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Water-tracing of the Severn Tunnel Great Spring

By

D. P. Drew, B.A., Ph.D., M. D. Newson, B.Sc. and D. I. Smith, M.Sc.

Historical Introduction

The construction of the Severn Tunnel commenced in March, 1873 with the sinking of the Sudbrook (Welsh side) shaft; actual tunnelling began in 1874. The length of the tunnel is 4 miles, 628 yards (7.1 km.) and it remains the longest subaqueous main-line railway tunnel in the world.

From the start the builders were preoccupied with the danger of flooding from water leaking in from the channel of the River Severn above. Indeed a number of "springs" were encountered in the Pennant and New Red Sandstone series (Richardson 1888) but their salinity indicated, as expected, a Severn source. Though one of these is said to have knocked a ganger flat and spurted out several metres there was no serious interruption to the tunnel construction.

There is some disagreement on the date of interception of the Great Spring. It was in October, 1879, Richardson stating the date as 16th (Richardson 1888, p. 70), while Walker (1888) prefers the 18th. This probably results from the great consternation caused—the whole of the Welsh section of the tunnel became flooded to river tide level within twenty-four hours! Miraculously there was no loss of life.

The account of the catastrophe of 1879 is not accompanied by many geological or hydrological details but it seems that the Spring was associated with the top heading of the main tunnel at the junction of the lithological units marked as "coal shale" and "clay shale". This is somewhat over 6 m. above a stratum of "limestone boulders" and 12 m. above "Mountain Limestone". However, this does not preclude the Spring being part of a karst system since faulting in the area could guide water into neighbouring non-calcareous lithologies (Morgan, 1888, p. 93 remarks that any interpretation of geology in the section may be "at fault"!).

The headings and tunnel works had to be drained so that construction could recommence. New shafts were sunk at Sudbrook to allow increases in pumping capacity and an attempt was made to close the flood doors at the seaward section of the heading. Thanks to the courage of a diver named Lambert, who walked 400 m. under water in the dark with dubious equipment, the door was closed.

Working began again in late 1881 and by 1883 the tunnel was nearing completion except for a length of about 180 m. adjoining the section where the Spring had broken in. Various means of by-passing this section were tried and when driving a new bottom heading, on 10th October, 1883, the Spring broke in again "in doubled quantity, and in such force that the miners and their half-loaded trolley were all washed out into the shaft together" (Richardson 1888, p. 73). The discharge was estimated at twenty million gallons per day (860 l./sec.). Again the intrepid Lambert was called to close the flood doors.

