THE USE AND MANAGEMENT OF THE COASTAL CHALK AQUIFER
OF THE SOUTH DOWNS, SUSSEX, UK

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ABSTRACT
Chalk borders the sea in several parts of England; in Yorkshire, East Anglia, the Thames estuary, and along the south coast between east Kent and Devon. In several of these areas saline intrusion has occurred as a result of over-abstraction, often for industrial use. In Sussex the Chalk is exposed to the sea for 45 km, but despite the aquifer having to meet the needs of the population of 600,000, saline intrusion has been kept in check by the adoption of a controlled abstraction policy. This paper looks at the utilisation of the groundwater resources of the area, the growth of public water supply over the last 150 years and, in particular, it describes the basis and operation of the aquifer management policy in the Brighton area.

INTRODUCTION
The Chalk of the South Downs extends from Eastbourne in the east to the Hampshire/Sussex boundary in the west, a total distance of some 90 km. (See Fig. 1a). It has an outcrop area of approximately 770 km². From Worthing to the west of Chichester, the Chalk underlies Tertiary and superficial deposits which fill the deep trough of the Chichester syncline. In East Sussex the gentle south-easterly dip of the strata gives rise to a spectacular cliff line distinguished by the Seven Sisters and Beachy Head, whereas in West Sussex there is a well-developed coastal plain comprising superficial, head, gravel and brickearth deposits which overlie the Upper Chalk and Tertiary formations. This coastal plain ranges in width from about 2 km. in the east to a maximum of 15 km. at Selsey Bill.

The relief is typically that of rolling Chalk downland. North to south cross-sections always show the characteristic escarpment profile of a steep scarp slope to the north with a more gentle dip slope running southwards to the sea (see Figs. 2a and b). The groundwater table follows this profile with a divide that approximates to the crest of the Downs (see Fig. 1b). From this crest, which reaches a height of some 250m above sea level, a succession of long spurs separated by winding dry valleys extends southwards, rising in places to form a secondary escarpment 120 to 150 mOD in height.

The Chalk outcrop itself is virtually devoid of surface drainage, although in certain locations ephemeral streams break out during high groundwater conditions. The continuity of the South Downs is
Fig. 1a Sussex South Downs: solid geology and pumping stations

Fig. 1b Geological structure and groundwater contours (Oct. 73)
Fig. 2a Section A-A across Chichester chalk block

Fig. 2b Section B-B across Brighton chalk block

Fig. 2c Temperature (T), differential temperature (dT), and formation resistivity (R) in a coastal borehole at Brighton

Fig. 2d Fluid conductivity logs in a coastal borehole at Brighton
broken by four river gaps, all cut well below present-day sea level and filled with deep alluvial deposits. From east to west these gaps are occupied by the Rivers Cuckmere, Ouse, Adur and Arun, and they effectively divide the Chalk aquifer into five hydrological units or blocks, as they will be referred to in this paper. Stream gradients through the gaps are very low, with the result that in all cases tidal influence extends well inland of the main escarpment.

Sussex has been an area of major growth with the population of the administrative counties of East and West Sussex increasing from 150,000 in 1801 to 1.3 million in 1981. Most of the growth in the last century was centred on Brighton, which together with its neighbouring town of Hove, reached 153,000 in 1901, and now has a population of 240,000. In the same period, the population of West Sussex has grown from 151,000 to 662,000. Most of the population of East and West Sussex live in the coastal towns between Bognor Regis and Eastbourne and of the total population of the two counties, some 713,000 live within the South Downs area of supply.

The Chalk is the primary aquifer of Sussex and over the years has been extensively exploited to provide public water supplies for the major coastal conurbation centres. Up to the early 19th Century the inhabitants of the area depended upon wells or springs for their domestic needs. In about 1825 the first move to provide a reliable piped supply was made with the formation of a waterworks company in Brighton which sunk a well to the north of the town. It seems to have been the first water supply source in the area but some years later wells were sunk in the Upper Greensand at Eastbourne. Similar sources of supply were developed for Worthing in 1857, Chichester in 1874, Bognor Regis in 1876, Littlehampton in 1888 and Seaford in 1896.

