URBAN STORM WATER DISCHARGES: EFFECTS UPON PLANKTON COMMUNITIES

H. F. Gast*, R. E. M. Suykerbuyk and R. M. M. Roijackers

Aquatic Ecology Section, Department of Nature Conservation, Agricultural University, P.O. Box 8080, 6700 DD Wageningen, The Netherlands

*Present address: Water Authority Veluwe, P.O. Box 9030, 7300 EN Apeldoorn, The Netherlands

ABSTRACT

From 1985 to 1987, effects of sewer discharges on communities of phyto- and zooplankton in receiving waters have been studied. Locations all over The Netherlands have been selected. The results were related to the type of sewer system, the discharges and the characteristics of the receiving water. Results were compared with those from samples taken from a corresponding water not influenced by sewer discharges, the reference water. Often either phyto- or zooplankton communities could be used successfully to describe the short- and medium-term effects of the discharges on the quality of the involved habitats. Plankton communities could also indicate permanent effects due to higher saprobic levels in the receiving water compared to the reference water: an obvious result of urban storm water discharges. In small and medium-sized stagnant waters, particularly in the immediate vicinity of the overflows, effects on plankton communities were more pronounced compared to large and running waters. Combined sewer system overflows (CSO) often proved to affect plankton communities more severely than separate sewer system discharges (SSD), except for some locations in industrial areas.

KEYWORDS

Urban storm water discharges; biological effects; phytoplankton; zooplankton; receiving waters; The Netherlands.

INTRODUCTION

Since the introduction of the Law on Pollution of Surface Waters in 1970 (WVO) in The Netherlands, nearly all domestic and industrial waste waters are treated in sewage treatment plants. The remaining waste waters will be sanitized in the near future. Urban storm water discharges (the estimated number of combined sewer systems in The Netherlands is 5500; NWRW, 1984) are the main remaining sources of direct organic pollution of surface waters in or directly near urban areas. The effects of urban storm water discharges on receiving waters depend largely on the type of sewer system, the intervals between overflows, the volume and load of the discharges, and the type of receiving water. Sufficient knowledge of the relationships between rainfall, interception, treatment and storage, overflows and effects upon receiving waters for the Dutch situation, however, was still lacking. Partly for this reason the National Working Group on Sewerage and Water Quality (NWRW) was founded in 1982. One aim of this working group was to clear the above-mentioned relationships.

In the present study, broad effects of discharges on receiving waters were investigated. The research was carried out from 1985 to 1987 on 63 locations spread all over The Netherlands. This choice represented the current combinations of types of sewer system and receiving water. At each location there were two sampling stations: the A-station in the immediate vicinity of the overflow and the B-station at some distance from the overflow but within its sphere of influence. Results from these sampling stations were compared with those from the C-station, a reference water not influenced by urban storm water.
In this research various organoleptic, bacteriological, physico-chemical and hydrobiological variables in water phase and sediments were investigated. The observed effects in the receiving waters were related to the type of sewer system, the discharges and characteristics of the water such as morphometry and flow conditions (NWRW, 1990). Preceding this study, in 1984 and 1985 detailed studies on physico-chemical, bacteriological and hydrobiological effects upon receiving waters were carried out at the locations Loenen and Bodegraven based upon a frequent sampling programme (NWRW, 1987, 1988; Roijackers and Ebbeng, 1986; Willemsen and Cuppen, 1986).

This paper primarily deals with short- and medium-term effects (within one or two weeks) of urban storm water discharges as reflected by communities of phyto- and zooplankton. Permanent effects on these communities will also be discussed. Willemsen et al. (1990) primarily discuss the long-term and permanent effects as reflected by communities of sessile diatoms and macro-invertebrates.

The relatively short reproduction time (several hours to days) of phytoplankton (algae) makes it suitable in reflecting short- and medium-term effects of discharges in (semi-) stagnant and open waterbodies. In other types of water, phytoplankton communities do not develop optimally, due to light limitation and short hydraulic retention times. As phytoplanktonic organisms are autotrophic, they react primarily to nutrient concentrations and fluxes and consequently reflect directly the trophic level of their aquatic surroundings. Similar to phytoplankton, zooplankton shows a relatively short reproduction time. Zooplanktonic organisms are heterotrophic, some of them living on organic particles, algae or bacteria, others living as parasites or predators. Their species composition and abundance is strongly related to the saprobic level of the aquatic environment. Thus zooplankton is also a very suitable group for reflection of short- and medium-term effects, particularly in small or medium-sized, stagnant waterbodies.

