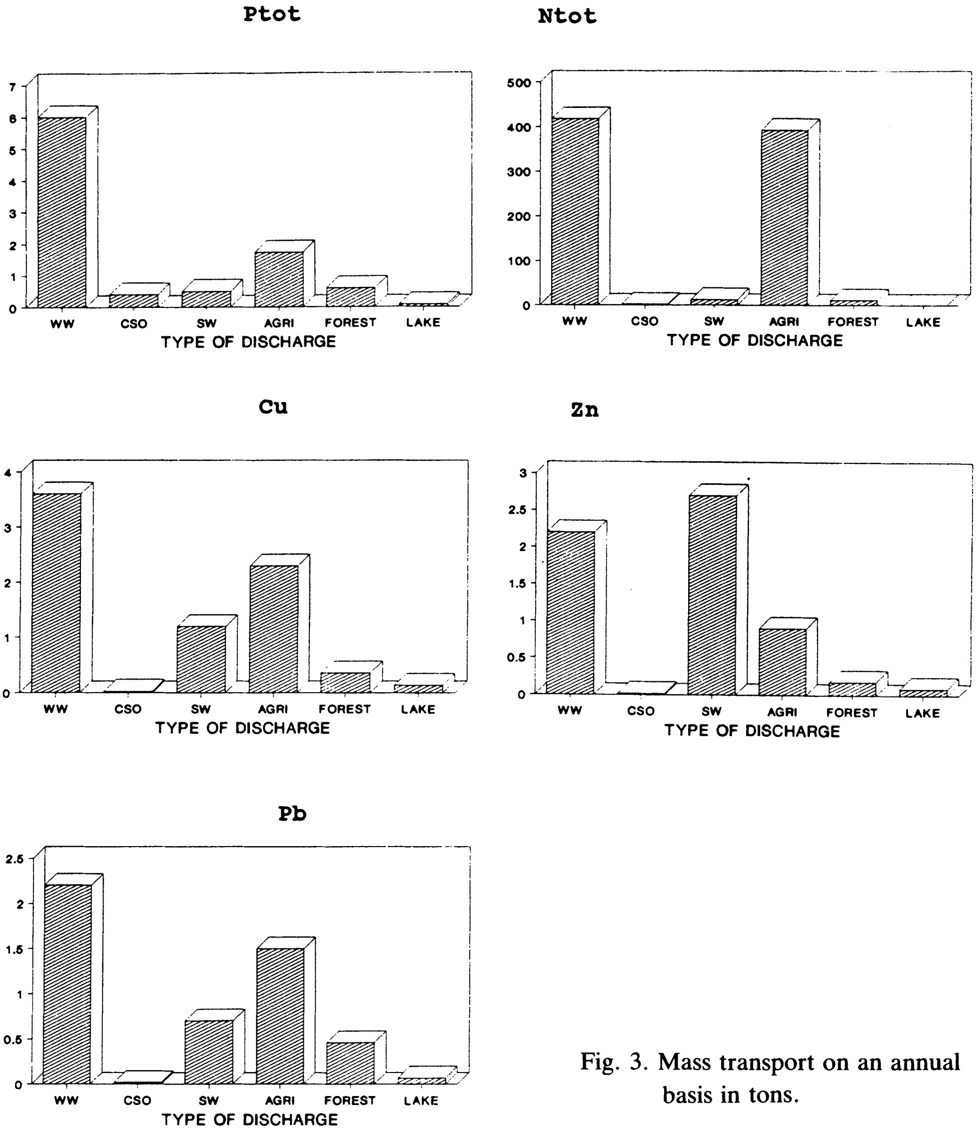
