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Verifying the NPS-WASHMO urban runoff component of the ACRU model

Summary

The collection and analysis of rainfall, stream flow and water quality data are described for an urban catchment used in model development. The data illustrates the existing hydrological conditions in the Palmiet River Catchment, and forms the basis of simulations for model verification. Grab water quality samples were collected once a week at ten points for two years and flow-related grab samples collected flood water quality samples at a weir. The results show an increase in water quality constituents in the flow from the Pinetown CBD and a decrease from the residential areas. The data is then used to verify the models, which are found to perform satisfactorily.

Verifiëring van die NPS-WASHMO stedelike afloop komponent van die ACRU-model

Die insameling en ontleding van reënval-, stroomvloei- en waterkwaliteitdata word bespreek. Die data illustreer die hidrologiese toestande in die Palmiet Rivier Opvanggebied, en vorm die basis vir simulasies vir modelstudies. Waterkwaliteitmonsters is een maal per week by 10 punte ingesamel vir twee jaar en 'n outomatiese monsternemer is gebruik om die kwaliteit van vloede te monster by 'n meetwal. Die resultate dui op 'n toename in besoedeling in die Pinetown sentrale sakekern en 'n afname in die woongebiede. Die resultate word dan gebruik om die modelle met bevredigend gevolge te toets.

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In a previous paper (De Villiers & Schmitz 1999) the development of an urban component of the ACRU model was discussed.[1] The topic of this paper is the verification of the models by means of hydrological data collected in the Palmiet River catchment area near Durban.

1. Study areas

Two areas were studied in the research, namely the Pinetown catchment and the Palmiet River catchment. The Pinetown catchment's data was collected by Simpson between 1982 and 1985 (Simpson 1986), while the present authors collected the data for the Palmiet catchment between 1992 and 1994.

The Palmiet River catchment is situated approximately 13 km to the west of Durban, between 29° 46,8' and 29° 50,2' South and 30° 50,2' and 30° 57,1' East. The river begins at Field's Hill just to the northwest of Pinetown CBD, then winds its way through Pinetown, including the CBD, through Westville, and past the University of Durban-Westville where it enters the Mgeni River close to the N2 viaduct near Springfield Flats. The area of interest is the Palmiet River from Field's Hill down to the weir at the University of Durban-Westville. The size of the catchment is 20,3 square kilometres.

The topography of the Palmiet catchment is undulating and dissected by the river except in the Pinetown CBD where it is relatively flat. The lowest point of the catchment is 78 m above mean sea level, at the weir at the University of Durban-Westville, and the highest point is 542 m at Field's Hill.

Figure 1 shows the main streams which are of interest to this project. The hydraulic length of the main channel is 15 330 m.

1 We thank the Water Research Commission for funding the project and all the individuals who assisted with it.

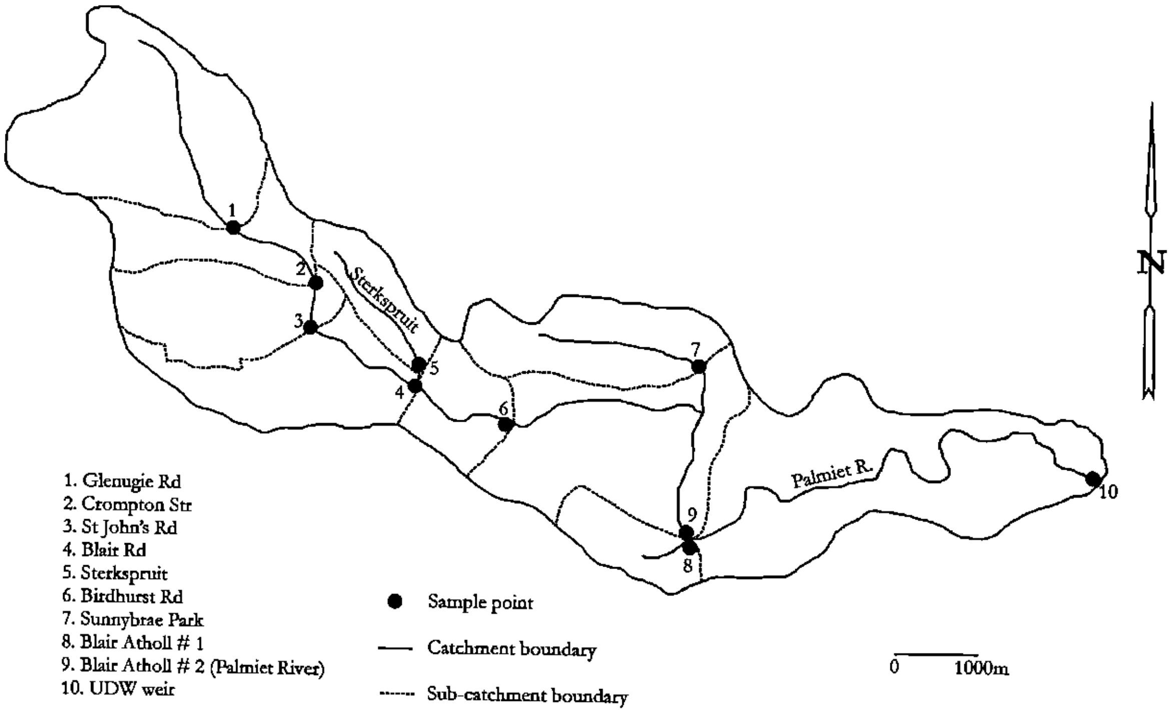


Figure 1: Hydrology and sub-catchments of the Palmiet River catchment

The soil data for the land types in the Palmiet River catchment was obtained from the Institute for Soil, Climate and Water (ISCW 1993). According to the ISCW (1993), a land type is an area displaying marked unifotmity of terrain, soil pattern and climate.

The following land types can be distinguished in the Palmiet River catchment: Aa12, Fa513, Fa504, Fa503, Fa501 and Fa505.