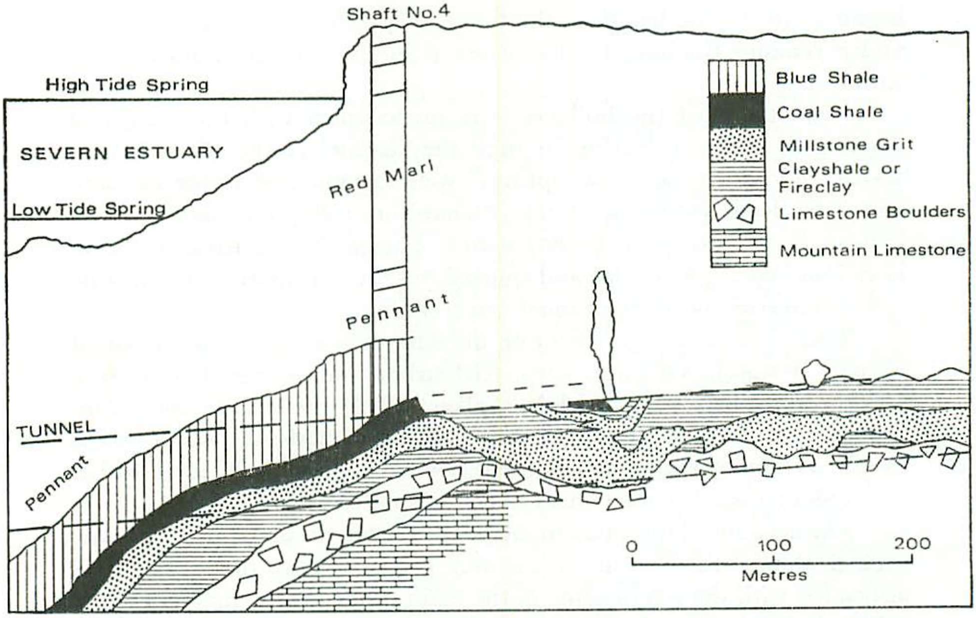

Fig. 34. Geological section of the Severn Tunnel in the area of the two major cavities —Welsh side, looking down stream. (After C. Lloyd Morgan, 1888).

It was decided to force a new heading to the north of the original line and on 19th. December, 1884 this new side heading reached a large open joint which had formed the channel for the water (Walker, 1888). The following extract from Walker leaves little doubt that the form was one of a completely flooded cave passage, . . . "the fissure through which the Great Spring had passed was found to follow a most erratic course. In one place it passed directly across the tunnel from side to side . . . at another place it passed from side to side in an oblique direction . . . at another point the water boiled up from a hole 18 feet (6 m.) in depth . . . with such force that stones the size of a man's fist, dropped into the water would descend about 10 feet (3 m.) and then begin to flutter like a leaf in the wind, and then be thrown out again by the water".

The points of overflow of the water were capped with large diameter pipes mounted in concrete. Pumping has gone on since 1886 with no major repair problems save for the replacement of the impressive steam-driven beam engines by electrically-operated pumps. The fresh water of high quality is used by a steel-works, a paper-mill and a research establishment. Formerly it was emptied into the Severn or, for a while, piped to houses near Sudbrook whose wells had dried up with the pumping of the Spring.

Water Tracing—Background

It is perhaps surprising to note that despite all the difficulties caused by the flooding from the Great Spring there is very little discussion in the literature as to the source of the water involved. Walker appears to favour the Nedern Brook (486888) as the source and parts of its bed were concreted in 1884. Previously the Nedern had become dry for a distance of more than 8 km. from the Tunnel. Springs and wells in the area were also reported to dry up. Carpmael (1932, p. 278) considers that though the Nedern may be a source it is not a direct one—citing the clarity of the Spring water as an indicator that no open connection with a surface stream is possible.

Karst Hydrology Studies in the Area

Work carried out in the supposed catchment for the Great Spring involved the mapping of the stream sinks and resurgences (see Standing and Standing, 1967), measurements of their discharges and chemical characteristics; the tracing of sinking streams both locally and to the Severn Tunnel, analysis of Spring water and the study of precipitation and discharge records for the previous six-year period.

A major difficulty in water tracing is that while a very good section was made of the Great Spring (*Fig.* 34) there are no detailed plans available and no exploration can be made to determine its directional trend.

The area most likely to comprise the catchment for the Spring lies between the River Usk in the west and the Wye in the east; between them stretches an arcuate outcrop of Carboniferous Limestone, dipping southerly and draining streams from the topographically higher Old Red Sandstone. The realistic area can be restricted on topographic and geological grounds to that between Whitebrook (A) in the west and St. Arvans (G) in the east. (Fig. 35).

