A case of delayed subsurface flow in an urban catchment

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Abstract

Since the establishment of the Montgomery Park watershed as an experimental catchment in 1982, a number of unexpected runoff hydrographs following storm events have been observed. These hydrographs consisted, in most cases, of two distinct parts. The first part appears to be the response to direct surface runoff, comprising a steep rise followed by a reasonably steep recession limb. The second part lagged the first part by a considerable length of time and consisted of a mild rise followed by a very slow recession. This paper attempts to explain this anomaly by attributing the presence of the second, lagged hydrograph portion to delayed interflow, or subsurface flow, and further draws attention to the importance of this component in the catchment studied.

Introduction

Interflow is one of the hydrological processes which takes place following rainfall over a catchment. It is defined in hydrology textbooks (e.g. Viessman *et al.*, 1977) as the process whereby a portion of the total rainfall infiltrates into the upper soil layers in the catchment, flows laterally below the surface and re-emerges as surface runoff after a relatively short distance. This part of the surface runoff joins the direct surface runoff and the base flow to form the total runoff hydrograph of the catchment for the storm event considered.

Except for its definition as a hydrologic process and, in some cases, an attempt to formulate a procedure for its separation from the total hydrograph (e.g. Crawford and Linsley, 1966), interflow was in the past often assumed to play an insignigicant role in hydrologic analysis. It was usually combined with the direct surface runoff and the two types of runoff were treated as one in subsequent analyses or modelling (e.g. Terstriep and Stall, 1974; Huber *et al.*, 1982).

The significance of interflow on the total hydrograph is highly variable – in some catchments it may form an important contribution to the channel flow whereas in others the overland flow contribution may completely dominate (Fleming, 1975). In many cases of storm water flow, the volume of runoff due to interflow is assumed to be small relative to that due to direct surface runoff, so that its inclusion as a separate component in modelling is deemed unnecessary for the overall modelling of the rainfall-runoff process in those cases.

However, there are occasions where subsurface flow greatly influences streamflow. According to Freeze (1972a) the importance of the subsurface response of watersheds has been vastly underrated in most studies of watershed behaviour. Recent studies by Zaslavsky and Sinai (1981) have shown that under certain conditions subsurface flow is indeed significant. They claim that major portions of the rainfall are absorbed by the soil and only later re-emerge as seepage. They question the hitherto conventional approach of assessing losses and propose a number of phenomena that can be related to lateral subsurface flow.

Ward (1982) outlines the conflicting hypotheses held by various researchers over the past fifty years with regard to the origin of streamflow. While some researchers contended that streamflow was solely due to direct surface runoff, others claimed that subsurface flow formed a significant contribution to streamflow under certain conditions.

Freeze (1972b) modelled surface and subsurface flow on hypothetical upstream catchments and concluded that subsurface flow may occur as a quantitatively significant runoff component on convex hillslopes with high saturated soil conductivities and feeding deeply incised channels. The mechanics of this subsurface flow forming a contribution to the total hydrograph are described by Ward (1982) who states that water does indeed infiltrate the slope surface and move as throughflow (interflow) in the slope mantle and that convergence and infiltration in the lower slope areas will lead to surface saturation and groundwater recharge which will create both an overland flow and groundwater contribution to the storm hydrograph.

In some instances, subsurface flow contributions to peak storm and snowmelt runoff have been reported to exceed 50% (Sklash and Farvolden, 1979). Mulder (1984) showed that the proportion of total runoff due to subsurface flow was approximately four times that due to direct surface runoff over a period of time for a catchment in the Natal coastal belt.

The prediction of interflow, where it is found to be significant, presents a problem in modelling as most of the single-event rainfall-runoff models in popular use only consider the overland flow component. Examples of such models are the Stormwater Management Model (SWMM) (Huber *et al.*, 1982) and the Illinois Urban Drainage Area Simulator (ILLUDAS) developed by Terstriep and Stall (1974). However, integrated models that account for surface and groundwater flow do exist. The Stanford Watershed Model (Crawford and Linsley, 1966) accounts for interflow in a continuous mode. A coupled surface and groundwater model developed by Cunningham and Sinclair (1979) is another example of an integrated model. Beven (1982) developed a subsurface model based on kinematic flow theory which can be applied to predict interflow from steep catchments with permeable soils. An example of a single event model incorporating both surface and subsurface flow components is also given by Krzysztofowicz and Diskin (1978).

In the course of a recent investigation on the modelling of urban watersheds, some unexpected hydrographs were observed for a number of storm events in the Montgomery Park catchment in Johannesburg. As these hydrographs occurred consistently, it was concluded that it was not a case of instrument malfunction or observational errors and a hydrologic explanation was sought. A plausible explanation for the hydrograph anomaly is that of a delayed interflow. The purpose of this paper is to describe the background and the observations in the Montgomery Park catchment and to outline a possible explanation for the unusual shape of the hydrographs observed.

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The Montgomery Park catchment

Located at the western boundary of the city of Johannesburg, the *Montgomery Park catchment is a 10,5* km^2 *urban watershed in* which the area covered by residential type development comprises some 75% of the total area. The remaining 25% includes parks, a cemetery and open undeveloped sections. The built up area is mostly single family houses on lots that vary in size between 0,10 and 0,30 ha. There are some multi-story apartment houses and at a few locations commercial development and some light industry. The paved area ratio for various sections of the catchment is estimated to be between 4% and 22%. The weighted value of the paved area ratio for the entire catchment is about 13%.

The topography of the catchment is fairly hilly with surface slopes ranging from 0,02 to 0,15 m/m. The highest elevation on the boundary of the catchment is about 1 800 m above sea level *and its outlet is at about 1 600 m. The main drainage system of* the catchment comprises both natural and artificial channel sections. The man-made sections comprise circular pipes, rectangular channels and some improved natural channels near the outlet. The circular pipes are 0,60 m to 1,00 m in diameter. The sizes of the rectangular channels range from approximately 1,0 m x 1,0 m to 3,0 m x 3,0 m. The slopes of the main drains are in the range of 0,01 to 0,09 m/m. A map indicating the boundaries of the catchment and its main drainage system is given in Figure 1. The length of the main stream in the catchment is about 5,1 km.

Runoff from the catchment is measured at a gauging station in which the measuring element is a set of three Crump weirs constructed in parallel in the three openings of a rectangular *culvert. The three weirs have their crests at different elevations so* that only one of them measures the low flows and all three come into operation at the high flows. Water levels are recorded at a recorder station located some 20 m upstream of the weirs. The water levels in the stream are measured by means of an air bubbling device operating in a stilling chamber in the stream bank. Rainfall over the catchment is recorded at five locations inside and near the catchment boundaries by autographic rain gauges. Two of these are float operated syphoning rain gauges. The other three gauges are tipping bucket gauges operating at a capacity of 0,5 mm/record. The locations of the rain gauges are shown in Figure 1.

Observed runoff hydrographs

Since its establishment as an experimental catchment in 1982, a number of storm events have been recorded in the Montgomery Park catchment. The storms recorded so far indicated only low rainfall and consequently also low rates of runoff. The average total rainfall for the catchment was in almost all events less than 20 mm per storm. There was only one case when it was higher, namely about 30 mm. The peak rates of runoff were, in all cases recorded prior to September 1984, less than 2,1 m^3/s. The runoff

