Summary

This report describes the concentrations and distributions of uranium (U) in groundwater from aquifers in Great Britain and discusses the most likely sources and controls on U mobility. The report also reviews the ranges of U observed in groundwater worldwide in order to place the British data within a wider context. Groundwater-chemistry results are presented from 116 samples of raw groundwater taken from 101 operational boreholes and springs across England & Wales. The samples are from a selection of public and private water sources. Twelve of the sources were sampled twice, once in the spring of 2005 and once in autumn 2005 in order to provide some limited assessment of the temporal variation in U concentrations. The report also describes the results from 1556 analyses of groundwater U collated from the BGS groundwater-chemistry database and various published accounts. This provides a basis for assessing the implications to the water industry and regulators of U in groundwaters in England & Wales in the event that a new European drinking-water limit for the element is introduced in the coming years.

The mobility of U in water is controlled by a number of factors, among the most important being pH, redox status and concentrations of coexisting dissolved ions. Uranium is a redox-sensitive heavy metal that occurs in water principally under oxic conditions in its hexavalent (U(VI)) form. It is usually complexed in solution, especially with carbonate ligands, but also less significantly with phosphate, fluoride or sulphate depending on their respective dissolved concentrations and ambient pH. Under anoxic conditions, U is reduced to its tetravalent U(IV) state and its concentration in water is usually low as a result of stabilisation of the sparingly soluble mineral, uraninite.

Groundwaters often have higher concentrations of U than surface waters because of the large solid/solution ratios in aquifers and the greater influence of water-rock interactions. Uranium occurs as a major constituent of minerals such as uraninite, coffinite and autunite. These can be significant localised sources of U in some groundwaters, especially those in mineralised areas and some granitic terrains. Uranium is also closely associated with iron oxides, phosphates, clays and organic matter and these minerals can be important sources, as well as sinks, of U. The abundance of phosphates in aquifers is usually limited but iron oxides and clays are common rock-forming minerals and are particularly important in iron-rich and argillaceous sediments and metasediments. The concentrations of U in abundant silicate minerals such as quartz and feldspar and carbonate minerals are usually low.

Results from the 101 groundwater sources analysed in England & Wales indicate a range in U concentrations of <0.02–48.0 µg L⁻¹ (median 0.39 µg L⁻¹). The vast majority of samples had U concentrations well below the WHO provisional guideline value for U in drinking water of 15 µg L⁻¹, with concentrations in only two samples exceeding it. Both these were from private supplies. The observed range compares reasonably with that from the collated dataset of 1556 groundwater samples from Great Britain, which was <0.01–67.2 µg L⁻¹ (median 0.29 µg L⁻¹). Of the latter dataset, 0.71% (11 samples) exceeded the WHO provisional guideline value for U in drinking water of 15 µg L⁻¹, while 0.45% (7 samples) exceeded 20 µg L⁻¹ (the Canadian standard) and 0.26% (4 samples) exceeded 30 µg L⁻¹ (the US-EPA maximum contaminant level). A large majority, 78.1% (1216 samples), had U concentrations less than 1 µg L⁻¹. This indicates that most British groundwaters have concentrations well below those that would become problematic if a European drinking-water limit comparable to the WHO provisional guideline value or current American regulations were to be imposed.

The distribution of U in the groundwaters has strong links with aquifer geology. Highest concentrations in the collated groundwater dataset (1556 samples) occur in borehole sources
in the Old Red Sandstone and Permo-Triassic Sandstone aquifers (up to 48 µg L\(^{-1}\) and 67 µg L\(^{-1}\) respectively). A single borehole sample from the Torridonian Sandstone of Scotland also had a relatively high concentration (6.6 µg L\(^{-1}\)). These aquifers are all red-bed sandstones, their most characteristic unifying feature being the abundance of Fe(III) oxides which occur as grain coatings and cements. The dissolved U in these aquifers is thought to be derived principally by desorption from iron oxides, facilitated by complexation with dissolved carbonate species at alkaline pH. The high U concentrations tend to be limited to the unconfined portions of these aquifers where oxidising conditions prevail, allowing the predominance of the oxidised U(VI)-carbonate complexes. In reducing confined aquifers, groundwater U concentrations tend to be low (<1 µg L\(^{-1}\)).

Concentrations were variable and occasionally high in groundwater from other aquifers, although none exceeded 15 µg L\(^{-1}\). Most carbonate aquifers had low groundwater U concentrations, with median values typically of 0.2–0.3 µg L\(^{-1}\) although values ranged up to 7.8 µg L\(^{-1}\) in the Carboniferous Limestone and 7.6 µg L\(^{-1}\) in the Chalk. These occasional high values may be linked to local U-mineralisation, and in the case of the Chalk to interaction of groundwater with phosphate horizons.

Concentrations in groundwaters from granites of south-west England were generally low (up to 3.6 µg L\(^{-1}\)) in our study, despite the known U mineralisation in the rocks of the region and the observation of groundwater U concentrations up to 11.6 µg L\(^{-1}\) by other researchers. High-U groundwaters appear not to be a widespread feature of the granites of the region, perhaps because of the short residence times of the groundwaters and their slightly acidic, low-alkalinity compositions. The sporadic nature of the U mineralisation may also be a factor.

Of the 12 sources that were sampled and analysed more than once during the study period, all but four had differences in dissolved U concentration of less than 15%. The variations in the remainder are difficult to interpret from the limited numbers of samples, particularly in the most extreme case which had concentrations varying between 3.48 µg L\(^{-1}\) and 48 µg L\(^{-1}\). However, the results suggest that at least a few sites can experience significant time variations in groundwater U concentrations. The causes are unknown but seasonal variations in groundwater level and pumping rates leading to differing flow patterns are possibilities.

The observed concentration ranges of U in British groundwater are relatively narrow compared to those in groundwaters from other parts of the world where concentrations can span some six orders of magnitude (<0.01–8000 µg L\(^{-1}\)). The higher concentrations tend to be found in U-mineralised areas and U-rich granitic terrains (e.g. western USA, Scandinavia), which are of relatively limited extent in Britain.