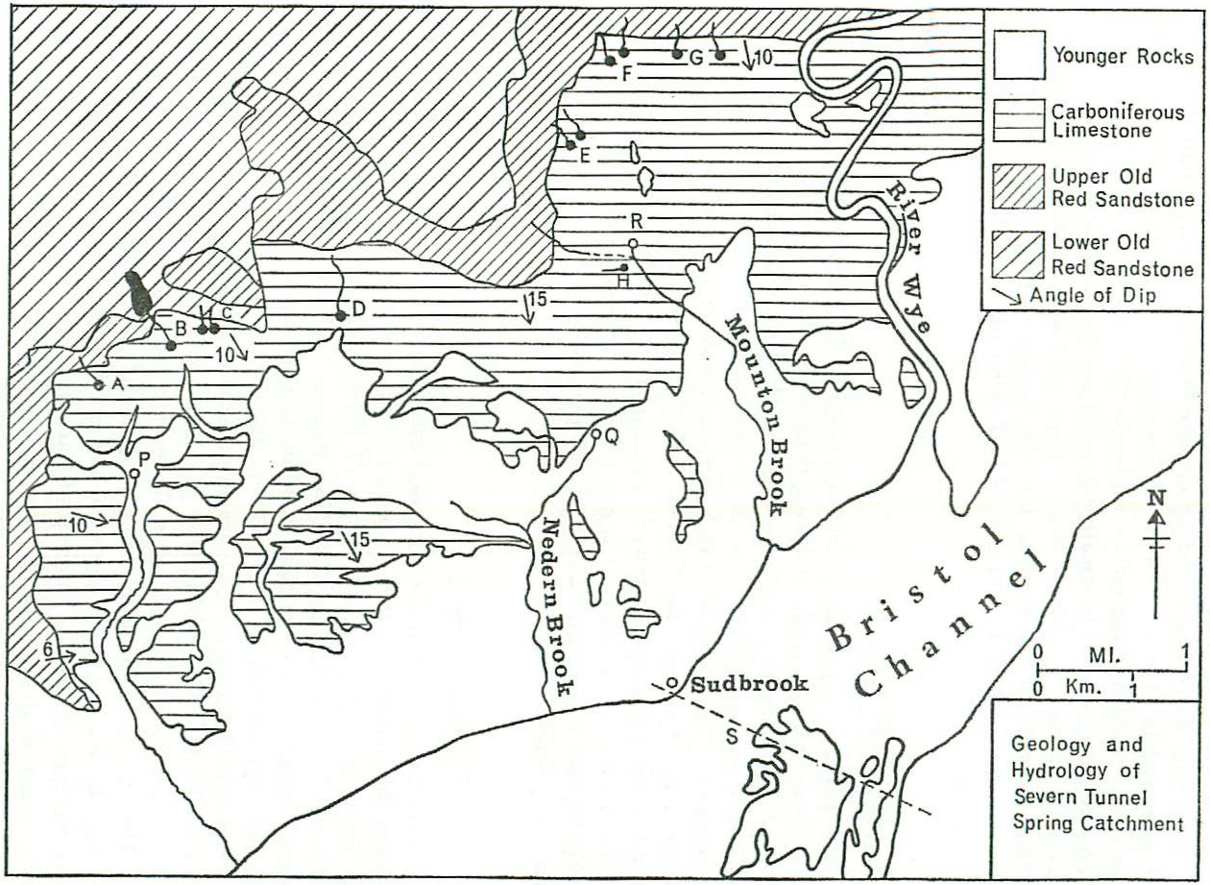

Fig. 35. Sinks: A. Whitebrook (1 and 2), B. Wentwood Reservoir, C. Llanvair Discoed, D. Cas Troggy, E. Itton, F. Llanguillan, G. St. Arvans, H. Grondra. Springs: P. Penhow, Q. Crick, R. Mounton Brook Tributary, S. Severn Tunnel Great Spring.

Stream Sinks

A series of small streams sink underground on reaching the limestone from the sandstone. They are:

A(1). Whitebrook Sink (419924)—the stream sinks in the floor of a deep valley, the dry valley below the sink being only 1 m. higher than the stream level, indicating recent development. Discharge was gauged at 50 l./sec.

A(2). Whitebrook II—a much smaller stream nearby. Discharge—1.5 l./sec.

B. Wentwood Reservoir Sink (434925)—the overflow from Wentwood Reservoir sinks at several sites in its bed and finally disappears some 250 m. below the reservoir outfall. Discharge—32.8 l./sec.

