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Howard Humphreys *Consulting Engineers*

National Rivers Authority
Anglian Region

REDGRAVE AND LOPHAM FENS RESTORATION PROJECT: HYDROLOGICAL AND ENVIRONMENTAL IMPACT ASSESSMENT

Final Report

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Howard Humphreys & Partners Ltd
Thorncroft Manor
Dorking Road
Leatherhead
Surrey
KT22 8JB

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Brown & Root *Civil*

NATIONAL RIVERS AUTHORITY
ANGLIAN REGION

REDGRAVE AND LOPHAM FENS RESTORATION PROJECT

HYDROLOGICAL AND ENVIRONMENTAL ASSESSMENT

FINAL REPORT

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Aquiclude	:	Geological unit which is impermeable and does not transmit water at all.
Aquifer	:	Geological unit permeable enough to yield economic quantities of water to wells.
Aquitard	:	Geological unit permeable enough to transmit water in significant quantities when viewed over large areas or long periods but its permeability is not sufficient to yield economic quantities of water.
Average Score per Taxon (ASPT) score	:	An index of biological quality based on sensitivity of aquatic invertebrates to organic pollution and derived from the BMWP
Biological Monitoring Working Party (BMWP)	:	Biological Monitoring Working Party score, an index of biological water quality which assigns high scores to families of invertebrates sensitive to organic pollution and low scores to pollution-tolerant families.
Confined aquifer	:	Aquifer bounded above and below by an aquiclude.
CORINE	:	A tool for the standardised recording of vegetation diversity within the surveyed areas, including the representation of pattern by vegetation mapping, used within the European Union.
Homeostasis	:	A system will tend to remain in balance until internal or external feedbacks become so out of balance that the system crashes precipitously to an altered state.
Leaky aquifer	:	Aquifer bounded above and/or below by an aquitard.
Natural Vegetation Classification (NVC)	:	A tool for the standardised recording of vegetation diversity within the surveyed areas, including the representation of pattern by vegetation mapping, used in the United Kingdom.
NWC	:	National Water Quality Classification Class 1a and 1b Good Class 2 Fair Class 3 Poor Class 4 Bad
Piezometry	:	Mapping of the Hydraulic heads for an aquifer to indicate the direction of groundwater flow.
Soligenous	:	High water tables of the fen are maintained by below-ground water inputs, either from aquifers or soil through flow.
Specific Yield	:	Volume of water released from storage in an unconfined aquifer per unit surface area of aquifer per unit decline in watertable.

Storativity	:	Volume of water released from storage in a confined aquifer per unit surface area of aquifer per unit decline in the component of hydraulic head normal to that surface ignoring the compressibility of water and the aquifer.
Topogenous	:	High water tables of the fen are maintained by above ground water inputs, such as springs, streams, rivers or sheet flow.
Transmissivity	:	Rate of groundwater flow under a unit hydraulic gradient through a cross-section of unit width over the whole saturated thickness of the aquifer.
Unconfined aquifer	:	Aquifer bounded below by an aquiclude but has no confining layer above.

EXECUTIVE SUMMARY

INTRODUCTION

This study forms part of work by the National Rivers Authority to appraise options to identify a preferred solution for obviating or mitigating ecological damage to Redgrave and Lopham Fens SSSI, some 7 km west of Diss on the Suffolk/Norfolk borders (see figure A). The Fen is a National Nature Reserve and is an internationally important wetland conservation site designated under the RAMSAR convention. It is considered to be adversely affected by the adjacent Redgrave public water supply sourceworks, and from lowered bed levels in the River Waveney resulting from dredging.

Identification of a satisfactory full solution is being undertaken by the NRA in consultation with Suffolk Water Company (now called Essex and Suffolk Water, owners of the sourceworks), Suffolk Wildlife Trust (who own part and manage the whole of the Fens), and English Nature (who are responsible for the overall protection and management of the Fens).

The study was aimed at assessment of the hydrological and environmental impact of a number of options for redeployment of the groundwater abstraction or of otherwise remediating Redgrave and Lopham Fens; viz:

- Do nothing and continue use of the existing Redgrave PWS sourceworks adjacent to the Redgrave and Lopham Fens;
- Seasonal irrigation from an adjacent source (at least 1 km away) to mitigate the drying out of the Fens, but with continuous use of the existing Redgrave PWS sourceworks;
- Relocation of the PWS source works to near North Lopham 5 km to the NNW of the Fens and 500 m from a NRA river augmentation borehole; to be considered with and without augmentation pumping;
- Relocation of the PWS sourceworks to two alternative sites in the Wortham/Mellis area 4.5 km and 2 km to the east of the Fens;
- Relocation of the PWS sourceworks to near Wetheringsett 14 km to the ESE of the Fens and 500 m from a NRA river augmentation borehole from the River Dove; to be considered with and without augmentation pumping;
- River restoration of the River Waveney from Redgrave and Lopham Fens to Denmark Bridge, near Diss, both in conjunction with and without, the previous options.

The primary conservation objective for the alleviation of Redgrave and Lopham Fens was agreed by all parties in December 1993 as to:

- "restore the full sequence of Target Fen types and re-establish the close mosaic of fen types within the fen sequence".

This would involve the following:

- restoration of Chalk groundwater levels at or above fen surface;
- restoration of groundwater flow;

- fen management practices expanded and capital works in Post-Borehole Move Management Strategy to be implemented.

Further environmental objectives applying to the wider scope of the project are:

- groundwater discharge sufficient to restore baseflow to River Waveney;
- conservation objectives of nearby wetlands should not be compromised by any relocation of abstraction.

These objectives were used to assess and compare the impact of options for abstraction redeployment and other remediation measures on surrounding water users, wetland conservation sites, and springs and rivers.

METHODOLOGY

The study was based on hydrological data held by the NRA, and on information on the wetland nature conservation sites held by Suffolk Wildlife Trust, Norfolk Naturalists Trust and English Nature. No new field surveys were undertaken.

For each of the potential redeployment abstraction sites, test pumping information made available by the NRA was used to characterise the hydrogeology, and to determine the likely response of the Chalk and drift water levels. Limitations to the analysis were the short period of testing, particularly at the Wortham/Mellis sites (3 day tests) and Wetheringsett (7 day test) and the lack of information on response in the drift to abstraction in the Chalk.

The interaction between the Chalk and drift aquifers in the study area is complex due to the highly variable nature of the drift cover, and in addition there is complex interaction with the rivers. A steady state leaky aquifer analytical model was used to estimate long term (steady state) changes in Chalk water levels resulting from the various abstraction options. Drift water levels were assumed to match the Chalk aquifer changes as under steady state conditions the Chalk and drift water levels would have equilibrated. This approach gives the "worst case" but indicative values to screen the options on a comparable and consistent basis. The analysis demonstrates the scale of possible water level changes in the Chalk and drift aquifers, but may not provide absolute values due to discontinuities, such as aquifer heterogeneity, buried channels and river recharge, which may influence long term pumping. Aquifer heterogeneity was included in the analysis where known.

The predicted effect of abstractions on the Chalk aquifer was used to determine the risk to existing abstractors, the overall impact on the 22 wetland conservation sites in the study area (R. Waveney and R. Waveney ESA are considered together) and the impact on river flows. The incremental effects of each development option on water levels and river flows was determined taking the 'Do nothing' option as the baseline condition. Positive impacts resulting from the cessation of pumping at Redgrave will be the opposite of the 'Do nothing' option for both water level changes at wetland sites and stream flow. Potential changes to river water quality were estimated from the present water quality classification and forecast flow changes.

For each of the 22 wetland conservation sites in the study area, geology and natural variation in Chalk groundwater levels were assessed to determine the overall hydrogeological sensitivity to changes in Chalk water levels. Ecological screening of the wetland sites was undertaken to estimate the sensitivity to changes in groundwater level, quality and throughflow, based on:

- sensitivity of plant species to groundwater level/flow changes;
- presence of species of conservation interest;
- presence of communities of conservation interest;
- sensitivity of communities to groundwater quality changes.

Five categories of plant species were drawn up according to water level preference, based on long term average water levels, and range from open water and flooded conditions to plants typical of drying soils. Estimated water level changes were used in conjunction with the distribution of species at the wetland sites to establish potential effects on the ecology of the sites.

Virtually every wetland site was found to be of high sensitivity and dependent on Chalk groundwater inputs. It is thought that the fen sites in the area are an inter-acting ecosystem dependent on a sufficient gene pool and an adequate area of similar habitat. The importance of survival of individual sites to the persistence of the wetland ecosystem is not known and therefore survival of all of the sites is important.

RESULTS OF ASSESSMENT

All of the groundwater redeployment options (3.6 tcmd) from Redgrave lead to significant predicted improvements at Redgrave and Lopham Fens. Positive effects resulting from cessation of pumping at Redgrave are the opposite of the 'Do nothing' option impacts, while impacts arise elsewhere from the redeployed abstraction.

'Do Nothing' Option

The 'Do Nothing' option of continuing abstraction at Redgrave P.S. (3.6 tcmd) would have significant impact on wetland sites and rivers. Redgrave and Lopham Fens would continue to be affected by reduced groundwater levels. There has been a significant decline (77%) in wetland species and an equally serious loss of habitat over the last 30 years, and under this option wetland communities could be lost, replaced by meadow or humid grasslands, in the next few decades. This option is predicted to affect a further 10 wetland sites, all of which are considered highly sensitive to changes in Chalk water levels. Reduction in the number and/or extent of wetland species has been observed at the majority of these sites, although water level change may not be the only cause. Low flows (Q_{95}) are estimated to be reduced in the River Waveney by 14% and in the Little Ouse River by 10%. In particular flow in the upper Waveney through Redgrave and Lopham Fens is severely affected.

North Lopham Option

The North Lopham relocation option without augmentation pumping, is predicted to result in benefits to 6 wetland sites, including Redgrave and Lopham. The latter would experience a 96% recovery of water levels and throughflow. There would however, be reduced water levels at 7 wetland sites, 3 of which appear to be relatively unaffected at present. The supply borehole would lower water levels in the adjacent NRA river augmentation borehole by up to 3 m. Two other licensed groundwater abstractors would be affected. The Waveney and Little Ouse low flows would improve by 6% and 3% respectively, while the River Wittle would experience a reduction of 21% with even higher figures in the upper reaches. Water quality in the Wittle is NWC Class 3 (poor) and the flow reduction would worsen this situation.

Concurrent operation of the adjacent NRA river augmentation borehole (11 tcmd) would result in significantly greater impact, with 11 wetland sites predicted to be affected by reduced water levels. However, Redgrave and Lopham Fens and the River Waveney would benefit, with the former experiencing an 84% recovery under this scenario. Under this scenario, up to 13 licensed groundwater abstractors could be subject to additional drawdowns greater than about 1m. River flows would decline in the Little Ouse, Waveney, Thet and Wittle, by 17%, 19%, 3% and 83% respectively, and changes in water quality class would be expected.

Wortham/Mellis Options

For the redeployment to Wortham/Mellis three sub-options were examined: (1) near exploratory/test Sites F/G (TM 080 760); (2) at Site B in a highly transmissive Chalk zone about 1 km from the River Waveney (TM 078 792); and, (3) a combination of the two sites.

Sub-option 1 is predicted to produce a 97% recovery of water levels of Redgrave and Lopham Fens, and recovery at 4 other wetland sites, including the River Waveney. Another 6 wetland sites could be affected by reduced water levels, although only 3 are considered highly sensitive and groundwater dependent. Eight licensed groundwater abstractors would be subject to additional drawdown greater than 1 m and the effect on yields could be significant. The changes in river flows would be slight.

Sub-option 2 predictions are based on high Chalk transmissivity derived from a 3 day pumping test which may not be representative of the aquifer characteristics prevailing in the longer term. The results should be treated with caution. Water levels at Redgrave and Lopham Fens are predicted to be restored by 94%, with corresponding improvements in the wetland. The River Waveney would also be improved together with 3 other wetland sites. Another 7 wetland sites would be likely to be affected by reduced water levels although only 4 are considered highly sensitive and groundwater dependent. No abstractors would be subject to additional drawdowns greater than 1 m. Changes in river flows would again be slight.

Sub-option 3, the combination of both Wortham/Mellis sites, with 50% of the abstraction at each, results in a predicted 96% recovery at Redgrave and Lopham, with benefits at 6 other wetland sites, and reduced water levels at 7 sites. Seven licensed abstractors would be affected by additional drawdowns greater than 1 m and yield changes could be significant. The changes in river flows would be slight.

Wetheringsett Option

The Wetheringsett option without river augmentation is predicted to fully restore water levels at Redgrave and Lopham Fens and not to reduce water levels at any wetland sites. There would be positive effects on water levels at the 11 sites thought from the analysis to be affected by the Redgrave source. Two licensed groundwater abstractions would be subject to additional drawdowns greater than 1 m, the NRA river augmentation borehole at 500 m (10 tcmd), and a small general agricultural borehole. However, the additional drawdowns are such that there would not appear to be any significant risk to yields of these boreholes. The Rivers Waveney and Little Ouse would experience improved low flows, 14% and 10% respectively and improved river class, while the flows in the River Dove (-17%) and River Deben (-6%) would decline. All of these rivers are designated as low flow rivers by the NRA. The impact on the River Dove would be mitigated by the existing NRA river augmentation borehole at Wetheringsett which discharges into the river, and potential may exist for augmentation boreholes for the River Deben to mitigate the effect of lower flows.

Operation of the adjacent NRA Wetheringsett augmentation borehole as well as the supply borehole would produce further impacts on groundwater abstractions and rivers flows, but no impacts on wetland sites. Around 23 abstraction boreholes would be subject to additional drawdowns ranging from 1 m to 3.7 m. The majority of the licensed abstractions are below 20 m^3/d and the drawdowns are not likely to produce a significant change in yield or affect pumps/pump settings. However, this would have to be investigated in detail if this option is to be pursued. Flows in the Waveney and Little Ouse would be unaffected, but the Dove and Deben would experience reductions of 66% and 20% respectively. However, the river augmentation support as described above would mitigate these effects, although the effects would still be pronounced in reaches above the discharge points.

Irrigation and River Restoration Options

Irrigation of wetlands has been proposed and attempted both in England and internationally. Irrigation systems are variants of either above-ground irrigation, usually in the form of ditches, or a sub-surface irrigation scheme of buried pipes. The wetlands in the areas of interest to this project are predominately non-topogenous (sub-surface water source), and a man-made system replicating the natural conditions would have to consist of a buried network of pipes.

There are a number of difficulties associated with sub-surface irrigation schemes including:

- Replicating the 'natural' pattern of water flow, with complex and heterogenous water level, soil moisture and nutrient gradients;
- Disruption resulting from the installation and maintenance of a sub-surface irrigation system;
- Sub-surface irrigation schemes have not, to date, been demonstrated to be successful in re-establishing or retaining wetlands.

Furthermore, an additional irrigation borehole 1 km away, either on the opposite side of the River Waveney or downstream would affect the neighbouring wetland sites. Therefore, the irrigation option is not considered a practical scheme and should be eliminated as an option.

The agreed River Waveney restoration measures comprise installation of sluices, raising of river bed, removal of emergent vegetation, lowering and reshaping of bank sections, reinstatement of drainage dykes and flood storage in the floodplain. These measures cannot in themselves provide effective remediation of the Redgrave and Lopham Fens and River Waveney, and are therefore not an alternative to the abstraction redeployment options. They are essential however, to enhancing the effects of improvement in baseflow arising from the groundwater development options.

CONCLUSIONS

The existing abstraction at Redgrave has a major impact on groundwater levels at Redgrave and Lopham Fens, on flows in the River Waveney and the River Little Ouse, and is predicted to have lowered groundwater levels at 9 wetlands in the area. Other factors such as land drainage, historical management practices and agricultural practices may have had significant impacts on the wetland sites. Continued abstraction would lead to further deterioration.

It is not considered practical to restore Redgrave and Lopham Fens using irrigation techniques. River restoration measures cannot in themselves provide effective remediation although they are essential to restoration of riparian habitats and to enhance the

improvements in baseflow arising from the groundwater relocation options. Wetland management practices would also ensure effectiveness of improved inflows to the wetland conservation sites.

All of the options to relocate the present Redgrave sourceworks are predicted to make a very significant improvement (80% to 100%) to groundwater flow to Redgrave and Lopham Fens SSSI. However, the options impact on other wetlands, groundwater abstractors and rivers to varying degrees, as summarised in Table A.

The Wetheringsett option would wholly reverse the groundwater level reductions predicted at Redgrave and Lopham Fens and the other 10 wetlands. This option would also reverse the changes in Waveney and Little Ouse flows, predicted to arise from the Redgrave source. None of the wetland conservation sites would be affected by reduced water levels. The abstraction would have a significant effect on flows in the headwaters of the River Dove, although this could be mitigated by enhanced support from the existing NRA river support boreholes, including the adjacent Wetheringsett augmentation borehole. During normal operation two licensed groundwater abstractors would be subject to an additional drawdown greater than about 1 m. However, concurrent use of the river support and the PWS boreholes would result in more than 20 licensed abstractors being subject to additional drawdowns greater than 1 m. Predicted drawdowns are unlikely to have a significant impact on yield, although in the extreme, lowering of pumps or deepening of boreholes could be required. The effect on unlicensed abstractors requires further investigation to determine whether the borehole(s) are still in use and the degree to which they are likely to be affected.

The Wortham/Mellis options would lead to substantial reversal of the effects of the Redgrave source at some wetland sites, particularly Redgrave and Lopham Fens, but would lead to risks of reduced water levels at other wetland sites which are likely to be groundwater dependent. Up to eight abstraction licences might also be subject to additional drawdowns greater than 1 m and significant changes in yield are likely. This could require remediation measures ranging from lowering of pumps to deepening of boreholes. The effect on unlicensed abstractors requires further investigation to determine whether the borehole(s) are still in use and the degree to which they are likely to be affected. Changes on river flows/quality would be very slight.

The North Lopham option would again lead to substantial reversal of the effects of the Redgrave source on some wetland sites but would reduce water levels at others. These effects would be even more pronounced with concurrent operation of the nearby augmentation borehole. There would be very significant effects on flows in the upper River Wittle in either case. Three licensed groundwater abstractors would be subject to additional drawdown greater than 1 m by the option, and 13 licensed groundwater abstractors would be affected by the same criteria during concurrent operation of the augmentation borehole. Again, significant changes in yield are not thought likely, but remediation measures could be required. The effect on unlicensed abstractors requires further investigation to determine whether the borehole(s) are still in use and the degree to which they are likely to be affected.

The results of the study can now be used together with other information by the collaborating parties to identify and justify a preferred strategy for restoring the Redgrave and Lopham Fens.

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Table A - SUMMARY MATRIX OF HYDROLOGICAL AND ENVIRONMENTAL EFFECTS OF GROUNDWATER DEVELOPMENT OPTIONS

Option	Wetland Conservation Sites			Groundwater Abstractors		Rivers		
	No. wetlands benefiting from water level rise	No. wetlands affected by water level fall	Impact ranking	No. Groundwater licences affected*	Impact ranking	No. rivers benefiting from option	No. rivers adversely affected by option	Impact ranking
Do Nothing	0	11	Severe	0	Nil	0	2	Mod.
North Lopham	6	7	High	3°	Low	2	1	High
North Lopham and Aug. Borehole	2	11	High	13	High	0	4	Severe
Mellis/Wortham (F-G) - Option 1	5	6	Mod.	8	High	1	2	Low
Mellis/Wortham (B) - Option 2	4	7	Mod.	0	Nil	1	1	Low
Mellis/Wortham (B + F-G) - Option 3	7	7	Mod.	7	Mod.	1	1	Low
Wetheringsett	11	0	Nil	2°	Low	2	2'	Mod.'
Wetheringsett' and Aug. Borehole	11	0	Nil	23°	High	2	3'	High '

Note: ' Part mitigated by Augmentation

" Yields unlikely to be significantly affected

* Additional drawdown about 1m or more

Ranking order: Low
Moderate
High
Severe

1. INTRODUCTION

1.1 Background

The National River Authority is carrying out an appraisal of options to identify a preferred solution for obviating or mitigating ecological damage to Redgrave and Lopham Fens SSSI. The SSSI lies adjacent to the River Waveney, about 7 km west of Diss on the Suffolk/Norfolk borders (see Figure 1.1). It is an internationally important wetland conservation site designated under the RAMSAR convention and as a National Nature Reserve.

The Fens are considered to be adversely affected by the adjacent Redgrave public water supply sourceworks, drawing on the underlying Chalk aquifer, and from lowered bed levels in the River Waveney resulting from dredging. The Upper Waveney (Redgrave and Lopham Fens) is listed by the NRA as one of their priority 20 sites for low flow alleviation.

Identification of a satisfactory full solution is being undertaken by the NRA in consultation with Suffolk Water Company (owners of the Redgrave sourceworks), Suffolk Wildlife Trust (who own part and manage the whole of the Fens), and English Nature (responsible for the overall protection and management of the Fens).

Howard Humphreys was appointed in December 1993 to carry out part of the overall comparison of different options for redeployment of groundwater abstraction and river management to remediate the Fens.

1.2 Objectives

The aim of this study is to estimate the hydrological and environmental impacts of a number of options for redeployment of the groundwater abstraction or of otherwise remediating Redgrave and Lopham Fens, viz:-

- Do nothing and continue use of the existing Redgrave PWS sourceworks adjacent to the Redgrave and Lopham Fens.

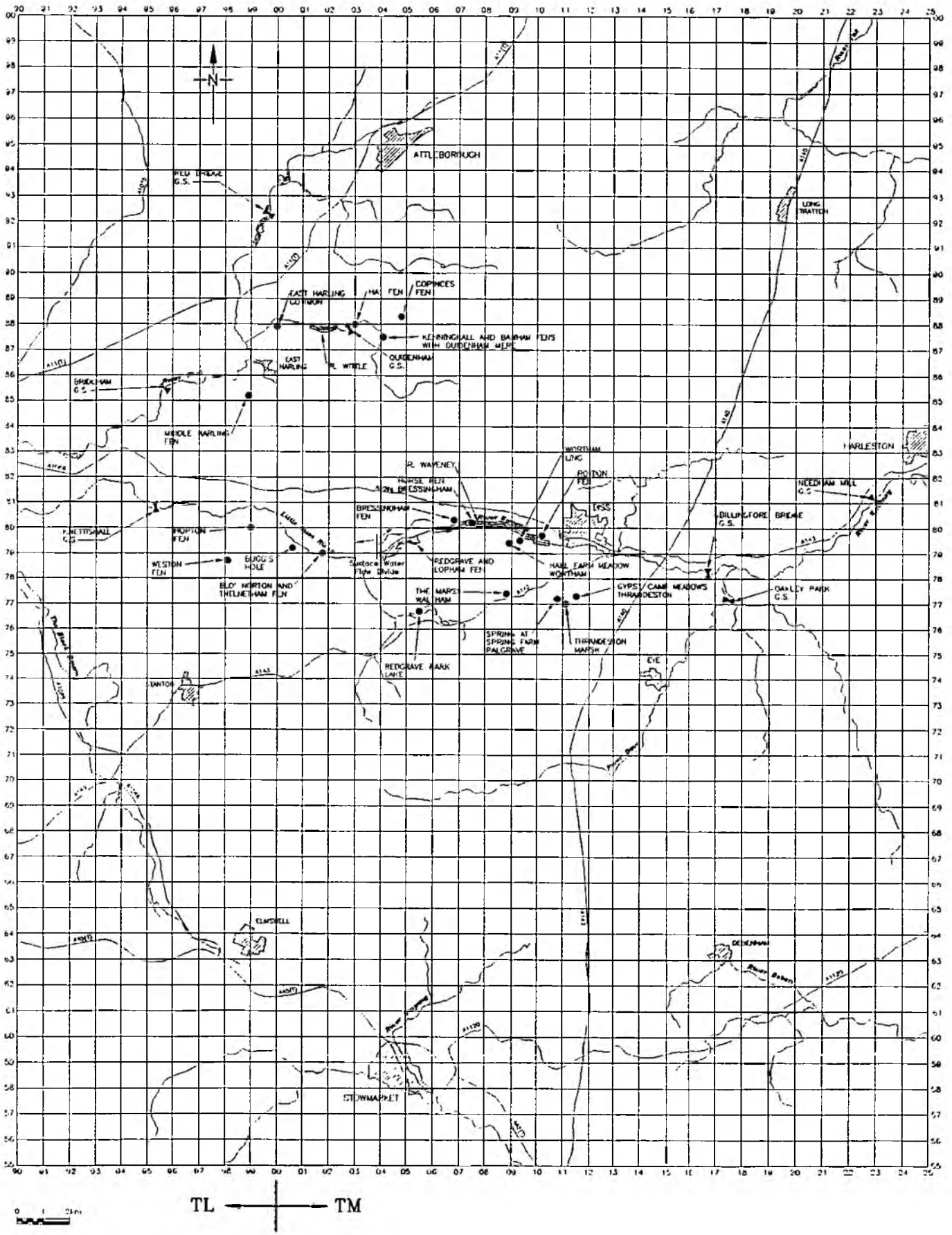
- Seasonal irrigation from an adjacent source (at least 1 km away) to mitigate the drying out of the Fens, but with continuous use of the existing Redgrave PWS sourceworks.

- Relocation of the PWS sourceworks to near North Lopham (5 km to the NNW of the Fens), 500m from NRA river augmentation borehole; with operation of both boreholes to be considered in determining the impact and cessation of use of Redgrave sourceworks;

Figure 1.1

REDGRAVE AND LOPHAM FENS

LOCATION MAP



- Relocation of the PWS sourceworks to two alternative sites in the Wortham/Mellis area (at 4.5 km and 2 km to the east of the Fens); cessation of use of Redgrave sourceworks;

- Relocation of the PWS sourceworks to near Wetheringsett (14 km to the ESE of the Fens), 500m from a NRA river augmentation borehole for the River Dove; operation of both boreholes to be considered in determining the impact and cessation of use of the Redgrave sourceworks;

- River restoration of the River Waveney from Redgrave and Lopham Fens to Denmark Bridge, near Diss, both in conjunction with and without, the previous options.

Suffolk Wildlife Trust drafted conservation and environmental objectives for the alleviation scheme, which were finalised with the NRA and English Nature in mid-December 1993. The primary conservation objective for Redgrave and Lopham Fen is to:

> **"restore the full sequence of Target Fen types and to re-establish the close mosaic of fen types within the fen sequence."**

The hydrological requirements necessary to achieve the conservation objectives at Redgrave and Lopham Fens are:

- establish Chalk groundwater levels at or above the fen surface so that artesian flows of groundwater are restored (pre-abstraction Chalk groundwater levels were in the order of 1m above the fen surface);

- groundwater flow into the fen should be sufficient to:

    - support the mean water table so that it is permanently at fen surface level for normal seasonal circumstances so that seepages from superficial deposits are restored

    - provide a groundwater seepage flow within runnels along the edge of the fen and at the marginal seepage sites with carbonate-rich water

    - restore the system to one of peat maintenance rather than peat degradation by maintaining permanently waterlogged conditions

    - restore the low fertility environment through saturation of the peat by oligotrophic water supplied from the aquifer; discharge of aquifer water will also restore soil processes which limit phosphate availability

- flood peat cuttings and other depressions with groundwater to restore the environment required by typical aquatic and semi-aquatic communities

- provide groundwater flow to the fen during periods of normal seasonal drought, thereby eliminating dependency on rainfall and storage of winter flood water

- replace winter storage conditions with predominantly lateral flow, thus reducing soil water residence times and therefore providing high redox potentials

- provide a positive flow from the fen to the adjacent River Waveney and thereby reduce the risk of seasonal incursions to the fen of river water that may be periodically contaminated from the adjacent agricultural catchment

- fen management practices should be expanded and capital works outlined in the Post-Borehole Move Management Strategy should be undertaken.

Further environmental objectives applying to the wider scope of the project have been set as:

- groundwater discharge should be sufficient to restore baseflow to the River Waveney thus ameliorating low flows throughout and downstream of Redgrave and Lopham Fens;

- any relocation of the groundwater abstraction should be sustainable in the long term and should not compromise the conservation objectives of nearby wetland conservation sites.

It is against these conservation and environmental objectives that the abstraction redeployment and other remediation options have been assessed and compared. Receptors to be considered include surrounding water users, wetland conservation sites, springs and rivers. The impact on wetland conservation sites includes the estimated physical impact together with an assessment of the significance of these changes to the conservation objectives of each site.

Following surveys in the summer of 1993, management proposals to improve the conservation value of the River Waveney and floodplains were made by Suffolk Wildlife Trust in December 1993, and agreed with the NRA in January 1994. These include:

- monitor river flow and quality and amend management measures as necessary;

- install a sluice at the downstream end of Great Fen below the drainage ditch on the south bank (and bunding of ditches as necessary) to fill channel back to sluice at Redgrave Fen;
- raise the river bed by about 0.5m over considerable sections;
- install riffle downstream of Wortham Ling, and consider lowering bank sections at this location;
- remove areas of emergent vegetation;
- reinstate old dyke system in floodplains depending on water quality in river;
- carry out measures to encourage flood storage in Waveney floodplain.

Suggested improvement of water quality in Worby's drain around Redgrave and Lopham Fen SSSI, or if quality could not be improved, re-routing of the drain, was excluded from consideration in this study by the NRA.

1.3 Methodology

Detailed methodology for assessment of hydrological and environmental changes associated with the remediation options is presented in Chapters 4 and 5.

Activities in the study have progressed through:

- collection of available reports and data on hydrogeology, abstraction and rivers;
- collection of available reports and data on wetland sites;
- characterisation of hydrogeology at each potential abstraction site, and of the region;
- production of maximum and minimum Chalk water level maps;
- estimation of water level changes in the aquifer and in shallow systems at each potential abstraction site; including rises occurring due to cessation of pumping at Redgrave PWS; using available data on aquifer characteristics;
- estimation of interception of throughflow to wetland and rivers for each potential abstraction site;
- characterisation of hydrogeology of each wetland site;

- characterisation of sensitivity of each wetland to groundwater level changes, and present wetland condition;

- estimation of effects of water level and throughflow changes on wetlands, particularly on Redgrave and Lopham Fens;

- estimation of effects of water level changes on licensed abstractions, including NRA river augmentation bores and PWS bores;

- estimation of likelihood of successfully irrigating Redgrave and Lopham Fens to meet the conservation and environmental objectives;

- estimation of effects of River Waveney management measures;

- assemblage of the hydrological and environmental impacts in an overall impact matrix, allowing comparison of the remediation options.

The ecological and hydrological methodology employed has been appropriate to the available data, and has been discussed and agreed with the NRA and other consultees throughout the course of the study. It has been intended to provide a consistent and robust approach, allowing direct comparison of the various remediation options so as to identify their environmental acceptability in terms of meeting the conservation and environmental objectives outlined earlier.

1.4 Format of Report

This report sets out the background, methodology and results of the study. Estimates of the hydrological and environmental impacts of the options listed in Section 1.2 are presented. In accordance with the terms of reference no recommendations are made as to the acceptability of these forecast changes; this will be done by the NRA.

Chapters 2 and 3 respectively describe the Redgrave and Lopham Fens SSSI, and other wetland sites in the study area, including historic trends, present status and management practices. In Chapter 3 the hydrogeology of the Chalk aquifer in the study area is outlined, together with interaction with drift and surface watercourses.

Ecological assessment methodology applied to the wetlands is set out in Chapter 5, while Chapter 6 sets out the hydrological assessment methodology, particularly for estimation of aquifer and shallow water levels changes. The hydrological and environmental effects of each abstraction redeployment option are presented in Chapter 7, with a similar format for each option to allow for ready comparison.

Chapter 8 describes the River Waveney above Denmark Bridge at Diss and considers the impact of the agreed management measures for the river and floodplains. The option to irrigate Redgrave and Lopham Fens from an adjacent source while operating the Redgrave sourceworks is examined in Chapter 9.

Chapter 10 presents an overall impact matrix allowing comparison of the remediation options on hydrological and environmental grounds.

2. REDGRAVE AND LOPHAM FENS

2.1 Description of Site

Redgrave and Lopham Fens is a 124.92 ha spring-fed valley fen of international importance for conservation, being declared a RAMSAR site in 1991 and a National Nature Reserve in 1992. The site, shown on Figure 1.1, supports several distinct fen vegetation types, ranging from *Molinia* - based grasslands, mixed sedge fen to reed-dominated fen. There are small areas of wet heath, sallow carr and birch woodland. The site is significant for its fine-grain mosaic of community types. A number of the communities, most notably *Schoeno-juncetum* and *Cladium* swamp, are identified in the EC Habitats and Species Directive as being notable habitats which are particularly threatened, and which member states have a commitment to maintain and/or restore.

The fen exhibits a classic zonation of vegetation types: Dry marginal birch woodland gives way to a band of fen grassland, which grades into a mixed fen community. Sandy ridges protrude into these two zones and support a damp heathy vegetation adding considerably to the diversity of the site. Towards the centre of the valley the mixed fen communities give way to more eutrophic tall fen.

Most of the fen communities are prone to invasion by sallow and locally this has developed into dense scrub and carr.

The River Waveney and its feeder drains are sluggish eutrophic waters supporting a rather narrow range of aquatic plants. In addition there are a number of small pools in the fen areas (some of which are flooded peat cuts) and these form the habitat for the Fen Raft Spider.

The historical vegetative status of Redgrave and Lopham is relatively well recorded, due to a botanical survey conducted by Bellamy and Rose in 1960 (Bellamy and Rose, 1960). Subsequent surveys have been conducted in 1983 (Suffolk Wildlife Trust, 1990) and 1990 (Suffolk Wildlife Trust, 1990; Fojt, 1990; Harding, 1993a).

Results show that over half the flowering plants have been lost from the areas of Redgrave Fen which have been surveyed in detail and all the *Sphagna* species; of those lost, 25 specifically require wet fen conditions. Many of the species lost are declining both regionally and nationally. Concomitant with the decline in wetland species is a rise in generalist, drought-tolerant species (e.g., *Phragmites australis*) and scrub encroachment. It is probable that similar changes have occurred throughout the site.

Redgrave and Lopham Fens are significant for the number of invertebrate species supported. An analysis of invertebrate populations over 40 years conducted by Harding (1993a) shows a decline of 77% of fen and bog species, and a loss in other categories of 66%. The Red Data Book

species have either been lost or face a significant population decline. The nationally endangered and internationally rare Fen Raft Spider (*Dolomedes plantarius*) has a remaining population of under 100 individuals and is thought to face extinction at the site.

2.2 Sensitivity to Chalk Groundwater

The very existence of a fen wetland presupposes a water level at or very near to the land surface. Both water level and water quality are both essential elements determining fen characteristics. Redgrave and Lopham Fens is a species-rich calcareous mire, reliant upon nutrient poor, alkaline water (pH greater than 5). The following points concerning water quality have been made by Suffolk Wildlife Trust (Harding, 1993b):

- Base-rich conditions are correlated with the vegetation type *Schoeno-Juncetum* and other communities related to the *Carex davallianae*. Invertebrates, such as snails, also require calcareous water.

- The redox potential (oxygen availability) at the rooting zone determines plant species composition. A number of fen species need a high redox potential (high oxygen, flowing water), although lower numbers of rare species need low redox (stagnant) water. To ensure a diversity of communities, a mosaic of redox potentials is required.

- Low fertility, especially nitrogen and phosphorus, is required to maintain the competitive advantage of the slow-growing fen species. In enriched water, particularly with a lowered water table, fast-growing ruderals invade and initiate scrub succession. Low fertility is inherent in saturated peat, the anaerobic conditions retarding peat degradation and nutrient release. Irrigation by aquifer-derived water, low in nutrients, is also essential. Invertebrate fauna similarly appear to be dependent upon spring-fed systems.

- Chalk groundwater is oligotrophic (nutrient-poor) and appears to play a critical role in reducing phosphate availability to plants. This is achieved by binding phosphate with calcite as it precipitates out of solution when the waters emerge out of the ground (Boyer and Wheeler, 1989). Furthermore, this reaction is thought to be a function of the rising groundwater, rather than a reaction between the calcareous water and the peat surface (Wheeler and Shaw, 1990), indicating surface or sub-surface irrigation of fen ecosystems may be unsuccessful.

In common with other fen and wetland ecosystems, plant species at Redgrave and Lopham are very susceptible to slight changes in groundwater levels. The abundance and probability of occurrence of both wetland communities and species have been correlated with soil

water regime (Gowing et al, 1993). Their results broadly support the Ellenburg rankings, in that assemblages of species have soil water preferences separated by a few centimetres. Most wetland plants prefer water levels to be within 10cm of the surface, while species of greatest conservation value, such as *Schoenus nigricans*, *Anagallis tenella*, *Parnassia palustris* and *Carex lepidocarpa* are characterised by preferred mean water levels of less than 5cm below the surface (Harding, 1993b).

Many of the most important species-rich fen bryophytes (e.g., *Riccardia chameadryfolia*, *R. multifida*, *Aneura pinguis*) and other regionally rare fen flowering plants (e.g., *Menyanthes trifoliata*, *Eriophorum angustifolium*, *Carex dioica*) are all characterised by a preference for mean water levels of less than 2cm below the surface. A further grouping of essentially aquatic plants (e.g., *Ranunculus flammula*, *Carex diandra*, *C. rostrata* and *Potamageton* species) only exist when the water is at or above the surface (Harding, 1993b).

It has been shown that the more vulnerable, and therefore rare species respond to drops of only 2-3 centimetres in groundwater levels (Wheeler and Shaw, 1987); thus although the biotype remains the same, the floristic composition may be very different. Furthermore, germination and young seedling survival, essential for system recruitment and persistence, are most susceptible to slightly adverse (sub-optimum) conditions. Thus although adult plants may appear vigorous, juvenile stages may be entirely lacking, resulting in the slow and chronic decline of the community.

Rising groundwater and permanently water logged conditions (that is, optimal conditions) are therefore essential to maintain the exacting conditions required by these rare communities and prevent degradation of the fen through drying out, peat oxidation, decomposition and nutrient release.

2.3 Effects of Historic Groundwater Level Changes

Before the 1950's calcareous nutrient-poor water rose under artesian pressure seeping into the fen from both around the margins and within the peats. However, in the late 1950's, two abstraction boreholes were commissioned near to the fen for public water supply and licensed for 3.6 tcmd in 1965. This abstraction and the deep dredging of the Worby's Drain and the River Waveney in the 1960's have reduced inputs to the fen such that rising groundwater has been eliminated. The hydrology of the site is now dominated by rainfall derived water moving down the soil profile replacing the spring-fed soligenous character.

Monitoring data comprehensively document the conversion over this period of rare, valuable *Schoeno-Junceta* fen communities into degraded types of *Cirsio-Molinietum*, *Juncus subnodulosus* fen meadow and highly fertile Phragmites fens (Harding, 1993). The wetland fauna was found

to be similarly degraded, with the rarer categories of species (those dependent of calcareous spring-fed conditions) suffering the most.

Groundwater level changes have resulted in five main processes of change (Harding 1993b), namely; alteration of competitive balance of the community dominants; change in environmental conditions required by individual species; increases in site fertility; increase in scrub cover; and a change from soligenous to rain-fed hydrology.

2.4 Effects of Management Practices

Redgrave and Lopham Fens has a long history of active management, being used by the poor of the Parish since the early nineteenth century for fuel, thatching materials and grazing which resulted in rotational scrub, sedge and reed cutting, grazing and peat cutting. This use had slowed since the 1930's, and virtually ceased by the 1940's.

In 1961, Suffolk Wildlife Trust instigated minor management practices such as footpath development and limited cuttings. The Trust management programme has been more active since the 1980's, when sedge bed reclamation and scrub removal occurred. Present day management is largely designed to maintain the status quo rather than to effect change.

Despite increased levels of plant community management, it is apparent that the key factor influencing the fen is water levels. The abstraction boreholes, located 30m from the fen, appear to be a significant factor in the reduction of water table levels, as shown by an experimental shutdown in February 1990, during and immediately after which piezometers recorded the disappearance of the cone of depression and the subsequent re-establishment of the water table mound. The cone of depression returned soon after abstraction resumed.

Dredging of the River Waveney to encourage fen drainage occurred in the 1960's. A sluice placed in the river downstream of Redgrave Fen in 1979 has effectively minimized this surface drainage, although fenland downstream of the sluice has continued to deteriorate.

A report published by the Suffolk Wildlife Trust (1990) clearly demonstrates the primary cause of deterioration of Redgrave and Lopham Fens is due to groundwater abstraction. The biologically rich, nearby Weston Fen has experienced similar management, but has had only very few species lost and no gross habitat change.

3. OTHER WETLAND NATURE CONSERVATION SITES

The following descriptions of the conservation sites are derived from SSSI and Trust vegetative data sheets, NVC survey reports where available and other published information. The information is summarised in the matrix shown on Table 3.1, and the site locations are shown on Figure 1.1.

3.1 Description of Statutory Conservation Sites

Blo'Norton & Thelnetham Fens is a 21.03 ha calcareous valley fen, situated near the head of the Little Ouse River. Presently degraded by large areas of invading scrub/woodland, the sites' main interest is limited to areas least affected by drainage, namely two small areas of herb-rich fen at Thelnetham which have a botanical interest similar to that of Redgrave and Lopham Fens. Blo'Norton Fen shows little signs of groundwater reduction, although there is evidence of eutrophication (NVC Survey, Jerram, 1992). Thelnetham Fen, once semi-floating peat and vegetation (Schwingmoor), has been greatly changed by the dredging of the Little Ouse River and the Schwingmoor has significantly reduced (NVC Survey, Ausden and Harding, 1991a). There is evidence of small reductions in groundwater and associated aerobic breakdown of the exposed peat.

