Proc. Univ. Bristol Spelaeol. Soc., 1979, 15 (2), 129-141

QUANTITATIVE FLUOROMETRIC DYE TRACING, RICKFORD AND LANGFORD RESURGENCES, NORTHERN MENDIP

by
R. W. CRABTREE, B.Sc.

ABSTRACT

During November and December 1977 a quantitative dye tracing programme was carried out on swallets draining into the Carboniferous Limestone above Burrington, on the northern flank of the Blackdown Pericline, Mendip.

Results from the Rickford and Langford Resurgences, known to be the only outlets for the swallets, showed that most of the swallet water flowed to Rickford, suggesting a systematic division of swallet water underground. This has been used to propose a new model for the hydrology of the Burrington area, where swallets rapidly converge to a master conduit system, which then bifurcates, sending water to Rickford and Langford. The larger discharge at Rickford resurgence is due to the eastward extension to Lamb Leer Cavern, taking in a large area of the Limestone plateau, providing a source area for percolation water which makes up some 95% of Rickford's discharge.

INTRODUCTION: HYDROLOGY OF THE BURRINGTON AREA

The limestone drainage system traced around Burrington has been studied since the beginning of the century by the Bristol Waterworks Company and the U.B.S.S. This early work has been summarized by Tratman (1963). Within the last fifteen years, the complex system has repeatedly been studied, for example, the initial tracing programme (Fig. 34) carried out by Drew, Newson and Simth (1968), and the hydrological study by Newson (1972).

The area is located some 20 km. south of Bristol and occupies the northern flank of the Blackdown Pericline, an elongated structural dome.

The summit of Blackdown is composed of Devonian Upper Old Red Sandstone, while Carboniferous Lower Limestone Shales and Carboniferous Limestone outcrop on the flanks of the denuded Hercynian structure. On the northern flank, the limestones dip steeply north at around 70°, and at the foot of Mendip pass uncomformably under the Triassic Dolomite Conglomerate and Keuper Marl. (Fig. 34).

One of the major features of karst hydrology is that surface streams flowing onto limestone pass underground into swallets, solutionally enlarged joints, fissures and bedding planes. The water then flows in discrete passages in the rock, called conduits, to form an underground drainage system.

