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DELINEATION OF THE BANWELL SPRING CATCHMENT AREA AND THE NATURE OF THE SPRING HYDROGRAPH

by

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ABSTRACT

Using water budgeting, the catchment area for Banwell Spring has been calculated to be 14 km^2, including both Carboniferous Limestone and Dolomitic Conglomerate aquifers. Dye tracing has fixed the eastern boundary of the catchment, but because of the failure of a dye trace from Singing River Mine the southern boundary in the Dolomitic Conglomerate had to be estimated based on the size and position of other springs. The northern boundary is limited by geology, and the eastern boundary by the location of other springs.

Banwell Spring has two distinctive sub-catchments which lie to the east and west of the spring, and which have similar storage and flow properties, but different recharge. The eastern sub-catchment has some concentrated surface recharge, which gives it a more 'flashy' discharge response than the west which has only dispersed recharge.

INTRODUCTION

Banwell Spring (N.G.R. ST 39875919), some 8 km west of Blackdown, is the fourth largest spring in the Mendips (after Cheddar, Wookey and St. Andrews Well). With an average annual discharge of about 7 M m^3 it drains almost the entire northern limb of the Blackdown pericline west of Langford Rising (Fig. 1). Bristol Waterworks Company have a license to abstract 4.85 M m^3 of water annually, and up to 16,000 m^3 daily, the remainder of the discharge being compensation flow to the River Banwell. Although located at the more maturely karstified western end of the Mendips, there are few caves or significant karst features in the catchment area, so the spring has been little studied. In this paper we report on the delineation and nature of the spring catchment, and its effect on the spring behaviour.

GEOLOGY

The core of the Blackdown pericline is composed of Devonian Old Red Sandstone, a 480 m thick conformable series of siliceous sediments, comprising sandstones, shales and conglomerates. Overlying these is the Carboniferous Limestone Series (Fig. 1), which is between 915 and 1,130 m thick, and is subdivided into four main units. The lowest of these, the Lower Limestone Shales, consists of interbedded shales and thin limestones which are largely (though not always) impermeable. These are overlain by thinly bedded to massive limestones of the Black Rock, Clifton Down and Hotwells groups which are hydrologically similar, and form the main aquifer in the area. The Carboniferous Limestone dips at some 70° (and occasionally more) to the north, and 30° to the south of the pericline. Unconformably over the Carboniferous Limestone Series lie Triassic deposits, of which the Mercia Mudstone Group are the most important. This group includes the Dolomitic Conglomerate which is proximal to the Carboniferous Limestone and is composed of fragments of limestone cemented in a matrix of sandy marl or fine grained limestone debris. This forms a second aquifer in the area which is often in hydraulic continuity with the Carboniferous Limestone aquifer.

