to implement an appropriate governance regime in which users are granted rights and responsibilities. Such a regime would encourage self-governance within the parameters set by the government that owns the resource on behalf of the people.

While the various user sectors may be responsible for establishing the informal institutional arrangements necessary for self-governance[7], it is the government's responsibility to establish the formal institutional arrangements for broader governance. However, the success of formal institutions such as national policy and regulation is strongly dependent on how effective informal institutions are in establishing and promoting the roles of non-state actors. ES

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Water security and shale gas exploration in the UK

Jenna Brown, Chad Staddon and **Enda Hayes** outline the water requirements of shale gas extraction and discuss the implications for UK water security.

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A GLOBAL ENERGY CHALLENGE

A global challenge has been set: how to meet a growing population's energy needs while reducing carbon emissions to *mitigate* climate change. Natural gas has been purported as a 'transition fuel', as the energy mix moves towards reduction targets set out in the Climate Change Act (2008). There is, however, the complication that at least 50 per cent of the 85 billion cubic metres (bcm) we consume annually in the UK has been imported since 2011. Owing to increased gas prices, shale gas has received interest as a resource, as the UK seeks to emulate the success of the USA in shale gas extraction and in doing so improve natural gas security of supply.

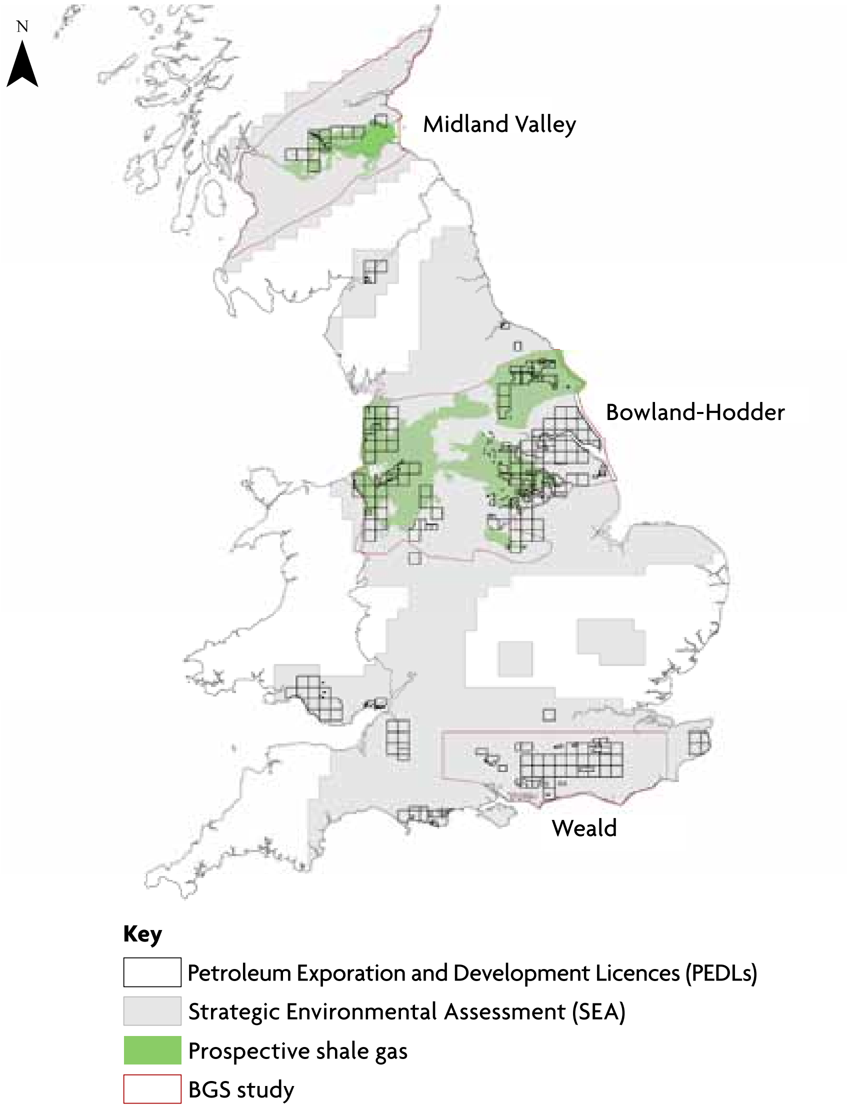
There is also a second parallel global challenge: how to produce energy to meet growing demand while *adapting* to climate change. Shale gas extraction is a water-intensive industry. In the UK alone we have seen the floods of 2007, followed by the environmental drought of 2012 and again the floods of winter 2013–2014. Climate change can influence our water security and, as population increases, finite freshwater resources per capita can only reduce. Are we therefore risking a trade-off of low-carbon energy security in shale gas for water security?