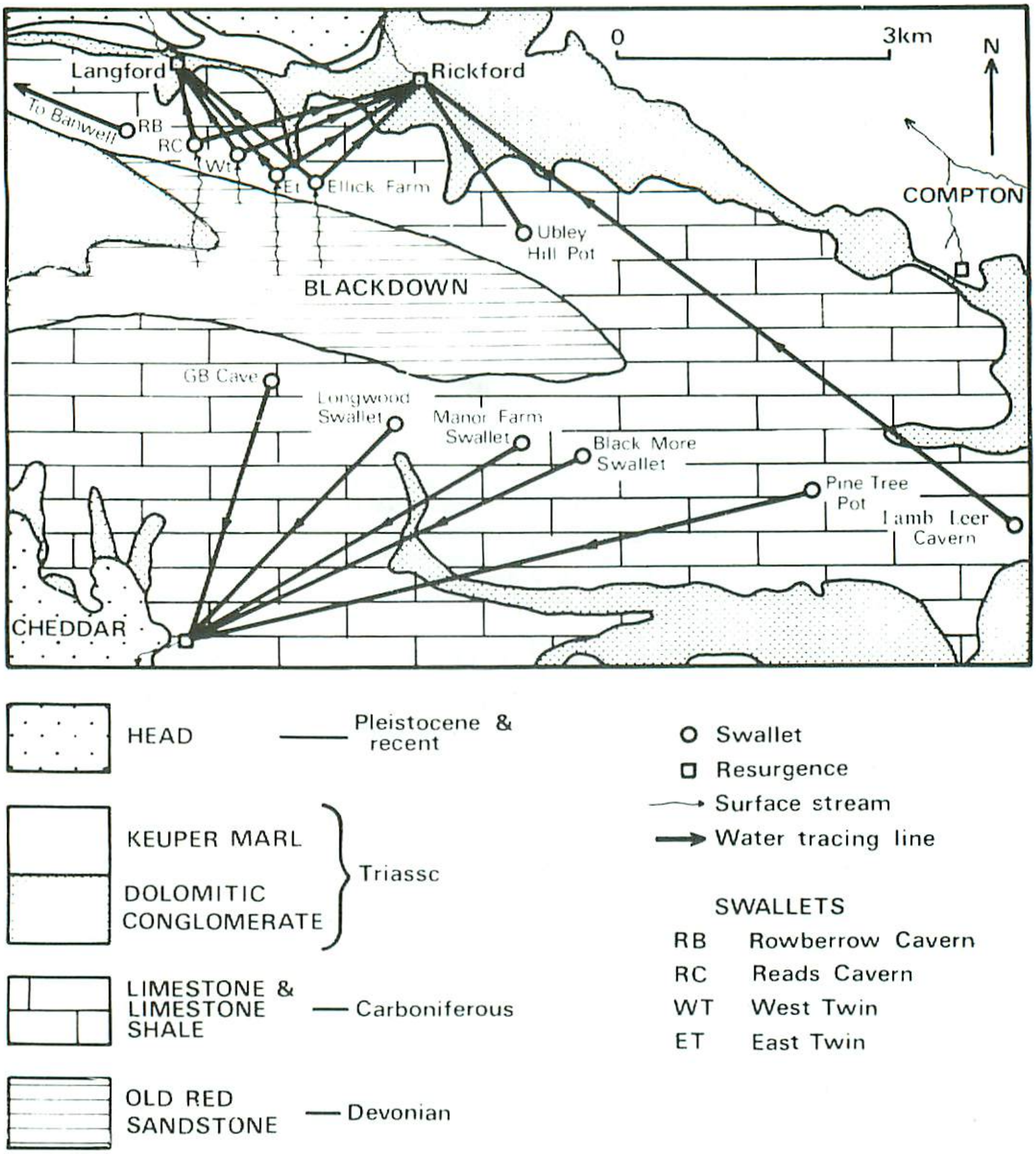

Fig. 34 THE GEOLOGY AND HYDROLOGY OF NORTHEN MENDIP

Drew (1970) suggests that swallet water only contributes some 5%-10% of water in the underground drainage system, the major contribution being percolation water from precipitation onto the soil above the limestone. Percolation and swallet water eventually emerge from the limestone at the foot of the outcrop at a resurgence or spring. Atkinson (1975) has found that for the Cheddar catchment on the southern flank of Blackdown all water flows in large conduits by the time it approaches the resurgence. This could also apply in the Rickford and Langford catchment.

Above Burrington, the summit of Blackdown is drained by four small streams which, on passing onto the Carboniferous Limestone, disappear down swallets. Descriptions of these can be found in Barrington and Stanton (1977):

READ'S CAVERN	ST 468584	161m. O.D.
WEST TWIN BROOK SWALLET	ST 476583	140m. O.D.
EAST TWIN BROOK SWALLET	ST 479581	159m. O.D.
ELLICK FARM SWALLET	ST 494576	229m. O.D.

Drew, Newson and Smith (1968), using dyed Lycopodium spores, traced these swallets to the resurgences at Rickford (ST 488592, 58 m. O.D.), and Langford (ST 466593, 47 m. O.D.). The water was found to flow from each swallet to both resurgences. To the east of the Blackdown group of swallets, a cave stream of percolation origin at the bottom of Ubley Hill Pot (ST 516570, 260 m. O.D.), was also traced and found to flow only to Rickford. The Rickford percolation water catchment is now known to extend beyond Ubley Hill Pot as far as Lamb Leer Cavern, (ST 549552, 225 m. O.D.). Stanton (1977) traced the percolation stream in Lamb Leer solely to Rickford. The western limit of the Rickford—Langford joint catchment was fixed by Pottinger (1976), who quantitatively traced the stream in Rowberrow Cavern to Banwell Spring. The water tracing lines are shown in Figure 34.

Within the Burrington area, the joint nature of the percolation water catchments and the swallet water catchments of the Rickford and Langford resurgences was demonstrated by Drew, Newson and Smith (1968), who traced percolation water from the surface at Burrington Ham to both resurgences.

