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THE HYDROGEOLOGY OF THE SCHWYLL SPRING CATCHMENT AREA, SOUTH WALES

by

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ABSTRACT

Schwyll Spring, located in an outcrop of Carboniferous Limestone in the Vale of Glamorgan, South Wales, has a catchment area estimated to be some 23 km^2 based on water balance calculations. Water tracing indicates a component of the spring discharge is comprised of leakage from rivers which flow across the limestone outcrop. The actual volume of leakage could not be determined due to limited river discharge data, however, spring water chemistry suggest that influent river water does not comprise the major proportion of discharge from Schwyll. Geological information, combined with water tracing results and the water balance has been used to estimate a conjectural groundwater catchment for Schwyll Spring. Based on this area sources of pollution to the spring are assessed, which include those from dispersed recharge, sinking streams and influent rivers.

INTRODUCTION — SITE LOCATION

Schwyll Spring is located in the Vale of Glamorgan, South Wales on the bank of the River Ewenny some 3 km south west of Bridgend at SS 8880 7706 (Figure 1). It originally consisted of some 13 springs (Knox, 1933), whose discharge used to flow into the River Ewenny until 1872 when water was first used to supply the town of Bridgend (Jones 1985). Early in the twentieth century a shaft was sunk to the south east of the springs, above the high water level of the River Ewenny, to limit the influx of river water to the spring abstraction point. Below the 3.6 m deep man made shaft a natural chamber was encountered (Knox, 1933) where the depth of water is generally of the order of 2-3 m. The spring chamber has been dived but cannot be penetrated for any great distance (Morris and Adams, 1985). Water not abstracted from the shaft continues to flow underground before emerging on the northern side of the B4524 from a series of solutionally widened fissures. It then flows to the River Ewenny. A number of much smaller springs also flow to the River Ewenny in the vicinity of the main spring.

The spring provides a cheap source of potable water for Bridgend and parts of the Vale of Glamorgan. It is generally of good quality, except following some rainfall events when it runs turbid and is taken out of supply. When river levels are high the pumps are switched off in order to prevent poor quality river water from entering the spring chamber. During these periods water from on site storage reservoirs is used for supply. The importance of the spring to the region has led to a number of studies being undertaken in order to try to determine its catchment area and therefore potential sources of pollution. It is not within the scope of this paper to review these studies, however, they are listed in the Bibliography and information from them has been used in an attempt to define the Schwyll Spring catchment area.

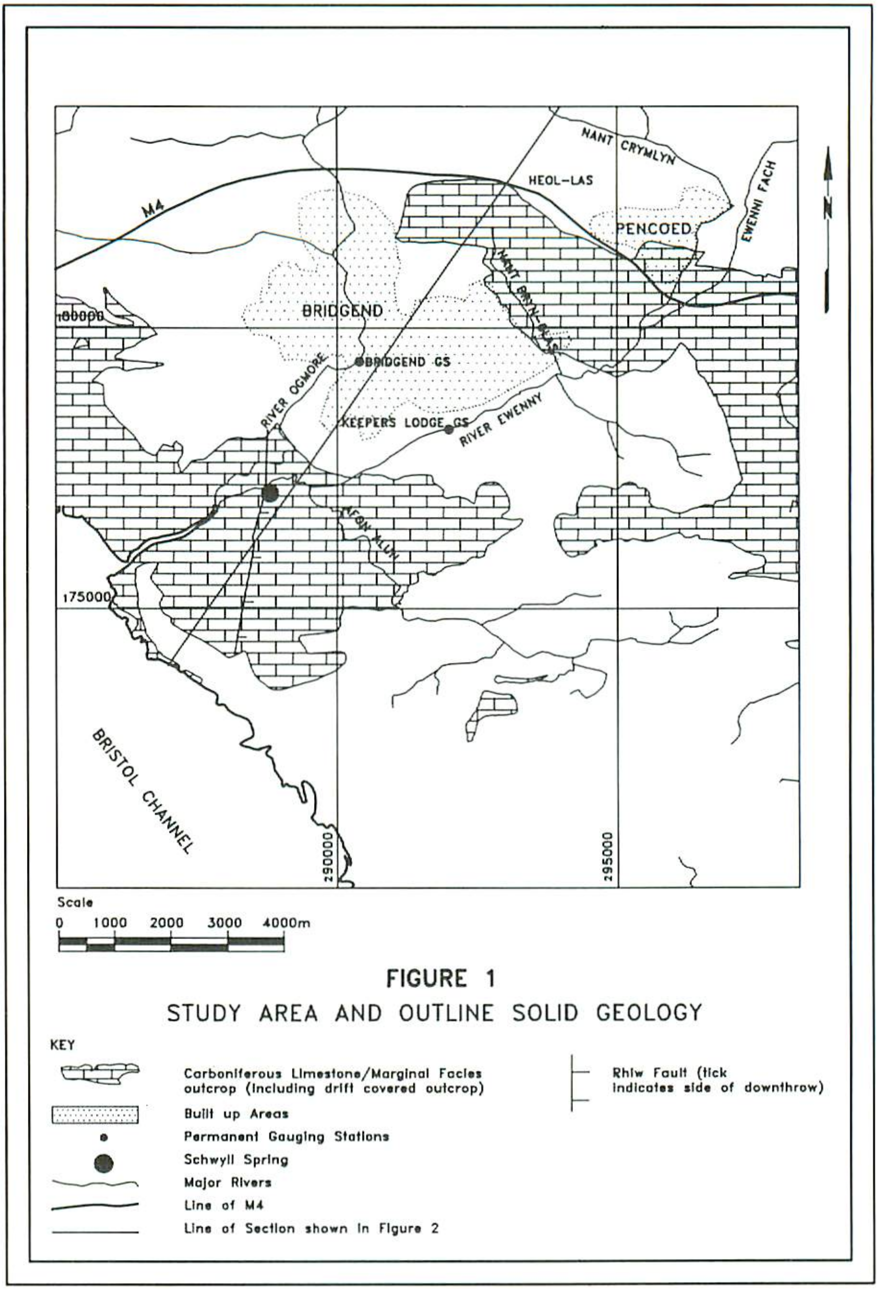
NANT CRYMLYN
HEOL-LAS
M4
EWENNI FACH
PENCOED
N
NANT BRYN-GLAS
BRIDGEND
180000
BRIDGEND GS
RIVER OGMORE
KEEPERS LODGE GS
RIVER EWENNY
AFON ALUN
175000
BRISTOL CHANNEL
290000
295000
Scale
0 1000 2000 3000 4000m
FIGURE 1
STUDY AREA AND OUTLINE SOLID GEOLOGY
KEY
Carboniferous Limestone/Marginal Facies outcrop (including drift covered outcrop)
Built up Areas
Permanent Gauging Stations
Schwyll Spring
Major Rivers
Line of M4
Line of Section shown in Figure 2
Rhiw Fault (tick indicates side of downthrow)

Figure 1.

