NRA

REDGRAVE AND LOPHAM FENS

ALLEVIATION SCHEME

PROJECT APPRAISAL REPORT

ENVIRONMENT AGENCY

National Rivers Authority
Anglian Region

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REDGRAVE & LOPHAM FENS - SUMMARY REPORT

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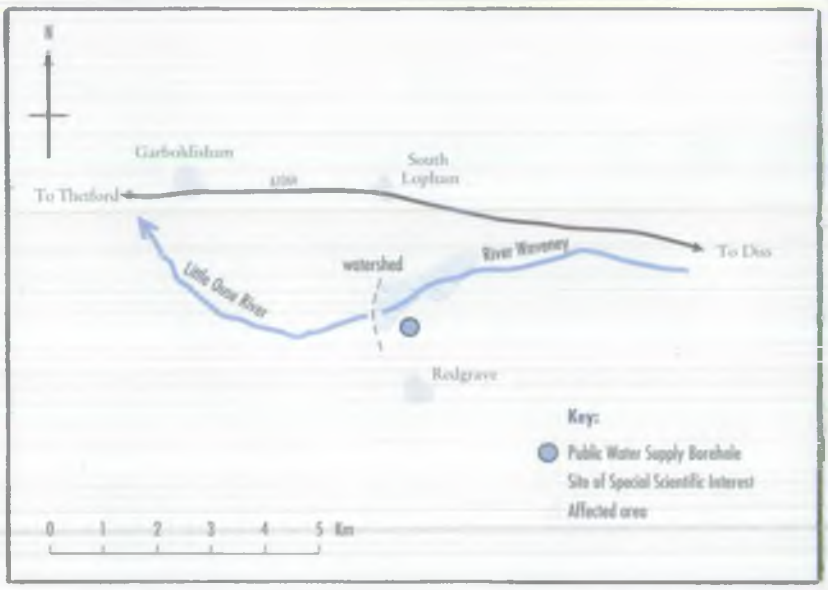
EXECUTIVE SUMMARY

SUMMARY

Redgrave and Lopham Fens SSSI comprises some 125 hectares of spring-fed valley fen located at the watershed of the rivers Little Ouse and Waveney in Suffolk. It is an exceptional wetland site which has long been recognised for its ecological interest and for its importance in being home to a number of rare invertebrates, including the Great Raft Spider. The site is designated as a Wetland of International Importance under the Ramsar convention and became a National Nature Reserve early in 1993.

The site is progressively drying out mainly due to the groundwater abstraction for public water supply located only 30 metres from the site boundary and partly due to land drainage works which have caused river water levels to fall.



If the ecology of the fen is to be preserved then abstraction must cease. Some changes to land drainage and fen management are also required.

Various options to provide a solution have been investigated. The preferred option for which approval is sought is relocation of the Redgrave borehole at Wortham along with river restoration works and extensive fen management at an estimated cost of £2.6M. An EC grant from the LIFE fund has been secured worth 50% of the total project cost up to a maximum of 1.8M ECUs (approx. £1.4M). The 4 year EC grant contract commenced on 1st January 1994 and is subject to NRA and Essex & Suffolk Water matching the residual funding.

The preferred option and its estimated cost is the same as approved in principle by the NRA Board and DOE in December 1993.

BACKGROUND

The progressive drying out of Redgrave & Lopham Fens SSSI in Suffolk has been the subject of debate for many years. The Fens are located at the watershed of the rivers Little Ouse and Waveney *(see Figures 1 & 2)* and have long been recognised for their ecological interest and importance as being home to a number of rare invertebrates including the Great Raft Spider. The Fen was designated as a Wetland of International Importance under the Ramsar Convention in 1991 and launched as a National Nature Reserve on 24th June 1993.

Redgrave & Lopham Fen is one of four Low Flow sites in the Anglian Region. It is included in the National top 20 list of sites in England and Wales identified by the NRA as suffering from excessive authorised abstraction. The NRA is committed to implementing a satisfactory solution.

After extensive investigations it has been proved that the major cause of the drying out is the nearby groundwater abstraction by Essex & Suffolk Water for public water supply. Abstraction commenced in the late 1950's and is authorised by a Licence of Right which at the time of issue did not take account of environmental impact. Such an abstraction would not be licensed today under current licensing policy.

The Fen is maintained and managed by Suffolk Wildlife Trust in partnership with English Nature.

In order to preserve the existing ecology of the fen, permanent abstraction from the existing Redgrave public water supply sourceworks must cease. To maintain water supplies to the 10000 customers supplied from the Redgrave borehole source an alternative source is required. Some changes to land drainage are also required along with an extensive programme of fen management to provide suitable conditions to support full ecological recovery.

OPTIONS

The key options examined to meet the above objectives include:

- Do Nothing
- Impounded storage in the Fen and/or irrigation of the Fen
- Relocation of the abstraction borehole
- Wider Scope alternatives to maintain public water supplies including seasonal pumping, bulk imports and re-zoning of the Company's existing supply.
- Licence revocation
- River Restoration
- Fen Management

The hydrological and environmental impact of various options has been assessed by Howard Humphreys & Partners (HHP) to determine their suitability as a solution. After consultation with interested parties and in conjunction with the HHP report a preferred solution is identified and agreed with the various parties collaborating on the project (ESW, SWT, EN, NRA).

The preferred option is a combination of the relocation of the Redgrave abstraction to Wortham, some 5km south east of Redgrave, along with river restoration works to the Upper Waveney and an extensive programme of fen management. The total scheme costs are estimated at £2.6M. The option is subject to granting of an abstraction licence following confirmation of the environmental and ecological acceptability that will be proven on completion of the development and testing of the production borehole(s).

River restoration works are also required to help recreate hydrological conditions similar to those experienced in the early 1950's prior to deep dredging of the Upper Waveney for land drainage purposes. This will involve remedial works to the section of the River Waveney adjacent to Middle and Great fens to retain water levels, thereby improving the hydrology at the eastern end of the fens.