Despite sharing the same catchment area, the resurgences differ greatly in terms of hydrological and chemical characteristics. Newson (1971) found that, though the hardness at Langford was substantially less than that at Rickford, the passage of a flood produced only slight dilution at Rickford but a large drop in hardness at Langford, presumably due to the arrival of large volumes of swallet water. This suggests a dominantly percolation source for the Rickford resurgence and swallet source for Langford resurgence. Newson (1972) studying the hydrology of the two resurgences, found Langford to have the more 'flashy' regime, again suggesting a dominantly percolation source for Rickford resurgence.

The existence of two major resurgences at different altitudes within the same area and sharing the same catchment area suggests the possibility of underground drainage capture. Drew, Newson and Smith (1968) hinted at the possibility of the smaller Langford resurgence, at the lower altitude, being a younger resurgence in the process of capturing the older, higher, better developed Rickford resurgence. However Newson (1972) found no evidence of capture from mean annual discharge records, the ratio of 2 : 1 for Rickford - Langford being stable for the previous forty years.

The differences in the two resurgences can be accounted for by the large eastward extension of the Rickford catchment supplying percolation water from beyond Langford's most easterly known source, Ellick Farm Swallet.

The object of this dye tracing study was to quantify the amounts of water flowing from each swallet to each resurgence under differing flow conditions to attempt to define the pattern of the underground drainage system.

DYE TRACING TECHNIQUE

Three fluorescent dyes were used simultaneously to trace the flow of three swallets at a time. Following the recommendations of Smart and Laidlaw (1977), the three fluorescent dyes used for simultaneous tracing were Rhodamine WT, Lissamine Yellow FF, and Amino - G Acid. These dyes fluoresce at different wavelengths without interference and are also the most conservative in terms of photo-chemical decay, adsorption and interference from the natural fluorescence of dissolved organic material in stream water. Smart and Laidlaw (1977) list the characteristics and details of each dye.

Known amounts of dye, dissolved in water, were put into the surface stream as near as possible to the swallet entrance. Turbulent flow conditions in the underground conduits, as suggested by Atkinson (1971), ensure adequate mixing of tracer dye and swallet water.

The amounts of dye used were as follows:

Rhodamine WT	100 ml. (20% solution)
Lissamine Yellow FF	150 g.
Amino - G Acid	250 g.

except for the tracing of the percolation trickle at the bottom of Ubley Hill Pot, when 200 ml. of Rhodamine WT were used. These amounts of dye were small enough for detection in the prevailing hydrological conditions without affecting water quality (Rickford and Langford resurgences are sources of supply for Bristol Waterworks Company).

Following dye slug injection, the resurgences at Rickford and Langford were sampled at two hourly intervals, using battery powered Rock & Taylor 48 Interval Water Samplers for fourteen days, the duration of each of the three tracing runs.

Samples were analysed using a Turner 111 Filter Fluorometer with Far UV Lamp and high sensitivity door, at a constant temperature of 21°C. Wilson (1968) gives details of the Turner 111 Filter Fluorometer and its use.

Detection of each dye is made by the use of filters to measure fluorescence at the characteristic emission wavelength of each dye. Determination of sample dye concentration is by comparison of sample fluorescence with a calibration curve of dye concentration against fluorescence for each dye.

Using this method the minimum detectable concentration for each dye is:

Rhodamine WT	0.013 μg/11
Lissamine Yellow FF	0.29 μg/11
Amino - G Acid	0.51 μg/11

(From Smart and Laidlaw 1977).

QUANTITATIVE ASSESSMENT OF DYE RECOVERY

Quantitative dye tracing can be achieved by comparing a known input of dye into a swallet with an assessment of dye recovery at each resurgence.

The method employed for assessing recovery is outlined by Smart and Smith (1976). Time/dye concentration curves from the samples collected and spring discharge records are required to quantify dye recovery.

$$\text{Then: } M = \int_{t=0}^{t=t} CQdt$$

where M - mass of dye passing sampling site in μg.

C - dye conc. in μg/l.

Q - discharge in l/sec.

t - Time for passage of dye pulse in seconds.