Physical Setting

Although in the Vale of Glamorgan the Carboniferous Limestone outcrop is generally devoid of surface drainage it is crossed by the River Ogmore and its tributaries, the Afon Alun and the River Ewenny (Figure 1). It is on the eastern bank of the latter that Schwyll Spring emerges at between 5 and 10 m AOD. To the south of the spring the land rises steeply to Ogmore Down which has a plateau surface at about 80 m AOD, dissected by several dry valleys on its north west and north east sides. The plateau continues further to the north east, but is cut by the Afon Alun which flows through a steep sided valley. To the north of Schwyll Spring lies the River Ogmore and to the west the sand dune system of Merthyr-mawr Warren. To the north east along the line of the River Ewenny the land rises gently towards Bridgend and the M4 (Figure 1). Few caves are known in the area, the exceptions being those at Merthyr Mawr and Coed-y-Mwstwr (Jones, 1984, 1988, Oldham, 1986, Stratford, 1986). A small number of disused mines are also present in the area (Foster-Smith, 1981).

The geological succession for the country around Bridgend is shown in Table 1, along with a general lithological description of the relevant rock units (after Wilson *et al.*, 1990). Carboniferous Limestone (of Dinantian age) outcrops in two main blocks in the study area, one to the south of Bridgend (in which Schwyll is located), the second to the north and east of Bridgend. The two outcrops are the north and south limbs of a syncline the axis of which is buried by Jurassic and Triassic rocks as shown schematically in Figure 2. In places the Carboniferous Limestone is also overlain by wind blown sand, alluvium and head deposits. The units of limestone represented in the area include the Friars Point Limestone, Gully Oolite, High Tor Limestone and the Cornelly Oolite (Table 1), the Caswell Bay Mudstone being absent from this area (Wilson *et al.*, 1990). The Jurassic rocks which outcrop in the Bridgend area include the Porthkerry Formation, the Lavernock Shales and the St Mary's Well Bay Formation, all of the Lower Lias. These overlie Triassic rocks including the Penarth Group and the Mercia Mudstone Group (Table 1). The latter includes the marginal facies of the Mercia Mudstone Group which consist of ''breccias and conglomerates with clasts dominantly of Dinantian limestone in a reddened matrix of limestone fragments'' (Wilson *et al.*, 1990). These are in hydraulic continuity with the Carboniferous Limestone Series and both are treated as a single unit here. They are discussed in detail by Tucker (1977).

The South Wales area has been subject to a number of tectonic events since the Lower Devonian which have resulted in a series of folds and faulted blocks. The study area is on the southern side of a regional syncline, the core of which is largely comprised of Upper Carboniferous (Silesian) rocks which form the South Wales coalfield. Associated with this are a number of smaller folds, including that discussed above, and the Cardiff-Cowbridge anticline. The latter is a major east-west fold, the axis of which runs from Porthcawl in the west to Cardiff in the east, and has a westerly plunge. The fold results in concealment of the limestone by Jurassic and Triassic rocks beneath Bridgend, before outcroping once more to the south of Heol-las and Pencoed (Figures 1 and 2). Associated with the

Table 1 *Geological Succession in the Bridgend District (after Wilson* et al., *1990)*

Period	Series/Group		Formation	Lithology	
QUATERNARY				Glacial silts and clays, peat, alluvium, sand and gravel till (boulder clay)	Thickness in metres
			UNCONFORMITY		
JURASSIC	Lower Lias		Marginal Facies	Conglomerates, calcarenites, oolitic, peloidal and bioclastic limestones	up to 90
			Porthkerry Formation	Thinly interbedded grey limestones and calcareous mudstones	120 +
			Lavernock Shales	Dark grey mudstones with subordinate limestones	10-12
			St Mary's Well Bay Formation	Thinly interbedded grey limestones and mudstones	16-20
TRIASSIC	Penarth Group		Undivided	Grey-green calcareous mudstones overlying dark grey mudstones; thin sandstones, limestones and oolites	8
			Marginal Facies	Red, purple and green mudstones with calcretes, overlying sandstones and sandy limestones	up to 20
	Mercia Mudstone Group		Blue Anchor Formation	Grey-green mudstones with subordinate dolomites, limestones and evaporites	14
			Undivided	Red-brown mudstones with some siltstones and evaporites	up to 70
			Marginal Facies	Red and grey breccias, conglomerates, calcarenites and siltstones	up to 25
			UNCOMFORMITY		
CARBON-IFFEROUS	Upper Coal Measures (Pennant Measures)		Llynfi Beds	Cycles of grey mudstone and siltstone; sandstones common in lower part and towards top (Llynfi Beds). Many workable coals; marine bands	100 +
	Middle Coal Measures				190-230
	Lower Coal Measures				125-360
	Millstone Grit			Grey mudstones, coarse pebbly sandstones and cherts	50-335
	Carboniferous Limestone Series		Oystermouth Beds	Thinly interbedded limestones, mudstones and cherts	up to 55
			Oxwich Head Limestone	Thick-bedded limestones, pseudobrecciation and numerous palaeokarsts. Sandstone at base (Pant Mawr Sandstone)	up to 130
		Hunts Bay Oolite Group	Stormy Limestone Formation	Calcite mudstones, bioclastic, oolitic, stromatolitic and oncolitic limestones, algal bioherms	55-65
			Cornelly Oolite Formation	Oolitic, bioclastic, peloidal and intraclast limestones	130-180
			HighTor Limestone	Bioclastic and peloidal limestones	55-115
			Caswell Bay Mudstone	Calcite mudstones and argillaceous limestones; cryptalgal lamination and desiccation structures	0-15
			Gully Oolite	Thick bedded oolitic, bioclastic and peloidal limestones, rhizoliths at top	30-70
		Black Rock Limestone Group	Friars Point Limestone	Dark grey, foetid bioclastic limestones with shale partings; extensive dolomitisation in upper part	85-260
			Brofiscin Oolite	Pale grey, oolitic limestones	8-20
			Barry Harbour Limestone	Thinly bedded bioclastic limestones and mudstones; widespread silicifcation, chert modules, cross-stratification	35-80
		Lower Limestone Shale Group	Cwmyniscoy Mudstone	Grey silty mudstones with thin argillaceous bioclastic limestones	45-50
			Castell Coch Limestone	Coarse bioclastic limestones; cross-stratification	15-25
			Tongwynlais Formation	Mudstones and bioclastic limestones, subordinate sandstones, oolitic and hematitic limestones	35-45
DEVONIAN	Upper Old Red Sandstone		Quartz Conglomerate Group	Pebbly micaceous sandstones, thin conglomerates, red-brown silstones and mudstones	40-50
			Cwrt-yr-ala Formation	Red-brown sandstones, siltstones and mudstones; calcretes	25-70
			UNCONFORMITY		
	Lower Old Red Sandstone		Brownstones	Red-brown micaceous sandstones, siltstones and mudstones	50-55
			Llanishen Conglomerate	Red-brown mudstones with sandstones and conglomerates; calcretes	100 +

anticline are a series of lesser faults and folds. The juncture of the Rhiw fault and Cardiff-Cowbridge anticline (Figure 3), is suggested by Aldous (June, 1988) as being a determining factor in the location of Schwyll Spring.

