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URBAN STORM RUNOFF QUALITY AND ITS DEPENDENCE ON SOME RAINFALL AND CATCHMENT CHARACTERISTICS

Matti Melanen & Risto Laukkanen

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An extensive storm water project is being performed in Finland. One of the objectives is to study the variations of urban storm runoff quality and its dependence on climatic and weather conditions, and catchment-related factors. In the paper conclusions are presented on the basis of experiments made in seven test basins over a two-year period. In each test site runoff sampling was performed automatically during summer-autumn periods (May-November) yielding flow-proportional composite samples. The variance of quality parameters was found to be wide both between and within the areas. The average runoff quality varied as follows: SS 86–490 mg/l, BOD_7 11–24 mg/l O_2, COD_{Cr} 110–240 mg/l O_2, tot P 0.24–0.56 mg/l P, tot N 1.3–2.1 mg/l N, Pb 110–500 µg/l Pb, and pH 6.4–7.4. As an average only 18 to 37 % of the variance of runoff quality parameters could be explained by linear models of the rainfall characteristics studied, the dominant independent variable being maximum intensity of the rainfall event. Finally, it was concluded that the storm runoff quality in the test sites cannot be generalized. This conclusion is supported by the atmospheric deposition measurements and emission inventories accomplished in the sites.

Index words: Urban runoff, water quality, water quality modelling, urban hydrology.

1. INTRODUCTION

An extensive research programme, called the Finnish Urban Storm Water Project, for obtaining data on urban storm runoff as part of the hydrological cycle was commenced in Finland in the year 1977. One of the main objectives of the investigation is to study the variations of urban runoff quality due to different climatic and weather conditions, and varying land use and other catchment-related factors.

In this preliminary study, conclusions drawn on the experiments made in summer-autumn periods (May-November) of the years 1977–1978 are presented. The report is based on the analysis performed for a conference paper by the authors (Melanen and Laukkanen 1980).

2. TEST AREA CHARACTERISTICS

The field observations of the project have been carried out in seven urban test catchments in the municipalities of Helsinki, Tampere, Oulu and Kajaani (Fig. 1). One of the criteria in choice of the test municipalities has been variation of the hydrometeorological factors.

The test areas differ from each other as to size, land use, urban activities and other physiographic characteristics (Table 1). All the catchments have separate storm drainage systems of concrete pipes roughly 10–15 years old.

2.1 Kontula

The test catchment of Kontula in Helsinki represents a multi-family residential area with houses of three to eight storeys (Fig. 2). The activities in the catchment are mainly related to dwelling. There is no industry in the test area or in its near surroundings.

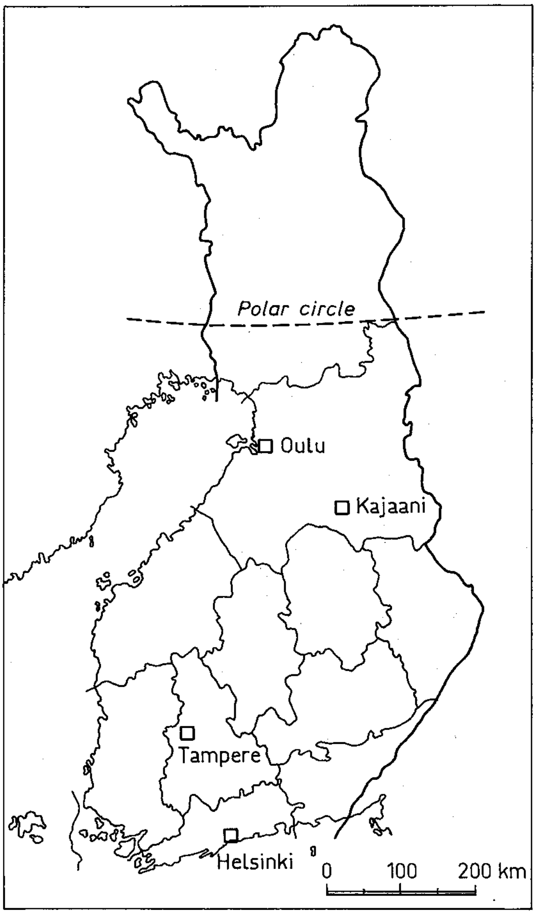

Fig. 1. Location of the four test municipalities in the Finnish Urban Storm Water Project.

2.2 Pakila

The Pakila catchment situating in Helsinki is an example of elder single-family residential areas (Fig. 3). There is no industry in this test site either. A motor-way (Tuusulantie) is passing by in close vicinity of the test site.

2.3 Herttoniemi

The Herttoniemi test catchment in Helsinki consists of a stretch of a motor-way (Itäväylä) and of a minor residential and industrial area in close surroundings of the route (Fig. 4). Traffic density on the motor-way is roughly 45 000 motor vehicles a day.

2.4 Nekala

The test site of Nekala in Tampere represents an area with mixed industry (Fig. 5). Among other things there are stocks and factories of food, metal and paper products in the catchment.

2.5 Hämeenpuisto

The Hämeenpuisto catchment in Tampere consists of multi-family residential and commercial blocks (Fig. 6). There is a substantial traffic volume in the test site because the main traffic routes of the city centre go through the site. There is no industry in the catchment itself; however, in near surroundings there exist establishments of textile, metal, food and paper-product industries.

2.6 Kaukovainio

The test catchment of Kaukovainio in Oulu represents a multi-family dwelling area with low

Table 1. Test catchment characteristics over the 1977—1978 period.

