A case study of urban runoff pollution:
1. Data collection, runoff quality and loads

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Abstract

A 91,5 ha urban catchment in Pinetown, Natal was equipped to measure flow and sample runoff automatically from rainfall at the catchment outfall. The purpose was to measure water quality and determine annual export coefficients for the nutrients which promote eutrophication, viz. nitrogen compounds and phosphates, and a number of toxic heavy metals. Design and operation of the purpose-made monitoring system is described. High variability in runoff quality and annual pollutant loads was found between years due to different climatic regimes experienced. In wet years washoff from pervious areas of the catchment became increasingly important. The possible harmful effect of runoff to the environment through washoff of toxic metals and the potential of urban development in catchments to promote eutrophication in receiving water is illustrated with results and discussed.

Introduction

Urbanisation within catchments increases both runoff volumes and peak flow rates because it increases impervious areas, reduces natural storage and introduces hydraulically more efficient drainage channels (Beard and Chang, 1979; Walker *et al.*, 1981). Consequently, urbanisation will greatly increase pollutant loads to receiving waters, not only because of increased surface runoff but also because higher runoff velocities enhance erosion, dislodgement and entrainment of particulate pollutants. Sonzogni *et al.* (1980) who studied the effect of land use upon pollutant export to the Great Lakes reported that loads of suspended solids, nitrogen species and phosphates from urban areas were 10 to 100 times greater than loads from equivalent areas of undisturbed land. A study by Weand *et al.* (1981) found that urban runoff, and not sewage discharges, was primarily responsible for eutropic conditions in a reservoir near Washington DC, particularly in wet seasons. Other researchers have reported on the degrading effects of urban runoff to the environment and also on the presence of potentially harmful pollutants (Whiting and Clifford, 1983; Field, 1985).

Many studies on urban runoff have been reported in the literature, mainly in North America and Europe, but little research has been done in the RSA. Thus a comprehensive investigation was conducted on a catchment in Pinetown to characterise runoff quality and determine annual export coefficients of pollutants. Some aspects of the study, essentially the data collection system devised and runoff quality and loads, are reported and discussed in this paper.

The catchment

The catchment covers an area of 91,5 ha and is located within the municipal areas of Pinetown, approximately 16 km inland from Durban. It is oblong in shape with drainage down its length which is approximately 1 720 m. The average slope is 0,025. The impervious surface area of the catchment (roads, pavements, buildings) was measured from an aerial photograph, and covers 46 per cent of the total area. Storm-water drainage is completely separate from the foul sewer system (domestic and industrial discharges).

Land use in the catchment is apportioned 30 per cent commercial, 19 per cent light industrial and 51 per cent multiple and single residential accommodation and parkland (Fig. 1). The commercial area comprises shopping centres, office blocks and parking lots while the industrial area has a variety of industries such as manufacture of caravans, textiles, furniture and plastics. The absence of a dominant industry, one which may strongly influence runoff quality and the combination of a busy commercial sector and all types of residential units made this catchment particularly suitable for study as this combination is fairly representative of the different types of land use which constitute urbanisation.

Methodology

Flow measurement

At the bottom end of the catchment a 1,52 m diameter conduit empties into a short trapezoidal channel before discharging into the Palmiet River. A standard flow control structure could not, however, be used, because of complications such as supercritical flow and probable back-flooding which would have occurred had any flow restriction been imposed. An alternative was to obtain a measure of water depth in the conduit by means of a bubbler: pressure transducer coupling and then to relate the pressure transducer output to flow rate.

Accordingly, nylon tubing was fixed to the invert of the conduit pointing downstream to minimise velocity effects on the measurement of water depth since Forty (1978) had reported larger velocity effects on the measurement of water depth for bubbler tubes aligned in any other direction. Compressed nitrogen from a cylinder was fed via a pneumatic control valve which delivers a low constant flow to a T-piece, one outlet of which was connected to a pressure transducer and the other to the bubbler tube. Output from the transducer was in volts. Since true water depth was not being measured because velocity effects on depth measurement were apparent and also because supercritical flow did occur in the conduit, the conventional empirical flow formula could not be applied and therefore it was necessary to establish a voltage: discharge relationship by field measurements.

The tracer dilution technique, after Grizzard and Harms (1974) was used for this purpose. The principle of the method is that a concentrated solution of a chemical is injected into a stream at a constant rate and after mixing the stream is sampled and

