Groundwater Development in England

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SUMMARY

Current groundwater protection policies for England and Wales and licence controls are the outcome of a complicated history of resource development, legislative change and institutional evolution. Conflicts emerged in the late nineteenth century reflecting the need to balance resource exploitation for public supply and industry with environmental considerations. This situation arose through a late appreciation of plausible scientific principles and the 'invisibility' of groundwater; the result has been a near crisis in resource management. The issues discussed provide an interface between 'green history' and frameworks for sustainable development. An overview of groundwater exploitation is presented with case studies of low flows, the nitrate issue and salinisation of chalk aquifers.

1. INTRODUCTION: 'GREEN HISTORY' INTO POLICY

Between 1974 and 1994, total groundwater abstraction in England and Wales was between 6,000,000 and 7,500,000 m^3 (6 and 7.5 billion litres) per day (Wilkinson and Brassington, 1991; EA, 1996). Groundwater provides 30 per cent of the total public supply, and recently the trend has been upward. In 1987 the figure for industrial use stood at around one billion litres per day with a gradual decline into the early 1990s (DoE, 1994).

The aim here is to chart the history behind the explosion in recent legislation and policy instruments for the protection of groundwaters from over-abstraction and from contamination. Groundwater problems are complicated, having their origins in industrial, agricultural and urban development and in waste and land management. For example, the context of groundwater contamination from agrochemicals involves changes in the international situation, food security needs and agricultural policy since 1940 (DoE, 1986). Protection from contamination and over-abstraction is high on the agenda of the Environment Agency in England and Wales, but this has not always been the case.

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Scholars concerned with the lag between interest in 'green issues' and historical enquiry have coined the notion of a 'green history'. There has been considerable discussion regarding the very nature of this 'sub-discipline' (Chase, 1992), differentiating it from other kinds of historical focus such as nation, region, class, race or gender.

Green history, being concerned with human interaction with the natural world is in part a social construction, and we might turn to the 'sustainable development debate' in an effort to find a focus. Here, the multi-faceted nature of information and opinion leads inevitably to a clash with 'Cartesian' or 'positivist' paradigms in natural science. These would see the world as controlled by immutable laws and viewed through some kind of objective reality (Pretty, 1995:13). It is argued that the positivist paradigm excludes other possibilities, and hence is unconducive to a pluralist approach to environmental issues. Alternative perspectives to positivism regard both *problems* and their *solutions* as always open to interpretation, depending upon the viewpoint taken and, importantly, the involvement of 'stakeholders'.

Redclift (1994) finds 'the environment' to be *a process between human beings and nature*, yet he finds sustainable development to be a concept whose time has come without anyone really knowing what it meant! The advantage of being without a strong paradigm in situations of great complexity is that it leaves commentators free to define their own focus. Parallels between the two debates – finding a focus for green history and the sustainable development debates – are strong, at least because the latter embraces ideas of inter-generational equity.

In any case, the very existence of ecological, environmental and landscape history must converge upon notions of 'real' green history, especially because they *promote the conservation ethic* (Sheail, 1993). The pursuit of green history will also prove to be fruitful precisely because *it informs the sustainable development debate*. While the Rio Summit of 1992 looked to a problem-solving future, investigation of the human-environment dynamic in the past is surely green history?

Groundwater is an open-access, common property resource (CPR), and as such regulation for the 'common good' is essential. Waters contained in fissures and pores are prone to over-abstraction and contamination from chemical and biological sources, while the aquifer itself may be damaged by mining or engineering operations. Full appreciation of 'how we got here' traces a history of conceptualisation, resource development, conflict identification and problem solving.

Plausible principles of groundwater behaviour have only really been understood in the 'scientific' age. By contrast, aspects of surface water management (legal, regulatory, protection and flood defence) can be found in Medieval England (Sheail, 1988). The management of surface water, as a CPR, has literally been centuries ahead. The long-term aim is the sustainable management of groundwater.

There is a priority for the environmental historian to trace the interplay between technical and policy considerations; the outcome being technical appraisals and critiques of past policy. Green history should become a tool in policy analysis alongside Environmental Assessment (e.g. Brookes, 1994) and may also provide retrospective Environmental Audits (Chase, 1992).

2. GROUNDWATER: THE HISTORICAL SOURCES

Water management information is *scientific, technical* and *historical* in nature and is to be gleaned from conventional historical, scientific, geographical and archaeological sources (Cook, 1994). Examples of surface waters include water meadows (Wade Martins and Williamson, 1994), grazing marshes (Cook and Moorby, 1993), and those concerned with river regulation (Sheail, 1988).

By contrast, information on groundwater development is comparatively recent and was collected by, and for, technocratic institutions. Documents are governmental or otherwise public, ‘grey literature’, or of the consultancy report variety (Lapworth and Partners, 1946, Sheail, 1982; Headworth and Fox, 1986). The gathering and survival of records depends upon the efficiency of institutions, their operation or the perceived need to retain records. Headworth (1994) felt it appropriate to write his professional memoirs upon retirement in order to avoid loss or dispersion of some 20 years of hydrogeological research.

Before the twentieth century, credible long-term records of the resource are rare. Two exceptions were the levels in the confined Chalk of the London Basin and at Chilgrave House for the South Downs aquifer. Both run from the middle nineteenth century (Doorgakant, 1995). Otherwise, a paucity of hydrogeological and hydrochemical data persisted, and has been remarked upon as forming an obstacle to effective groundwater management policy (Selby and Skinner, 1979).

