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Preliminary estimates of recharge and river-aquifer interaction in the South of Butterknowle Fault area

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Preliminary estimates of recharge and river-aquifer interaction in the South of Butterknowle Fault area

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1 INTRODUCTION

1.1 Background

Within the Northumbrian Area of the Environment Agency's North East Region, the Magnesian Limestone aquifer forms the main groundwater resource. The aquifer is particularly important as a resource for public water supplies.

For some time it has been known that this aquifer was at risk from the inflow of poor quality mine water due to the rise in water levels in old mine workings following mine closures and subsequent cessation of mine dewatering. In the area south of the Butterknowle Fault (Figure 1.1) high sulphate groundwater has been detected in monitoring boreholes, which poses a potential risk to public water supply abstractions, in particular those operated by Hartlepool Water, owned by Anglian Water Services (AWS). In order to monitor and manage this developing situation, the Environment Agency has set up a Technical Advisory Group.

To assess the risk to its PWS sources, AWS is proposing to develop a groundwater risk assessment model for the Magnesian Limestone in the area to the south of the Butterknowle Fault. AWS is still in the process of refining the conceptual understanding of the area, but has identified recharge to the Magnesian Limestone as one aspect of the water balance that remains uncertain at this stage. As a result of a Scoping Study on the Magnesian Limestone, completed in September 2006, the Environment Agency is intending to develop a full conceptual model of the whole aquifer. However, the results of this are unlikely to be available within the timescales required by AWS for developing its model.

To resolve this issue, ESI was contracted by the Environment Agency to develop a preliminary estimate of recharge in the area south of the Butterknowle Fault using the data currently available, including outputs from an ongoing geological study being undertaken by the British geological Survey (BGS). Some additional work on an assessment of the scale of the interaction between the River Skerne and the aquifer was requested as this could also have implications for the contaminant transport model.

1.2 Objectives

Two objectives have been defined for the study:

Recharge: Provide a likely range of values for recharge over the area of limestone outcrop where direct recharge can occur. This will be undertaken using the Environment Agency's spreadsheet recharge calculator and will use a similar methodology used to undertake sensitivity studies on recharge for major groundwater modelling projects.

River Skerne: To develop an understanding of the areas of inflow and outflow from the Magnesian Limestone using the permanent flow gauging data available from the Environment Agency supported by, if possible, any relevant spot flow gauging data. Water quality data available from the River Skerne will also be reviewed to assess if there is any chemical evidence for discharge from the aquifer.

1.3 This Report

This report sets out the results of this scoping exercise. Section 2 presents the results of the assessment of direct recharge and associated sensitivity analysis. This includes a brief review of the geology and groundwater quality data. Section 3 presents the review of surface water flow and quality data. Section 4 presents a summary and recommendations.

2 RECHARGE

2.1 Geology

At the request of the Environment Agency, the BGS has undertaken a study into the distribution of superficial deposits overlying the Magnesian Limestone. Only a summary description is given here, a detailed description, with cross sections, is available in the BGS report on the project (Price *et al*, 2007).

The study defined 11 hydrodomains, which are presented in Table 2.1 and shown on Figure 2.1.

Table 2.1 Hydrogeological domains for the South Durham area

	Hydrodomain	Included in direct recharge area?
1	> 30 m aquitard over limestone	No
2	10 - 30 m aquitard over limestone	No
3	10 - 30 m aquitard over > 5 m aquifer over limestone	No
4	> 5 m aquifer over 10 – 30 m aquitard over limestone	No
5	5 – 10 m aquitard over limestone	No
6	5 – 10 m aquitard over > 5 m minor aquifer over limestone	No
7	> 5 m minor aquifer over 5 - 10 m aquitard	No
8	> 5 m minor aquifer over > 30 m aquitard	No
9	> 5 m minor aquifer over < 5 m aquitard	Yes
10	< 5 m aquifer or aquitard over < 5 m aquitard over limestone	Yes
11	Region of dominantly sand and sand and gravel. Other areas are mainly clay and silty clay	No

The immediate point to note is the very limited area of outcrop of the Magnesian Limestone present in the study area. There is a slightly larger area covered by Domain 10 which is also considered to allow direct recharge.

2.2 Hydrochemistry

ESI (2004) presents a summary of the data from the Environment Agency's groundwater quality data for the Skerne Magnesian Limestone Groundwater Quality Monitoring Unit (GQMU). The following is a summary of the findings regarding major ion chemistry in the area.

Groundwater in the Skerne Magnesian Limestone unit is predominantly of a calcium magnesium bicarbonate type, attributable to the natural influence of dolomite within the Magnesian Limestone.

Sulphate is high relative to the drinking water standard; of 1146 samples 14 percent are over the quality level of 250 mg/l. High sulphate concentrations are generally encountered at sample locations to the north, west and east of Newton Aycliffe. High sulphate concentrations are usually associated with water sourced from Coal Measures strata, where they are derived from the oxidation of pyrite. High sulphate concentrations may also be caused by interaction between the Middle and Upper Limestone units and the gypsum-rich Permian Marls separating them.

Nitrate concentrations are elevated relative to natural concentrations. Of 1163 samples, approximately five percent exceed the quality level of 11.3 mg/l. The majority of sample locations with elevated nitrate concentrations occur in the west of the GQMU near to, or in, areas where Drift cover is absent, although the two highest concentrations of nitrate occur in areas of Magnesian Limestone confined by Drift. Clusters of elevated nitrate concentrations are located to the north east, south west and west of Newton Aycliffe. These areas are within the direct recharge area and have arable land use. Very low concentrations of nitrate are detected to the east of the unit where the Magnesian Limestone is confined by thick, impermeable drift. In this area groundwaters are older waters and reducing conditions may have removed nitrate.

2.3 Previous recharge estimates

Previous recharge rate estimates for the aquifer have varied widely. Recharge through the drift cover is poorly understood as there are few hydrogeologically relevant observations of the drift, which varies laterally in both composition and thickness. A study on the recharge of the Magnesian Limestone aquifer by Rabi (1993) has been identified, but was not available for review. Neymeyer (2003) made an attempt to quantify recharge rates over a small portion of the area as part of a modelling study.

A summary of recharge rates from various sources is given in Table 2.2.

Table 2.2 Magnesian Limestone recharge values used in previous studies

Project	Estimation method	Recharge rates
Pollution modelling (Neymeyer, 2003)	Soil Moisture Balance method	281 mm/a for drift free areas 43.8 mm/a for drift covered areas (originally 80 mm/a but reduced during modelling)
SPZ delineation (1993)	Recharge factors: No drift/thin drift (<10m) 75% effective rainfall Thick drift (10-70m) 25% effective rainfall Very thick drift (>70m) no recharge	For Thorpe/Mill Hill/Hawthorne sources: No drift/thin drift 176 mm/a Thick drift 58 mm/a
Recharge estimate by Armstrong (1960)	?	330 mm/a over areas with no streams (drift free?) 76mm/a over clay covered areas

2.4 Sensitivity study – recharge calculation input parameters

Using the BGS hydrodomains, an area of the aquifer has been selected where direct recharge is likely. A sensitivity study, using the Environment Agency's spreadsheet recharge calculator, has been carried out to give an indication of recharge to the aquifer. The selected area is shown on Figure 2.2 and is referred to in this report as the *direct recharge area*. This is based on the hydrodomains where there is limestone outcrop or less than 5m of aquifer/aquitard over the limestone. There are also a few small areas of the hydrodomain defined as '>5m minor aquifer over < 5m aquitard' included in the direct recharge area.

The Northern boundary is defined by the Butterknowle fault, and the Southern boundary by a narrowing of the Magnesian Limestone outcrop area at Heighington. The area of direct recharge zone shown in Figure 2.2 is 64.91 km^2. There are some additional small areas of outcrop/thin drift separated from the direct recharge area shown in Figure 2.2 to the south (at NGRs 432300, 524200 and 428400, 522500). These have a combined area of 1.88 km^2.

Recharge has been estimated using Environment Agency's WFD Recharge Calculator (EA, 2007). This has been produced through collaboration between the Environment Agency and the Scotland and Northern Ireland Forum For Environmental Research (SNIFFER). The primary aim of the recharge toolbox is to provide users with an opportunity to explore quantitatively the influence of various catchment parameters on recharge. The data required to perform the calculations are discussed in the following sections.

2.4.1 Rainfall data

The spatial distribution of long-term average (LTA) rainfall is shown in Figure 2.3. This shows the long-term average rainfall (as Standard Annual Average Rainfall – SAAR) for the period 1961 to 1990 at each rainfall station and also the spatial distribution as calculated by the Meteorological Office for each square kilometre. In the direct recharge area the SAAR varies from 633-681 mm/a.

There are three rain gauges within the area of direct recharge, and three more just outside the area. Rainfall data from Thrislington Quarry were used as this is fairly central to the area and has a long term record (1966 to present). The SAAR (1961-90) for Thrislington Quarry is 651 mm/a.

The period 1977-2006 was chosen for the recharge estimate as it gave a 30 year period, with 2006 being the last complete year of the Thrislington Quarry record available. The average rainfall for Thrislington Quarry for this period was 660 mm. There are many gaps in the daily record for Thrislington Quarry as, although the cumulative rainfall at that site is usually recorded daily it is frequently only recorded after a longer period. Where there are data gaps, the rainfall at the end of the data gap period has been distributed evenly over the data gap period. Sensitivity analysis was carried out to assess the effect of this assumption and it was concluded that it did not significantly affect the estimated long term average recharge.

The rainfall data for Thrislington Quarry was multiplied by a factor in order to make it representative of the average rainfall across the direct recharge area as follows:

Daily rainfall for recharge estimation = Daily rainfall at Thrislington x f

Where f = SAAR 1961-1990 in the direct recharge area ÷ SAAR 1961-1990 at Thrislington

The average SAAR 1961-1990 in the direct recharge area is 658.8 mm/a (calculated from values for km^2 which are more than 50% within the direct recharge area). Therefore the rainfall was multiplied by a factor of 1.012.

2.4.2 Potential evaporation data

The weekly potential evaporation (PE) for grass for MORECS square 80 has been used. A daily record of PE was derived from the weekly values by evenly distributing it across the seven days. The annual average PE for grass for the period 1977-2006 was 602 mm/a (the MORECS actual evapotranspiration for grass was 526 mm/a and the rainfall was 654 mm/a which is a good correlation with Thrislington Quarry).

