British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Recharge through Drift: Progress Report

Groundwater Systems and Water Quality Programme

Internal Report IR/01/49

BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/01/49

Recharge through Drift: Progress Report

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Key words

East Anglia, River Stour, Chalk, Lowestoft till, Boulder Clay, Glacial Sands & Gravel, Clay-with-flints, recharge, Drift domains, low-permeability, fracture flow, intergranular flow, rest water level, porewater, monitoring piezometer.

Bibliographical reference

MARKS R J, DARLING W G, LAWRENCE A R & HUGHES A G. 2001. Recharge through Drift: Progress Report. *British Geological Survey Internal Report* IR/01/49. pp.

Keyworth, Nottingham British Geological Survey 2001

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1.1 OBJECTIVES

The overall objective of this study is to quantify amounts of recharge to aquifers overlain by a covering of drift and to understand the flow mechanisms by which this occurs. This requires an identification of the key Chalk and Sherwood Sandstone Drift hydrogeological environments, the understanding of recharge processes and a quantification of recharge for each of these domains.

The approach adopted by this project is to investigate three aspects:

1. Identify the various Drift domains, develop conceptual models for each domain and with the help of simple spreadsheet type calculations, perform sensitivity analysis to test recharge rates for a range of parameters and boundary conditions within their range of uncertainty.
2. Determine recharge mechanisms and likely rate at field sites in East Anglia and the Tern catchment. In the Tern catchment the study is based on recharge of the Sherwood Sandstone through a thin drift cover. The East Anglia field site has been established at a site where the Chalk is overlain by thick till. The study here will be largely based on water quality data including geochemical residence time indicators and will include the following objectives:
    - to ascertain whether recharge occurs through the till and to quantify rates.
    - to establish the degree of importance of (a) fissure-related bypass flow, and (b) flow through higher permeability sand lenses.
    - to determine the residence times of the various groundwater components in the till and underlying Chalk.
    - to determine the extent of denitrification within the till.

    Calculate catchment scale recharge rates using regional Environment Agency data (groundwater levels, hydrological and water quality) and working closely with the Environment Agency. Review recharge models associated with regional groundwater studies in the Environment Agency.

1.2 BACKGROUND

Major aquifers in the UK have extensive Drift cover, which can have a significant influence on recharge, particularly where dominated by low-permeability lithologies such as clay. The extensive till sheet of East Anglia, characterised by a thick sequence of low-permeability deposits overlying the important Chalk aquifer, is one such example.

The complexity of drift cover in Britain, coupled with a wide variety of depositional environments, means that a large number of hydrogeological settings or 'domains' exist. Clearly these need to be characterised and their influence on recharge assessed.

The predominant route taken by recharge in low-permeability drift-covered areas remains far from well-established. In till for example it could be more or less direct (Scenario 1, Figure 1a), via intergranular movement. Oxidised till is likely to have a higher permeability than unoxidised till. Previously it had generally been considered that till is unlikely to possess significant fracture permeability. However, in recent years fracturing in till has been widely observed and its potential for providing a route for recharge recognized (Gerber et al, 2001; Hossain, 1992; Lloyd et al, 1981 and Kamp, 2001)(Scenario 2, Figure 1b). Other routes for recharge to aquifers overlain by Drift are possible and include permeable lenses within the till (Scenario 3, Figure 1c) or direct recharge at the edge of the till (Scenario 4, Figure 1d). It is also possible that no significant recharge occurs (Scenario 5).

Earlier investigation of the East Anglian till by the former Fluid Processes & Waste Management Group of BGS (Klinck and Wealthall, 1995; Klinck et al, 1993, 1996) left unexplored several aspects of the effect of Drift cover, which it is intended to study in this project. The biggest questions left unresolved were: (i) the residence times of the various groundwater components, (ii) the degree of importance of fissure-related bypass flow and (iii) the mechanism of attenuation of dissolved nitrate.

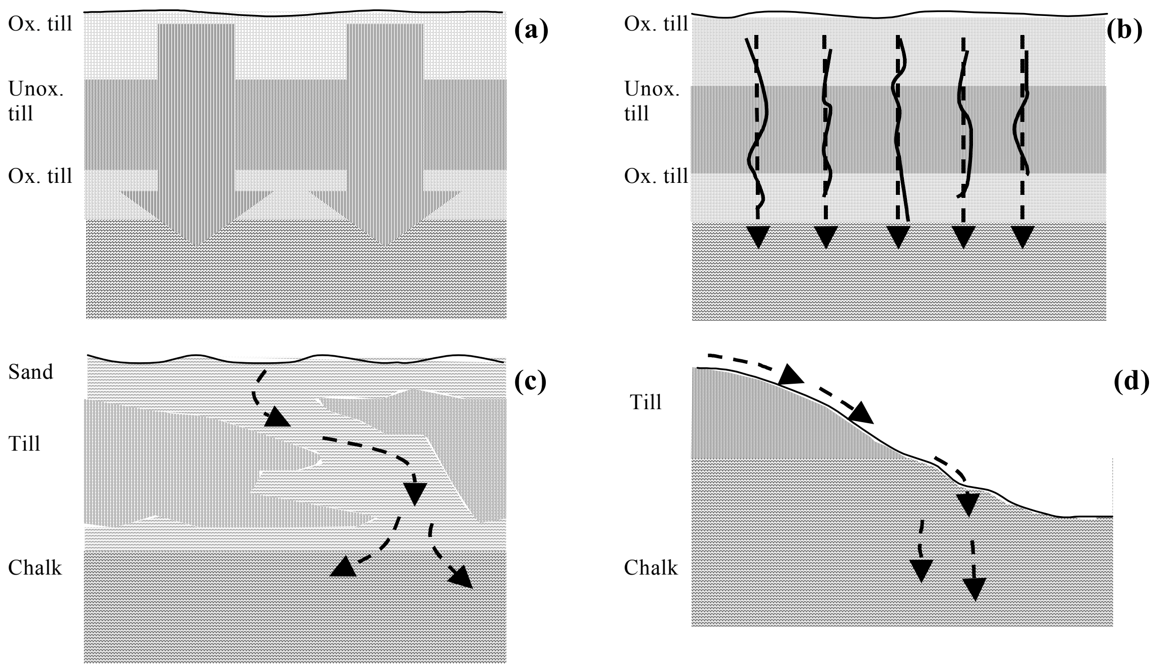

Figure 1 Scenarios for Chalk recharge through till.

