Surface and subsurface flow from a Natal coastal catchment

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Abstract

The following parameters were monitored over a two-year period on two experimental plots in a Natal coastal catchment under subclimax grassland: rainfall, vegetation cover, surface flow, subsurface flow and the total dissolved solids, organic matter and sediment content of these flow components. A system was installed to collect the flow components from the experimental plots. Subsurface flow and soil removal were found to be substantial. TDS concentrations were found to be relatively low.

Introduction

Surface flow comprises the water which, failing to infiltrate, travels over the soil surface towards a stream either as quasi-laminar sheet flow or, more usually, anastomosing in small trickles and minor rivulets (Ward, 1975). The presence or absence of surface flow has a number of implications. Surface flow provides the quickest and most direct route that rain water can take to the stream. It may alter stream-flow response both in terms of storm-flow (timing, peak discharge and total volume) and flow recession. Surface flow will also affect water quality directly through the surface transport of sediment and organic matter, and indirectly through reduced subsurface routing and leaching (Versfeld, 1981). As rainfall intensity in humid areas seldom exceeds soil infiltrability, stormflow is considered to be derived mainly from subsurface flow (Hewlett and Nutter, 1970).

Subsurface flow is considered to be caused largely by what Hewlett and Hibbert (1967) have called translatory flow, which is flow produced by the displacement of water already present in the lower slopes by water falling on, and infiltrating these and the upper slopes. The variable source area concept treats surface flow as an expansion of the perennial channel system into zones of low storage capacity (Hewlett and Nutter, 1970), but also explains stormflow responses, where no surface flow is in evidence. This explanation is well suited to this study which aimed to compare the quantity and quality of surface flow with subsurface flow.

Study area

Two experimental plots were established at the base of a south-facing 22% slope on the campus of the University of Durban-Westville. The campus is situated at an altitude of 450 m a.m.s.l. on the north-west outskirts of Durban on latitude 29°50'S and longitude 30°56'E. Bedrock consists of Dwyka tillite with a strongly weathered regolith. The tillite is covered by soils of the Umzinto system and Williamson series. The grey fine sandy clay loam topsoil is 200 to 400 mm thick. It is relatively porous and averages infiltration rates of about 7 mm/h. It sets hard when dry and has a moderate erodibility of about k = 0,06 using the Wischmeier *et al.* (1971) nomograph. The yellow brown moderately porous subsoil is 800 to 1 100 mm thick. The study area is densely covered by perennial tall mixed grassland dominated by *Cymbopogan* and *Hyparrhenia* species with patches of *Aristida*, *Digitaria*, *Eragrostis* and *Themeda*. For the duration of this study the mean per cent canopy cover was 92% and 87% for the rainy and dry seasons, respectively.

Per cent basal cover averaged 28% showing no significant seasonal variation. The average annual rainfall for the region is about 1 000 mm of which approximately 75% falls during the summer months, from October to March. Rainfall occurs mainly in the form of relatively high intensity thunderstorms. Daily average maximum temperatures vary between 26°C in February and 20°C in July. The average daily minimum temperature for July is about 11°C, but temperatures may drop as low as 6°C. Frost does not occur.

Method

The surface and subsurface flows from the two experimental plots positioned 3 m apart were collected using apparatus modified from a description by Atkinson (1978). Vertical soil faces were exposed by digging 2 m wide tranches down to bedrock level across the base of the slope. A 1,5 m length of 180 mm diameter PVC piping with a 30 mm wide aperture across its length was sealed in place at the soil surface for the collection of the surface flow. Perspex strips were dug into the surface and extended upslope along the borders of the plots to prevent any loss of surface flow through lateral movement. A series of 1,5 m long and 180 mm wide asbestos gutters coated on their upper surface with bituseal were positioned against the vertical soil face in the manner shown in Figures 1a and 1b. To ensure good hydraulic contact between the guttering and the soil, the gutters were packed with coal ash and protected and sealed at the front with perspex shuttering. Polythene sheeting was dug into the face at the appropriate height for each gutter, to ensure that each drew its flow from only a single layer of soil. As subsurface flow appears to build up just above an impeding layer in the soil (Kirby, 1968), the gutters were located so as to drain the soil at the boundaries of the pedogenic horizons. The depth below the surface of the boundaries is detailed in Table 1. Surface flow collected in the pipes and subsurface flow collected in the gutters was diverted into 10 ℓ plastic containers through flexible plastic tubing. A standard non-recording rain gauge was positioned at the base of the slope between the two plots. According to the theoretical principals detailed by Weyman (1975) the upslope plot distance contributing surface and subsurface flow to the collecting apparatus is 40 m. The actual contributing area and any fluctuations in it were however not determined in this study. The collecting apparatus was installed by the end of August 1982. However, in order to allow the system time to flush itself of dust contained in the coal ash fill and time for settlement of the soil on the

