Nordic Hydrology, 23, 1992, 245-256

High Resolution Measurements of Pollution Wash-Off from an Asphalt Surface

Å. Spångberg and J. Niemczynowicz

Dept. of Water Resources Eng.,
University of Lund, Sweden

The paper describes a measurement project aiming at delivering water quality data with the very fine time resolution necessary to discover deterministic elements of the complex process of pollution wash-off from an urban surface. Measurements of rainfall, runoff, turbidity, pH, conductivity and temperature with 10 sec time resolution were performed on a simple urban catchment, *i.e.* a single impermeable 270 m^2 surface drained by one inlet. The paper presents data collection and some preliminary results.

Introduction

Quantitative runoff models are successfully used in many urban hydrological applications. Examples of applications where runoff modelling is essential, are design of sewerage network, analysis of performance of the network during different hydraulic conditions, real-time operation of complex urban water systems including operation of pumping stations, detention basins and overflow structures.

Parallel to increasing environmental concern, the necessity to accurately model the quality of urban runoff grows. The goals of urban water management nowadays include solving water pollution problems. There is a need for models to support water quality optimization of discharges from the city via treatment plants, stormwater systems and overflow structures.

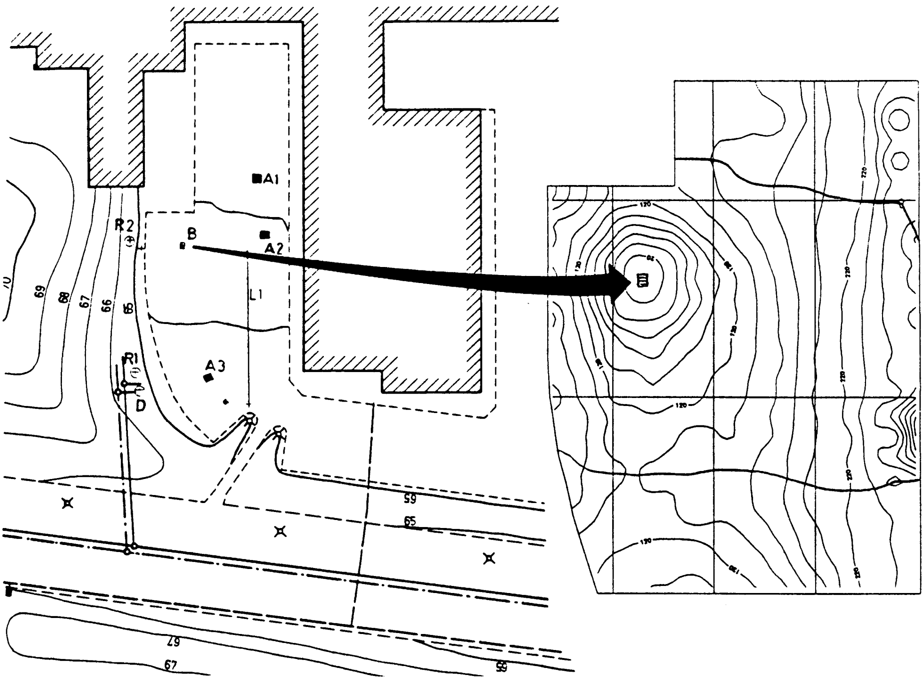
Existing pollution transport models, however, still cannot adequately reproduce the complex processes of pollution accumulation and wash-off occurring in urban catchments. The reason may probably be found in oversimplification used in the mathematical description of these processes. This, in turn may be related to the lack of understanding the physical and hydrochemical processes that govern pollution accumulation and release from urban surfaces. In order to develop functional urban pollution transport models, adequate data with a time scale that is relevant for the processes must be supplied.