The systematic recording of groundwater carried out by the Institute of Geological Sciences started as late as the 1950s. Although surface water data are better recorded, and in longer time-series, the groundwater archive still has some of the longest records in the World. These are proving invaluable in analysing the results of periods of low rainfall (such as the period 1988 to 1992), changing abstraction patterns and longer-term considerations of climate change. The Water Resources Act 1991 gives the British Geological Survey a statutory right to water data for boreholes drilled over 15m deep (Doorgakant, 1995), having variously been maintained by River Authorities (until 1974) and the Water Data Unit until 1980. Historic groundwater level data from 3000 observation wells were not updated after 1975. However, the production of hydrogeological maps by the Institute of Geological Sciences covering main groundwater sources between 1967 and 1982 proved a valuable source of information (eg IGS/SWA, 1979), as did the assessment of resources of the European Community (Monkhouse and Richards, 1982).

Subsequently 157 representative observation boreholes across England and Wales have been identified. These are based upon the ‘hydrographic entity’ groundwater units (Monkhouse and Richards 1982) which constitute the Current Groundwater Level Archive which is regularly updated. One-half of these are in the Chalk, one quarter in the Permo-Triassic sandstones. Since 1982, the preparation and maintenance of a National Groundwater Level Archive, on behalf of the DoE (now DETR), has been carried out by the Institute of Hydrology and the British Geological Survey at Wallingford with current data from the Environment Agency and water companies.

3. CONCEPTUAL DEVELOPMENT AND MATERIAL EVIDENCE

Tracing the history of ideas about the nature of groundwater requires viewpoints which may be pre-scientific, quasi-scientific (based upon deduction but short on empirical observation) or scientific in the Cartesian sense. Earliest ideas were linked with notions of spirits, or invoked Divine intervention to explain flow at springs (e.g. Deuteronomy 8:15). In Britain, Iron Age and later communities are known to have endowed water sources with religious significance, and to have made votive offerings at wells (Cunliffe, 1993:161).

Early philosophical speculation was quasi-scientific, but ideas concerning the hydrological cycle were often off-track (Adams, 1928). However, the Roman engineer Vitruvius understood not only that evaporation and condensation in clouds were a critical part of the cycle, but also that water infiltrated mountainsides to emerge at their base as springs, as did Bernard Palissy (c1510-1589).

René Descartes (1596-1650) tried to quantify hydrology and his ideas regarding large-scale vaporisation and condensation paved the way to modern concepts. Edmund Halley (1656-1742), established that the origin of water on land could be accounted for by precipitation, and that oceanic evaporation could account for the worldwide precipitation (Smith, 1972).

The discovery of overflowing ‘artesian’ conditions (especially in Artois) led to the development of borehole drilling to tap deeper strata (Price, 1985:108). The work of Henry Darcy (1803-1858) enabled basic physical principles for the transport of water in porous media to be quantified. In the twentieth century, developments in hydrogeology tended to shift from Europe to the United States (Todd, 1980:6). Notable is the work of C.V. Theis during the 1930s, which improved the determination of storage and transmission features of aquifers. In Britain, real interest in hydrogeological matters began after World War Two.

Regarding the material evidence, well construction is ancient and undoubtedly advanced the frontier of prehistoric settlement and agriculture. Generally speaking, wells in earlier (including Biblical) times probably reached 20 or more metres in depth and could be 1 to 10 metres in diameter (Todd, 1980:165).

A shaft in the head of a dry valley (IGS/SWA 1979) at Wilsford near Stonehenge yielded organic remains ranging in date from 450 to 2700 BC, with five determinations clustering around 1200 BC (Ashbee *et al.*, 1989). Remains found have been interpreted as those of a rope and bucket (Cunliffe, 1993:161) and palaeoenvironmental evidence suggests continuous waterlogging since prehistory.

Evidence from Dorset suggests falling watertables in the chalk in the fourth century AD (Sheail, 1988). Wells were being dug deeper in a futile effort to secure water supply and it is suggested that clearing, cultivation and settlement were resulting in enhanced runoff from arable land which was reducing aquifer recharge. This local effect is consistent with studies of prehistoric soil erosion on chalklands (e.g. Boardman, 1992). The climate in Roman times is likely to have been similar to today (Favis-Mortlock *et al.*, 1995) making land use change a plausible cause of a fall in watertables.

Medieval domestic wells have been excavated in Norwich, frequently on property boundaries (Atkin and Margeson, 1985) but showing no regard for the location of cesspits, making contamination an ever-present threat. Piped supply is known here from the sixteenth century.

Before groundwater pumping technology was widely available in the nineteenth century (when many English villages had a reciprocating piston hand-pump), water was lifted by hand or windlass and for deeper wells treadmills using human or animal power were employed. In southern England typically this would be to abstract water from the chalk. Harris (undated) describes a probable early seventeenth century tread wheel and house, probably turned by a man or boy. It was in operation until about 1910 and originally from Catherington (Hampshire) where water was said to be lifted over 90 metres from the chalk, a depth consistent with contemporary information (IGS/SWA, 1979).

In the nineteenth century steam power made it not only possible to improve pumping, but also to sink boreholes by percussion or drilling. Wells constructed at this time are typically 1-3m in diameter, and relatively shallow, although some reach 125m (Hall, 1989:34). They may also be lined (this is generally a requirement in Lower Greensand aquifers, for example). Boreholes are drilled, less than a metre in diameter and are generally deeper than wells which are dug. Later nineteenth century bores could be over 300m deep (Whitaker, 1908:4); modern bores are as deep as 500m (Wilson, 1983: 87).

Unlined public and private wells or borings are common within the Chalk. Most extractable water is from above the Melbourn Rock which marks the base of the Middle Chalk, above which fissures become common. The normal operation of water undertakings has been to sink to levels a short distance below the rest level of the water, then drive adits horizontally in order to maximise yields through fissure interception. Whitaker (1908) reports that there were some 5.6km of galleries associated with the Ramsgate waterworks dug into the Upper Chalk. In the south-east of England, chalk wells and bores are located in the dry valleys (where fissuring is greatest and depth to watertable is reduced) or on the lower dipslope.