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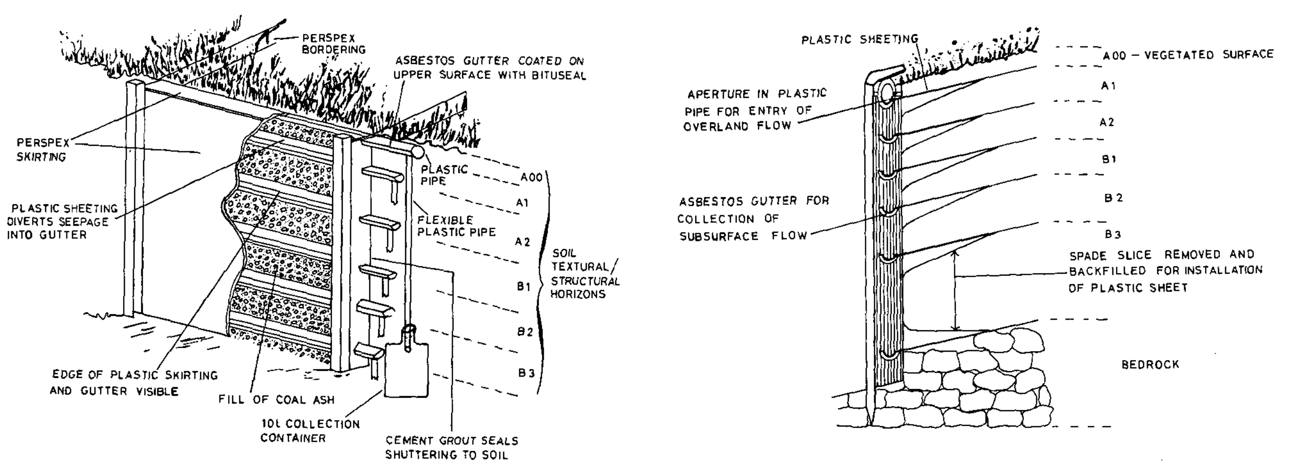

(A) GENERAL VIEW OF THROUGHFLOW TROUGHS

(B) SECTION SHOWING INSTALLATION OF PLASTIC SHEETING AND GUTTERS

Figure 1
Construction of throughflow troughs (redrawn after Atkinson, 1978)

polythene sheeting to take place, surface and subsurface flow was not collected for data purposes until the end of November 1982. The system was operated through until the end of November 1984.

At the termination of each rainfall event the rainfall was recorded and the 10 ℓ plastic containers were transferred to the laboratory where the volume of the flow collected was measured. The organic matter, sediment and dissolved solids contents of the flows were measured following specifications detailed by the Environmental Protection Agency (1974). Once a week nine soil samples were collected from locations adjacent to the plots at the base of the slope. The samples were taken from the following levels below the surface: 50 mm, 150 mm and 250 mm. The moisture content of these samples was determined using standard gravimetric procedures.

The organic matter content, particle size distribution, structure and permeability of the slope's soils were determined using standard procedures detailed by Black (1965). The Wischmeier *et al.* (1971) nomograph was used to determine the k factor of the soils. The compositional classification of the slope's vegetation cover and estimates of the per cent canopy and basal cover were obtained in seasonal surveys using the "Levy Bridge" and following the methodological specifications detailed by Brown (1954).