Bugg's Hole Fen is a 4.0 ha calcareous valley fen, situated in the valley of the Little Ouse River, 1km downstream of Blo'Norton & Thelnetham Fens. A clear zonation of habitats occur at the site, ranging from mown grassland on the driest soils to calcareous fen vegetation dominated by *Caladium mariscus* or *Schoenus nigricans* where a number of springs arise (NVC Survey, Jerram, 1992). The site is isolated from the river and is unlikely to receive topogenous inputs, although drains in the area may be important in controlling the fen water table. There are no clear signs that the fen is drying out.

East Harling Common includes a system of glacial ground ice depressions, the largest of which forms a deep permanent mere. The pingos support a unique relict community of aquatic beetles, in addition to more common invertebrates and amphibians. The area is one of the best preserved fens in the area, supporting important plant species and communities. There is no documented degradation of the plant communities, although scrub and woodland are developing as successional stages around the margins.

Gypsy Camp Meadows, Thrandeston is a species-rich wet meadow situated on poorly drained boulder-clay. A wide range of vegetation types are supported, from base-rich marsh to alluvial meadow and drainage ditch flora. Summer grazing by cows and cutting for hay has allowed the development of a very diverse flora, including orchids. The site is thought to rely almost entirely on surface water from springs and

Table 3.1: Current Status of Wetland Conservation Sites

Site Name	Grid Ref	Size (ha)	Importance (Status)	Past Management	Water Supply	Predominant Nutrient Status	Deterioration Observed
Blo' Norton and Thelnetham Fens	TM017790	21.03	National (SSSI)	- SWT Reserve - Ditches and river dredged 1960's - Reed and sedge cutting - Turf cutting - Scrub removal	- Calcareous valley fen, spring fed site - Hydraulic continuity with chalk	Nutrient poor	Yes (scrub and woodland invasion, summer drying of certain areas. Some eutrophication. Fire in 1970's
Bressington Fen	TM060809	7.28	Local (County Wildlife Site)	- Turf cutting	- Calcareous valley fen, spring fed soligenous hydrology	Nutrient poor	Yes (scrub and woodland invasion)
Bugg's Hole Fen	TM006792	4.00	National (SSSI)	- Grazing and mowing - Turf cutting	- Calcareous valley fen, spring fed soligenous hydrology	Nutrient poor, some nutrient rich areas	No
Copince's Fen	TM048883	6.96	Local (County Wildlife Site)	Not known	Not known	Nutrient rich	Yes (scrub invasion)
East Harling Common	TM000879	14.90	National (SSSI)	- Grazing	- Spring fed, soligenous hydrology	Nutrient poor to nutrient rich	No
Gypsy Camp Meadows	TM115773	2.46	National (SSSI)	- SWT Reserve - Summer grazing - Vegetation mowing - Drainage ditches	- Calcareous, spring fed - Some topogenous inputs	Nutrient poor to nutrient rich	No
Hall Farm Meadow, Wortham	TM089794	1.20	Local (County Wildlife Site)	- Drainage ditches	Not known	Not known	No

Table 3.1: Current Status of Wetland Conservation Sites (contd)

Site Name	Grid Ref	Size (ha)	Importance (Status)	Past Management	Water Supply	Predominant Nutrient Status	Deterioration Observed
Hay Fen	TM030880	9.67	Local (Country Wildlife Site)	- Turf cutting	Not known	Nutrient rich	Yes (scrub and woodland invasion)
Hopton Fen	TM990800	14.37	National (SSSI)	- SWT Reserve - Turf cutting - Drainage ditches - Reed cutting - Vegetation mowing - Scrub removal	- Calcareous valley fen, predominantly spring fed, soligenous hydrology - Some topogenous inputs	Nutrient rich	Yes (localised drying out with some scrub and woodland invasion, some eutrophication)
Horse Fen, Bressingham	TM075802	4.39	Local (County Wildlife Site)	- Vegetation planting	- Predominantly topogenous hydrology	Nutrient rich	Yes (scrub invasion)
Kenninghall and Banham Fens with Quidenham Mere	TM041875	48.90	National (SSSI)	- Summer grazing - Vegetation mowing	- Calcareous valley fen, spring fed soligenous hydrology - Topogenous inputs from river, surface run-off	Nutrient poor to nutrient rich	Generally no. Possible enrichment from agricultural runoff
Middle Harling Fen	TM989852	12.70	National (SSSI)	- Grazing	- Calcareous valley fen, spring fed soligenous hydrology - Important topogenous inputs	Nutrient poor, some nutrient rich areas	No
Redgrave Park Lake	TM055767	20.00	Local (County Wildlife Site)	Not known	- Topogenous hydrology	Not known	No

Table 3.1: Current Status of Wetland Conservation Sites (contd)

Site Name	Grid Ref	Size (ha)	Importance (Status)	Past Management	Water Supply	Predominant Nutrient Status	Deterioration Observed
Redgrave and Lopham Fen	TM050797	124.92	International (RAMSAR site) National (SSSI) National (NNR)	- SWT Reserve - Dredging drainage channels - Grazing and mowing - Turf cutting - River embankment - Scrub removal	- Calcareous valley fen, spring fed soligenous hydrology	Predominantly nutrient poor, some nutrient rich areas	Yes (transition of fen to degreaded highly fertile fen communities, scrub and woodland invasion, some localised drying out of fen)
R. Waveney	TM060799 - TM070801 and TM089790 - TM105795	1.60	Local (County Wildlife Site)	- Dredging - Drainage cuts	- Predominantly soligenous hydrology, some topogenous inputs	Mesotrophic	Yes (some enrichment)
R. Whittle	TM013880 - TM023879	23.17	Local (County Wildlife Site)	- Vegetation managed for game shooting	- Predominantly topogenous hydrology	Nutrient rich	Yes (scrub and woodland invasion of fen, localised drying out)
Roydon Fen	TM102797	15.08	Local/National (Site of Nature Conservation Interest, proposed SSSI)	- SWT Reserve - Dredging of drainage ditches - Sedge cutting - Turf cutting - Scrub removal	- Calcareous valley fen, spring fed soligenous hydrology - Vulnerable to river dredging	Nutrient poor to moderate	Yes (scrub and woodland invasion, some localised drying out adjacent to ditches)
Spring at Spring Farm, Palgrave	TM108772	n/a	Not known	Not known	Spring	Not known	Not known
Thrandeston Marsh	TM111770	5.00	Local (County Wildlife Site)	Not known	Not known	Not known	No

Table 3.1: Current Status of Wetland Conservation Sites (contd)

Site Name	Grid Ref	Size (ha)	Importance (Status)	Past Management	Water Supply	Predominant Nutrient Status	Deterioration Observed
Weston Fen	TL981787	48.60	National (SSSI)	- SWT Reserve - Scrub removal - Grazing and mowing - Draining - Turf cutting	- Calcareous valley fen, spring fed soligenous hydrology	Nutrient poor, some nutrient rich areas	No
Wortham Ling	TM093795	51.30	National (SSSI)	- SWT Reserve - Grazing and mowing - Scrub removal	- Predominantly, topogenous hydrology	Nutrient poor, some mesotrophic base rich areas	Yes (population extinction of Natterjack Toad)
Wortham Marsh	TM088774	2.50	Local (County Wildlife Site)	Not known	Not known	Not known	No

SWT = Suffolk Wildlife Trust
NNT = Norfolk Naturalists Trust
EN = English Nature
SSSI = Site of Special Scientific Interest
NNR = National Nature Reserve

run-off from the railway (personal communication, EN, NRA, SWT). There is no record of significant vegetation deterioration.

Hopton Fen is a SSSI and SWT Reserve of 14.4 ha lying in the bottom of a small tributary of the Little Ouse River. The shallow peat overlays sand glacial deposits which overlie the Chalk aquifer. The fen is predominantly dependent upon soligenous water inputs although the water table is below ground level in summer in much of the fen. It includes a complex of rich-fen communities (NVC Survey, Ausden and Harding, 1991b), including *Phragmites-Eupatorium* with *Caladium mariscus*. However, most of the communities are eutrophic and scrub invasion indicates drying out. The nationally scarce *Carex lasiocarpa* is found at the fen.

Kenninghall & Banham Fens with Quidenham Mere is in the valley of the River Wittle, and the river is considered to control the water levels and impact water chemistry for much of the site. The large catchment indicates surface water run-off is an important component of the fen water balance. The fen supports highly diverse plant communities, including species-rich fen, calcareous meadow, wet carr woodland and a natural, deep mere with fringing vegetation. A number of unusual plant species grow on the site. The fen and grassland is grazed by cattle and horses during summer months, and managed reed and sedge beds are harvested. There is no record of significant vegetation deterioration.

Middle Harling Fen is situated at the head of a tributary to the River Thet. Important communities identified at the site include *Carex elata* swamp, *Caladium mariscus* and *Juncus subnodulosus* (Fojt, 1990), and plant species uncommon to East Anglia are found at the site. The fen meadow is currently grazed by cattle and horses, which maintain the species diversity. However, the site and stream were dry when surveyed, thought to be due to groundwater abstraction (Fojt, 1990). The site supports a good range of breeding birds. There is, at present, no record of significant vegetation deterioration.

Roydon Fen remains a diverse wetland, supporting tall and species-rich short fen communities in addition to fen scrub and carr woodland. River drainage, in conjunction with groundwater abstraction and cessation of management, has resulted in vegetation deterioration. Management of the fen has been re-established.

Weston Fen is in the upper reaches of a tributary of the Little Ouse River. It has varied soils ranging from acid and base rich sands to wet fen peat. The vegetation communities are similarly varied. A NVC survey (Ausden and Harding, 1991c) identified Weston Fen as one of the most important concentrations of fen communities remaining in East Anglia. In addition, the fen has a number of plants of both national and regional conservation interest, and supports important assemblages of invertebrates. It has apparently not been significantly affected by changes in groundwater levels.

Wortham Ling, a heath with occasional damp hollows, is located near the River Waveney on sandy river terraces. Water inputs are predominately topogenous. The endangered Natterjack Toad was found at the site until the Roydon Fen to Doit Bridge drainage cut resulted in a drying out of the seasonal ponds where it was found.

3.2 Description of Non-statutory Conservation Sites

Bressingham Fen is a 7.28 ha calcareous valley fen situated just north of the River Waveney, 4km west of Diss. A designated County Wildlife Site, the site comprises mixed fen and tall herb fen flora and associated plant communities. Encroaching carr vegetation consists of willow and alder woodland.

Copince's Fen is a 6.96 ha fen south of Banham Moor. The County Wildlife site is presently degraded and encroached by hawthorn-dominated scrub and unimproved grassland.

Hall Farm Meadow, Wortham is a low-lying meadow supporting a diverse bird community. Based on the limited information available, it appears that there are no signs of plant community deterioration.

Hay Fen includes remnants of true fen, although encroaching scrub and woodland indicates a progressive drying out of surface water.

Horse Fen, Bressington is bounded by the diverted River Waveney and the old river course. The site is now an example of carr woodland, a successional vegetation stage which developed on a former fen wetland at the site.

Redgrave Park Lake is a ground-water fed lake, fringed by small areas of reed. It is an important site for birds. There is no record of significant vegetation deterioration.

River Waveney is a spring fed river forming part of the Norfolk Broads system. It has suffered from a lowered base flow and now has very low flows in summer months and large seasonal fluctuations in water level. It is a mesotrophic river supporting a poor aquatic species diversity. Major works were carried out between 1953 and 1963, with river dredging and the creation of drainage cuts predominately in the stretch between Roydon Fen and Redgrave and Lopham Fen (Suffolk Wildlife Trust, 1993).

River Wittle is a small fen bordering the river. The vegetation of scrub, grassland and woodland indicates the fen is drying out.

Spring at Spring Farm, Palgrave, identified from Ordnance Survey maps, has no vegetative information associated with the site.

Thrandeston Marsh is a species-poor site, predominately grassland with some water-logged herb-rich stands. There is no record of significant vegetation deterioration.

Wortham Marsh is low-lying common land including some wetland communities. There is no record of significant vegetation deterioration.

3.3 Effects of Management Practices

Historically, all the fens have been subject to reed and sedge cutting, and peat extraction, both of which had the secondary effect of maintaining the fen vegetation by creating a water regime and vegetative mosaic. Early forms of water control apparently had little effect on fen community composition (Suffolk Wildlife Trust, undated). Many fens were also grazed, which slowed carr succession and scrub invasion. Indeed, some communities (*Juncus subnodulosus-Cirsium palustre* and *Molinia caerulea-Cirsium dissectum*) are thought to owe their origin and maintenance to management (Fojt, 1990).

With the greatly reduced harvesting of fen resources, the natural process of carr succession has been exacerbated by current management practices designed to lower the water table and drain the wetlands (see Section 2.4). Of particular note, a drainage cut created between 1953 and 1963 drained Wortham Ling and led to the drying out of the Ling and the site extinction of the Natterjack Toad (a protected species).

Most of the fens in the area under study are thought to benefit from active management (Wetland Dossiers, University of Birmingham) although there is no indication as to the relative importance of active management versus groundwater levels in maintaining wetland community structure in these dossiers. Active management could include the re-introduction of grazing, cutting or mowing, occasional burning, rotational turf cutting, and peat stripping to remove the aerobic decomposing peat layers.

3.4 Summary

It is undeniable that over the past 40 years or so, a number of the wetland sites have deteriorated in terms of plant and animal species and in community interest. Without question, lack of vegetation management, surface water drainage and lowered groundwater levels by abstraction have contributed to the observed deterioration. It is difficult to attribute the cause of change to any one factor, although a number of studies indicate water levels and chemistry override management factors (Wheeler and Shore, 190; Boyer and Wheeler, 1989; Tyler, 1979).

Fen meadow communities (such as *Phragmites* and *Molinia Caerulea-Circium dissectum*) owe their origin and maintenance to management (Fojt, 1990; Harding, 1993a). Other communities, such as *Carex elata* swamp or *Schoeno-juncetra* are dependent upon suitable groundwater levels (Fojt, 1990). Furthermore, lack of saturated soil conditions leads to peat decomposition, an irreversible physical process which affects plant communities.

It is not possible to state with certainty for each site whether surface water drainage, groundwater abstraction, or a synergistic interaction between the two is the primary cause of soil drying. However it is true that for any fen management to be successful, the groundwater must be maintained at suitable levels.

4. HYDROGEOLOGY OF THE PROJECT AREA

4.1 Geology

The whole of the project area is situated on Cretaceous Upper Chalk which is unconformably overlain by Crag of Quaternary age. However, the Crag is generally absent north of a line from TM 25 86 through TM 18 78 to TL 90 60, but it does appear as isolated discontinuous lenses north of this line. Overlying the Upper Chalk and Crag is a complex sequence of interbedded and reworked Recent and Pleistocene drift of glacial and fluvial origin as shown on the geological sections given in Figures 4.2 to 4.4. The line of the sections is presented on Figure 4.1, which shows the surface contours of the Upper Chalk indicating that the Chalk outcrops at a number of locations throughout the project area. The geology of the project area is summarised in Table 4.1.

During the last ice age the surface of the Chalk was eroded leaving an uneven topographic surface with incised valleys up to 80 m deep in places. Subsequent deposition has infilled these features giving rise to the present gently undulating topography. A number of these buried valleys occur in the project area (see Figures 4.1 to 4.4).

The Upper Chalk varies in thickness from about 100 m to 200 m and forms the main aquifer in the project area. It is a fissured limestone with layers of flint nodules and a well defined layer of hard well fissured Chalk (Chalk Rock) marking its base. The Crag overlying the Upper Chalk is discontinuous and can be up to about 50 m thick. It comprises two distinct layers, the Norwich Crag which includes fine to medium sands with thin clay laminations, and the Red Crag which is identified by iron-stained medium to coarse shelly sands with clay layers. The Norwich Crag overlies the Red Crag. The Crag is regarded as a single water bearing unit which is largely in hydraulic continuity with the underlying Chalk. The Recent and Pleistocene drift deposits comprise discontinuous layers of Alluvium, Valley Gravels, Brickearth, Loams and Silts, Sands and Gravels, and Boulder Clay. The combined thickness of these sediments can be as much as 60 m where they infill the buried valleys in the Upper Chalk, although generally they range between 20 m and 40 m in thickness. Of these deposits only the Sand and Gravels can yield any significant volumes of water. The extent of hydraulic continuity between the Sands and Gravel and the underlying Crag and Chalk depends largely on the presence or otherwise of Boulder Clay and clayey layers within the drift sediments. Figure 4.5 and the sections in Figures 4.2 to 4.4 show the extent and influence of the Boulder Clay.

4.2 Aquifer Parameters

Due to the fissured nature of the Upper Chalk aquifer the aquifer parameters vary considerably throughout the project area. Transmissivity values range from 0.6 m^2/day to 7000 m^2/day and the Chalk aquifer varies from being confined, leaky to unconfined.

Figure 4.1

REDGRAVE AND LOPHAM FENS

CONTOUR MAP FOR THE SURFACE OF THE CHALK (TAKEN FROM BGS MAPS)

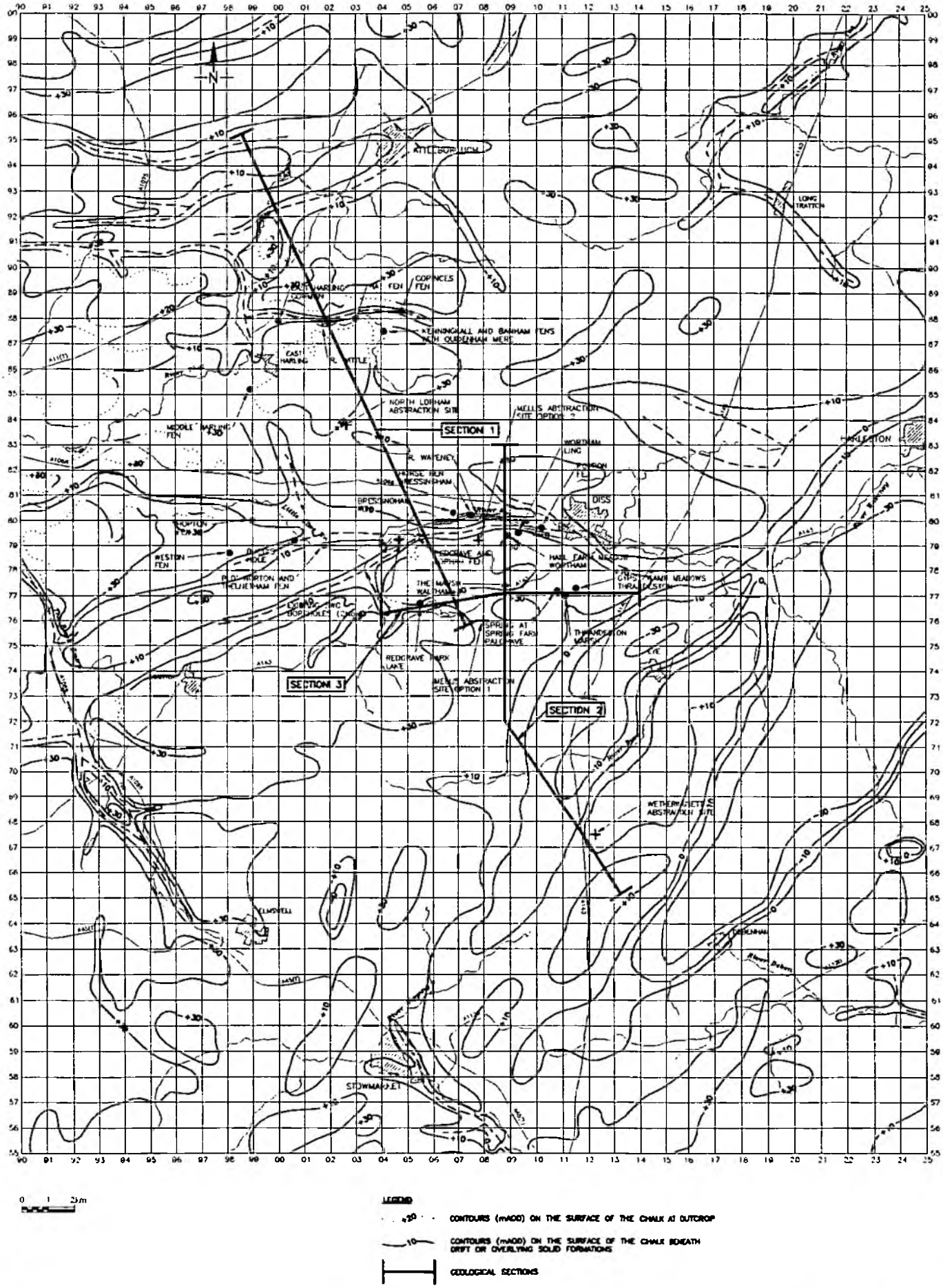
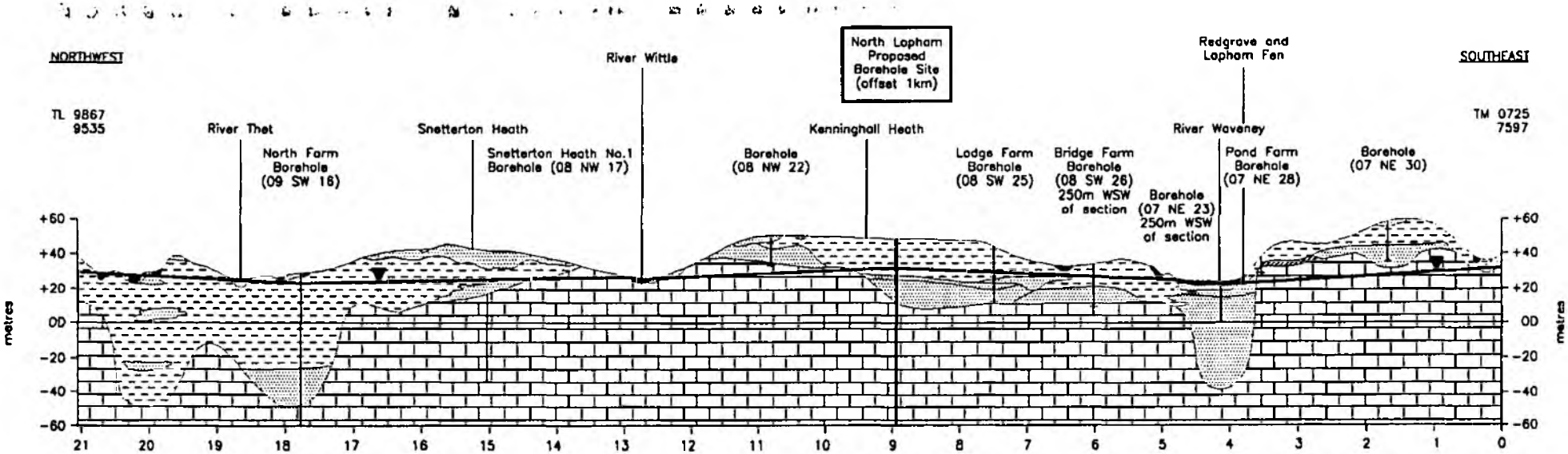


TABLE 4.1: GEOLOGICAL SEQUENCE IN THE PROJECT AREA

Age	Formation	BGS Description	Thickness (m)	Occurance
Recent & Pleistocene	Peat	Peat and clayey peat	<2	Generally follows palaeovalleys, overlies river terrace deposits in Waveney valley although elsewhere overlies boulder clay and chalk
	Alluvium	Silt and clay but sandy in places	0 – 4	Follows present surface drainage routes
	River Terrace Deposits	Sand and flint rich gravel	0 – 4	Follows present surface drainage routes
	Head Clay & Gravel	Clayey sand and sandy clay, locally pebbly. Head Gravel poorly sorted clayey gravel	0 – 4	Isolated lenses along the margins of present drainage routes
	Glacial Sands & Gravels	Sand and gravel, mainly flint rich	0 – 20	Occurs at the margins of present drainage routes as well as fill in palaeovalleys
	Boulder Clay or Lowestoft Till	Pebbly silty clay and pebbly sandy clay	0 – 50	Forms an undulating plateau throughout the whole of the project area. Generally absent in palaeovalleys although does occur as thin lenses within these palaeovalleys
	Glacial Silt & Clay	Silt and clay commonly laminated	0 – 60	Generally as infill to palaeovalleys. Outcrops on the margins of palaeovalleys
	Glacial Lake Deposits	Largely silt and clay but includes sand and gravel with pebbles of quartz, quartzite and flint	0 – 15	Occurs as isolated lenses particularly in the project area between Kenninghall and Attleborough
	Kesgrave Sands & Gravels	Quartz, quartzite and flint rich pebbly sand and gravel	0 – 15	Discontinuous lenses overlying Crag or Chalk. Outcrops with Crag and Chalk. Appears absent about 3 km north of Waveney valley
	Crag	Iron stained medium to coarse shelly sands with clay layers	0 – 60	Forms generally continuous sheet in the southwest of the project area. Few isolated lenses elsewhere
Cretaceous	Upper Chalk	Massively bedded, soft white limestone with occassional bands of nodular flint. The top 2 m to 3 m putty chalk	100 – 200	Forms basement to whole region. Forms undulating topography with deep palaeovalleys

REDGRAVE AND LOPHAM FENS
GEOLOGICAL SECTION 1



LEGEND

- Peat: Peat and clayey peat
- Drift: Including glacial sand and gravel, silt, clay
- Boulder clay
- Crag
- Upper chalk
- 1976 Chalk piezometric level

0 1000 2000 3000m

Horizontal Scale

Note: Based on BGS data

Figure 4.2

REDGRAVE AND LOPHAM FENS
GEOLOGICAL SECTION 2

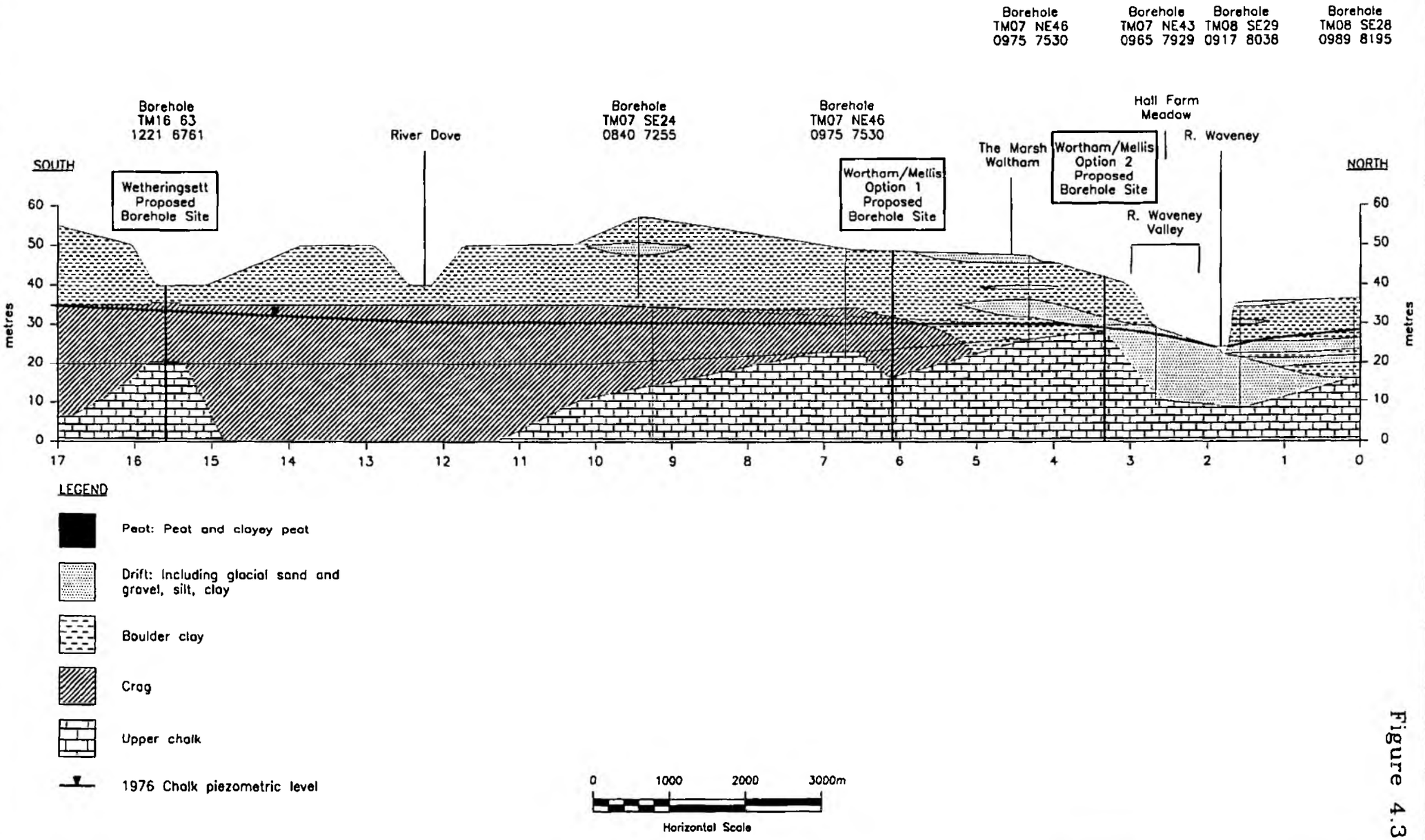
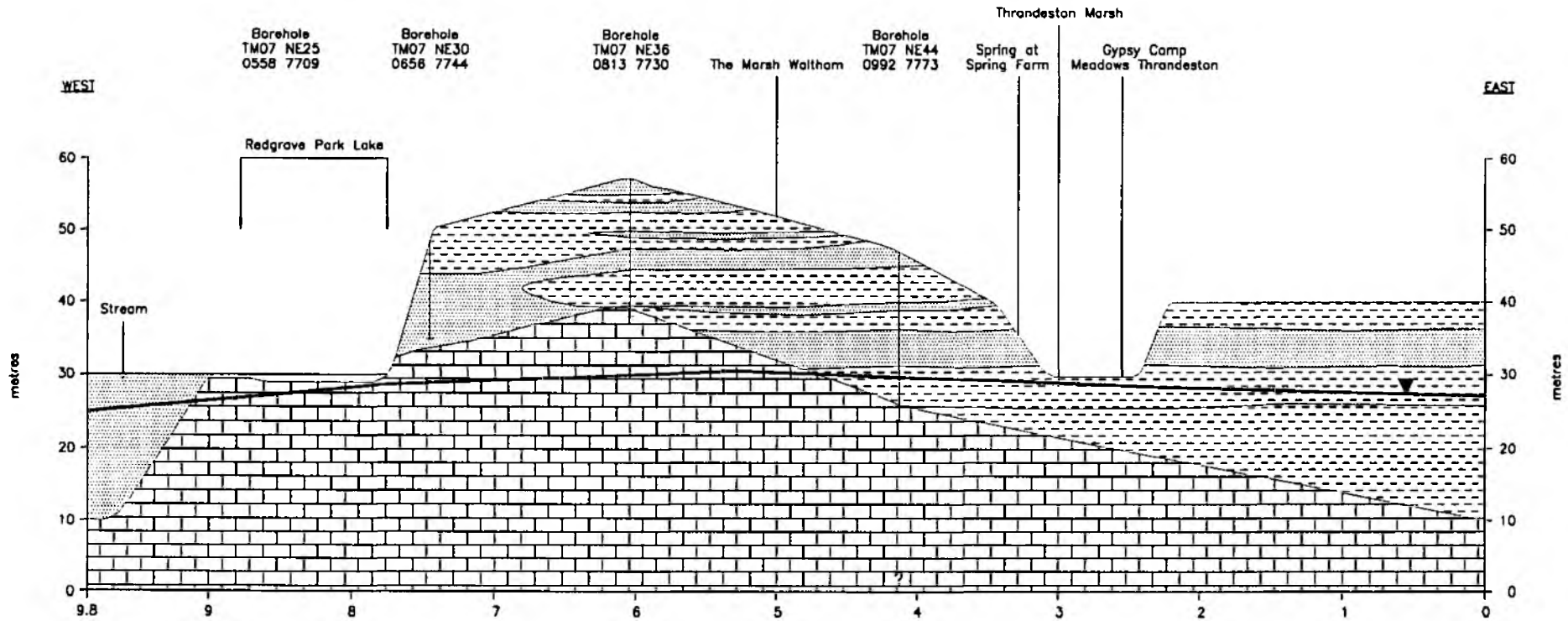


Figure 4.3

REDGRAVE AND LOPHAM FENS
GEOLOGICAL SECTION 3



LEGEND

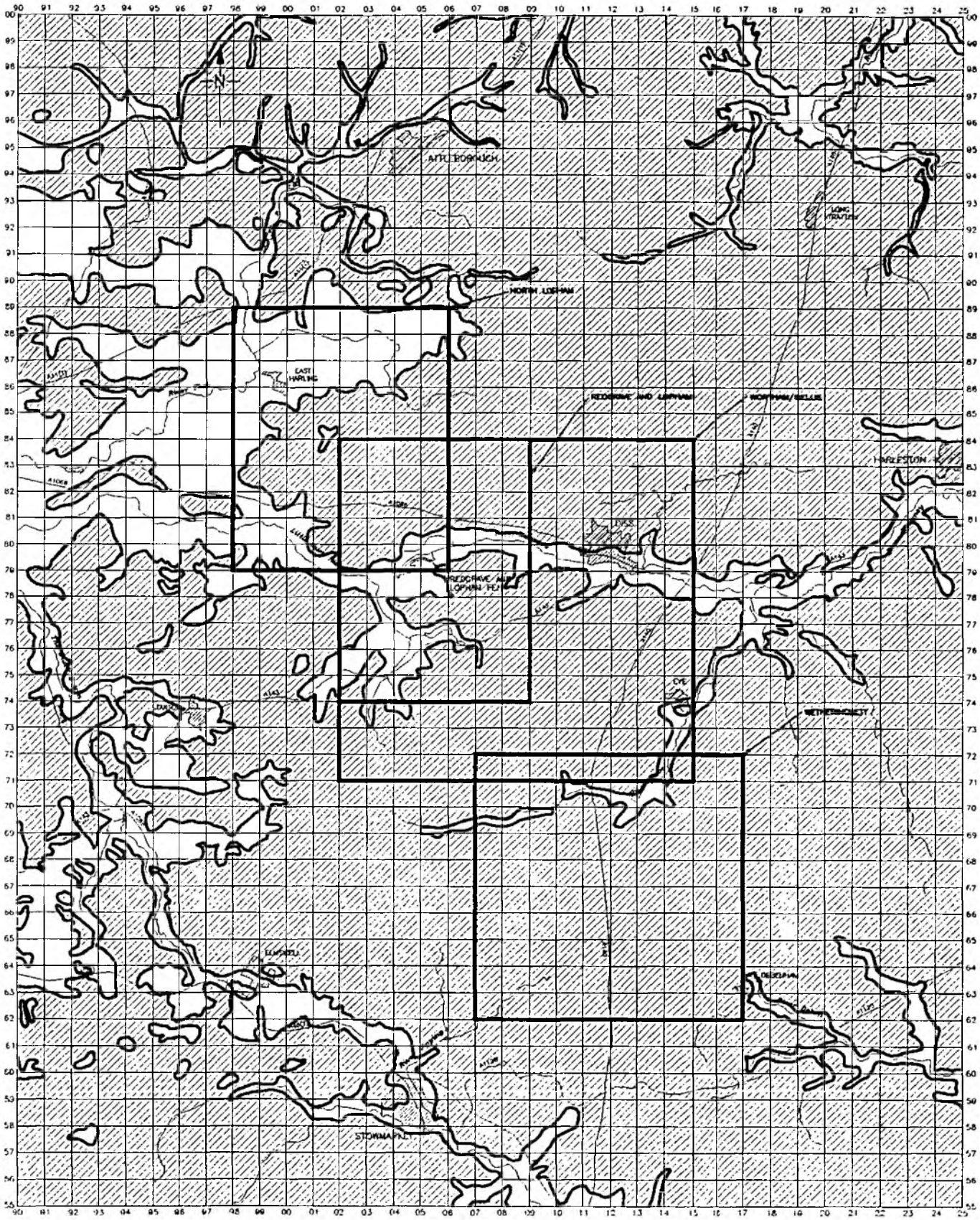
- Peat: Peat and clayey peat
- Drift: Including glacial sand and gravel, silt, clay
- Boulder clay
- Crag
- Upper chalk
- 1976 Chalk piezometric level

Figure 4.4

Figure 4.5

REDGRAVE AND LOPHAM FENS

BOULDER CLAY OUTCROP



In the Wortham/Mellis area transmissivity values generally range from 200 m^2/day to 500 m^2/day, although in one area it varies from 5000 m^2/day to 7000 m^2/day (Southern Science 1993). Storativity is estimated at 0.012. The Chalk aquifer in the south of the Wortham/Mellis area is leaky whereas in the north towards the River Waveney it is unconfined. At the Wetheringsett site in the south of the project area a pumping test provided highly variable estimates of transmissivity and storativity. The transmissivity ranged from 350 m^2/day to over 2000 m^2/day whereas the storativity ranged between 0.000004 to 0.0014. The aquifer at this location is clearly leaky. In the North Lopham area transmissivity estimates are of the same order of magnitude, between 200 m^2/day and 2500 m^2/day, whereas the storativity value is about 0.005. In the Redgrave area the transmissivity is about 1000 m^2/day and the Chalk aquifer is partially confined by the overlying drift.

No pumping test data exist for the shallow Sand and Gravel aquifer or the Crag. As discussed previously the Crag is generally regarded as being in hydraulic continuity with the Chalk and therefore they can be treated as one hydrogeological unit. The Sand and Gravel aquifer is likely to have highly variable aquifer parameters depending on the nature and extent of clayey layers within these sediments. Previous modelling studies in the Redgrave area have shown the drift is likely to have horizontal and vertical hydraulic conductivities of about 0.1 m/d and 0.0001 m/d respectively (Aspinwall 1992). In this study the vertical hydraulic conductivity was taken as 0.002 m/d, the low vertical value being due to the presence of significant clay layers within the drift.

4.3 Piezometry

Groundwater contour maps for the Chalk aquifer in the project area for 1976 (taken from BGS maps), 1988 (historical high) and 1992 (historical low) are presented in Figures 4.6 to 4.8. These show that there is a considerable variation in the natural range of Chalk groundwater levels, in some cases by only a few tens of centimetres and elsewhere by between 5 m and 10 m. These variations are due to the variable Boulder Clay cover and saturated thickness of the Chalk aquifer which means that it is confined in some places and unconfined in others, together with variable leakage from the overlying strata. The maximum hydraulic gradients vary between about 0.012 and about 0.008 however, in general they are considerably lower than this ranging between 0.0005 and 0.002.

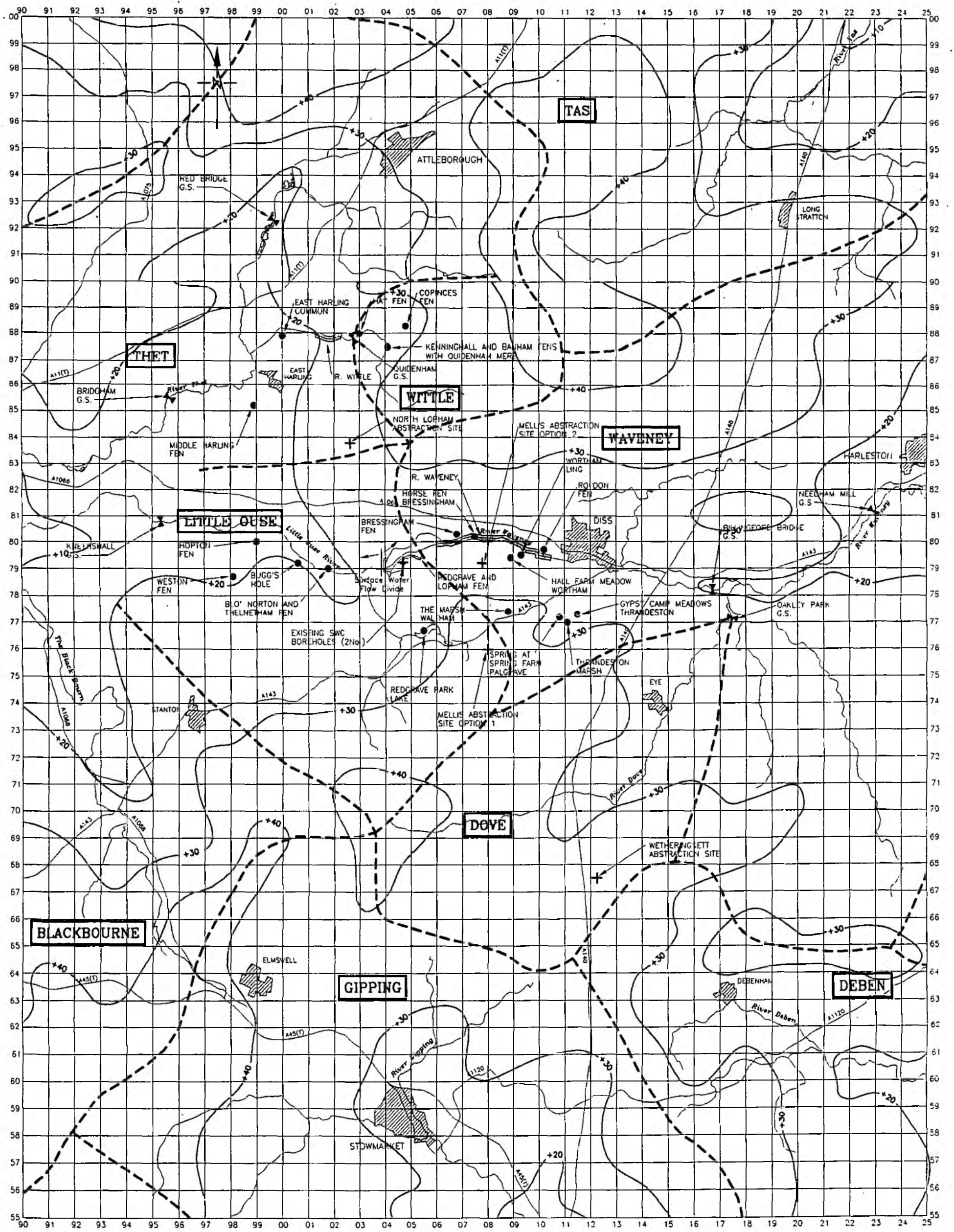
4.4 Groundwater Catchments

The groundwater catchments coincide, in general, with the surface water catchment boundaries. However, due to the low hydraulic gradients, variable abstraction patterns and highly variable drift cover the groundwater catchment boundaries do vary on a seasonal basis. The groundwater catchments are shown on the groundwater contour maps presented in Figures 4.6 to 4.8. The surface water catchment boundaries are shown on Figure 4.9.

