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Groundwater Management: the Shropshire Groundwater Scheme

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VOYCE, K.J. (2009). Groundwater Management: the Shropshire Groundwater Scheme. *Proceedings of the Shropshire Geological Society*, **14**, 20–29. Shropshire's water is dominated by the River Severn catchment. This covers a huge area and is responsible for supplying much of the West Midland's water needs. The Environment Agency is responsible for the operation and development of the Shropshire Groundwater Management Scheme (SGMS). Located solely within North Shropshire this is the largest of the UK's groundwater regulation projects. SGMS has grown to include 50 groundwater abstraction boreholes linked to a series of underground pipes that discharge into the River Severn. The scheme employs boreholes to abstract groundwater for supply and others which are drilled to establish geological formations and to enable decisions to be made regarding the availability of water. The scheme has six development areas and is being constructed in eight stages. At the present time, four phases have been completed and the fifth is underway.

The SGMS is designed to be used, on average, once every three years to meet peak dry weather demands for water. Water is pumped from groundwater reserves naturally stored within the North Shropshire Permo-Triassic Sandstone formations and released in conjunction with surface water reservoir releases to balance the demands of abstractors while safe guarding the ecological needs of the river environment.

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BACKGROUND

Water supply requires a multi-disciplinary approach in order to maintain a sustainable supply of sufficient quality for industrial and domestic usage. This paper considers the management of water in Shropshire, a subject first addressed by the Society over 20 years ago (Skinner, 1981). A brief introduction to the ways in which water is held within the ground is given in the New Scientist article by SGS member Michael Price (1991), and his text book *Introducing Groundwater* provides greater insight (Price, 1996).

Shropshire's water is dominated by the River Severn catchment (Figure 1). This covers a huge area and is responsible for supplying much of the West Midlands and beyond, including Shrewsbury, Wolverhampton, Coventry and Bristol. The public perception is that most water is impounded behind a series of dams across the Elan Valley, built between 1893 and 1906 for the Corporation of Birmingham, held in reservoirs from where an aqueduct, largely underground, transports it to supply the city. But this was not the first: a similar scheme had been completed in 1892 to export water from the catchment to Liverpool via the Vyrnwy reservoir. Further demand for water in the 1960's resulted in the construction of Llyn Clywedog reservoir at the head waters of the River Severn.

However, the natural river system is also used to transport water and a huge resource also exists *within* the ground. Consideration for development of groundwater in North Shropshire as a resource began in the 1970's, culminating in the first phase of the Shropshire Groundwater Management Scheme (SGMS) being commissioned in 1984.

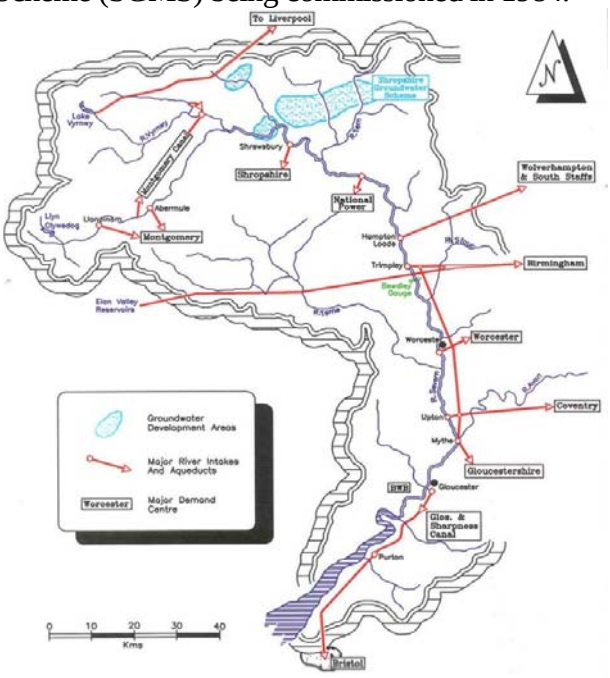

Figure 1. Overview of the River Severn water resources and supply systems. © Environment Agency, all rights reserved.

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GEOLOGY OF WATER SUPPLY

Water is held within the ground either within pores or within fractures, in the bedrock and/or in the overlying superficial deposits (soil and "drift"). The ability to extract and recharge groundwater depends upon the openness ("permeability") of the connections between the pores and fractures, and between the various geological units; it also depends upon the disturbances to the continuity of these units, primarily the effects of faults but also unconformities and the weathered profiles trapped beneath them.