The vegetation in the Palmiet catchment varies from remnants of sub-tropical coastal forest and grassland, most dominant in the Palmiet Nature Reserve, to a mixture of indigenous and exotic trees and shrubs and lawns in the built-up areas of the catchment. Disturbed areas in the catchment have a high number of alien and invasive alien plants.

The Pinetown catchment is located in the western upper part of the Palmiet catchment within Pinetown's municipal area and is about 16 km to the west of Durban. The geographical location is 29° 48' South and 30° 51' East and it comprises 0,915 square kilometers (Simpson 1986).

The topography of the Pinetown catchment is relatively flat with a slope average of 2,5 percent. The height varies from between 318 m at the outlet of the catchment to 360 m above mean sea level. The catchment is fully reticulated for stormwater and fully separated from the foul sewer system. The hydraulic length of the reticulation system is 1 720 m (Simpson 1986: 26).

The only soil types present in the Pinetown CBD are those discussed under land type Fa504. Vegetation in the Pinetown catchment consists mainly of indigenous and exotic trees and shrubs and lawns in the built-up areas. Most of the open spaces in the Pinetown catchment are maintained open spaces with cut lawns and trimmed beds. Other open spaces in the catchment are disturbed areas with grass as well as indigenous trees and schrubs, benign aliens and invasive alien plants.

Table 1 shows the land-use in detail for each sub-catchment in the Palmiet catchment area.

Table 1: Land-use in the sub-catchments of the Palmiet River catchment

Sub-catchment	Land use (units = square kilometers)		
Glenugie Rd	Residential:	Medium	1.254
		Low	1.023
	Open spaces / Recreational		1.023
	Total:		3.300
Crompton St	Residential:	Medium	0.333
	Industrial		0.387
	Open spaces / Recreational		0.180
	Total:		0.900
St John's Rd	Residential:	High	0.088
		Medium	0.704
	Industrial		0.572
	Commercial		0.528
	Open spaces / Recreational		0.308
	Total:		2.200
Blair Rd	Residential:	Medium	0.060
	Industrial		0.800
	Commercial		1.140
	Total:		2.000
Sterkspruit	Industrial		0.658
	Open spaces / Recreational		0.042
	Total:		0.700
Birdhurst Rd	Residential:	Medium	0.528
	Open spaces / Recreational		0.572
	Total:		1.100
Sunnybrae Park	Residential:	Medium	1.748
	Open spaces / Recreational		0.552
	Total:		2.300
Blair Atholl #1	Residential:	Medium	1.200
	Total:		1.200
Blair Atholl #2 (Palmiet River)	Residential:	Medium	3.100
	Total:		3.100
UDW	Residential:	Medium	2.765
	Commercial		0.035
	Open spaces / Recreational		0.700
	Total:		3.500

According to Simpson (1986: 32) the land use in the Pinetown catchment is 30 percent commercial, 19 percent light industrial and 51 percent multiple and single residential areas and parkland.

2. Methodology

Water samples were collected on a weekly basis at ten points along the Palmiet River and its tributaries for a period of two years from 1 October 1992 to 30 September 1994. Rainfall data was collected for the same period using a syphon and a standard rain gauge. At the weir, which was one of the ten sample points, water samples were collected on a weekly basis as well as on days of high flow. All the collected samples were sent to the Waste Water Treatment Works of the Pinetown municipality for water quality analysis. The water samples from high-flow events were collected with the aid of an ISCO sampler, which took a 200 ml sample for every 5 cm rise or fall in the level of the river's flow. Samples from three high-flow events were sent to Umgeni Water for analysis of water quality changes by means of a hydrograph. All the data recorded was sent to the Dept of Agricultural Engineering for digitising purposes, and the digitised data was downloaded onto the computer at the Computing Centre for Water Research (CCWR).

Data collected by Simpson (1986) on the Pinetown catchment were used to test the model on a fully reticulated catchment. Verification runs were done to test and calibrate the model against the data collected in order to provide realistic outputs from the various simulation runs.

3. Rainfall

A syphon recording rain gauge measured continuous rainfall data on weekly charts. A standard rain gauge was used to record daily rainfall and was also used as a control. The standard rain gauge provided a backup of daily rainfall values in case the recording rain gauge broke down. Both rain gauges were set up on the terrain of the University of Durban-Westville's meteorological station. The charts were sent to the Dept of Agricultural Engineering at the University of Natal to be digitised. The digitised rainfall data was used for the simulation runs on the Palmiet catchment.

Figure 2 depicts the monthly rainfall values for the period October 1992 to September 1994. The second year (October 1993 to September 1994) shows a higher rainfall than the first year. The annual totals are 530 mm for October 1992 to September 1993 and 1054 mm for October 1993 to September 1994. The low values in the first year coincide with a severe drought experienced in 1992 and 1993. The mean annual rainfall for the area is about 1000 mm (Weather Bureau 1984), which suggests that the rainfall total for the second year was normal for the region, while the first year received only approximately half of the mean.

The daily rainfall data used in the Pinetown catchment was obtained from the Computing Centre for Water Research (CCWR) and the individual storm distributions at two-minute intervals were obtained from Simpson (1986: 36).

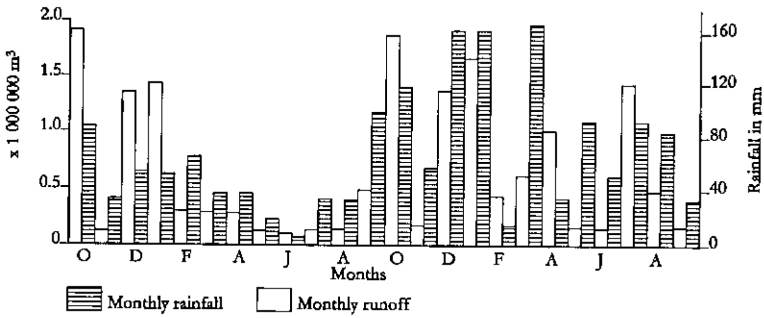


Figure 2: Monthly rainfall and runoff totals in mm from October 1992 to September 1994

4. Stream flow

Stream flow was recorded at a rectangular weir constructed in the Palmiet River on the campus of the University of Durban-Westville, which is situated in the lower part of the catchment.

