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ASPECTS OF THE HYDROLOGY OF A GLEY ON A DRUMLIN

W. Burke
An Foras Talúntais, Kinsealy, Malahide Road, Dublin

J. Mulqueen and P. Butler
An Foras Talúntais, Ballinamore, Co. Leitrim

ABSTRACT

The results are presented of a study of precipitation, surface run-off from an undrained plot, and mole flow and surface run-off from a mole-drained plot during the period 1965 to 1971 on a heavy clay near Ballinamore. The findings are described under the headings, quantities, frequency of events, pattern of precipitation and run-off and water balance. Some rainfall fell on almost 250 days per year on average. Surface run-off and mole flow were more common in winter than in summer. Moles discharged more and mole flow was more frequent than surface run-off. Mole drainage almost eliminated surface run-off.

INTRODUCTION

Drumlin hills are about 80 hectares in area and are a feature of some glacial landscapes. They are ellipsoid in outline with a steep sloped nose and a more gently sloping tail. Slopes vary from flat to about 20°. The weighted average slope is about 10°. Most of the soils of the drumlin belt of North-Central Ireland are essentially two-layered with a shallow topsoil variable in depth but averaging 7 to 50 cm, resting on a tight practically impervious clay. Heavy texture and massive structure (structureless) result in subsoil hydraulic conductivities of the order of 1×10^{-2} to 1×10^{-4} cm/day while topsoil hydraulic conductivities can be 30 cm/day. A shallow topsoil resting on a tight subsoil is rapidly saturated and surplus water ponds the surface and flows over the soil as surface run-off. Field observations confirm this and show that hoof marks and minor depressions become filled with flowing water. Frequent light rainfalls serve to maintain the topsoil in the saturated state throughout the winter. Only in late April when the average rainfalls are light and evapotranspiration is significant does significant soil drying take place. In wet growing seasons the topsoil can be wet for much of the time.

Mole drainage or modifications of it are the recognised methods of drainage in these soils. Mole drainage has two advantages in this situation: i) it fractures the soil above the mole invert and results in structure formation under favourable conditions where this is required; ii) a close spacing of drains, which is required since the soil below the drain invert is essentially impervious, can be economically installed. As part of the general study of the drainage of these soils an investigation was undertaken to determine the major hydrological features of a shallow topsoil clay drumlin near Ballinamore, Co. Leitrim.

The main objectives of the study were: a) to determine the relationships between precipitation and surface run-off from an undrained area; b) to determine the influence of effective mole drainage on the hydrology of a moled area; and c) to measure the losses of applied fertilisers in surface run-off and drainage water. The fertiliser relationships are reported elsewhere (1). The project began in 1965 and continued until the end of 1971 to cover as far as possible a variety of seasonal and annual rainfall patterns.

EXPERIMENTAL

Two plots, 2.14 m wide and 22 m long, were demarcated on a uniform slope of 10° (Fig. 1). A shallow drain about 30 cm deep (the depth of the top soil layer) was cut across the slope a short distance above the plots to exclude water coming from higher up the slope. Each plot was surrounded on the top and on each of the two long sides by a 15-cm deep steel strip to exclude foreign water. On each side the strip was made continuous by welding and was driven into the soil. The strip projected 5 to 50 mm above the soil surface.

Surface run-off was collected by an eave and gutter arrangement. A steel plate 15 cm wide and 2.14 m long was driven about 8 cm into the face of the plot at an acute angle to the surface. This plate came within 6 to 10 cm of the surface to function as an eave. Thus surface run-off flowed onto the eave and into the gutter from where it was conveyed to the collecting tanks.

A 15-cm length of 10-cm bore PVC watermain was used to line the terminal end of each mole drain and there was an 8-cm overhang. The pipe was carefully inserted as a sleeve into the mole for a distance of 7 cm and caulked. All eaves and gutters were roofed to prevent access of precipitation and minimise soil cracking.

The collecting tanks were fitted with float and pan mechanisms to record the rate of surface run-off or mole flow and could hold approximately 18 mm of water from the study areas. Rainfall was also recorded. The tanks were emptied by a manually controlled valved outflow as often as necessary and thus full records of precipitation, surface run-off and mole flow were obtained for 6 years. Water samples were taken