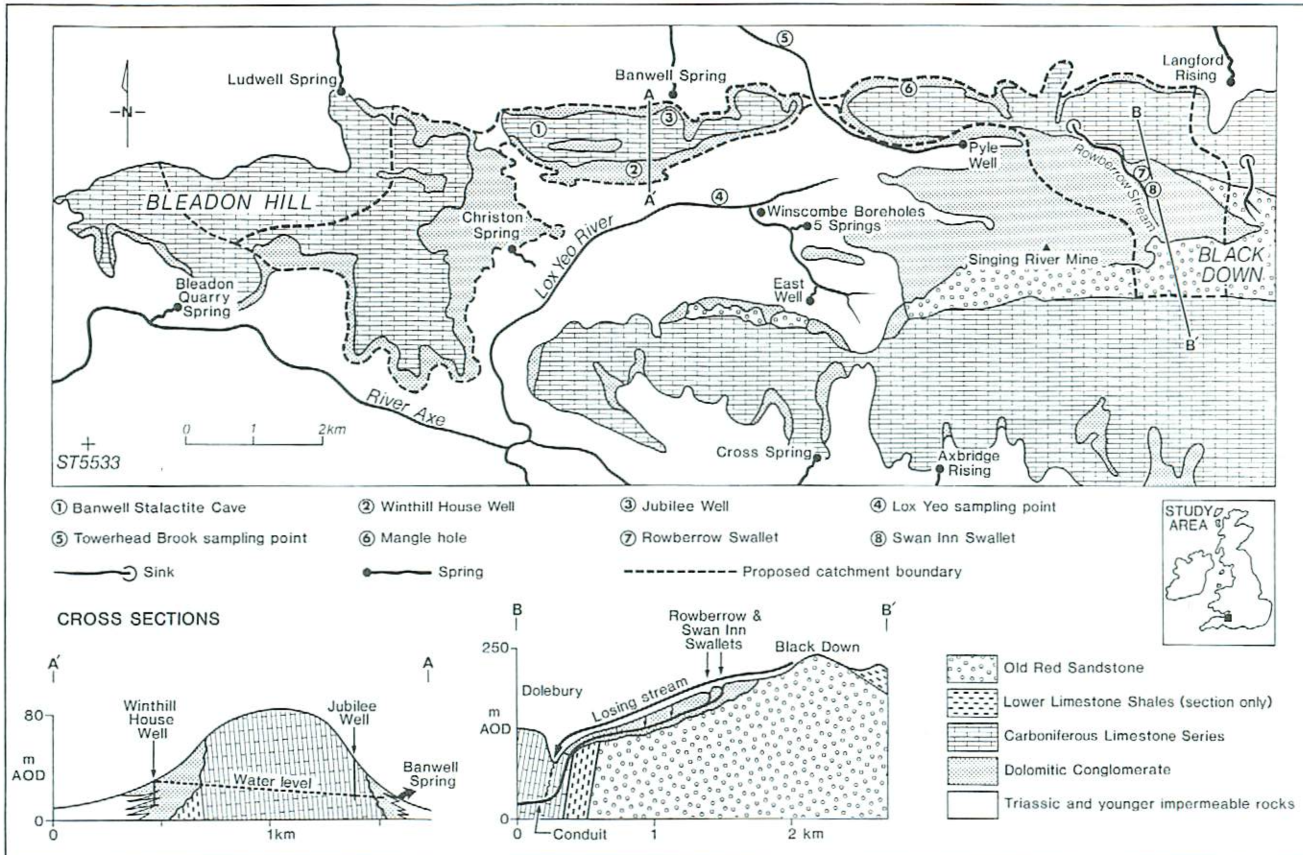

FIG. 1—CATCHMENT AREA OF BANWELL SPRING

Both aquifers are confined by the impermeable red-brown silty mudstones which comprise the bulk of the Mercia Mudstone Group, and form the low-lying land at the margin of the Mendip Hills. In the centre of the eroded Blackdown pericline the mudstones overlie the Dolomitic Conglomerate. The latter formation is 'inter-fingered' with the former (FIG. 1, section A'A), a relationship which can have an important role in controlling water levels in the Dolomitic Conglomerate, as will be seen later. Further details of the geology can be found in Green and Welch (1965).

CATCHMENT AREA

Water Budgeting

The Banwell Spring catchment area was estimated to be 14.7 km^2 by Pottinger (1976a & b) who also traced the stream flowing off Blackdown through the Rowberrow Valley and sinking at Rowberrow Swallet and Swan Inn Swallet to Banwell Spring some 5½ km away. This, and dye traces made to Langford Rising (Tratman, 1963), effectively set the easternmost boundary for the catchment. More recent dye traces (Hobbs, 1988) have confirmed that this water flows through the conduit in the lower levels of Mangle Hole (N.G.R. ST 42715929), a cave on Sandford Hill.

A water budget using more detailed figures (daily) was calculated for 1979 using the total annual rainfall (967 mm) and discharge determined at Banwell Spring (6388 Ml), combined with evapotranspiration data synthesized by the Meteorological Office from daily sunshine for a site on the Mendip plateau near Cheddar (491 mm). This yielded a catchment area of 13.4 km^2 (assuming that soil moisture deficit did not limit evaporation). The total area of Carboniferous Limestone available to drain to Banwell Spring (as determined from sheets 279 and 280 of the British Geological Survey maps) is about 10.3 km^2; however, this must also supply Ludwell Spring and Bleadon Quarry Spring. Using a discharge value suggested by Barrington and Stanton (1977) for the former (1.8 Ml/d), and average annual precipitation (868 mm) and evapotranspiration (568 mm) values quoted by the Meteorological Office, the catchment area for Ludwell Spring was estimated to be 2.2 km^2. The discharge figures quoted by Barrington and Stanton are only based on occasional gauging and are thus used with caution; however, they are the only data available for this site. No data was available for Bleadon Quarry Spring, but its position at the western end of Bleadon Hill, and non-quantitative accounts of its flow from local residents, suggest an area of drainage of about 1.5 km^2. Christon Spring also drains Bleadon Hill, but is very small and only seasonally active, so is not included in these calculations. The total Carboniferous Limestone available to drain to Banwell Spring is thus 6.6 km^2 (i.e. $10.3 - [2.2 + 1.5]$ km^2), very much smaller than the 13.4 km^2 calculated from the water budget.