(a) Scenario 1: dispersed recharge occurs through till pores, (b) Scenario 2: recharge occurs through till fractures, (c) Scenario 3: recharge occurs through permeable lenses in the till, (d) Scenario 4: recharge occurs at the edge of the till outcrop.

1.3 WORK PROGRAMME

The work in this project falls into several discrete areas, which are listed in Table 1 with the timing of these activities.

Table 1 Work programme

Areas of work	2000/01	2001/2	2002/3
Drilling of investigation boreholes in East Anglia	•		
Piezometer monitoring in East Anglia		•	•
Tern catchment field study		•	•
Identification of important Drift domains and modeling		•	•
Collection, processing and interpretation of available data in East Anglia		•	

2 Recharge through Drift Domains

In this chapter the important parameters controlling recharge through low-permeability Drift are discussed. Two categories of Drift are considered - till and Clay with Flints - and a number of recharge domains are identified in each. They are probably the most important, but other 'minor domains' in other Drift deposits will be considered.

2.1 CONTROLLING PARAMETERS

Recharge of aquifers beneath Drift can be considered to be controlled by five Drift parameters. These are (1) thickness of low-permeability deposits, (2) proportion of coarse grade sediment present, (3) presence of fractures, (4) presence of integral high-permeability beds and (5) proximity to the edge of the Drift deposit. Each of these has a range of influence from insignificant to controlling and it should be possible to define ranges of values with similar recharge properties. There is also likely to be a relationship between the parameters, which will also influence recharge.

It would be possible to develop a large number of recharge domains based on these five parameters and ranges within each, but it is likely that only a small number are areally significant. No significant recharge may occur where the drift is thick, consists largely of unfractured clay without any integral sand and gravel bodies and the edge of the deposit is outside the catchment. However, significant recharge may be possible where (I) the Drift thickness is relatively thin, (II) the till contains discontinuous lenses of material other than clay, (III) a degree of fracturing is present, (IV) more extensive sand and gravel bodies are present or (V) the Drift is dissected. Where several of these parameters are combined the recharge might be expected to be greater and could approach that of the unconfined aquifer. It is important to recognise that the identification of domains, development of conceptual models and quantification of possible recharge (sensitivity analysis) is an iterative process. The final classification of domains may be different to the initial classification discussed below.

2.2 IMPORTANT DOMAINS IN THE EAST ANGLIAN TILL SHEET

It may be possible to divide the East Anglian till sheet into 5 or more recharge domains where it overlies the Chalk, each with significantly different recharge rates. An initial description of these domains is given below.

2.2.1 Domain: Thick till (low recharge)

There is a large domain of thick till (>15m), which may be restricted to the plateaux. The oxidised surface of the till is likely to have a higher permeability than the underlying unoxidised till. There are numerous pebbles in the till, which are mostly Chalk and could act as a preferential route for recharge, although the intervening clay matrix would be a limiting factor. Recharge though fractures in the till could prove important. However, experience of drilling in the till suggests these routes are not thought to represent significant recharge routes. Typically there is no surplus water seen in the till and, if recharge was significant, it might be expected that the till would have been oxidised down recharge conduits. It is possible that such conduits exist, but that they only form a small part of the total area. Apart from this recharge, will be limited to the movement through the matrix.

2.2.2 Domain: Till with some bodies of sand and gravel (low-moderate recharge)

The till may contain bodies of silt, sand and gravel deposits sandwiched between the till and the Chalk, and within the till. Sand and gravel layers beneath the till probably do not influence recharge rates as they pass the water from the base of the till to the Chalk, but deposits within the till may significantly improve rates of recharge as they offer high-permeability routes through the till. The form of such bodies is not well known. They do not appear to be continuous beds and probably most have an elongate lens form. This recharge domain would have high-permeability horizons within the till allowing recharge water to be collected from the matrix and fractures in the overlying till and be channelled to the higher permeability routes in the till beneath the lens. Where till thicknesses are limited zones of seepage may be developed with time and may relate to original fractures. Significant recharge could be occurring by such sinuous routes through the till and as a result recharge could be concentrated in particular areas of the thick till sheet. Experience of drilling shows that such high-permeability bodies are typically bounded by oxidised till and they are usually at least partially saturated.

2.2.3 Domain: Till with numerous interconnected sand and gravel bodies (moderate recharge)

A significant area of the till sheet of East Anglia is a complex sequence of till with beds and extensive lenses of silt, sand and gravel. In such domains recharge could be relatively rapid through interconnected sinuous high-permeability routes.

2.2.4 Domain: Thin till in valleys (moderate recharge)

Dissecting valleys may not cut right through the till, but often reduce the thickness considerably. Recharge routes may have been developed through the unoxidised till due to the till’s limited thickness and the concentration of available surface water. Arable farming covers a large part of the till sheet, which is characterised by heavy clay soils. As a result much of the area is covered with land-drains and a network of ditches, which concentrate surface water into the valley system where it is available for recharge. This domain may represent an important environment for recharge.

2.2.5 Domain: Till edge (moderate-high recharge)

Many of the deeper valleys cut through the till exposing either underlying beds of sand and gravel or the Chalk aquifer. In this domain surface water flowing off the till is able to recharge the Chalk directly or via the sands and gravels. In such areas karst features may have been developed in the Chalk at the contact. Typically the valleys contain a stream, which is in hydraulic continuity with the Chalk aquifer. Where this is the case recharging water may return to surface water as springs in the stream bed.

2.3 DOMAINS IN THE CLAY WITH FLINTS

Besides till the Clay with Flints is an important low-permeability Drift deposit, which directly overlies the Chalk aquifer with considerable total areal extent.

2.3.1 Domains: Thick Clay with Flints (low-moderate recharge)

The thickness of the Clay with Flints is typically between 2 and 10 metres, although it does reach over 15 metres in places. The interface with the Chalk is often very irregular, which seems to relate to the weathering of the Chalk surface. Recharge in this domain is likely to be restricted through the clay matrix, but the interface with the flint pebbles could form a route through part of the deposit and, as in the till fractures, may also offer a recharge route. This domain is probably one of limited recharge. In places sandy horizons can be developed in the Clay with Flints and these may form important routes for recharge.

2.3.2 Domain: Clay with Flint edge (moderate-high recharge)

Typically the Clay with Flints is restricted to the plateaux and is cut into relatively small areas by dry valleys. An important recharge domain is likely to be the edge of the deposit where surface water can recharge the Chalk directly. It is not uncommon to find subsidence features in this zone, which may relate to concentrated areas of recharge and collapsed karst features. Typically the unsaturated zone is quite thick (>10 metres) and the distance to spring discharge can be considerable.