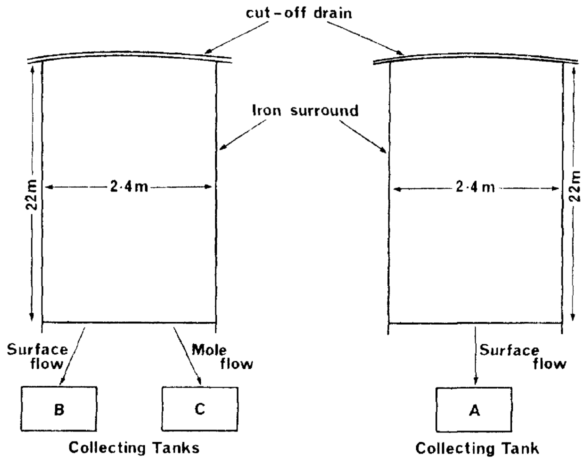

Fig. 1: Diagrammatic representation of plots and collecting tanks

from the tanks for chemical analysis before they were emptied. Measurements on the two plots commenced in July 1965. One plot was mole ploughed by winch in April 1966 and thereafter surface run-off and mole flow were monitored separately. The trench to accommodate the eave and gutter arrangement was 25 cm deep in the surface run-off alone plot A and was 55 cm deep in the mole-drained plot B.

From July 1965 to April 1966 the arrangement was mainly used to perfect the installations and uniformity tests of the site were made. In the uniformity test (only surface run-off water) plot A always discharged more water than plot B which was mole drained on 18.4.66. The percentage difference in the discharge varied according to the volume of run-off. It was only 1.3% in November when two large storms virtually caused the entire run-off (115 mm) and was 8.1% in October when the total run-off was small (40 mm) and rainfall intensity was moderate. The range of variation is shown in Table 1 for February 1966 when there were numerous storms of varying intensity and duration. The monthly surface run-off from plot A was commonly 4 to 7% greater than from plot B. This bias was not considered too large.

The soil on the experimental site has a 10 cm organic clay loam (A_1 horizon) on 15 to 20 cm of aggregated subangular blocky structured clay loam grading into a gravelly clay. The effective topsoil (structured soil layer) on this site is 25 to 30 cm. The 10-cm-bore mole drains were drawn uphill by winch at a depth of 45 cm and at a spacing of 107 cm in plot B on the 18.4.66 when the soil was wet, since late March was wet and the rainfall in the 4 days prior to drawing the moles was 3.4, 30.8, 3.9 and 0.0 mm. Heavy rain fell soon after drawing the moles; on April 21, 22 and 23 the rainfall was 17.6, 4.1 and 5.4 mm. The subsequent May and June were exceptionally wet with 117 mm and 139 mm rain respectively compared with average rainfalls of

TABLE 1: Uniformity test on site of hydrology investigations for February 1966 showing surface run-off from each plot

Dates (inclusive)	Plot A (mm)	Plot B (mm)	DifferenceA–B (% of A)
2–4	4.1	3.7	10
5	8.4	7.5	11
6	0.5	0.3	40
7–8	22.6	21.7	4
9–12	9.4	9.2	2
13	0.2	0.1	50
14–15	27.7	26.7	4
16–17	2.3	2.0	13
18	10.8	9.8	9
19–21	10.0	9.8	2
22	3.0	2.5	16
23	2.5	2.1	13
24–25	3.0	2.6	12
26–28	14.8	14.5	2
Total	119.1	111.9	6

75 and 77 mm respectively. There was surface run-off from plot A almost daily from April 18 to May 25. In spite of the unfavourable weather conditions mole drains performed very satisfactorily on this site because of the deep topsoil and the absence of traffic. Drawing mole drains on this clay directly with tracked tractors under such climatic conditions and drain spacing is known to be relatively ineffective, especially where the topsoil is less than about 20 cm, since the hydraulic conductivity of the soil slab above the mole drain invert is not much increased (2). After mole draining plot B, surface run-off water continued to be collected in tank B and mole flow water in tank C which was then brought into commission. Tank A continued to record surface run-off water from the undrained plot A.

RESULTS AND DISCUSSION

The surface run-off and mole flow data are presented under four headings: quantities, frequency, pattern and water balance. Monthly and yearly summaries are given in Tables 2 to 8 inclusive. During the 6 years, rainfall varied from a high of 1393 mm in 1966 to a low of 906 mm in 1971. Thus the range of expected rainfall amounts for the area (3) was covered during the period under study. Furthermore, annual rainfalls close to the mean annual of 1193 mm were encountered in 1967 and again in 1970 (Table 2).