WHAT IS SHALE GAS?

There are three key differences between conventional (e.g. the North Sea) and shale gas: the geological location, the process of extraction and the well intensity.

In conventional gas extraction, a pocket of gas capped by an impermeable rock is located. A single well is drilled vertically into the pocket with the difference in pressures forcing the predominant volume of gas to the surface. Although the pockets of gas are dispersed, once one has been located and developed it can produce gas for around 30 years.

In unconventional gas such as shale, the volume of gas *in situ* is greater than for conventional gas, but the concentration and permeability is reduced. Shale therefore requires stimulation for the gas to be released. This is accomplished by a process known as hydraulic fracturing or 'fracking'. Following the drilling of a vertical well into the shale (at a depth greater than 2,900 m), a water-based fluid is pumped into a designated section of a horizontal well at pressures greater than the geology causing it to fracture; a proppant (sand) is pumped into the well to hold open the fractures, enabling the gas to be released. The volume of water and pressure required are a function of the geology and depth of the well, varying on a site-by-site basis. The 'reach' of the stimulation is in the order of 300 m from the horizontal well; therefore to increase economic output, multiple wells may be developed form a single site creating a 'well pad'. As the shale in the UK is over 1,000 m deeper than in the USA, the geology lends itself to multiple wells. The design reduces the surface footprint of development, but in doing so increases the resources required per site.



▲**Figure 1. Prospective shale basins in the UK**
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Box 1. Shale gas resources versus reserves (Source: DECC[6])	
Resources	**Reserves**
An estimate of the amounts of oil and gas that are believed to be physically contained in the source rock. Gas in place (GIP) is an estimate of the total amount of gas that is trapped within the shale rock. Because of measurement uncertainty, the DECC report provides a range of values for GIP rather than a single value. There is an 80 per cent chance that the true GIP value lies within this range, a 10 per cent chance that it lies below and a 10 per cent chance that it lies above.	An estimate of the amount of gas that is technically and economically viable to be extracted from a geological formation. DECC does not consider that there is sufficient understanding of the geology, or experience of the engineering or costs of production to make a reliable estimate of shale gas reserves at this stage. Estimates of reserves will develop and improve with increasing exploration drilling in the years ahead.

▼**Table 1. Water use of shale gas extraction (adapted from CIWEM, 2013).**

			Water use per well pad		
Process	**Duration**	**Per well**	**4 wells**	**8 wells**	**12 wells**
Drilling **	2 – 8 weeks	1 – 2ML	4 – 8ML	8 – 16ML	12 – 24ML
Hydraulic Fracturing ***	5 – 7 weeks	10-20ML	40 – 80ML	80 – 160ML	120 – 240ML
Production	5 – 20 years	0ML	0	0	0
Total		11 – 22ML	44 – 88ML	88 – 176ML	132 – 264ML

* The potential exists for some of the water returned to the surface to be re-used following treatment.
** Drilling includes both the initial vertical well and horizontal, therefore for an additional well the water use will be reduced.
*** A well may be fractured more than once.