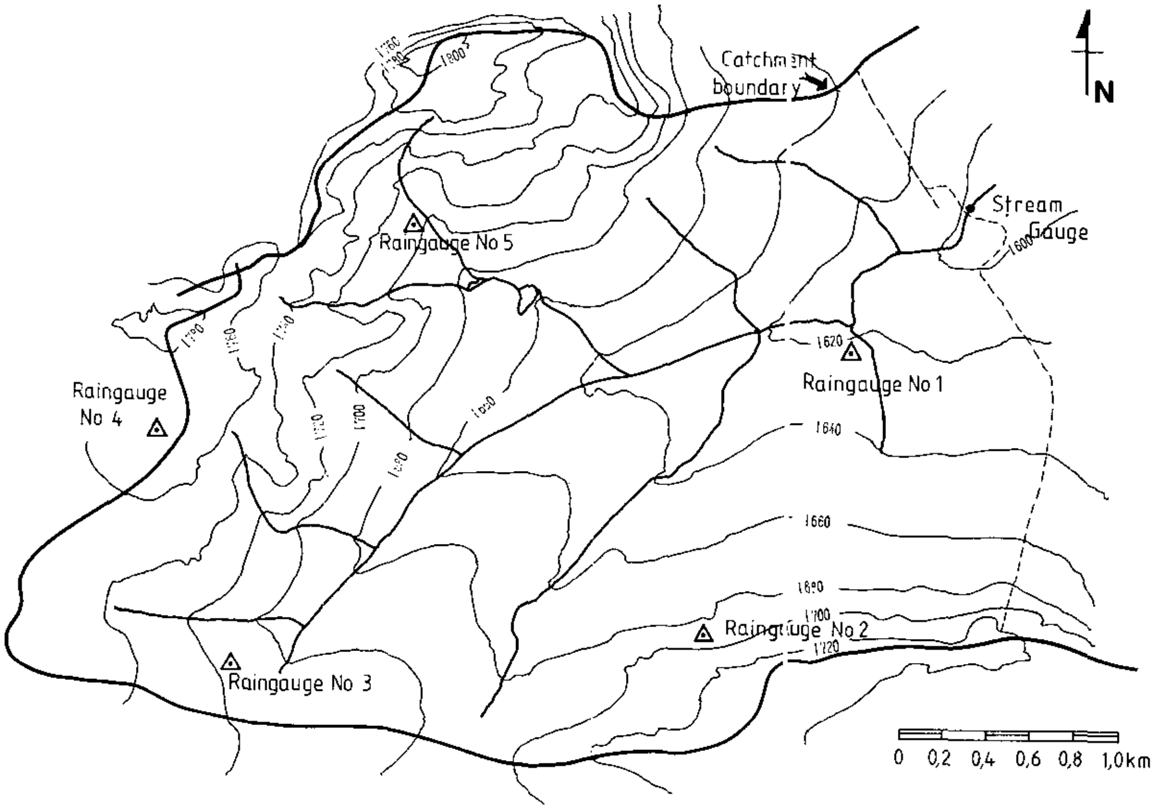

Figure 1
Map of the Montgomery Park catchment.

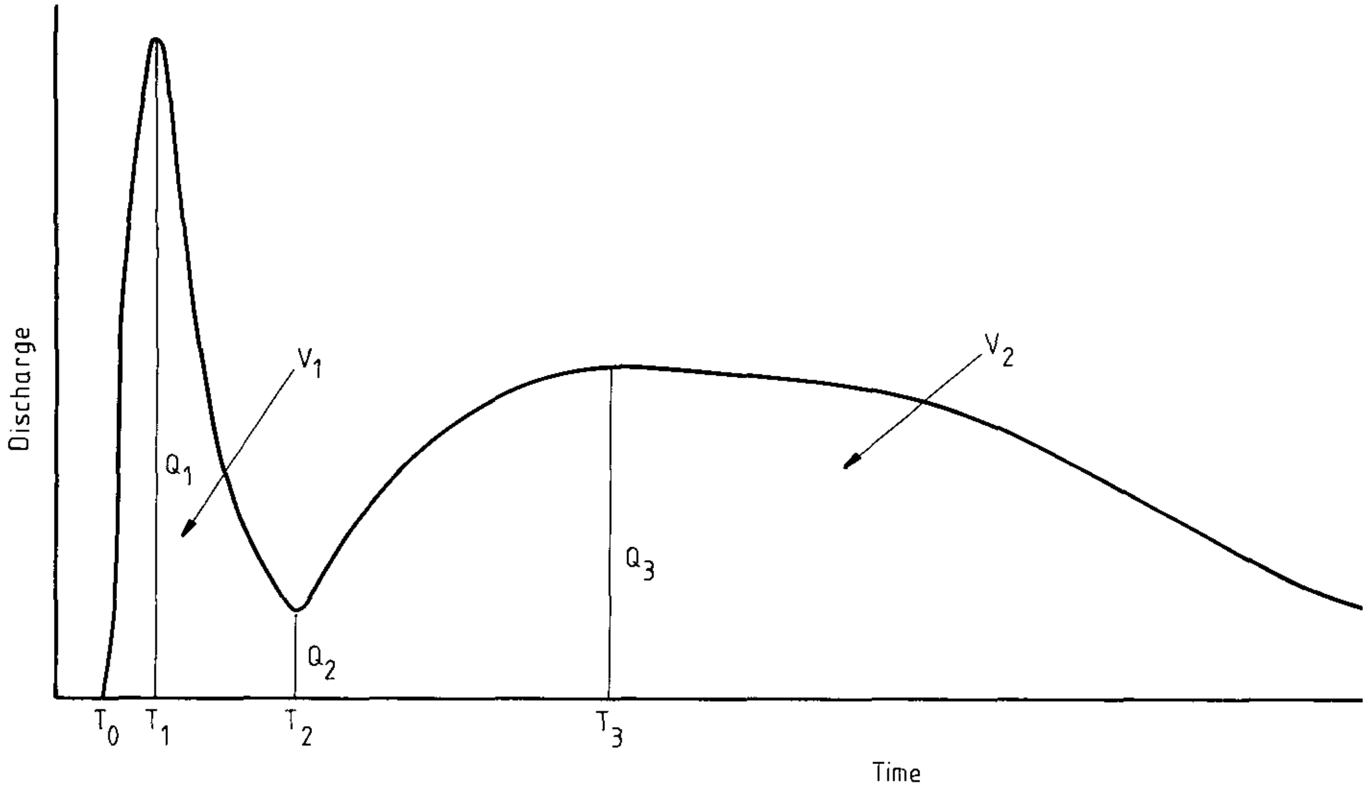

Figure 2
Schematic shape of observed hydrographs.

hydrographs for these storms displayed, in most cases, two peaks separated by a time period of one to five hours. The lag times between the two peaks differed from storm to storm and the peaks did not have equal magnitude. In some cases the second peak was smaller and in others larger than the first.

Each of the runoff hydrographs appears to be composed of two separate parts. The first part of the hydrograph is of relatively short duration. It consists of a very steep rise followed by a milder but nevertheless steep recession. The second part usually displays a slow rise followed by a nearly constant flow over a relatively long period of time and a very slow recession. A typical hydrograph is drawn schematically in Figure 2. The Figure also defines the notation adopted herein to describe the double peaked hydrographs.

Examination of the recorded runoff events indicated that in all cases where the flow exceeded 0,10 m^3/s, a double peaked hydrograph was recorded. All hydrographs conform to the general shape displayed in Figure 2. Sixteen such storms, recorded in the cathment during the period November 1982 to June 1983, and conforming generally to Figure 2, are listed in Table 1. The table gives the characteristic times and flow rates as defined by Figure 2. Included in the table are all the storms in which at least one of the recorded peaks was more than 0,10 m^3/s.

As examples of the actual records, the runoff hydrographs and rainfall hyetographs for three storm events are reproduced in Figures 3 to 8, where each event is represented by a pair of Figures. Thus the runoff hydrograph for the storm of January 19, 1983 is given in Figure 3 and the corresponding rainfall hyetographs for the five rain gauges in the catchment for the same storm are shown in Figure 4.

Considering this storm, it appears that the total rainfall recorded at the individual gauges ranged from 12,7 mm to 17,0 mm. The weighted mean rainfall for the cathment (using Thiessen weights) was 14,9 mm. The volume of runoff included in the first part of the runoff hydrograph, up to the time of minimum discharge, was 2 120 m^3 and the corresponding volume in the second part was 5 590 m^3. Converting these values to equivalent depths of runoff over the area of the catchment yields 0,20 mm for the first part and 0,53 mm for the second part of the runoff hydrograph. Assuming the first part of the hydrograph to be produced only by the paved area of the catchment yields 1,5 mm as the equivalent depth of runoff for the paved area, or a higher value for the directly connected paved area.

The other two storms used as examples are displayed in Figures 5 and 6 for the storm of January 23, 1983, and in Figures 7 and 8 for the storm of January 29, 1983. The rainfall and runoff

TABLE 1
CHARACTERISTICS OF OBSERVED HYDROGRAPHS (TIMES ARE IN HOURS AND MINUTES, FLOWRATES ARE IN m^3/s – SEE FIGURE 2 FOR A DEFINITION OF SYMBOLS)

Date	T_0	T_1	T_2	T_3	Q_1	Q_2	Q_3
20/11/82	14h02	14h20	16h40	19h16	0,675	0,035	0,117
29/11/82	14h32	14h53	15h47	17h42	1,772	0,248	2,013
01/12/82	18h49	22h36	01h05	01h15	0,086	0,031	0,138
07/12/82	06h20	09h32	10h20	10h47	1,860	0,872	1,614
10/12/82	17h06	17h41	18h26	20h45	1,425	0,266	1,936
19/01/83	18h27	18h32	20h13	20h53	1,556	0,041	0,409
23/01/83	00h30	01h05	02h14	04h00	0,730	0,067	0,487
29/01/83	19h55	20h06	22h11	01h04	0,460	0,008	0,150
10/02/83	20h55	22h20	00h44	02h03	0,025	0,009	0,155
12/02/83	02h15	02h46	04h23	07h35	0,235	0,020	0,084
07/03/83	16h32	16h40	18h48	19h54	1,296	0,050	0,162
08/03/83	11h39	11h56	14h02	20h16	1,422	0,077	0,744
11/04/83	11h50	12h32	16h13	18h08	0,062	0,008	0,147
20/05/83	23h16	02h31	03h39	04h53	0,481	0,120	0,302
13/06/83	03h28	06h45	08h08	11h51	0,284	0,123	0,339
17/06/83	17h58	19h03	20h54	21h38	0,115	0,048	0,264
*21/01/85	13h59	14h23	15h26	16h34	4,409	0,692	3,824

*See postscript

information for these storms is summarised in Table 2. The table lists the maximum, minimum and weighted mean rainfall depths recorded at the individual gauges and the volumes and corresponding depths of runoff over the area for the first and second parts of these hydrographs. The weighted mean rainfall for the catchment was computed using the Thiessen polygon weighting procedure for all the events. It was felt that this approach was justified in the present case because although the spatial and temporal effects of the rainfall on this size catchment may have an influence on the hydrograph shape, this effect would not be as marked as that observed for the storms recorded – up to a five hour lag time was observed in the one instance (see Table 1).