The stream flow was recorded on a flow level recorder using a six-week roll chart. The charts were also sent to the Dept of Agricultural Engineering at the University of Natal, Pietermaritzburg, for digitising purposes. The flow at the other sampling points in the Palmiet River was established using a one-litre beaker for the smaller tributaries and a five-litre bucket with a stop-watch. The volume of the filled beaker or bucket, divided by the number of seconds it took to fill, gave the flow in litres per second. Figure 1 also gives the monthly runoff from the Palmiet catchment at the weir and clearly shows the wet and dry seasonal flow. The runoff is distinctly lower in the first year (October 1992 to September 1993) than in the second year (October 1993 to September 1994), due to the drought experienced in 1992 and 1993.

5. Water quality

Although a large variety of constituents can pollute water resources it was decided to use only parameters common to urban areas. These parameters are: chemical oxygen demand (COD), chlorides, nitrogen, total phosphorus, suspended solids, total dissolved solids (TDS) and the following heavy metals: chromium (Cr), copper (Cu), zinc (Zn), nickel (Ni), lead (Pb) and iron (Fe). These constituents also form part of the Pinetown municipality's water sampling programme which aims at detecting pollution from several sources in the Palmiet catchment.

5.1 Water sampling methods

Water samples were collected by two methods. The first method was the use of weekly grab samples from the sampling points given in Figure 1. Each of the sampling points was chosen to represent certain dominant land use types such as commercial, medium density residential or industrial land use. The reason for this was to establish base flow values for each of the constituents over a period of two years. These values were then compared with the high-flow values. The analysis was done by the Waste Water Treatment Works of the Pinetown municipality. In total, 88 samples were collected at each point.

High-flow samples were collected only with an automatic sampler at the weir. The sampler was programmed to collect a sample when the stream level rose or fell by 5 cm, in order to establish changes in water quality by means of a hydrograph. Three of these storm events were analysed by Umgeni Water and will be discussed later. For the other storm events a composite sample was taken and analysed by the Pinetown municipality. The results from these samples are discussed in the next section.

6. Data analysis

Table 2 gives the monthly base flow water quality values for twelve constituents at two of the ten sampling points, namely St John's Road in the Pinetown CBD and the exit of the catchment. The St John's Road values are generally higher than the other values, demonstrating the impact of the CBD. Metals in particular are substantially higher at St John's Road. Total phosphorus (TP) testing was done only on samples from the last four points, i e Sunnybrae Park (SBP), Blair Atholl 1 (B/Atholl #1) and Blair Atholl 2 (B/Atholl #2), and the weir at the University of Durban-Westville (UDW). The first six sampling points form part of Pinetown municipality's ongoing monitoring programme, which does not include the testing of total phosphorus. To avoid duplication, the data from the Pinetown municipality were incorporated into the data collected at the last four points for the duration of the project.

One of the salient features of the non-point source models is the inclusion of monthly base flow water quality values for streams, in order to include the effect of base flow on the water quality of the stream. Johanson *et al* (1984) used monthly base flow water quality values (or a single value) to facilitate the determination of this effect and it was decided to include these values to represent water quality during non-rainfall events. The aim of establishing a monthly base flow water quality data base is to be able to make provision for monthly changes in water quality. To illustrate the monthly changes, suspended solids, chloride and copper will be used as examples in this discussion.

For suspended solids (SS) (Table 2 and Figure 3) it is difficult to find a common trend based either on seasonal fluctuations or on data from the sampling points along the Palmiet River. During certain months of the year there is a high concentration of SS, while other months show a lower concentration. This irregular pattern could possibly be ascribed to earthmoving activities in the Sterkspruit and Blair Road areas. The residential areas, Glenugie, Birdhurst Road, Sunnybrae Park, Blair Atholl #1 and #2 and UDW, however, show a more uniform trend than the other sampling points. The higher concentrations recorded in the winter months could be related to lower flow.

St John's

Chemical (mg/1)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Average
COD	47	79	65	19	39	48	43	39	56	56	67	41	49.9
Cl	61	49	58	60	62	52	57	80	69	66	61	64	61.6
Nitrate	0.8	1.4	1.8	1.4	1.0	1.2	1.4	1.4	2.0	1.8	1.0	1.5	1.392
TP													
Sus solids	250	282	287	271	310	236	253	308	319	345	289	288	286.5
TDS	288	277	291	305	312	274	285	329	332	332	291	315	302.
Cr	0.012	0.009	0.006	0.043	0.021	0.024	0.008	0.028	0.026	0.026	0.025	0.007	0.020
Cu	0.081	0.045	0.066	0.026	0.087	0.084	0.056	0.156	0.024	0.031	0.027	0.048	0.061
Zn	0.068	0.210	0.225	0.469	0.204	0.196	0.332	0.622	0.456	0.745	0.543	0.462	0.378
Ni	0.013	0.018	0.038	0.002	0.027	0.014	0.047	0.039	0.040	0.014	0.032	0.055	0.028
Pb	0.020	0.012	0.017	0.008	0.014	0.012	0.023	0.009	0.009	0.016	0.016	0.015	0.014
Fe	0.540	0.700	0.960	0.670	0.790	1.290	0.660	0.870	0.920	1.110	0.960	0.620	0.841