Relocation and river restoration works alone will not restore the fens ecology. Some of the changes are irreversible, such as peat mineralisation and consequent eutrophication within the fens surface layers. Following the return of water levels and the hydrology of the fens to conditions similar to those of the early 1950's an extensive programme of fen management is required. The main elements of this will involve peat stripping and scrub removal over a large area of the site. *See Appendix 1.*

BENEFITS

The benefits of this project have not been quantified as Redgrave was not chosen as a pilot project for the contingent valuation study. Some 5,000 people visit the site annually, this includes both National and International visitors. Visitors are expected to more than treble following successful rehabilitation. The benefits for the project include:

- Protection of an Internationally Important Wetland SSSI, NNR and Ramsar site.
- An increase in fen valley communities within the Fens, a decrease in the extent of uncharacteristic fen communities, a decrease in scrub invasion, and an increase in floristic quality of fen vegetation.
- An increase in fauna, (eg Great Raft Spider) in terms of population size and area of fen utilised.
- Restoration of the full sequence of the fen communities with attendant invertebrate communities throughout the site.
- Prevention of further degradation and loss of Ramsar status.

- Continued enjoyment by the public and future generations of this rare and exceptional wetland.

- Maintenance of a secure public water supply to some 10,000 people in the Hartismere supply zone.

Improved site facilities funded with the EC grant will provide information and promote greater public awareness of the Fens flora and fauna.

FUNDING

Suffolk Wildlife Trust in collaboration with the NRA and Essex & Suffolk Water have been successful in securing a contribution towards funding of the project from the European Commission under the LIFE fund. The 4 year grant worth 50% of the total project cost up to a maximum of 1.8M ECUs (approx. £1.4M) and commenced on 1st January 1994. This funding relied on the collaborating bodies signing the contract with a commitment to jointly match the contribution.

Funding of the residual costs will depend on the amount of investment allowed by Ofwat in Essex & Suffolk Water's Strategic Business Plan. Advice is awaited from Ofwat on the likely cost pass through provisions and hence investments levels. The NRA will be required to fund the remainder of the costs although a contribution will be made by the Water Company for betterment.

The National Nature Reserve agreement between English Nature and Suffolk Wildlife Trust currently provides £35k/annum towards the existing maintenance of the fen. Both organisations have indicated they have no further funds available for the project.

PROGRAMME AND FUTURE RESPONSIBILITIES AND COSTS

The project is a joint collaboration between English Nature, Suffolk Wildlife Trust, Essex & Suffolk Water and the National Rivers Authority.

Appendix II shows the programme of works. The construction of a replacement borehole and ancillary works will be promoted by Essex & Suffolk Water. The fen restoration programme will be undertaken by Suffolk Wildlife Trust and the NRA will carry out the necessary river restoration works. English Nature will continue to provide advise to the project and funding towards basic fen management via the NNR agreement.

Relevant stages within the project:

- Re-confirmation of approvals by August 1994.

- Drill and test production borehole at Wortham by February 1995.

- Environmental Report to support an abstraction licence application including independent environmental and hydrological audit by May 1995.
- Commence extensive fen management programme August 1994.
- Commence 12 month river restoration works during October 1994.
- Complete licence determination and issue licence during September 1995.
- Undertake site investigation/option for land acquisition at Wetheringsett in the unlikely event that the Wortham option prove unacceptable.
- Development of new source at Wortham commencing September 1995 over 18 months.
- Close Redgrave source by March 1997.

RECOMMENDATIONS FOR APPROVAL

Approval is sought to the preferred option consisting of three main parts:

- **Relocation of the PWS source at Wortham - Cost £1.5M (Subject to granting an abstraction licence).**
- **River restoration works to retain water levels in the Upper Waveney adjacent to Middle and Great fens subsequently raising groundwater levels in this part of the fen - £120k**
- **An extensive programme of fen management - £800k over 4 years.**
- **Total project costs £2.6M. (Includes current and previous studies at Wortham)**

Approvals are requested for expenditure of up to £0.65M by the NRA towards the total project cost of £2.6M. The residual funding will be provided by an EC LIFE grant of £1.3M (1.8M ECUs) and by £0.65M from Essex and Suffolk Water. The ESW contribution is subject to funding approval by Ofwat as part of their AMP2 Strategic Business Plan. Confirmation to this approval is expected from Ofwat by the end of July 1994.

1. INTRODUCTION

The site known as Redgrave & Lopham Fens SSSI comprises 125 hectares of spring-fed valley fen located at the watershed of the rivers Little Ouse and Waveney. It is a wetland site and has long been recognised as being of considerable ecological interest. On 15th February 1991 the site was designated as a Wetland of International Importance under the Ramsar Convention and launched as a National Nature Reserve on 24th June 1993. As a signatory to the Ramsar Convention, the UK Government is committed to promoting the conservation of such sites and the wise use of wetlands in general.

The Fens are managed and maintained by Suffolk Wildlife Trust in partnership with English Nature. As a nature reserve it is available for the enjoyment of any member of the public free of charge at any time all year. It has good visitor facilities including car parks, detailed information boards, a well maintained path network, a boardwalk for disabled access and a high public profile. Some 5,000 people visit the fen annually, including both National and International visitors.

Figures 1 & 2 show the site and area of interest. Redgrave & Lopham comprises one of a number of fens spreading from Roydon fen to Weston Fen in the Little Ouse and Waveney Valleys.

Over the past 30 years the fen has experienced progressive drying out which has induced detrimental changes in vegetation and habitat.

This report identifies what influences are bringing about this effect from summary findings of various reports and investigations carried out in and around the fens. Also identified are the options available to curtail or recover the situation with estimated costs. Conclusions are drawn with subsequent recommendations.