Figure 4.6

REDGRAVE AND LOPHAM FENS

GROUNDWATER CONTOUR MAP FOR THE CHALK AQUIFER 1976 (TAKEN FROM BGS MAPS)



LEGEND

——— +30 ——— GROUNDWATER CONTOURS (mAOD)

– – – – – GROUNDWATER DIVIDE

BROKEN CONTOUR LINES INDICATE THAT THEY ARE INFERRED

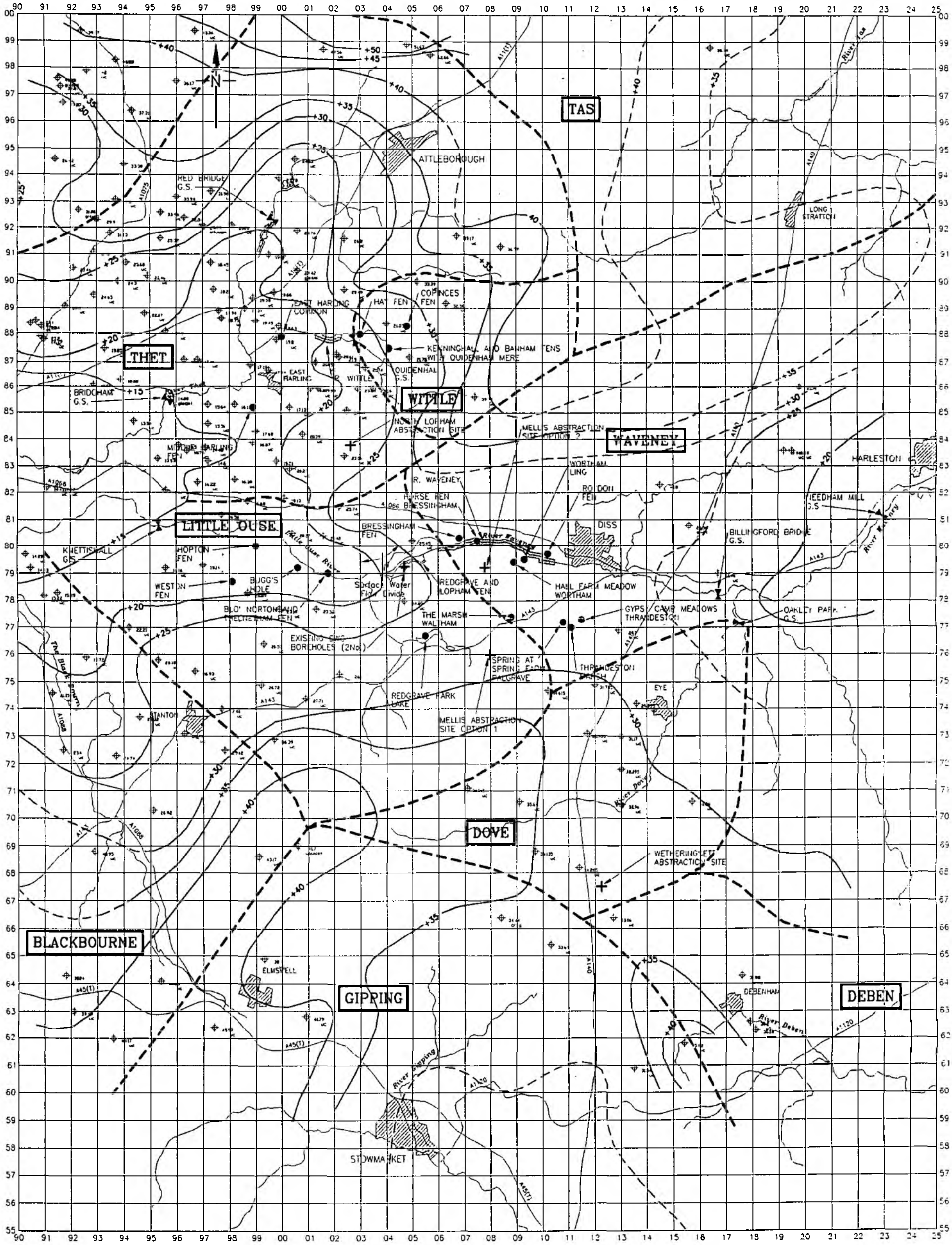
DEBEN CHALK GROUNDWATER CATCHMENTS

NOTE: DISCONTINUITY IN CONTOURS AT 90 NORTHING DUE TO EDGE EFFECTS FROM COMPUTER CONTOURING

Figure 4.7

REDGRAVE AND LOPHAM FENS

GROUNDWATER CONTOUR MAP FOR THE CHALK AQUIFER OCTOBER 1992 (HISTORICAL LOW)



0 1 2km

LEGEND

——— +30 ——— GROUNDWATER CONTOURS (mAOD)

– – – – – GROUNDWATER DIVIDE

BROKEN CONTOUR LINES INDICATE THAT THEY ARE INFERRED

DEBEN — CHALK GROUNDWATER CATCHMENTS

WATER LEVEL (mAOD) AQUIFER — OBSERVATION BOREHOLES

Figure 4.8

REDGRAVE AND LOPHAM FENS

GROUNDWATER CONTOUR MAP FOR THE CHALK AQUIFER MAY 1988 (HISTORICAL HIGH)

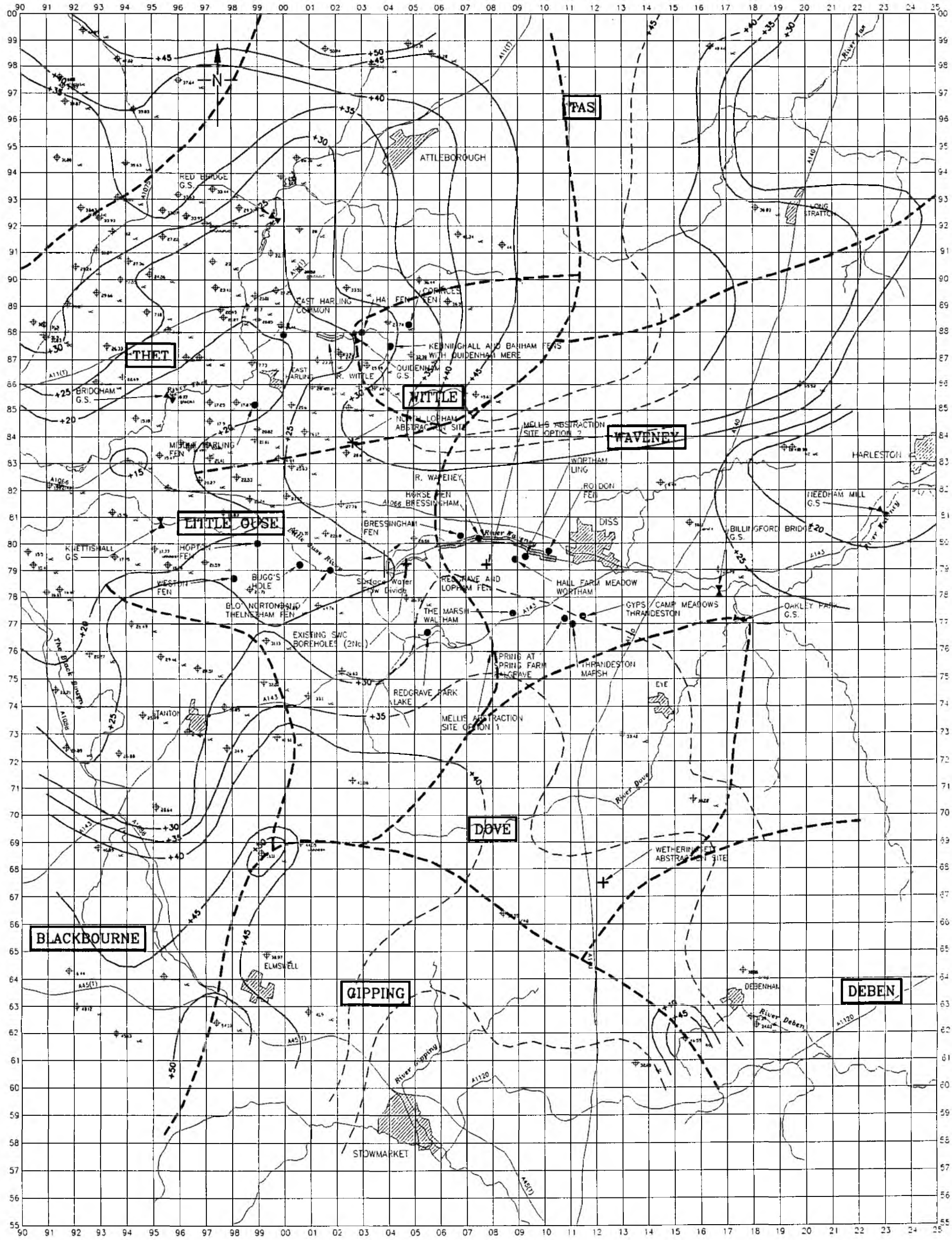
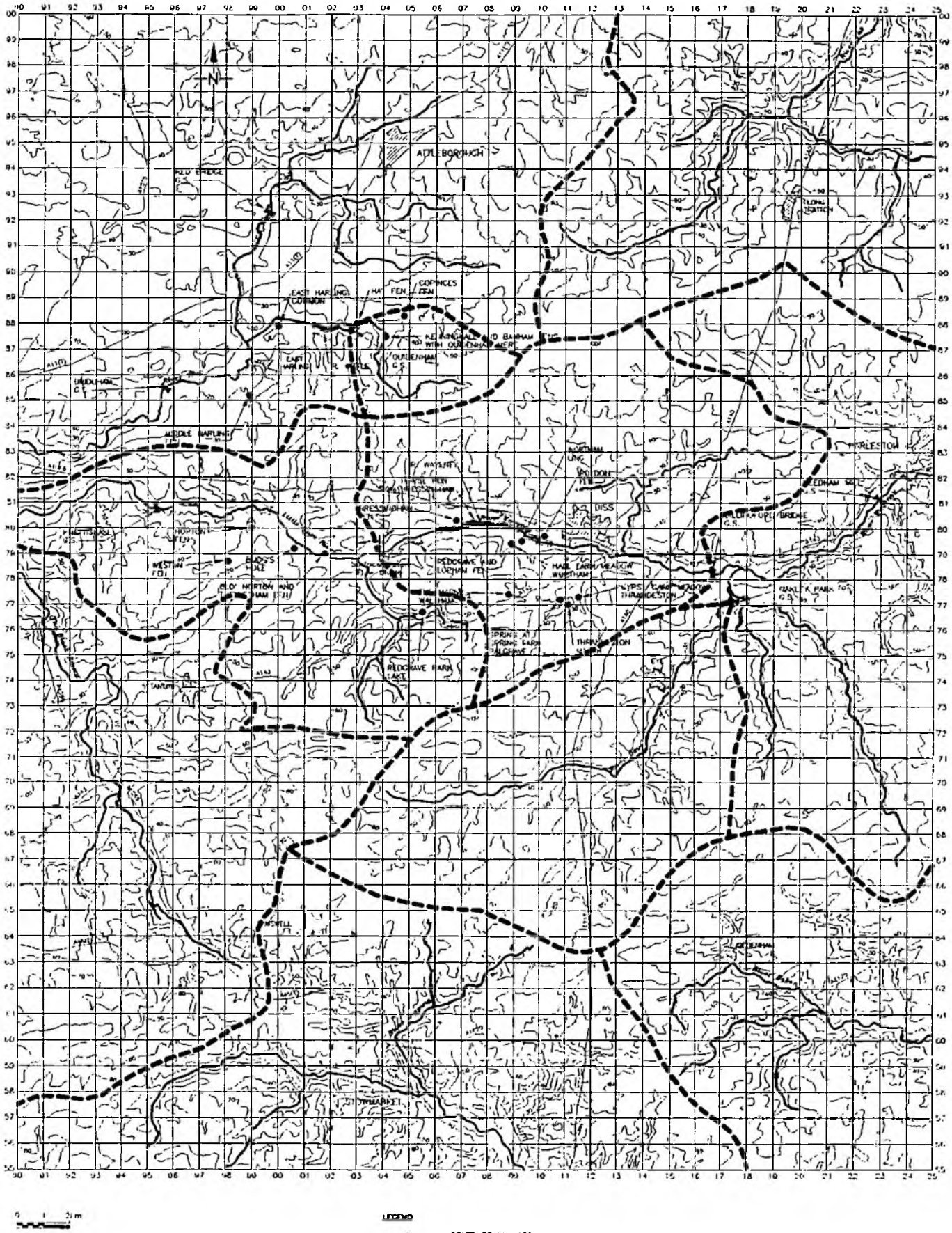


Figure 4.9

REDGRAVE AND LOPHAM FENS

TOPOGRAPHIC MAP SHOWING SURFACE WATER CATCHMENT BOUNDARIES



The existing Redgrave sourceworks together with the proposed alternative abstraction sites all lie either on or close to groundwater catchment boundaries. The seasonal variation in the groundwater levels means that all these abstractions could impact different catchments at different times of the year. In addition, these abstractions could move groundwater catchment boundaries slightly from their existing positions. The groundwater catchments likely to contribute to each of the abstraction boreholes are:

Abstraction Site	**Groundwater Catchment**
Redgrave	Little Ouse Waveney
North Lopham	Little Ouse Wittle Thet
Wortham/Mellis	Little Ouse Waveney
Wetheringsett	Dove Deben Gipping

4.5 Interaction with Drift and Watercourses

There has been little long term monitoring of the drift and the Chalk aquifers throughout the project area; however, there are a number of piezometers in the drift at wetland conservation sites monitored by the NRA and Suffolk Wildlife Trust. In some cases these piezometers show little or no variation in head with depth, while at some sites there is a clear transition during the year. During the recharge period in the winter and spring there is a clear downward hydraulic gradient in the drift, whereas in the summer this reverses due to evaporation and possible upward leakage from the Chalk aquifer.

The groundwater contour maps (see Figures 4.6 to 4.8) clearly show that all the rivers in the project area are gaining from the Chalk aquifer.

4.6 Water Quality

The Chalk aquifer provides a major source of water for potable, agricultural and industrial purposes in East Anglia. Iron concentrations in the project area are often above EC limits. This is the case at the existing Redgrave sourceworks and in the Wortham/Mellis area (Southern Science 1994). However, at Wetheringsett and North Lopham the existing river augmentation boreholes indicate that the groundwater in these areas can meet the EC Directive on Drinking Water Quality. Other minor water quality problems encountered in the Wortham/Mellis area were with suspended solids and one borehole had unacceptable

levels of ammoniacal nitrogen and hydrogen sulphide odour was observed (Southern Science). None of these problems is considered to preclude the development of an alternative public supply source in the Wortham/Mellis area.

More detailed water quality information would be required from a long term pumping test in order to ensure that the water meets the required standard for all determinands.

4.7 Abstractions

There are several hundred licensed groundwater sources in the project area whereas there are less than twenty surface licenses, indicating the importance of groundwater as the main source of water. The locations of the current groundwater and surface water abstraction licences are presented in Figure 4.10, together with the associated maximum daily licensed abstraction rates.

Much of the groundwater abstraction is for agricultural purposes (spray irrigation) although there are a number of major public supply boreholes, either for direct supply or supporting rivers for downstream abstractions. The latter is the case with the NRA GOGWS scheme where groundwater abstraction is for export to Essex reservoirs as part of the Ely Ouse-Essex Scheme. In addition to these abstractions there are also a number of NRA river augmentation boreholes for maintaining flow during drought periods.

4.8 Water Balances for Catchments

The NRA have recently undertaken a review of the available water resources for the main catchments within the project area (NRA 1992). This detailed review includes a number of different techniques for the assessment of the available groundwater resources including the following:

- Wright (1974) method based on geological assessment of infiltration rates and areas and calibrated to baseflows, with reduction of 5% to allow for reliable flow decrease. This was used for the Little Ouse and Thet catchments.

- Baseflow analysis was used for the Waveney, Dove and Deben catchments.

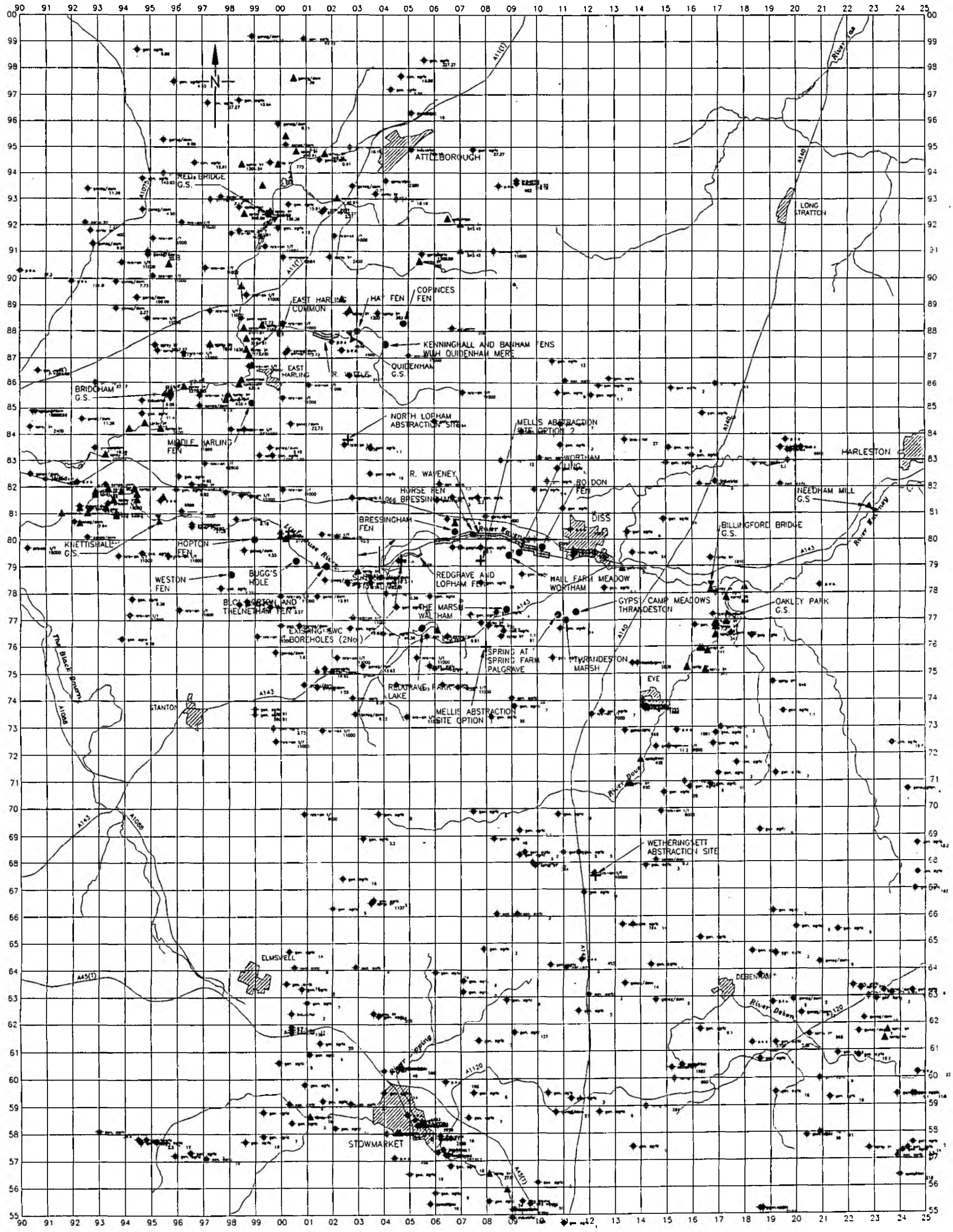
- Distributed groundwater model was used for the Gipping catchment.

The catchment water balances are based on the licensed groundwater and surface water abstractions. Surface water returns, to account for effluent returns, are estimated where dry weather flows or consents are

Figure 4.10

REDGRAVE AND LOPHAM FENS

GROUNDWATER AND SURFACE WATER ABSTRACTIONS



0 1 2km

LEGEND

LICENSED GROUNDWATER ABSTRACTIONS
- ✦ LICENSED USE
  LICENSED ABSTRACTION (m^3/day)

LICENSED SURFACE WATER ABSTRACTIONS
- ▲ LICENSED USE
  LICENSED ABSTRACTION (m^3/day)

not available, using a number of assumptions depending on the category of use.

The water balances for the Little Ouse and Thet catchments have been undertaken together to below Abbey Heath gauging station on the Little Ouse as they are both within the same unit within the Cambridgeshire Chalk. The water balance for the Little Ouse catchment includes the existing Redgrave sourceworks, although the groundwater catchment boundary at this location is unclear and could be located several kilometres either east or west from its position in the Waveney valley suggested by BGS (see Figure 4.6). The water balance shows that even including the Redgrave sourceworks there is only 2.2 tcmd of available resource due to the large proportion of the available groundwater resources required for river flow needs (based on the Q_{95} flow). Even if the river allocation were to be reduced to 50% of gross resource only a further 9 tcmd could be licensed in this catchment. There is 78.8 tcmd of licensed abstraction as part of the NRA groundwater scheme which has not been included in the overall water balance as it used to support the in-river environmental requirements.

The water balance for the Waveney catchment to the gauging station at Billingford Bridge shows that there is a nominal surplus in groundwater resources of 5.3 tcmd. This indicates that there are sufficient resources to enable the transfer of the Redgrave borehole(s) into the Waveney catchment in the Wortham/Mellis area. There are no NRA groundwater schemes in operation within the Waveney catchment to Billingford Bridge.

The River Dove catchment to Oakley Park gauging station has a nominal groundwater surplus of 3.8 tcmd. This would only just cover the required abstraction for the replacement for the Redgrave borehole of 3.6 tcmd. The Dove catchment has an NRA groundwater scheme licensed for 16.3 tcmd used to support the PWS surface water abstraction at Shipmeadow by Suffolk Water Company. However, of this 16.3 tcmd only 8 tcmd is required for in-river needs and therefore the balance of 8.3 tcmd is regarded as an abstraction with no returns as the water is exported out of the catchment.

The water balance for the River Deben catchment to Naunton Hall gauging station shows a nominal surplus of 3.5 tcmd. The alternative abstraction site at Wetheringsett is generally within the Dove catchment however, it is likely to impinge slightly on the Deben catchment as well. The surplus of 3.5 tcmd is sufficient to support this additional abstraction as it will only be partially drawing from the Deben catchment.

The River Gipping catchment in the southern part of the project area is estimated to have a groundwater deficit of 4.4 tcmd to Bramford gauging station. Clearly there are insufficient groundwater resources to support any further abstraction at the present time in the Gipping catchment. The close proximity of the proposed Wetheringsett abstraction site to the

River Gipping catchment means that it is possible that there will be a minor impact on this catchment. This is in part due to the seasonal variations in groundwater levels together with uncertainties about the exact position of groundwater catchment boundaries. However, this impact is considered to be insignificant.

4.9 Historic Changes in Groundwater Levels

The Chalk groundwater levels throughout the project area show typical seasonal fluctuation due to variation in recharge. The more pronounced variations in water levels in the interfluves at the catchment divides. From the mid to late 1970s the long term moving average groundwater levels were stable or showing a slight increase, reflecting the return to average rainfall patterns following the 1976 drought. This culminated in historically high groundwater levels in about May 1988. However, the drought from 1988 to 1991 caused a general decline in groundwater levels. This decline also reflects the increase in abstraction during this period, particularly for spray irrigation, which would be expected during a period of prolonged drought. The decline in water levels ranged from a few tens of centimetres to 4 m. Since 1992 there has been a general recovery of water levels to pre-1988 levels with the major recharge events in the winters 1992/93 and 1993/94.

5. ECOLOGICAL METHODOLOGY AND ASSESSMENT

In this chapter, the methodology used for estimating the ecological sensitivity of wetland sites to changes in groundwater level, quality and throughflow is described.

An ecological screening was conducted on the 22 sites set out in Chapters 2 and 3 to identify which sites are significant groundwater dependent wetlands. The screening incorporated the following elements:

- Sensitivity of plant species to groundwater changes
- Presence of species of conservation interest
- Presence of communities of conservation interest
- Sensitivity of communities at sites to groundwater quality

The data used to assess current site sensitivity were derived from the species lists in the SSSI and Trust data sheets. These were compiled between 1972 and 1990 by various (unknown) surveyors using unspecified methodology. It is unlikely that the species lists are complete, with an emphasis probably given to the more unusual or more noticeable species. In some cases the lists were very incomplete with no English or Latin names given, only generic groupings. Furthermore, there are no estimates of habitat area, so the relative importance of each species/assemblage cannot be assessed.

In some cases National Vegetation Survey data have been collected and analyzed (for Hopton Fen [Ausden and Harding, 1991b]; Redgrave & Lopham, Buggs Hole, Blo'Norton [Jerram, 1992]; Thelnetham Fen [Ausden and Harding, 1991a]; Weston Fen [Ausden and Harding, 1991e]). Where available, these data were also used in the analysis.

Using the available data, community types for each site have been developed, using computerised programs developed for the EC (Hills et al, 1994, Hill, 1993). The results are presented in Appendix D.

5.1 Plant Species Water Level Preference

Five categories of plant species are grouped according to water level preference, based on the long-term average water table (Table 5.1, and Appendix C), using information consolidated from a number of sources (Commission of the European Communities, 1991; Wheeler and Shaw, 1992; Hills et al, 1994; van Wirdurn, 1993; Harding, 1993b,). The scheme has been applied to herbaceous vascular plants, since these are best described in the species lists, are good indicators of wetland habitats and are responsive to water stress. Although bryophytes are the most sensitive group of plants responsive to water level stress, data on bryophytes were not sufficiently uniform to enable their use as the basis for comparison of all sites.

Table 5.1: Plant Species Groupings based on Preferred Mean Water Table Level

Mean Water Level Category	Details
Class 1	Plants of open water and flooded conditions (water table 0cm or higher)
Class 2	Plants characteristic of wetland soils (water table 0 to -2cm below ground level; very wet conditions)
Class 3	Plants typical of wet conditions (water table -2 to -5cm below ground level)
Class 4	Plants typical of wet conditions (water table -5 to -10cm below ground level; damp soils)
Class 5	Plants typical of drying soils, includes tolerant wetland species and species typical of non-wetland habitat (water level -10cm below ground level and lower)

These categories are based on mean values for summer water table conditions in UK wetlands. Plant species with a preference for high water levels (Class 2, some Class 3 species) are those most under threat from past land and water management practices, and have declined in number over much of south eastern England. Some plant species in Class 4 and all in Class 5 are generally more widely distributed, and have wider tolerances. For example the common reed *Phragmites australis* (Class 4) grows in a mean water table of -6cm, but is found in water tables ranging from +24 to -100cm. However, it can be assumed that the long-term average water table levels provide a realistic indication of the ability of the plant species to survive and reproduce. Plants of open water (Class 1) are a unique category, totally dependent upon high groundwater levels or reliable surface water.

A fundamental concept applying to all systems (chemical, physiological, species or community) is that of homeostasis: that a system will tend to remain in balance until internal or external feedbacks become so out of balance that the system crashes precipitously to an altered state (Harding, 1963). Radical shifts in community composition, peat degradation rate, and species extinction are examples of wetland systems changing their homeostatic balance. Typically a change in environmental conditions and altered feedbacks are tolerated with no observed response, until a critical point is reached at which catastrophic decline is normally observed (Odum, 1971). To return the system to the initial condition requires an input of energy (second law of thermodynamics); in the case

of fen restoration, in the form of human management such as shrub clearing and weed control.

Work by Gowing et al (1993) applies this concept at a species level. Over 1000 $1m^2$ quadrats were measured for species abundance and soil water levels. The average abundance for all the sites (irrespective of water levels) was calculated (average in Figure 5.1). The actual abundance were then plotted against water level. Results show the Common Sedge is either significantly more common than expected (average), at high water levels, or significantly less common than expected at low water levels. The shift between the two states is a precipitous decline.

The plant species listed for each site have been classified according to their tolerances as defined in Table 5.1. A conservative approach to assessing plant sensitivity has been taken, based on presence/absence of species at the individual sites, and the results are given in Table 5.2.

5.2 Presence of Plant Species of Conservation Interest

A second assessment was made for species of conservation interest. More data were available for plants than for fauna, and the presence/absence of plants of both national and regional scale conservation interest (as defined in the Nature Conservancy Council, 1989) was identified (see Table 5.2). Further details can be found in Appendix C, which lists the species by their water preference category and their rarity.

5.3 Presence of Animal Species of Biological Interest

Animal species of biological interest were taken to include 'Red List Data Book' invertebrates, important assemblages, identified bird feeding or nesting areas, and known presence of protected mammals. The occurrence of significant animal species or assemblages was difficult to ascertain, but presence/absence is indicated in Table 5.2, Notable Fauna/Communities.

5.4 Presence of Communities of Conservation Interest

Plant communities are perhaps a more significant and important level of ecological analysis. Not only are the communities made up of individual species, which could in themselves be rare, but the community may also be rare (see Nature Conservancy Council, 1989, for discussion of rarity). Many of the communities of the fens are nationally rare or restricted, and East Anglia is the most important area in England for their conservation. NVC communities of conservation importance are given in Appendix C.

Furthermore, some communities are internationally rare, being identified on the EC Habitats and Species Directive (92/43/EEC) as being notable habitats which are particularly threatened. The Directive lists a number

Figure 5.1 Typical response of a population to a major ecological stress. In this case, common sedge response to drought stress, based on experimental data, is used as an example (Gowing et al, 1993).

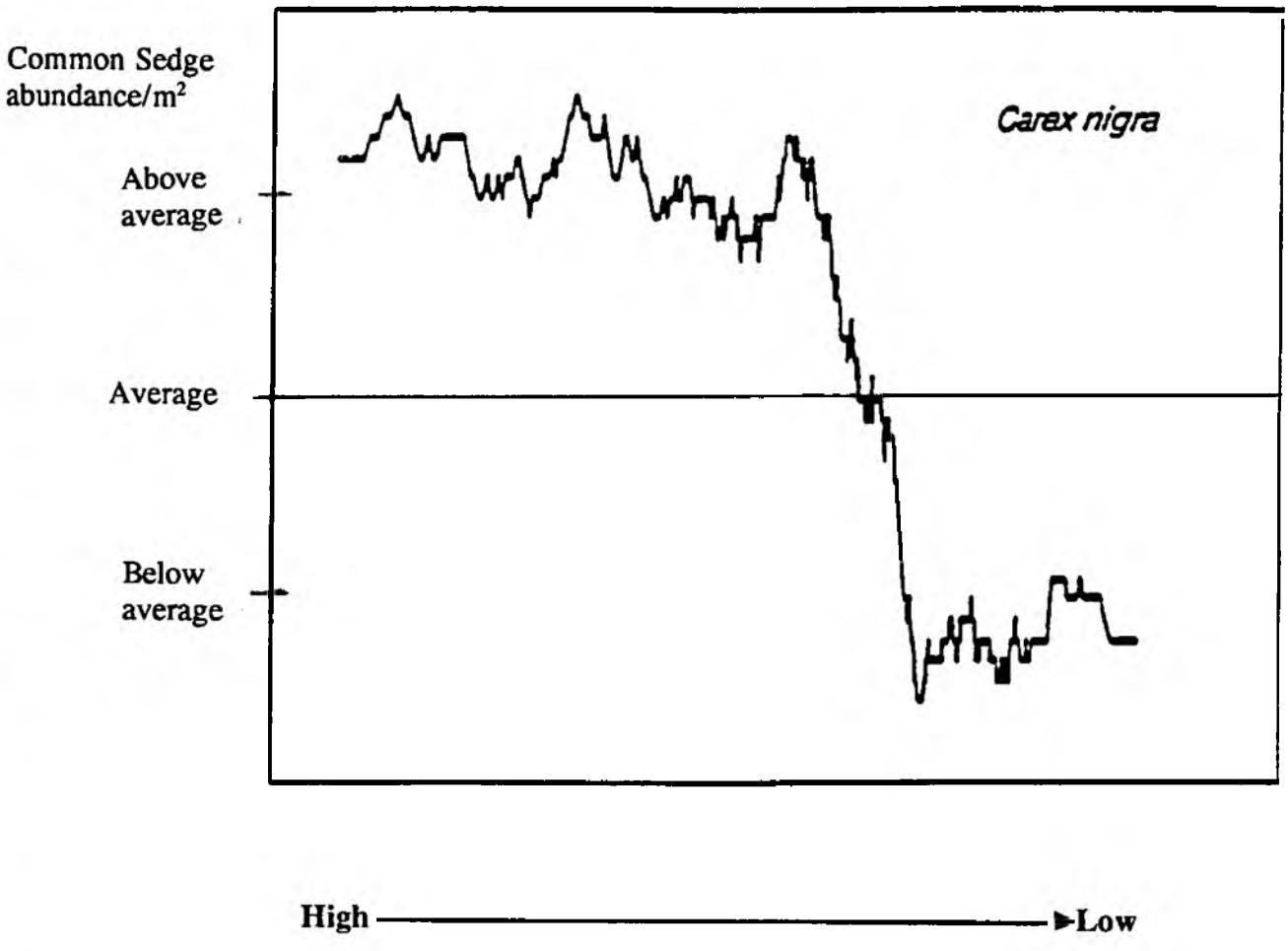


Table 5.2 : Species Recorded at Wetland Sites

	Plant Species Mean Water Level Category					Species of Conservation Interest				
Site Name	**Class 1 Plants**	**Class 2 Plants**	**Class 3 Plants**	**Class 4 Plants**	**Class 5 Plants**	**Plants of National Conservation Interest**	**Plants of Regional Conservation Interest**	**Notable Fauna/ Communities**	**Date of Survey**	**Communities of Conservation Interest (NVC)[1]**
Water table (cm below ground level)	Open Water	0 to -2 cm	-2 to -5 cm	-5 to -10 cm	> -10 cm					
Blo' Norton and Thelnetham Fens	-[2]	Present	Present	Present	Present	Present	Present	nd [3]	1972, 1991, 1992	W2, M22, M13, S24, M24
Bressington Fen	-	Present	Present	Present	Present	-	-	nd	1983	W2
Bugg's Hole Fen	-	Present	Present	Present	Present	Present	Present	nd	1984, 1992	M24, M13, S2
Copince's Fen	-	-	-	Present	Present	-	-	nd	1983	-
East Harling Common	Present	Present	Present	Present	Present	Present	Present	Present	1989	S1 CG6
Gypsy Camp Meadows	Present	Present	Present	Present	Present	-	Present	nd	1987	-
Hall Farm Meadow, Wortham	Insufficient Data							Present?		
Hay Fen	Insufficient Data									
Hopton Fen	-	-	Present	Present	Present	Present	Present	nd	1984, 1991	M24, S24
Horse Fen, Bressingham	-	-	-	-	Present	-	-	nd	1983	-
Kenninghall and Banham Fens with Quidenham Mere	Present	Present	Present	Present	Present	Present	Present	nd	1985	M13, S2 CG3
Middle Harling Fen	-	Present	Present	Present	Present	Present	Present	Present	1986	MG1, M13
Redgrave Park Lake	Insufficient data							Present ?		

Table 5.2 : Species Recorded at Wetland Sites (contd)

	Plant Species Mean Water Level Category					Species of Conservation Interest				
Site Name	**Class 1 Plants**	**Class 2 Plants**	**Class 3 Plants**	**Class 4 Plants**	**Class 5 Plants**	**Plants of National Conservation Interest**	**Plants of Regional Conservation Interest**	**Notable Fauna/ Communities**	**Date of Survey**	**Communities of Conservation Interest (NVC)[1]**
Water table (cm below ground level)	Open Water	0 to -2 cm	-2 to -5 cm	-5 to -10 cm	> -10 cm					
Redgrave & Lopham Fen	Present	Present	Present	Present	Present	Present	Present	Present	1985, 1992	M24, M25, M13, S2, M22, W2, H1
R. Waveney	Present	Present	Present	Present	Present	Present	Present	nd	?	-
R. Whittle	-	-	-	Present	Present	-	-	nd	1983	-
Roydon Fen	-	-	Present	Present	Present	Present	Present	nd	1983	S2, M25, W2
Spring at Spring Farm, Palgrave	Insufficient data									
Thrandeston Marsh	Insufficient Data									
Weston Fen	Present	Present	Present	Present	Present	Present	Present	Present	1972, 1991	M24, M22, MG1, S2, M13, H1
Wortham Ling [4]	-	-	Present	Present	Present	-	-	nd	1990	MG1, H1
Waltham Marsh	Insufficient data									

Key

1 National Vegetation Classification communities described in Appendix C
2 Not present
3 No data available
4 Not wetland communities
? Status indicated in observations/casual writings

of habitat types (classified under the European vegetation classification, CORINE, not NVC) which are of Community interest due to their being in danger of disappearing within the natural range, or if they have a small natural range. Forty-two of the habitat types are asterisked, indicating these as priority habitats which are in danger of disappearance, and which community members have particular responsibility to maintain and/or restore. Calcareous fen habitats identified in the Directive are given in Appendix C.

The communities for all sites have been analyzed using the TABLEFIT package (Hill, 1993), which allocates vegetation to NVC categories on the basis of species present. Plant community data have also been independently derived by Suffolk Wildlife Trust (SWT) who conducted NVC surveys in 1991 and 1992 for Hopton Fen, Redgrave and Lopham Fens, Buggs Hole, Blo'Norton, Thelnetham Fen and Weston Fen, using standard NVC methodology. Both TABLEFIT and surveyed NVC data have been used.

5.5 Groundwater Quality

Data on water quality at the sites are sparse. Wetland site dossiers available for 8 sites include a section on hydrochemistry. In all but three cases this section is not quantified, with water quality estimates based on vegetation present or by extrapolation to nearby sites.

Due to the lack of site specific water quality data, water quality has not contributed to the prioritisation of sites, and rather than inferring water quality from an analysis of species and vegetation present, these biological data have been used directly in Sections 5.2, 5.3 and 5.4.

In general, the sites are important for their calcareous fens, and all are likely to have calcium-rich, nutrient-poor soligenous water inputs. Changes in water quality will certainly effect changes in the floristic composition of the sites (such as an increase in *Phragmites* and ruderals such as nettle) (Harding, 1993a).

5.6 Summary of Ecological Sensitivity

It is apparent from Table 5.2 that many of the sites are significant, supporting either wetland plants or communities, plants that are considered to be of national or regional significance, or notable faunal species or assemblages. The information in Table 5.2 is consolidated in Table 5.3, as described below.

Plant Species Water Level Preference: The Wetland Plant Species is based on presence/absence of any one (or more) species. If a species in Class 1 or 2 is listed, the site is ranked 'high'; the presence of a Class 3 or 4 species gives the site a 'medium' ranking; and only Class 5 species listed results in a 'low' ranking.

Table 5.3 : Estimated Site Ecological Sensitivities Based on Current Status

Site Name	Grid Ref	Wetland Plant Species	Plants of Conservation Interest	Faunal Sensitivity	Community Sensitivity	Overall Ecological Sensitivity
Blo' Norton and Thelnetham Fens	TM017790	High	High	nd	High	High
Bressington Fen	TM060809	High	Low	nd	High	High
Bugg's Hole Fen	TM006792	High	High	nd	High	High
Copince's Fen	TM048883	Moderate	Low	nd	Low	Moderate
East Harling Common	TM000879	High	High	High	High	High
Gypsy Camp Meadows	TM115773	High	Moderate	nd	Low	High
Hall Farm Meadow, Wortham	TM089794	nd	nd	High ?	nd	High *
Hay Fen	TM030880	nd	nd	nd	nd	Low *
Hopton Fen	TM990800	Moderate	High	nd	High	High
Horse Fen, Bressingham	TM075802	Low	Low	nd	Low	Low
Kenninghall and Banham Fens with Quidenham Mere	TM041875	High	High	nd	High	High
Middle Harling Fen	TM989852	High	High	High	High	High
Redgrave Park Lake	TM055767	nd	nd	High ?	nd	High *
Redgrave & Lopham Fen	TM050797	High	High	High	High	High

Table 5.3 : Estimated Site Sensitivities Based on Current Status (contd)

Site Name	Grid Ref	Wetland Plant Species	Plants of Conservation Interest	Faunal Sensitivity	Community Sensitivity	Overall Ecological Sensitivity
R. Waveney	TM060799 - TM070801 and TM089790 - TM105795	High	High	nd	Low	High
R. Wittle	TM013880 - TM023879	Moderate	Low	nd	Low	Moderate
Roydon Fen	TM102797	Moderate	High	nd	High	High
Spring at Spring Farm, Palgrave	TM108772	nd	nd	nd	nd	Low *
Thrandeston Marsh	TM111770	nd	nd	nd	nd	Moderate *
Weston Fen	TL981787	High	High	High	High	High
Wortham Ling	TM093795	Moderate	Low	nd	Low	Moderate
Waltham Marsh	TM088774	nd	nd	nd	nd	Moderate *

? Uncertain status

* In the absence of information we have assumed the Overall Ecological Sensitivity to be as indicated

Plant Species of Conservation Interest: This is based on the presence/absence of any one (or more) species. If a species of national conservation interest is present, the site is ranked 'high'; while species of regional conservation interest gives a 'medium' ranking.