UDW

Chemical (mg/l)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Average
COD	42	48	56	43	30	32	31	37	44	75	35	48	43.5
Cl	61	60	56	56	46	51	58	56	63	64	62	61	57.8
Nitrate	0.7	0.7	1.0	1.4	0.9	0.7	1.0	1.2	0.9	1.2	0.7	0.7	0.925
TP	0.3	0.5	0.3	0.4	0.2	0.1	0.2	0.3	0.2	0.2	0.6	0.5	0.317
Sus Solids	263	230	273	238	219	222	269	262	291	320	267	261	259.6
TDS	253	267	350	223	232	234	235	257	292	264	274	274	262.9
Cr	0.001	0.007	0.004	0.004	0.009	0.016	0.006	0.011	0.011	0.016	0.008	0.011	0.009
Cu	0.033	0.008	0.012	0.008	0.008	0.005	0.006	0.008	0.011	0.008	0.006	0.004	0.010
Zn	0.011	0.035	0.054	0.038	0.046	0.035	0.025	0.053	0.076	0.042	0.027	0.032	0.040
Ni	0.005	0.005	0.005	0.009	0.007	0.012	0.007	0.006	0.006	0.006	0.007	0.016	0.008
Pb	0.010	0.005	0.005	0.021	0.004	0.010	0.007	0.008	0.024	0.008	0.006	0.009	0.010
Fe	0.270	0.360	0.420	0.460	0.300	1.400	0.780	0.350	0.570	0.480	0.410	0.290	0.508

Table 2: Palmiet River: Average monthly water quality values (October 1992 - September 1994) at two sampling points

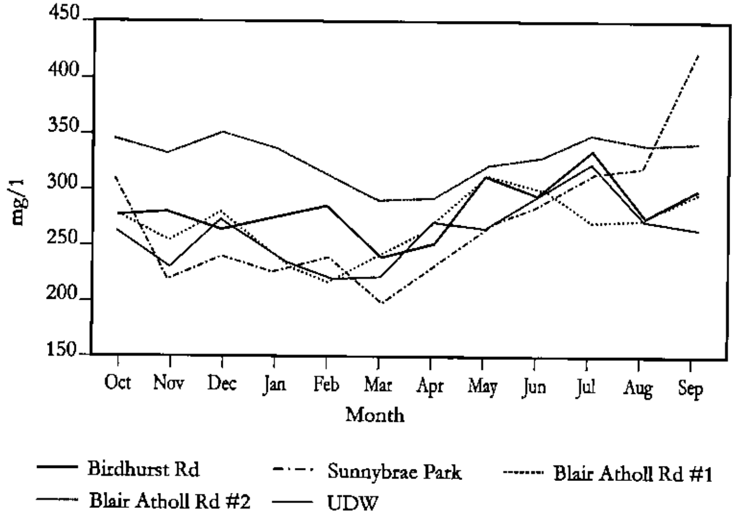
At many of the sampling points, the lowest chloride concentrations appear during February, March and April. This can be attributed to the higher flows during this period.

According to Figure 5 there is a difference between predominantly non-residential and predominantly residential areas in terms of fluctuation in copper concentrations on a monthly basis. The non-residential areas, such as those around Crompton Street, St John's Road, Blair Road, Sterkspruit and Birdhurst Road, show fairly high fluctuations from month to month, when compared with the values of the residential areas. The only exception is Glenugie Road, which is residential, where the same trend as in the non-residential areas may be seen. A possible explanation is that, since the Arthur Hopewell Highway forms part of the sub-catchment's boundary, the higher copper content may originate from the deposition of copper from the rivets in clutchplates and brake shoes of motorcars, which then washes off the road into the Palmiet River. The primary sources of pollutants from motor vehicles are, according to Ahmed & Schiller (1980: 11), oil, grease, tyre fragments, brake lining fragments and exhaust fumes.

Another possible reason for the high copper content at Glenugie Road is the leaching of copper in solution from the old landfill site in the upper reaches of the Palmiet River. If the rainfall is sufficient, the copper in solution is flushed out from the landfill and enters the stream, causing a rise in the coppet content of the water (Dunlevey 1995). Motor vehicles and spillages from other sources such as electro-plating facilities are primary sources of copper in the Palmiet River in the non-residential areas. The fairly constant presence of copper in the samples from residential areas can be ascribed to the regular movement of traffic, as well as to the settling of copper, which is relatively heavy, onto the stream bed upstream from the residential areas.

7. Annual base flow data

Table 3 gives the annual average concentration in mg/l of the constituents at sample points along the Palmiet River's main stream. In this discussion the tributaries are excluded in order to highlight the



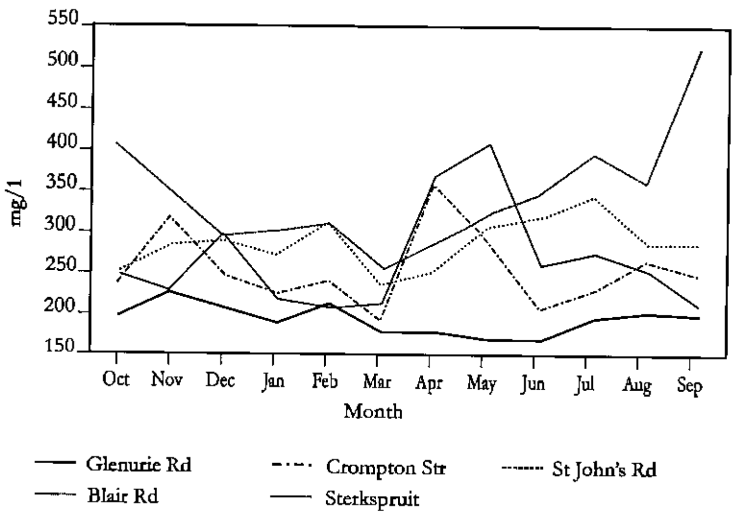
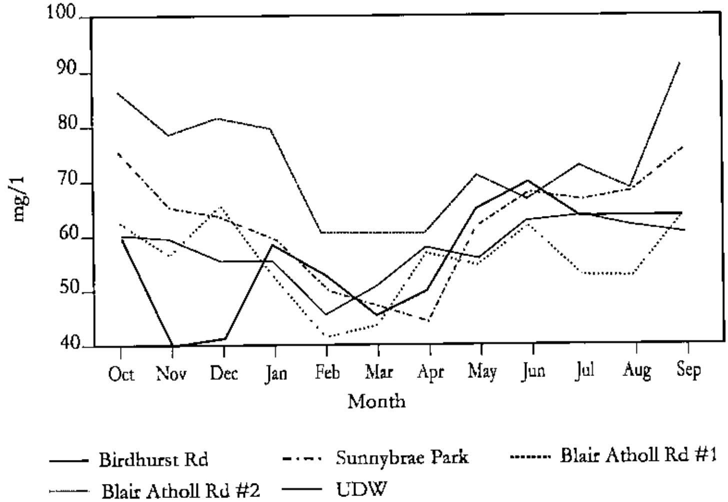