TABLE 1
DEPTH OF PEDOGENIC HORIZONS BELOW SURFACE (mm)

Horizon	Plot A	Plot B
A1	A00 - 400	A00 - 250
A2	400 - 450	
B1	450 - 600	250 - 590
B2	600 - 740	590 - 730
B3	740 - 1 080	730 - 920

Data analysis and discussion

Surface flow

Storms varying in depth between 3,0 mm and 127,0 mm were analysed. Storms of less than 3,0 mm did not yield surface flow, whilst storms in excess of 127 mm overflowed the collection containers and were therefore excluded from the analysis. The mean storm size for the 36 storms that were recorded was 34,4 mm. Storm size was seen as one of the most important variables that could influence variations in runoff. A linear regression analysis was therefore calculated for each plot, relating gross rainfall (Pd) to surface flow (Sf). The regression equations were defined as: $Sf = 497{,}03\ Pd + 46{,}52$ and $Sf = 716{,}96\ Pd + 56{,}42$ for Plots A and B respectively. The coefficients of determination were however relatively low, viz. 0,45 and 0,51 respectively. Various curvilinear relationships were subsequently tried on the same data, but no meaningful improvement in the coefficients of determination resulted. A relationship was therefore sought between gross rainfall, rainfall intensity, soil moisture and runoff. The initial regression analysis equations were developed to predict surface flow from all possible linear combinations of the independent variables mentioned. From this it was apparent that the differences between the different combinations were relatively small, but that the inclusion of rainfall intensity and soil moisture resulted in the best improvements of the coefficients of determination. Table 2 gives the data used for the different variables, and Table 3 the regression models. The first two models in Table 3 depict the relationship between gross rainfall (Pd), rainfall intensity (I), soil moisture (Sm) and surface flow (Sf) for the two plots. The next two explain the relationship between gross rainfall, rainfall intensity and surface flow, and the last two relationships between gross rainfall, soil moisture and surface flow. The coefficients of determination in Table 3 show an improvement on those calculated earlier in the linear regression analysis, but nevertheless do not explain the rainfall/surface flow process adequately. The combined explanatory power of rainfall intensity and soil moisture is in fact at best only 11%. From the above discussion it is clear that the relationship between increasing rainfall and surface flow is relatively weak which sug-

TABLE 2
DATA SET FOR MULTIPLE LINEAR REGRESSION ANALYSIS

Storms	Rainfall (mm)	Rainfall intensity (mm/h)	Soil moisture %	Surface flow A (ml)	Surface flow B (ml)
1	8,0	14	6	199	43
2	9,5	30	9	910	1 387
3	35,5	17	13	1 970	2 799
4	9,0	22	7	690	780
5	18,5	9	9	460	516
6	21,8	10	6	525	554
7	6,8	14	6	1 357	1 900
8	13,3	17	6	1 570	1 932
9	3,0	20	6	25	55
10	23,2	18	6	1 600	1 800
11	13,4	17	7	1 703	4 600
12	12,5	13	7	1 140	1 290
13	26,0	26	1	5 000	1 200
14	65,0	14	7	1 660	3 680
15	7,4	20	13	820	1 000
16	13,0	25	13	390	510
17	12,9	35	14	740	890
18	20,0	10	5	500	1 050
19	60,0	35	5	2 600	4 570
20	10,2	22	10	420	427
21	37,0	10	10	350	313
22	27,0	12	12	800	935
23	34,2	34	12	2 160	2 840
24	127,0	30	9	1 972	4 340
25	26,5	13	13	570	670
26	10,0	20	13	1 410	3 275
27	52,0	25	17	6 400	8 000
28	26,0	20	8	1 730	1 375
29	6,8	12	8	1 492	3 721
30	125,0	30	12	8 240	8 510
31	80,0	40	12	8 460	9 500
32	50,0	30	14	4 120	4 360
33	17,0	10	7	476	520
34	46,0	20	16	4 120	4 360
35	76,0	26	12	6 640	7 210
36	110,0	24	13	7 425	7 645
Total	1 239,0	734	344	80 644	98 557
Mean	34,43	20,30	9,55	2 240	2 737,69