With the ever-increasing growth in population, the demand for piped supplies necessitated the development of new sources, and by the turn of the century a number of new wells had been constructed in the Chalk throughout the South Downs. More recently, with improvements in sanitation, the introduction of labour-saving domestic appliances and a general increase in living standards, per capital consumption has increased considerably, giving rise to ever-greater demands. Today most parts of the South Downs Chalk aquifer are almost fully developed.

By 1957, increasing salinities in several of their sources led Brighton Corporation to introduce an abstraction policy which sought to conserve inland aquifer storage and place greater emphasis on intercepting coastal outflows which would otherwise be lost to the sea. This policy has been successful in controlling salinities and, despite an increase of a third in abstraction, groundwater levels in the aquifers are higher now than they were nearly thirty years ago.

HYDROGEOLOGY

The extensive outcrop of the Chalk, its permeability and thickness, provide a large catchment with considerable storage capacity, which make it by far the most important aquifer of Sussex and of southern England generally. Lithologically, chalk is a soft, white, fine-grained homogeneous limestone with nodular and tabular flint bands, nodular beds and marl seams. Thicknesses are variable as a result of subsequent erosion but are in excess of 330m beneath the Tertiary cover and range between 150 and 300m along the outcrop.
The conventional classification provided for a three-fold subdivision into Lower, Middle and Upper Chalk, but recent remapping has shown that in Sussex at least, the boundary between the Middle and Upper formation is difficult to recognize and may not be valid. For this reason on all recent maps produced by the British Geological Survey, they are shown as one unit called The Sussex White Chalk (Mortimore, 1979, 1983). Hydrogeologically this formation is by far the most important for water supply purposes and well yields from the White Chalk can exceed 200 litres per second. By contrast, yields from the Lower Chalk which is notably more argillaceous, are generally poor.

The main groundwater divide closely follows the east-west watershed of the South Downs. The northerly outflow emanates from a generally well-defined perennial spring line just above the base of the Lower Chalk, whereas the positions of springs on the gentler dip slope vary seasonally in response to infiltration, giving rise to bournes or intermittent streams. Springs also occur along the coastal margin, particularly to the east of Brighton, where they can be seen arising at low tide at the base of the cliffs or from the wave-cut platform. In 1971 a thermal infra-red linescan aerial survey was carried out along the coast between Bognor Regis and Eastbourne in order to identify possible freshwater springs arising in the foreshore below high water mark. (Davies, 1973; Brereton and Downing, 1975). No submarine springs were detected but numerous spring seepages were indicated on the foreshore around low water mark. These appear to issue from the Chalk through overlying superficial deposits, particularly to the west of the River Adur where groundwater is thought to be diverted eastwards along the northern edge of the Chichester syncline.

Although relatively simple, the structure of the Chalk has quite a marked effect upon the hydrogeology of the area and it is dominated by a number of complementary anticlinal and synclinal folds (see Fig. 1b). In the west, the Chichester syncline, infilled with impermeable clays of Tertiary age, provides an effective barrier to saline intrusion across the southern portions of the Chichester and Worthing blocks. Across the north of the Brighton block the Kingston anticline, with the complementary Mount Caburn syncline have given rise to the development of an easterly component of groundwater flow which, under high saturation conditions, results in the appearance of the Lewes Winterbourne. Similar structural features in the north of the Chichester block give rise to outflow of groundwater via the Lavant.

Where an aquifer is in direct contact with the sea prolonged abstraction may result in a local reversal of the natural hydraulic gradient towards the land causing movement of saline water into the aquifer. This is particularly the case in fissured aquifers such as the Chalk in which fissures act as easy conduits for hydraulic communication between the aquifer and the sea.

The risk of saline intrusion was recognized towards the end of the 19th Century. Indeed Whitaker (1899, 1911) stated 'whilst the freshwater has a head that prevents the draught on it from being lowered beneath sea level all is well; but should that draught constantly lower the level of water in the well to some depth below the level of the sea, then danger is at hand'. In the early years of development of public water supplies this danger was not appreciated and knowledge was gained by experience. Thus, of the seven main
sources constructed during the 19th Century to supply the major coastal conurbations, those at Eastbourne, Bognor Regis, Littlehampton and Seaford subsequently became saline, necessitating replacement sources further inland.

