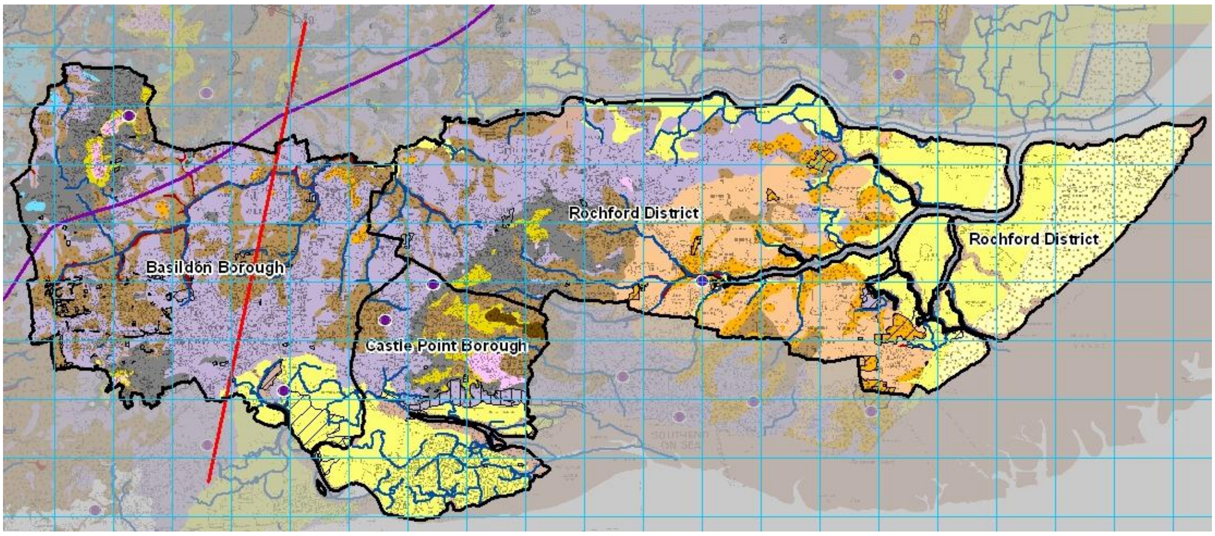
South Essex Surface Water Management Plan

Intermediate Assessment of Groundwater Flooding Susceptibility

Phase 2
May 2011



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Revision Schedule

Surface Water Management Plan – Intermediate Assessment of Groundwater Flooding Susceptibility

May 2011

Rev	Date	Details	Prepared by	Reviewed by	Approved by
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Abbreviations

ACRONYM	DEFINITION
BGS	British Geological Survey
DEFRA	Department for Environment, Fisheries and Rural Affairs
EA	Environment Agency
LiDAR	Light Detection and Ranging
SUDS	Sustainable Drainage Systems
SWMP	Surface Water Management Plan

Glossary

TERM	DEFINITION
Aquiclude	Formations that may be sufficiently porous to hold water, but do not allow water to move through them.
Aquifer	Layers of rock sufficiently porous to hold water and permeable enough to allow water to flow through them in quantities that are suitable for water supply.
Aquitard	Formations that permit water to move through them, but at much lower rates than through the adjoining aquifers.
Climate Change	Long term variations in global temperature and weather patterns, caused by natural and human actions.
Flood defence	Infrastructure used to protect an area against floods, such as floodwalls and embankments; they are designed to a specific standard of protection (design standard).
Floods and Water Management Act	Legislation constituting part of the UK Government's response to Sir Michael Pitt's Report on the Summer 2007 floods, the aim of which is to help protect ourselves better from flooding, to manage water more sustainably and to improve services to the public.
Fluvial flooding	Flooding by a river or a watercourse.
Groundwater	Water that is underground. For the purposes of this study, it refers to water in the saturated zone below the water table.
Pluvial Flooding	Flooding as a result of high intensity rainfall when water is ponding or flowing over the ground surface before it enters the underground drainage network or watercourse, or cannot enter it because the network is full to capacity.
Risk	The product of the probability and consequence of the occurrence of an event.
Sewer flooding	Flooding caused by a blockage, undercapacity or overflowing of a sewer or urban drainage system.
Sustainable Drainage Systems	Methods of management practices and control structures that are designed to drain surface water in a more sustainable manner than some conventional techniques. The current study refers to the 'infiltration' category of sustainable drainage systems e.g. soakaways, permeable paving.

1 Introduction

1.1 Groundwater Flooding

1.1.1 Groundwater flooding occurs as a result of water rising up from the underlying aquifer or from water flowing from abnormal springs. This tends to occur after long periods of sustained high rainfall, and the areas at most risk are often low-lying where the water table is more likely to be at shallow depth. Groundwater flooding is known to occur in areas underlain by major aquifers, although increasingly it is also being associated with more localised floodplain sands and gravels.

1.1.2 Groundwater flooding tends to occur sporadically in both location and time, and because of the more gradual movement and drainage of water, tends to last longer than fluvial, pluvial or sewer flooding. When groundwater flooding occurs, basements and tunnels can flood, buried services may be damaged, and storm sewers may become ineffective, exacerbating the risk of surface water flooding. Groundwater flooding can also lead to the inundation of farmland, roads, commercial, residential and amenity areas.

1.1.3 It is also important to consider the impact of groundwater level conditions on other types of flooding e.g. fluvial, pluvial and sewer. High groundwater level conditions may not lead to widespread groundwater flooding. However, they have the potential to exacerbate the risk of pluvial and fluvial flooding by reducing rainfall infiltration capacity, and to increase the risk of sewer flooding through sewer / groundwater interactions.