2.4.3 Soil types

The soils types in the direct recharge area are shown in Figure 2.4. The soil types are summarised in Table 2.3. In the direct recharge area the soils are 76% loam, 20% loam to clay 4% clay and 0.01% peat (area %).

Table 2.3 Summary of soils in the NE Magnesian Limestone direct recharge zone

Area covered by soil (km^2)	Soil unit	Soil name	Simple Description	Dominant Soil
20.76	0713g	BRICKFIELD 3	seasonally wet deep loam	Slowly permeable seasonally waterlogged fine loamy fine loamy over clayey and clayey soils.
13.27	0711p	DUNKESWICK	seasonally wet deep loam to clay	Slowly permeable seasonally waterlogged fine loamy and fine loamy over clayey soils
11.88	0511a	ABERFORD	loam over limestone	Shallow locally brashy well drained calcareous fine loamy soils over limestone.
8.93	542	NERCWYS	deep loam	Deep fine loamy soils with slowly permeable subsoils and slight seasonal waterlogging.
6.47	0541r	WICK 1	deep loam	Deep well drained coarse loamy and sandy soils locally over gravel.
2.06	0511d	BLEWBURY	clayey over chalk	Well drained calcareous clayey and fine silty over clayey soils over argillaceous chalk.
0.95	0541x	EAST KESWICK 1	deep loam	Deep well drained fine loamy soils and similar soils with slowly permeable subsoils and slight seasonal waterlogging.
0.52	712f	CREWE	seasonally wet deep red clay	Slowly permeable seasonally waterlogged reddish clayey and fine loamy over clayey soils often stoneless.
0.06	543	ARROW	deep loam	Deep permeable coarse loamy soils affected by groundwater.
0.01	1024a	ADVENTURERS' 1	peat	Deep peat soils.

*assuming 100% predominant soil type in each km^2.

NB The soil data for each km^2 were analysed in detail to ensure that no bias was being introduced by this assumption. A good correlation was found between predominant soil area percentages and soil area percentages derived from analysis of all soils within each km^2. However, since the distribution of soils within each km^2 is not known, a detailed analysis of the soil areas cannot be made for an irregular shape such as the direct recharge area, so the predominant soils were used.

2.4.4 Land use

Land use data have been provided by the Environment Agency and are shown in Figure 2.5. There are five categories and the coverage is shown in Table 2.4.

Table 2.4 Summary of land use in the direct recharge area

Land Use	km^2	Area %
Arable	35.28	54.83%
Managed grassland	15.18	23.59%
Forestry/woodland	0.55	0.86%
Semi-natural grassland	3.16	4.91%
Urban	10.18	15.82%

The arable land use has to be subdivided into crop types in order to derive crop parameters for input to the Environment Agency's recharge calculator spreadsheet.

The Environment Agency's crop calendar dataset (Holman and Hess, 2005) provides information on indicative crop rotations in different regions of the UK for various soil types. For the local soils, which are generally loams, the crop rotations for the North East region (for soil type 'other mineral') are:

Primary: oilseed rape, winter wheat, winter wheat, winter barley

Secondary: oilseed rape, winter wheat, spring field beans, winter barley

Set-aside: winter barley, oilseed rape, winter wheat, set-aside.

The crop calendar dataset has been developed to derive accurate crop parameters for the UK using more accurate dates that reflect the local planting and harvesting practices. In addition corrections can be made to the crop coefficients to more accurately reflect the UK climate. This more detailed analysis has not been carried out for this preliminary recharge assessment in which the default FAO crop parameters from the WFD spreadsheet were used.

2.4.5 Runoff

Runoff is usually defined as the rainfall that flows directly to rivers without entering the soil zone. This component of the water balance is ideally calibrated against river flow data. However there are no suitable time series stream flow data for the direct recharge area. In limestone areas it is likely that rainfall that does not directly enter the soil zone may subsequently enter the ground via solution features, rather than flowing into streams. T here are three main streams on the direct recharge area shown on the OS 1:50 000 map:

- The Rushyford Beck which starts at Middlestone (NGR 425200,531000)
- The Woodham Burn starts to the west of the direct recharge area (Corner Beck) and flows across the direct recharge area through Newton Aycliffe to join the River Skerne. This also has a tributary running north across the direct recharge area to Eldon Moor House (NGR 426300, 526900).
- The River Skerne arises along the northern edge of the direct recharge area and flows across it further downstream.

The amount of flow gain in these streams as they cross the direct recharge area is not known. Elsewhere there are few streams arising on the direct recharge area which supports the hypothesis that the runoff to surface water is low in these areas.

The base case for recharge estimation therefore used zero runoff and a range of possible values have been used to investigate the sensitivity of the recharge estimate to this parameter. The runoff percentage typically varies according to the soil type, with clayey soils having higher runoff than sandier soils. The baseflow index of a catchment gives an

[illegible] 10 to 20 %

indication of the runoff. Values of BFI for different soils are given in the national soils database (ref), which gives typical values of around 0.8-9 for sandy soils and 0.3-0.8 for loams and clays.

2.4.6 Bypass

Bypass of the soil zone represents rain that directly becomes potential recharge without taking part in the soil moisture balance. In the Environment Agency's recharge calculator spreadsheet, the bypass percentage is defined in terms of a daily rainfall threshold and a bypass percentage of the rainfall. If the daily rainfall exceeds the threshold, then the rainfall in excess of the threshold becomes potential recharge and is not available for evapotranspiration. Evidence for this process comes from observations of recharge (i.e. groundwater level rise) at times when there is a soil moisture deficit.

This bypass process may represent the effects of redistribution of rainfall at the surface due to localised topographical changes (puddling) rather than the existence of direct routes for rainfall to flow down past the soil zone. Where rainfall is concentrated into localised puddles, the soil moisture deficit beneath these will be reduced to zero much quicker and allow recharge to occur earlier than for the average soil. Clearly, at a larger scale, this process would become equivalent to runoff recharge and there is in reality probably a continuum across the scales between these two processes.

There are few data to define the parameters that control bypass flow but it has been incorporated into the spreadsheet with two key parameters:

1. a threshold of daily rainfall below which no bypass occurs; and
2. a percentage of rainfall above the threshold that bypasses the soil zone.

Initially these parameters were set to 0 mm and 10% (i.e. 10% of all rainfall bypasses the soil zone) but this was tested as part of the sensitivity analysis. bias toward higher recharge.

2.5 Sensitivity study – results

The base case scenario has the following input parameters:

- pasture land use
- loam soil type
- zero runoff
- bypass flow of 10%, threshold 0 mm

Sensitivity runs were carried out by varying one parameter at a time to determine the effect on the average recharge over the 30 years of the simulation (1977-2006).

2.5.1 Soil type

The default values for soil parameters were used from the WFD spreadsheet to represent the soils in the direct recharge area.

The changes in annual average recharge for the soil types in the area are shown in Table 2.5, for pasture land use, zero runoff and a bypass flow of 10%. This shows that the variation in soil type within the direct recharge area has a small effect on the total calculated potential recharge.

Table 2.5 Results of sensitivity to soil type

Soil type	Annual average recharge (mm/a)
Loam	194
Silt clay loam	195
Clay	189

2.5.2 Land use

The changes in annual average recharge for various land uses are shown in Table 2.6, for loam soil, zero runoff and a bypass flow of 10%. This shows that the land use has a large effect on the total calculated potential recharge, with the recharge in forested areas being particularly low.

Table 2.6 Results of sensitivity to land use

Land use	Annual average recharge (mm/a)
Pasture	194
Urban	215
Deciduous	99
Coniferous	152
Winter wheat	200
Winter barley	249
Oilseed rape	227

2.5.3 Runoff

The changes in annual average recharge for various runoff percentages are shown in Table 2.7, for pasture land use, loam soil and 10% bypass. This shows that the runoff % has a large effect on the total calculated potential recharge.

Table 2.7 Results of sensitivity to runoff

Runoff %	Approximate equivalent BFI*	Annual average recharge (mm/a)
0	1	194
5	0.83	189
10	0.67	182
15	0.55	176
20	0.33	169

*assuming that recharge is 30% of rainfall, see Section 2.4.5.

2.5.4 Bypass

The changes in annual average recharge for various bypass percentages and threshold levels are shown in Table 2.8, for loam soil, pasture land use and zero runoff. Introducing a threshold rainfall intensity below which the bypass is zero reduces the recharge; the recharge is lower for higher thresholds.

Table 2.8 Results of sensitivity to bypass flows

Bypass %	Bypass threshold (mm)	Annual average recharge (mm/a)
0	0	175
5	0	184
10	0	194
15	0	206
20	0	219
10	1	194
10	3	190
10	5	186

2.5.5 Rainfall

There is some evidence that rainfall gauges may be underestimating the true amount of rainfall by 6% (Rodda and Smith, 1986), therefore sensitivity to this parameter was investigated. It was found that increasing the daily rainfall by 5% for loam, pasture land use 10% bypass and zero runoff increased the potential recharge from 194 mm/a to 219 mm/a, an increase of 13%. Errors in rainfall measurement are therefore proportionally more important in terms of their impact on potential recharge.

2.5.6 Recharge best estimate

A best estimate of recharge has been calculated based on the weighted average of results for six land uses categories, shown in Table 2.9. The soil type was assumed to be loam and the runoff was zero. Bypass flow was 10% with a threshold of 0 mm.

Table 2.9 Land use categories for best estimate of recharge

Land Use	km^2	Area %	Average recharge 1977-2006 (mm/a)
Arable	35.28	(total 54.8%)	
Winter wheat		27.4%	200
Winter barley		13.7%	249
Oilseed rape		13.7%	227
Managed and semi-natural grassland	15.18	28.5%	194
Forestry/woodland	0.55	0.9%	125.5*
Urban	10.18	15.8%	215
Average weighted by land use area %			**210**

*average of coniferous and deciduous values

The area of direct recharge zone shown in Figure 2.2 is 64.91 km^2, which implies that the best estimate of total average recharge to the direct recharge area in would be 13,700 Ml/a.

There are some additional small areas of outcrop/thin drift separated from the direct recharge area shown in Figure 2.2 to the south (at NGRs 432300, 524200 and 428400, 522500). These have a combined area of 1.88 km^2. If these are assumed to be receiving recharge at the same rate then this would increase the total recharge to 14,100 Ml/a.