2. PROJECT OBJECTIVES

- **To restore the hydrology of the fens and provide a suitable environment to allow the re-establishment of the fens ecology to conditions similar to those experienced in the 1950's and hence the full sequence of Target Fen types and to re-establish the close mosaic of these within the fen sequence.**

- **To provide a permanent public water supply source with adequate yield, water quality and operational security which will not cause detrimental environmental damage or cause unacceptable derogation to other abstractors.**

3. APPRAISAL REPORT OBJECTIVES

This report:

- identifies what influences are bringing about the change in the fens ecology;
- identifies the changes and where possible, quantifies these changes.
- includes costed solutions and preferred options that have been discussed and agreed by all involved parties ie. National Rivers Authority, Essex & Suffolk Water, Suffolk Wildlife Trust and English Nature.

4. THE PROBLEM

The wetland habitats are extremely sensitive to small changes in water levels over and above that which would naturally occur. Even small scale reductions in groundwater levels and/or changes to the direction of flow can cause significant ecological problems within **this fen.**

Over the period 1958 to 1990 it has been proven that the environment has changed from the characteristic of spring and seepage fen to that associated with drier ecological conditions. There has been a consequent loss of rare fen plant species and a marked decline in more than 120 rare invertebrates including the Great Raft Spider *Dolomedes plantarius* for which the fen is renowned. It is one of only two sites in the UK where this rare spider exists.

(Refs. "Redgrave & Lopham Fens, East Anglia, England - A case study of the changes in flora and fauna due to groundwater abstraction" - SWT 1993 (Appendix III). "Redgrave Stage II Study: Data collation and Analysis - Draft Report" - Aspinwall & Co 1992).

5. NATURE AND EXTENT OF CHANGE IN THE FEN

The site has changed in hydrological characteristics from one dominated by upward and lateral movement of chalky seepage water to one dominated more by rainfall and winter water storage. The principle direction of water movement is now from the surface to the aquifer rather than the reverse. Essentially, the water table level has changed from being at, or above, the fen surface to one which is sub-surface. This will also have the effect of depleting baseflows to the upper River Waveney consequently extending the periods of low flows in the river.

The change in hydrological characteristics has resulted in subsequent changes in the flora and fauna. There has been a dramatic loss of many rare characteristic flowering plants and mosses associated with a substantial decline in species richness. Proven change in the nature of the habitat has also occurred *(SWT 1993 - Appendix III)*. There has been a replacement of nationally rare communities by those which are widespread and associated with drier conditions. In 1958 Redgrave Fen had a distinctive arrangement of calcareous fen communities irrigated by chalky groundwater, overlain by acidic fen communities irrigated

by non-calcareous water derived from rainfall and seepage from sandy deposits. By 1990 these communities have been replaced by rank fen with non-fen species indicative not only of drier environments but also increased nutrient availability associated with peat mineralisation. In tandem with these changes there has been a decline in the number of rare fen invertebrates, most of which are indicative of calcareous fens and bogs, and scrub has been able to colonise large areas of the now drier fen surface.

6. THE CAUSES OF THE CHANGE

i) Abstraction of groundwater by Suffolk Water Company

The Redgrave public water supply abstraction is located 30 metres from the fen boundary. Drawdowns due to pumping has reduced water levels and altered flow regimes across the fen including the depletion of calcareous spring flows. The Company are authorised to abstract 3.63tcmd *(See Appendix IV - Licence to Abstract)*, although actual abstraction has been reduced to around 2.8tcmd since 1986 by "agreement" in recognition of the impact on the fens ecology. This being the minimum amount the Company could practically reduce abstraction to, at this time, whilst still being able to meet demands for public supplies. However, this has not reduced or slowed down the rate of decline in the Fens ecology.

The extent to which the borehole is contributing to the lowering of groundwater levels in the fen has been assessed following hydrological studies of the fen and surrounding area. Extracts from relevant reports as follows:

The Fillenham Report (1977, s7.5) noted when the second public water supply borehole was constructed in 1954 a rest water level of 1.53 mbgl (25.6mAOD) was recorded. *"This is about 1m above the general level of the fen". "Bearing in mind that this was a summer level, and comparing it to recent levels. It can be concluded that pumping has caused a drop in the piezometric head in the chalk in the Fen area of the order of 1.5m. This employs a change from an initial situation in which the head in the chalk was above the fen surface at all seasons of the year to one in which it is below the Fen surface for a large part of the time and throughout dry periods such as 1973 and most of 1974."*

Furthermore, there has been a marked decline in the botanical diversity and interest at the fen since the study by *Bellamy & Rose (1960)*. This has been shown by *SWT (1990), Fojt & Harding (1992)*. These studies have concentrated on the western part of Redgrave Fen. This was the area studied by Bellamy because it was considered to have the greatest botanical interest *(Fojt & Harding, 1992)*. The loss of species diversity and changes in communities have been attributed to *"the removal of calcareous spring and surface water and the lowering of the water table in general" (SWT, 1990)*.

Aspinwalls (1992, s4.27), referring to the March/April 1991 recovery test, note *"During pumping downward vertical flow is occurring from the Fen Drift deposits, particularly beneath the part of Redgrave Fen to the south west of the abstraction. Following switch off water levels quickly began to recover in both the Drift and the Chalk. The Chalk water level recovery is such that the vertical head gradient is reversed, and upward flow from the Chalk*

into the Drift commences. At certain places the Chalk becomes artesian. Such changes in the groundwater regime could prelude to the re-establishment of seepage flows into the Upper Waveney."

It is therefore, concluded that groundwater levels are being depressed by the abstraction and that an effective solution to remedy the problem of fen damage and alleviation of low flows would involve the cessation of the current pumping regime from the Redgrave abstraction boreholes.

ii) Land Drainage Improvements.

Lowering and improvement of the river channel and bed of the River Waveney in its upper reaches and immediately downstream of the site has been carried out over the years for land drainage purposes. This activity has contributed to the problem by exacerbating reduced water table levels in the fen.