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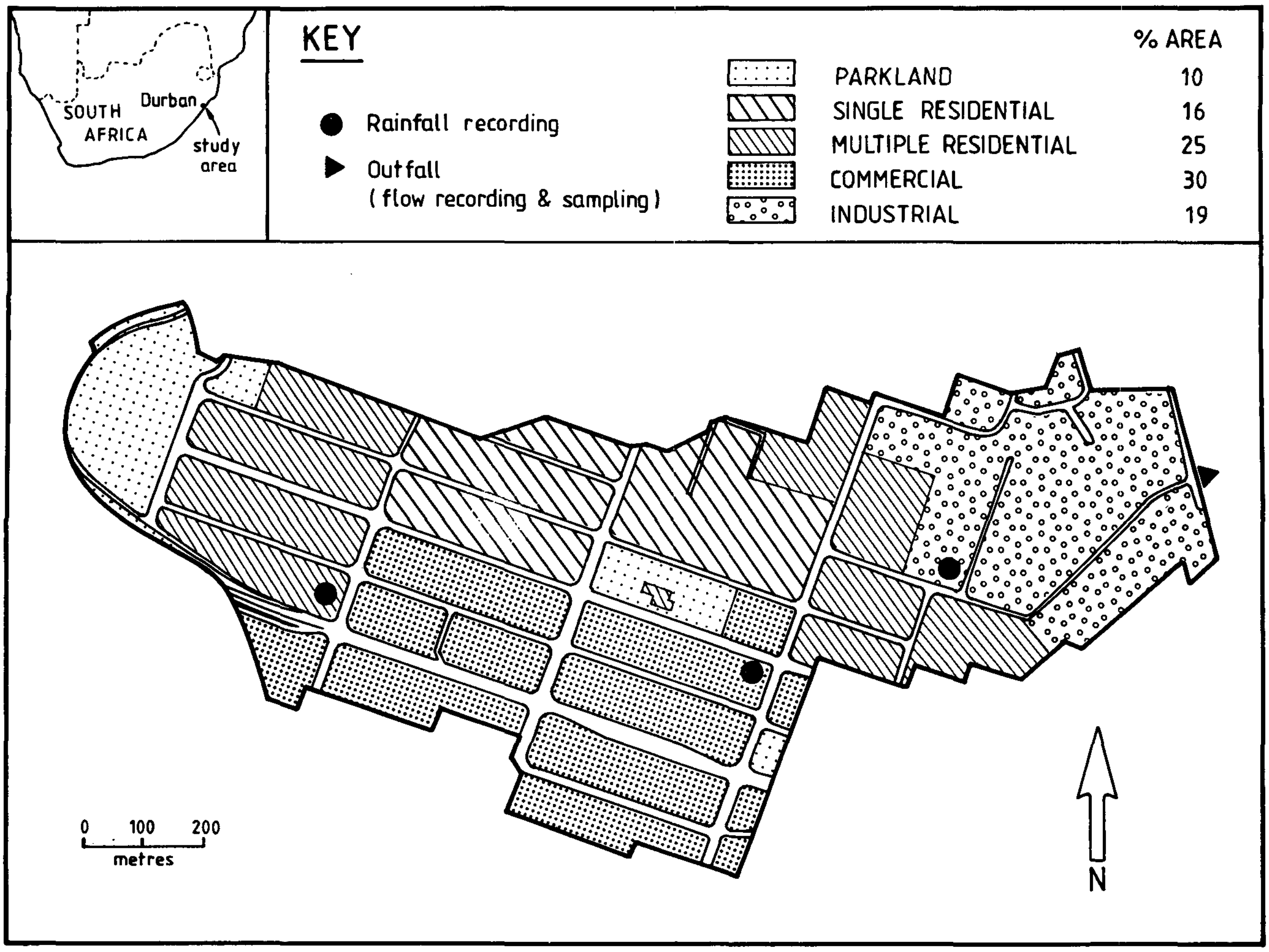

Figure 1
Location and land-use map of catchment.

analysed for the lower concentration of the chemical. From a knowledge of the original and diluted concentrations and injection rate, the flow rate in the stream can be calculated by a simple mass balance.

Lithium was chosen as the tracer and a strong lithium chloride solution and a dosing pump were installed in a manhole 100 m upstream from the sampling station. Provision was made to activate the dosing pump when flow in the conduit occurred and samples were automatically taken at the sampling station. A schematic diagram of the system is shown in Fig. 2. In addition, manual flow measurements using an Ott current meter were made at low flows when in-stream mixing of the tracer was inadequate, resulting in unreliable results. The final discharge curve relating flow to measured pressure transducer output is given in Fig. 3, together with measured data points. The formula for the curve is similar to that of the Hazen-Williams empirical formula, but with an experimentally derived constant. Data were obtained up to a flow of 4 $m^3 s^{-1}$ and for calculation of higher flows extrapolation of the curve formula was necessary. In practice, flows greater than 4 $m^3 s^{-1}$ did not often occur for any length of time and therefore errors incurred in volume measurement due to extrapolation would not have been great. The National Bureau of Standards (1975) reported the accuracy of the tracer dilution method for measurement of discharge to be 3 to 5 per cent for field work.

Rainfall measurement

Three rain gauges were installed on the roofs of buildings in the catchment. Their location may be seen in Fig. 1. Two of them were the standard tipping bucket type and the other a Casella siphon chart recorder rain gauge. Since it was desirable to record time synchronised rainfall and flow data, the tipping bucket rain gauges were equipped with electronic counters and connected to the data logging centre at the outfall by means of "private telephone wires". The other chart recording rain gauge served as a back-up for times when line troubles were experienced with the other two. For runoff events the mean rainfall between all 3 sites was used for calculation of the percentage runoff.