In the period under study there were variations in the seasonal distribution of rainfall, for example, the wet summer of 1966 and the dry autumn of 1969. There were also variations in the proportion of rainfall that emerged as surface run-off and as mole flow. The variations in run-off and mole flow were mainly attributed to the intensity

TABLE 2: Annual precipitation, surface flow and mole flow (1966–71 inclusive)

		Undrained	Drained	
	Precipitation (mm)	A—surface flow (mm)	B—surface flow (mm)	C—mole flow (mm)
1966	1392.9	637.4	—[a]	—[a]
1967	1172.7	352.6	16.8	565.0
1968	1269.1	462.0	45.0	735.0
1969	966.7	265.8	13.7	456.0
1970	1177.1	328.6	61.3	505.4
1971	906.3	154.1	39.6	265.5

[a] Data excluded as moling was not done until April

TABLE 3: Summary of amounts of precipitation, surface flow and mole flow

Period	Precipitation (mm)	Flow (mm) A	Flow (mm) B	Flow (mm) C	Flow as % of precipitation A	Flow as % of precipitation B	Flow as % of precipitation C
Nov. 1, 1965 to[a] April 30, 1966	882.0	578.1	500.3	—	65.6	56.7	—
May 1, 1966 to Oct. 31, 1966	568.7	151.6	17.9	129.0	26.7	3.1	22.7
Total	1450.7	729.7	—	129.0	50.2	—	—
Nov. 1, 1966 to April 30, 1967	599.8	325.6	21.4	426.0	54.3	3.6	71.0
May 1, 1967 to Oct. 31, 1967	654.7	163.0	0.5	255.9	24.9	0.1	39.1
Total	1254.5	488.6	21.9	681.9	38.9	17.5	54.4
Nov. 1, 1967 to April 30, 1968	540.0	263.0	38.4	375.1	48.7	7.1	69.5
May 1, 1968 to Oct. 31, 1968	664.2	120.8	1.9	228.3	18.2	0.3	34.4
Total	1204.2	383.8	40.3	603.4	31.9	3.3	50.1
Nov. 1, 1968 to April 30, 1969	559.2	265.5	11.1	461.3	47.5	2.0	82.5
May 1, 1969 to Oct. 31, 1969	393.8	25.7	2.0	80.1	6.5	0.5	20.3
Total	953.0	291.2	13.1	541.4	30.6	1.4	56.8
Nov. 1, 1969 to April 30, 1970	636.5	275.3	34.5	385.5	43.3	5.4	60.6
May 1, 1970 to Oct. 31, 1970	567.4	98.2	8.1	161.2	17.3	1.4	28.4
Total	1203.9	373.5	42.6	546.7	31.0	3.5	45.4
Nov. 1, 1970 to April 30, 1971	489.6	148.5	53.1	243.7	30.3	10.8	49.8
May 1, 1971 to Oct. 31, 1971	463.5	26.5	1.1	70.6	5.7	0.2	15.2
Total	953.1	175.0	54.2	314.3	18.4	5.7	33.0
Mean annual[b]	1113.7	342.4	34.4	537.5	30.7	3.1	48.3

[a] Data for moled plot are omitted for period Nov. 1, 1965 to Oct. 31, 1966 since moling was done in April 1966
[b] From Nov. 1, 1966 to Oct. 31, 1971

and duration of the rainfall and the antecedant moisture status of the soil. The few minor discrepancies which occurred were attributed to such factors as the overlapping of rainfall and run-off events, temporary malfunction of the recorders, a few overflows and to the already demonstrated small differences between the plots.

Quantities of precipitation, surface run-off and mole flow

Quantities of precipitation, surface run-off and mole flow are summarised in Tables 2, 3 and 4. The designation is the same as already mentioned in the previous section viz.:

A — surface run-off from undrained plot A
B — surface run-off from drained plot B
C — mole flow from mole drains of drained plot B

Table 2 gives a summary of annual surface flow and mole flow. In presenting the data in Table 3 the years are divided into two periods corresponding with the average summer season (May 1 to October 31) and winter season (November 1 to April 30). Table 4 gives monthly data for 1967, a year which had near average annual rainfall for the area. This was selected to show the typical average pattern. Tables 2 and 3 also permit a comparison of annual and summer data for both 1967 and 1970. The main pattern emerging in all three tables is a high surface run-off and mole flow in winter when evaporation is low, with the opposite effect in summer. The chief conclusions from Tables 2, 3 and 4 are:

a) Surface run-off from plot A and total flow from plot B increased almost linearly with increasing annual rainfall (Table 2). In winter time the linear relationship was very marked (Fig. 2) and since most of the run-off and drainage events took place then, this was mainly responsible for the linear relationship of the annual values. Invariably the flow from the mole drains exceeded the surface run-off from the undrained plot while the rate of increase of discharge with rainfall was more or less equal. This happened despite the fact that surface run-off from plot A invariably exceeded that from plot B prior to moling. Since the mole drains were drawn by winch at a very close spacing of 107 cm, the plots were not grazed and the topsoil at the site is deep, the moling could be regarded as ideal apart from the unfavourable weather at and after installation. However, climatic conditions at the time were not very important in the site with the method of installation used.

