Rural Rivers and the Impact of Rural Development on Rivers and Water Supply

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A simulatIon model, WASHMO, is used to illustrate how development influenced flood peaks and volumes for the 1:50 year event. The impact of storm water on the channel, and the water quality of rivers are discussed. Suggestions are made for better storm water control.

The morphology and dynamics of rivers are not only related to each other, but are also dependent on environmental variables. All these variables interact to determine the configuration of rivers and the processes and rates of their operation in a specific fluvial system. Whenever one or more of the determining environmental factors change, there is a response which alters the dynamics and morphology of the river (Morisawa, 1985). Development has dramatic effects on the hydrology of a catchment such as introducing large water imports, often from other basins, and changes to the precipitation and evaporation regimes (Kuprianov, 1988). Fundamental changes also occur to the surface in the form of impermeable areas which inhibit infiltration and lead to larger volumes of direct runoff. The impervious areas, furthermore, prevent groundwater replenishment, whilst larger quantities of groundwater are often used. The base flow in rivers under the influence of development, therefore, progressively decreases (Kuprianov, 1988). The smoothing of surfaces reduces the capacity of depression storage, which, coupled with the provision of concrete-lined pipes and channels, increases stormwater flow velocities. This in turn shortens the response time of catchments. The provision of concrete-lined channels in major watercourses also reduces the flow area with a similar reduction in the available in-channel storage of these watercourses, resulting in higher peak flow rates at the downstream end (Stephenson, Green and Lambourne, 1986).

The impact of this increased runoff on stream flow is discussed by, amongst others, Leopold (1978) and Beard and Chang (1979) while the overall complicating effect of development on the hydrological cycle is presented by Schneider (1975) and Alley and Veenhuis (1983).

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The increased flow rates and flow volumes which follow development disturb the equilibrium of streams resulting in increased bed and bank erosion. However, negative feedback effects could eventually allow a stable adjustment to be reached under the new conditions (Morisawa, 1985).

DEVELOPMENT AND FLOODS

Some of the changes that are caused by the development of a catchment are difficult to detect especially when the hydrometric records are short termed. Streamflow is a good example, and changes in it are therefore often studied with models. Ullah, Marsalek and Pollock (1988) used a model to study the effects of development on the water resources of the Waterford River Basin, England and Niemczynowicz (1988) used the Storm Water Management Model in a simulation of the effects of permeable pavements on discharge near Lund, Sweden.

In this study the Watershed Multiple Options Model (WASHMO), which is based on the Soil Conservation Service method, was used to illustrate how development changed the stormflow in the Palmiet river catchment. One rainfall event, the hypothetical one day 50 year event of 250 mm was analyzed. This event is important because the flood peak water level associated with it is often regarded a line below which development may not take place.

MODEL VERIFICATION

Ward, Wilson and Bridges (1980) demonstrated that the WASHMO model is capable of simulating the hydrological response of a catchment with only a limited amount of calibration data. An evaluation was made in four urban catchments and a rural catchment in Kentucky, U.S.A. Twenty storm events were used in the study.

To extend the application of the WASHMO model to southern African conditions, a further evaluation was made with data from three catchments in Natal and two catchments in KwaZulu. A total of 19 storm events were used in this evaluation (Middleton, Ward and Van Schalkwyk, 1984). De Villiers (1985) also undertook an evaluation involving four rural catchments, one urban catchment, and 20 storms, varying in depth between 50 mm and 100 mm. The urban catchment is situated in the Pinetown CBD, in the Palmiet catchment.

A statistical analysis was conducted on the data of the studies by Ward et al. (1980), Middleton et al. (1984) and De Villiers (1985) to determine the ability of the model to predict peak discharges and flow volumes for the different storm events. With coefficients of determination (R^2) for the three studies respectively above 0.80, it follows that the model gave fairly good estimates of the peak discharges and flow volumes for most of the events. A further study which also involved WASHMO was undertaken by Campbell, Ward and Middleton (1986; 1987). Seven models, namely: Rational (NTC Model), SCS WASHMO, SCS-SA, SCS-USA, HDYPOI, Illudas and Witwat were evaluated in 26 catchments. In the latter study WASHMO performed adequately with large storms, but under-prediction occurred with smaller events. The authors concluded by stating that in general the models did not perform adequately with uncalibrated parameters, but that they did work adequately with calibrated parameters. Schulze, Schmidt, Neuwirth and Weston (1986) subsequently undertook a statistical analysis of the Campbell et al. (1986) evaluation which excluded rainfall events of less than 20 mm. From their findings it was concluded that the SCS-based models performed well enough to be recommended for design purposes.