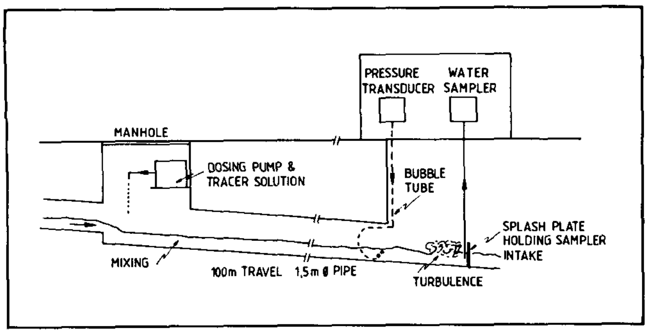

Figure 2
Schematic of tracer dilution system for calibration of conduit for flow.

Data logging and sampler control

An electronic unit was built to regulate the monitoring system (Stone and Bailey, 1982) by performing the following basic functions:

- to start regular recording of flow data above a threshold flow;
- to record incoming rain gauge signals from the rain gauges;
- to activate the water samplers when required; and
- to activate the chemical dosing pump when required.

When the water level in the conduit rose above a pre-set threshold value (about 2 to 3 cm. water depth) recording of flow and rain gauge data at 2-min intervals was automatically initiated. Two water samplers were used, the one a discrete bottle sampler equipped to take 24 individual samples and the other a composite sampler with a single large bottle which could accommodate many small subsamples, normally of the order of 200. Sampler control was programmed on a flow interval basis in that signals were sent to activate the samplers after passage of pre-set volumes of runoff. By reference to the discharge curve which was stored in memory, flow readings were integrated by the programme until a certain volume was reached and the samplers activated. All the data consisting of date, time, flow, rainfall and sample number were stored on magnetic tape.

The equipment was housed in a hut erected upon a platform above the discharge channel. The system was powered by a 24 V DC supply which was continuously trickle-charged from a mains supply. A schematic diagram illustrating the interactions of the monitoring system is shown in Fig. 4. Provision was also made to interrogate and change variables within the control unit from the laboratory via a modem and telephone line. This facility proved to be extremely useful for determining whether runoff events had occurred or not.

Chemical analysis

Chemical analyses for most constituents were done by established methods and auto-analytical techniques (Methods for Chemical Analysis of Water and Wastes, 1979; Standard Methods for the Examination of Water and Wastes, 1980). Analysis for acid-extractable metals was done by atomic absorption spectroscopy. Total dissolved salts (TDS) concentration was calculated from conductivity according to the relationship given by Kemp (1977).

Results

Variation in quality of runoff

During the period September 1982 and September 1985 a total of 149 runoff events were analysed. Mean concentrations of constituents during each event were obtained from analysis of composite samples, taken as described above. For some events individual samples taken during runoff were analysed and typical quality variation for one such event is shown in Fig. 5.

The hydrograph shows a small peak soon after the start of the event, followed by a large peak flow of 1,5 $m^3 s^{-1}$ at 140 min. The vertical arrows in Fig. 5 indicate when samples were taken, which amply illustrates the flow-interval strategy of sampling at equal increments in volume resulting in rapid sampling about the flow peak. If a time-interval sampling strategy had been used then clearly it would have been quite possible to have missed sampling at the peak flow when quality variation was high and the bulk load of pollutants was being delivered.

The upper section of Fig. 5 shows the changing concentrations for total nitrogen and phosphorus compounds, chemical oxygen demand (COD), suspended solids, lead and zinc. All pollutants show a "first flush" effect. The initial concentration for total nitrogen is high whereas the concentrations for the other constituents have peak values coinciding with the first small peak in the hydrograph. The dry period preceding this 13 mm rainfall event was 28 d, thus allowing for a considerable build-up of pollutants on catchment surfaces. Thereafter concentrations fall until the major peak flow when all rise sharply to maximum values which actually occur just before the hydrograph peak. Concentrations then decrease indicating the end of wash-off of accumulated materials from the catchment surfaces. Constituent concentrations during the event ranged from a change of 7 times

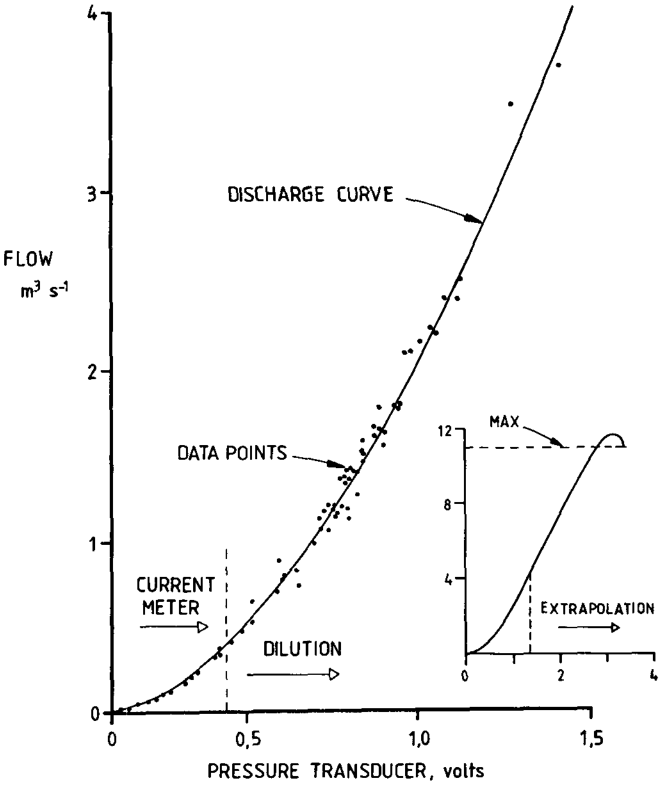

Figure 3
Experimentally derived discharge curve.