MATERIALS AND METHODS

In order to register short- and medium-term effects of sewer discharges, samples of phyto- and zooplankton were collected at three different intervals after a storm water event:
- immediate (within 24 hours) after the event: S-programme (Short-term);
- 3 to 7 days after the event: M-programme (Medium-term);
- 1 to 2 weeks after the event: L-programme (Long-term).

Furthermore, in some cases at least one month after the most recent storm water event, samples were collected in order to determine the background conditions and permanent effects on the planktonic communities (B-programmes). Over 500 phytoplankton samples and over 400 zooplankton samples from respectively 35 and 27 locations were collected.

Phytoplankton was collected in the field according to generally accepted methods (Roijackers, 1985) and concentrated in the laboratory by membrane filtration. Zooplankton was collected using a planktonnet (60 litres, 60 μm mesh width). At the laboratory identification of most of the plankton taxa was carried out as soon as possible on living specimens. If possible, specimens were preserved in 4% formaldehyde and identified later. The abundance of the organisms was estimated using a scale from 1 (rare) to 5 (abundant) (Roijackers, 1985). Phytoplankton biomass was estimated by chlorophyll-a concentrations (Roijackers, 1981).

Species lists were used to calculate the saprobic level, using values by Sládecek (1973) for indicative weights and saprobic valency of the species and the formula for saprobic level as suggested by Sládecek (1977). Furthermore, the (co)occurrence of taxa at the stations A, B and C has been investigated using the ordination technique DECORANA (Hill, 1979). In this way the composition of plankton communities is visualized in two-dimensional plots, revealing relative differences or similarities between samples. Ordination of a specific sample along a principal axis (score) depends on the composition of the planktonic community. The closer samples are ordered, the more similar communities will be. Samples ordinated with a different score along an ordination axis will have different planktonic communities, resulting from, for instance, the degree of organic pollution, the influence of overflows, or seasonal effects. Hence scores along the ordination axis can be related to one or more different variables.

RESULTS

Phytoplankton

Particularly on locations with a combined sewer system, the immediate effects on phytoplankton were a decrease in biomass and species diversity as a result of flushing followed by an increase in biomass and sometimes algal blooms as recorded in the
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M- and L-sampling programmes. Dilution due to flushing was most obvious when the volume of storm water was relatively large compared to the volume of the receiving water. The water often became transparent for some days, which enabled the phytoplankton inoculated from littoral and sediments to increase biomass due to optimal light-use. This was particularly utilized by fast growing taxa, until the resulting bloom caused light-limitation. Communities of these fast growing algae often consisted of species of Euglenophyta, Cryptophyta and Chlamydomonas. Complete recovery was often not established within the sampling period (up to two weeks after the event) and deviations with the background situation were obvious. One should realize that effects of discharges are always superimposed on effects caused by natural events such as seasonal effects.

Figure 1 gives an example of a phytoplankton DECORANA-ordination plot in which clear effects of storm water discharges at a specific location are shown. In this case the results indicate a seasonal effect on the first principal ordination axis (I); the background samples were taken in spring (1 and 2) and the effects of the overflow were observed in September (3 to 5). At A- and B-station effects are pronounced, indicating permanent disturbance of the receiving water due to overflows in the past.

On the second axis (II) disturbance by the overflow on September the 20th is the most important factor. The scores on this axis of the reference water samples are always lower than the scores of the samples from the receiving water, indicating medium-term to permanent effects on phytoplankton. At the A-station also a short-term effect is shown by the deviating position of the sample collected shortly after the storm water event (A3). This effect is due to a sudden large reduction of biomass by flushing. Within 4 days recovery was established. The remaining effect of the overflow is reflected by the large number of fast growing polysaprobic Euglenophyta at the A- and B-stations, which are absent at the C-station. The phytoplankton community at the A- and B-stations can be characterized as β-mesosaprobic, whereas phytoplankton at the C-station indicates oligo- to β-mesosaprobic conditions.

The great weight of seasonal influences upon the composition of phytoplankton communities is even better illustrated by figure 2. The scores of the samples collected on the same dates from the three sampling stations on the location in question are much the same (on both axes). Differences between sample scores correspond with different dates. In this case on the 8th and 22nd of June 1987 no pronounced effects of the overflows could be observed due to improvement of the combined sewer system in question, resulting in less voluminous overflows. In the receiving water as well as in the reference water.
phytoplankton communities indicate ß- to α-meso-saprobic conditions. There is a constant bloom of Chrysococcus and a high density of Euglenophyta.

