Proc Univ.Bristol Spelaeol.Soc., 1997, 21 (1), 9-24

CHANGES IN THE DISTRIBUTION OF WATER BETWEEN SURFACE SINKS AND STREAM INLETS IN ST. CUTHBERT'S SWALLET, PRIDDY, SOMERSET

by

R.D. STENNER

ABSTRACT

When St. Cuthbert's Swallet was discovered, the two large streams entering the cave flowed in routes extensively altered by the lead mining industry, and susceptible to change. The sink of the larger stream moved by 50 m around 1970 and about 20 years later the route of this stream changed completely, joining the second stream about 160 m from the Main Stream Sink. The distribution of the streams changed, the Entrance Pitch is now considerably wetter than previously, and the characteristics of Plantation Inlet Stream have changed considerably. Distribution changes between the Soakaway Sink and Pulpit Passage are described. As a result of the major stream change the chemical characteristics of water at the major sinks and many of the inlets in the cave have changed significantly. Minor inlets and the problem of water flowing from The Lake are considered.

STREAMS WHICH ENTER ST. CUTHBERT'S SWALLET

The natural drainage of large parts of North Hill and Stock Hill was via the valley between these two hills, into the blind valley drained by St. Cuthbert's Swallet to the Wookey Hole rising. Considerable physical changes in the valley were caused by lead mining companies in the 19th Century. Water, needed for washing and concentrating ores, was diverted from natural routes, stored in reservoir pools, and distributed around the mineries by artificial channels, controlled by sluice gates.

The geology of the area has been described elsewhere (Irwin, 1991). No detailed description of the current hydrology of the cave has been published. Hydro-chemical studies in the cave were carried out by the Author between 1965 and 1973 and preliminary reports of work in progress were published (Stenner, 1966, Stenner, 1968a). Atkinson studied the two main tributary streams between 1969 and 1970 (Atkinson, 1971), providing data for comparison with those of Stenner.

The hydrology of St. Cuthbert's Swallet has undergone considerable changes since the cave was first entered in 1953. In this respect, the cave is unlike any other major cave on Mendip. When St. Cuthbert's Leadworks closed in 1908, three streams associated with the cave flowed in the valley. They were: 1. The Mineries Pool Outflow Stream, the largest stream in the valley, which flowed via a marshy pool (midway), to the Maypole Overflow Corner, where it turned to the west to sink in Plantation Swallet; 2. St. Cuthbert's Stream, which drained a part of Stock Hill, flowed beneath the tramway from Chewton minery and slag-heaps, and rose in a marsh to flow 170 m to the main swallet near the cave entrance; 3. Ladywell Stream, which rose in a spring near the Mineries Pool, crossed the Pool Outflow stream near Plantation Swallet by means of an aqueduct, and flowed as far as the field opposite the Queen Victoria Inn in Priddy, NGR ST 527509, supplying villagers in the eastern part of Priddy with drinking water.

The Pool Outflow stream and the Ladywell streams flowed, in 1908, in artificial courses which were higher than their natural courses, and were therefore susceptible to leakage into natural drainage routes. Ladywell stream was maintained regularly until about 1960; the water course was kept free from obstruction, and leaks were sealed with clay. The Pool Outflow stream was not maintained and leakage of water from the Maypole Overflow Corner seriously hampered early attempts to enter the cave (Irwin, 1991) and subsequent intermittent leakages at this point between 1968 and 1985 altered drainage patterns in the valley.

Leakages from Ladywell stream have been noted at various times. In 1953, the Ladywell stream flowed only as far as Eastwater Lane (NGR ST 538504) 180 m to the west of the Belfry (the headquarters of the Bristol Exploration Club, NGR ST 542504) Since 1970, water has not re-emerged from the culvert which carried the stream underneath the Belfry. Between the spring and the Drinking Pond at the Belfry, the stream visibly shrinks in size. Two points were located in 1996 where intermittent leakage currently takes place. Leakage rates can be expected to increase.

STREAM INLETS IN ST. CUTHBERT'S SWALLET

Water traces were carried out by various workers to establish connections between stream sinks and inlets in the cave, shown in Figures 1, 2 and 3 (Stenner, 1968a, Stenner, 1972a, 1972b, Irwin, 1991). Four stream sinks fed water to up to 14 inlets. Water leaking from Ladywell stream near the footpath to the cave in 1971 was traced to the intermittent stream in Coral Chamber, which is believed (because of a reported visual pyranine trace [Stenner, 1972a]) to flow to the Lake, joined by water from the Main Stream. The author considers that water from the Lake is unlikely to re-enter the known cave. Percolation water entering at three sites, Cascade, Dining Room Stream, and Pyrolusite Stream, joins the Main Stream. Water from the Kanchenjunga drip is thought to join the Coral Series Stream. With techniques so far available, it has not been possible to measure the sizes of the Cascade drip or the Dining Room Stream (hydro-chemical characteristics of the Main Stream showed no measurable change between Traverse Chamber Choke and Stalagmite Pitch). The size of Pyrolusite Stream been measured only once.

CHANGES IN THE HYDROLOGY OF THE CAVE

In the forty three years the cave has been open, there has been a considerable sequence of hydrological changes. In 1966, an old dig 20 m upstream of the Dining Room started to take water from the Main Stream. In 1967, the flow from an inlet fed by the Soakaway Sink switched from Pulpit Passage East Inlet to Arête Chamber North-East Inlet (Stenner 1969a). Between 1968 and 1971, the site of the Plantation Stream sink gradually shifted 50 m from Plantation Swallet to Maypole Overflow Corner. Between 1985 and 1991, the largest change in the surface hydrology of the system took place: in 1991, it was noticed that the largest stream entering the cave (the outflow stream from Mineries Pool, previously called Plantation Stream) had changed its course (see Figure 1). Instead of sinking in or near Plantation Swallet, it joined St. Cuthbert's Stream, to sink in the Main Stream Sink near the Entrance. At some time between 1985 and 1991, the artificial bank of Plantation Stream had been breached at a small overgrown pool mid-way between the Pool Outflow and Maypole Overflow corner, allowing the stream to revert to its ancient natural route into the depression. Finally (so far!) a line of sandbags diverted the stream away from the Soakaway Sink into the culvert leading into the cave.