Animal Species of Biological Interest: Faunal Sensitivity is assessed as 'high' if any significant animal or assemblage of animals are identified.

Communities of Conservation Interest: The surveyed or predicted presence of a community asterisked on the EC Habitats Directive is assessed as 'high' in Table 5.3, Community Sensitivity.

Groundwater Quality: The groundwater data are insufficient to enable site comparisons and are not included in this analysis.

Overall Ecological Sensitivity: An overall ranking of the importance of individual sites has been attempted. On scientific grounds, it is impossible to rank the relative importance of plants of national conservation value against wetland communities or animal assemblages; each category is equally significant in terms of ecosystem value. Therefore, the Overall Sensitivity of the individual sites is determined by the highest sensitivity in the matrix row. Due to the general nature of the available data, and therefore the conservative approach taken in the assessment, virtually all the sites are classified as having an overall 'high' sensitivity.

Furthermore, the persistence of an ecosystem is dependent upon both a sufficient gene pool and an adequate area of similar habitat. Island biogeography theory (MacAuther and Wilson, 1967) supports the value of 'island' habitats, in that if one 'island' suffers a catastrophic decline, recruitment occurs from near-by, unaffected 'islands'. In the current situation, the remaining fen sites are almost certainly an interacting system, and it is not known how critical the survival of all the individual sites is to the persistence of the wetland ecosystem in the area. Again, this indicates that the survival of all sites is important.

6. HYDROGEOLOGICAL AND HYDROLOGICAL METHODOLOGY

6.1 Introduction

This chapter describes the methodology adopted for estimating the water level changes in the Chalk and the subsequent changes in the shallow drift deposits. The impact on the Chalk aquifer was used as a means of classifying the overall risk of derogation to the wetland sites and of estimating the likely effects on groundwater abstraction licenses, and river flows and quality. The impact of these changes in water levels in the Chalk aquifer was then translated into changes in water levels in the overlying drift deposits and provided the basis for the comparative assessment of the various development options.

The methodology adopted in this study was based on analytical models of steady state leaky aquifer conditions to provide a 'maximum' assessment of the possible changes in the Chalk aquifer water levels. The aquifer parameters used were obtained from the results of pumping tests and summarised in Appendix F.

6.2 Estimations of Changes in Chalk Groundwater Levels

Assessment of the impact of the development options proposed by the NRA on Chalk water levels is discussed in Chapter 7 and was based on the following geological and hydrogeological data.

Wetheringsett

At this site a 7 day pumping test was undertaken by the NRA on the existing river augmentation borehole in October and November 1993. Observations were made in two Chalk observation boreholes up to 1 km away. No monitoring was carried out in the overlying deposits. There was a significant leakage effect during the test, presumably from overlying deposits, and this limited the cone of depression around the well. It is not clear whether this effect would be sustained in the long term, or whether the leakage/drainage from above would be maintained by storage between recharge seasons. Transmissivity values are significantly different between the pumped well and the observation boreholes, suggesting a limited thickness of fissured aquifer below the overlying cover, and considerable variation in permeability, perhaps with preferential flow paths.

A steady state 'leaky' analytical model based on DeGlee (1930 and 1951) was adopted for this site to estimate the changes in Chalk and drift water levels. This model assumes that the storage in and recharge to the overlying deposits can maintain leakage to the Chalk. Transmissivity was varied with distance to fit observed data (see Appendix F). This model does not taken into account recharge and as such the observed drawdown at the wetland sites will be less than that predicted by the

model. However, this conservative approach has been adopted in order to safeguard the wetland sites from potential changes in water levels.

Detailed geological maps are not available for this area, however the BGS hydrogeological map does cover this site and together with borehole information from the NRA provides adequate geological information.

Since 1988 the NRA has established a number of monitoring boreholes in the Chalk aquifer as well as in the overlying Crag within a 6 km radius of the Wetheringsett site. There are no monitoring sites in the overlying drift.

North Lopham

At this site a 42 day pumping test was carried out by the NRA on the existing river augmentation borehole between the end of June and the beginning of August 1993, with observations made in Chalk observation boreholes up to 5 km distance. No monitoring was carried out in the overlying deposits near the pumping site, however shallow piezometers in the drift were monitored at a number of wetland sites. Again, significant leakage effects occurred during the test, assumed to be from overlying deposits. The response of the shallow piezometers cannot be interpreted on the basis of the pumping test. In some cases the water levels fell, as would be expected during the summer, but could be partially due to the test pumping, while in other cases water levels remained constant or exhibited some recharge.

A similar analytical modelling technique to that used for the Wetheringsett site was adopted.

Detailed geological mapping has been undertaken for this area by BGS, which together with the BGS mineral assessment boreholes and the BGS hydrogeological map provides detailed geological information.

There are a number of monitoring boreholes in the Chalk aquifer within a 6 km radius of the Wetheringsett site. There are no monitoring sites in the overlying Crag and drift.

Wortham/Mellis

Investigations undertaken by Southern Science in the Wortham/Mellis area in late 1993/early 1994 (Southern Science 1994) provided the basis for the assessment of this area. The site investigation involved the drilling of five test boreholes and a number of observation boreholes. Three day constant rate pumping tests were carried out in each of these test boreholes. There does not appear to have been monitoring of overlying deposits, nor of the river/buried channel. The short duration of these tests does not allow unequivocal determination of the nature of the aquifer response. It is not clear whether delayed yield or leakage was occurring, and the derivation of aquifer and aquitard hydraulic

constants is very difficult. In addition, significant recharge events occurred during the pumping tests making analysis difficult.

Analytical modelling, as described earlier, was used to identify the scale and extent of water level changes produced by the proposed abstraction(s) to provide a conservative estimate of water level change.

Redgrave

Pumping test information for the existing production borehole operated by Suffolk Water Company (SWC) was available from the study undertaken by Aspinwall (1992). There does not appear to be any information on hydraulic characteristics of Alluvium, buried channel deposits, Boulder Clay or Crag, in the Waveney valley. However, Aspinwall (1992) produced a two layer radial flow model of the Chalk and drift aquifer systems. In order to calibrate this model using the observed piezometric response in the drift, aquifer parameters for the drift were estimated.

A similar analytical modelling exercise was undertaken for this site based on 'leaky' aquifer conditions to assess the likely drawdown in the Chalk and drift aquifers around the site. The selection of aquifer and leakage parameters was based on the available data from Aspinwall (1992).

General

The impact of the estimated drawdowns on surrounding groundwater licenses is shown in Figure 6.1. The effective limit of the drawdown cone is taken as 6 km, which is considered conservative but nevertheless appropriate, due to the uncertainties of the recharge to the Chalk aquifer in areas where it is overlain by Boulder Clay. This is equivalent to two times the radius of the borehole catchment area assuming an infiltration rate of 47mm/yr (NRA 1992).

6.3 Wetland Sensitivity to Chalk Groundwater Levels

Chalk groundwater level data gathered from the NRA central and eastern area offices, were used to produce groundwater level maps for 1992 (minimum recorded), 1988 (maximum recorded), and 1976 (taken from BGS hydrogeological maps) - Figures 4.6 to 4.8. These maps illustrate the natural range of variation in Chalk groundwater levels at each of the conservation sites. Based on this natural range of variation and the topographic elevations at these sites, an assessment of the sensitivity of the wetland sites to changes in Chalk groundwater levels and their likely dependence on Chalk inflow was made.

From BGS maps and borehole records the geology at each of the wetland conservation sites was determined in order to assess the degree to which hydraulic continuity exists between the wetland sites and the underlying Chalk aquifer. This was then combined with the water level

data to determine the overall hydrogeological sensitivity of the sites to variation in Chalk groundwater levels. The hydrogeological matrix also takes account of the location of the site, for example at geological boundaries - spring lines at edge of Boulder Clay or Alluvium. A summary of the sensitivity of the wetland sites to changes in Chalk groundwater levels is given in Table 6.1.

6.4 Assessment of Hydrogeological Effects of Borehole Sites

6.4.1 Water Level and Throughflow Changes

Estimates of drawdowns in the Chalk and drift aquifers around the boreholes were determined as described in 6.1 above and are shown in Figure 6.1.

The change in groundwater throughflow may have a more significant impact on wetland plant communities than water level change alone. However, the change in throughflow is not possible to quantify without detailed modelling studies as there are vertical and horizontal flow components leading to throughflow which form part of the overall water balance of a wetland site. Therefore, the potential change in throughflow has been assessed on a risk basis i.e. where drawdown in the Chalk and drift water level is predicted at a particular wetland site there is a risk of change in throughflow which could impact on the plant communities.

6.4.2 Conservation Sites

The predicted drawdowns discussed in 6.2 above were compared with the hydrogeological sensitivity of the sites as identified in 6.3, to determine the likely degree of impact on the hydrology of the wetland sites.

6.4.3 Groundwater Abstractions

Predicted Chalk aquifer and drift drawdowns were compared with locations of licence holders (see Figure 4.10) to determine the number affected, type and scale of water level change. It is considered that a change of less than 1 m will be insignificant in terms of yield change; thus limiting consideration to within 3 km or so of the bores. It was not possible to investigate effects on neighbouring bores in detail, for example by considering depth and pump setting, and base of aquifer. Assessment was therefore based on scale of drawdown and category of licence.

Effects on abstractors will generally only be significant within 1 km of the bores. Particular attention was paid to effects on NRA river augmentation bores which will be within 500 m of some of the sites. The effects on abstractors are summarised in Appendix F.

Figure 6.1

REDGRAVE AND LOPHAM FENS

ESTIMATED CHALK DRAWDOWN CONE AT EACH PUMPING SITE

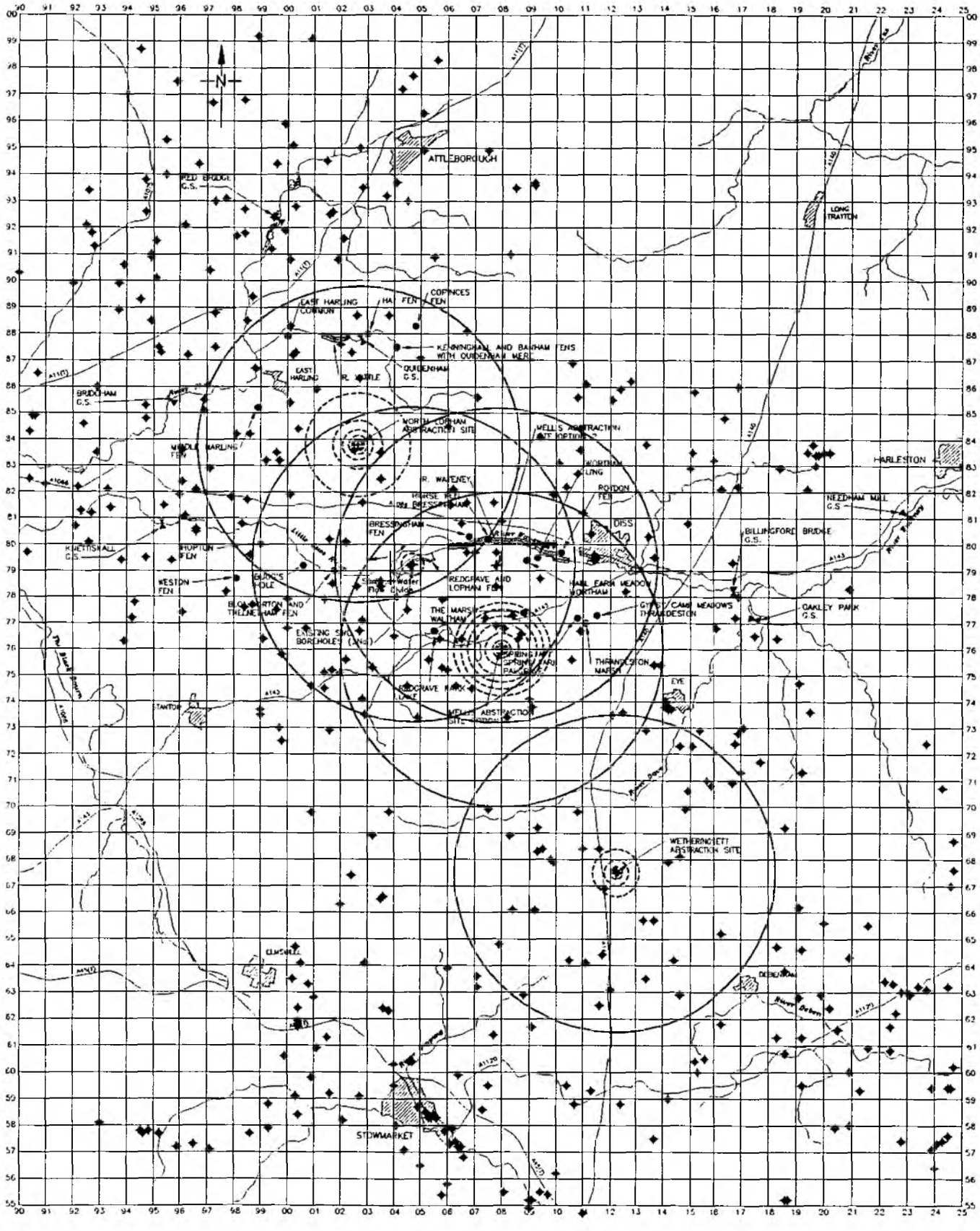
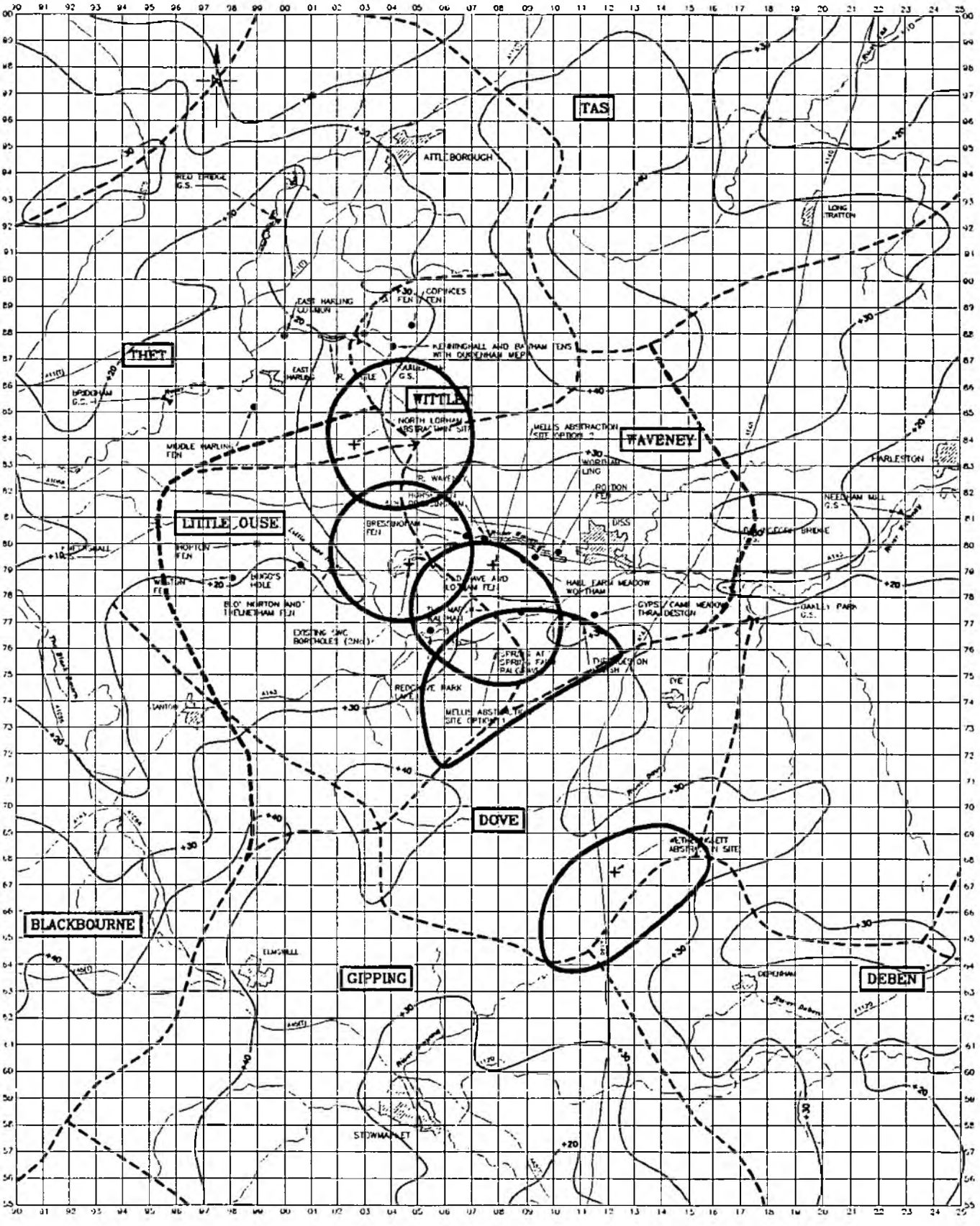


Figure 6.2

REDGRAVE AND LOPHAM FENS

GROUNDWATER CATCHMENT AREAS FOR DEVELOPMENT OPTIONS



NOTE: BASED ON BGS 1976 GROUNDWATER CONTOURS AS 1976 TAKEN AS AN AVERAGE

6.4.4 River Flows

Quantitative estimates of the impact on river flows were determined from review of changes to regional water level contours and the reduction in Chalk groundwater catchment areas resulting from the proposed abstraction boreholes as shown on Figure 6.2. This identified affected reaches, and movement of perennial spring heads.

The additional abstraction was apportioned to the rivers on the basis of the affected reaches, and possible effects on low flows, that is Q_{95} at the various gauging sites. These changes were then put into the context of existing low flow problems identified in water courses in the project area.

An assessment of the likely interaction of Chalk aquifer outflows with adjacent river reaches was undertaken, to determine effects on contributions to baseflows.

6.4.5 River Water Quality

Based on river flow changes, river water quality effects were assessed on the basis of impact on the present NWC class or more detailed information used in NWC classification if readily available from the NRA in summary form.

6.4.6 River Abstractors

From estimated flow and quality changes, the effects on river abstractors (see Figure 4.10), for example licensed agricultural abstractors (spray irrigation) and public water supply were ascertained in discussions with Area Water Resources Officers.

6.5 Catchment Water Balances

The effect of the proposed borehole developments was made based on a review of the NRA document 1992 - Groundwater Balances Review, considering the analysis for each component of the water balance for the catchments in the project area.

For the development options amended water balances were prepared, to the extent that changes in the components could be quantified. The effects on the catchment balances were identified, particularly showing if available resources would be exceeded. The amended balances are presented in Appendix E.

7. GROUNDWATER DEVELOPMENT OPTIONS

7.1 Introduction

This chapter describes the various groundwater development options alone without the river restoration option, which is discussed in Chapter 8.

The incremental effects of each of the development options on water levels and river flows is determined taking the 'Do nothing' option as the baseline condition. Positive impacts resulting from cessation of pumping at Redgrave will be the opposite of the 'Do nothing' option both for water level changes at wetland sites and streamflow.

The drawdown figures calculated for the Chalk and drift aquifers only demonstrate the scale of possible water level changes and may not estimate absolute values due to discontinuities which may influence the results. These discontinuities include aquifer heterogeneity, buried channels, and river recharge. The details of drawdown estimates are presented in Appendix F.

7.2 Do Nothing Option

This is the baseline case whereby the existing Suffolk Water Company sourceworks at Redgrave would remain in operation.

7.2.1 Effects on Chalk and Drift Aquifers

The effects of the Redgrave borehole on the Chalk and drift aquifers have been investigated in previous studies undertaken by Aspinwall (1992) and Harding (1993a). Prior to the installation of the production borehole at the Redgrave site the Chalk aquifer was reported as being artesian by about 1 m and there was a hydraulic gradient towards the River Waveney. Following the installation of the borehole the Chalk groundwater gradient towards the River Waveney was reversed with the cone of depression affecting Chalk water levels throughout Redgrave and Lopham Fens. In addition to the reduction in Chalk water levels the borehole intercepted groundwater flowing towards the river, reducing the throughflow and therefore the baseflow in the river. There are no long term records of Chalk water levels in the vicinity of the Redgrave borehole however, the change in plant communities interpreted from aerial photography (Harding, 1993a) indicate a change in the long term average water levels resulting from the abstraction of groundwater for public supply.

The interaction between the Chalk and drift aquifers in the Redgrave area is complex due to the highly variable nature of the drift cover. In general clayey layers within the drift deposits reduce the vertical hydraulic conductivity and hence the hydraulic continuity between the drift and the underlying Chalk. This has the effect of attenuating changes

in water level in the drift resulting from changes in Chalk water levels. However, in places there appear to be 'windows' in the clayey layers within the drift. This radically increases the hydraulic continuity between the two aquifers and reduces the attenuating effect. This interaction between the Chalk and the drift was first studied by Aspinwall (1992) and Harding (1993a). These studies investigated the effects of the Redgrave borehole on the Chalk and drift aquifers. The substantial drawdown effect in the Chalk aquifer resulted in a hydraulic gradient being set up in the overlying drift and reduction in water levels. This cone of depression in the drift was centred on an area to the southwest of the Redgrave borehole confirming the theory that flow was occurring through a 'window' in the clay layers within the drift. In addition, the relatively small changes in water levels (up to 0.8 m) in the drift indicates relatively poor hydraulic continuity between the drift and the Chalk. This also indicates that the fen still receives substantial inputs from the superficial drift aquifer and from springs in the Chalk aquifer occurring up-gradient (to the south of the site).

In this study, as described in Chapter 6, the methodology adopted involves the screening of each development option using a steady state leaky analytical approach in order to estimate the incremental effect on wetland conservation sites for comparison of development options.

The Do Nothing option is estimated to reduce the water levels in the Chalk aquifer at eleven wetland sites within 6 km of the Redgrave site (see Figure 6.1). All of these are considered to be highly sensitive to changes in Chalk water levels. The other eleven wetland sites are estimated to remain unaffected. This response is directly translated to water levels in the drift as under steady state conditions the Chalk and drift water levels would have equilibrated. It has been assumed that no recharge occurs which means that the actual drawdown observed in the drift will be less than that predicted. The drawdown estimates are presented in Table 7.1.

In addition to the potential lowering of water levels within the wetland sites there is in some cases a reduction in the throughflow of Chalk groundwater. This may be a more significant impact on the wetland sites than changes in water levels. The reduction in Chalk groundwater throughflow at Redgrave and Lopham Fens could be a significant contributory factor in the derogation of the Fen. In contrast, the reduction in throughflow at other wetland sites is likely to be small as the predicted drawdowns are much less than that predicted for Redgrave and Lopham Fen.

7.2.2 Effects on Redgrave and Lopham Fens

The hydraulic continuity between the drift and Chalk aquifers in the Redgrave area, together with the fact that plant community response to these changes is slow, has meant that the decline in the long term average water levels in the Chalk aquifer has resulted in a derogation of

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TABLE 7.1: ESTIMATED INCREMENTAL EFFECTS ON WETLAND SITES

Development Option: DO NOTHING

Wetland Site	Chalk g/w component *	Approx. Glacial Drift Thickness (m)	Water Level response at Wetland Sites (m)	Risk of reduction in Throughflow	Impact
The Marsh Waltham	N	21	NA	No	unaffected
Gypsy Camp Meadows	M	4	NA	No	unaffected
Thrandeston Marsh	M	4	NA	No	unaffected
Spring at Spring Farm	M	9	NA	No	unaffected
Redgrave Park Lake	Y	0	−0.19	Yes	−ve
River Waveney	Y	11	−0.35	Yes	−ve
Hall Farm Meadow Wortham	Y	6	−0.08	Yes	−ve
Wortham Ling	Y	6	−0.06	Yes	−ve
Roydon Fen	Y	6	−0.03	Yes	−ve
Horse Fen Bressingham	Y	7	−0.14	Yes	−ve
Bressingham Fen	Y	7	−0.21	Yes	−ve
Bio'Norton & Thelnetham Fen	Y	11	−0.14	Yes	−ve
Buggs Hole	Y	11	−0.08	Yes	−ve
Hopton Fen	Y	10	−0.03	Yes	−ve
Weston Fen	Y	5	NA	No	unaffected
Middle Harling Fen	Y	1	NA	No	unaffected
East Harling Common	Y	2	NA	No	unaffected
River Wittle	Y	1	NA	No	unaffected
Hay Fen	Y	1	NA	No	unaffected
Copinces Fen	Y	1	NA	No	unaffected
Kenninghall & Banham Fen with Quidenham Mere	Y	20	NA	No	unaffected
Redgrave & Lopham Fen	Y	11	−2.30	Yes	−ve

Notes:
* Y = yes
N = no
M = maybe
NA = not applicable as greater than 6 km from proposed borehole site or definitely not Chalk groundwater fed
River Waveney includes both the River Waveney and River Waveney ESA

the wetland plant communities towards species more suited to drier conditions. Table 7.1 shows the estimated effects on water levels as detailed in Chapter 6 while Table 7.2 presents the estimated impacts on Redgrave and Lopham Fens.

Over the last 30 years, there has been a significant decline (77%) in wetland species and an equally serious loss in habitat. In fact ecological observations on the ground tie in with the drawdown predictions made in 7.2.1 above. A shift in wetland status of this magnitude in a comparatively short time (in ecological terms) suggests the system has lost its buffer capacity and that future change will be accelerated. Under this scenario, it is likely that the wetland communities will be lost, replaced by meadow or humid grasslands in the next few decades (Table 7.2).

7.2.3 Effects on Other Wetlands

The effects on other wetland sites surrounding the Redgrave area are unclear as no monitoring of Chalk or drift water levels has taken place, particularly prior to the installation of the Redgrave borehole. More recently however, monitoring of water levels has been undertaken but it is too early to determine whether any long term changes have occurred. In addition, the overall volume of groundwater abstraction from the Chalk aquifer has increased since the 1940's to the level today where there are only small surpluses or deficits of groundwater resources within the project area.

The predictions made for the other affected wetlands are summarised in Table 7.1 and Table 7.2 for the estimated water level change. In one instance (Buggs Hole), scrub invasion and wetland deterioration has not been catalogued, and it appears that the wetland is still within its buffering capacity.

However, for the other sites (Blo'Norton & Thelnetham Fens, Bressingham Fen, Hopton Fen, Horse Fen, Roydon Fen and Wortham Ling), wetland deterioration has been observed, and it is likely that the buffering capacity of these systems has been exhausted. The predicted changes are likely to be observed in the future should the Do Nothing option be followed. There would be a significant loss of both Class 2 and Class 3 (as defined in Table 5.1) species in the region and of significant wetland habitats. As has been noted previously, a certain total area of habitat type is required for ensured ecosystem survival (MacAuthur and Wilson, 1967). Continued decline of these wetland communities puts into question the future survival of this ecosystem type within the region.

It should be noted that the drying stress exhibited by the majority of these wetlands could be due to the existing abstraction borehole at Redgrave or to other abstraction/land drainage effects.

TABLE 7.2 : Predicted Effects of the Do Nothing Option

Site	Drift Water Level Change (cm)	Effect on Species	Effect on Community	Mitigation Measures
Blo'Norton & Thelnetham Fen	-14	- Loss of Class 2 species - Loss of Class 3 species - Reduction in sensitive Class 4 species	- Shift towards drier grassland biotope - Enhancement in scrub colonisation	Management will prevent scrub invasion. It will slow down but not prevent long term decline of sensitive species or fen quality. Mowing will prevent invasion by ruderals.
Bressingham Fen	-21	- Loss of Class 2 species - Loss of Class 3 species - Loss of some Class 4 species	- Possible shift towards alder wood	Management will slow down but not prevent long term decline of sensitive species or fen quality. Mowing will prevent invasion by ruderals.
Bugg's Hole	-8	- Loss of Class 2 species - Loss of Class 3 species - Slight reduction in sensitive Class 4 species	- Shift towards fen meadow and humid grassland biotopes - Shift towards willow carr - Scrub enhancement	Management will prevent scrub invasion. It will slow down but not prevent long term decline of sensitive species or fen quality. Mowing will prevent invasion by ruderals.
Hall Farm Meadow	-8	nd	nd	nd
Hopton Fen	-3	- Loss of some Class 2 species - Slight reduction in Class 3 species	- No change	Management will prevent scrub invasion. Mowing likely to maintain current floristic quality.
Horse Fen	-14	- Loss of Class 3 species - Reduction in sensitive Class 4 species	- Enhancement in scrub colonisation - Possible increase in alder wood	Management will prevent scrub invasion. It will slow down but not prevent long term decline of sensitive species or fen quality. Mowing will prevent invasion by ruderals.

Note: nd = no data
N/A = Not applicable

TABLE 7.2 : Predicted Effects of the Do Nothing Option (Contd)

Site	Drift Water Level Change (cm)	Effect on Species	Effect on Community	Mitigation Measures
Redgrave & Lopham Fens	-230	- Loss of Class 2, 3 species - Damage to all other wetland species present - Destruction of open water pools, Class 1 species - Loss of species of high conservation interest	- Loss of fen-sedge and rich-fen biotopes : Probable shift to meadow or humid grassland within a few years of change - Loss of communities of high conservation interest	Mitigation measures not feasible due to extent of hydrological damage and irreversible damage to the peat.
Redgrave Park Lake	-19	- No change	- Slight increase in shoreline wetlands - No change in aquatic community	No mitigation measures necessary
River Waveney	-35	nd	nd	nd
Roydon Fen	-3	- Loss of some Class 2 species - Slight reduction in Class 3 species	- No change	Management will prevent scrub invasion. Mowing likely to maintain current floristic quality.
Wortham Ling	-6	- No change in heathy species - Reduction in damp habitats and associated species	- Possible scrub invasion	Scrub invasion could be prevented by management

Note: nd = no data
N/A = Not applicable

7.2.4 Effects on Abstractions

There are no abstraction licenses which are estimated to be derogated by more than 1 m drawdown as a result of the Redgrave abstraction (see Figures 6.1 and 4.10).

7.2.5 Effects on Rivers

The incremental effects on rivers from this option have been estimated on the basis of reduction groundwater catchment areas resulting from the existing Redgrave borehole. The effects are presented in Table 7.3 below:

Table 7.3: Incremental effects on Rivers for the Do Nothing option

River	Gauging Station	Old Q_{95} (m^3/sec)*	New Q_{95} (m^3/sec)	% Flow Change*	% Reduction in Catchment
Little Ouse	Knettishall	0.135	0.123	-10	10
Waveney	Billingford Bridge	0.084	0.074	-14	14

Note: * As flow records only started some 20 years after borehole was constructed and as they are not naturalised, the flow prior to borehole construction could be greater than at present by the percentage of catchment affected.

The uncertain position of the Chalk groundwater catchment divide in the Redgrave area means that it is difficult to estimate the effect the borehole is having on the flows in the Little Ouse and the Waveney. In this case the area of influence of the borehole has been assumed to be equally affecting both catchments.

The reduction in flow estimated for the gauging stations is relatively small however, these are some distance downstream from the existing borehole site at Redgrave. The percentage effects of the groundwater abstraction will increase upstream of these gauging sites to the extent that in the Redgrave area this could be as much as 100%, with drying up the upper river reaches. This is confirmed by the fact that the Upper Little Ouse and Waveney are both designated by the NRA as being 'low flow' rivers.

The increase in impact on river flows going up the catchment is currently having a significant effect on water quality. The Waveney and the Little Ouse are both categorised as Class 2 rivers from source to the gauging stations at Billingford Bridge and Knettishall respectively. However, with the Redgrave borehole operating the upper reaches of these rivers dry up during the summer. The Redgrave borehole was installed in 1957 and the gauging stations at Billingford Bridge and Knettishall were installed in 1968 and 1980 respectively, so there is insufficient flow and water quality data to comment in detail on the water

quality changes of the Rivers Waveney and Little Ouse. However, it is likely that the Redgrave borehole has been derogating river water quality in the Redgrave area since its construction.

7.3 Relocate Abstraction to North Lopham

This option involves moving the abstraction borehole to North Lopham, about 500 m from the existing NRA river augmentation borehole.

7.3.1 Effects on Chalk and Drift Aquifers

The Chalk aquifer at North Lopham is overlain by Boulder Clay and the storativity values obtained from the pumping test undertaken by the NRA indicates that the aquifer is confined at this location. However, it is possible that away from this site the aquifer is not fully saturated even though it is overlain by Boulder Clay. In general, in areas not covered with Boulder Clay (see Figure 4.5) the Chalk aquifer is either confined or leaky. However, the geological section through this site (see Figure 4.2) indicates that the Chalk aquifer is unconfined in some areas where there are 'windows' in the overlying drift. The regional hydraulic gradient is about 0.002 towards the west/southwest.

There has been long term monitoring of the Chalk aquifer in the North Lopham area (borehole TM 08/003) which shows a natural range of variation of up to 9 m, with seasonal variations between 1 m and 5 m. This record clearly shows the effect of the drought between 1989 (historical high) and 1992 (historical low) with 9 m difference in the water levels.

The effect of moving the abstraction borehole to North Lopham is estimated to be a negative effect on the Chalk aquifer levels at seven wetland sites within 6 km of the proposed abstraction borehole (see Table 7.4). Of these all are considered to be highly sensitive to changes in Chalk water levels. There are six wetland sites which could benefit from the move to North Lopham, while the remaining nine wetland sites are estimated to remain unchanged from the present situation.

Should the existing NRA river augmentation borehole at North Lopham be operating as well as the proposed abstraction this would considerably increase the impact on the surrounding wetland sites (see Table 7.5). Under these circumstances eleven wetland sites would be affected and the degree of water level change would be much greater. Of these eleven sites all are considered to be highly sensitive to changes in Chalk water levels.

In addition to the potential lowering of water levels within the wetland sites there is in some cases a reduction in the throughflow of Chalk groundwater. This may in fact be a more significant impact on the wetland plant communities than the changes in water level alone. However, in this instance the relatively small drawdowns predicted mean

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TABLE 7.4: ESTIMATED INCREMENTAL EFFECTS ON WETLAND SITES

Development Option: NORTH LOPHAM (no river augmentation pumping)

Wetland Site	Chalk g/w component *	Approx. Glacial Drift Thickness (m)	Water Level response at Wetland Sites (m)	Risk of reduction in Throughflow	Impact
The Marsh Waltham	N	21	NA	No	unaffected
Gypsy Camp Meadows	M	4	NA	No	unaffected
Thrandeston Marsh	M	4	NA	No	unaffected
Spring at Spring Farm	M	9	NA	No	unaffected
Redgrave Park Lake	Y	0	NA	No	unaffected
River Waveney	Y	11	0.28	No	+ve
Hall Farm Meadow Wortham	Y	6	NA	No	unaffected
Wortham Ling	Y	6	NA	No	unaffected
Roydon Fen	Y	6	NA	No	unaffected
Horse Fen Bressingham	Y	7	0.09	No	+ve
Bressingham Fen	Y	7	0.15	No	+ve
Blo'Norton & Thelnetham Fen	Y	11	0.05	No	+ve
Buggs Hole	Y	11	0.01	No	+ve
Hopton Fen	Y	10	−0.03	Yes	−ve
Weston Fen	Y	5	NA	No	unaffected
Middle Harling Fen	Y	1	−0.18	Yes	−ve
East Harling Common	Y	2	−0.09	Yes	−ve
River Wittle	Y	1	−0.15	Yes	−ve
Hay Fen	Y	1	−0.14	Yes	−ve
Copinces Fen	Y	1	−0.09	Yes	−ve
Kenninghall & Banham Fen with Quidenham Mere	Y	20	−0.15	Yes	−ve
Redgrave & Lopham Fen	Y	11	2.21	No	+ve

REDGRAVE & LOPHAM FEN

TABLE 7.5: ESTIMATED INCREMENTAL EFFECTS ON WETLAND SITES

Development Option: NORTH LOPHAM (with river augmentation pumping)

Wetland Site	Chalk g/w component *	Approx. Glacial Drift Thickness (m)	Water Level response at Wetland Sites (m)	Risk of reduction in Throughflow	Impact
The Marsh Waltham	N	21	NA	No	unaffected
Gypsy Camp Meadows	M	4	NA	No	unaffected
Thrandeston Marsh	M	4	NA	No	unaffected
Spring at Spring Farm	M	9	NA	No	unaffected
Redgrave Park Lake	Y	0	NA	No	unaffected
River Waveney	Y	11	0.07	No	+ve
Hall Farm Meadow Wortham	Y	6	NA	No	unaffected
Wortham Ling	Y	6	NA	No	unaffected
Roydon Fen	Y	6	NA	No	unaffected
Horse Fen Bressingham	Y	7	−0.06	Yes	−ve
Bressingham Fen	Y	7	−0.03	Yes	−ve
Blo'Norton & Thelnetham Fen	Y	11	−0.22	Yes	−ve
Buggs Hole	Y	11	−0.20	Yes	−ve
Hopton Fen	Y	10	−0.21	Yes	−ve
Weston Fen	Y	5	NA	No	unaffected
Middle Harling Fen	Y	1	−0.72	Yes	−ve
East Harling Common	Y	2	−0.36	Yes	−ve
River Wittle	Y	1	−0.60	Yes	−ve
Hay Fen	Y	1	−0.56	Yes	−ve
Copinces Fen	Y	1	−0.36	Yes	−ve
Kenninghall & Banham Fen with Quidenham Mere	Y	20	−0.60	Yes	−ve
Redgrave & Lopham Fen	Y	11	1.94	No	+ve

Notes:
* Y = yes
N = no
M = maybe
NA = not applicable as greater than 6 km from proposed borehole site or definitely not Chalk groundwater fed
River Waveney includes both the River Waveney and River Waveney ESA

that this reduction in throughflow is likely to be small. In addition, these potential reductions in throughflow may be offset by groundwater throughflow induced by pumping effects. The reduction in flow in the River Wittle may have an impact on the river wetland sites along this water course but is unlikely to reduce the Chalk groundwater throughflow. This is discussed in more detail below.

7.3.2 Effects on Redgrave and Lopham Fens

The predictions of effects of the abstraction for the affected wetlands are summarised in Table 7.6, on the basis of the PWS borehole only. The predictions of the effects of abstraction for PWS and river augmentation are presented in Table 7.7. The effects would be significantly worse when the augmentation borehole is pumping. The relocation of the abstraction borehole to North Lopham results in a predicted rise in drift water levels of 221 cm. Such a rise is expected to significantly increase the vigour and colonisation of sensitive wetland species (Class 2 and 3), and reduce the vigour of non-wetland invaders. The natural reversion to predominately wetland communities would take a number of years, although management will greatly speed the reinstatement. There is likely to be a rapid response to drift water levels, and pool area and persistence, leading to improved habitat conditions for the Fen Raft Spider.

The water levels are predicted to recover by 194 cm should augmentation pumping be undertaken. Although this recovery is slightly less than under no augmentation pumping it is not considered significant. The improvements to the wetland system given above are expected to be observed under these conditions.

7.3.3 Effects on Other Wetlands (see Tables 7.6 and 7.7)

Under the no augmentation pumping scenario, five of the sites (excluding Redgrave and Lopham Fens which were addressed above) are predicted to experience raised soil water levels. At Bressingham Fen, which is currently showing signs of wetland deterioration, the increase is expected to be high enough to result in improvements to the wetland species and communities. The other rises are unlikely to result in improvements, but will delay or reduce deterioration.

A number of the sites are predicted to have reduced soil water levels which could cause a further deterioration in the wetland status of the sites. A number of the sites (Copinces Fen, Hay Fen, Hopton Fen and the River Wittle) already show wetland decline, and are predicted to suffer lowered water table levels, with the associated species and community changes. Many of the sites have declined to the extent that they no longer include communities of national conservation interest; the exception being Hopton Fen. The existing rate of decline will be exacerbated under this option.