Since samples were only collected at two hourly intervals, a modified version of the recovery equation was used.

$$M = \sum_{n=0}^{n=n} CQ$$

M - mass of dye passing sampling site in μg.
C - dye concentration of sample in $\mu g/1$
Q - discharge for two hour period of sample in 1
n - number of samples.

In theory, total assessed dye recovery should be 100% of dye input. This however, is rarely the case, and Smart and Smith (1976) give the possible sources of error:

Dye injection	± 5%
Instrumentation	± 1%
Discharge records	± 5%

This does not take into account any dye losses, loss of fluorescence, or interference due to organic matter, though for the dyes used and the type and duration of the tracings, these would be minimal. In theory, sampling should be continuous, but with the equipment available this was impracticable.

Errors in discharge records were probably in excess of 5%. The discharge records were obtained from weirs at Bristol Waterworks Gauging Stations at the two resurgences and due to autumn leaf fall and summer weed accumulation the weirs, (particularly at Langford), were partly choked. The discharge records were therefore probably some 10% in excess of the actual discharge.

DYE TRACING RESULTS

Three tracing runs, each of three simultaneous dye injections were carried out during November and December, 1977. Each run took place under differing hydrological conditions to give a repeat of tracings. Eight traces were successful; the results are summarized in Table 1. Figure 35 shows examples of dye recovery curves.

The results showed a similar pattern of swallet to resurgence connections as those found by Drew, Newson and Smith (1968), as shown in Figure 34. Quantitative results showed a preferential division of swallet water flow to Rickford, with Rickford generally taking 50%-70% of the flow of each of the four Blackdown swallets: Read's Cavern, West Twin, East Twin and Ellick Farm. The accuracy of the quantitative results is generally within the margin of error of the method employed (± 20%). For results outside this margin the low recovery for the first set of tracings was due to the breakdown of sampling equipment at Rickford after 59 hours. When sampling was restarted after 90 hours, fluorescence had returned to natural background levels. However,

SWALLET	RICKFORD		LANGFORD		TOTAL RECOVERY %
	ARRIVAL TIME (HOURS)	% DYE RECOVERY	ARRIVAL TIME (HOURS)	% DYE RECOVERY	
Run No. 1 1/11/77	MEAN DISCHARGE 236 l/sec.		MEAN DISCHARGE 30 l/sec.		
Read's Cavern	46	29.0*	45	47.8	76.8
West Twin	47	26.2*	46	40.9	65.1
East Twin	NO RECOVERY		NO RECOVERY		0.
Run No. 2 13/11/77	MEAN DISCHARGE 280 l/sec.		MEAN DISCHARGE 47.5 l/sec.		
East Twin	192	59.9	118	48.7	108.6
Ellick Farm	41	71.8	50	28.7	100.5
West Twin	NO RECOVERY		127	29.2	29.2
Run No. 3 6/12/77	MEAN DISCHARGE 380 l/sec.		MEAN DISCHARGE 60 l/sec.		
East Twin	95	72.9	105	22.5	95.4
Read's Cavern	97	76.9	57	30.7	107.6
Ubley Hill Pot	85	12.0	NO RECOVERY		12.0

* Sampler failure, recovery incomplete

Table 1. Dye Tracing Results

assuming 100% total recovery, the amounts of dye recovered at Langford suggest that a total of 52.2% from Read's Cavern and 50.1% from West Twin reached Rickford.

Of the other unsuccessful tracings, East Twin (Run 1, Rickford and Langford) and West Twin (Run 2, Rickford) both used 100 ml. of 20% Rhodamine WT, which suggests an insufficient amount of dye was injected into the swallet to remain detectable, when mixed with large amounts of percolation water at the resurgence, particularly at Rickford which has the higher discharge maintained by percolation water.

In an attempt to overcome dilution, 200 ml. of 20% Rhodamine WT was injected at Ubley Hill Pot. Of this, the assessed recovery was 12% at Rickford. No dye was detected at Langford. The low recovery can again be attributed to dye losses at input and dilution, since the dye was put into a very small trickle at the bottom of Ubley Hill Pot.

With the tracing of West Twin (Run 2), the 29.2% recovery at Langford suggests that 70.8% of the dye went to Rickford without detection. Also with East Twin (Run 1) dye may have reached Rickford whilst the sampler was not operating.

