**Cuckmere Estuary Strategy: Groundwater Quality Report**

It is paramount that we protect the quality of groundwater in Southern Region, particularly given the heavy reliance on this resource for around 75% of public water supply. Moreover, the Water Framework Directive states that we must protect all groundwater, not just that used as a resource. It is therefore necessary to investigate the potential of the proposed tidal inundation of the Cuckmere Estuary to have an adverse impact on freshwater groundwater quality.

The key issues include:
(i) whether the local Chalk hydrogeology leaves the Seaford and Eastbourne Chalk blocks vulnerable to saline intrusion via tidal inundation; in particular what the implications are for the management of South East Water's Friston source in the Eastbourne Chalk.
(ii) whether 1) no active intervention, 2) managed realignment or 3) holding the line is preferable for groundwater protection.

**1. Summary of Current Hydrogeological Knowledge**

The Chalk is of dual porosity with flow occurring through both matrix and fracture pathways. Flow through the matrix is slow since although it is characterised by well connected, small diameter pores, narrow pore necks retard drainage. More rapid flow occurs within fractures and from storage within greater aperture pores. There are 6 main deformational fracture sets within the Eastbourne Chalk Block trending roughly 012°, 038°, 058°, 112°, 138° and 158° from true north (BGS, 1999).

Transmissivity is highest in river valleys compared to interfluves, since there is a greater density of active fractures within the valley setting, with enlarged apertures due to weathering processes. Transmissivity values for the Chalk of England vary from 16 - 9500 $m^2$/day (Jones & Robins, 1999, within Lee, 2003). Flow for the matrix and fractures has been calculated using Darcy's Law to be approximately 3 -5 mm/yr and approximately 100's of m/yr, respectively (Price et al., 1992, within Lee, 2003). The Eastbourne and Seaford blocks are broadly characterised by variable transmissivities. South East Water (2006) used T values ranging from12 to 83 $m^2$/d for low flow conditions and 112 to 441 $m^2$/d for high flow conditions as a crude calibration for flow modelling of the Eastbourne Chalk.

There is a relatively poor storage capacity in both Eastbourne and Seaford Chalk blocks. Groundwater levels rapidly cease to be maintained at higher levels at the end of the winter recharge period (Harries, 1980). Storativity values for the South Downs range between 0.0002 - 0.032 (Jones & Robins, 1999, within Lee, 2003). Aquifer discharge volumes draining from the Seaford and Eastbourne Chalk blocks during the summer are rapidly replenished each year, given normal winter recharge. (South East Water, 2006).

The depth of effective aquifer with regards to flow within the Chalk of England is generally taken to be 50-60 m; however, zones of preferential flow created during past base levels exist within the Chalk of the South Downs, giving localised effective depths of up to 150m (Jones & Robins 1998, within Lee, 2003).

The Seaford and Eastbourne aquifer blocks comprise Upper Chalk, with the exception of the northern escarpment that is formed of Middle and Lower Chalk. The Chalk dips gently to the SSW at an angle of approximately $3^{o}$ (BGS, 1999) from the groundwater divide of the northern escarpment.

Groundwater water flow generally follows the dip of the Chalk from the northern escarpment in a SSW direction towards the coast, but is toward the Cuckmere in the western section of the Eastbourne Block. The dry valleys across the Eastbourne Block have enhanced transmissivity and are rapid preferential flow corridors (South East Water, 2006).

Groundwater contours do not follow surface topography (see figure 1 for surface contours). The groundwater gradient is very shallow from the coastline up to the base of the groundwater mound of the northern escarpment. Hydrogeological maps show that the 5 m contour occurs some 5.0 km and 3.0 - 4.0 km inland for the Seaford and Eastbourne aquifer blocks, respectively. The low gradients are particularly pronounced during years of low recharge (Harries, 1980). Whilst a groundwater divide can be seen between contours further up the river, the 0 m groundwater contour straddles the mouth of the Cuckmere Estuary and the river is considered to be a constant head, no-flow boundary (South East Water, 2006).

Groundwater levels in both Seaford and Eastbourne aquifer blocks show little variation from summer to summer, irrespective of the volumes of winter recharge. In the absence of sustained recharge during the summer, levels quickly fall to approximately 1 m AOD across the whole coastal portion of the Seaford Block (Harries, 1980). This is due to the low storage and high transmissivity of the chalk near the coast. Transmissivities may be lower along the coast of the Eastbourne Block, since groundwater levels remain slightly higher here during the summer (South East Water, 2006).

