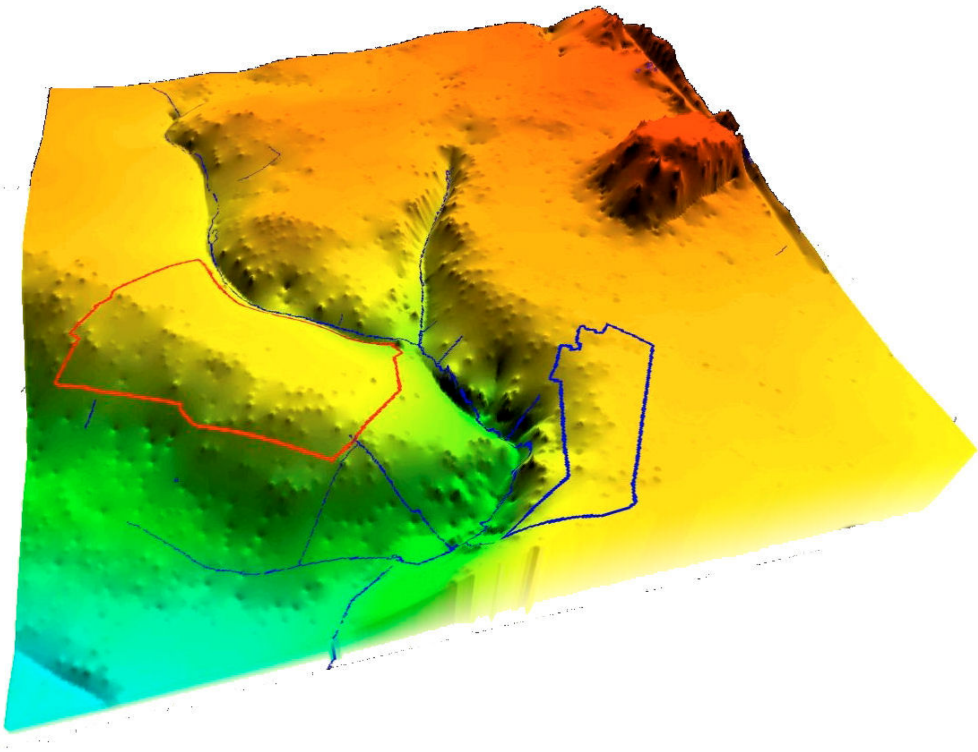
Investigation of the possible hydrological effects on the Lye Valley Sites of Special Scientific Interest and the riparian zones of the Lye and Boundary Brooks as a result of development on Southfield Golf Course



A pre-EIA assessment

October 2007

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About the Author

Curt Lamberth has been an environmental consultant since setting up Oxford Environmental Solutions Ltd in 2000. He specialises in the ecotoxicology of natural habitats and reducing the effect of man on the environment. He has resolved a wide variety of issues ranging from the after-effects of a major airline crash on ancient woodland for the National Trust to the commissioning of private water supplies.

The business was closed and merged with Haycock Associates Ltd in 2003 where Curt worked as a senior consultant in the areas of restoration, creation and management of freshwater and terrestrial habitats, contaminated land remediation, private water supplies and catchment management, wastewater treatment systems, and atmospheric pollution. The projects were varied and required a mix of skills including geology, hydrology, chemistry, diplomacy and the spatial manipulation of data as well as the construction of electronic datalogging equipment. Haycock Associates had a strong link with clients such as the National Trust, the Royal Society for the Protection of Birds, English Heritage, and the Corporation of London.

Curt left Haycock Associates in 2004 to follow a more varied career and now provides support and guidance to local non-profit organisations, councils and individuals about water supplies, pollution and water resource protection including a number of small-scale studies for Pond Conservation.

SUMMARY

Oxford City Council recently consulted on 'Oxford 2026 Core Strategy Preferred Options Document', which contained options for possible housing development of 380 dwellings on Southfield Golf course East and 1,260 dwellings on Southfield Golf Course West.

The proposed development areas are located in the proximity of the riparian corridors of the Boundary and Lye Brooks, which contain very environmentally sensitive sites including two SSSIs and two Sites of Local Importance for Nature Conservation which adjoin the golf course.

The SSSIs are noted for their rare valley fen habitats that are dependent on special local hydrological conditions.

The scope of this study concentrated on the *off-site* hydro-ecological impacts of the proposed developments on the wider area and not on the areas of development themselves in terms of available data, evaluation, prediction and mitigation. This study has not considered monitoring.

This study has concluded that the size of the groundwater catchment areas of the Lye Valley and Boundary Brooks have been reduced considerably by the surrounding urban developments. The groundwater catchment for Lye Valley North SSSI is considerably larger than that of the South SSSI. Therefore, it is very important that the size of the groundwater catchment zone for the South fen is not reduced especially in the light of predicted UK climate changes over the next 30 to 50 years.

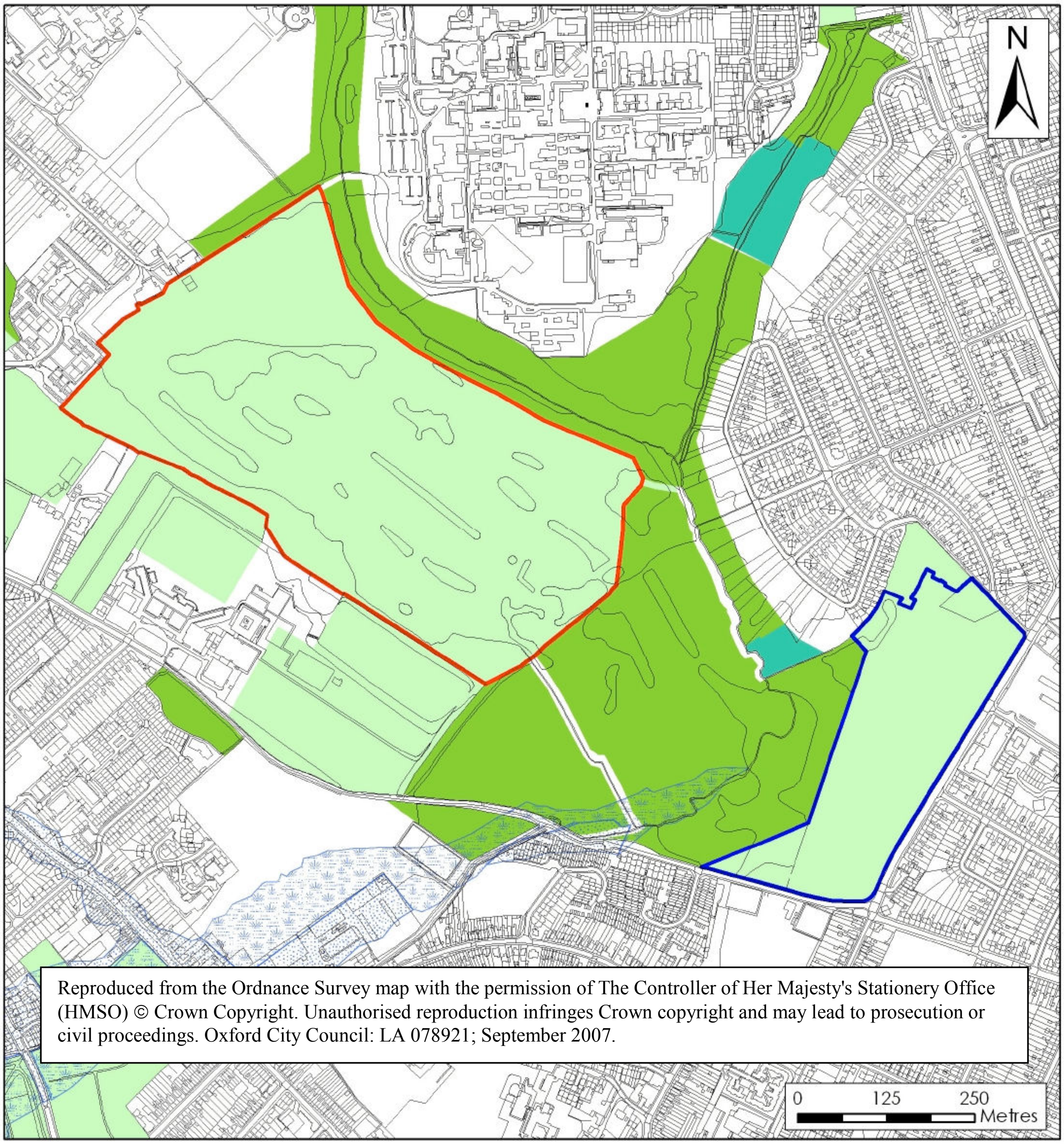
Likewise, the nature of the surface water catchments have been altered by urban development and have increased rates of erosion within both the Lye and Boundary Brooks causing damage to the SSSI and to the SLINC areas.

This study has shown that development on the northeastern part of Southfield Golf Course West would have a moderate effect on the hydrology of the riparian corridor of Boundary Brook SLINC in terms of surface water runoff and groundwater recharge.

This study has shown that ***any*** development on Southfield Golf Course East will affect the hydrology of Lye Valley South SSSI and SLINC in both terms of groundwater quality and quantity even if SUDS measures were incorporated into the design. Such an effect may not be noticeable in the short term but will be evident over a period of 10 years or more.

The idea of protected groundwater and surface water protection zones for the SSSI and SLINC areas have been discussed. Possible mitigation measures and wetland restoration schemes have been proposed which would reduce the stream erosion rates, increase wetland areas, improve the stability of the fen, and decrease downstream flooding.

Figure 1 Map showing the study area with possible housing development locations outlined in red (Southfield Golf Course West) and blue (Southfield Golf Course East).



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INTRODUCTION AND SCOPE

Oxford City Council recently consulted on 'Oxford 2026 Core Strategy Preferred Options Document', which contained options for possible housing development on Southfield Golf course East and West. The estimated number of dwellings that these two sites could accommodate are:

- Southfield Golf Course East: 380
- Southfield Golf Course west: 1,260

The proposed development areas are located in the proximity of the riparian corridors of the Boundary and Lye Brooks, which contain very environmentally sensitive sites including two Sites of Special Scientific Interest (SSSI) and two Sites of Local Importance for Nature Conservation (SLINC) which adjoin the golf course.

The SSSIs are noted for their rare valley fen habitats that are dependent on special local hydrological conditions.

- This study will concentrate on the *off-site* ecological impacts of the proposed developments on the wider area and not on the areas of development themselves.
- This study will outline the possible ecological impacts on the SSSI areas as a result of changes in hydrology caused by changes in land use, more specifically development on sites Southfield Golf Course East and West. This study will consider a time frame of 50 to 80 years where possible to take into account predictions for climate change.
- This study will identify possible methods to mitigate adverse impacts.
- This study will seek to identify areas of concern such as:
    - vandalism
    - recreation pressures
    - loss of habitat in the vicinity of the Lye Valley fens and effect on species
    - impacts of the development during pre and post construction
    - size of any buffer zones
    - comments on habitat ‘creation’ opportunities
    - comments on possible ‘enhancements’ to the biodiversity of Lye Valley
    - impacts on flooding
    - impacts on sediment load
- This study is not designed to be a full EIA but will be written as a part basis for an EIA.
- The investigation of ecological impacts not related to hydrological changes will be outlined by Dr Judy Webb in a separate document.

Study Inputs

- Consultation with key stakeholders including Natural England, the Environment Agency and the County Ecologist. Thames Water and the Highways Agency will be consulted if time permits.
- On-site visit(s) and surrounding area to identify hydrological features and obtain a general water quality indication of source using calibrated electrical conductivity probe, and where necessary, simple in-house tests for water hardness (Ca content), phosphate and nitrate. The tests will not be NAMAS accredited[1] and should be used for reference only. The significance of each feature to be identified.
- Surface water inputs to the Lye Valley and riparian corridor.
- Wastewater inputs to the Lye Valley including anthropological inputs.
- Nutrient loading on the Lye Valley in relation to the new developments.
- Geological data from boreholes and British Geological Survey studies to identify aquifer path routes and possible water flow directions.
- Historic data on localised water level if available.
- Reference to historic ecological data including species lists where known and if relevant from sources such as TVERC and Oxford University Museum.
- Use of CAD and DTM OS maps to provide approximate elevations, illustrate effects and record data.

Outline of methodology

- Gather geological, topological and hydrological data to map water flows and plot on CAD map. Assess impact of developments.
- On-site walkabout to identify local hydrological features, check water quality and locate changes of vegetation with respect to habitats. Other key features to be identified at this point.
- Investigation of existing drainage using Oxford County Council data (CD from Thames Water). Map on CAD map and identify influences and routes of wastewater drainage from development sites.
- Meetings with key organisations. Link to ecologists doing survey to identify historic hydrological links with ecology if possible.
- Identification of possible impacts at this stage.