Figure 3: Monthly changes in suspended solids at various points in the Palmiet River (Average monthly values from October 1992 to September 1994)



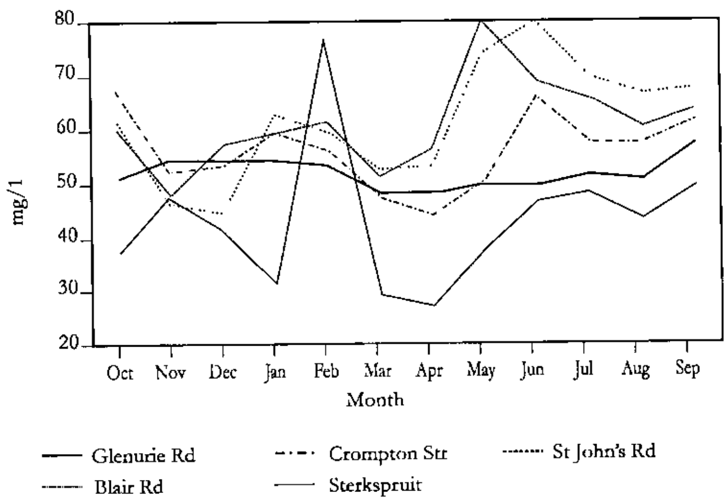
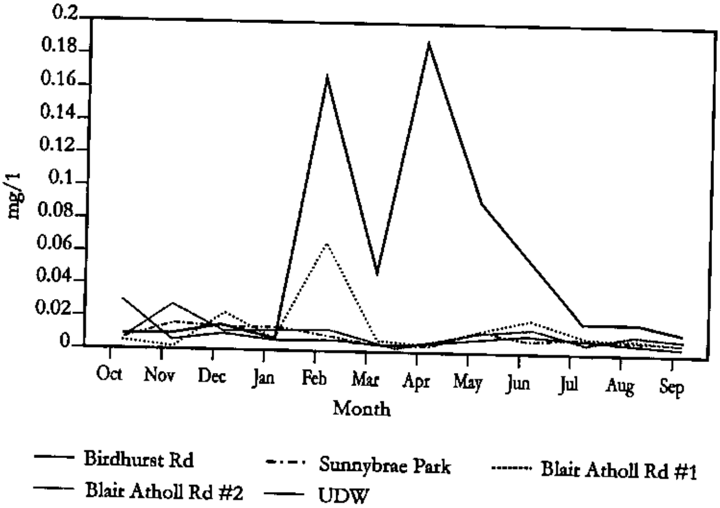


Figure 4: Monthly changes in chlorides at various points in the Palmiet River (Average monthly values from October 1992 to September 1994)



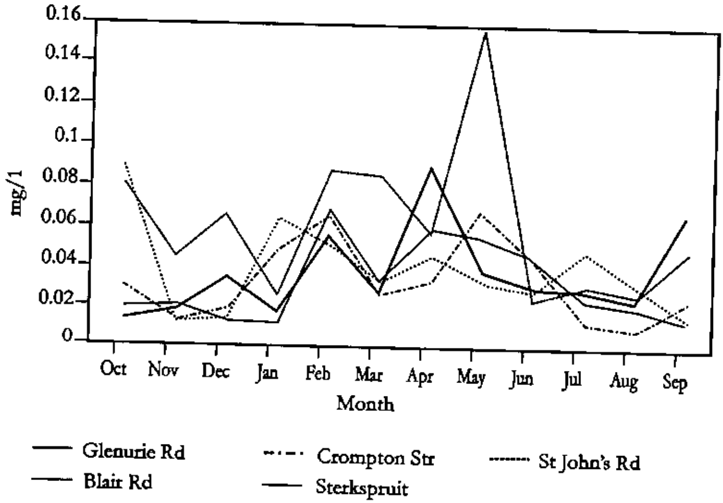


Figure 5: Monthly changes in copper at various points in the Palmiet River (Average monthly values from October 1992 to September 1994)

changes in water quality in the main stream itself. The aim of this table is to explain the influence of land use patterns on the chemical content of the receiving bodies of water. The high nitrate content at Glenugie is probably the result of the vehicular traffic on the highway and of the use of garden fertilisers in the residential area. The other constituents show an increase in the industrial and commercial areas, and a decline as the river passes through residential areas.

Chemicals Annual ave (mg/l)	Sampling points						
	Glenugie	Crompton	St John's	Blair Rd	Birdhurst	B/Athol#2	UDW
COD	26.1	27.1	49.9	85.3	36.2	44.2	43.4
Cl	52.5	56.7	61.7	61.9	56.6	55.8	57.8
Nitrate	2.430	1.080	1.390	1.250	0.860	1.380	0.930
TP						0.480	0.320
Sus solids	194.0	255.0	287.0	345.0	280.0	267.0	260.0
TDS	242.0	255.0	303.0	324.0	316.0	272.0	263.0
Cr	0.016	0.015	0.020	0.021	0.016	0.012	0.009
Cu	0.037	0.033	0.061	0.038	0.054	0.015	0.010
Zn	0.037	0.061	0.378	0.216	0.205	0.068	0.040
Ni	0.010	0.067	0.028	0.015	0.018	0.013	0.008
Pb	0.012	0.010	0.014	0.011	0.011	0.009	0.010
Fe	0.554	0.646	0.841	1.205	0.907	0.497	0.508

Table 3: Palmiet River main stream: annual averages at seven sampling points

8. Base flow data against high-flow data

Table 4 shows the data from high-flow events, giving the chemical constituents in mg/l and the flow in litres per second. These are composite samples taken with the sampler at the UDW weir. Some of the water quality values are lower than the annual average values for base flow. This may be attributed to the fact that there was little wash-off from the catchment during such events and that dilution occurred, which lowered the concentration of the given constituent.