gests high infiltration rates. The lack of a direct rainfall/runoff relationship however made further regression analyses of the surface flow data a futile exercise. Ordering of the data was therefore attempted by categorizing it into four storm size categories, viz. 10 mm to 20 mm, 21 mm to 50 mm, 51 mm to 100 mm and 100 mm (Table 4). This table firstly revealed relatively little surface flow from both plots at all times, which indicates that infiltration is not a limiting factor. Secondly, Table 4 shows a large variation in surface flow in the same storm size category for the same plot. In the category 10 mm to 20 mm, 2 storms of 10 mm for example yielded surface flow of 420 mℓ and 1 410 mℓ respectively. The 1 410 mℓ surface flow storm was however preceded by a 26 mm storm approximately 24 h earlier, whilst the other 10 mm storm was preceded by a dry period of more than ten days. Spatial and temporal variations in infiltration, and variations in antecedent moisture conditions and evapotranspiration rates are apparently the most likely agents causing the variations in surface flow. Thirdly, the distinct difference in the average runoff from the two plots is striking. The average surface flow from Plot B is higher in three rainfall categories, with the first category showing a difference of nearly 100%. Individual storms in Table 4 are better examples of the same phenomenon with several storms showing differences in surface flow which exceed 100%. An analysis of variance (p 0,05) was computed on the surface flow data to establish whether the difference between the plots was meaningful, and the results indicated that significant differences exist. This appears to be a clear indication of variations in the characteristics of the contributing areas of the plots.

Subsurface flow

Subsurface flow is the water which infiltrates into the soil surface and then moves laterally through the upper soil horizons towards the stream channel. It moves either as unsaturated flow or more

TABLE 3
SURFACE FLOW, GROSS RAINFALL, RAINFALL INTENSITY AND SOIL MOISTURE RELATIONSHIPS

$Sf = 1\,106{,}87 + 35{,}49\,Pd + 83{,}20\,I + 23{,}68\,Sm$	$R^2 = 0{,}56$
$Sf = -1\,233{,}36 + 46{,}14\,Pd + 61{,}84\,I + 106{,}49\,Sm$	$R^2 = 0{,}58$
$Sf = -1\,311{,}34 + 34{,}05\,Pd + 31{,}98\,I$	$R^2 = 0{,}58$
$Sf = 880{,}97 + 36{,}88\,Pd + 44{,}05\,I$	$R^2 = 0{,}58$
$Sf = -223{,}36 + 36{,}42\,Pd + 40{,}52\,Sm$	$R^2 = 0{,}47$
$Sf = 124{,}83 + 57{,}1\,Pd + 48{,}37\,Sm$	$R^2 = 0{,}56$

TABLE 4
SURFACE FLOW FROM EXPERIMENTAL PLOTS FOR FOUR STORM SIZE CATEGORIES

Storm size category	Rainfall (mm)	Surface flow A (mℓ)	Surface flow B (mℓ)
10 mm to 20 mm	18,5	460	516
	13,3	1 570	1 932
	13,4	1 703	4 600
	12,5	1 140	1 290
	13,0	390	510
	12,9	740	890
	20,0	500	1 050
	10,0	420	427
	10,0	1 410	3 275
	17,0	476	520
Total	140,6	8 809	15 010
Mean	14,0	881	1 501
21 mm to 50 mm	35,5	1 970	2 799
	21,8	525	554
	23,2	1 600	1 800
	26,0	5 000	1 200
	37,0	350	313
	27,0	800	935
	34,2	2 160	2 840
	26,5	570	670
	26,0	1 730	1 375
	50,0	3 840	4 610
	46,0	4 120	4 360
Total	353,2	22 665	21 456
Mean	32,1	2 060	1 951
51 mm to 100 mm	65,0	1 660	3 680
	60,0	2 600	4 570
	52,0	6 400	8 000
	80,0	8 460	9 500
	76,0	6 640	7 210
Total	333,0	25 760	32 960
Mean	66,6	5 152	6 592
> 100 mm	127,0	1 972	4 340
	125,0	8 240	8 510
	110,0	7 425	7 645
Total	362,0	17 637	20 495
Mean	120,7	5 879	6 831