The change in the route of the Mineries Pool outflow stream made previous hydro-chemical studies of the cave obsolete, the distribution of the streams in the cave had changed considerably, and much of the previous field work needed to be repeated. Two current St. Cuthbert's leaders (J. Williams and E. Sandford) collected sets of samples from the cave between May 1994 and August 1997, and the current hydrology of the cave was studied.

The aim of the present study was to determine the current distribution of the streams throughout the cave on a number of occasions, using data provided by hydro-chemical stream studies. The distribution pattern was determined in summer and winter, in high and low water conditions. The stream distribution had been calculated on a number of occasions between 1966 and 1968 and by comparing the two sets of data the changes have been described and quantified.

The Method of Mixtures made it possible to determine the ratio of stream sizes at stream junctions, using hydro-chemical data. A number of direct measurements of discharge were made (between 1966 and 1968 by using a rectangular-notch weir, and between 1994 and 1997 by using salt dilution (Stenner and Stenner, in prep.) and on a small number of occasions sizes of small inlets were measured using a polythene sack, a watch and a measuring cylinder). The direct measurements made it possible to calculate the stream distribution in the cave from stream ratio data. This was done for five occasions between 1966 and 1968 and seven occasions between 1994 and 1996, leaving out the small intermittent stream in the Coral Series, depending on four assumptions: (a) sampling trips took place so quickly that changes in the measured factors during the trip were negligible; (b) water flowing through Coral Chamber to the Lake does not re-enter the known cave; (c) between 1966 and 1968 the discharge value of the inlet stream at Plantation Junction was equal to that of Plantation Stream at the surface; (d) the volume of water leaving the Main Stream upstream of the Dining Room is negligible. Data relevant to the assumptions will be discussed later.

The studies had other objectives; to quantify the hydro-chemical characteristics of surface streams and stream inlets within the cave, and to study changes in the streams between surface sinks and inlets within the cave. Results of these studies will be presented elsewhere.

DETAILS OF FIELD AND LABORATORY STUDIES

The methods used to determine the characteristics of the streams have been described elsewhere (Stenner, 1968a, Heathwaite, Knights and Stenner in prep.). Briefly, total hardness was measured by EDTA titration, and aggressiveness by the Stenner procedure (Stenner, 1969b). Water temperatures were measured on many of the sampling trips between 1994 and 1996, using an electronic thermometer.

Data concerning stream distribution patterns from 1965 to 1973 are summarised in Table 1, and those from 1994 to 1997 are summarised in Table 2.

YEAR	1966							1967		1968			1971	1973
DATE	26.03	23.04	1.06	22.06	27.07	20.08	23.10	28.01	29.11	28.01	10.02	9.11	11.04	19.08
DISCHARGE, SURFACE SINKS														
Plantation Swallet		1200		280	1.5	5	900	415	300		165	140		
Maypole Sink		90						38	44		8	52		
Soakaway Sink		90						56	38		17	9		
Culvert		30						15	38		9	6		
P.S. Weir		1200	303	284	1.5	5	940	415	303	140	151	45		
DISCHARGE, CAVE SITES														
Pulpit Passage, E. Inlet		50						38	19		11	9		
Pulpit Passage, W. Inlets		30						15	19		5.6	0.0		
Pulpit Pitch		75						56	38		17	9		
Disappointment Passage Stream											0.6	0.0		
Drinking Fountain Stream		35						15	23		2.3	19		
Old Route Stream		41						15	38		9	5.5		
Maypole Stream		48						23	11		6	33		
Main Stream, Traverse Cha. Choke		200						106	110		35	67		
Main Stream, Sewer Passage		200		28			155	106	110		35	67		
Plantation Inlet Stream		1200		280			940	415	300		165	140		
Main Stream, Beehive Chamber		1400		310			1100	520	410		200	160		
DISCHARGE RATIOS														
Pulpit Pitch : Old Route		1.8 : 1									1.89 : 1	1.64 : 1		
Main Stream : Plant. Inlet Stream		1 : 6.0		1 : 10.0	1 : 20	1 : 13	1 : 6.1	1 : 3.9	1 : 2.7		1 : 4.8	1 : 2.1		
TOTAL HARDNESS ppm $CaC0_3$														
Pool Outflow	77									81	57		78	97
Plantation Swallet	108	77	105	114	151	116	87	90	140	108	88	108	125	142
Plantation Inlet Stream				117	146	133	113	94	142		114			153
% CHANGE OF TOTAL HARDNESS														
Pool Outflow to Plantation Swallet	40.3									33.3	54.4		60.3	46.4
Plant. Swallet to Plant. Junction				2.6	-4	14.7	29.9	4.4	1.4		29.5			8.2