The problem of the lowered river bed levels has to some extent been mitigated by the installation of a radial sluice-gate water- retaining structure at NGR TM0539 7964 in 1979 along the Waveney. The installation was funded by Anglian Water Authority and the World Wildlife Fund. A board dam upstream of this was also installed. These allow water to be retained within the fens at a higher level during the winter months. This has the effect of extending the period of water storage within the fen but due to the locality of the sluice gate installed on the Waveney is only effective in the area upstream of Great Fen. Seepage around the sluice gate and losses from Great Fen downstream of the gate continues and Suffolk Wildlife Trust are investigating methods to minimise these losses. However, it must be noted that the nature of this site is one of through flow from the western end to the eastern output end and therefore sustaining inputs is of greater significance than minimising outputs.

A recent review of river management practices/changes in the Upper Waveney over the past 30 years has identified that lowered bed levels has caused a reduction in groundwater levels in the eastern end of the fen; Middle and Great fens. The report recommends remedial works to raise river levels in the section downstream of the existing sluice-gate to retain groundwater levels in Middle and Great fens recreating environmental conditions similar to those prior to land drainage improvements. The exact nature of these works is subject to confirmation and detailed design. Their appropriateness/effectiveness been further assessed in the current Hydrological and Environmental Impact Assessment which concluded that river restoration alone will not provided an effective solution, but should form part of an overall solution including borehole relocation and fen management.

The Broads ESA has recently been extended from Scole near Diss to the source of the Waveney which includes Redgrave & Lopham Fens. This provides increased opportunities within riparian areas adjacent to the fen and downstream through incentive payments to farmers to retain higher water levels and revert back to more traditional farming practices involving the requirement to maintain water levels in ditches.

iii) Changes in Reserve Management.

Higher water levels in the past supported by nutrient-poor calcareous spring water is considered to have been important in maintaining a nutrient-poor fen ecosystem. This would have been characterised by only limited plant productivity and a diverse range of fen plant species benefiting by only low levels of management (eg. light grazing).

In the early 19th century, the Fen was managed as a Poors Fen, that is it was given over to the poor of the parish to provide them with fuel from the peat, grazing for their animals, thatching material from sedge and reed, faggots from scrub on the dry margins, marsh hay for stock and for bedding horses, and a range of other wetland produce such as fish and fowl. During this period, most of the fen would have been managed in some form, with a variety of cutting regimes on a variety of cycles from two to five years. As rural land use practices declined, the level of management of the fen also declined.

This decline in management was probably most acute during and just after the Second World War. During the War, labour was short and such practices would have been a low priority, while just after the War, changing agricultural practices, increased mechanisation and increased wealth meant traditional Poors Fen practices were doomed. However, whilst the original hydrology remained in-tact, the irrigation with low nutrient chalky water and the saturation of the peat kept productivity of the fen vegetation to a minimum, preventing loss of rare fen species and inhibiting scrub invasion.

The establishment of Suffolk Wildlife Trust (SWT) in 1961 more or less coincides with the establishment of the Redgrave borehole and the deep drainage of the Waveney. In the early years of the reserve, management inputs were restricted to the establishment of footpaths and routes for extraction of produce, with some management of the fen vegetation and scrub cutting. Some reinstatement of sedge rotations were undertaken. In the 1970's it became apparent that the fen was being invaded by large amounts of scrub as water levels dropped and scrub removal became an increasing feature in the reserve management. In the early 1980's the Trust ran two Manpower Services Commission teams at Redgrave, when reserve management received a considerable boost. Much reclamation of sedge beds and scrub removal occurred at this time.

Due to the changes in Government employment policy, Manpower Services Commission teams were disbanded, and in 1990, reserve management was wholly resourced between English Nature and the Suffolk Wildlife Trust. In 1993, the National Nature Reserve was established and spending on the reserve has been around £35,000 for the last three years. The NNR is for 31 years and English Nature's contribution is currently £17k for the first 3 years of the project. The remainder being provided by Suffolk Wildlife Trust.

Management of the reserve after water resource mitigation works are complete is a key issue. The Trust and English Nature remain firmly committed to the programme as shown by the NNR Agreement. At today's costs of £35k/year it can be assumed that over £1M will be spent over the NNR period on routine fen maintenance representing considerable commitment to the project. However, substantial additional works will also be required to repair damage which cannot be addressed through maintenance management. These aspects are identified

in *Appendix I* and forms an intricate part of the justification/requirements submitted to the EC which secured the 1.8M ECU contribution to the funding of the project. These works include peat stripping, large scale scrub removal, and extension of fen grazing.

At least since 1947 and 1986 there was a progressive increase in the cover of scrub *(Figure 5 - Aerial photos of fen)* and a decline in traditional management practices, including peat cutting. Since the Suffolk Wildlife Trust obtained the fen as a Nature Reserve, scrub clearance and traditional management practices have been partially reinstated. The hydrogeological implications are difficult to quantify, however, it is unlikely that this would have had any significant influence on the hydrology of the fens. Loss of this irrigating water has allowed the development of rank growth in the fen plant communities, and allowed the development of scrub woodland. *Figure 5* demonstrates that scrub removal has been concentrated at the western end, particularly Redgrave and Little Fens, with some in the central areas of Middle Fen. This coincides with those areas where the most valuable plant and animal communities were located and hence attracted the highest priority for clearance. Great Fen located to the east, is downstream of the sluice gate installed in the Waveney during 1979 and hence does not benefit from retained water levels further enhancing the ability for scrub to establish.

iv) Change in Weather Patterns.

Changes in weather patterns and in particular changes in yearly precipitation have occurred during the century; viz the droughts of 1933/34, 1947/49, 1975/76 and 1988/1992.