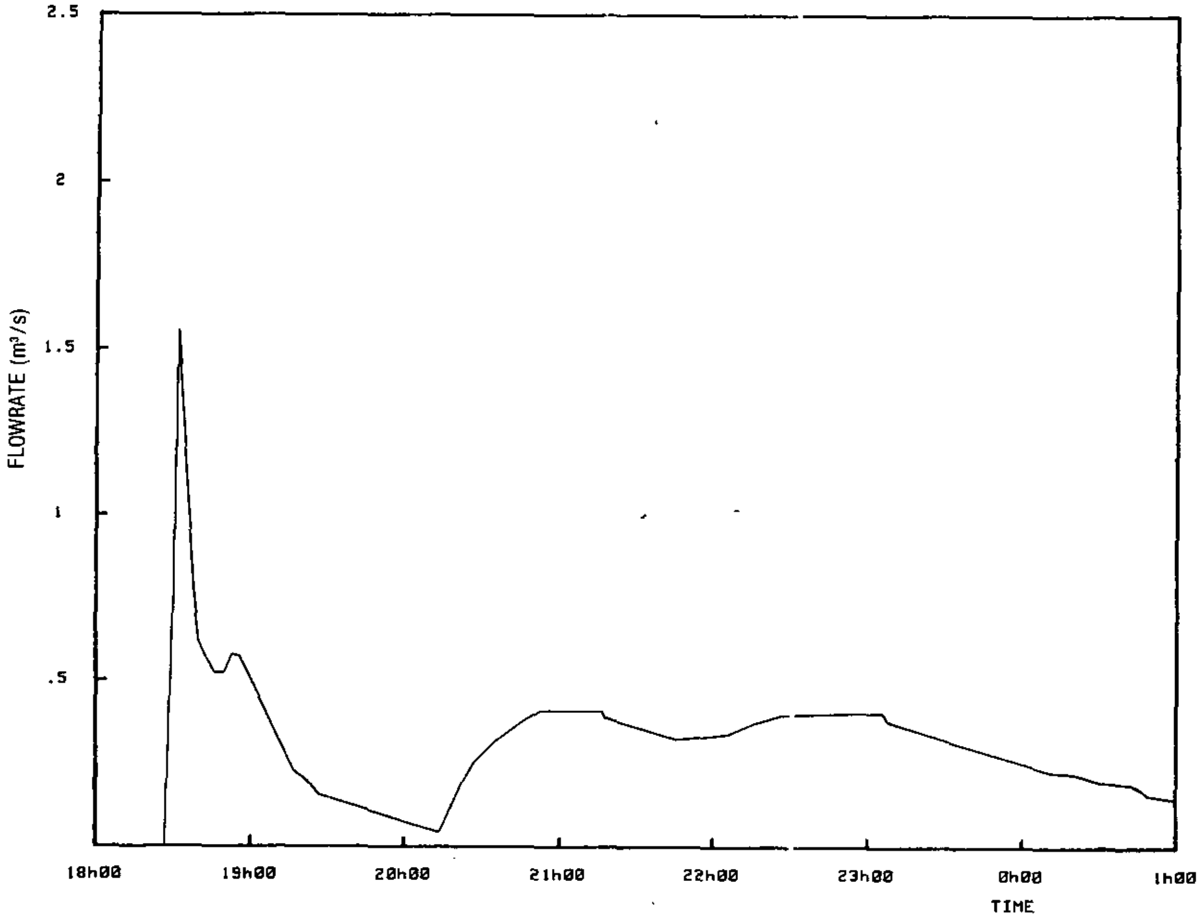

Figure 3
Runoff hydrograph for the storm of January 19, 1983.

Surface runoff models for catchment

A number of models were applied to the Montgomery Park data as part of a comparative study. The models included the Storm Water Management Model (SWMM), described by Huber *et al.* (1982), the ILLUDAS model developed by Terstriep and Stall (1974), the WITWAT model developed by Green (1984), and the URBCEL model, which is a modified version of the cell model (CELMOD) described by Diskin and Simpson (1978) and Diskin *et al.* (1984). This modified version is an adaptation of the cell model for urban catchments. By adjusting the parameters of the various models, it was found possible to get fairly good agreement between the hydrographs predicted by the models and the first part of the observed hydrographs for a number of storm

TABLE 2
RAINFALL DEPTHS AND RUNOFF VOLUMES RECORDED FOR DIFFERENT EVENTS PRESENTED AS EXAMPLES

Date	Number of Active Rainfall Recorders	Recorded Rainfall Depths (mm)			Runoff Volumes (m³)		Equivalent Depths (mm)		Figure Nos.
		Min	Max	Average	1st part	2nd part	1st part	2nd part	
19/1/83	5	12,7	17,0	14,9	2 120	5 [illegible]90	0,20	0,53	3;4
23/1/83	5	11,0	19,5	15,6	2 090	5 [illegible]40	0,20	0,53	5;6
29/1/83	4	7,4	11,0	8,8	1 040	2 [illegible]70	0,10	0,24	7;8
*21/1/85	3	12,4	35,9	20,8	10 230	46 [illegible]30	0,97	4,44	13;14

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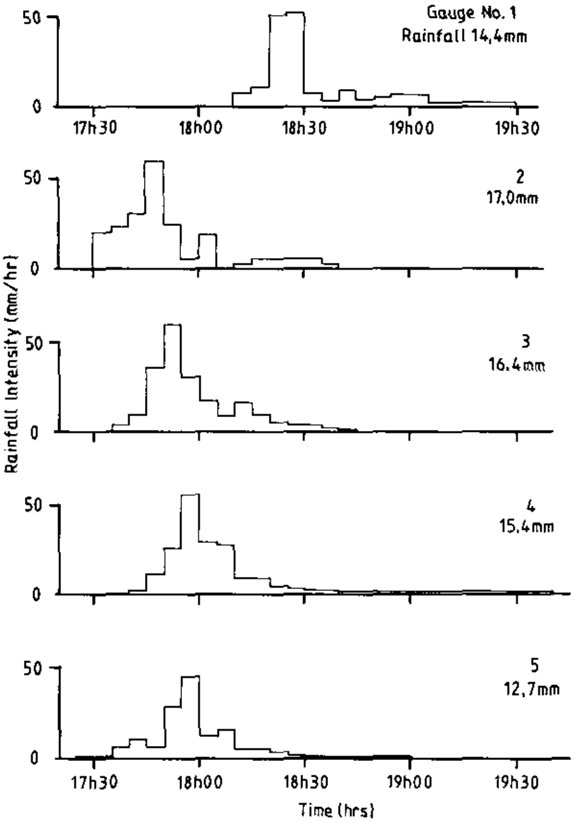

Figure 4
Recorded hyetographs for the storm of January 19, 1983.

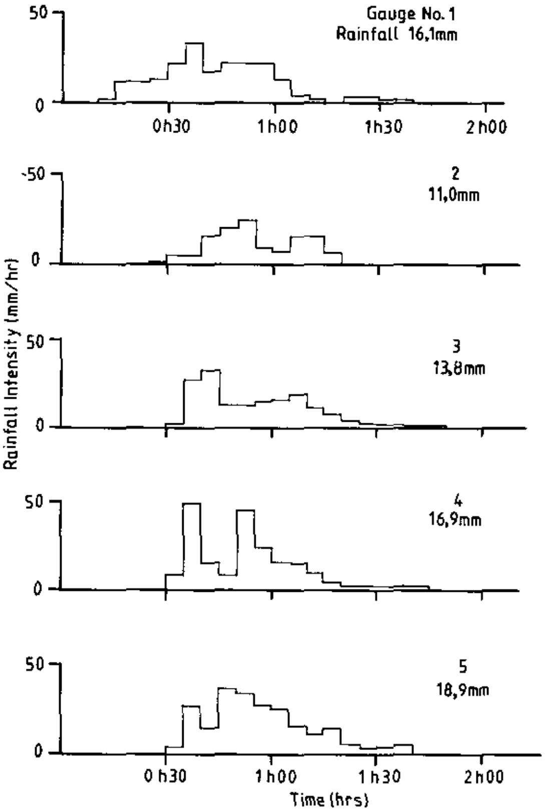

Figure 6
Recorded hyetographs for the storm of January 23, 1983.