1.1.4 The need to improve the management of groundwater flood risk in the UK was identified through Defra's Making Space for Water strategy. The review of the July 2007 floods undertaken by Sir Michael Pitt highlighted that at the time no organisation had responsibility for groundwater flooding. The Flood and Water Management Act identified new statutory responsibilities for managing groundwater flood risk, in addition to other sources of flooding and has a significant component which addresses groundwater flooding.

1.2 The Current Report

1.2.1 Basildon Borough Council, Rochford District Council, Castle Point Borough Council and Essex County Council have commissioned Scott Wilson to complete their Surface Water Management Plan (SWMP). A SWMP is a plan which outlines the preferred surface water management strategy in a given location. In this context surface water flooding describes flooding from sewers, drains, groundwater, and run-off from land, small water courses and ditches that occurs as a result of heavy rainfall (DEFRA, March 2010).

1.2.2 The current report provides an intermediate assessment of groundwater flooding susceptibility as part of the SWMP Phase 2, and provides recommendations for Phase 3. The following sections outline the geology and hydrogeology in the Basildon Borough Council, Rochford District Council and Castle Point Borough Council administrative areas, part of Essex County Council administrative area. From this analysis:

- Potential groundwater flooding mechanisms are identified;
- Evidence for groundwater flooding is discussed;
- Areas susceptible to groundwater flooding are recognised; and
- Recommendations are provided for further investigation.

2 Topography, Geology and Hydrogeology

2.1 Topography and Hydrology

2.1.1 Within the administrative areas of Basildon Borough Council (BC), Castle Point Borough Council and Rochford District Council (DC) - referred to as 'South Essex' in this report, part of Essex County Council area - ground levels in the interfluvial areas reach 82 maOD at Thundersely and more than 90 maOD at Billericay, falling to sea level (0 maOD) in the east and south. There are a number of surface water courses within the South Essex area and these are shown on Figure 1 and described further below. Figure 1 illustrates the complex drainage system within the South Essex area, which comprises predominantly of minor streams, channels, and ditches, with the exception of the River Crouch.

2.1.2 The River Upper Crouch has a mixed rural and urban catchment, including a substantial proportion of Basildon, Wickford and Billericay. The flow in the River Upper Crouch is monitored at a gauging station at Wickford, where the mean average flow is reported as 0.33 m^3/s with a Q_{95} as 0.05 m^3/s (Entec, 2006). The flow is responsive to rainfall, and groundwater is identified as a small component of the flow. Dunton Brook is a tributary of the River Upper Crouch with a substantial flow – as much as half that observed in the Upper Crouch at Wickford. Other tributaries of the Upper Crouch have been assessed by JBA Consulting (September 2010), some of which are known to dry out (Entec 2006).

2.1.3 Rawreth Brook flows northwards from Thundesley into the Lower Crouch. It has a mostly rural catchment, with some urban areas to its south and western parts of its catchment. Much of its channel has been heavily modified to enhance land drainage within its catchment.

2.1.4 The Asheldham Brook has a recently constructed flow gauge, such that flow data has not been brought into this assessment.

2.1.5 Canvey Island is reclaimed marshland and tidal flats, separated from the mainland by a network of creeks. Sea defences were strengthened after the sea-inundation of 1953. Canvey Island was established partly by a succession of sea-wall enclosures, forming a low relief feature, largely man-made, which forms its own hydrometric catchment. As a result, its drainage network is dominated by artificial drains and dykes. A similar situation is observed along much of the north bank of the Thames Estuary.

2.1.6 Foulness Island is low relief island, comprising of reclaimed marshlands and tidal flats, established partly by natural causes, and partly by a succession of sea-wall enclosures. The size of the island has been observed to increase with periodic deposition of saline rich alluvium. Foulness Island forms its own hydrometric catchment, with drainage via a series of dykes and field drains, with water levels and flows controlled. Sea defences should prevent repetition of the major flooding by sea water, notably in 1953.

2.1.7 Prittle Brook is maintained predominantly by the Environment Agency. It flows west to east though the Southend-on-Sea Council area, before turning northwards to join the River Roach in Rochford DC. Following a flood event in 1968, major channel improvements were undertaken and the Prittle Brook is now heavily modified. In the 1970s Anglian Water installed the Prittle Brook flood relief tunnel, which diverts excess flows to the Thames Estuary during times of flooding and largely relieves drainage from the western part of Southend-on-Sea

(Scott Wilson, April 2010). This in turn affects the flows in the lower reaches, as it passes through Rochford DC into the tidal reaches of the River Roach.

2.1.8 As with the Prittle Brook, the Eastwood Brook is maintained by the Environment Agency and flows west to east though Southend-on-Sea Borough Council's area into Eastwood and then northeast towards its confluence with the River Roach at Rochford Hundred Golf Club. The Eastwood Brook is also heavily modified (Scott Wilson, April 2010).

2.1.9 Mucking Hall Brook is culverted beneath the Royal Artillery Way, flowing north-eastwards through the Essex Golf Complex, before flowing northwards into the upper tidal reaches of the River Roach.

2.2 Geology

2.2.1 Figures 2 and 3 provide geological information for the South Essex councils and the surrounding area from the British Geological Survey (BGS) 1:50,000 scale geological series for the bedrock and superficial geology, respectively. Figure 4 illustrates a geological cross section for the study area and this has been used to improve the conceptual understanding of the area. The BGS 1:10,000 scale geological series does not exist for a more detailed geological assessment. However, 233 borehole logs were identified from the BGS to provide local data and their locations are shown in Figure 2.

Bedrock Geology

2.2.2 The bedrock geology of the area comprises the Upper Chalk[1], which in turn is overlain by Lower London Tertiaries (Thanet Sand Formation and Lambeth Group), the London Clay Formation, Claygate Member and the Bagshot Formation.