SHALE GAS IN THE UK

The rights to natural gas are vested with the Queen and are managed by the Department of Energy and Climate Change (DECC), who has commissioned the British Geological Society (BGS) to advise DECC on resource estimates. Operators purchase the right to extract gas through licences – petroleum exploration and development licences (PEDLs). Purchased licences are displayed in **Figure 1**. Of the many companies that have already purchased licences, Cuadrilla, based in Lancashire, is the only company to have drilled and fractured a well.

In 2013 DECC commissioned a strategic environmental assessment for conventional and unconventional onshore oil and gas development in the UK with the purpose of identifying and quantifying potential environmental impacts, and identifying measures for mitigation[1]. This permitted 57 per cent of England and Wales to be made available to offers for additional PEDLs from July of this year, although this is not a guarantee that shale gas resources exist within the PEDLs nor that they will be developed[2].

There are three basins of shale in the UK that have been explored by the BGS, with prospective areas shown in **Figure 1**: the Bowland-Hodder in the north of England, containing 37,633 bcm[3], the Weald, located in the south-east, which has since been reported as containing shale oil for extraction[4]; and the Midland Valley in Scotland, containing a comparatively modest 2,265 bcm[5] of 'gas in place' (see **Box 1**).

As the UK geology is favourable to shale gas extraction, it is thought that a shale gas well would produce up to 85 million cubic metres (mcm) of gas in its lifetime compared to less than 74 mcm per well in the USA[7]. However, due to the short lifespan of a well, a cumulative number of wells must be developed. Based on the production profile of the Barnett shale in the USA, providing 10 per cent of natural gas demand in the UK would require 300 wells to be drilled annually[8], with the strategic environmental assessment consider the environmental impact of between 30 and 120 pads being developed (each having between 6-24 wells)[1].

WATER DEMAND OF SHALE GAS

The water demand of shale gas extraction has been reported, notably by the Chartered Institute of Water and Environmental Management[9] (CIWEM) in late 2013. They estimated that to drill and fracture a single well would use 11–22 ML (1 ML = 1,000 m^3), the equivalent of 4–9 Olympic swimming pools (**Table 1**). However, CIWEM base their figures on the assumption that a well will be fractured only once, whereas it is possible to refracture a well to increase productivity, thereby increasing the water use.

It is unlikely that a single well will be drilled per site, a well pad being developed instead with a minimum of four wells per pad. Using the CIWEM per-well estimates, a four-well pad would use 44–88 ML (the equivalent of up to 35 Olympic swimming pools) of water. The environmental statement for Cuadrilla's Preston Road and Roseacre Wood developments in

FEATURE

Box 2. What options exist for water re-cycling?

Water returning to the surface following fracturing, flowback, contains the same chemical additives as the water-based fluid used to fracture the shale in addition to sediment and low-level naturally occurring radioactive material. It is not suitable for re-use without prior treatment with two options available: thermal distillation and membrane filtration. Treatment research and development is continuing in the USA where shale gas extraction is advanced, but treatment is not yet common practice at each site with a wide range of 5–80 per cent of produced water being re-cycled (Nicot and Scanlon).[11]

Lancashire each include four wells per well pad with the estimated water use (provided by mains water) being 97.25 ML for drilling and fracturing the four wells[10]. This is nearly 10 ML above the CIWEM upper estimate and includes water recycling (options for water recycling are given in **Box 2**).

It is therefore important to consider that local geology, vertical well depth, and horizontal well length and density will influence water usage. Should a well pad increase to 12 wells per pad (as considered in the strategic environmental assessment[1]), the water use will therefore increase to 132–264 ML, the equivalent of over 100 Olympic pools.

The CIWEM estimate that to meet 10 per cent of the UK gas demand from shale gas over 20 years, the water demand of extraction would be in the order of 1.2–1.6 million m^3 per year, the equivalent of 480 —640 Olympic swimming pools. This would be less than 0.1 per cent of total abstraction for industry and agriculture when compared to annual licensed water abstraction in England and Wales. Nonetheless, in consideration of development density, the stress placed upon water resources would be concentrated. Industry analysts have often suggested that shale gas has a relatively high water efficiency compared to other fossil fuels and also biofuels such as ethanol[12]— a single well producing 85 mcm[5] requiring 23 ML of water produces over 3,696 m^3 of natural gas per m^3 of water.