In the 2 years of almost average rainfall (1967 and 1970, Table 2), the surface run-off from the undrained plot totalled 353 and 329 mm respectively and averaged 29% of the rainfall. In 1966, surface run-off was 46%. The corresponding total water flow from plot B was 582 and 567 mm respectively and averaged 49% of the rainfall over the 2 years. Since surface run-off on the moled plot was negligible, the effectiveness of the mole drainage is apparent.

b) In 1967, which was a year of near average annual rainfall, some surface run-off took place from the undrained plot (A, Table 4) in all months except June and July.

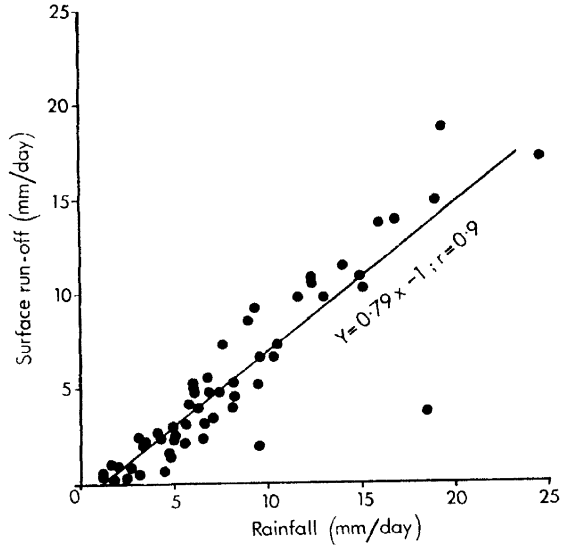

Fig. 2: Effect of amount of daily rainfall on the surface run-off per day in winter 1965

TABLE 4: Monthly precipitation and flow 1967

Month	Precipitation (mm)	Flow (mm) A	Flow (mm) B	Flow (mm) C	Flow as % of precipitation A	Flow as % of precipitation B	Flow as % of precipitation C
Jan.	87.0	30.5	9.1	54.1	35	10	62
Feb.	86.9	46.5	4.0	53.7	54	5	62
Mar.	95.9	30.8	1.4	56.9	32	1	59
April	59.1	12.0	1.0	9.2	20	3	16
May	128.7	26.1	0.5	51.0	20	—	40
June	36.3	0	0	0.7	0	0	2
July	85.9	0	0	3.2	0	0	4
Aug.	94.0	4.8	0	9.9	5	0	11
Sept.	130.2	34.4	0	66.0	26	0	51
Oct.	190.0	97.7	0	125.1	51	0	66
Nov.	86.9	37.0	0.8	62.2	43	1	72
Dec.	91.8	32.8	0	73.0	36	0	80
Total	1172.7	352.6	16.8	565.0	30	1	48

This pattern in general was maintained in most years. However, in the wet growing season of 1966 the run-off from plot A was 36.5 mm in May and 49.7 mm in June. The occurrence of surface run-off in summer depended on the amount and intensity of rainfall. Table 4 indicates that the soil surface layer is at or near saturation for much of the summer season, with the obvious risks of difficulty with machine operation and of treading damage by livestock.

c) Both 1967 and 1970 were years of average annual rainfall. However, in 1967 summer rainfall was almost 90 mm greater than in 1970. Surface run-off from A and mole flow from C were greater in 1967 than in 1970 by about 7 and 11% respectively (Table 2). For a given rainfall, surface run-off and mole flow are likely to be more erratic in summer in view of the great variation in the status of antecedant soil moisture.

d) In view of the very close drain spacing and the limited depth of the topsoil, the soil capacitance or storage is limited. In May 1967, the rainfall (128.7 mm) was not far short of twice its average value (75 mm). Mole flows of about 1 mm/hr were common over short periods of up to 2 hours. Peak discharges of over 5 mm/hour were recorded on a few occasions.

e) Since surface run-off did take place, implying ponded water conditions, the aggregate hydraulic conductivity of the soil slab above the mole drain invert can be computed from Kirkham's equation 15 (4). It is assumed that the soil layer below the drain invert is effectively impervious and the flow is two-dimensional. At a discharge of 5 mm/hr (measured over ½ hourly intervals) the aggregate hydraulic conductivity of the soil slab over the drain inverts is 74 cm/day. This is about the order of the hydraulic conductivity of the top 13 cm of the topsoil which has a measured hydraulic conductivity of about 30 cm/day in the undisturbed state. This indicates the subsoiling effectiveness of the mole drainage at the spacing of 107 cm on this site.