STUDY AREA

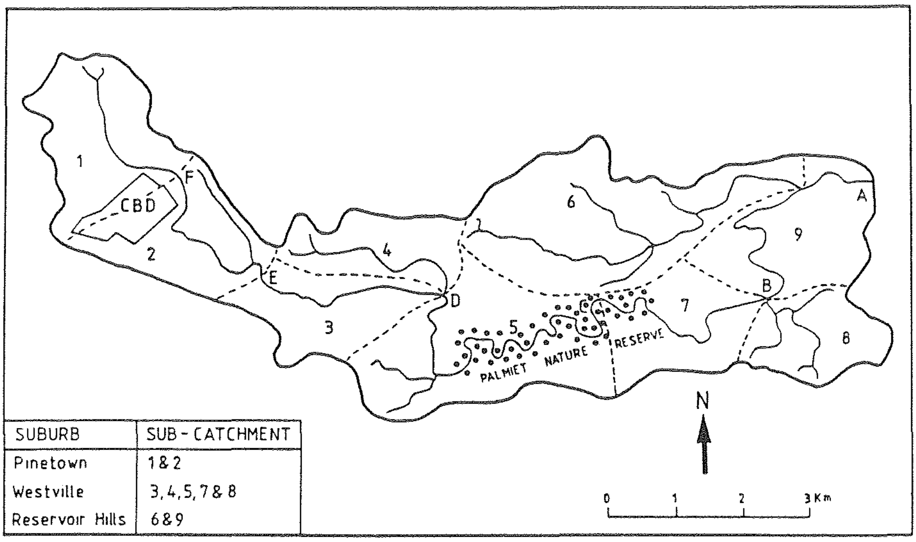
The study focusses on the short coastal rivers around the city of Durban, Natal, which is situated on the east coast of South Africa. The topography of the region is undulating and well dissected by rivers like the Palmiet, Isipingo, Umbogintwini, Amanzimtoti and Umbilo. The mean annual rainfall for the region is 1,000 mm and development is in an advanced stage in most areas. The Palmiet catchment (37 km^2) is, for example, fully urbanized with the exception of a small nature reserve, and scattered relics of subtropical forests and grassland. The effects of development on flood peaks was studied in this river, whilst pollution and river development problems were analysed in the others.

METHODOLOGY

The Palmiet drainage region was first divided into nine sub-catchments (Fig. 1). This division was based on land-use, soils, geology, drainage pattern, channel characteristics and overland slope. Land-use and soil type are required for calculating the runoff curve numbers. Four basic land-uses were distinguished in the study area, namely business areas, industrial districts, residential areas and a nature reserve. The lot sizes in the residential areas varied between 1,000 m^2 and 2,000 m^2. Land-use and the proportions of a particular land-use type in relation to the area of the sub-catchment was determined from orthophotos. Open spaces, parks and parking lot areas were also quantified and adjustments were made for these.

The classification of soil types was based on the parent rock material and soil sampling and analysis in selected parts of the catchment. Four soil groups were identified, viz. B, BC, C and CD. Soil group B has a moderately low runoff potential, soil Group C a moderately high runoff potential, whilst BC and CD are intermediate soil groups. Soil type CD, which has a relatively high runoff potential, covers more than 50 percent of the area of the main catchment. The hydrological conditions of the land-use categories, as described by Schulze and Arnold (1979) and Schmidt and Schulze (1987) were accepted for the purpose of this study. These are 85 percent impervious conditions for the CBD, 72 percent for the industrial districts, 25 percent impervious conditions for high income group housing and 38 percent for middle income group housing. Plot size was the determining factor in categorizing the housing types.

Figure 1: The Palmiet River catchment.



The model input variables viz: area, curve numbers, overland slopes, channel slopes, hydraulic length and channel length were subsequently calculated for each sub-catchment (Table 1). A further subdivision of the catchment was necessary in most cases to compensate for different land-uses within them. This resulted in composite curve numbers. The nine catchments are relatively small, the largest being just less than 600 ha. The average overland slope is, however, relatively steep, with only Catchment 2 below 10 percent. All the others have slopes above 20 percent. It can also be seen in Table 1 that urban land-use dominates in all the catchments with the exception of Catchment 7 with its nature reserve. It follows that the curve numbers are relatively high, which implies a relatively high runoff potential. In Table 1 hydraulic length refers to the length of the longest water course in the sub-catchment, and channel length to the distance from the sub-catchment exit to the confluence between the Palmiet River and the Umgeni River i.e., point A in Figure 1.

