Hydrogeology of Wales: Ordovician and Silurian aquifers - groundwater studies

From Earthwise

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This page is part of a category of pages that provides an updated review of the occurrence of groundwater throughout Wales.

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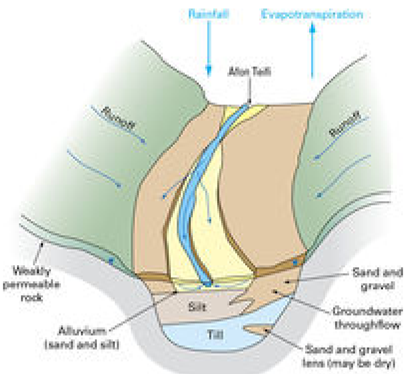
The Afon Teifi at Cenarth flowing over on of several rock ledges that constrict the valley. P802420.

Although the Ordovician and Silurian strata are recognised as being generally weakly permeable, there have nevertheless been a number of investigations into groundwater flow and occurrence within them. These case studies illustrate the specific hydraulic qualities of the rocks in different catchments.



Schematic section of the central area of the lower Afon Teifi catchment showing the main flow components (after Robins et al., 2000). P859266.

Much of the work concentrates on shallow groundwater circulation on a catchment scale. Two studies were recently carried out in contrasting catchments in west Wales. **Robins et al. (2000)** investigated the occurrence of groundwater in the Silurian and Ordovician rocks of the Teifi valley (**Plate P802420**), whereas **Hiscock and Paci (2000)** concentrated on the more arenaceous deposits of the Rheidol catchment. Both these investigations highlight the interaction between groundwater in bedrock and in the superficial cover particularly along valley bottoms.

The bedrock in Afon Teifi comprises mudstones of Ordovician and Silurian age. Springs are common and issue primarily from weaknesses in the shale, or the contact between bedrock and the overlying superficial material. Many of the springs are seasonal reflecting low storage capacities. Storage may be enhanced where fissure storage is in hydraulic contact with overlying superficial deposits which possess intergranular storage, particularly in valley-bottom areas (**Figure P859266**).

Sustainable yields from bedrock are low, although adequate for many private uses. Spring flows occur up to 2 to 3 l s^{-1}, and exceptionally 5 l s^{-1}, but flows of less than 1 l s^{-1} are more typical. Typical sustainable borehole yields are around 0.3 l s^{-1}; pumping rates of up to 1 l s^{-1} invariably dewater boreholes. Boreholes are generally about 40 m deep; exceptions include one borehole which is 140 m deep. A short duration pumping test at Dan yr Allt [SN 1871 4162] indicates a transmissivity of 0.63 m^2 d^{-1}. A nearby boundary condition is apparent which reduces the transmissivity to 0.33 m^2 d^{-1} after only 17 minutes pumping. A borehole at Tandderi [SN 5037 4354] indicates a transmissivity of 1.1 m^2 d^{-1} from the early data, and 0.64 m^2 d^{-1} from the later data, and a third test at Cyttir-bach [SN 2448 4838] suggests a transmissivity is about 0.49 m^2 d^{-1}.

Water levels are rarely more than 10 m from the surface, irrespective of the ground elevation. No clear piezometric surface can be created from water level data from boreholes and spring elevations. This reflects the nature of a fractured aquifer beneath relatively steep surface topography, and perching of groundwater bodies.

A best estimate of the quantity of groundwater abstracted from the catchment is based on data maintained by the Environmental Health Departments (see **Groundwater consumption table**). Although it is not possible to estimate the proportions abstracted from the drift and bedrock aquifers the majority is believed to derive from bedrock (mains water is available throughout most of the catchment but private supplies are preferred by many on the grounds of cost). The majority of the private groundwater sources are springs. The analysis shows that less than 2 Ml d^{-1} groundwater is being used in the catchment area.

Groundwater consumption in the Teifi catchment (principally from bedrock) excluding the Alwen public supply source which draws from superficial gravels (source local Environmental Health Departments).