In recent years detailed studies have been carried out in order to establish the extent to which the Chalk aquifer could be developed without the risk of further saline intrusion (Anon, 1972, 1974, 1979). In the Brighton block where demand is greatest three lines of deep coastal observation boreholes have been constructed at right angles to the coast and along the line of major dry valley systems. Geophysical down-hole logging is carried out in these boreholes on a regular basis in order to monitor movements of the salt/freshwater interface. Formation resistivity, temperature, differential temperature and fluid conductivity logs have been run as part of a continuing programme, but the complex nature of the saline intrusion has been most clearly demonstrated by the fluid conductivity logs. The picture which emerges (Monkhouse and Fleet 1975) is of freshwater flowing seawards and saline water moving inland along discrete horizontal fissures which extend to a depth of approximately 100m below sea level. Below a depth of about 130m the down-hole logging suggests that a static but predominantly freshwater zone exists.

Analysis of pore water in the Chalk between the fissured zones, obtained from cored boreholes constructed in close proximity to those logged, shows this to be predominantly fresh groundwater. Examples of down-hole logs for two 200m deep boreholes situated on the Brighton sea front are given in Figs. 2c and d. Analysis of seasonal changes in the logged boreholes shows that the salinity increases in response to the natural depletion of groundwater storage in the Chalk during the summer and can respond rapidly to changes in the abstraction rate from wells located as much as 6 km inland.

WATER RESOURCES

Availability of Resources

The coastal district of Sussex is one of the mildest and sunniest parts of Britain, with average summer and winter temperature of 16.1°C and 5.5°C respectively, and it receives an average of seven hours of sunshine per day during the summer. Average rainfall for the five Chalk blocks is 844mm, but it is strongly influenced by topography, with the more-elevated Chichester and Brighton Blocks having over 25% more rainfall than those of lower elevation. Potential evaporation exceeds 500mm/annum reaching 550mm/a along the coast, but the actual evaporation derived from this method is 485mm/a. This leaves an average annual rainfall residual, or aquifer recharge, of 359mm/a. Again, the Chichester and Brighton areas have appreciably more. For the months of April to August, potential evaporation exceeds rainfall and with a build-up in soil moisture deficit each summer, recharge is effectively limited to the winter period, October to March.

The hot dry summer which was experienced in Europe in 1976 followed a winter of exceptional dryness. In Sussex the October to March winter recharge decreased westwards, being 36% of average in the Chichester area. This amount would be expected to occur with an average frequency of 1 in 150 years. This return period is given credence by the continuous 148-year groundwater level record in a Chalk well in the Chichester Block at Chilgrove (SU 835144).
Analysis of its annual minimum water levels since 1836 show that the autumn groundwater level in 1976 was the lowest which has been experienced, but that it had a return period similar to the length of the record. Although the recharge in 1975/76 was low, its effects were made worse because the recharge took place mainly in November and December. None occurred after February, and this resulted in groundwater levels falling two to three months earlier than normal.

**Resources of Chalk Blocks**

<table>
<thead>
<tr>
<th>Chalk Outcrop area (km²)</th>
<th>Chichester</th>
<th>Worthing</th>
<th>Brighton</th>
<th>Seaford</th>
<th>Eastbourne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. Annual rainfall (mm)</td>
<td>904</td>
<td>739</td>
<td>901</td>
<td>705</td>
<td>777</td>
</tr>
<tr>
<td>&quot; recharge (mm)</td>
<td>476</td>
<td>391</td>
<td>477</td>
<td>373</td>
<td>411</td>
</tr>
<tr>
<td>1975/76 recharge (mm)</td>
<td>173</td>
<td>168</td>
<td>219</td>
<td>176</td>
<td>200</td>
</tr>
<tr>
<td>% of average</td>
<td>36%</td>
<td>43%</td>
<td>46%</td>
<td>47%</td>
<td>48%</td>
</tr>
</tbody>
</table>