The main hypothesis behind the present observation program is that the apparent randomness in the pollution wash-off process, observed by several researchers (Geiger 1987, Harremoes 1986, Driver and Lystrom 1987, Ellis and Harrop 1984, Morrison *et al.* 1985) may be related to the lack of adequate data, especially with respect to the time scale of the measurements. As a logical conclusion from such an assumption, an observation program was geared in order to deliver water quality data with very fine time resolution necessary to discover deterministic elements, *e.g.*, particle removal from surface by impact of rain and surface flow, in the complex process of pollution wash-off from an urban surface. The present study aims at investigating these processes on a simple part of an urban catchment, *i.e.*, a single impermeable surface drained by one inlet. If the processes of pollution formation and wash-off can be satisfactorily measured, explained, and modelled on such an elementary surface, the logical next step would be to perform measurements on a more complex part of an urban catchment consisting of several parts with different surface use. However, if the study shows that pollution wash-off from a simple surface still cannot be explained by a deterministic approach it would mean that there are small chances to use a deterministic model on a more complex surface.

This paper presents measuring equipment, methodology and some results of the high resolution water quality observations conducted on a 270 m^2 asphalt surface in Lund, Sweden. The measured quality parameters were: turbidity, pH, conductivity, and temperature. The choice of turbidity as the main quality-related parameter was motivated by the relatively low cost of the measuring equipment and the simplicity of continuous measurements as well as by the fact that, according to several researchers, a good correlation between the turbidity and other quality parameters can be found (Marchandise *et al.* 1987, Ellis *et al.* 1986).

The Catchment

The experimental catchment in this study is a single parking-lot outside the Department of Water Resources Engineering in Lund. The size of the catchment is 270 m^2, the average slope measured as an average value on twelve directions from the inlet to the water divide is 2.33% (see Fig. 1). On two sides, the catchment is separated from the bordering green area by curb-stones. The two other sides are limited by a water divide on the asphalt surface. The water divide line was carefully established by levelling. The surface is exposed to local traffic, cars, bicycles, and pedestrians.



A1, A2, A3, L1 – Surface-dust sampling sites
R1, R2 – raingauges
B – inlet with measuring equipment
D – Air-dust collector

Fig. 1. A map of the catchment used in the investigation.

Since the project is conducted in cooperation with the University of Belgrade, another similar catchment was found and identical measuring equipment installed in Belgrade. Results of measurements in Belgrade are, however, not included in this paper.

Equipment and Monitoring Program

Hydrological Variables

– The rainfall intensity was measured continuously throughout the whole observation period by use of two tipping-bucket gauges with a volume resolution of 0.2 mm/tipping and 0.035 mm/tipping, respectively.

– The stormwater discharge to the inlet was measured by use of a collection box of 22 × 22 × 80 cm^3 with a carefully calibrated 30° v-notch (see Fig. 2). The design of the collection box has been described by Falk and Niemczynowicz (1979). The water level in the box was measured using a linear level-sensor type GYTL/TLC-07.

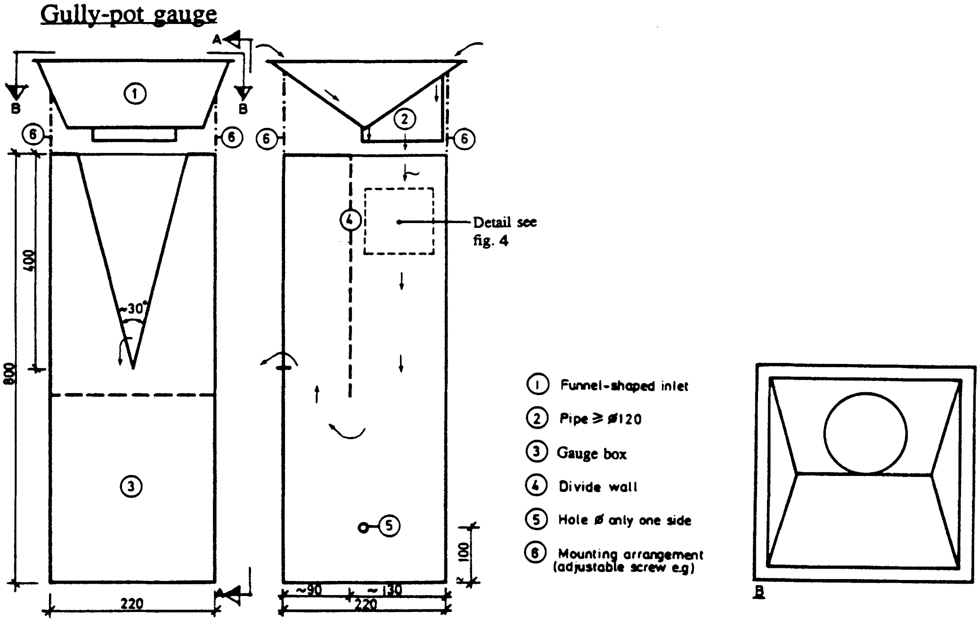


Fig. 2. Measuring box with v-notch placed in the inlet.