2.2.3 The Claygate Member (formerly the Claygate beds) rests conformably on the London Clay Formation, and the Bagshot Formation overlies the Claygate Member. In the Castle Point BC and Rochford DC area, the Claygate Member and Bagshot Formation are exposed northeast of South Benfleet, through Thundersley and Rayleigh to Hockley. The bedrock units are also exposed in the north west of Basildon BC in the Billericay area and less extensively in the south west. The Claygate Member comprises of sand with silt and clay horizons and ranges from 17 m to 23 m in thickness. The Bagshot Formation comprises of sand and has a thickness of up to 23 m in South Essex.

2.2.4 The London Clay Formation dominates the western side of the South Essex study area, notably in the Basildon BC administrative area; and the northern part of the South Essex study area south of the River Crouch, as far east as Canewdon; with minor fragmented outcrops of London Clay Formation found in the centre of the Rochford DC administrative area where superficial deposits are absent. The full thickness of London Clay Formation is known only where the formation is capped by the Claygate Member and is around 130 m.

2.2.5 The Lower London Tertiaries are mainly sands which vary in thickness from approximately 45 m in the north to more than 50 m adjacent to the River Thames Estuary in the south. The Lower London Tertiaries are overlain by the London Clay Formation across the whole region.

[1] According to new nomenclature for the Chalk, the term 'Upper Chalk' is no longer in formal use, and the unit has been split into several formations including the 'Lewes Nodular Formation', 'Seaford Chalk Formation', 'Newhaven Chalk Formation' and 'Culver Chalk Formation'. For ease of reporting, the term 'Upper Chalk' is retained.

Superficial Geology

2.2.6 The superficial geology of the area consists of Alluvium, Head, River Terrace Deposits, Beach and Tidal Flat deposits, Tidal Flat Deposits, Lowestoft Formation, Glaciofluvial Deposits, Stanmore Gravel Formation and Sand and Gravel of Uncertain Age and Origin.

2.2.7 Several deposition cycles of River Terrace and Storm Beach and Tidal Flat Deposit sediments are present within the eastern and south-eastern part of the study area. The River Terrace Deposits mainly consist of sand and gravel or silt and clay. They dominate the superficial geology in the south and east of the study area. The thickness of the sand and gravel River Terrace Deposits varies between approximately 2 and 18 m, and generally overlie the River Terrace Deposits comprising silt and clay which range in thickness from 2 to 7 m (Figure 3). Substantial areas of the River Roach catchment and south of the tidal reaches of the River Crouch are underlain by River Terrace Deposits. Along the River Roach catchment, the River Terrace Deposits include buried sand channels ranging in thickness from 11 to 13 m. The River Terrace Deposits are also locally overlain by Head deposits which are variable in composition and their thickness ranges from 0.5 m to 3.5 m over the region, thickening westward in the River Crouch catchment.

2.2.8 Alluvium comprising clay, silt, sand and gravel is present in the valley and floodplain of the River Crouch, and is found associated with the Eastwood Brook, one of the tributaries of the River Roach.

2.2.9 The Tidal Flat and Beach Deposits comprising silty clay with sand lenses are located along the banks of the Thames estuary and cover wide areas of the Foulness Island. Borehole records indicate slightly coarser grained deposits in the Grays area where they comprise silt and sands, with more clay and silt dominating the eastern areas of Rochford DC. These deposits are 1 m to 5 m thick. A thin basal sand and gravel horizon usually underlies the Tidal Flat Deposits.

2.2.10 In the higher elevated land in the south east and north east of Castle Point BC, significant deposits of Sand and Gravel of Uncertain Age and Origin and Glaciofluvial Deposits overlie the Claygate Member and Bagshot Formation bedrock geology. Where these bedrock geology units are present in the northwest of the Basildon BC, they are overlain by smaller deposits of Lowestoft Formation and Stanmore Gravel Formation.

2.2.11 The southern limit of glaciers during the Pleistocene glaciations is marked on Figures 2 and 3. This limit is found to the northwest of Basildon BC administrative area. No significant glacial deposits associated with these glaciations remain in this area, and are therefore not considered as part of this study.

2.3 Hydrogeology

2.3.1 The hydrogeological significance of the various geological units within the study area is provided in Table 1. The range of permeability likely to be encountered for each geological unit is also incorporated in Table 1, based on the BGS minimum and maximum permeability data, as presented in Figures 5-1 and 5-2.

Table 1: Geological Units in the Study Area and their Hydrogeological Significance

Geological Units		Permeability (based on BGS permeability map)	Hydrogeological Significance
Superficial Geology	Alluvium	High to very low	Variable (but probably an aquitard)
	Beach and Tidal Flat Deposits	Moderate to very low	Variable (but probably an aquitard)
	Glaciofluvial Deposits	Very high to high	Secondary Aquifer (A)
	Head	High to very low	Secondary Undifferentiated. Variable (probably an aquitard but may locally form a secondary aquifer)
	Lowestoft Formation	Moderate to low	Secondary Undifferentiated. Variable (but probably an aquitard)
	River Terrace Deposits (silt and clay)	Low to very low	Aquitard
	River Terrace Deposits (sand and gravel)	Very high to high	Secondary Aquifer (A)
	Sand and Gravel of Uncertain Age & Origin	Very high to high	Secondary Aquifer (A)
	Stanmore Gravel Formation	Very high to high	Secondary Aquifer (A)
	Tidal Flat Deposits (silt and clay)	Low to very low	Unproductive strata / Aquiclude
	Tidal Flat Deposits (sand and silt)	High to moderate	Secondary Aquifer (A)
Bedrock Geology	Bagshot Formation	High	Secondary Aquifer (A)
	Claygate Member	Very low to high	Secondary Aquifer (A)
	London Clay Formation	Moderate to very low	Aquiclude[2]
	Lower London Tertiaries	N/A	Principal aquifer
	Chalk	N/A	Principal aquifer

'Principal Aquifer' - layers that have high permeability. They may support water supply and/or river base flow on a strategic scale.
'Secondary Aquifer (A)' - permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers.
'Secondary Undifferentiated - In most cases, the layer in question has previously been designated as both minor and non-aquifer in different locations due to the variable characteristics of the rock type.
'Aquitard' - allows some groundwater movement (see glossary)
'Aquiclude' - does not allow groundwater movement (see glossary)

Bedrock Geology

2.3.2 The London Clay Formation is a stiff low permeability silty clay covering most of the South Essex and all of the study area. The unit is an aquiclude and does not permit groundwater flow, and is thereby classified as unproductive strata.