TABLE 7.6 : Predicted Effects of Relocation to North Lopham (no river augmentation pumping)

Site	Drift Water Level Change (cm)	Effect on Species	Effect on Community	Mitigation Measures
Blo'Norton & Thelnetham Fen	5	No change	No change	N/A
Bressingham Fen	15	- Slight increase in Class 2 species - Increase in Class 3 species	- Halt in spread of drying habitat - Increased vigour of carr, no change in community	N/A
Bugg's Hole Fen	1	- No change	- No change	N/A
Copinces Fen	-9	- Loss of Class 2 species - Loss of Class 3 species - Slight reduction in sensitive Class 4 species	- Increase in Phragmites dominated reed beds - Shift towards grasslands communities	Management can mitigate scrub invasion but may not prevent species loss or change in community in the longer term.
East Harling Common	-9	- Loss of Class 2 species - Loss of Class 3 species - Slight reduction in sensitive Class 4 species	- Shift towards Phragmites or drier grassland communities.	Management can mitigate scrub invasion but may not prevent species loss or change in community in the longer term.
Hay Fen	-14	- Loss of Class 2 species - Loss of Class 3 species - Reduction in sensitive Class 4 species	- Shift to drier grassland community - Shift to drier fen vegetation	Management can reduce scrub and delay community change.
Hopton Fen	-3	- Loss of some Class 2 species - Slight reduction in Class 3 species	- No change	Management could mitigate reduction.
Horse Fen	9	- No change	- No change	N/A

Note: nd = no data
N/A = Not applicable

TABLE 7.6 : Predicted Effects of Relocation to North Lopham (no river augmentation pumping) (Contd)

Site	Drift Water Level Change (cm)	Effect on Species	Effect on Community	Mitigation Measures
Kenninghall & Banham Fens with Quidenham Mere	-15	- Loss of Class 2 species - Loss of Class 3 species - Reduction in sensitive Class 4 species	- Scrub enhancement - Increase in Phragmites fen - Shift towards tall-herb fen species tolerant of reduced water levels, eg, Phalaris reed beds	Mitigation would slow loss of wetland species and change to drier fens
Middle Harling Fen	-18	- Loss of Class 2 species - Loss of Class 3 species - Reduction in sensitive Class 4 species	- Shift towards drier grassland biotope - Increase in Phragmites dominated fen - Small increase in scrub encroachment	Management would slow down changes.
Redgrave & Lopham Fens	221	- Increase in Class 2, 3 species - Reduction in ruderals - Long term prospect of wetland species recolonisation	- Increased open water pools, less likely to dry out - Increased vigour of wetland communities, particularly those of high conservation interest, and expansion of range - Reduction in scrub encroachment	N/A
River Waveney	28	nd	nd	N/A
River Wittle	-15	- Loss of Class 2 species - Loss of Class 3 species - Reduction in sensitive Class 4 species	- Shift towards drier grassland such as lowland hay meadow	Scrub invasion could be prevented by management

Note: nd = no data
N/A = Not applicable

TABLE 7.7 : Predicted Effects of Relocation to North Lopham (with river augmentation pumping)

Site	Drift Water Level Change (cm)	Effect on Species	Effect on Community	Mitigation Measures
Blo'Norton & Thelnetham Fen	-22	- Loss of Class 2 species - Loss of Class 3 species - Loss of some Class 4 species	- Shift towards drier grassland biotope - Enhancement in scrub colonisation	Management will prevent scrub invasion, and will slow down but not prevent long term decline of sensitive species.
Bressingham Fen	-3	- Loss of some class 2 species - Slight reduction in Class 3 species	- No change	N/A
Bugg's Hole Fen	-20	- Loss of Class 2 species - Loss of Class 3 species - Loss of some Class 4 species	- Shift towards fen meadow and humid grassland biotope - Shift towards willow carr - Scrub enhancement	Management will prevent scrub invasion and will slow down but not prevent long term decline of sensitive species.
Copinces Fen	-36	- Loss of Class 2 species - Loss of Class 3 species - Slight reduction in sensitive Class 4 species	- Increase in Phragmites dominated reed beds - Shift towards grassland communities	Management can mitigate scrub invasion but may not prevent species loss or change in community in the longer term.
East Harling Common	-36	- Loss of Class 2 species - Loss of Class 3 species - Slight reduction in sensitive Class 4 species	- Shift towards drier Phragmites or grassland communities	Management can mitigate scrub invasion but may not prevent species loss or change in community in the longer term.
Hay Fen	-56	- Loss of Class 2 species - Loss of Class 3 species - Reduction in sensitive Class 4 species	- Shift to drier grassland community - Shift to drier fen vegetation	Management can reduce scrub and delay community change.
Hopton Fen	-21	- Loss of Class 2 species - Slight reduction in Class 3 species	- No change	Management could mitigate reduction in wetland communities

Note: nd = no data
N/A = Not applicable

TABLE 7.7 : Predicted Effects of Relocation to North Lopham (with river augmentation pumping) (Contd)

Site	Drift Water Level Change (cm)	Effect on Species	Effect on Community	Mitigation Measures
Horse Fen	-6	- No change	- No change	N/A
Kenninghall & Banham Fens with Quidenham Mere	-60	- Loss of Class 2 species - Loss of Class 3 species - Reduction in sensitive Class 4 species	- Scrub enhancement - Increase in Phragmites fen - Shift towards tall-herb fen species tolerant of reduced water levels eg. Phalaris reed beds	Mitigation would slow loss of wetland species and change to drier fens
Middle Harling Fen	-72	- Loss of Class 2 species - Loss of Class 3 species - Reduction of sensitive Class 4 species	- Shift towards drier grassland biotope - Increase in Phragmites dominated fen - Small increase in scrub encroachment	Management would slow down changes
Redgrave & Lopham Fens	194	- Increase in Class 2, 3 species - Reduction in ruderals - Long term prospect of wetland species recolonisation	- Increased open water pools, less likely to dry out - Increased vigour of wetland communities particularly those of high conservation interest, and expansion of range - Reduction in scrub encroachment	N/A
River Waveney	7	nd	nd	N/A
River Wittle	-60	- Loss of Class 2 species - Loss of Class 3 species - Reduction in sensitive Class 4 species	- Shift towards drier grassland such as lowland hay meadow	Scrub invasion would be prevented by management.

Note: nd = no data
N/A = Not applicable

Most significantly, three sites (East Harling Common, Kenninhall & Banham Fens with Quidenham Mere and Middle Harling Fen), which currently show no sign of recorded scrub encroachment, are predicted to face a measurable decline in wetland species and communities should this abstraction option be selected.

The predicted effects of this abstraction option with concurrent augmentation pumping are potentially more serious for a number of wetland sites than without augmentation pumping (Table 7.7). All the sites listed, except Redgrave and Lopham Fens and the River Waveney, are expected to experience further drops in soil water levels. For a number of sites, including sites not currently showing signs of wetland deterioration, the drop in predicted water levels (generally ranging from -20 to -72 cm) would be sufficient to result in severe shifts and declines in the wetland communities.

7.3.4 Effects on Abstractions

Three abstraction licences are estimated to be affected by greater than 1 m of drawdown as a result of the proposed borehole at North Lopham. One is the existing NRA river augmentation borehole and the other two are agricultural boreholes about 800m and 1600m away. If the new public supply borehole was located 500 m away from the existing river augmentation borehole it is estimated that there would be an additional drawdown of about 3 m. Further study would be required to determine the likely loss in yield, if any, in these boreholes. Details of the licensed and unlicensed sources affected with and without river augmentation pumping are presented in Appendix F.

7.3.5 Effects on Rivers

The incremental effects on rivers from this option have been estimated on the basis of the reduction in groundwater catchment areas resulting from the alternative borehole site at North Lopham. The effects are presented in Table 7.8 and 7.9 below:

Table 7.8: Incremental effects on rivers for the North Lopham option (no river augmentation pumping)

River	Gauging Station	Old Q_{95} (m^3/sec)	New Q_{95} (m^3/sec)	% Flow Change	% Reduction in Catchment
Little Ouse	Knettishall	0.123	0.127	+3	7
Waveney	Billingford Bridge	0.074	0.078	+6	8
Wittle	Quidenham	0.015	0.012	-21	21
Thet	Bridgham	0.394	0.391	-1	1

Table 7.9 : Incremental effects on rivers for the North Lopham option (with river augmentation pumping)

River	Gauging Station	Old Q_{95} (m^3/sec)	New Q_{95} (m^3/sec)	% Flow Change	% Reduction in Catchment
Little Ouse	Knettishall	0.123	0.102	-17	27
Waveney	Billingford Bridge	0.074	0.060	-19	33
Wittle	Quidenham	0.015	0.003	-83	83
Thet	Bridgham	0.394	0.382	-3	3

In this option the Redgrave source would be removed and replaced by one at North Lopham. This would result in a reduction in the Chalk groundwater catchment area of the Little Ouse and Waveney rivers, however, this is less than under the 'Do Nothing' option resulting in a net benefit to the rivers. This benefit is particularly important to the Little Ouse and the Waveney as both are designated by the NRA as 'low flow' rivers.

The reduction in flow estimated for the gauging station at Bridgham on the River Thet is relatively small as this site is some distance downstream from the proposed borehole site. However, the effect on the River Wittle at Quidenham is estimated to be a reduction of 21% in the Q_{95} flow. The effects of groundwater abstraction on river flow in the River Thet will increase only slightly going upstream as the catchment area affected does not intercept the water courses (see Figure 6.2). However, the effects on flows in the River Wittle upstream of Quidenham are likely to be even greater than 21%, with the possibility of the river drying up for periods during the summer.

The impact of these changes to the low flow regime in the affected rivers may have some effect on the water quality. The Little Ouse upstream of Knettishall gauging station is Class 2 and the River Thet upstream of the Wittle confluence is Class 3 but downstream of this point it becomes Class 1b. The small change in Q_{95} low flow in the River Thet is unlikely to put the river out of class. The effect on the River Wittle is potentially much greater however, it is categorised as being Class 3 (poor) upstream of the confluence with the Thet. This is probably due to agricultural runoff. It is possible that this river, particularly in the upper reaches, will be put out of class. The Waveney classified as Class 2 is unlikely to be improved to Class 1b.

The effects of the additional abstraction from the river augmentation borehole would result in significant flow reduction in the Little Ouse and Waveney, with the possibility of the Wittle drying up altogether. These changes would affect river water quality possibly putting each out of class.

7.4 Relocate Abstraction to Wortham/Mellis: Option 1

This option would replace the existing Redgrave borehole with a borehole in the southern part of the Wortham/Mellis area, taken nominally to be at TM 080 760. This site is close to the exploratory sites F and G (Southern Science 1994).

7.4.1 Effects on Chalk and Drift Aquifers

The Chalk aquifer at this site is overlain by Boulder Clay and is considered to be confined or leaky (Southern Science 1994). This is confirmed by the geological section through the site (see Figure 4.3). There is a lens of Crag underlying the site which is considered to be in hydraulic continuity with the Chalk aquifer. There is a regional hydraulic gradient to the north towards the River Waveney of about 0.001.

There is no long term monitoring of the Chalk aquifer in the northern part of the Wortham/Mellis area however, the hydrogeological regime is considered to be similar to that at borehole TM 07/003 (about 3 km to the northwest). At this site there is a seasonal variation in groundwater levels of between 0.5 m and 1 m. The maximum natural range of variation is about 2 m, based on the historic high and low levels observed in 1988 and 1992 respectively.

There is estimated to be a negative effect on Chalk groundwater levels at six wetland sites within 6 km of the proposed abstraction borehole, a positive effect at five sites, with eleven others remaining unaffected from the present condition (see Figure 6.1). Of the three negatively affected sites all are considered to be only moderately sensitive to changes in Chalk water levels. The extent to which these changes in Chalk groundwater levels are translated to the overlying drift will depend on the degree of hydraulic continuity between the two aquifers and the thickness of drift present at each wetland site. The results of the predicted water levels are presented in Table 7.10.

In addition to the reduction in water levels there may also be a reduction in the Chalk groundwater throughflow within the wetland sites. This impact may be a more significant change than the lowering of water levels alone. However, the relatively small drawdowns predicted indicate that the reduction in throughflow is likely to be slight.

7.4.2 Effects on Redgrave and Lopham Fens

The predictions of effect of the abstraction made for the wetlands are summarised in Table 7.11. The relocation of the abstraction borehole to Wortham/Mellis (Option 1) results in a predicted rise in drift water levels of 223 cm. Such a rise is expected to significantly increase the vigour and colonisation of sensitive wetland species (Class 2 and 3), and reduce the vigour of non-wetland invaders. The natural reversion to

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TABLE 7.10: ESTIMATED INCREMENTAL EFFECTS ON WETLAND SITES

Development Option: WORTHAM/MELLIS OPTION 1 (at site TM 080 760)

Wetland Site	Chalk g/w component *	Approx. Glacial Drift Thickness (m)	Water Level response at Wetland Sites (m)	Risk of reduction in Throughflow	Impact
The Marsh Waltham	N	21	NA	No	unaffected
Gypsy Camp Meadows	M	4	−0.09	Yes	−ve
Thrandeston Marsh	M	4	−0.10	Yes	−ve
Spring at Spring Farm	M	9	−0.11	Yes	−ve
Redgrave Park Lake	Y	0	0.06	No	+ve
River Waveney	Y	11	0.27	No	+ve
Hall Farm Meadow Wortham	Y	6	−0.02	Yes	−ve
Wortham Ling	Y	6	−0.03	Yes	−ve
Roydon Fen	Y	6	−0.05	Yes	−ve
Horse Fen Bressingham	Y	7	0.06	No	+ve
Bressingham Fen	Y	7	0.14	No	+ve
Blo'Norton & Thelnetham Fen	Y	11	NA	No	unaffected
Buggs Hole	Y	11	NA	No	unaffected
Hopton Fen	Y	10	NA	No	unaffected
Weston Fen	Y	5	NA	No	unaffected
Middle Harling Fen	Y	1	NA	No	unaffected
East Harling Common	Y	2	NA	No	unaffected
River Wittle	Y	1	NA	No	unaffected
Hay Fen	Y	1	NA	No	unaffected
Copinces Fen	Y	1	NA	No	unaffected
Kenninghall & Banham Fen with Quidenham Mere	Y	20	NA	No	unaffected
Redgrave & Lopham Fen	Y	11	2.23	No	+ve

Notes:
* Y = yes
N = no
M = maybe
NA = not applicable as greater than 6 km from proposed borehole site or definitely not Chalk groundwater fed
River Waveney includes both the River Waveney and River Waveney ESA

TABLE 7.11 : Predicted Impacts of Relocation of Wortham/Mellis (Option 1 at TM 0876)

Site	Drift Water Level Change (cm)	Effect on Species	Effect on Community	Mitigation Measures
Bressingham Fen	+ 14	- Slight increase in Class 2 species - Increase in Class 3 species	- Slow development of patchy fen communities - Increased vigour of swamp carr	N/A
Gypsy Camp Meadow	-9	- Loss of Class 2 species - Loss of Class 3 species - Slight reduction in sensitive Class 4 species	- Possible shift towards drier grassland biotope - Scrub encroachment	Management would slow the invasion of ruderals and the change to dry grassland types.
Hall Farm Meadow	-2	nd	nd	nd
Horse Fen	6	- No change	- No change	N/A
Redgrave & Lopham Fens	223	- Increase in Class 2, 3 species - Reduction of ruderals - Long term prospect of wetland species recolonisation	- Increased open water pools, less likely to dry out - Increased vigour of wetland communities, particularly fen-sedge communities of high conservation interest, and expansion of range - Reduction in scrub encroachment	N/A
Redgrave Park Lake	6	- No change	- No change	N/A
River Waveney	+27	- Increase in river corridor value	- No change	N/A

Note: nd = no data
N/A = Not applicable

TABLE 7.11 : Predicted Impacts of Relocation of Wortham/Mellis (Option 1 at TM 0876) (Contd)

Site	Drift Water Level Change (cm)	Effect on Species	Effect on Community	Mitigation Measures
Royden Fen	-5	- Loss of some Class 2 species - Reduction in some Class 3 species	- No change	Management could prevent scrub encroachment
Spring at Spring Farm	-11	nd	nd	nd
Thrandeston Marsh	-10	nd	nd	nd
Wortham Ling	-3	- No change	- No change	N/A

Note: nd = no data
N/A = Not applicable

predominately wetland communities would take a number of years, although management will greatly speed the reinstatement. There is likely to be a rapid response to drift water levels, and pool area and persistence, leading to improved habitat conditions for the Fen Raft Spider.

7.4.3 Effects on Other Wetlands

The majority of the affected sites, Bressingham Fen, Horse Fen, River Waveney, Redgrave Park Lake, and Wortham Ling face either small declines in soil water levels that are not expected to have any significant effect on either the species or communities, or will experience an increase in water levels.

Two of the sites, Gypsy Camp Meadow and Roydon Fen, are predicted to face significant drops in drift water levels which are likely to result in either further deterioration of the wetlands (Roydon Fen) or to initiate wetland deterioration (Gypsy Camp Meadow).

There is insufficient information to make predictions for a number of the sites, viz: Hall Farm Meadow, the Spring at Spring Farm and Thrandeston Marsh.

7.4.4 Effects on Abstractions

There are eight abstraction licenses within 2 km of the proposed abstraction site which could be affected by water level changes greater than 1 m (see Figure 4.10). The affected licenses are for generally small abstractions for spray irrigation and general agriculture. Additional drawdowns are expected to be between about 2m and 4.5m. The effects of these changes on borehole yields should be looked at in more detail as they could be significant. Details of the licensed and unlicensed sources affected are presented in Appendix F.

7.4.5 Effects on Rivers

The incremental effects on rivers from this option have been estimated on the basis of reduction groundwater catchment areas resulting from a new borehole located at Wortham/Mellis. The effects are presented in Table 7.12 below:

Table 7.12: Incremental effects on rivers for the Wortham/Mellis Option 1

River	Gauging Station	Old Q_{95} (m^3/sec)	New Q_{95} (m^3/sec)	% Flow Change	% Reduction in Catchment
Little Ouse	Knettishall	0.123	0.122	-1	11
Waveney	Billingford Bridge	0.074	0.078	+5	9
Dove	Oakley Park	0.148	0.142	-4	4

Under this option the existing source at Redgrave would be replaced by one at Wortham/Mellis. This would result in a slight reduction in the Chalk groundwater catchment areas of the Little Ouse and Waveney. Because of the uncertainty as to the exact location of the boundary divide, the reduction has been split equally between the two rivers. However, this reduction is slightly more severe than the 'Do Nothing' option for the Little Ouse, resulting in a net reduction in low flow, and slightly less severe for the Waveney resulting in a net benefit to the river. This net benefit to the Waveney is useful as the river is designated by the NRA as suffering from low flows. However, this benefit is to some extent cancelled by the effect on the Little Ouse, also a designated low flow river.

The reductions in flow estimated for the Little Ouse at Knettishall and the Dove at Oakley Park are relatively small as these sites are some distance from the proposed borehole site. The negative effect on the low flows in the Dove will increase only slightly going upstream of Oakley Park as the water course is not intercepted by the borehole's cone of depression (see Figure 6.1). In addition, the effects on the River Dove are likely to be reduced by the fact that the existing NRA river augmentation borehole at Wetheringsett discharges into the Dove. Although this borehole is actually used to support downstream abstractions for public supply it will have a positive impact on the low flow regime. However, the negative effect on the Little Ouse will become more severe in the reaches upstream of the gauging station, perhaps by as much as 30%. However, this is still an improvement on the 'Do Nothing' option whereby as much as 100% of the baseflow derived from the Chalk is intercepted before it can enter the Little Ouse and Waveney.

The impact of these changes to the low flow regime in the Little Ouse and the Dove are unlikely to have an effect on the water quality as the changes are small. The Little Ouse and the River Dove are already categorised as Class 2. It is unlikely that these small changes to the low flows in the Little Ouse and the Dove will put the rivers out of class.

7.5 Relocate Abstraction to Wortham/Mellis: Option 2

This option would replace the existing Redgrave borehole with a borehole in the northern part of the Wortham/Mellis area, taken nominally to be at TM 078 792. This site coincides with the exploratory site B (Southern Science 1994).

7.5.1 Effects on Chalk and Drift Aquifers

The Chalk aquifer at this site is unconfined as the aquifer is not fully saturated, however the site is overlain by about 10 m of Boulder Clay (Southern Science 1994). The geological section (see Figure 4.3) shows the approximate position of the site. Southern Science (1994) suggest that the Boulder Clay is underlain by 3 m of Sand and Gravel. The regional hydraulic gradient in the Chalk aquifer is 0.001 towards the River Waveney, north of the proposed borehole site.

There is no long term monitoring of the Chalk aquifer in the northern part of the Wortham/Mellis area, however the hydrogeological regime is considered to be similar to that at borehole TM 07/003 (about 3 km to the west). At this site there is a seasonal variation in groundwater levels of between 0.5 m and 1 m. The maximum natural range of variation is about 2 m, observed between 1988 and 1992 based on the historic high and low levels.

This option is estimated to have a negative impact on water levels in the Chalk aquifer at seven wetland sites within 6 km of the proposed borehole site (see Figure 6.1). However, out of these seven sites three are considered to be only moderately sensitive to changes in Chalk water levels. Four sites are expected to be positively affected, including Redgrave and Lopham Fens, whilst the remaining fifteen sites would remain unaffected. The results of the water level predictions are presented in Table 7.13.

In addition to the reduction in water levels there may also be a reduction in the Chalk groundwater throughflow within the wetland sites. This impact may be a more significant change than the lowering of water levels alone. The impact of the proposed borehole on throughflow will, in part, depend on the extent to which lateral recharge is induced along the buried valley as a result of pumping. However, the relatively small drawdowns predicted indicate that the changes in throughflow are likely to be slight.

7.5.2 Effects on Redgrave and Lopham Fens

The predictions of effects of the water level and throughflow changes for the affected wetlands are summarised in Table 7.14. The relocation of the abstraction borehole to Wortham/Mellis (Option 2) results in a predicted rise in drift water levels of 216 cm. Such a rise is expected to significantly increase the vigour and colonisation of sensitive wetland

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TABLE 7.13: ESTIMATED INCREMENTAL EFFECTS ON WETLAND SITES

Development Option: WORTHAM/MELLIS OPTION 2 (at TM 078 792 which coincides with Southern Science site 'B')

Wetland Site	Chalk g/w component *	Approx. Glacial Drift Thickness (m)	Water Level response at Wetland Sites (m)	Risk of reduction in Throughflow	Impact
The Marsh Waltham	N	21	NA	No	unaffected
Gypsy Camp Meadows	M	4	−0.08	Yes	−ve
Thrandeston Marsh	M	4	−0.08	Yes	−ve
Spring at Spring Farm	M	9	−0.10	Yes	−ve
Redgrave Park Lake	Y	0	0.08	No	+ve
River Waveney	Y	11	0.14	No	+ve
Hall Farm Meadow Wortham	Y	6	−0.13	Yes	−ve
Wortham Ling	Y	6	−0.11	Yes	−ve
Roydon Fen	Y	6	−0.10	Yes	−ve
Horse Fen Bressingham	Y	7	−0.08	Yes	−ve
Bressingham Fen	Y	7	0.03	No	+ve
Blo'Norton & Thelnetham Fen	Y	11	NA	No	unaffected
Buggs Hole	Y	11	NA	No	unaffected
Hopton Fen	Y	10	NA	No	unaffected
Weston Fen	Y	5	NA	No	unaffected
Middle Harling Fen	Y	1	NA	No	unaffected
East Harling Common	Y	2	NA	No	unaffected
River Wittle	Y	1	NA	No	unaffected
Hay Fen	Y	1	NA	No	unaffected
Copinces Fen	Y	1	NA	No	unaffected
Kenninghall & Banham Fen with Quidenham Mere	Y	20	NA	No	unaffected
Redgrave & Lopham Fen	Y	11	2.16	No	+ve

Notes:
* Y = yes
N = no
M = maybe
NA = not applicable as greater than 6 km from proposed borehole site or definitely not Chalk groundwater fed
River Waveney includes both the River Waveney and River Waveney ESA

TABLE 7.14 : Predicted Impacts of Relocation to Wortham/Mellis (Option 2)

Site	Drift Water Level Change (cm)	Effect on Species	Effect on Community	Mitigation Measures
Bressingham Fen	3	- Increase in Class 3 species	- Halt in spread of drying habitat - Increased vigour of carr community	N/A
Gypsy Camp Meadow	-8	- Loss of Class 2 species - Loss of Class 3 species - Slight reduction in sensitive Class 4 species	- Scrub encroachment - Possible shift to drier grassland	Management would prevent scrub encroachment. It might prevent community change.
Hall Farm Meadow	-13	nd	nd	nd
Horse Fen	-8	- Loss of Class 2 species - Loss of Class 3 species - Slight reduction in sensitive Class 4 species	- Scrub encroachment	Management would prevent scrub encroachment. It might prevent community change.
Redgrave and Lopham Fens	216	- Increase in Class 2, 3 species - Reduction in ruderals - Long term prospect of wetland species recolonisation	- Increase in open water pools; less susceptible to drying out - Increased vigour of wetland communities, particularly fen-sedge communities of high conservation interest, and expansion of range - Reduction in scrub encroachment	N/A
Redgrave Park Lake	8	- No change	- No change	N/A
River Waveney	14	- Increase in river corridor value	- No change	N/A
Roydon Fen	-10	- Loss of Class 2 species - Loss of Class 3 species - Slight reduction in sensitive Class 4 species	- No change	For maximum effects, management would eliminate scrub problems but would only slow down species loss and community change.

Note: nd = no data
N/A = Not applicable

TABLE 7.14 : Predicted Impacts of Relocation to Wortham/Mellis (Option 2) (Contd)

Site	Drift Water Level Change (cm)	Effect on Species	Effect on Community	Mitigation Measures
Spring at Spring Farm	-10	nd	nd	nd
Thrandeston Marsh	-8	nd	nd	nd
Wortham Ling	-11	- Shift in favour of species preferring damper soil conditions	- Slow development of wet heath community - Development of damp acid grasslands	N/A

Note: nd = no data
N/A = Not applicable

species (Class 2 and 3), and reduce the vigour of non-wetland invaders. The natural reversion to predominately wetland communities would take a number of years, although management will greatly speed the reinstatement. The recovery in groundwater levels will result in an increase in pool area and persistence, leading to improved habitat conditions for the Fen Raft Spider.

7.5.3 Effects on Other Wetlands

The predicted changes in drift water levels show both positive and negative effects on the various wetland sites. Of the sites experiencing a water level rise (Bressingham Fen, Redgrave Park Lake and River Waveney), improvements are predicted for both the wetland species and communities. On some sites, scrub encroachment has been observed and this is expected to be reversed. Over the long term, there is the potential for the development of a more varied wetland community structure.

Gypsy Camp Meadow is predicted to have a decline in drift water levels, although it is not certain how reliant this site is upon soligenous inputs. The predictions made in Table 7.14 assume complete dependence of the site upon groundwater, which is not thought to be the case (personal communications, NRA, EN, SWT). Roydon Fen, a site currently showing signs of wetland deterioration yet retaining communities of national conservation importance, is likely to experience reductions in wetland species and an acceleration of the current observed decline under the maximum water level change predictions.

Horse Fen and Wortham Ling, both of which show signs of wetland deterioration, are likely to experience further loss of wetland species and contraction of wetland communities.

There is insufficient information to make predictions for Hall Farm Meadow, the Spring at Spring Farm and Thrandeston Marsh.

7.5.4 Effects on Abstractions

There are no groundwater abstraction licenses which would be affected by greater than 1m of drawdown as a result of the proposed borehole abstraction (see Figure 4.10).

7.5.5 Effects on Rivers

The incremental effects on rivers from this option have been estimated on the basis of reduction in groundwater catchment areas resulting from a new borehole located at Wortham/Mellis. The effects are presented in Table 7.15 below:

Table 7.15 : Incremental effect on rivers for the Wortham/Mellis Option 2

River	Gauging Station	Old Q_{95} (m^3/sec)	New Q_{95} (m^3/sec)	% Flow Change	% Reduction in Catchment
Little Ouse	Knettishall	0.123	0.124	+1	9
Waveney	Billingford Bridge	0.074	0.073	-1	15

This option involves the transfer of the existing source at Redgrave to a site at Wortham/Mellis approximately 1 km from the River Waveney. This would result in an estimated reduction in the Chalk groundwater catchment areas to the Little Ouse and the Waveney. However, this is less severe than the 'Do Nothing' option which means that there is a net benefit to these rivers, both identified as suffering from low flows. However, this benefit is less obvious in the reaches upstream of the gauging stations as the zone of influence from the proposed borehole intercepts both rivers (see Figure 6.2). This impact could be as high as 50%, but this is still an improvement on the 'Do Nothing' option whereby possibly as much as 100% of the Chalk baseflow in the upper reaches of these rivers is intercepted.

The net benefit to low flows in both the Little Ouse and the Waveney will improve the existing river water quality. Both rivers are classified as Class 2 however, and the relatively small improvements in low flows are unlikely to raise these rivers to Class 1b.

7.6 Relocate Abstraction to Wortham/Mellis: Option 3

This option is a combination of Wortham/Mellis Options 1 and 2. Under Wortham/Mellis option 3 the existing Redgrave borehole would be replaced with two boreholes, one at or near TM 080 760 and the other at TM 078 792. The two boreholes would pump concurrently, each yielding 1800m^3/day.

7.6.1 Effects on Chalk and Drift Aquifers

This option is estimated to have a negative effect on water levels in the Chalk aquifer at seven wetland sites within 6km of the two proposed borehole sites (see Figure 6.1). However, of these seven wetland sites three are considered to be only moderately sensitive to changes in Chalk water levels. Seven sites are expected to be positively affected, including Redgrave and Lopham Fens, whilst the remaining eight sites would remain unaffected. The results of the water level predictions are presented in Table 7.16.

The potential changes in groundwater throughflow at wetland sites are likely to be slight as the predicted drawdowns are small. The impact of the proposed boreholes will in part depend on the extent to which

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TABLE 7.16: ESTIMATED INCREMENTAL EFFECTS ON WETLAND SITES

Development Option: WORTHAM/MELLIS OPTION 3
(Combination of 1800m³/day at both TM 080 760 and TM 078 792 i.e combination of Wortham/Mellis Options 1 and 2)

Wetland Site	Chalk g/w component *	Approx. Glacial Drift Thickness (m)	Water Level response at Wetland Sites (m)	Risk of reduction in Throughflow	Impact
The Marsh Waltham	N	21	NA	No	unaffected
Gypsy Camp Meadows	M	4	−0.09	Yes	−ve
Thrandeston Marsh	M	4	−0.09	Yes	−ve
Spring at Spring Farm	M	9	−0.11	Yes	−ve
Redgrave Park Lake	Y	0	0.07	No	+ve
River Waveney	Y	11	0.21	No	+ve
Hall Farm Meadow Wortham	Y	6	−0.08	Yes	−ve
Wortham Ling	Y	6	−0.07	Yes	−ve
Roydon Fen	Y	6	−0.08	Yes	−ve
Horse Fen Bressingham	Y	7	−0.01	Yes	−ve
Bressingham Fen	Y	7	0.09	No	+ve
Bio'Norton & Thelnetham Fen	Y	11	0.14	No	+ve
Buggs Hole	Y	11	0.08	No	+ve
Hopton Fen	Y	10	0.03	No	+ve
Weston Fen	Y	5	NA	No	unaffected
Middle Harling Fen	Y	1	NA	No	unaffected
East Harling Common	Y	2	NA	No	unaffected
River Wittie	Y	1	NA	No	unaffected
Hay Fen	Y	1	NA	No	unaffected
Copinces Fen	Y	1	NA	No	unaffected
Kenninghall & Banham Fen with Quidenham Mere	Y	20	NA	No	unaffected
Redgrave & Lopham Fen	Y	11	2.20	No	+ve

Notes:
* Y = yes
N = no
M = maybe
NA = not applicable as greater than 6 km from proposed borehole site or definitely not Chalk groundwater fed
River Waveney includes both the River Waveney and River Waveney ESA

lateral recharge is induced along the buried valley as a result of pumping.

7.6.2 Effects on Redgrave and Lopham Fens

The predictions of the effects of the water level and throughflow changes for the affected wetlands are summarised in Table 7.17. The relocation of the abstraction borehole to Wortham/Mellis (Option 3) results in a predicted rise in drift water levels of 220 cm. Such a rise is expected to significantly increase the vigour and colonisation of sensitive wetland species (Class 2 and 3), and reduce the vigour of non-wetland invaders. The natural reversion to predominantly wetland communities would take a number of years, although management will greatly speed the reinstatement. The recovery in groundwater levels will result in an increase in pool areas and persistence, leading to improved habitat conditions for the Fen Raft Spider.

7.6.3 Effects on Other Wetlands

Six other sites are expected to experience an increase in drift water levels, of which Blo'Norton and Thelnetham Fen, Hopton fen, Bressingham Fen and the River Waveney have already experienced wetland degradation. The increase in water levels is likely to halt the decline and possibly reverse the trend, enabling wetland species colonisation and wetland community development. The remaining two sites, Bugg's Hole Fen and Redgrave Park Lake are not currently showing deterioration, and the wetland communities should stabilise and increase in vigour.

Seven sites are predicted to experience a drop in drift water levels. Of these, Horse Fen, Roydon Fen and Wortham Ling are already showing deterioration of wetland communities and this condition is expected to worsen. Gypsy Camp Meadow, which currently shows no sign of recorded scrub encroachment is predicted to face a shift to non-wetland communities and loss of sensitive wetland species.

There is insufficient information to make predictions for Hall Farm Meadow, the Spring at Spring Farm and Thrandeston Marsh.

7.6.4 Effects on Abstractions

There are seven groundwater abstraction licenses which would be subject to an additional drawdown greater than 1m as a result of the proposed borehole developments (see Figure 4.10). The details of licensed and unlicensed sources affected are presented in Appendix F.

TABLE 7.17 : Predicted Impacts of Relocation of Wortham/Mellis (Option 3)

Site	Drift Water Level Change (cm)	Effect on Species	Effect on Community	Mitigation Measures
Blo'Norton & Thelnetham Fen	14	- Slight increase in Class 2 species - Increase in Class 3 species	- Slow development of patchy fen communities - Increased vigour of swampy carr	N/A
Bressingham Fen	9	- Increase in Class 3 species	- Increased vigour of swamp carr	N/A
Buggs Hole Fen	8	- Increased vigour of Class 3 species	- No change	N/A
Gypsy Camp Meadow	-9	- Loss of Class 2 species - Loss of Class 3 species - Slight reduction in sensitive Class 4 species	- Possible shift towards drier grassland biotope - Scrub encroachment	Management would slow the invasion of ruderals and the change to dry grassland types.
Hall Farm Meadow	-8	nd	nd	nd
Hopton Fen	3	- No change	- No change	N/A
Horse Fen	-1	- No change	- No change	N/A
Redgrave & Lopham Fens	220	- Increase in Class 2, 3 species - Reduction of ruderals - Long term prospect of wetland species recolonisation	- Increased open water pools, less likely to dry out - Increased vigour of wetland communities, particularly fen-sedge communities of high conservation interest, and expansion of range - Reduction in scrub encroachment	N/A
Redgrave Park Lake	7	- No change	- No change	N/A

Note: nd = no data
N/A = Not applicable

TABLE 7.17 : Predicted Impacts of Relocation of Wortham/Mellis (Option 3) (Contd)

Site	Drift Water Level Change (cm)	Effect on Species	Effect on Community	Mitigation Measures
River Waveney	21	- Increase in river corridor value	- No change	N/A
Roydon Fen	-8	- Loss of some Class 2 species - Reduction in some Class 3 species	- No change	Management could prevent scrub encroachment
Spring at Spring Farm	-11	nd	nd	nd
Thrandeston Marsh	-9	nd	nd	nd
Wortham Ling	-7	- No change in healthy species - Reduction in damp habitats and associated species	- Possible scrub invasion	Scrub invasion could be prevented by management

Note: nd = no data
N/A = Not applicable

7.6.5 Effects on Rivers

The incremental effects on rivers from this option have been estimated on the basis of reduction in groundwater catchment areas resulting from the two new boreholes located at Wortham/Mellis. The effects are presented in Table 7.18 below:

Table 7.18: Incremental effects on rivers for the Wortham/Mellis Option 3

River	Gauging Station	Old Q_{95} (m^3/sec)	New Q_{95} (m^3/sec)	% Flow Change	% Reduction in Catchment
Little Ouse	Knettishall	0.123	0.123	0	10
Waveney	Billingford Bridge	0.074	0.075	+2	12
Dove	Oakley Park	0.148	unchanged	-0.2	0.2

This option has a similar effect on the Little Ouse and the Waveney as Wortham/Mellis Option 2 discussed above. However, the conjunctive use of two boreholes would have a slightly beneficial effect on the Waveney. In addition, there would be similar benefits to the upper reaches of the Little ouse and Waveney as with Wortham/Mellis Options 1 and 2.

The net benefits to low flows in the upper reaches of the little Ouse and Waveney will improve existing river water quality. However, the effects further downstream of the gauging stations are unlikely to change the existing class of these rivers.

7.7 Relocate Abstraction to Wetheringsett

This option would replace the existing source at Redgrave with a new borehole at Wetheringsett in the south of the project area about 11 km south of the Waveney valley and 14 km away from Redgrave and Lopham Fen. The new borehole would be sited about 500 m from the existing river augmentation borehole. Discussion below involves the effects of the new PWS sourceworks only, since operation of the augmentation borehole does not lead to different conclusions for the wetland sites or abstractions.

7.7.1 Effects on Chalk and Drift Aquifers

The Chalk aquifer at Wetheringsett is overlain by Boulder Clay and about 15 m of Crag (Figure 4.3). The Crag is assumed to be in hydraulic continuity with the Chalk aquifer. Pumping test data from the NRA indicates that the Chalk aquifer is probably confined or leaky at this site. However, as a result of pumping the Chalk aquifer was dewatered around the borehole. This site is situated in the River Dove catchment although it is close to the Deben and Gipping catchments. The regional

hydraulic gradient is about 0.001 to the northeast towards the River Dove.

There are a number of NRA observation boreholes surrounding this site. The seasonal variation in groundwater levels is about 0.25 m to 0.5 m. The natural range of variation in water levels between 1988 (historic high) and 1992 (historic low) is about 2 m. The effect of the drought between 1989 and 1992 is clearly demonstrated at this site.

The Wetheringsett option is estimated not to have negative effects on any of the wetland sites identified by the NRA and conservation organisations. There would be a positive effect on all eleven sites currently impacted by the Redgrave source. Even if the existing river augmentation borehole was pumped this site is sufficiently distant from the Waveney valley to have no impact on any wetland sites. The incremental effects on wetland sites in the project area for this option are presented in Table 7.19.

In addition to not having negative impacts on the water levels at any of the wetland sites there would be no reduction in the Chalk groundwater throughflow. This would be a significant benefit to all the wetland sites within the Waveney valley.

7.7.2 Effects on Redgrave and Lopham Fens

The predictions made for the affected wetlands are summarised in Table 7.20. The relocation of the abstraction borehole to Wetheringsett results in a predicted rise in surface water levels of 230 cm. Such a rise is expected to significantly increase the vigour and colonisation of sensitive wetland species (Class 2 and 3), and reduce the vigour of non-wetland invaders. The reversion to predominately wetland communities would naturally take a number of years, although management will greatly speed the reinstatement. There is likely to be a rapid response to surface water levels, and pool area and persistence, leading to improved habitat conditions for the Fen Raft Spider.

Concurrent augmentation pumping would have no effect on the water levels of Redgrave and Lopham Fen and therefore the effects discussed above also apply to the Wetheringsett augmentation pumping scenario.

7.7.3 Effects on Other Wetlands

Under this option, all of the wetland sites are expected to experience water level rise. The rise at the sites varies from negligible, with no expected effect on the site, to quite significant, with the potential for wetland species and possible wetland community enhancement.

Some of the sites, Blo'Norton & Thelnetham Fen, Hopton Fen and Roydon Fen, are currently showing signs of wetland deterioration, although they still contain habitats of national conservation significance.

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TABLE 7.19: ESTIMATED INCREMENTAL EFFECTS ON WETLAND SITES

Development Option: WETHERINGSETT
(This option applies to both with and without river augmentation pumping)

Wetland Site	Chalk g/w component *	Approx. Glacial Drift Thickness (m)	Water Level response at Wetland Sites (m)	Risk of reduction in Throughflow	Impact
The Marsh Waltham	N	21	NA	No	unaffected
Gypsy Camp Meadows	M	4	NA	No	unaffected
Thrandeston Marsh	M	4	NA	No	unaffected
Spring at Spring Farm	M	9	NA	No	unaffected
Redgrave Park Lake	Y	0	0.19	No	+ve
River Waveney	Y	11	0.35	No	+ve
Hall Farm Meadow Wortham	Y	6	0.08	No	+ve
Wortham Ling	Y	6	0.06	No	+ve
Roydon Fen	Y	6	0.03	No	+ve
Horse Fen Bressingham	Y	7	0.14	No	+ve
Bressingham Fen	Y	7	0.21	No	+ve
Blo'Norton & Thelnetham Fen	Y	11	0.14	No	+ve
Buggs Hole	Y	11	0.08	No	+ve
Hopton Fen	Y	10	0.03	No	+ve
Weston Fen	Y	5	NA	No	unaffected
Middle Harling Fen	Y	1	NA	No	unaffected
East Harling Common	Y	2	NA	No	unaffected
River Wittle	Y	1	NA	No	unaffected
Hay Fen	Y	1	NA	No	unaffected
Copinces Fen	Y	1	NA	No	unaffected
Kenninghall & Banham Fen with Quidenham Mere	Y	20	NA	No	unaffected
Redgrave & Lopham Fen	Y	11	2.30	No	+ve

Notes:
* Y = yes
N = no
M = maybe
NA = not applicable as greater than 6 km from proposed borehole site or definitely not Chalk groundwater fed
River Waveney includes both the River Waveney and River Waveney ESA

TABLE 7.20 : Predicted Impacts of Relocation to Wetheringsett (no river augmentation pumping and with river augmentation pumping)

Site	Drift Water Level Change (cm)	Effect on Species	Effect on Community
Blo'Norton & Thelnetham Fen	14	- Increased vigour of Class 2, 3 species - Increase in Class 3 species	- Reduction in drying habitat - Increase in range of calcareous valley fen
Bressingham Fen	21	- Increase in Class 2, 3 species	- Slow development of patchy fen community - Increase in swamp carr at expense of drying habitat
Buggs Hole	8	- Increased vigour of Class 3 species	- No change
Hall Farm Meadow	8	nd	nd
Hopton Fen	3	- No change	- No change
Horse Fen	14	- Possible colonisation of Cerex, Phragmites Salix species - Increased vigour of Class 2, 3 species	- Shift towards carr community - Reduction in drying habitat
Redgrave & Lopham Fen	230	- Increase in Class 2, 3 species - Reduction in ruderals - Long term prospect of species recolonisation wetland	- Increased open water pools, less likely to dry out - Increased vigour of wetland communities, particularly those of high conservation interest, and expansion of range - Reduction in scrub encroachment
Redgrave Park Lake	19	- No change in aquatic species - Possible loss of shoreline wetland species	- Upshore development of shoreline wetlands; possible development in new locations
River Waveney	35	- Increase in river corridor interest	- Increase in fringing wetland communities possible
Roydon Fen	3	- No change	- No change
Wortham Ling	6	- No change	- No change

Note: Mitigation Measures not included as all sites have positive benefits

nd = no data
N/A = Not applicable

A rise in drift water levels would halt the existing deterioration and probably allow expansion of these significant wetland communities.