Drought as an individual factor is not considered to be a significant factor for two main reasons. Firstly, droughts are a regular part of the climatic fluctuations to which all fens are subjected. The support they receive from groundwater, which is less susceptible than surface water to dry periods, continues to sustain them. Secondly, plant and animal communities have a certain amount of inertia or elasticity. This carries them through short periods of adverse conditions, after which recovery is generally straightforward. Most droughts fall within the range of conditions which fens can tolerate.

Although the recent drought of 1989-1992 was severe it was well within the range of tolerance for such wetlands. For instance, Market Weston Fen located some 5km west is very similar to Redgrave in its hydrology and associated wildlife. However, the springs at Market Weston continued to flow throughout the drought period. Furthermore, key wetland wildlife has continued to flourish or even expand as the management at Market Weston Fen continues to progress.

Droughts can have a significant impact if acting in tandem with other external influences such as in the case of Redgrave, abstraction. Here abstraction has depleted groundwater support to the fen, making it dependent on surface water inputs. These are reduced or eliminated during droughts, pushing the fen beyond its normal limits of elasticity and causing more permanent change. Drought events in isolation are not considered to be a key factor at Redgrave.

7. PROJECT OBJECTIVES AND CRITERIA

Against the described background of ecological damage and the history of use of water resources in the area, the principle objectives for the Project are:

- **To restore the hydrology of the fens and provide a suitable environment to allow the re-establishment of the fens ecology to conditions similar to those experienced in the early 1950's and hence restore the full sequence of Target Fen types and to re-establish the close mosaic of these within the fen sequence.**

- **To provide a permanent public water supply source with adequate yield, water quality and operational security which will not cause detrimental environmental damage or cause derogation to other existing abstractors.**

Criteria which options must satisfy are as follows:

Environmental Criteria:

- The solution must allow the re-establishment of the fens hydrology to conditions similar to those prior to the early 1950's. This will represent conditions similar to those prior to PWS abstraction at the Redgrave site reducing groundwater levels and spring flows to the fens and prior to significant land drainage improvements reducing surface water levels.

- The solution employed shall not detrimentally impinge on the hydrological regime of Redgrave & Lopham Fens or other wetlands.

- The solution must be sustainable in the long term and provide conditions suitable for the restoration of the fens ecology.

Operational Criteria:

- The solution must incorporate provision of a suitable public water supply source with a reliable output of at least 3.63tcmd sufficient to achieve Ofwat Levels of Service and DWI water quality standards.

- The abstracted water must be of a suitable quality capable of economical treatment to EC requirements for public water supply.

- The water supply source must be suitably located to maximise existing mains infrastructure and Company assets.

8. OPTIONS FOR CORRECTIVE ACTION

SUMMARY LIST:

a) Do Nothing
b) Irrigation of the Fens
c) Relocate PWS Abstraction
    i) Mellis/Wortham
    ii) North Lopham
    iii) Wetheringsett
d) Seasonal Pumping at Redgrave
e) Impounded Storage within the Fens
f) Wider scope Alternatives - utilising/uprating existing sources
g) Revocation/Variation of Redgrave Licence
h) Bulk Imports
i) River Restoration
j) Fen management

Options (a), (b), (c) and (i) were considered in greater detail in the report: "Hydrological and Environmental Impact Assessment" by Howard Humphreys & Partners (HHP) 1994. Options (b), (c) and (i) were evaluated as they were considered to be the most appropriate and realistic options to provide a solution. Although it was considered that option (a) - "do nothing" - was not appropriate or realistic, it was included so as to present a reference against which the options may be compared

The approach adopted by HHP in the study gives "worst case" predictions of changes in groundwater levels and predicts the ecological impact on flora and fauna. The methodology uses a simple approach, and whilst predictions are not absolute, they are considered indicative and suitable for comparison. All options to relocate the existing Redgrave sourceworks are predicted to make a significant improvement (80-97%) to groundwater flow to Redgrave and Lopham Fens. However, the options impact on other wetlands, groundwater abstractions and rivers to varying degree.

a) DO NOTHING ie. Continue existing abstraction and fen management practices.

No action will allow the processes of degradation to continue on the fen. The peat will continue to waste, releasing large amounts of nutrients which will further degrade the fen communities. Water levels will remain at their lowered levels, continuing to affect populations of rare fen animals and the rate of species extinctions of rare fen plants will continue. Rare communities based around short fen sedges and rushes will be replaced by more commonplace communities dominated by grasses and characterised by non-fen characteristic species making fen management utilising normal treatments such as mowing and grazing extremely difficult. Scrub encroachment will continue outstripping clearance works leading to progressive overgrowth of the fen by woodland. In time, the status of the fen as a Ramsar site is likely to be threatened.

This option was further investigated within the Hydrological and Environmental Impact of Assessment by HHP. The report found that 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 a total of 11 wetland sites. The report concluded that continued abstraction would lead to further deterioration.

This option is not recommended.

b) IRRIGATION OF THE FENS

Irrigation of the fen would involve the pumping of sufficient quantities of groundwater (up to 30 l/s) from the edges of the fens for up to 5 months of the year. The irrigation network to convey the water around the fen is likely to be complex and there are doubts whether installation of such a scheme could practically be achieved without causing further ecological damage.

The plant and animal communities are a reflection of the interaction of several complex factors. Firstly, the superficial geology. This is complex in terms of the variation of the permeability of the deposits, its inherent chemical nature (particularly ph, base status, content of minerals such as sulphur and iron, and salinity) and variations in the physical structure of the superficial deposits. This interacts with a complex pattern of hydrology which encompasses waters of differing origin (rainwater, acid water derived rom superficial sands, river water and chalk groundwater) and therefore of differing chemistries. The strength and emergence of groundwater, and the relative proportion of base poor and calcareous water in the irrigating supply will depend on variation in the superficial permeability and in changes in artesian pressure. All such factors interact to produce a very small scale mosaic of hydrological types, where conditions may vary from acid to alkaline over short distances, or where acid conditions may overlay calcareous conditions. This complexity, which is the essence of the ecological interest, would be extremely difficult to replicate.