usually, as shallow perched saturated flow, above the main ground-water level (Ward, 1975). The dense grassland covering the experimental plots facilitated a relatively high percolation of rain water into the soil. Such a cover serves to increase the permeability of the surface soil horizons and reduces the velocity of surface flow (Stratham, 1977). With the exception of one storm of 18,5 mm all the storms that failed to produce subsurface flow from the A1 soil horizon in this study were smaller than 9 mm.

Table 5 shows the frequency of occurrence of subsurface flow as well as the mean storm sizes and mean subsurface flows at the different soil horizons in the two experimental plots. From the table it is clear that the highest subsurface flow was recorded in the middle flow which substantiates the findings by Hewlett and Nutter (1970). The highest at-a-point subsurface flow which was recorded, resulted from a 80 mm storm, i.e. 8 420 mℓ from the B1 horizon, Plot A. The B1 horizon Plot B delivered 4 110 mℓ for the same storm. The total subsurface flow for the study period was significantly higher than the surface flow on Plot A, 96 162 mℓ as against 80 644 mℓ. In the case of Plot B the opposite happened i.e. the total surface flow (98 557 mℓ) was higher than the subsurface flow (90 220 mℓ). This is a further indication of variations in the contributing areas of the plots which were mentioned earlier in this paper.

Table 5 suggests that storm size determines subsurface flow. This relationship was tested with a regression analysis on A horizon data and the following equations were defined:

Ssf = 250,59 Pd + 43,49 .... Plot A
Ssf = 225,85 Pd + 44,74 .... Plot B

where

Ssf = subsurface flow and Pd = gross rainfall.

The relatively low coefficients of determination of 0,36 and 0,50, however, indicate that a weak relationship exists between the two variables. As with surface flow, this may be caused by variations in evapotranspiration, infiltration and antecedent soil moisture conditions. The large vertical and lateral translatory flow described by Hewlett and Hibbert (1967), which results in a time lag between rainfall events and subsurface flow, was also noted in this study. A storm of 26,5 mm, for example, yielded no flow from the B3 horizon of Plot B, but a 10 mm event the next day resulted in a 592 mℓ flow from the same horizon.

Total dissolved solids

The factors which reduce the surface transport of rain water are generally those which favour solutional loss from soils due to the increased importance of subsurface flow. Since subsurface flow is many orders of magnitude slower than surface flow it is in contact with soil grains for longer and has more time to reach chemical equilibrium with soluble components (Stratham, 1977). Table 6 shows the mean concentration and total loss of dissolved solids from the experimental plots. The mean TDS concentration and total loss in the subsurface flow was substantially higher than in the surface flow (2,6x and 1,4x for Plots A and B, respectively). As noted earlier the surface flow from Plot B appears to be derived from a larger contributing area than Plot A. The potential to remove a larger quantity of soluble minerals may account for Plot B's significantly higher surface flow total TDS loss and mean TDS concentration. The B1 and B3 horizons of Plot A, and B2 horizon of Plot B yielded the highest dissolved solids concentrations indicating that they may be relatively impermeable horizons that permit a longer water residence time.

The TDS values recorded in this study are low in comparison with the values recorded for Natal rivers (see Natal Town and Regional Planning Commission, 1967; 1969 and 1976). The surface and subsurface soil water temperature, the rate of surface and subsurface water movement and solute availability, all exert a strong influence on solution. The low correlations between the TDS concentration and surface flow volume (r = 0,48 and r = 0,28 for plots A and B respectively) and between TDS and subsurface flow volume (0,34 and 0,5 for Plots A and B, respectively) are therefore to be anticipated. Application of the standard Students t-test indicated that differences in the surface and subsurface TDS between Plots A and B were significant at a 99,9% confidence level.