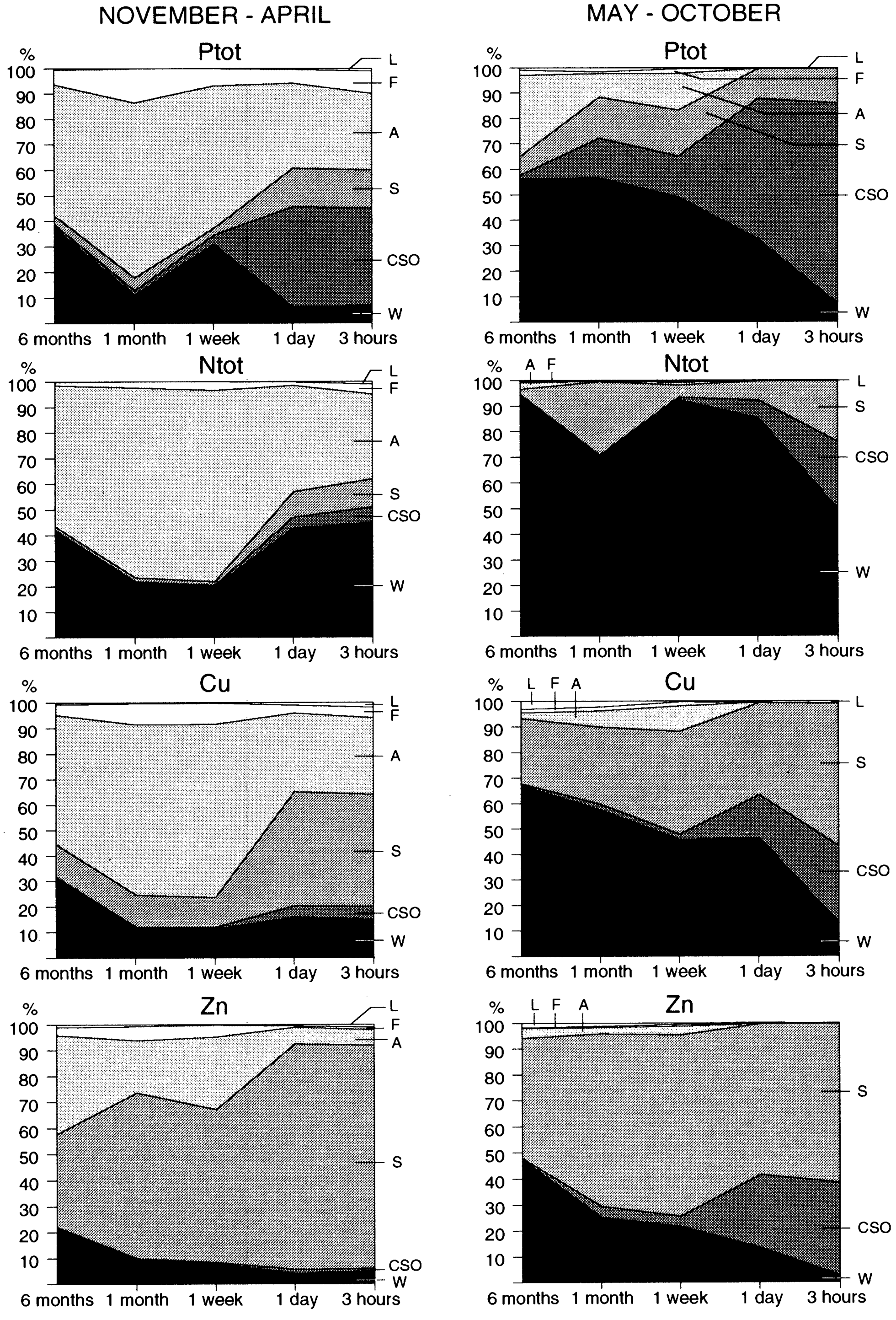