Catchment	Type	Drainage area ha	Percentage paved surfaces %	Population density p/ha
Kontula[a]	Multi-family residential	22.9	40	160
Pakila[a]	Single-family residential	20.2	29	30
Herttoniemi[a]	Traffic (motor way)[e]	14.2	33	e
Nekala[b]	Industrial	14.1	40	-
Hämeenpuisto[b]	Multi-family residential, commercial	13.2	67	125
Kaukovainio[c]	Multi-family residential	40.5	30	85
Kajaani centre[d]	Multi-family residential, commercial	18.5	64	65

a: Helsinki; b: Tampere; c: Oulu; d: Kajaani; e: 45 000 motor vehicles a day

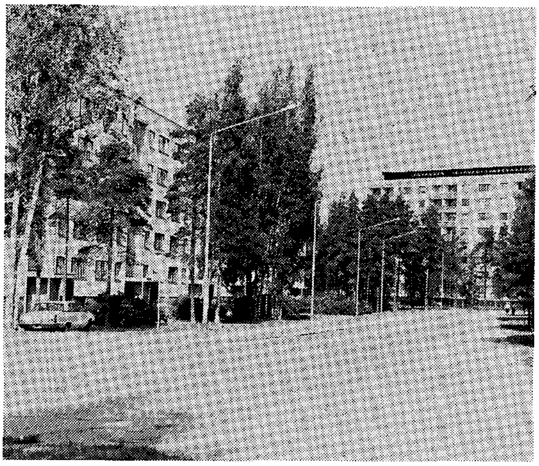

Fig. 2. View from the test catchment Kontula.

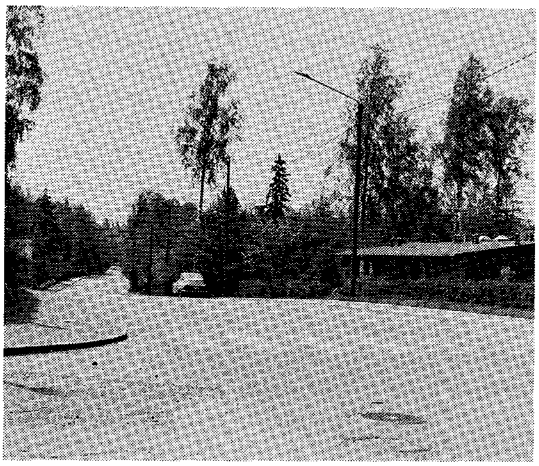

Fig. 3. View from the test catchment Pakila.

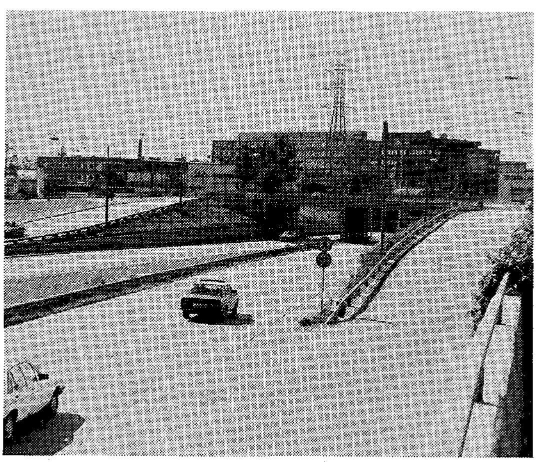

Fig. 4. View from the test catchment Herttoniemi.

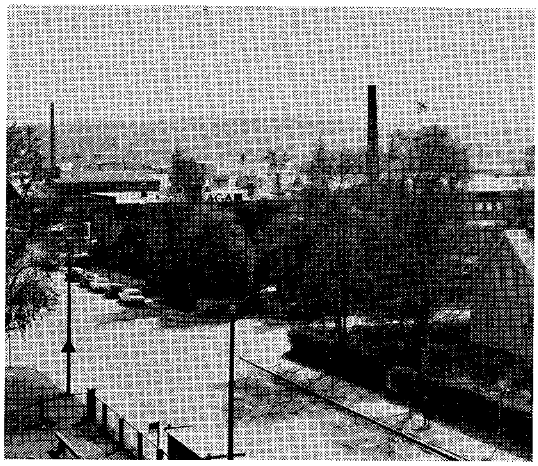

Fig. 5. View from the test catchment Nekala.

Fig. 6. View from the test catchment Hämeenpuisto.

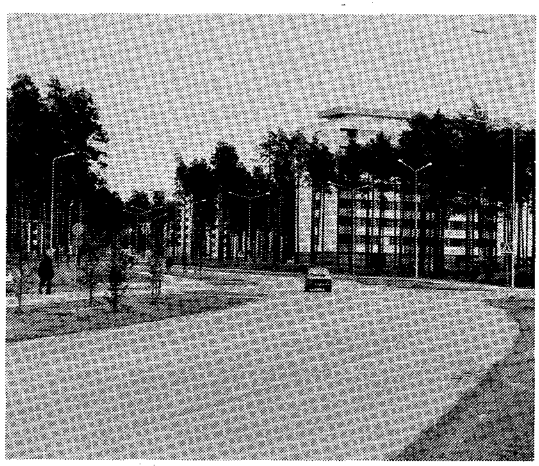

Fig. 7. View from the test catchment Kaukovainio.

residential density (Fig. 7). In this test site there are no industrial activities.