As a short term measure, for the benefit of the Great Raft spider *Dolomedes plantarius*, water was conveyed from the existing Redgrave public water supply source to provide support to a selection of spider pools within the fen where drying out has been exacerbated

by the 1989-1992 drought. This scheme has cost in the region of £35K, jointly funded by ESW, NRA and English Nature and has been successful in avoiding almost certain extinction of the spider at this site.

The option to irrigate the fens was further investigated within the Hydrological and Environmental Impact of Assessment by HHP. The report concluded that it is not considered practical to restore Redgrave and Lopham Fens using irrigation techniques.

This option is not recommended.

c) RELOCATE PWS ABSTRACTION

This would involve relocating the Redgrave groundwater abstraction sufficiently far enough from the fen to transfer the influence of the abstraction away from the wetland site. This option was further investigated within the Hydrological and Environmental Impact Assessment by HHP.

There are other public water supply and private abstractors within the area as well as other wetlands of conservation importance which restricts the field of search for alternative local groundwater sources.

Careful consideration has been given to surface water abstraction and none of the water courses and rivers have sufficient reliability to establish a surface water abstraction within 25Km of Redgrave.

Three potential areas have been identified for groundwater abstraction relocation:

(i) Mellis/Wortham
(ii) North Lopham
(iii) Wetheringsett

i) Development of a satellite replacement source in the Mellis/Wortham area - Potential exists in the Mellis/Wortham area (some 5km SE of Redgrave) to develop a new satellite source and pipeline to convey abstracted water to the existing Redgrave site for subsequent treatment and distribution *(see Figure 4)*. Sufficient groundwater resources are available. Site investigations have recently been carried out by Southern Science to identify potential sites within the area for development as a replacement source. This involved the drilling and testing of investigation boreholes to ascertain yield and aquifer characteristics at 5 locations. *(Ref. Southern Science, "The Drilling & Testing of 5 Pilot Production Boreholes at Wortham, Nr Diss, Suffolk" Feb 1994).*

This option was further investigated within the Hydrological & Environmental Impact Assessment by HHP. The report found that this option would lead to substantial reversal of the effects of the Redgrave source at most wetland sites, particularly Redgrave and Lopham Fens, but their "worst case prediction" suggested that there is a slight risk of slightly lower

groundwater levels at 6 other wetland sites. Three agricultural boreholes may have reduced yield which could require remediation measures ranging from lowering of pumps to deepening of the borehole.

In conjunction with the HHP report findings and consultation with the Water Company and conservation bodies it is proposed to carry out further investigations to assess the suitability of development of a replacement source within in this area. One site has been recommended and agreed as the preferred site, however, there is a potential problem with the maximum yield available from this site. Therefore, it has also been agreed that another two possible combinations could be considered. The three sites are as follows in order of preference (the location of sites is shown on Figure 4):

1 Beans Lane, Wortham - (Site "G" and referred to by HHP as Mellis/Wortham Option 1).

2 Beans Lane, Wortham with additional source within 500m - (Site "G" + son of "G").

3 Beans Lane,Wortham + Magpie Hill, Wortham - (Site "G" + Site "B" and referred to by HHP as Mellis/Wortham Option 3).

Southern Science are currently investigating the preferred site to determine the maximum yield. Subject to satisfactory yield and water quality a production borehole will be developed and ecological impact will be assessed in support of an application for licence. Hydrological and environmental impact acceptability will be subject to independent technical audit. Similar investigations will follow at the subsequent sites above should investigations at Beans Lane alone prove inadequate.

Development of this option will also require the construction of approximately 5km of pipeline and negotiation for pipeline easements.

Estimated Capital Cost (in the above order of preference):

1 £1.2M

2 £1.5M (Appraisal assumes this to be the likely development option)

3 £1.6M

Estimated additional operating Cost: £3000/year. ***(See Appendix VII)***

This is the preferred option subject to satisfactory abstration licence determination.

ii) Development of a Satellite replacement source at North Lopham

The NRA owns and operates 27 river regulation support boreholes as part of its Great Ouse Groundwater Scheme. Four boreholes are located within the Little Ouse catchment and discharge into the Little Ouse during times of drought and low flow to regulate river flows for subsequent transfer to Essex via the Ely Ouse-Essex transfer scheme *(Figure 4)*.

Potential may exist in the North Lopham area (some 5km NW of Redgrave) to develop a new satellite source and pipeline to convey abstracted water to the existing Redgrave site for subsequent treatment and distribution. Test pumping of the existing NRA river support borehole at North Lopham has been carried out, the results of which have been included within the HHP "Hydrological and Environmental Impact Assessment". The assessment of the suitability and viability of a site assumed that the replacement source would be located within 500m of the existing NRA river augmentation borehole. If developed, this option will also require the construction of approximately 5km of pipeline and negotiation for pipeline easements. The source is outside the Company's area of supply, however, this is not considered a constraint.

Studies indicate that groundwater resources in this catchment are fully utilised. *(Relocation of Suffolk Water Company borehole" and "Further review into the relocation of Suffolk Water Company borehole at Redgrave - D Seccombe 1992)*. However, it is recognised that the existing Redgrave abstraction may already draw water from this catchment, therefore, relocation of a "like for like" source at North Lopham may be acceptable.

This option was further investigated within the Hydrological & Environmental Impact Assessment by HHP. The report found that the option would lead to substantial reversal of the effects of Redgrave source on some wetland sites while having an adverse effect on other wetland sites. One agricultural borehole could have reduced yield which may require remediation measures ranging from lowering of pumps to deepening of the borehole. The number of licences effected as well as the effects on wetland sites would be more pronounced with the concurrent operation of the NRA river augmentation borehole.