In mid-Wales, the upper part of the catchment is underlain by low permeability Ordovician and Silurian shales, grits and mudstones. Thus most water storage in this area is above ground and found in discrete, relatively small isolated areas. At Llyn Clywedog there is a concrete buttress dam constructed in the 1960s which retains some 55 million cubic metres of water. During periods of low flow on the River Severn (measured by a gauge at Bewdley) release valve at Llyn Clywedog can be opened to provide additional flow support.

By contrast, North Shropshire is underlain by significant thicknesses of Permo-Triassic sandstone. This forms a major aquifer with excellent natural storage properties and an ability to readily transmit water. Following a prolonged period of increase in demand for water during the 1960s and 1970s, investigations commenced to assess the potential of this area for using groundwater to supplement river water during dry periods. A similar scheme, but on a much smaller scale, was successfully installed for the River Lambourn within the River Thames catchment (Thames Conservancy, 1972).

Figure 2. Rig used for drilling boreholes for the Shropshire Groundwater Management Scheme employing a rotary reverse circulation drilling technique. © Environment Agency, all rights reserved.

THE SHROPSHIRE GROUNDWATER MANAGEMENT SCHEME

Following a ten year investigation, a public enquiry was held in 1979 and the Act of Parliament passed in 1981; thus was born the Shropshire Groundwater Management Scheme (SGMS). The SGMS comprises abstraction points linked to a series of underground pipes that discharge into the River Severn or its major tributaries. Four phases of the scheme are complete, one is programmed and a further three have been identified for when demand justifies their introduction. With a current deployable yield of 190 megalitres per day (1 megalitre = 1 million litres) the scheme is licensed to allow the development of up to 330 megalitres per day. It has been used during the summers of 1984, 1989, 1995, 1996 and 2006 to top up flows in the Severn.

Development of the scheme was carried out by drilling production and observation wells, using drilling equipment similar to the specially adapted oil rig from Texas featured in Figure 2. Information was used to produce contours of groundwater table to define groundwater flow directions. Pumping tests were carried out to confirm aquifer parameters (conductivity, transmissivity, storage coefficient and porosity) and thereby calculate the quantity of groundwater likely to be obtained or stored.

The boreholes for the wells also revealed the detailed geological profiles, in particular information concerning local faulting. One example is the Hodnet Fault in the valley of the River Tern. Here a number of theoretical structures could have explained the mapped terrain but, as more information was gleaned with additional boreholes, so the ground was discovered to include previously unmapped faults. These could explain local thinning of sandstone and anomalous observations of groundwater drawdown that had been made during pumping tests.

Locally, the hydrogeology is further complicated by overlying Devensian glacial sediments (Figure 3). The British Geological Survey was commissioned to look at the detailed sedimentology of the drift and its influence on the recharge of the aquifer.

The average rainfall on the Shropshire Plain is 600 mm a year and studies were carried out into the fluctuation of water levels in the sandstone as a consequence of changes in effective rainfall (i.e.

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the proportion of total rainfall that does not run off in to rivers but soaks in to the ground).

Work has also been carried out to ensure that farming, the major land use within Shropshire, would not be adversely affected by the scheme. In order to verify this, a series of soil moisture vulnerability maps, based on the relationship between groundwater levels and crop root depth, were produced. Such information can also be used to ensure that pumped boreholes are kept away from high risk zones.

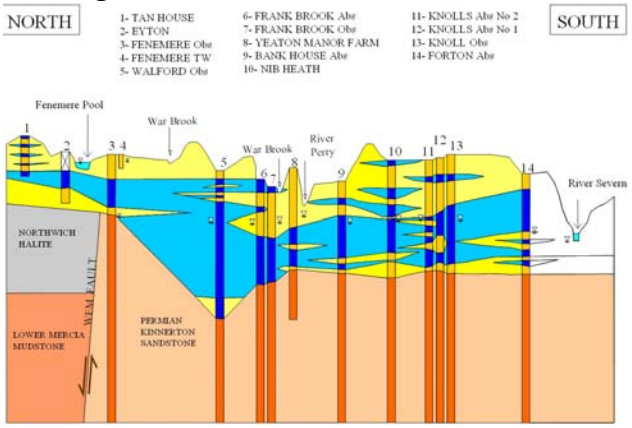

Figure 3. Complexity of the Quaternary glacial and fluvioglacial sediments overlying Permo-Triassic formations displaced by the Wem Fault as revealed by investigation boreholes. © Environment Agency, all rights reserved.

HYDROGEOLOGY

The SGMS has now become a vital component of River Severn regulation whereby flows in the river are artificially supported during times of low flow.

The scheme comprises groups of boreholes, which draw water from groundwater reserves naturally stored within the Permo-Triassic beds underlying much of North Shropshire, in particular the sandstones. This water is pumped out and released to the River Severn to enhance flows in the river.