Points of specific discharge from the two aquifer blocks are not well characterised. Flows from both blocks provide baseflow to the Cuckmere, but these volumes are unquantifiable due to the tidal nature of the estuary and much of the river. Lee (2003) suggests that the deficit in known discharge points from the Eastbourne Block indicated by water balance calculations could be accounted for by flow under the Cuckmere into the Seaford Block. However, this seems unlikely given the low gradients. South East Water (2006) state that local geology and geography dictate that there can be no significant flow into the Eastbourne Block from underlying or adjacent aquifers under normal conditions.

Known significant springs are limited to the northern chalk escarpment and the coastline for both Seaford and Eastbourne Chalk blocks. There is negligible flow from the coastal springs of the former block, compared with flows of up to 1300 Ml/a from the latter for the two relatively large volume springs at Limekiln Bottom and Birling Gap (Harries, 1980; volumes are from winter recharge period – NB this is not all freshwater but a mixture of seawater and freshwater. Attempts by Eastbourne WWKs Co to intercept this water proved fruitless with very low borehole yields).

Lee (2003) mentions anecdotal reports of springflows along the eastern bank of the Cuckmere, north of Exceat, during periods of high water level. South East Water (2006) suggest that the absence of major springs along the western boundary of the Eastbourne chalk block is due to the maintenance of groundwater baseflow to the river, which keeps groundwater levels below the ground surface. However, swallow holes may be present that could provide rapid flowpaths to the underlying Chalk. It has been suggested that the sparsity of visible discharge may be explained by drainage at the southern block margins via submarine springs (Harries, 1980). Lee, however, (2002) reports infra-red surveys suggest that this is not the case.

The Chalk of the Cuckmere Estuary floodplain is overlain by superficial deposits. These comprise valley gravels, deposited by high energy rivers during early valley development, overlain by silts that were progressively deposited when the environment became estuarine. These deposits are thought to act as an aquitard. An archaeological augur survey into the top 3m of the alluvium showed.3.0 m topsoil, 0.15 m structure less sandy silt, 1 m laminated silty sand, and 0.5 - 2.0 m of silts with medium to coarse grained sand horizons (National Trust, 2004). Gravel layers are thought to be present at greater depths. However, the depth and spatial extent of these is unknown.

Green (2002) gives depths for the Cuckmere Valley alluvium along the river long profile ranging from 3.0m to 19.6m, the latter thickness coinciding with the environs of the study area. Green reports that Bridgland (2000) noted relict knick points in the underlying Chalk south of the Litlington area as a result of responses to past changes in sea level, that led to a this deepening of the Chalk surface and so the greater accumulation of alluvium.

**2. Summary of Current Hydrogeochemical Knowledge**

Test pumping within the Seaford Block has shown that proximal boreholes may exploit differing hydrogeological pathways, which may draw in fresh or saline waters (South East Water, pers.comm., April 2006). High fracture densities and flow rates give rise to short term and seasonal variations in the position of the sub-surface saline wedge (Harries, 1980) at the coastal margin of both the Seaford and Eastbourne Chalk.

Salinity within the Seaford Chalk is generally only encountered in boreholes that intercept coastal fractures subject to the intrusion of brackish/saline waters during tidal surges. In addition, chloride concentrations may increase by the drawing-in of saline water along high transmissivity dry valleys linked either to the coast or to the Cuckmere valley. Harries (1980) suggests that this phenomenon was responsible for rises in chloride concentrations found at the Rathfinny source (west of the project study area) - chloride levels at the nearby Cradle Hill borehole situated on a topographical high closer to the coast were unchanged.

South East Water (2006) report that saline intrusion has never been a problem in the eastern side of the Eastbourne Chalk block, within the project study area (ie. at the Friston source). Abstractions at Friston have average chloride concentrations of 40mg/l, which are well within the Drinking Water Standard of 200 mg/l. Chloride concentrations at the linked Deep Dean source to the north are lower, between 28-32mg/l (South East Water, 2006).