**Utilisation of Resources**

By UK standards, the South Downs Chalk aquifer is highly utilised for water supplies, and only in a few localities is there considered much potential for further development. Industrial and private abstraction from groundwater is small, being mainly limited to the processing of sand and gravel aggregate around Chichester, for which all but about 0.3% of the quantity abstracted is estimated to be returned to the aquifer. Abstraction for agriculture (animal husbandry, spray irrigation and horticulture), although important, is again small by comparison with abstractions for public water supplies, which make up between 89 and 97% of the total groundwater abstractions from the five Chalk Blocks (Anon 1980). The amount of groundwater used for public water supply can be examined in several ways. A comparison of licensed abstractions with average available resources (i.e. average annual recharge) shows that for the five Chalk blocks, the commitment of resources is between 34 and 45%. For a coastal aquifer, subject to the threat of saline intrusion, it is prudent to base its management needs on the resources available in drought years. Using the computed recharge for the drought year 1975/76, the licensed commitment of resources is between 81 and 106%, while the actual use of resources under these drought conditions is between 60 and 90%. Lastly, based on the total autumn drought yields (c.f minimum reliable yields) of the forty-eight groundwater sources in the Chalk blocks, the degree of commitment amounts to between 80 and 94% of the available resources in a drought year.

**Utilisation of Resource of the South Downs for Public Water Supply (ML/d)**

<table>
<thead>
<tr>
<th>Average recharge</th>
<th>Chichester</th>
<th>Worthing</th>
<th>Brighton</th>
<th>Seaford</th>
<th>Eastbourne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought recharge</td>
<td>114.5</td>
<td>60.8</td>
<td>115.9</td>
<td>25.1</td>
<td>32.9</td>
</tr>
<tr>
<td>Licensed abstr.</td>
<td>121.1</td>
<td>60.5</td>
<td>108.5</td>
<td>20.5</td>
<td>31.1</td>
</tr>
<tr>
<td>1983 abstr.</td>
<td>69.6</td>
<td>53.4</td>
<td>82.7</td>
<td>16.4</td>
<td>24.9</td>
</tr>
<tr>
<td>Autumn drought yields</td>
<td>107.2</td>
<td>54.5</td>
<td>92.5</td>
<td>21.3</td>
<td>30.8</td>
</tr>
</tbody>
</table>
THE BRIGHTON ABSTRACTION POLICY

Brighton's abstraction policy was introduced in the late 1950's because of growing concern over the threat of rising aquifer salinities. Prior to that time abstraction had been largely piecemeal and unintegrated. The increasing demand for public water supply and the fear of rising chlorides at a number of pumping stations led to the recognition of the need for a fresh approach.

In 1957 the practice was introduced of making use of pumping stations located around the margins of the Brighton block so as to intercept outflows from the aquifer, while at the same time reducing abstraction from inland pumping stations in order to conserve aquifer storage. In addition to this overall shift in abstraction from the 'storage' stations to the 'leakage' stations, the policy has sought to make use of the annual cycles of aquifer recharge and groundwater recession so that aquifer losses to the sea in the winter are reduced as far as possible while at the same time permitting inland storage levels to recover to support increased output in the summer. In drought years, following winters with below-average recharge, coastal outflows from the aquifer decline, and inland storage levels, increased as a result of operating the policy, allow greater use to be made of inland pumping stations to meet the high summer demand. The following paragraphs illustrate the success of the abstraction policy in securing increased abstraction from the aquifer during the last twenty-eight years.

At the turn of the century the total abstraction from the Brighton block of 10,300 M^3/a was derived from only five pumping stations, but by 1950 the total output of these five stations had risen to 20,400 M^3/a, half of which was derived from storage across the centre of the outcrop.