Grain size, porosity and permeability are much more important to hydrogeologists than the classical geological characteristics of stratigraphy and petrology portrayed on geological maps (Table 1; Figure 4). Also of great interest are the frequency and openness of joints, faults and aquifer geometry. Faults throw aquifers about, change their thickness, and affect the amount of storage capacity in the ground. It is therefore important to know the three dimensional picture of the rocks underground, and how it changes with depth. This reduces the risk of drilling boreholes into inadequate aquifers or developing short-term resources.

The Permo-Triassic sediments reach significant depths, up to 4400 m centred on the Wem Fault in Shropshire, representing the southern margin of the Cheshire depositional basin. (Figures 5 and 6). The sandstones comprise fluvial as well as aeolian deposited sands resulting in a range of potential porosity and thus storage capacity typically between 5 to 34%. While the sandstone beds are up to 1800 m thick allowing for a large storage capacity, the porosity and therefore storage does decrease with depth. Stratigraphically, the sandstones give way to Triassic mudstones and evaporates (the latter could, reduce groundwater quality by introducing water rich in salt, sulphate or barytes). Overall, the sandstone component constitutes a thick aquifer with good storage and high transmissivity.

Table 1: North Shropshire Adopted Nomenclature based on Cheshire & Stafford Basin Stratigraphy

System & Lithostratigraphical Division					
System	Group	West of the Hodnet Fault – Southern Cheshire/west Shropshire Basin		East of the Hodnet Fault – East Shropshire/Stafford Basin	Previous Name
Triassic	Mercia Mudstone Group	Eldersfield Mudstone		*Eldersfield Mudstone*	Keuper Marl
		Tarporley Siltstone		*Tarporley Siltstone*	Keuper Waterstones
	Sherwood Sandstone Group	Helsby Sandstone Formation	HODNET FAULT	*Bromsgrove Sandstone Formation*	Upper Mottled Bunter Sandstone
		Wilmslow Sandstone Formation		*Wildmoor Sandstone Formation*	
		Chester Pebble Beds Formation		*Kidderminster Pebble Beds Formation*	Bunter Pebble Beds
Permian*		Kinnerton Sandstone Formation		*Bridgnorth Sandstone Formation*	Lower Mottled Bunter Sandstone
		Alberbury Breccia			
Carbonife rous	Warwickshire Group	Salop Formation (Enville & Alveley Members)		*Salop Formation: (Enville & Alveley Members)*	Enville & Keele Formations

Property	Data Source	Min – Max Range	Interquartile Range	Median	Geometric Mean
Bulk Hydraulic Conductivity	APM	0.094 to 25m/d	5.9 to 15m/d	10.6m/d	6.94m/d
	ESGM	0.1 to 26.6m/d	1.6 to 4.9m/d	-	3m/d
Transmissivity	APM	9 to 4770m²/d	97 to 440m²/d	240m²/d	200m²/d
	ESGM	10 to 2737m²/d	151 to 508m²/d	-	282m²/d
Storage Coefficient	APM	2.3×10^{-8} to 0.19	3.5×10^{-4} to 3.8×10^{-3}	9.4×10^{-4}	7.9×10^{-4}
	ESGM S_c	2.1×10^{-4} to 1.7×10^{-2}	-	3.3×10^{-3}	1.6×10^{-3}
	ESGM S_y	0.02 to 0.14	-	0.09	0.08
Porosity	APM	6 to 34%	20 to 27%	24%	23%

Figure 4. Typical hydrological properties of Triassic sandstones in North Shropshire. Values taken from Aquifer Properties Manual (BGS, 1997) and East Shropshire Groundwater Model Report (Streetly & Shepley, 2005). © Environment Agency, all rights reserved.