Frequency of daily occurrence of precipitation, surface run-off and mole flow

The frequency of occurrence of specified daily quantities of precipitation, surface run-off and mole flow arranged in order of magnitude is given in Tables 5 and 6. In these tables both precipitation and flow events cover the period 9.00 hours GMT on one day to 9.00 hours GMT on the next. Table 5 shows data for the summer and winter periods and the totals refer to a water year rather than a calendar year.

The main conclusions are:

a) The number of days per year on which some rain fell varied from 219 in 1971 to 263 in 1970. During the summer season the number of rainy days varied from 103 to 130. The range 1 to 5 mm/day occurred most frequently and the distribution was non-symmetric. Rainfall was more frequent in winter than in summer except in 1967 and 1969, but in both those years most of the excess of rain days were in the range 0.1 to 1.0 mm.

b) The number of surface run-off events from plot A varied from 74 in 1971 to 165 in 1966. The frequency of surface run-off was related to the frequency of rainfall amounts greater than 5 mm which varied from 72 in 1971 to 108 in 1966. Surface

TABLE 5: Classification of daily events of precipitation and run-off by amount and frequency—Nov. '65–Dec. '71

Period	No. of daily precipitation events					No. of daily run-off events												Total of run-off events		
	0.1-1 mm	1-5 mm	5-10 mm	> 10 mm	Total	0.1-1.0 mm			1.0-5.0 mm			5.0-10.0 mm			> 10.0 mm					
						A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Nov. 1, '65 to April 30, '66	27	40	39	27	133	43	40	—	28	25	—	23	26	—	19	11	—	113	102	—
May 1, '66 to Oct. 31, '66	23	44	27	15	109	24	20	33	18	4	21	6	0	7	4	0	0	52	24	61
Total	50	84	66	42	242	67	60	33	46	29	21	29	26	7	23	11	—	165	126	61
Nov. 1, '66 to April 30, '67	25	60	27	11	123	31	22	32	32	3	53	14	1	23	8	0	8	85	26	116
May 1, '67 to Oct. 31, '67	30	54	30	16	130	21	2	29	25	0	25	6	0	17	2	0	5	54	2	76
Total	55	114	57	27	253	52	24	61	57	3	78	20	1	40	10	0	13	139	28	192
Nov. 1, '67 to April 30, '68	35	45	24	11	115	28	10	49	20	6	50	14	3	22	6	0	4	68	19	125
May 1, '68 to Oct. 31, '68	29	39	22	17	107	22	6	32	12	0	29	5	0	8	2	0	7	41	6	76
Total	64	84	46	28	222	50	16	81	32	6	79	19	3	30	8	0	11	109	25	201
Nov. 1, '68 to April 30, '69	36	46	15	19	116	40	11	57	18	6	55	9	0	14	8	0	8	75	17	134
May 1, '69 to Oct. 31, '69	53	46	23	5	127	11	0	31	4	1	13	2	0	1	0	0	2	17	1	47
Total	89	92	38	24	243	51	11	88	22	7	68	11	0	15	8	0	10	92	18	181
Nov. 1, '69 to April 30, '70	50	54	24	15	143	41	13	48	24	12	53	9	1	18	11	0	8	85	26	127
May 1, '70 to Oct. 31, '70	34	51	24	11	120	12	2	23	7	3	15	4	1	6	4	0	2	27	6	46
Total	84	105	48	26	263	53	15	71	31	15	68	13	2	24	15	0	10	112	32	173
Nov. 1, '70 to April 30, '71	30	49	23	14	116	30	22	40	28	12	50	2	3	11	4	0	1	64	37	102
May 1, '71 to Oct. 31, '71	27	41	27	8	103	5	4	22	3	0	10	1	0	4	1	0	1	10	4	37
Total	57	90	50	22	219	35	26	62	31	12	60	3	3	15	5	0	2	74	41	139

TABLE 6: Classification of daily events of precipitation and run-off by amount and frequency 1967

1967	No. of rainfall events					No. of run-off events												Total of run-off events		
	0.1-1.0 mm	1-5 mm	5-10 mm	> 10 mm	Total	0.1-1.0 mm			1.0-5.0 mm			5.0-10.0 mm			> 10 mm					
						A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Jan.	5	12	2	2	21	4	3	7	7	0	11	1	1	4	0	0	0	12	4	22
Feb.	4	8	4	2	18	5	4	5	4	1	8	3	0	3	1	0	1	13	5	17
Mar.	7	12	6	0	25	4	4	6	9	0	11	1	0	5	0	0	0	14	4	22
Apr.	1	4	3	1	9	5	0	4	0	1	1	0	0	1	1	0	0	6	1	6
May	3	9	7	3	22	8	2	8	7	0	9	1	0	4	0	0	0	16	2	21
June	5	5	1	1	12	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2
July	9	11	3	1	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug.	5	10	2	3	20	0	0	3	1	0	1	0	0	1	0	0	0	1	0	5
Sept.	2	9	8	3	22	1	0	6	7	0	10	2	0	3	0	0	1	10	0	20
Oct.	6	10	9	5	30	11	0	10	10	0	5	3	0	9	2	0	4	26	0	28
Nov.	5	9	5	2	21	5	1	5	4	0	8	4	0	5	0	0	0	13	1	18
Dec.	10	12	5	0	27	6	0	11	7	0	15	2	0	3	0	0	0	15	0	29
Total	62	111	55	23	251	50	14	67	56	2	79	17	1	38	4	0	6	126	17	190