A second major aquifer in the area is the Dolomitic Conglomerate. The outcrop of this rock which potentially drains to Banwell Spring is some 9.3 km^2, but this aquifer also supports flows to the Bristol Waterworks' Winscombe Supply Boreholes (at the site of the natural spring, Cox's Well), and to Five Springs. Using discharge figures for the former supplied by Bristol Waterworks Company, and discharge figures for the latter suggested by Barrington and Stanton (2.3 Ml/d and 0.5 Ml/d respectively), and Meteorological Office figures for precipitation (868 mm/a) and evapotranspiration (557 mm/a), the catchment areas of these springs were calculated as 2.7 and 0.5 km^2 respectively. Subtracting the sum of these two areas from the total Dolomitic Conglomerate available, yields a value of 6.1 km^2. If this is added to the total Carboniferous Limestone available (6.6 km^2), and the 1.9 km^2 of Old Red Sandstone that supplies the Rowberrow Stream (as determined by topography), the total catchment is estimated to be 14.6 km^2. Considering the large errors involved in the estimates used, this compares favourably with the value of 13.4 km^2 calculated above. A value of 14 km^2 (± 0.6 km^2) is suggested as being of the correct order for the catchment size.

Potentiometric Surface Data

In an attempt to further delineate the spring catchment area, water levels at well sites were monitored in order to construct a potentiometric surface map. However, too few sites were found that reliably represented water level fluctuations in the Carboniferous Limestone/Dolomitic Conglomerate aquifier to do this with any accuracy. Those water levels measured do show a general hydraulic gradient towards Banwell Spring, the nature of which is illustrated in the geological cross-section from Winthill House Well to Banwell Spring in FIG. 1, section A′A. This demonstrates that water flow between the Dolomitic Conglomerate and the Carboniferous Limestone must take place by movement against the dip of the former. Water level changes in the Dolomitic Conglomerate at Winthill House Well are very large, and often rapid (FIG. 2), and are associated with the 'inter-fingering' between the impermeable mudstones and the Dolomitic Conglomerate. When the 'fingers' of Dolomitic Conglomerate are recharged, water levels rise slowly due to the high storage of the formation. Once these are saturated, then water level will rise rapidly through the 'finger' of impermeable mudstone, before slowing once more when a 'finger' of Dolomitic Conglomerate is reached.

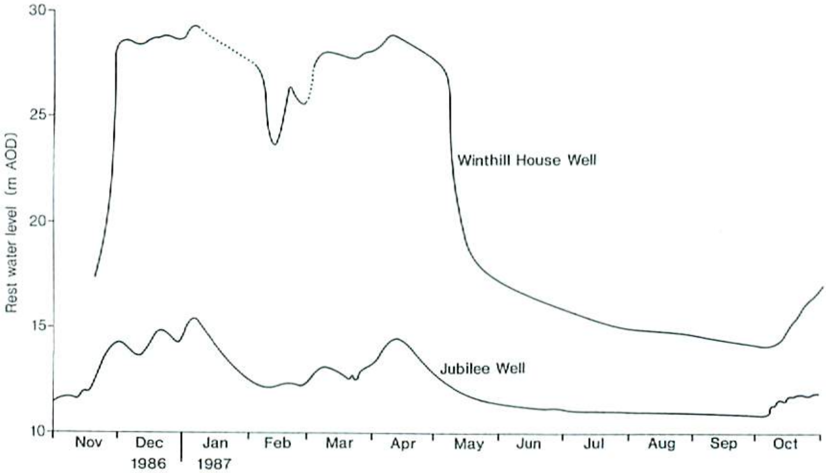

FIG. 2—SEASONAL WATER LEVEL CHANGES IN THE DOLOMITIC CONGLOMERATE AT WINTHILL HOUSE WELL AND IN THE CARBONIFEROUS LIMESTONE AT JUBILEE WELL

Flow from the stream sinks in the Dolomitic Conglomerate at Rowberrow Warren must also cut against the dip of the Dolomitic Conglomerate to enter the Carboniferous Limestone. In the area where this occurs, the Dolomitic Conglomerate overlies the much less permeable Lower Limestone Shales, causing perching of the recharge water (FIG. 1 section BB′).