Estimated Capital Cost £1.9M
Estimated additional operating Costs £3000/year. (See Appendix VII)

This option is not recommended.

iii) Development of a replacement source at Wetheringsett

More distant relocation of the Redgrave groundwater abstraction should ideally utilise as much of the Water Company's existing infrastructure as possible. This would minimise operating costs and maintain a satisfactory operating system for the future.

It is feasible, from an operational stand point, that the development of additional resources and associated treatment and distribution network between Eye and Mendlesham could be incorporated into the Company's development strategy.

Potential exists to develop a new replacement source in the vicinity of Wetheringsett some 14km south of Redgrave *(Figure 4)*. The assessment of the suitability and viability of a site assumed that the replacement source would be located within 500m of th existing NRA river support borehole. This option would require the development of a new purpose built source remote from Redgrave involving the construction of a pumping station, storage facility, treatment works and incorporate modifications to existing mains infrastructure.

This option may attract additional funding from the Water Company in the form of "betterment" as development here could form part of the Company's future development strategy, being well placed to meet increased demand in the Hartismere supply zone. The Hydrological & Environmental Impact Assessment by HHP concluded that due to its remoteness from Redgrave and Lopham fens and other wetlands, this option offers the source with the least ecological impact. It has to be recognised, however, that should the Water Company wish to develop a source for quantities greater than 3.63tcmd the Company's licensed abstraction downstream at Shipmeadow may have to be reduced accordingly as this abstraction relies on NRA's Waveney river support scheme which draws water from the same Dove catchment.

Studies indicate that sufficient groundwater resources exist to support an equivalent abstraction of 3.63tcmd within the catchment. *(Relocation of Suffolk Water Company borehole" - D Seccombe 1992).*

Test pumping of the existing NRA river support borehole at Wetheringsett has been carried out, the results of which were included within Hydrological and Environmental Impact Assessment by HHP. The report found that the option would totally reverse the effects of the Redgrave source at all wetlands, as well as substantially improving flows in R. Waveney and R. Little Ouse. However, this option will have significant effects on the flows in the R. Dove which can be mitigated by the extended use of the existing river support scheme - including the adjacent NRA Wetheringsett borehole. One agricultural borehole could have reduced yield and which may require remediation measures ranging from lowering of pumps to deepening of the borehole. The number of licences effected as well as the effects on wetland sites would be more pronounced with the concurrent operation of the NRA river support borehole.

This is a preferred option but due to its high estimated development costs is recommended as a "fall back" option to development at Wortham should this prove unacceptable. Meanwhile, it has been agreed that Essex and Suffolk Water will pursue site selection and options to purchase land in the event that development should be required.

Estimated Capital Cost: £3.9M
Estimated additional operating Cost: £9000/year ***(See Appendix VII)***

d) SEASONAL PUMPING AT REDGRAVE

This would involve seasonal pumping of the Redgrave abstraction during the winter months when ground water levels in the fen have recovered. Abstraction would cease during the summer months eg April to October.

The effect of implementing this option would be a deficiency in public water supply during the peak summer months affecting up to 10,000 customers. The amelioration would be to increase abstraction at other works in the Company's supply operating group, namely Syleham, Rickinghall, Mendlesham and Eye *(fig 3)*. This entails up-rating plant, providing additional potable water storage, and upgrading mains infrastructure, the revision of seasonal operational procedures and revalving of the supply network. This could cause disruption to customers supplies, increased revenue operating costs and is likely cause seasonal dirty water complaints due to changes in flow direction.

This option would significantly increase the risk to the Water Company. In output terms, the Company would be unable to meet its legislative obligations to supply water should any one of these sources in the operating group fail. This level of service for reliability would not meet the requirements of the water industries regulator, Ofwat.

The ecological benefit to the fen is dubious and the practicalities of implementing very doubtful. Operating the system would be labour intensive and involve potentially large additional revenue operating costs. The Company have indicated that such an arrangement would not be acceptable in terms of operating risk and lack of security of supply. Also, Conservation bodies expressed a lack of confidence in this option as it is anticipated that full recovery of water tables at Redgrave Fen due to a cessation of pumping could take as long as 5 years. Seasonal pumping would not therefore allow sufficient recovery.

This option is not recommended.

e) IMPOUNDED STORAGE WITHIN THE FENS

Impounded storage of winter water within the fen would increase the period over which the fen peat remains wet. This would involve the installation of a sheet piled "bund" around areas of the fen. This operation would be expensive, piles would need to be driven in excess of 25 metres to ensure location within the chalk strata. These works, however, would not reinstate the spring and seepage input at the margins of the fen and would not recreate suitable conditions for the restoration of the base-rich fen communities. In addition, it would have the effect of converting a hydrological system characterised by laterally moving groundwater to one characteristic of static conditions. There are further concerns that such an arrangement would not retain sufficient water for the fen's total summer requirement, that the quality of the retained water (largely agricultural run- off and rain water) may be damaging to the fen, and that such impoundment could cause flooding in the upstream catchment. This option is not acceptable and has not been costed.

This option is not recommended.

f) WIDER SCOPE ALTERNATIVES - UTILISING/UPRATING EXISTING SOURCES

The Company's existing Rickinghall source (*Figure 3*) is not supported by good mains infrastructure or plant capacity. Water resources in this locality are limited and insufficient to meet uprating requirements, also, water quality at this source is generally poor. Rickinghall already suffers from a resource operating problem. Uprating this source is not considered viable and is not a preferred option.

The Water Company's Syleham source is located some 17km to the east of Redgrave (*Figure 3*). Some mains infrastructure exists between the source and Redgrave which could be uprated to convey additional water abstracted at Syleham to the existing Redgrave works for storage and subsequent redistribution. This would involve major modifications to the distribution mains network as the mains are sized and designed to facilitate west to east flow ie. from Redgrave towards Syleham. Groundwater resources within the Chalk at Syleham are limited. Resources within the overlying Crag deposits is relatively untapped, however, these are in hydraulic continuity with the surface water and additional abstraction is likely to be at the expense of river flows in the Waveney. Water quality may also be a problem. Development at Syleham would carry a high degree of risk as there is no standby or alternative for Syleham in the event of operational failure, either quantity or quality.