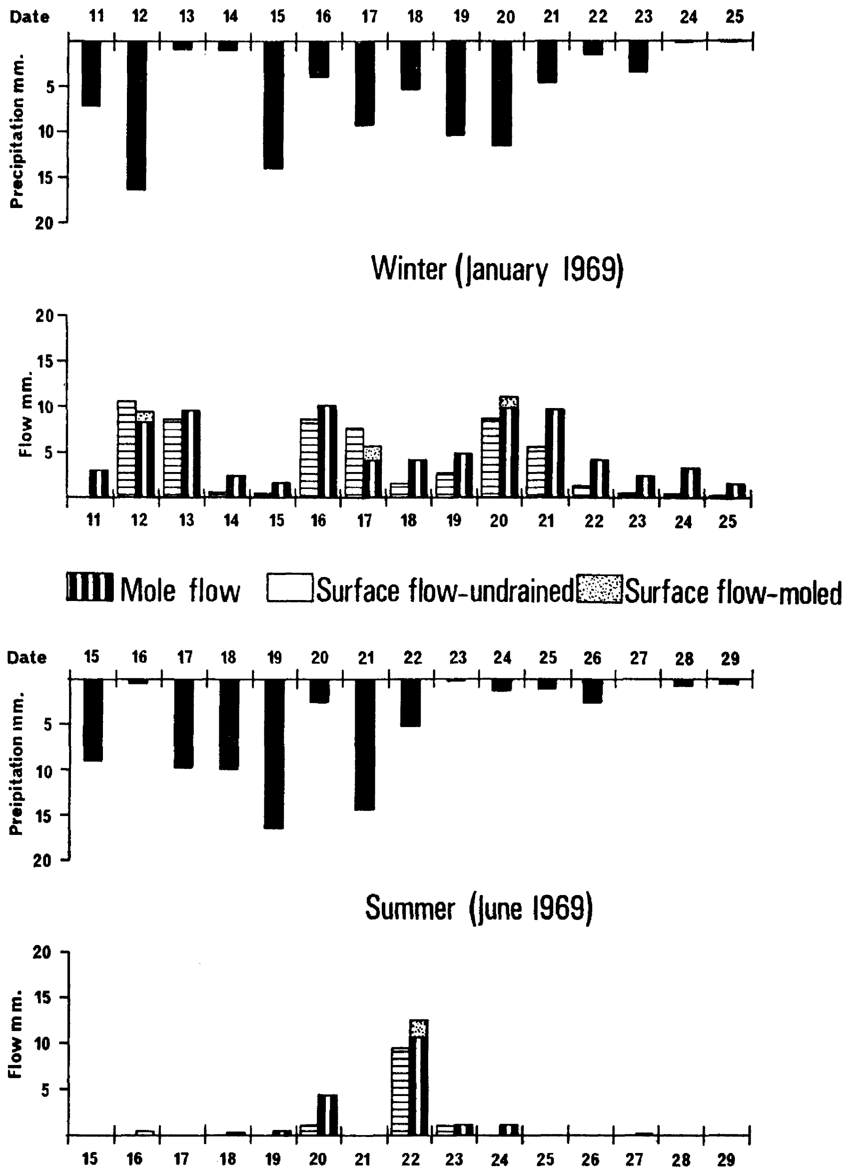

Fig. 3: Typical winter and summer sequences of precipitation, surface run-off and mole flow

run-off was relatively infrequent in summer when evaporation was high and the ground dry.

c) The frequency of mole flow (C) was up to twice that of surface run-off (A). The big differences in the frequency of flow were in the low discharge ranges of 0.1 to 5.0 mm. There was little difference in frequency between A and C for discharges greater than 10.0 mm/day. Surface run-off (B) from the moled plot was very infrequent and virtually all occurred in the 0.1 to 1.0 mm range and mostly in the winter season.

d) Table 6 shows that most surface run-off and mole flow events took place in winter. Surface run-off (A) was as high as 97% of rainfall in November 1965, when 96.6 mm fell in 4 days. In May 1967, 10 of the 22 rainfall events were greater than 5 mm/day and total fall was 128.7 mm. In this month, surface run-off (A) occurred on 16 days and amounted to 26 mm while mole flow (C) occurred on 21 days and amounted to 51 mm. This highlights the function of effective mole drainage to remove excessive quantities of rainfall mainly in the grazing season. Even under the ideal conditions, surface run-off from the moled plot did take place on two occasions, indicating ponded conditions which were confined to short periods since the total discharge was small.