C. Llanvair Discoed—two trickles disappearing near to the road (440925–443925).

D. The Cas Troggy (459928)—the largest stream in the area (56.6 l./sec.) which normally sinks at a point where it debouches from a narrow valley ("The Cwm"), although in wet weather it may flow further towards the Nedern Brook.

E. Itton (491958)—two small streams sink a few metres apart at the head of an impressively wide dry valley.

F. Llanguilan. Two extremely small sinks (494963), (495965).

G. St. Arvans (515968). A stream (11.5 l./sec.) sinks in a well-developed blind valley at the foot of a cliff. There are further small sinks at Rogerstone Grange (506966).

H. Grondra (490935)—a small stream sinks in a narrow valley (4.8 l./sec.).

Springs

During the period in which field work was carried out (March–August, 1968), many of the springs marked on maps were dry and appeared to issue water only under extreme wet conditions. However, all the sinks were active. The springs were:

P. Penhow Spring (419910). This emerges lower down the valley from Whitebrook sink, with which there is no proved connection. Discharge 4.2 l./sec.

Q. Crick Stream (491906). This seeps out among water-cress beds at Broadwell Farm, to enter the Nedern Brook. Discharge—7.0 l./sec.

R. Mounton Brook Tributary (300 l./sec.) (501941). A large spring issues from the north bank of the Mounton Brook valley, shortly downstream of the main sink. It has no proved connection with any other swallets and, on the basis of a salt solution trace, most if not all the water appears to be of Mounton Brook origin—especially since the volumes are not very different and the surface valley would allow underground water to cut off a significant dog-leg bend. This section appears to have responded to changes which affected the Wye—it is deeply incised. Cave remnants are rare and digging the modern sink has had little result (Bristol Exploration Club).

Thus the total input of swallets in the area (162.2 l./sec. at the time of gauging) is far greater than outflow at springs within the area. Therefore some 90% of the water does not reappear.

Precipitation and Discharge Records

Weekly discharge figures for the Great Spring were compared with weekly rainfall figures for the Pumping Station (courtesy of British Rail) and for Llanvaches and Nantypridd in the upper catchment area (Meteorological Office). Graphical analysis was chosen (*Fig.* 36) because of the unsuitability of the data for more rigorous mathematical techniques.

The results of analysis may be divided into those limbs of the graphs showing positive visual correlation and those in which the spring's response to rainfall is limited or lacking.

Experience at the pumping station has shown that pumping must be stepped up roughly three weeks after heavy rainfall in the local area. This figure is the same as the modal response delay derived from the graphs, both rises and falls in discharge occurring three weeks after storms or droughts on the surface.

There are distinct periods in which rainfall over the catchment produces little or no response at the Spring. The typical situation is in summer and early autumn—in mid 1964 there was a 30 week period of falling discharge which remained unaffected by 11 separate weekly totals of over 12.5 mm. This is probably the combined effect of low soil moisture conditions and evapotranspiration. It is worthy of further investigation.

One further point to emerge from the analysis is an apparent steady increase in rainfall over the period studied (*Fig.* 36).

Water Tracing

Two sets of experiments were carried out—one to see if the sinks of the area resurged at any of the local springs, and the second to test one such stream to the Severn Tunnel Great Spring.

The local tracings were carried out using the fluorescent dye Pyranine Conc. The sinks tested were Whitebrook (A) (100 g. Pyranine), Itton