Fig. 3. Mass transport on an annual basis in tons.

agriculture. Heavy metals are introduced into the river by wastewater, storm water and from agricultural land.

During the winter period November-April the urban discharge of pollutants accounts for 25-60% of the total load to the river. During this period about 60-95% of the annual runoff occurs. In the summer period, the urban discharge of pollutants constitutes more than 90%, except for phosphorous, of which urban discharge accounts for 65% of the total.


NOVEMBER - APRIL
MAY - OCTOBER
Ptot
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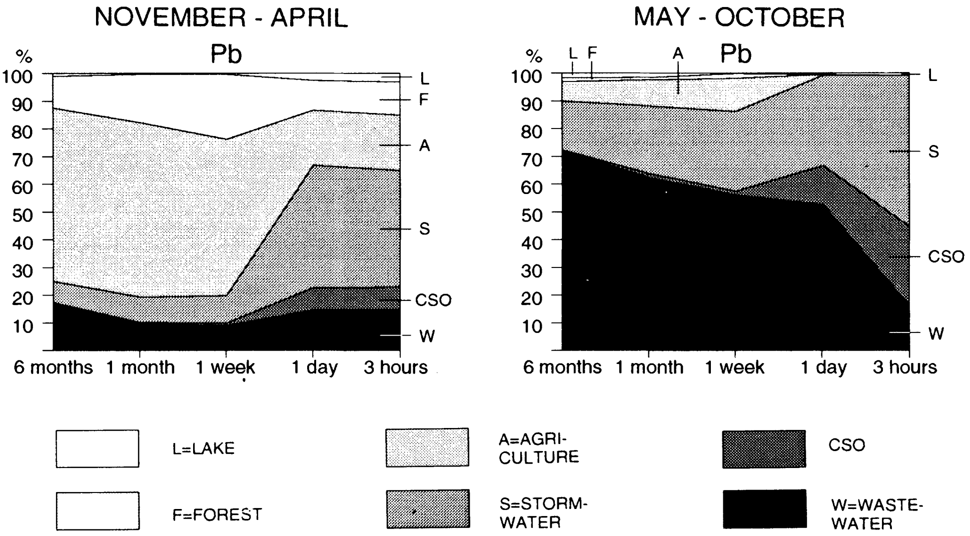

Fig. 4. Percentage of pollutant transport for different time scales during the periods November-April and May-October, 1978/79 (Annual mass transport for P_{tot}, N_{tot} Cu, Zn and Pb into the river Höje).

On an annual basis leaching from agricultural areas constitutes about 50% of the total nitrogen discharge to the river. Less than 2% of the annual nitrogen transport from agricultural land occurs during the vegetation period. Studies carried out during the period 1985 to 1991 (Länsstyrelsen 1992) show a mass transport in the river Höje of 9.9-16.8 ton/yr P_{tot} (0.31-0.53 kg/ha yr) and 545-869 ton/yr N_{tot} (17.2-27.5 kg/ha yr). Although some denitrification occurs, the retention of nitrogen within the river basin during the winter period is low (Persson and Bengtsson 1992). Since the river flow is low in the summer, the mass transport is also small.

In Fig. 4 the year is divided into a winter and a summer period and the relative pollutant load from different sources is given on different time scales. For extreme conditions lasting for periods longer than a week, the urban contribution is only 25% for all pollutants except Zn. During shorter periods of time, the urban mass transport is 55-95% of the total load to the river.

In the summer, urban discharge accounts for more than 85% of all pollutants for durations longer than days; for intervals shorter than a day, 99% or more. On a short time scale, stormwater dominates and accounts for 50% for all constituents except nitrogen.

Extreme Runoff Situations

Besides analyzing observed events, it is meaningful to forecast and analyze extreme situations that may occur. Runoff conditions of interest are those that occur during extreme wet and dry years which cause long-time effects in the basin, and those rainfall events (duration 1 day or less) that cause short-time effects in the river. Runoff has been estimated for the maximum observed annual rainfall during the 20th century, the 30-year average runoff, driest year during the 20th century (SMHI 1987), the 10-year (return period) rainfall with duration of 1 hour and with duration 10 min (Dahlström 1979). The annual runoff was determined as the annual precipitation minus the regional annual evaporation. For the short-term events, the urban runoff was calculated by multiplying precipitation by impermeable area, adding the same amount of leaching into the sewer system as during the 1.5 year intense measurement period in Lund. Since the intense rain storms occur during summer, extreme short-term events were assumed to occur when there was little natural flow in the river.

The maximum annual precipitation during this century is 836 mm, which is about 30% higher than the annual mean. The basin runoff as the sum of the computed runoff from agricultural land and the urban mean runoff is 435 mm/yr or 13.9 l/s km^2, of which nearly 75% comes from rural areas. Wastewater discharge accounts for 15% of the annual runoff, which is half of the corresponding discharge for an average year.

In the driest year since the year 1900 the precipitation was 382 mm, and the calculated runoff 135 mm. The runoff from rural and urban areas is almost equal in a dry year.