However, this representation makes the fundamental error of neglecting to distinguish between water withdrawal defined as "water diverted or *withdrawn* from a surface water or groundwater source" and water *consumed*, "water use that permanently withdraws water from its source … or [is] otherwise removed from the immediate water environment"[13].

Between 20 and 80 per cent of the water used is retained by the shale this translates as up to 80 per cent of the water withdrawn for the use of hydraulic fracturing could be consumed, removed from the immediate water environment and the hydrogeological cycle. In light of climate change and a reducing freshwater resource per capita, is this an appropriate use of water?

POTENTIAL FOR WATER STRESS

Concerns for water resources generally include the adequacy of water for human and industrial uses beyond environmental need, particularly in areas already susceptible to drought or a history of water stress, with the impact on ecosystems a major concern. The amount of water required for shale gas development is of particular concern to communities due to the geographical variability of water resources. This is particularly true in England and Wales, as shown in **Figure 2**, the lighter areas representing a reduced ability to meet water resource demands[14].

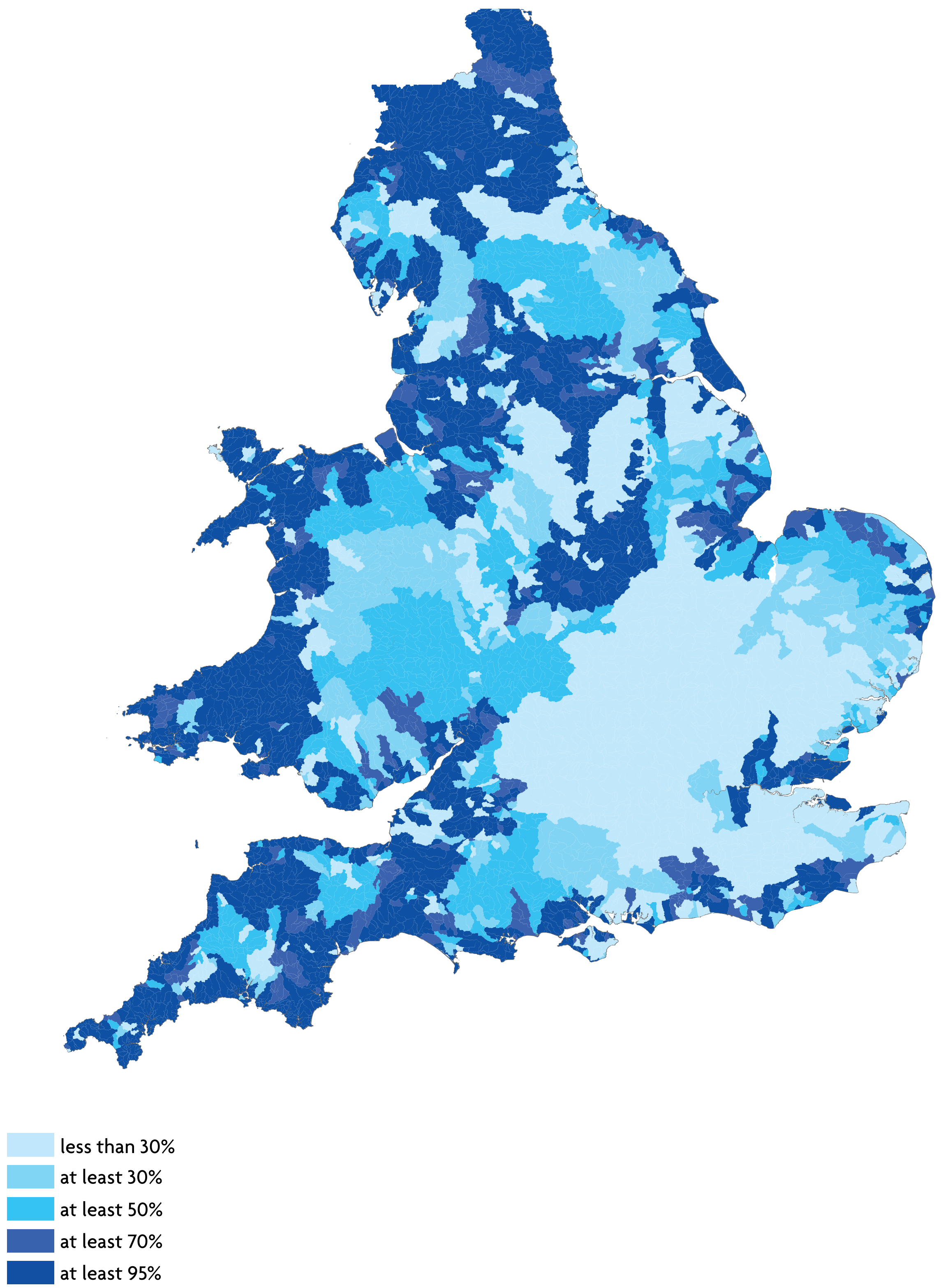
For inland England, Cambridgeshire to Gloucester and to Surrey in the south, water resources for new abstraction licences will only be available 30 per cent of the time, while the west's coastal boundaries have greater water resource availability. Shale gas distribution, however, does not follow postcodes.