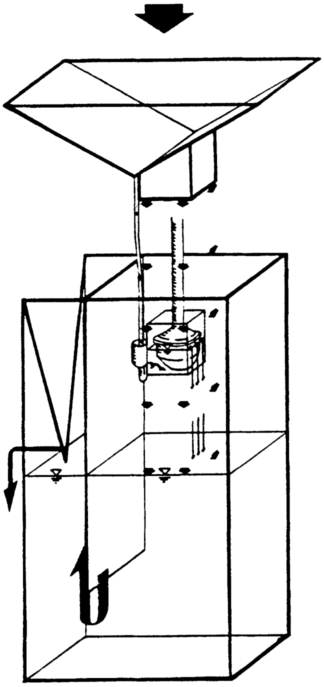
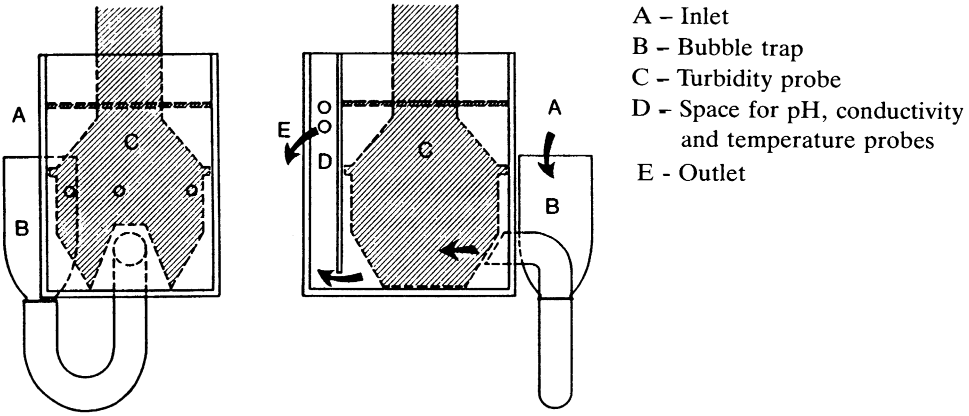


Fig. 3. Geometry of quality parameters measurement.



A – Inlet
B – Bubble trap
C – Turbidity probe
D – Space for pH, conductivity and temperature probes
E - Outlet

Fig. 4. Details of the box for measurement of inlet water quality (front and side view).

Water Quality Variables

– The turbidity was measured direct in the water coming to the inlet using an optic-electrical sensor type IT 500 connected to the turbidimeter type CSP-A. The design of the pipe leading runoff to the sensor placed in a small box of 10 × 12 × 15 cm^3 (see Figs. 3 and 4) ensures that the time delay between the beginning of runoff and measurement is of the order of 3-5 sec. The volume of water in which the incoming water mixes before the actual turbidity observations is less than 20 ml.

– The pH was measured in the above box permanently containing 500 ml of water. Incoming water passes the turbidity sensor and directly enters the box where pH is measured. An analog pH meter type WTW pH-219 with sensor WTW Sensolyt SE was used.

– The conductivity was measured in the same box as pH using an analog conductivimeter type WTW LF219 with sensor WTW KI/pH/T.

– The temperature of incoming water was measured by a traditional thermometer type K connected direct to the datalogger.

All water quality variables were registered with a 10 sec integration time. The design of the equipment for all quality parameters is shown in Figs. 2-4.