YEAR	1994		1995		1996		
DATE	25.05	15.06	11.07	3.09	13.02	10.03	24.03
DISCHARGE, SURFACE STREAMS							
Pool Outflow Stream	800	270	165	0	1320	444	590
St. Cuthbert's Stream	2860	470	374	20	4450	1000	930
DISCHARGE, SURFACE SINKS							
Maypole Sink	1520	310	171	3	1260	1080	1030
Soakaway Sink	2200	325	119	2	580	350	135
Culvert	660	145	255	19	3870	650	795
DISCHARGE, CAVE SITES							
Pulpit Passage, E. Inlet		23	42	0.18	145	177	112
Pulpit Passage, W. Inlets		297	77	0	430	170	24
Pulpit Pitch	2200	320	119	0.18	580	350	135
Disappointment Pass. Stream	200	80	40	0	125	43	11.3
Drinking Fountain Stream	220	80	32	0.3	135	34	38
Old Route Stream	660	145	255	19	3870	650	795
Maypole Stream	1100	155	99	2.7	1000	1000	980
Main Stream, Traverse Cha. Choke	4400	780	545	23	5710	2120	1960
Main Stream, Sewer Passage	4400	780	400*	1	5710*	2120	1960
Plantation Inlet Stream	2200	1300	400*	30	270*	195	104
Main Stream, Beehive Chamber	6600	2100	800*	31	5980*	2310	2060
DISCHARGE RATIOS							
Pulpit Pitch : Old Route	3.33 : 1	2.21 : 1	1 : 2.14	1 : 100	1 : 6.67	1 : 1.87	1 : 7.26
Main Stream : Plant. Inlet Stream	2.00 : 1	1 : 1.67	1 : 1.00	30 : 1	21 : 1	10.9 : 1	18 8 : 1
TOTAL HARDNESS ppm $CaCO_3$							
Pool Outflow Stream	71.8	97.9	103.1	dry	68.0	86.8	68.0
St. Cuthbert's Stream Culvert	103.5	146.9	170.1	166.9	93.3	123.8	108.5
Main Stream, Sewer Passage	128.6	154.9	175.6	190.6	107.3	134.7	121.1
Plantation Inlet Stream	209.7	205.1	206.7	189.0	203.5	189.8	203.6

Table 2. *The distribution of the streams on the surface and in St. Cuthbert's Swallet between 1994 and 1996; estimates of discharge at each site (l/min), and changes in total hardness between some sites (ppm $CaCO_3$). Figures marked thus * may be less reliable as a possibly significant proportion of the Main Stream was leaking away 20 m upstream of the Dining Room.*

Table 1. (Opposite) *The distribution of the streams on the surface and in St. Cuthbert's Swallet between 1966 and 1973; estimates of discharge at each site (l/min), and changes in total hardness between some sites (ppm $CaCO_3$). On 27.07.66 and 20.08.66, the volume of water going over the weir at Plantation Swallet was so small that the stream sizes could not be estimated reliably.*

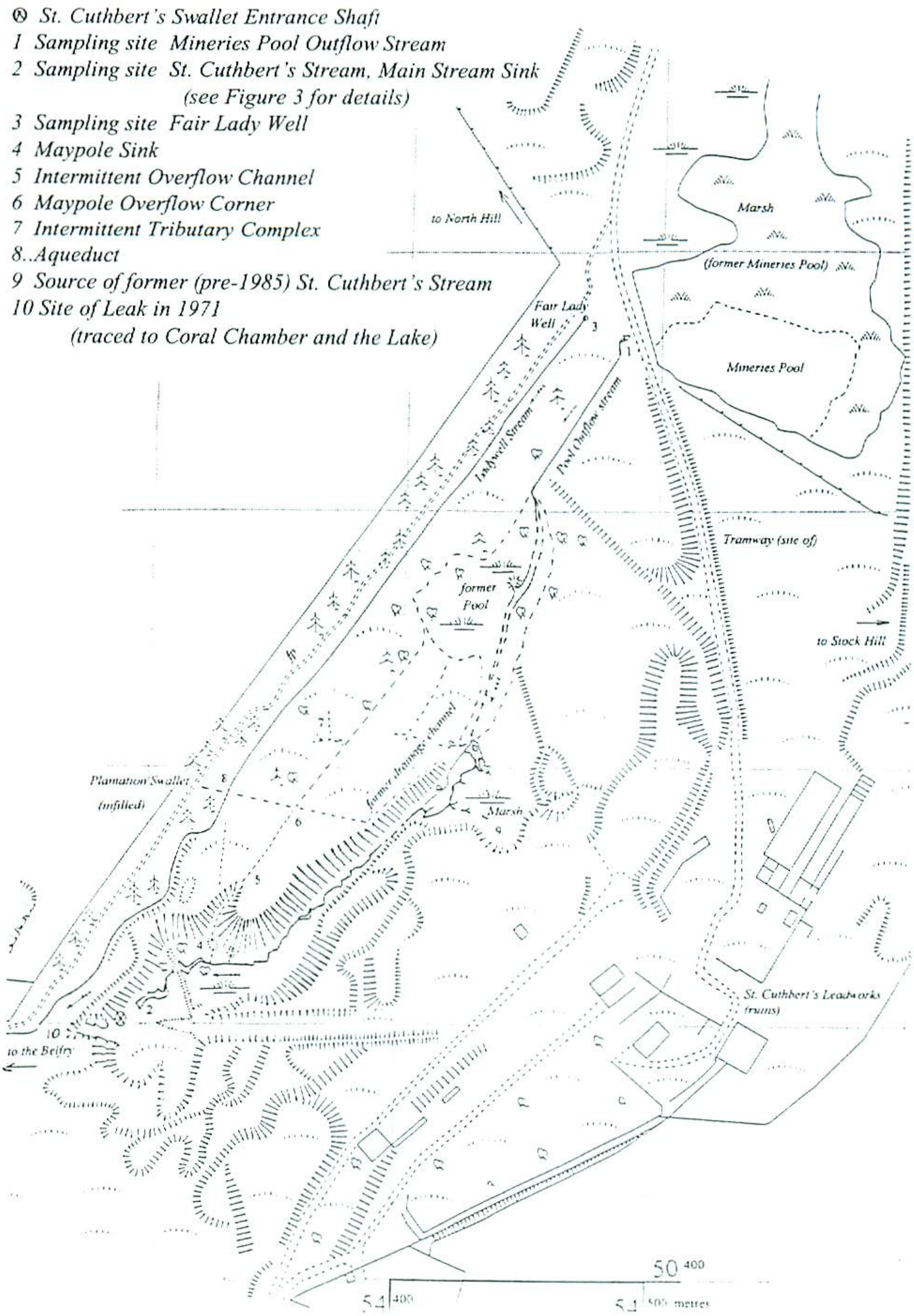

Figure 1. *Location map showing streams and other surface features near St. Cuthbert's entrance mentioned in text. Part of square ST 5450, resurveyed by R.D. & F.L. Stenner in 1996.*