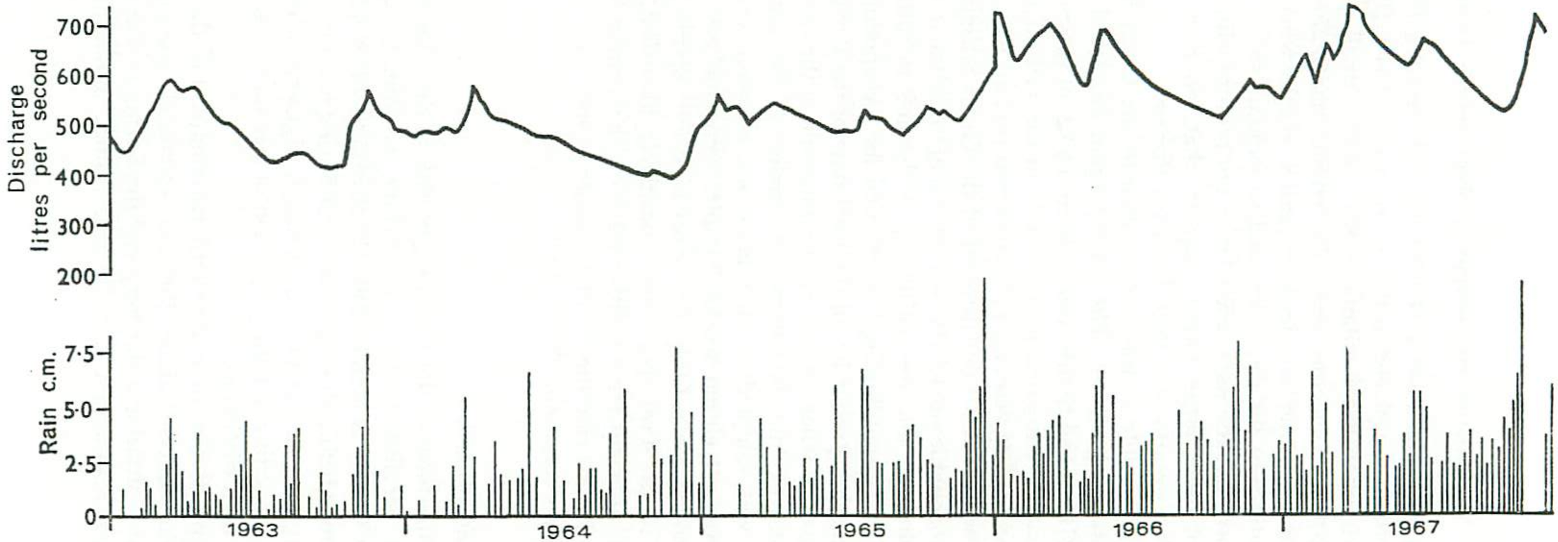

Fig. 36. Graph of Discharge of the Severn Tunnel Great Spring in relation to the rainfall at Sudbrook.

Lower (E) (75 g.), Itton Higher (E) (25 g.) and Grondra (H) 100 g.). Charcoal detectors were placed in the resurgences at Crick (P), Penhow (Q), and the Mounton Brook tributary (R), and at a small spring in the Itton valley (487947). Detectors were collected one month after insertion, (the month was wet), and all yielded negative results when analysed. Sufficient quantities of the dye were used to validate these results and it is thus assumed that the water traced does not resurge within the area. The absence of other large springs suggests that, on negative results alone, the swallet streams may feed the Great Spring.

It was only possible to trace one stream to the Great Spring, the Cas Troggy (D) being chosen. The tracing agent employed was Lycopodium spore (Drew and Smith, 1969). Some 15 kg. of spores dyed with Malachite Green were inserted into the sink on the 11th of June, 1968. Two 50 cm. diameter, 150 cm. long plankton nets (nylon) were positioned in the conduit some 100 m. downstream of the Great Spring. This was the closest approachable site for the nets. It was not possible to cap a large proportion of the flow and the positioning of the nets to catch only the upper parts of the water flowing was unusual for Lycopodium tracing. Nor is it known what proportion of the total flow of the Great Spring is led to the pumps and what proportion continues along the natural route. These factors may explain the low rate of recovery of the spores.

Each net was sampled on ten occasions between 14/6/68 and 28/8/68—a period of eleven weeks. Samples were analysed for spores and other suspended solids. Only on one occasion were spores detected—ten days after input. Two spores were positively identified. Normally this would be insufficient for a positive trace on the grounds of possible contamination. In this case the definite absence of spores during the first nine days disproves contamination.