Fig. 2. DECORANA-ordination plot of phytoplankton samples from a location with an improved combined sewer system (sedimentation basin), discharging on a medium-sized, semi-stagnant water: Mijdrecht-Molenland. Sampling dates and programmes: - 1: (B-programme): May 7, 1987; - 2 and 3: (S- and M/L-programme): June 8 and 16, 1987; after a small overflow on June 8, 1987; - 4, 5 and 6: (S-, M- and L-programme): June 22 and 25 and July 6, 1987, after a very small overflow on June 22.

Table 1 summarizes the effects of urban storm water discharges on phytoplankton communities. This table shows that at both A- and B-stations storm water discharges from all types of sewer system except improved separate sewer systems have a distinct effect on phytoplankton communities. Seasonal effects, however, are present on nearly all locations.

Table 2 summarizes the saprobic levels of receiving waters before and after storm water discharges, and the saprobic levels of reference waters. From these results, short-term effects of discharges on the saprobic level are not very distinct. Only CSO resulted at A- and B-stations with an oligo- to ß-mesosaprobic level in some decrease in that level, whereas receiving waters at stations with a ß-meso- to α-mesosaprobic level resulted in some increase of that level. More obvious are the medium-terms and even the permanent effects: the saprobic level at C-stations is generally lower than at A- and B-stations. Moreover, some C-stations are oligo- to ß-mesosaprobic.
TABLE 2  Saprobic Levels Of Receiving Waters Before And After Urban Storm Water Discharges And Of Reference Waters. Indicated Are The Numbers Of Locations As Percentages Of The Total Numbers

<table>
<thead>
<tr>
<th>Saprobic level Time</th>
<th>o-β</th>
<th>β</th>
<th>β-α</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>before</td>
<td>after</td>
<td>before</td>
</tr>
<tr>
<td>Station</td>
<td>CSS (n=25)</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>SSS (n=10)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>station</td>
<td>CSS (n=25)</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>SSS (n=10)</td>
<td>9</td>
<td>8</td>
</tr>
</tbody>
</table>

o-β: oligo- to β-mesosaprobic; β: β-mesosaprobic; β-α: β-meso- to α-mesosaprobic
CSS: combined sewer system; SSS: separate sewer system; n: number of locations

Zooplankton

Obvious discharge effects on zooplankton communities were observed in small stagnant waters on locations with CSO, close to the overflow (A-stations). Zooplankton reflected short- and medium-term effects in their community structure. In the first place there are rapid changes, either part of the community was lost due to flushing or polysaprobic ciliates, commonly known from sewage sludges, appeared. These ciliates could enter the receiving water via the sewer system and flourish immediately after an overflow. Secondly medium-term changes emerged. Polysaprobic taxa increased, sometimes forming blooms, and there was a loss of other taxa partly by their less competitive strength and partly as a result of their restricted tolerance. Thirdly permanent changes appeared. Compared to the reference waters the saprobic level could be permanently raised. The above-mentioned saprobic communities often have few taxa. Common taxa are polysaprobic ciliates (Paramecium, Metopus and Caenomorpha) and rotators (Rotaria).

Figure 3 illustrates both short-term and permanent effects of storm water discharges at a specific location. Scores on the first axis (I) of samples of the C-station are situated together and differ from scores of samples of A- and B-station in the background situation.

Fig. 3. DECORANA-ordination plot of zooplankton samples from a location with CSO, discharging on a small semi-stagnant water (ditch): Driebergen. Sampling dates and programmes: - 1: (B-programme): June 10, 1986; - 2, 3 and 4 (S-, M- and L-programme): July 23 and 28 and August 5, 1986, after a medium-sized overflow on July 23.
After a CSO event, scores of samples of the C-station remain fixed but scores of samples of the A- and B-station move further along axis I. On axis II there is some sign of recovery at the A- and B-station: scores in the L-programme at A- and B-station resemble those in the background situation.

Figure 4 illustrates all types of effects. The scores on axis I reflect permanent disturbances and those on axis II the short- and medium-term effects.

For each sampling station the saprobic level was calculated. In general, particularly the samples of some of the A-stations reflected obvious short- and medium-term effects of storm water discharges by indicating a-meso- to polysaprobic conditions against oligo- to a-mesosaprobic levels at C-stations. Figure 5 illustrates these effects of overflows on the saprobic level in the receiving water, compared with the reference water, of the earlier mentioned location Montfoort-AF.

Permanent effects on saprobic level were very obvious on most locations. These temporal and spatial effects are summarized in Table 3. The temporal effects were not clear, but the spatial effects were very obvious; both for locations with CSO and SSD the conditions at A-stations were β- to o-mesosaprobic and at C-stations were oligo- to β-mesosaprobic.