In the West Dean dry valley that trends approximately WNW-ESE there are 5 observation boreholes, numbered 1 to 5 from east to west (Figure 1). South East Water use these as "early warning" boreholes to monitor whether saline water is moving towards their Friston source. This suggests that there has long been acknowledged to be a perceived significant risk of saline infiltration as a result of large groundwater abstraction from a coastal chalk aquifer. South East Water reported in 2006 that chloride concentrations in the two boreholes closest to the Cuckmere River are the highest, and are subject to most variation. For example, concentrations at borehole 5 range from 50 to 650mg/l, while levels at borehole 4 fluctuate between 50 and 100mg/l. Variations in level at both sites follow similar patterns, but are of much longer periodicity than a tidal cycle. South East Water (2006) assume the Chalk to be in hydraulic continuity with both the Cuckmere and the alluvium and that both therefore receive fresh water from the Chalk aquifer. Chloride levels at borehole 3 are about 50 mg/l, with occasional peaks of 75 mg/l. Concentrations at boreholes 2 and 1 were consistently between 40 and 50 mg/l from 1997-2000. Only those boreholes closest to the Cuckmere Valley (ie. 5, 4 and 3) are now monitored since chloride levels in boreholes 1 and 2 have remained stable at low values for many years. Well catalogue data gives the depths of boreholes 4 and 5 as 30.5 m and borehole 1 as 39.6 m. Borehole 5 is located in the valley floor. The elevated chloride values recorded at this site suggests that it intercepts brackish water within the Chalk, the valley alluvium hereabouts having an approximate depth of 19.6m (Green, 2002). The marked decrease in chloride levels along the high transmissivity West Dean dry valley suggests there is a limited movement of saline water towards the Friston source.

Harries (1980) gives chloride values 1680-6300mg/l for the coastal spring at Limekiln Bottom draining the Eastbourne Block margin to the south of Friston. Such concentrations suggest that the discharge comprises a mixture of saline and fresh waters.

**3. Implications of the Cuckmere estuary strategy options on Groundwater Quality**
Although the Seaford and Eastbourne Chalk blocks are essentially vulnerable to saline intrusion along the coastline due to their high transmissivity, fracture density and the low groundwater gradient, the proposed estuarine realignment schemes are not considered to exacerbate this threat. The greatest risk of saline infiltration is the pumping of groundwater from the aquifer which has the potential to reverse hydraulic gradients and allow migration of sea water landwards. South East Water manage their sources to eliminate this risk. A key feature of this is the maintenance of a positive hydraulic gradient to the coast and river valley to prevent saline ingress. The need to maintain this

positive gradient effectively obviates the risk of saline infiltration resulting from the proposed changes in flood defences.

The presence of thick valley alluvium south of Exceat Bridge, will assist in the prevention of saline intrusion into the chalk via inundating tidal water although the implicit (and existing) need for South East Water to manage hydraulic gradients will in any case serve to prevent any such movement. Gravel layers, which may well be in hydraulic continuity with the underlying chalk are likely to be present at depth beneath the valley alluvium.

The National Trust (2004) archaeological augur survey comprised 48 maximum 3.0m deep boreholes with 0.6m x 0.25m deep inspection pits. These were all subsequently back-filled, compacted and turfed over. The Survey added that consultants, Jacobs Babtie, had warned that any modification of the defences could cause localised erosion of up to1.5m at the western side of the present defences. However, this was when a phased managed realignment options was proposed – this is no longer the case. The NT survey, however, indicated that the alluvium remains silty/sandy to this depth, (thus any gravels present at depth would not be exposed)

There is potential for tidal flood waters to use fracture/solution pathways into the chalk along the valley margins. **Any such superficial intrusion will not, however, have any progressive impact on groundwater quality due to the prevailing hydraulic gradient within the chalk aquifer and the continuing replenishment of groundwater to the coast and valley sections from the recharged areas of the block**.

Under high recharge conditions numerous spring discharges from the Eastbourne Chalk have been reported along the road between Exceat and Litlington (pers.comm. S. Vipond). No springflows (or possible sinkhole sites) were observed along the banked eastern valley margin southwards from Exceat to Foxhole (M.O'Shea and S. Vipond inspection on 15.02.07.).

The presence of a groundwater divide between the Seaford and Eastbourne Chalk will ensure that any saline intrusion within one block should not be transferred to the other, unless a major change in hydraulic gradient occurs to provide a driving head. The onus is upon on-going abstraction management to ensure that this will never occur.

The Cuckmere estuary strategy proposes three broad options for the future management of flood defences, namely: **1) no active intervention, 2) managed realignment, and 3) Hold the line.**

Since the risk to groundwater quality through realignment of the estuary is deemed to be negligible, holding the line of the current defences is not considered an imperative, or (hence) reasonable option to pursue. Of the two other options, **managed realignment** would allow more control. This option is likely to provide the controlled inundation of tidal saline waters across the floodplain during the initial stages of change. Under **no active intervention** the location of a breach/breaches would be largely unpredictable.