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[1] NAMAS, tests performed under a 'scope of accreditation' similar to the the ISO quality system and run by the United Kingdon Accreditation Servis (UKAS).

- Identification of possible mitigation methods including buffer zones. Identify any novel or long-term mitigation or planning issues on a 50-year plus basis.

- Identify any further investigations that would be required as part of the EIA process.

- Compile a draft report of findings with illustrated CAD maps. One draft revision and one final report included.

- Meetings with OCC as required.

Investigation Methods

The hydrology of the area to be investigated using the following methods:

- Geological maps of the area, both drift and solid.

- The mapping of spring and seepage locations using GPS and OS maps.

- Analysis of seepage waters for pH, conductivity, hardness, ammonium and nitrate concentration where appropriate.

- Mapping of the known drainage routes in the area.

Area Description

The study area has been divided up into areas in order to be able to discuss the possible effects. The areas are indicated in Figure 1.

1. Southfield Golf Course West

2. Southfield Golf Course East

3. Lye Valley North SSSI, the Site of Special Scientific Interest (SSSI) formerly known as Bullingdon Bog, an area of calcareous valley fenland. Perimeter: 657 m, Area: 18060m^2.

4. Lye Valley South SSSI, the SSSI includes private gardens. Perimeter: 332 m, Area: 5450m^2.

5. SLINC areas referenced in green.

HYDROLOGICAL RISK ASSESSMENT

Methodology

A variety of data inputs were used to investigate the hydrology of the study area by creating a water level surface that was then used to determine groundwater flow directions.

Data

The following data were used in the study;

- Topology: Digital Terrain Model, format ASCII XYZ, resolution 5 m, size 2 x 2 km. Projection British National Grid (OSGB36), vertical datum OSD, Newlyn, OSGM91. Flown at 30,000 feet, accuracy +/- 1.5 m RMSE. At 20, 000 feet, +/- 1.0 m. Horizontal accuracy +/- 2.5 m on slopes less than 20 degrees.

- OS 500 x 500m tiles for the area provided by Oxford City Council.

- Hydrological features with a resting or permanent water level such as springs, seeps, streams, ponds, and fen areas.

- Borehole records obtained from the British Geological Society.

- Geological Solid and Drift for the area. However, most of the geology has been interpreted from the borehole data which on this more local scale is more accurate.

- Water quality using simple analysis. Samples were analysed for pH (calibrated using pH 7.01 standard), electrical conductivity (EC) calibrated at 1406uS cm^{-1}, nitrate as mg/l of NO_3 using an aquarium test kit, assume 5 mg/l resolution; ammonium as mg/l NH_4 using a standard aquarium test kit, resolution 0.25 to 0.5 mg/l; calcium hardness (concentration of Ca and Mg) as mg/l and general hardness as CO_3^{2-} and HCO_3^-, mg/l, resolution for both 20 mg/l, titrimetric aquarium test kit. Note none of the data are NAMAS accredited and should be used for reference only.

Assumptions

Several assumptions were made, as the numbers of borehole records within the area with accurate elevation data were limited. These assumed data points are indicated as items numbered 34 to 38 in Table 4 and are based on the following:

1. Shallow groundwater will tend to follow the topology of the surface.

2. Groundwater flows will be influenced by geological strata direction. Fissured flow is not expected in this geology.

3. Assumed water depths have been made where the geology is similar to known local boreholes and at a similar surface elevation and strata depth.

Calculations

The model output the following data;

1. A groundwater level surface and contours generated from that point data.
2. A groundwater vector analysis showing flow directions.
3. A stream corridor profile generated using the DEM file.

It should be noted that there is a degree of uncertainty with all modelled data. Figures have omitted computer generated fine detail in order to avoid over interpretation.

Geology

The study area consists of solid Upper Jurassic geology mainly of the Corallian Formation (146 to 205 Ma) and later drift deposits such as head (upper river deposition) and alluvium (BGS, 1994; BGS, 1979).

The simplified geology is shown in Figure 2.

Figure 2 The simplified geology of the study area. Oxford Clay and Temple Cowley Member to the West, the main Beckley Sand aquifer in the central area in yellow, rising to Wheatley Limestone (red) and Ampthill Clays (blue) and Whitchurch Sand Formation (unmarked).

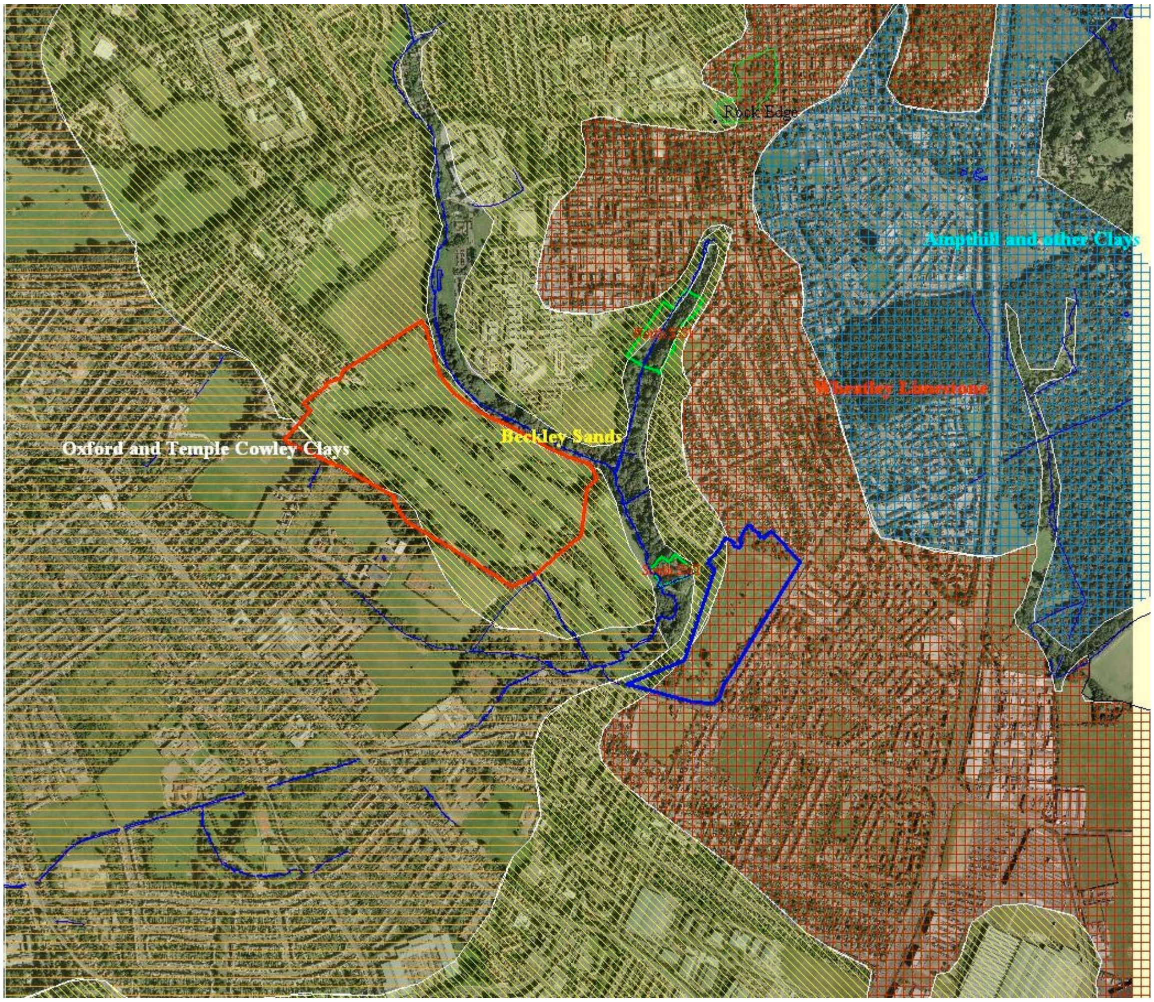
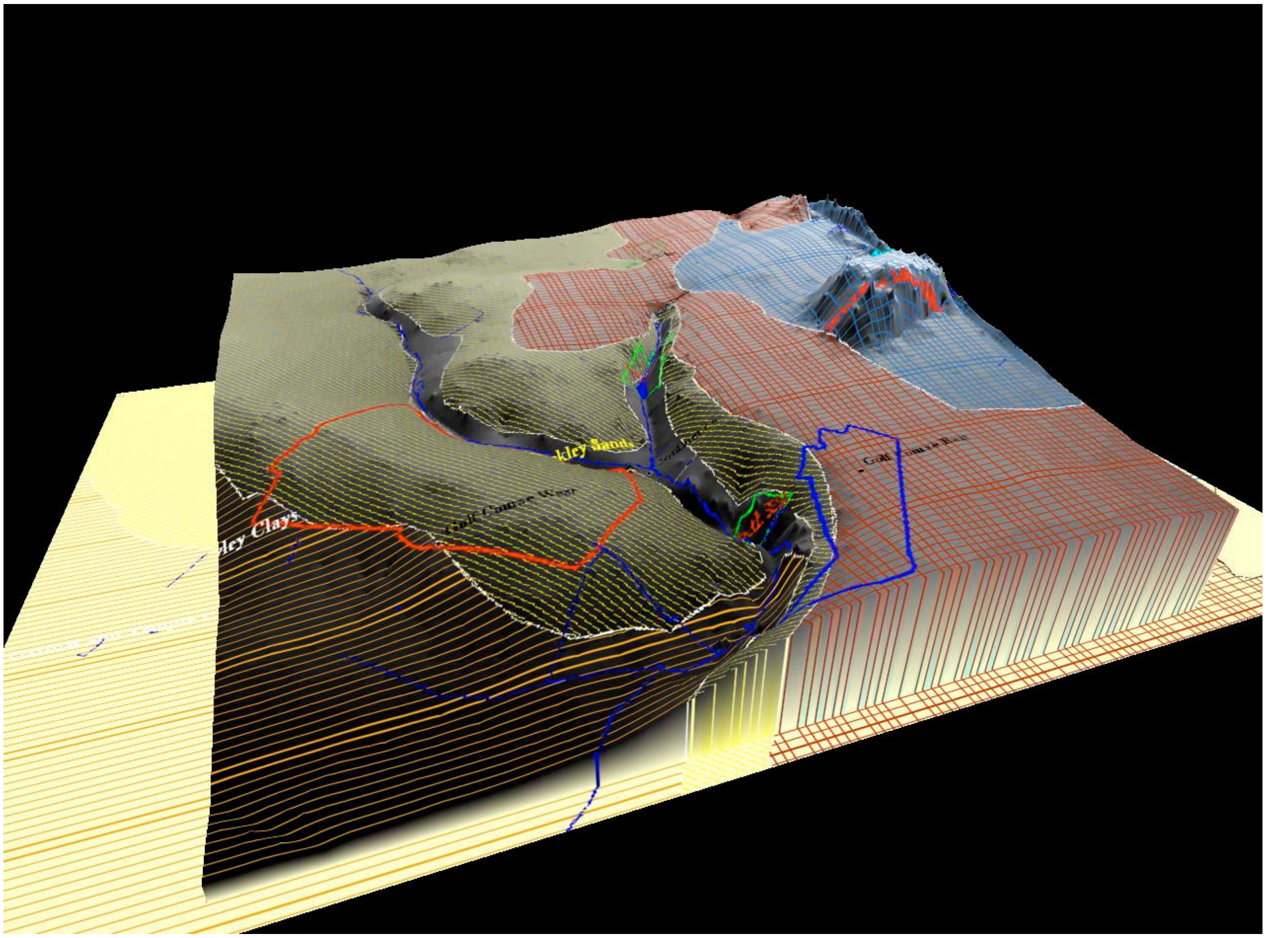


Figure 2a Simplified geology of the study area in 3D. Note the ground surface has been shaded by gradient.



The geology can be simplified into three layers:

1. The lower 'clays' of the Lower Corallian Temple Cowley Member and the start of the Upper Oxford Clay (ca. 63 mOD). The upper transition zone to the more permeable beds of the Corallian gives rise to a series of springs at approximately 75 mOD. This spring line is responsible for a number of minor springs around Headington Hill including Boundary Brook and Lye Valley.

2. The permeable Corallian beds making up a series of minor and perched aquifers including Beckley Sands (BeS) and Wheatley Limestone.

3. An impermeable layer of Ampthill Clay.

The strata are approximately flat but have a slight NW to SE gradient. Table 1 shows the geological periods associated with the study area.

Table 1 Geological Periods Associated with the study area (Horton 1994). Not all are present within the study area.