Three other sites, Bressingham Fen, Horse Fen and Wortham Ling, also show signs of wetland deterioration, although they do not currently contain communities of national conservation interest. There is the potential for wet heath, fen and carr community development which would increase the diversity and area of wetlands within the region.

The same water level rises are predicted should augmentation pumping be undertaken, and all wetland sites will experience increased wetland species vigour and possible expansion of wetland communities as discussed above.

7.7.4 Effects on Abstractions

There are two abstraction licences which are estimated to be affected by greater than 1 m of additional drawdown by abstractions from the supply borehole (see Figure 4.10). One of these abstractors is situated about 900 m to the southwest of the proposed abstraction site. It is a small general agricultural license which would be subject to an estimated 1 m of additional drawdown. The other licensed source which would be affected by the proposed replacement for the Redgrave source is the existing NRA river augmentation borehole. Should the proposed new borehole be 500 m away from the existing river augmentation borehole, as suggested by the NRA, the existing source would be subject to an estimated additional 2 m of drawdown. Although a more detailed investigation should be undertaken if this option is to be pursued, there would not appear to be any significant risk to yields of these boreholes.

With concurrent operation of the NRA augmentation borehole, 23 groundwater abstractors would be affected with drawdown ranging from just over 1m to 3.5m. Most of the licensed abstractions are very small (< 100 m^3/d), and effects on yield are not expected to be significant. However, if this option was to be pursued, detailed investigation and testing would be required to establish the need for mitigation/remediation measures.

Details of the licenced and unlicensed sources affected with and without river augmentation pumping are presented in Appendix F.

7.7.5 Effects on Rivers

The incremental effects on rivers from this option have been estimated on the basis of reduction of groundwater catchment areas resulting from the existing Redgrave borehole. The effects are presented in Table 7.21 and 7.22 below:

Table 7.21: Incremental effects on rivers for the Wetheringsett option (no river augmentation pumping)

River	Gauging Station	Old Q_{95} (m^3/sec)	New Q_{95} (m^3/sec)	% Flow Change	% Reduction in Catchment
Little Ouse	Knettishall	0.123	0.135	+10	0
Waveney	Billingford Bridge	0.074	0.084	+14	0
Dove	Oakley Park	0.148	0.123	-17	17
Gipping	Stowmarket	0.080	0.080	0	Negligible
Deben	Naunton Hall	0.100	0.094	-6	6

Table 7.22: Incremental effects on rivers for the Wetheringsett option (with river augmentation pumping)

River	Gauging Station	Old Q_{95} (m^3/sec)	New Q_{95} (m^3/sec)	% Flow Change	% Reduction in Catchment
Little Ouse	Knettishall	0.123	0.135	+10	0
Waveney	Billingford Bridge	0.074	0.084	+14	0
Dove	Oakley Park	0.148	0.050	-66	66
Gipping	Stowmarket	0.080	0.078	-2	2
Deben	Naunton Hall	0.100	0.080	-20	20

Under this option the existing borehole at Redgrave would be replaced by one at Wetheringsett, about 500 m from the NRA river augmentation borehole. This would result in a reduction in the Chalk groundwater catchment areas to the River Dove and the River Deben, the latter being designated as already suffering from low flows. However, the impact on the River Dove is likely to be mitigated to some extent as the existing NRA river augmentation borehole at Wetheringsett discharges into this river. Although designed for supporting surface abstraction for public supply this borehole will reduce the impact on low flows in the River Dove. The impact on the River Deben is slight and there are NRA plans to support the river on environmental grounds by pumping of Chalk groundwater into the upper reaches. There is no impact on the Chalk baseflows to the Little Ouse or the Waveney, resulting in the maximum possible net benefit to these rivers. This impact will be particularly significant in their upper reaches, around Redgrave and Lopham Fens. At present and therefore under the 'Do Nothing' option it is possible that as much as 100% of the Chalk groundwater is intercepted before reaching these upper river reaches. Unlike any of the other borehole sites this effect would be completely removed if the abstraction were to be moved to Wetheringsett.

The Little Ouse, Waveney, Dove, and Deben are all classified as being Class 2 (fair) rivers. The River Gipping is classified as Class 3 (poor). The substantial benefit to low flows, particularly in the upper reaches of the Little Ouse and the Waveney are likely to improve water quality. In the Redgrave area this could even raise the quality to Class 1b (good), although is unlikely to have the same impact further downstream. The impact on the Deben and Gipping is unlikely to have a significant impact on water quality. However, the impact on the River Dove could be significant particularly in the upper reaches if the river augmentation borehole is not in operation. It is considered unlikely that the river would become out of class, however this would also depend on the reasons for its present poor status.

If the river augmentation borehole were also in operation there would only be significant changes from the no augmentation abstraction case in the Rivers Deben and Dove. The Deben could be put out of class as a result of the lowering of the Q_{95} by 20%. The large impact on the River Dove would be reduced to a 17% reduction in Q_{95} (the same as with no augmentation) as the augmentation borehole discharges into the River Dove. However, upstream of the augmentation point the river would be significantly affected.

8. RIVER WAVENEY

8.1 Historic Changes

The River Waveney has undergone a number of anthropogenic changes, possibly as long ago as Roman times (SWT 1994). Certainly canalisation of some degree did occur in the 19th century to assist in the digging for peat. This may not have resulted in lowered water tables in the surrounding wetland sites as the raised river banks may impede groundwater flow into the river (SWT 1994). Major changes were made to the river and nearby drainage channels in the 1950's and 1960's with the objective of land drainage for agricultural development.

In addition to the increase in land drainage over the past hundred years there has been an increase in groundwater abstraction for both public supply and agricultural purposes. In particular the existing PWS borehole at Redgrave, installed in the late 1940s, has substantially reduced the Chalk groundwater input to both the Waveney and Little Ouse. The source of these rivers at Redgrave and Lopham Fens now regularly dries up during prolonged dry periods, and both rivers are now designated by the NRA as suffering from low flows. An attempt to mitigate the lowering of water levels in the river by the installation of a sluice at the downstream end of Redgrave and Lopham Fens. This has not been particularly successful in maintaining higher water levels as much of the flow passes around the sluice, and the main problem of reduced groundwater inputs has not been addressed.

8.2 River Restoration

As outlined in Chapter 1, river restoration proposals have been made by the conservation organisations with the specific objective of assisting the recovery of Redgrave and Lopham Fen (SWT 1994). Much of the restoration involves land management which would assist in speeding up recovery of the wetland and reduce the nutrient input from surrounding agricultural land. However, in addition to land management practice Suffolk Wildlife Trust propose the following river restoration works:

- Installation of a sluice at the downstream end of Great Fen.
- Raise river bed levels by 0.5 m along some sections of the upper Waveney.
- Reprofiling banks, in some cases lowering and in others raising.
- Installation of riffle just downstream of Wortham Ling.

The river restoration option is not proposed as a mutually exclusive option to the relocation options represented in Chapter 7 above as the improvements in river flow gained from the relocation of the Redgrave borehole alone would not restore the riparian wetland plant communities. In order to return the river corridor to the state prior to the installation of the Redgrave borehole, the above restoration work is required to raise water levels in the Waveney upstream of Worby's Drain. In addition, the plant communities at Redgrave Fens which have been altered by the lowered water levels would be unlikely to recover without active management of the fens in addition to the cessation of pumping.

9. IRRIGATION OF REDGRAVE AND LOPHAM FENS

Irrigation of wetlands has been proposed and attempted both in England and internationally. Irrigation systems are variants of either above-ground irrigation, usually in the form of ditches, or a sub-surface irrigation scheme of buried pipes. The wetlands in the areas of interest to this project are predominately non-topogenous (sub-surface water source), and a man-made system replicating the natural conditions would have to consist of a buried network of pipes.

There are a number of difficulties associated with sub-surface irrigation schemes identified by English Nature (Fojt, personal communication):

- The natural pattern of water flow, with complex and heterogenous water level, soil moisture and nutrient gradients, will not be replicated by a man-made system, resulting in the degradation of the fine-scale vegetation patterning.

- The installation and maintenance of a sub-surface irrigation system is likely to disturb the existing vegetation.

- 'Naturalness' is one of the criteria used by English Nature to assess the nature conservation value of sites. Within the Guidelines for Selection of Biological SSSI's it is stated that 'habitats must .. satisfy a certain level of quality marked by a lack of features which indicate gross or human modification' (paragraph 2.10.1, Nature Conservancy Council, 1989).

- Sub-surface irrigation schemes have not, to date, been demonstrated to be successful in re-establishing or retaining wetlands. It is not acceptable to propose an experimental technique as mitigation. With increased experimentation and time, irrigation techniques may be demonstrated to maintain or restore wetlands and at this future date may be reconsidered as a mitigative option.

Reproducing the 'natural' water levels in the Fen as well as the 'natural' throughflow pattern which would occur without the Redgrave borehole would be extremely difficult. Furthermore, an additional irrigation borehole 1km away, either on the opposite side of the River Wavency or downstream would affect the neighbouring wetland sites.

It is the conclusion of this report that, for the above reasons, irrigation cannot at present be considered an acceptable mitigative option.

10. COMPARISON OF REMEDIATION OPTIONS

10.1 Aims of Remediation

The conservation and environmental objectives for remediating Redgrave and Lopham Fens are:

- restore the full sequence of fen types and distribution of fen types;
- restore baseflow to the River Waveney;
- avoid risk of derogation of other wetlands;
- minimise derogation of licensed abstractions;
- minimise risk to other rivers.

It is against these objectives that the effectiveness and suitability of the various remediation options have to be assessed and compared.

10.2 Irrigation and River Restoration Options

The irrigation option has been examined and is not considered a practical scheme because:

- groundwater abstraction for the scheme would affect Redgrave and Lopham Fens and possibly other wetland sites;
- construction of the irrigation infrastructure would damage Redgrave and Lopham Fens;
- the complex natural pattern of flow and water quality on which the fens are based could not be reproduced;
- effects on other wetlands predicted to be impacted by the Redgrave source would not be remediated, nor would there be improvement in the River Waveney flows;
- research into such irrigation schemes is in an early stage and the technology is not established.

The agreed River Waveney restoration measures comprise installation of sluices, raising of river bed, removal of emergent vegetation, lowering and reshaping of back sections, reinstatement of drainage dykes and flood storage in the floodplain. These measures cannot in themselves provide effective remediation of the Redgrave and Lopham Fens and River Waveney, and are therefore not an alternative to the abstraction redeployment options. They are essential however, to enhancing the improvement in baseflow arising from the groundwater development

options. Wetland management practices at the fens would also enhance the effectiveness of their improved inflows.

10.3 Groundwater Development Options

10.3.1 Do-Nothing Option

The 'Do Nothing' option of continuing abstraction at Redgrave P.S. (3.6 tcmd) would have significant impact on wetland sites and rivers. Adverse effects on Redgrave and Lopham Fens would continue. There has been a significant decline (77%) in wetland species and an equally serious loss of habitat over the last 30 years, and under this option wetland communities could be lost, replaced by meadow or humid grasslands, in the next few decades. This option is predicted to affect a further 10 wetland sites, all of which are considered highly sensitive to changes in Chalk water levels. Deterioration has been observed at the majority of these sites, although water level change may not be the only cause. Low flows (Q_{95}) are estimated to be reduced in the River Waveney by 14% and in the Little Ouse River by 10%. In particular flow in the upper Waveney through Redgrave and Lopham Fens is severely affected.

10.3.2 Groundwater Redeployment Options

All of the groundwater redeployment options (3.6 tcmd) from Redgrave lead to significant predicted improvements at Redgrave and Lopham Fens. Positive effects resulting from cessation of pumping at Redgrave are the opposite of the 'Do nothing' option impacts, while impacts arise elsewhere from the redeployed abstraction.

North Lopham Option

The North Lopham relocation option is predicted to result in benefits to 6 wetland sites, including Redgrave and Lopham. The latter would experience a 96% recovery of water levels and throughflow. There would, however, be adverse effects on 7 wetland sites, 3 of which appear to be relatively unaffected at present. The supply borehole would lower water levels in the adjacent NRA river augmentation borehole by up to 3 m. Two other licensed groundwater abstractors would be subject to additional drawdown of more than 1m. The Waveney and Little Ouse low flows would improve by 6% and 3% respectively, while the River Wittle would experience a reduction of 21% with even higher figures in the upper reaches. Water quality in the Wittle is NWC Class 3 (poor) and the flow reduction would worsen this situation.

Concurrent operation of the adjacent NRA river augmentation borehole (11 tcmd) would result in significantly greater impact, with 11 wetland sites predicted to be adversely affected, and only the Redgrave and Lopham Fens and River Waveney benefitting, with the former experiencing an 84% recovery under this scenario. In addition, up to 13 licensed groundwater abstractions would be subject to additional

drawdowns of 1m or more. River flows would decline in the Little Ouse, Waveney, Thet and Wittle, by 17%, 19%, 3% and 83% respectively, and changes in water quality class would be expected.

Wortham/Mellis Options

For the redeployment to Wortham/Mellis three sub-options were examined: (1) near exploratory/test Sites F/G (TM 080 760); (2) at Site B in a highly transmissive chalk zone about 1 km from the River Waveney (TM 078 792); and, (3) a combination of the two sites.

Sub-option 1 is predicted to produce a 97% recovery of water levels of Redgrave and Lopham Fens, and recovery at 4 other wetland sites, including the River Waveney. Another 6 wetland sites could be adversely affected, although only 3 are considered highly sensitive and groundwater dependent. Eight licensed groundwater abstractors would be affected and the effect on yields could be significant. The changes in river flows would be slight.

Sub-option 2 predictions are based on high Chalk transmissivity derived from a 3 day pumping test which may not be representative of the aquifer characteristics prevailing in the longer term. The results should be treated with caution. Water levels at Redgrave and Lopham Fens are predicted to be restored by 94%, with corresponding improvements in the wetland. The River Waveney would also be improved together with 3 other wetland sites. Another 7 wetland sites would be likely to deteriorate although only 4 are considered highly sensitive and groundwater dependent. No licensed abstractors would be affected. Changes in river flows would again be slight.

Sub-option 3, the combination of both Wortham/Mellis sites, with 50% of the abstraction at each, results in a predicted 96% recovery at Redgrave and Lopham, with benefits at 6 other wetland sites, and adverse impacts at 7 sites. Seven licensed groundwater abstractors would be affected and yield changes could be significant. The changes in river flows would be slight.

Wetheringsett Option

The Wetheringsett option is predicted to fully restore water levels at Redgrave and Lopham Fens, and not to adversely impact on any wetland sites. There would be positive effects on the 11 sites thought from the analysis to be affected by the Redgrave source. Two licensed groundwater abstractions would be affected, the NRA river augmentation borehole at 500 m (10 tcmd), and a small general agricultural borehole. Drawdowns are such that there would not appear to be any significant risk to yields of these boreholes. The Rivers Waveney and Little Ouse would experience improved low flows, 14% and 10% respectively and improved river class, while the flows in the River Dove (-17%) and River Deben (-6%) would be adversely affected. All of these rivers are

designated as low flow rivers by the NRA. The impact on the River Dove would be mitigated by the existing NRA river augmentation borehole at Wetheringsett which discharges into the river, and there are plans for augmentation boreholes for the River Deben.

Operation of the adjacent NRA Wetheringsett augmentation borehole as well as the supply borehole would produce further impacts on groundwater abstractions and rivers flows, but no impacts on wetland sites. Under this scenario around 23 licensed abstraction boreholes would be affected, with additional drawdowns from 1 m to 3.7 m. The majority of the licensed abstractions are below 20 m^3/d and the drawdowns are not likely to produce a significant change in yield or affect pumps/pump settings. However, this would have to be investigated in detail if this option is to be pursued. Flows in the Waveney and Little Ouse would be unaffected, but the Dove and Deben would experience reductions of 66% and 20% respectively. However, the river augmentation support as described above would mitigate these effects, although the effects would still be pronounced in reaches above the discharge points.

10.4 Conclusions

The existing abstraction at Redgrave has a major impact on groundwater levels at Redgrave and Lopham Fens, on flows in the River Waveney through the fens, and is predicted to lower groundwater levels at 9 other wetlands in the area. Other factors such as land drainage, historical management practices and agricultural practices may have had significant impacts on the wetland sites. Continued abstraction would lead to further deterioration.

It is not considered practical to restore Redgrave and Lopham Fens using irrigation techniques. River restoration measures cannot in themselves provide effective remediation although they are essential to restoration of riparian habitats and to enhance the improvements in baseflow arising from the groundwater relocation options. Wetland management practices would also ensure effectiveness of improved inflows to the wetland conservation sites.

All of the options to relocate the present Redgrave sourceworks are predicted to make a very significant improvement (80-95%) to groundwater flow to Redgrave and Lopham Fens SSSI. However, the options impact on other wetlands, groundwater abstractors and rivers to varying degrees, as summarised in Table 10.1.

Table 10.1 SUMMARY MATRIX OF HYDROLOGICAL AND ENVIRONMENTAL EFFECTS OF GROUNDWATER DEVELOPMENT OPTIONS

Option	Wetland Conservation Sites			Groundwater Abstractors		Rivers		
	No. wetlands benefiting from water level rise	No. wetlands affected by water level fall	Impact ranking	No. Groundwater licences affected*	Impact ranking	No. rivers benefiting from option	No. rivers adversely affected by option	Impact ranking
Do Nothing	0	11	Severe	0	Nil	0	2	Mod.
North Lopham	6	7	High	3°	Low	2	1	High
North Lopham and Aug. Borehole	2	11	High	13	High	0	4	Severe
Mellis/Wortham (F-G) - Option 1	5	6	Mod.	8	High	1	2	Low
Mellis/Wortham (B) - Option 2	4	7	Mod.	0	Nil	1	1	Low
Mellis/Wortham (B + F-G) - Option 3	7	7	Mod.	7	Mod.	1	1	Low
Wetheringsett	11	0	Nil	2°	Low	2	2⁺	Mod.⁺
Wetheringsett⁺ and Aug. Borehole	11	0	Nil	23	High	2	3⁺	High ⁺

Note:
⁺ Part mitigated by Augmentation
° Yields unlikely to be significantly affected
* Additional drawdown about 1m or more

Ranking order:
Low
Moderate
High
Severe

The Wetheringsett option would wholly reverse the groundwater level reductions predicted at Redgrave and Lopham Fens and the other 10 wetlands, and the changes in Waveney and Little Ouse flows, predicted to arise from the Redgrave source, and would not adversely affect any wetlands. The abstraction would have a significant effect on flows in the headwaters of the River Dove, although this could be mitigated by enhanced support from the existing NRA river support boreholes, including the adjacent Wetheringsett augmentation borehole. During normal operation two licensed groundwater abstractors would be affected, with up to 23 affected during operation of the PWS and river support boreholes. Predicted drawdowns are unlikely to have a significant impact on yield, although in the extreme, lowering of pumps or deepening of boreholes could be required. The effect on unlicensed abstractors requires further investigation to determine whether the borehole(s) are still in use and the degree to which they are likely to be affected.

The Wortham/Mellis options would lead to substantial reversal of the effects of the Redgrave source at most wetland sites, particularly Redgrave and Lopham Fens, but would lead to risks of adverse effects on other wetland sites which are likely to be groundwater dependent. Eight abstraction licences might also be affected and significant changes in yield are likely. This could require remediation measures ranging from lowering of pumps to deepening of boreholes. The effect on unlicensed abstractors requires further investigation to determine whether the borehole(s) are still in use and the degree to which they are likely to be affected. Changes on river flows/quality would be very slight.

The North Lopham option would again lead to substantial reversal of the effects of the Redgrave source on some wetland sites but would adversely affect other sites. The adverse effects would be even more pronounced with concurrent operation of the nearby augmentation borehole. There would be very significant effects on flows in the upper River Wittle in either case. Three licensed groundwater abstractors would be affected by the option, and 13 licensed groundwater abstractors would be affected during concurrent operation of the augmentation borehole. Again, significant changes in yield are not thought likely, but remediation measures could be required. The effect on unlicensed abstractors requires further investigation to determine whether the borehole(s) are still in use and the degree to which they are likely to be affected.

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APPENDIX A

Terms of Reference

NATIONAL RIVERS AUTHORITY (ANGLIAN REGION)

REDGRAVE AND LOPHAM FENS ALLEVIATION SCHEME

EVALUATION OF THE HYDROLOGICAL AND ENVIRONMENTAL IMPACT OF OPTIONS

Consultants Terms of Reference

D Seccombe
Hydrogeologist

4 October 1993

NRA
National Rivers Authority
Anglian Region

1. Introduction

Redgrave and Lopham Fens SSSI is an internationally important wetland conservation site designated under the RAMSAR convention and as a National Nature Reserve which lies 7km west of Diss on the Suffolk/Norfolk borders. Currently both the water balance and shallow groundwater levels within the Fens are considered to be adversely affected by:

a) groundwater abstraction from the adjacent Redgrave public water supply (p.w.s.) sourceworks, and
b) the lowered bed level of the adjacent R. Waveney and hence the base level to which the Fens drains.

These developments have lead to the drying out of the Fens, a deterioration in the conservation value of the Fens and, hence, a conflict with the long term conservation objectives for managing the Fens.

The Upper Waveney (Redgrave and Lopham Fen) has been listed as one of the priority 20 sites scheduled for low flow alleviation. The NRA is committed to identifying a satisfactory full solution. This study will form an integral part in identifying this solution.

2. Study Overview

The NRA is currently progressing with a project appraisal to assess a number of options defined by the NRA and to identify a preferred option for obviating or mitigating the ecological damage to the SSSI. The objective of this tender is to appoint consultants to undertake a study to identify and estimate the scale of the hydrological impact each option may have on the surrounding water users and the water environment. This study will assess for each of the defined options:-

a) the overall effect of that option on the availability of water resources,
b) estimates of the budget cost of mitigating (to be referred to as mitigation costs) any derogation of established water rights caused to the total water users by that option, and
c) the ecological and environmental significance of any changes in flow, depth of shallow water tables, and in water quality experienced by surface water courses, springs and wetland conservation sites (including Redgrave and Lopham Fens) as a result of the implementation of that option.

This study is only part of the overall comparison to be made of the different options. The comparison with respect to costs (other than mitigation costs) and technical suitability for p.w.s. of each option will be carried out by the NRA project appraisal group - which includes representatives from Suffolk Water Company (owners of the Redgrave p.w.s. borehole adjacent to the Fens), the Suffolk Wildlife Trust (who own part and manage the whole of the Fens), and English Nature (responsible for the overall protection and management of the Fens).

The project appraisal report, of which the results of this study will form a part, will be drafted by the project appraisal group to make the case to the Department of Environment for future expenditure towards the restoration of the Fens, as well as justifying the expenditure of EC "Life" funds which have become available for this purpose.

3. Options to be Investigated

The following options were identified after consultation with Suffolk Water Company (SWC), Suffolk Wildlife Trust (SWT) and English Nature (EN). The consultant is to estimate the hydrological and environmental impacts of each of the following options:-

A) Do nothing and continued use of the existing Redgrave p.w.s. sourceworks adjacent to the Fens

B) Seasonal irrigation from an adiacent source to mitigate the drying out of the Fens, but with continued use of the existing Redgrave p.w.s. sourceworks.

C) Relocation of the p.w.s. sourceworks to near North Lopham (5km to the NNW of the Fens)

D) Relocation of the p.w.s. sourceworks near the Wortham/Mellis area (5km to the East of the Fens)

E) Relocation of the p.w.s. sourceworks to near Wetheringsett (14km to the ESE of the Fens)

F) River Restoration of the R Waveney from the Fens to Denmark Bridge, near Diss, (i) with and, (ii) without the continued use of the Redgrave p.w.s. sourceworks.

A detailed description of each option is included in more detail in Appendix I.

The consultant will fully investigate each identified option separately. While investigating options B, C, D,and E, the consultant will also be required to investigate the impact of river restoration (option F(i) or F(ii) as appropriate) in conjunction with each of these separate options.

The NRA will rank the options with regard to cost, suitability and impact and will, after consultation, make recommendations as to further works. The consultant is only required to estimate the impact that each option will have on surrounding water users, wetland conservation sites, springs and river flows in such a way that a comparison of the options may be made. The impact on wetland conservation sites is to be considered as the estimated physical impact (changes in shallow water levels, water balance) together with an assessment of the significance of these changes on the conservation objectives of each site. Any subsequent recommendations as to the acceptability of these forecast changes will be made by the NRA.

In considering alternative p.w.s. sources the consultant will assume that the average abstraction rate at any of the relocated sourceworks will be 3.6 t.c.m.d. - equivalent to the current licensed p.w.s. abstraction at the Redgrave sourceworks. When considering the relocation options (C,D, and E) the consultant will estimate the impact based on the assumption that the existing p.w.s. sourceworks will not be abstracting.

4. Data Available

The consultant may use the following available data from NRA offices at either Peterborough, Brampton, or Ipswich:-

- Groundwater level monitoring locations and records
- River gauging locations and records
- Current metering locations and records
- Wetland site descriptions
- Previous investigation reports including:-
    - "River Waveney Groundwater Scheme - Stage 1", Norfolk and Suffolk River Division, Anglian Water Authority, March 1983
    - Report by Southern Science Ltd on the Wortham/Mellis Groundwater Investigation (to be issued late 1993)
    - Report by Suffolk Wildlife Trust on the R. Waveney management review (to be issued mid October 1993)
    - Various internal investigation reports

The following data is also available to the consultant from NRA offices but is either confidential or the copyright is held by other bodies.

- Rainfall records
- "Morecs" effective rainfall estimates
- Abstraction licence database
- Licence determination well surveys
- Actual licence returns
- Test pumping results from production and investigation boreholes in the area
- Reports
    - Aspinwall & Co (1992), "Redgrave Stage II Study: Data Collection and Analysis". Unpublished report for Suffolk Water Company.
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- British Geological Society (BGS) well catalogue

The Aspinwall & Co (1992) report collated all the available *hydrological and hydrogeological data pertaining to Redgrave and Lopham Fens*. The investigation described in the report comprised a *desk study supported by small-scale fieldwork and radial groundwater flow modelling*. The main contents page is presented in Appendix II. However, during the tender period the full report will be made available for consultation.

The Harding (1993) paper identified in detail the changes in flora and fauna of the Fens from 1959 to 1991. The paper highlighted that the Fens have changed over the 30 year period *from species-rich, soligenous calcareous mire communities with a very rich associated wetland fauna to degraded topogeneous fen communities with a high degree of ruderalism and an impoverished invertebrate fauna.* The main processes causing this degradation were identified.

5. Scope of Assessment of Options

For each of the defined options the consultant will:-

5.1 Review and assess the geological, hydrogeological, and hydrological characteristics within the Area of Interest of that option - see Appendix IV.

5.2 Develop a conceptual model of the hydrology of that option with particular regard to groundwater and surface water flow mechanisms. This is to include vertical flow components in the vicinity of affected wetland conservation sites and how these flows may effect shallow groundwater levels.

5.3 Predict any changes in groundwater quality and the quality of surface water within the wetland conservation sites listed in Appendix III.

5.4 Present a water resource balance to show the effect of that option as outlined below. The methodology used in the resource balance must be able to estimate the effects on the following:-

Wetland Conservation Sites

The consultant will estimate the effect of that option on each of the wetland conservation sites listed in Appendix III and determine whether the effect is due to changing groundwater levels or the capture of water from the respective sites catchment or both. The impact on wetlands is to be considered as the estimated physical impact together with an assessment of the significance of these changes to the conservation objective of each site.

River, Stream and Spring Flows

The consultant will estimate the effect of that option on river, stream, and spring flows and calculate the change in flow. The estimation of change in flow will take into account whether the change is due directly or indirectly to changing chalk water levels. The significance of any impact on river water quality objectives as well as the in situ river needs will also be assessed.

Current Water Users

The consultant will estimate the effect of that option on existing water users and whether or not the rights of each water user are likely to be adversely affected. The consultant will be required to estimate the budget cost of remedial works of that option.

5.5 Estimate the effect that option will have on the overall groundwater catchment water balance in which that option is located. The consultant will also estimate any associated changes to the groundwater divide of the contiguous groundwater catchments, as well as estimating the change to the overall water balance on each affected groundwater catchment. The groundwater catchments are presented in Appendix V, while the associated water balances and the methodology used to estimate these balances will be available from the NRA.

6. Programme of Work

6.1 The work is expected to commence in mid-November 1993 and will be completed within three calendar months of the actual commencement date.

6.2 A draft report, "Redgrave and Lopham Fens Restoration Project: Hydrological and Environmental Impact Assessment", will be written by the consultant and delivered to the Authority at least two weeks prior to the end of the consultancy period. The report will describe the investigations in detail, and present the results of the impact assessment in a summary table form so as to be included within the overall project appraisal to be completed by the NRA project group. The NRA does not require recommendations from these calculations, however, the report will highlight the limitations of the calculations and results for each option. Three copies of the draft report will be required.

6.3 Following the acceptance by the NRA of the draft report, a definitive report, "Redgrave and Lopham Fens Restoration Project: Hydrological and Environmental Impact Assessment",will be written and delivered to the NRA before the end of the consultancy period. Ten copies of the final report will be required.

7. Administration of the Study

7.1 The NRA contacts for this study will be:-

Project Manager: Alan Hull
Consultancy Contract Administrator: Barry Barton
Conservation Officer: Claire Redmond
Hydrogeologist: David Seccombe

All the above NRA officers are based at Kingfisher House, Peterborough.

7.2 The consultant is expected to discuss their progress with the NRA throughout the consultancy period at monthly meetings. The consultant should allow for three such meetings to take place at Kingfisher House, Peterborough or other agreed location. A written progress report detailing work completed and projected, consultancy fees/expenses incurred and projected, contractual matters, etc., will be submitted to the NRA Project Manager at or before each progress meeting.

7.3 All documents, papers and data collected as part of the investigations will be handed over to the NRA on completion of the contract. The consultant may, with the prior written consent of the NRA, publish with due acknowledgement to the NRA any learned papers, articles, photographs, or other illustrations relating to the task. Copyright of the report will be vested with the NRA.

Appendices

APPENDIX I - Description of Options

A) Do Nothing

This is to be considered as the baseline case. The consultant will be required to assess the long term hydrological and environmental impact of current SWC sourceworks at Redgrave and whether the effect on the ecological value of the site will impinge on the international obligations under the Ramsar convention. An existing report by Aspinwalls details current understanding of the hydrology of the site (see Appendix II for contents page)

B) Irrigate Redgrave Fen

Irrigation of the Fens would involve the pumping of sufficient quantities of groundwater from a source at least 1km away from the Fens. The consultant will be required to assess the impact of current abstraction with the addition of irrigation to the Fens, as well as the impact on the water quality of the Fens. This option assumes that the Fens will be irrigated by means of a system of drainage channels and control structures which would evenly distribute the water over the entire area.

C) Relocate to North Lopham

The NRA has a river augmentation borehole located at TM 0251 8361 which is currently used as part of the Great Ouse Groundwater Scheme (GOGWS). This borehole has recently been pump tested at 4tcmd for forty days to determine the aquifer parameters as well as the water level changes. The pump test data, to be analysed by the NRA, will be made available early in the contract period. The consultant will assess the impact of an equivalent abstraction to the Redgrave sourceworks within 500m of the existing GOGWS borehole. The operation of two boreholes will be considered in determining the impact - these being the effect of river augmentation in drought periods, as well as the continuous sourceworks pumping.

D) Relocate to Wortham/Mellis

The NRA has initiated the investigative drilling and testing of five sites in the Wortham/Mellis area with a rectangular area of interest between TM 0800 7600 and TM 1000 7900. The purpose of this investigation is to prove the aquifer yield as well as obtaining aquifer parameters. The Wortham/Mellis investigation is still current, but it is anticipated that the data from the investigation will be available early in this contract period. Although it is expected that the replacement supply will be available from only one source, the NRA may require the consultant to estimate the impact from a combination of two or three sources. The NRA will indicate the borehole(s) to be used in this investigation following the completion of the Wortham/Mellis investigation.

E) Relocate to Wetheringsett

The NRA has a river support borehole located at TM 1220 6750 which is used as part of the Waveney (Dove) river support scheme. This borehole is to be pump tested by mid October 1993 for five days to determine the aquifer parameters. The pump test data will be made available. The consultant would be expected to assess the impact of an equivalent abstraction to the Redgrave sourceworks within 500m of the existing support borehole. The operation of two boreholes near Wetheringsett will be considered in determining the impact - these being the effect of river support, as well as the continuous sourceworks pumping. For the purposes of this assessment it will be assumed the Redgrave sourceworks will not be abstracting.

F) River Restoration

The NRA has initiated a review of the upper 8km of R. Waveney from the source to Denmark Bridge, near Diss. The review, which is to be completed by mid October 1993, will detail the history of river management, the current status of the river and riparian habitats, as well as making recommendations for river restoration. Following the river restoration review the NRA will supply the consultant with alternatives to be considered as part of this assessment. The consultant is required to estimate the impact from three probable recommendations. These are likely to be:-

a) Location of sluice gates at various locations along the R. Waveney, especially immediately downstream of Redgrave and Lopham Fen;

b) Limited bed reinstatement of the R. Waveney to Denmark Bridge;

c) Hydrological isolation of the Fens from the R. Waveney using sheet piling.

The consultant will fully investigate each identified option separately. While investigating seasonal irrigation (option B), relocation to North Lopham (option C), relocation to Wortham/Mellis (option D), and relocation to Wetheringsett (option E), the consultant will also be required to investigate the impact of using river restoration (option F) in conjunction with each of these separate options.

APPENDIX II. - Aspinwall 1992 report - Contents page

The following is an extract from the contents page from "Redgrave Stage II Study: Data Collation and Analysis - Draft Report", Aspinwall & Co, March 1992.

APPENDIX III. - Wetland Conservation Sites

Site Name:	Blo' Norton and Thelnetham Fen
Grid reference:	TM 0177 7900
Site Status:	Notified as a Site of Special Scientific Interest
Notes Available:	SSSI Citation Birmingham University wetland site dossier
Size of Area:	21.03 ha
Site Management:	Suffolk Wildlife Trust
Monitoring Points:	Two piezometers installed adjacent to Blo' Norton Fen - data available from NRA. Four piezometers installed on Thelnetham Fen - data available from Suffolk Wildlife Trust.
Brief Description:	The site is of interest mainly because of the plant communities associated with the remaining areas of open fen. Additional interest is provided by the areas of carr woodland and by some of the meadows adjacent to the fen.

Site Name:	Bressingham Fen
Grid Reference:	TM 0680 8030
Site Status:	County Wildlife Site
Notes Available:	No
Size of Area:	7.28 ha
Site Management:	Norfolk Naturalists Trust
Monitoring Points:	None
Brief Description:	Broadleaved semi-natural coppice. The fen comprises of both scrub and woodland, and other plant communities associated with the remaining areas of fen.

Site Name:	Bugg's Hole
Grid Reference:	TM 0060 7920
Site Status:	Notified as a Site of Special Scientific Interest
Notes Available:	SSSI citation Birmingham University wetland site dossier
Size of Area:	4.0 ha
Site Management:	English Nature
Monitoring Points:	None
Brief Description:	A Small spring-fed calcareous fen situated in a valley of the Little Ouse. A wide range of habitats occur from the mown grassland on the driest soils to tall fen vegetation on shallow fen peat. The diversity of the vegetation types is reflected in the richness of the flora which includes a number of uncommon species.

Site Name:	R. Whittle
Grid Reference:	TM 0130 8795 - TM 0230 8790
Site Status:	County Wildlife Site
Notes Available:	Site Description
Size of Area:	23.17 ha
Site Management:	Norfolk Naturalists Trust
Monitoring Points:	None
Brief Description:	A site of scrub, fen, grassland and woodland bordered by the R. Whittle. The fen may be drying out.

Site Name:	Roydon Fen
Grid Reference:	TM 1020 7970
Site Status:	Site of Nature Conservation Interest. It is proposed to notify this as a Site of Special Scientific Interest
Notes Available:	Site Description Birmingham University wetland site dossier
Size of Area:	15.08 ha
Site Management:	Suffolk Wildlife Trust
Monitoring Points:	Two piezometers installed - data with Suffolk Wildlife Trust
Brief Description:	A mixed site of woodland and scrub with a varied ground flora. Drainage has been affected due to dredging

Site Name:	Spring at Spring Farm, Palgrave
Grid Reference:	TM 1080 7720
Site Status:	Spring
Notes Available:	No
Size of Area:	N/A
Site Management:	N/A
Monitoring Points:	No
Brief Description:	A spring source identified from Ordnance Survey Pathfinder Series 964 (TM07/17)

Site Name:	The Marsh, Wortham
Grid Reference:	TM 0880 7740
Site Status:	County Wildlife Site
Notes Available:	No
Size of Area:	2.5 ha
Site Management:	Suffolk Wildlife Trust
Monitoring Points:	No
Brief Description:	Common land. Consists of low lying wet areas, dry grassland, scrub, and flowering plants

Site Name:	Thrandeston Marsh
Grid Reference:	TM 1110 7700
Site Status:	County Wildlife Site
Notes Available:	No
Size of Area:	5 ha
Site Management:	Suffolk Wildlife Trust
Monitoring Points:	No
Brief Description:	Species poor common land. Grassland with some water logged herb-rich community

Site Name:	Weston Fen
Grid Reference:	TL 9810 7870
Site Status:	Notified as a Site of Special Scientific Interest.
Notes Available:	SSSI citation Birmingham University wetland site dossier
Size of Area:	48.6 ha
Site Management:	Suffolk Wildlife Trust
Monitoring Points:	No
Brief Description:	This site contains a very valuable example of a species-rich, spring-fed valley fen, with areas of fen grassland and relict heath. These are fringed by a wide variety of grassland scrub and woodland communities. Of all the fens in the Waveney/Little Ouse valley it has been the least affected by drainage or water abstraction. The water table remains high and stable throughout the year and this is reflected in the rich and varied flora of the site.

Site Name:	Wortham Ling
Grid Reference:	TM 093 795
Site Status:	Notified as a Site of Special Scientific Interest
Notes Available:	SSSI citation
Size of Area:	51.3
Site Management:	Suffolk Wildlife Trust
Monitoring Points:	No
Brief Description:	Wortham Ling is important for its lowland dry heath and acid grassland communities, which have developed on a sandy, glaciofluvial drift deposit. Although the site is isolated from the Brecklands, lying as it does within a predominantly boulder clay area, the vegetation has close similarities with the Breck grass heaths

Site Name:	Kenninghall and Banham Fens with Quidenham Mere
Grid Reference:	TM 04100 87500
Site Status:	Notified as a Site of Special Scientific Interest
Notes Available:	SSSI citation Birmingham University wetland site dossier
Size of Area:	48.9 ha
Site Management:	English Nature
Monitoring Points:	Two piezometers installed - data with NRA
Brief Description:	The site occupies a section of valley of the R. Whittle. It consists of areas of tall fen, species-rich fen, and calcareous grassland, as well a deep mature mere. Additional interest is provided by areas of wet woodland and by an area of drier unmanaged fen.

Site Name:	Middle Harling Fen
Grid Reference:	TL 9890 8520
Site Status:	Notified as a Site of Special Scientific Interest
Notes Available:	SSSI citation Birmingham University wetland site dossier
Size of Area:	12.7
Site Management:	English Nature
Monitoring Points:	Two piezometers installed - data with NRA
Brief Description:	A small calcareous valley fen situated at the head of a tributary of R. Thet. The site lies in a shallow valley and a number of springs, bearing water from the underlying chalk, emerge on sloping ground. A wide range of grassland types is present including both wet and dry communities. The species-rich fen vegetation includes several plants that are uncommon in East Anglia due to the drainage of many similar fens.

Site Name:	Redgrave Park Lake
Grid Reference:	TM 0550 7670
Site Status:	County Wildlife Site
Notes Available:	No
Size of Area:	20 ha
Site Management:	Suffolk Wildlife Trust
Monitoring Points:	No
Brief Description:	Lake fringed with emergent vegetation, mainly common reed. Important for birds.