Chemicals (mg/l)	Date										Annual Average
	12/11/92	16/11/92	11/12/92	12/12/92	09/01/93	08/02/93	03/03/93	15/03/93	27/04/93	11/08/93	
COD	51	18	76	46	58	37	21	76	20	30	43
Cl	64	54	47	50	65	26	56	32	52		58
Nitrate	2.0	1.0					3.4	0.2	1.0	1.0	0.93
TP	0.84	1.1	0.2		0.9	0.19		0.03	0.21	0.31	0.32
Sus solids	291	248	193	189	260	209		740	278	531	260
TDS	301	247	212	205	192	151	212	158	233	212	263
Cr	0.013	0.015	0.003	0.010	0.001	0.003	0.010	0.001	0.023	0.045	0.009
Cu	0.003	0.015	0.030	0.003	0.015	0.001	0.005	0.010	0.015	0.015	0.010
Zn	0.010	0.040	0.033	0.048	0.003	0.001	0.001	0.035	0.120	0.250	0.040
Ni	0.003	0.008	0.003	0.005	0.003	0.003	0.001	0.001	0.018	0.003	0.008
Pb	0.008	0.001	0.003	0.001	0.001	0.008	0.001	0.050	0.035	0.103	0.010
Fe	0.240	1.040	0.035	0.033	0.110	0.580	0.450	1.620	2.800	3.290	0.508
Flow (Vs)	797	952	652	952	6780	5708	4185	531	625	2305	

Table 4: High flow vs baseflow values at UDW weir

9. Hydrograph water quality sampling

Samples from three high-flow events were sent to Umgeni Water for chemical analysis. Table 5 shows the change in concentration for two events, while Figures 6 and 7 show the hydrographs and the points at which samples were taken. In all three cases, the first flush effect can be clearly detected.

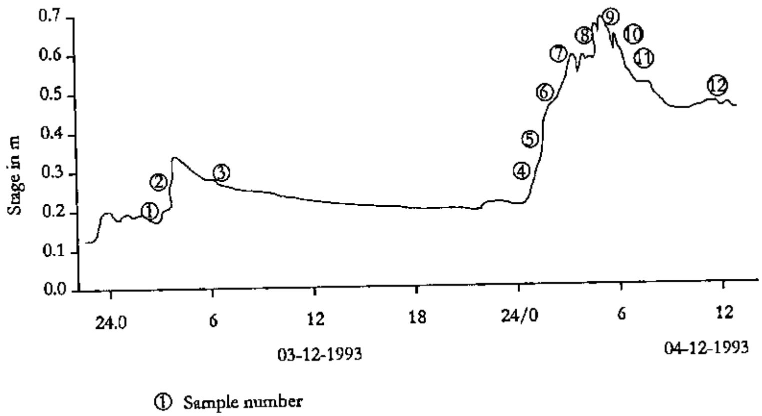


Figure 6: Hydrograph of 3 and 4 December 1993

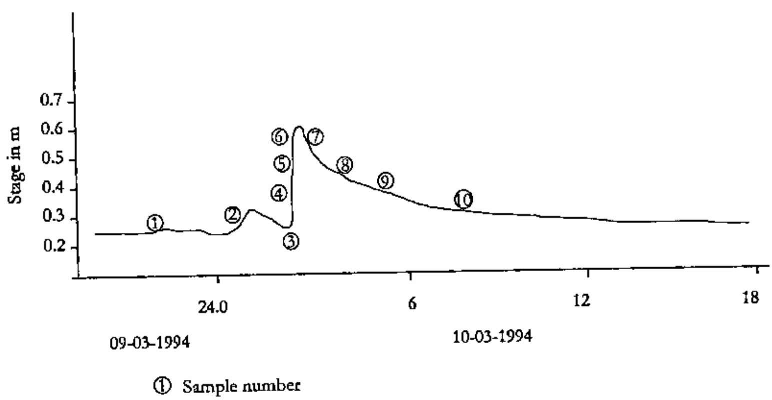


Figure 7: Hydrograph of 9 and 10 March 1994

Date	04/12/93						
Sample	SS mg/l	TP ug/l	NO_3 mg/l	Cu mg/l	Cr ug/l	Pb ug/l	Zn mg/l
1	293	456	1.37	<0.02	0.8	2.9	0.26
2	341	514	1.54	<0.02	1.7	2.8	0.34
3	618	1187	1.71	0.03	4.3	3.9	0.66
4	276	479	1.56	<0.02	1.1	1.3	0.29
5	367	505	1.33	<0.02	1.5	2.1	0.32
6	130	234	0.87	<0.02	<0.5	<1.0	0.12
7	82	173	0.89	<0.02	<0.5	<1.0	0.08
8	96	206	0.96	<0.02	<0.5	<1.0	0.10
9	77	159	0.88	<0.02	<0.5	<1.0	0.08
10	30	117	0.74	<0.02	<0.5	<1.0	0.04
11	18	98	1.25	<0.02	<0.5	<1.0	0.02
12	18	139	0.88	<0.02	<0.5	<1.0	0.02
Date	09/03/94						
Sample	SS mg/l	TP ug/l	NO_3 mg/l	Cu mg/l	Cr ug/l	Pb ug/l	Zn mg/l
1	64	88	0.94	0.03	11.5	<1.0	0.40
2	503	463	0.66	0.06	35.5	7.0	0.18
3	810	1088	0.56	0.05	67.5	20.0	0.42
4	199	1462	0.34	0.05	84.0	26.0	0.68
5	242	462	0.63	0.04	47.0	50.1	0.29
6	127	411	0.66	0.03	42.5	37.0	0.29
7	140	252	0.76	<0.02	27.9	26.0	0.13
8	62	279	0.85	0.04	24.5	36.0	0.14
9	89	289	0.86	<0.02	27.0	29.5	0.17
10	94	255	0.94	0.03	19.5	24.0	0.13