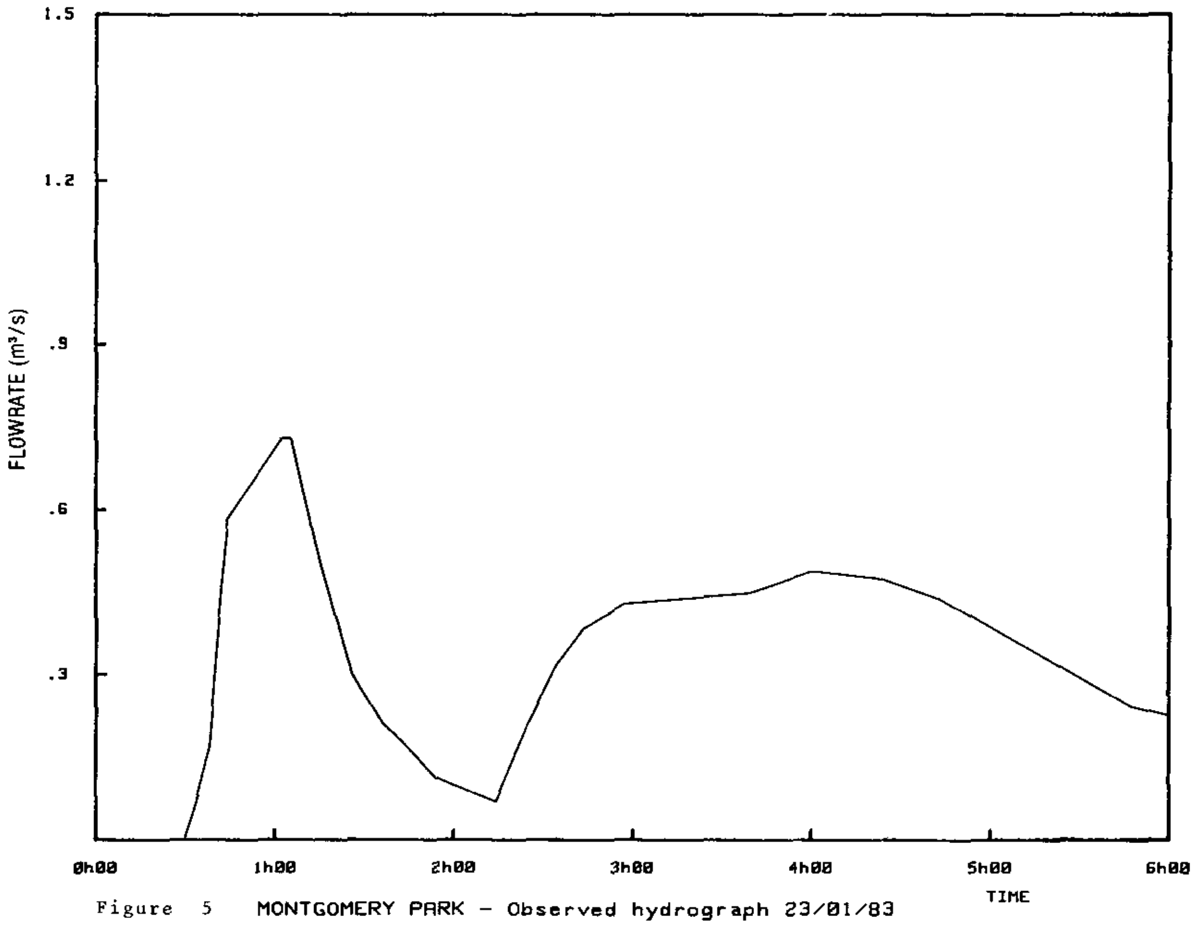

Figure 5
Runoff hydrograph for the storm of January 23, 1983.

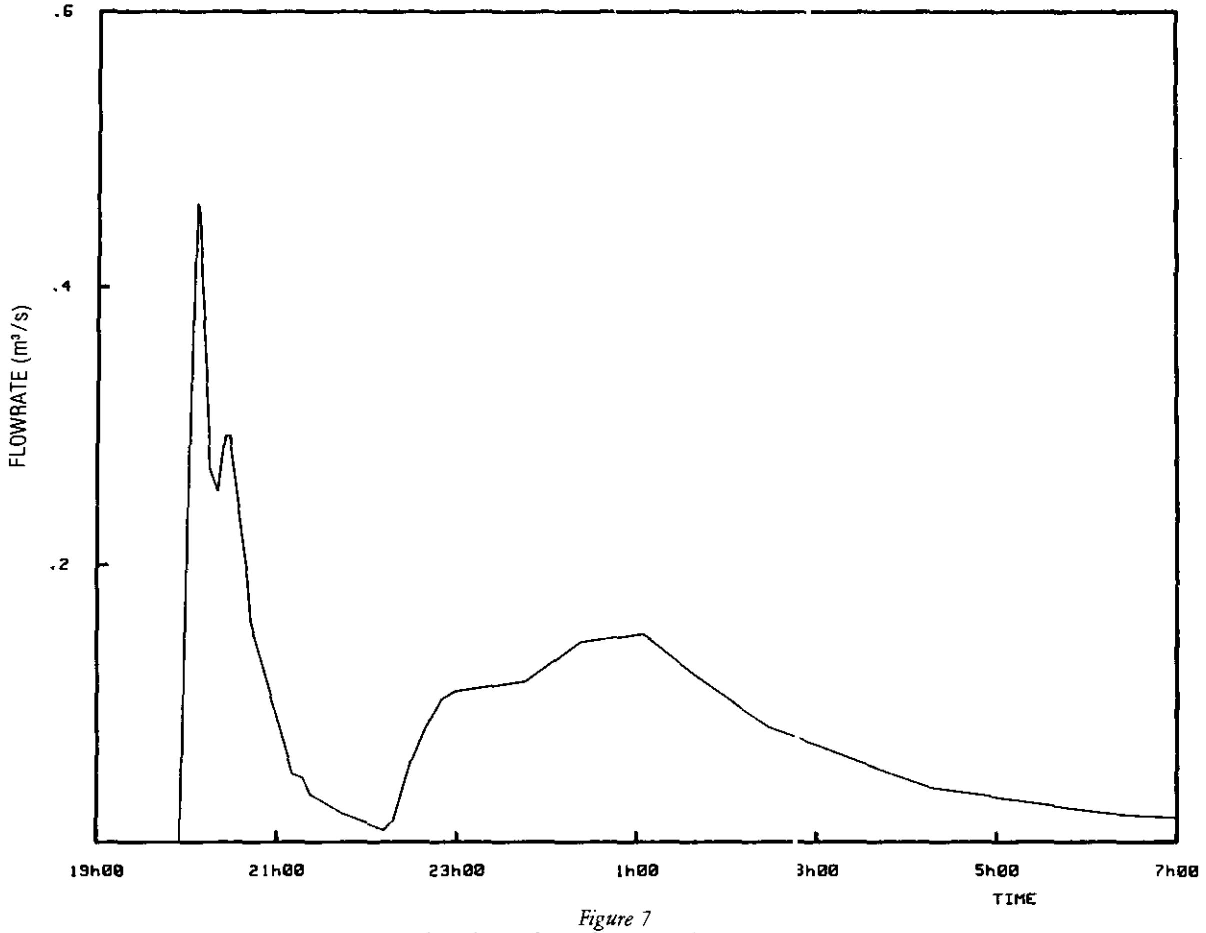

Figure 7
Runoff hydrograph for the storm of January 29. 1983.

events. It was, however, impossible to calibrate these models when the total hydrograph, i.e. including its two parts, was considered. In other words, if the models mentioned cannot be calibrated for this catchment, they are unlikely to be able to simulate or predict the runoff hydrograph to any reasonable degree of accuracy.

The feature common to the various models used in the comparative study was the fact that they were all single event surface runoff system models (although SWMM can be operated in a continuous mode), which carried out the computations in two stages. The first consists of separating the rainfall excess for various parts of the catchment, and in the second stage this rainfall excess is routed to the outlet of the catchment. None of the models has the facility to generate any component of the total hydrograph other than the direct surface runoff.