Hydrographs

Hydrographs showed great variety. For similar rainfalls the antecedent soil moisture status determined the amount, duration and time lag in surface run-off and mole flow relative to precipitation. For example, small rainfalls in winter when the soil was at or near saturation produced substantial surface run-off and mole flow while after a dry spell in summer even heavy rainfalls produced no discharge (Fig. 3). This figure illustrates how fairly similar precipitation patterns in winter and summer result in completely different flow patterns. It is not intended that the data (Fig. 3) should convey any information on time relationships between precipitation and flow.

Figure 4 shows cumulative rainfall and hydrographs for mole discharge (C) and surface flow (A) for the period May 18 to 26, 1967. This figure further illustrates the effectiveness of mole drains in removing excess precipitation during wet weather in summer. In general the rate of surface run-off was lower than the rate of mole discharge at peak flows. There was also a time lag between peak surface run-off and peak mole discharge.

Water balance

The water balance is an accounting of all water for an area. It can be written as:

$$I = O + E \pm S,$$

where I = inflow, O = outflow, E = evaporation and S = change in storage

In our case I is the precipitation. The term O includes surface run-off, mole flow and losses to deep and lateral seepage. No attempt was made to measure deep seepage or seepage through the thin surface layer parallel to the land surface. Table 7 shows the water balances for the years 1966 through 1971 and Table 8 shows the water balance

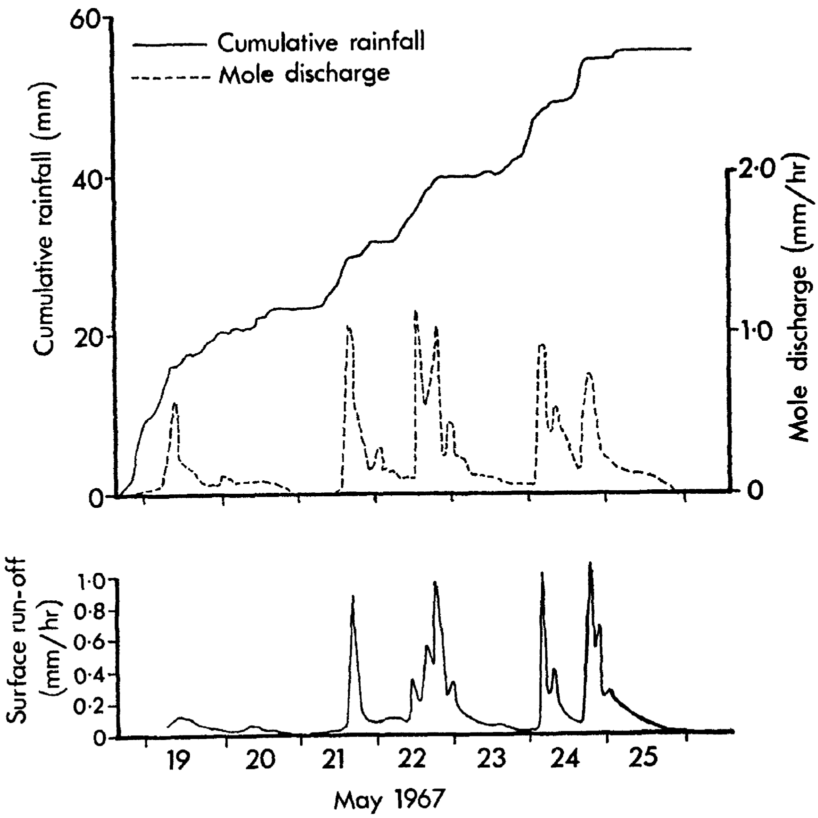

Fig. 4: Cumulative rainfall and the corresponding mole discharge and surface flow hydrographs for late May 1967

for a year of near average rainfall (1967). In Table 7 the figures in the second last column show the differences between precipitation and surface run-off on the undrained plot A and the last column shows the differences between precipitation and the combined flow from surface run-off and mole flow. Although the term S is subject to constant variation, it generally returns to a constant value at or above field capacity about November 1. The storage between field capacity and saturation on this soil is small (about 30 mm water in the top 45 cm).