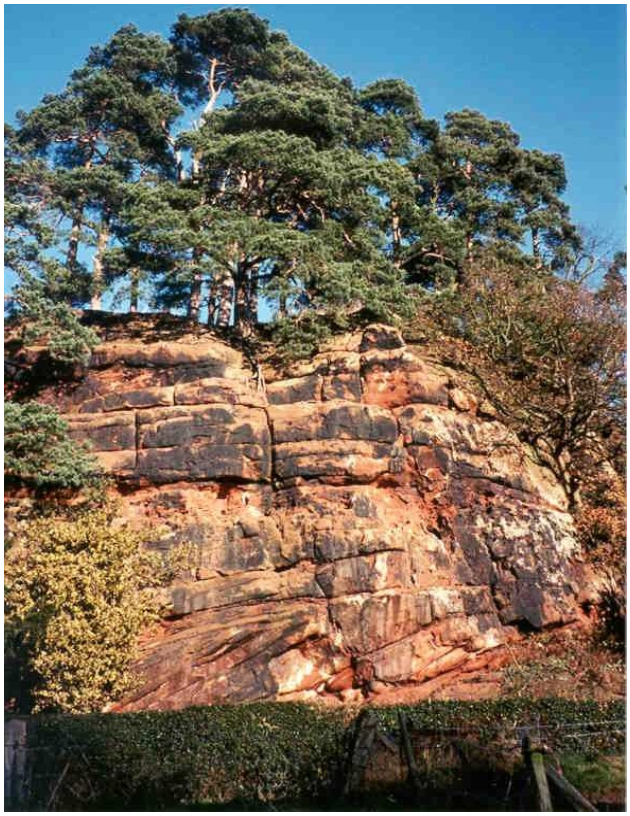

Figure 5. Typical exposure of Triassic sandstone at Myddle, North Shropshire. This is the type of rock into which the SGMS boreholes are drilled, characterised by extensive beds of cross-bedded sandstones cut by horizontal and vertical fractures. © Environment Agency, all rights reserved.

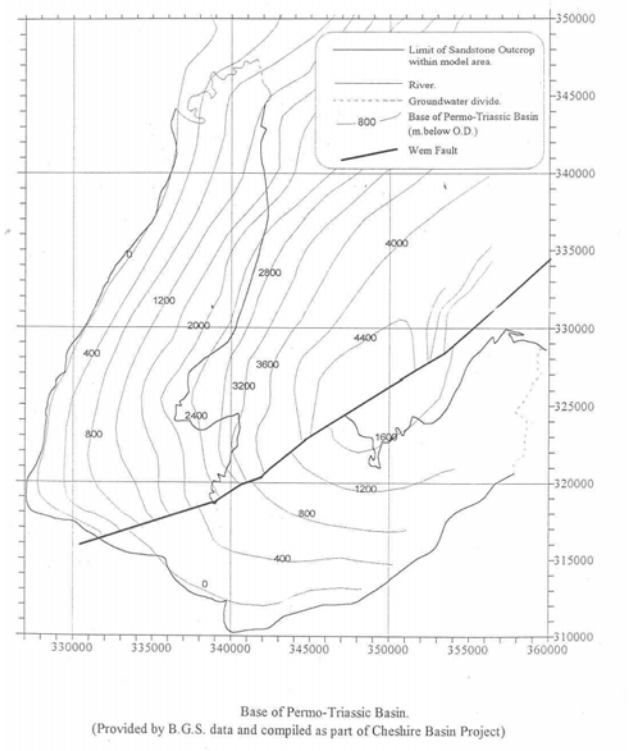

Figure 6. Depth to the base of the Triassic sequence in the Cheshire Basin. The Shropshire Groundwater Management Scheme concerns the southern part of this area. © Environment Agency, all rights reserved.

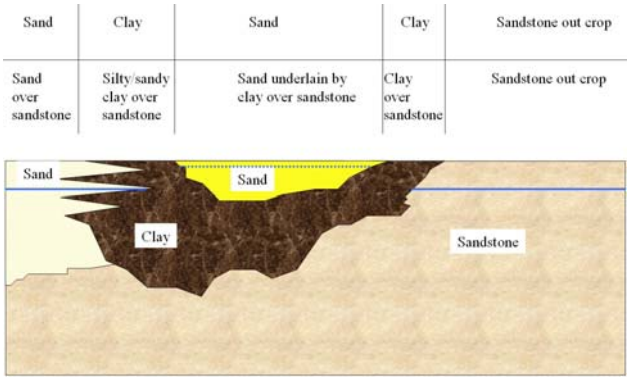

Figure 7. Contrasting hydrogeological settings for a hypothetical typical profile in North Shropshire. Clays generally prevent vertical recharge of aquifers beneath, but help protect them from ingress of surface pollution. © Environment Agency, all rights reserved.

Recharge of the aquifer is influenced by the extensive cover of Quaternary glacial and fluvioglacial sediments, largely Devensian in age. This provides effective recharge flow paths or barriers between surface sources (rivers and rainfall onto open ground) and the underlying Permo-Triassic sequence (Figure 7). The spread of Quaternary sediments is determined by the evolution of the Devensian glaciers, dominated by the southerly passage of ice from the Irish Sea Basin and the easterly passage of ice from Northern and Central Wales, these bodies meeting in the tract west of Shrewsbury.