Divisions	Abbreviation	Member
Ampthill and Kimmeridge Clays	AmC, KC	
Corallian Division	WL	Wheatley Limestone Member (including Coral Rag at Headington)
	Lit	Littlemore Member (marl and limestone)
	Oa	Oakley Member (marl and limestone)
	BeS	Beckley Sand Member (sand and calcareous sandstone, 0 to 25 m)
	AnS	*Arngrove Spiculite Member (not present, 0-5 m)*
	TC	Temple Cowley Member (fine grained sandstone, sands and siltstones, 0-12 m)
West Walton Formation	WW	West Walton. Dark grey silty mudstone (transition between the Corallian and Oxford Clay, 0-45 m)
Upper Oxford Clay	UOxC	Weymouth Member (pale gray calcareous mudstone)

Other data were used to verify the geology of the study area because investigation of the hydrology on such a local scale required very precise elevation data. Data from BGS archives on boreholes and data obtained locally were used. Historically, permission was given by Oxford City Council to investigate the nature of the geological transition at South Park Spring. A 70mm hand auger was used to obtain the geological profile in Table 2 at a location approximately 2 m above the spring issue. The Beckley Sands showed considerable saturation (mostly light gray) in the upper layers giving rise to the spring itself. The layers of sand show no recent disturbance from ground level to 1.70 m. Deposits of lignin obviously from reed and wood fragments were seen at 1.70 to 1.97 m, thought to be the historic base of a channel or stream bed now buried and filled in. It is possible that this feature is several thousand years old. Deposits of calcium sulphate were seen below the lignic layer. Finally, the hard clays of the upper layer of the Temple Cowley Member were encountered at about 2 m below ground level. This is the aquitard for the spring confirming the transition between the Beckley Sands and sandy-clays of the Temple Cowley Member.

Table 2 Auger data for South Park Spring NGR 0453200 0206172, 77 mOD. Date 04/08/2002.

Description	Depth, m	Comments
Black, dark brown loam-sand	0-0.22	Saturated with water.
Lighter brown loam	0.22-0.32	
Dark orange clay-sand	0.32-0.82	
Light grey coarse washed sands	0.82-1.70	
Lignin (reed, woody) and darker grey washed sands	1.70-1.97	Base of historic streambed, perhaps filled in by landslip or human activity – very old. Small crystals of calcium sulphate at base.
Sandy clay, grey.	1.97-2.15 (end of borehole)	Hard base – aquitard, start of the Temple Cowley Member at about 75 mOD.

Groundwater Flow, Quality and Quantity

It was necessary within this study to separate the effects on surface and groundwater of land use changes.

The riparian corridor which include the SSSIs and SLINCs depend on groundwater and to determine the effect of land use changes on the hydrology it was necessary to work out the direction of groundwater flow.

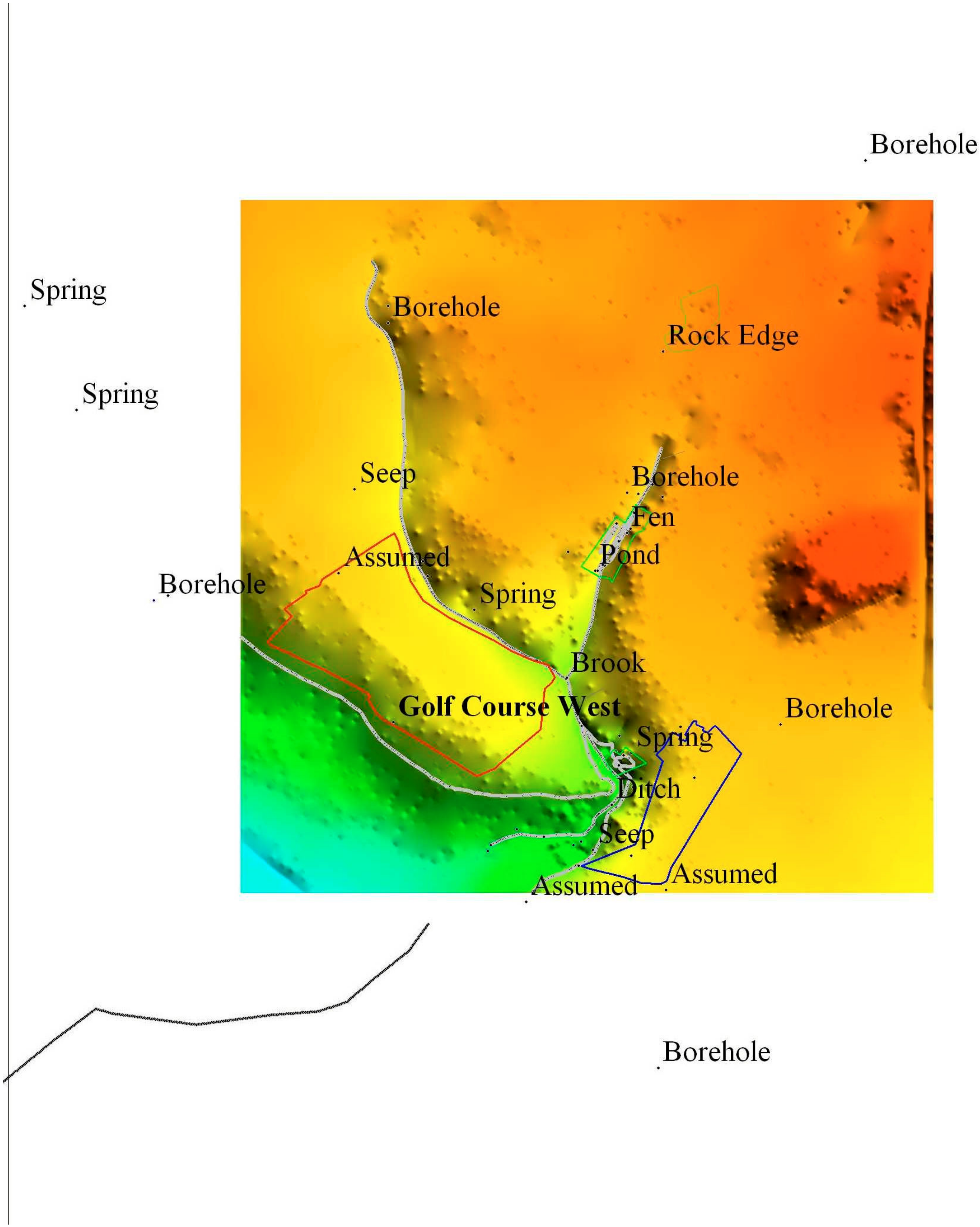
A groundwater flow computer generated surface was developed using multiple sources of data including 12 hours on site to map springs, flushes, ditches and fen areas. Simple chemical tests were performed to ensure that the origin of the water could be verified as natural or anthropogenic.

Figure 3a shows the location of water level data used to develop the model.

Figure 3b shows the groundwater contours derived from the computer model based on 18 springs, 6 seeps, 2 streams, 11 boreholes and 5 assumed water levels. To make it easier to interpret a vector line diagram was developed base on these contours.

Figure 4 shows the vector lines derived from the contours for the study area.

Figure 3a Water level features used to create the groundwater surface model. Note that the Lye and Broundary Brooks and Temple Cowley transition to the Beckley Sands are included in the dataset.



<u>Figure 3b</u> Groundwater contours derived from a computer model based on the known elevations of water levels derived from groundwater and surface water features. Interpretation of fine detail should be avoided as contours are only approximate especially where the groundwater surface is flat.

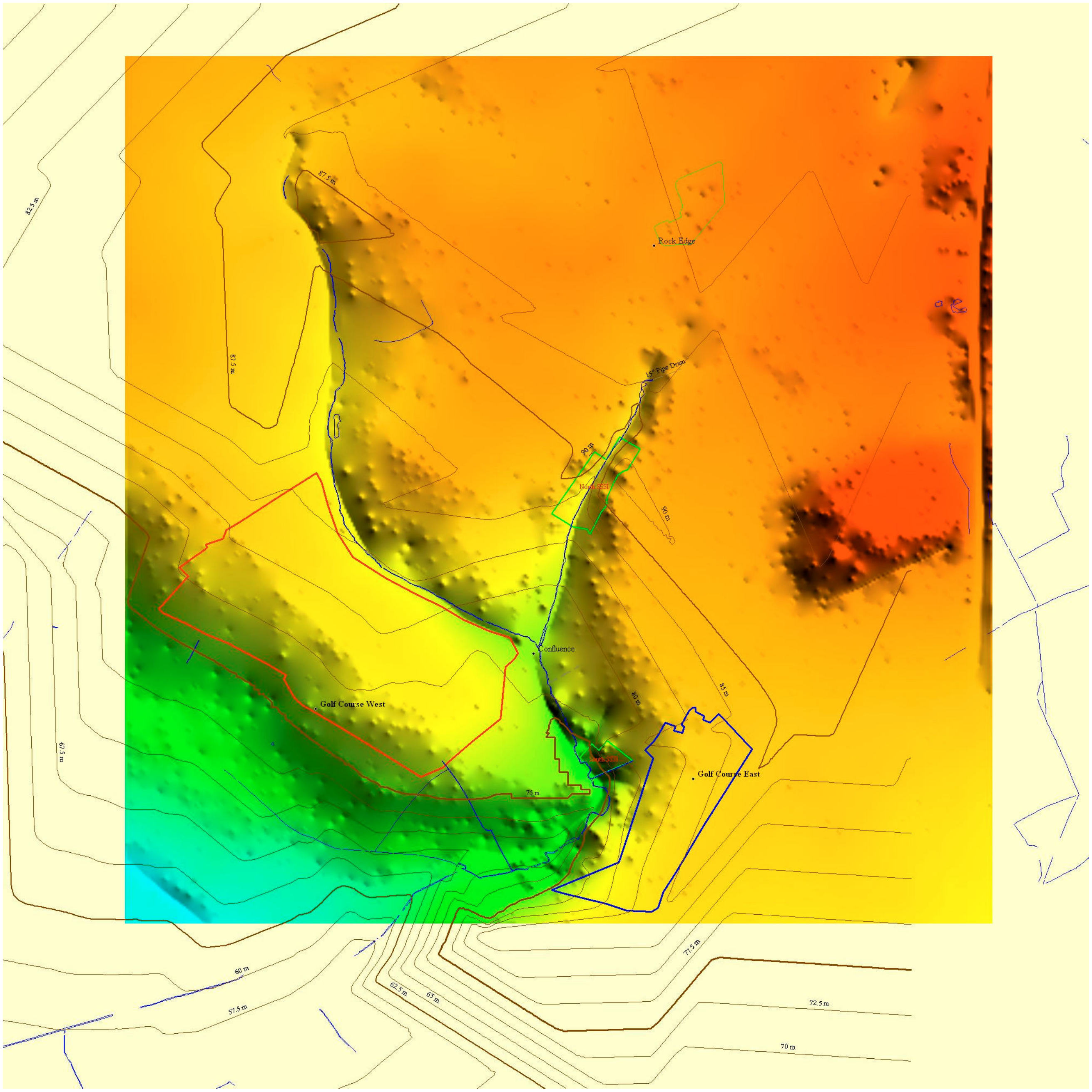
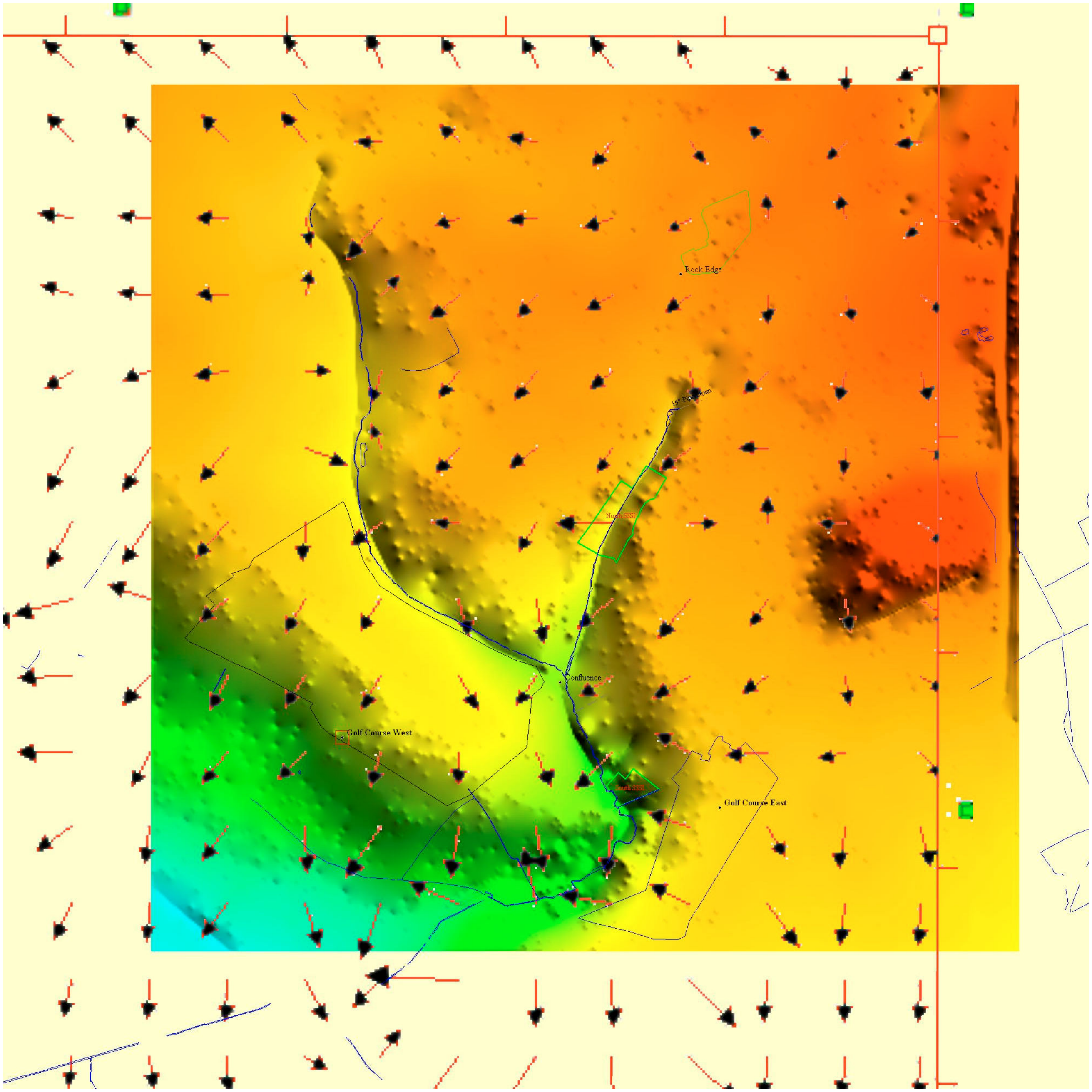