Dye recoveries in excess of 100% can be attributed to over-estimation in the discharge records.

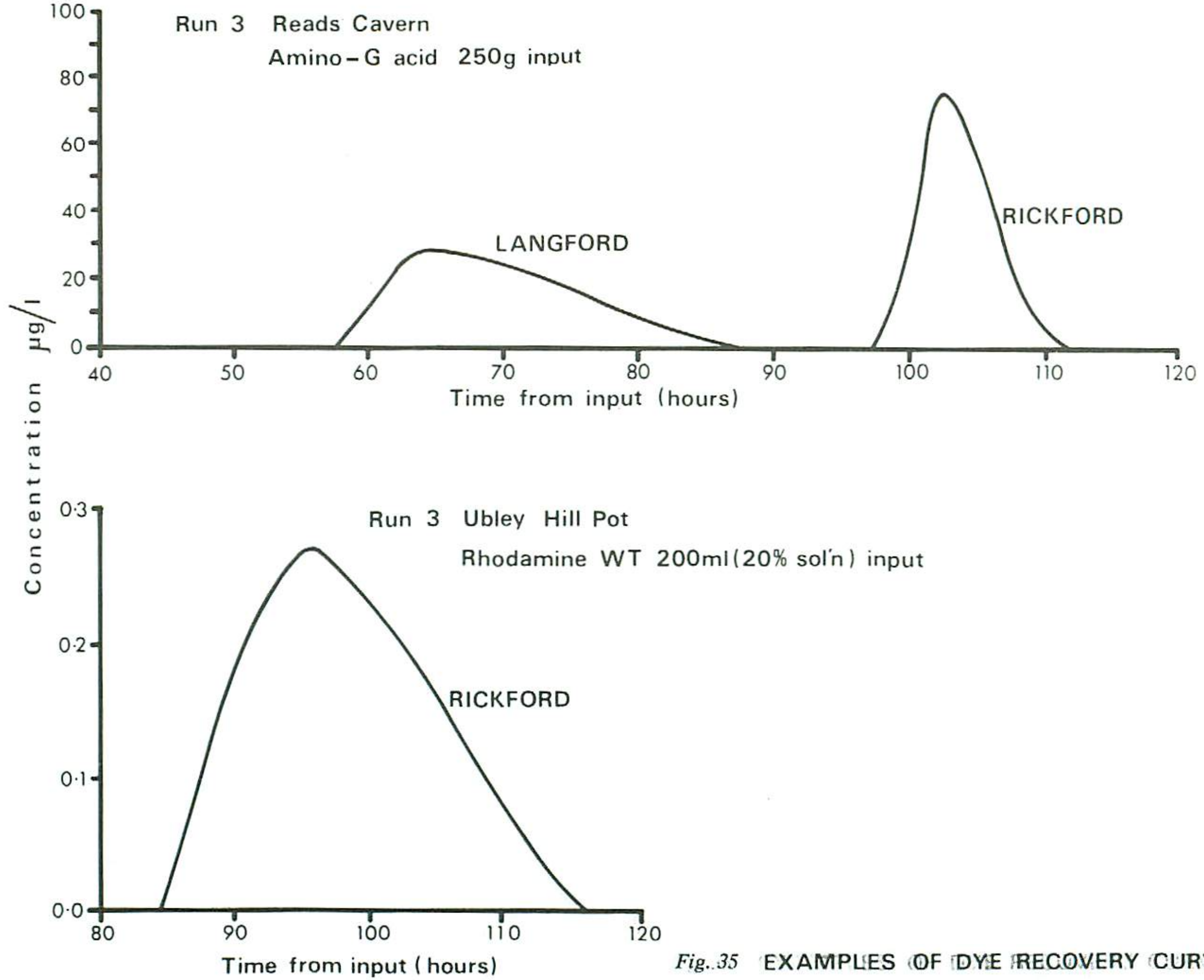

Fig. 35 EXAMPLES OF DYE RECOVERY CURVES

PAST AND PRESENT TRACING RESULTS

Although tracing results obtained by this study show a similar swallet - resurgence connection pattern (Fig. 34), to that obtained by Drew, Newson and Smith (1968), the first arrival times obtained in this study are far longer than those obtained previously using Lycopodium spores under lower discharge conditions in March and April, 1967, as shown in Table 2.