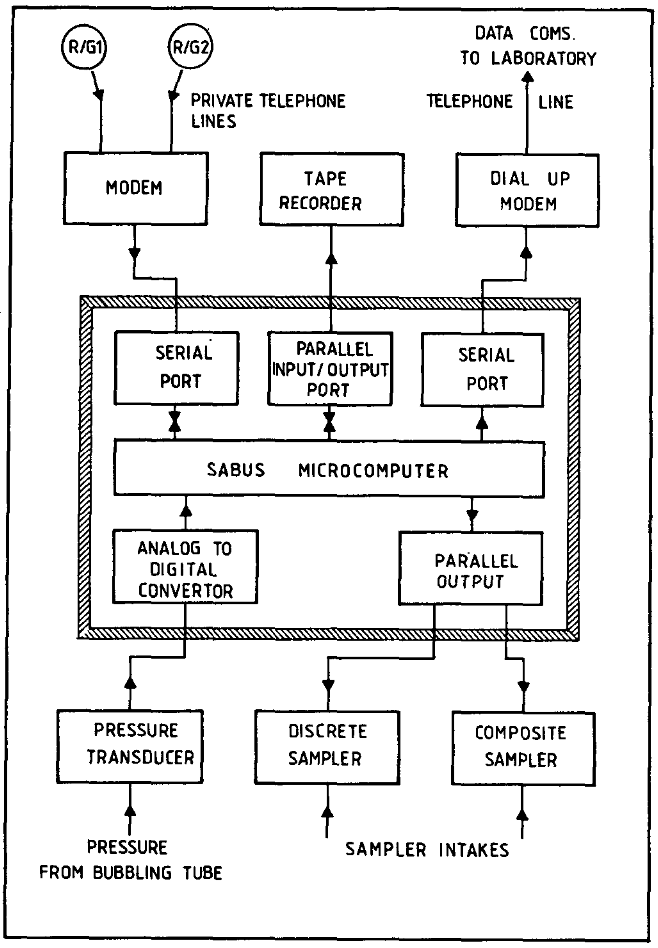

Figure 4
Schematic of data collection system.

for nitrogen (high/low) to 39 times for suspended solids. These results clearly show that sampling throughout runoff events is essential to obtain representative composite samples for calculation of accurate runoff loads of pollutants.

As mentioned previously, a total of 149 runoff events were measured for quality between 1982 and 1985. The duration of events ranged from small ones lasting less than an hour to large ones of 2 to 3 d. Just as quality varied greatly during runoff as shown in Fig. 5, so did mean event concentrations of pollutants also vary. The spread of mean event concentrations for some constituents is shown in Fig. 6 as the frequency of occurrence of certain concentration ranges. Also shown is the variation in runoff yields as percentages of catchment rainfall. A narrower distribution of runoff yields was expected because of the substantial impervious area of the catchment, 46 per cent of the catchment area, and the fact that for the majority of rainfall events most of the runoff would be derived from impervious surfaces. Consequently a more or less regular yield (runoff as a percentage of rain) would be anticipated, but other factors such as evaporation, absorption, surface cracks and seepage and rainfall intensity must have played important roles influencing yield. Mostly, runoff was between 20 and 45 per cent of rainfall amount with a maximum of 85 per cent for one event which lasted for 2 to 3 d.

The distributions of the pollutant concentrations all show positive skewness with a bias to low results. For most events suspended solids concentrations were between 50 and 300 mg ℓ^{-1}, while dissolved salts were between 60 and 100 mg ℓ^{-1}. Variation of nutrient concentrations was also considerable with total nitrogen and phosphorus compound values up to 26 800 and 10 200 μg ℓ^{-1} respectively. Soluble nitrogen concentrations varied from 400 to a maximum of 7 800 μg ℓ^{-1} and soluble phosphate levels from 20 to a maximum of 500 μg ℓ^{-1}. The metals also showed a wide distribution of mean concentrations. Chromium levels were mostly between 40 and 80 μg ℓ^{-1}, but a peak also occurred between 140 and 160 μg ℓ^{-1}. Five chromium values exceeded 400 μg ℓ^{-1} with a maximum of 2 300 μg ℓ^{-1}. Extremely high values such as these were found for all the metals and were usually associated with small events. The wide distribution of these samples emphasises the potential errors which may be incurred, should too few samples or too short an observation period be used to characterise runoff quality.