Riverflow hydrographs were generated for each subcatchment for one synthetic rainfall event, the 24 hour 1:50 year event of 250 mm. The influence of urbanization on the 50-year flood peak was subsequently determined by changing the curve numbers so that they conform to conditions of 80 percent veld and 20 percent forest i.e., a hypothetical predevelopment stage.

Table 1: Present-day land use and catchment information.

Sub-catchment	*Composite Curve Number*	*Unit Hydro-graph*	*Sub-catchment Area (ha)*	*Hydraulic Length (m)*	*Land Use*		
					Forest	*Urban*	*Veld*
1	85.2	Haan's	383.3	3268	2	94	4
2	89.9	Haan's	431.4	2567	2	95	3
3	83.3	Haan's	269.4	2929	2	95	3
4	83.0	Haan's	218.2	3010	3	94	3
5	83.4	Haan's	547.3	5517	5	90	5
6	77.7	Haan's	597.6	6722	4	93	3
7	73.2	Haan's	362.5	5090	30	69	1
8	78.6	Haan's	243.1	2346	2	95	3
9	75.3	Haan's	410.7	2764	3	95	2

continued:

Sub-catchment	*Over-land slope*	*Channel Characteristics*		
		Slope	*Length*	*Type*
1	22.3	2.6	20380	
2	9.2	1.3	17812	
3	26.7	2.7	14883	(all
4	22.3	2.7	14883	channels
5	22.2	3.5	9366	are
6	26.7	2.8	6722	natural
7	28.6	1.9	4276	streams)
8	23.7	2.9	4276	
9	25.7	2.1	0	

RESULTS AND DISCUSSION

Table 2 shows the simulated flow volumes and peak flow rates for the nine subcatchments for the hypothetical one day 50 year event of 250 mm rainfall. In considering the volumes from the urban areas, the fairly large flow from Catchment 2 is apparent. Although not the largest catchment, it generates the greatest flow volume, because of its high degree of urbanization. Catchment 2 generated on average 219 x 10^3 m^3 per 100 ha whilst Catchment 5 and 6 generated 198 x 10^3 m^3 and 180 x 10^3 m^3 respectively. The fairly large flow volume in Catchment 2 is mainly due to the Pinetown CBD which is located partly within the catchment. Table 2 also indicates relatively small differences between the simulated flow volumes of urban and rural land-uses, 21 percent being the highest and 4.1 percent the lowest difference. The first case again illustrates the influence of the CBD, and the second, the impact of the Palmiet nature reserve. The differences between urban and rural stormflow volumes are small because the hypothetical rainfall value (250 mm) is large in comparison with the initial abstraction (the depth of rainfall occurring before runoff commences) which was below 20 mm in all cases. For smaller storms this would not apply as the rainfall depth value would be closer to the initial abstraction. Any variation in the initial abstraction (i.e., from the rural to urban land-use) would therefore be reflected significantly in the discharge volumes. An increase in discharge volume due to urbanization would thus be caused mainly by increased runoff from small storms rather than from large, less frequent storms.

In considering the simulated urban peak flow rates, Catchment 2 again has the highest value (161.9 m^3s^{-1}) with Catchment 5 having about the same rate. The overland slopes of Catchment 2 are substantially less than those of Catchment 5. From this it follows that the CBD is the main agent that determines the relatively high flow rate in Catchment 2.

The differences in simulated peak flow rates between urban land-use and rural land-use (the hypothetical predevelopment stage) varied between just less than four times to nearly five times (Table 2). The increase in Catchment 2 is again the highest, although several of the other catchments show peak flow rate increases close to that of Catchment 2 in spite of a much lower degree of urbanization. In these catchments other factors, like relatively steep overland slopes and channel slopes apparently had a significant effect on the peak flow rates.

The effects of urbanization on the discharge are also visible in the flow velocities for the 50 year rainfall event which were calculated upstream and downstream of the Pinetown CBD (Figure 1). In the upstream section, which has a slope of 1:50, the velocities varied around 3 ms^{-1} whilst they doubled to about 6 ms^{-1} downstream of the CBD which has a slope of 1:80. In the eastern part of Catchment 3 the velocity dropped to 5 ms^{-1} in spite of a relatively steep slope of 1:60. The flow velocity values were calculated by the formula:

$$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

The n-values varied between 0.015 and 0.045. They were based on the advice of Pinewood Engineering section personnel.

From this it follows, that stormwater drainage in general, and flood peaks and flow velocities in particular, could develop into serious problems in rivers under influence of development. The problem is complicated by the greater flood frequency of the river, where even small storms could result in floods. Such a condition requires flood peak attenuation as well as adjustments and protection.

Table 2: Simulated changes in discharge volumes (x 10^3 m^3) and peak flow rates (m^3 s^{-1}) as a result of urbanization.