The commencement of the abstraction policy in 1957 put greater emphasis on abstraction from leakage stations, and by the early 60s these supplied 65% of the total. Several new sources of supply have been introduced since then and they have allowed the abstraction to spread more evenly across the aquifer. In 1983 thirteen pumping stations met the demand of 28,900 M^3/a with some 35% taken from storage stations and 65% from leakage stations. Fig. 3a shows the abstractions of all the storage and leakage stations since 1898 and illustrates how the emphasis has shifted from the one group to the other.

Since its introduction in 1872 Goldstone, located 2km from the sea, has experienced problems with high chlorides. These rose to 600 mg/l when the output of the station reached 27 M^3/d. The problem lessened when additional stations were introduced between 1900 and 1910.

Balsdean pumping station, commissioned in 1936, has encountered similar difficulties. This station is situated 2.5 km from the sea, with maximum water levels of only 3.7 mOD, and annual minimum levels of between 0.3 and 1.2 mOD, and it exhibits features of a typical leakage station. Particular problems occurred during the dry year of 1949 when chlorides reached 400 mg/l. Studies of groundwater flow in the boreholes, carried out between 1957 and 1961 (Warren 1962, 1972) showed that when groundwater levels were low, the chlorides exhibited a cyclic pattern which reached a peak during spring tides. As a consequence, abstraction at Balsdean in most summers has to be related to the tides, and it is customarily suspended for two hours each side of high water. Fig. 4a shows maximum monthly chlorides at Balsdean since 1949 when routine records commence. The graph shows
the regularity with which chlorides exceed normal levels (30-40mg/l) while the uniformity of the peak values around 100-150mg/l reflects the control exercised during abstraction rather than natural climatic variation. Since the late 50's Balsdean has been pumped in conjunction with three other stations, Patcham, Goldstone and, more recently, Surrenden. Fig. 3b shows how it has been possible to make full use of Balsdean since 1957 by using it in association with these other stations which now, despite increased demand, operate at only 80-90% of their 1950 output.

To the west of Brighton the sources at Mile Oak and Shoreham are also used conjunctively in 'storage and leakage' mode. Prior to 1957 Shoreham was not greatly used. Mile Oak on the other hand has always been an important inland storage station and abstraction gradually increased during the first half of this century until by 1954 3800 M1/a was being abstracted. With the implementation of the Brighton abstraction policy in 1957 the output of Shoreham was stepped up to 2500 M1/a and that at Mile Oak severely cut back to 1200 M1/a (see Fig. 4b).

Shoreham, although less vulnerable to salinity than Balsdean, can suffer saline intrusion from the estuary in the summer. In most years abstraction does not have to be curtailed, but chlorides are continually monitored and, if in a dry year they reach 100mg/l abstraction is cut back and switched to Mile Oak. Abstraction from Shoreham and Mile Oak also demonstrates the advantage of the policy in drought years. In 1959, 1964-65, and 1972-74, abstraction from Mile Oak was increased while that from Shoreham was reduced. Output from Mile Oak did not need to be increased during the 1976 drought to meet the shortfall resulting from the cut-back from Shoreham because summer output was suppressed as a consequence of public awareness of potential water shortages.

The switch in abstraction from Mile Oak to Shoreham which occurred in the late 50's is clearly demonstrated by their annual minimum pumping levels. Prior to 1948 water level measurements at Shoreham were made in its spring collector, but subsequently they relate to the replacement boreholes. The wide variations in pumping levels which have occurred in the last twenty-five years reflect the use of Shoreham as a leakage station of which maximum use is made subject to climatic conditions. By comparison, water levels at Mile Oak have risen by 6m as a result of the changed abstraction regime (see Fig. 4b).