2.3.3 The Lower London Tertiaries are fine to medium grained sands with varying proportions of silt and clay, underlying the London Clay Formation throughout South Essex. They typically form a secondary aquifer, with moderate storativity and Transmissivity and are in hydraulic continuity with the Chalk beneath, providing additional storage to the Chalk aquifer. The physical properties for minor aquifers in England and Wales (Allen *et al.,* 1997) suggests 'The Thanet Sand Formation, Lambeth Group and the Harwich Formation are often considered as a single

[2] The BGS permeability data set suggests a moderate to very low permeability. However, the London Clay is expected to behave as an aquiclude.

groundwater unit, known as the 'Basal Sands' aquifer, which is in hydraulic continuity with the Chalk'. Due to the significant thickness of the overlying London Clay Formation the Basal Sands aquifer and Chalk are not considered pertinent to the hydrogeology of the study area.

2.3.4 The Claygate Member permits groundwater flow but can significantly vary in permeability. The unit is hydraulically separated from the Chalk and 'Basal Sands' by the London Clay Formation. The Claygate Member may also be in hydraulic continuity with overlying superficial deposits and is of interest to this study.

2.3.5 The Eocene Bagshot Formation consists mainly of fine-grained sand with thin, interbedded clay horizons; classified as a Secondary Aquifer (A). It has a limited lateral extent within the study area; however, this Formation could be in hydraulic continuity with the underlying Claygate Member or overlying superficial deposits and is of interest to the current study.

Superficial Geology

2.3.6 Head deposits are expected to behave as an aquitard, although sand horizons may locally form a secondary aquifer depending on their lateral extent and thickness. These deposits may be in hydraulic continuity with the bedrock geology aquifers in the Castle Point BC where the Bagshot Formation and Claygate Member outcrop beneath the superficial deposits. In addition, perched aquifers may exist where the Head deposits overly the London Clay Formation. These deposits are of interest to the current study.

2.3.7 The Sands and Gravels of Uncertain Age and Origin found in the Thundersley and South Benfleet (Castle Point BC) area, and the Stanmore Gravel Formation in the Billericay area (Basildon BC) are classified as Secondary Aquifer (A) and could be in hydraulic continuity with the underlying Claygate Member and Bagshot Formation. These deposits are of interest to the study.

2.3.8 Small deposits of Lowestoft Formation exist in the north west of the Basildon BC. The deposits are classified as Secondary Undifferentiated and are expected to have variable permeability. These deposits may be in hydraulic continuity with the underlying Claygate Member where present. The deposits are only of interest in the Basildon BC.

2.3.9 The sand and gravel River Terrace Deposits deposited in south-eastern Essex, particularly in the River Roach catchment, can form a locally important aquifer with moderate to high hydraulic permeabilities and storativities. However, in many areas these deposits are overlain by the silt and clay River Terrace Deposits aquitard. The sand and gravel River Terrace Deposits are of primary interest to the current study and are a Secondary Aquifer (A).

2.3.10 Alluvium along the Eastwood Brook, Tidal Flat Deposits, and Beach and Tidal Flat Deposits along the coastline are expected to behave as aquitards. However, variable grain size and distribution mean that the groundwater hydraulics within these units are spatially variable, with lenses and channel deposits allowing preferential groundwater movement and storage.

2.3.11 The clayey to sandy sediments of the Tidal Flat Deposits occur along the banks of the Thames estuary and much of Foulness Island. Based on borehole records, Entec (2006) assert that in the Grays area, these deposits are slightly coarser grained comprising silt and sands, potentially acting as a Secondary Aquifer, compared with the more clay and silt dominated deposits to the east of Rochford DC, where the Tidal Flat Deposits are expected to behave as an aquitard.

2.3.12 The superficial geology aquifers are expected to be in good hydraulic continuity with the bedrock geology aquifers in the South Essex area where they overly the Claygate Member and Bagshot Formation.

Groundwater Levels

Bedrock Geology

2.3.13 Groundwater level data for one borehole located at the North Thames Gas Works has been obtained from the Environment Agency (TQ88SE12 on Figure 2). The borehole monitors the principal aquifer (Chalk with Lower London Tertiaries) and the piezometric level is approximately 2 m below ground surface. Chalk groundwater levels have not been considered further as part of this study due to the significant thickness of London Clay Formation, which confines the Chalk aquifer in the South Essex study area

2.3.14 The Environment Agency does not monitor groundwater levels in the Claygate Member or Bagshot Formation in the study area.

Superficial Geology

2.3.15 There are no known Environment Agency records of groundwater levels in the superficial deposits. However, it is understood that the South Essex Councils hold a limited number of historic site investigation reports, which often contain groundwater level data. Borehole logs are also available from the BGS and a limited number of these provide details of groundwater levels. The boreholes were drilled in different years and so groundwater contours cannot be constructed, although comments on groundwater levels can provide an indication of depth to groundwater. It is recommended that these water levels are collated as part of a more detailed assessment.