The variation in annual rainfall, recharge, actual evapotranspiration and soil moisture deficit throughout the 30 year period of the simulation is shown in Figure 2.6, for grazing pasture land use. This shows that the annual recharge varies from 413 mm/a (in 2000) to as low as 40 mm/a in 1989.

2.5.7 Conclusions

The average annual recharge for the period 1977-2006 simulated by the WFD recharge spreadsheet, weighted for land use and assuming zero run off and 10% bypass flow was 210 mm/a. The variation of annual recharge within this period was from 40 - 413 mm/a.

Significant uncertainties in the recharge estimate include:

1. Bypass flow - the parameterisation of the bypass recharge component has a large effect on the calculated recharge and there are no field data to constrain the size of this parameter. Bypass flows of 20% increase the recharge by 13%, whilst assuming no bypass reduces the recharge by 10%.
2. Runoff – this parameter also has a large effect on the calculated recharge. The best estimate recharge assumes that there is zero runoff from the limestone. If runoff is assumed to be 20%, this reduces the recharge by 13%.
3. Rainfall - underestimation of the rainfall by 5% would increase the recharge by 13%.

The total uncertainty of the above parameters gives a possible range of +26% to -23% which gives range of average recharge estimates of 149-244mm.

Other uncertainties in the results are the type of potential evaporation data used; on the basis of experience on other studies, MOSES data may increase the recharge slightly compared to the MORECS data that was used in this study.

In addition, more accurate crop parameters based on Environment Agency's crop calendar dataset could be included as the default FAO parameters in the WFD spreadsheet for crops such as cereals are not representative of UK conditions. The uncertainty associated with these parameters has not been quantified in this study.

However the large uncertainties in bypass flow and runoff mean that it will always be difficult to constrain the estimate of recharge without using stream flow data to constrain these parameters. It would be useful to conduct field surveys of the streams in the area under wet and dry conditions to support estimates of runoff percentage.

3 RIVER SKERNE

3.1 Background

The River Skerne is a tributary of the River Tees, and flows across the Magnesian Limestone for almost all its length (see Figure 3.1). In this area, the aquifer is largely concealed beneath superficial deposits and historically river/aquifer interactions were thought to be limited for this reason. To the east of the River Skerne, the superficial deposits are typically greater than 30 m thick, up to a maximum of 84.5 m. In contrast, to the west of the river, the deposits were found to be sandier and thinner, generally being less than 3 m thick (Cairney and Hamill, 1977).

However, Cairney and Hamill (1977) demonstrated that the River Skerne was in fact quite well connected to the aquifer at specific points and the river provided a potentially significant source of recharge to the aquifer. At the time of their investigation, groundwater was pumped out of the mines to maintain dry working conditions. Due to various connections (e.g. faults, collapsed workings etc.) between the Magnesian Limestone aquifer and the coal workings there was a considerable amount of leakage from the Magnesian Limestone to the coal workings, resulting in lowered groundwater levels in the Magnesian Limestone.

From a study of the data from newly installed flow gauges and periodic minewater discharges, Cairney and Hamill established that the river lost approximately 37% of its flow to the aquifer between the Preston-le-Skerne and South Park gauging stations (Figure 3.1). It was suspected that this water was ultimately abstracted by a group of groundwater abstractions located to the east of the river. They believed that the most likely location for the river loss was a reach 4 km downstream of Preston-le-Skerne where Magnesian Limestone outcropped in the stream bed.

On cessation of mining, pumping was stopped and water levels in the workings rose. Where these levels have reached the base of the Magnesian Limestone, the leakage rates from the Magnesian Limestone have reduced resulting in a rise in groundwater levels in the Magnesian Limestone.

A review of recent groundwater levels in the Magnesian Limestone suggests that the hydraulic gradient is very flat in the area between Preston le Skerne and Bradbury and this could be consistent with groundwater discharge in this area. However, the available data on the superficial deposits suggest that there is a significant thickness of aquitard in this area (Figure 2.1).

It is not possible to assess potential loss of flow from the river since the cessation of mine dewatering in the same manner as Cairney and Hamill as their work was based on tracking periodic releases of water to the river from the mine dewatering. Instead, data from the three main permanent flow gauges, very limited spot flow data and water chemistry have been reviewed.

This review has not taken into account any anthropogenic influences (abstractions or discharges) and so the conclusions should be treated with some caution until this has been checked.

3.2 Permanent Flow Gauges

Details of the three main permanent flow gauges (plus a fish pass) on the Skerne are presented in the following table. The locations of the gauges are shown on Figure 3.1.

Table 3.1 Summary details of gauging sites on the River Skerne

Station ID	Station Name	Watercourse	NGR	Start	End	Status	LTA daily Flow (Ml/d)	Q_{95} (Ml/d)	Catchment size (km^2)
F3702A	South Park, Fish Pass	River Skerne	NZ284129	01/06/96	to date	Current	1.1	0.432	
F3702	South Park	River Skerne	NZ284129	01/01/1982	to date	current	138.9	29.5	250
F3705	Preston Le Skerne	River Skerne	NZ292238	01/01/1982	to date	Current	73.3	7.7	147
F3707	Bradbury	River Skerne	NZ318285	01/01/1982	to date	current	34.0	4.8	70

Data from the three main gauges have been assessed to compare the gain in flow along the two reaches Bradbury-Preston and Preston-South Park. The change in flow along each reach has been normalised by the difference in catchment area with results reported as mm/a.

The change in flow is presented in Figure 3.2, with data from the observation borehole Swan Carr also shown to indicate when the major rise in groundwater levels occurred following cessation of mine dewatering.

A number of comments can be made regarding the data as follows, but it should be noted that no assessment of anthropogenic influences has been made:

- Prior to the rise in groundwater levels in 1978, the gain in flow was less over the Preston to South Park reach than the Bradbury to Preston reach, particularly in the summer months.
- Once groundwater levels had stabilised (1980 onwards), this trend appears to be reversed with summer gain greater in the Preston to South Park reach.

To quantify this observation, the average gain has been calculated for the two periods before and after the groundwater level recovery following dewatering cessation. The data have been subdivided into summer (taken as June to September) and the rest of the year. Data for 1976 and 1978 have been excluded due to some apparent anomalies. The data are presented in Table 3.2.

Table 3.2 Comparison of river gain.

Period	Reach	Average gain 1973-2005 (mm/a)	Average gain 1973-77 (excl 1976) (mm/a)	Average gain 1979-2005 (mm/a)
October to May	Bradbury to Preston	245	172	250
	Preston to South Park	221	198	224
	Bradbury to South Park	231	187	235
June to September	Bradbury to Preston	73	67	69
	Preston to South Park	104	64	113
	Bradbury to South Park	91	66	94
January to December	Bradbury to Preston	187	136	189
	Preston to South Park	182	149	187
	Bradbury to South Park	184	144	188

Over a 12 month period, the average gain for each reach is very similar both before and after the groundwater rise (the difference in average flows between the two periods probably reflects differences in rainfall). However, for the summer period, when there is less runoff, the gain over all the reaches was similar pre-groundwater rise but post-groundwater rise, the lower Preston to South Park reach shows much more gain than the Bradbury to Preston reach. This would suggest that following the rise in groundwater levels, the rate of baseflow discharge to the river south of Preston le Skerne has risen. Presumably most of this discharge is via the areas of thin drift and outcrop shown on Figure 2.1. The fact that this change is not apparent between Bradbury and Preston would tend to suggest that the rate of discharge from the limestone along this reach has not changed and the flattening of the groundwater contours is due to other reasons.

Overall, the average gain in the river is typically equivalent to 180-190 mm/a. If there is no net anthropogenic effect, then this would be a good estimate for the effective precipitation. This figure is slightly lower than the best estimate recharge figure presented in Section 2.5.7 which would be consistent with there being a net negative anthropogenic influence (abstraction exceeds discharge).

3.3 Spot Flow Data

There are very limited spot flow data for the River Skerne, at locations shown on Figure 3.1. There are two monitoring events at spot gauging sites 1 to 5 at the top of the river from September 1998, and the data are presented as flow accretion profiles in Figure 3.3. Units of flow were not provided (presumably m^3/s), but the limited data suggest that overall there is relatively little accretion over this reach. The erratic pattern could either be due to discrepancies in the gauging data at individual sites or reflect a high degree of interaction with a groundwater system with a water table that closely parallels the stream bed.

3.4 Surface Water Chemistry

Concentrations of sulphate in the river have been monitored at locations shown on Figure 3.4. The data for January and June from each year monitored are presented in Figure 3.5, plotted as distance upstream from the most downstream monitoring location.

The data indicates high sulphate concentrations in the uppermost reaches of the river, particularly at Holdforth Bridge, suggesting the influence of groundwater from the Magnesian Limestone in these upper reaches (where drift is thin). These concentration decrease significantly downstream due to dilution from water that is presumably predominantly from the drift. There is no data on sulphate concentrations in the drift to allow the degree of dilution to be calculated.

Summer baseflow could be approx recharge
ie ~100mm/a.

winter gains may give indication of runoff

4 SUMMARY AND RECOMMENDATIONS

4.1 Summary of Recharge Estimates

This short technical report presents a scoping assessment of the amount of recharge to the Magnesian Limestone in the area south of the Butterknowle Fault.

A re-assessment of the superficial geology of the area has allowed the area over which direct recharge is likely to occur to be defined more accurately. The area of direct recharge zone shown in Figure 2.2 is 64.91 km^2. There are some additional small areas of outcrop/thin drift separated from the direct recharge area shown in Figure 2.2 to the south (at NGRs 432300, 524200 and 428400, 522500). These have a combined area of 1.88 km^2.

Smaller rates of recharge may occur through areas of thicker drift but these have not been considered at this stage as the recharge through these areas is probably head dependent.

The rate of recharge in the areas of direct recharge has been estimated using the Environment Agency's spreadsheet recharge calculator. The average annual recharge for the period 1977-2006, weighted for land use and assuming zero run off and 10% bypass flow was 210 mm/a. The variation of annual recharge within this period was from 40 – 413 mm/a.

Significant uncertainties in the recharge estimate include:

1. Bypass flow - the parameterisation of the bypass recharge component has a large effect on the calculated recharge and there are no field data to constrain the size of this parameter. Bypass flows of 20% increase the recharge by 13%, whilst assuming no bypass reduces the recharge by 10%.
2. Runoff – this parameter also has a large effect on the calculated recharge. The best estimate recharge assumes that there is zero runoff from the limestone. If runoff is assumed to be 20%, this reduces the recharge by 13%.
3. Rainfall - underestimation of the rainfall by 5% would increase the recharge by 13%.