An exception to the general hydraulic gradient was noted at Banwell Stalactite Cave (N.G.R. ST 38305897) at the western end of Banwell Hill.

In the lower levels of this cave access can be gained to a water surface known as The Green Lake which fluctuates by up to 11 m from winter to summer. This water surface represents the local water table in the fossil conduit, no flow having been observed by cave divers (M. R. Owen, pers. comm.). Summer water levels at the site appear to be below Banwell Spring, suggesting either an anomalous flow direction, or more probably that the published survey data is incorrect. Attempts to trace Green Lake to Banwell Spring using fluorescent dyes have failed (W. I. Stanton, pers. comm.) due largely to the lack of flow within the Green Lake.

Dye Tracer Studies

Previous dye tracing work has established the eastern boundary of the Banwell Spring catchment area; however, no successful traces have been completed in the Dolomitic Conglomerate in the centre of the Blackdown pericline. This is important as water can flow in the latter, under the impermeable mudstones to recharge the Carboniferous Limestone in the Banwell Hill area (FIG. 1, section BB′). A dye trace was therefore undertaken from a small westward-flowing stream in the lower levels of Singing River Mine, Shipham. Previous attempts to trace the stream using Rhodamine WT, injected as a series of 250 ml pulses every 2 weeks for three months, had failed (Hodge and Stanton, pers. comm.). It was felt by Hodge and Stanton that a nearby sewage treatment works was responsible for the failure, bacteria in the effluent sinking underground somehow breaking down the dye. Initially, large slugs of dye were avoided due to the likelihood of it reappearing at one of Bristol Waterworks Company's water sources, but the failure of the first traces left this as the only course of action.

Because tracing was already being carried out in the area using Rhodamine WT and Fluorescein, an optical brightner was chosen (Smart, 1976). These are advantageous due to their low toxicity (Smart, 1984). Contamination of water samples and equipment is a much greater problem due to their wide use in many materials such as washing powders. Two kg of the dye, Tinopal CBS-X, was poured into Singing River Mine stream on June 9th, 1987 as a 20:1 solution. All precautions were taken to ensure that none of the injection vessels came into contact with the detectors.

In all, ten sites were monitored from June 5th to July 14th, 1987, including: Langford Rising, Towerhead Brook (fed by Pyle Well), Banwell Spring, Lox Yeo River, Winscombe Supply Borehole (Cox's Well), Five Springs, East Well, Cross Spring, Cheddar Springs (N.G.R. ST 466539) and Axbridge Rising (Barrington and Stanton, 1977). Axbridge Rising ceased to flow soon after the experiment started, so monitoring was discontinued. The detectors used consisted of calico strips and activated charcoal bags which were changed on a weekly basis, when a water sample was also taken. Furthermore, water samples were taken from Banwell Spring every 12 hours by automatic water sampler, whilst samples from Winscombe Borehole were taken once daily, Monday to Friday, by Bristol Waterworks Company employees. Detectors were analysed using standard procedures (Smart and Friederich, 1982). Water samples and elutant from the activated charcoal were analysed in a Turner filter fluorometer using filters for the blue and green fluorescent dyes, which when plotted against one another should yield a straight line if no dye is present (Smart and Laidlaw, 1977).

Neither the plots of fluorescence versus time, nor the plots of fluorescence at two wavelengths (Hobbs, 1988) show any positive sites where the dye was detectable. Unfortunately, no firm conclusions can be gained from a negative dye trace. A repeat trace using a larger quantity of dye when water levels are higher, and therefore travel times quicker, is the only way that a connection may be proven. This, and the previous failed trace by Hodge and Stanton, suggests that flow in the Dolomitic Conglomerate may be diffuse, even though it has a concentrated input at Singing River Mine.