Water Supply Abstractions

2.3.16 In the 1960s and 1970s numerous abstractions targeted the Chalk aquifer in South Essex. As a consequence of local over-abstraction, a pronounced cone of depression developed in this area, with saline water ingress into the Chalk aquifer (Entec UK Limited, June 2006). The abstractions ceased in the 1980s, leading to recovery in groundwater levels by up to 40 m.

2.3.17 There are many groundwater abstractions within the Basildon BC, Rochford DC, Castle Point BC administrative boundaries as shown by Figures 6-1 to 6-3. These abstractions vary in licensed volume and the aquifer from which they abstract.

2.3.18 The Environment Agency confirmed that there are no Source Protection Zones (SPZ) delineated within the South Essex area; reflecting the fact that superficial deposits dominate the area and the principal aquifers are too deep for economic development.

Artificial Groundwater Recharge

2.3.19 Additional recharge by leaking mains could result in a local rise in groundwater levels. This rise might not prove significant under dry conditions, but could exacerbate the risk from groundwater flooding and other sources of flooding following periods of heavy rainfall.

2.3.20 The drainage/sewer network can act as a further source of artificial recharge. When pipes are empty, groundwater may leak into the drainage network with water flowing in through cracks and porous walls, draining the aquifer and reducing groundwater levels. When pipes are full leaking pipes can artificially recharge groundwater and subsequently increase groundwater levels with potential impacts on groundwater quality.

2.3.21 Water mains leakage data for the administrative area of the South Essex Councils were requested from Essex and Suffolk Water. The water company does not assess leakage estimates at this level of detail. Nonetheless, for the area of Essex served by Essex and Suffolk Water, the reported leakage for 2006/07 was 68.0 Ml/d (Essex and Suffolk Water, April 2008).

Surface Water / Groundwater Interactions

2.3.22 As identified in Section 2.1, flow is measured at gauging stations at Wickford for the River Upper Crouch, and the Asheldham Brook has a recently constructed flow gauge. River flow data has been requested from the Environment Agency. However, this information was not available at the time of writing.

2.3.23 Groundwater / surface water interactions will be limited by the extensive historic modification of surface water courses. For example, approximately 7.6 km of channel improvements have been carried out on the River Crouch through Wickford; the River Roach through Rochford; Hockley Brook through Hockley; and Hawkwell Brook through Hawkwell, including channel straightening, deepening, and lining the bed and banks with concrete to increase the capacity and flow rate (Environment Agency, August 2008). The lining of the bed and banks with concrete will limit surface water and groundwater interaction.

2.3.24 It has been reported that during the summer months, base flows in the Prittle Brook and Eastwood Brook are very low due to the small volumes of groundwater that can be stored naturally in the superficial deposit aquifers present in the area (Environment Agency, August 2008). However, they may also be low owing to limited hydraulic connectivity with the superficial geology aquifers resulting from the river channel modifications. Without groundwater level data for the superficial geology aquifers, it is not possible to gain an understanding of the relationship between surface water and groundwater.

3 Assessment of Groundwater Flooding Susceptibility

3.1 Groundwater Flooding Mechanisms

3.1.1 Based on the current hydrogeological conceptual understanding, there is potential for groundwater flooding in the South Essex councils' administrative area. There are six key groundwater flooding mechanisms that may exist:

- **Superficial aquifers along the River Roach, Prittle Brook, Eastwoood Brook (Eastwood Area) and the Mucking Hall Brook):** groundwater flooding may be associated with the substantial sand and gravel River Terrace Deposits, or to a lesser degree, sand lenses within Tidal Flat Deposits and Head deposits, where they are in hydraulic continuity with surface water courses. Stream levels may rise following high rainfall events but still remain "in-bank", and this can trigger a rise in groundwater levels in the associated superficial deposits. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars, which have been constructed within the superficial deposits. In the UK, houses with cellars / basements were largely built in the Victorian era and into the early 1900s. Therefore, the older developed areas in south Essex are more likely to comprise properties with cellars / basements.

- **Superficial aquifers not in hydraulic continuity with surface water courses:** a second mechanism for groundwater flooding is also associated with substantial River Terrace Deposits (gravel and sand), Sand and Gravel of Uncertain Age and Origin, Stanmore Gravel Formation, Lowestoft Formation, Glaciofluvial Deposits, sand lenses within Tidal Flat Deposits and Head deposits, but occurs where they are not hydraulically connected to surface water courses. Perched groundwater tables can exist within these deposits, developed through a combination of natural rainfall recharge and artificial recharge e.g. leaking water mains. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars.

- **Superficial aquifers along the coastline (Foulness Island, Wallasea Island, east of Great Wakering):** a third mechanism for groundwater flooding could occur where River Terrace Deposits (gravel and sand), or sand lenses within Tidal Flat Deposits are present behind coastline flood defences. It is possible that tidal fluctuations propagate northwards through the superficial deposits, increasing the potential for groundwater flooding. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars.

- **Claygate Member and Bagshot Formation (bedrock) outcrop in central and western study area:** Water levels within the outcropping Claygate Member and the Bagshot Formation will be perched on top of the London Clay Formation aquiclude. This means that basements / cellars in this area may be at risk from groundwater flooding following periods of prolonged rainfall, increased utilisation of infiltration SUDs and / or artificial recharge from leaking pipes.

- **Impermeable (silt and clay) areas downslope of superficial aquifers in various locations:** a fifth mechanism for groundwater flooding may occur where groundwater springs / seepages form minor flows and ponding over impermeable strata where there is poor drainage. This mechanism may occur as a result of natural (e.g. rainfall) or artificial (e.g. water main leakage) recharge.