The total uncertainty of the above parameters gives a possible range of +26% to -23% which gives range of average recharge estimates of 149-244mm.

Other uncertainties in the results are the type of potential evaporation data used; on the basis of experience on other studies, MOSES data may increase the recharge slightly compared to the MORECS data that was used in this study.

4.2 Summary of Groundwater-Surface Water Interaction

The available stream flow and surface water quality data has been reviewed to try and identify whether it provides any information on groundwater-surface water interaction. This review has not taken into account any anthropogenic influences (abstractions or discharges) and so the conclusions should be treated with some caution until this has been checked.

It appears that there has been an increase in the rate of groundwater discharge downstream of Preston le Skerne since the recovery of groundwater levels in the late 1970s. Discharge is presumably mainly through windows in the drift cover. It appears that there is relatively little discharge from the Magnesian Limestone over the reach between Bradbury and Preston le Skerne due to the thick drift cover in this area.

The surface water quality data and available spot flow gauging data suggests that there is good interaction between the Magnesian Limestone and the river upstream of Bradbury.

The available stream flow data suggests that, assuming that the net anthropogenic influence is negative (i.e. abstraction exceeds discharge), the effective precipitation in the catchment exceeds 180-190 mm/a. This would be consistent with the recharge estimates presented above (210 mm/a best estimate).

4.3 Recommendations

There are a number of tasks that could assist in refining the estimates of recharge in this area.

More accurate crop parameters based on Environment Agency's crop calendar dataset could be included as the default FAO parameters in the WFD spreadsheet for crops such as cereals are not representative of UK conditions. .

The large uncertainties in bypass flow and runoff mean that it will always be difficult to constrain the estimate of recharge without using stream flow data to constrain these parameters. It would be useful to conduct field surveys of the streams in the area under wet and dry conditions to support estimates of runoff percentage. This could also assist in selecting stream reaches that could be the focus of more detailed stream gauging and/or surface water sampling to assist in determining the degree of groundwater surface water interaction.

It is noted that there are a number of large quarries in the area of direct recharge and it could be worth reviewing any reports and datasets associated with these.

The available surface water abstraction and discharge data should be reviewed to form an opinion as to the likely net anthropogenic effect on stream flows. This would help to refine estimates of effective precipitation and thus of recharge. This exercise will be carried out as part of the Tees CAMS exercise which is due for completion in April 2008.

5 REFERENCES

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Environment Agency, 2007. WFD recharge calculator spreadsheet version 2.59 and manual (draft). Developed by the Environment Agency and the Scotland and Northern Ireland Forum For Environmental Research (SNIFFER)

Cairney, T. and Hamill, L. 1977. Interconnection of surface and underground water resources in southeast Durham. Journal of Hydrology 33 (1977) pp73-86.

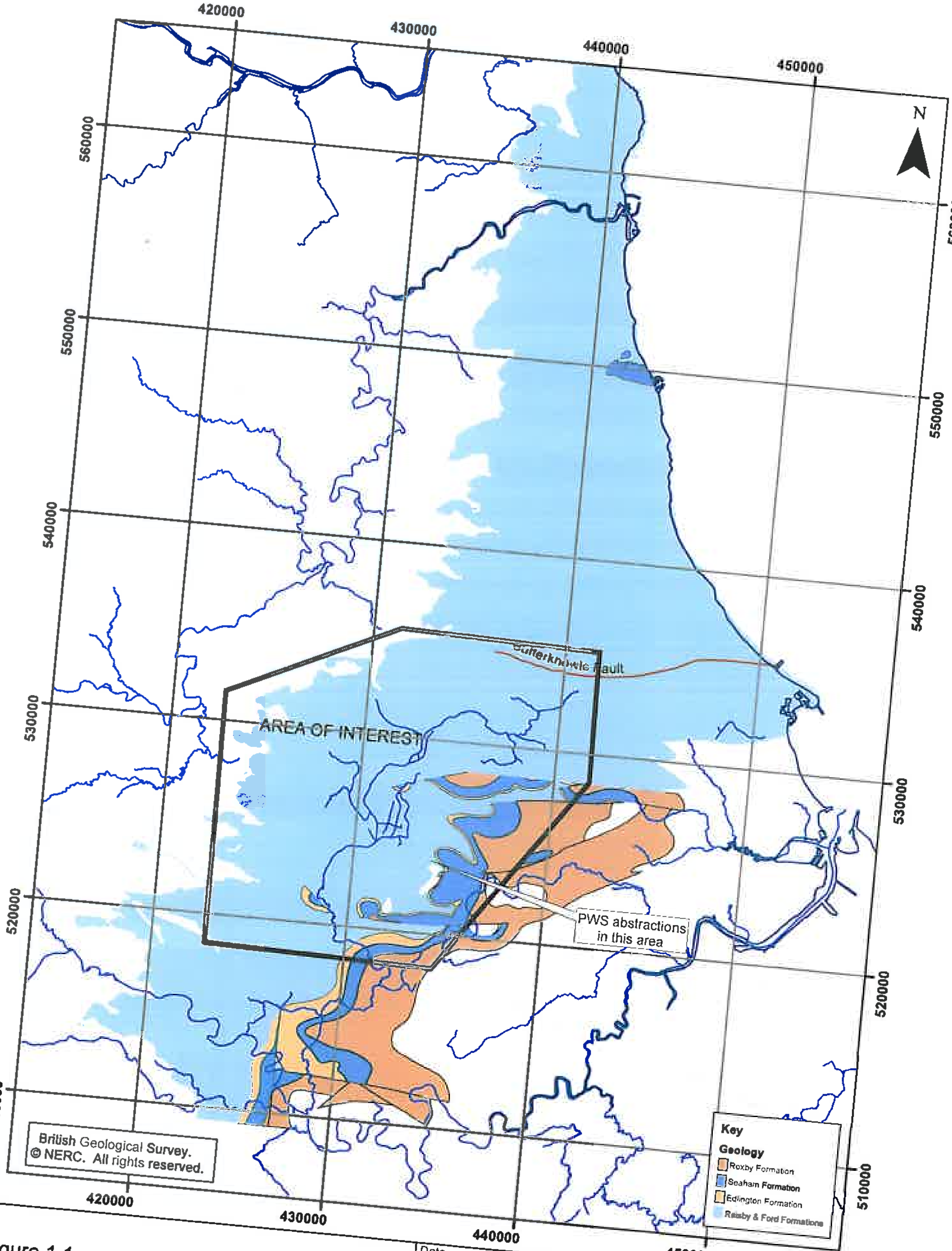

Figure 1.1
Location of study area

Date May 2007	Drawn CDB
Scale 1:250,000	Checked LRB
Original A4	Revision 1
File Reference O:\6886 NW Magnesian Limestone Model\reports\Prelim recharge estimates\6886R1 Figure 1.1.mxd	

esi soil & groundwater

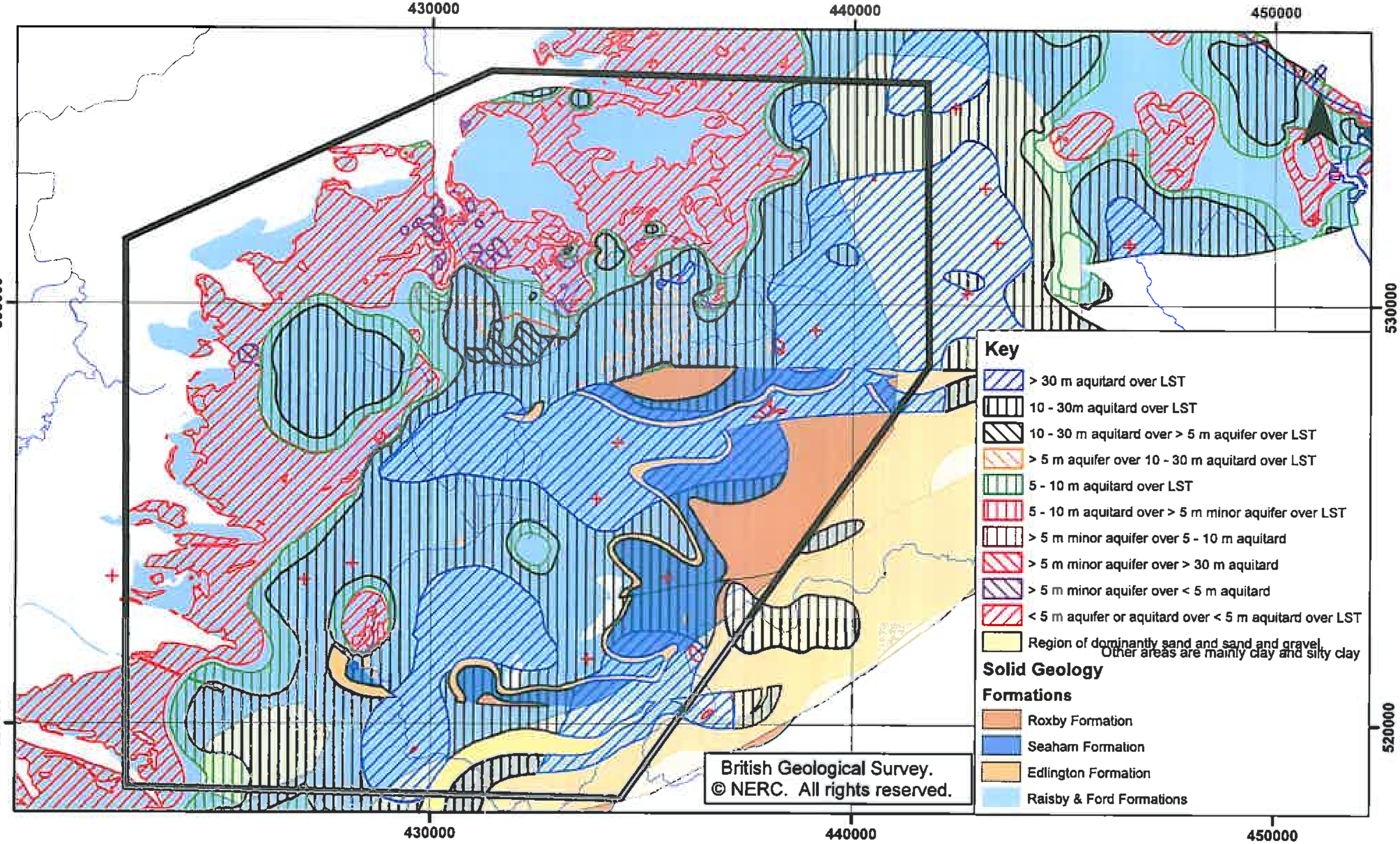

Figure 2.1
Drift Hydrodomains

Date May 2007	Drawn LRB
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Original A4	Revision 1
File Reference O:\5886 NW Magnesian Limestone Model\reports\Prelim recharge estimates \Figure 2.1.mxd	