4. LEGAL AND INSTITUTIONAL ASPECTS OF OVER-ABSTRACTION

Over-abstraction of groundwaters leads to the drying of springs and rivers, a problem which emerged in the nineteenth century. Under common law there are no riparian rights in underground percolating water (Wisdom, 1979 ch 8), and there was no entitlement to compensation under statute for the adverse effects of abstraction, such as the diminished recharge of surface waters from springs. A landowner had the right to abstract water from a well sunk and villagers had the right to draw water from a communal well (Elworthy, 1994:46); English law provided no effective control.

In 1922, in his presidential address to the Institution of Water Engineers, W.J.E. Binnie stated ‘there is nothing to prevent a private individual sinking a well immediately adjacent (to a public source) by means of which the community may be deprived of its water supply.’ He then called for a licensing system to be introduced, a situation not fully realised for some 40 years (Binnie, 1995).

1857	Thames Conservancy established
1868	Lee Conservancy Board established
1916	Federation of British Industry created
1925	Report of the Ministry of Health’s Advisory Committee
1930	River Catchment Boards established
1945	Water Act framework for regional resource planning and establishes Central Advisory Water Committee
1948	River Boards established
1963	Water Resources Act introduces abstraction licences and establishes the Water Resources Board
1973	Water Act creates Regional Water Authorities (1 April, 1974)
1989	Water Act created National Rivers Authority with responsibility for total water environment
1991	Water Industry Act
1991	Water Resources Act consolidates provision for protection zone definition
1995	Environment Act creates Environment Agency responsible for all aspects of water regulation and most aspects of environmental pollution

TABLE 1. Timeline for key nineteenth and twentieth century events leading to groundwater resource management.

The legislative response to problems of over-abstraction was gradual (Sheail, 1982) and matched by slow evolution of water institutions. The Thames Conservancy was established in 1857 and the Lee Conservancy Board in 1868 but River Catchment Boards were established in 1930 and dealt soley with land drainage. The trend since has been for the responsibilities of regulatory bodies to increase (DoE, 1971), yet it was to be decades before groundwaters were effectively protected.

It must not be assumed that institutional interests in groundwaters lay only with public institutions. The Federation of British Industries (FBI) was founded in 1916 and was the precursor to the Confederation of British Industry. Both have served as the 'voice of British industry'. Sheail (1998) presents an analysis of its relationship with public authority which evolved over time.

Following a drought in 1921, the Ministry of Health's Advisory Committee on Water (composed mainly of waterworks officials) pressed, in a report of 1925, for closer controls on groundwater abstraction. After some discussion involving the Mining Association, the FBI sought compromise; business interests should be considered in drafting legislation, while industry must retain the right to sink shafts wherever it chose or compensation be paid. Dialogue between interest groups (government, water undertakings and industry) assisted the development of protection policies, and in the promotion of subsequent legislation. Significant progress was subsequently made in promoting 'green issues' and groundwater conservation played a part.

The 1945 Water Act set a framework for regional water policy and planning for the first time including the beginning of a national groundwater archive (Grey *et al.*, 1995 p9). This was achieved through a limited licensing system for underground water sources in vulnerable areas (Part III) operated by central government, and the establishment of a Central Advisory Water Committee (CAWC) to advise the Ministry of Health on conservation and use of water resources. The Committee drew attention to a lack of basic information for water resource planning during the 1950s (Smith, 1972). However, the Act has been criticised for failing to recognise the close relationship between surface and groundwaters (Grey *et al.*, 1995 p. 8). It also reduced the number of statutory water undertakings, a process which has continued.

The abstraction of groundwater before 1940 led to local reductions in water-table height, affecting urban and neighbouring rural areas alike. Paradoxically, post-second World War rising groundwater levels in older industrial areas are today a cause for concern. Wilkinson and Brassington (1991) ascribe this to wartime damage, the loss of wells, licensing controls under the 1945 Water Act and the deterioration of groundwater quality due to salinisation and pollution. To these may be added the recent decline of older industries.

The 1963 Water Resources Act represents a real milestone in abstraction control, which was achieved through abstraction licences issued in 1965 for surface and groundwater sources with charges used to finance conservation works (Smith, 1972). Existing abstraction was designated 'licences of right' with licences granted in perpetuity. Excluded were small abstractions for domestic purposes and farms, but irrigation licences were required. Twenty-nine River Authorities (replacing the River Boards of 1948) were formed to provide regional, catchment-based integrated management of resources (Grey *et al.*, 1995). Legal provision was made for the setting of minimum acceptable flows in rivers. Surface flows could be augmented from underground supplies, and groundwater stores recharged from surface waters (DoE, 1971). A real appreciation of the interconnectability of surface and groundwaters had finally emerged, however the setting of (minimum) flows in legal terms has still not yet been satisfactorily achieved. A criticism of the 1963 Act is an inability to coordinate water resource development with water quality controls (Grey *et al.*, 1995 p. 9).

The 1973 Water Act created 10 Regional Water Authorities (RWAs) which adopted the notion of 'integrated catchment management' in England and Wales, thereby aiming to address this shortcoming. All-embracing authorities dealt with water supply, regulation, planning, conservation, land drainage, flood control, abstraction, treatment and sewage disposal. It thereby gave the Water Industry hydrogeological, rather than political boundaries (Leeson, 1995:109). Sadly, the integration of regulation, supply and water treatment was never satisfactorily achieved because there was conflict between service demands and regulation of the water environment. The 1973 Act is not noted for creating benefits for groundwater conservation.

The Water Act 1989 separated the utility functions of the RWAs (which were privatised) from regulation and established the National Rivers Authority (NRA). Based upon the same catchment boundaries as the RWAs, the NRA was to make decisive steps in the protection of groundwaters. Following the Environment Act 1995 it was merged in the Environment Agency 1 April 1996.