Investigations in this area undertaken by the BGS on behalf of the SGMS (1997; 2001) have shown the thickness of Pleistocene drift deposits over the sandstone to vary from less than 10 metres to over 100 metres. The drift is thicker in western Shropshire than eastern Shropshire, and striking linear features have been revealed. If the data is portrayed as contour maps of the sandstone surface, these reveal the Pre-Pleistocene topography. There is a vast thickening of drift along the line of the River Severn, between Llandrinio and Montford Bridge This delineates the Severn Trench which represents an infilled sub-glacial linear channel feature, carved 50 metres below sea level (Figures 8 and 9).

The level of the groundwater table is at or around the level of the River Severn, with a slight rise beneath upland areas. The level of the water table responds directly to the amount of recharge as determined by effective rainfall (Figures 10 and 11).

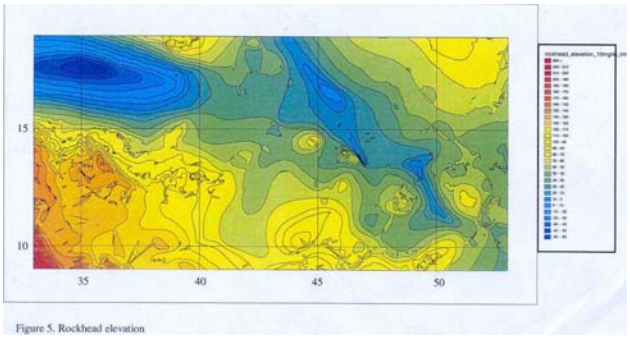

Figure 8. Elevation of base of Triassic sandstone outcrop west of Shrewsbury, from a BGS study (2001) carried out on behalf of the Environment Agency. © Environment Agency, all rights reserved.

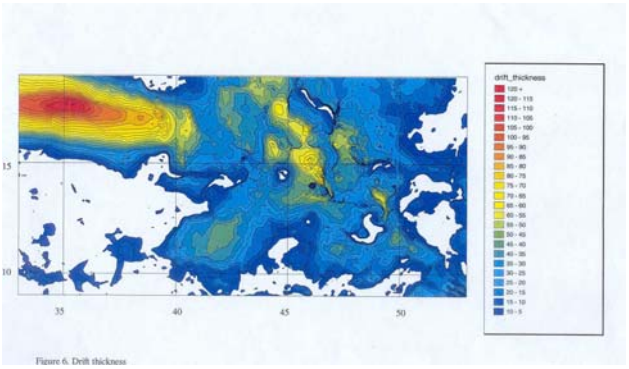

Figure 9. Thickness of Quaternary "drift" deposits west of Shrewsbury, from a BGS study (2001) carried out on behalf of the Environment Agency. © Environment Agency, all rights reserved.

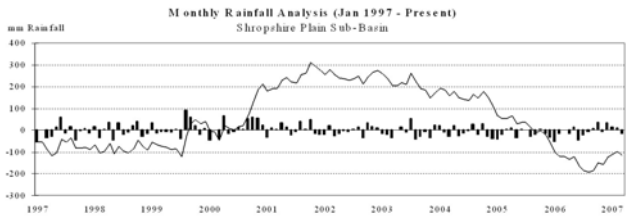

Figure 10. Monthly rainfall for North Shropshire, 1997-2007. © Environment Agency, all rights reserved.

Figure 11. Long term water table trend, Permo-Triassic Sandstone North Shropshire observation well, 1976-2006. © Environment Agency, all rights reserved.

The contours reflect groundwater elevation. These can be analysed to indicate groundwater flow directions, which tend to be southwards north of Shrewsbury (Figure 12). It is not currently known whether this drainage is towards the present-day River Severn or to Devensian glacial or fluvioglacial sediments.

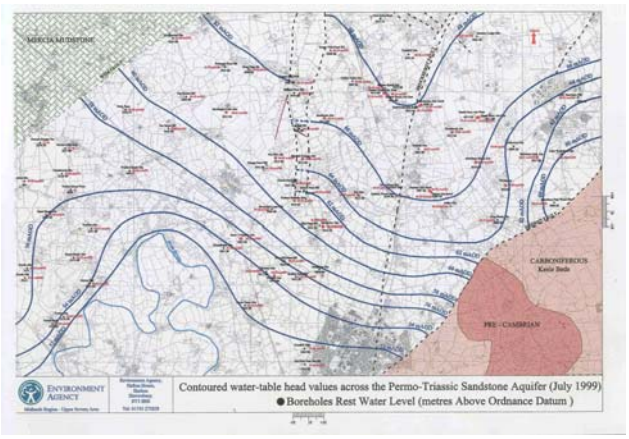

Figure 12. Contours of groundwater level north of Shrewsbury. © Environment Agency, all rights reserved.