The pollutant load from agricultural land is calculated by multiplying the discharge by concentrations representative for wet and dry years, Brink *et al.* (1978). Nitrogen is stored during dry years and washed out during wet years. For urban areas, average concentrations measured in wastewater and stormwater during weeks with high amount of leaching into the sewer system were used for wet-year calculations, and concentrations during weeks with low amount of leaching for dry-year calculations. In Table 8 the pollutant loads estimated for extreme wet and dry years are shown.

The pollutant load is much higher in a wet than a dry year. During a dry year the transport of nitrogen and phosphorous via treated wastewater dominates the load from agricultural land.

For short periods of the order less than days, stormwater and combined sewer overflow discharge dominates the runoff and the pollutant load to the Höje river (Hogland and Niemczynowicz 1980). Single daily summer rainfall has little effect on the runoff from rural areas. For the daily precipitation of 5-year return period 41.1 mm/day Dahlström (1979), the runoff from impermeable areas in Lund is calculated as 170 l/s km^2, which corresponds to 1.4 m^3/s stormwater in the separ-

Table 8 – Predicted mass transport of pollutants during an extremely wet, dry and average year, respectively

	Wet year		P=836 mm	Dry year		P=382 mm	30 year average		P=633 mm
	N_{tot}	P_{tot}	Q	N_{tot}	P_{tot}	Q	N_{tot}	P_{tot}	Q
Treated waste-water	550	8.6	68	370	5	55	418	6	62
CSO	2	0.45	1	0.7	0.05	<0.3	1.9	0.4	0.6
Storm-water	17	0.9	26	6	0.25	10	13	0.5	20
Agricult.	800	4	78	130	1	52	393	1.7	1.500
Forest/ meadow	20	1.3	247	4	0.1	16	11.8	0.6	0.375
Dep. on Lakes	0.1	0.1	4	0.05	0.05	2	0.09	0.08	0.03
Total	~1,390	~15	424	~510	~6	~135	~840	~10	2.7

Unit: ton/yr and mm/yr

ated stormwater system, 0.8 m^3/s combined sewer overflow, and 0.9 m^3/s increased wastewater discharge. The leakage also increases. The total urban runoff evenly distributed over a full day is 3.9 m^3/s. The different sources of runoff contribution are shown in Fig. 5.

Calculations are also made for the 10-year maximum hourly precipitation, 25 mm/h. Stormwater runoff is 17 m^3/s.

The pollutant load during extreme rainfall conditions is difficult to estimate. Conditions of the surfaces just before the extreme event are of importance for the pollutant transport. Using the concentrations of the storm- and wastewater measured during rainy weeks, the CSO contribution during one hour is 0.2 t nitrogen and 0.03 t phosphorous. The stormwater contribution is 0.2 t nitrogen and 0.005 t phosphorous.

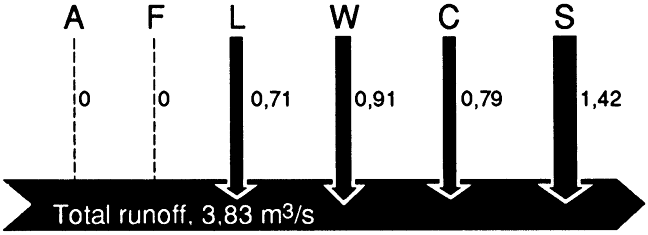

Fig. 5. Runoff for short time extreme rainfall conditions. Rainfall with return period 5 years and duration 24 h. Unit: m^3/s.

Measures for Reducing the Pollutant Load

Urbanization increases runoff. Although in general the increase is not wanted, it may be beneficial during certain dry periods when there is little flow in the Höje river. It has been found from previous studies (Hogland 1986; Berndtsson 1990) that treated wastewater constitutes the main part of the summer flow in the Höje river. Thus, the urban water, although polluted, makes it possible for many species in the river to survive. If the city of Lund was replaced by agricultural land, single budget calculations show that the river discharge during the driest week in the summer would decrease from 1 m^3/s to 0.1 m^3/s. Therefore, it is not obvious that the urban discharge should be reduced, but only the pollutant load and the peak runoff flows.