SITE	DATE	Discharge litres/min.			Total hardness ppm $CaCO_3$			Temperature °C			Aggressiveness ppm $CaCO_3$		
		No.	Mean	S.D.	No.	Mean	S.D.	No.	Mean	S.D.	No.	Mean	S.D.
Mineries Pool Outflow Stream	1994-97	57	579	839	60	94	20.6	40	9.6	5.4	60	13.4	5.9
St Cuthbert's Inlet Stream	1994-97	45	522	601	45	169	28						
St Cuthbert's Stream Main Sink	1994-97	91	793	875	97	135	26.7	70	10.3	3.2	96	-1.5	3.5
Mineries Pool Outflow Stream	1965-73				4	78	14.3	3	5.6	3.7	4	11.8	6.9
Plantation Swallet	1965-73	16	260	51	22	113	20.1	18	8.8	2.9	11	6.4	7.0
St. Cuthbert's Stream Main Sink	1965-73				21	134	17.5	17	7.2	3.4	10	0.5	2.2
Plantation Swallet (1)	1969-70	15	600	540	33	100	38					10.7	
St. Cuthbert's Stream Main Sink (1)	1969-70	31	170	245	33	137	23					1.2	
Main Stream Sewer	1994-97	7	2140	2130	7	147	34.9	6	8.6	1.4	7	1.1	3.0
Plantation Inlet Stream	1994-97	7	660	806	7	204	6.4	6	9.4	0.8	7	-5.8	8.7
Main Stream Beehive Chamber	1994-97	7	2810	2500	7	159	36.6	6	8.6	1.45	7	0.4	3.3
Main Stream Sewer	1966-73	7	99	67	5	169	20.4	8	8.8	0.45			
Plantation Inlet Stream	1965-73	7	480	443	6	129	17.4	8	8.9	1.8			
Main Stream Beehive Chamber	1965-73	5	493	307	7	125	6.2	8	8.9	1.46			
Old Route Showerbath - Wire Rift	1994-97	7	915	1340	5	136	37.5	5	8.1	3.2			
Old Route Showerbath - Wire Rift	1965-73	5	22	17	6	137	22.9	5	8.1	1.4			
New Route Stream Pulpit Pitch	1994-97	7	528	762	5	137	18.3	5	8.4	1.5			
New Route Stream Pulpit Pitch	1965-73	5	39	27	9	144	14.0	12	8.3	1.1	1	4.4	
Pulpit Passage Main West Inlet	1994-97	6	81	106	5	147	17.7	5	9.0	0.8	3	-1.9	2.2
Pulpit Passage Main West Inlet	1965-73	4	10	10.4	9	152	17.9	12	8.5	0.7	2	4.5	3.5
Pulpit Passage East Inlet	1994-97	6	69	74	6	136	25.0	6	8.6	1.7	5	0.4	1.1
Pulpit Passage East Inlet	1965-73	4	19	15.0	8	143	19.9	11	8.2	1.6	2	7.0	3.5
Fair Lady Well	1994-97				46	161	5.1	28	10.0	0.3	45	4.9	2.4

(1) from Atkinson (1971)

Table 3. *A summary of selected hydro-chemical characteristics at sites between 1965 and 1973, and between 1994 and 1997, showing effects of changes in the hydology of St. Cuthbert's Swallet.*

DISCUSSION OF THE RESULTS

ASSUMPTIONS MADE IN CALCULATING STREAM DISTRIBUTION PATTERNS.

(a) *Changes taking place in the characteristics of a stream during a sampling trip.*

Data from studies in this cave and in G.B. have shown that stream characteristics are stable, except when a heavy rainstorm takes place while the sampling trip is taking place (Stenner and Stenner, in prep.). In the present studies, there was heavy rain during the trip on 11.07.95. The total hardness was 178 ppm calcite in the Main Stream upstream of Disappointment Pot and 162 ppm at Pulpit Pitch; the two values were usually equal. However, as the time needed to move from the first site to the second was significantly longer than the time needed to collect samples and data from each stream junction, the data from this trip were accepted as valid, reservations due to the passage of the rainstorm pulse being noted.

(b) *The coral series stream leaves the known cave at the Lake.*

The intermittent Coral Series stream flows into a steep, muddy boulder choke at the end of Rocky Boulder Passage. At the "Bridge" in Lake Chamber, 20 m horizontally and 10 m vertically below, heavy drip enters through boulders in the roof. No samples from the Coral Stream have been analysed, but samples from the Main Stream 20 m upstream of the Dining Room, the stream underneath Cerberus Hall and from the Lake on 10.02.68 had total hardness of 142, 142 and 152 ppm calcite respectively, showing that water from the Main Stream had been mixed with water from a different, harder source. The survey shows that the altitude of the minimum height of the Lake is exceeded at all points in the Main Stream above a point a few metres upstream of the upstream end of The Sewer. Water from the Lake therefore cannot re-enter the Main Stream anywhere upstream of that point. Downstream of this point there is no inlet which can be explained by discharge from the Lake. For these reasons, the author believes that water discharging erratically from the Lake is not believed to re-enter the Main Stream this side of Sump 2 (Stenner, 1968b). The calculations used to determine the distribution of the streams, including the tributary streams, from the Entrance to Sump 2 were, consequently, unaffected by the decision not to attempt to measure the size of the Coral Series Stream. The problem of the Lake will be considered again below.

(c) *Between 1966 and February 1968, the sizes of the streams at Plantation Swallet and Plantation Junction were equal.*

On 10.02.68, the size of Pulpit Passage East Inlet was measured directly (with polythene sack, watch and measuring cylinder). Stream ratios along the stream passage to Plantation Junction gave a value of 165 l/min for Plantation Inlet, which is very close to the value of 151 l/min given by the Plantation Swallet weir. This supported the assumption that between Plantation Swallet and Plantation Junction there was a negligible change in volume.

Changes in salt concentrations between Plantation Swallet and Plantation Junction were small, sometimes within the analytical precision of the measurements. The changes were similar in magnitude to those found by Stenner in the Main Stream of G.B. Cave, between the surface and the main inlet in the cave (Stenner, 1973). Changes between the Pool Outflow and Plantation Swallet were very much larger.