	Estimated daily consumption (m^3)	Estimated number of sources	Total abstraction (m^3 d^{-1})
Domestic – single property	0.6	809	485.4
Domestic – <25 people	1.2	83	99.6
Farm (livestock)	1.5	68	102
Farm (dairy)	6.5	132	858
Commercial (hotel, youth hostel, abattoir, quarry, etc.)	8.0?	20	160
Total		1112	1705

Run-off and potential evaporation exceed precipitation (see **Precipitation, run-off and AE table**), but run-off includes groundwater base flow (infiltration). As the BFI (base flow index) is 0.54 AT Glan Teifi (Centre for Hydrology and Ecology/British Geological Survey, **2003**), something of the order of 540 mm derives from groundwater discharge. This represents a renewable resource of 540 Ml a^{-1} km^{-2} of aquifer, a considerable surplus over the total estimate of just 622 Ml a^{-1} withdrawn throughout the whole catchment from all the boreholes, wells and spring discharges.

Representation precipitation, run-off and AE for Afon Teifi (source Hydrological data UK and Meteorological Office).

	Precipitation (mm/a)	Run-off (mm/a)	Actual evaporation (mm/a)
IH: Glan Teifi (1959–1990)	1349	999	
IH: Llanfair (1971–1981)	1446	988	
MORECS (1961–1990)	1102		544.5

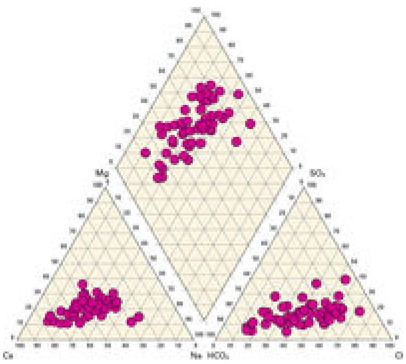
The magnitude of the groundwater through flow along the length of the valley based on Darcy's law is given by:

$$Q = T\ y\ i$$

where T is the transmissivity and y is the width of the catchment and i is the prevailing hydraulic gradient. Using a transmissivity value of 0.6 $m^2\ d^{-1}$ (from pumping test analysis) and an average catchment width of 17 km, and estimating the hydraulic gradient to be equal to the gradient of the river (2.5×10^{-3}), then:

$$Q = 0.6 \times 17\ 000 \times 2.5 \times 10^{-3}$$
$$= 25\ m^3\ d^{-1} \text{ or only } 0.025\ Ml\ d^{-1}$$

This is a small amount compared to the total estimated base flow and the majority of the base flow component of river flow derives from local recharge and discharge via flow paths perpendicular to the axis of the valley, and not from longitudinal flow paths down the length of the valley. Abstraction and spring flow are small elements of the overall infiltration indicated by base flow indices.

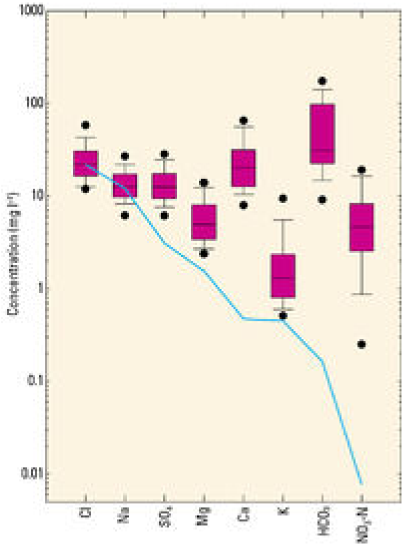


Piper diagram showing major ion distribution in groundwaters in Afon Teifi (after Robins et al., 2000). P859267.

Temperatures do not vary significantly in the groundwaters in Afon Teifi with a median value of 9.6 °C (**Shand et al. 2005**). Temperatures as low as 4 °C were measured in some of the smaller springs implying short and shallow flow paths. There is a range in pH from 5.2 to 7.6, however, waters with pH less than 6 are confined to the catchment east of Llechryd (SN21794364). The waters are relatively low in total dissolved solids (TDS) and SEC varies from 117 to 662 µS cm^{-1} with the highest values located close to the coast.

Bedrock groundwater quality ranges from Ca-HCO_3 to Ca-Cl type. The major cations show a tighter grouping than the anions on piper diagrams, typical of upland waters (**Figure P859267**). Mean concentrations of major elements for the boreholes are, in general, slightly higher than the springs and wells, but ranges are similar. Fe and Mn concentrations are low in most waters reflecting the presence of oxygen while Si concentrations are variable.