Figure 4 Vector groundwater flow lines derived from the contour map. Assuming flow perpendicular to the contours shown in Figure 3 has derived vector lines of flow direction shown here. Fine detail of flow has been lost by this conversion to avoid over interpretation.



Groundwater flow direction

In general terms the groundwater flows within the Corallian Division follow the dip in strata from NW to SW (BGS, 1994; C. Lamberth unpublished data based on borehole logs). However, on a local level the topology starts to influence the direction of groundwater movement. This means that the Boundary and Lye Brooks receive groundwater generally from a NE direction. There are a number of consequences of this as follows:

- Springs in the Lye Valley occur on both sides and of a similar flow, generally following an altitude of 83 to 86 mOD.

- Springs in the Boundary Brook valley originate from the NE side, at around the 84 mOD contour. There were no significant springs discovered on the Southfield Golf Course West side in agreement with the observation that groundwater supply is from the NE.

- The transition between the Beckley Sands and Temple Cowley clay is at 75 to 80 mOD. Springs have to be at or above this level. The Boundary Brook is almost entirely within the Corallian Division. Only at the confluence with Lye Brook does the streambed consist of clay material similar to Temple Cowley. It should be noted that the transition between Temple Cowley clay and Beckley Sands might not be consistent and obvious.

- The Warneford Meadow area shows a line of minor springs along the Boundary Brook, but groundwater flows may well restrict the spring influence on the brook. However, surface water catchment is most definitely towards the Boundary Brook. Surface water runoff will be discussed later.

It was difficult to be certain of the groundwater flow under Southfield Golf Course West due to limited data. It appears that there could be some infiltration from Boundary Brook into the lower layers of the Beckley Sands. Springs are obvious on the SW side of the golf course. However, due to the lack of a catchment these springs are small and difficult to locate. Groundwater from Southfield Golf Course East will join eventually the Lye Brook in the area of Cowley Marshes. Southfield Golf Course does not have a borehole so no water levels were available (Personal Comm., 2007a).

The influence of land use changes on Southfield Golf Course West and East will be discussed below.

Note that the effect of land use changes on the surface run-off may be more dramatic and bypass groundwater flows. Surface water will be considered separately.

Groundwater Infiltration Catchment

A catchment zone for Boundary and Lye Brooks can be estimated from the groundwater flow direction.

Boundary Brook has a groundwater catchment area of 800,000 m^2.

Lye Valley, from the head to the point when it leaves the golf course, has a catchment area of 900,000 m^2.

The two catchment zones should be considered in terms of protection zones where land use is carefully controlled. These catchment zones will be discussed later on with specific reference to developments.

Figure 5 shows the groundwater catchment boundary and the implications of this area will be discussed later.

Figure 5 Groundwater catchment boundary marked in yellow for Boundary Brook to the confluence with the Lye Brook and the Lye Brook from source to the southern edge of the Golf Course.

Groundwater Quality

There have been numerous studies on the water chemistry of fens and groundwater quality is essential for the formation of fenland. The Lye and Boundary Brooks are fed in part from a series of springs originating from the calcareous sands and sandstones of the Beckley Sand geology.

Fenland depends on a constant flow of 'base rich' groundwaters with high concentrations of 50 to 300 mg/l calcium balanced by hydrogencarbonate (or bicarbonate), dissolved carbon dioxide and sulphate (Hájek, 2002). Magnesium and calcium have similar chemistries and magnesium is often included in the calcium analysis! The concentration of calcium depends on the partial pressure of carbon dioxide and the sulphate concentration in the calcareous geology of the aquifer.

A set of water quality parameters have been proposed by Fojt, 1993, for very low to very high base richness. In general, following the same classification, all the water samples were in the high to very high category.

Groundwater quality is easy to determine but does have seasonal variations. As part of another study the water quality of a series of springs in the Marston area were monitored. The springs are listed in Table 3 and originate from the same geology. The springs as Dunstan Park and Headington Hill Park show tufa deposition.

The deposition of tufa is a very important aspect of the water chemistry of Headington springs including the Lye Valley. Tufa, a term very loosely used, refers to the deposition of calcium carbonate rock from springs or streams by loss of dissolved carbon dioxide. The correct mineralogical name for this material is ***travertine*** and can be seen as white deposits, sometimes very thick, of hard but brittle calcium carbonate, coating streambed rocks and wet wood.

Photograph 1 Classic tufa deposition at a Lye Valley spring.

Other tufa depositing springs have been observed elsewhere such as the Everlasting Spring at the Northmoor Trust reserve. Everlasting Spring, situated within woodland, deposits tufa and has been studied in detail to supplement the reserve management plan (Lamberth, 2003).

Table 3 Springs monitored for water quality as part of another study but originating from the same geology. (Lamberth, 2001)

Name of spring	Altitude	Aquifer	Aquitard
Camels Head Car Park, JR Hospital.	85	Beckley Sand Member	Temple Cowley Member
Dunstan Park	85	Beckley Sand Member	Temple Cowley Member
Above Milham Ford	85	Beckley Sand Member	Temple Cowley Member
Morrell Hall	80	Beckley Sand Member	Temple Cowley Member
Headington Hill Park	80	Beckley Sand Member	Temple Cowley Member
South Parks	80	Beckley Sand Member	Temple Cowley Member

Tufa deposition is a good indicator of the activity of the calcite (calcium carbonate) deposition process that affects the water quality of the Lye Valley fens. Tufa deposition depends on:

Infiltration of carbon dioxide rich surface water and the presence of carbon dioxide rich groundwater within the aquifer. Surface water plays an important part in tufa formation. Carbon dioxide is formed as a natural process in active soils where the decay of humic material and the effect of plant roots and biological activity generate CO_2 from respiration. This CO_2 saturates rainwater percolating through the soil. In turn this CO_2 rich water dissolved more calcium carbonate from the aquifer. Therefore, it is vital that catchments in the vicinity of a tufa spring have an active soil horizon. Active soil horizons could be grassland, woodland or even an agricultural field but not hardstanding or a conventional SUDS system. Any man made system must have an indefinite lifetime.

The dissolution of calcium carbonate from aquifer rock by the effect of dissolved carbon dioxide. This process forms calcium bicarbonate, which is soluble in water unlike calcium carbonate. There may be other compounds present in the groundwater such as calcium sulphate (Plaster of Paris, gypsum etc) which is also readily soluble in water and present in many clays. The common ion effect will mean that the presence of sulphate will enhance tufa deposition.

Groundwater that is saturated or super saturated with bicarbonate issues form a spring and the dissolved carbon dioxide is released slowly reversing the reaction and converting hydrogen carbonate back to carbonate. The carbonate then precipitates as calcium and magnesium carbonates and tufa is formed.

Tufa deposition is most intense when the temperature difference between water and air is greatest (Hájek, 2002). The higher the temperature, the less carbon dioxide can dissolve in the water and so the deposition reaction rate is increased.

The type of spring influences the rate of tufa deposition. Springs issuing from a wide flat aquifer having similar partial pressures of CO_2 show the most deposition of tufa. Where springs are isolated, less tufa is deposited (Hájek, 2002).

Some data were collected on groundwater quality for this study. Simple electrical conductivity (EC) measurements were taken using a temperature-compensated and calibrated hand held probe. Conductivity, in micro-Siemens (uS cm^{-1}), gives a general clue as to the number of dissolved ions in solution, and so in an indirect way, the base richness of a water source. This method can be used to distinguish the difference between rainwater, surface water runoff, groundwater and polluted or saline water. Confirmatory tests were done to check field observations such as nitrate (as NO_3) and ammonium (NH_4) and calcium and bicarbonate hardness (as mg/l). Note that ammonium is the correct term for the major ion species whilst ammonia is use incorrectly by the Environment Agency and others. Ammonia is a very poisonous choking gas not normally found above ***trace*** levels even in the most polluted areas.

Table 4 lists the chemical data.

Spring water quality

In general the water of Headington Hill springs is hard with approximately 300 to 400 mg/l hardness as $CaCO_3$ giving rise to a high conductivity of 600 to 850 uS. Sulphate is one of the major anions from $CaSO_4$ derived from Temple Cowley clay. The pH tends to be neutral or alkaline (equal to or greater than pH 7) with higher pH values observed where there is some biological activity. Nitrate concentrations are moderate with around 4 to 6 mg/l nitrate-N depending on the type of land use within each catchment. Phosphate concentrations are mostly low with soluble reactive phosphate ranging from 0.1 to 0.6 mg/l, again depending on the land use within the catchment (Lamberth, 2001).

In general the water quality of the Lye Valley and Boundary Brook springs was good.

Nitrate concentrations were typical for groundwater in this area (0 to 5 mg/l) and elevated by activities on the golf course such as irrigation and application of fertilizers and ground works (> 5 mg/l).

Ammonium concentrations were all low showing that there was no detectable wastewater infiltration to the groundwater.

Calcium and bicarbonate concentrations were high (>250 mg/l and >320 mg/l respectively) with EC ranges 700 to over 1000 uS cm^{-1}.

Tufa deposition was observed at a number of springs.

Fen water quality

The water quality of the fen was good. Base richness was high and there was evidence of a decrease in pH due to peat formation and a gradual removal of ions as water passed through the fen. This is entirely in line with expectation. Nitrate depletion was obvious showing the ability of fens to de-nitrify water.

Boundary Brook water quality

The water quality of Boundary Brook was considered poor. Elevated EC levels (1000uS plus rather than 820 uS) indicated the presence of an alternative water source such as wastewater. Analysis of water from the upper catchment of Boundary Brook to the confluence with the Lye Brook showed that ammonium concentrations were slightly elevated above the hospital site (0.25 mg/l) but were markedly increased below the hospital site (2 mg/l). Nitrate concentrations followed a similar pattern . The odour of wastewater was obvious along the entire stretch of Boundary Brook and still water pools were hazy blue indicating the presence of suspended solids not observed in the Lye Brook.

It can be concluded that there is a *minor* discharge of wastewater at the head of Boundary Brook, above the hospital, and a *larger* discharge from around the hospital. A check of the public access register of the Environment Agency web site showed that there were no published discharge licenses into the Boundary or Lye Brooks.

Lye Valley water quality

The water quality of the Lye Brook was considered good. Base richness was high in line with the spring water quality. Nitrate and ammonium concentrations were below detection levels except for a trickle of water entering the brook just below the allotments at ID 39, OSGB 454892-206059. This water inflow was considered to be wastewater from illegal sewage[2] discharges into the surface water drain showing high concentrations of ammonium (8 mg/l) and nitrate (10 mg/l). This drain is very likely to be connected to the surface water system and is responsible for the erosion streambed and partial dewatering and loss of fen habitat from the North SSSI.

The mixed waters below the Lye Valley Boundary Brook confluence show intermediate water quality.

