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THE USE OF NATURAL TRITIUM IN HYDROGRAPH ANALYSIS

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ABSTRACT

Water samples taken during a summer storm in the Nant Iago and Nant Tanllwyth catchments were measured for tritium, pH and conductivity. An analysis of the tritium results show that it is possible to build a model of an isolated storm hydrograph. Separation into the direct (sheet overland flow) runoff, and indirect (displaced storage) runoff components was performed, not using the conventional geometrical methods, but using the tritium budget method.

THE USE OF NATURAL TRITIUM IN HYDROGRAPH ANALYSIS

1. GENERAL HYDROLOGY

1. 1 Hydrological context

The experiment was conducted in two catchments within the headwaters of the Wye and Severn (Fig. 1.)

Nant Iago catchment is 1.03 km^2 of rough mountain pasture used for sheep grazing. Within the area there is 372600 m^2 of peat exceeding a depth of 0.5m of which 74% is greater than 1.0 metre deep. (Photographs 1 & 2.)

Nant Tanllwyth catchment is 1.14 km^2 and 93% of the area consists of coniferous forest intensively drained. The remaining 7% consists of rough pasture and eroded peat (Photographs 3 & 4.)

During the latter half of July 1969 50mm of rain fell (less than half the July mean) which allowed the streams to recess to base flow. In the first 10 days of August a further 22mm of rain fell, which caused no increase in recorded river stage. On 11th August 12mm of rain fell during the afternoon and night, and it continued to rain during the next day, when 65.5mm fell, 29.7mm up to 12.00 hrs and then during the next 2 hours a further 20.8mm, most of which fell during a 10 minute period.

The Nant Iago stage started to rise at about 05.00 hrs and at 11.00 had increased from 0.03 to 0.13 cumecs. The stage then rose rapidly and a peak of 1.22 cumecs was reached between 12.15 and 12.30 and by 17.00 had dropped to 0.58 cumecs (Fig. 2.)

The Tanllwyth began rising about 04.00 and rose from 0.03 to 0.19 cumecs at 11.00. The peak discharge, occurring at 13.05 was 3.06 cumecs and at 17.00 the discharge was again 0.19 cumecs, this represents an increase in stage of 1.5 metres.

Further rainfall, 70.8mm (Fig. 2 for distribution) fell up to 27th August, when a dry spell of 14 days allowed base flow to be reached.

1.2 Sampling Procedure

Samples of the river water were taken during the summer prior to the storm event to be assayed for tritium; pH and conductivity measurements were also taken (Appendix A). Samples were taken 22 days before the storm, when both rivers were at base flow. Samples were fortuitously taken at or near the peak discharge and subsequently various additional samples were taken until 9th September when base flow was again reached.

The samples were collected from two stations within each catchment; one being the gauging site, the other at a waterfall upstream of (a) Nant Iago mine and (b) the Forestry road on the Tanllwyth (Fig. 1). The general form of the tritium curves is similar (Fig. 3). The curves were obtained by drawing a smooth curve through the experimental results (Table 1.)

Table 1: Nant Iago and Nant Tanllwyth tritium results

Date	Iago gauge Tritium content TU	Iago Waterfall TU	Tanllwyth gauge TU	Tanllwyth waterfall TU*
17.7.69	133			
19.7.69	104		114	
21.7.69	127	131	120	126
12.8.69	275	285	256	286
13.8.69	206	229	196	203
14.8.69	173	198	150	182
15.8.69			152	170
16.8.69			153	152
17.8.69	148	179	147	154
18.8.69	161	197	153	160
19.8.69			159	178
20.8.69	134	214	154	181
25.8.69	155	178	135	165
2.9.69	151	156	146	150
10.9.69	130		137	

Rainfall at Severn Met. Site	TU
12.8.69	340
13.8.69	390

* Tritium Unit (TU) is one atom of ^3H in 10^{18} atoms of ^1H = 7.2 dpm/l = 3.2 pCi/l

2. WATER AND TRITIUM BALANCE

2. 1 Rainfall and Runoff Relationship

Although a water balance is not necessary, it was felt that by performing one a better understanding of the processes involved would be of help. Initially a time interval of 2 hours was taken and rainfall and discharge data converted into the equivalent of cubic metres of water over the whole catchment for each period.