From the end of the last century the three stations at Mile Oak, Patcham, and Falmer, which are situated in a line across the centre of the Chalk block, have been vital sources of supply. In 1905 they met 63% of the total demand. Between 1900 and 1957 their combined output increased from 4300 to 13,000 M1/a. In 1957 their output was severely cut back and since then their aggregate abstraction has been between 4000 and 6000 M1/a (see Fig. 5b). This cut-back in abstraction has led to a significant rise in their pumping and rest water levels. Fig. 5a shows that prior to 1957 the minimum annual pumping levels, as averages of these three stations, were generally 0-4 mOD but since that time they have recovered and are now 5-8 mOD. A clearer indication of the post-1957 rise in levels in these sources can be obtained by comparing them with natural groundwater levels recorded at Chilgrove, near Chichester (NGR 835144) since 1836 (see Fig. 5c) and with winter (October to March) rainfall (Fig. 5d). Comparison of the annual minimum water levels at Chilgrove with the average of

- 132 -
Fig. 3a Annual abstractions from Brighton block of storage, leakage and all pumping stations 1898-1983

Fig. 3b Annual abstractions from Brighton block of leakage (lower) and storage (upper) pumping stations
Fig. 4a Monthly maximum chlorides at Beldean

Fig. 4b Comparison of annual minimum pumping levels at Shoreham and Mile Oak with their annual abstractions
Fig. 5 Comparison of annual abstractions (b) at Mile Oak, Patcham and Falmer with their annual minimum water levels (a), winter rainfall (d) and with annual minimum water levels at Chilgrove (c)
the annual minima of Mile Oak, Patcham and Falmer, (Figs. 5b and 5c) using a double mass plot, shows that the average levels in these three stations are now 5.0m higher than they would have been if the pre-1957 rates of abstraction had been maintained. Similar comparison using annual mean water levels shows an improvement of 4.4m over 1957 conditions.

A better assessment of the overall improvement in aquifer groundwater levels since 1957 can be made using a two-dimensional finite difference numerical model for the Brighton block, constructed in 1972 (Nutbrown, 1975; Nutbrown et al, 1975) and modified and recalibrated twice since. For steady-state conditions, groundwater levels, when averaged over the whole 193 km² block, are 0.6m higher now than in 1953, despite the 33% increase in total output during that time. If the current quantity had been pumped in 1953 with the abstraction regime then in force, the improvement in mean water level since then, resulting from the adoption of the abstraction policy, is shown to be 1.6m.

Much of the area of the Brighton chalk aquifer comprises either the low-permeability upland area with high and unresponsive groundwater levels, or the coastal margin where groundwater levels are influenced more by sea level than inland pumping. For this 62 km² central part of the aquifer, therefore, where most of the active aquifer storage exists, the numerical model shows that for steady-state conditions the present groundwater levels, averaged over this area, are 1.9m higher than those which occurred under 1953 conditions. Moreover, if the present-day output had been pumped in 1953 with the abstraction regime then in force, the improvement in levels since then, averaged over this central area, is shown to be 4.3m. This figure is considered to represent the best measure of the benefit of the adoption of the Brighton abstraction policy in 1957.

ABSTRACTION POLICY IN OTHER CHALK BLOCKS

By virtue of its size and exposure to the sea along the whole of its southern margin, the Brighton block provides the stimulus for developing an integrated abstraction policy. While none of the other Chalk blocks is as suited or has quite the need for such a policy, they nevertheless possess characteristics worthy of description.

Worthing Chalk Block

The Worthing Chalk Block supplies a population two-thirds that supplied from the Brighton sources. Until 1960 the demand was met from three only but with an expansion of the area supplied, three more sources were soon added and the 1960 output of 8900 Ml/a had risen to 15,900 Ml/a by 1964. The Block is largely protected from the threat of saline intrusion by the eastward extension of the Chichester syncline which runs out to sea 3km east of Worthing. While there has been less need to introduce the 'storage/leakage' mode of abstraction, the two pumping stations situated on the west and east flanks of the Block possess the characteristics of leakage stations of low groundwater levels and periodic salinities. Burpham, in particular, is vulnerable to high salinities and turbidities from the River Arun at times of spring tides in the late summer and autumn. These contaminants are drawn speedily towards the pumping station, 1.3 km inland, as a result of the reversal of flow via large spring outlets in the river bank. Output from the station, which can yield 28 Ml/d, may
cease for several consecutive days to prevent chlorides and turbidities reaching unacceptable levels.