Organic matter

Table 7 shows the seasonal variation in the total and mean mass of organic matter removed in the surface and subsurface flow. The surface flow removed a substantially greater quantity of organic matter than the subsurface flow (5,4x and 1,2x from Plots A and B, respectively). This is attributed to the greater surface biomass and turnover rates. The quantity of organic matter removed in both the surface flow and subsurface flow from Plot B was substantially greater than Plot A (1,8x and 7,8x, respectively). This is seen as a further indication of the difference in

TABLE 5
FREQUENCY OF OCCURRENCE OF SUBSURFACE FLOW AND MEAN SUBSURFACE FLOW (mℓ) FROM SOIL HORIZONS IN EXPERIMENTAL PLOTS

	Plot A					Plot B			
Pedogenic horizons	A1	A2	B1	B2	B3	A1	B1	B2	B3
Frequency of occurrence	27	14	8	3	2	27	15	7	9
Mean storm size (mm)	34,9	46,3	47,0	70,6	102,5	34,9	45,0	49,9	44,2
Mean subsurface flow (mℓ)	1 269	2 011	2 537	2 870	2 417	1 337	1 823	2 303	1 181

respective contributing area of the plots. In contrast to Plot B, the removal of organic matter from the B horizon of Plot A is 1,3x greater than from the A horizon. The explanation of this presents difficulties as the greater subsurface flow volume (1,7x); the greater soil loss (2,6x); and the confinement of the grassland community root system to the A horizon all indicate its potential for greater organic matter removal.

Despite the limited winter surface flow from Plot B the largest amount of organic matter was removed during this season when the largest proportion of dead, detached material is available. The absence of surface flow from Plot A during winter delayed the removal of organic matter until spring. The subsurface removal of organic matter from Plot B was highest during spring. The limited subsurface flow from Plot A during this season restricted organic matter removal. This removal peaked during autumn when the largest subsurface flow occurred.

TABLE 6
TOTAL DISSOLVED SOLIDS FROM SOIL HORIZONS IN EXPERIMENTAL PLOTS

	Surface flow	Total dissolved solids in flow from various soil horizons				
		A1	A2	B1	B2	B3
Plot A						
(Mean) (mg/ℓ)	49	92	65	137	75	125
Plot B						
(Mean) (mg/ℓ)	57	91		75	125	54
Plot A						
Total (g)	3,9	3,2	1,8	4,1	0,6	0,6
Plot B						
Total (g)	5,6	3,3		2,1	2,0	0,6

The low correlations between surface flow and organic matter removal (r = 0,12 and 0,18 for Plot A and B, respectively) and between subsurface flow and organic matter removal (r = 0,27 and r = 0,24 for Plots A and B, respectively), and the absence of a significant difference between the means of organic matter removal from the two plots indicate that the seasonal availability of transportable organic matter and the bonding between organic matter and soil particles which facilitates the transport of the former, are major controlling factors.

Soil

To date only a limited amount of research has been carried out on the transfer of soil particles through soils. The removal of soil by subsurface flow is generally considered to be negligible when compared to the removal by surface flow. Soil removal by subsurface pipe flow may be appreciable, but such flow tends to rather be considered as part of the stream network. The entrainment and transport of soil by subsurface flow is restricted by the availability of particles smaller than the general pore size and velocities of flow capable of supporting these particles in suspension through the pore structure against resistive forces of physiochemical absorption (Kirkby, 1968; Stratham, 1977). Although the fine sandy clay loam of the study area is a well sorted soil with a small range in particle sizes, it has a well aggregated structure which it owes to its relatively high organic matter content. This structure and the findings of this study suggest that the pore sizes of this soil are larger than the soil particles. There is no doubt that the soil collected in the surface flow represents particles detached and transported by it. The interpretation of the data on soil collected in the subsurface flows in this study assumes that most of the particles were transported through the horizons from which the flow was collected. Exposing the vertical soil face to accommodate the collecting apparatus obviously causes some disturbance to the soil profile. The system was allowed three months to flush itself and settle before data was collected. The close packing of ash against the face should have functioned to protect it from shedding particles throughout the study in response to weathering processes.