For the short time period a record from a continuously recording raingauge would have to be used. Unfortunately the nearest recorder to the Nant Iago was at Carreg Wen, 2.5 km north, where a Dines Rain Recorder is installed. However, for Nant Tanllwyth there is Carreg Wen, which lies within the catchment and also the Severn Meteorological Site 100 metres from the outfall of the catchment.

Daily figures were also calculated for rainfall and for this a network of daily raingauges were used and the catchment rainfall determined, using the Thiessen Polygon method.

Discharge was measured at each gauging site for both catchments, where a continuous record of stage is obtained. The stage was read and the discharge calculated for 15 minute intervals and then expressed as cubic metres discharged over a 2 hour period.

It was found that a balance for Nant Iago, assuming negligible evaporation, resulted in the discharge exceeding the rainfall by 4.7%. However, if evaporation is taken into account as a rate of 2mm for each dry day, then the rainfall is exceeded by the runoff plus evaporation by 23% for the period taken. It must be assumed that this is only a short-term input deficit.

In the Tanllwyth for the same period of 11th August to 6th September, the rain exceeded the runoff by 42%. Work carried out in low rainfall forest areas by Rakhmanov (1962) showed that evaporation accounted for about 50% of the precipitation and this showed that for the forest area evaporation must be taken into account as it is a significant parameter. By assuming that intercepted water is evaporated as open water, and that no evaporation occurs while it is raining and there is a 50% reduction in the rate of evaporation during non-sunshine hours, then the rainfall exceeds to discharge plus evaporation by 5%. Table 2 gives a daily summary of the results.

Table 2: Daily rainfall, runoff and evaporation totals

	NANT IAGO			NANT TANLLWYTH			
	Rainfall R m^3	Runoff Q m^3	R - Q	Rainfall R m^3	Runoff Q m^3	Evaporation E m^3	R-Q-E
Aug.11 1969	12010	1728	10282	28598	1644	1631	25323
12	67747	32085	35662	67079	27979		39100
13	7904	31323	-23419	3588	8656	548	5616
14	2463	10515	- 8052	2962	2568	767	373
15	1129	4008	- 2879	581	2413	1726	3558
16		3232	3232		2269	4330	- 6599
17		3198	- 3198	4044	2144	4617	- 2717
18	15397	5962	9435	16978	2475	238	14265
19	6262	7163	901	2740	2660	2339	- 2259
20	4414	3272	858	5264	2316	1029	1919
21	10162	7210	2952	10247	3988	2177	4082
22	5748	5820	- 72	6559	2556	2057	1946
23	2566	4968	- 2402	1348	2376	2390	3418
24	5030	4056	974	6856	2304	3488	1064
25	3080	4576	- 1496	1815	2292	3069	- 3546
26	14987	6020	8967	7137	2929	2602	1606
27		4980	- 4980		2329	3302	5631
28		3948	- 3948		2304	2571	- 4875
29		3456	- 3456		2304	2845	- 5149
30		3048	- 3048		2304	3370	- 5674
31		2748	- 2748	243	2304	3439	- 5500
Sep. 1		2556	- 2556	-	2304	2319	- 4623
2		2352	- 2352		2256	2194	- 4450
3		2208	- 2208		2208	3188	5396
4		2044	- 2044		2208	1771	- 3979
5		1992	- 1992		2208	1611	3819
6		1920	- 1920		2208	1691	3899

2. 2 Tritium Budget

A tritium budget was then calculated for the total amount of tritium which entered each catchment in the rainfall and left by the stream, and evaporation (assuming the water evaporated had the same tritium content as the rain.) In order to simplify the units the budget was performed using microcuries (µCi) rather than tritium units.