Table 2. Lycopodium Arrival Times
From: Drew, Newson and Smith (1968)

	RESURGENCE ARRIVAL TIME (HOURS)	
SWALLET	RICKFORD	LANGFORD
Read's Cavern	4	44
West Twin	19	17
East Twin	6	17
Ellick Farm	4	4
Ubley Hill Pot	4	-

Only in the tracing of Read's Cavern to Langford were similar arrival times obtained. Tratman (1963) using fluorescent dyes in the area obtained arrival times similar to those found in this study.

Arrival times from this study for repeated tracings showed that swallets responded differently to differing discharge, whereas Read's Cavern and West Twin arrival times increased with increased discharge. For example, arrival times from East Twin decreased with increased discharge. This suggests that the complex hydrological behaviour of the underground flow system includes the preferential ponding up of some swallet water by percolation water while other swallet water is speeded up by percolation water under flood conditions, as for example during Run 3. The rapid arrival times obtained by Drew, Newson and Smith (1968) could be explained in part by the lower flow conditions prevailing during their study, without any ponding up of swallet water by conduits filled with percolation water allowing the rapid passage of swallet water along the conduits. Also the use of Lycopodium spores does trace the quick flow component of the swallet water, whereas dyes tend more to trace the mean flow (Drew and Smith 1969).

Since no major changes appear to have occured in the underground system since 1968, a further possible explanation of the differences of the arrival times is that the rapid arrival times of four hours obtained by Drew, Newson and Smith (1968) could be due to sample contamination, since the Lycopodium sampling nets were changed at four hourly intervals, possibly giving erroneous spore recovery in the first sampling period. Analysis of the spore recovery curves produced by Drew, Newson and Smith (1968) also suggests this as spore recovery was not in the form of a single continuous pulse, as was the case using fluorescent dyes in this study (Fig.35). The spore recovery was in the form of a series of small broken pulses or a single pulse for the first sampling period, followed by a larger pulse spanning several sampling periods. Removing these single period Lycopodium pulses as possibly having been caused by contamination, the arrival times then become similar to those obtained in this study.

Therefore the rapid flow of water to Rickford, questioned by Newson (1972), particularly from Ubley Hill Pot, need not occur, nor does any 'hosepipe hypothesis', as suggested by Stanton (1969), need to be invoked to account for the rapid flow of water through small low gradient conduits.

CONCLUSIONS - A NEW POSSIBLE PATTERN FOR THE SUBTERRANEAN DRAINAGE SYSTEM

The implications of the quantitative tracing results for the Burrington area are that some systematic process is at work underground, which allows the preferential flow of water from each swallet to flow to Rickford, the remainder flowing to Langford. The ratio appears to vary with discharge conditions.

Under the low flow conditions of Run 1, Rickford only took some 50%-60% of the swallet water, but with the increased discharge of Run 2 and Run 3, this was increased to 60%-77%.

Smith and Drew (1975), suggest that the underground flow system is composed of separate discrete conduits, which carry water from each swallet and bifurcate near the swallet, to reach both resurgences without mixing with water from other swallets until near the resurgence. The conduits occur at various levels in the Limestone and could therefore cross without mixing. The anisotropic Carboniferous Limestone is an ideal medium for the development of such a system, based on the tracing pattern of Drew, Newson and Smith (1968), which is shown in Fig. 34.

Such an underground flow system of discrete conduits becomes impracticable to explain the apparent systematic division of swallet water. Either each swallet must bifurcate at the same proportions before the conduits flow to the resurgence, or the flow from the swallets merges and mixes in a large conduit which then bifurcates to the two resurgences.

The quantitative results suggest the latter case, the proposed flow pattern being shown in Fig. 36. A possible outline explanation is that water from each swallet flows down through the vadose zone and merges in a master conduit in the phreatic zone where swallet and percolation water mix. The master conduit then bifurcates, 60%-70% of the flow going to Rickford and the remainder to Langford. Rickford's higher discharge is due to percolation water reaching the resurgence from the eastern extension of Rickford's catchment as far as Lamb Leer Cavern, via a separate conduit. Water from this conduit mixes with the percolation and swallet water conduit from the Burrington area before reaching the resurgence to give no inhomogeneity in the water chemistry of the resurgence. The Burrington area is therefore the joint percolation and swallet water catchment for both resurgences.