The main objective of taking any measures for improving the nutrient status of the Höje basin is to reduce the transport of nitrogen to the sea. This is in order to fulfill the goal of 50% reduction of nitrogen set up by the Swedish government. For the Höje basin this means a reduction of more than 400 ton/yr. A reduction of phosphorus is also important, since for the river itself and for the small lakes in the river system phosphorus usually is the limiting growth factor (Ryding 1978; Welch 1980). Heavy metals in the discharge do not create any problems in the river. The concentrations in the urban runoff water are lower than the drinking water standards for Cu and Zn, and close to it for Pb.

For improving the nutrient status of the Höje river and reducing the transport of nitrogen to the sea, a combination of measures can be used. The low flows during summer should not be kept as low as they are now. The nitrogen in the wastewater can be reduced by improved treatment at the wastewater plant in Lund. By different agricultural strategies and by establishing ponds and wetlands, nitrogen can be removed from the agricultural runoff. Agricultural strategies also affect the leakage of phosphorous to the river. The transport of phosphorous from urban areas can be reduced by taking actions concerning the storm water and the combined sewer overflow, but to significantly reduce the phosphorous content in treated wastewater the toilets must be disconnected from the sewerage pipe system.

Biological methods can be introduced to remove nitrogen by about 70% in the wastewater treatment plants. Doing so, the nitrogen load from wastewater on the Höje river is reduced from 420 ton/yr, Fig. 3, to 160 ton/yr. Storm water and combined sewer overflow do not significantly contribute to the annual nitrogen load to the river.

Wetlands are traps for nutrients and heavy metals. Denitrification takes place and nitrogen is taken up by vegetation. Persson and Bengtsson (1992) found in a neighboring basin to Höje a nitrogen reduction, mainly due to denitrification, on inundated meadows of 50 kg/ha month during spring and no reduction during late autumn. The total annual reduction was estimated to be 300 kg/ha yr. The seasonal nitrogen dynamics depend on combinations of biological, physical, and hydrological factors (Lowrance *et al.* 1984). If 200 ha wetlands are established within the Höje basin, a nitrogen reduction of 60 ton/yr could be expected. If all wetlands from the beginning of the 19th century, 9.5 km^2, are restored, the removal of nitrogen should be 270 ton/yr.

The river flow can to some extent be controlled by dams and ponds. Denitrification takes place in the ponds. Fleisher *et al.* (1989) and Jansson *et al.* (1990) claim that 1.8-4.2 ton N/ha yr can be removed when streams are directed into ponds. Using the lower number and assuming that small streams within the basin are directed through ponds extending over a rural area of 20 ha, the N-reduction will be 36 ton/yr, which, however, is not a significant part of the total load.

By using special crops the nitrogen uptake from the agricultural land can be increased and the nitrogen load to the river can be reduced to very low values. If the leaching can be reduced to that for unfertilized forest, the leaching to the river will decrease by 19 kg N(tot)/ha yr, which means that the total load of nitrogen from the entire Höje river basin is reduced by 350 ton/yr.

Disregarding the choice of crop, reestablishment of wetlands would cause a decrease of the annual nitrogen load from agricultural land from about 400 t, Fig. 3, to 100 t. Thus in summary by reestablishing all old wetlands, 3% of the basin, and introducing biological methods for nitrogen removal at the wastewater treatment plant in Lund, the amount of nitrogen transported by the Höje river to the sea can be reduced from 800 ton/yr to less then 300 ton/yr.

The strategy for distribution of manure and fertilizers, which crop is grown, and how the yearly maintenance of the land is done, all affect the leakage of nutrients from agricultural land. In LRD (1988) a large amount of low cost, moderate cost and high cost measures for reducing the leakage are presented. The effects of these measures have not been quantified, but since phosphorous is mainly transported by overland flow, SNV (1990), the leakage of phosphorous can be kept low if vegetative strips (Show *et al.* 1991) are maintained along ditches and if the distribution of manure and fertilizers is restricted when the soil is bare. The phosphorous content in tile drained water is much lower than the content in ditch drained water, Seuna (1988). Omernik *et al.* (1987) studied 75 basins. However, they found no significant effect of riparian land on the nutrient transport. Smith (1992) claimed that a basin must be afforested to a higher degree than 20% for the basin runoff quality to be affected. If all agricultural land within the Höje basin was to be afforested, or if the leakage could be reduced in other ways to that from forested areas, the leakage of phosphorous would be reduced by about 1 ton/yr.