Atmospheric Fall-Out and Dust Deposition

– Dry and wet atmospheric fall-out was measured in a plastic container type SF1 placed 2 metres above the observation surface (see Fig. 1). The container was carefully washed with distilled water once a week and the content filtered through a glass-fibre filter (type Whatman GF/C, surface weight 53 g/m^2, thickness 0.25 mm, retention 1.2 μm, filter velocity 10.5 ml/s). The filter dried for two hours at 110° C and was weighed.

– Dry deposition on the surface was measured by vacuum-cleaning (Nilfisk, 1000W) three marked asphalt surfaces of 1×1 m^2 and one 20×0.3 m^2 surface (see Fig. 1). Vacuum-cleaning was performed twice a week by moving the nozzle with constant velocity of 0.1 m/sec to cover all surfaces twice. The dust was collected in conventional dust bags weighed before and after the vacuum-cleaning.

Data Collection

All the electronic measuring devices were connected to a datalogger type DT500. Registration started when the first impulse was observed on any tipping-bucket (in most cases the 0.035 mm bucket) and continued for 30 minutes after the last rainfall pulse. The time resolution of all the measurements was 10 sec. During dry periods data were recorded every hour. Data registered on the datalogger were transferred to a personal computer and stored on floppy discs.

Measurements

Continuous measurement of runoff and water quality parameters with small time resolution and good accuracy in a tough environment of an inlet, is not a trivial task. During 1990, several different design configurations of a measuring equipment were tested in order to assure good accuracy and to get observations of water incoming to the inlet without dilution. Air-bubbles sucked with the water, large particles oscillating in the measurement sample, leaves blocking the inlet *etc.*, were distorting turbidity measurements. These problems were finally solved by special design and setup of the measuring box.

In spring 1991 the equipment was finally installed and continuous measurements (with some short failures) started and continued from May throughout summer until the first frost in December 1991. For further details about equipment and measurements, see Spångberg and Niemczynowicz (1992).

Some Preliminary Results

As a first step in the statistical analysis, a cross-correlation between all measured parameters was calculated for all events with and without a time lag. Table 1 and Fig. 5 give an example of typical correlation values. It may be noticed that turbidity is strongly correlated to rainfall intensity and runoff. Correlation is further improved after introduction of a time lag to the turbidity values. The average time lag for obtaining a maximum correlation coefficient is about +35 sec for turbidity *versus* rainfall intensity, and about −60 sec for turbidity *versus* run-off. This means that the peak of turbidity comes very shortly after a peak of rainfall intensity and earlier than the peak of discharge. Such relation was observed for all significant

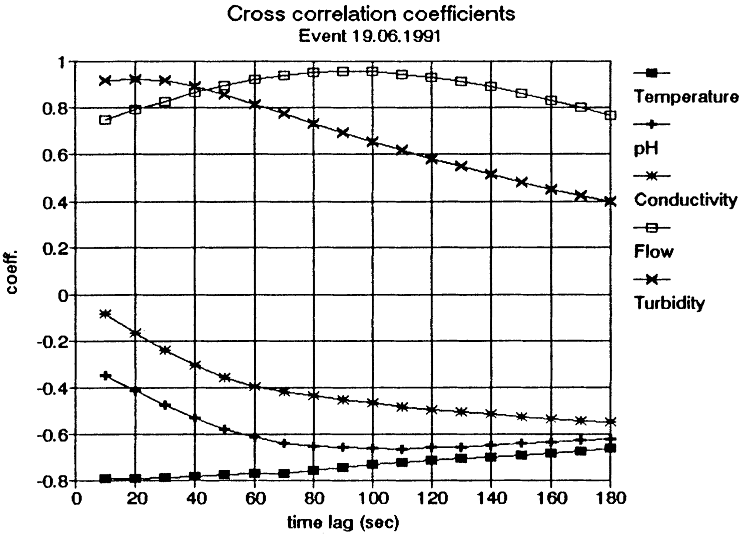


Fig. 5. Cross correlation coefficients for event 19.06. 1991. Rain-intensity versus temperature, pH, conductivity, flow and turbidity, respectively.

events. It is evident that a first flush effect exists at least in a very small catchment. The correlation between the rainfall intensity and the turbidity is generally higher for short, intensive rainfalls than for long and less intensive ones. A general tendency, observed in many events, of the turbidity in multi-peak rain events is a decrease of the turbidity in successive peaks (see Fig. 6).