3 Investigation Boreholes

3.1 SITE SELECTION

The thick till domain (2.2.1 above) is probably the most important from the point of view of areal extent and restriction of recharge. As a consequence it was decided to use this domain for the field study. The required site characteristics included a till sequence between 15 and 30 metres thick resting directly on Chalk and an unsaturated Chalk sequence beneath the till. It was felt that a homogeneous till sequence on Chalk would reduce the number of uncertainties in the study, although the presence of higher permeability sand and gravel beds is almost ubiquitous.

The comparison between till, unsaturated and saturated Chalk porewater would hold important information on recharge through the overlying till. The operating scenario in the till at the site of the investigation boreholes will be illustrated by the age of the various groundwaters; the age of the groundwater being determined by use of stable isotopes and tritium as appropriate. Table 2 shows the conceptual models to be used. Modern water in all four environments in Scenario No 1 would demonstrate relatively rapid recharge through the till matrix. Scenario No 2 with old till porewater implies that fissure flow is an important recharge route. Scenarios Nos 3 & 4 relate to high-permeability routes for recharge, but would be difficult to resolve from each other, though geological evidence would probably enable a distinction to be made. Where the water is old in all the environments it would suggest that little recharge is occurring.

Table 2 The interpretation of water residence time ('age') as an aid to determining recharge routes through a till cover.

Sample type	Sample source	Scenario 1 permeable till	Scenario 2 fissured till	Scenario 3 sand lenses	Scenario 4 till edge	Scenario 5 impermable till
Till porewater	Vertical b/h	Modern	Old	Old	Old	Old
Chalk porewater	Vertical b/h	Modern	Modern	Modern or old	Modern	Old
Till groundwater	Inclined and vertical b/h	Modern	Modern	Old	Old	Old
Chalk groundwater	Vertical b/h	Modern	Modern	Modern*	Modern*	Old

* Chalk groundwater could be out of age-equilibrium with porewater if there are strong abstraction effects

These requirements limited the available sites to a number of small areas and a site at Boyton End (NGR TL 7142 4477) just south of Kedington in the Stour Valley, Suffolk, was selected for drilling. While thick till (Section 2.2.1) was expected at this site it also relates to the till edge domain (Section 2.2.5). The requirement was to drill (a) a cored vertical investigation borehole through the till into the Chalk for porewater analysis and groundwater sampling, and (b) an inclined borehole within the till to intercept any recharge draining through the till. The vertical borehole was to be constructed with piezometers for monitoring groundwater levels and composition in the Chalk, and gas composition in the till and unsaturated Chalk. The inclined borehole was to be constructed with a sump at the base in which any drainage would accumulate for periodic sampling.

3.2 GEOLOGY

The drilling site at Boyton End is situated on the Lowestoft Till to the east of the River Stour. The ground elevation in the area ranges from about 53 m AOD at the level of the river, rising to about 100 m on the interfluve. The geological map (Figure 2) shows Upper Chalk underlying the till with an outcrop on the lower slopes of the Stour valley. A thin sequence of head and alluvium rests on Upper Chalk in the valley floor. The Chalk dips south-east at about 1 in 200 (Pattison et al, 1993). The Chalk has a total thickness in this area of approximately 270 m. It is often described as Putty Chalk at its surface, owing to the lack of structure and soft, putty–like consistency, thought to be due to weathering. The Lower London Tertiaries subcrop about 10 km to the south-east of the site.

The overlying Lowestoft Till (Quaternary) is sometimes referred to as the Chalky Boulder Clay. This till covers most of the district in a plateau-forming sheet (Figure 3), and is commonly between 30 and 50 m in thickness (Moseley et al, 1981), which locally varies with the elevation of the ground. The Drift/Chalk interface is largely a planar feature with a regional dip to the south-east (Berridge et al, 1991). The adjacent Stour valley is considered part of the glacial buried valley, which has cut down into the planar surface of the Chalk.

The Lowestoft Till is characteristically an unstratified bluish-grey silty sandy clay with pebbles where it is unoxidised (Marks, 1981). A weathered, oxidised zone of browns and orange-browns between 0.2 and 2 m thick is commonly developed beneath the soil and an oxidised zone is often present at the base of the sequence. Fractures with oxidised faces are occasionally found in the till. The pebble erratics are usually some 50-75 mm in diameter and consist largely of well-rounded Chalk clasts, but also include sub-angular flint and a variety of other minor constituents mostly Jurassic in age. The till was deposited during the Middle Pleistocene glaciation, which was also the source of much of the other drift cover in the area.

In most areas the till is underlain by a sequence of Glacial Sand and Gravel (Berridge et al, 1991), which was thought to be absent in the area of the drilling site; although a small area is mapped at NGR 710 448. Lenses of sand and gravel, and silt are commonly found at various levels within the till, most of which are sub-horizontal in nature. Their lateral extent and thickness varies significantly and a small area is mapped close to the drilling site at NGR 711 448. These deposits are proglacial or subglacial in origin and in the area of the drilling site they may relate to the buried valley and therefore have limited lateral extent. The alluvium associated with the River Stour consists of silts and clays overlying a basal gravel sequence (Marks, 1981).

