"Non-parametric statistics as a tool for the hydraulic and hydrogeochemical characterization of hard rock aquifers"

David Banks and others

The new EU Water Directive implies that hard rock units will need to be considered as aquifers, and to be hydrogeologically and hydrogeochemically characterized. This is not a straightforward task, given that the aquifers are heterogeneous, discontinuous and strongly three-dimensional in the distributions of both hydraulic and hydrochemical properties. The Geological Survey of Norway has recently carried out characterizations of Norway's hard rock aquifers using simple non-parametric statistical techniques, focusing on median and percentile values for aquifer properties and concentrations of chemical parameters. Such characterizations reveal far larger parameter ranges within given aquifer lithological units than between different units. Indeed, for most lithologies, median well yields and concentrations of major chemical parameters (e.g. pH, major ions) are remarkably similar. For certain elements, however, systematic differences can be detected. For example, elements such as uranium, radon and fluoride are significantly enriched in Precambrian granites and gneisses, and depleted in anorthosites.

Developing hydrogeological understanding for groundwater management: the example of the Dumfries Permian basin aquifer

Brighid O Dochartaigh

European & UK legislation, including the Water Framework Directive, requires that groundwater pollution be prevented & groundwater resources managed sustainably. Regulators need to address the risks imposed by point and diffuse sources of pollution and abstractions on the groundwater resource. In practice, this will involve a range of measures including the designation of nitrate vulnerable zones, the use of groundwater vulnerability maps in development planning, and the introduction of groundwater abstraction licensing. The successful use of risk assessments and implementation of control measures will depend on a sound scientific understanding of groundwater processes. In Scotland, much research is still needed to reach the level of hydrogeological understanding required for effective implementation of the Water Framework Directive.

The Permian sandstone/breccia aquifer in the Dumfries basin is one of the most productive aquifers in Scotland, supporting large and important abstractions for public supply, industry and agriculture. Management of the aquifer under the Water Framework Directive will be a key challenge. Although it has been the most extensively researched of all the Scottish aquifers, there remain a number of uncertainties in our understanding of its hydrogeology. It is useful to use the aquifer as a model to examine issues such as the design of groundwater studies, and the type and amount of hydrogeological data required to develop sufficiently robust conceptual models. A brief history of hydrogeological research and the development of understanding of the Dumfries basin aquifer is given. Emphasis is placed on recent work designed to address knowledge gaps and to develop a new and robust conceptual model for the groundwater system, in preparation for the next stage of investigation, which is the numerical simulation of the aquifer. A robust, predictive numerical model is a key tool for effective groundwater management of the Dumfries aquifer, enabling further development to take place in a controlled manner without risk to existing abstractions or to the resource in general.

Pentland Springs – an untapped store of knowledge

Dr Andrew R Black Department of Geography, University of Dundee, DUNDEE, DD1 4HN a.z.black@dundee.ac.uk

Springs issuing from the northern flank of the Pentland Hills have been utilised for water supply and monitored since 1862. A programme of extracting records into digital form for

analysis has recently been undertaken. Some records have yielded more than 100 years of essentially continuous flow readings at either monthly or weekly time intervals, with daily rainfall readings available from 1904. Together, the three spring flow records and one rainfall record captured provide the scope to examine the hydrological effects of climatic variability over a time period far in excess of that which is possible using river flow records. Furthermore, the spring flows provide information directly relevant to groundwater interests, based on direct measurement rather than modelling, and capture the hydrogeological response of contrasting aquifers to some of the most extreme droughts of the 20th century. Between 1904 and 1982, the years registering lowest instantaneous inflows are 1959, 1972, 1955 and 1960, showing some similarities with the reconstructed 88-year inflow series for Talla Reservoir in the Scottish Borders, but also some notable differences.

Land use changes or changes to the flows being captured by the spring heads may be responsible for some changes in the long-term behaviour of the spring flows. As a means of enhancing the utility of the records, it is proposed to undertake field and water chemistry investigations to improve understanding of the provenance of the spring flows, and to use rainfall records to introduce corrections to the observed series in order to achieve homogeneity. It is hoped that the records will then be of value in assessing the sensitivity of these spring flows to climatic shifts and their reliability as resources.