Little site specific information is available concerning the aquifer characteristics in the area. Limited pumping details obtained by the Institute of Hydrology for three boreholes on the Bridgend Industrial Estate suggests an average hydraulic conductivity over the screened section of the borehole of the order of 0.6-0.7 m/d. However, permeabilities are likely to range by four to eight orders of magnitude around this depending upon the number of solutionally enlarged voids that are encountered. Work by Young and Connor (1978) at Tythegston landfill some 3 km north west of Schwyll suggests that the effective porosity of the Carboniferous Limestone ranges between 6 and 8% in the upper 8 to 10 m of the aquifer with values between 0.5 and 2% below this. The aquifer is unconfined in the vicinity of Schwyll, but becomes confined where overlain by the Lower Lias and Penarth Group.

Recharge to the aquifer is dominantly dispersed from rainfall, however, concentrated inputs from stream sinks do occur in the Heol-las area adjacent to the M4 to the north east of Bridgend (Figure 3). Further recharge is derived from rivers which lose water to the limestone where they cross the outcrop. Some leakage from the Lower Lias and Penarth Group may also recharge the Carboniferous Limestone. The presence of a spring the size of Schwyll indicates a dominantly conduit flow system. The Carboniferous Limestone is hundreds of metres thick in this area which represents a potentially very large volume, however, due to the closing of voids with depth, storage may effectively be limited to the upper 100 m of saturated thickness.

As well as Schwyll Spring there are a number of other hydrogeological features in the area including minor springs, sinks and wells, many of which were monitored during water tracing (discussed below). These will be detailed here as they provide further background hydrogeological information. They are also shown on Figure 3.

(i) Merthyr Mawr sinks — these are located on the western bank of the River Ogmore at NGR SS 8901 7807. The water from these flows through a series of cave passages, intersected in places by pot holes, to rise at two springs which flow into the River Ogmore via the Merthyr Mawr Mill Leat at NGR SS 8865 7763.

(ii) Adams Well — this is located at NGR SS 8795 7682 on the River Ewenny.

(iii) Pitcot Pool — also known as Pwll y Mêr, this pond, which lies to the south east of St Brides Major at NGR 8955 7443, is fed by small springs which are thought to drain from the Carboniferous Limestone (Aldous, 1988).

(iv) Jacobs Well — a series of springs which rise alongside the Afon Alun at NGR 9121 7480. These are to the south of the limestone outcrop, but are thought to be limestone fed (Aldous, 1988).

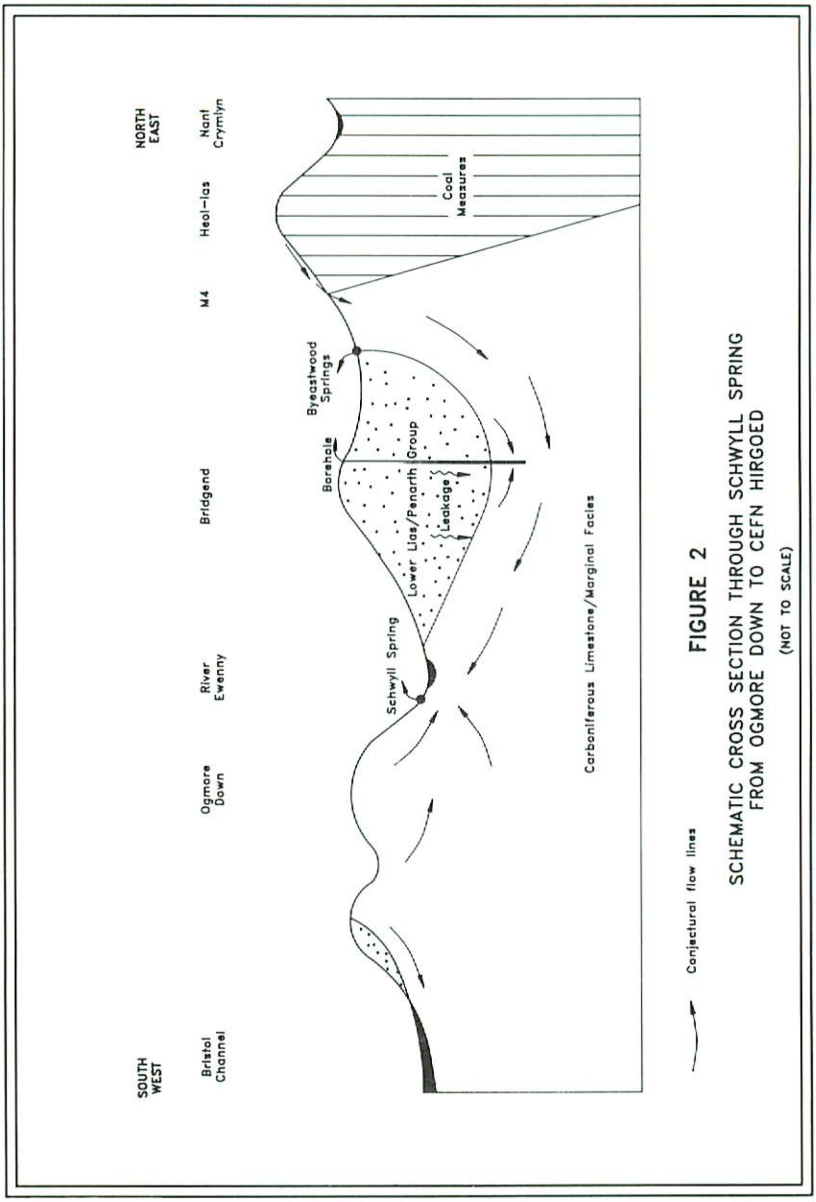

FIGURE 2

SCHEMATIC CROSS SECTION THROUGH SCHWYLL SPRING FROM OGMORE DOWN TO CEFN HIRGOED

(NOT TO SCALE)

Figure 2.

(v) Byeastwood Springs — these are located at NGR SS 9298 8099 and SS 9258 8060 and flow into the Nant Bryn-glas and thence to the River Ewenny. They are thought to be overflow springs for the limestone block to the north east of Bridgend.

(vi) Pwllwy Borehole and Springs — the borehole at NGR SS 9917 7761 is a public water supply which derives water from both overlying river gravels and Carboniferous Limestone. The borehole is thought to be located at the site of the original springs, whose discharge are now much reduced.