Chemical and Sediment Analysis

The total hardness of the Cas Troggy sink during the tracing was 100 milligrams per litre (mg./l.), comprising 68 mg./l. $CaCO_3$ and 32 mg./l. $MgCO_3$—this is high because the stream flows several hundred metres on limestone before sinking. The Great Spring has a total hardness of 290 mg./l. (195 mg./l. $CaCO_3$ and 95 mg./l. $MgCO_3$), which appears to be constant, suggesting a high proportion of percolation water which is undiluted at high discharge.

The high proportion of magnesium carbonate, together with increased chloride concentrations (Stenner—personal communication) suggest that some estuarine water may feed the Spring or mix within the conduit. Neither magnesium nor chloride values make the authors believe that such water is any but a very small contribution to the flow of the Spring.

The solid load of the Great Spring consists of relatively fresh organic matter—suggesting a local swallet origin for some of the water—and fine calcite grains, many of which are rhombic in shape. These are possibly the result of solutional action rather than abrasion.

CONCLUSIONS

As has been discussed above the geological structure of the area, the close relationship of discharge to rainfall and the quality of water all tend to suggest a local origin for the Great Spring water. The water tracing, on both scales, confirms this view.

It seems that 75% or more of the Spring's water is of percolation origin and this explains the three week delay in response to rainfall, while spores introduced at the swallet took only 10 days to reach the tunnel.

It is possible that there are other sources. Since the Nedern Brook was not monitored for spores it is not known whether Cas Troggy water resurges there in any volume before reaching the Spring. From observation of the Nedern bed and banks this appears unlikely. The small contamination by estuarine water could be from the lower Wye, which flows between limestone cliffs near Chepstow and could follow the regional strike to the Spring. However, on the basis of discharge/catchment area relationships established on Eastern Mendip (Drew, 1967) it seems that 25.2 l./sec. per km^2. of catchment is not unreasonable for these climatic and geological conditions. Thus 20 sq. km. on the Welsh side of the Severn (probably the whole of the limestone outcrop west of the Mounton Brook) could be the catchment for the Great Spring. (It is possible that not all the water issuing from the Great Spring is pumped.)

There is evidence of a Severn-orientated karst system for fresh water emerges from the floor of the Severn Estuary around the islands of Steepholm and Flatholm. It is not however suggested that this is connected to the Great Spring. Water samples taken from a dredger in that area show decreasing hardness figures and salt content towards the bed. However even at the bed the contamination by estuarine water is great enough to mask the quality of possibly fresh water.

Commercially exploited sand and gravel from this area has been naturally winnowed of most sand and silt and is said to require no treatment to remove excess of natural salt. These qualities may result from an upwelling of fresh water at the site of the extraction. Such submarine springs are common in the karst areas of Yugoslavia and Greece (Mistardis, 1968). Research in the Severn Estuary planned by

Bristol University may examine the effects of tidal currents and upwellings in this area, under the programme of the *Sabrina Project.*

Evidence in the field and local opinion suggests that the area of land around Sudbrook has only recently "dried up". 16th Century maps in Cardiff Museum show the Cas Troggy as a strongly-flowing stream reaching the estuary. It may be that the karst system in the area was developed when the sea level in the Severn Estuary was lower than today (there is a buried channel, probably dating from the last glaciation—Wills, 1938). The water from the limestone may have resurged near the then coast and these outlets were blocked and silted when sea level rose to its present position. Thus a surface regime was resumed, only to be reversed again by the building of the Tunnel.

No further conclusions can be made until further water tracing is done, accurate water budget studies are made, and investigation of the Severn Estuary springs is pursued.

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The historical section mentioned above has been very much shortened and the authors would like to point out that a fuller version is available for consultation in the Geography Department of the University of Bristol, or in the book by Walker (1888).

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