Under statute, Skinner (1991) reports a common definition: groundwaters are considered to be waters contained in underground strata, in a well, borehole or similar and where water enters excavations from adjacent strata (the Water Resources Act, 1963:Section 2(2), and Water Act 1989, Section 103 (1) and 124 (2)(b)).

Consolidation legislation should help avoid over-abstraction. The Water Industry Act 1991 promotes the efficient use of water as a part of 'demand management', while the Water Resources Act 1991 replaced and re-enacted the 1989 Water Act. It consolidates all provisions in respect of abstraction control from groundwaters under the Water Resources Act 1963 (NRA, 1992), and represents in part a revision of the Water Act 1945. UK law potentially recognises water in the unsaturated zone (which may percolate to the watertable), and groundwater exposed at the surface and which flows into excavations.

5. ABSTRACTION AND SURFACE WATER PROBLEMS

Resource balances are tight in many English aquifers, especially in the chalk aquifer of Kent, Suffolk, Essex and Cambridgeshire (NRA, 1994b). Some 26 out of 76 groundwater units in the Severn-Trent Region of the former NRA have licenses issued beyond their recharge ability, with 14 actually exceeding recharge (NRA, 1993).

Early problems resulted from urban supplies to west London, SE London and Wolverhampton. Beneath cities such as London (the chalk aquifer), Birmingham, Liverpool, Manchester and Nottingham (which draw water from Permo-Triassic strata) substantial abstraction from the late 1800s to the 1940s saw falling groundwater levels, the drying of springs and loss of artesian overflow (Wilkinson and Brassington, 1991). The falls were sometimes measured in tens of metres. Headworth (1994) considers past practices showed scant regard for river flows and wetland ecosystems.

At Redgrave and Lopham Fen in the Waveney Valley, drying dates from the 1960s causing certain vascular plant and invertebrate species to be lost (POST, 1993). Two causes were identified: the adjoining River Waveney channel had been deepened, and a public supply borehole in the adjoining chalk had been pumping 19 hours per day since 1957. It could have been treated as a ‘licence of right’, but the Suffolk Water Company has agreed to relocate borehole abstraction to permit the recovery of water levels.

During 1897/8, abstraction from the chalk of Hertfordshire to supply west London was not only sufficiently great to affect local river flows and springs, but that the supply to the Metropolis itself was under threat (Sheail, 1982). Although Hertfordshire apparently experienced greater resource conflicts, groundwater in Kent was most intensively exploited. Here around 1,522 m^3 day^{-1} were abstracted on average during 1839 and supplied to London (Whitaker 1908: 2-4). Between 1873 and 1902 abstraction varied between 78,583 and 95,492 m^3 day^{-1} while the population supplied rose from 33,600 to over 632,000. In 1906 there was said to be less than one day’s supply in reservoir capacity; this illustrates the reliance upon groundwater.

Low and zero flows in chalk streams have to be seen in their hydrogeological context. The dipslopes of chalklands are dissected by dendritic valley systems whose bottoms are mostly above contemporary watertable heights (IGS, 1970). Dry valleys are usually continuous with present watercourses, and their lower reaches experience periodic flows as ‘bournes’, ‘winterbournes’, or ‘nailbournes’ (in Kent). This flow corresponds with wet periods in the winter when watertables are sufficiently high to prevent percolation through the valley bottoms. Earlier theories involved the periodic filling and overtopping, or syphoning, of subterranean cisterns, and folklore states nailbournes only flow every six or seven years (Snell, 1938). Records of nailbournes in Kent date from the fifteenth century. Later, the River Cray and the Ravensbourne suffered low flows attributed to groundwater abstraction in Kent for the Metropolitan supply Whitaker (1908: 54-63).

Pronounced reduction in watertable levels causes springs to migrate down-valley. Owen (1991) reports that abstraction between 1950 and 1985 in the catchment of the River Ver rose from around 10,000m^{3}day^{-1} to around 45,000m^{3}day^{-1}. With a licensed quantity set at 48,000m^{3}day^{-1}, there can have been little appreciation in 1965 of what the consequences might be. In response, watertables fell, drying the upper 10km of the river. The result has been an increase in the intermittent flow in the upper Ver (in Hertfordshire), and losses in habitat, fisheries, watercress farming and amenity.

6. THE DARENT – A RIVER UNDER THREAT

The River Darent in Kent derives its flow from the Lower Greensand and Chalk aquifers. In the 'groundwater drought' of 1988 to 1993, stretches periodically dried up completely (Herbertson, 1994; Rippon and Wyness, 1994). The historical background is described.

Catchment groundwater abstraction commenced in the late nineteenth century, being initially below 10,000 m^{3}day^{-1}, increasing, and soon doubling (Herbertson, 1994). Abstraction information supplied by the Metropolitan Water Board during 1904 for chalk sources at Wilmington, Darenth and Dartford totalled 24,300m^{3}day^{-1} (Whitaker, 1908:3). In addition to public supply, the chalk aquifer on the north side of its outcrop was continually pumped by cement manufacturers in order to maintain dry quarries. Furthermore, the total of industrial abstraction had, by the early 1920s, exceeded the quantity abstracted by the Metropolitan Water Board and increasing quantities were drawn from the Thames to augment the supply (Dewey *et al.*, 1924).

The Advisory Committee on Water Supplies for Kent was convened by the County Council in 1935 to advise on future requirements, and arrange co-ordination of schemes for water resources in the County (Donaldson and Bishop, 1958). This commissioned a hydrogeological report for 1938, but only published in 1947. A dry spell in the late 1940s further focused attention on bulk supply and there was a public appeal to use water sparingly.