Evidence for the proposed bifurcating master conduit lies in the studies of the development of the cave system around Burrington. A sequence of cave development has been proposed by Tratman (1963) who suggested that Aveline's Hole in Burrington Combe was the original outlet for the Blackdown swallets, then with a change in hydrological conditions, Aveline's Hole was abandoned and the swallets fed a lower level resurgence near the present mouth of Burrington Combe. Donovan (1969) considers this resurgence, the original outlet for the master conduit after Aveline's Hole, to have been blocked by the outwash fan at the mouth of the Combe during the Würm Interstadial, causing the flow to bifurcate along the strike to the present resurgences at Rickford and Langford.

Near the head of the Combe, a recent extension of the East Twin cavern - Lionel's Hole cave system, is reported in the Belfry Bulletin (1978). The new passage contains flowing water at the bottom, which may possibly be water from Ellick Farm swallet. This requires further tracing work to prove a connection which should show a joining of the proposed swallet water conduit from East Twin and Ellick Farm swallets.

Finally, returning to the problem of underground drainage capture, the percentage of the swallet water reaching Langford is highest under the lower discharge conditions. This may reflect head changes in the conduits, or the greater water carrying capacity of larger conduits leading to Rickford. Rather than this indicating underground capture, it may be that Langford resurgence is an overflow, albeit at a lower level, due to the nature of the anisotropic limestone, for the Blackdown swallet and percolation water reaching Rickford. In support of this Newson (1972) reports that Langford resurgence has dried up after long periods of drought, whereas Rickford resurgence has never been known to dry up.

ACKNOWLEDGEMENTS

Resurgence discharge data for Rickford and Langford gauging stations were provided by Mr. P. Hodge of Bristol Waterworks Company. The company in conjunction with Wessex Water Authority also gave permission for the dye tracing. Dr. W. I. Stanton of Wessex Water Authority provided details of the tracings of Lamb Leer Cavern.

The dye tracing was carried out as an undergraduate project at the University of Bristol, Department of Geography.

The author would like to thank Mr. P. L. Smart for his comments and encouragement and in particular for his assistance in the descent of Ubley Hill Pot.

REFERENCES

ATKINSON, T. C.	1975	Diffuse flow and conduit flow in a limestone terrain in the Mendip Hill, Somerset, England. *12th Cong. Int. Assoc. Hydrol. Huntsville.*
BARRINGTON, N. and STANTON, W. I.	1977	*Mendip. The Complete Caves and A View of the Hills.* David & Charles. 180p.
BELFRY BULLETIN	1978	*J. Brist. Exploration Club.* Vol. 32 (5), 13.
DONOVAN, D. T.	1969	Geomorphology & hydrology of the central Mendips. *Proc. Univ. Bristol Spelaeol. Soc.* **12** (1), 63-74.
DREW, D. P.	1970	The importance of percolation water. *Groundwater* **8** (8), 8-11.
DREW, D. P., NEWSON, M. D. & SMITH, D. I.	1968	Karst Research Project Phase Three. *Wessex Cave Club Occasional Publ.* 2 (2). 28p.
DREW, D. P. and SMITH, D. I.	1969	Techniques for the tracing of subterranean drainage. *Brit. Geomorph. Res. Gp. Tech. Bull.* **2**, 36p.
NEWSON, M. D.	1971	A model of subterranean limestone solution in the British Isles. *Trans. Inst. Brit. Geog.* **54**, 55-70.
NEWSON, M. D.	1972	Rickford & Langford Resurgences Mendip Hills, Somerset. A problem in limestone hydrology. *Proc. Univ. Bristol Spelaeol. Soc.* **13** (1), 105-112.
POTTINGER, S.	1976	Water tracing on western Mendip. *Journ. Wessex Cave Club.* **14** (163), 12-15.
SMART, P. L. and SMITH, D. I.	1976	Water tracing techniques in tropical regions. The use of fluorometric techniques in Jamaica. *Journ. Hydrol.* **30**, 179-96.
SMART, P. L. and LAIDLAW, I. M. S.	1977	An evaluation of some fluorescent dyes for water tracing. *Water Res. Res.* **13** (1), 15-33.
SMITH, D. I. and DREW, D. P.	1975	*Limestones & Caves of the Mendip Hills.* David & Charles. 424p.
STANTON, W. I.	1969	Letter to the Editor. *Journ. Wessex Cave Club.* **10** (122), 286-88.
STANTON, W. I.	1977	Water Tracing Notes. *Journ. Wessex Cave Club.* **15** (171), 15-16.
TRATMAN, E. K.	1963	The hydrology of the Burrington area, Somerset. *Proc. Univ. Bristol Spelaeol. Soc.* **10** (1), 22-57.
WILSON, J.	1968	Fluorometric procedures for dye tracings, in *Techniques of Water Resources Investigations of the U.S.G.S.* Vol. **3**.