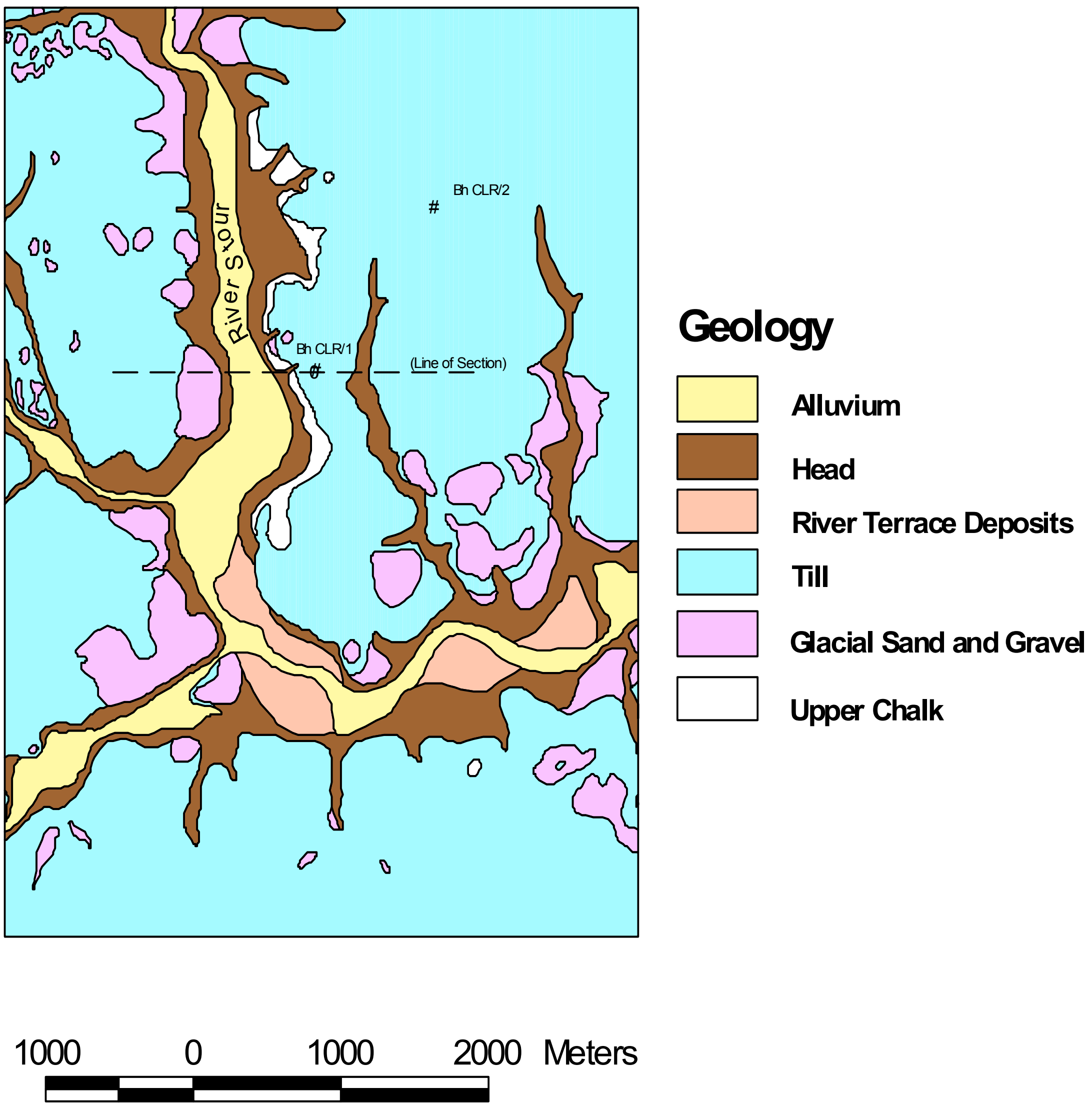

Figure 2 Geological map and field area.

3.3 HYDROGEOLOGY

The principal aquifer in the region is the Chalk which is extensively developed for water supplies (Moseley et al, 1981). It is mostly confined by the overlying till, but in the drilling area it is unconfined with a potentiometric surface of about 53 mAOD (Figure 3) and the regional hydraulic gradient is towards the south-east. The River Stour is likely to be in hydraulic continuity with groundwater and the elevation is similar to that of the potentiometric surface (the precise elevation of the site will be determined, which will allow the relationship to be established). Contours on the potentiometric surface (Moseley et al, 1981) show highs of over 70 mAOD beneath the till plateau, indicating Chalk recharge through the thick till sequence (Figure 4). Annual fluctuation of the potentiometric surface where the Chalk is confined by the till is about 2 m in a hydrograph to the east (NGR TL 846 410) of the drill site, which compares with about 9 m in a hydrograph from the exposed Chalk to the north-west (NGR TL 594 591). The end of the recession and recovery periods on the confined hydrograph (Moseley et al, 1981) coincides closely with the times on the exposed Chalk hydrograph. This suggests that there is little if any time lag in the recovery beneath Drift compared to the exposed Chalk environment.

The Chalk is a dual-porosity aquifer that relies on fractures and jointing for much of its transmissivity. The upper 10-20 m of the Chalk, particularly where it is exposed, may be poorly-jointed putty-chalk, and have a reduced permeability. Storage of water takes place mostly in the intergranular matrix of the Chalk, which has high porosity but low hydraulic conductivity.

Beneath the till the Chalk groundwater carbonate hardness rises to 260-350 mg l^{-1} and non-carbonate hardness to 300-400 mg l^{-1} (Moseley et al, 1981). This compares to a non-carbonate hardness of 50–100 mg l^{-1} in exposed Chalk. The chloride ion concentration increases to over 100 mg l^{-1} (Figure 4) and sulphate also shows high concentrations where the till cover is thickest. This compares to a concentration of 15-50 mg l^{-1} Cl in the exposed Chalk. Whilst these highs might generally reflect reduced recharge they also coincide with highs in the groundwater surface which are indicative of recharge through the till. These highs in the groundwater surface may partly relate to low transmissivity in the Chalk in these areas

The boulder clay itself has a low intergranular permeability. However, fractures and sand lenses in the clay may enhance the overall permeability, although the extent and properties of these is not well known. The boulder clay in this area probably reduces recharge to the Chalk and also reduces the vulnerability of the Chalk aquifer to contamination. Furthermore, clay minerals (especially smectitic clays) within the boulder clay have the ability to attenuate contaminants by sorption and cation exchange (Klinck et al, 1997).

Beds of sand and gravel within the till can be unsaturated, but most are partially or fully saturated. These perched water tables typically have limited storage indicative of their isolated nature. Groundwater derived from sands and gravels within the till and beneath the till, where they overly low-permeability bedrock, is characterised by high non-carbonate hardness (calcium sulphate and magnesium sulphate). Total dissolved solids (TDS) concentrations often exceed 700 mg l^{-1} and chloride ion concentrations are mostly between 60 and 110 mg l^{-1} (Moseley et al, 1981).