The 1945 Water Act enabled the Minister of Health to make orders that specified special measures for the conservation of waters. Two orders, The Metropolitan South-East Area (Conservation of Water) Order 1947, and the Kent Area (Conservation of Water) Order 1948 covered the chalk and other water bearing strata of Kent outside the Weald. Between 1948 and 1956, the Committee advised on 67 applications to sink boreholes, principally by industrial undertakings. The County Council frequently lodged objections, suggesting their perception of a real problem. Re-organisation of water supplies and the Kent Water Act, 1955 created the statutory Joint Advisory Water Committee for

Kent (excluding the area served by the Metropolitan Water Board) which came into being 1 July 1958.

The Committee (which comprised representatives from both statutory water undertakings and local authorities) had turned its attention to the representations from the Kent River Board in 1957 concerning the effect of the abstraction of underground water in relation to river flow, and recommended in certain instances that care should be taken in pumping in order to protect the rivers.

The Darent Catchment was suffering from a combination of high abstraction for industry and export to urban areas. Consumption rose sharply during the 1950s and 1960s; today licensed abstraction in the Catchment is 173,000 m^3 day^{-1} of which 123,000 is for chalk sources. The balance is from the Lower Greensand. 155,000 m^3 day^{-1} is authorised for abstraction by five water companies with the remainder mostly licensed to industry on the north side. Aquifer recharge exceeds actual abstraction by 15 to 20 per cent and abstraction is limited to 70 per cent of the licensed volume by voluntary agreement. Figure 1 shows the application of historic data on river flows and groundwater levels in a finite difference model for the Darent (Herbertson, 1994).

Flow accretion and depletion are given down-catchment for the condition of a 1:20 year drought under differing abstraction conditions. ‘Target flow’ is regarded as 50 per cent the modelled natural flow and requires a reduction in the

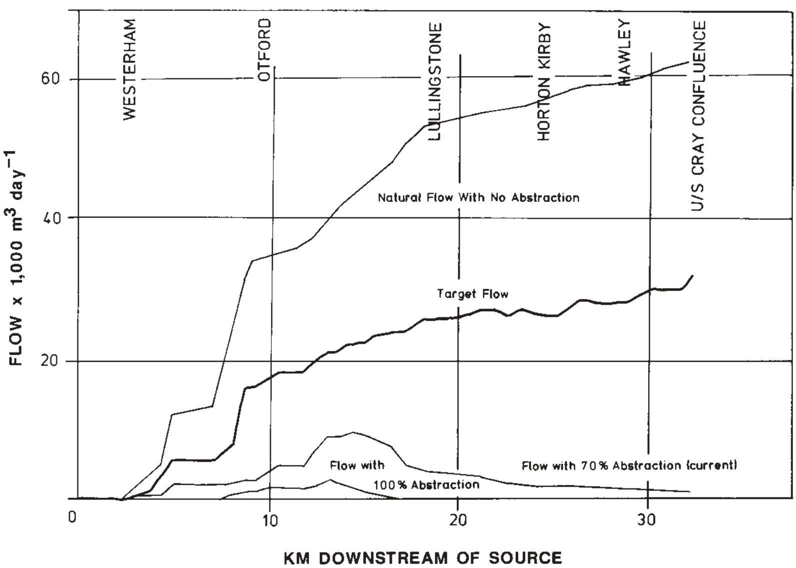

FIGURE 1. Modelled flows under 1:20 year drought conditions Source: Herbertson, 1994.

(current) position whereby 70 per cent of permitted licensed abstraction is taken. Such an exercise is valuable in setting an 'environmentally acceptable flow regime' which accounts for temporal, including seasonal, flow variation and aim to provide for habitat and fishery protection. Historical data both illustrates the development of resource conflict, and enables the calibration of numerical groundwater models. It is anticipated that the sinking of 'augmentation boreholes' alongside the river, and changing the abstraction pattern, should sustain future flow.

7. THE CONTEXT OF GROUNDWATER CONTAMINATION

Groundwater is 'out of sight and all too often this has come to mean 'out of mind' (NRA, 1992) a situation which applies both to contamination and over-abstraction. A recent case, that of *Cambridge Water Co* v. *Eastern Counties leather plc* (1994), concerned contamination from industrial solvents. The case established strict liability for the escape of contaminants, and operated on the principles of tort (i.e., nuisance). The judgement did impose a 'foreseeability requirement' as a pre-requisite to liability (Leeson, 1995:160); this legal clarification will probably prevent retrospective claims. On the other hand, EU Directives require preventative measures such as groundwater protection zones, Directives are translated into UK law in order to establish a framework for land-use based solutions to contamination (Cook and Norman, 1996). So what of the history?

Long-term industrial contamination has been found beneath Coventry and Birmingham (Lerner and Tellam, 1993). In Birmingham inorganic contamination from metal ions is complicated by rising groundwater levels in an unconfined Triassic aquifer system. Coventry draws water from Permian and Carboniferous strata and has a problem with industrially derived chlorinated solvents.

Early concern came to be focused on nitrates, originally from sewage (Headworth, 1994), and on saline intrusion from seawater. For example, abstraction at the Tivoli Gardens Well in Margate was just below 0m OD and caused the infiltration of sea water, with deterioration in the quality of supply (Whittaker, 1908: 168). In north Kent, adjacent to the Plumstead and Erith marshes, water levels in certain wells have been observed to 'rise and fall with the tide' with waters displaying brackishness which increased as pumping increased well drawdown (Dewey *et al.*, 1924). The outflow of fresh groundwater in pumped aquifers should be towards the sea. While this condition may be inferred from hydraulic gradients, seaward fissure flow may be observed as horizontal flows at a well (Whittaker, 1908:122).