2.7 Kajaani centre

The test area consists mainly of multi-family residential and commercial blocks in the centre of Kajaani (Fig. 8). The main traffic routes going via Kajaani pass through the catchment. There is no actual industry within the test area itself.

3. OBSERVATION TECHNIQUES

3.1 Rainfall

In each test area rain amount and intensity have been registered by a float recording gage, pluviograph Hellman (Fig. 9). (In some catchments a Soviet pluviograph P–2 has been used, too).

3.2 Runoff

In six of the catchments storm runoff from the test basin has been measured by a modification of the Palmer-Bowlus venturi flume for pipes which was developed in the Hydraulics Laboratory of the Helsinki University of Technology (Hepojoki and Koskelo 1978, also described by Airaksinen and Tähtelä 1978). In the catchment of Herttoniemi a 90° V-notch weir was used for runoff measuring. The flumes and the weir were calibrated for determination of rating curves in the laboratory, in conditions similar to the actual operation conditions. The flumes have been calibrated in situ, too.

In all, the measuring system (Fig. 10) consisted of a pipe venturi flume installed through a manhole, of an electronic liquid level transmitter (Finnish made pressure transducer LTR 200) placed in a stilling well beside the manhole, and of a control unit (Finnish made FLO 110) located in an instrument shed above the ground. The flow rate was registered continuously on a chart by the control unit.

3.3 Runoff sampling

The storm runoff was sampled in the runoff measuring manhole (Fig. 10) by an automatic sample collector (Finnish made SAM 120, Fig. 11) located in the instrument shed.

By the control unit the sampler could be steered to take either time-discrete or flow-proportional samples. Sampling was based on underpressure created by a pump. The samples were stored in a cooled container before transportation to the laboratory.

Runoff sampling was initiated automatically during rainfall events as soon as a pre-determined flow rate (water stage) was reached. The sampling point was in the middle of the manhole, some centimeters above pipe bottom to ensure sampling even during low flows.

4. STATISTICAL AND COMPUTATIONAL PROCEDURES

4.1 Statistical methods

To estimate the distributions of variables, two test statistics are available. In this study, the Kolmogorov-Smirnov test (Afifi and Azen 1972, p. 50–52) has been applied because it does not require a large number of observations like the chi-square goodness-of-fit test.

If the hypothesis on normal distribution was not rejected the sample variances have been tested first. In the case of two samples, the variance ratio test has been used (Afifi and Azen 1972, p. 64–65). Bartlett's test (Malik and Mullen 1973, p. 280–281) has been applied in the case of several samples.

The assumption of equality of the population means can be tested by the one-way analysis of variance, if the hypothesis of equal variances is accepted. However, because this was not the case in this study, the one-way analysis of variance was omitted. Instead, the means of two samples have been tested by the Student's statistic (Malik and Mullen 1973, p. 179–183) when the population variances were equal, and by the Welch's approximation (Malik and Mullen 1973, p. 179–183) in the case of unequal variances.

The stepwise regression (Afifi and Azen 1972, p. 120–135) has been applied to model the dependent variables. In the method the solution is to regress the dependent variable on all possible subsets of the independent variables and then to select the best subset according to a certain procedure.

4.2 Computation techniques

The test statistics dealing with two samples have been programmed for the desk calculator HP 97. For large samples the test statistics have

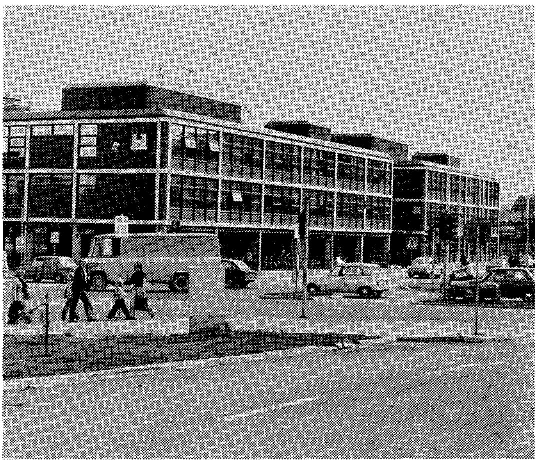

Fig. 8. View from the test catchment Kajaani centre.

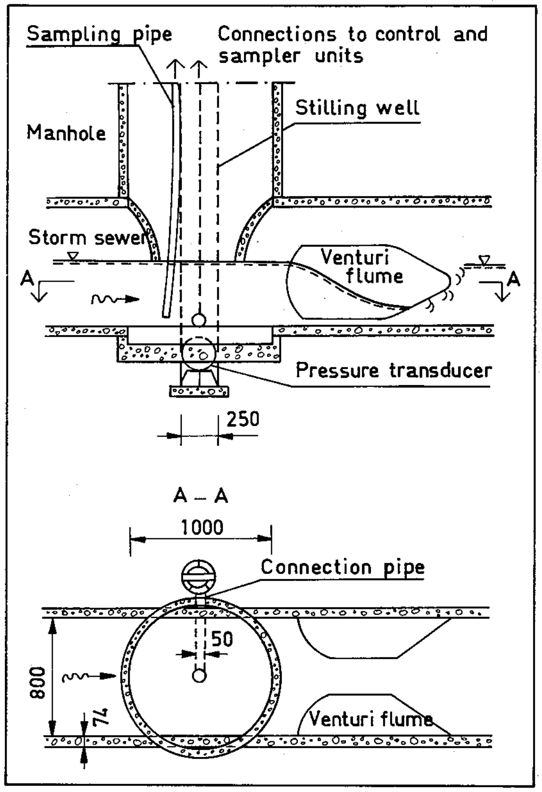

Fig. 10. Principle of storm water flow measurement.