Implementing The Water Framework Directive – Implications To Groundwater Abstraction Case Study On Scottish Water's Silkirk (Howden) WTW

Water supply provision is both an investment and a public service. It is an investment because it is constructed as part of a local infrastructure towards generating future economic activities and is a public service because it must meet basic human needs (quality and quantity), at a fee or for free depending on local policies. The development of a water infrastructure therefore, should be such that meets the present needs of the people without compromising the ability of future generations to meet their own needs. Water and sewerage is a major industry in Scotland with virtually everyone in Scotland as a customer. As customers they expect that the water will flow when the tap is turned on and that their dirty water will disappear when the plug is pulled. Scottish Water is responsible for providing both of these services.

SW is the fourth largest water and sewerage services provider in the UK with a customer base of 5 million, producing 2.5 billion litres of water a day, covering 6,200 miles of coastline and will be investing £1.8b in assets up to 2005. In order to meet the varied and wide customer expectations, SW abstract raw water from varied sources (rivers, reservoirs, locks, and aquifers), treat the water, supply it to customers; domestic, industrial and commercial; through a vast array of pipe networks. It also receives wastes via sewers; treat them before discharging to natural watercourses.

In discharging both functions, there are economic, quality and health and safety standards to be met and the implementation is through various regulatory bodies (the economic, quality, environmental and health and safety regulators). Over the years there have been various UK and European legislations relating to water and sewerage services and enforcement is through the various regulators. In Scotland, the Water Industry Commissioner (WIC), Drinking Water and Quality Regulator (DWQR), Scottish Environmental Protection Agency (SEPA) and the Health and Safety Executive (HSE) are the major regulators.

River Ettrick is a major watercourse in the Borders region of Scotland and SW currently operate a WTW adjacent to the river and its raw water source is from groundwater (from wells drilled into the gravel beds of the alluvial deposits). The suspicion is that there maybe interaction between the groundwater and the river.

Currently in Scotland, groundwater abstraction is not subject to Water Order (WO) and there are no legal requirements for SW to comply with at present. Also, under the current Environmental Impact Assessment (EIA) Regulations 1999, the abstraction intended for the treatment works (15Ml/d) is less than the threshold at which the Planning Authority would

require a full EIA given that the area covered by the works is less than one hectare. Under the current European Union (EU) Water Framework Directive (WFD), which came into force on 22nd of December 2000, and the new Water Services and Environmental Bill (WSEB), a comprehensive control regime for all abstractions of water in Scotland will be introduced.

This paper therefore will explore the implications of implementing the EU's WFD and the UK's WSEB, which are the most comprehensive and recent of existing legislations relating to water resources. They aim of these legislations is to establish a new, integrated approach to the protection, improvement and sustainable use of rivers, lakes, estuaries, coastal waters and groundwater.

In view of these, the main aim of this paper is to determine the implications of the WFD on the operation of the Selkirk (Howden) WTW based on groundwater abstracting at the designed capacity of 15Ml/d and to ascertain if this abstraction will have any effects on the Ettrick watercourse. This project will have three main objectives or aspects: -

· Review and examine the general implication of implementing the WFD to SW,

· Specifically investigate the implications of WFD with respect to groundwater abstraction and operation of Selkirk (Howden) WTW and

· To investigate possible environmental and ecological effects of this abstraction on the Ettrick watercourse.

Derivation of a Methodology for Groundwater Recharge Assessment in Scotland and Northern Ireland for Water Framework Directive (WFD) Initial Characterisation.

Richard Church, Entec

Recharge estimation is an important component in the characterisation of groundwater bodies for WFD, and few recharge calculations have previously been attempted in Scotland and Northern Ireland. The environmental influences on recharge processes differ from much of the rest of the UK and the ability of the groundwater body to accept recharge is a key criteria.

The WFD timescales required a pragmatic methodology for enabling efficient assessment of recharge to each groundwater body in Scotland and Northern Ireland to be developed. The method proposed is based on a water budget approach which estimates direct and indirect recharge flow components. It includes estimation of effective rainfall, actual evapotranspiration and run-off in addition to the potential impacts of snow-melt, bypass flows, urban recharge and surface water leakage where appropriate. This is calculated on a daily or monthly time step with the use of a spreadsheet software tool.