Poor scientific understanding and a lack of institutional frameworks created problems for groundwater conservation, and this was reflected by inadequate legal definition (Skinner, 1991; 1994). There remains a lack of legal recognition that groundwater actually flows within porous strata. Nineteenth century civil actions saw plaintiffs upheld where damage to property occurred once water was appropriated for a specific purpose. Whilst the abstraction or diversion of percolating water is not actionable, a person who pollutes underground percolating water is liable to an action (Wisdom, 1979 ch 8). In the Mendip Hills, Somerset, lead mining contaminated waters and presented a health hazard to humans and cattle alike (Gough, 1930); a notable test case was *Hodgkinson* v. *Ennor* (1863). Judgement saw the plaintiff, a paper manufacturer, upheld against pollution of water issuing from Wookey Hole arising from lead workings. Groundwater contamination here was considered to affect an *underground river*.

Parliament has granted powers to make bye-laws for the protection of water supplies. They included the Birmingham Corporation Water Act 1892 (by which the corporation had acquired commons within the catchment of Birmingham's water supply in upland Wales) and similar legislation had benefited the water supply for Leeds (Sheail, 1992). The Margate Corporation Act 1902 (a groundwater source) and Northampton Act 1913 took powers to protect supplies from sewage contamination.

Two initiatives in groundwater quality conservation have been implemented in managing the 'Brighton Block' of the South Downs chalk aquifer. First, during the inter-war period, concern was expressed regarding speculative urbanisation around Brighton, and the effects upon both water supply and water quality through cess pits draining into the aquifer. Following the Brighton Corporation Water Bill 1924, land was purchased by the corporation which came to be used as source protection zones. The preferred land use was grazed grassland, the desired radius of protection two miles (Sheail, 1992). Second, large and poorly controlled abstraction led to concern over salinisation of groundwaters from coastal saline intrusion. To prevent this, the condition of seaward groundwater flow has deliberately been maintained through careful abstraction management since the 1950s (Headworth and Fox, 1986).

Groundwater 'wellhead' protection zone definition to avoid contamination from industrial and other sources has been enforceable in (West) Germany since 1953 (McCann and Appleton, 1993); statutory protection zones were adopted in Bavaria in the 1960s (Headworth, 1994). In France the practice also started in the 1960s (Risler, 1995), although adoption was slow. The survival of pathogens in groundwater governed German, as later British practice. Overall, definitions of protection zones on a basis of fixed radii has tended to be replaced by supposed travel times as hydrogeological information and modelling improved.

In England and Wales the 10 RWAs were charged with the duty of securing the protection and proper use of both inland waters and water in underground strata. Concern was expressed that large blocks of aquifers may become polluted and unusable (Selby and Skinner 1979) but implementation of suitable measures was slow and had to be reiterated under subsequent legislation in 1989 and 1991. Progress was handicapped by inadequate hydrogeological and hydrochemical information used to inform decisions. Furthermore, there was a lack of consistency within an RWA area; inherited guidelines and codes of practice from previous undertakings were potentially effective but varied.

The model adopted, and in force today, has its origins in West German practice. In the UK, the pioneering authority was Severn-Trent Water, who mapped protection zones at a scale of 1:50,000 and these were in operation in the late 1970s. Subsequently, RWAs published groundwater protection policies; Southern in 1985, Severn-Trent in 1987, Thames in 1988, Yorkshire and Anglian in 1989 (Adams and Foster, 1992; Harris and Skinner, 1992).

Identification of zones and proscribed activities within them anticipated later practice (NRA, 1992). By the 1980s, point and diffuse pollution from agriculture were the subject of considerable research. Groundwater Source Protection Zones (SPZs) are now defined for England and Wales (Cook and Norman, 1996). These are not pollutant specific, are based upon groundwater travel times (reflecting improving modelling procedures), and incorporate considerations of pathogen survival. There is now a basis upon which to protect specific aquifers and their waters from physical damage or contamination from a range of waste disposal, agricultural and industrial operations, mining and engineering works.

8. AQUIFER CONTAMINATION IN THE KENT COALFIELD

The defunct Kent Coalfield presents a localised, but serious source of chalk groundwater salinisation derived from minewaters. Kent had the last British coalfield to be developed, and was the only one in which the coal measures were completely concealed by younger (Mesozoic) strata.

In 1890, a boring through the chalk at Shakespeare Cliff near Dover located coal measures (Forster Brown, 1923). Little coal, however, was extracted from the Shakespeare Colliery (commenced in 1896) due to difficulties encountered from the ingress of water; at one point some 3,273 m^3 day^{-1} was yielded by the quartzose sands at the base of the Inferior Oolite. Economically viable coal extraction commenced in 1913 at the Snowdown Colliery (MFP, 1945), given an impetus by the fuel demands of the First World War.

In the extreme east of Kent the Chalk is approximately 250m in total thickness, but most extractable water is above the Melbourn rock, above which there is a thickness of the Middle and Upper Chalk around 180m. Typical depths of wells in the unconfined Chalk are anything from 15 to 80m (Whittaker, 1908; IGS, 1970). Coal measures are encountered at between 250 and 400m, with workable coal seams two or three times this order of depth. Hence coal mining was deep; depths recorded for pits operated in the 1960s (Gallois and Edmunds, 1965:24) were: Betteshanger (740m), Tilmanstone (925m), Snowdown (920m) and Chislet (457m). Abstraction for public and private supply is from considerably shallower depths than the pumping required to maintain mining operations. Consequently, the two kinds of groundwater were not managed in concert, to the detriment of Chalk water quality.

Water from the Oolite at Shakespeare Colliery was found to be saline in the early years of exploitation (Forster Brown, 1923). During the Second World

War, water undertakings experienced increased demand for water from military, agricultural and domestic as well as industrial demand. In the early days there was little concern for the impact of mining on the quality of water supply, with the Tilmanstone and Snowdown Collieries discharging between 9090 and 11,360m^3 day^{-1} of pumped groundwater at the surface during the first ten years of full coalfield operation; this was entering the chalk groundwater at a volume of around 30 per cent of that abstracted for public supply.