No firm boundaries to the Banwell Spring catchment area can therefore be fixed in the Dolomitic Conglomerate, based on either water level data or dye tracing information. However, they can be estimated using the size and position of other springs, geological information, and the total size of the Banwell Spring catchment area.

THE HYDROLOGICAL RESPONSE OF BANWELL SPRING

The boundaries set out above indicate that Banwell Spring has an elongated catchment area. This can be divided into east and west sub-catchments of similar area, but with substantially different recharge characteristics. The eastern sub-catchment has a large proportion of concentrated surface recharge, consisting of surface stream sinks, and a section of losing stream, whilst the western sub-catchment is characterized wholly by dispersed recharge (Hobbs, 1988). A significant difference might therefore be expected between the response time to rainfall of water flowing to Banwell Spring from the east compared to the west. To examine this the discharge flowing through Mangle Hole conduit (as measured using an Aanderaa RCM 4 submersible current meter) was subtracted from that resurging at Banwell Spring (as measured by Bristol Waterworks Company's gauging station) to yield a theoretical discharge hydrograph for the western sub-catchment. This will emphasize the contrast as water feeding Banwell Spring from the eastern sub-catchment west of Mangle Hole is excluded. There is however also uncertainty because the velocity distribution at the measurement site in Mangle Hole is unknown.

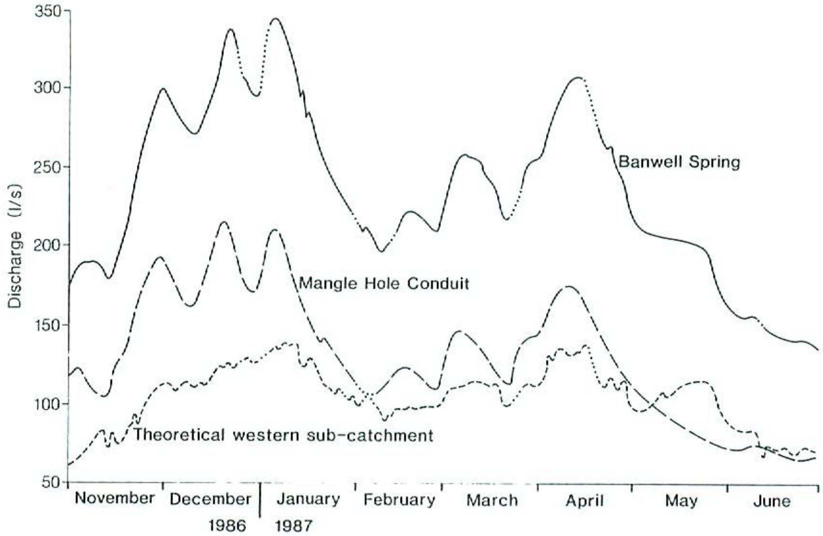

FIG. 3—HYDROGRAPH FOR BANWELL SPRING, MANGLE HOLE CONDUIT AND THE WESTERN SUB-CATCHMENT

The hydrograph for the western sub-catchment is substantially damped compared to that for Banwell Spring (FIG. 3). The former is however more noisy, due partly to the complicated lags which exist between Mangle Hole conduit and Banwell Spring discharge (Hobbs, 1988). The damping may be expected on *a priori* grounds as proposed by Smart and Hobbs (1986). Where two catchments are examined which have similar flow and storage but substantially different recharge types, then as the recharge becomes less concentrated, the flow hydrograph will undergo a reduction in peakedness. In this case the east and west sub-catchments both have conduit flow, as observed in Mangle Hole in the east, and as deduced in the west from the presence of the fossil conduit in Banwell Stalactite Cave. The sub-catchments will also have similar storage characteristics, as evidenced by the base level recession plots from the centre of the catchment (Jubilee Well), west sub-catchment (Hillend House Well), and from a site in the Dolomitic Conglomerate (Winthill House Well) (FIG. 4). However, the western sub-catchment has no concentrated recharge component. The hydrograph for the west is thus damped compared to the east, and compared to the combined hydrograph observed at Banwell Spring. A similar effect can be seen when Rickford and Langford Risings are compared. The former has a more 'flashy' discharge response than the latter (Newson, 1972), and also has a much larger concentrated surface input (there being no known surface sinks in the western sub-catchment; Crabtree, 1979).