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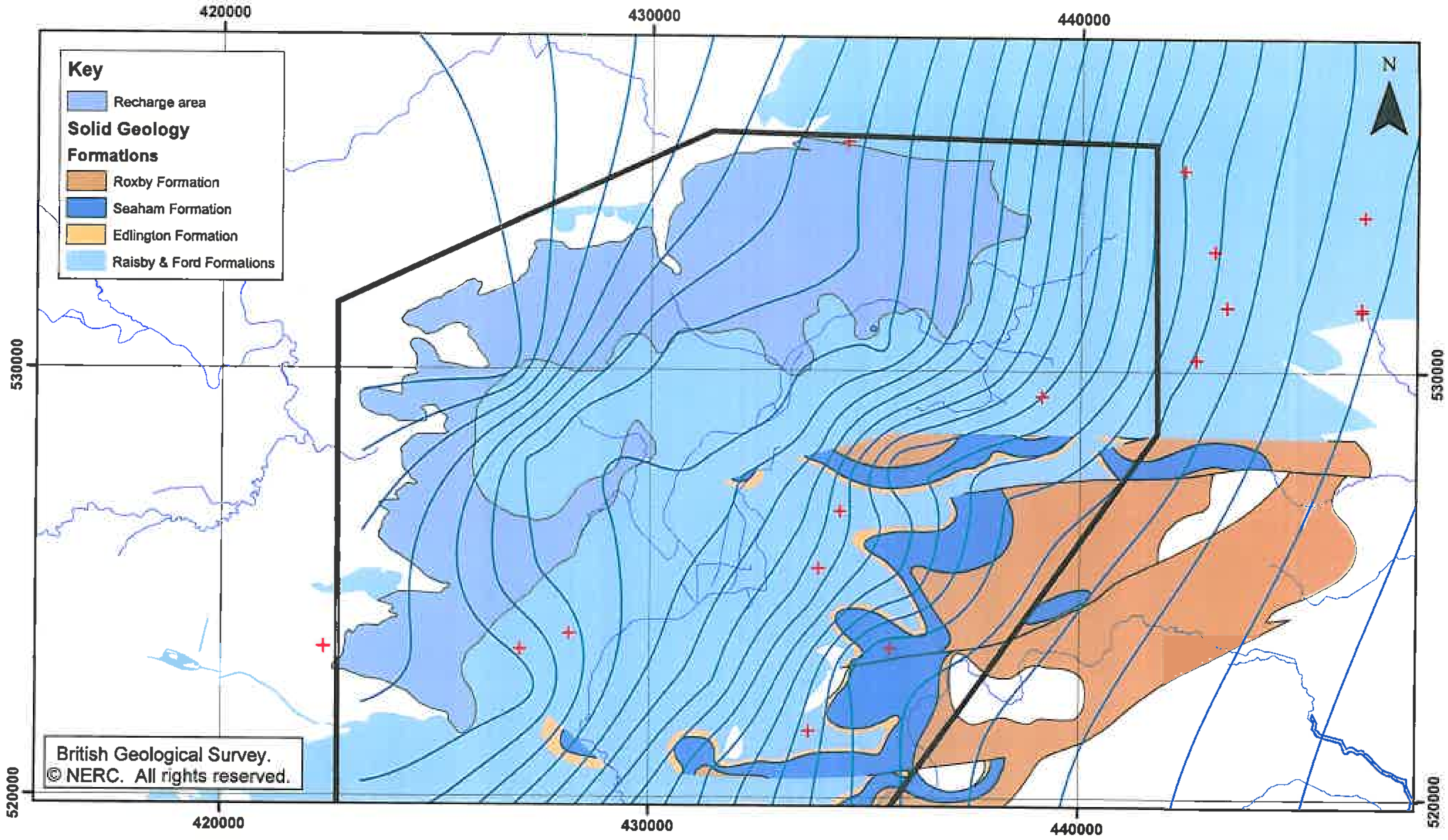

Figure 2.2
Area considered for direct recharge

Date May 2007	Drawn LRB
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Original A4	Revision 1
File Reference O:\6886 NW Magnesian Limestone Model\reports\Prelim recharge estimates \Figure 2.1.mxd	

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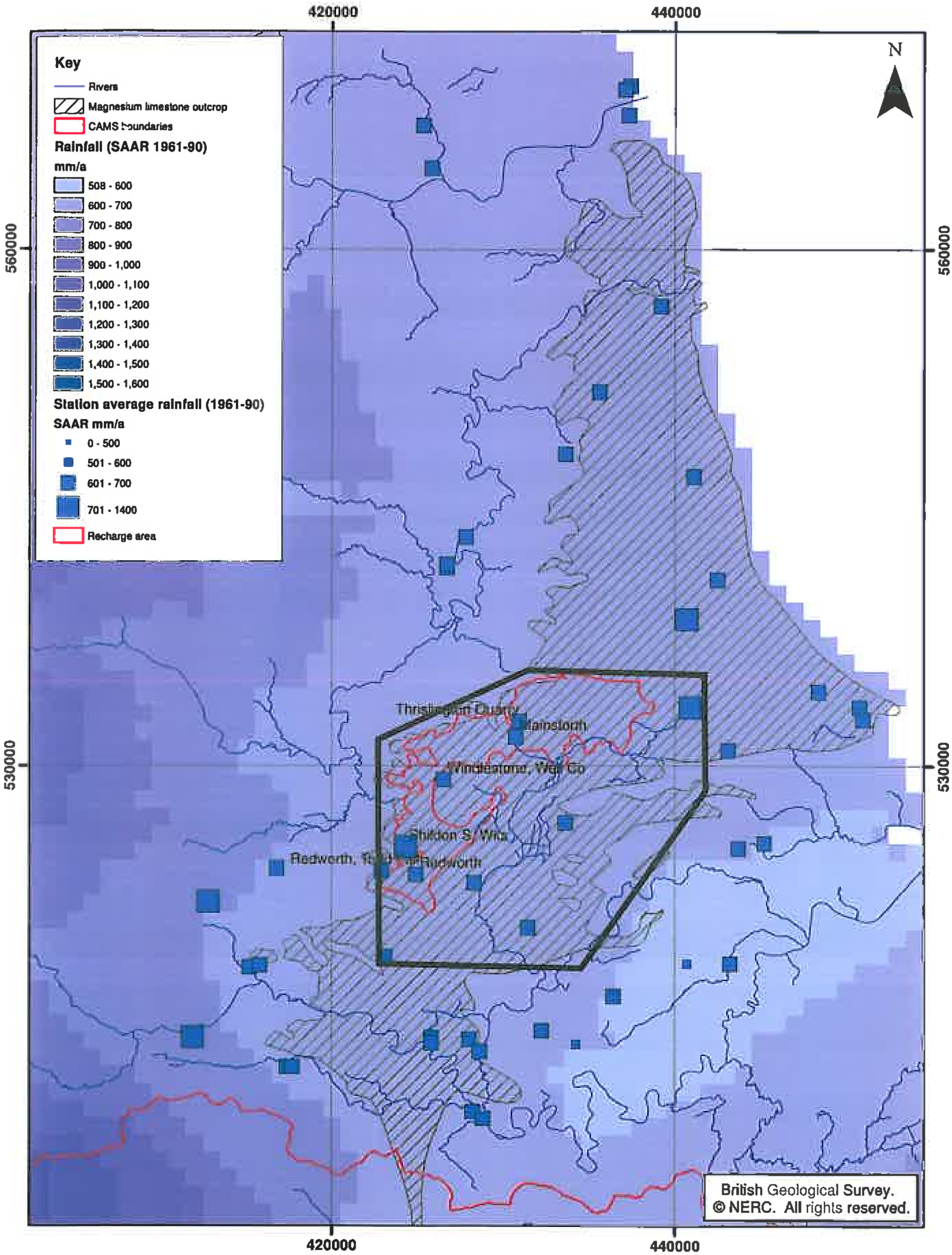

Figure 2.3
Spatial variation in rainfall -
standard average annual rainfall (1961-90)

Date May 2007	Drawn HRS
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Original A4	Revision 1
File Reference O:/6886/Reports/prelim recharge estimates/Figure 2.3.mxd	

