International Association of Hydrogeologists

Strategic Overview Series

THE ENERGY SECTOR & GROUNDWATER

KEY MESSAGES

- the energy sector interacts with groundwater in many ways and applied hydrogeological science is required to understand and manage the linkages
- this is highly relevant to the sustainable development of hydrogeothermal energy (particularly 'very low enthalpy' resources used for space cooling/heating) and to the nuclear power sub-sector for power station siting and radioactive waste disposal
- in non-renewable hydrocarbon development the principal concern is to prevent shallow aquifer pollution with formation brines, hydrocarbon compounds and fracking fluids
- injection into gas and oil wells is important for hydrocarbon waste management, but knowledge of the 'intermediate zone' between aquifers exploited for groundwater supply and deeper hydrocarbon-producing strata is generally inadequate
- globally groundwater pumping, notably for irrigated agriculture, is a major energy consumer and much more effort needs to be put into reducing inefficient use due to aquifer depletion and inappropriate waterwell design
- effective land management for municipal groundwater source protection is an urgent need to avoid the large energy cost associated with water-supply treatment to remove pollutants (such as nitrates, pesticides and industrial chemicals)

How does the energy sector interact with the groundwater domain ?

The generation, consumption and management of energy interacts with the groundwater domain in surprisingly varied ways. In consequence specific inputs from hydrogeological science are needed to understand these linkages, and for risk assessment and effective management of the interactions. To facilitate discussion it is helpful to classify the interactions under the following headings :

- sustainable exploitation of renewable energy resources
- groundwater impacts of non-renewable energy sources
- energy consumption for groundwater pumping and use.

How is renewable energy development linked with groundwater ?

- ***High Enthalpy Hydrogeothermal Resources***

These resources usually occur deep underground and are characterised by high temperature (>150° C) and in-situ pressure, but are of limited geographical distribution being mainly associated with volcanic activity. Where present they can be exploited by extracting water directly for power generation.


GEOTHERMAL POWER PLANT

This Series is designed both to inform professionals in other sectors of key interactions with groundwater resources and hydrogeological science, and to guide IAH members in their outreach to related sectors.

Hydrogeological investigations are required to assess the design of geothermal wells and their sustainable yield/temperature relation.

- ***Low Enthalpy Hydrogeothermal Resources***

There is a current boom in exploiting shallow, very low enthalpy resources (< 50° C at atmospheric pressure) using either :

- ground-coupled heat-pumps for winter space heating and summer air conditioning (with warm water injected for later recovery)
- groundwater directly for space cooling.

Indeed some cities are having to regulate well construction to avoid thermal (as well as hydraulic) interference between neighbouring installations. Given the high standards of thermal insulation in modern office buildings (and the ubiquitous presence of transformer heat sources), it is commonplace for such buildings to have very limited heating needs but to have almost year-round cooling requirements. Hydrogeological analysis and modelling are crucial for the assessment of just how sustainable such systems are in relation to borehole spacing, aquifer properties and thermal breakthrough.

- ***Nuclear Power Stations & Waste Disposal***

Groundwater conditions are a key siting consideration for nuclear power-generation plants – and the possibility of groundwater flooding is one of the numerous hazards that must be evaluated. Risk assessment and management of radionuclide release from nuclear installations relies on understanding groundwater flow, hydrogeochemical conditions affecting radionuclide mobility, and how potential contamination might impact biological receptors.

Radioactive waste management is a chronic technological challenge posed by all nuclear activities (including medical radionuclide use, uranium mining and processing) not only power generation. Safe long-term disposal of radwaste is the ultimate aim, and geological disposal is widely recognised to impose least burden on future generations and lowest risk in the context of climatic and environmental change. Groundwater can affect both the integrity of engineered barriers and the transport of released radionuclides. When assessing potential host rocks and adjacent formations the relatively great depth involved poses a hydrogeological challenge. Characterisation and modelling of these deep low-permeability systems is necessary to assess ground capacity to retain radionuclides and prevent their transport to the surface.