Table 5: Changes in concentration on a hydrograph reflecting two events

10. Weekly fallout rates

Weekly bulk atmospheric fallout rates were collected and analysed with a spectro-photometer. Table 6 shows the weekly fallout rates as well as corresponding constituents from Simpson (1986). The reason for this procedure was to compare the two sites in terms of fallout, since both are in urban settings.

Chlorides, chromium, lead, nitrogen and suspended solids all compare well. The difference in the results for copper, zinc and phosphorus may be ascribed to emissions from the University of Durban-Westville's campus. These values may therefore not be a true reflection of general fallout rates for residential land use, yet it is important to simulate the impact which a university has on its immediate environment in terms of pollutant deposition and washoff, leading to the eventual conramination of bodies of water. The stormwater runoff from a university will eventually end up in a body of water via its storm-water drainage system.

Constituent	UDW kg/ha/wk	Simpson 1986 kg/ha/wk
Chloride	0.8600	0.8000
Copper	0.0220	0.0022
Chromium	0.0060	0.0040
Lead	0.0090	0.0110
Nitrogen	0.2300	0.2800
Zinc	0.4100	0.0160
Suspended solids	7.0000	6.1000
Phosphorus	0.1070	0.0120

Table 6: Weekly fallout rates for selected constituents

11. Model applications

Since the Pinetown catchment area was used as a control in testing the improvements and changes made in the various models, the results from this catchment will be discussed first. A consideration of the applications to the Palmiet River catchment will follow.

Water quality simulations in terms of annual export loads in kg/ha/a were done with ACRU-NPS on the Pinetown catchment. No base-flow simulations were done since this is a fully reticulated catchment. After plotting the observed and the simulated values, it became clear that the model closely simulates the observed values, except for chlorides where the model tended to under-simulation. The model also over-simulated the values for zinc.

Eleven rainfall events from Simpson's (1986) study were used to test the WASHMO model's incorporation into ACRU. Since these were single-storm events, ACRU was also run as a single-storm event hydrograph model.

The rainfall increment occurs at a two-minute interval and the same interval is used for WASHMO's own rainfall distribution option in ACRU. Figures 8, 9 and 10 show some of the observed and simulated hydrographs, together with the rainfall distribution.

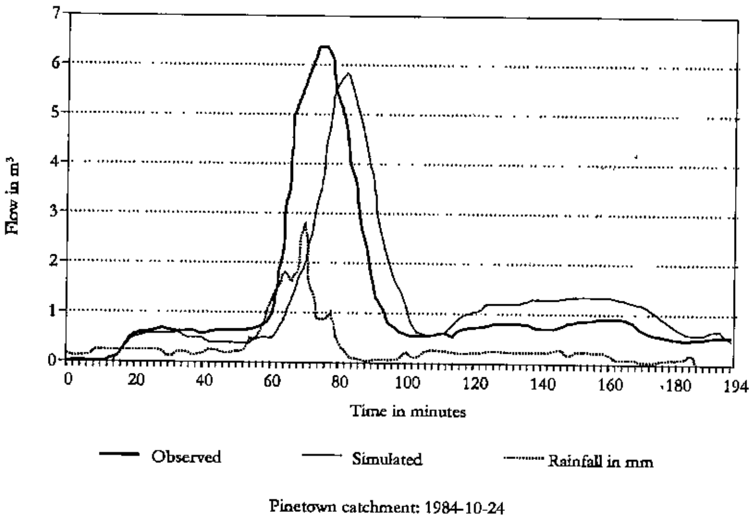
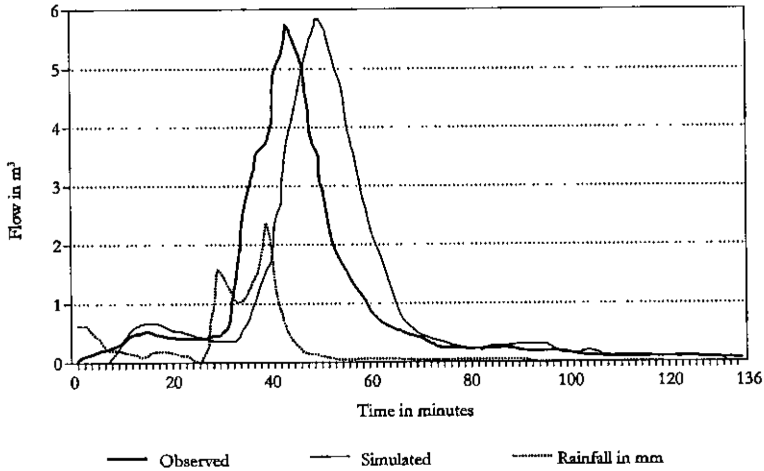
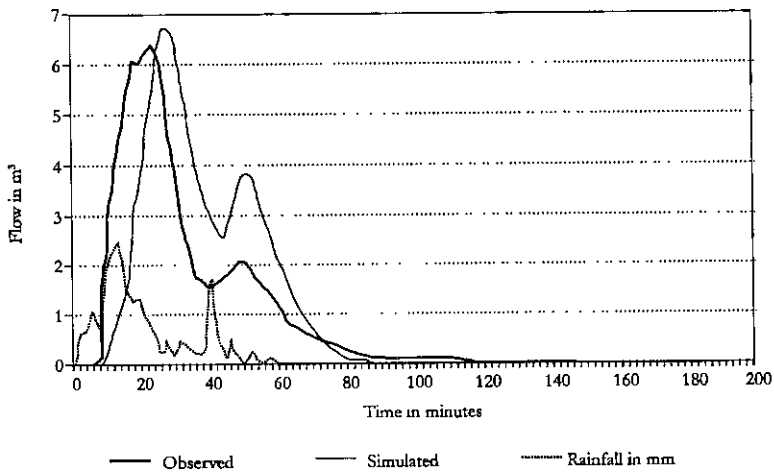