Faults can provide effective aquifer management boundaries. Sometimes they act as conduits and sometimes as barriers to groundwater flow, depending upon whether they throw sandstone against sandstone, or against mudstone, an whether or not clay or crushed quartz is smeared along the fault gouge. Generally faults act as barriers to flow across them (with smears of clay or crushed quartz), yet can enhance flow along them (if broken rock fragments prevail).

Some faults are known from British Geological Survey (BGS) mapping work. However, not all faults can be detected from the surface outcrops and sometimes previously unknown faults are discovered during investigation work for the SGMS. For instance, asymmetry in drawdown around a test well could be indicative of a near by fault. In addition, breaks in drawdown curve show a change in the availability of groundwater; an increase may indicate a fault changing the geometry of the water-bearing sandstone, as shown by the effect of the Hodnet Fault near the River Tern, north of Wellington. Various conceptual models have been constructed to explain the observed water level responses (Figures 13 to 15).

The River Tern area has been looked at in detail. Starting with the BGS map and using additional information from boreholes and geophysical surveys, a three dimensional picture has been constructed. This shows three main faults: the Preston Brockhurst Fault, the Hodnet Fault and the Childs Ercall Fault, all trending northeast-southwest. These are the same trends (and presumably stress patterns) as exist in South Shropshire, but they are not as obvious. The dotted fault lines on the BGS map indicate their speculative nature but this is not good enough for

hydrogeologists, who need to know exactly where the faults lie. Because it is necessary to know the thickness of strata within the fault blocks, an isopachyte map was drawn for the sandstone. This showed that the thickness varies from 30 metres to 240 metres over a short distance, indicating a significant feature controlling the base of the Permian Bridgnorth Sandstone. A minimum thickness of 60 metres is needed for a significant water supply aquifer, a condition which is satisfied here.

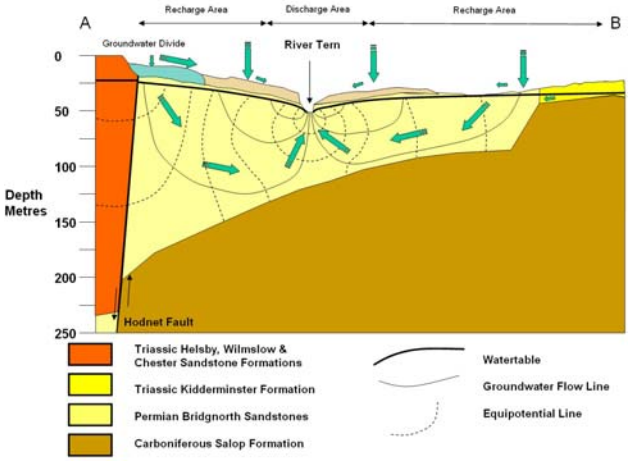

Figure 13. Simple conceptual model of groundwater flow in the vicinity of the River Tern, with only the Hodnet Fault. © Environment Agency, all rights reserved.

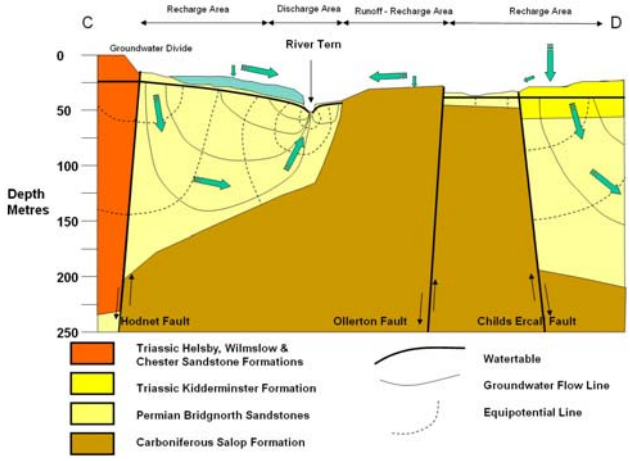

Figure 14. Simple conceptual model of groundwater flow in the vicinity of the River Tern, with the mapped Hodnet Fault and Childs Ercall Fault and postulated Ollerton Fault with minor displacement and little "drift" cover. © Environment Agency, all rights reserved.