(vii) Heol-las stream sink — located under the M4 at NGR SS 9288 8267 this takes a small stream which flows off the Coal Measures to the north. To the east of this, between NGR SS 9320 8242 and NGR SS 9278 8213 in the vicinity of Giblet Farm, are a series of other small sinks which also drain from the north.

(viii) Tymaen Sink — takes a small stream at NGR SS 8943 7705.

(ix) Ewenny Fach Sink — a sink in the bed of the River Ewenny at NGR SS 9542 7990 which only becomes exposed at low flow.

(x) Bridgend Industrial Estate boreholes (WDA boreholes) — these are located at NGR SS 9336 7951 and NGR SS 9352 7937 and are public supply boreholes which pass through Jurassic and Triassic material to abstract water from the Carboniferous Limestone.

Water Balance

If a water balance can be calculated for Schwyll Spring then a first estimate of the catchment area can be made. Assuming that storage in the aquifer remains constant over a year then inflows to the aquifer should balance abstractions plus outflow from Schwyll. Inflows identified are as follows:

(i) effective rainfall — direct to the limestone outcrop (less runoff and evapotranspiration);
(ii) leakage — from rock formations overlying to the Carboniferous Limestone in the Bridgend area, and from water mains;
(iii) river recharge — from rivers influent to the Carboniferous Limestone;
(iv) sinking streams — concentrated surface inputs from streams draining areas away from the limestone outcrop.

Effective Rainfall

Data from the Schwyll Spring raingauge (supplied by the National Rivers Authority (NRA), Welsh Region) has been combined with potential evapotranspiration (PE) data for Rhoose airport (adjusted using a weighting factor for the site as determined by the Meteorological Office) in order to determine the effective rainfall for the area. It has been assumed that all effective rainfall over the Carboniferous Limestone outcrop enters the ground with no surface runoff. Calculations have been made using daily rainfall and daily PE (calculated from monthly PE using the method of Penman, 1948) for the period 1980 to 1991, and using a root constant for grass (which is dominant in the catchment). A mean annual effective rainfall of 538 mm is indicated.

Leakage

In the Bridgend area the Carboniferous Limestone underlies the Lower Lias, the Penarth Group and the Mercia Mudstone Group. The Porthkerry Formation consists of wackestones and calcareous shaley mudstones underlain by the Lavernock Shales. No information has been obtained concerning the vertical permeability of these units, however, given their nature they are likely to be aquicludes. Some leakage through them is possible, but in percentage terms their contribution to Schwyll Spring is likely to be small and so will not be taken into account here.

Leakage from water mains to groundwater has been assessed for the study area using information supplied by Dwr Cymru (Welsh Water). An order of magnitude estimation suggests that the recharge component from leakage is of the order of 0.4% of the annual effective rainfall in the Schwyll area. As such it is insignificant, even if the estimation is grossly in error.

River Recharge

Within the Ogmore Catchment the rivers Ogmore, Ewenny and Alun all flow across the limestone outcrop along part of their length (Figure 1). In such areas loss of river water to groundwater takes place, perhaps the most striking example of which is via sinkholes on the banks of the River Ogmore at Merthyr Mawr. At other locations, such as in Bridgend, loss of river water by diffuse bed seepage is more common (Welsh Water Authority, undated). In order to try to assess the amount of surface water influent to the Carboniferous Limestone, long term river gauging data and spot gaugings have been assessed. There are four permanent gauging stations in the River Ogmore catchment, but only two of these are within the area of interest (Figure 1), and neither of these are suitably located to determine losses to the aquifer. However, it has been reported (Welsh Water Authority, undated) that water is lost to the ground from the River Ewenny at the confluence of the Ewenny and Ewenni Fach (Figure 1). It is also reported that the lost flow is regained before the Ewenny gauging station is reached. In dry weather sections of the Afon Alun are completely lost to groundwater.

Data obtained from spot gaugings along the length of the River Ogmore system have also been examined but are limited as they are largely random and discontinuous in nature. Fifteen sites have been monitored intermittently since 1965 but only on one occasion is the data suitable for examining river losses to the aquifer. A survey of 5 points on the River Ogmore carried out on 11 August 1986 indicates that 20% of the flow in the river (some 135 Ml/d) entered the ground between the Pen y Cae Bridge over the M4 and the Swing Bridge in Bridgend. If this is all lost to the aquifer it represents six times the licensed abstraction volume at Schwyll (and four times the estimated discharge — see below). Glamorgan River Authority (1971) reported a 4 Ml/d loss from the River Ogmore in the Bridgend area, less than one fifth of the licensed abstraction at Schwyll. There are a number of explanations for the very large total river loss

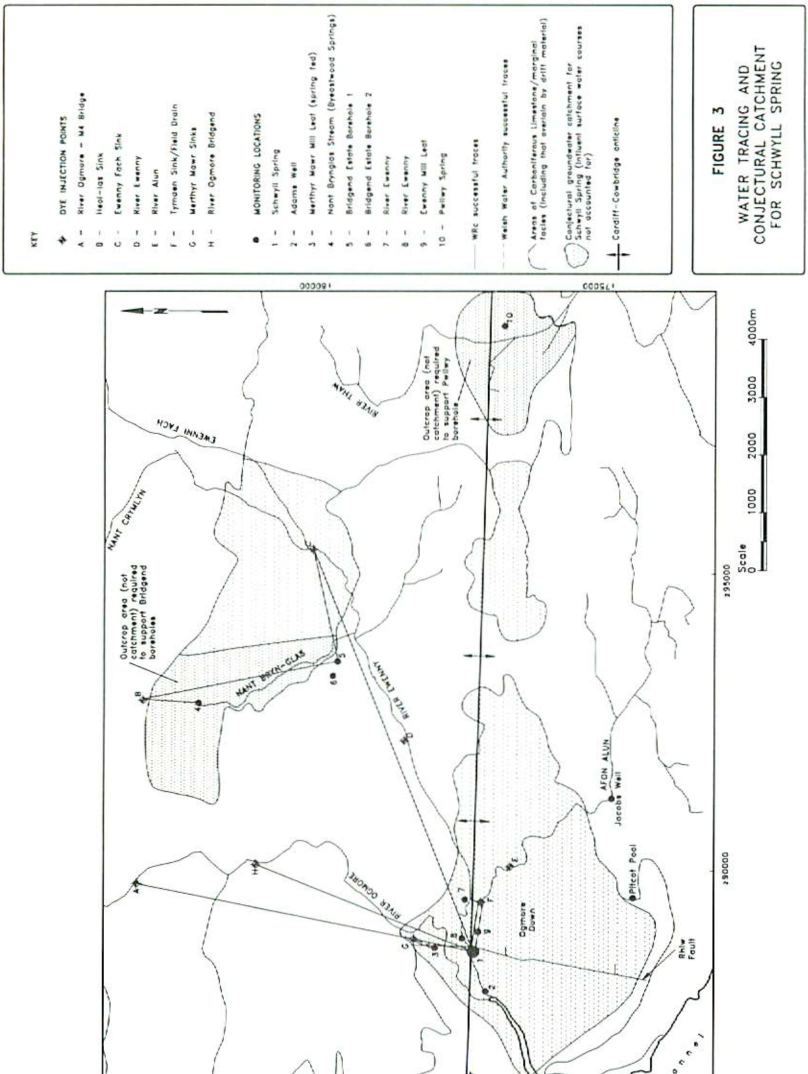
KEY
DYE INJECTION POINTS
A – River Ogmore – M4 Bridge
B – Heol-las Sink
C – Ewenny Fach Sink
D – River Ewenny
E – River Alun
F – Tyrmaen Sink/Field Drain
G – Merthyr Mawr Sinks
H – River Ogmore Bridgend
MONITORING LOCATIONS
1 – Schwyll Spring
2 – Adams Well
3 – Merthyr Mawr Mill Leat (spring fed)
4 – Nant Bryngias Stream (Byeastwood Springs)
5 – Bridgend Estate Borehole 1
6 – Bridgend Estate Borehole 2
7 – River Ewenny
8 – River Ewenny
9 – Ewenny Mill Leat
10 – Pwllwy Spring
WRc successful traces
Welsh Water Authority successful traces
Areas of Carboniferous Limestone/marginal facies (including that overlain by drift material)
Conjectural groundwater catchment for Schwyll Spring (influent surface water courses not accounted for)
Cardiff–Cowbridge anticline
FIGURE 3
WATER TRACING AND CONJECTURAL CATCHMENT FOR SCHWYLL SPRING
N
Outcrop area (not catchment) required to support Bridgend boreholes
NANT CRYMLYN
EWENNI FACH
RIVER THAW
Outcrop area (not catchment) required to support Pwllwy borehole
NANT BRYN-GLAS
RIVER EWENNY
RIVER OGMORE
AFON ALUN
Jacobs Well
Ogmore Down
Pitcot Pool
Rhiw Fault
Merthyr-mawr Warren
Bristol Channel
180000
175000
185000
290000
295000
Scale
0 1000 2000 3000 4000m