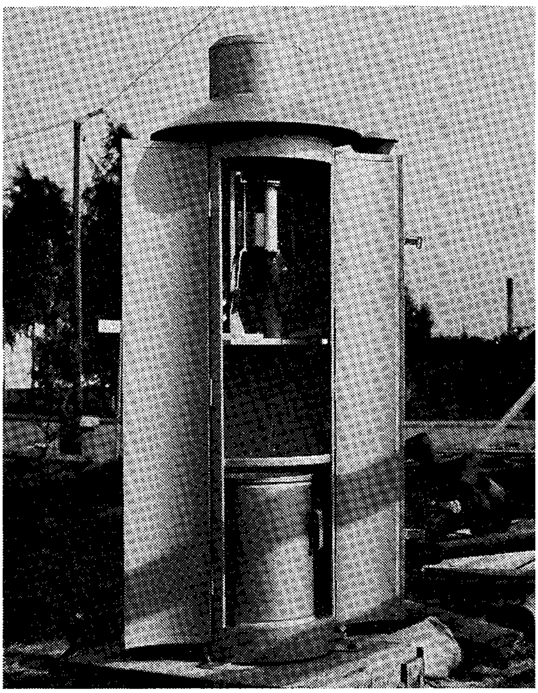

Fig. 9. Pluviograph Hellman.

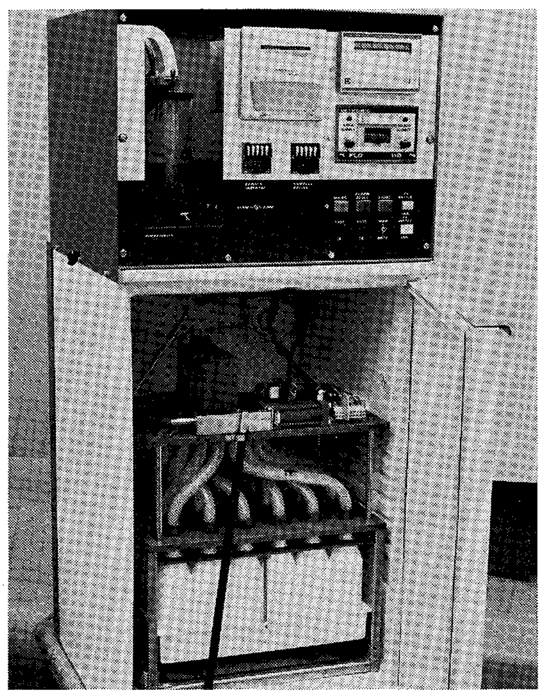

Fig. 11. Automatic storm water sampler SAM 120.

been programmed for UNIVAC 1108 computer. Hereby the IMSL-subroutines (International Mathematical & Statistical Libraries, Inc.) have been utilized.

5. RESULTS AND DISCUSSION

5.1 Parameters studied

The urban storm runoff quality parameters dealt with in this study are suspended solids (SS), biochemical oxygen demand (BOD_7), chemical oxygen demand (COD_{Cr}), total phosphorus (tot P), total nitrogen (tot N), lead (Pb) and pH. All the observations are from flow-proportional composite samples (one sample per rainfall-runoff event).

The rainfall characteristics by which the storm runoff quality parameters are tried to model, are the volume of the rainfall event causing the sampled runoff (rain volume), maximum 5-minute intensity of the rainfall event (max rain intensity), duration of the rainfall event (rain duration), volume of the preceding rainfall event generating an observed runoff (preceding rain volume), and time to the preceding rainfall event (preceding dry period). The storm runoff volume (runoff volume) and maximum flow rate (max flow rate) during sampling are also included in the analysis.

5.2 Numbers of observations and parameter distributions

The total numbers of rainfall-runoff events studied are given in Table 2.

In Table 3 the results of distribution testing by the Kolmogorov-Smirnov test and the numbers of parameter observations are presented. Practically all parameters allow parametric testing, i.e. can be regarded normally distributed, the most prominent exceptions being the preceding dry period in the catchments of Kontula, Pakila and Nekala, and some other parameters in the Pakila test site.

The parameters for which the hypothesis on normal distribution had to be rejected were excluded from further analyses.

As can be foreseen in Tables 2 and 3, the varying numbers of events in different catchments and missing parameter observations will make any statistical analysis cumbersome.

Table 2. Numbers of rainfall-runoff events analysed.

Catchment	Number of events
Kontula	44
Pakila	48
Herttoniemi	31
Nekala	41
Hämeenpuisto	39
Kaukovainio	24
Kajaani centre	17

Table 3. Numbers of parameter observations and conclusions on the hypothesis on normal distribution of the parameters. Kolmogorov-Smirnov test at the significance level of 99 %.