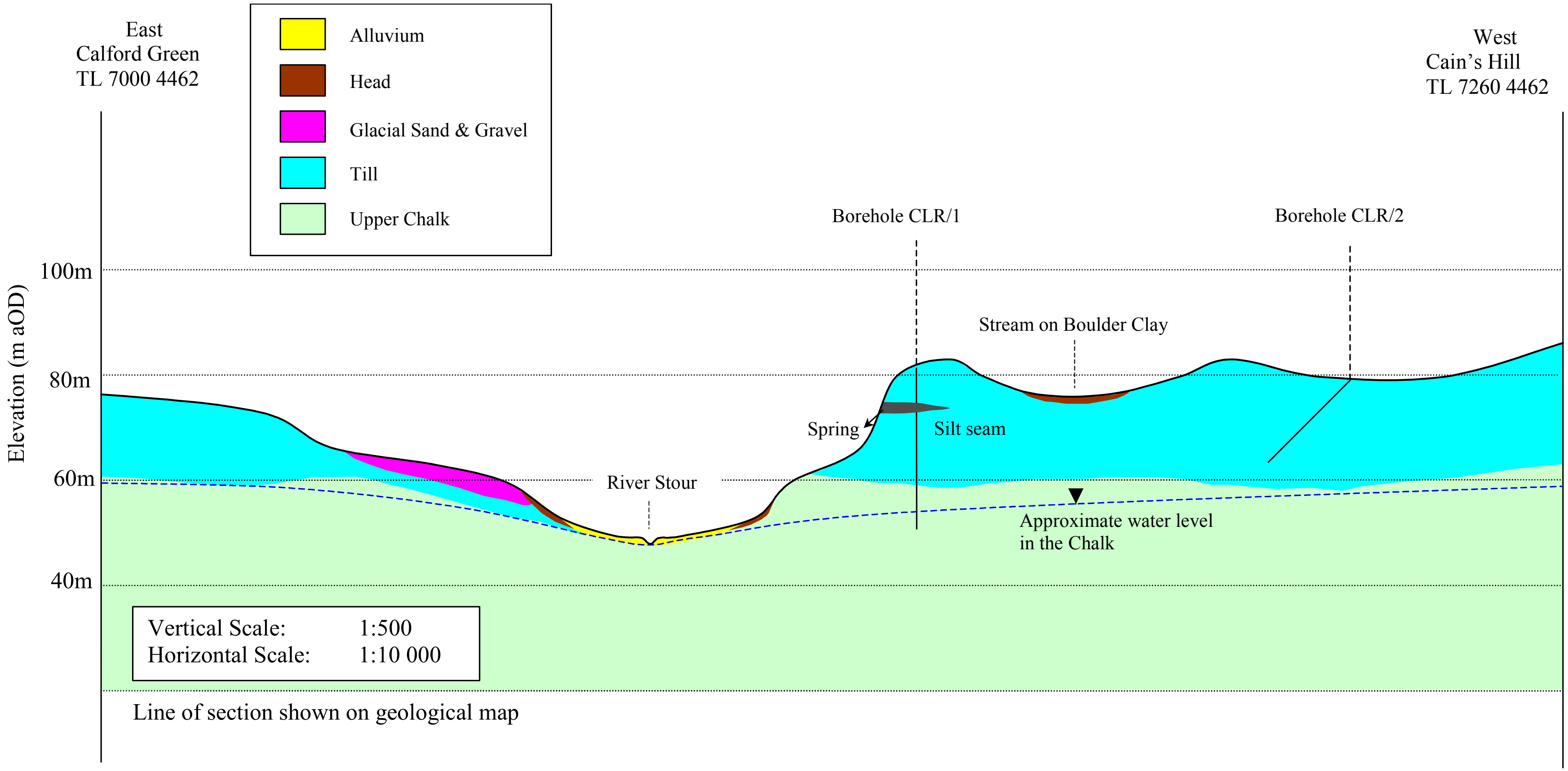

Figure 3 Geological cross-section.