The role of the subsurface as a barrier and attenuating mechanism must be moderated by credible assessment of risks to groundwater resources. Hydrogeological expertise needs to be engaged by both implementing organisations and regulatory agencies to ensure :

- acquisition of site-specific data, interpretation of groundwater processes, and statistical evaluation of hydrogeological uncertainty
- development and testing of conceptual hypotheses for long-term processes in these unusual groundwater environments
- calibration of numerical groundwater models at appropriate scales and degree of complexity relative to potential radionuclide release, and their application for prediction under 'realistic' and 'worst-case' scenarios.

IRRIGATED OIL-SEED CULTIVATION

- ***Biofuel Crop Cultivation***

The extensive cultivation of crops destined for biofuel production widely implies large applications of fertilisers and pesticides, and sometimes requires significant crop irrigation and process water. For example, in the USA bioethanol production from soya beans under groundwater irrigation has expanded rapidly since the introduction and amplification of subsidies in 1998 and 2005 respectively. Evaluation of the impact of such cultivation on groundwater systems should follow a similar approach to that used for other agricultural land-use practices.

- ***Solar Energy Capture***

In countries like India major impetus is now being put on the capture of solar energy. Farmers are strongly encouraged to use solar panels for powering pumps in irrigation water-wells. Other solar energy panels in arid terrains require water for regular cleaning, and a dedicated waterwell is often the preferred source.

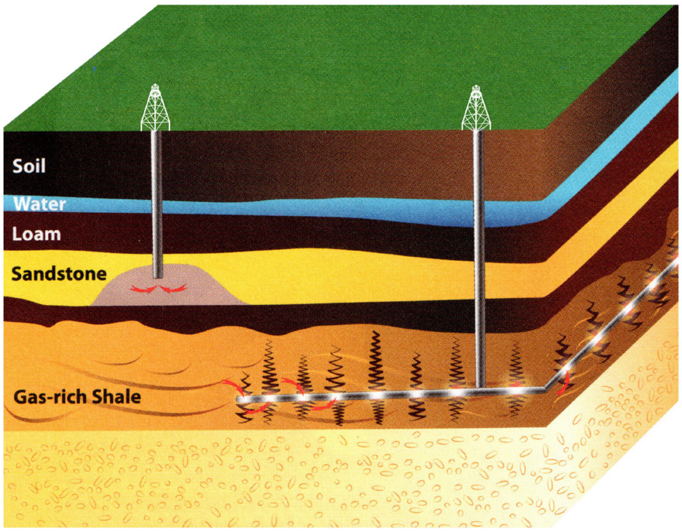
Which groundwater impacts can arise from non-renewable energy sources ?

- ***Conventional On-Shore Hydrocarbon Exploitation***

The development of hydrocarbon resources (oil and gas) can require the use of substantial groundwater resources and can pose a significant risk to the quality of shallow groundwater through infiltration or seepage of formation brines and/or hydrocarbon compounds from surface lagoons. The activity requires full hydrogeological risk assessment, appropriate environmental regulation and diligent operational control. But there is now extensive global experience as regards the processes and procedures to follow.

- ***Unconventional On-Shore Hydrocarbon Exploitation***

The current boom in unconventional hydrocarbon development, especially for shale gas (and sometimes shale oil) deploys directional drilling



COMPARITIVE SUB-SURFACE COMPLETION OF CONVENTIONAL AND UNCONVENTIONAL GAS-WELL

techniques and then fluid injection at high-pressure (>2000 kg/cm^2) in horizontal gas-well sections at 1,500-2,000m depth to generate fissures (usually <300 m length). The technique, known as 'fracking', requires 8,000-30,000 m^3/well of injection fluid (90% water plus sand and various additives). 'Flow-back fluids' (fracking liquids, formation water, and possibly leached salts and radionuclides) are extracted from shale-gas wells after fracking and stored at the surface before re-use or deep-well disposal.

Fracking has been conducted in vertical gas-wells to enhance production for many years, but its deployment in horizontal gas-well sections (often >1 km long) requires much larger fluid volumes and more complex additives. Although the utilisation of natural gas in power plants can greatly reduce their water-supply demand some concern has been voiced about :

- surface infiltration of formation waters and/or fracking fluids leading to contamination of shallow groundwater
- gas migration through natural and induced faults and fractures, and fugitive gas leakage from active or abandoned gas-wells.