Table 1 – An example of correlation matrix for measured variables.

Date of event:	19.06.1991
Number of rows:	306
Runoff volume:	1.3756 m^3
Rain volume:	5.53 mm
Contributing area:	248.8 m^2
Rain duration:	0.32 h

Correlation Coefficients
Time-lag: 0 sec

Variable	Rain	Temp.	Ph	Cond.	Flow
Temperature	−0.792				
Ph	−0.282	0.599			
Conductivity	0.002	0.349	0.904		
Flow	0.710	−0.787	−0.684	−0.493	
Turbidity	0.896	−0.794	−0.487	−0.223	0.709

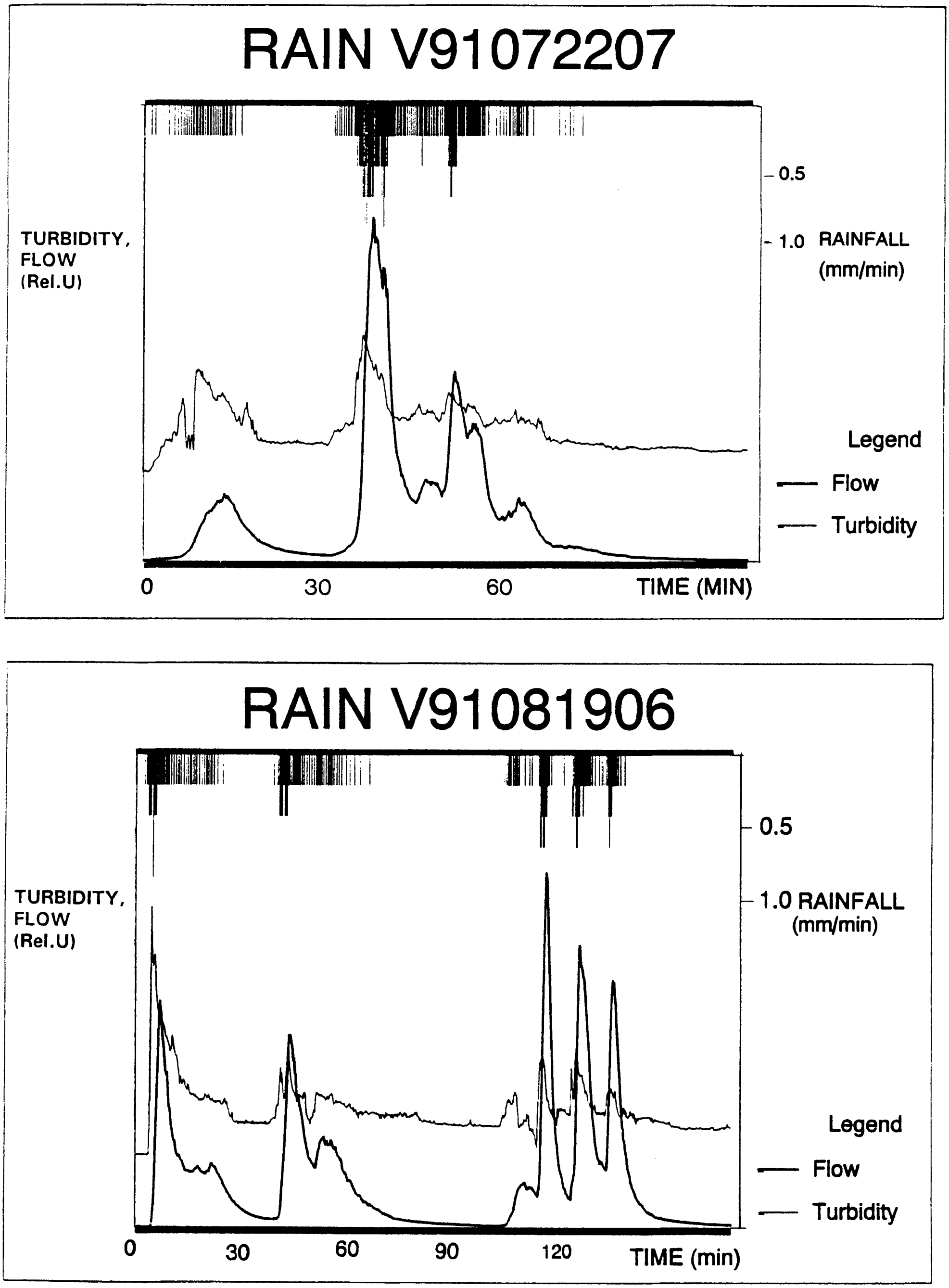


Fig. 6. Time variation of rainfall intensity, runoff and turbidity. a) event No. V91072207, b) event No. V91081906.

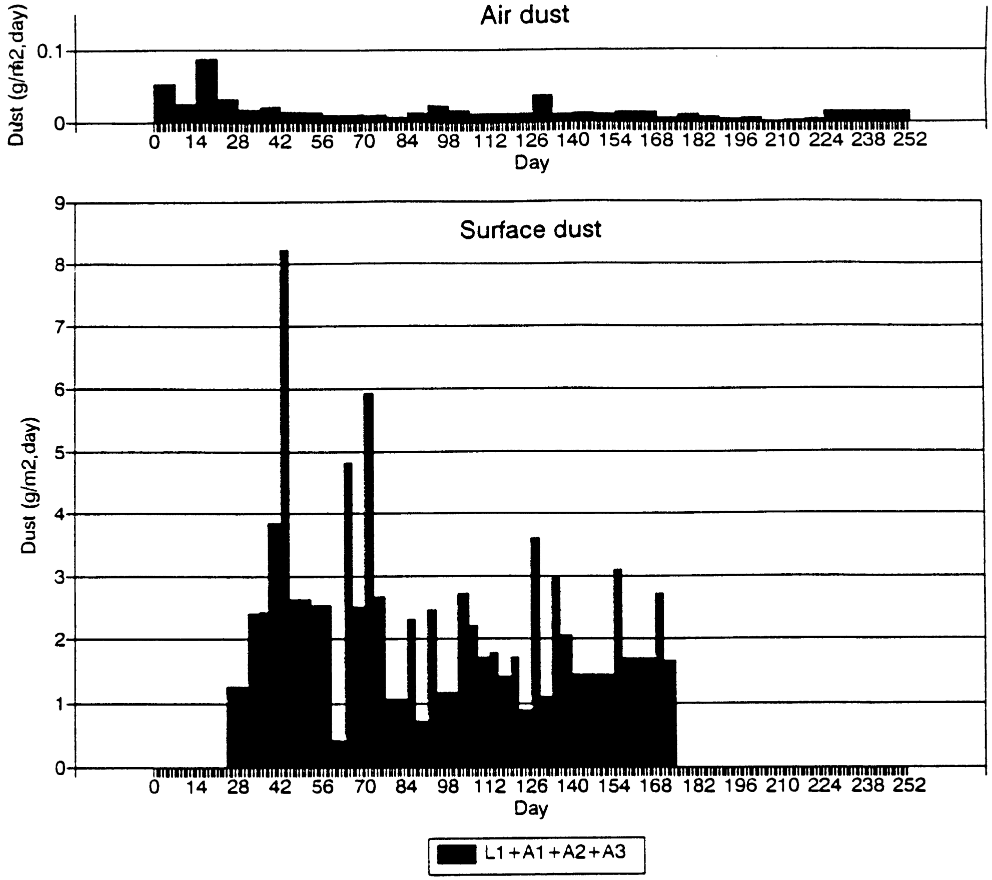


Fig. 7. Time variation of dust collected on the surface and air fall-out.

Table 2 – Correlation coefficients between weight of dust collected from the three sample surfaces on the ground and from the fall-out sampler on 2 m above ground level.