The degree of uncertainty in the recharge estimation increases with the scarcity of data available to the groundwater body. Many areas in Scotland and Northern Ireland will rely on national scale mapping of climatic, landuse, soil and aquifer properties. It is important that the confidence in the recharge estimation is balanced against the perceived risk of stress to the groundwater body. Validation of the recharge calculations is ongoing and the assessment of run-off and interflow has been determined as critical to the accuracy of the calculation.

Groundwater Challenges of the Water Framework Directive in Scotland: (0- 60 in 12 months…)

Clews, Jean; Conroy, Peter; Fitzsimons, Vincent; Morrison, Paul and Simpson, Elaine
Scottish Environment Protection Agency, Erskine Court, Castle Business Park, Stirling, FK9 4TR

Until recently, there has been no major driver to focus attention on the groundwater environment in Scotland: an abundance of surface water resources has led to only limited use of groundwater for public water supply. Although groundwater is extensively used for private supply in rural areas, groundwater has often been overlooked in the planning process. Tools for groundwater quality management, such as groundwater vulnerability maps and source protection zones have not been widely available and there has been no coherent strategy for water resource planning.

The Water Framework Directive 2000/60/EC (WFD) has introduced new objectives for groundwater protection and improvement. This has been transposed into Scottish law in the Water Environment and Water Services (Scotland) Act 2003 (WEWS). These new objectives refer to both groundwater quality and quantity and require an understanding of the interaction between groundwater and surface water ecosystems. This requires an understanding of groundwater as a receptor in its own right, along with interactions with associated receptors such as wetland ecosystems. The Directive has therefore forced a rapid increase in the groundwater knowledge base in Scotland and has necessitated the rapid development (or adaptation) of fit-for-purpose tools and methodologies.

This paper will consider an example of how the process of characterisation took place on the Isle of Arran, describing the delineation of groundwater bodies and the process of assessing the risk of failing to meet the WFD objectives.

Nitrate Vulnerable Zones In Scotland

Derek F Ball[1], Allan Lilly[2] and Alan M MacDonald[1]

[1]British Geological Survey, Murchison House, West Mains Road, Edinburgh, EH4 SQX, 0131 667 1000

[2]The Macaulay Institute, Craigiebuckler, Aberdeen, AB15 8QH

Nitrate derived from agricultural activity is a serious concern to Scotland's water environment. As well as being a source of drinking water, groundwaters also help to maintain summer base flow in many streams and rivers. Elevated nitrate concentrations in groundwater can therefore lead to eutrophication of surface waters.

European legislation (91/676/EEC) requires that waters with a concentration of NO_3 greater than 50 mg L^{-1} (and those at risk of exceeding this concentration) should be identified – and the catchment areas designated as Nitrate Vulnerable Zones (NVZs).

Groundwater nitrate vulnerable zones for Scotland were developed by BGS and The Macaulay Institute using a methodology which combined several Scottish datatsets (see Figure 1). The risk of nitrate leaching was determined from soil and land use data. Digital solid and superficial geology data (at 1:50k) for the country were interpreted to give an indication of aquifer vulnerability. This was combined with the information on the risk of nitrate leaching from crops and soils. The final zones were then calculated by identifying local water catchments associated with areas of highest risk and vulnerability.

The results of the vulnerability/risk analysis were consistent with the available nitrate data for much of Scotland. Groundwater nitrate data was collated from SEPA's monitoring network, water authority boreholes and private water supplies; additional data was collected from targeted sites. Within the NVZs, 25% of approximately 2000 samples exceed 50 $mg.l^{-1}$. Throughout the rest of Scotland, less than 5% of approximately 1000 samples exceed 50 $mg.l^{-1}$.

The nitrate vulnerable zones have now been designated by the Scottish Executive and action programmes are being established to reduce nitrate contamination in these areas.

Mapping groundwater vulnerability in Scotland: a new approach for the Water Framework Directive.

Vincent Fitzsimons, *SEPA, Edinburgh*

Derek Ball, Brighid Ó Dochartaigh, Alan MacDonald, Maria del Rio Maria and Clive Auton, British Geological Survey, Edinburgh

Alan Lilly, The Macaulay Institute, Aberdeen

Groundwater is a valuable asset in Scotland. It supports around 30,000 private water supplies in rural areas. It is also used as a source for public water supply and to support many industries, including agriculture and food and drink sectors. Groundwater maintains flow to streams and wetlands throughout the year and maintains these ecosystems throughout dry periods.