To reduce these risks good design and sound construction are essential, and more hydrogeo-


A SHALE-GAS FRACKING OPERATION

logical monitoring and evaluation of operations are required to identify those settings in which shallow groundwater is more susceptible to degradation. Addressing this will require improved cooperation and joint research between hydrogeologists and hydrocarbon reservoir engineers.
The same can be said of other unconventional hydrocarbon exploitation techniques such as:

- coal-bed methane extraction, which is generally from shallower depths (< 1,000m), and can require fracking with nitrogen gas
- coal-bed gasification, which involves injecting oxygenated steam to transform coal into a gas-stream.

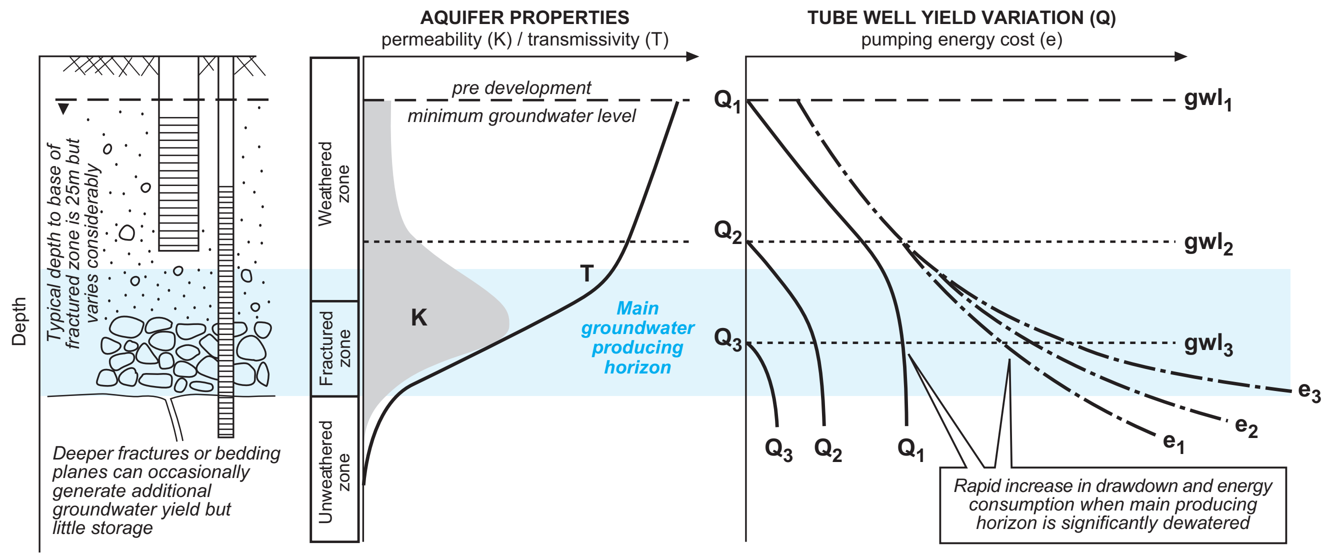
- ***Subsurface Wastewater Injection***

More generally injection into gas and oil wells is an effective waste management facility for the hydrocarbon sub-sector – but the risks remain poorly understood and are becoming more apparent with the need to handle much larger volumes of wastewater. Very large numbers of wells can be involved – for example 7% the 700,000 wells in Western Canada have already been used for injection. Cumulative injection volumes are large compared to natural groundwater flow, and responsible for the bulk of recharge to deep aquifers – thus changes in groundwater flow pattern are inevitable. Not enough effort is made to track injected brines. The distribution and properties of aquitards confining deep formations into which water is injected is often inadequately characterised, leading to a risk that the brine can migrate upwards to shallower formations. Too many areas lack adequate injection infrastructure, and the understanding and experience needed to predict the subsurface response and risk of potable aquifer contamination.

- ***Impacts of Coal-Mine Drainage & Water-Table Rebound***

In some regions major open-cast or subsurface coal mining continues to supply thermal power plants. In many cases this involves large-scale groundwater dewatering to facilitate safe mining, and this modifies the regional flow system and reduces resource availability for other users. Such activity is best planned using detailed hydrogeological knowledge, which will also be required to manage water-table rebound following mine closure. If this is not managed and treated appropriately, it is likely that unpredictable highly acidic spring discharges will appear, which can contain elevated concentrations of heavy metals. There is a huge historical legacy in this regard, which is presenting a major environmental challenge.