Water quality – other sources of pollution

There will be minor impacts on the water quality on the area from atmospheric deposition of nitrogen and to a lesser extent sulphur and metals as dusts. The deposition of nitrogen is of most significance to nutrient poor habitats. Fortunately, fen systems have a high capacity to remove nitrate or ammonium from surface waters and so are highly effective sinks. Deposition of nitrogen around Oxford is in the region of 17 to 25 kgN/ha/year. This means that habitats such as wood and heath are nitrogen saturated (NEGTAP, 2001).

The influence on faecal matter from dogs will have a localised long-term effect on terrestrial habitats. The effects of concentrated pulse run-off from dog areas into the Lye and Boundary Brooks will only have a short duration effect because of the ‘washing through’ process of the hydrological system.

Pollution from litter appears to be more an eyesore than any effect on the water quality. Three shopping trolleys were discovered during the study. The effect of metal corrosion will be negligible compared to the rather useful formation of dams within the stream and piles of waste wet wood.

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[2] Here sewage refers to raw untreated sewage not gray water or surface water.

Photograph 2 A rather useful trolley dam in the riparian zone of the Lye Valley. This location is a long way from any convenient access points.

Pollution from spilt oils and chemicals should be considered as a high risk. The risk is greatest for the Boundary Book as the upper catchment is located in a very urban location. The Lye Valley stream source is more protected and could be isolated if the drain at the source was to be removed.

Table 4 Chemical data from the study. Note that these data were obtained using non NAMAS accredited methods. For Reference Only. pH and conductivity probes were calibrated. Other measurements made using simple aquarium test kits of limited colourimetric resolution.

ID	Feature	Comments	Tufa	EC, uS cm^{-1}	pH	NO_3 mg/l	NH_4 mg/l	Ca/Mg mg/l	CO_3/HCO_3 mg/l
1	Spring	Tufa depositing spring	y	879	8.0	7.5	0	358	465
2	Ditch	Runs alongside golf course		785	8.2	5	0	340	465
3	Fen	Best part of remaining fen.		913	7.8	0	0	394	465
4	Spring	Dry, Sandra Diesel's sink, tufa depositing.	y						
5	Lye Brook	Sample from Brook		990	8.2	5	0	269	394
6	Spring	Golf course spring.		719	8.3	7.5	0	251	412
7	Spring	Golf course drain and springs, lower than 2/ tufa depositing.	y	730	8.2	7.5	0	251	430
8	Spring	Golf course woodland riparian zone. Tufa depositing.	y	684	8.2	10	0	251	376
9	Spring	Golf course interception drain.		788	8.5	20	0	251	376
10	Ditch	Point when dritch from 9 enters Lye Brook.		772	8.2	5	0	304	483
11	Spring	Wet flush on the N side of brook.		715	7.9				
15	Lye Brook	Lye Brook, Confluence of Lye Brook and Boundary Brook		820	8.7	0	0	269	412
15	Boundary Brook	Boundary Brook, Confluence of Lye Brook and Boundary Brook		999	7.8	2.5	2	269	412
16	Boundary Brook	Boundary Brook		1024					
18	Spring	Tufa deposition at spring issue point.	y	1018	7.9	0	0	269	322
19	Boundary Brook	Boundary Brook		1020	7.8	5	0.25	269	394
20	Land Drain	Under Bridge		905	8.0				
21	Spring	Peat deposition		1154	8.0				
22	Spring	Major spring area.		852	7.6	0	0	215	394
32	Spring	Headington Hill Park	y	782	7.0	5			
33	Spring	South Parks		598	7.0	5			
39	Pipe Drain	15" pipe surface water issue to Lye Brook head.		792	7.7	10	8	286	322
40	Spring	Next to path as enter Lye Valley		887	8.2	0	0	269	376
42	Lye Brook	Bridge over brook.		850	8.4	0	0.1	251	412
43	Fen	Fen 10 m east of stream.		769	7.7	0	0	286	376
44	Fen	Fen 10 m east of stream.		647	7.4				
45	Fen	Fen 20 m east of stream.		723	7.2				
46	Fen	Fen 15 m east of stream.		766	7.0				
48	Lye Brook	Near fen.		854	7.7				
49	Spring	Tufa depositing spring on west side.	y	696	7.8				
50	Pond	Small Pond, man made.		770	7.7				
53	Spring	Soil wet with standing water.		765	7.7				

Surface Water Catchment

Introduction

A surface water catchment area can be developed based on the surface topology of the area. Figure 6 shows the surface water catchment for the Lye and Boundary Brooks.

Surface water inputs to Boundary Brook

The catchment area for Boundary Brook ignoring urban drainage will have extended to 860,000 m^2, but is now much reduced because of the diverting of surface water by road drainage. The result of this will be to protect the riparian corridor from erosion. The exact catchment area could not be determined without measurement of stream flow rates versus rainfall. Erosion within Boundary Brook appears to be less than that of the Lye Valley.

There are a number of storm drains discharging into the top of Boundary Brook along with some sewage effluent as detected by water quality measurements.

Changes to land use within the catchment will alter the flow regime if not undertaken carefully. The analysis of surface runoff from the Warneford Meadow was done extensively by URS Corporation Ltd. They calculated that 50% of the site would be impermeable and a system of water retention would be necessary to maintain the greenfield run-off regime (URS, 2006).

Any other developments within the surface water catchment zone should use the most extensive SUDS applicable and achieve greenfield runoff rates or more preferably to divert storm water away from Boundary Brook.

Surface water inputs to Lye Brook

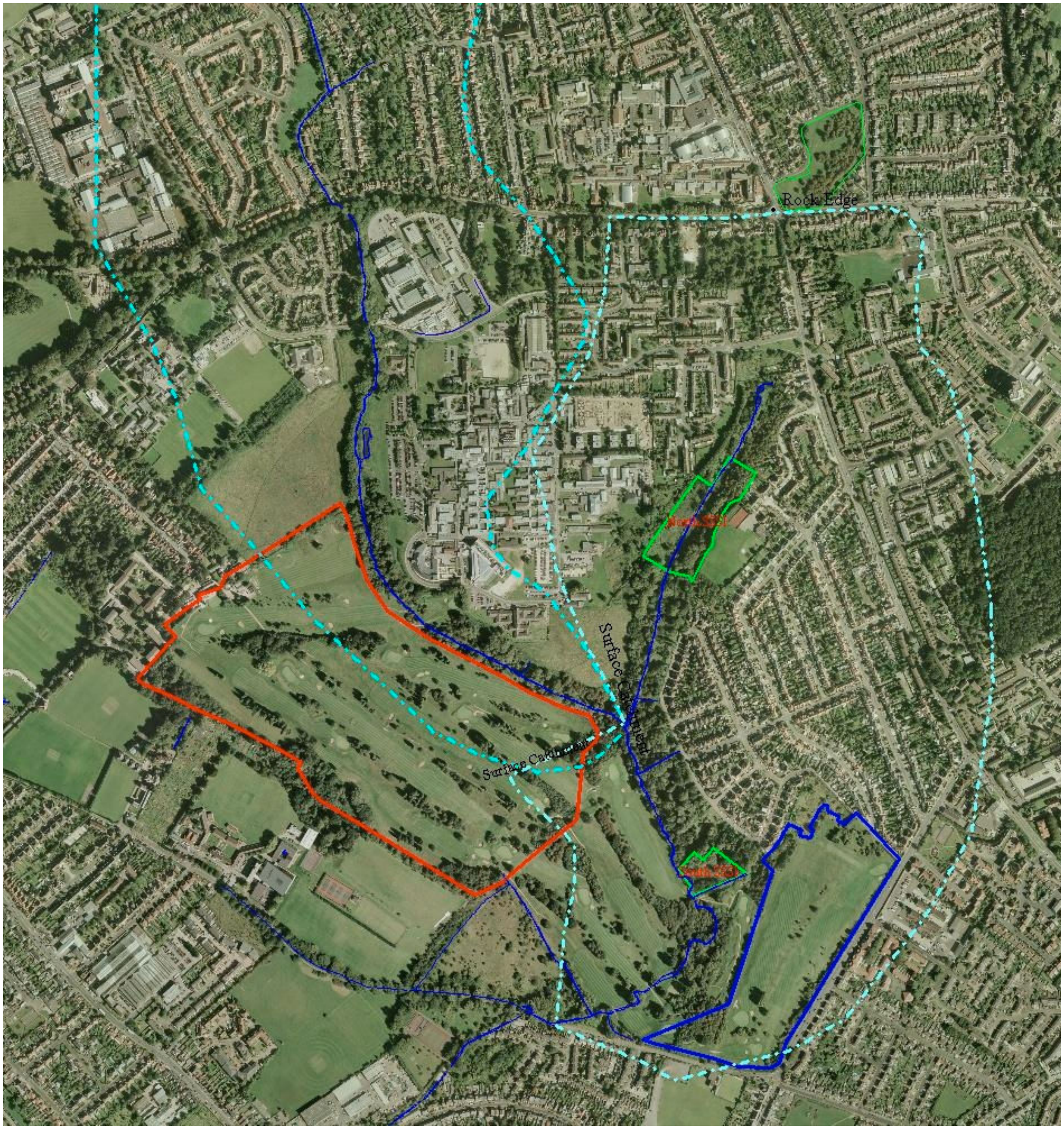
The catchment area for Lye Brook ignoring urban drainage and excluding Boundary Brook and ending at Barracks Lane is approximately 1,000,000 m^2, but is now reduced because of road drainage. The exact catchment area could not be determined without measurement of stream flow rates versus rainfall.

The origin of the main Lye Brook water source could not be traced, but the water quality indicates that this is consistent with a spring source having nitrate and ammonium levels below detection and a high calcium and bicarbonate content (See Table 4).

The number of storm water inputs to Lye Brook from source to the confluence with Boundary Brook were restricted to a 15” pipe at the source marked on the OS as ‘issues’. This storm pipe at the head of the valley was entirely of anthropogenic origin and the dry weather flow was analysed and found to have the water quality signature of unprocessed sewage (Table 4). It is likely that this is a storm water input and is the major cause of the increased erosion noted in 1979 (Oxford City Council, 1986).

From the confluence with Boundary Brook, there are some minor land drains and two further pipes near to the public footpath at SP54649-05358 (ID52) one approximately 15” and one 8” diameter. It is assumed that these are surface water runoff from the developments to the east.

Figure 6 Surface water catchments for the Boundary Brook to the confluence with the Lye Brook and the Lye Brook from source to Barracks Lane top the south. Marked in blue dashed line.



Lye Valley North fen water levels

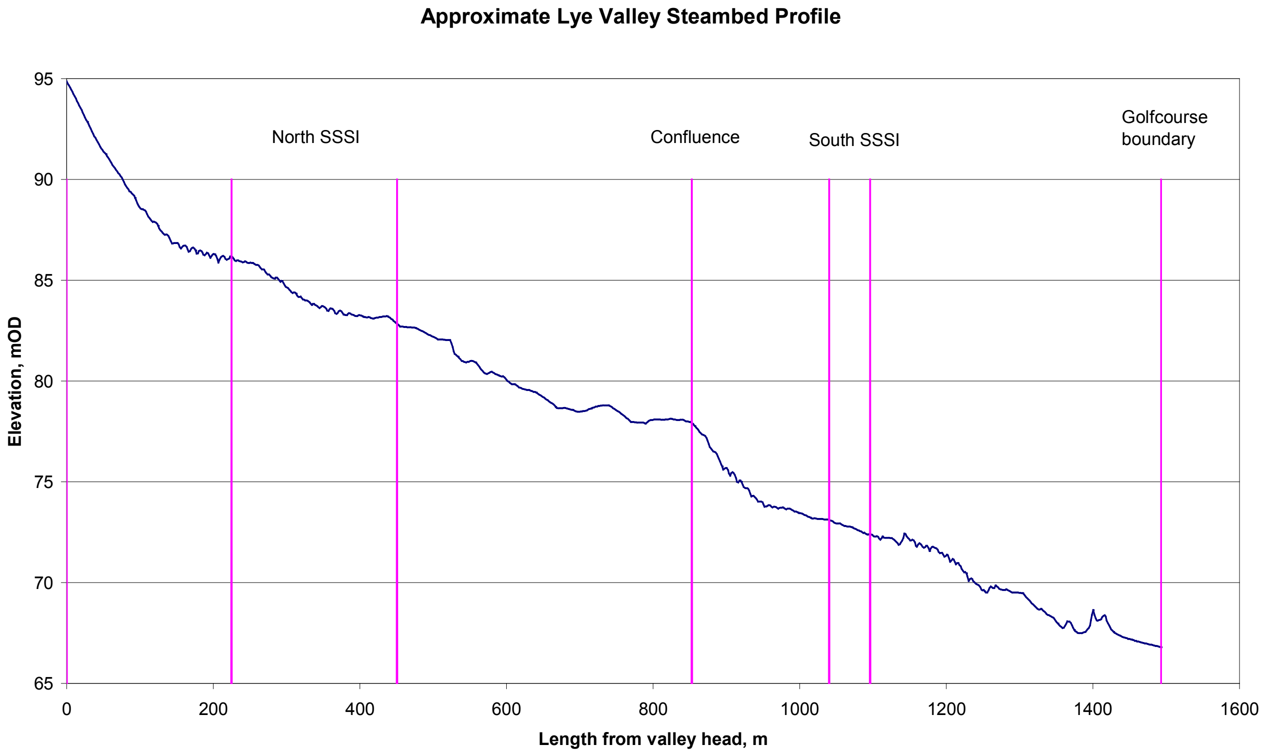
Historically, the Lye Valley fen north is clearly marked on the OS maps back to 1886. The path that runs down the centre of the valley was at a different location from today. In 1900 the path crossed the stream further down the valley and continued along the spring line on the eastern side.