	Sub-Catchment No.	1	2	3	4	5	6
Discharge volume	Rural	692.3	779.2	486.6	394.1	996.5	942.6
	Urban	780.7	942.7	531.7	429.3	1085.4	1073.5
	% Increase	12.8	21.0	9.3	8.9	8.9	13.9
Peak discharge	Rural	33.9	32.7	29.6	20.6	32.7	38.3
	Urban	149.2	161.9	114.1	89.3	160.7	154.9
	% Increase	440	496	386	435	492	404

continued:

	Sub-Catchment No.	7	8	9
Discharge volume	Rural	574.2	365.8	597.5
	Urban	597.5	443.8	507.7
	% Increase	4.1	21.3	18.1
Peak discharge	Rural	21.8	23.4	29.1
	Urban	78.9	103.6	131.5
	% Increase	363	444	453

URBANIZATION AND THE STREAM CHANNEL

Changes in river channel morphology following urbanization have seen a growing number of studies (Harvey, 1969; Hollis and Luckett, 1976; Knight 1979; Morisawa and Laflure, 1979; Neller, 1988). Although enlargement appears to be the normal response of channels to the imposition of an urban regime, the extent of enlargement seems to vary with the nature of the channels.

The soils in the study region consists mostly of porous, well-weathered sands and loams with clay in the subsoils. These soils cannot resist the high velocity urban discharge. This results in dramatic channel changes throughout the study area. The data of five sites are presented in Table 3. It shows channel growth at different depths after an urban induced flood. The flood peak was in an out-of-bank condition at all the sites and particularly affected the sandy left bank over a distance of about 5 km. Drastic changes also occurred to the channel bed which was substantially raised. It is believed that the bulk of this deposition was merely a displacement of bank material to the river bed. This was confirmed by soil analyses which showed the homogeneous nature of the bed- and bank material.

Table 3: Cross-sectional channel growth (m^2) for 5 sections at different depths (m).

Depth	*Section AA* *1.5*	*Section AA* *3.0*	*Section AA* *4.5*
Before	22.13	75.40	164.60
After	47.94	180.62	371.66
Growth	25.81	105.22	207.06
%	116.6	139.5	125.8
Depth	*Section BB* *1.5*	*Section BB* *3.0*	*Section BB* *4.5*
Before	41.63	117.39	239.52
After	62.60	221.90	479.15
Growth	20.97	104.51	239.63
%	50.4	89.0	100.0
Depth	*Section CC* *1.5*	*Section CC* *3.0*	*Section CC* *4.5*
Before	35.06	80.25	143.48
After	102.71	253.21	408.27
Growth	67.65	172.96	264.79
%	193.0	215.5	184.5
Depth	*Section DD* *1.5*	*Section DD* *3.0*	*Section DD* *4.5*
Before	39.89	105.15	225.41
After	95.24	235.30	396.85
Growth	55.35	130.15	171.44
%	138.8	123.8	76.1
Depth	*Section EE* *1.5*	*Section EE* *3.0*	*Section EE* *4.5*
Before	35.01	111.39	291.54
After	97.09	281.63	501.26
Growth	62.08	170.24	209.72
%	177.3	152.8	71.9

With the exception of section BB in Table 3, all the sites experienced an average enlargement of more than 100 percent, with section CC showing an average enlargement value of nearly 200 percent. From this it follows that channel enlargement presents serious problems for further development and stabilization of the rivers which are of particular importance.

POLLUTION AND THE RIVER UNDER INFLUENCE OF DEVELOPMENT

The effects of watershed changes on water quality are real and frequently of serious consequence. Such changes may be of great variety, ranging from construction of impoundments to urban development and industrial expansion. Urbanization usually has a detrimental effect on water quality and the aquatic environment which necessitates a policy of adequate treatment, nondegradation and water quality management (Moore, 1969). The effects of urbanization on river water quality in South Africa have been studied, amongst others, by Hart, 1982; Watling and Watling 1982; Watling and Emmerson, 1981; Toerien and Walmsley, 1979, and Walmsley and Toerien, 1978.

The Natal Town and Regional Planning Commission in conjunction with the National Institute for Water Research, CSIR, also published several reports on water quality and abatement of pollution in Natal rivers (Natal Town and Regional Planning Commission, 1967, 1967(a), 1967(b), 1969, 1976). Simpson and Kemp (1982) and Simpson and Hemens (1978), in their assessment of urban stormwater quality in two concrete stormwater pipes in Pinetown, included the impact of atmospheric fallout.