Some of the phosphorous released from urban areas to the river can be retained by handling the storm water in new ways. About 1/2 ton phosphorous is released into the Höje river every year by urban storm water and another 1/2 ton from combined sewer overflow, as was shown in Fig. 3. Storm water can be distributed over meadows or wetlands, where the water infiltrates or moves slowly as overland flow before reaching receiving waters. Martin (1988) reported a removal of 17% of phosphorous in solution and 66% of suspended solids for storm water flowing through constructed wetlands. Since about half of the phosphorous is attached to particles, the total nitrogen reduction should be about 50%. By constructing storages, the combined sewer overflow can be eliminated, and thus most of the phosphorous load from the water that used to form the overflow. Still, the total amount of phosphorous would only be reduced by about 700 kg/yr. The water from toilets constitutes 25% of the wastewater and contains about 50% of the phosphorous, SNV (1991). In a long perspective, a system where toilets are disconnected from the traditional wastewater system can be introduced, although it is complicated to do so in existing downtown areas. Disconnection of toilet water would reduce the phosphorous load by 30% (1.8 ton/yr). The reduction of the total pollutant load to the river may include means taken for handling storm and wastewater which can reduce the annual discharge of phosphorous from 7 to 4.5 ton. Of course if the toilets are disconnected from the present sewerage system, most of the nitrogen is removed and there is no need for special nitrogen removal at the treatment plant.

The summer flow in the Höje river can be maintained only because water is transported from other basins for the water supply. The water consumption and thus the amount of water that needs to be imported is reduced by about 7% if the toilets are disconnected from the sewer system. This means that the summer flow should decrease from 0.26 m^3/s to 0.22 m^3/s. Today 3 km^2 of agricultural land is irrigated. The river water used is 0.04 m^3/s and 0.03 m^3/s from groundwater or marl ponds, during the summer. In order to keep the minimum flow at present levels, the amount of water used for irrigation must be completely restricted. The overall effects on the Höje river of different measures for reducing the nutrient transport to the sea are summarized in Table 9. Significant reduction on the order of 50% can be obtained only if actions are taken in urban areas as well as in rural areas.

Table 9 – Summary of pollutant reduction of different measures in the river Höje basin

Measure	N_{tot} (ton/yr)	P_{tot} (ton/yr)
Present conditions	840	10
Disconnecting toilets	−350	−2.5
Infiltration of storm water	–	−0.3
Improved wastewater treatment	−260	–
Elimination of CSO	−2	−0.4
Rural ponds (20 ha)	−36	−1
Rural wetlands (200 ha)	−60	?
Reestablishment of old wetlands (3% of the basin)	−270	−1
Completely changed agricultural strategies or total afforestation	−350	−1

Nitrogen can be reduced by 60% by improved wasterwater treatment, method 4 in Table 9, and by reestablishing large areas of wetlands, method 8 in Table 9, 3% of the basin. In order to remove large amounts of phosphorous, the present water toilet system must be abandoned.

River Influence on Coastal Waters

The river Höje debouches into the Sound between Sweden and Denmark. The total load of nitrogen into the Sound from Sweden is 6,300 ton/yr (SNV 1988; Enell 1989; SCB 1990). The relative contribution from the Höje river is 13%. If all possible means, including total afforestation of the basin, are taken to reduce the transport of nitrogen by the Höje river into the Sound, the relative contribution reduces to 5%. However, the total load would still be 5,800 ton/yr. A reduction of the nitrogen discharge of 50% from all the Swedish rivers debouching into the Sound should give a reduction of 2,300 ton per year, or a reduction of the total nitrogen load to the Sound by about 35%. To obtain this reduction, improved nitrogen removal processes at the wastewater plants must be introduced, and wetlands should be reestablished over 3% of the part of southern Sweden from which the rivers discharge into the Sound.

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