Parameter	Number of observations and conclusion in catchment[a]						
	Kontula	Pakila	Herttoniemi	Nekala	Hämeenpuisto	Kaukovainio	Kajaani centre
SS	41	45	28	36	38	18	16
BOD_7	17	29	13	31	22	16	12
COD_{Cr}	43	46	28	41	39	9	8
tot P	43	48	29	39	37	23	16
tot N	24	31	16	39	37	23	16
Pb	44	48	30	41	39	23	15
pH	23	31	18	41	39	21	16
rain volume	32	45	29	38	31	22	13
max rain intensity	32	45	29	38	31	22	13
rain duration	44	48	31	41	38	24	17
preceding rain volume	38	44	30	38	25	24	13
preceding dry period	44	47	30	40	37	24	17
runoff volume	44	47	30	41	33	23	17
max flow rate	44	48	30	38	35	24	17

a: number non-circled: hypothesis on normal distribution cannot be rejected (allows parametric testing)
number circled: hypothesis on normal distribution has to be rejected (non-parametric testing)

5.3 Parameter means and deviations

The arithmetic parameter means for the events studied are given in Table 4. The deviations expressed as lower and upper parameter limits $\bar{x} \pm s$ are presented in Table 5.

As to the hydrological inputs, the volumes and maximum intensities of the rainfall events are of the same order of magnitude. A common feature for all catchments is relatively long duration of the studied rainfall events. Some variation occurs in the length of preceding dry periods.

According to Table 4 the average storm runoff quality is as follows:

SS	260 mg/l	tot N	1.8 mg/l N
BOD_7	18 mg/l O_2	Pb	240 μg/l Pb
COD_{Cr}	150 mg/l O_2	pH	6.9.
tot P	0.4 mg/l P		

Table 4. Arithmetic means of the parameters.

Parameter	Unit	Mean of parameter in catchment						
		Kontula	Pakila	Hertto-niemi	Nekala	Hämeen-puisto	Kauko-vainio	Kajaani centre
SS	mg/l	165	169	358	493	300	86	258
BOD_7	mg/l O_2	12	11	20	24	24	17	15
COD_{Cr}	mg/l O_2	110	108	241	127	167	128	139
tot P	mg/l P	0.31	0.24	0.40	0.56	0.45	0.44	0.29
tot N	mg/l N	1.32	1.68	1.79	1.87	2.07	2.00	1.64
Pb	μg/l Pb	145	106	331	210	504	139	254
pH		6.9	6.9	7.4	7.3	6.9	6.6	6.4
rain volume	mm	6.4	6.7	5.5	5.4	6.6	5.5	4.6
max rain intensity	mm/h	14.1	8.9	13.6	10.7	9.3	8.0	6.3
rain duration	min	165	280	160	185	155	285	225
preceding rain volume	mm	4.4	4.6	4.0	5.0	4.1	3.8	1.6
preceding dry period	h	38	64	39	37	42	63	33
runoff volume	mm	2.2	0.8	0.9	1.4	2.5	0.6	1.3
max flow rate	mm/h	3.0	0.8	1.3	2.1	3.2	0.5	1.7

Table 5. Deviations of the parameters expressed as intervals from $\bar{x} - s$ to $\bar{x} + s$, where $\bar{x}$ is arithmetic mean and s standard deviation.

Parameter	Unit	Deviation of parameter in catchment						
		Kontula	Pakila	Hertto-niemi	Nekala	Hämeen-puisto	Kauko-vainio	Kajaani centre
SS	mg/l	28[a]–302[b]	0[c]–376	81–635	9–977	101–499	32–140	50–466
BOD_7	mg/l O_2	1–23	2–20	12–28	6–42	8–40	3–31	2–28
COD_{Cr}	mg/l O_2	28–192	21–195	91–391	44–210	82–252	45–211	80–198
tot P	mg/l P	0.00–0.62	0.00–0.48	0.15–0.65	0.10–1.02	0.17–0.73	0–0.99	0.13–0.45
tot N	mg/l N	0.67–1.97	0.74–2.62	1.01–2.57	0.74–3.00	0.85–3.29	0.51–3.49	0.33–2.95
Pb	μg/l Pb	35–255	0–213	94–568	41–379	241–767	0–304	110–398
pH		6.8–7.0	6.7–7.1	7.0–7.8	7.0–7.6	6.6–7.2	6.2–7.0	5.9–6.9
rain volume	mm	2.5–10.3	2.4–11.0	0.7–10.3	2.1–8.7	0–18.9	2.2–8.8	1.1–8.1
max rain intensity	mm/h	1.7–26.5	0–18.2	2.5–24.7	2.8–18.6	0.9–17.7	0–16.6	0.6–12.0
rain duration	min	55–275	45–515	25–295	70–300	50–260	95–475	60–390
preceding rain volume	mm	0.0–8.8	0.6–8.6	0.0–8.0	0–11.5	0.5–7.7	0–9.5	0–3.6
preceding dry period	h	0–87	0–189	0–96	0–107	0–101	0–127	0–111
runoff volume	mm	0.6–3.8	0–1.7	0.1–1.7	0.4–2.4	0.5–4.5	0.2–1.0	0.5–2.1
max flow rate	mm/h	0.7–5.3	0.2–1.4	0.5–2.1	0.6–3.6	0.4–6.0	0.1–0.9	0.8–2.6

a: $\bar{x} - s$; b: $\bar{x} + s$; c: minimum value used for $\bar{x} - s$ is 0

5.4 Correlations between runoff quality parameters

The significance levels of correlations between the storm runoff quality parameters are given in Table 6. To the analysis only catchments with more than 20 observations for each parameter pair, were chosen.