Figure 8: Simulated vs observed flow in the Pinetown catchment



Pinetown catchment: 1984-10-28

Figure 9: Simulated vs observed flow in the Pinetown catchment



Pinetown catchment: 1985-12-04

Figure 10: Simulated vs observed flow in the Pinetown catchment

The model under-simulated the peak flow for some events and over-simulated for others. This can clearly be seen in Figure 11, which compares observed peak flow and simulated peak flow. A product-moment correlation analysis was done using the actual flow and the simulated values, giving a correlation coefficient of 0.954. This indicates a high positive correlation between the values, which implies that the model is capable of simulating runoff accurately.

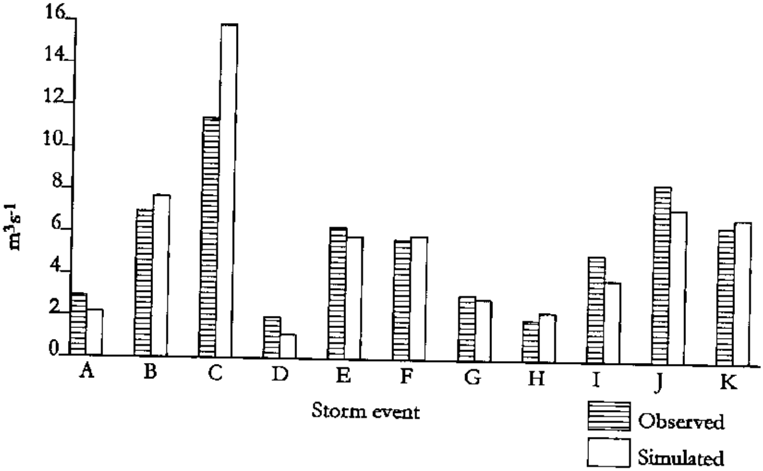


Figure 11: Simulated vs observed peak flow for selected storm events at Pinetown

Daily accumulation rates were used to simulate the build-up of pollutants available for washoff. Table 7 gives the export values from the catchment in kg/ha/day for the selected storm events. Table 7 shows that the model does in some instances over-simulate and under-simulate, but that is generally a good reflection of the actual situation. This is confirmed by Table 8, where there is a good correlation between the observed and the simulated values, with the exception of chromium (Cr) and nitrogen (N), which show a low negative correlation indicating strong over-simulation or under-simulation.

Date	12/11/92		16/11/92		11/12/92		12/12/92		09/03/93	
Chemicals (kg/ha/day)	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed
COD	1.0	2.0	2.0	1.0	1.0	2.0	1.0	2.0	23.0	17.0
Cl	1.0	2.0	1.0	2.0	0.4	1.0	0.4	2.0	10.0	19.0
Nitrate	0.033	0.08	0.047	0.041						
Sus solids	6.0	10.0	9.0	10.0	4.0	5.0	4.0	8.0	107	75
TDS	1.0	6.0	2.0	1.0	1.0	1.0	1.0	1.0	19.0	6.0
Cr	<0.001	<0.001	0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.009	0.001
Cu	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.004
Zn	0.002	<0.001	0.002	0.002	0.001	0.001	0.001	0.002	0.027	0.010
Pb	0.001	0.002	0.001	<0.001	0.001	<0.001	0.001	<0.001	0.017	0.014
Fe	0.020	0.010	0.030	0.040	0.010	0.001	0.010	0.001	0.400	0.100

Date	08/02/93		03/03/93		15/03/93		27/04/93		11/08/93	
Chemicals	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Obsrved
(kg/ha/day)										
COD	3.0	6.0	1.0	0.1	4.0	2.0	3.0	1.0	2.0	2.0
Cl	1.0	4.0	0.3	0.3	2.0	1.0	1.0	1.0		
Nitrate			0.018	0.016	0.109	0.010	0.070	0.030	0.06	0.06
Sus solids	14.0	32.0			20.0	18.0	13.0	7.0	11.0	32.0
TDS	2.0	2.0	1.0	0.1	4.0	1.0	2.0	1.0	2.0	1.0
Cr	0.001	0.001	<0.001	<0.001	0.002	<0.001	0.001	0.001	0.001	0.003
Cu	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.001
Zn	0.004	<0.001	0.001	<0.001	0.005	0.001	0.003	0.003	0.003	0.010
Pb	0.002	0.001	0.001	<0.001	0.003	0.001	0.002	0.001	0.002	0.001
Fe	0.050	0.090	0.012	0.002	0.070	0.040	0.050	0.070	0.040	0.200

Table 7: Export values in kg/ha/day for selected storm events

Chemical	r
COD	0.955
Cl	0.973
N	-0.392
Suspended solids	0.914
Cr	-0.180
Zn	0.633
Pb	0.986
Fe	0.561

Table 8: Product-moment correlation coefficient between selected chemicals for the storm events shown in Table 7

11. Conclusion

In terms of hydrograph generation as well as daily, monthly and annual water quality simulation from urban areas, the new structure in ACRU (WASHMO and NPS) performed satisfactorily under verification. In terms of water quality simulations, the model performs better on reticulated catchments which minimise base flow than on natural streams with base flow components. Guidelines for setting up the ACRU-NPS and WASHMO models have been compiled.

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