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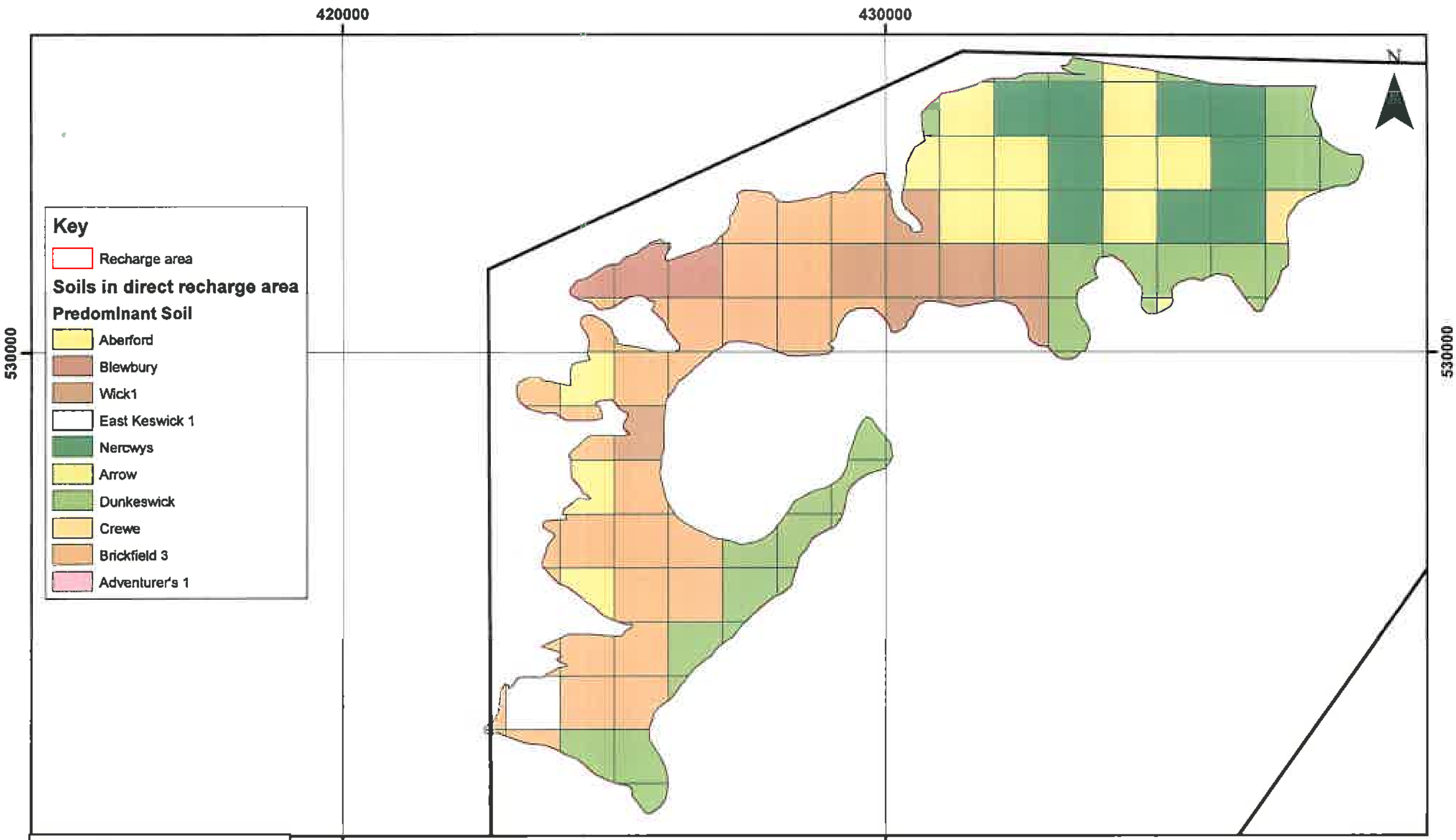

Figure 2.4
Soils in area considered for direct recharge

Date May 2007	Drawn LRB
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Original A4	Revision 1
File Reference 6886 NW Magnesian Limestone model/Reports /Prelim Recharge estimates/Figure 2.4.mxd	

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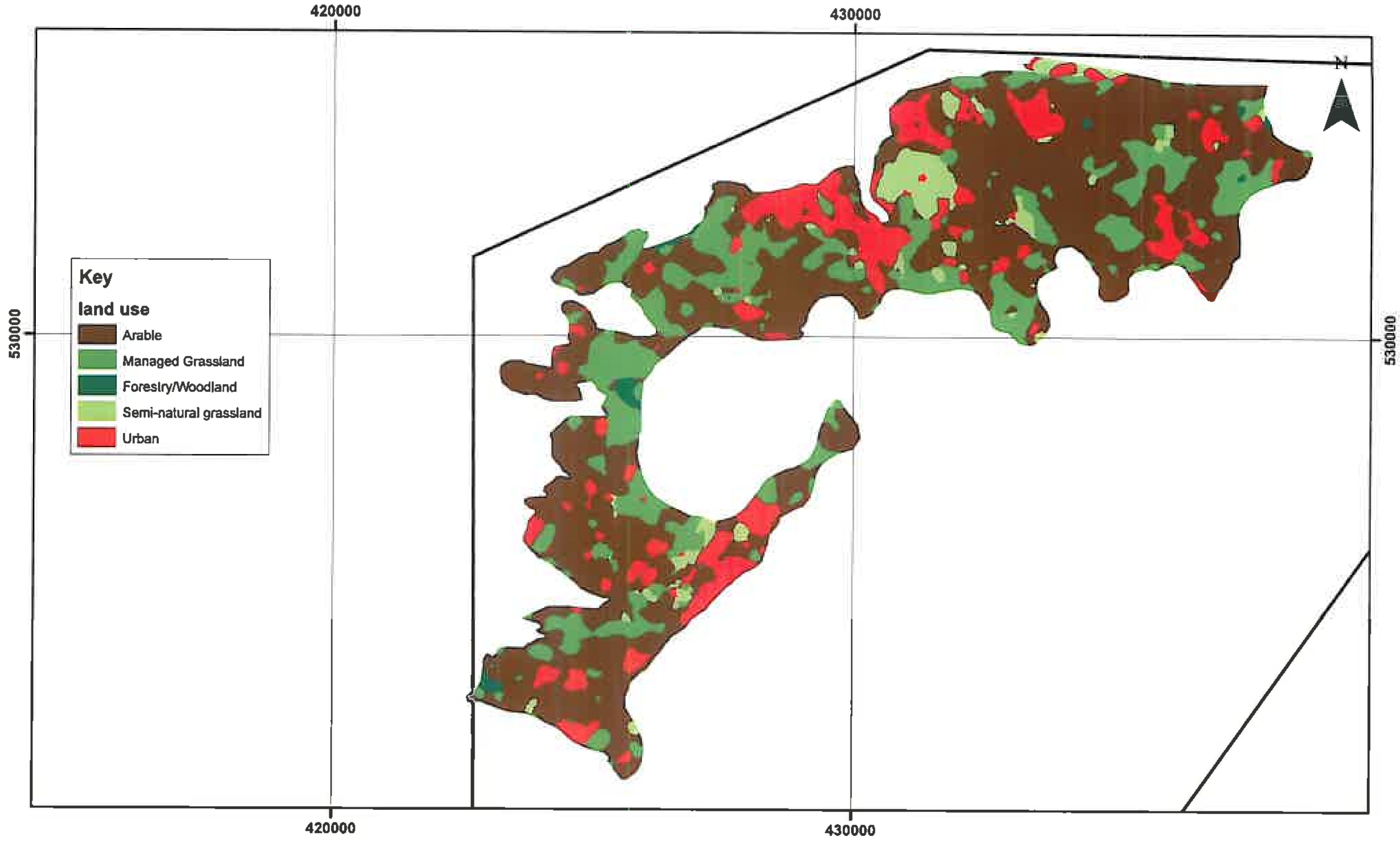

Figure 2.5
Land use in area considered for direct recharge

Date May 2007	Drawn HRS
Scale 1:100,000	Checked MJS
Original A4	Revision 1
File Reference 8886 NW Magnesian Limestone model/Reports/ Prelim Recharge estimates/Figure 2.5.mxd	

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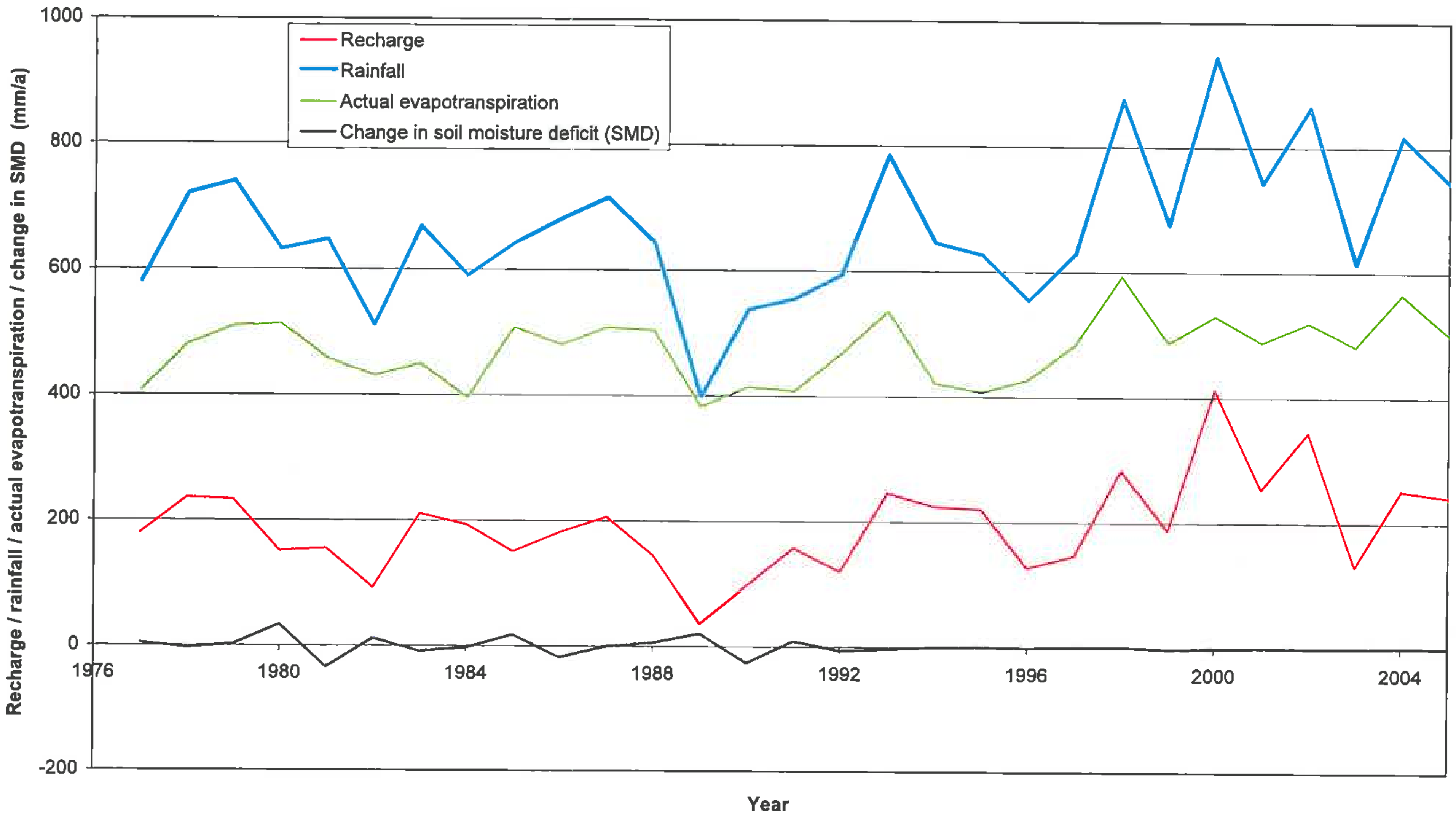

Figure 2.6

Variation in annual rainfall, recharge, actual evapotranspiration and soil moisture deficit

NB Positive change in SMD is releasing water from the soil,
negative change in SMD is an increase in storage of moisture in the soil.