At the significance level of 99.9 % SS, COD_{Cr}, tot P and Pb have positive correlations with each other. BOD_7 and tot N have positive correlations with the other quality parameters at 99 % level, pH excluded. pH was not found to correlate significantly with any other parameter.

Table 6. Significance levels of correlations between the runoff quality parameters. Only catchments with more than 20 observations included.

	Significance level of correlation between parameters						
	SS	BOD_7	COD_{Cr}	tot P	tot N	Pb	pH
SS		+++[a](2)[c]	+++(4)	+++(5)	++(4)	+++(4)	
BOD_7			++[b](2)	++(2)	++(2)	++(1)	
COD_{Cr}				+++(5)	+++(3)	+++(4)	
tot P					+++(4)	+++(4)	
tot N						++(3)	
Pb							
pH							

a: +++ = significance level 99.9 %; b: ++ = significance level 99 %; c: number of catchments in brackets

5.5 Modelling runoff quality with rainfall characteristics

The missing observations have made the statistical analysis laborious. In the tests no more than roughly 10 % of missing observations have been allowed (missing values replaced by the parameter means).

5.51 Correlations between runoff quality and rainfall parameters

In this study, the correlations varied widely depending on the number of observations or from one catchment to another. In some cases contradictory results occured, i.e. the correlations changed from positive to negative with increasing or decreasing number of observations, or from one test site to another when the total number of observations was less than 20.

However, general conclusions on the dependence of storm runoff quality on the rainfall characteristics studied can be drawn on the basis of observations in the seven test sites (Table 7).

Of the rainfall parameters rain volume, rain duration and storm runoff volume during sampling have negative correlations with the runoff quality parameters. This reflects occurence of the "first flush" phenomenon, i.e. during long rainfall-runoff events low concentrations after the "first flush" effectively decrease the composite concentrations. "First flush" phenomenon has been studied and verified in the Kontula catchment in the 1978 period; an example is given in Fig. 12. The dry period correlates positively with the runoff concentrations indicating accumulation of pollutants on the catchment surfaces during dry weather. The volume of preceding rainfall event has negative correlations with the quality parameters expressing flushing effect of runoff on the catchment. The growing maximum intensity of rainfall event and related maximum flow rate tend to increase runoff concentrations. No distinct correlations could be found between pH and the rainfall parameters.

Table 7. Dependence of storm runoff quality on the rainfall characteristics studied.

Rainfall parameter	Runoff quality parameter						
	SS	BOD_7	COD_{Cr}	tot P	tot N	Pb	pH
rain volume	?	(–)	(–)	(–)	–	?	?
max rain intensity	+	(+)	?	(+)	(–)	(+)	?
rain duration	(–)	–	–	–	(–)	–	?
preceding rain volume	(–)	?	(–)	(–)	(–)	(–)	?
preceding dry period	?	(+)	?	(+)	(+)	?	?
runoff volume	(–)	(–)	?	(–)	–	(–)	?
max flow rate	?	(+)	(+)	(+)	?	?	?

+ or – = in all catchments studied, increase or decrease in the quality parameter value with growing value of the rainfall parameter

(+) or (–) = generally, increase or decrease in the quality parameter value with growing value of the rainfall parameter; yet, one or two catchments contradictory to the others

? = various catchments in distinct contradiction to each other

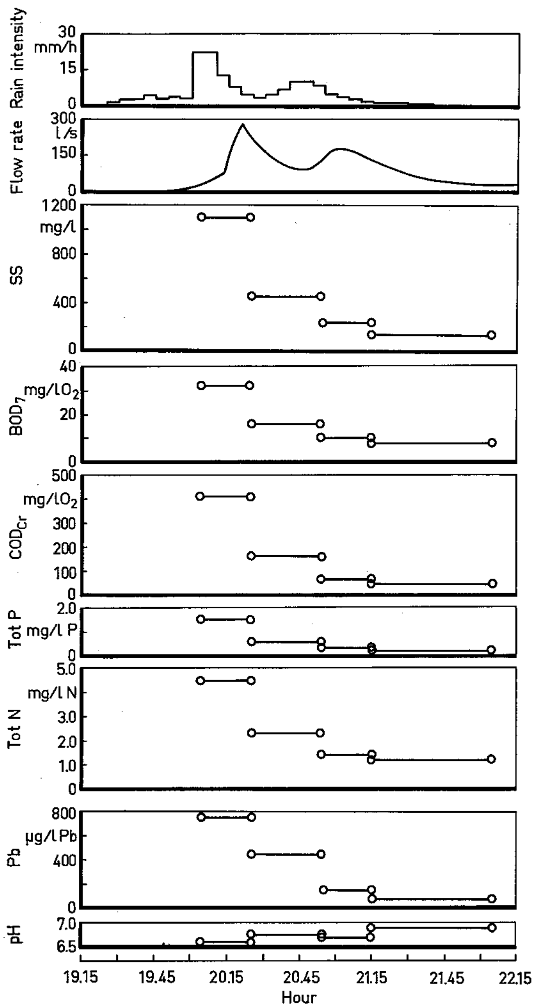

Fig. 12. Example of "first flush". Kontula catchment: June 27, 1978 (o—o = sampling interval).

5.52 Fractions of variances of runoff quality parameters explained by linear models of rainfall parameters

The storm runoff quality in each catchment was modelled by the rainfall parameters using multiple stepwise regression. The non-parametric variables were excluded from the analysis (Table 3).