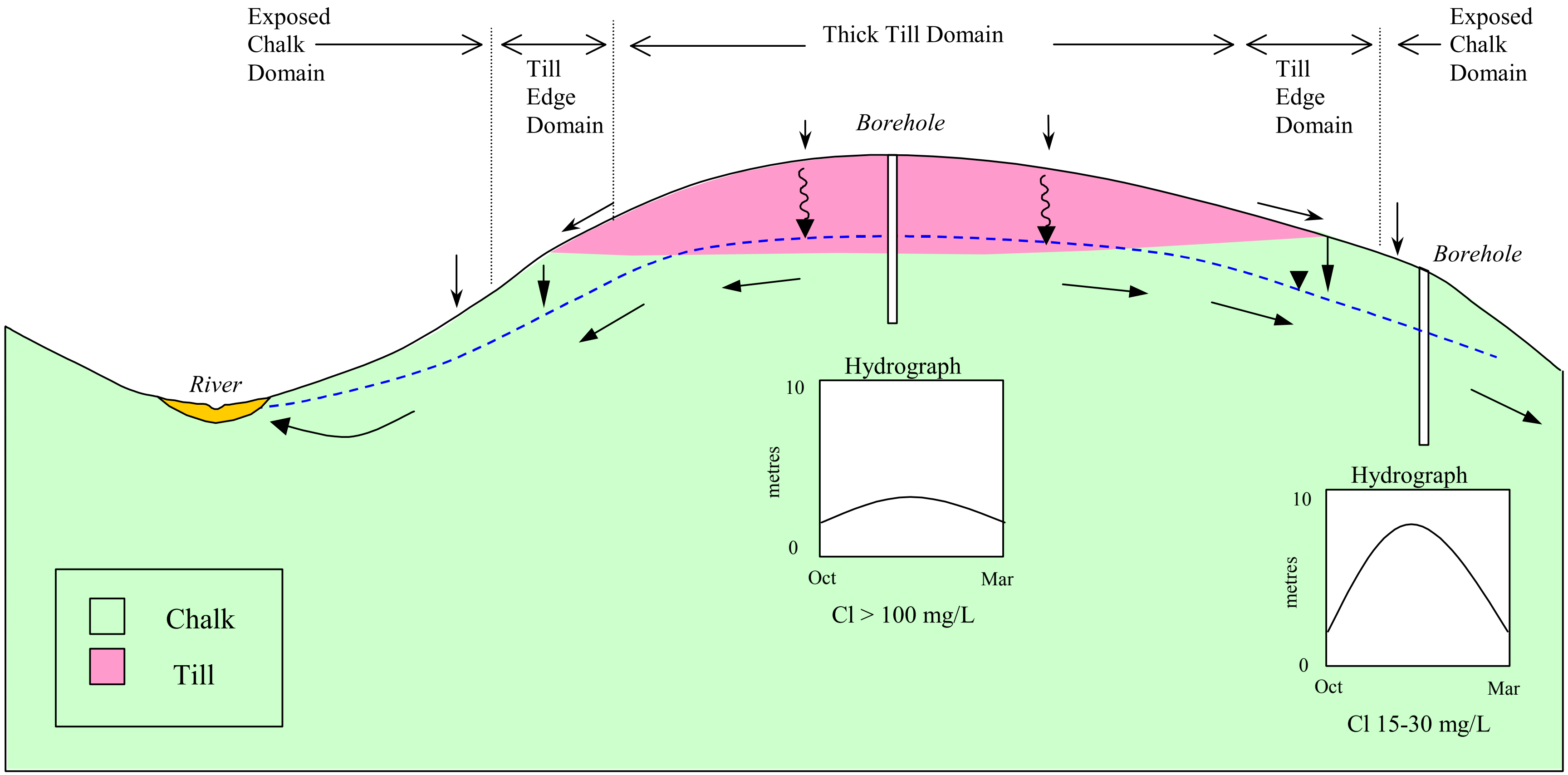

Figure 4 **Schematic cross-section.**

3.4 CORED BOREHOLE AND MULTIPLE LEVEL PIEZOMETER CLR/1

A vertical borehole number CLR/1 was drilled north-west of Boyton End on an agricultural track between arable fields in November 2000 (NGR 7142 4477) in a till edge domain. It was drilled by a light percussion drilling rig commencing at 260 mm diameter and telescoping down to 150 mm diameter at the base. The ground level at the site is about 80 mAOD and the borehole was fully cored using U4 tubes to a total depth of 31 m (Figure 5), through 21.4 m of Glacial Drift and into the unsaturated and saturated Chalk. Most of the Glacial Drift was unoxidised Chalky Boulder Clay, but it also included a sequence of sandy gravel between 2.05 and 3.55 m below ground level (bgl) and saturated silt band between 4.75 and 5.30 mbgl. Oxidised boulder clay was present at the top of the till sequence and a bed of clayey sand (Glacial Sand and Gravel) was present at the interface with the Chalk between 20.45 and 21.4 mbgl. Temporary casing was used to seal the wet silt seam and also to support the Chalk.

The core has been logged and porewaters are being extracted for analysis. The Chalk core was centrifuged to obtain porewaters and the Glacial Drift is being compressed in a triaxial cell. Porewater samples are being analysed for major ion concentrations, stable isotopes and tritium.

The site had been selected on the basis of surrounding information that mostly showed a sequence of homogeneous boulder clay resting directly on Chalk. Such a site would have allowed the study to focus on water movement through the till matrix and any fracturing present in the till. The presence of a perched water horizon within the till had not been anticipated and modified the intended construction of the borehole. It had been intended to construct the inclined investigation borehole on the same site, but the presence of the wet silt seam precluded this.

The borehole was constructed with two groundwater piezometers and seven gas piezometers (Figure 5). The installation is completed with a manhole at the ground surface in which the piezometers are terminated and there is storage for instrumentation. The groundwater piezometers are constructed from 52 mm ID HDPE shoulder-less pipe and they are fitted with caps at the base and surface. A 4 m slotted screen piezometer is present in the base of the borehole to enable groundwater sampling of the Chalk and monitoring of Chalk groundwater levels. Groundwater levels were unconfined at 26.8 mbgl in November 2000 approximately coincident with the top of the slotted screen and test bailing of this installation did not significantly affect groundwater levels. A second groundwater piezometer with a slotted geotextile wrap screen was installed opposite the wet silt band and included a sump beneath the screen for the collection of groundwater samples and monitoring of perched water levels. The piezometric level was 4.5 mbgl in November 2000 showing the seam to be confined. Test bailing showed that the piezometer could be pumped dry after drawing 11 litres although it had fully recovered within 24 hour illustrating the low-permeability of the silt.

The gas piezometers are 0.3 m long and fabricated from perforated PVC pipe capped at each end and filled with glass wool. They are connected to the ground surface with quarter-inch OD nylon tubing with taps fitted at the surface to isolate each installation from atmospheric contamination. Two gas piezometers are installed within the unsaturated Chalk (Figure 5) and a further three piezometers are installed within the unoxidised boulder clay beneath the silt seam.