- **Artificial ground in various locations:** a final mechanism for groundwater flooding may occur where the ground has been artificially modified to a significant degree. If this artificial ground is of substantial thickness and permeability, then a shallow perched water table may exist. This could potentially result in groundwater flooding at properties with basements, or may equally be considered a drainage issue. Areas mapped by the BGS as containing artificial ground are shown in Figures 2, 3, 5, 6 and 7.

3.2 Evidence of Groundwater Flooding

3.2.1 No groundwater flooding incidents within the study area have been reported to the Environment Agency. Recorded flooding events since April 2007 are shown on Figures 6-1, 6-2 and 6-3. The majority of these flooding events are expected to be related to surface water flooding but it is possible that some of these incidents were influenced by groundwater conditions, although there are no available data to confirm this.

3.3 Groundwater Flooding Susceptibility Datasets

3.3.1 The BGS has produced a data set showing areas susceptible to groundwater flooding on the basis of geological and hydrogeological conditions. The high and very high susceptibility bands are shown on Figures 6-1, 6-2 and 6-3.

3.3.2 The BGS data indicates that susceptibility to groundwater flooding is very high to high in some areas where Head deposits, River Terrace Deposits and Marine Alluvium Sands are present at surface; notably along the east of Foulness Island, the River Roach, Eastwood Brook, the Prittle Brook, and the River Crouch and its tributaries. As expected, these locations coincide with areas where the BGS has identified higher permeability (see Figure 5-2) and ground elevations are low.

3.3.3 Areas where the Claygate Member and Bagshot Formation outcrop are not areas identified as being susceptible to groundwater flooding despite the bedrock units being assigned high permabilities in Figure 5-2. However, in the Billericay and Thundersley / Hadleigh area there are many flooding events where these bedrock units outcrop.

3.3.4 In general, it is thought that the approximate areas identified by the BGS as being susceptible to groundwater flooding are as expected. However, it is possible that the various categories from ‘very high’ to ‘very low’ may not be accurate given the poor availability of groundwater level data to the BGS; the Environment Agency does not monitor superficial, Claygate Member or Bagshot Formation bedrock groundwater levels within the study area.

3.3.5 The BGS groundwater flooding susceptibility data indicates a high susceptibility to groundwater flooding in areas where Head deposits outcrop. However, in reality the Head deposits are variable in composition (clay, silt, sand and gravel) and their thickness and lateral extent is limited over the study area. Based on the current assessment, it is thought that the Head deposits are not as susceptible to groundwater flooding as indicated by the BGS data.

3.3.6 The London Clay Formation is an aquiclude and does not permit groundwater flow. Therefore in areas where there are no overlying superficial deposits and the London Clay Formation is of an appreciable thickness, the potential for elevated groundwater levels is considered to be negligible. However, where the London Clay Formation has been removed and replaced with more permeable artificial ground, there may be increased potential of elevated water levels as groundwater becomes trapped in these deposits.

3.3.7 Finally, those areas identified by the BGS as having no susceptibility to groundwater flooding could still be affected where groundwater springs / seepages form minor flows and ponding over impermeable strata such as the London Clay Formation. This mechanism may have resulted in the regular ponding of water observed adjacent to drainage on Canvey Island, where it is possible that groundwater seepages from the River Terrace Deposits seep onto the relatively impermeable Tidal Flat Deposits. It is recommended that rolling ball analysis in Geographical Information System (GIS) is undertaken as part of a more detailed assessment.

3.4 Importance of Long Term Groundwater Level Monitoring

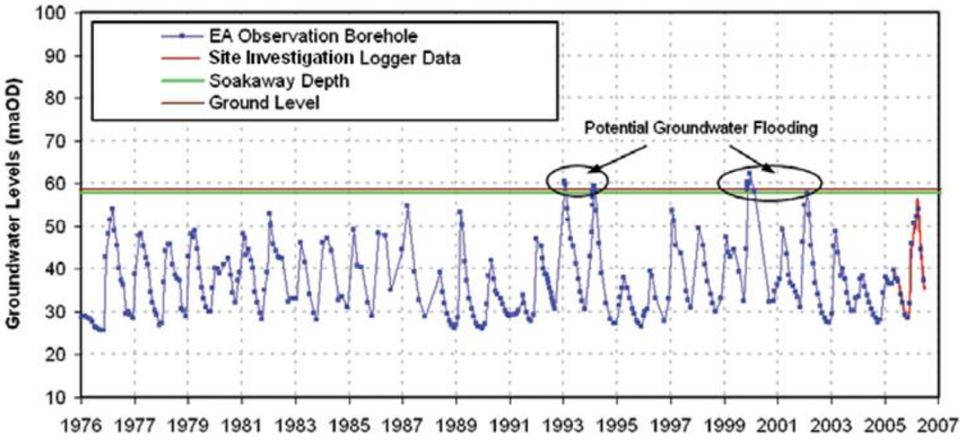
3.4.1 Groundwater flow direction, depth to groundwater, topography and the degree of artificial influence in the subsurface (e.g. leaking water mains or groundwater abstractions) play an important role when considering the susceptibly of an area to groundwater flooding. Unfortunately groundwater level data for the superficial aquifers is limited to recorded water strikes or rest water levels on BGS borehole logs, which only provide groundwater levels at one location and for one point in time. Without long term groundwater monitoring, it is not possible to derive groundwater level contours, or understand maximum seasonal fluctuations. Therefore it is not possible to provide a detailed assessment of groundwater flood risk or provide detailed advice on suitability for infiltration SUDS.

3.4.2 It is not sufficient to rely on the work undertaken by developers through the planning application process. Groundwater levels are often only measured once or, at most, for a number of weeks. It would be advisable for the South Essex councils, in combination with the Environment Agency, to begin long term monitoring of superficial aquifer and bedrock aquifer (Claygate Member and Bagshot Formation) groundwater levels. This data would also be useful for understanding groundwater / surface water interactions, which is important when considering the design of fluvial or coastal style flood defences.