The delayed subsurface flow hydrograph

Examination of the runoff hydrographs recorded for the various storm events failed to produce any consistent relationship between their two parts. There was no fixed ratio between the two peaks. Also, the volumes produced in the two parts were not related. A possible conclusion is that each of the recorded runoff hydrographs was actually composed of two independent hydrographs generated in the catchment by two different processes from the same rainfall input. This conclusion is further supported by the multi-peaked hydrograph recorded in the storm of March 8, 1983. Figure 9 illustrates this hydrograph resulting from two bursts of rainfall separated by a number of hours. Each burst of rainfall resulted in a double peaked hydrograph, and the two hydrographs were superimposed to produce the recorded compound hydrograph. The delayed second part of each of the two

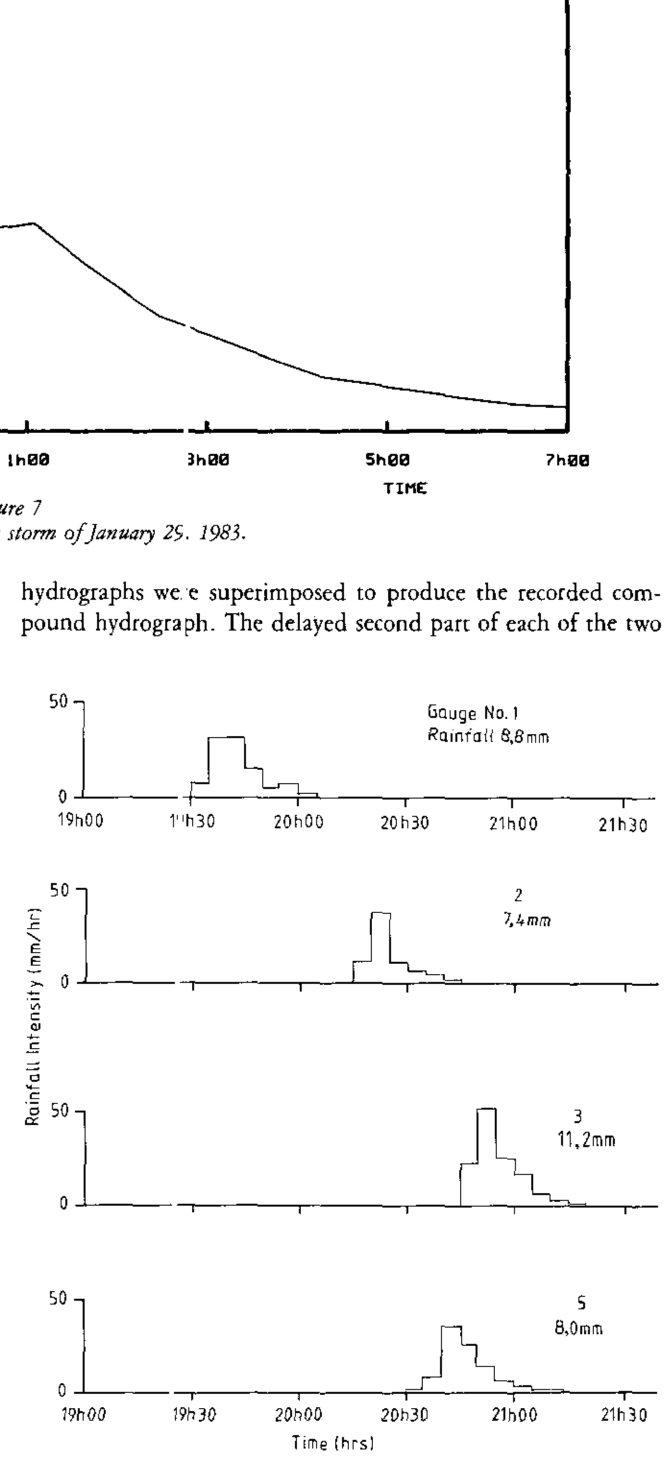

Figure 8
Recorded hyetographs for the storm of January 29, 1983.

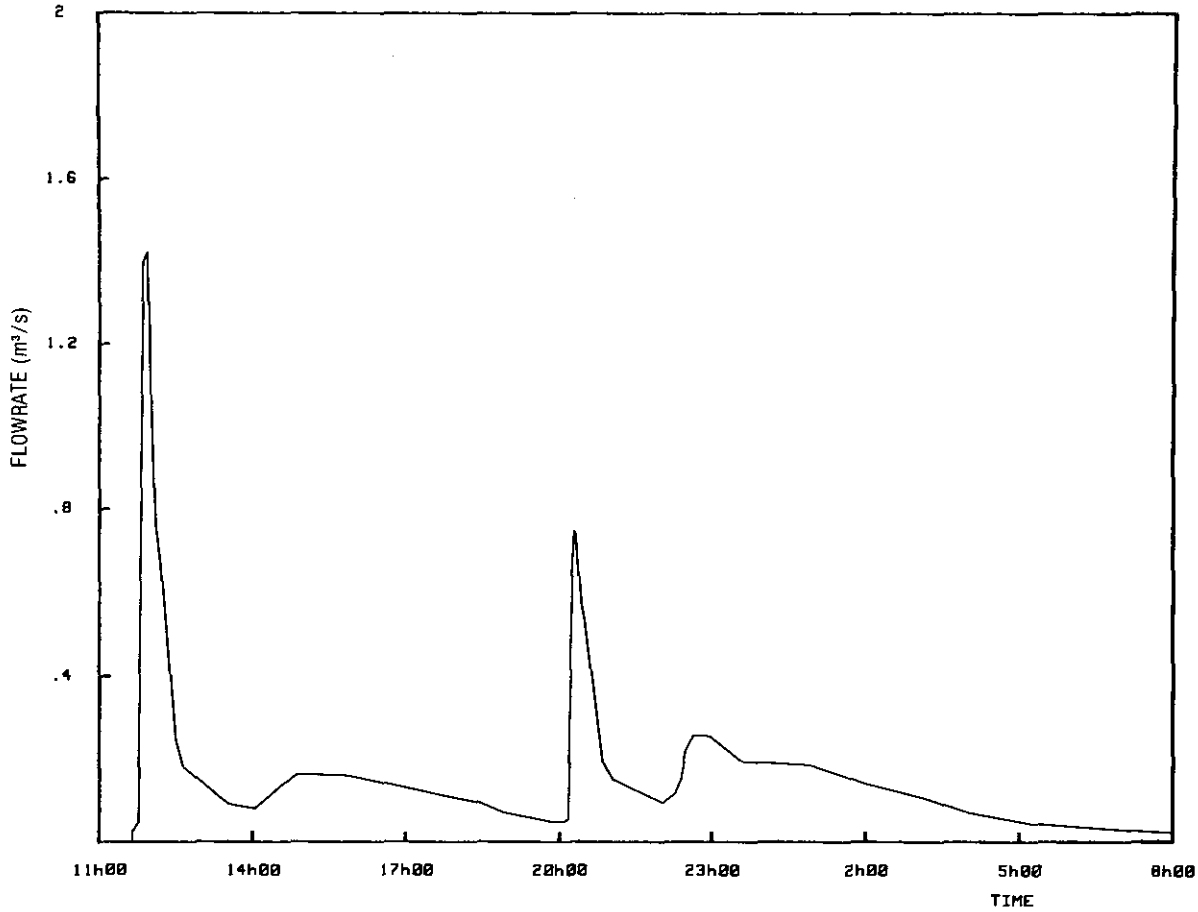

Figure 9
Runoff hydrograph for the storm of March 8, 1983.

superimposed hydrographs can be clearly seen in Figure 9, where it is more pronounced in the hydrograph following the second burst of rainfall.

A few possible explanations were considered for the unusual hydrographs observed in the Montgomery Park catchment. One such explanation was that the hydrographs reflect the structure of the main drainage system (Figure 1), where two major streams are joined a short distance upstream of the flow measuring station. Another possible explanation for the double hydrographs was that the first represents surface runoff from impervious parts of the catchment and the second the surface runoff from the pervious areas. The hypothesis common to the two explanations is that the double peaked hydrographs are caused by two portions of the catchment surface operating in parallel.

The above explanations were deemed unlikely because of the relatively large differences in timing between the two parts of the hydrographs. The two parts of the catchment drained by the two major streams appear to have fairly similar hydrological characteristics, so that the first explanation given above is unlikely. Also, for a catchment of 10,5 km² a time difference of the order of 3 hours is too large to be produced by the pervious and the impervious components of the surface runoff flowing in the same main drainage system having fairly steep slopes. As mentioned earlier, the large difference in timing also discredits the possibility of the observed hydrograph shape being due to the spatial and temporal distribution of the rainfall. This conclusion is further supported by inspection of the rainfall records for the various raingauges, as shown for example in Figures 4, 6 and 8.