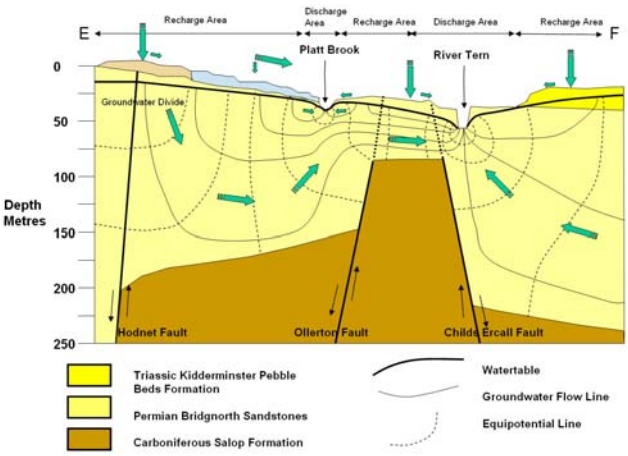

Figure 15. Simple conceptual model of groundwater flow in the vicinity of the River Tern. The unmapped southern extension of the Ollerton Fault is interpreted to form a horst block with the Childs Ercall Fault, causing localised thinning of the Permian Sandstone aquifer. © Environment Agency, all rights reserved.

GROUNDWATER DEVELOPMENT

The first phase of the SGMS development comprised 9 water abstraction wells over an area of 33 square kilometres, plus 50 observation wells (Figures 16 and 17) (Shepley & Streetly, 2007).

When flows in the River Severn start to fall, additional water is released into the river from the conjunctive use of both surface water (Llyn Clywedog) and groundwater (SGMS). Artificial regulation of the river aims to balance the demands of abstractors while safe guarding the ecological needs of the river environment. Initially, water is released from Llyn Clywedog and Lake Vyrnwy reservoirs in the headwaters of the River Severn catchment. If the low flows continue for a long period, there is not enough water in these reservoirs to maintain the required releases.

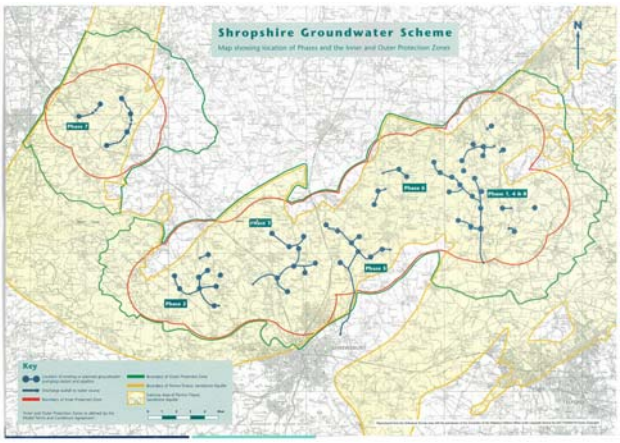

Figure 16. Extent of the Shropshire Groundwater Management Scheme, showing linked boreholes for each phase of development. Shrewsbury is in the lower middle of the map. © Environment Agency, all rights reserved.

Phase	Gross Yield	Regulation Seasons Requiring SGS Support
Phase 1 (commissioned 1984/85)	45Ml/d	1984, 1989, 1995, 1996, 2006
Phase 2 (commissioned 1991)	50Ml/d	1995, 1996, 2006
Phase 3 (commissioned 1999)	50Ml/d	2006
Phase 4 (commissioned 2005)	45-50Ml/d	2006
Phase 5	60-65Ml/d est.	Underdevelopment
Phase 6	20-25Ml/d est.	Not developed
Phase 7	35-40Ml/d est.	Not developed
Phase 8	40-45Ml/d est.	Not developed
TOTAL SCHEME	(max 330Ml/d)	

Figure 17. Phases of development for the Shropshire Groundwater Management Scheme boreholes are drilled. © Environment Agency, all rights reserved.

Like any other water user, the Environment Agency has an abstraction licence that allows the drilling and pumping of the SGMS boreholes. The licence contains conditions which state where the boreholes can be drilled and exactly how much water can be pumped from them. The licence also states that the Scheme can only be used for the purpose of supporting flows in the River Severn when the water stored in Llyn Clywedog cannot meet the expected demand for water.

Before the decision is taken to go ahead with drilling the boreholes, investigations are carried out to see what impact pumping the groundwater might have (Figures 18 to 21). This monitoring continues now the scheme is in place and includes checks on water levels in observation boreholes and pools, as well as analysis of water quality and wildlife populations. This is to ensure that the scheme has a minimal environmental impact.

The Environment Agency has put in place safeguards to protect other water users in the locality who may be affected by the scheme. For example, if pumping from the SGMS boreholes causes water levels in a nearby well to fall causing a problem for users of that well, the Environment Agency will provide an alternative supply of water (Figure 22), if the well existed before the Scheme was fully licensed in 1981. Such sources are deemed to have "protected rights" in the event of derogation.