Annual mean concentrations and load

An important objective of the study was to determine annual export coefficients of pollutants from this category of land use, the annual variation and mean concentrations. The data under review covered 3 years and provide a reasonable understanding of temporal variation in constituent loads. Annual mean concentrations were calculated in the following manner:

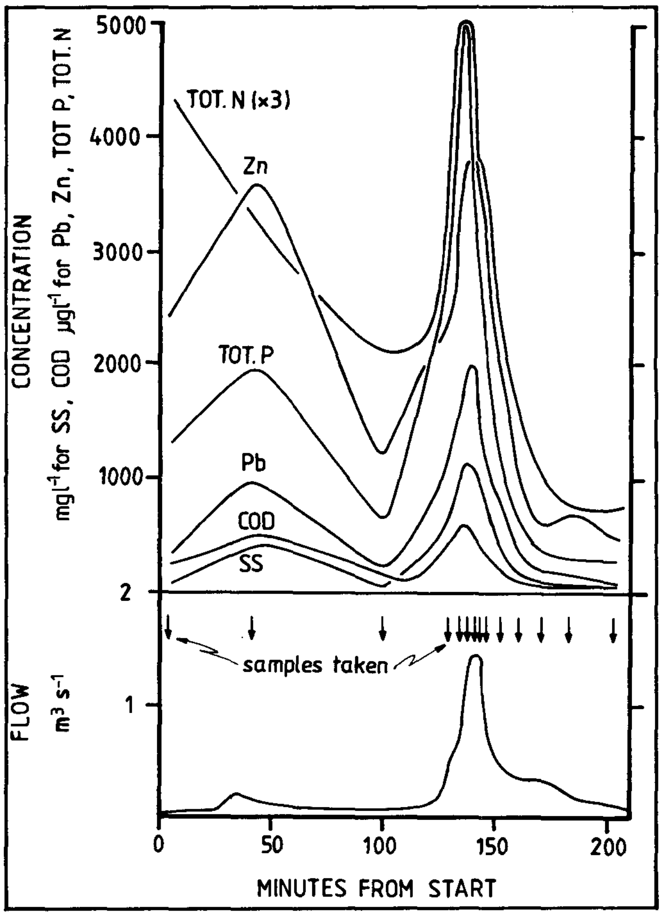

Figure 5
Temporal variation in pollutant concentrations and flow.

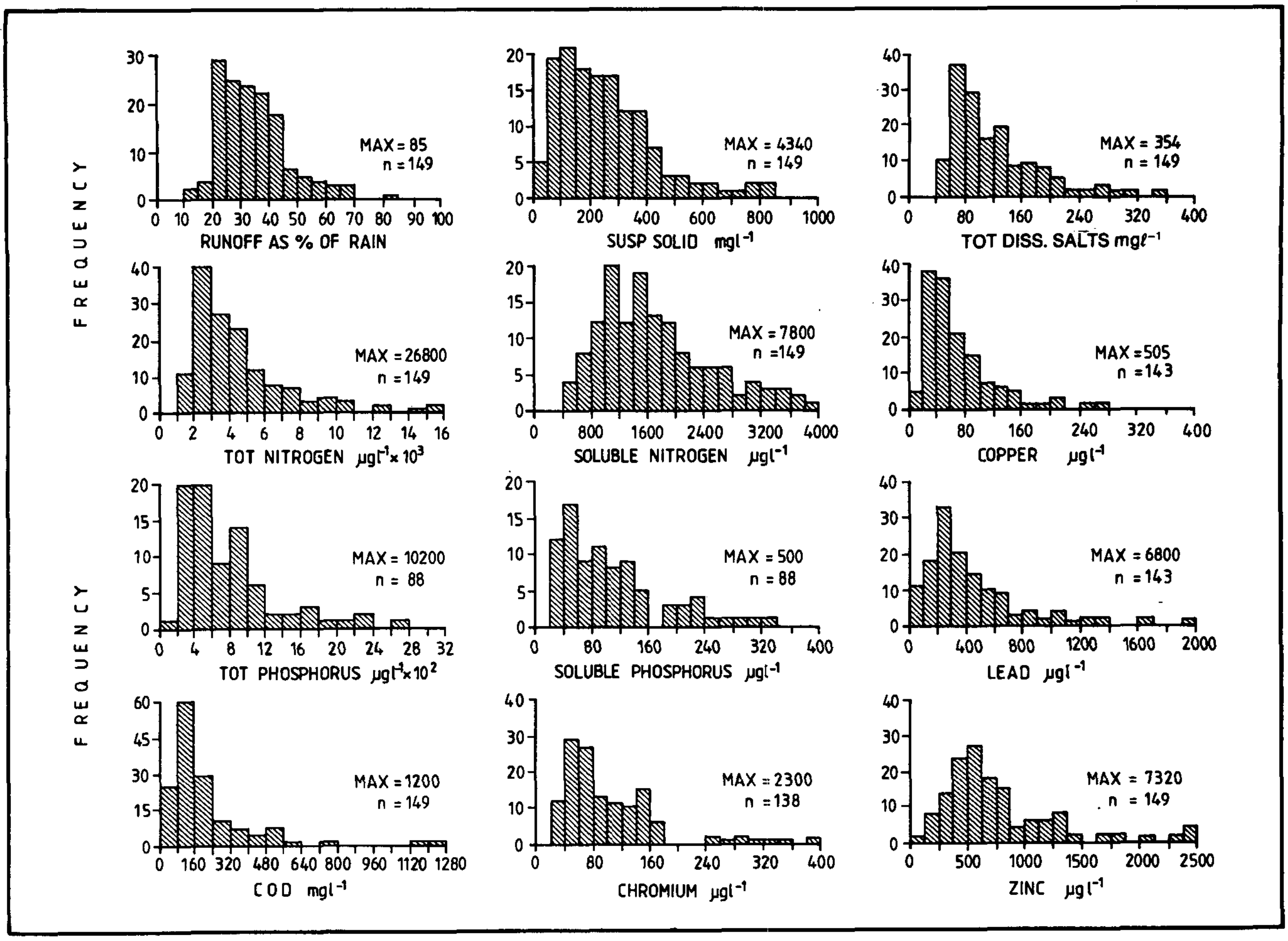

Figure 6
Frequency distribution of mean runoff event concentrations.