Another explanation for the two hydrographs is that the first one is due to surface runoff, mostly from directly connected paved areas but possibly including some pervious area contribution. The second hydrograph, according to this explanation, may be that derived from rain water that is delayed by first infiltrating into the ground and flowing some distance below the surface before being discharged into the channel system and thereafter conveyed to the outlet. This inference is in agreement with the findings of Hewlett and Nutter (1970) who stated that runoff having travelled for part of its journey as interflow will often be sufficiently delayed to form a second peak on the hydrograph. In other words, it appears that the first hydrograph is direct surface flow and the second is due to interflow. The reason for the relatively large time difference between the two is due to the steep surface slopes in the catchment producing the rapid runoff for the first hydrograph and the geological and pedological structure of the upper strata and soil layers in the catchment causing the delayed release of part of the water that infiltrated into the ground. It should be noted at this juncture that the term interflow has been used here rather broadly to include various forms of subsurface flow, some of which may even be outflow from some small local perched aquifers.

The existence of the two independent processes resulting in the two parts of the runoff hydrograph is also demonstrated in Figures 10 and 11. Figure 10 presents the relationship between peak flowrates and volumes included in the first parts of the recorded hydrographs. Similarly, Figure 11 displays the same relationship for the second part of the recorded hydrographs. As can be seen, the two relationships are definitely different, although each relationship is almost linear, the coefficients of cor-

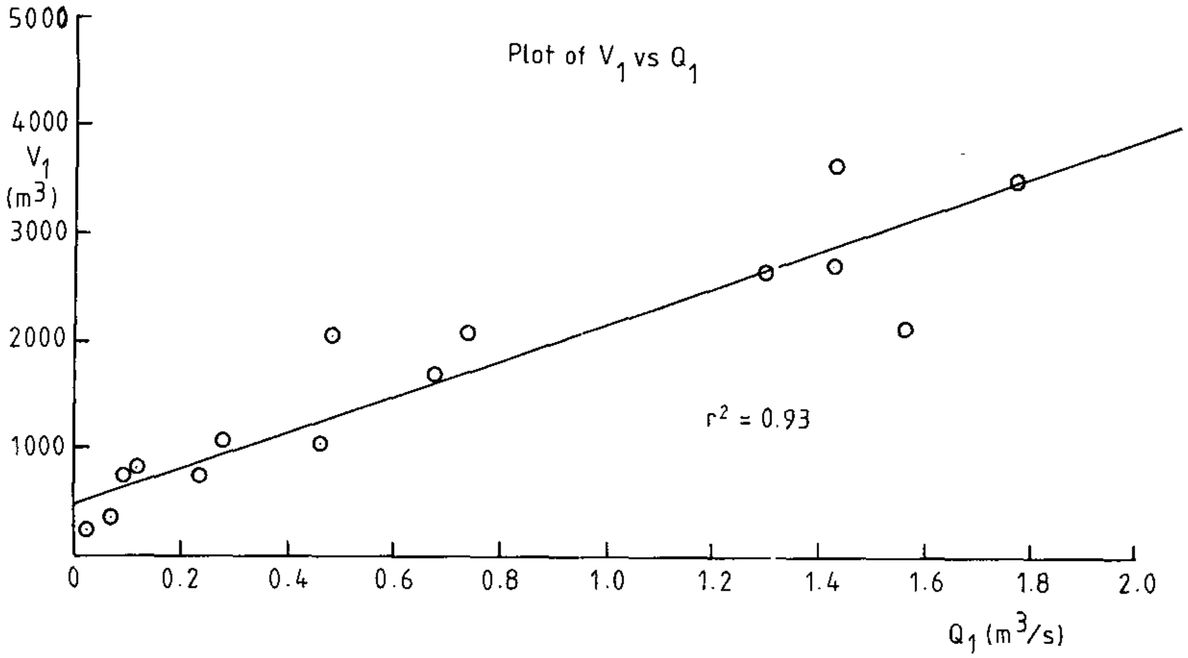

Figure 10
Plot of volume versus peak flowrate for first part of hydrograph.

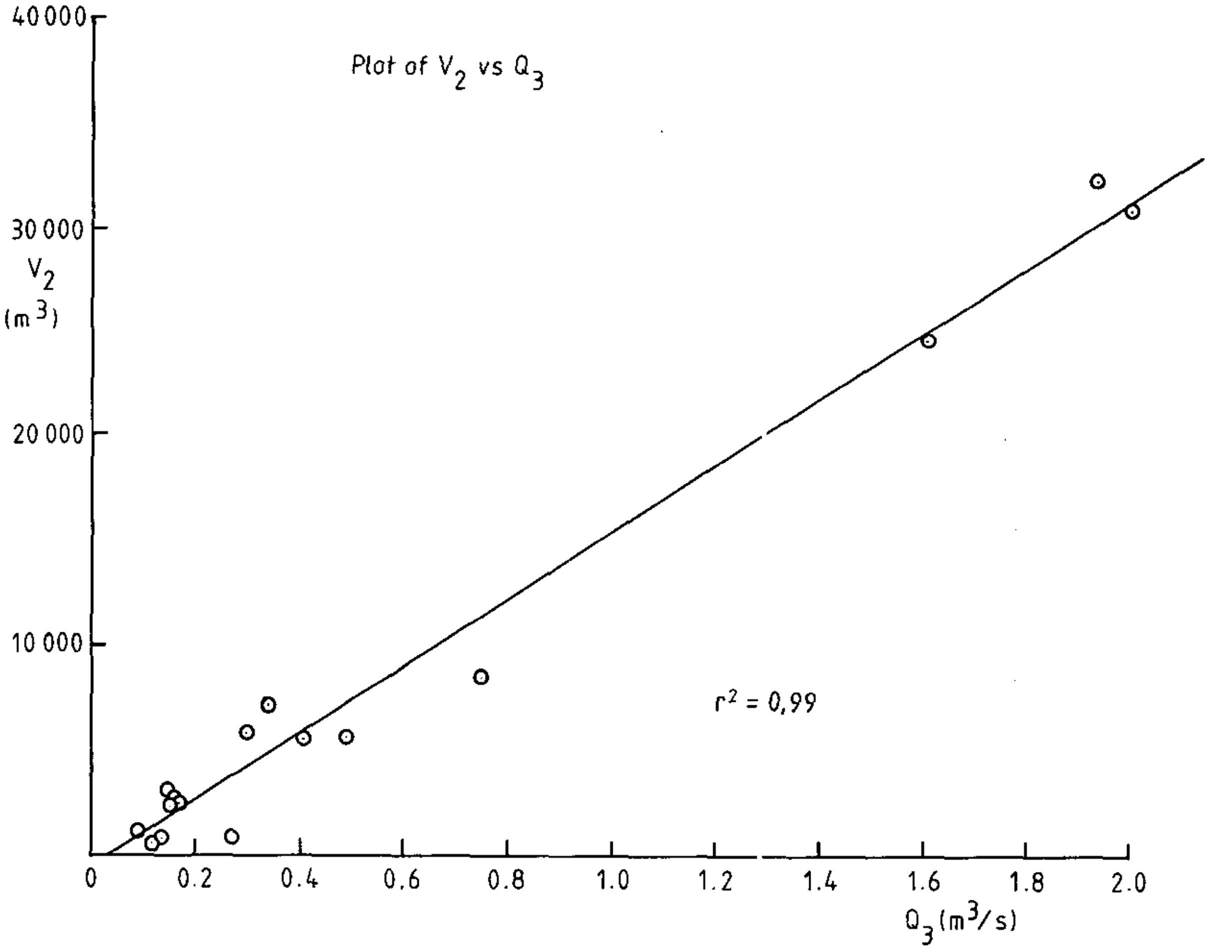

Figure 11
Plot of volume versus peak flowrate for second part of hydrograph.

relation being 0,93 and 0,99 for the two parts respectively. The fact that the relationship for the second part has less scatter and a higher correlation coefficient can be interpreted to mean that the second process is due to a more stable storage system. This is consistent with the conclusion that the second part of the hydrographs is indeed due to subsurface flow, or interflow. The larger scatter displayed in Figure 10 may be evidence of some nonlinearity in the surface runoff system, but it also reflects the influence of the time distribution of the rainfall excess in the various storms. The fact that the duration of rainfall excess is large relative to the time base of the first hydrograph may also be a contributing factor. Both factors are less significant relative to the longer time base of the second part of the hydrographs.

Geologic and pedologic considerations

The geology of the Montgomery Park catchment is interesting in that three distinct geological sequences are found in the catchment. The first of these sequences is the Johannesburg-Pretoria granite dome. This dome is bounded to the south by the Witwatersrand Supergroup, which is the second formation found in the catchment. The third sequence which is present in the area consists of ultramafic rocks of the Swaziland Sequence. These rocks constitute some of the oldest rocks in the world. According to Anhaeusser (1973) the occurrences of ultramafic rocks are mainly around the western, south-western and south-eastern boundaries of the Johannesburg-Pretoria granite dome. The Montgomery Park catchment is situated on the boundary between the first two sequences. The locality of the catchment with respect to these geological sequences is indicated in Figure 12.