Table 4 presents water quality data for the Palmiet river and the Polela river, a mountain stream which is not effected by urbanization. The data reflects the results of water sampling programmes between 1980 and 1991 in which samples were taken on a fortnightly and weekly basis at a minimum of six selected points. The deterioration in water quality over time and the difference between the water quality of urban and rural rivers are clearly illustrated. The deterioration in Palmiet river water quality could be explained by an increase in urbanization and urban activities. The median and maximum values for water quality criteria (Kempster, Hattingh and Van Vliet, 1982) were nonetheless only exceeded in less than 30 percent of the samples.

Figure 2 shows the changes in the mean dissolved solids content along the course of the river. From the figure it is apparent that the TDS values generally increased in a downstream direction. This is in keeping with previous findings that there is usually a deterioration in water quality downstream (Du Preez, 1985).

There is, furthermore, a marked increase in total dissolved solids in, and just below, the Pinetown CBD. The effect of industrial pollution is thus quite visible. The seasonal variation of the TDS is also illustrated in Figure 2. From the figure it is clear that the general pattern along the course of the river does not change from season to season. The most significant change is rather the general decrease in TDS values in summer and the concomitant increase in TDS values in winter.

Rivers are often also used as solid waste disposal sites. The study area is no exception. This type of pollution, together with low water quality, affects the recreational value and use of the river. It is unrealistic to expect river water qualities under the influence of development to be similar to that of mountain streams. However, the water quality of the river should be such as to allow for the survival of aquatic life and plants, and no solid waste disposal should be allowed in the river environment. From this it follows that education is very important in river management.

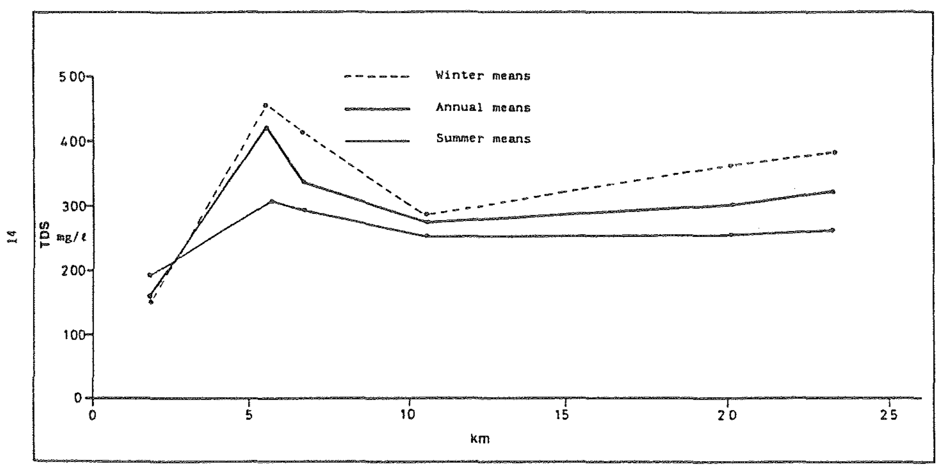
Table 4: Results of chemical analyses of the Palmiet and Polela river water: Annual geometric mean values for macro-analyses (mg/ℓ).

	pH	*Conductivity* (mSm^{-1})	Ca^{2+}	K^+	Mg^{2+}	Na^+	Cl^-
Palmiet river 1980/81	7.3	33.4	15.7	3.41	7.72	33.9	39.9
Palmiet river 1984/85	7.3	52.1	22.5	4.13	11.2	55.7	71.1
Palmiet river 1990/91	7.4	64.1	25.6	5.21	13.4	60.4	82.1
Polela river	6.7	5.10	4.42	0.45	1.91	2.31	1.7

continued:

	$PO_4^{3-}-P$	SO_4^{2-}	$NO_3^- - N$	$NH_4^+ - N$	*Si*	F^-	*Total Alkalinity*	*TDS*
Palmiet rv. 1980/81	0.092	26.1	0.97	0.15	6.4	0.18	50.5	184.9
Palmiet rv. 1984/85	0.039	39.5	1.48	0.22	8.9	0.36	41.6	302.4
Palmiet rv. 1990/91	0.074	48.6	1.74	0.31	9.4	0.42	44.4	362.3
Polela river	0.042	1.0	0.13	0.06	4.8	0.04	27.2	52.6

Figure 2: Changes in the mean dissolved solid content along the course of the Palmiet River.



CONCLUSION

In the past the river under influence of development was often degraded into an ill-smelling channel discharging low-quality water and was of no further use to man. It can alternatively be developed into an environmental asset, like a park or a protection area, with many recreational functions. Protection, maintenance, education and proper planning are essential components of river upgrading. An ecologically sound river is, however, an attainable goal.

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