Figure 3.

in comparison to the Schwyll Spring discharge:

(i) the gauging data are inaccurate;
(ii) the gauging data are accurate, but only a small portion of the influent water flows to Schwyll (the remainder flowing elsewhere, or returning to surface water courses);
(iii) a combination of (i) and (ii).

Sinking Streams

A number of small streams are known to drain the Coal Measures to the north of the limestone between Bridgend and Pencoed. These flow south and sink into a series of swallow holes in the Carboniferous Limestone at Heol-las and just to the east adjacent to Giblet Farm. When groundwater levels are high it is thought that water from these reappears at springs just to the south (such as at Byeastwood, Figure 3, Aldous, *pers comm*). Attempts have been made to trace the Heol-Las sinking stream (see below), however, none have been particularly successful, and none have been traced to Schwyll. Inclusion in any water budget calculations is therefore not warranted.

SCHWYLL SPRING DISCHARGE

Water at Schwyll rises at a number of locations which makes determination of total discharge very difficult. Gauging carried out on the River Ewenny above and below the spring (Knox, 1933) at the end of the dry summer of 1921 suggests a minimum discharge of 5973 Ml/a (3.6 M g/d). In their report, the Water Research Centre (WRc) (Aldous, 1988) use a spring yield of 9125 Ml/a. Dwr Cymru have a licence to abstract up to 7955.5 Ml/a from Schwyll Spring. Their actual abstraction is confidential therefore the licensed value will be used here. Welsh Water Authority gauged the overflow from Schwyll Spring on five distinct occasions in 1986 and 1987 (Table 2). The data has been extrapolated assuming that each measurement is representative of a period, the beginning and end of which are dependant upon the date of the previous and next measurements as shown in Table 2, column 3. The exception to this is the measurement on 3/10/87 which represents a short duration storm flow. In lieu of any actual data a 3 day storm duration period has been assumed. On this basis the annual overflow at Schwyll has been estimated at 4.3×10^3 Ml. When added to the annual licensed abstraction at Schwyll this represents a total annual discharge of the order of 12.3×10^3 Ml. Given gauging errors and the assumptions of extrapolation, at best this figure will have an associated error of the order of $\pm$ 20% (ie overflow discharge ranges between 3.4×10^3 and 5.2×10^3 Ml/a). This higher discharge (compared to that used by WRc) will result in an overestimation of the size of Schwyll Spring catchment area if it is in error. However, if a significant number of extreme discharges occur (such as that above) then the discharge used here will represent a minimum.

Table 2. *Schwyll Spring Overflow Discharge*

Date	Discharge (m^3/S)	Representative Data Range	Number of Days	Discharge per Period (ml)
11/4/86	0.124	11/12 to 22/4	133	1425
3/5/87	0.193	23/4 to 18/5	26	434
3/6/86	0.068	19/5 to 11/7	54	317
12/8/86	0.143	12/7 to 1/10 5/10 to 10/12	67	828
3/10/87	1.196	2/10 to 4/10	3	310
ANNUAL TOTAL			**365**	**4327**

Water Balance

In the absence of water level data it is assumed that groundwater storage remains constant from one year to the next. Ignoring leakage through the Lower Lias and from water mains, and disregarding input from surface water courses the following estimate can be made of the groundwater catchment area of Schwyll Spring (using the effective rainfall over grass) :

$$\begin{aligned} \text{Total Annual Discharge} &= \text{Catchment Area} \times \text{Annual Average Effective Rainfall} \\ 12.3 \times 10^6 \text{m3} &= \text{A} \times 0.538 \text{ m}^2 \\ \text{A} &= 22.8 \text{ km}^2 \ (\pm\ 1.6) \end{aligned}$$

Although a very simplistic approach this does allow a first estimate of the catchment area of Schwyll Spring to the made. By excluding any contribution from influent surface water courses it over estimates the size of the groundwater catchment. This is of importance for assessing likely sources of pollution to the spring.

SCHWYLL SPRING CHEMISTRY

A brief examination of the spring chemistry has been made in order to assess the likely contribution, in gross terms, of river water to spring discharge. It is hypothesised that if influent river water comprises a large proportion of the total spring discharge then this should be apparent from the spring chemistry. Some changes to influent river water chemistry will take place as it flows underground towards Schwyll. However, if rapid flow in conduits, with only limited dilution by groundwater occurs, then changes should not be sufficient to mask its source.

Schwyll Spring water is generally of good quality; electrical conductivity (EC) is moderate, turbidity is low except following rainstorms, chloride is low (indicating no salt water intrusion) and hardness is high. However, nitrate is slightly elevated due to use of fertilizers within the catchment. A typical summary for a range of determinands analysed is presented in Table 3 (after Aldous, 1988).