$$C = \sum_{n=1}^{i} C_i V_i \,/\, \sum V_i$$

where C = annual mean concentration for a constituent, mg ℓ^{-1}
C_i = mean constituent concentration for event i, mg ℓ^{-1}
V_i = volume of runoff for event i, m^3

Annual export coefficients were then calculated as follows:

$$E = C\,V\,10^{-3} \,/\, A$$

where E = export coefficient for a constituent, kg ha^{-1} a^{-1}
V = total volume of runoff for the year, m^3
A = area of the catchment, ha

In calculating the annual mean concentrations, the mean analysis for each event is weighted according to the runoff volume for the event. On the few occasions when the flow measuring equipment failed, runoff volume was estimated from measured rainfall and use of a statistical technique. The results are given in Table 1.

Rainfall in the first year was low at only 693 mm (mean 1 000 mm for last 25 years), almost double at 1 347 mm in the second year and intermediate in the third year. Consequently, the results reflect extremes for rainfall and runoff. On an annual basis runoff volume varied between 33 and 62 per cent of rainfall for the first and last years.

Concentrations for some parameters such as TDS, organic nitrogen compounds, copper, iron and chromium were not very different between years, showing little effect of the different rainfall regimes. Conversely, greater differences are apparent for the soluble and suspended forms of the nutrients. Both suspended phosphorus and nitrogen compound concentrations were 50 to 70 per cent higher in the first year than in the later years, but the reverse was true for suspended solids which was 25 per cent lower in the first year. Calculation shows that nutrient attachment to particulate material (suspended P or N / suspended solids) in the first year was approximately double that for the wetter second and third years. Similarly, using COD as a measure of organic content, the data also show much greater enrichment of particulate material in the dry year. These results indicate the dif-

TABLE 1
WEIGHTED MEAN CONCENTRATIONS IN RUNOFF AND ANNUAL EXPORT COEFFICIENTS FOR 3 YEARS

Parameter	Concentration			Export kg ha^{-1} a^{-1}		
	Year 1st	2nd	3rd	1st	2nd	3rd
Susp. sol. mg ℓ^{-1}	204	272	273	468	1 629	1 574
TDS mg ℓ^{-1}	78	80	77	179	479	444
Sol. P µg ℓ^{-1}	124	85	80	0,28	0,51	0,46
Susp. P ''	697	413	469	1,6	2,5	2,7
Inorg. N ''	637	965	870	1,5	5,8	5,0
Org. N ''	491	470	441	1,1	2,8	2,5
Susp. N ''	1 951	1 452	1 282	4,5	8,7	7,4
COD mg ℓ^{-1}	136	102	87	312	611	502
Copper µg ℓ^{-1}	46	38	45	0,11	0,23	0,26
Cadmium ''	10	3	1	0,02	0,02	0,01
Lead ''	287	231	324	0,66	1,4	1,9
Zinc ''	560	355	401	1,3	2,1	2,3
Iron ''	6 612	6 081	6 519	15	36	38
Chromium ''	77	74	66	0,18	0,44	0,38
Manganese ''	121	116	97	0,28	0,69	0,56
No. events	46	57	46			
No. subsamples	1 003	4 029	2 876			
Rainfall mm	693	1 347	982			

Note:		From	To
	1st year	820916 —	830915
	2nd year	830916 —	840915
	3rd year	840916 —	850915

ferent nature of suspended material washed off the catchment by different weather cycles. Since the major source of solids washed off the catchment in the dry year is likely to have been from impervious areas because of the low rainfall, it follows that solids that accumulate on pavements and streets are more nutrient and organically enriched than those derived from runoff from the pervious areas which would have occurred in the higher rainfall second and third years.

The lower mean soluble phosphorus concentrations for the wetter second and third years indicate dilution by rainfall of a limited source of the soluble form of phosphorus. Conversely inorganic nitrogen compounds (nitrate + ammonia) concentrations for the wet years were appreciably higher, 37 to 52 per cent, than in the dry year. Since annual bulk wet and dry atmospheric fallout loading rates of inorganic nitrogen to the catchment were found to be very similar for the 3 years (Simpson, 1987), the source of the higher nitrogen concentrations has to be from catchment surfaces alone rather than from rainfall. As stated above, runoff from the pervious areas of the catchment would have occurred in the wet years and probable sources are leaching and mobilisation of garden fertilisers and the decay of vegetation. Unlike nitrogen compounds, phosphates are not leached appreciably from fertilisers as they tend to be strongly bound to soil particles.

With conversion of concentration data into annual pollutant export coefficients, the differences caused by the variable rainfall become very marked. The results, also shown in Table 1, show that the levels for the wet second and third years are, in most cases, not very different, except for lead, but all coefficients for the first dry year are very much lower by factors as high as 3,5 times for suspended solids, 1,8 and 1,7 times for soluble and suspended phosphorus respectively, and 3,9 times for inorganic nitrogen. Export of all metals, except for cadmium was also higher for the second and third years by factors of 2 to 3 times.