3.4.3 It is also important to understand how changing policies relating to infiltration SUDS can impact upon groundwater levels. For example, the introduction of infiltration SUDS (e.g. soakaways) may cause a rise in peak groundwater levels. This could prevent soakaways from operating and the reduction in unsaturated zone thickness may not be acceptable to the Environment Agency owing to its responsibilities under the Water Framework Directive. It may also cause groundwater flooding of infrastructure, basements / cellars etc that were designed and constructed during a period of reduced groundwater recharge.

3.4.4 Long term groundwater level monitoring is required to support decision making with respect to future land development and future co-ordinated investments to reduce the risk and informing the assessment of suitability for infiltration SUDS. Once sufficient data has been collected, it may be suitable to develop a groundwater level warning system using the observation borehole network.

Schematic demonstrating the importance of long term groundwater level monitoring



4 Water Framework Directive and Infiltration SUDS

4.1.1 The Water Framework Directive approach to implementing its various environmental objectives is based on River Basin Management Plans (RBMP). These documents were published by the Environment Agency in December 2009 and they outline measures that are required by all sectors impacting the water environment. The Anglian River Basin District is considered within the current study, since infiltration Sustainable Drainage Systems (SUDS) have the potential to impact the water quality and water quantity status of aquifers.

4.1.2 Improper use of infiltration SUDS could lead to contamination of the superficial deposit aquifers, leading to deterioration in aquifer quality status or groundwater flooding / drainage issues. However, correct use of infiltration SUDS is likely to help improve aquifer quality status and reduce overall flood risk.

4.1.3 Environment Agency guidance on infiltration SUDS is available on the website at: http://www.environment-agency.gov.uk/business/sectors/36998.aspx. This should be considered by developers and their contractors, and by Basildon BC, Castle Point BC, Rochford DC and Essex County Council when approving or rejecting planning applications.

Key Water Level Considerations (Figures 6-1, 6-2 and 6-3)

4.1.4 The areas that may be suitable for infiltration SUDS exist where there is a combination of high ground and permeable geology. However, consideration should be given to the impact of increased infiltration SUDS on properties further down gradient. An increase in infiltration / groundwater recharge will lead to an increase in groundwater levels, thereby increasing the susceptibility to groundwater flooding nearby and at a down gradient location. This type of analysis is beyond the scope of the current report.

4.1.5 It is important to be aware of groundwater level conditions at a potential development site. As many of the permeable deposits are River Terrace Deposits associated with surface water courses, it will be important to understand the degree of hydraulic continuity between groundwater and surface water. Maximum likely groundwater levels should be assessed, to confirm that soakaways will continue to function even during prolonged wet conditions.

Key Geological Considerations (Figure 7-1, 7-2 and 7-3)

4.1.6 The infiltration SUDS suitability assessment shown on Figures 7-1, 7-2 and 7-3 is based on minimum permeability data obtained from the BGS. There also exist maximum permeability data, however, only the minimum permeability is used, as this is understood to be more representative of the bulk permeability.

4.1.7 Three permeability zones have been identified:

1) **Infiltration SUDS potentially suitable:** Minimum permeability is high or very high for bedrock (and superficial deposits if they exist).
2) **Infiltration SUDS potentially unsuitable:** Minimum permeability is low or very low for bedrock (and superficial deposits if they exist).
3) **Infiltration SUDS suitability uncertain:** Minimum permeability is low or very low for bedrock and high or very high for superficial deposits OR minimum permeability is low or very low for superficial deposits and high or very high for bedrock.

4.1.8 The third category is required because the thickness of superficial deposits is uncertain. If they are thick and impermeable, shallow soakaways may not intercept underlying higher permeability bedrock. If they are thin and permeable, but perched over impermeable bedrock, they may not have the capacity to receive the additional recharge from infiltration SUDS. Under the third category, it is particularly important that the developer undertakes an appropriate site investigation to determine infiltration SUDS suitability.

4.1.9 Figures 7.1, 7.2 and 7.3 shows that there are areas in Basildon BC, Rochford DC and Castle Point BC, respectively, which are potentially suitable for infiltration SUDS. Within the Basildon BC, the areas potentially suitable for infiltration SUDS are largely located in the north west of the borough and are associated with the Bagshot Formation bedrock and overlying permeable Stanmore Gravel Formation deposits. Within the Castle Point BC, the areas potentially suitable for infiltration SUDS are found in the northern half of the BC and are associated with the Bagshot Formation outcrop and overlying permeable Sand and Gravel of Uncertain Age and Origin and Glaciofluvial Deposits. In Rochford DC only the small outcrop of the Bagshot Formation in the west, close to Rayleigh has been identified as being potentially suitable for infiltration SUDS.

4.1.10 The majority of the southern half of Castle Point BC, much of Basildon BC and the central and west parts of Rochford DC are potentially unsuitable for infiltration SUDS. This is owing to the outcrop of London Clay Formation, Claygate Member or overlying impermeable superficial deposits.

4.1.11 Areas where River Terrace Deposits (sand and gravel), Tidal Flat Deposits (sand and silt), Glaciofluvial Deposits and Sand and Gravel of Uncertain Age and Origin exist, but are not underlain by the permeable Bagshot Formation are shown as areas which might be suitable for SUDS, but enhanced site investigation is required. This is because the thickness of these deposits is not known and therefore the ability of the deposits to store and transmit groundwater without causing flooding / drainage issues is uncertain.

It is noted that this is a high level assessment and only forms an approximate guide to infiltration SUDS suitability; a site investigation is required to confirm local conditions in all cases.