It was difficult to assess the change in Fen water levels over time. Photographs published in the management plan and comments made on the hydrology indicate that water levels within the fen were higher before 1979. Indeed estimates of the area of fen in 1939 to be 4 ha and 1 ha in 1983 suggesting a change in water levels. However, the area of SSSI at present is 1.8 ha so it is difficult to see how there could be 4 ha of fen unless all fen areas within the Lye Valley were included. It is possible that 4 *acres* of fen existed, which is equivalent to 1.6 ha.

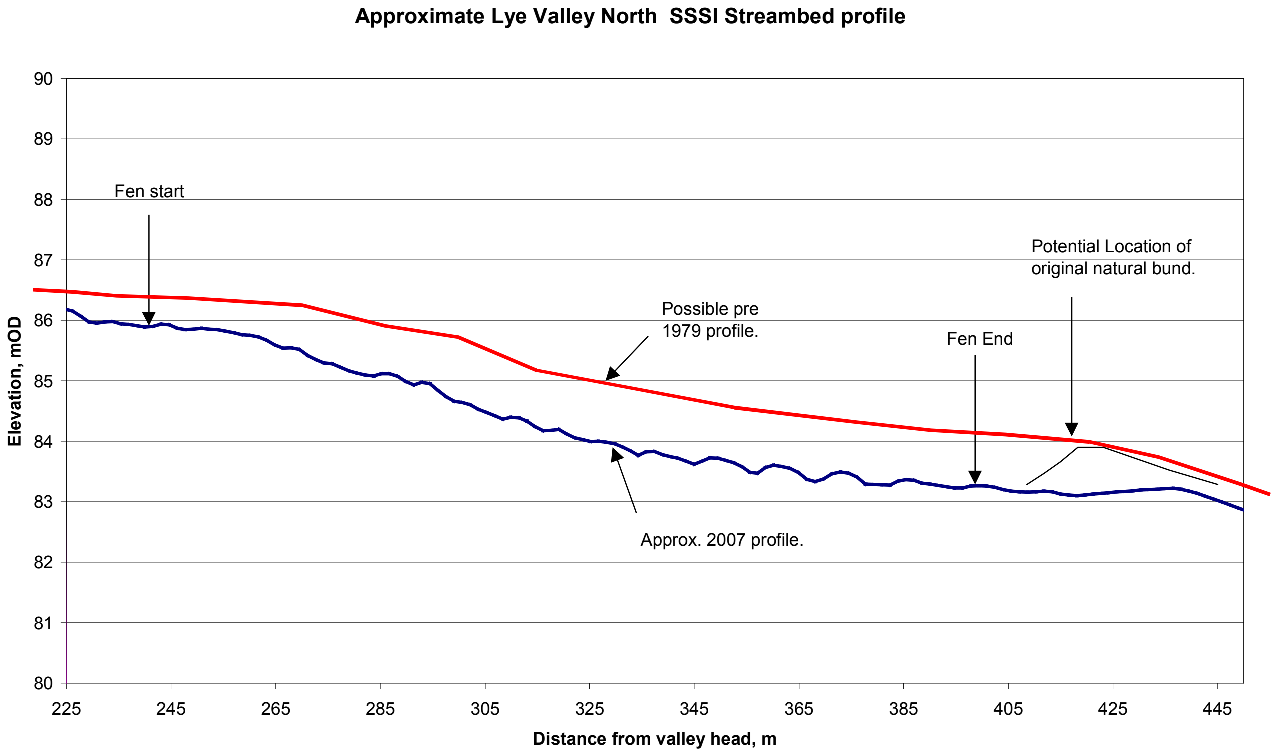
There is some evidence from the later editions of the OS map (approximately 1950 to 1960) that show clearly the start of a stream corridor just at the end of the existing fen area at OS 454725-205771. Thus the stream corridor above the fen was not of sufficient size to be surveyed prior to this date.

It was noted that major erosion of the peat and streambed occurred in the months July to December 1979. During that period A. Sandels recorded a loss of 1.25 m in stream base and an increase of 0.9 m in stream width. A further 1.5 m of bank erosion was observed between January and March 1980. Upstream cutting was about 1 m over the period July 1979 to March 1980. If the current topology of the streambed is used now to predict the levels of streambed in 1979 it can be seen that the water levels must have been considerably higher. Figure 7 shows the approximate streambed profile of the Lye Valley and Figure 8 is the North SSSI profile.

Figure 7 The stream bed profile derived from the DEM data. Note that this is only approximate.



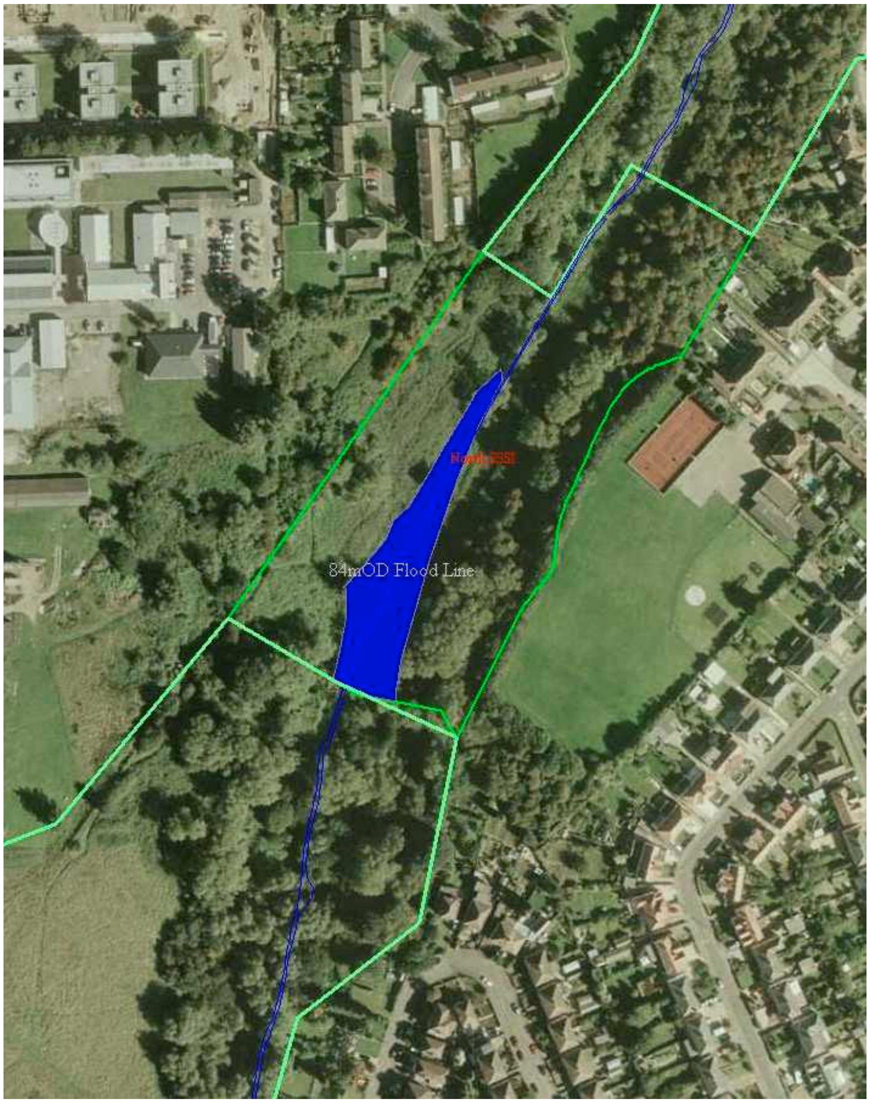
<u>Figure 8</u> Stream Bed profile of Lye Valley North SSSI. The lower blue line is the 2007 stream profile and the upper red line is an approximation to an increase in stream bed level of 1 m. The figure shows the possible location of a 'natural' bund which may have been damaged and eroded away in the 1970s.



Assuming a loss of stream bed depth in 1979 of about 1 m, the red line would have been the profile pre-1979. It may be that a natural bund at the specified location impeded the movement of water and causing a back up of water raising water levels. It could be that the crossing place indicated in the 1900 OS map was a possible bund as is indicated by its approximate location. Current water levels in the fen at that location are approximately 1 m above streambed.

An increase in the level of water by 1 m in the central stream area would result in an increase of wetted fen. For example if a bund was made at the lowest part of the fen to a crest elevation of 84 mOD then the area of backwater would be 0.22 ha. It should be noted that the shape of the flooded area corresponds to the observed dewatered fen, see Figure 9.

Figure 9 Possible re-wetted fen area based on a bund 1 m high and at 84 mOD.



Lye Valley South fen water levels

It has been more difficult to assess the historic fen water level changes of the South fen. It appears that there has been a gradual drying up of the springs that feed the fen. One local resident observed that her tufa depositing spring used to flow continuously (ID4, OS454768-0205258 at 77.5 mOD).

This means that the gradual encroachment on the groundwater catchment zone as a result of the developments to the east have caused a gradual change in the supply of groundwater to the south fen. The loss of groundwater started in 1922 when construction of the housing estate begun. This process is undoubtedly still occurring not only as a result of loss of catchment but as residents continue to install impermeable surfaces for car parking.

Infiltration rates lowered by urban catchments where impervious surfaces comprise 50 to 75% of the area can be calculated after making a number of assumptions. But, talking simply, if 50% of the area is impermeable and created surface runoff, then 50% is lost to infiltration and, one could argue, 50% loss to groundwater supply. In reality it is not as simple as this but the concept of a groundwater protection zone should be adopted for both fens.

There have been minor changes to the path of the Lye Brook since the 1880s. Erosion of the outside sides of stream bends is obvious by comparing the OS maps from then to now. It is possible that the streambed has be eroded, thereby improving the land drainage either side of the stream. In turn this allows the south fen to drain in much the same way as the north fen. However, there is less evidence of this and at the moment should remain as an hypothesis.

Mitigation of the effects of erosion and a method of re-wetting the fen would be to bund the Lye Brook at a point 145m below the south fen to a height of 73 mOD. This bund would be approximately 1 to 1.5m at the maximum point. The bund would flood an area of approximately 0.2 ha or slightly more, and force groundwater back into the south fen. Figure 10 shows the approximate flood area. Note that the digital elevation surface and the OS map do not coincide as the elevations are always more approximate under woodland cover.

Figure 10 Possible re-wetted fen area based on a bund 1 m high and at 73 mOD. Note that the DEM profile does not match the OS map. The OS map is more accurate.

Erosion and Flooding

Evidence of past erosion is obvious in both the Boundary and Lye Brooks. See Photographs 3 to 6.

Photograph 3 Bank erosion typical within the lower reaches of the Lye Valley. Note that the upper dark peat layer can be seen just below the overhanging vegetation.

Stormwater influx to the Lye Brook may have started in 1922 with the development of housing estates to the east of the Lye Valley and these were completed between the period 1930 to 1950. There have been no reports of erosion prior to erosion observed by Adrian Sandels in 1979. Interestingly the only major intervention event prior to that period was in 1978 when about 50 tonnes of rubbish clearance was undertaken. Could it be that some of the works disturbed the streambed allowing erosion to proceed or was it coincidental with the installation of the storm water drain marked on the OS maps as 'issues'.

The peak water flows within both streams are high due to the urban catchment area, and the lack of instream capacity and moderate gradient. The increased pulse flows have caused erosion. There is much evidence along the Lye Brook of bank erosion and works were undertaken to reduce streambed erosion in 1985. Photographs taken during heavy rain on the 9th October 2007 have confirmed that pulsed flows do occur.

Flooding of the Lye Valley had been noted in Southfield Golf Course (Oxford NHS Trust, 2006). It is likely that flooding has been experienced by residents around Barracks Lane but time constraints have prevented investigation.

Photograph 4 Lye Valley during heavy rain (not storm) on 9th October 2007. Photograph looking downstream jut above confluence. Note fast flowing water overtopping banks.