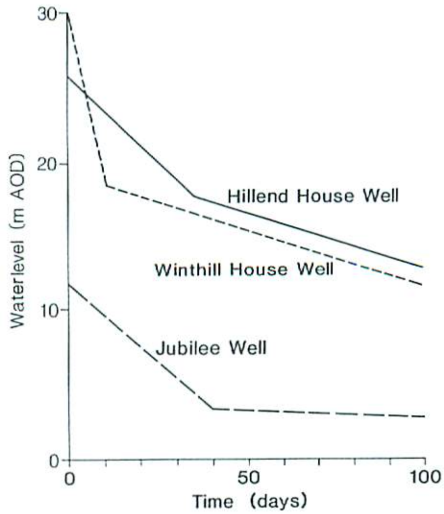

FIG. 4—STORAGE CHARACTERISTICS OF THE SUB-CATCHMENTS, SHOWN BY BASE LEVEL RECESSION PLOTS

Although discussed above as a two-component catchment, Banwell Spring also has a third component, the Dolomitic Conglomerate. However, because there are elements of this to both the east and west of the spring, it is difficult to identify any aspects of the discharge hydrograph that may be attributed solely to this aquifer.

CONCLUSIONS

The separated hydrograph at Banwell Spring has important implications both for the methods used to study such springs, and for spring management. From the annual hydrograph observed at Banwell Spring there is no evidence of a two-component response. If a 'black box approach' to hydrograph analysis had been undertaken, then serious misinterpretations of the data might have occurred. In terms of management, the two-component response means that only one sub-catchment is responsible for rapid recharge water. Such water can often be of low quality, especially following heavy storms when surface streams have high sediment loads. Furthermore, the effect of a pollution incident on Banwell Spring will be partially dependent upon which half of the catchment the pollutant had been introduced. If the water from the two sub-catchments could be isolated, the the impact of low quality water, and of any pollution incidents could be reduced.

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REFERENCES

BARRINGTON, N. and STANTON, W. [I.] 1977. *Mendip The complete caves* . . . 3rd edn. Cheddar, Cheddar Valley Press.

CRABTREE, R. W. 1979. Quantitative fluorometric dye tracing, Rickford and Langford Resurgences, northern Mendip. *Proc. Univ. Bristol Spelaeol. Soc.* **15**(2), 129–141.

GREEN, G. W. and WELCH, F. B. A. 1965. *Geology of the country around Wells and Cheddar.* London, H.M.S.O.

HOBBS, S. L. 1988. Recharge, flow and storage in the saturated zone of the Mendip limestone aquifer. Unpub. PhD thesis, Univ. Bristol.

NEWSON, M. D. 1972. Rickford and Langford Resurgences, Mendip Hills, Somerset, a problem in limestone hydrology. *Proc. Univ. Bristol Spelaeol. Soc.* **13**(1), 105–112.

POTTINGER, S. 1976a. Investigation into the groundwater hydrology of a limestone catchment, Banwell, Mendip Hills, Somerset. Unpub. Dissert., School of Env. Sci., Univ. of East Anglia, (copy available at University of Bristol—Dr. P. L. Smart).

POTTINGER, S. 1976b. Water tracing on western Mendip, *Wessex Cave Club J.* **14** (163), 12–15.

SMART, P. L. 1976. The use of optical brighteners for water tracing, *Trans. Br. Cave Res. Assoc.* **3**(2), 62–76.

SMART, P. L. 1984. A review of the toxicity of twelve fluorescent dyes used for water tracing. *Natl. Speleol. Soc. Bull.* **46**(2), 21–33.

SMART, P. L. and FRIEDERICH, H. 1982. An assessment of the methods and results of water tracing in the Gunong Mulu National Park, Sarawak. *Trans. Br. Cave Res. Assoc.* **9**(2), 100–112.

SMART, P. L. and HOBBS, S. L. 1986. Characterisation of carbonate aquifers: a conceptual base. *Proc. Env. Problems in Karst Terranes and their Solutions Conf., Bowling Green, Kentucky*, 1–14.

SMART, P. L. and LAIDLAW, I. M. S. 1977. An evaluation of some fluorescent dyes for water tracing. *Water Resour. Res.* **13**, 15–33.

TRATMAN, E. K. 1963. The hydrology of the Burrington area, Somerset. *Proc. Univ. Bristol Spelæol. Soc.* **10**(1), 22–57.

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