Date: May 2007	Drawn: HRS
Scale: dns	Checked: MJS
Original: A4	Revision: 1
File Reference: O:/6886/calculations/recharge/WFD V2.59 MagLst results.xls	

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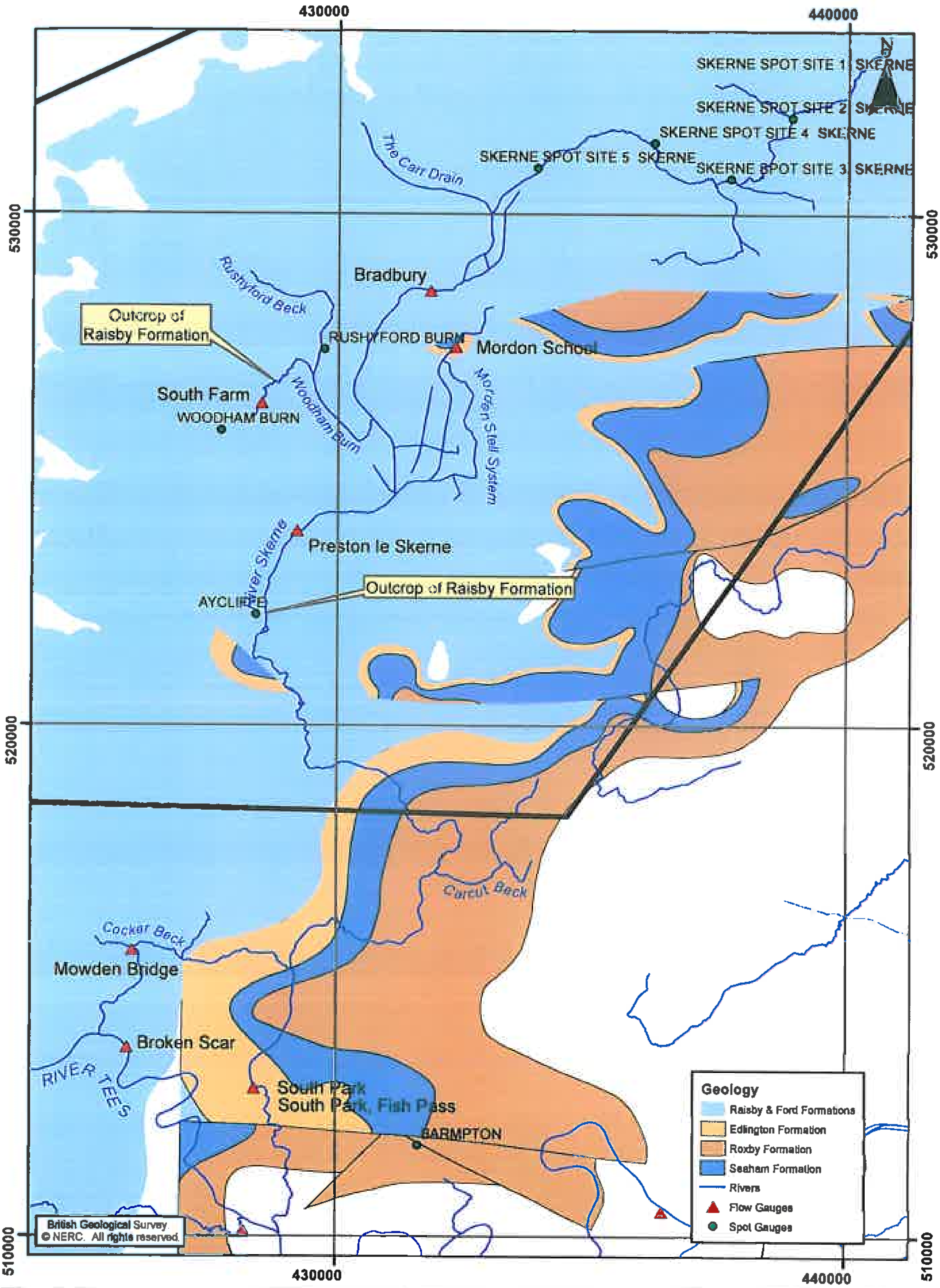

Figure 3.1
Flow gauges on the River Skerne

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Original A4	Revision 1
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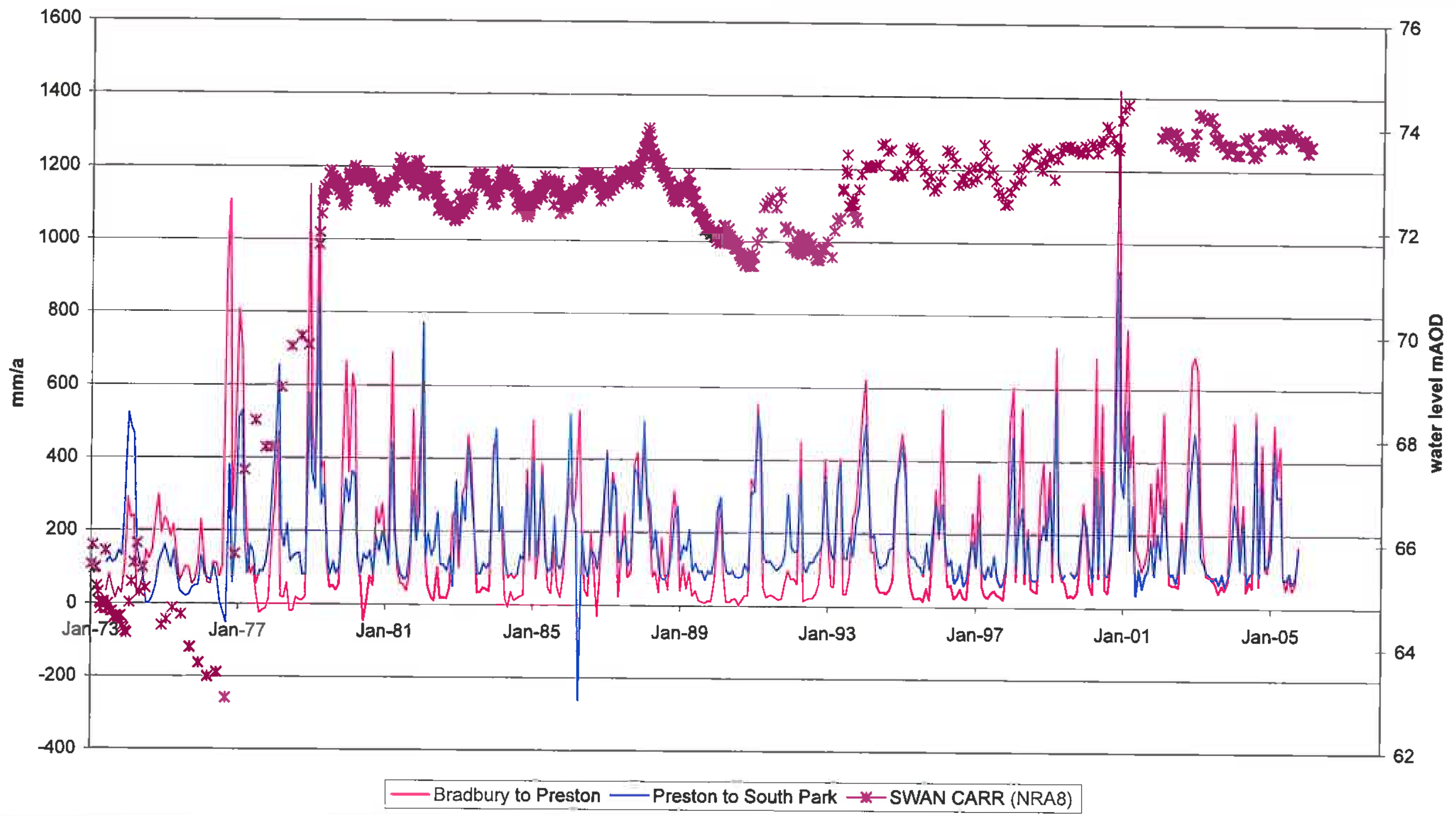

Figure 3.2
Comparison of flow gain

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Scale	dns	Checked	MJS
Original	A4	Revision	1
File Reference	O:\6886\reports\Prelim recharge estimates\Fig3.2		