**TABLE 3** Effects Of Urban Storm Water Discharges On The Mean Saprobic Level Of Zooplankton Communities In Receiving And Reference Waters

<table>
<thead>
<tr>
<th>Programme</th>
<th>CSS (n=21)</th>
<th>SSS (n=5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling station</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>B</td>
<td>o/β</td>
<td>β</td>
</tr>
<tr>
<td>S</td>
<td>o/β</td>
<td>β</td>
</tr>
<tr>
<td>M</td>
<td>o/β</td>
<td>β</td>
</tr>
<tr>
<td>L</td>
<td>o/β</td>
<td>β</td>
</tr>
</tbody>
</table>

o/β: oligo- to β-mesosaprobic; β: β-mesosaprobic; o/β: o/β-mesosaprobic

CSS: combined sewer system; SSS: separate sewer system; n: number of locations
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Fig. 5. Saprobic levels of receiving and reference water at Montfoort-AF. Sampling programmes are explained in figure 4.

Table 4 summarizes the effects of urban stormwater discharges on zooplankton communities. This table shows that at both A- and B-stations stormwater discharges from all types of sewer system, except separate systems in urban areas, have a distinct effect on zooplankton communities. The effects of discharges from separate systems in industrial areas were most severe. Improved separate systems were not studied.

**TABLE 4 Effects Of Urban Stormwater Discharges On Zooplankton Communities In Receiving Waters**

<table>
<thead>
<tr>
<th>Type of sewer system</th>
<th>n</th>
<th>Effect overflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined sewer systems</td>
<td>21</td>
<td>(+)</td>
</tr>
<tr>
<td>Improved combined sewer systems</td>
<td>3</td>
<td>(+)</td>
</tr>
<tr>
<td>Separate systems urban areas</td>
<td>2</td>
<td>(+)</td>
</tr>
<tr>
<td>Separate systems industrial areas</td>
<td>3</td>
<td>++</td>
</tr>
</tbody>
</table>

- : no (or small) effects; + : evident effects; ++ : pronounced effects
n : number of investigated locations

**DISCUSSION AND CONCLUDING REMARKS**

In the present study phyto- and zoopankton communities were successfully used to determine short- and medium-term effects of disturbances by urban storm water discharges in receiving waters. Long-term and permanent effects as first goal were studied by Willemsen et al. (1990), who used macro-invertebrates and sessile diatoms as bio-indicators. The suitability of plankton communities as biological indicators of this type of disturbance was based on their relatively short regeneration time as shown in a detailed study by Roijackers and Ebbeng (1986). In both the present study at a variety of locations and situations and in the detailed study at the detention pond at Loenen the ability of plankton communities to reflect permanent effects became obvious.
Reactions of the planktonic communities to this type of pollution were an initial biomass and species diversity decrease due to flushing, followed by an increase of biomass and species diversity, in some cases resulting in a bloom. Inoculation of plankton was possible from sediments and littoral and, for some ciliates, even from the sewer system. These planktonic dynamics were also established by Roijackers and Ebbeng (1986). The long-term and permanent effects of the discharges on plankton communities were reflected by a higher saprobic level due to essentially different communities and by a higher biomass. As also observed by Roijackers and Ebbeng (1986), pollutional effects of overflows mainly resulted in a change in saprobic level rather than a change in trophic level. Practically all studied waters, including the references, were eutrophic and remained so after continuous overflow events. This condition of surface waters is nowadays no exception in The Netherlands, as the majority of surface waters has become eutrophic by previous waste water drainage, effluents of sewage treatment plants, agricultural influences (mainly run-off of manure) and hydrological management which makes the inlet of eutrophic water from the river Rhine common practice.

From the present study it can be concluded that the degree and duration of disturbance by storm water discharges on biological communities depend first of all on the type of receiving water. In isolated, small and stagnant waters such as ponds and dead ending branches of canals and ditches, effects were most severe due to the long exposure to pollution. Effects from CSO seemed to be more severe than effects from SSD, except for discharges in industrial areas, (see also Willemse et al., 1990), although the relatively low number of studied locations is reason for some caution. If conclusions can be generalized, improved separate systems are a good alternative in new building from the biological point of view.

Because of their life cycles phytoplankton proved to be the most suitable planktonic component to study in stagnant open waters like ponds and canals, whereas zooplankton proved to be suitable for small stagnant waters like ditches and small ponds. In running waters another microscopic component is suitable to track overflow effects, namely sessile diatoms (Willemse et al., 1990).

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