The fact that hardness changes between Plantation Swallet and Plantation Junction were relatively small was a second, independent piece of evidence supporting the conclusion that at the time, the stream at Plantation Swallet accounted for 100% of the inlet at Plantation Junction. The magnitude of the changes in total hardness between the Pool Outflow and Plantation Swallet suggested the possibility that a separate independent stream was mixing with Plantation Stream somewhere in the marshy ground downstream of the Pool. However, another possibility was that the stream was leaking into the marsh, becoming enriched with CO_2 from decaying vegetation, and seeping back into the stream, and until 1994 there was no evidence to show which explanation was correct.

(d) *The volume of water leaving the Main Stream near the Dining Room is negligible.*

In 1966, an old dig 20 m upstream of the Dining Room started to swallow water from the Main Stream. Between 1966 and 1968, when the Main Stream was usually relatively small, it was easy to avoid the problem of the loss of water due to this leakage, by using the heel of a boot to redirect the whole of the stream back into its "proper" route. It re-emerged under Cerberus Hall, forming a pool from which water seeps to the Lake. If care is not taken to deflect the stream away from the dig in low water conditions, there would be significant errors in the measurement of Plantation Inlet stream from discharge ratios at Plantation Junction.

CHANGES NEAR PLANTATION SWALLET BETWEEN 1968 AND 1974

Between 1968 and 1973, the bank at Maypole Overflow Corner was frequently breached by human interference, diverting Plantation Stream into the depression, where it sank in Maypole Sink, overflowing in wet weather into the Main Stream. The flow was directed back into Plantation Swallet, but it was noticed that the stream seemed to be beginning to sink through the stream bed in the 50 m between the corner and the swallet.

On 4.11.68, while water was leaking to the Maypole Sink, Plantation Stream also seemed to shrink in size between the Overflow Corner and the weir. This possible leakage was investigated. Pulpit Passage East Inlet was again measured directly. Stream ratios along the stream passage gave a value of 140 l/min for Plantation Inlet at Plantation Junction, compared with 45 l/min at the weir. This gave a measure of the leakage between the Overflow Corner and the weir of 95 l/min.

The leakage through the stream bed increased, and by 1971, no water flowed west from Maypole Overflow corner, except in unusually heavy rainstorms. Maypole Overflow Corner had become the normal sink for Plantation Stream. A trace using Pyranine Conc. proved that the water reached the previous route to Plantation Junction (Stenner, 1972b). Hydrochemical data from Plantation Junction from 19.08.73 (Table 1) showed that the chemical characteristics of Plantation Inlet Stream were unchanged.

In 1974, Plantation Swallet was filled in.

THE CHANGE OF THE ROUTE OF THE MINERIES OUTFLOW STREAM BETWEEN 1985 AND 1991

The results from the first set of samples in the new study, from 25.05.94, showed that since the first period of study, a major change in the distribution of streams in the cave had taken place, in absolute terms and in proportion to the size of the Main Stream upstream of Plantation Junction. Comparing values for the ratio of Plantation Inlet to the Main Stream in Table 2 with those in Table 1, it can be seen that the inlet at Plantation Junction is now smaller than in the first period of study. In its earlier state, Plantation Inlet had been described as an overfit in the cave passages through which it flowed, and apparent re-solution of flowstone deposits in the stream had attracted comment.

THE SOURCE OF THE PRESENT PLANTATION INLET STREAM

Although the largest stream entering St. Cuthbert's Swallet no longer flows via the Plantation Inlet Stream, and the size of Plantation Inlet Stream has consequently reduced very considerably in size, the remaining Inlet stream is still a major stream. Table 3 shows that it has sometimes been the largest, and never less than the third largest tributary stream entering the cave. Total hardness measurements indicated a source considerably harder than known surface streams. Furthermore, this previously unknown source had, during the earlier years of the study, joined the Pool Outflow Stream on the surface, somewhere between the "halfway pool" and the Maypole Overflow Corner, causing significant changes in the chemical characteristics of the Pool Outflow Stream.

It was thought possible that with the new stream regime, an overflow route from Maypole Sink to Plantation Inlet Stream might have been activated. This suggestion is not implausible. Maypole Sink is already known to feed three inlets in the cave and, looking at the cave survey, the route from Plantation Junction to September Series could pass quite close to Maypole Series. However, this possibility is inconsistent with the present chemical characteristics of the Plantation Stream inlet, compared with those of the three inlets fed by Maypole Sink.

The unknown source had previously been responsible for the changes in the chemistry of the former Plantation Stream between the Pool Outflow and Plantation Swallet. It was characterised by a high total hardness, because the Plantation Junction inlet is now so very much harder than previously. The source could only be one or more springs at the boundary between the Old Red Sandstone and the Lower Limestone Shales.

At Plantation Junction, the present stream is super-saturated with $CaCO_3$ and capable of depositing calcite, unlike the earlier pre-1985 stream.

Certain that the new source had formerly been evident on the surface, the author kept an eye on the old stream bed upstream of the Maypole Overflow Corner, which remained suspiciously "soggy". Following a period of sustained heavy rain, on 9.11.94 a stream was found, flowing from a deep spring-fed pool, joining the old course of the Plantation Stream a few metres upstream of the Maypole Overflow Corner. Water samples were subsequently taken regularly for analysis.