Figure 18. A Shropshire Groundwater Management Scheme weir for measuring surface water flow in the Potford Brook. © Environment Agency, all rights reserved.

Figure 19. Collecting a sample for water quality testing. © Environment Agency, all rights reserved.

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Figure 20. In-stream flow gauging. © Environment Agency, all rights reserved.

Any water users who are potentially at risk from impacts of the scheme are identified during the initial construction of each phase of borehole development. This means that problems are identified in advance of them occurring and solutions can be put in place.

The Shropshire Groundwater Scheme is designed to be used, on average, once every three years to meet peak dry weather demands for water. Even then, the Scheme is only pumped in short bursts for up to a maximum of 148 days in any year. In addition, the scheme is licensed to be used for approximately 250 days in any five year period.

Figure 21. Apparatus for measuring water depth within an observation well. It is important to study fluctuations especially in times of drought or after pumping water in or out of the ground. In the case of artesian wells, where water is under pressure, the recorder is placed in a pipe extending up to several metres above ground. © Environment Agency, all rights reserved.

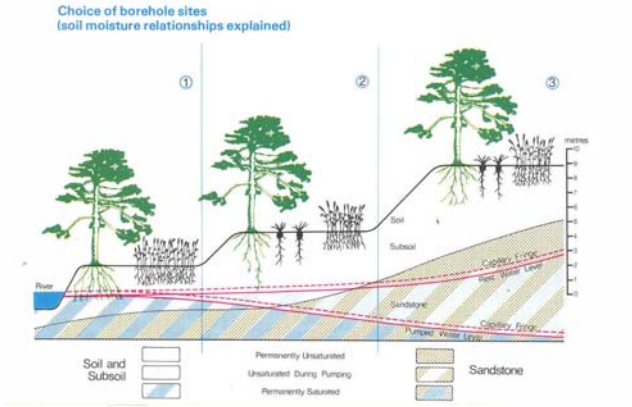

Figure 22. Range of possible relations between groundwater level, soil moisture and root depth. © Environment Agency, all rights reserved.

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CONCLUDING REMARKS

In the United Kingdom there are four principal rock formations which provide porous aquifers *viz.* Carboniferous Limestone, Permo-Triassic sandstone, Jurassic limestone and Cretaceous chalk. There are other rock types which provide small, local aquifers, but the bulk of the public water supply is taken from these four.

The proportion of water taken from the ground varies across the country. In the southeast it is 80%, largely from chalk and greensand; in Wales it is only 3-4% because there are few aquifers; and in the Midlands it is 39%, which is a typical figure for most of England and Wales.

Working in conjunction with principal water users, the Environment Agency aims to balance the growing demands on dwindling natural resources through short, medium and long term strategic water resource planning. This calls for greater efficiencies and more innovative use and deployment of existing surface and underground water resources in the face of increasing population demands and the uncertainties of future climatic change. To meet this challenge it is necessary to secure and preserve vital surface and underground water resources.

The Environment Agency is responsible for the operation and development of the Shropshire Groundwater Management Scheme. Located solely within North Shropshire this is the largest of the UK's groundwater regulation projects. The Shropshire Groundwater Scheme has been identified by the Environment Agency and water companies as one of the key strategic options for developing further water resources within the River Severn supply zone in order to meet growing water demands within the foreseeable short to medium term future.

The Shropshire Groundwater Scheme is designed to be used, on average, once every three years to meet peak dry weather demands for water. Water is pumped out and released to the River Severn to enhance flows in the river from groundwater reserves naturally stored within the sandstone underlying much of North Shropshire. Around each borehole a pumping station is built, which is designed to have a minimal impact on the local environment.

The scheme has six development areas and is being constructed in eight stages. At the present time, four phases have been completed and the fifth is underway.

If all phases of the scheme had been developed at once it is estimated that it would have cost around £20 million. This is significantly cheaper than the construction of a new dam for a reservoir, and has the added advantage of there being negligible visual impact; it also allows a phased development to complement demand.

In discussion, Professor Brian Wilkinson, former Director of the Centre for Ecology & Hydrology, showed the audience his original hand drawn map and hand written manuscript used to consider the groundwater potential of Shropshire. Prepared in June 1970, before the advent of personal computers, the predictions deduced from a desk study supported by hand calculations have been found to be remarkably close to the actual groundwater yields now that the scheme is in operation.

In conclusion, a couple of interesting figures: UK surface reservoirs store 2,500 million m^3 of water. The upper twenty metres of the three principal UK aquifers can store twenty times this volume; the Permo Triassic sandstone alone stores 36,000 million m^3.

ACKNOWLEDGEMENTS

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