The fractions of the variance of runoff quality parameters explained are given in Table 8 for the cases with more than 20 observations (rainfall-runoff events) and F value equalling at least 95 % point of the F distribution (i.e. significance level $\geqslant$ 95 %). Altogether, the explained fraction of variance is low, roughly 30 %.

The dominant independent variable was found to be maximum rain intensity in the catchments of Kontula, Nekala and Kaukovainio (in Kontula also rain duration), maximum flow rate in the Pakila area, and sampled runoff volume in the Herttoniemi catchment.

As to all the seven catchments, the computer runs showed that with small numbers of rainfall-runoff events (less than 20) substantially higher fractions of variances explained by the models may be gained than those given in Table 8 (especially in the test sites of Kaukovainio and Kajaani centre). On an average, SS was best modelled in all catchments. The fraction of variance of Pb explained was found to be distinctly higher in the catchments with high traffic volume. In all, the best explaining variable was found to be maximum rain intensity, the least explaining being rain volume.

The models in this study were derived by using linear stepwise regression. Non-linear parameter transformations and other rainfall parameters will be tried on three-year data in further analyses of the project.

5.6 Assumption on equal runoff quality in test areas

The first step in analysing whether storm runoff quality for the studied parameters can be generalized, was to study the hypothesis on equal variances of the parameters in the seven test catchments. This was done by Bartlett's test (Table 9). For each quality parameter, the Bartlett's test statistic exceeded the critical value, i.e. the variances could not be considered equal. This means that the one-way analysis of variance could not be used in testing the equality of the sample means of all seven catchments.

Because of the unequality of the sample variances, maximum and minimum quality parameter averages were tested to determine whether a difference could be proved between the two test sites. First the equality of the two variances was tested by the variance ratio test (Table 10). The test statistic exceeded the critical value for other parameters but Pb and pH. This means that the variances of the two populations of Pb and pH could be assumed equal but all the other variances were considered unequal.

Finally, the differences of the maximum and minimum means were tested by the Welch's approximation and t test (t test for Pb and pH) (Table 11).

Table 8. Fractions of the variance of runoff quality parameters explained by linear models of the rainfall characteristics studied and numbers of rainfall-runoff events. Only cases with more than 20 observations[a] and F value equalling at least 95 % point of F distribution included.

Catchment	Fraction explained of parameter (%) SS	BOD_7	COD_{Cr}	tot P	tot N	Pb	pH	Rainfall parameters excluded (non-parametric)[d]
Kontula	41 (32)[b]	-	24 (32)	-	-	27 (32)	-	preceding dry period
Pakila	34 (48)	23 (29)	-	13 (48)	-	N[c]	34 (29)	max rain intensity, preceding dry period, runoff volume
Herttoniemi	40 (31)	-	31 (31)	-	-	53 (31)	-	-
Nekala	26 (41)	13 (31)	30 (41)	25 (41)	19 (41)	19 (41)	29 (41)	preceding dry period
Hämeenpuisto	-	-	-	-	-	-	-	rain volume
Kaukovainio	-	-	-	N[c]	55 (24)	25 (24)	16 (24)	-
Kajaani centre	-	-	-	-	-	-	-	-
catchments, average	35	18	28	19	37	31	26	

a: see Tables 2 and 3; b: number of events in brackets; c: non-parametric, see Table 3; d: see Table 3

Table 9. Test of the equality of runoff quality parameter variances in the catchments studied. Bartlett's test at the significance level of 99 %.

	Quality parameter SS	BOD_7	COD_{Cr}	tot P	tot N	Pb	pH
Bartlett's test statistic[a]	110.2	19.0	22.7	32.4	20.0	34.9	42.7
Degrees of freedom (df)	6	6	6	5	6	5	6

a: $\chi^2_{0.99}$ (df = 5) = 15.1, $\chi^2_{0.99}$ (df = 6) = 16.8

Table 10. Test of the equality of variances for runoff quality parameters with maximum and minimum sample means. Variance ratio test at the significance level of 99 %.

	Quality parameter SS	BOD_7	COD_{Cr}	tot P	tot N	Pb	pH
Variance ratio	80.00	3.87	3.02	3.67	3.52	2.54	1.31
Degrees of freedom	(35,17)	(30,28)	(27,45)	(38,47)	(36,23)	(38,22)	(15,17)
Critical value of F distribution	3.04	2.44	2.21	~2.1	~2.6	2.60	3.31

Table 11. Interval estimation of the difference of means of the runoff quality parameters with maximum and minimum average concentrations (in mg/l, except for pH). Welch's approximation and t test at the significance level of 99 %.

Quality parameter	Arithmetic mean $\bar{x}_1$	$\bar{x}_2$	Standard deviation s_1	s_2	Number of observations n_1	n_2	Value of test statistic t[a]	Degrees of freedom df[a]	Test used	$\bar{x}_1$ and $\bar{x}_2$ differ from each other
SS	493	86	484	54	36	18	4.98	36.7	Welch	yes
BOD_7	24	11	13	9	31	29	4.53	53.6	Welch	yes
COD_{Cr}	241	108	150	87	28	46	4.27	38.2	Welch	yes
tot P	0.56	0.24	0.46	0.24	39	48	3.93	54.5	Welch	yes
tot N	2.07	1.32	1.22	0.65	37	24	3.12	57.2	Welch	yes
Pb	0.504	0.139	0.263	0.165	39	23	5.99	60	t test	yes
pH	7.4	6.4	0.4	0.5	18	16	6.48	32	t test	yes

a: percentiles of Student's t distribution (t (df, 99 %)): t (30, 99 %) = 2.75, t (40, 99 %) = 2.70, t (60, 99 %) = 2.66

The test indicated that for every quality parameter studied, a difference can be proved between some test sites, i.e. the storm runoff quality cannot be considered equal in the test catchments. This conclusion is supported by the findings of atmospheric deposition measurements performed in the test sites (Table 12), and by the emission inventories accomplished (Hokkanen et al. 1979).