	Surface 1	Surface 2	Surface 3
Surface 2	0.949		
Surface 3	0.839	0.976	
2 m a. groundlev.	0.378	0.346	0.234

A good correlation between weight of dust collected by vacuum-cleaning from the three sample sites on the surface was observed. However, dry fall-out collected in 2 m height is only weakly correlated to the dust from the surface (see Table 2). This suggests that local wind conditions may influence pollution accumulation on the surface more than the air fall-out. Fig. 7 shows the time variation of dust

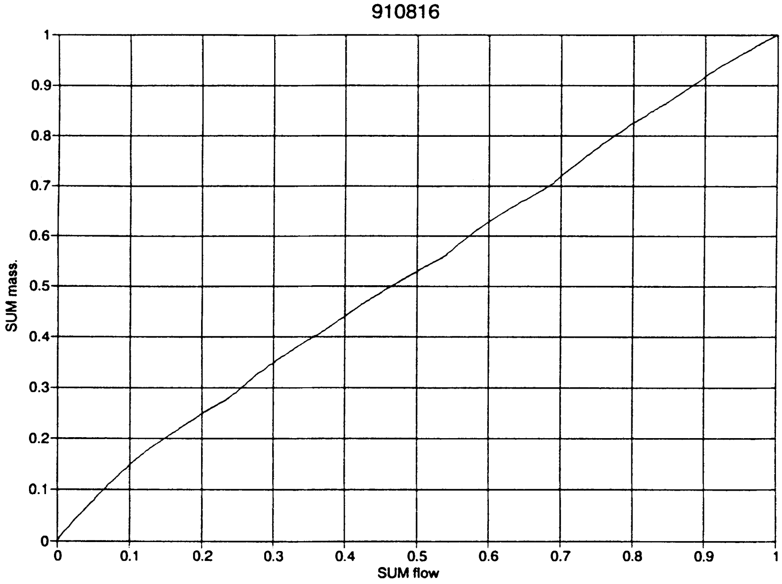


Fig. 8. Example of relation between cumulative values of "suspended solids" wash-off and cumulative runoff.

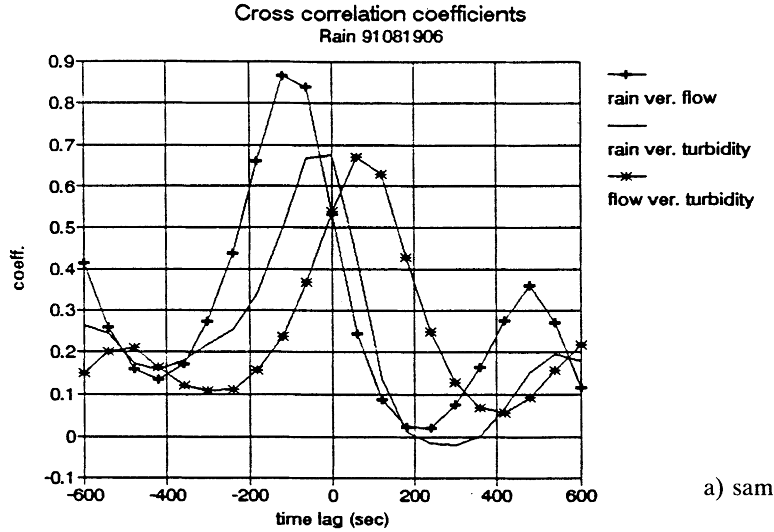
sampled from the asphalt surface with the vacuum-cleaner in relation to dust collected in the dust collector 2 m above ground (notice the y-axis scale).

The process of pollution wash-off from the surface, expressed as mass-transport in time, assuming a linear relationship between the turbidity and concentration of suspended solids, can be roughly divided in two phases: the first, initial phase which begins directly with the beginning of runoff and lasts between 2 and 10 minutes, and the second phase lasting for the rest of the event.