Chichester Chalk Block

The chalk outcrop of the Chichester Chalk block, like the Worthing block to the east, is protected on its south side by the Chichester syncline which reaches a depth of 130 m. Flow gauging and chemical analysis of streams draining the central part of this block indicate that outflows are blocked by a mass of low-permeability chalk. In consequence, groundwater flows are directed eastwards towards Arundel and westwards towards Chichester. At Arundel, spring discharges averaging 50 Ml/d are used for amenity and conservation purposes, and add to the abstractions of 18 Ml/d from the three nearby sources. To the west of Chichester, the syncline is pierced by several estuary creeks, the location of which appear to coincide with arching along the axis of the syncline through which groundwater discharges copiously as springs. The springs, partly intercepted by Portsmouth Water Company at Fishbourne, have flows of between 13 and 36 Ml/d. Intercepting these springs, either at their outlets, or north of the syncline offers the best opportunity for further exploitation of resources in the Chichester block, which at present is less-utilised than the other four Chalk blocks.

Seaford Chalk Block

The Seaford Chalk block is the smallest of the blocks with an area of 52 km$^2$. It possesses unusually high transmissivities which give rise to very speedy groundwater outflows and flat hydraulic gradients. Groundwater retention time in the aquifer is short and this is not conducive to the conservation of storage by seasonal abstraction switching. Mid Sussex Water Company has two sources which in 1983 abstracted 4500 Ml/a, but which are licensed to abstract 6600 Ml/a. Poverty Bottom is the older and larger source with its four wells connected by 480m of headings at -1.7mOD. Salinities at Poverty Bottom, and the duration over which normal levels are exceeded, have been gradually rising during the last twenty years. One of its consequences has been that molecular diffusion of the chlorides from the fissures into the pores of the chalk has gradually caused background levels to rise from 40mg/l in 1967 to 60mg/l at the present day.

Because of its potential effect on Poverty Bottom, Southern Water Authority were not able to authorise abstraction by Eastbourne Waterworks Company from their newly constructed and tested source at Rathfinny, and in 1982 MSWC acquired Rathfinny from EWWC. Rathfinny lies towards the centre of the Seaford block and its operation in conjunction with Poverty Bottom, the latter being used mainly in the winter and Rathfinny mainly in the summer, should permit MSWC to make the fullest use of their licensed abstractions from their three sources in this difficult aquifer while permitting greater control over chloride levels.

Eastbourne Block

The base of the Chalk rises progressively eastwards and in the Eastbourne block the basal beds of the Lower Chalk are exposed along the foot of the cliffs from Beachy Head to Eastbourne. The structure of the Chalk in this area is complex with transmissivities across the block varying considerably. As a result of these factors saline intrusion of the Chalk aquifer has never been a problem. Chlorides
are however regularly monitored, particularly at Friston, where in 1897 five observation boreholes were constructed between the station and the River Cuckmere to warn of any reversal of hydraulic gradient. These precautions were undoubtedly triggered by the problems encountered at Waterworks Road Pumping Station, Eastbourne which was eventually taken out of supply in 1896 when chlorides exceeded 2,000 mg/l. The station was brought back into supply in the 1950s and engineering works carried out in recent years should ensure that the problem does not recur.

The Eastbourne Waterworks Company operate seven sources within the Block which in 1983 abstracted 9,000 Ml/a and which are licensed for a total of 11,400 Ml/a.

MANAGEMENT OF THE SOUTH DOWNS AQUIFER

Efficient management of a coastal aquifer which is vulnerable to saline intrusion, such as is the case along much of the South Downs, requires six ingredients:

i. Sound knowledge of available resources.
ii. Control of private abstractions.
iii. Close monitoring of abstraction, water levels and coastal salinities.
iv. Implementation of a clear abstraction policy.
v. Operational control.
vi. Predictive capability.

Knowledge of the availability of resources is fundamental. In a fissured coastal aquifer the major uncertainty is the degree to which theoretical resources can be utilised for abstraction. In large aquifers possessing inter-granular flow and high storativities, the permissible degree of development might be related to the average available resources, or even higher for short periods. This is not so in the case of smaller fissured aquifers. In Britain in the last twenty years, it has become customary to design water resources development schemes on the basis of the availability of resources with a return period of 1 year in 50, and it is considered prudent to apply this criteria to the South Downs as the standard for resource development.