Table 8 shows the seasonal variation in the total and mean mass of soil removed in the surface and subsurface flow. The subsurface soil removal from Plot A was 1,5x greater than the surface removal. The high percentage grass canopy and basal cover clearly exerted a severe constraint on surface soil availability and transportability. There was no significant difference between the surface and subsurface soil removal from Plot B. Both the surface and subsurface soil removal from plot B were substantially greater than Plot A (5,4x and 3,3x, respectively).

TABLE 7
SEASONAL VARIATION IN ORGANIC MATTER

	Surface flow	Organic matter in mg Flow from various soil horizons				
		A1	A2	B1	B2	B3
Plot A						
Spring Total	4 780	20	40	**	10	**
Mean	956	**	**	**	**	**
Plot B						
Spring Total	3 400	4 420		1 740	**	80
Mean	567	884		580	**	**
Plot A						
Summer Total	440	70	60	80	10	40
Mean	40	14	12	20	**	13
Plot B						
Summer Total	1 190	620		190	60	70
Mean	85	86		32	20	18
Plot A						
Autumn Total	150	200	5	220	40	140
Mean	50	50	**	110	**	47
Plot B						
Autumn Total	1 030	60		180	90	90
Mean	172	20		60	45	45
Plot A						
Winter Total	10	30	**	**	**	30
Mean	**	15	**	**	**	**
Plot B						
Winter Total	4 060	50		70	**	20
Mean	1 015	25		**	**	

**Inadequate data due to low flow occurrence.

Differences between the plots were found to be significant at a 99,9% confidence level using the standard Students t-test, and are seen to be a further indication of difference in the respective runoff contributing areas of the plots.

The horizon of Plot A yielded 2,6 times more soil than the B horizon. This is a direct reflection of the greater (1,7x) subsurface flow through the A horizon. There was no significant difference between the soil removed from the A and B horizons of Plot B despite a substantially large subsurface flow from the B horizon (1,5x). The surface removal of soil from both plots was greatest during summer. Factors influencing the transport of soil particles are seen to have exerted a major control during this period of

TABLE 8
SEASONAL VARIATION IN SOIL LOSS

	Soil in mg					
	Surface flow	Flow from various soil horizons				
		A1	A2	B1	B2	B3
Plot A						
Spring Total	573	150	590	90	140	**
Mean	143	**	**	**	**	**
Plot B						
Spring Total	5 240	2 280		2 220	**	1 910
Mean	873	570		74	**	**
Plot A						
Summer Total	4 040	1 090	950	660	280	290
Mean	337	182	158	165	93	97
Plot B						
Summer Total	15 290	13 440		2 210	780	1 120
Mean	1 698	1 680		316	260	280
Plot A						
Autumn Total	2 010	4 820	50	588	460	330
Mean	402	1 205	**	294	230	165
Plot B						
Autumn Total	14 700	1 240		1 820	6 640	1 600
Mean	2 450	310		607	3 320	800
Plot A						
Winter Total	240	60	**	**	**	140
Mean	120	30	**	**	**	**
Plot B						
Winter Total	1 660	160		90	**	10
Mean	415	**		**	**	**

**Inadequate data due to low flow occurrence.

high and frequent rainfall. Surface removal of soil remained high throughout autumn when factors influencing the rate of transportable grain release from the surface are seen to have exerted a major control. The subsurface soil removal from both plots was highest during summer and autumn and corresponded closely to peaks in subsurface flow.

The low correlations between surface flow and soil removal (r = 0,21 and r = 0,6 for Plots A, B respectively), and between subsurface flow and soil removal (r = 0,48 and r = 0,41 for Plots A and B, respectively) indicate that the seasonal availability of transportable soil particles and the influences of the dense grass cover on the entrainment and transport of soil particles are major controlling factors.