This said, in a severe flood event, such as a severe storm, **managed realignment** is not likely to have any advantage over **no active intervention** since the defences are low here and the consequences of such an event are likely to be the same in both cases. Groundwater quality can be continuously monitored with equal effectiveness under both no active intervention and managed realignment scenarios.

A measure of managed realignment is however preferred in terms of the construction of a closing bank seaward of the A259 if rising sea levels mean that the road could be regularly inundated in the future. With regard to levels reaching the road, Mean High Water Springs (MHWS) would reach the lowest spot on the road by 2087 based on current sea level rise allowances (Defra, October 2006). Although this is the lowest level identified on the road, the adjacent banks may be higher protecting the road. It is important to note that a closing bank would not prevent saline water coming out of bank north of Exceat Bridge and studies to determine the future of the flood defences in this reach need to take account of the presence of the West Dean dry valley.

The availability of data on groundwater quality, level, and flow within the study area and its immediate environs is fairly limited. The collection and analysis of further data would enable a better understanding of the hydrogeological conditions which might affect groundwater quality within the chalk in this area.

**4. Implications for Groundwater Quality at South East Water Abstractions**

South East Water's Friston source is within 3.0km of the project study area. The borehole source is linked to a series of adits . The adits are ideally aligned perpendicular to flow. The main adit runs northward to link with the Deep Dean source but others lead 100m to the south, east and west.

The adit floor lies at -2.1m AOD at Friston (South East Water, 2006).
Saline intrusion is avoided at Friston and Deep Dean by ensuring that the abstraction regime maintains a positive hydraulic gradient between the two sources and the River Cuckmere/coast. Management is crucial since the total volume abstracted plus the previous winter's recharge directly control storage, which in turn prevents chloride intrusion occurring in summer.

Chloride levels in the sources are maintained close to background, well below both the Drinking Water Standard and the 100mg/l trigger level set for remedial action. In the event of short term, low impact saline intrusion, South East Water should be able to manage their sources to prevent further derogation of groundwater quality. It should be possible to alleviate any temporary increases in chloride levels via adjustments in the rates of abstraction.

Several high transmissivity dry valley preferential flow pathways support Friston. The area of catchment supporting the source is also the largest within the Eastbourne Chalk, comprising some 25km$^2$ (South East Water, 2006).

## 5. Implications under the Water Framework Directive

The Environment Agency must fulfil its groundwater protection obligations under the Water Framework Directive to reverse any current trends of poor quality and prevent any future deterioration. Specifically, it is an Environmental Objective under Article 4 that all groundwater bodies must be of good chemical status and that they must not suffer any deterioration in quality, especially via saline intrusion.

Under the Water Framework Directive Groundwater Body Test 2, groundwater bodies with known areas of elevated chloride in a coastal setting are classed as being of good chemical status if they show trends of falling or stable chloride. They are classed as being of poor chemical status if trends of increasing Cl, indicative of intrusion, are seen. For both outcomes, it is assumed that known areas of elevated Cl are managed to Prevent any further degradation.

Classifications of groundwater body status are given a confidence rating depending on the level of understanding upon which current conceptual models are based and the availability of suitable time series monitoring data of adequate spatial distribution for both groundwater level and salinity determinands. The very localised nature of saline intrusion in the Seaford and Eastbourne Chalk , in association with the management measures put in place by South East Water, give confidence that the Seaford and Eastbourne Chalk are likely to be classified as having **good** chemical status.

The current groundwater body risk maps, developed during the River Basin Characterisation 1 programme, show the risk of failing good chemical status on grounds of saline intrusion. The Seaford and Eastbourne Chalk are shown as having a low risk of failure. A full assessment of further time series data will be fed into the forthcoming River Basin Characterisation 2 programme.

## 6. Conclusions and recommendations

The risk to groundwater quality through tidal inundation of the Cuckmere estuary (south of Exceat Bridge) is assessed as negligible. The following recommendations should be followed:

(i) Future plans for flood risk management north of Exceat Bridge should take the West Dean valley and proximity to the Friston source into account.

(ii) A survey should be performed south of Exceat Bridge during the recharge season to confirm whether there is a spring line at the margins of the Cuckmere valley. Particular care should be taken to identify any swallow holes. This survey was undertaken by M. O'Shea and S. Vipond on 15.02.08.