Photograph 5 Lye Brook opposite South SSSI fen, on a dry day and during heavy rain on the 9th October 2007. Approximate water level increase of 1 to 1.2 m approximate flow at 1 m^3s^{-1}.

Photograph 6 Southfield Golf Course (East), looking southwest downstream on the 9th October 2007 during heavy rain.

Aquifer recharge and long term water supply – the effect of Climate Change

Data from the UKCIP program using the medium high emission scenario indicate climate change driven precipitation changes will cause an annual 10% reduction in rainfall by 2020. Summer rainfall will be 30% down by 2050 and 40 to 50% down by 2080 (UKCIP, 2002). The consequences of a changing rainfall pattern to the health of the fen areas and spring zones is difficult to estimate. With a lower summer rainfall, fen water levels in summer will drop to a greater extent allowing the invasion of plants that prefer drier conditions. This will affect the fen vegetation community and the amount of effort required to manage the sites. Higher elevation springs are expected to become dry in summer, with loss of invertebrate communities that depend on a constant water supply. The intensity of rainfall events is also expected to increase, in turn run-off rates increase and erosion rates increase.

There has been an investigation into the impacts of climate change on nature conservation resources of Britain and Ireland called MONARCH (Modelling Natural Responses To Climate Change) (MONARCH, 2007). They applied the MONARCH methodology to 120 BAP species in Britain and Ireland. Interestingly, many southern species showed potential gains of distribution but the use of BAP species rather than habitat distribution means that predicting the effect on fen species is difficult. Loss of fen by reduction in groundwater flow and summer infiltration means loss of habitat.

In summary the effect of Climate Change will be similar to that of a reduced groundwater catchment area;

1. A decrease in summer groundwater levels.
2. A reduction or cessation of the flow of higher springs.
3. A reduction in the level of fen water because of lack of supply.
4. The increased erosion of the riparian zone due to more intense rainfall.

Therefore, it is very important that the size of the groundwater catchment zone is not reduced and that run-off from the urban catchment is diverted away from the Lye and Boundary Brooks.

ANTHROPOGENIC RISK ASSESSMENT

Introduction

The first section of this study investigated the current status of the geology, hydrology and geomorphology of the Lye and Boundary Brooks and local area.

This section describes the effects of land use changes on the riparian zones that contain the SSSI and SLINC areas.

Some of the comments made in the previous section will be repeated here with, if necessary, more explanation.

The scope of this study was to investigate the possible ecological and hydrological effects on the riparian corridor and broader offsite areas if two areas of Southfield Golf Course were developed for housing. The estimated numbers of dwellings that these two sites could accommodate are 380 for Southfield Golf Course East and 1,260 for Southfield Golf Course west. To make the discussion simpler and to offer different options the environmental impacts will be described in terms of land use. If the land was not developed for housing and the golf course closed then alternative land uses should be considered. Each land use will have a different impact on the riparian corridor and should be considered on its own merit. For instance a public park, with large areas of mown grassland may be a suitable alternative for parts of the golf course but not others in terms of loss of grassland species. Likewise, use of land for allotments will increase nutrient infiltration from the surface and put groundwater quality at risk.

Previous studies and methodology

The Water Framework Directive (EU Directive 2000/60/EC) was brought in to take a broader perspective of the assessment and protection of water and water bodies. For further information see the DEFRA or Environment Agency web sites. As a result much research into suitable assessment criteria has been completed. A methodology has been proposed and assessed by Krause, 2007 in which information from 900 wetland sites were used to develop a method to assess the likelihood of damage to groundwater-dependant wetlands in the UK from human activities.

This study follows a similar methodology in developing a level of ‘pressure’ or ‘risk’ on the riparian habitats, followed by a interpretation of whether or not the pressures are groundwater related or otherwise, and methods by which these risks or pressures can be reduced.

To make understanding easier, the study area has been divided into:

1. Lye Valley North SSSI
2. Lye Valley South SSSI
3. The riparian corridor of Boundary Brook to the confluence with Lye Brook
4. The riparian corridor of the Lye Brook from source to confluence
5. The riparian corridor from confluence to Lye Valley South SSSI

6. The riparian corridor from Lye Valley South SSSI to the boundary of the golf course at Barracks Lane

Groundwater

Effect of land use changes on groundwater in the Southfield Golf Course West area

Groundwater flows in the Southfield Golf Course West are predominately to the SW. This means that land use changes on this site will have a minor effect on the riparian (stream) corridor of the Lye Brook from Lye Valley South SSSI to the Lye confluence with the Boundary Brook and Boundary Brook itself. Lye Valley North SSSI would be unaffected. This may be understood more easily of it is remembered that the land dips steeply to the SW. Variations of the line of influence may well be 200 m either way where the land or groundwater surface is relatively flat.

Based on this study, the riparian corridor of Boundary Brook will be affected by changes to groundwater flows if land use changes occur within 50m of the brook. Due to the uncertainty of the data analysis, any buffer zone should extend to 100m, but is unlikely to extend further.

This means that development on part of Southfield Golf Course West would significantly affect the hydrology of the riparian corridor of Boundary Brook SLINC. The extent of the effect are indicated in Table 5. Reference should be made to Figure 5 which shows the groundwater catchment areas for the area.

Table 5 Natural areas affected by changes in groundwater flows as a result of development on Southfield Golf Course West

Area affected by Housing Development via GROUNDWATER	Vulnerability / Risk
Lye Valley North SSSI	Nil
Lye Valley South SSSI	Nil
The riparian corridor of Boundary Brook to the confluence with Lye Brook	Within 50 m
The riparian corridor of the Lye Brook from source to confluence	Nil
The riparian corridor from confluence to Lye Valley South SSSI	Within 50 m
The riparian corridor from Lye Valley South SSSI to the boundary of the golf course at Barracks Lane	Within 300 m

Effect of land use changes on groundwater in the Southfield Golf Course East area

The groundwater flow in the Southfield Golf Course East area is predominately E to W. This means that land use changes on the northern part of Southfield Golf Course East, and the private gardens to the north and east will have an effect on Lye Valley SSSI South, and the riparian corridor of the southern Lye Brook.

Based on this study the riparian corridor of the lower Lye Valley including Lye Valley South SSSI will be affected by land use changes within 300 to 500m to the eastern side of the valley.

This means that any land use change on Southfield Golf Course East will affect the hydrology of Lye Valley South SSSI. More specifically the use of Southfield Golf Course East for housing will cause a significant effect on the fen areas of the SSSI.

The risks to the fen are due to changes to groundwater quantity and water quality. Groundwater quantity in terms of loss of infiltration area and water quality in terms of the chemical signature (base richness and carbon dioxide levels) given to the groundwater by infiltration through an active soil profile and calcareous carbon dioxide rich geology. Thus the use of SUDS in any development would not achieve the important water quality chemical signature because urban system mean the loss of active soil profiles. SUDS are primarily concerned with the maintenance of infiltration and runoff rates.

Table6 Natural areas affected by changes to groundwater conditions as a result of development on Southfield Golf Course East

Area affected by Housing Development via GROUNDWATER	Vulnerability / Risk
Lye Valley North SSSI	Nil
Lye Valley South SSSI	300 to 500 m
The riparian corridor of Boundary Brook to the confluence with Lye Brook	Nil
The riparian corridor of the Lye Brook from source to confluence	Nil
The riparian corridor from confluence to Lye Valley South SSSI	Nil
The riparian corridor from Lye Valley South SSSI to the boundary of the golf course at Barracks Lane	Within 300 m

Critical groundwater catchment areas and suggested groundwater protection zones

It is possible to identify areas that should be considered as critical for the maintenance of the hydrology to the riparian corridor and SSSIs. These areas are essential and perform the following functions:

The QUANTITY of groundwater is provided by a catchment area allowing slow infiltration of rainwater into the Corallian aquifer. This excludes areas where clay overlies the geology but does not prevent groundwater from moving through this confined aquifer being supplied from a catchment further away.

The QUALITY of water is ensured by a combination of dissolved carbon dioxide in infiltrating rainwater, humic acids derived from an active organic and productive surface soil profile and biological and chemical processes occurring within the calcareous rocks of the Corallian aquifer. An active surface soil could be a mixed or deciduous woodland, grass, pasture or public park or even an arable field.

The critical groundwater catchment area, equivalent to the suggested groundwater protection zone, is marked in yellow on Figure 5. This groundwater protection zone should be considered to have a resolution of 300 m either way where the topology of the groundwater surface is flatter, and less than 50 m where the land surface has a significant slope.

Surface Water

Critical surface water catchment areas and protection zones

In the same way as there should be a protected groundwater catchment there should be a protected surface water catchment. The surface water catchment will be similar to the groundwater catchment and will differ where the surface topology is different from the groundwater flow direction. The surface water protection zone is shown in Figure 6 in blue. Protected surface water catchments should be considered to fulfill the following functions:

1. To protect vulnerable riparian corridors from the effects of contaminated water spills, discharges and run-off.
2. To protect stream flow rates by using planning restrictions to control the method of removal of surface water to surface drains and the implementation of SUDS system where there is unavoidable use of impermeable surfaces.
3. By ensuring that any urban catchment areas are drained away from the riparian corridor then damage due to erosion will be reduced or is much more controllable and any effects on water quality are reduced.

Effect of land use changes on surface runoff from Southfield Golf Course East and West

The effects of development on runoff from Southfield Golf Course East and West are simpler to control and would be affected more by the willingness of any builders to incorporate SUDS into development plans and the location of drains than by natural topology and geology.

It is essential that any developments within the catchment areas ensure that infiltration of runoff into the natural aquifer is optimised as far as possible. Schemes should have an optimal 50-year plus lifetime and take into account predicted changes to rainfall due to Climate Change.

Uncontrolled discharges to the streams should be banned. Controlled discharges, although less favoured over infiltration, are a last resort substitute.

The poplar use of balance ponds to mitigate surface run-off should be considered carefully in the light that they are engineering structures, have a limited lifetime and do not always increase, by their very nature, the wildlife interest. Balancing ponds should remain low or empty and fill when storm surges and infiltration require and be emptied slowly after the storm event. Habitat disturbance and water quality changes mean that these aquatic systems are not optimal for many aquatic species.

For instance there is a current outline planning application by the NHS Trust to develop Warneford Meadow. It is interesting to note the claims made about the potential biodiversity increase by using a balancing pond situated in the wildlife corridor and swales sited on the boundary of Warneford Meadow. No data or citations were made to support this statement. Balancing ponds are pulsed high flow systems where habitat and water quality will be so severe that only the most pioneering aquatic wetland species will be able to survive. Swales are temporary ponds with potentially high sediment load and again will offer habitat to a very select number of species associated with ephemeral ponds (Indigo, 2007).

MITIGATION AND ENHANCEMENT OPTIONS - SUMMARY

A number of mitigation and enhancement options for the riparian corridors of the Lye and Boundary Brooks have been described as part of this study. The following mitigation measures could be considered:

Groundwater Protection Zones

This is similar to the methodology used by the Environment Agency but applied locally to protect specific natural areas. An area has been defined using the groundwater flow model to protect the SLINC and SSSIs contained within the riparian corridor of the Lye and Boundary Brooks. Figure 5 shows the groundwater protection zone for the area.

Groundwater protection zones are not fully mitigated by the use of SUDS therefore development within these areas must be restricted or eliminated. Thus development must be restricted or eliminated on Southfield Golf Course East in order to protect the South SSSI and development must be restricted or eliminated within the buffer areas indicated in Tables 5 and 6 to protect the Lye and Boundary Brook riparian corridors.

Catchment Protection Zones

Normally the groundwater protection zone would coincide with the catchment protection zone. The use of SUDS should be compulsory within a catchment protection zone. Figure 6 shows the surface water catchment zone.

Re-wetting of Lye Valley North and South fens

Prior to any works to do with re-wetting the fen, it would be vital that storm runoff assumed to be piped directly into the head of the Lye Brook be diverted. No consideration has been made as to where the water would be diverted to but the essential requirement is that storm flows should be removed. It is important that water flow or levels be measured pre- and post intervention to assess success. Once peak flow rates have been reduced it would then possible to install simple and inexpensive bunds made of local clay, logs and brash to:

- Raise water levels in both the north and south fens
- Reduce the level of instream erosion by reducing stream flow rates
- Increase the wetted area providing sites for peat regeneration and natural damming of the stream corridor.
- Generate areas of slow moving water to encourage aquatic and emergent vegetation thereby increasing the wetland habitat.
- Increase wetter areas based on approximate elevation data by 0.4 ha or more by the use of just two bunds of approximately 1 m height. Ideally there would be more than two bunds.

It is recommended that a geomorphologist be contracted to design a system based on the morphology of the stream(s). It would be necessary before any design work to start to have the stream bed and valley floor accurately surveyed.