Table 3: Daily tritium contents

	NANT IAGO			NANT TANLLWYTH			
1969	Activity in Rainfall RT µCi	Activity in Runoff QT µCi	RT - QT	RT	QT	Activity in Evap. ET	RT-QT-ET
Aug. 11	13990	732	13258	33311	636	1900	30775
12	78913	26292	52621	78134	21041	-	57093
13	9207	23197	-13990	4179	5997	638	- 2456
14	2869	6066	- 3197	3450	1262	893	1295
15	1315	2008	- 693	677	1161	2010	- 2494
16	-	1534	- 1534	-	1099	5044	- 6143
17	-	1489	- 1489	4710	1023	5378	- 1691
18	17936	2982	14954	19776	1200	277	18299
19	7296	3593	3703	3192	1340	2724	- 872
20	5142	2474	2668	6132	1155	1199	3778
21	11838	3137	8701	11936	2051	2536	7349
22	6695	2461	4234	7640	1295	2396	3949
23	2989	2146	843	1570	1141	2784	- 2355
24	5859	1845	4014	7986	1075	4063	2848
25	3587	2202	1385	2114	1111	3575	- 2572
26	17457	2949	14508	8313	1485	3031	3797
27	-	2438	- 2438	-	1200	3846	- 5046
28	-	1920	- 1920	-	1181	2995	- 4176
29		1680	- 1680	-	1157	3314	- 4471
30		1483	- 1483	-	1122	3925	- 5047
31		1338	- 1338	283	1088	4006	- 4811
Sep. 1		1232	- 1232	-	1063	2701	- 3764
2		1116	- 1116	-	1028	2556	- 3584
3		1039	- 1039		979	3713	- 4692
4		946	- 946		947	2063	- 3010
5		907	- 907		906	1876	- 2782
6		861	- 861		888	1970	- 2858

It was found that from the Nant Iago the output was (q) 44.6% less ignoring evaporation and (b) 29.1% less with evaporation than the rainfall input.

The amount of tritium that was held in the Nant Tanllwyth, i.e., rainfall minus runoff minus evaporation, was 34.3% of the input.

The reason for these large differences of 44.6%, 29.1% and 34.3% is probably due to either one of two reasons, or a combination of both:

(i) there may be some form of preferential retention of the tritium within the peat or vegetation,

(ii) the rainwater enters storage and forces older water, with a lower tritium content out. This could be achieved by a 'knock on' or displacement effect.

2. 3 Hydrograph Separation

Separation of the stream hydrograph in this context is a partition of the discharge into a groundwater or displaced storage component, and a direct runoff component composed of rainwater from the storm which initiated the flood runoff event. Hydrograph separations are usually attempted by geometrical methods, but if water from the two sources could be identified an objective separation would be achieved.

Fig. 4(a) shows a theoretical discharge hydrograph in which the hatched area represents direct runoff, while the remainder is indirect runoff from storage. In order to analyse in this manner, the hydrograph using tritium measurements, it is necessary to make two assumptions:-

(i) the stream discharge is composed of two components only, one of which is rainwater at most several hours old, and the other is older water which has been held in storage, e.g., in the peat of the Nant Iago Catchment. This old water can be expected to have a uniform tritium content owing to prolonged mixing and to constitute the baseflow of the stream between rainstorms.

(ii) the direct runoff component, being composed of recent rainwater, will have the same tritium content as the rainfall at the time of the storm, while the indirect runoff component will have the same tritium content on the basflow as measured before and after the storm.

Let the baseflow tritium content ($\equiv$ indirect runoff component) be B, the rainfall tritium content ($\equiv$ direct runoff component) be R, and the fraction of the total stream discharge composed of direct runoff be p.

Then the tritium content of the stream $T = pR + (1-p)\,B$

$$= B + p\,(R-B)$$

This gives:- $p = \frac{T-B}{R-B}$

B, R and T have been measured (R and B are assumed constant throughout the storm. (Fig. 4(b)).