Hydrogeological investigations were undertaken (Lapworth, 1930) with a second commissioned in 1938 and summarised in a 1946 report by H. Lapworth and Partners, at the instigation of local authorities and water undertakings. The first investigation of the contamination of well water by pumping from coal mines being undertaken by Messrs. H. Rolfe and Sons for the Broadstairs Bill of 1923. At Tilmanstone Colliery, chloride concentrations in minewaters were found to be 1,590 ppm while at Snowdown an astounding figure of 5350 ppm was recorded. In November 1929, wells within 5 km of Tilmanstone Colliery were analysed for carbonates, chlorides, nitrates, sulphates and total solids. Overall salinity was caused by chlorides of calcium, sodium and magnesium, largely from Snowdown, while Tilmanstone also discharged sodium carbonate.

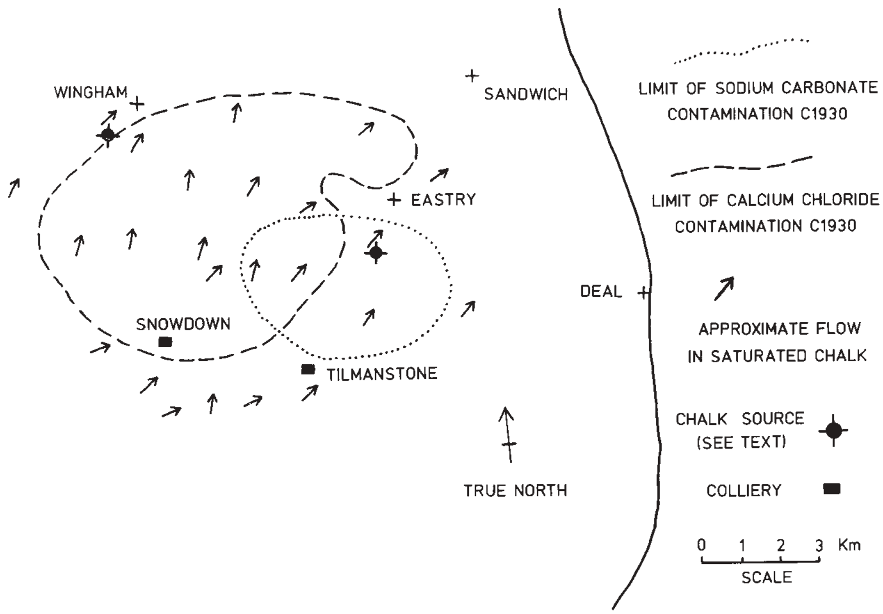

FIGURE 2. The extent of groundwater contamination in 1930. Sources: Lapworth (1930) and IGS (1970).

Figure 2 shows the serious state of affairs in the late 1920s, with information drawn from well and borehole contamination in the area. Water reaching Margate Water Works rose to 91 ppm sodium chloride in Nov 1929. For comparison, saline intrusion from sea water on Thanet has produced saturated zone concentrations in excess of 100ppm (IGS, 1970). Concentrations above this figure may cause a saline taste in drinking water.

At the Wingham well (then operated by the Margate Corporation) salinity had increased (measured as chlorine in chlorides) from a normal (for chalk waters) of 20 ppm in 1926 to 90ppm in 1930, reaching a peak of 320ppm in late 1936. The 1930 report had recommended that waters from Tilmanstone and Snowdown be led away either to the sea, or to watercourses north of the chalk outcrop. A decline in salinity at Wingham followed the installation, by the water undertaking, of a mine water pipe at Snowdown Colliery. This became operational in November 1935 and led water away to the Blackhole Ditch, some 10.5 km from the colliery. It was not until 1943 that all water was led away, although by 1945 the salinity at Wingham had fallen to around 120 ppm. The Wingham source is operational today.

The Advisory Committee on Water Supplies for Kent (Donaldson and Bishop, 1958) had stated that the 1945 Water Act covered the conservation of ‘the chalk and other water bearing strata of Kent outside the Weald’ under two orders (Section 6). The matter of pollution from minewaters had not, by the 1950s ‘reached a satisfactory conclusion’. In the 1960s concentrations exceeding 1000ppm of chloride were mapped in the vicinity (IGS, 1970). Water shortages in the area caused an exploratory boring at Tilmanstone Colliery with test pumping at 216 m^3 day^{-1} in June 1992 (T. Howes, 1996, *pers comm*). This found groundwater to contain between 370 and 1233 ppm total sodium, 142 and 822 ppm chloride and 104 to 3654 ppm sulphate. There is furthermore a licensed source at Eastry rendered unusable without (expensive) reverse osmosis treatment (P.B. Harnett, 1996, *pers comm*). It is hoped that eventually the aquifer will naturally discharge saline waters, but on present form that could take some time (Headworth, 1994).

9. NITRATES IN GROUNDWATERS

Research since the 1970s has shown there are rising groundwater nitrate concentrations in certain aquifers, attributed to agricultural activities since 1940. Diffuse contamination arises from ploughing grassland and indirectly from organic manure applications and nitrogenous fertilisers (DoE, 1986).

There is provision under the Water Resources Act 1991 to define protection zones. Nitrate Sensitive Areas (NSAs) have their origins in the 1980 Drinking Water Directive (80/778/EEC) which concerns the quality of water for human consumption (MAFF, 1994). These are voluntary and farmers are compensated for loss of income through reducing nitrogen fertiliser input to arable land, or by conserving or restoring low input grassland.