Although on 9.11.94 the flow of this previously unknown stream was sufficiently strong to overflow into the Maypole Sink, its size quickly shrank. On 12.11.94 it was still flowing, but by 28.11.94 the flow was reduced to isolated pools of open (but flowing) water

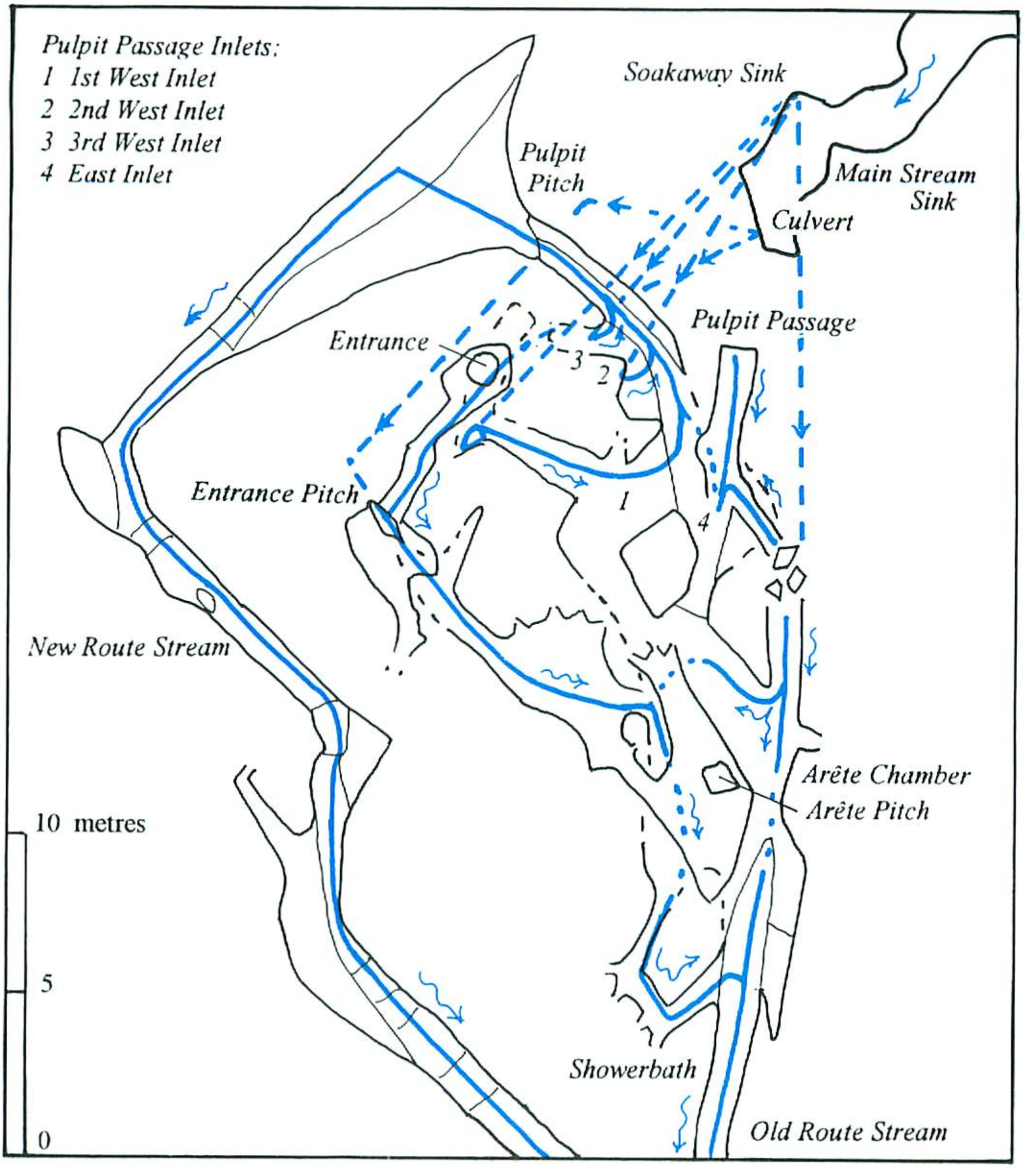

Figure 3. *Details of the connections between the Main Stream Sink and inlets in St. Cuthbert's Swallet between the Entrance and Arête Chamber and Pulpit Passage. Disappointment Passage, which is beneath the Wire Rift and Arête passage has been omitted. Since July 1995, a sand bag embankment prevents water from reaching the Soakaway Sink.*

Based on the cave survey by D.J. Irwin, with his permission, and original survey notes.

Surface survey by Stenner & Stenner.

separated by stretches of boggy marsh. Very heavy rain caused the stream to flow strongly once more on 22.01.95, when once again it overflowed into the Maypole Sink. The flow subsided once more until surface water could no longer be seen, leaving the stream bed as a strip of soggy marsh.

On 22.01.95, when the discharge value of St Cuthbert's Stream was the highest on record, two smaller intermittent stream were located, both of which flowed into the old Plantation Stream bed. Ladywell Stream was also overflowing into a marshy area which drains into Plantation Swallet.

Water temperature measurements on the surface on 22.01.95 confirmed that the newly found stream was spring fed. The high total hardness of samples lead to the suggestions that this stream, together with other similar spring fed streams in the vicinity, and the overflow from Ladywell Stream; (a) was responsible for the majority of the changes recorded in Plantation Stream between the Pool Outflow and Plantation Swallet between 1966 and 1973 and (b) is the source of the inlet stream now entering the cave at Plantation Junction.

Unusually prolonged heavy rain is needed for these intermittent streams to appear on the surface. After rainstorms in 1996, these streams did reappear on the surface. Increased flow of the Plantation Inlet Stream, shown in Table 2 for 13.02.96, demonstrated that the intermittent inlet stream had continued to operate, below the surface.

The results are consistent with the data from water tracing experiments.

CHANGES AT ARÊTE CHAMBER AND PULPIT PASSAGE BETWEEN 1968 AND 1985

The soak-away sink fed water to up to six inlets in Arête Chamber and Pulpit Passage (depending on the size of the stream). Between August 1965 and January 1967, the most direct flow had been to an inlet in boulders to the North-East of Arête Chamber, which then flowed to the East Inlet in Pulpit Passage, and to Pulpit Pitch. Between May 1967 and July 1968, the flow of this inlet switched to the North-East Inlet in Arête Chamber and to the Old Route Stream (Figure 2). On 29.11.68, flow from this source was divided between these two inlets. Between the two inlets and surface there is a boulder ruckle and it is likely that settling and movement of boulders within the ruckle led to the change of the flow route. The changes demonstrated the natural variability of hydrology (Stenner, 1969).