The runoff can now be multiplied for each time t by the corresponding value of p (Fig. 5) which will give the direct runoff component, and by 1-p to give the indirect runoff component.

	NANT IAGO		NANT TANLLWYTH	
	Indirect $(1-p)Qm^3$	Direct $pQ\ m^3$	Indirect $(1-p)Qm^3$	Direct $pQ\ m^3$
11 Aug '69	1675	53	1644	0
12	14564	17520	14797	13182
13	18147	13174	5233	3423
14	8095	2420	2213	355
15	3481	527	2112	301
16	2918	314	1973	296
17	2921	276	1890	254
18	5183	779	2156	319
19	6214	949	2252	408
20	4798	474	1976	340
21	6880	330	3327	661
22	5646	174	2159	397
23	4760	208	2085	291
24	3764	292	2057	247
25	4092	484	1997	295
26	5317	703	2467	462
27	4397	583	1940	389
28	3504	444	2247	377
29	3071	385	1955	349
30	2704	344	2002	302
31	2440	308	2044	260
1 Sep '69	2284	272	2069	235
2	2125	227	2049	207
3	2005	207	2038	170
4	1873	171	2081	117
5	1846	146	2132	76
6	1795	125	2148	60

3. 1 Conclusion

It is possible to perform a separation of the hydrograph into both the direct or sheet flow and the indirect or displacement from storage flow (Fig. 6.) Although in this treatment a water and tritium balance was performed, these are not necessary but were included so that a better understanding of the mechanisms involved could be gained.

3. 2 Future Work

The need for future work is apparent if the use of tritium is to be verified as a method of hydrograph separation. There will have to be a programme of sampling throughout a dry period so that antecedent conditions may be fully documented. All rainfall should be collected, preferably as individual storms and not hourly or daily samples. In the event of a surge in the stream stage, river samples, for tritium analysis, should be taken throughout the rise and recession until base flow is again reached.

References:

Rakhmanov, V.V. Role of Forests in Water Conservation, 1962.

APPENDIX A

CONDUCTIVITY AND pH MEASUREMENTS

A. 1 Sampling Procedure

Samples for pH and conductivity determinations were taken from the latter half of July until mid-September 1969. The samples were stored for about 8 weeks before the determinations were made.

Conductivity was measured, using a Portland conductivity meter with a platinum dip cell, and pH measured with an EIL pH meter with a glass electrode.

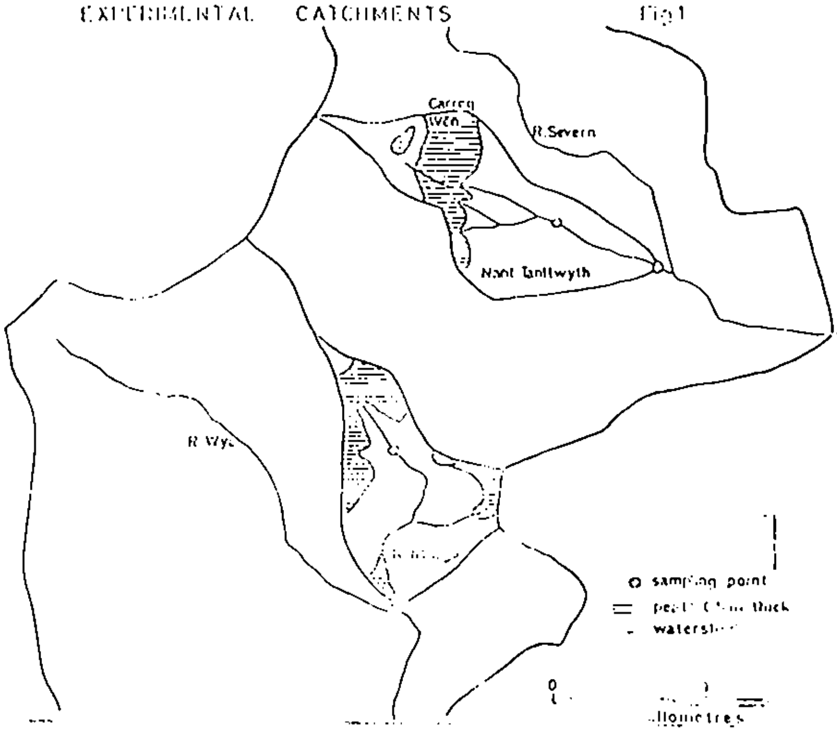
Table 1: Conductivity and pH results:

1969	NANT IAGO Conductivity mhos cm^{-1}	NANT IAGO pH	NANT TANLLWYTH Conductivity mhos cm^{-1}	NANT TANLLWYTH pH
July 17	89	8.2		
18	-	-	48	8.5
19	87	7.7	49	7.3
22	90	7.7	48	8.0
Aug. 12	40	6.3	70	4.3
13	44	6.9	51	4.6
14	56	6.7	50	4.9
15	52	6.9	43	5.2
16	64	7.1	42	5.6
17	66	7.0	42	5.7
18	60	7.7	35	5.4
19	57	7.6	50	5.7
20	68	6.9	75	5.6
21	45	6.8	60	4.6
22	50	6.8	44	5.5
23	60	7.2	51	5.9
24	55	6.0	44	5.0
25	54	6.8	47	6.6
26	48	6.9	55	5.1
27	53	7.0	59	5.8
28	56	7.1	42	5.9
Sep. 4	81	7.6	56	6.9
5	80	7.5	58	7.1
6	86	6.0	45	6.6

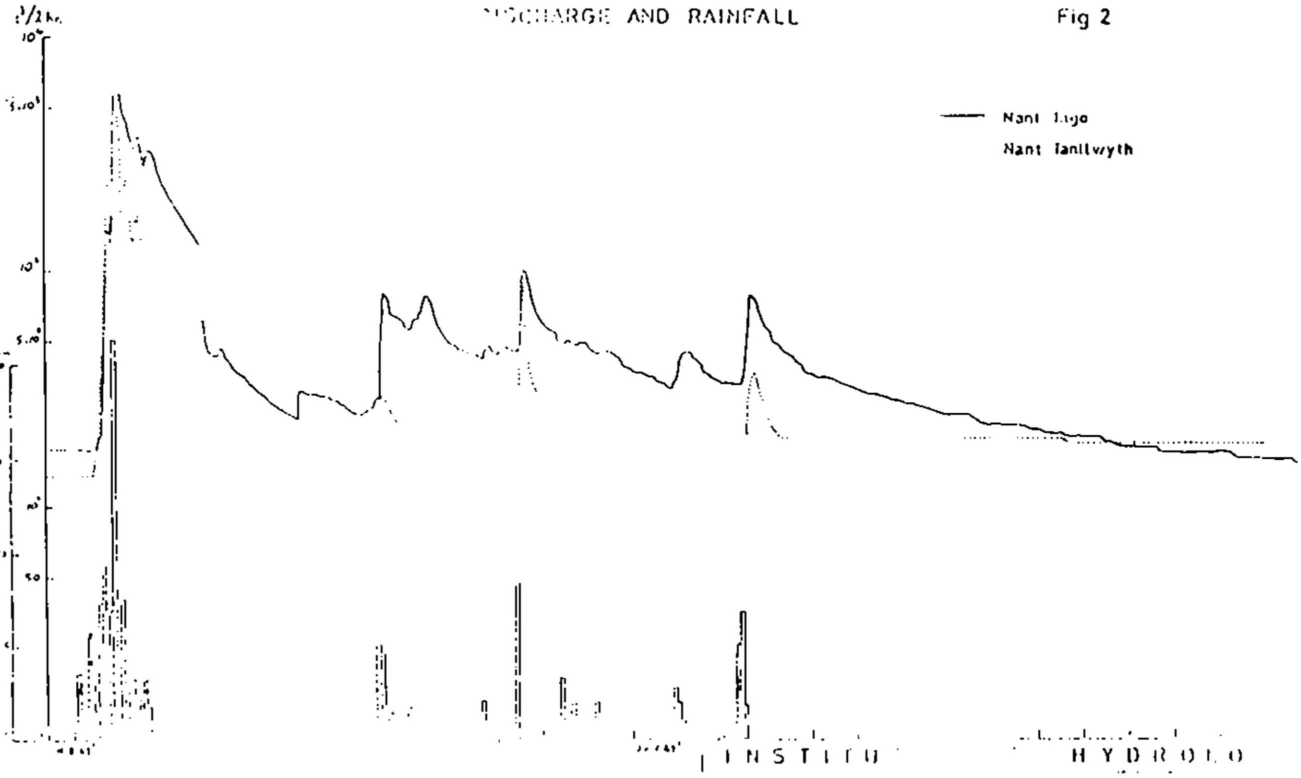
A. 2 Conclusions

The conductivity results show the expected correlation of a decrease in conductivity with an increase in discharge. This is because the water in the high discharge has had less time to dissolve salts as most of the flow is from sheet flow. The pH results show that there may have been bacterial action owing to the long storage time. This action may also have affected the conductivity.