Groundwater, however, can be degraded by human activity, including the disposal of domestic septic tank effluent, waste disposal and landspreading of industrial and agricultural wastes. Planning considerations and site investigations (where applicable) might be most efficiently focused on areas where the likelihood of contamination is greater. Maps of groundwater vulnerability provide measure of the relative likelihood that contamination on the groundwater surface will reach the water table. For such maps to be useful to non specialists, they should be: (1) easy-to-use, (2) based on objective criteria and (3) underpinned by sound scientific principles.

Driven by the Water Framework Directive a methodology has been devised for mapping groundwater vulnerability in Scotland. The methodology has been applied to the whole of Scotland to produce a 1:50 000 scale groundwater vulnerability map. A general vulnerability methodology was used which assessing the *intrinsic* properties of the pathway between the ground surface and the water-table (or top of aquifer) to a non-specific *general* contaminant.

The main datasets developed to generate the vulnerability map were:

- Superficial deposit permeability developed from a combination of geology and soil maps
- Depth to water table within aquifers with significant intergranular flow
- Superficial deposit thickness
- Groundwater flow mechanism within bedrock aquifers
- Soil permeability

A key difference between this and previous groundwater vulnerability assessments in Scotland is that this current method does not take into consideration the importance of the groundwater resources – it rates only the vertical flow pathway between ground surface and aquifer. This allows the flexibility to assess different receptors; some of which may occur directly below the vertical pathway (e.g. groundwater in drinking water protected areas), while others may lie at some distance downstream (e.g. groundwater dependent terrestrial ecosystems). Downstream receptors require a consideration of the vertical pathway to groundwater and the lateral pathway within an aquifer. Thus, the vulnerability assessment can be used flexibly within a Geographic Information System (GIS) to combine land use (the potential "hazard"), vulnerability (the vertical "pathway"), the lateral pathway (where relevant) and different receptors in order to provide an assessment of relative risk in different areas.

The vulnerability maps are intended to help underpin many of the implementation measures to be developed under the Water Framework Directive. Vulnerability maps, along with hazard

and receptor maps, can help provide regional-level indications of higher risk areas and, as such, can be used to help focus planning, regulatory, and investigatory attention more defensibly on key areas.

Groundwater - surface water interactions and the ecological status of rivers in the Scottish uplands: emerging research and management issues

Soulsby, C., Gibbins, C.N., Rodgers, P.J. Department of Geography and Environment, University of Aberdeen.

Malcolm, I.A., Youngson, AF Fisheries Research Services, Freshwater Laboratory, Pitlochry.

Hannah, D.M. School of Geography, Earth and Environmental Sciences, University of Birmingham.

Waldron, S. Scottish Universities Environmental Research Centre, East Kilbride.

Until recently groundwater in the Scottish uplands was largely ignored both in terms of its influence on catchment hydrology and potential as a water resource. Recent research has shown this view to be erroneous; despite being sometimes small in volume, groundwater reservoirs in drifts and rock fractures contributes a significant proportion of annual river flows and exert a strong control the quality of surface waters. It is becoming increasingly apparent that groundwater - surface water interactions also play a key role in influencing the "ecological status" of headwater streams, and indeed larger river systems downstream. Understanding these interactions between groundwaters and the "ecological status" of surface water is a key research requirement needed to underpin the EC Water Framework Directive.

This paper, which draws from a range of interdisciplinary studies at several experimental sites in the Scottish highlands, will illustrate some of the key issues that are emerging from current research. The contribution of groundwater to annual stream flows will be shown to vary between 25-60% in catchments with broadly similar environmental characteristics. Isotopic tracer studies have been used to show the nature of different upland groundwater stores, which help explain such variations in terms of the size of storage and mean residence times. The importance of groundwater contributions to the thermal regimes of upland streams will also be examined; recent energy balance studies show that 30% of the annual heat flux to surface waters can be ascribed to groundwater discharge through the gravel beds of streams. The ecological implications of these hydrological influences, energy transfers and the hydrochemical properties of discharging groundwater for salmonids and invertebrates in upland streams will be highlighted. Some implications of management activities which affect these groundwater-surface interactions, such as river regulation, will also be examined in terms of their effects on the ecological functioning of aquatic ecosystems.