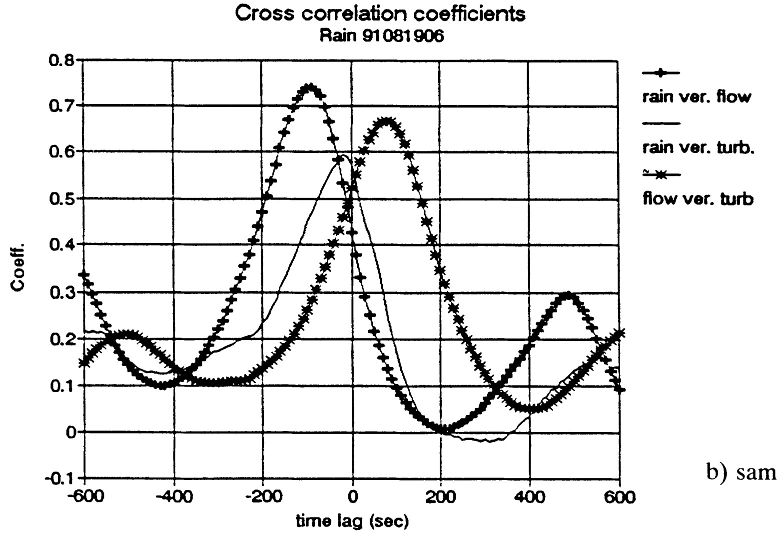
The mass-transport per unit of rainfall is higher during the first phase compared with the second phase. During both phases, the relation between accumulated wash-off and accumulated runoff may be approximated to straight lines (see Fig. 8). However, these relations differ significantly between rainfall events.

Conclusions

The first flush phenomenon has been clearly documented on a small asphalt surface by observed data. A significant part of the pollution wash-off occurs during the initial stage of the runoff process, just before the runoff peak. The wash-off of measured pollution variables is strongly correlated to the rainfall intensity. This means that pollution wash-off from an asphalt surface during a single rainfall event may be described and modeled using simple deterministic relationships comprising rainfall intensity as a main parameter. In the next stage of investigation we will try



a) sampling time 1 min



b) sampling time 10 sec

Fig. 9. Cross correlation coefficients for rain event 91091906.

to relate parameters of such single event models to inter-event characteristics as length of dry period, magnitude of previous event, dust accumulation, and climatic variables.

The selection of the time resolution 10 sec for the measurements is relevant regarding the relationship between rain-intensity and turbidity, but concerning the relationship of rain and flow respectively, flow and turbidity a resolution time of *e.g.* one minute would be satisfactory (see Fig. 9).

References

Driver, N.E., and Lystrom, D.J. (1987) Estimation of Urban Storm-Runoff Loads and Volumes in the United States, Proc. of 4th Int. Conf. on Urban Storm Drainage, Lausanne, Switzerland.

Ellis, J.B., Harrop, D.O., and Revitt, D.M. (1986) Hydrological control of pollutant removal from highway surface, *Water Research, Vol. 20,* (5), pp. 589-595.

Ellis, J.B., and Harrop, D.O. (1984) Variations of solid loadings to roadside gully pots, *J. of the Science of Total Environment, Vol. 33,* pp. 203-211.

Falk, J., and Niemczynowicz, J. (1979) Modelling of runoff from impermeable surfaces, Dept. of Water Resources Engineering, University of Lund, Report No. 3024, Lund, Sweden.

Geiger, W.F. (1987) Flushing effects in combined sewer systems, Proc. of 4th Int. Conf. on Urban Storm Drainage, Lausanne, Switzerland.

Harremoes, P. (1986) Interaction between quantity and quality models for urban storm drainage, Proc. Fifth Int. Symp. on Comparison of Urban Drainage Models with Real Catchment Data, UDM '86 Dubrovnik, Yugoslavia.

Marchandise, P., Ruben, G., and Legendre, J.P. (1987) Continuous acquisition of pollution data in sewers with optical sensors, Proc. 4th Internat. Conf. on Urban Storm Drainage, Lausanne, Switzerland.

Morrison, G.M., Sjölander, B., and Svensson, B. (1985) The continuous on-line monitoring of environmental pollution in stormwater, *Vatten, Vol. 41,* Lund.

Spångberg, A., and Niemczynowicz, J. (1992) Kontinuerlig mätning av några kvalitetsparametrar från en asfaltyta (in Swedish), Dept. of Water Resources Engineering, University of Lund, Report No. 3154, Lund, Sweden.

First received: 3 March, 1992
Revised version received: 27 July, 1992
Accepted: 30 July, 1992

Address:
Department of Water Resources Engineering,
University of Lund,
Box 118,
S-221 00 Lund,
Sweden.