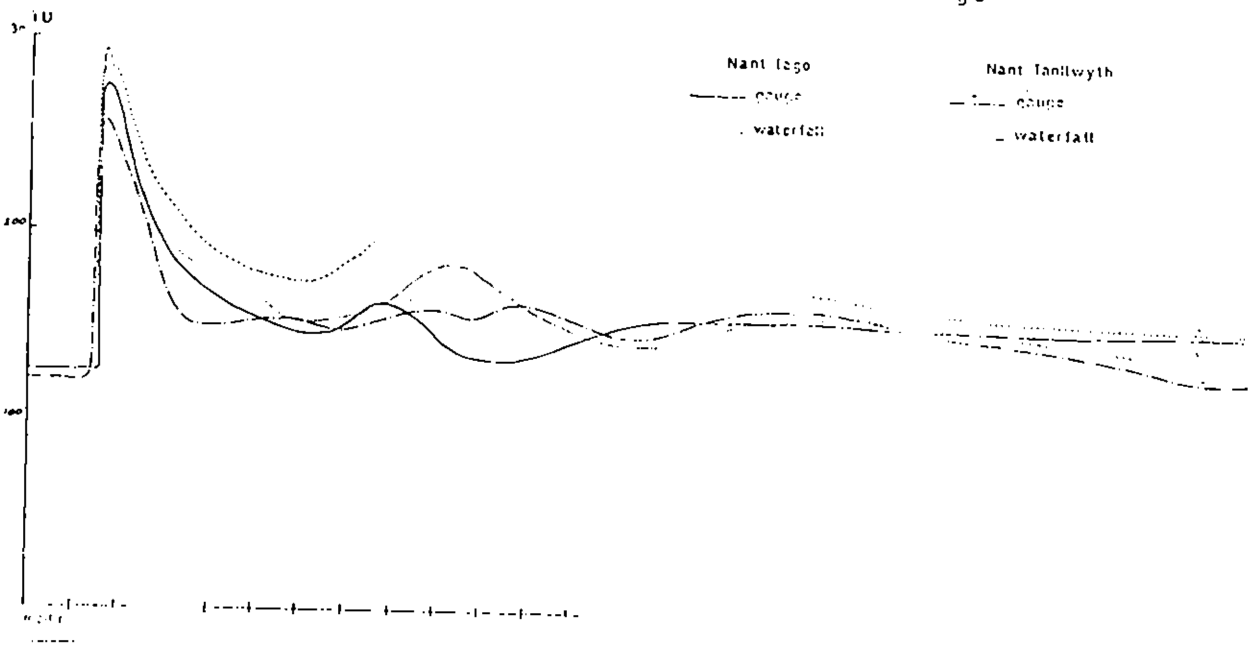
EXPERIMENTAL CATCHMENTS Fig 1



DISCHARGE AND RAINFALL Fig 2

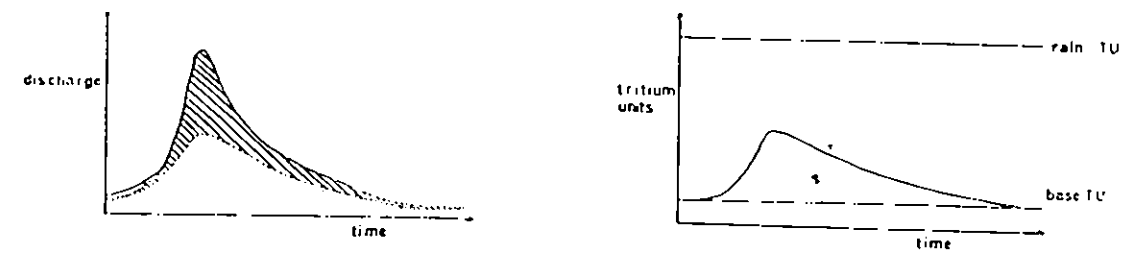