The distribution of the streams between the various inlets, presented in Table 1, show the consequences of these local changes in the hydrology of the cave.

THE FORMER ST. CUTHBERT'S STREAM AND THE PRESENT STREAM ENTERING THE CAVE

The former St. Cuthbert's Stream continues to be a tributary to the Main Stream entering St. Cuthbert's Swallet. This tributary drains part of Stock Hill via a marsh about 170 m north-east of the cave entrance. Water from the Pool Outflow Stream now flows into the outer parts of this marsh, making it impossible to sample the tributary stream directly under normal conditions. From samples taken from trickles within the marsh, from samples taken when the Pool Outflow Stream dried up and from estimates of the chemical characteristics of water added to the Pool Outflow stream (using the Method of Mixtures, assuming that changes in salt concentrations were due entirely to mixing with the former St. Cuthbert's Stream inlet), the data was similar to earlier data for the previous St. Cuthbert's Stream (Stenner and Stenner, in prep.). The results proved that the former St. Cuthbert's Stream did not pass through the Mineries Pool. The present suggestion is that lines of drainage from Stock Hill still operate, in spite of being buried under the tramway from the Mineries Pool, and under large heaps of slag, and the past and present St. Cuthbert's Inlet Stream was fed by this drainage.

CHANGES AT MAYPOLE SINK

Maypole Sink was proved to feed water from two different sources (overflow from Plantation Stream at Maypole Overflow Corner, and overflow from St. Cuthbert's Stream) to three inlets in the cave; Maypole Stream, Drinking Fountain Stream, and Disappointment Pot. An infilled depression between the surface and the inlets absorbs a large quantity of water which discharges slowly through the inlets, maintaining a flow through the inlets for many weeks after flow to Maypole Sink has ceased. The capacity of the sink may be exceeded, and the Maypole Sink then floods and the level may then rise to that of the Main Stream. Thereafter, any additional water from Maypole Overflow Corner causes the flow between the Main Stream and Maypole Sink to reverse, and water discharges into the Main Stream

Between 1953 and 1968, Plantation Stream leaked from Maypole Overflow Corner only in high water conditions. In 1968, serious intermittent leaks started to occur at this point, as described above. Results in Table 1 show that the size of the stream entering the Maypole Sink was higher than previously on 9.11.68, in proportion to other streams entering the cave.

The change in route of the Pool Outflow Stream (in 1985 - 1991) led to generally increased levels of flow from St. Cuthbert's Stream into Maypole Sink. Figures for flow rates of Maypole Series Stream in Table 2 show that on four out of seven occasions, flow levels were considerably higher than any recorded in Table 1 (although no sampling took place after the flood of July 1968). The figures also suggest that the flow to Maypole Series has a maximum value of just over 1000 litres/min, consistent with the observed backing up of flood water at the Maypole Sink.

CHANGES OF HYDRO-CHEMICAL CHARACTERISTICS CAUSED BY STREAM DISTRIBUTION CHANGES

The hydrological changes could reasonably be expected to affect the hydro-chemical characteristics of sites on the surface and inside the cave. Effects of the largest change, the change of the route of the Pool Outflow Stream, were considered in detail. Major characteristics of a number of sites before and after this change are presented in Table 3. A complete description of characteristics of all sites will be published elsewhere. The data contain a completely unexpected results. Although the route switch more than doubled the size of the stream at the Main Stream Sink with apparently relatively soft water, the apparent lack of change of total hardness at this site (verified by Atkinson's data) is difficult to understand. It may be that the aggressiveness of the Pool Outflow water had resulted in increased limestone solution by this stream before the confluence, and this factor had reduced the apparent difference in total hardness of this water, compared with the original St. Cuthbert's Stream. Changes in discharge, magnesium, chloride, nitrate and potassium at the Main Stream Sink were significant at the p=5% level.

At Plantation Junction, the effects of the switch of flow on the hydro-chemical characteristics were considerable. The low variability of the characteristics of the present Plantation Inlet stream is extremely striking. In addition to total hardness, changes of calcium, magnesium, alkaline hardness, non-alkaline hardness, and chloride at this inlet were significant. Temperature differences were not significant, yet the temperature characteristics of similar seepage streams may differ considerably from streams which flow directly from surface sinks (Stenner, 1968a). The electronic thermometers used between 1994 and 1997 proved to be much less precise and reliable than mercury-in-glass thermometers used between 1965 and 1973. Although changes of absolute values of discharge at the site were insignificant, the decrease of the discharge in proportion to that of the Main Stream upstream of Plantation Junction (from Tables 1 and 2) was significant.

The decrease of total hardness at the Main Stream in Sewer Passage because of the switch of flow was not significant, the increase in total hardness downstream of the Junction (at Beehive Chamber) seen in Table 3 was significant (at the $p=5\%$ level).

Results presented in Table 3 show that in spite of the increased flow of water into the Main Stream Sink, the characteristics of the Old Route and New Route Streams showed no significant changes. This was true for most of the measured characteristics, to be published later. The same position was also true for the characteristics of the main inlets in Pulpit Passage, and the large majority of those of the inlets fed by the Maypole Sink. At many of these sites, the huge variability of discharge reduced the value of the statistical examination of these data.

EFFECTS OF DIVERTING THE STREAM FROM THE SOAKAWAY SINK

Results in Table 2 show that after 15.06.94, the proportion of the surface stream entering the New Route via the inlets in Pulpit Passage was greatly reduced as a result of the diversion of the water away from the Soakaway Sink, into the Culvert. This was to be expected, because the Soakaway Sink, which previously took the largest proportion of the surface stream, is known to feed the Pulpit Passage inlets and the Arête Chamber North-east Inlet (Stenner, 1968a,). The exact distribution between these inlets was subject to variation, most probably because of settlement of boulders in the ruckle between Arête Chamber/Pulpit Passage and the Soakaway Sink. The diversion at the surface had the direct result of channelling the large majority of the flow down the Entrance Pitch, through boulders of dubious stability above Arête Chamber, to the Old Route Stream. The size of the flow of water through these boulders had already increased, compared with pre-1985 values, and the rate of limestone solution here has consequently increased. With the example of boulder settlement as a consequence of limestone solution in the Soakaway boulder ruckle (where boulder movements will do no harm), and the lessons learned in Eastwater Cavern and Swildon's Hole (that streams running through boulder ruckles inevitably lead to instability), the wisdom of the stream diversion at the Entrance Culvert needs to be reconsidered.