After the intrusion of the Johannesburg-Pretoria granite dome into the Swaziland Sequence, the sedimentary rocks of the Witwatersrand Supergroup were deposited and these now dip at various angles away from the granite dome due to tectonic movements. The underlying strata of the Witwatersrand Supergroup and therefore the oldest, known as the Orange Grove Quartzites, form a prominent ridge which, according to Truswell (1970), is the ridge giving rise to the name Witwatersrand. Subsequent tectonic movements resulted in a fault system which displaced the western portion of this ridge by approximately two kilometres northwards, forming what is now known as the Northcliff ridge. This displacement resulted in the formation of a valley between the two quartzite ridges.

The valley formed by the fault and subsequent movement is drained by two streams which have caused a certain amount of erosion and deposition, so that both transported and residual material are to be found in the valley. The residual material consists mainly of clays from the weathered schists, granites and gneisses from the Swaziland Sequence while the transported material is hillwash from the quartzites and shales of the Witwatersrand Supergroup (Ball, 1984). Granites of the Johannesburg-Pretoria granite dome are also in evidence at various places within the catchment.

The Geotechnical Data Bank of the City Engineer's Department of the Johannesburg Municipality was consulted in order to obtain a more detailed description of the pedology and underly-

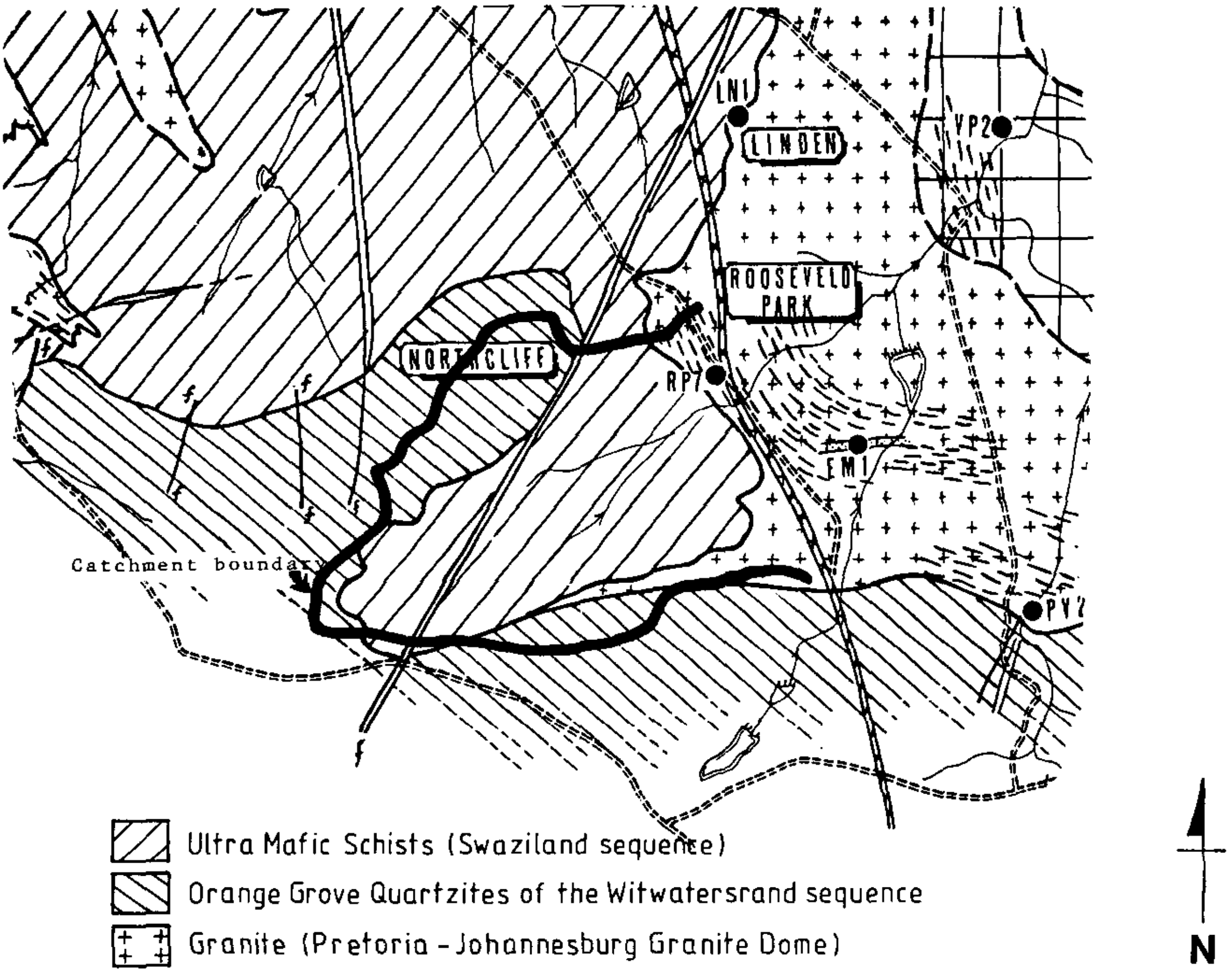

Figure 12
Geological locality plan of the Montgomery Park catchment.

ing geology of the area. It appears that the only comprehensive investigation documented is that undertaken in the region of the Waterval sanitary landfill site, located near the western boundary of the catchment. Apart from this study, very little other pedological and geological information exists for the area. The additional information is from a number of trial pits which have been dug in the past at various locations in the catchment for the purpose of geotechnical investigations related to building and development projects. Some records have been kept of these trial pits, but in general the paucity of geotechnical information allows no conclusive estimate of the underlying geology to be made.

The indications are however that a harder (and possibly less permeable) stratum exists at between 2,5 m and 4,0 m below a large portion of the catchment. This conclusion is supported by the fact that some of the records from trial pits at various locations showed refusal in this depth range. In most cases there was evidence of the pebble marker just above refusal level. In addition, about 30 trial holes were excavated at the site of the old Montgomery Park dam near the eastern boundary of the catchment. Some 25% of these holes met refusal at a depth range of between 0,3 m and 2,8 m.

Another possible indication of the presence of a relatively impervious layer below the surface of parts of the catchment is the occurrence of ground water at shallow depths. Measurements of water table fluctuations have been taken in the Waterval sanitary landfill site as well as in the area a short way downstream of the landfill site. These measurements revealed the water table to be at an average depth of 2,9 m with an average range of fluctuation of 1,5 m.

The presence of an impervious layer at a depth of between 0,5 m and 3,0 m under a relatively extensive part of the catchment can explain the occurrence of the delayed subsurface flow hydrograph. Viessman *et al.* (1977) maintain that interflow occurs when infiltrated water strikes a relatively impervious stratum near the soil surface and flows approximately parallel to it until an outlet is reached. Amerman and Naney (1982) endorse this viewpoint by stating that lateral flow over a sloping impeding layer is thought to be the mechanism by which interflow takes place. While interflow is unlikely to take place at a depth of 3 m, delayed flow may well take place at this level in the form of subsurface flow.

The pervious top layers in the catchment would, according to this explanation, transmit the infiltrating water in excess of the field capacity of these layers downwards to the saturated zone above the impervious layer. This water would then start to move laterally until it emerges into the drainage system of the catchment and then flow to the outlet. The presence of a pebble marker, usually found at the interface between transported and residual soils, would greatly facilitate the lateral movement referred to as it is generally more permeable.

This model is however inconsistent with the theory of Zaslavsky and Sinai (1981) who contend that lateral flow in a soil is not caused by boundary conditions, such as the position of the water table or the presence of an impermeable layer, but by soil anisotropy caused by soil layering. This layering produces a flow component pointing downhill which is proportional to the slope and also to the rainfall rate. Zaslavsky and Sinai consequently maintain that interflow, or lateral flow beneath the soil surface, is related more to the pedology of an area rather than its geology.

Whatever the mechanism of lateral subsurface flow is, be it dependent on the geology as proposed by Viessman *et al.* (1977) and by Amerman and Naney (1982) or on the pedology as proposed by Zaslavsky and Sinai (1981), or on a combination of the two, the slow movement of the water in the upper soil layers of the catchment can thus explain the relatively large time lag between the two parts of the observed runoff hydrographs.

Conclusions

Historically, the significance of interflow has been neglected in urban drainage applications, the emphasis being placed purely on the contribution of direct surface runoff when computing the flood hydrograph. This paper illustrates that such a practice could, in some cases, lead to a gross under-estimation of the runoff hydrograph in a catchment where the influence of interflow is appreciable. As has been noted, the conditions under which interflow, or more generally subsurface flow, becomes significant are the presence of convex hillslopes with an upper layer of permeable soil (Freeze, 1972b), or, as proposed by more recent research, the presence of permeable anisotropic layered upper soil horizons (Zaslavsky and Sinai, 1981). The presence of impervious layers underlying shallow layers of pervious material will, in all probability, further contribute to this effect (Viessman *et al.*, 1977). If these conditions occur over an appreciable part of the catchment, the volume of water appearing at the outlet as interflow or subsurface flow will be significant. If, in addition, the surface slopes in the catchment are steep, the direct surface runoff hydrograph can appear as a separate hydrograph preceding that due to interflow.