Table 12. Average atmospheric deposition of some constituents in the test catchments over 1977–1978 period. Sampling interval 30 ± 2 days.

Catchment	Deposition in mg/m^2 over 30 days of parameter			
	total deposition	tot P	tot N	Pb
Kontula	2400 (10)[a]	3.3 (10)	100 (10)	1.3 (10)
Pakila	2400 (10)	4.0 (10)	95 (10)	1.1 (10)
Herttoniemi	2800 (9)	4.3 (10)	60 (11)	2.3 (11)
Nekala	1600 (9)	1.9 (10)	45 (10)	1.4 (12)
Hämeenpuisto	3800 (11)	4.2 (12)	70 (11)	4.4 (12)
Kaukovainio	1500 (15)	2.9 (17)	45 (16)	0.8 (15)
Kajaani centre	3600 (15)	3.9 (15)	35 (15)	1.7 (14)

a: number of observation months in brackets

5.7 Accuracy of observations

Following accuracy is estimated for various measurements:

runoff	± 10 %	tot P	± 5–10 %
SS	± 10 %	tot N	± 15–20 %
BOD_7	± 20 %	Pb	± 10 %
COD_{Cr}	± 15–20 %	pH	± 0.1.

Standard methods of analysis have been used. An intercalibration study has been made between the three laboratories performing the analyses.

5.8 Conclusions

The following conclusions were derived from an analysis of the data collected during this study:

1. In general, parametric testing can be applied in the statistical analysis of urban storm runoff quality parameters and related rainfall variables.
2. The quality of urban storm runoff varies widely between and within different urban areas. The average runoff quality in the seven catchments studied varied as follows: SS 86–490 mg/l, BOD_7 11–24 mg/l O_2, COD_{Cr} 110–240 mg/l O_2, tot P 0.24–0.56 mg/l P, tot N 1.3–2.1 mg/l N, Pb 110–500 μg/l Pb and pH 6.4–7.4. Runoff quality cannot be generalized with regard to any parameter studied. This is supported by the results of atmospheric deposition measurements and emission inventories performed.
3. The fraction of the variance of urban runoff quality parameters explained by linear models of the rainfall characteristics is low, roughly 30 % in this investigation, the best explaining parameter being maximum rain intensity.

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Of the authors, Mr. Melanen works as leader of the Finnish Urban Storm Water Project. He has been responsible for data collection and preparation, and written the manuscript. Mr. Laukkanen has planned and performed the test and model runs needed in the study and written chapter 4. Conclusions on the results of the study have been drawn jointly by the authors.

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LOPPUTIIVISTELMÄ

Kolmivuotisen "Valtakunnallinen hulevesitutkimus 1977–1979" -projektin yhtenä päätavoitteena on tutkia suomalaisten taajamien viemäröitävien hulevesien laadun vaihteluja ja laadun riippuvuutta hydrometeorologisista ja aluekohtaisista tekijöistä.

Projektissa on suoritettu kolmivuotiskaudella 1977–1979 kenttäkokeita yhteensä seitsemällä taajamakoealueella Helsingissä, Tampereella, Oulussa ja Kajaanissa. Kullakin koealueella on mitattu sulana kautena (touko-marraskuussa) sadanta ja hulevesivalunta sekä kerätty automaattisella laitteistolla virtaamaan verrannollisia huleveden kokoomanäytteitä.

Vuosina 1977 ja 1978 kerätyn aineiston käsittely on johtanut mm. seuraaviin johtopäätöksiin, joita tullaan tarkentamaan vuoden 1979 aineistolla:

1. Huleveden laatuparametrit (tässä tarkastelussa kiintoaine SS, biokemiallinen hapenkulutus BOD_7, kemiallinen hapenkulutus COD_{Cr}, kokonaisfosfori tot P, kokonaistyppi tot N, lyijy Pb sekä pH) ja tutkittaviin sadantavaluntatapauksiin liittyvät hydrologiset muuttujat voidaan yleensä olettaa normaalijakautuneiksi.
2. Taajamien hulevesien laatu vaihtelee huomattavasti sekä yhden alueen sisällä että erityyppisten alueiden välillä. Tutkituilla seitsemällä koealueella keskimääräinen huleveden laatu vaihteli seuraavasti: SS 86–490 mg/l, BOD_7 11–24 mg/l O_2, COD_{Cr} 110–240 mg/l O_2, tot P 0,24–0,56 mg/l P, tot N 1,3–2,1 mg/l N, Pb 110–500 µg/l Pb ja pH 6,4–7,4. Koealueiden hulevesien laatua ei voida yleistää em. parametrien suhteen. Tätä tukevat myös alueilla suoritetut laskeumamittaukset ja emissioinventaariot.
3. Lineaarisella hydrologisten muuttujien mallilla selitetty huleveden laadun varianssi on alhainen, noin 30 % tässä tutkimuksessa. Paras huleveden laatua selittävä muuttuja on sadetapauksen maksimirankkaus.

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