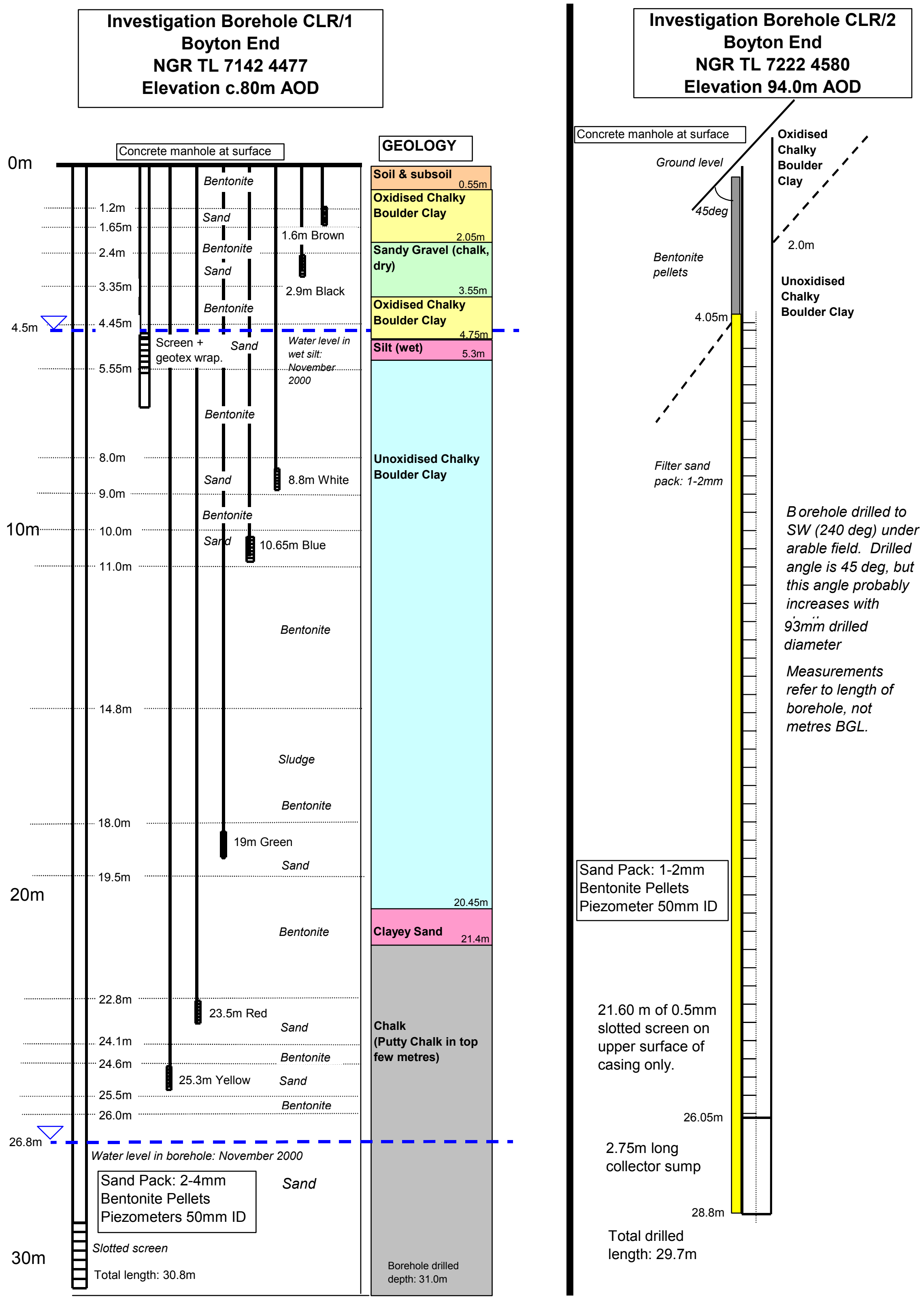

Figure 5 Geology and construction of investigation boreholes.

A sixth gas piezometer has been placed within the sandy gravel seam and a seventh positioned within the oxidised boulder clay above. All piezometer installations are enclosed by a 2-4 mm grade sand-pack, which extends to just above and below the open zone of the piezometer and effectively limits the sampling depths. The piezometer zones are usually isolated by intervening bentonite pellet seals, although the zone between 14.8 and 17.8 mbgl is filled with spoil material.

All the surrounding fields have a system of piped land-drains, which were flowing in November 2000, and these are overlain by a system of mole drains. This network catches a proportion of the infiltrating water and transfers it into the ditch system, which may reduce recharge rates into the boulder clay. A spring (NGR 7130 4473) down gradient of the borehole at an elevation of approximately 73 mAOD may represent the out-fall of the wet silt seam in the valley side (Figure 3). The elevation in the borehole is approximately 75 mAOD. This relationship may be confirmed by a comparison of water compositions. The flow rate is difficult to estimate because of the length of the seepage line, but it was of the order of 0.5 m^3 hr^{-1} in November 2000.

The sequence between the base of the boulder clay, the underlying sand and gravel and the Chalk is fairly well exposed in a ditch lower down the valley side and gives an approximate elevation of the top of the Chalk of 63 mAOD, which is supported by the mapped line for the top of Chalk. This compares to an approximate elevation of 59 mAOD in the borehole. In the ditch the intervening sand and gravel has a thickness of about 1-2 m. This is not present on the geology map; although Glacial Sand and Gravel is mapped at the contact to the north-west at NGR 710 448. There is also a small mapped outcrop of Glacial Sand and Gravel at NGR 711 448, which has a mid-elevation of approximately 72 mAOD. The sand and gravel sequence near the surface in the borehole has an approximate elevation of 77 mAOD. It is intended to level-in the borehole and related surface features to aid the comparison.

3.5 INCLINED PIEZOMETER CLR/2

The purpose of the inclined piezometer was to collect samples of groundwater, most likely fracture flow, draining from the till. It had been intended to construct the inclined piezometer on the same site as borehole CLR/1, but the presence of the perched water table precluded this, because of the additional complications in drilling and constructing the inclined piezometer, and the potential for contaminating the collection of underlying groundwater. A second site was selected in the tick till domain adjacent to borehole TL74NW20 (Marks, 1981), which proved the Chalky Boulder Clay to be homogeneous to a depth of over 25 m. No precise information was available on fracture directions in the area and local valleys do not give a clear indication; although there are two prevalent directions 40° to 220° and north to south. An orthogonal set may be developed and there may be cambering into the local valley, which would have an orientation of 40° to 220° (J P Bloomfield, personal communication).

The borehole was located in the corner of an arable field (NGR 7222 4580) (Figure 2) adjacent to woodland at an elevation of 94.0 mAOD. The inclination of the borehole was 45° and the direction was to the south-west (240°). The borehole was drilled with a rotary drilling rig at 100 mm diameter using compressed air as a flush medium. It was drilled to a total length of 29.7 mbgl, which would have a vertical depth of 21 mbgl. Drilling proved oxidised boulder clay beneath soil to a length of 2.0 mbgl (1.4 mbgl depth) and the remainder of the borehole penetrated unoxidised boulder clay. No evidence of fractured boulder clay was seen in the drill returns. Drilling occurred at a particularly wet time in December 2000 and the borehole was left at total length over the weekend, but was dry on the following Monday.

The piezometer is constructed with 52 mm ID HDPE shoulder-less pipe (Figure 5) to a total length of 28.8 mbgl (20.4 mbgl depth) and this rests on the lower surface of the borehole. The lower part consists of a 2.75 m long sump with a capacity of 6 litres to collect water samples. Above is a 21.6 m long slotted screen, which is only slotted on the upper half of the casing. The horizontal open area of the screen is 0.93 m^2. The slotted section and sump is packed with a 1-2 mm grade sand. The upper 4 m long section of the piezometer is unslotted and is encased in bentonite pellets. The piezometer is capped and terminates in a manhole with cover for security and to allow space for instrumentation. Fracture flow or matrix water draining through the till onto the top half of the sand-packed borehole should move through the sand and piezometer slotted screen and drain down the piezometer to be collected in the sump. Should the sump become full any further infiltration would overflow and saturate the sand pack below before water levels rose any further. This surplus water would be available to drain down through the boulder clay matrix and any fractures present in the lower part of the borehole.

The surrounding arable fields are all drained with land drains and overlying mole drains that were flowing in December 2000 into the ditch network. The closest ditch is adjacent to the piezometer, which is sealed in the upper part to prevent any surface water entering the borehole. This drainage system intercepts some of the infiltrating rain water and transfers it back to surface drainage thereby reducing the available water for recharge.

4 Planned Work for 2001/2

4.1 MODELLING DOMAINS OF RECHARGE THROUGH DRIFT

An initial description of the likely domains in the till and the Clay with Flints has been given in Section 2 above. Other low-permeability Drift domains with significant geographic extent also need to be identified.