The increased landward acreage of the offered PEDLs increases the likelihood that they will be located in within areas of low water resource availability: 30 per cent of land offered for PEDLs reside in catchments with water resource availability less than 30 per cent of the time and 14 per cent of land in catchments with water resource availability less than 50 per cent of the time. The potential therefore exists for shale gas water requirements to exacerbate local or regional water shortage areas of existing over-abstracted parts of the country (see **Figure 3**).

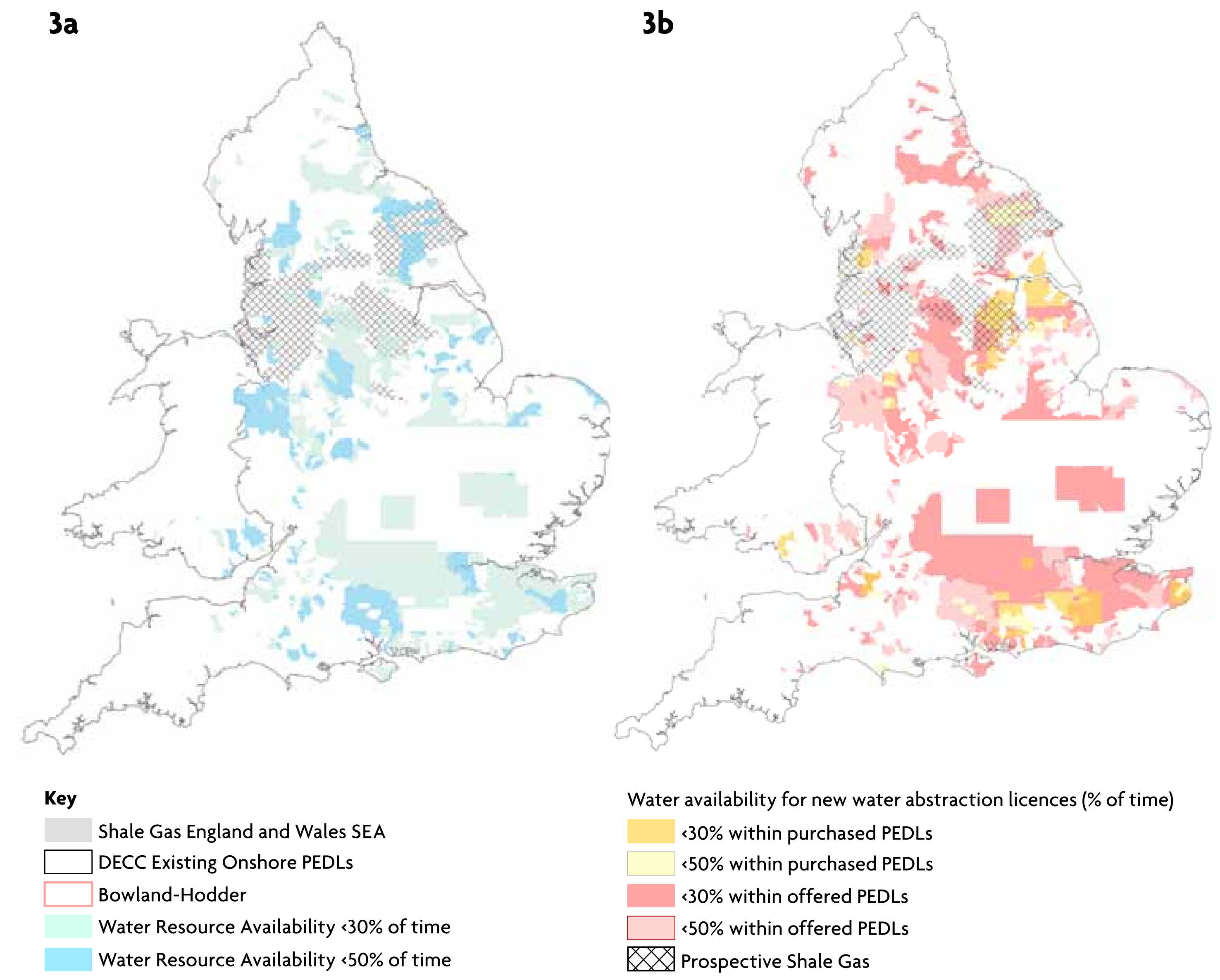
An area spanning western Buckinghamshire and Oxfordshire, and a second within Cambridgeshire and Essex, are centrally located within an area of low resource availability. In addition, the high concentration of PEDLs on the eastern side of the Bowland-Hodder is a cause for concern, falling within an area of low water availability.