The mean difference between precipitation and surface run-off, and precipitation and the combined flow from the mole-drained plot, was 771 and 536 mm respectively. Estimates indicate that the potential evapotranspiration for the area is about 450 mm. In the drained plot most of the precipitation was accounted for by mole flow, surface

TABLE 7: Summary of water-balance—Nov. 1, 1965 to Oct. 31, 1971

Period	Precipitation (mm) P	Flow (mm) A Undrained	Flow (mm) B+C Drained	P–A mm	P–(B+C) mm
Nov. 1, 1965 to[a] April 30, 1966	882.0	578.1		303.9	
May 1, 1966 to Oct. 31, 1966	568.7	151.6		417.1	
Total	1450.7	729.7		721.0	
Nov. 1, 1966 to April 30, 1967	599.8	325.6	474.4	274.2	125.4
May 1, 1967 to Oct. 31, 1967	654.7	163.0	256.4	491.7	398.3
Total	1254.5	488.6	730.8	765.9	523.7
Nov. 1, 1967 to April 30, 1968	540.0	263.0	413.5	277.0	126.5
May 1, 1968 to Oct. 31, 1968	664.2	120.8	230.2	543.4	434.0
Total	1204.2	383.8	643.7	820.4	560.5
Nov. 1, 1968 to April 30, 1969	559.2	265.5	472.4	293.7	86.8
May 1, 1969 to Oct. 31, 1969	393.8	25.7	82.1	368.1	311.7
Total	953.0	291.2	554.5	661.8	398.5
Nov. 1, 1969 to April 30, 1970	636.5	275.3	420.0	361.2	216.5
May 1, 1970 to Oct. 31, 1970	567.4	98.2	169.3	469.2	398.1
Total	1203.9	373.5	589.3	830.4	614.6
Nov. 1, 1970 to April 30, 1971	489.6	148.5	296.8	341.1	192.8
May 1, 1971 to Oct. 31, 1971	463.5	26.5	71.7	437.0	391.8
Total	953.1	175.0	368.5	778.1	584.6
Mean annual[b]	1113.7	342.4	577.3	771.3	536.4

[a] Data for moled plot is omitted for period Nov. 1, 1965 to Oct. 31, 1966 since moling was done in April 1966
[b] From Nov. 1, 1966 to Oct. 31, 1971

flow and potential evapotranspiration. There is evidence from hydraulic conductivity data that deep seepage on this soil is small. Table 7 indicates circumstantial evidence for substantial lateral flow through the moderately permeable topsoil.

Table 8 shows a water balance on a monthly basis. The last two columns in the table permit a comparison between estimated potential evapotranspiration (Class A pan) and the difference between precipitation and combined surface and mole flow. It is seen that up to the end of May there is fair agreement between both columns. In June the rainfall was low resulting in a soil moisture deficit. From July onwards the surface soil layer began to wet. In September and October there were heavy rainfalls and a substantial amount of water may have been lost through lateral seepage downslope ending up as seepage into the mole drain gutter trench. There was fair agreement again in November and December. The total quantity of water remaining unaccounted for is relatively small with some going to deep and lateral seepage. In the undrained plot the difference between precipitation and run-off exceeded the estimated potential evapotranspiration in all months except April and June. June was the only month in which an appreciable moisture deficit arose. Considerable rewetting of the soil took place from September onwards. These data show that not only did mole drainage facilitate more complete soil drying in summer but it also coped with excessively wet months such as May, September and October. Effective mole drainage therefore copes efficiently with excessive quantities of precipitation in summer and extends the grazing season on these gley soils.

TABLE 8: Water-balance 1967

Month	Precipitation (mm) P	Run-off (mm) A	Run-off (mm) B+C	P − A mm	P − (B+C) mm	Potential evapo-transpiration mm (estimated)
Jan.	87.0	30.5	63.2	56.5	23.8	6.6
Feb.	86.9	46.5	57.7	40.4	29.2	22.7
Mar.	95.9	30.8	58.3	65.1	37.6	35.1
April	59.1	12.0	10.2	47.1	48.9	55.6
May	128.7	26.1	51.5	102.6	77.2	59.8
June	36.3	—	0.7	36.3	35.6	71.5
July	85.9	—	3.2	85.9	82.7	57.2
Aug.	94.0	4.8	9.9	89.2	84.1	56.1
Sept.	130.2	34.4	66.0	95.8	64.2	39.1
Oct.	190.0	97.7	125.1	92.3	64.9	23.1
Nov.	86.9	37.0	63.0	49.9	23.9	12.0
Dec.	91.8	32.8	73.0	59.0	18.8	10.1
Total	1172.6	352.6	581.8	820.1	590.9	448.9

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