The Afon Teifi groundwaters show geographical variations in solute chemistry along the length of the catchment. This is particularly pronounced for SEC and the major elements Ca, Mg, HCO_3 and Si, which show a wide range of concentrations in the western part of the catchment but less variation and a slightly lower baseline for some solutes in the east. There is also a tendency towards higher Na and Cl, but less so for SO_4, towards the coast in the Cardigan area. Most waters with low pH are confined to the eastern half of the catchment but are variable in both areas. The western enrichment is also matched to a similar degree by many of the minor and trace elements e.g. Br, Li, B and Sr, whilst others show no significant trend e.g. K, NO_3-N, Pb and Y. The close proximity of the western part of the catchment to the coast is shown by higher concentrations of Na and Cl in the area around Cardigan. Enhanced concentrations of these elements due to sea spray and salt deposition are typical of surface waters along the west coast of the UK, forming steep chemical gradients away from the coast (**Shand et al., 1995**). The dominant control over groundwater chemistry is, however, water rock interaction as illustrated by the normalised plot of the major ions which shows considerable enhancement of both Ca and HCO_3 (**Figure P859268**).



Box and whisker plot of major ion concentrations and the normalised sea water line. The mean 25th and 75th percentile are bars and the 5 and 95th percentile are dots (after Robins et al., 2000. P859268.

Hiscock and Paci (2000) studied the contrasting Rheidol catchment which enters the sea at Aberystwyth. The principal difference is that a more granular and generally better water-bearing bedrock is present in the Rheidol than in the Teifi. Other differences include surface waters polluted by mine-water discharge from former metal mining activities (see Management and regulation of groundwater), and stream-flow regulation for hydropower. Bedrock comprises Silurian Llandovery Series consisting of:

Aberystwyth Grits Formation

Borth Mudstones Formation

Devil’s Bridge Formation

Cwmsymlog Formation

Derwenlas Formation

Cwmere Formation

The three uppermost formations are considered by **Hiscock and Paci (2000)** to offer the better conditions for groundwater occurrence in fractures and minor groundwater abstractions. This reflects a decrease in metamorphic grade and increase in depth of weathering in the younger formations coupled with occurrence of sandstones in the upper part of the sequence.

The overall porosity of the series is between 2 and 4 per cent. However, depth of weathering can be up to 20 m and brick-lined pits have been used effectively to capture springs and divert otherwise shallow groundwater to gravity-fed systems for domestic usage. These are commonly situated in bedrock at the junction between the Aberystwyth Grits Formation and the Borth Mudstones Formation, but may also occur at the base of the superficial deposits, drawing on the upper weathered zone of bedrock or within the superficial material itself, e.g. gravel over clay. In the Rheidol the majority of sources relate to contact with superficial deposits. In the upper parts of the catchment there are distinct spring lines parallel to the river. There are few sources recorded upstream of Devil’s Bridge.

The Rheidol catchment covers an area of 182 km^2. Hiscock and Paci note there are 65 sources providing 3.6 Ml d^{-1}. Twenty-nine of the sources are in bedrock and a further ten occur in superficial deposits in contact with bedrock, tapping the upper weathered zone of bedrock. The estimated water balance for the catchment using an evapotranspiration value based on base flow separation and a BFI of 0.51 is shown in the **Comparative water balance table** .

Comparative water balance estimates (mm a^{-1}) for the Teifi and Rheidol catchments (after Robins et al., 2000; **Hiscock and Paci, 2000**).

	Teifi	Rheidol
Rainfall	1349	1790
AE	544 (Morecs) 350 (base-flow separation)	753 (base-flow separation)
Run-off	459	667
Base flow	540	363

Investigation of the local-scale transport process in the Upper Severn catchment at Plynlimon provides further insight into the hydraulics of the Lower Palaeozoic aquifer. This work specifically tackles the issue highlighted by **Shand et al. (1999)** concerning the role of groundwater in sustaining base flow and its important contribution to storm flow as demonstrated by isotopic indicators analysed for groundwater and surface water both during dry and rainfall events.

Neal et al. (1997) identified the importance of base flow to the stream and recorded a damping of the rainfall chloride signal in base flow. Fractal analysis of the chloride output demonstrated that there was a range in travel times to groundwater arriving in the stream (**Kirchner et al. 2001**). **Shand et al. (2001)** have used isotopic evidence to show that the stream waters lie on a mixing line between groundwater and rainfall.