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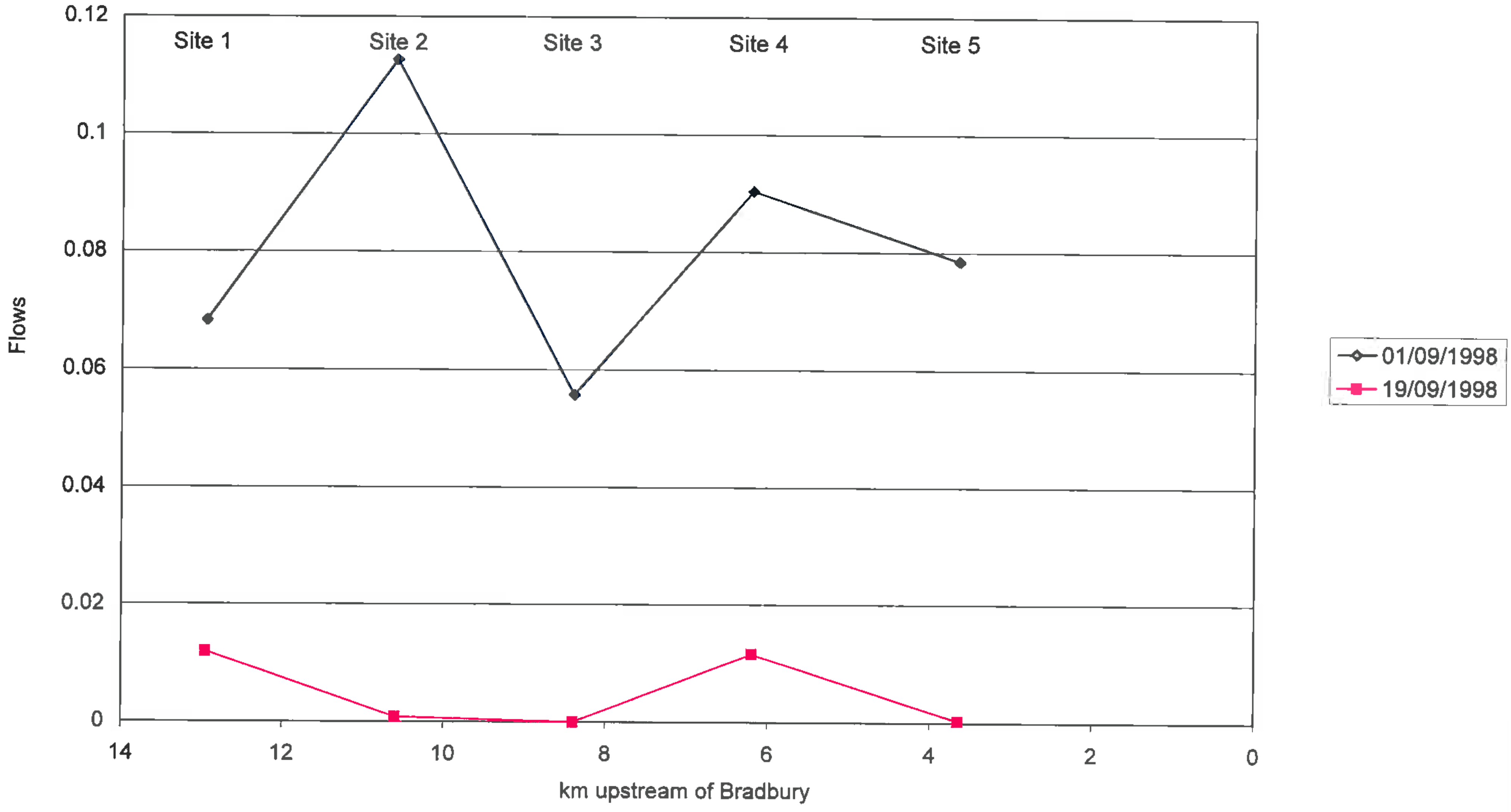

Figure 3.3
Spot flow gauging data

Date May 2007	Drawn ACY
Scale dns	Checked MJS
Original A4	Revision 1
File Reference O:\6886\reports\Prelim recharge estimates\Fig3.3	

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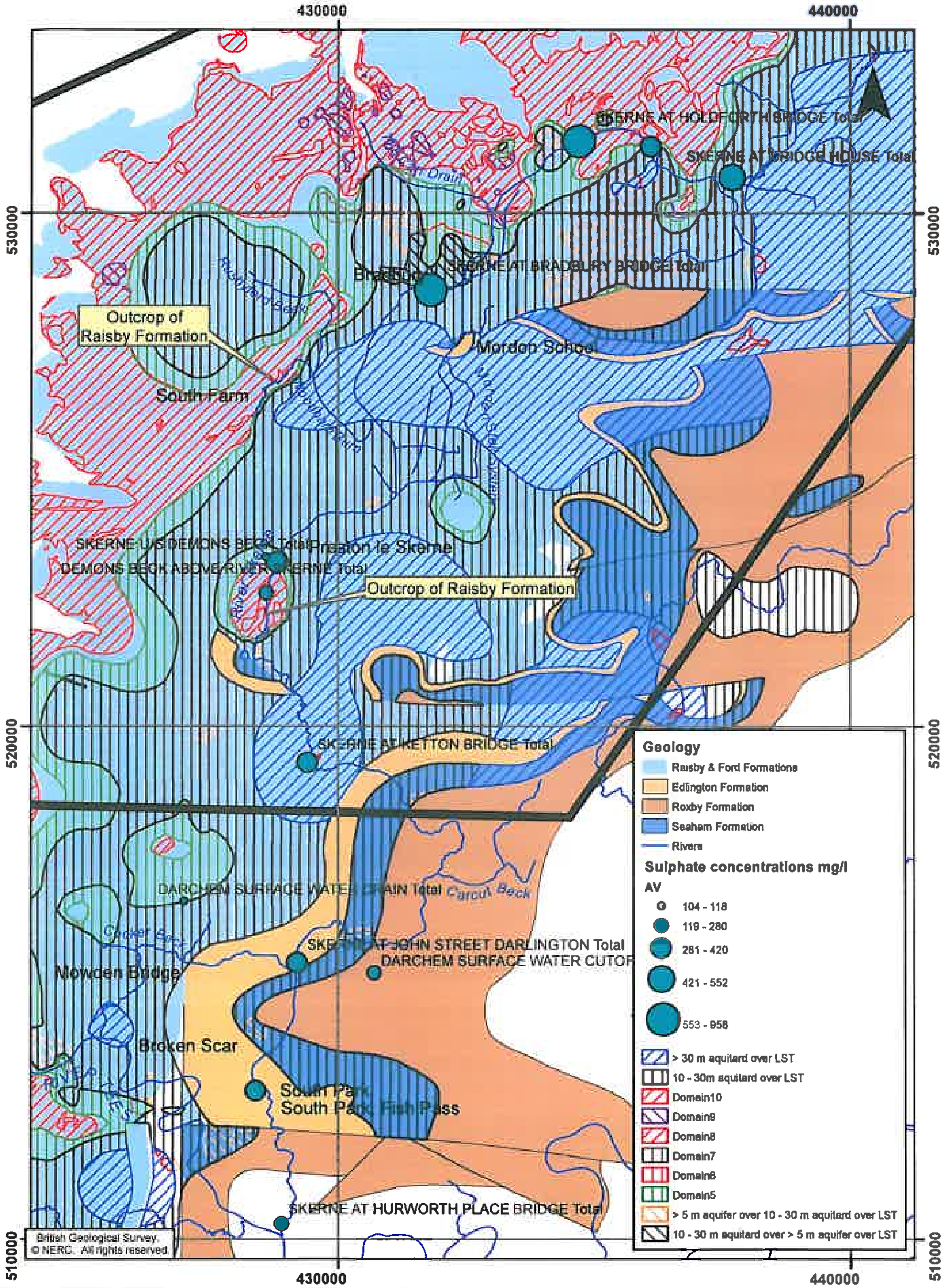

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Figure 3.4
Sulphate monitoring locations

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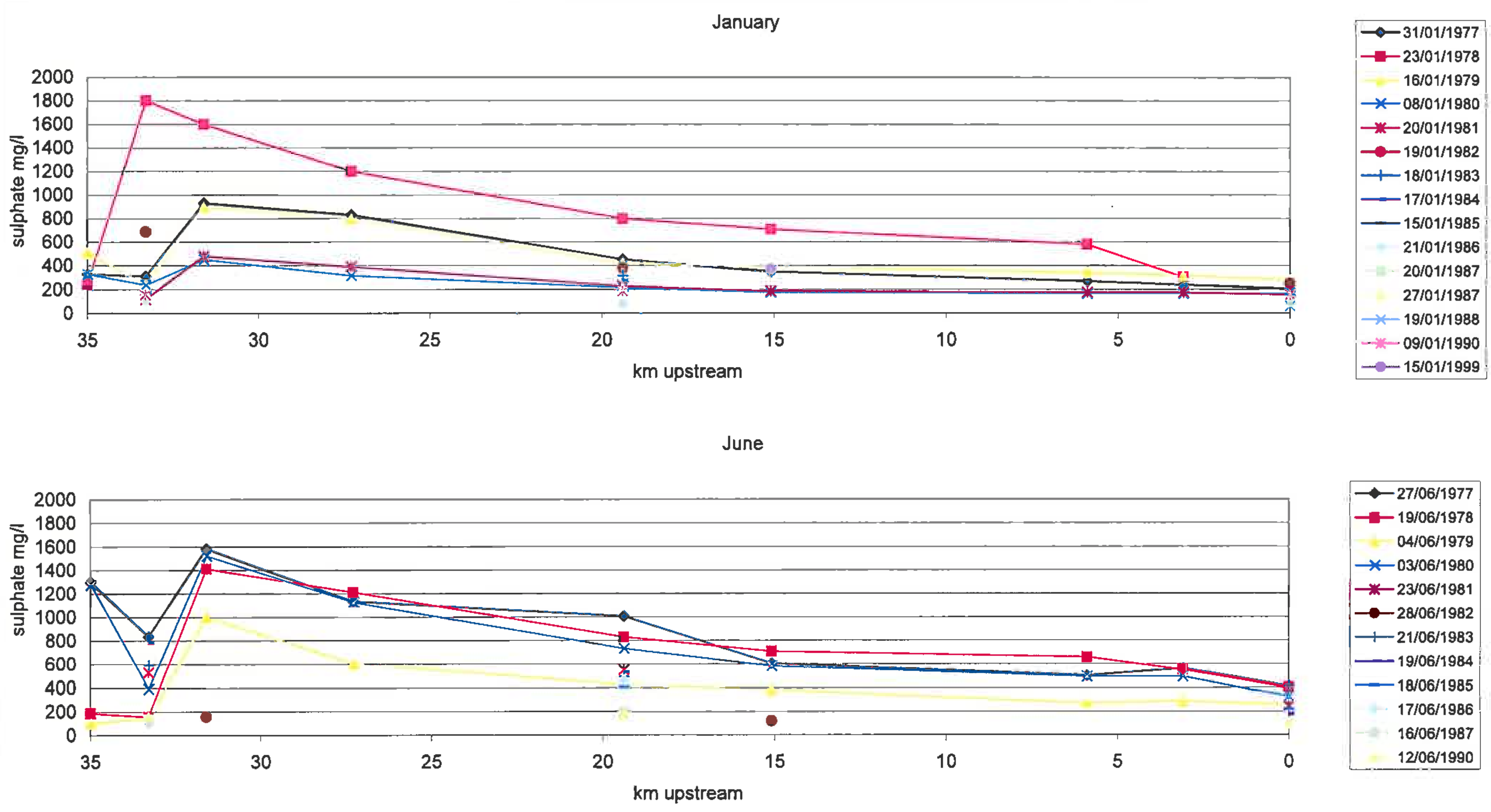

Figure 3.5
Sulphate concentrations

Date May 2007	Drawn ACY
Scale dns	Checked MJS
Original A4	Revision 1
File Reference O:\6886\reports\Prelim recharge estimates\Fig3.5	

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