4.1.1 Assign recharge mechanisms for each domain

While low hydraulic conductivity environments generally do not allow significant vertical movement of water, even a small component could play a significant part in the water balance when recharge through the drift occurs over a large area. It is therefore important to quantify the vertical flow. An important first step is to determine likely mechanisms operating in the system. This will be undertaken as follows:

- Take Drift domains identified
- Determine likely recharge mechanisms operating in each domain
- Produce schematics describing processes

Deliverable: Series of draft conceptual models expressed as schematics.

4.1.2 Quantify flow through the different pathways; fractures or sand lenses

Having identified the likely recharge mechanisms for each domain (section 4.1.1) the next step is to attempt to quantify how much recharge occurs. This will involve the following:

- Quantify each pathway based on likely parameter values and create spreadsheet
- Determine the effect of uncertainty of values on recharge calculations ("sensitivity analysis")
- Document process

Deliverable: Spreadsheet containing calculations for each domain.

4.1.3 Review recharge models associated with regional groundwater studies in East Anglia

There have been a number of regional groundwater modelling studies which have been undertaken or are on-going in East Anglia. By reviewing the approaches to recharge used in each study, mechanisms can be identified that are likely to be relevant to understanding recharge through drift in this area.

Deliverable: Brief review of each model summarising mechanisms.

4.1.4 Wider study using Environment Agency data

Once a methodology has been developed for assessing recharge for a particular domain, it can be extended to other domains in East Anglia. It will be necessary to examine what data is available from the Environment Agency and to determine how this can be used. The data which are routinely collected by the EA include:

- groundwater levels
- water quality data
- river flow data

This will be assessed to determine its suitability for use with the techniques developed.

Deliverable: Feasibility study of applying EA data to other drift domains.

4.1.5 Boyton End site

The study sites offer the opportunity to test the assumptions made in developing the conceptual model of the particular Drift domain. By undertaking a detailed water balance at both the site scale and the catchment scale it should be possible to determine the importance of different recharge processes. The local-scale water balance will contain the following elements:

- Potential recharge
- Runoff to field drains
- Spring discharge
- Groundwater flow to River Stour

On a catchment scale, once a groundwater catchment has been defined, the following need to be estimated:

- Recharge
- Runoff/interflow to River Stour
- Baseflow to River Stour
- Change in groundwater storage

Undertaking a catchment scale water balance enables the recharge processes within the study area to be set in context.

Deliverable: A local and catchment scale water balance for the study area.

4.2 BOYTON END SITE

4.2.1 Piezometer Monitoring

Monitoring has been halted at the present time due to the foot-and-mouth epidemic. Also there are difficulties in finalising the contract with the farmers land agent. It is intended to make monthly field visits to monitor the two investigation boreholes, but after the recharge period this may be reduced if conditions remain similar over successive months.

Water level data are to be collected at 6-hourly intervals by loggers and the data downloaded at each visit for each of the three piezometers. These data will show any seasonal variation in groundwater levels in both the silt band in the boulder clay and also in the underlying Chalk. The variation in the piezometric head in the silt will have implications for the assessment of recharge through the Drift. The deeper piezometer should illustrate Chalk recharge in this area. The logger in the inclined borehole should demonstrate the presence of any water in the sump for sampling. If present it would indicate recharge through the boulder clay, but this would be restricted by the volume (6 litres) of the sump and would need to be emptied at each visit.

Water samples will be collected by pump from the two piezometers in borehole CLR\1. These will be analysed for major ions, O & H stable isotopes, $\delta^{13}C$ and tritium or CFCs to characterise the aquifers, monitor seasonal variations (and attribute to recharge) and for dating the water, but major chemical changes are not anticipated. It should also be possible to take pumped samples for dissolved gas analysis to assess the N systematics. There are seven colour-coded gas piezometers for sampling gas in the unsaturated zone in both the boulder clay and Chalk. The main focus of this monitoring activity will be on periodic sampling until it is clear that they have ‘settled down’, at which point a greater range of determinands will be measured in order to understand better any processes etc that may be occurring particularly within the boulder clay.

The inclined borehole CLR/2 will be periodically monitored through the spring period to collect samples of any drainage through the boulder clay that may be intercepted. If sufficient sample water can be obtained an analysis for tritium will be made in addition to other isotopic and chemical determinands.

Deliverable: Groundwater levels and chemical analysis including age of water, that will provide useful information on the recharge environment at the site.

4.2.2 Monitoring of other water sources and other field activities

The spring below the site of borehole CLR/1 will also be sampled for chemistry and isotopes as considered appropriate for comparison with results from the silt piezometer. Samples of

River Stour water will also be collected for analysis and comparison with Chalk piezometer groundwater and to illustrate seasonal change. It may also be appropriate to collect water samples from the boulder clay stream at Boyton End and ditches for comparison. Estimates of flow will also be collected for all sources.

One additional experiment would be to apply a suitable tracer above the open section of the inclined borehole at the end of the 'natural' monitoring period and monitor recharge collected in the piezometer sump. Another experiment could be conducting falling-head tests in augered boreholes into the boulder clay. A significant number of these to give statistical result on infiltration rates.

Deliverable: Information from this work would give a greater understanding of the results from the investigation boreholes and generally improve our understanding of the recharge site.

4.2.3 Porewater chemistry and time series chemistry data processing

The porewater samples obtained from the cored borehole CLR/1 via squeezing or centrifugation will provide chemical and isotopic profiles at the time of drilling. Groundwater obtainable from the perched water table in the silt band and the main Chalk water table will give time series analysis. The time series data will give a useful comparison to the porewater and show seasonal changes.

Deliverable: Porewater profiles through the till, unsaturated and saturated Chalk will describe the hydrogeological environment and give information on the recharge regime at the site.

4.2.4 Existing data

Records from the National Well Record Archive for sheet TL74 and a further five surrounding sheets with similar geology have been input into WellMaster© (BGS database). The data can now be processed. A series of queries have to be designed. These could identify boreholes in the area, which utilise sources within the Drift and Chalk and enable us to compare yields and chemistry in this recharge domain. We should also be able to distinguish the confined and unconfined Chalk environments. Similar work could be undertaken with the SOBI records (Single onshore borehole index. BGS database).

Deliverable: Comparison between the hydrogeology of the site and the surrounding area giving general information on the recharge domain.

4.3 WORK IN THE TERN CATCHMENT

The Drift in the Tern catchment consist largely of till and glacio-fluvial deposits that have a thin and patchy distribution. Using a CASE student from Birmingham University it is intended to carry out a comparable study looking at recharge through the Drift. The detail of the field work at this site needs to be defined at a meeting, but it is generally intended to utilise shallow auger holes in the Drift to study recharge rates on a statistical basis.

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