TRITIUM CURVES — Fig 3

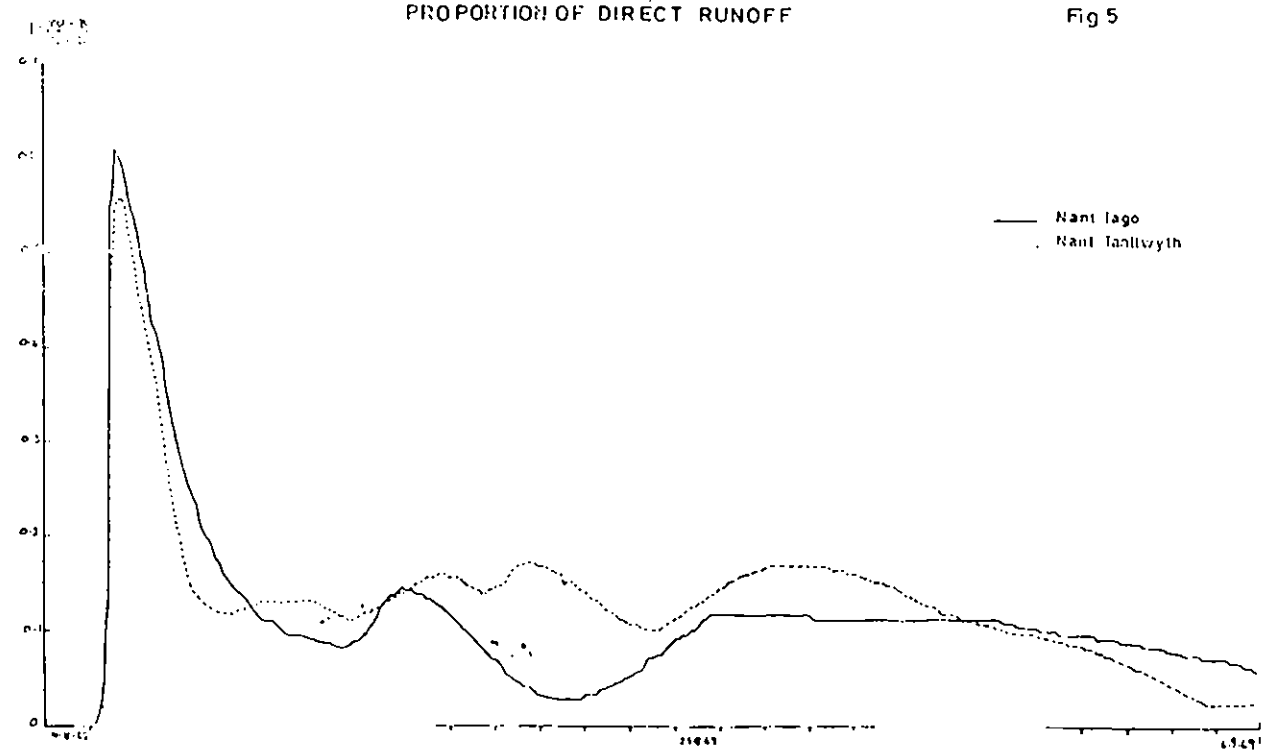


SCHEMATIC DISCHARGE AND TRITIUM CURVES — Fig 4

(a) (b)