ACIDIC SPRING DISCHARGE FROM COAL-MINE WATER-TABLE REBOUND



ESCALATING WATERWELL ENTRY LOSSES & UNIT ENERGY CONSUMPTION WITH DEWATERING OF A SHALLOW AQUIFER

- ***Carbon Capture & Storage at Conventional Power Stations***

Continued reliance on some fossil fuel use is unavoidable for a few more decades. Thus ways need to be found to reduce its carbon footprint. One option is to deploy carbon capture-and-storage at conventional power stations using hydrocarbon energy. There is a pressing need for better understanding of the hydrogeological principles underlying the injection of compressed carbon dioxide (which has the density of a liquid) into target deep aquifers (at depths of >650m) to displace existing groundwater and accumulate below confining aquitards, such that very little will escape via geological faults or inadequately-completed boreholes over a very long time horizon (> 10,000 years).

How does groundwater exploitation affect energy consumption ?

- ***Energy Consumption for Waterwell Pumping***

The vast majority of groundwater supply sources (except for springheads and overflowing artesian waterwells) require considerable energy for pumping (but far less energy for treatment than surface-water sources). The bulk of energy consumption is by irrigation waterwells (and this is said to represent as much as 15% of global energy use), but it also represents a significant issue for public water-supply utilities. Advances in pumping technology can only deliver marginal efficiency gains – since most energy is used for raising a given mass of water against a certain lift. However, improved waterwell design can significantly reduce head losses and a rational distribution of waterwells in a wellfield can optimise the total drawdown required for a given yield.

Groundwater pumping can be an important component of national and local energy demand, and needs to be appraised in related energy sector policies. India has over 10 Mha of agricultural land under groundwater irrigation of which 70% uses electric-motor pumps, consuming a colossal 87,000 GWhr. The remaining 30% is irrigated with waterwell pumps powered by diesel fuel. In states with a high coverage of rural electrification (Gujurat, Maharastra, Andhra Pradesh & Tamil Nadu) farmers rely exclusively on electric-engined pumpsets and receive a large subsidy via ‘flat-rate tariffs’ (only paying for 20% or less of the electricity they consume). In areas with rapidly-depleted aquifers (such as the weathered hard-rock systems of Peninsular India), there is a very high consumption of energy per unit of groundwater pumped, with much being consumed

THE ENERGY SECTOR & GROUNDWATER

because of very high well-entry and pump-friction losses. Rural energy subsidies exert a major influence over farmer attitudes towards waterwell use – and policy harmonization is required to provide a clear incentive for energy conservation. Moreover, much more effort needs to be put into critically assessing and improving waterwell efficiency, and into reducing aquifer depletion to mitigate this effect.

- ***Groundwater Supply Treatment & Desalination***

The operation of treatment plants for the removal of nitrates, pesticides and/or industrial chemicals at water-utility groundwater sources implies a substantial electrical energy cost, which can be largely avoided by implementing effective co-management of the neighbouring land as part of systematic groundwater source protection programmes.

Brackish groundwater will be much preferred to sea-water as the source-water for desalination, because it will generally be of lower salinity and sediment free – and thus reduce energy consumed and operational cost. Hydrogeological evaluation and monitoring are required to design sustainable waterwells for brackish groundwater abstraction.

PRIORITY ACTIONS

- **long-term monitoring and modelling of groundwater system response to very low enthalpy hydrogeothermal development is needed to assess sustainabiity and to improve design**
- **political and public confidence needs to be built-up on the ability of hydrogeological science to guide the selection of safe geological repositories for radioactive waste**
- **on-shore hydrocarbon exploitation of all types requires full hydrogeological risk assessment, appropriate environmental regulation and diligent operational control**
- **improved cooperation and joint research between hydrogeologists and hydrocarbon reservoir engineers is required to monitor and evaluate the groundwater impacts of shale-gas fracking and fluid injection wells**
- **energy consumption due to ground-water resource over-exploitation needs to be more critically assessed, and coordinated trans-sector policies put in place that constrain energy use for groundwater pumping and conserve aquifer storage reserves**
- **improved protection of potable groundwater sources through effective land management is required to avoid the large energy cost associated with water-supply treatment to remove nitrates, pesticides and industrial chemicals**

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