Haria and Shand (2004) carried out intensive investigations in the Hafren subcatchment of the upper Severn near Plynlimon. They used a transect some 50 by 10 m in area perpendicular to the stream with monitoring boreholes into weathered bedrock as well as soil piezometers. The time series physical and chemical data so gathered highlight the role of groundwater in stream flow generation. Key conclusions include:

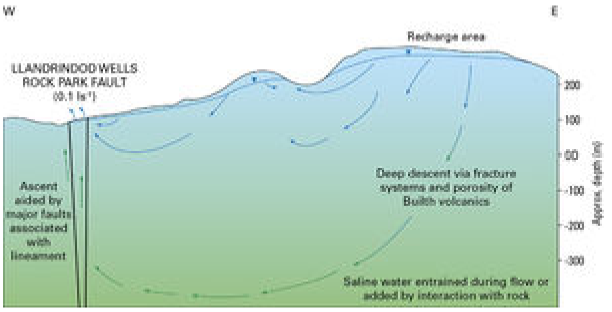
- The system is complex with discrete flow paths in individual (confined) fractures which mix at the valley bottom.
- All fracture flow paths appear to respond rapidly to rainfall events.
- The upper weathered 1.5 m horizon of bedrock contributed significantly to stream flow.
- Groundwater from the less weathered zone to 10 m depth also contributed to stream flow.
- Some upwelling of ‘older’ groundwater into the soil zone suggests not all soil water is ‘new’.
- The stream is always gaining even at low flow.

The Chalybeate Spring of Llandrindod Wells. P802421.

In south-west Wales the Raglan Mudstone Formation offers transmissibilities in the range 4 to 13 m^2

d^{-1}. A 40 m deep borehole in the Usk valley at Llanilowell [SO 33955 19858] penetrating the Raglan Mudstone Formation has a specific capacity of 45 m^3 d^{-1} m^{-1} and a transmissivity of 60 m^2 d^{-1}.

There is evidence of some deep groundwater circulation in central Wales. The saline waters of the spa sources in the Llandrindod Wells [SO 0400 5102] and Builth Wells [SO 0589 6107] area of central Wales have been a focus of interest since Roman times (**Plate P802421**). The Builth Inlier is characterised by typically weakly permeable metasedimentary and volcanic rocks with a deeper than normal fracture system associated with the north-westerly trending Tywi Lineament, itself a south-westward extension of the Pontesford Lineament. Small volume discharges of iron-rich and sulphur-rich waters, some with total dissolved solids greater than 16 000 mg l^{-1}, suggest that some deeper-than-normal groundwater flow paths exist within this area of Ordovician and Silurian strata (**Edmunds et al., 1998**). The normal shallow active groundwater flow zone in weathered and fractured bedrock tends to dilute upwelling deeper-circulating and older waters suggesting that higher salinities may occur at depth.



Schematic cross-section of the Builth Inlier illustrating probable evolution of the Llandrindod wells spa waters (after Edmunds et al., 1998). P859269.

The discharge from all the springs including the nearby Llangammarch Wells [SN 9381 4725] and Llanwrtyd Wells [SN 8783 4661] sources are collectively < 1 l s^{-1}. The high salinities indicate a slow passage to considerable depth, there being no evaporite or hydrothermal deposits in the area. The discharge temperature is close to mean annual air temperature between 11 and 13 °C, reflecting a slow upward journey of small flow volumes which equilibrate with the surrounding rock temperatures near surface before discharging. Stable isotope and radiocarbon evidence suggest the waters are of Late Pleistocene age. The Br/Cl ratio is enriched, suggesting that there has been prolonged water–rock contact with the Lower Palaeozoic marine shales to create a Br-rich composition. Some entrainment of Cl from ancient sea-water entrapped in the rocks may also have taken place. **Figure P859269** illustrates a probable flow system with upward flow concentrated in faults on which the spa springs occur.

Although the Builth Wells spa waters are more saline than those at Llandrindod Wells, the stable isotope data indicate that residence times of the Builth waters are shorter. Nevertheless the circulation mechanism is likely to be similar to that at Llandrindod (**Figure P859269**). The less mineralised waters at Llangamarch and Llanwrtyd derive from a shallower system. Mixing with locally derived near-surface systems tends to obscure the saline signature of the low-volume deeper waters as they rise to the surface. Thus, although no other sources of deep circulation in the Lower Palaeozoic aquifers of Wales have so far been discovered, there is every reason to infer that they may exist.

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