Site Name:	Redgrave and Lopham Fen
Grid Reference:	TM 0500 7970
Site Status:	Notified as a Site of Special Scientific Interest and is listed under the Ramsar convention
Notes Available:	SSSI citation Birmingham University wetland site dossier
Size of Area:	124.92
Site Management:	English Nature and Suffolk Wildlife Trust
Monitoring Points:	The are several piezometers installed, principally for site investigations
Brief Description:	The site consists of an extensive area of spring fed valley fen at the headwaters of R. Waveney. It supports several distinct vegetation types, ranging from Molinia based grasslands, mixed sedge fen, to reed dominated fen. There are small areas of wet heath, Sallow carr and Birch woodland. The invertebrate fauna is extensive and well studied, and the fen is the only British locality of the Fen Raft Spider. Aspinwall & Co was commissioned by Suffolk Water Company to collate all hydrologic and hydrogeologic data.

Site Name:	R. Waveney ESA
Grid Reference:	
Site Status:	Forms part of the Broads ESA
Notes Available:	No
Size of Area:	
Site Management:	MAFF
Monitoring Points:	No
Brief Description:	

Site Name:	R. Waveney
Grid Reference:	TM 0600 7990 - TM 0700 8010 TM 0890 7900 - TM 1050 7950
Site Status:	County Wildlife Site
Notes Available:	No
Size of Area:	1.6 ha
Site Management:	Norfolk Naturalists Trust
Monitoring Points:	None
Brief Description:	R. Waveney forming the county boundary from South Lopham Fen across Bressingham Fen to TM 0700 8010. Mesotrophic and of 'C' quality until TM 0700 8010 where river continues as a 'B' quality site due to species diversity being considerably reduced.

Site Name:	Copinces Fen
Grid Reference:	TM 0480 8830
Site Status:	County Wildlife Site
Notes Available:	Site description
Size of Area:	6.96 ha
Site Management:	Norfolk Naturalists Trust
Monitoring Points:	None
Brief Description:	Fen south of Banham Moor which is encroached by scrub

Site Name:	East Harling Common
Grid Reference:	TM 0000 8790
Site Status:	Notified as a Site of Special Scientific Interest.
Notes Available:	SSSI citation
Size of Area:	14.9 ha
Site Management:	English Nature
Monitoring Points:	Two piezometers installed for English Nature by NRA - data available from NRA.
Brief Description:	Situated on chalk, is of importance for its system of periglacial ground ice depressions (pingos) retaining a relict community of rare aquatic beetles. The fen, a declining habitat, is rich in flora which has developed in and around many of the depressions. The surrounding chalk grassland supports a diversity of plants, several of which are uncommon locally.

Site Name:	Gypsy Camp Meadows, Thrandeston
Grid Reference:	TM 1150 7730
Site Status:	Notified as a Site of Special Scientific Interest
Notes Available:	SSSI citation
Size of Area:	2.46 ha
Site Management:	Suffolk Wildlife Trust
Monitoring Points:	None
Brief Description:	One of the few remaining wet meadow sites in Suffolk and consists of a large and a smaller species rich wet meadow. It is situated on poorly drained boulder clay. A system of drainage ditches runs through the site and adds further diversity to plant communities present.

Site Name:	Hall Farm Meadow, Wortham
Grid Reference:	TM 0890 7940
Site Status:	County Wildlife Site
Notes Available:	Site description
Size of Area:	1.2 ha
Site Management:	Suffolk Wildlife Trust
Monitoring Points:	None
Brief Description:	Low lying wet meadow enclosed by ditches. Important for birds and a species divers grassland.

Site Name:	Hay Fen
Grid Reference:	TM 0300 8800
Site Status:	County Wildlife Site
Notes Available:	Site description
Size of Area:	9.67 ha
Site Management:	Norfolk Naturalists Trust
Monitoring Points:	None
Brief Description:	Area of tall fen turning to scrub and includes a small woodland to the east.

Site Name:	Hopton Fen
Grid Reference:	TL 9900 8000
Site Status:	Notified as a Site of Special Scientific Interest
Notes Available:	SSSI citation Birmingham University wetland site dossier
Size of Area:	14.37 ha
Site Management:	Suffolk Wildlife Trust
Monitoring Points:	Two piezometers installed - data with Suffolk Wildlife Trust
Brief Description:	One of a series of valley fens spanning the watershed between the headwaters of the Waveney and Little Ouse.

Site Name:	Horse Fen, Bressingham
Grid Reference:	TM 0750 8020
Site Status:	County Wildlife Site
Notes Available:	Site Description
Size of Area:	4.39
Site Management:	Norfolk Naturalists Trust
Monitoring Points:	No
Brief Description:	Fen bounded by the new diverted course of the R. Waveney and the old river course. Scrub habitat with varied ground flora.

APPENDIX IV. - Areas of Investigation

Within in this study there a four main Areas of Investigation. The rectangular areas are as follows:-

Option	Lower Left Grid Reference	Upper Right Grid Reference
Redgrave & Lopham	TM 0000 74000	TM 0900 8400
North Lopham	TL 9800 7900	TM 0600 8900
Wortham/Mellis	TM 0300 7100	TM 1500 8400
Wetheringsett	TM 0700 6200	TM 1700 7200

The Areas of Investigation are presented in Maps 1 and 2.

APPENDIX B

List of Contacts

CONTACTS LIST

Name	Organisation	Address	Tel/Fax Nos.	Role
Barry Barton	NRA - HQ	Kingfisher House Goldhay Way Orton Goldhay Peterborough PE2 5ZR	Tel: 0733 371811 Fax: 0733 231840	Consultancy Contract Administrator
Alan Hull	NRA - HQ	Kingfisher House Goldhay Way Orton Goldhay Peterborough PE2 5ZR	Tel: 0733 371811 Fax: 0733 231840	Project Manager
Claire Redmond	NRA - HQ	Kingfisher House Goldhay Way Orton Goldhay Peterborough PE2 5ZR	Tel: 0733 371811 Fax: 0733 231840	Conservation Officer
David Seccombe	NRA - HQ	Kingfisher House Goldhay Way Orton Goldhay Peterborough PE2 5ZR	Tel: 0733 371811 Fax: 0733 231840	Hydrogeologist
Angela Wallace	NRA - HQ	Kingfisher House Goldhay Way Orton Goldhay Peterborough PE2 5ZR	Tel: 0733 371811 Fax: 0733 231840	Hydrometric Officer
Steve Dines	NRA - Eastern	Cobham Road Ipswich Suffolk IP3 9JE	Tel: 0473 727712 Fax: 0473 724205	Area Water Resources Manager

Name	Organisation	Address	Tel/Fax Nos.	Role
Pat Sones	NRA - Central	Bromholme Lane Brampton Huntingdon Cambridgeshire PE18 9NE	Tel: 0480 414581 Fax: 0480 413381	Area Water Resources Manager
Jeremy Clitherow	English Nature	Norman Tower House 1-2 Crown Street Bury St Edmunds Suffolk IP22 1QX	Tel: 0284 762218 Fax: 0284 764318	
Mike Harding	Suffolk Wildlife Trust	Brooke House The Green Ashlocking Ipswich Suffolk IP6 9JY	Tel: 0473 890089 Fax: 0473 890165	Reserves Manager
Arthur Rivett	Suffolk Wildlife Trust		Tel: 0379 88618 No fax	R&L Fen Warden
Jackie Lewis	Norfolk Naturalists Trust	72 Cathedral Close Norwich Norfolk NR1 4DF	Tel: 0603 625540 Fax: 0603 614430	Reserves Manager

APPENDIX C

Categories of Plant Species Sensitive to Ground Water Levels

Categories of Plant Preference to Water Table Levels

Class 1: Open Water Plants
Water table at 0 cm or higher

Plants of National Scale Conservation Interest

Fen Pondweed (Potamogeton coloratus)

Plants of Regional Scale Conservation Interest

Bladderwort (Utricularia vulgaris)
Bottle Sedge (Carex rostrata)
Water Violet (Hottonia palustris)

Others

Amphibious Bistort (Persicaria amphibia)
Club Rush (Scirpus lacustris)
Curled Pondweed (Potamogeton crispus)
Fennel Pondweed (Potamogeton pectinatus)
Floating Pondweed (Potamogeton natans)
Floating Sweet-grass (Glyceria fluitans)
Great Reedmace (Typha latifolia)
Lesser Reedmace (Typha angustifolia)
Marestail (Hippuris vulgaris)
Starwort (Callitriche sp.)

Class 2: Very Sensitive Plants, characteristic of wetland soils
Water table 0 to -2 cm

Plants of National Scale Conservation Interest

Common Sundew (Drosera rotundifolia)
Narrow-leaved Marsh orchid (Dactylorhiza traunsteineri)

Plants of Regional Scale Conservation Interest

Common Cotton Grass (Eriophorum angustifolium)
Marsh Lousewort (Pedicularis palustris)
Southern Marsh Orchid (Dactylorhiza praetermissa)
Tubular Water Dropwort (Oenanthe fistulosa)

Others

Bogbean (Menyanthes trifoliata)
Cuckoo Flower (Cardamine pratensis)
Lesser Water Parsnip (Berula erecta)
Lesser Pond Sedge (Carex acutiformis)
Marsh Horestail (Equisetum palustre)
Marsh Marigold (Caltha palustris)
Reed Grass (Glyceria maxima)

Class 3: Sensitive Plants, typical of wetland conditions
Water table -2 to -5 cm

Plants of National Scale Conservation Interest

Black Bog Rush (Schoenus nigricans)
Bog Pimpernel (Anagallis tenella)
Grass of Parnassus (Parnassia palustris)
Long-stalked Yellow Sedge (Carex lepidocarpa)
Marsh Stichwort (Stellaria palustris)

Plants of Regional Scale Conservation Interest

Common Butterwort (Pinguicula vulgaris)
Marsh Orchid (Dactylorhiza incarnata)
Marsh Cinquefoil (Potentilla palustris)
Pink Water Speedwell (Veronica catenata)

Others

Brooklime (Veronica beccabunga)
Carnation Sedge (Carex panicea)
Common Marsh Bedstraw (Galium palustre)
Devil's-bit Scabious (Succisa pratensis)
Fiorin (Agrostis stolonifera)
Greater Tussock Sedge (Carex paniculata)
Marsh Arrow-grass (Triglochin palustris)
Marsh Pennywort (Hydrocotyle vulgaris)
Purging Flax (Linum catharticum)
Purple Moor Grass (Molinia caerulea)
Sharp-flowered Rush (Juncus acutiflorus)
Water Cress (Nasturtium officinale)
Water Forget-me-not (Myosotis scorpioides)
Water Mint (Mentha aquatica)
Yellow Flag Iris (Iris pseudacorus)

Class 4: Moderately Sensitive Plants,
Water table -5 to -10 cm

Plants of National Scale Conservation Interest

Cowbane (Cicuta virosa)
Marsh Helleborine (Epipactis palustris)
Tufted Sedge (Carex elata)

Plants of Regional Scale Conservation Interest

Blunt-flowered Rush (Juncus subnodulosus)
Brown Sedge (Carex disticha)
Fragrant Orchid (Gymnadenia conopsea)
Meadow Thistle (Cirsium dissectum)
Water Avens (Geum rivale)

Others

Common Quaking Grass (Briza media)
Common Reed (Phragmites australis)
Common Spotted Orchid (Dactylorhiza fuchsii)
Gipsywort (Lycopus europaeus)
Great Hairy Willowherb (Epilobium hirsutum)
Hairy Sedge (Carex hirta)
Hemp Agrimony (Eupatorium cannabinum)
Large Bird's Foot Trefoil (Lotus uliginosus)
Marsh Valerian (Valeriana dioica)
Meadowsweet (Filipendula ulmaria)
Ragged Robin (Lychnis flos-cuculi)
Red Fescue (Festuca rubra)
Reed Canary-grass (Phalaris arundinacea)
Soft Rush (Juncus effusus)
Sweet Vernal Grass (Anthoxanthum odoratum)
Tormentil (Potentilla erecta)
Valerian (Valeriana officinalis)
Wild Angelica (Angelica sylvestris)
Yorkshire Fog (Holcus lanatus)

Class 5: Tolerant Plants
Water table at least -10 cm

Only plants of interest are listed:

Plants of National Scale Conservation Interest

Green-winged Orchid (Orchis morio)
Saw Sedge (Cladium mariscus)

Plants of Regional Scale Conservation Interest

Cowslip (Primula veris)
Small Scabious (Scabiosa columbaria)*

* Excluded from Plants of Conservation Interest, Matrix 2

Plant Communities of Conservation Importance, National Vegetation Classification

Rare or highly localised communities identified as importance by the Nature Conservancy Council (1989)

Topogenous fens

	Community	Description	Habitat conditions and range
S24	*Phragmites australis - Peucedanum palustre* fen (Peucedano-Phragmitetum australis p.p. and Caricetum Paniculatae peucedanetosum)	Composed of tall monocotyledons (eg. *Phragmites* and *Cladium*) and herbaceous dicotyledons with a lower layer of sedges and rushes and a patchy bryophyte layer. Generally species-rich (24).	Associated with flood-plain fens in England, especially in Broadland, where it occupies an intermediate zone between swamp and carr. pH, bicarbonate and calcium all moderate (pH 5.5-6.9). Mean water levels are low, though winter flooding occurs. Fertility is moderate; S24b is higher.
M9	*Carex rostrata* - *Calliergon cuspidatum* mire (Acrocladio-Caricetum diandrae p.p. and Peucedano-phragmitetum caricetosum p.p.)	Medium to tall fen vegetation, often species-rich, typically dominated by such species as *C. rostrata C. diandra, C. lasiocarpa* and *Eriophorum angustifolium*. Sometimes there is patchy *Cladium* and/or *Phragmites*. Bryophytes, particularly *Calliergon* species, are conspicuous. Species-richness very variable (25).	In northern and western Britain mainly associated with basin fens, whilst in the south often hydroseral within flood-plain or even valley fens (but usually associated with topogenous hollows). Calcium and bicarbonate values are usually low and pH moderate. Mean water level is high. Low fertilities are associated with optimal community development.

Swamp communities

S1	*Carex elata* swamp	Vegetation dominated by *C. elata* tussocks with some taller herbaceous dicotyledons. Generally species-poor (12). Found with S2 and S27.	Associated with open water transitions, mesotrophic to eutrophic, shallow pools and turf-cutting, only in west Norfolk, Cumbria and Anglesey. pH range 5.5-7.2 (Norfolk). Water levels up to +40 cm.
S2	*Cladium mariscus* swamp and sedge-beds (Cladium mariscí)	*Cladium*-dominated vegetation. Pure stands common and no other species frequent. Species-poor (7). Associate with S1 and S4 in East Anglia and S27 in NW England	Found in open water transition, flood-plain and especially basin fens. Usually calcareous and base-rich. Shallow sanding water tables. Tolerant of the range -15 to +40cm. Local including Anglesey, Norfolk, Cheshire and Cumbria.

Soligenous fens

M13	*Schoenus nigricans* - *Juncus subnodulosus* mire (Schoeno-Juncetum subnodulosi p.p.)	This vegetation is usually distinguished by both *S. nigricans* and *J. subnodulosus* and a wide range of low-growing associates. *Phragmites, Molinia* and sometimes *Cladium* may be important. the community has a high mean species-richness (27). When occurring as a hydroseral stage in turf-cuttings it grades into S24 and S25.	Predominantly found in soligenous mires (valley and spring fens) on a wide range of soil types and geological strata in lowland England and Wales. It is usually associated with high base-richness, water pH (6.5-8.0) and calcium concentration, though high base-richness does not seen to be a prerequisite. Summer water levels range from low to high, though moderate to high levels without stagnation appear to be optimal. Sites have a low productivity.
M14	*Schoenus nigricans* - *Nartbecium ossifragum* mire (Schoeno-juncetum subnodulosi ericetorum p.p.)	*S. nigricans* is usually dominant, with *Molinia* generally abundant and bryophytes variable in cover. Regarded as poor fen.	Characteristic of soligenous zones in valleys on peats or mineral soils irrigated by only moderately base-rich and slightly calcareous water. pH 5-6. Calcium levels 5-35 mg/l. So far recorded from SW England and west Norfolk.

	Community	Description	Habitat conditions and range
M21	*Narthecium ossifragum* - *Sphagnum papillosum* valley mire	Carpets of *Sphagna* are characteristic with scattered herbs and sub-shrubs. Of medium species-richness (14). Associated with M29 water-tracks and M14 flushed zones and often grades into M16 wet heath. Regarded as poor fen.	A local community of permanently waterlogged, acid, oligotrophic peats in the lowlands of England and Wales, mainly in the south. Waters base-poor and nutrient-poor, with pH 3.5-4.5. Peat depths often quite shallow (20-150 cm).
Fen meadow			
M22	*Juncus subnodulosus* - *Cirsium palustre* fen-meadow (Rich-fen meadows p.p)	Variable but usually dominated by a range of grasses, rushes (especially *Juncus subnodulosus*) and sedges (eg. *Carex acutiformis* and *C. disticha*). Species richness variable. Regarded as rich fen-meadow.	Found in a wide variety of situations both topogenous and soligenous, on various soil types and geology (though usually on chalk or limestone) in England and Wales. Generally pH, bicarbonate and calcium levels are high. Water level is variable. Fertility values moderate. • M22c *Carex elata* sub-community occurs mostly in East Anglia as local small stands in topogenous mires. • M22d *Iris pseudacorus* sub-community is somewhat more widespread but still local in England; stands may be larger.
M26	*Molinia caerulea* - *Crepis paludosa mire* *Carex nigra* - *Sanguisorba officinalis* community	*Molinia* and often *Carex nigra* form tussocks. Herbs are quite frequent, both tall and short-growing species	A very local community of moist, moderately base-rich and calcareous peats and peaty mineral soils in both topogenous and soligenous mires in the northern Pennines and Lake District. Prefers a degree of substrate aeration even though it may be flooded in the winter.
Fen woodland			
W2	*Salix cinerea* - *Betula pubescens* - *Phragmites australis* woodland	Canopy of *S. cinerea*, *B. pubescens* and *Alnus glutinosa*. Ground flora related to previous community, from which this has developed.	Found on topogenous sites, particularly flood-plain mires. Most extensive examples in East Anglia and around the Cheshire and Shropshire mires.

Plant Communities of Conservation Importance, CORINE Classification listed in EC Directive 92/43/EEC
The sign "*" indicates priority habitat types

Dry Heaths *** 31-2**

CORINE Biotype	Description	Habitat	Approximate NVC Type
C31.2251	East Anglian Calluna-Fesuca heath	Heath	H1c
C31.2251	East Anglian Calluna-Fesuca heath	Relict heath	H1b
C31.2251	Lowland Calluna-Fesuca heath	Damp heath	H1b

Semi-natural dry grasslands **34.32**

CORINE Biotype	Description	Habitat	Approximate NVC Type
C34.3216	Tall calcareous grassland	Chalk grassland	CG3b
C34.32161	Southern English tall grassland	Chalk grassland	CG6a

Semi-natural tall-herb humid meadow **37.31**

CORINE Biotype	Description	Habitat	Approximate NVC Type
C37.31	Purple moorgrass meadow	Short-fen	M24

Mesophile grasslands **38.2**

CORINE Biotype	Description	Habitat	Approximate NVC Type
C38.22	Lowland hay meadow: Arrhenatherion	Calcareous grassland	MG1a
C38.22	Mesophile grassland: lowland hay meadow	Mesotrophic grassland	MG1

Calcareous fens with *Cladium marisais* ***53.3**

CORINE Biotype	Description	Habitat	Approximate NVC Type
C53.3	Fen Cladium beds	Tall fen	S2
C53.3	Fen Cladium beds	Tall fen	S2b

Alkaline fens **54.2**

CORINE Biotype	Description	Habitat	Approximate NVC Type
C54.21	Calcareous Schoenus nigricans	Calcareous fen	M13
C54.21	Calcareous Schoenus nigricans	Marshy grassland	M13a
C54.21	Calcareous Schoenus nigricans	Fen grassland	M13b
C54.21	Tall herb fen: Phragmites - Eupatorium fen	Tall fen	S25

APPENDIX D

Plant Communities at Wetland Sites

APPENDIX D: Plant Communities at Wetland Sites

Site	Habitat Code	Habitat	NVC Type	NVC Description	Description
Blo'Norton & Thelnetham Fens	BNTF1	Calcareous valley fen	M13a	Schoenus nigricans-Juncus subnodulosus; Subcommunity: Festuca rubra-Juncus acutifolius	Calcareous Schoenus nigricans - rich fen
	BNTF2	Drying habitat	M27b	Filipendula vulgaris-Angelica sylvestris	Meadowsweet grassland
	BNTF3	Woodland & scrub	W6a	Alnus glutinosa-Urtica dioica wood	Mesoeutrophic alder
Bressingham Fen	BF1	Swamp carr	W2a	Salix cinerea-Betula pubescens-Phragmites australis carr	Sallow scrub
	BF2	Drying habitat	W6a	Alnus glutinosa-Urtica dioica wood; Subcommunity: typical	Meso-eutrophic alder
"Bugg's Hole Fen, Thelnetham"	BHFT1	Fen grassland	M13b	Schoenus nigricans-Juncus subnodulosus; Subcommunity: Briza media-Pinguicula vulgaris	Calcareous schoenus nigricans
	BHFT2	Marshy grassland	M13a	Schoenus nigricans-Juncus subnodulosus; Subcommunity: Festuca rubra-Juncus acutifolius	Calcareous Schoenus nigricans
	BHFT3	Tall fen	S2b	Cladium mariscus swamp; Subcommunity: Menyanthes trifoliata	Fen Cladium beds
Copinces Fen	CF1	Tall fen	S4a	Phragmites reed bed; Subcommunity: Phragmites australis	Phragmites reed bed
	CF2	Unimproved grassland	MG9b	Mesotrophic grassland:Holcus lanatus-Deschampsia cespitosa	Deschampsia cespitosa meadow
	CF3	Scrub	W21c	Crataegus monogyna-Hedera helix scrub	Hawthorn scrub

APPENDIX D: Plant Communities at Wetland Sites (Cont'd)

Site	Habitat Code	Habitat	NVC Type	NVC Description	Description
East Harling Common	EHC1	Deep permanent mere	A10	Polygonum amphibium	Rooted floating
	EHC2	Fen	S1	Carex elata swamp	Carex elata beds
	EHC3	Acid fen	M4	Carex rostrata-Sphagnum recurva	Acidic Carex rostrata
	EHC4	Chalk grassland	CG6a	Dry calcareous grassland: Avenula pubescens	Southern English tall mesobromion
	EHC5	Reed	S28	Phalaris arundinacea fen	Phalaris arundinacea beds
	EHC6	Woodland	W6e	Alnus glutinosa-Urtica dioica wood; Subcommunity: Betula pubescens	Alnus glutinosa woods
"Gypsy Camp Meadows, Thrandeston"	GCMT1	Base-rich marsh	S7	Carex acutiformis swamp	Carex acuta/acutiformis
	GCMT2	Wet alluvial meadow	S22	Glyceria fluitans water margin	Glyceria water margin
	GCMT3	Water meadow	MG7c	Lolium perenne flood pasture; Subcommunity: Lolium-Alopecurus-Festuca pratensis	Mesophile grassland: unbroken pasture: ryegrass pasture
	GCMT4	Ditches	S14c	Sparganium erectum swamp; Subcommunity: Mentha aquatica	Sparganium erectum beds
	GCMT5	Grassland	MG69	Mesotrophic grassland: Lolium perenne-Cynosurus cristatus	Mesophile grassland: unbroken pasture: ryegrass pasture
Hay Fen	insufficient data to describe vegetation types	nd	n.d.	n.d.	n.d.

APPENDIX D: Plant Communities at Wetland Sites (Cont'd)

Site	Habitat Code	Habitat	NVC Type	NVC Description	Description
Hopton Fen	HF1	Reed fen	S25	Phragmites-Eupatorium fen	Tall-herb fens
	HF2	Seepage areas	S3	Carex paniculata swamp	Large Carex beds:Greater tussock sedge tussocks
	HF3	Scrub	W1	Salix cinerea-Galium palustre wood	Sallow scrub
Horse Fen	H1	Woodland	W6	Alnus glutinosa-Urtica dioica wood	Meso-eutrophic alder
	H2	Scrub	W6d	Alnus glutinosa-Urtica dioica wood; Subcommunity: Sambucus nigra	Alnus glutinosa wood
Kenninghall & Banham Fens with Quidenham Mere	KBF1	Chalk grassland	CG3b	Tall Bromus erectus; Subcommunity: Centaurea nigra	Tall mesobromion calcareous grassland
	KBF2	Fen	M13	Schoenus nigricans-Juncus subnodulosus	Calcareous Schoenus nigricans
	KBF3	Tall fen	S2b	Cladium mariscus swamp; Subcommunity: Menyanthes trifoliata	Fen Cladium beds
	KBF4	Mere	S8	Scirpus lacustris swamp	Common clubrush beds
	KBF5	Unmanaged tall fen	S5a	Glyceria maxima swamp	Glyceria maxima reedbed
	KBF6	Carr woodland	W8a	Fraxinus excelsior-Acer campestris-Mercurialis perennis; Subcommunity: Primula vulgaris-Glechoma hederaceus	British ash-field maple-mercury wood
Middle Harling Fen	MHF1	Calcareous grassland	MG1a	Mesophile grassland: Arrhenatherum elatius; Subcommunity: Festuca rubra	Lowland hay meadow: Arrhenatherion
	MHF2	Unimproved neutral grassland	MG11	Mesophile grassland: Festuca rubra-Agrostis stolonifera-Potentilla anserina	Grassy flood swards
	MHF3	Calcareous fen	M13	Schoenus nigricans-Juncus subnodulosus	Calcareous Schoenus nigricans

APPENDIX D: Plant Communities at Wetland Sites (Cont'd)

Site	Habitat Code	Habitat	NVC Type	NVC Description	Description
Middle Harling Fen (Cont'd)	MHF4	Carr woodland: no species information available	insufficient data to calculate vegetation types	n.d.	n.d.
Redgrave & Lopham Fens	RLF1	Woodland	insufficient data to calculate vegetation types	n.d	n.d
	RLF2	Fen grassland	M13	Schoenus nigricans-Juncus subnodulosus	Calcareous Schoenus nigricans
	RLF3	Mixed fen	S2	Cladium mariscus swamp	Fen Cladium beds
	RLF4	Damp heath	H1b	Calluna-Festuca ovina heath	Lowland Calluna-Festuca heath
	RLF5	Tall fen	S25	Tall-herb fen	Tall herb fen:Phragmites-Eupatorium fen
	RLF6	Lentic	A1.1b	Potamogeton pectinatus-Myriophyllum spicatum	Rooted submerged
	RLF7	Pools	A24a	Juncus bulbosus; Subcommunity: Utricularia vulgaris	Sphagnum-Utricularia pools
River Wittle	RW1	Scrub	W25a	Pteridium aquilinum-Rubus fruticosus underscrub	Acid-soil bramble thicket
	RW2	Fen grassland	M27	Filipendula ulmaria-Angelica sylvestris	Meadowsweet grassland
	RW3	Unimproved grassland	M27	Filipendula ulmaria-Angelica sylvestris	Meadowsweet grassland
	RW4	Woodland	W6a	Alnus glutinosa-Urtica dioica wood	Meso-eutrophic alder

APPENDIX D: Plant Communities at Wetland Sites (Cont'd)

Site	Habitat Code	Habitat	NVC Type	NVC Description	Description
Roydon Fen	RF1	Tall fen	S2	Cladium mariscus swamp	Fen Cladium beds
	RF2	Short-fen	M25	Molinia-Potentilla erecta mire	Purple moorgrass meadow
	RF3	Scrub	W2a	Salix cinerea-Betula pubescens-Phragmites australis; Subcommunity: Alnus glutinosa-Filipendula ulmaria	Mire willow scrub
	RF4	Woodland	W6	Alnus glutinosa-Urtica dioica wood	Meso-eutrophic alder
Weston Fen	WF1	Tall fen	S2b	Cladium mariscus swamp	Fen Cladium beds
	WF2	Eutrophic fen	S12	Typha latifolia swamp	Reedmace beds
	WF3	Tall fen grasslands	M27c	Filipendula vulgaris-Angelica sylvestris; Subcommunity: Juncus effusus-Holcus lanatus	Meadowsweet grassland
	WF4	Damp neutral grasslands	MG1a	Mesotrophic grassland: Arrhenatherum elatius; Subcommunity: Festuca rubra	Mesophile grassland: lowland hay meadow: Arrhenatherion
	WF5	Relict heath	H1b	Calluna-Festuca ovina heath	East Anglian Calluna-Festuca heath
	WF6	Wet hollows	S3	Carex paniculata swamp	Carex appropinquata etc. beds
	WF7	Secondary woodland and scrub	W6e	Alnus glutinosa-Urtica dioica wood; Subcommunity: Betula pubescens	Alnus glutinosa wood
Wortham Ling	WL1	Heath	H1c	Calluna-Festuca ovina heath	East Anglian Calluna-Festuca heath
	WL2	Dry acid grassland	U1d	Festuca ovina-Rumex acetosella-Agrostis capillaris; Subcommunity: Anthoxanthum odoratum-Lotus corniculatus	Perennial open siliceous grassland
	WL3	Mesotrophic grassland	MG1	Arrhenatherum elatius	Mesophile grassland: lowland hay meadow: Arrhenatherion

APPENDIX E

Groundwater Catchment Water Balances

REDGRAVE & LOPHAM FEN

CATCHMENT WATER BALANCES

Based on NRA Anglian Region "1992 Groundwater Balances Review" for the purposes of internal water resource planning

Development Option: DO NOTHING

Resources			River Need					Abstractions & Nominal Surplus				
Groundwater Catchment	Gross Resource (tcmd)	Effective Resource (tcmd)	Gross Environmental Full Allocation (tcmd)	Allocation Limited to 50% Gross Resource Change	Net Reliable Effluent minus Unconstrained Abstractions (tcmd)	Groundwater Allocation to River (tcmd)	Allocation with 50% Gross Resource Change (tcmd)	Total Abstraction *2 (tcmd)	Balance Nominally Available (tcmd)	Balance Nominally Available with Environmental Limited to 50% Gross Resource Change (tcmd)	Fraction of proposed Borehole Catchment within Groundwater Catchment *1	Balance Nominally Available with Proposed Development Option (tcmd)
1	2	3	4	5	6	7=4−6	8=5−6	9	10=3−(7+9)	11=3−(8+9)	12	13=10−(3.6tcmd*12)
Little Ouse (Unit 9 Cambs. Chalk)	263.4	210.8	138.7	131.7	13.5	125.2	118.2	79.6	5.8	12.8	0.50	4.0
Waveney (Waveney Chalk 34/16)	21.9	17.5	5.7		3.4	2.3		9.9	5.3		0.50	3.5

Notes

NA not applicable

*1 Assuming a borehole catchment area of 28 km² (equivalent to infiltration rate of 47 mm/yr)

*2 The total abstraction for Unit 9 Cambs. Chalk given in NRA Groundwater Balances Review (1992) is 83.4 tcmd and includes the Redgrave source

REDGRAVE & LOPHAM FEN

CATCHMENT WATER BALANCES
Based on NRA Anglian Region "1992 Groundwater Balances Review" for the purposes of internal water resource planning

Development Option: NORTH LOPHAM

Resources			River Need					Abstractions & Nominal Surplus				
Groundwater Catchment	Gross Resource (tcmd)	Effective Resource (tcmd)	Gross Environmental Full Allocation (tcmd)	Allocation Limited to 50% Gross Resource Change	Net Reliable Effluent minus Unconstrained Abstractions (tcmd)	Groundwater Allocation to River (tcmd)	Allocation with 50% Gross Resource Change (tcmd)	Total Abstraction *2 (tcmd)	Balance Nominally Available (tcmd)	Balance Nominally Available with Environmental Limited to 50% Gross Resource Change (tcmd)	Fraction of proposed Borehole Catchment within Groundwater Catchment *1	Balance Nominally Available with Proposed Development Option (tcmd)
1	2	3	4	5	6	7=4-6	8=5-6	9	10=3-(7+9)	11=3-(8+9)	12	13=10-(3.6tcmd*12)
Little Ouse (Unit 9 Cambs. Chalk)	263.4	210.8	138.7	131.7	13.5	125.2	118.2	79.8	5.8	12.8	0.32	4.6
Waveney (Waveney Chalk 34/16)	21.9	17.5	5.7		3.4	2.3		8.9	5.3		0.30	4.2
Thet (Unit 9 Cambs. Chalk)	Included in Little Ouse balance above											
Wittle (Unit 8 Cambs. Chalk)	Included in Little Ouse balance above											

Notes
NA not applicable
*1 Assuming a borehole catchment area of 28 km² (equivalent to infiltration rate of 47 mm/yr)
*2 The total abstraction for Unit 9 Cambs. Chalk given in NRA Groundwater Balances Review (1992) is 83.4 tcmd and includes the Redgrave source

REDGRAVE & LOPHAM FEN

CATCHMENT WATER BALANCES
Based on NRA Anglian Region "1992 Groundwater Balances Review" for the purposes of internal water resource planning

Development Option: MELLIS OPTION 1 (AT SITE TM 08 76)

Resources			River Need					Abstractions & Nominal Surplus				
Groundwater Catchment	Gross Resource	Effective Resource	Gross Environmental Full Allocation	Allocation Limited to 50% Gross Resource Change	Net Reliable Effluent minus Unconstrained Abstractions	Groundwater Allocation to River	Allocation with 50% Gross Resource Change	Total Abstraction *2	Balance Nominally Available	Balance Nominally Available with Environmental Limited to 50% Gross Resource Change	Fraction of proposed Borehole Catchment within Groundwater Catchment *1	Balance Nominally Available with Proposed Development Option
	(tcmd)	(tcmd)	(tcmd)		(tcmd)	(tcmd)	(tcmd)	(tcmd)	(tcmd)	(tcmd)		(tcmd)
1	2	3	4	5	6	7=4-6	8=5-6	9	10=3-(7+9)	11=3-(8+9)	12	13=10-(3.6tcmd*12)
Little Ouse (Unit 9 Cambs. Chalk)	263.4	210.8	138.7	131.7	13.5	125.2	118.2	79.6	5.8	12.8	0.54	3.9
Waveney (Waveney Chalk 34/16)	21.9	17.5	5.7		3.4	2.3		9.9	5.3		0.32	4.1
Dove (Waveney Chalk 34/17)	29.9	23.9	8.0		3.1	4.9		15.2	3.8		0.14	3.3

Notes
NA not applicable
*1 Assuming a borehole catchment area of 28 km² (equivalent to infiltration rate of 47 mm/yr)
*2 The total abstraction for Unit 9 Cambs. Chalk given in NRA Groundwater Balances Review (1992) is 83.4 tcmd and includes the Redgrave source

REDGRAVE & LOPHAM FEN

CATCHMENT WATER BALANCES

Based on NRA Anglian Region "1992 Groundwater Balances Review" for the purposes of internal water resource planning

Development Option: MELUS OPTION 2 (AT SITE 'B')

Resources			River Need					Abstractions & Nominal Surplus				
Groundwater Catchment	Gross Resource (tcmd)	Effective Resource (tcmd)	Gross Environmental Full Allocation (tcmd)	Allocation Limited to 50% Gross Resource Change	Net Reliable Effluent minus Unconstrained Abstractions (tcmd)	Groundwater Allocation to River (tcmd)	Allocation with 50% Gross Resource Change (tcmd)	Total Abstraction *2 (tcmd)	Balance Nominally Available (tcmd)	Balance Nominally Available with Environmental Limited to 50% Gross Resource Change (tcmd)	Fraction of proposed Borehole Catchment within Groundwater Catchment *1	Balance Nominally Available with Proposed Development Option (tcmd)
1	2	3	4	5	6	7=4−6	8=5−6	9	10=3−(7+9)	11=3−(8+9)	12	13=10−(3.6tcmd*12)
Little Ouse (Unit 9 Cambs. Chalk)	283.4	210.8	138.7	131.7	13.5	125.2	118.2	79.8	5.8	12.8	0.43	4.3
Waveney (Waveney Chalk 34/16)	21.9	17.5	5.7		3.4	2.3		9.9	5.3		0.57	3.2

Notes

NA not applicable

*1 Assuming a borehole catchment area of 28 km² (equivalent to infiltration rate of 47 mm/yr)

*2 The total abstraction for Unit 9 Cambs. Chalk given in NRA Groundwater Balances Review (1992) is 83.4 tcmd and includes the Redgrave source

REDGRAVE & LOPHAM FEN

CATCHMENT WATER BALANCES
Based on NRA Anglian Region "1992 Groundwater Balances Review" for the purposes of internal water resource planning

Development Option: MELUS OPTION 3 (COMBINATION OF OPTIONS 1 AND 2 AT SITE TM 08 78 AND SITE 'B')

Resources			River Need					Abstractions & Nominal Surplus				
Groundwater Catchment	Gross Resource (tcmd)	Effective Resource (tcmd)	Gross Environmental Full Allocation (tcmd)	Allocation Limited to 50% Gross Resource Change	Net Reliable Effluent minus Unconstrained Abstractions (tcmd)	Groundwater Allocation to River (tcmd)	Allocation with 50% Gross Resource Change (tcmd)	Total Abstraction *2 (tcmd)	Balance Nominally Available (tcmd)	Balance Nominally Available with Environmental Limited to 50% Gross Resource Change (tcmd)	Fraction of proposed Borehole Catchment within Groundwater Catchment *1	Balance Nominally Available with Proposed Development Option (tcmd)
1	2	3	4	5	6	7=4−6	8=5−6	9	10=3−(7+9)	11=3−(8+9)	12	13=10−(3.6tcmd*12)
Little Ouse (Unit 9 Cambs. Chalk)	263.4	210.8	138.7	131.7	13.5	125.2	118.2	79.8	5.8	12.8	0.48	4.1
Waveney (Waveney Chalk 34/16)	21.9	17.5	5.7		3.4	2.3		9.9	5.3		0.45	3.7
Dove (Waveney Chalk 34/17)	29.9	23.9	8.0		3.1	4.9		15.2	3.8		0.07	3.5

Notes
NA not applicable
*1 Assuming a combined borehole catchment area of 28 km² i.e. 14 km² for each site (equivalent to infiltration rate of 47 mm/yr)
*2 The total abstraction for Unit 9 Cambs. Chalk given in NRA Groundwater Balances Review (1992) is 83.4 tcmd and includes the Redgrave source

REDGRAVE & LOPHAM FEN

CATCHMENT WATER BALANCES
Based on NRA Anglian Region "1992 Groundwater Balances Review" for the purposes of internal water resource planning

Development Option: WETHERINGSETT

Resources			River Need					Abstractions & Nominal Surplus				
Groundwater Catchment	Gross Resource	Effective Resource	Gross Environmental Full Allocation	Allocation Limited to 50% Gross Resource Change	Net Reliable Effluent minus Unconstrained Abstractions	Groundwater Allocation to River	Allocation with 50% Gross Resource Change	Total Abstraction	Balance Nominally Available	Balance Nominally Available with Environmental Limited to 50% Gross Resource Change	Fraction of proposed Borehole Catchment within Groundwater Catchment *1	Balance Nominally Available with Proposed Development Option
	(tcmd)	(tcmd)	(tcmd)		(tcmd)	(tcmd)	(tcmd)	(tcmd)	(tcmd)	(tcmd)		(tcmd)
1	2	3	4	5	6	7=4−6	8=5−6	9	10=3−(7+9)	11=3−(8+9)	12	13=10−(3.6tcmd*12)
Deben (Deben Chalk 35/06)	25.5	20.4	8.2		1.0	7.2		9.6	3.5		0.32	2.3
Gipping (Gipping Chalk 35/08)	57.7	46.2	16.9		12.2	4.7		45.9	−4.4		0.00	−4.4
Dove (Waveney Chalk 34/17)	29.9	23.9	8.0		3.1	4.9		15.2	3.8		0.68	1.4

Notes
NA not applicable
*1 Assuming a borehole catchment area of 26 km² (equivalent to infiltration rate of 47 mm/yr)

APPENDIX F

Hydrogeological Summary for Each Development Option
- includes drawdown estimates, geological section,
and listing of groundwater abstraction licenses and unlicensed sources affected.