It is believed that the conditions in the Montgomery Park catchment satisfy some of the abovementioned criteria and that, in consequence thereof, interflow, or more generally subsurface flow, is a significant component of the effective flood hydrograph. The evidence leading to this conclusion is, however, by no means conclusive. Field observations, by way of measuring water table fluctuations during and following a rainstorm event, as well as the study of many more rainfall-runoff events would be required to conclusively indicate that interflow is in fact responsible for the anomalous shapes of the observed runoff hydrographs. Even if this were found to be the case, it would still have to be ascertained whether the interflow component is significant also for the less frequent, more severe storm events, or whether its effect is exaggerated for the rainfall events recorded so far.

However, the indications presented in this paper are that in the case studied an interflow component may exist and that this component may significantly influence the shape of the effective flood hydrograph. This being the case, any drainage facilities proposed for the area, especially those where the total volume of runoff is of importance, such as a detention facility, should take this phenomenon into account. If a detention facility were designed purely on the basis of the direct runoff contribution, resulting in the first part of the hydrograph and the initial peak of the total hydrograph, then the effectiveness of the facility will be decreased. With the omission of the volume contained in the lagged secondary hydrograph, hydraulic failure of such a facility becomes a distinct possibility.

A further important finding emerges from this study, namely that the simulation models applied to the catchment were incapable of fitting the second peak of the total hydrograph and therefore also the total volume of runoff in each case. As this second hydrograph has in some cases exceeded the first in terms of peak flowrate and volume, a major shortcoming in the models used for the present study is in evidence. It is felt that more research should be undertaken in this direction, so that an interflow component can be included in some of the more popular urban drainage hydrological simulation models for use in situations such as the present case.

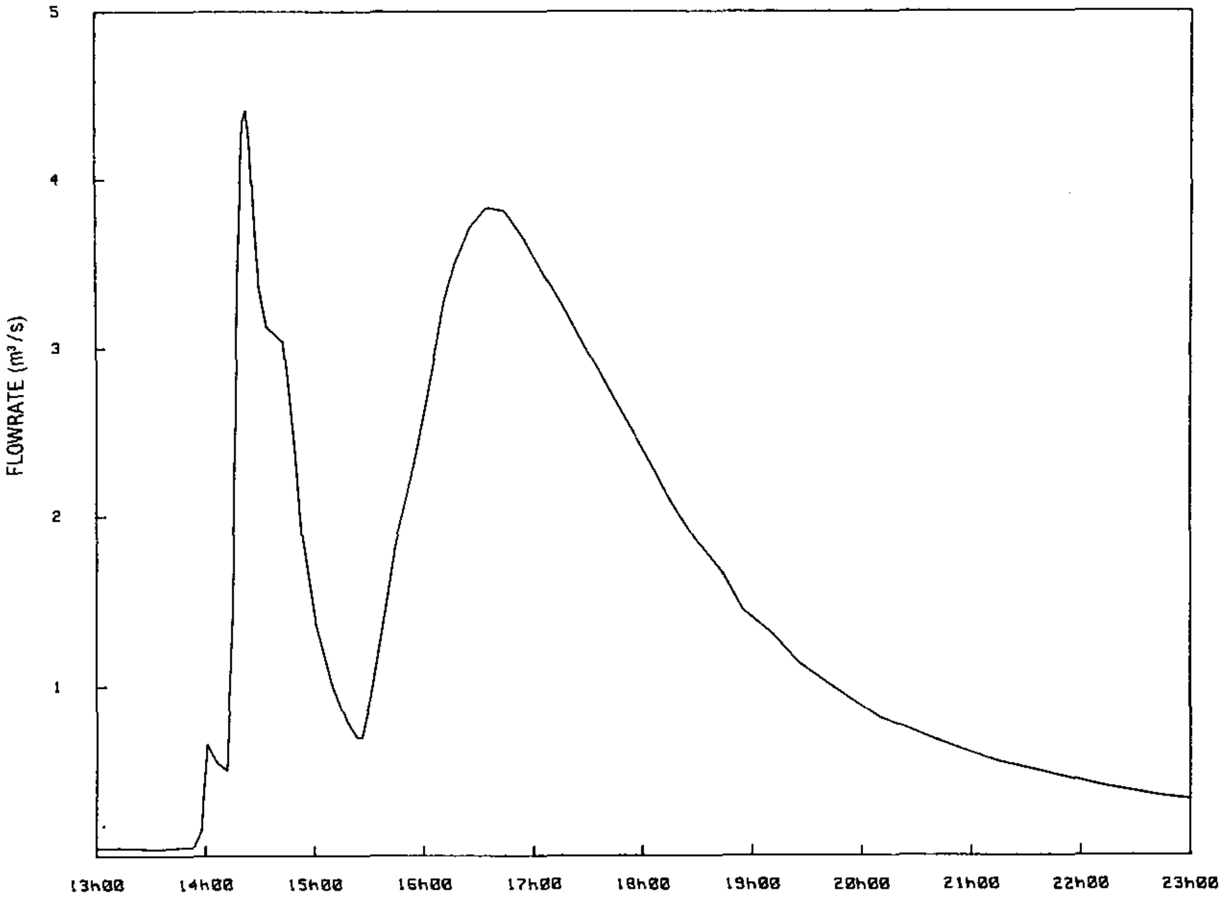

Figure 13
Runoff hydrograph for the storm of January 21, 1985.

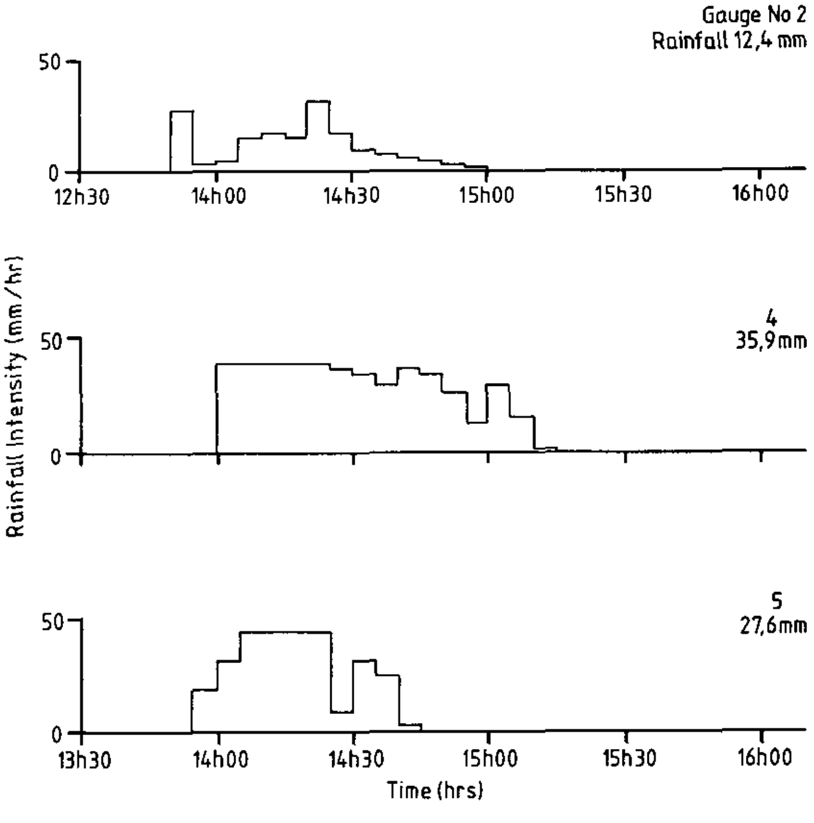

Figure 14
Recorded hyetographs for the storm of January 21, 1985.

Postscript

The paper submitted for publication was based on rainfall and runoff data available as at the end of September, 1984. After submission, a number of storm events occurred over the Montgomery Park catchment in January, 1985, producing runoff hydrographs with peaks ranging from 1,0 m³/s to 6,7 m³/s. All these more recent hydrographs displayed the delayed subsurface flow hydrographs discussed in this paper. The hydrograph and hyetographs for the storm of January 21, 1985 are depicted in Figures 13 and 14 respectively, the former figure demonstrating very clearly the delayed interflow or subsurface flow component of the hydrograph in the Montgomery Park catchment at a relatively high flowrate. The rainfall and runoff information corresponding to this event has been added to Tables 1 and 2.

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