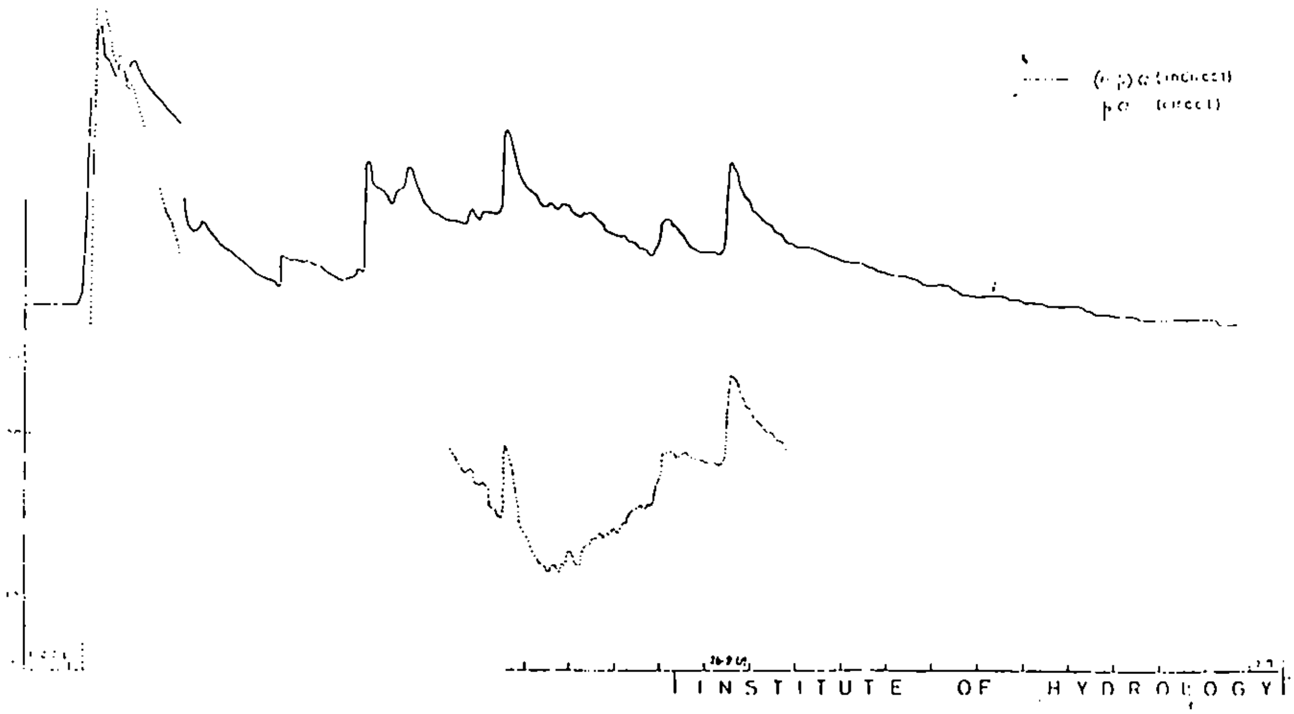
PROPORTION OF DIRECT RUNOFF — Fig 5



HYDROGRAPH CONTRIBUTIONS OF DIRECT AND INDIRECT RUNOFF

NANT IAGO

Fig 5a



HYDROGRAPH CONTRIBUTIONS OF DIRECT AND INDIRECT RUNOFF

NANT TANLLWYTH

Fig 6b