RESOURCE PROVISION AND IMPACT

In the UK, rights to water do not follow land ownership – just as neither do mineral and gas rights. Abstraction is included in the planning process on a well-by-well basis: the operator applies for a permit from the Environment Agency, who has the power



▲ **Figure 2. Water resource availability in England and Wales (percentage of time). (Environment Agency)**



▲ **Figure 3. 3a Water availabilty for new water abstraction licences (% of time) 3b Water availability for new water abstraction for purchased and offered Petroleum Exploration and development licenses (% of time)**

to issue a permit for a fixed period. Work done by the Environment Agency through its Catchment Abstraction Management Scheme and Restoring Sustainable Abstraction programmes shows that most catchments in the country are already at or near maximum sustainable abstraction.

The UK government has delayed reform of the abstraction licensing system, but any new abstraction management system is likely to include mechanisms for reducing, rather than increasing, the amount of water available to existing or new abstractors. In general, shale-related water withdrawals are small with respect to irrigation of agriculture and cooling associated with electricity production. It is the timing, location and concentration of shale-associated water withdrawals that have the potential to create water adequacy issues.

In the Barnett shale, operators rely upon groundwater for 45–100 per cent of their water needs placing additional stress on aquifer systems, which are already stressed from rural and municipal pumping[10].

When the consumptive proportion is considered (in addition to the water security threat associated with climate change and the increase in extreme weather conditions), it is clear that the potential exists for shale gas development to induce water scarcity on a local scale. A report by Ceres[15] recorded that, of the nearly 40,000 oil and gas wells (conventional and unconventional) drilled since 2011 in the USA, three-quarters were located in areas where water is already scarce, and 55 per cent were in areas already experiencing drought.

In a bid to mitigate climate change by shale gas extraction, attention needs to be given to the cumulative effects of significant fracking operations on county and even national water balance assessments as water resource are influenced by the effects of climate change. There exists a key policy disconnect that needs to be addressed if a well-regulated shale industry, one that learns from experience in the USA, is to be developed. It is crucial that water withdrawals should be monitored and coordinated so that they are sustainable, with the cumulative effect of developed wells considered by catchment and not on a site-by-site basis. **ES**

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