Key Water Quality Considerations

4.1.12 Infiltration SUDS should be located away from areas of historic landfill and areas of known contamination or risk of contamination, where possible, to ensure that the drainage does not re-mobilise latent contamination or exacerbate the risk to groundwater quality and possible receptors, such as abstractors, springs and rivers. A preliminary groundwater risk assessment should be included with the planning application.

4.1.13 Restrictions on the use of infiltration SUDS apply to those areas within Source Protection Zones (SPZ). Developers must ensure that their proposed drainage designs comply with the available Environment Agency guidance. However, at present there are no SPZ defined within the South Essex councils' administrative area.

5 Conclusions and Recommendations

5.1 Conclusions

5.1.1 The following conclusions can be drawn from the current study:

- The significant thickness of London Clay Formation hydraulically separates the underlying Chalk principal aquifer and Lower London Tertiaries from the overlying Claygate Member, Bagshot Formation and superficial deposits. Therefore, the Chalk aquifer and Lower London Tertiaries are not pertinent to the current study.
- The River Terrace Deposits are expected to form a significant perched aquifer over the London Clay Formation aquiclude across much of Rochford DC administrative area. Furthermore, localised areas within the Head deposits in western Rochford DC and Basildon BC areas will behave as aquifers. The Environment Agency and the respective councils do not currently monitor groundwater levels in the superficial deposits.
- The Claygate Member and Bagshot Formation may also act as local aquifers. However, there is no monitoring of these units by the Environment Agency or the South Essex Councils.
- A number of potential groundwater flooding mechanisms have been identified. Of significance are (1) those flooding mechanisms associated with the superficial aquifers and their hydraulic continuity with surface water courses and Thames Estuary tidal fluctuations (2) response of groundwater levels within the Claygate Member and Bagshot Formation to increased use of infiltration SUDS, leaking pipes and barriers to groundwater flow such as sheet piling. Properties at most risk are those with basements / cellars, and areas where these properties are likely to exist can be identified through an assessment of historic stages of building development.
- No groundwater flooding incidents within the study area have been reported to the Environment Agency.
- The BGS has produced a data set showing areas susceptible to groundwater flooding on the basis of geological and hydrogeological conditions. These appear to be reasonable and are in agreement with the identified groundwater flooding mechanisms i.e. they highlight low lying areas with permeable superficial deposits. The data set does not consider areas where the Claygate Member and Bagshot Formation outcrop, due to insufficient monitoring data.
- Those areas identified as having no susceptibility to groundwater flooding may still be affected where groundwater springs / seepages from adjacent aquifers form minor flows and ponding over impermeable strata such as the London Clay Formation. This mechanism may have resulted in the regular ponding of water observed adjacent to drainage on Canvey Island, where groundwater seepages from the River Terrace Deposits may seep onto the relatively impermeable Tidal Flat Deposits.
- The Environment Agency and Councils do not currently monitor groundwater levels in the aquifers that outcrop in this area. Without long term groundwater monitoring, it is not possible to derive groundwater level contours or understand maximum seasonal fluctuations and potential climate change impacts. Therefore, at this stage, the assessment of groundwater flood risk and advice on suitability for infiltration SUDS is preliminary. Ground

investigations and groundwater risk assessments should be carried out for all proposed developments.

5.2 Recommendations

5.2.1 The following recommendations are made based on the current report:

- The areas identified as being susceptible to groundwater flooding should be compared with those areas identified as being susceptible to other sources of flooding e.g. fluvial, pluvial and sewer. An integrated understanding of flood risk will be gained through this exercise;
- Data identifying properties with basements / cellars should be collated by the Councils and used to improve the understanding of susceptibility to groundwater flooding;
- Further assessment of the proportion and distribution of clays, silts, sands and gravels within many of the stratigraphic drift horizons – notably in the Head Deposits, River Terrace and Storm Beach Deposits – would improve an understanding of groundwater flow mechanisms within these units;
- Acquisition of 1:10,000 scale geological mapping, if it exists, for the areas identified as being at potential risk from groundwater flooding. It would also be useful to obtain further BGS data to generate a superficial thickness contour map to help understand the thickness of superficial deposits and therefore assist with SUDs guidance;
- Review site investigation reports held by the respective councils in South Essex, to identify whether groundwater level data is held within them. This could be used to enhance the assessment of groundwater flooding susceptibility and infiltration SUDS suitability;
- As the historic flooding recorded by the councils of South Essex, and Fire and Rescue, do not distinguish between groundwater, fluvial or pluvial flooding incidents, further evaluation of these events is required to establish which of the reported historic flood events are a result of groundwater flooding rather than fluvial or pluvial flooding;
- Data identifying the areas of Landfills should be obtained from the respective councils in South Essex to assist with SUDs guidance;
- Monitoring boreholes should be installed in the permeable superficial deposits and bedrock geology, fitted with automatic level recording equipment for a minimum period of one year and water quality sampling undertaken. At this point a review of the monitoring network should be undertaken and an update on potential for groundwater flooding and infiltration SUDS guidance provided;
- The proposed monitoring boreholes should assist the Environment Agency with water quality and quantity assessments for the next River Basin Management Plan. Therefore, site selection should be agreed with the Environment Agency and the necessity for water quality monitoring agreed;
- Rolling ball analysis in GIS should be undertaken to identify the likely drainage path of springs / seepages emerging from superficial aquifers and the Bagshot Formation and Claygate Member;
- Construction of a numerical groundwater model for the permeable superficial aquifers should be considered when at least 3 years of monitoring has been undertaken and a conceptual model developed. The numerical model could be used as a tool for assessing

the impact of infiltration SUDS, other water management options and climate change on the aquifers;

- Information on foul sewer leakage and groundwater infiltration could be obtained from Anglian Water, if available, to help understand the water balance for the area.

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