Control of private abstractions is essential if resources are to be properly managed. This is well catered for in England and Wales under the licensing provisions of the Water Resources Act 1963. In the South Downs area industrial development is limited, and the light chalky soils of the Downs are well suited to the growth of arable crops, such as barley and oats, for which irrigation is not needed. Private abstraction, therefore, is generally small (less than 10% of the total abstraction) and it is not thought that it is likely to expand significantly in the future. Allied to resource assessment and abstraction control is the need for the monitoring and receipt of information on, or from, private abstractors. Again, adequate provision is made for this in the Water Resources Act 1963.

Of all the hydrometric monitoring which it is necessary to undertake, that of coastal salinity is the most important. In the South Downs area regular geophysical down-hole logging of purpose-drilled coastal boreholes (150-250mm diam. and up to 250m deep) is undertaken. Full suites of logs have been run in all these boreholes, as well as in similarly-constructed inland boreholes using resistivity, gamma,
flow, temperature, differential temperature and conductivity, but it is the last two logs which are used for regularly monitoring seasonal and long-term changes in salinities. Experience has shown that for most coastal boreholes, down-hole logging has to be phased with the tides and such a programme of tide-cycle logging has now been carried out for nearly ten years. It is hoped that it will allow conductivity and temperature features to be identified in the borehole water columns, even though differing hydrostatic pressures may not make borehole and aquifer conditions directly comparable, so that any long-term trends in aquifer salinities can be identified.

Abstraction control, monitoring and the acquisition of hydrometric information, facilitate the adoption of a sound abstraction policy. Over the last twenty-eight years in the Brighton area, the policies of maximising the interception of coastal outflows and adopting the practice of 'leakage and storage' abstraction have been successful in permitting a 33% increase in abstraction in that time, while at the same time causing a 2m rise in average groundwater levels. The seasonal abstraction policy is being followed now in the Seaford block with the acquisition by Mid Sussex Water Company of their new inland source. Although less essential in the Worthing and Chichester blocks, where the coastal margin is largely protected by Tertiary strata, the principle of seasonal abstraction is being applied. In the Chichester block the interception of large spring discharges is likely to be the main target for further groundwater development, but in the smaller Eastbourne block, high nitrates and difficulty in acquiring suitable sites for test drilling, compound the problems posed by an already fully-committed aquifer.

The ability to control abstraction hour-by-hour so as to respond to fluctuating demand, varying electrical tariffs, pumping levels and aquifer salinities, is vital for proper management. This is achieved in the Brighton and Worthing areas by full telemetered control from Southern Water Authority's Divisional centre. It is thought that Brighton Corporation was the first water undertaking in Britain to install a centralised telemetry system in about 1957. The original electrical/mechanical system has now changed to full automated electronic control, and the sensitivity and range of information interrogated is being enhanced.

Aquifer management is aided if problems can be anticipated before they occur. The numerical aquifer models of the South Downs blocks can be used for this purpose. The complexity of the Brighton distribution system, with fourteen separate sources and sixteen booster stations feeding via thirty-three service reservoirs to six separate pressure zones under four different electrical tariffs, has so far defied several attempts at mathematical simulation. Nevertheless, SWA is currently constructing a water distribution network model (WATNETS) for Sussex, and when completed, it is hoped that it will provide the basis for the construction of an effective model for abstraction control. The Brighton aquifer model can then be used during the year, in conjunction with the operational model, to test the effectiveness of different abstraction regimes, and in particular, provide guidance on when seasonal switching from leakage to storage stations should be made. By this means, the aquifer can be safeguarded against saline intrusion, and the unnecessary penalty of operating more costly inland sites can be avoided.

Present estimates suggest that the operation of the Brighton Abstraction Policy accounts for some 5% of SWA's annual power costs of
£684,000 for its twenty-four South Downs sources, compared with the cost which would be incurred if the cheapest sources were used to the maximum. However, this is considered an acceptable price to pay for the aquifer security which it affords.

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