WATER FLOWING AWAY FROM THE MAIN STREAM, AND THE LAKE

Results of water analyses suggested that the Lake contained a mixture of water from Main Stream (coming via Cerberus Hall) and water from Coral Series Stream (Stenner 1972b).

Water levels in the Lake suggest that water is discharged on infrequent irregular occasions, which may not be related to current rainfall.

The question as to whether water leaving the Main Stream close to the Dining Room re-enters the known cave has not yet been answered. The author's view is that this is unlikely, and there is the intriguing possibility that it crosses the Gour Hall/Lake fault into unknown cave. Earlier, it was suggested that it would be very difficult to answer this question (Stenner, 1968b, Irwin, 1991, p.66). In 1968, the stream temperature in the Main Stream between the Dining Room (mean 8.8°C, S.D. 0.45°C) was normally very close to that of the Lake (mean 8.7°C, S.D. 0.17°C). Also, chemical characteristics at the two sites were similar (Tables 2 and 3). Since the route of Plantation Stream changed, the characteristics of the Main Stream between the Dining Room and Plantation Junction have changed, and the question of the fate of water from the Lake is now capable of being answered. If the Lake is discharging when the temperature in the Main Stream is substantially different from that of the Lake, and if this water re-enters the known cave, it is certain that a sensitive thermometer would reveal the point where water from the Lake rejoins the Main Stream.

CONCLUSIONS

The number of the significant changes of stream distribution in St. Cuthbert's Swallet in a relatively short time span calls for comment. Examples of flow switching from one inlet to another are known elsewhere (for example the switch of Tyning's Swallet Stream between North-East Inlet and the Devil's Elbow route in G.B. Cave in 1968 [Stenner, 1973]), but the frequency of the changes in St. Cuthbert's Swallet is unusual. Collapses in the depression in 1921 and 1937 (Irwin, 1991) show that there are still more potential stream routes which have not yet been identified and that future changes should not be a surprise. Three factors are significant:

1. There is a very complicated network of passages which distribute the water between the active swallets and the cave. However, in Eastwater Cavern and Swildon's Hole the stream distribution is apparently straightforward, in spite of there being abandoned routes in these caves also. It may be that in these two examples, the distribution may have been more complicated at some time in the past.
2. Human interference has been important at St. Cuthbert's Swallet. Two streams were left in an unstable state, and interference has been directly instrumental in causing stream route changes. The streams have been considerably modified by mining activities in the Charterhouse/Velvet Bottom area and further work here may reveal similar consequences of mining activity.
3. There are relatively few examples of stream distribution studies. As more studies are carried out, it is quite possible that examples of changes of hydrology will turn out to be more common than expected.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the help given by J. Williams, Miss E. Sandford, R. King and the late R. Bennett for collecting samples and making measurements in the cave, D.J. Irwin for permission to use parts of the St. Cuthbert's survey, Dr. T. Atkinson for permission to quote some of his data and for advise in preparing this paper, A.V. Knights for assistance in analysing water samples, Dr. G. Nickless for advice and for making it possible for the author to use advanced analytical techniques where these were appropriate, for many years, and Mrs. F.L. Stenner for help in making the survey of the surface streams, and for helping to collect data and water samples from the surface streams.

REFERENCES

ATKINSON, T.C. 1971. *Hydrology and Erosion in a Limestone Terrain.* PhD Thesis, University of Bristol (unpub).

IRWIN, D.J. 1991. *St. Cuthbert's Swallet.* Bristol Exploration Club, 82pp.

STENNER, R.D. 1966. The variation of temperature and hardness in streams in St. Cuthbert's Swallet: a progress report. *Belfry Bulletin, The Journal of the Bristol Exploration Club.* **226**. p117-p122.

STENNER, R.D. 1967. The Maypole Sink. *Belfry Bulletin, The Journal of the Bristol Exploration Club.* **227**. p3-p4.

STENNER, R.D. 1968a. Water tracing in St. Cuthbert's Swallet, Priddy, Somerset. *Transactions of the Cave Research Group of Great Britain.* **10.** 2. p49-p60.

STENNER, R.D. 1968b. St. Cuthbert's Swallet. Lake Chamber. Problems solved and unsolved. *Belfry Bulletin, The Journal of the Bristol Exploration Club.* **242**. p72-p73.

STENNER, R.D. 1969a. The variability of limestone hydrology. *Belfry Bulletin, The Journal of the Bristol Exploration Club.* **252**. p30-p31.

STENNER, R.D. 1969b. The measurement of the aggressiveness of water towards calcium carbonate. *Transactions of the Cave Research Group of Great Britain..* **11.** 3. p175-p200.

STENNER, R.D. 1972a. Water tracing in St. Cuthbert's 1971. *Belfry Bulletin, The Journal of the Bristol Exploration Club.* **293**. p52-p55.

STENNER, R.D. 1972b. Water tracing in St. Cuthbert's. *Belfry Bulletin, The Journal of the Bristol Exploration Club.* **296**. p147-p148.

STENNER, R.D. 1973. A study of the hydrology of G.B. Cave, Charterhouse-on-Mendip. *Proceedings of the University of Bristol Spelæological Society* **13.** 2. p171-p226.

Roger Stenner
18, Stafford Place,
Weston super Mare,
North Somerset
BS23 2QZ

Figure 2: *Routes taken by water flowing from stream sinks to inlets in St. Cuthbert's Swallet and the flow of the streams through the cave to Gour Hall. The grid is part of ST5450.*
Outline plan of the major passages and chambers based on the cave survey by D.J. Irwin, with his permission