Table 3. *Summary of Water Quality at Schwyll Spring (After Aldous, 1988). All values in mg/l except where otherwise stated.*

Determinand	No of Samples	Minimum	Maximum	Mean	Standard Deviation	Coefficient of Variation
pH (no units)	202	6.9	8.0	7.3	0.16	2
Conductivity @ 20 (μs/cm)	202	413	1008	530	63.2	12
Turbidity (FTU)	143	0.2	42	2.2	5.2	236
Colour (Hazen)	199	2.5	50	5.1	4.3	84
Temperature (°C)	199	2.5	6	5.1	4.2	82
BOD	18	0.05	1.1	0.4	0.2	50
COD	19	6	20	19.3	3.1	16
Ammonia	35	0.02	0.06	0.03	0.01	33
Nitrate	35	2.2	5	3.8	0.6	16
Particulate solids	20	0.4	28	4.78	6.64	139
Alkalinity as $CaCO_3$	36	176	261	217	19.8	9
Sodium	28	7.4	16.9	12.6	1.92	15
Potassium	28	1.6	5.2	2.6	0.76	29
Chloride	119	12	48	27.7	4.35	16
Sulphate	33	19.8	39	26.2	7.3	28

In order to assess the importance of influent river water to Schwyll Spring, EC and biological oxygen demand (BOD) were examined for the period 1979 to 1992 inclusive. If influent river water comprises a substantial proportion of Schwyll discharge then reduced EC and elevated BOD might be expected. This is not the case. The EC generally remains high, and the BOD low (Table 4). The annual statistics show occasional extreme values, probably associated with storm events, but the mean values are as would be expected from a largely groundwater fed spring. The moderately low coefficients of variation also indicate that the data are dominantly grouped about the mean, with few extremes. Although the above suggests influent river water to be of lesser importance to spring discharge than groundwater *per se*, it must be noted that similar chemistry could be obtained with high river inflow, slow travel times and dilution by groundwater. The likelihood of this will be further examined using results from water tracing.

Table 4. *Annual Summaries of EC and BOD at Schwyll Spring*

Year	Electrical Conductivity				Biological Oxygen Demand (mg/l)			
	Minimum	Maximum	Mean	No of Samples	Minimum	Maximum	Mean	No of Samples
1979	420	500	475	8				
1980	370	565	477	13				
1981	424	647	529	49				
1982	460	621	536	58				
1983	428	1000	529	88	0.1	1.2	0.4	8
1984	n/d	1008	530	104	0.1	0.7	0.4	9
1985	97	615	529	86	0.3	1.1	0.5	6
1986	369	597	524	60	0.2	1.7	0.7	40
1987	409	701	553	111	0.1	1.8	0.6	104
1988	400	610	511	157	0.1	1.7	0.6	95
1989	200	649	526	144	0.2	3.3	0.8	98
1990	449	1700	550	150	0.2	1.8	0.7	9
1991	230	694	537	160	0.3	1.2	0.6	12
1992	229	570	531	163	0.5	1.2	0.7	14

WATER TRACING

The above data suggests that the Schwyll Spring catchment is some 23 km^2 in area. Spring chemistry indicates that its discharge is dominated by rainfall recharge over Carboniferous Limestone outcrop, with an unknown portion of recharge from influent rivers. This does not, however, delimit the catchment boundaries. In order to assess these reference has to be made to water traces carried out from a number of sites. These have been listed in Table 5 and are shown on Figure 3. They will not be discussed in depth here. The WRc traces are detailed in Aldous (1986, 1988) and the Welsh Water traces in Dixon *et al.* (1986) and Williams and Brown (1989). The only other known trace is that cited by Knox (1933) (trace 1 in Table 5).

River Ogmore Traces

Two bactriophage traces have been undertaken from different sections of the River Ogmore (traces 2 & 3 in Table 5) both of which proved a positive connection to Schwyll Spring, affirming the presence of influent river water in the water discharged at Schwyll. Flow velocities of 1500 m/d to 7800 m/d have been obtained, with similar results from both traces (Table 5). These velocities are typical of flow in conduits. No recovery was estimated for either trace, and breakthrough of bacteriophage was sporadic. The latter may have been due to only a small portion of influent water moving to Schwyll, due to phage mortality, or due to the majority of the bacteriophage remaining in the river system. Of the latter a number were detected in the Merthyr Mawr Mill leat demonstrating movement of water from the Ogmore via the Merthyr Mawr sinks.

Table 5. *Summary of Water Traces carried out in the Schwyll Spring Area*

Trace No.	Completed by	Date	Type of Tracer	Input Location	Recovery Location	Travel Time		Flow Velocity		% Tracer Recovery	Comments
						First (hrs)	Peak (hrs)	First (m/d)	Peak (m/d)		
1	Knox	1920s	Fluorescein	Schwyll Spring Pumping Shaft (SS 8880 7706)	12 of the 13 other springs which rise in the vicinity of Schwyll	N/D	N/D	N/D	N/D	N/D	No breakthrough at spring in bed of R. Ewenny
2	Welsh Water Authority	1986	Bacteriophage	River Ogmore, Bridgend (SS 9013 8065)	Schwyll Spring	11.4	57.7	7800	1500	N/D	Sporadic Breakthrough
3	Welsh Water Authority	1989	Bacteriophage	River Ogmore, Bridgend (SS 8980 8283)	Schwyll Spring MerthyrMawr Mill Leat	23 8	53 17	6100 —	2600 —	N/D N/D	Sporadic Breakthrough
4	Welsh Water Authority	1989	Bacteriophage	Merthyr Mawr Sinks (SS 8901 7807)	Merthyr Mawr Mill Leat Schwyll Spring	4 10	6 20	3000 2400	2000 1200	<1% N/D	Sporadic Breakthrough
5	Welsh Water Authority	1989	Bacteriophage	Ewenny Fach Sink (SS 9542 7990)	Schwyll Spring WDA BH No. 1	20 50	50 N/D	8500 900	3400	N/D N/D	Sporadic Breakthrough Sporadic Breakthrough
6	Welsh Water Authority	1989	Bacteriophage	River Ewenny (SS 9213 7822)	Schwyll Spring	32	38	2600	2200	0.01%	Sporadic Breakthrough
7	Welsh Water Authority	1989	Bacteriophage	Afon Alun (SS 9007 7652)	No recovery	—	—	—	—	—	
8	Welsh Water Authority	1989	Bacteriophage	Field Drain (SS 8943 7705)	Schwyll Spring River Ewenny	1	3	15600	5200	<1%	
9	WRC	1988	Fluorescein Sodium	Tymaen Sinkhole (SS 8943 7705)	Schwyll Spring River Ewenny	4.5	5.5	3500	2800	20%	
10	WRC	1988	Fluorescein Sodium	Ewenny Fach Sink (SS 9542 7990)	No dye recovered	—	—	—	—	—	Test repreated twice, once using 7 kg, then 14 kg of fluorescein dye
11	WRC	1988	Fluorescein Sodium	Merthyr Mawr Sinks (SS 8901 7807)	Mill Leat Rising River Ogmore	4.75 5	6.5 7	2500 —	1800 —	57% 17%	
12	WRC	1988	Fluorscein Sodium	M4 sink at Heol Las (SS 9288 8267)	River Ewenny (via Byeastwood Springs) Bridgend Estate BH	9 21	11 31	— 3900	— 2600	63%	25 kg of fluorescein used much lost to overflow culvert

Note: all flow velocities are based on straight line connections.