(iii) Collection and analysis of further data, including through extended monitoring of the existing boreholes in the West Dean valley would enable a better understanding of the hydrogeological conditions which might affect groundwater quality within the chalk in this area.

(iv) Construction of a closing bank seaward of the A259 if rising sea levels mean that the road could be regularly inundated in the future.

**7. References**

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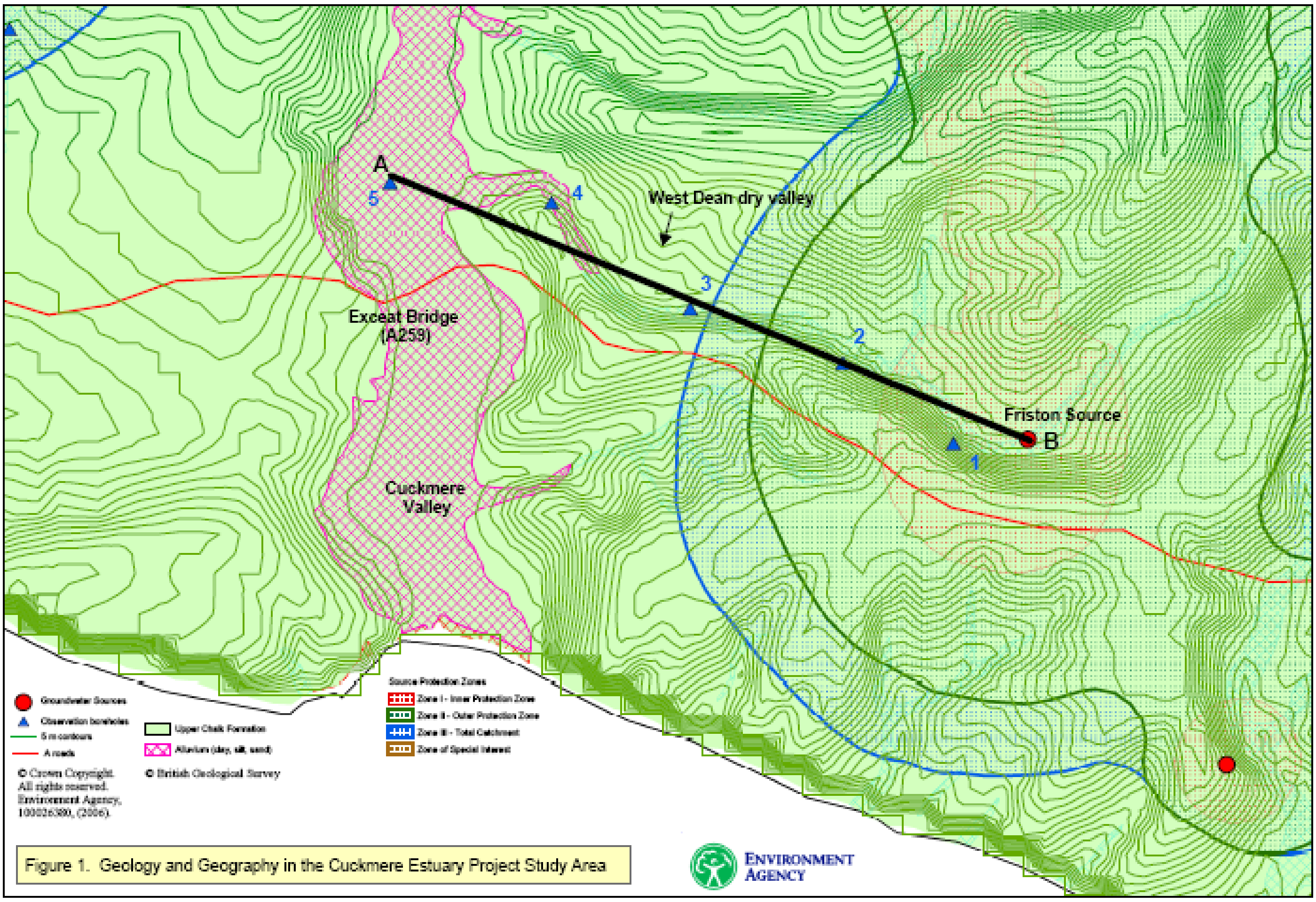


Figure 1. Geology and Geography in the Cuckmere Estuary Project Study Area