DO-NOTHING OPTION

REDGRAVE AND LOPHAM FEN

ESTIMATE OF THE ZONE OF INFLUENCE ASSUMING THE AQUIFER IS LEAKY
Using DeGlee's method where Ko is a function of (r/L) and is found from tables

Abstraction Well Name: REDGRAVE
Observation Well Name:
Observation Well Name:
Rest Water Level (RWL) = NA mBGL

Discharge (m^3/day)	Transmissivity (m^2/day)	r (m)	L (m)	r/L	Index Position Above	Index Position Below	Index Value Above	Index Value Below	Ko(r/L)	sm (m)
3600	990	50	2087	0.024	1	2	4.028	3.623	3.868	2.24
3600	990	100	2087	0.048	3	4	3.336	3.114	3.160	1.83
3600	990	200	2087	0.096	8	9	2.531	2.427	2.470	1.43
3600	990	300	2087	0.144	9	10	2.427	1.753	2.132	1.23
3600	990	360	2087	0.172	9	10	2.427	1.753	1.938	1.12
3600	990	400	2087	0.192	9	10	2.427	1.753	1.809	1.05
3600	990	500	2087	0.24	10	11	1.753	1.372	1.602	0.93
3600	990	1000	2087	0.479	12	13	1.114	0.924	0.964	0.56
3600	990	2000	2087	0.958	17	18	0.487	0.421	0.449	0.26
3600	990	3000	2087	1.437	18	19	0.421	0.214	0.240	0.14
3600	990	4000	2087	1.917	19	20	0.214	0.114	0.131	0.08
3600	990	5000	2087	2.396	20	21	0.114	0.062	0.073	0.04
3600	990	6000	2087	2.875	21	22	0.0623	0.035	0.042	0.02
3600	990	7000	2087	3.354	22	23	0.0347	0.02	0.024	0.01
3600	990	8000	2087	3.833	23	24	0.0196	0.011	0.014	0.01
3600	990	9000	2087	4.312	24	25	0.0112	0.006	0.008	0.00
3600	990	10000	2087	4.792	25	26	0.0064	0.004	0.005	0.00
3600	990	20000	2087	9.583	26	27	0.0037	0	0.004	0.00

APPENDIX F

Licences Affected

Option: Do Nothing

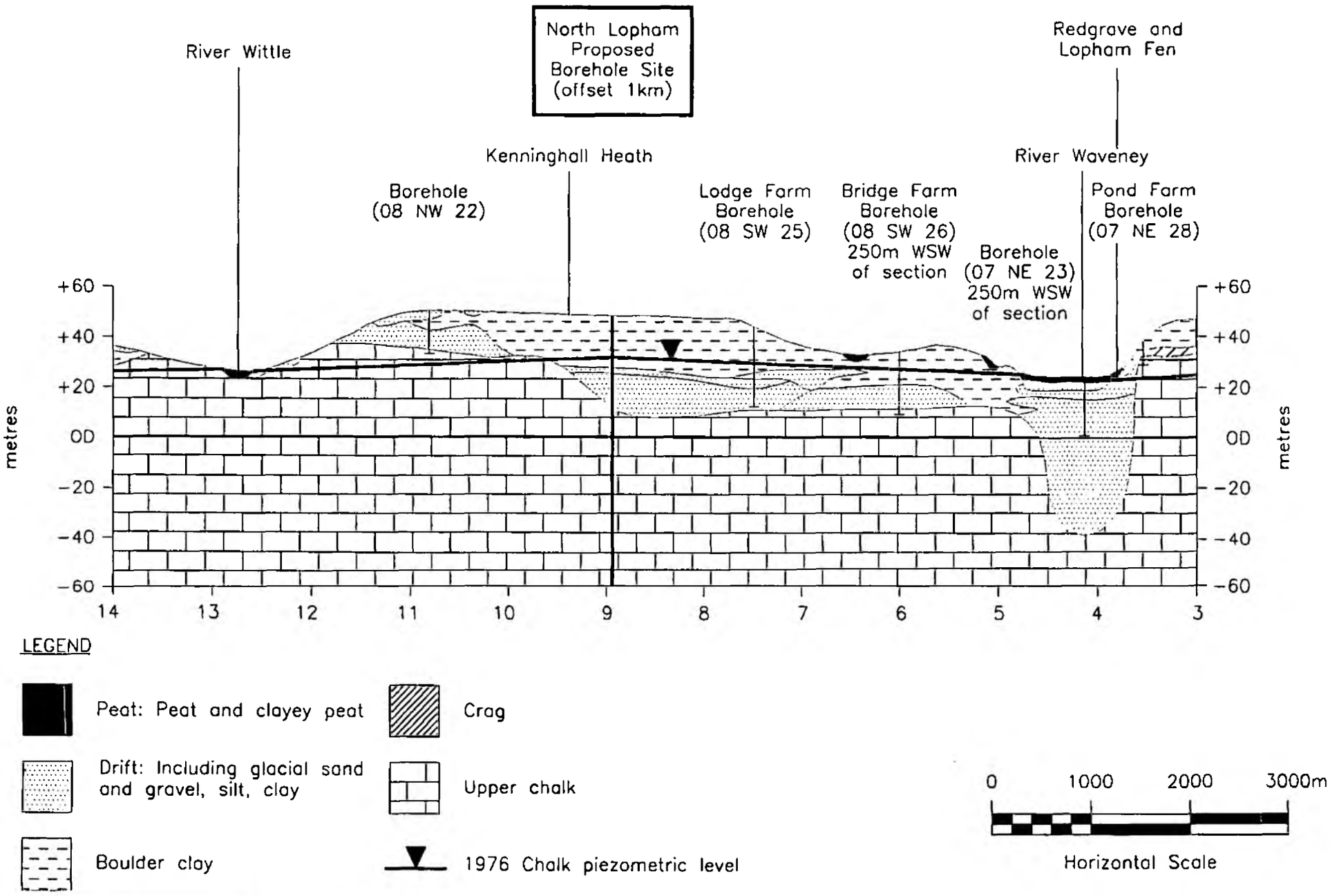
Licence No.	Distance (m)	Licensed Amount (m^3/day)	Additional Drawdown (m)
No licences affected			

UNLICENSED SOURCES TO BE INCLUDED AS AN ADDENDUM

AT A LATER DATE

NORTH LOPHAM OPTION

NORTH LOPHAM OPTION



REDGRAVE AND LOPHAM FEN

ESTIMATE OF THE ZONE OF INFLUENCE ASSUMING THE AQUIFER IS LEAKY
Using DeGlee's method for steady state flow where Ko is a function of (r/L) and is found from tables

Abstraction Well Name: NORTH LOPHAM
Observation Well Name: MAIN (main observation well for upto 500m)
Observation Well Name:
Rest Water Level (RWL) = 20.93 mBGL
Discharge = 3600 (m^3/day)
Transmissivity = 238 (m^2/day)

Discharge (m^3/day)	Transmissivity (m^2/day)	r (m)	L (m)	r/L	Index Position Above	Index Position Below	Index Value Above	Index Value Below	Ko(r/L)	sm (m)
3600	238	50	1580	0.032	2	3	3.623	3.336	3.576	8.61
3600	238	100	1580	0.063	5	6	2.933	2.78	2.883	6.94
3600	238	200	1580	0.127	9	10	2.427	1.753	2.248	5.41
3600	238	237	1580	0.15	9	10	2.427	1.753	2.090	5.03
3600	238	300	1580	0.19	9	10	2.427	1.753	1.821	4.38
3600	238	400	1580	0.253	10	11	1.753	1.372	1.550	3.73
3600	238	500	1580	0.316	11	12	1.372	1.114	1.330	3.20
3600	238	1000	1580	0.633	14	15	0.777	0.66	0.738	1.78
3600	238	2000	1580	1.266	18	19	0.421	0.214	0.311	0.75
3600	238	3000	1580	1.899	19	20	0.214	0.114	0.134	0.32
3600	238	4000	1580	2.532	21	22	0.0623	0.035	0.061	0.15
3600	238	5000	1580	3.165	22	23	0.0347	0.02	0.030	0.07
3600	238	6000	1580	3.797	23	24	0.0196	0.011	0.015	0.04
3600	238	7000	1580	4.43	24	25	0.0112	0.006	0.007	0.02
3600	238	8000	1580	5.063	26	27	0.0037	0	0.004	0.01
3600	238	9000	1580	5.696	26	27	0.0037	0	0.004	0.01
3600	238	10000	1580	6.329	26	27	0.0037	0	0.004	0.01
3600	238	20000	1580	12.66	26	27	0.0037	0	0.004	0.01

APPENDIX F

Licences Affected

Option: North Lopham (no river augmentation pumping)

Licence No.	Distance (m)	Licensed Amount (m^3/day)	Additional Drawdown (m)
6/33/42/*g/074	500	11,000.00	3.20
7/34/16/*g/031	800	1.10	2.35
7/34/16/*g/069	1600	19.00	1.16

Option: North Lopham (with river augmentation pumping)

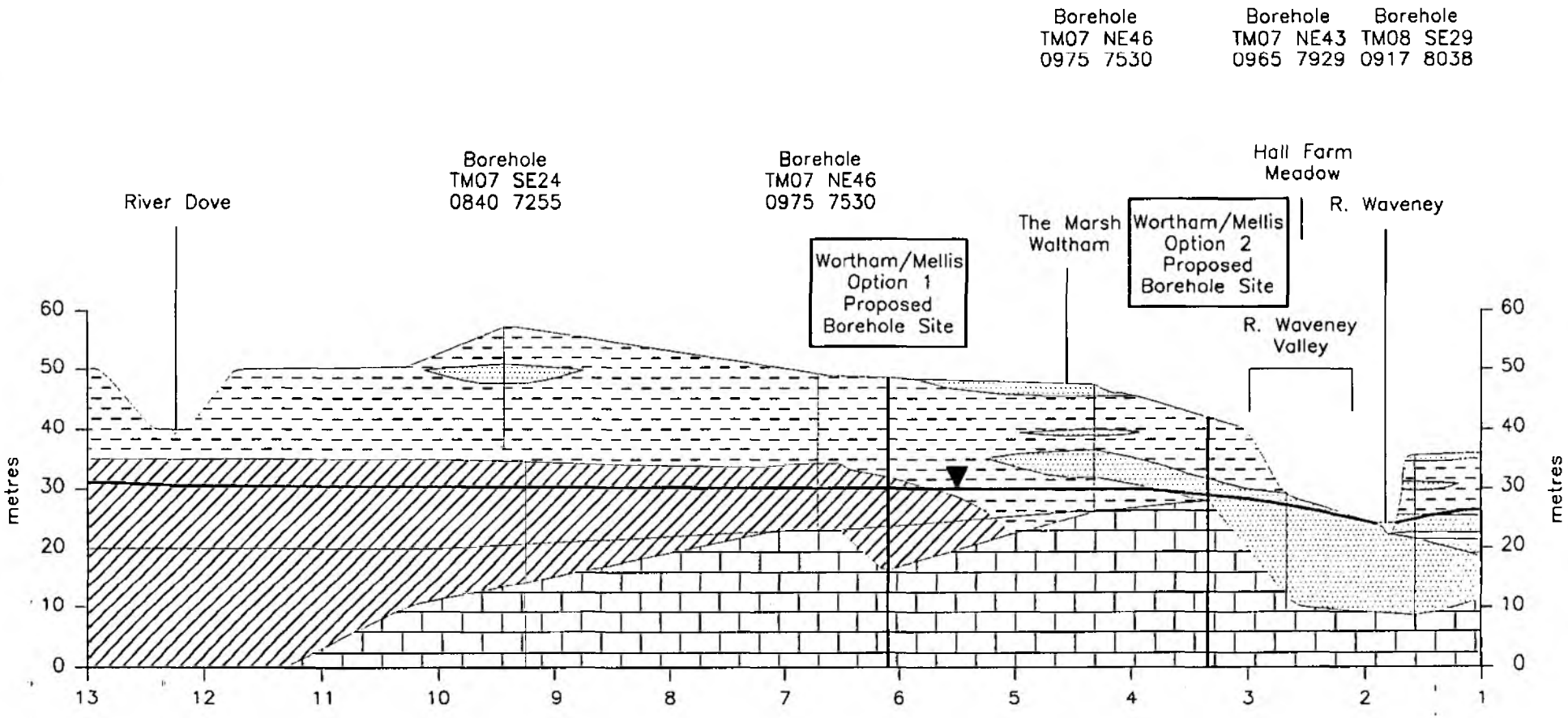
Licence No.	Distance (m)	Licensed Amount (m^3/day)	Additional Drawdown (m)
7/34/16/*g/031	800	1.10	9.52
7/34/16/*g/069	1600	1.90	4.71
6/33/42/*g/074	3400	11,000.00	1.02
6/33/42/*g/087	3500	45.50	0.95
7/34/16/*g/070	2000	41.00	3.04
6/33/42/*g/074	3000	11,000.00	1.31
6/33/44/*g/015	3000	5.45	1.31
6/33/44/*g/061	2900	4.55	1.48
6/33/44/*g/207	3400	1300.00	1.02
6/33/44/*g/117	2300	22.73	2.52
6/33/44/*g/137	3100	11,000.00	1.24
6/33/44/*g/137	2800	11,000.00	1.66
6/33/44/*g/222	2700	2117.00	1.83

UNLICENSED SOURCES TO BE INCLUDED AS AN ADDENDUM

AT A LATER DATE

WORTHAM/MELLIS OPTIONS

WORTHAM/MELLIS OPTIONS



LEGEND

- Peat: Peat and clayey peat
- Drift: Including glacial sand and gravel, silt, clay
- Boulder clay
- Crag
- Upper chalk
- 1976 Chalk piezometric level

0 1000 2000 3000m

Horizontal Scale

NOTE: Wortham/Mellis Option 3 is a combination of Options 1 and 2

REDGRAVE AND LOPHAM FEN

ESTIMATE OF THE ZONE OF INFLUENCE ASSUMING THE AQUIFER IS LEAKY
Using DeGlee's method where Ko is a function of (r/L) and is found from tables

Abstraction Well Name: MELLIS OPTION 1 AT TM 080 760
Observation Well Name: OBS1 (main observation well for less than 2000m and data for site '8' beyond 2000m)
Observation Well Name:
Rest Water Level (RWL) = NA mBGL

Discharge (m^3/day)	Transmissivity (m^2/day)	r (m)	L (m)	r/L	Index Position Above	Index Position Below	Index Value Above	Index Value Below	Ko(r/L)	sm (m)
3600	282	100	6000	0.017	0	1	4.721	4.028	4.259	8.65
3600	282	200	6000	0.033	2	3	3.623	3.336	3.527	7.17
3600	282	300	6000	0.05	4	5	3.114	2.933	3.114	6.33
3600	282	360	6000	0.06	5	6	2.933	2.78	2.933	5.96
3600	282	400	6000	0.067	5	6	2.933	2.78	2.831	5.75
3600	282	500	6000	0.083	7	8	2.647	2.531	2.608	5.30
3600	282	1000	6000	0.167	9	10	2.427	1.753	1.978	4.02
3600	5000	2000	6000	0.333	11	12	1.372	1.114	1.286	0.15
3600	5000	3000	6000	0.5	13	14	0.924	0.777	0.924	0.11
3600	5000	4000	6000	0.667	14	15	0.777	0.66	0.699	0.08
3600	5000	5000	6000	0.833	16	17	0.565	0.487	0.539	0.06
3600	5000	6000	6000	1	18	19	0.421	0.214	0.421	0.05
3600	5000	7000	6000	1.167	18	19	0.421	0.214	0.352	0.04
3600	5000	8000	6000	1.333	18	19	0.421	0.214	0.283	0.03
3600	5000	9000	6000	1.5	19	20	0.214	0.114	0.214	0.02
3600	5000	10000	6000	1.667	19	20	0.214	0.114	0.181	0.02
3600	5000	20000	6000	3.333	22	23	0.0347	0.02	0.025	0.00

REDGRAVE AND LOPHAM FEN

ESTIMATE OF THE ZONE OF INFLUENCE ASSUMING THE AQUIFER IS LEAKY
Using DeGlee's method where Ko is a function of (r/L) and is found from tables

Abstraction Well Name: MELLIS OPTION 2 AT TM 078 792 AND COINCIDES WITH SOUTHERN SCIENCE SITE 'B'
Observation Well Name: USE PUMPING WELL & S VALUES FROM MELLIS C
Observation Well Name:
Rest Water Level (RWL) = NA mBGL

Discharge (m^3/day)	Transmissivity (m^2/day)	r (m)	L (m)	r/L	Index Position Above	Index Position Below	Index Value Above	Index Value Below	Ko(r/L)	sm (m)
3600	5000	100	6000	0.017	0	1	4.721	4.028	4.259	0.49
3600	5000	200	6000	0.033	2	3	3.623	3.336	3.527	0.40
3600	5000	300	6000	0.05	4	5	3.114	2.933	3.114	0.36
3600	5000	360	6000	0.06	5	6	2.933	2.78	2.933	0.34
3600	5000	400	6000	0.067	5	6	2.933	2.78	2.831	0.32
3600	5000	500	6000	0.083	7	8	2.647	2.531	2.608	0.30
3600	5000	800	6000	0.133	9	10	2.427	1.753	2.202	0.25
3600	5000	1000	6000	0.167	9	10	2.427	1.753	1.978	0.23
3600	5000	2000	6000	0.333	11	12	1.372	1.114	1.286	0.15
3600	5000	3000	6000	0.5	13	14	0.924	0.777	0.924	0.11
3600	5000	4000	6000	0.667	14	15	0.777	0.66	0.699	0.08
3600	5000	5000	6000	0.833	16	17	0.565	0.487	0.539	0.06
3600	5000	6000	6000	1	18	19	0.421	0.214	0.421	0.05
3600	5000	7000	6000	1.167	18	19	0.421	0.214	0.352	0.04
3600	5000	8000	6000	1.333	18	19	0.421	0.214	0.283	0.03
3600	5000	9000	6000	1.5	19	20	0.214	0.114	0.214	0.02
3600	5000	10000	6000	1.667	19	20	0.214	0.114	0.181	0.02
3600	5000	20000	6000	3.333	22	23	0.0347	0.02	0.025	0.00

APPENDIX F

Licences Affected

Option: Wortham/Mellis (Option 1 at TM0876)

Licence No.	Distance (m)	Licensed Amount (m^3/day)	Additional Drawdown (m)
6/33/42/*g/074	1800	11,000.00	0.92
6/33/42/*g/054	1500	6.81	2.09
7/34/16/*g/059	1400	9.00	2.47
7/34/16/*g/019	1400	4.00	2.47
6/33/42/*g/104	900	91.00	4.28
6/33/42/*g/095	800	218.20	4.53
7/34/16/*g/008	900	1.10	4.28
7/34/16/*g/064	700	91.00	4.79

Option: Wortham/Mellis (Option 2 at site 'B')

Licence No.	Distance (m)	Licensed Amount (m^3/day)	Additional Drawdown (m)
No licences affected			

Option: Wortham/Mellis (Option 3 which combines Options 1 and 2 but each at 1800 m^3/day)

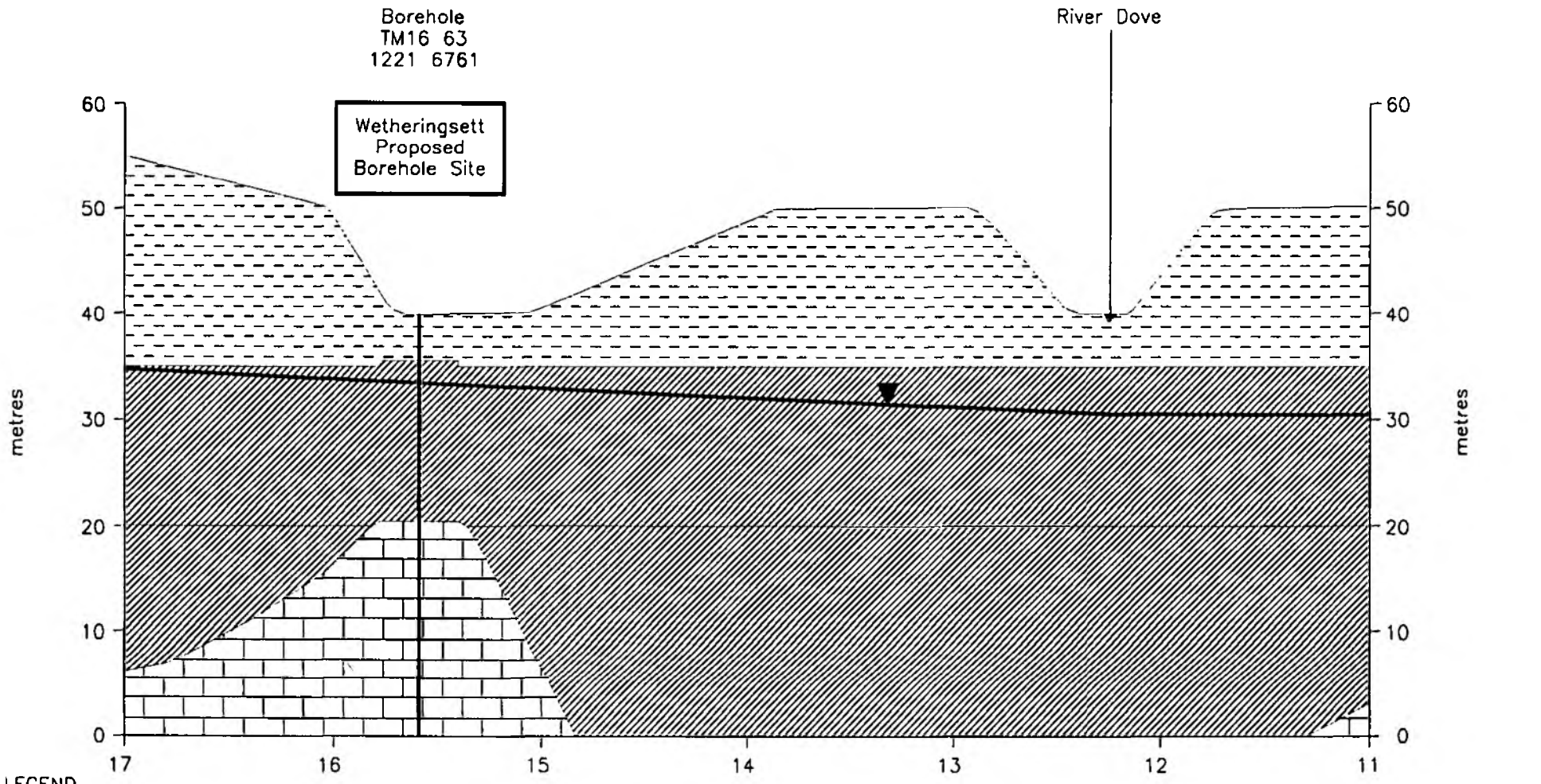
Licence No.	Distance (m)	Licensed Amount (m^3/day)	Additional Drawdown (m)
6/33/42/*g/104	900	91.00	2.14
6/33/42/*g/095	800	218.20	2.27
7/34/16/*g/008	900	1.10	2.14
7/34/16/*g/064	700	91.10	2.40
6/33/42/*g/054	1500	6.81	1.05
7/34/16/*g/059	1400	9.00	1.24
7/34/16/*g/019	1400	4.00	1.24

UNLICENSED SOURCES TO BE INCLUDED AS AN ADDENDUM

AT A LATER DATE

WETHERINGSETT OPTION

WETHERINGSETT OPTION



LEGEND

- Peat: Peat and clayey peat
- Drift: Including glacial sand and gravel, silt, clay
- Boulder clay
- Crag
- Upper chalk
- 1976 Chalk piezometric level

0 1000 2000m

Horizontal Scale

REDGRAVE AND LOPHAM FEN

ESTIMATE OF THE ZONE OF INFLUENCE ASSUMING THE AQUIFER IS LEAKY
Using DeGlee's method where Ko is a function of (r/L) and is found from tables

Abstraction Well Name: WETHERINGSETT
Observation Well Name: WETHOBS1 (main observation well for upto 500m)
Observation Well Name: WETHOBS2 (Brockford Common Police Station for beyond 500m)
Rest Water Level (RWL) = 3.94 mBGL

Discharge (m^3/day)	Transmissivity (m^2/day)	r (m)	L (m)	r/L	Index Position Above	Index Position Below	Index Value Above	Index Value Below	Ko(r/L)	sm (m)
3600	398	36	1580	0.023	1	2	4.028	3.623	3.915	5.64
3600	398	50	1580	0.032	2	3	3.623	3.336	3.576	5.15
3600	398	100	1580	0.063	5	6	2.933	2.78	2.883	4.15
3600	398	200	1580	0.127	9	10	2.427	1.753	2.248	3.24
3600	398	300	1580	0.19	9	10	2.427	1.753	1.821	2.62
3600	398	400	1580	0.253	10	11	1.753	1.372	1.550	2.23
3600	398	500	1580	0.316	11	12	1.372	1.114	1.330	1.91
3600	1564	1000	6466	0.155	9	10	2.427	1.753	2.059	0.75
3600	1564	2000	6466	0.309	11	12	1.372	1.114	1.348	0.49
3600	1564	3000	6466	0.464	12	13	1.114	0.924	0.992	0.36
3600	1564	4000	6466	0.619	14	15	0.777	0.66	0.755	0.28
3600	1564	5000	6466	0.773	15	16	0.66	0.565	0.590	0.22
3600	1564	6000	6466	0.928	17	18	0.487	0.421	0.469	0.17
3600	1564	7000	6466	1.083	18	19	0.421	0.214	0.387	0.14
3600	1564	8000	6466	1.237	18	19	0.421	0.214	0.323	0.12
3600	1564	9000	6466	1.392	18	19	0.421	0.214	0.259	0.09
3600	1564	10000	6466	1.547	19	20	0.214	0.114	0.205	0.07
3600	1564	20000	6466	3.093	22	23	0.0347	0.02	0.032	0.01

APPENDIX F

Licences Affected

Option: Wetheringsett (no river augmentation pumping)

Licence No.	Distance (m)	Licensed Amount (m^3/day)	Additional Drawdown (m)
7/34/17/*g/068	500	10,000.00	1.91
7/34/17/*g/021	900	1.00	0.98

APPENDIX F

Licences Affected

Option: Wetheringsett (with river augmentation pumping)

Licence No.	Distance (m)	Licensed Amount (m^3/day)	Additional Drawdown (m)
7/34/17/*g/021	900	1.00	3.73
7/34/17/*g/009	1000	5.00	2.85
7/34/17/*g/016	1500	5.00	2.36
7/34/16/#g/048	3000	455.00	1.37
7/34/17/*g/037	3800	11.00	1.11
7/34/17/*g/038	3600	5.00	1.18
7/34/17/*g/047	4100	7.00	1.03
7/34/17/*g/033	3400	3.00	1.24
7/34/17/*g/057	2300	764.00	1.72
7/34/17/*g/034	2400	14.05	1.67
7/34/17/*g/006	2900	2.00	1.42
7/34/17/*g/036	3000	5.00	1.37
7/34/17/*g/036	2500	7.00	1.62
7/34/17/*g/041	2400	364.00	1.67
7/34/17/*g/047	4100	46.00	1.03
7/34/17/*g/013	3300	1.10	1.27
7/34/17/*g/003	2600	9.00	1.57
7/34/17/*g/068	3500	8000.00	1.21
7/34/17/*g/031	4100	20.00	1.03
7/35/06/*g/013	4200	14.00	1.00
7/35/06/*g/042	4000	2.20	1.05
7/34/17/*g/002	2500	8.20	1.62
7/34/17/*g/017	2100	3.00	1.82

UNLICENSED SOURCES TO BE INCLUDED AS AN ADDENDUM

AT A LATER DATE

Howard Humphreys *Consulting Engineers*

National Rivers Authority
Anglian Region

REDGRAVE AND LOPHAM FENS RESTORATION PROJECT: HYDROLOGICAL AND ENVIRONMENTAL IMPACT ASSESSMENT

Addendum to Final Report

Ref. 84.307.0/3122/REDLOP1.AO2

Howard Humphreys & Partners Ltd
Thorncroft Manor
Dorking Road
Leatherhead
Surrey
KT22 8JB

July 1994

Brown & Root *Civil*

REDGRAVE & LOPHAM FEN: APPENDIX F
UNLICENSED SOURCES AFFECTED

Option: Do Nothing

Code Number	NGR			Data Source	Site Name	Borehole Depth (m)	Radial Distance (m)	Additional Drawdown (m)
167	TM	50	790	MSDC	Hempland, The Bungalow, Fen Street, Redgrave, Diss (approx.)		400	1.05
168	TM	51	791	MSDC	Musk Meadow Farm, Fen Street, Redgrave, Diss (approx.)		500	0.93

Notes:
NRA = National Rivers Authority
MSDC = Mid Suffolk District Council
BDC = Breckland District Council
SNDC = South Norfolk District Council

REDGRAVE & LOPHAM FEN: APPENDIX F
UNLICENSED SOURCES AFFECTED

Option: North Lopham (no river augmentation pumping)

Code Number	NGR			Data Source	Site Name
58	TM	12	840	NRA	Uphall Farm, Garboldisham
37	TM	12	840	NRA	Uphall Farm, Garboldisham
35	TM	15	824	NRA	Ling Farm, Garboldisham
86	TM	16	822	BDC	Shillings Farm, North Lopham
27	TM	18	845	NRA	Kenninghall
28	TM	18	846	NRA	Kenninghall
84	TM	22	831	BDC	Finchams Farm, North Lopham
25	TM	24	834	NRA	Ling Farn, Highfield Lane, Garboldisham
30	TM	33	833	NRA	Council houses, North Lopham
61	TM	35	834	NRA	The Cedars, North Lopham, Diss
68	TM	36	829	NRA	The Lynden House, North Lopham
32	TM	36	829	NRA	The Limes, North Lopham, Norfolk
67	TM	36	829	NRA	The Cottage, North Lopham, Diss
66	TM	36	830	NRA	White House, North Lopham, Diss
65	TM	36	832	NRA	Fern Villa, North Lopham, Diss
60	TM	36	833	NRA	15 The Street, North Lopham
59	TM	36	836	NRA	Ivey Dene, North Lopham, Diss
64	TM	37	833	NRA	The Green, North Lopham, Diss
85	TM	38	827	BDC	Fortunes Well, The Street, North Lopham

Notes:
NRA = National Rivers Authority
MSDC = Mid Suffolk District Council
BDC = Breckland District Council
SNDC = South Norfolk District Council

	Borehole Depth (m)	Radial Distance (m)	Additional Drawdown (m)
	141.75	1400	1.37
	43.2	1400	1.37
	44.5	1600	1.16
		1700	1.06
		1100	1.68
		1200	1.57
		600	2.92
	160	200	5.41
	66.44	900	2.06
		1000	1.78
		1300	1.47
	68.58	1300	1.47
	4.4	1300	1.47
		1300	1.47
	2.9	1200	1.57
		1100	1.68
		1100	1.68
	3.66	1200	1.57
		1600	1.16

REDGRAVE & LOPHAM FEN: APPENDIX F
UNLICENSED SOURCES AFFECTED

Option: North Lopham (with river augmentation pumping)

Code Number	NGR			Data Source	Site Name	Borehole Depth (m)	Radial Distance (m)	Additional Drawdown (m)
22	TM	1	818	NRA	Lovers Lane, Garboldisham	140	3000	1.31
56	TM	4	843	NRA	Flint Hall	30	2200	2.69
39	TM	4	843	NRA	Flinthall Cottages, East Harling	9.4	2200	2.69
57	TM	4	843	NRA	Flint Hall		2200	2.69
40	TM	4	844	NRA	Flint Hall Farm, East Harling	30	2200	2.69
31	TM	5	822	NRA	The Hall, Garboldisham	36.57	2400	2.35
16	TM	5	850	NRA	R Kemp & Son, East Harling, Norfolk		2400	2.35
36	TM	7	826	NRA	Garboldisham	40.84	2100	2.87
15	TM	7	827	NRA	Manor Cottage, Kenninghall Road, Garboldisham	5.2	2000	3.04
58	TM	12	840	NRA	Uphall Farm, Garboldisham	141.75	1400	5.54
37	TM	12	840	NRA	Uphall Farm, Garboldisham	43.2	1400	5.54
35	TM	15	824	NRA	Ling Farm, Garboldisham	44.5	1600	4.71
23	TM	16	804	NRA	Nr Willow Farm, Blo' Norton	150	3300	1.09
86	TM	16	822	BDC	Shillings Farm, North Lopham		1700	4.29
20	TM	16	863	NRA	Taylor Manor Farm, Quidenham	12.42	2800	1.66
27	TM	18	845	NRA	Kenninghall		1100	6.79
28	TM	18	846	NRA	Kenninghall		1200	6.38
13	TM	19	814	NRA	T & P Reader, Lopham Road, Garboldisham	8.84	2300	2.52
19	TM	19	860	NRA	Taylor Manor Farm, Quidenham	7.96	2500	2.18
24	TM	22	814	NRA	Ling Farm, Garboldisham	210	2200	2.69
84	TM	22	831	BDC	Finchams Farm, North Lopham		600	11.83
17	TM	23	859	NRA	Downhill Farm, Kenninghall	30	2300	2.52
25	TM	24	834	NRA	Ling Farn, Highfield Lane, Garboldisham	160	200	21.95
33	TM	24	859	NRA	Downhill Farm, Kenninghall	34.74	2300	2.52
26	TM	28	862	NRA	Kenninghall water tower		2600	2.00
30	TM	33	833	NRA	Council houses, North Lopham	66.44	900	8.36
61	TM	35	834	NRA	The Cedars, North Lopham, Diss		1000	7.21
68	TM	36	829	NRA	The Lynden House, North Lopham		1300	5.96
32	TM	36	829	NRA	The Limes, North Lopham, Norfolk	68.58	1300	5.96
67	TM	36	829	NRA	The Cottage, North Lopham, Diss	4.4	1300	5.96
66	TM	36	830	NRA	White House, North Lopham, Diss		1300	5.96
65	TM	36	832	NRA	Fern Villa, North Lopham, Diss	2.9	1200	6.38
60	TM	36	833	NRA	15 The Street, North Lopham		1100	6.79
59	TM	36	836	NRA	Ivey Dene, North Lopham, Diss		1100	6.79
64	TM	37	833	NRA	The Green, North Lopham, Diss	3.66	1200	6.38
85	TM	38	827	BDC	Fortunes Well, The Street, North Lopham		1600	4.71
29	TM	38	862	NRA	Council houses, Kenninghall	28.04	2900	1.48
34	TM	39	864	NRA	Breckland District Council, Council houses	24.38	3100	1.24
38	TM	40	818	NRA	Hall Farm, South Lopham	55.47	2300	2.52
62	TM	41	815	NRA	The Cottage, The Street, South Lopham	2.95	2600	2.00
12	TL	999	831	NRA	Hall Farm, Garboldisham	6.4	2600	2.00

Notes:
NRA = National Rivers Authority
MSDC = Mid Suffolk District Council
BDC = Breckland District Council

REDGRAVE & LOPHAM FEN: APPENDIX F
UNLICENSED SOURCES AFFECTED

Option: Wortham/Mellis Option 1

Code Number	NGR			Data Source	Site Name	Borehole Depth (m)	Radial Distance (m)	Additional Drawdown (m)
71	TM	70	772	NRA	Spears Hill, Wortham		1600	1.70
70	TM	70	774	NRA	Hill Croft, Wortham		1700	1.31
1	TM	73	746	NRA	Unknown		1600	1.70
10	TM	75	751	NRA	Willow Cottage, Burgate	51.82	1000	4.02
75	TM	77	750	NRA	Waveney Lodge, Burgate		1000	4.02
11	TM	77	750	NRA	Waveney Lodge, Burgate	57.91	1000	4.02
6	TM	77	764	NRA	Oaktree Farm, Burgate	57.91	500	5.30
74	TM	77	764	NRA	Oak Tree Farm, Wortham	57.9	500	5.30
72	TM	77	774	NRA	Netherhouse, Long Green, Wortham		1400	2.47
5	TM	80	770	NRA			1000	4.02
78	TM	80	772	NRA	Wortham Stones, Long Green, Diss	2.87	1200	3.25
3	TM	81	762	NRA	Public bore handpump, Burgate Great Green, Nr. Diss, Suffolk	63.09	200	7.17
2	TM	81	772	NRA	The Old Stores, Long Green, Wortham, Diss, Norfolk	3.2	1200	3.25
76	TM	82	757	NRA	The Old Rectory, Burgate		400	5.75
79	TM	84	772	NRA	Cherry Tree Cottage, Wortham		1300	2.86
7	TM	84	774	NRA	Limetree Farm, Wortham	54.86	1500	2.09
4	TM	85	770	NRA	Council houses, 11 & 12 Mellis Road, Wortham, Diss	76	1100	3.63
9	TM	86	764	NRA	The Brook, Wortham	76.2	700	4.79
77	TM	86	766	NRA	Brook Road, Burgate		800	4.53
80	TM	87	773	NRA	Wortham Road		1500	2.09
81	TM	89	773	NRA	R.D.C. The Marsh, Wortham		1600	1.70

Notes:
NRA = National Rivers Authority
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BDC = Breckland District Council
SNDC = South Norfolk District Council

REDGRAVE & LOPHAM FEN: APPENDIX F
UNLICENSED SOURCES AFFECTED

Option: Wortham/Mellis Option 3

Code Number	NGR			Data Source	Site Name	Borehole Depth (m)	Radial Distance (m)	Additional Drawdown (m)
10	TM	75	751	NRA	Willow Cottage, Burgate	51.82	1000	2.01
75	TM	77	750	NRA	Waveney Lodge, Burgate		1000	2.01
11	TM	77	750	NRA	Waveney Lodge, Burgate	57.91	1000	2.01
6	TM	77	764	NRA	Oaktree Farm, Burgate	57.91	500	2.65
74	TM	77	764	NRA	Oak Tree Farm, Wortham	57.9	500	2.65
72	TM	77	774	NRA	Netherhouse, Long Green, Wortham		1400	1.24
5	TM	80	770	NRA			1000	2.01
78	TM	80	772	NRA	Wortham Stones, Long Green, Diss	2.87	1200	1.62
3	TM	81	762	NRA	Public bore handpump, Burgate Great Green, Nr. Diss, Suffolk	63.09	200	3.59
2	TM	81	772	NRA	The Old Stores, Long Green, Wortham, Diss, Norfolk	3.2	1200	1.62
76	TM	82	757	NRA	The Old Rectory, Burgate		400	2.86
79	TM	84	772	NRA	Cherry Tree Cottage, Wortham		1300	1.43
7	TM	84	774	NRA	Limetree Farm, Wortham	54.86	1500	1.04
4	TM	85	770	NRA	Council houses, 11 & 12 Mellis Road, Wortham, Diss	76	1100	1.82
9	TM	86	764	NRA	The Brook, Wortham	76.2	700	2.39
77	TM	86	766	NRA	Brook Road, Burgate		800	2.27
80	TM	87	773	NRA	Wortham Road		1500	1.04

Notes:
NRA = National Rivers Authority
MSDC = Mid Suffolk District Council
BDC = Breckland District Council
SNDC = South Norfolk District Council

REDGRAVE & LOPHAM FEN: APPENDIX F
UNLICENSED SOURCES AFFECTED

Option: Wortham/Mellis Option 2

Code Number	NGR	Data Source	Site Name	Borehole Depth (m)	Radial Distance (m)	Additional Drawdown (m)
No sources affected						

Notes:
NRA = National Rivers Authority
MSDC = Mid Suffolk District Council
BDC = Breckland District Council
SNDC = South Norfolk District Council

REDGRAVE & LOPHAM FEN: APPENDIX F
UNLICENSED SOURCES AFFECTED

Option: Wetheringsett (no river augmentation pumping)

Code Number	NGR			Data Source	Site Name	Borehole Depth (m)	Radial Distance (m)	Additional Drawdown (m)
42	TM	118	672	NRA	Garage Bungalow, Buckford	76	600	1.68
195	TM	120	670	MSDC	Post Office, Church Road, Wetheringsett (approx.)		600	1.68
44	TM	126	669	NRA	The Post Office, Wetheringsett	6.35	800	1.21

Notes:
NRA = National Rivers Authority
MSDC = Mid Suffolk District Council
BDC = Breckland District Council
SNDC = South Norfolk District Council

REDGRAVE & LOPHAM FEN: APPENDIX F
UNLICENSED SOURCES AFFECTED

Option: Wetheringsett (with river augmentation pumping)

Code Number	NGR			Data Source	Site Name	Borehole Depth	Radial Distance (m)	Additional Drawdown (m)
47	TM	88	679	NRA	Surwood Farm, Wickham Steith	94	3400	1.24
48	TM	90	655	NRA	Mendlesham Hall Farm, Mendlesham	91	3800	1.11
52	TM	90	698	NRA	Brookside, Thornham Road, Wickham Skeith, Eye		3900	1.08
49	TM	92	661	NRA	Mendlesham Lodge, Mendlesham	92	3400	1.24
50	TM	94	684	NRA	Great Oak Farm, Thwaite Road, Wickham Skeith, Eye	72	2900	1.42
51	TM	98	681	NRA	Elm Tree Farm	91	2500	1.62
41	TM	98	692	NRA	The Hall, Wickham Steith	60	2900	1.42
202	TM	99	681	MSDC	Elm Farm, Thwaite Road, Wickham Skeith, Eye		2400	1.67
153	TM	101	667	MSDC	White House Farm, Mendlesham, Stowmarket		2300	1.72
43	TM	115	694	NRA	Well Cottage, Stoke Ash	9.93	1900	1.97
42	TM	118	672	NRA	Garage Bungalow, Buckford	76	600	6.35
195	TM	120	670	MSDC	Post Office, Church Road, Wetheringsett (approx.)		600	6.35
45	TM	126	668	NRA	The Old Forge, Church Road, Wetheringsett	4.22	900	3.73
44	TM	126	669	NRA	The Post Office, Wetheringsett	6.35	800	4.60
46	TM	129	669	NRA	Manor House, Wetheringsett	61	1000	2.85
54	TM	133	661	NRA	Wetheringsett Hall, Wetheringsett	61	1900	1.97
180	TM	142	680	MSDC	Shorts Farm, Wetheringsett Road, Thorndon, Eye		2000	1.87
53	TM	143	680	NRA	Shorts Farm, Thomdon Eye	115	2100	1.82
55	TM	145	643	NRA	Sycamore Farm, Wetherup Street, Wetheringsett	45	4000	1.05

Notes:
NRA = National Rivers Authority
MSDC = Mid Suffolk District Council
BDC = Breckland District Council
SNDC = South Norfolk District Council

Doc.No. 843070/3122/REDLOP1.A02

Title: Redgrave + Lopham Fens

Rev	Date	Description/Reason for Issue	Orig	Ckd	Appd
A02	29/4/94	Final Report (Client Comments)	JMC	DI	DI
A02	15/6/94	Final Report	JMC	DI	DI