River Ewenny Traces

The River Ewenny has been traced four times from two locations. Three traces have been completed from a sink in the bed of the Ewenny, one by Welsh Water using bacteriophage (trace 5) and two by WRc using differing quantities of fluorescent dye (trace 10). Welsh Water also carried out a trace using bacteriophage input to the river bed some 4 km downstream of the sink (trace 6). Of the traces from the sink only that by Welsh Water proved positive, both at Schwyll and at WDA borehole 1, however, breakthrough was sporadic in both cases. Flow velocities calculated from these traces indicate water movement in conduits, at between 8500 and 3400 m/d to Schwyll, and a maximum of 900 m/d to the WDA borehole. The latter suggests that the borehole has by chance intersected a conduit, a conclusion which is at odds with the estimated hydraulic conductivity for the borehole of 0.6-0.7 m/d. The latter is an average value for the full depth of the borehole, however, if all of the permeability arises from a single 0.5 m wide conduit this only represents a potential value of 140 m/d.

The differing results from traces 5 and 10 requires further consideration. Of the WRc traces that involving the most dye was carried out by diluting 14 kg of fluorescein in 227 litres of water to yield a concentration of 61.7×10^6 μg/l (Aldous, 1988). With a limit of detection of 0.05 μg/l (Aldous, 1988) this represents a required dilution in excess of 1.2×10^9 for the dye to pass undected at Schwyll. Let us assume that all of the dye moves towards Schwyll at a rate of 8500 m/d (trace 5, Table 5). If the peak breakthrough lasts up to 18 hours, with 80% of the dye being recovered, this represents 2.7×10^6 μg of dye per hour. With a spring discharge of 1.4 Ml/hr (12 300 Ml/a) this is equivalent to an average concentration of 2 μg/l of dye. Even if half of the dye is lost to the WDA boreholes, the fluorescein should still be detectable at a level above background fluoresecene (0.1 μg/l at Schywll). Although very general with many assumptions and ignoring seasonal variations etc, the calculations indicate that at the flow rates determined by the Welsh Water traces, if the fluorescein input to the Ewenny Fach sink did flow to Schwyll, it was at a rate considerably less than that estimated from the bacteriophage tracing. Dilution by groundwater is likely to be large, possibly with dispersion along a number of flow routes. A single open conduit connection between the sink and Schwyll is highly improbable (based on the above).

The second bacteriophage trace by Welsh Water from the bed of the River Ewenny (trace 6) again proved positive at Schwyll, however, breakthrough was sporadic and recovery very low (possibly due to bacteriophage mortality). Again flow velocities indicative of water movement in conduits have been calculated (Table 5).

The various traces from the River Ewenny suggest the presence of influent river water, with some movement towards Schwyll. However, dilution is high, and, based upon the WRc trace, it is likely that flow velocities are lower than those indicated in Table 5 for traces 5 and 6. A direct open conduit link with Schwyll is not thought probable.

Afon Alun Trace

Completed by Welsh Water, using bacteriophage (trace 7), no recovery at Schwyll or any of the groundwater monitoring points is thought due to high bacteriophage mortality. Measurements downstream of the injection point, where the Alun meets the Ewenny demonstrated a bacteriophage recovery in the river of less than 1%, compared to 90% recovery of Rhodamine WT used under similar flow conditions some years earlier to determine surface water travel times. This indicates high phage mortality.

Tymaen Sinkhole/Field Drain Traces

This sinkhole, just over 0.5 km east of Schwyll Spring, has been traced by Welsh Water using bacteriophage (trace 8) and WRc using fluorescent dye (trace 9), both of which proved positive to Schwyll with travel times of the order of a few hours. Flow rates between 15 600 m/d and 2800 m/d have been calculated. The former is very high and may be due to high flow at the time of tracing. Both breakthrough curves are bi-modal in nature, the Welsh Water more so than the WRc. A similar bi-modal turbidity pulse is often seen at Schwyll, indicating that this sink could be the source of turbidity at the spring. Both traces were also positive to the River Ewenny, which partly explains the low recovery. Bacteriophage mortality was also a problem for the Welsh Water trace. A multi-conduit link (distributory system) between the sink, Schwyll Spring and the River Ewenny is indicated by the results of this tracing.

Merthyr Mawr Sinks Traces

These sinks were traced by both Welsh Water Authority (trace 4), and WRc (trace 11), the former using bacteriophage, the latter fluorescent dye. Both traces were positive at the spring fed Mill Leat with flow velocities indicated as being between 1800 and 3000 m/d (Table 3), indicative of conduit flow. This is not unexpected as parts of the system are open cave passage which have been explored (Oldham, 1986). The dye trace (WRc) also demonstrated loss from the system to the River Ogmore upstream of where the Mill Leat enters the river, but no dye was detected at Schwyll. However, dye recovery was only 74% so it may be that dye did move to Schwyll, but was below the limit of detection. The bacteriophage trace did prove positive at Schwyll Spring, although detection was sporadic.

Thus, the majority of water sinking at the Merthyr Mawr sinks flows through a conduit or conduits to resurge into the Mill Leat channel. Some movement takes place from the conduit(s) to groundwater, which flows under the Ogmore and Ewenny towards Schwyll, along with a component which rises up into the Ogmore (and possibly, though not proven, the Ewenny). Actual losses from the Merthyr Mawr system are likely to be highly dependant upon the relationship between river level and groundwater level at the time of tracing.

Heol-Las Trace

WRc completed a trace (trace 12 in Table 5) from the sink hole beneath the M4 at Heol-las using 25 kg of fluorescein dye. Unfortunately, shortly after injection a heavy rainstorm washed much of this in to an adjacent overflow culvert. Some dye also appeared at the Byeastwood springs which are thought to be overflow springs (Aldous, *pers. comm*). Finally, a proportion of the dye emerged at the WDA borehole with travel times indicating velocities of 3900 to 2600 m/d indicative of conduit flow. This, and the positive result from trace 5, suggests that the WDA borehole has penetrated a network of conduits trending both north-south and east-west, the cone of depression around the borehole drawing in water along these.