The effect of different weather cycles is more easily seen in Fig. 7 where export coefficients for some constituents are plotted against runoff. Although there are only 3 data points per constituent the increase in export with runoff is clearly evident. The relationships between dissolved salts and suspended solids with runoff are almost linear, while those for total nitrogen and COD appear curvilinear. A slight anomaly is shown for total phosphorus compounds in that there is a small decrease in export with a rise in runoff from 577 to 600 mm. These results show that the magnitudes of export coefficients for pollutants are mainly functions of runoff amount and that no single value may be considered typical for a catchment but rather a range can be given to cover different rainfall regimes.

Discussion

Since annual bulk atmospheric fallout rates of pollutants to the catchment were found to be almost independent of total rainfall (Simpson, 1987), the higher rainfall in the second and third years can be discounted as sources of the higher pollutant loads. Part of the reason for the higher loads may be the accumulation of pollutants on impervious surfaces due to incomplete washoff in the first dry year followed by greater washoff in the following wet year. Other possibilities are from some building activity in the catchment during the course of the study and, in the case of lead, from a natural increase in traffic flow. The main reason, however, is considered to be due to washoff from the pervious areas caused not only be the high rainfall but also by the high intensities experienced.

It is appropriate here to place into perspective the potential threat of urban runoff of this quality to the aquatic environment from the toxicity point of view and also the potential effect of urbanisation within catchments on export coefficients of the

TABLE 2
COMPARISON OF MAXIMUM AND MEDIAN WATER QUALITY CRITERIA (KEMPSTER *et al.*, 1980) FOR SUSPENDED SOLIDS AND TOXIC METALS FOR THE PROTECTION OF AQUATIC LIFE WITH URBAN RUNOFF CONCENTRATIONS FOUND IN THIS STUDY

Parameter	Criteria specified		This study	
	Maximum	Median	Mean	Maximum
Susp. sol. mg ℓ^{-1}	80		263	4 340
Cadmium * $\mu g\ \ell^{-1}$	30	3	3	57
Copper * "	200	5	42	505
Lead * "	100	30	280	6 800
Chromium + "	100	50	71	2 300
Iron + "	1 000	200	6 350	101 000
Zinc + "	100	100	404	7 320

Note: * metals listed as highly toxic
+ metals listed as moderately toxic

eutrophication related water quality variables, nitrogen and phosphorus compounds. A number of elements and compounds in water are both harmful and toxic depending upon the end use, such as for drinking water or recreation. Kempster *et al.* (1980) summarised criteria from the world literature for water quality constituents. For the protection of aquatic life the maximum specified and the median criteria for some constituents are compared in Table 2 with the results of this study. The overall mean concentrations for these constituents for the three-year study were calculated using the method given earlier, i.e. weighting the annual mean concentrations according to volume of runoff. Levels of suspended solids, lead, iron and zinc exceed maximum specified levels by factors from 3 to 6 times, while the median criterium values are equalled or exceeded for cadmium, copper and chromium. Comparison of the criteria with the maximum event concentrations found in the study shows values greater than an order of magnitude for some constituents. Examination of event concentration frequencies given in Fig. 6 shows that for almost all events, concentrations of suspended solids, lead and zinc were greater than the maximum criteria for the protection of aquatic life and for copper and chromium greater than the median criteria.

These environmentally undesirable levels of harmful and toxic elements in runoff do not necessarily mean that treatment is essential to avoid degradation of the environment. Rather, a decision on how to handle the problem should be based on the potential dilution of urban runoff in the receiving water course, which in many cases may result in dilution to well below toxic levels. Each new or existing development needs to be assessed in this manner to meet water quality objectives. From an export of pollutant loads point of view the difference between urban and rural catchments is even greater than quality differences because of higher runoff coefficients from urban areas. Table 3 shows a comparison of the export coefficients for suspended and dissolved solids and the nutrients between a few large rural catchments and the mean results of this study. The rural catchment export data, obtained from Archibald and Warwick (1987), were calculated from continuous flow data and generally 2-weekly sampling and analysis for up to 6 years. None of the catchments have point sources of any consequence and broad categories of land use within each catchment are given below Table 3.

Export of soluble and total forms of phosphorus compounds from the urban catchment is 42 times and between 15 and 39 times higher respectively than the highest of the export coefficients for the rural catchments. For soluble and total nitrogen compounds the differences are less but still considerable at 7 to 10 and 9 to 15 times higher respectively. Export of suspended solids for the rural catchments is highest for Henley Dam, where the main land use of subsistence farming generally promotes soil erosion, but even this value is only 21 per cent of that of the urban catchment. The comparisons made, however, are open to criticism because of the large differences in catchment sizes and the fact that whereas settlement and transformation of pollutants are likely to occur in the streams and rivers of rural catchments, this is unlikely to be the case for the small urban catchment where pollutant transport is rapid. In other words, the scale effect gives the urban export coefficients a positive bias. Although not perfect, the comparison does give a good indication of different land uses as sources of diffuse pollution.