Nitrate Vulnerable Zones (NVZs) follow the 1991 Nitrate Directive (91/676/EEC) where agricultural practices are encouraged which are environmentally beneficial in vulnerable areas designated by Member States (Grey *et al.*, 1995). These are compulsory in that nitrogen management prescriptions are laid down by statutory code (MAFF, 1991). The two schemes contrast in approach, and they show a need for both regulation and incentive to ensure the participation of farmers.

The specific issue of protection from nitrates in the chalk may be illustrated through two studies, one the 'Cornish Source' operated by the (then) Eastbourne Waterworks Company in the Eastbourne Block of the South Downs, the other the Chalk of Thanet (Headworth, 1994; DoE, 1986).

Around the Cornish Source the soil is mainly light, flinty loam and landuse either permanent grass or in a long rotation of grass and cereals. During the period 1969 to 1972 the nitrate concentration reached a maximum of 71 mg l^{-1} NO_3 falling to 35 mg l^{-1} by the end of the decade, and this was attributed to restricting nitrogen application to 60 kgN ha^{-1}. Hydrogeological investigations had identified fast fissure flow as the main transport mechanism and restrictions applied over some 100 to 120 ha, made possible because the local authority either owned or managed the land. Management agreements with the tenant farmer (commenced in 1952) affected 70 per cent of the borehole catchment.

In a particularly far-sighted way, inner and outer zones were identified, with more stringent measures in the inner zone. Although Headworth (1994) found the pattern of fertiliser use could not readily be linked to the hydrogeology or the observed concentrations, he regards the outcome as beneficial and a pioneering example of cooperation between farmer and water undertaking.

The Isle of Thanet has long been an area of intensive agricultural and horticultural land-use, locally exceeding 80 percent of land areas (Cook, 1991). Concern over nitrate concentrations at source had been expressed since the middle of the nineteenth century. Raised nitrate concentrations in the order of the EU limit of 50mg l^{-1} $N0_3$ have been noted since the 1870s (Headworth, 1994). Recent investigations and modelling have linked agricultural land use to raised levels of nitrate in the unsaturated zone. Fertilised grassland displays higher levels than unfertilised, fertilised arable still higher. Abrupt changes of land-use (such as ploughing) produced highest peaks of all. Unlike general purpose groundwater source protection zones, schemes designated for specific protection from nitrates are very recent.

A groundwater NVZ has been designated for the Isle of Thanet. Alongside arable and horticultural land use, urban development caused much early contamination from sewage and led to the problem identified for over a century. However, current prescriptions are only concerned with nitrates of agricultural origin (Osborn and Cook, 1997). Here, policy might evolve towards tighter targeting and land-use prescriptions, incorporating all that is known from technical and historic information.

10. CONCLUSIONS

The Environment ministers of the European Community, at a meeting in The Hague during November 1991, adopted a resolution which recognised the need for the ‘management and protection of groundwater on a sustainable basis’ (NRA, 1992).

This article has attempted to analyse the problems affecting groundwater in England and catalogue progress toward sustainable management. Initiatives to improve water quality have been manifest in England and Wales since the first half of the twentieth century, while diffuse pollution from agriculture became an issue after the Second World War. The widescale adoption of protection measures follows supra-national legislation. The kinds of institutional, legal and pragmatic solutions adopted were derived from north America and other European states (Stanners and Bordeau, 1995).

Initiatives to curb over-abstraction, by contrast, have been taken at the national level. Responses to over-abstraction have been slow; a lag may be observed between Victorian groundwater engineering initiatives and subsequent over-exploitation. Rising levels in older urban areas may appear a reversal of the pre-War trend, and while it brings its own problems, the overall concern is to avoid over-abstraction wherever manifest.

There has been understandable self-congratulation among contemporary legislators, policy makers and scientists regarding the conservation of groundwaters, but this comes after a century of neglect. While it is true that plausible scientific ideas were a long time in gestation, the ideas and observations recorded in Whitaker (1908) and reported by Sheail (1982) show that water managers in the late nineteenth century were capable of reasonable deductions regarding over-abstraction and river flow. Concepts of groundwater source protection were not far behind.

The negligence implied by such observations suggest problems arising from resource invisibility linked to a culture of engineers (and others) who considered groundwater fit for plunder, while failing to contemplate the likely impacts upon river flow and wetland conservation. The imperatives for resource abuse were the demands of urbanising and industrialising regions in lowland England. However, the economic consequences and a need for common interests in groundwater protection emerged in the inter-war years. To an extent, industry and water undertakings identified a common cause. The case of the Kent Coalfield remains an enduring reminder of the folly of treating aquifers as dustbins for liquid waste.

Aggravated by both pressures for increasing abstraction and by dry periods, threats to wetland sites (such as East Anglian fens) and the chalk stream flows have come to the fore. Solutions gained through better regulation and underpinned by sound legislation require considerable data and information, obtained through modelling scenarios which require historical information for calibration. Arguably, the paucity of historic data, already noted, is in part compensated by the development of modelling procedures.

The post-Second World War period also saw the emergence of diffuse pollution from agriculture and alongside it an international effort to develop useable, and scientifically defensible protection zone policies. In common with a range of water quality problems, the real impetus for the adoption of groundwater protection zones comes from EU directives and not from local water management problems. Their implementation is timely.

The late nineteenth and twentieth century saw many mistakes due to urban, industrial and agricultural development. Viewed optimistically, the history of this resource has provided many lessons for the sustainable development debate in terms of legal and institutional frameworks, and technical and policy developments. Responses are not only to proscribe certain activities through the coercive threat of legal action, but are preventative and increasingly integrated into the planning process.

Through reference to groundwater development in England the case has been proposed that 'green history' is a useful tool in environmental management. It undeniably informs the 'sustainable development debate'; an appreciation of historic issues is essential in setting policy frameworks.

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