SCHWYLL SPRING CATCHMENT AREA

It has been suggested by Lapworth (1921), Knox (1933) and Anon (1991) that a portion of the discharge at Schwyll Spring is derived from recharge over the limestone outcrop in the Brecon Beacons area some 40 km to the north of the spring. This water would sink, flow underneath the Coal Measures and rise into the southern Carboniferous Limestone outcrop to re-emerge at Schwyll. However, analysis of helium-4 concentrations at this spring (Thomas *et al.*, 1983) suggests that the water has a more local origin. Given the absence of other major springs and the large outcrop of Carboniferous Limestone for which recharge is unaccounted (in water balance terms), this conclusion is concurred with here.

The Schwyll Spring discharge can be considered as being comprised of two components a groundwater component *per se* and a component due to influent surface water courses. Analysis of discharge gauging data and water tracing suggests that surface water is lost to the aquifer in the Ogmore catchment. However, estimation of the percentage of spring discharge that this comprises has not been possible. Two scenarios will therefore be considered to estimate the catchment extent. In scenario one influent river water comprises a major component of spring discharge, whilst in scenario two it is a negligible component. In actuality it is somewhere between these extremes. Spring chemistry suggests that rainfall recharge comprises the dominant portion of spring discharge, inputs from influent rivers being secondary.

The influent surface water is of importance as potentially it allows a small proportion of all surface water upstream of a point of influence to contribute to the discharge at Schwyll Spring, provided that the influent water flows to that spring. Therefore, in the strictest sense, the majority of the River Ogmore catchment can be contributory to Schwyll Spring, albeit in only a very small percentage of total flow in the river. This has implications with regard to protection of the source from pollution (see below).

The inflow from surface water courses as a percentage of spring outflow has not been determined due to limited data availability. By ignoring the influent surface water as a component of discharge at Schwyll Spring (scenario two), calculation of the groundwater catchment will over estimate the groundwater source. Based on a catchment area of 23 km^2 and on available hydrogeological information an attempt has been made to define the catchment boundaries (Figure 3). Previous work (Aldous, 1988) defined the Schwyll catchment based on geological information; the boundary to the north was formed by the edge of the limestone outcrop, the west by the Rhiw Fault, the south by the Cardiff-Cowbridge anticline while the eastern boundary was uncertain, but probably running north-south between Llangan and Pencoed. These inferred boundaries are open to question.

The Rhiw Fault is not named as such on geological maps of the area, nor is it as extensive as maps by Aldous (1988) show. Although it may well form an impermeable barrier as Aldous suggests, it must be borne in mind that this inference is based on extrapolating research carried out some 50 km to the east in the Chepstow area on a different set of faults. Furthermore, the fault is penetrated by water from the River Ogmore, sinking at the Merthyr Mawr sinks, which crosses the fault before resurging on its western side. Until further evidence becomes available it should be treated as a limitation to west/east flow, but not necessarily as a barrier. Its presence may also result in enhanced north/south flow. The southern boundary to the Schwyll catchment (the Cardiff-Cowbridge anticline) was chosen by Aldous on the basis that groundwater on the southern side of the anticline flows down the dip in a south easterly direction emerging at two small springs (Pitcot Pool and Jacobs Well), whilst that on the northern side flows towards Schwyll. However, it is possible that groundwater flows both east and west along the strike of the limestone, on both the north and south sides of the anticline, towards the Rhiw Fault and then north towards Schwyll. If this is the case then much of the Ogmore Down area comprises part of the Schwyll Spring catchment. Further water tracing is required. Such flow could take place on both the eastern and western sides of the fault. In the vicinity of Schwyll Spring the evidence of the anticline as indicated on geological maps is not as obvious as elsewhere in South Wales.

The eastern boundary of the Schwyll catchment is uncertain as there are no strong geological controls (with the exception of the area of outcrop of the limestone). To some extent it can be defined by establishing the boundary of the groundwater catchment of Pwllwy Springs and borehole which are to the east of Schwyll (Figure 3), however, the uncertainties associated with this are probably as great as those for determining the catchment of Schwyll Spring. Alternatively, the eastern boundary for Schwyll can be established ''by default'' using the outcrop area available, effective rainfall and Schwyll Spring discharge. However, this takes no account of the heterogeneities associated with flow in karstified limestone.

The approximate extent of catchments for other springs and boreholes in the study area has been made based upon an effective rainfall of 528 mm, upon licensed discharges for abstraction boreholes and using spring discharge data extrapolated from a single estimate made when the site was visited. Although very approximate in nature, such calculations allow a check on outcrop area versus discharges to the made, and also help to better refine the catchment area of Schwyll Spring. The catchment areas for the main abstraction/springs are as follows:

(i) Pwllwy borehole — 3 km^2. This area has been increased over the area obtained by dividing the discharge by effective rainfall in order to take account of boulder clay cover in the vicinity of the borehole and potential inflow from adjacent river gravels. Some 30% of effective rainfall is assumed to leak through the boulder clay to recharge the aquifer.
(ii) Bridgend Industrial Estate boreholes — 4 km^2.
(iii) Jacobs Well — 0.2 km^2.

These, combined with the Schwyll catchment, represent a total area of 30 km^2. The available outcrop, assuming 538 mm of effective rainfall per annum is more than sufficient to sustain these (Figure 3).

The nature of the groundwater flow network in the Schwyll catchment can be hypothesised based upon results from the water tracing experiments. Flow velocities and the large volume of water emerging at Schwyll all indicate conduit flow. However, more than one system appears to be present. Two positive traces, from orthogonal directions, towards the randomly positioned WDA borehole 1 indicate a network rather than master conduit system. This is reinforced by traces from Tymaen sink and the Merthyr Mawr sinks, all of which have a portion of flow both to springs and to rivers. Similarly, groundwater loss from rivers does not appear to go to a master conduit system, but more likely flows underground for some time before re-emerging in the river (unproven by tracing). Any master conduit at Schwyll is likely to originate from the east or south east in the Ogmore Down area, probably following the strike of the limestone.

Based on the above, the outcrop area required to support known abstractions (discharge/rainfall) and upon water tracing a first estimate has been made for the Schwyll Spring groundwater catchment. This is shown in Figure 3. Of the boundaries those to the south and east have the most uncertainty associated with them. No attempt has been made to include surface water catchments of influent rivers within the Schwyll Spring catchment area. The groundwater catchment suggested is therefore likely to be an overestimate.

POTENTIAL FOR POLLUTION

Defining the catchment area for Schwyll Spring (albeit conjectural) allows the potential for contamination of the spring from pollution to be assessed. Based on the hydrogeological work outlined above three potential routes by which pollutants can reach the aquifer have been identified:

(i) As dispersed recharge over the limestone outcrop area;
(ii) As concentrated recharge into stream sinks; and
(iii) Via dispersed and concentrated recharge from influent rivers, with contamination arising both within and without the Schwyll catchment.

The first of these potential sources of pollution is common to many aquifers. Contaminants may include fertilizers and pesticides used by farmers, historical