Construction Phase

A formal EIA will consider the environmental impacts of noise, water (hydrological effects), air quality and any effects specific to protected or rare species during the construction phase.

There are specific and relevant areas that should be considered with respect to the close proximity of the sensitive natural areas, these are as follows:

1. There should be careful scrutiny of the disposal of excess soil and excavated material to level a site. Areas that should be protected should be clearly marked and preferably fenced at this point to prevent the ‘occasional’ dumping of excess soil from site works. This has been observed at other construction sites where fragile habitats have been partially and unintentionally buried. Man made slopes of should be gentle (preferably less than 30° to prevent erosion) to allow for the development of natural vegetation and to lower sediment generation from surface runoff.

2. Surface water runoff should be strictly controlled during works. Settling ponds should be compulsory prior to the disposal of surface water. It is very damaging to any aquatic habitat to have excess sediment loads. Works close to the edge or within the catchment zone should be done with care to avoid sediment rich runoff entering watercourses. Use of bunds or shallow interception ditches is recommended.

3. Ground compaction, especially near to trees, should be avoided. Ground compaction lowers soil infiltration and increases surface runoff. The effect of tree root compaction is not normally observed untill well after the construction phase is complete. By which time the builders will not take responsibility for tree loss.

4. Pollution from spilt hydrocarbons should be avoided. Similar controls as mentioned in 2/ can be used.

5. The effects of noise and air quality on the SSSI and SLINCs are considered in the ecological appraisal.

Tables 7 to 9 show the estimated risk-receptor impacts during any construction phase for developments on Southfield Golf Course West, East and West and East combined.

Table 7 Matrix of impact-receptor effects of ecological significance during any construction phase for Southfield Golf Course West with respect to hydrological parameters and considering the immediate riparian corridor.

Southfield Golf Course West Impacts - Receptors	***Lye Valley North SSSI***	***Lye Valley South SSSI***	***The riparian corridor of Boundary Brook to the confluence with Lye Brook***	***The riparian corridor of the Lye Brook from source to confluence***	***The riparian corridor from confluence to Lye Valley South SSSI***	***The riparian corridor from Lye Valley South SSSI to the boundary of the golf course at Barracks Lane***
Groundwater quality and quantity.	Nil	Nil	Severe within 50 m	Nil	Slight Severe within 50m	Slight Severe within 300m
Surface runoff - water quality	Nil	Nil	Severe within 160 m	Nil	Slight	Slight
Surface runoff - erosion	Nil	Nil	Moderate	Nil	Moderate	Moderate
Ground compaction	Nil	Nil	Slight	Nil	Nil	Nil
Litter, illegal dumping.	Nil	Nil	Moderate	Nil	Slight	Slight
Groundwork – soil dumping	Nil	Nil	Severe	Nil	Slight	Nil

<u>Table 8</u> Matrix of impact-receptor effects of ecological significance during any construction phase for Southfield Golf Course East with respect to hydrological parameters and considering the immediate riparian corridor.

Southfield Golf Course East Impacts - Receptors	***Lye Valley North SSSI***	***Lye Valley South SSSI***	***The riparian corridor of Boundary Brook to the confluence with Lye Brook***	***The riparian corridor of the Lye Brook from source to confluence***	***The riparian corridor from confluence to Lye Valley South SSSI***	***The riparian corridor from Lye Valley South SSSI to the boundary of the golf course at Barracks Lane***
Groundwater quality and quantity.	Nil	Severe within 300 to 500m	Nil	Nil	Nil	Severe within 300m
Surface runoff - water quality	Nil	Slight	Nil	Nil	Nil	Severe
Surface runoff - erosion	Nil	Nil	Nil	Nil	Nil	Severe
Ground compaction	Nil	Nil	Nil	Nil	Nil	Slight
Litter, illegal dumping.	Nil	Nil	Nil	Nil	Nil	Severe
Groundwork – soil dumping	Nil	Nil	Nil	Nil	Nil	Severe

Table 9 Matrix of impact-receptor effects of ecological significance during any construction phase for Southfield Golf Course West with respect to hydrological parameters and considering the immediate riparian corridor.

Southfield Golf Course West and East COMBINED Impacts - Receptors	***Lye Valley North SSSI***	***Lye Valley South SSSI***	***The riparian corridor of Boundary Brook to the confluence with Lye Brook***	***The riparian corridor of the Lye Brook from source to confluence***	***The riparian corridor from confluence to Lye Valley South SSSI***	***The riparian corridor from Lye Valley South SSSI to the boundary of the golf course at Barracks Lane***
Groundwater quality and quantity.	Nil	Severe within 300 to 500m	Severe within 50 m	Nil	Slight Severe within 50m	Severe within 300m
Surface runoff - water quality	Nil	Nil	Severe within 160 m	Nil	Slight	Severe
Surface runoff - erosion	Nil	Nil	Moderate	Nil	Moderate	Severe
Ground compaction	Nil	Nil	Slight	Nil	Nil	Slight
Litter, illegal dumping.	Nil	Nil	Moderate	Nil	Slight	Severe
Groundwork – soil dumping	Nil	Nil	Severe	Nil	Slight	Severe

Post-Construction Phase

Any developments allowed within the groundwater or surface water protection zones outlined above will mean that there is an increased risk from any post construction phase from ground and surface water contamination, increased drainage, and an increase in the visual impact of litter, illegally disposed garden and other wastes. Dr Webb will discuss the idea of a buffer zone in the ecology report. Tables 10 to 12 show the estimated risk-receptor impacts for developments on Southfield Golf Course West, East and West and East combined.

Table 10 Matrix of impact-receptor effects of ecological significance during the post-construction (i.e. housing estate) phase for Southfield Golf Course West with respect to hydrological parameters and considering the immediate riparian corridor.

Southfield Golf Course West Impacts - Receptors	***Lye Valley North SSSI***	***Lye Valley South SSSI***	***The riparian corridor of Boundary Brook to the confluence with Lye Brook***	***The riparian corridor of the Lye Brook from source to confluence***	***The riparian corridor from confluence to Lye Valley South SSSI***	***The riparian corridor from Lye Valley South SSSI to the boundary of the golf course at Barracks Lane***
Groundwater quality and quantity.	Nil	Nil	Severe within 50 m	Nil	Slight Severe within 50m	Slight Severe within 300m
Surface runoff - water quality	Nil	Nil	Severe within 160 m Slight if diverted	Nil	Slight	Slight
Surface runoff - erosion	Nil	Nil	Moderate without SUDS	Nil	Moderate without SUDS	Moderate without SUDS
Ground compaction	Slight	Nil (No access)	Slight	Slight	Slight	Slight
Litter, illegal dumping.	Nil	Nil	Severe due to access	Slight	Moderate due to access	Moderate due to access
Groundwork – soil dumping	Nil	Nil	Nil	Nil	Nil	Nil

Table 11 Matrix of impact-receptor effects of ecological significance during the post-construction (i.e. housing estate) phase for Southfield Golf Course East with respect to hydrological parameters and considering the immediate riparian corridor.

Southfield Golf Course East Impacts - Receptors	***Lye Valley North SSSI***	***Lye Valley South SSSI***	***The riparian corridor of Boundary Brook to the confluence with Lye Brook***	***The riparian corridor of the Lye Brook from source to confluence***	***The riparian corridor from confluence to Lye Valley South SSSI***	***The riparian corridor from Lye Valley South SSSI to the boundary of the golf course at Barracks Lane***
Groundwater quality and quantity.	Nil	Severe within 300 to 500m	Nil	Nil	Nil	Severe within 300m
Surface runoff - water quality	Nil	Slight	Nil	Nil	Nil	Severe without SUDS
Surface runoff - erosion	Nil	Nil	Nil	Nil	Nil	Severe without SUDS and diversion
Ground compaction	Slight	Nil (No access)	Slight	Slight	Slight	Moderate
Litter, illegal dumping.	Slight	Nil (No access)	Slight	Slight	Moderate	Severe
Groundwork – soil dumping	Nil	Nil	Nil	Nil	Nil	Moderate (Garden wastes)

<u>Table 12</u> Matrix of impact-receptor effects of ecological significance during the post-construction (i.e. housing estate) phase for Southfield Golf Course East and West COMBINED with respect to hydrological parameters and considering the immediate riparian corridor.

Southfield Golf Course West and East COMBINED Impacts - Receptors	***Lye Valley North SSSI***	***Lye Valley South SSSI***	***The riparian corridor of Boundary Brook to the confluence with Lye Brook***	***The riparian corridor of the Lye Brook from source to confluence***	***The riparian corridor from confluence to Lye Valley South SSSI***	***The riparian corridor from Lye Valley South SSSI to the boundary of the golf course at Barracks Lane***
Groundwater quality and quantity.	Nil	Severe within 300 to 500m	Severe within 50 m	Nil	Slight Severe within 50m	Severe within 300m
Surface runoff - water quality	Nil	Slight	Severe within 160 m Slight if diverted	Nil	Slight	Severe without SUDS
Surface runoff - erosion	Nil	Nil	Moderate without SUDS	Nil	Moderate without SUDS	Severe without SUDS and diversion
Ground compaction	Slight	Nil (No access)	Slight	Slight	Slight	Moderate
Litter, illegal dumping.	Slight	Nil	Severe due to access	Slight	Moderate due to access	Moderate due to access
Groundwork – soil dumping	Nil	Nil	Nil	Nil	Nil	Moderate (Garden wastes)

CONSULTATION SUMMARY

Introduction

Part of the scope was to discuss the proposal with statutory consultees and key players. The following questions asked;

1. What information would you require in order to assess and comment on the likely effects of the developments on the two SSSI areas and the SLINC areas of the riparian corridor?
2. If you have sufficient information at present do you think that the areas identified for development would affect the SSSIs and SLINCs if the current proposals went ahead and why?

Below is a summary of their replies.

Natural England

In response to your email to me dated 12 September 2007, I have outlined the information Natural England would require when considering any proposal for housing development near to Lye Valley SSSI.

1) Natural England would seek assurances that the proposed development would not impact upon the groundwater supply mechanism to the SSSI. The integrity of the SSSI is highly dependent on both the quantity of groundwater and also on the quality of the water supply.

Our concerns would relate chiefly to the southern unit of the SSSI, because of its location relative to the proposed development.

It could be that the groundwater to the site is supported by a much larger goundwater body which is not affected by local infiltration. This seems probable given the ability of the northern unit of the SSSI to survive, despite being heavily urbanised round about.

However there is a risk that the southern unit is dependent in part upon groundwater recharge locally. If so the area proposed for development (blue) is one of the few windows left available for that recharge. We would like it confirmed that this is not the case.

Existing hydrogeological understanding may be enough to provide that reassurance. Field investigations may not be necessary. We do not have the expertise to make that determination. We can only pose the question and insist that the answer is supported by a good evidence base.

2) It is also worth noting that the brook is already destabilised by flash flows from the urbanised catchment. The resultant erosion is a risk to the fen. This development should include SUDS measures to avoid compounding that problem.

Received from Alison Muldal, Natural England, 17th September 2007.

Environment Agency

Comments were received from the Environment Agency (Pedro Collins, Conservation Officer) on the 19th October 2007 highlighting the following points;

- EA support the comprehensive reply given by Natural England.
- The implementation of buffer zones to protect watercourses would be required.
- The EA would be seeking enhancements to the natural areas as part of the development such as additional wet features and water vole habitats.
- There may be other requirements not listed here such as completing flood risk assessments for the scheme.

County Ecologist for Oxfordshire

Due to resource limitations Craig Blackwell was unable to comment on this proposal. He reinforced that the opinions of Natural England and the Environment Agency should be sought. Received 26th September 2007.

Thames Water

Not contacted.

FURTHER INVESTIGATIONS

Verification of groundwater flow directions

Verification of the groundwater surface profile by the investigation of groundwater levels especially within Southfield Golf Course West. This will require a number of boreholes to be installed and the resting water levels to be measured, preferably for an extended period of time to encompass summer and winter levels.

Investigation of the current water level profiles of the North and South fens

This investigation would require water levels to be measured accurately (to within at least 5 mm elevation) over the fen area. It may be necessary to install fixed dip-well of limited depth thrust into the underlying clay to prevent vertical movement. Water levels would then be used to verify that any re-wetting work has been effective.

Investigation of spring water response to scrub clearance

An investigation into the water quality and quantity of a single spring within the Lye Valley and the effect of clearing scrub and woodland just above the spring point. This will verify the correct conditions to optimise water flow and water quality into the fen. This type of study would take two years to complete and would require matching of seasonal changes. Careful experimental design protocol would be required.

Investigation of erosion rates

The erosion rates and water levels during storm discharge should be investigated. Data from this analysis area likely to support the diversion of storm runoff from the head of the Lye Valley. This analysis could be conducted pre- and post- diversion and prior to re-wetting operations suggested under mitigation.

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