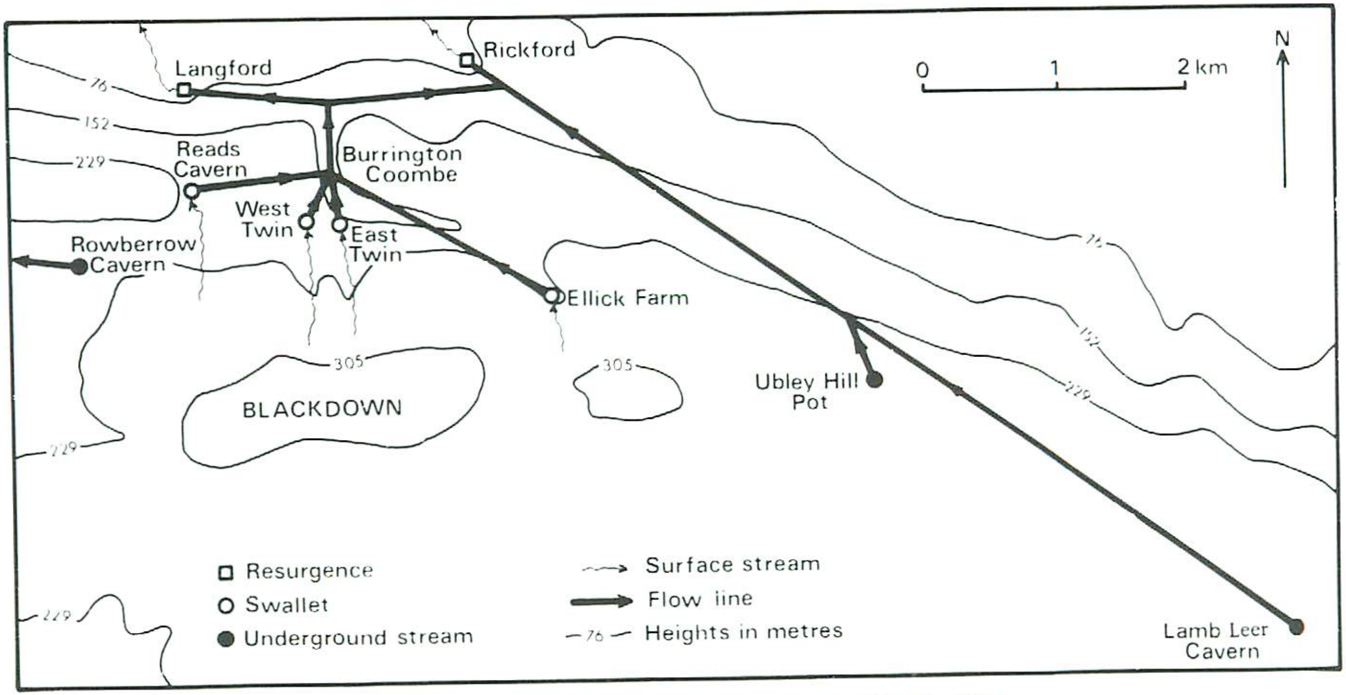

Fig. 36 PROPOSED UNDERGROUND FLOW SYSTEM FOR THE BURRINGTON AREA