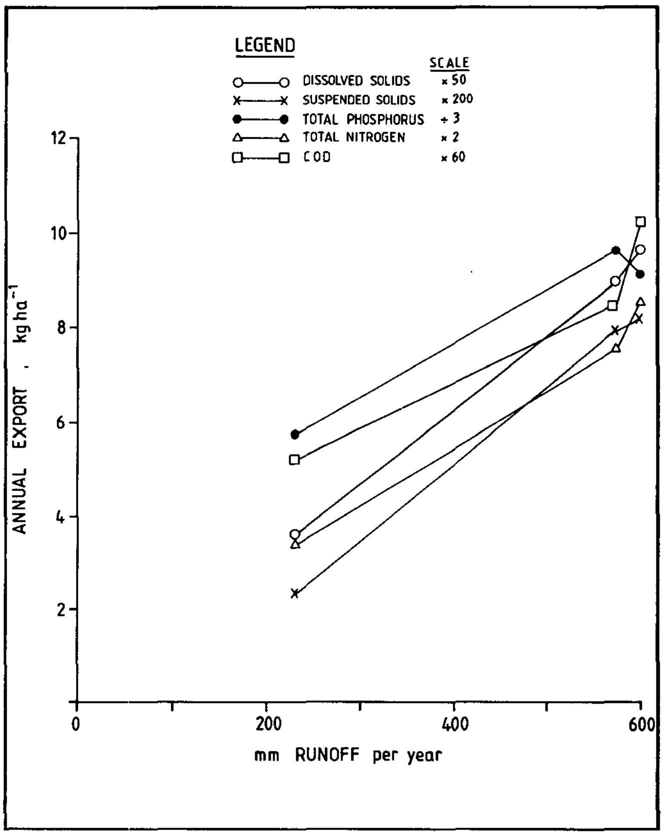

Figure 7
Relationship between annual export coefficients of pollutants and runoff.

TABLE 3
COMPARISON OF MEAN ANNUAL EXPORT COEFFICIENTS (kg ha^{-1} a^{-1}) OF RURAL AND URBAN CATCHMENTS

Parameter	Rural catchments			This study
	Midmar Dam	Karkloof River	Henley Dam	
Susp. sol.	33	56	261	1 224
T D S	49	49	37	367
Sol. P	0,01	0,01	0,01	0,42
Tot. P	0,07	0,08	0,18	2,70
Sol. N	0,62	0,86	0,88	6,30
Tot. N	0,91	1,16	1,53	13,20
Area km^2	803	341	219	0,9

Land use (after Kroger, 1981)

Midmar	Open and natural	82%,	Plantations	8%	Crops	10%
Karkloof	Open and natural	56%,	Plantations	33%	Crops	11%
Henley	Open and natural	37%,	Plantations	7%	Subsistence farming	54%

In the real world situation the impact of urban runoff to water quality in a catchment will depend on the ratio of urban: rural land area. In some cases urbanisation may be insignificant as a source of nutrients to a river or impoundment. Using the above data, hypothetical cases may be considered for moderate urban developments of 5 km^2 in the Midmar and Karkloof catchments. This would amount to 0,6 and 1,5 per cent urbanisation in the Midmar and Karkloof River catchments respectively. Corresponding increases in soluble and total phosphorus compound export coefficients of 26 and 23 per cent respectively for Midmar and 60 and 48 per cent for Karkloof would be possible. Whether or not such increases would result in water quality degradation is not the point here. Rather, the point is that a relatively small development can have a significant influence on catchment nutrient flux. Factors such as these need to be taken into account when siting an urban development in catchments so that measures to reduce pollution may be considered by planners.

Conclusions

Data analyses have shown the wide variability of runoff quality both during rainfall events and also between mean event concentrations. A "first flush" effect was observed and high concentrations of pollutants during events were associated with peak flows. It follows that in order to obtain representative samples for events, sampling strategy should be based on a flow rather than a time-interval basis, otherwise large errors may be incurred in either assessing quality or in calculating runoff loads.

Annual mean concentrations in runoff for the 3 years of the study were inconsistent due to different rainfall cycles. In the higher rainfall years concentrations of suspended solids and inorganic nitrogen were higher than in the low rainfall year due to more washoff and leaching from the pervious areas of the catchment. Export coefficients of all pollutants were very much higher in the wet years by factors up to 3,9 for inorganic nitrogen compounds, 3,5 for suspended solids and 1,8 and 1,7 times for soluble and suspended forms of phosphorus compounds respectively. Because of the highly variable annual export coefficients reported here, due cognizance should be taken in any future studies of hydrological conditions experienced when assessing how representative the results are.

Urban runoff is a potential threat to the environment both as a source of harmful and toxic elements and as a source of the plant nutrients which promote eutrophication in waters. Maximum concentration criteria for suspended solids, lead, iron and zinc for the protection of aquatic life were greatly exceeded by the 3-year weighted mean concentrations in runoff. Mean event concentrations of other toxic metals measured were greater than median criteria given. The real environmental threat will depend upon the dilution achieved in receiving water courses.

Compared to large rural land-use catchments, export coefficients of total nitrogen and phosphorus compounds from the urban catchment of this study were greater by factors of 9 to 15 and 15 to 39 times respectively. The net effect of urbanisation within catchments on nutrient enrichment in receiving waters will, however, depend upon the ratio of developed to undeveloped land.

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