Conclusion

The study suggests that a substantial portion of the rain that falls on dense Natal coastal subclimax grassland infiltrates into the soil resulting in limited surface flow. The associations between gross rainfall, rainfall intensity, soil moisture and surface flow are relatively weak, and do not explain the rainfall/surface flow process adequately. This suggests other regulating factors like spatial and temporal variations in infiltration and variations in evapotranspiration and antecedent soil moisture conditions.

The generation of subsurface flow by storms of less than 9 mm is rare, but the total subsurface flow was nonetheless substantially higher than the surface flow. The poor association between storm characteristics and subsurface flow suggests that the same variables influencing the rainfall/surface flow process also play a role in regulating this process.

The volume and rate of subsurface flow are indicated as the most important variables regulating the TDS concentration in subsurface flow. The average value for the two plots is relatively low, viz. 86 mg/ℓ, suggesting that fairly good quality water should reach the streams in non-urbanized areas.

Subsurface soil loss is substantially higher than surface soil loss. This needs to be considered in engineering projects in the region. It is, for example, believed that surface damage to roads (potholes) in the Natal coastal region are to a large extent caused by subsurface material collapse resulting from subsurface erosion. The evolution of slope profiles is traditionally explained in terms of sediment transfer by mass movement and fluvial surface transport processes (Selby, 1982). The appreciable subsurface soil loss found in this study indicates that under certain conditions slope profiles may be influenced by subsurface transport processes. Seasonal variations in the availability of detachable organic matter and soil particles, and in the volume of surface and subsurface flow are the major factors controlling the removal of organic matter and soil.

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References

ATKINSON, T.C. (1978) Techniques for measuring subsurface flow on hillslopes. In: Kirkby M.J. (Ed.) *Hillslope Hydrology.* John Wiley and Sons, Chichester. 73-120.

BLACK, C.A. (1965) Methods of soil analysis. American Society of Agronomy, Wisconsin. *Agronomy* 9(2).

BROWN, D. (1954) Methods of surveying and measuring vegetation. *Commonwealth Bureau of Pastures and Field Crops Bulletin* **42**.

ENVIRONMENTAL PROTECTION AGENCY (1974) *Methods for chemical analysis of water and wastes.* EPA 625/6 – 74 – 003, Washington D.C.

HEWLETT, J.D. and HIBBERT, A.R. (1967) Factors affecting the response of small watersheds to precipitation in humid areas. In: *Proceedings of the International Symposium on Forest Hydrology* (1965), Pennsylvania State University, Pergamon. 275-290.

HEWLETT, J.D. and NUTTER, W.L. (1970) The varying source area of streamflow from upland basins. Symposium on Interdisciplinary Aspects of Watershed Management, Montana State University, Bozemann, American Society of Civil Engineers, New York. 65-83.

KIRKBY, M.J. (1968) Infiltration, throughflow and overlandflow. In: Chorley, R.J. (Ed.) *Water, Earth and Man.* Methuen.

NATAL TOWN AND REGIONAL PLANNING COMMISSION (1967; 1969 and 1976) *Water quality and abatement of pollution in Natal rivers.* Parts 1 – 5, National Institute for Water Research, CSIR.

SELBY, M.J. (1982) *Hillslope materials and processes.* Oxford University Press. 204-213.

STRATHAM, I. (1977) *Earth surface sediment transport.* Clarendon Press, Oxford. 57-68.

VERSFELD, D.B. (1981) Overland flow on small plots at the Jonkershoek Forestry Research Station. *SA Forestry Journal* 119 26-27.

WARD, R.C. (1975) *Principles of Hydrology.* 2nd ed. McGraw-Hill, London. 239-241.

WEYMAN, D.R. (1975) Runoff processes and streamflow modelling. *Theory and Practice in Geography.* Oxford University Press. 2,3.

WISCHMEIER, W.H., JOHNSON, C.B. and CROSS, B.V. (1971) A soil erodibility nomograph for farmland and construction sites. *Journal of Soil and Water Conservation*, Sept. – Oct., 189-193.