Further investigation into available resources, water quality and yield would need to be carried out if this option were to be pursued. The Water Company have expressed their opinion that development at Syleham would not be favoured from an operational stand point. This option is also expensive.

This option is not recommended.

g) REVOCATION/VARIATION OF REDGRAVE LICENCE

It would be impractical to simply revoke the Redgrave licence as this would render some 10,000 customers without public water supplies. This is not practical and contrary to the legal requirements of the Water Company to provide water to its customers.

Revocation would require compensation which, under present legislation, is likely to cost the equivalent of finding an alternative supply. More applicable is to identify and provide a suitable replacement source with a scheduled programme for development, say 3 years, after which revocation or licence variation could be implemented. The cost of revocation is that of providing a replacement source less any betterment to the Water Company.

This option is not recommended.

h) BULK IMPORTS

There are no suitable economic bulk imports available for the area.

This option is not recommended.

i) RIVER RESTORATION

A recent review of river management practices and subsequent changes in the Upper Waveney over the past 30 years has identified that lowered bed levels has contributed towards a reduction in groundwater levels in the eastern end of the fen; Middle and Great fens. Remedial works are required to raise river levels in the section downstream of the existing sluice-gate to retain groundwater levels in Middle and Great fens recreating environmental conditions similar to those experienced in the early 1950's prior to land drainage improvements. The exact nature of these works is subject to detailed design. Their appropriateness/effectiveness has been assessed in the HHP Hydrological and Environmental Impact Assessment by HHP which identified that river restoration alone is not sufficient to provide a solution but required to ensure that the benefits of raising groundwater levels are maximised. This option is recommended in conjunction with borehole relocation and fen management.

This option is recommended in conjunction with borehole relocation and fen management.

Estimated Capital Cost: £120k

i) FEN MANAGEMENT

Relocation and river restoration works alone will not restore the fens ecology. Some of the changes are irreversible, such as peat mineralisation and consequent eutrophication within the fens surface layers. The eutrophication of the peat mineralisation is a fundamental change. The reintroduction of straightforward management in such situations is unlikely to lead to the re-emergence of previous communities because of the very high fertility of the soil. Following the return of water levels and the hydrology of the fens to conditions similar to those of the early 1950's an extensive programme of fen management is required. This involves wide scale peat stripping and scrub removal over a large area of the site plus extension of grazing areas, litter spreading to reintroduce fen plant species along with a comprehensive monitoring programme to gauge the success of the project - *see Appendix I.* This programme of works also includes the provision of enhanced access and visitor facilities at the Fen including an information centre and additional wardening.

This option is recommended in conjunction with borehole relocation and river restoration works.

Estimated Costs: £800 over 4 years.

9. THE PREFERRED OPTIONS

Only those options which are considered the most appropriate and realistic in providing a solution were compared to show the relative effects of environmental and hydrological impacts and associated development costs. Although it was considered that the "do nothing" was not appropriate or realistic, it was included so as to present a reference against which the options may be compared. The options identified were as follows:

- Irrigation of the Fens
- Relocate PWS Abstraction
  - i) Mellis/Wortham
  - ii) North Lopham
  - iii) Wetheringsett
- River Restoration
- Fen Management

Howard Humphreys investigated these options (excluding Fen management) to provide the framework from which the preferred option may be identified. The relocation of the PWS abstraction to Mellis/Wortham had three sub-options, these being: Mellis/Wortham Option 1 - Site G only; Mellis/Wortham Option 2 - Site B only; Mellis/Wortham Option 3 - Site G and Site B (*refer to Appendix 4 for locations).*

The Hydrological & Environmental Impact Assessment by HHP of the realistic options to provide a solution the key findings of the study are summarised follows:

- The existing abstraction at Redgrave has a major impact on groundwater levels and river flows through the Fen.

- The existing abstraction is predicted to lower groundwater levels at 11 wetlands in the area which are believed to be groundwater dependent. The extent of impact is difficult to quantify and it is not yet possible to definitely link change in groundwater level to any observed deterioration. At most sites other factors such as land drainage, historical management practices and agricultural practices in the area may have had more significant impacts.

- The irrigation option is not practical and has been eliminated as an option.

- River restoration cannot itself provide effective remediation although it can enhance the impact of improvement in baseflow arising from groundwater relocation options.

- All the options to relocate the present Redgrave PWS sourceworks would lead to an improvement at the Fen.

- The North Lopham option could lead to substantial reductions in groundwater levels and hence a deterioration in ecology at a number of wetlands.

- The Wetheringsett option would affect no designated wetlands. The reductions in groundwater level predicted at Redgrave and the 11 wetland sites predicted as being affected by the Redgrave source would be reverted entirely.

- Abstraction at Wetheringsett, at the headwaters of the River Dove would have a significant impact on river flows. To help mitigate any environmental impacts, this would require more frequent operation of the existing river support boreholes in the Waveney Groundwater Scheme constructed in the 1980's to augment Essex & Suffolk Water's supplies at Shipmeadow for supplies to Lowestoft. A new site would need to be purchased for a permanent PWS source. Some 20 existing agricultural boreholes may also be affected and would require remediation measures ranging from lowering of pumps to deepening of boreholes.

- The "worst case" predictions suggest the Wortham option will lead to 95% hydrological recovery at the Fen. Three additional wetland sites which may be groundwater dependent could be affected by slightly reduced groundwater levels (one is an SSSI). It is believed the groundwater level changes would not lead to ecological impacts which would affect the ecological value of the sites. In addition some of the wetlands that may currently be affected by the Redgrave abstraction may still be affected with this option. Three small agricultural licences may also be affected and may require remediation measures ranging from lowering of pumps to deepening of boreholes.

The environmental and hydrological impacts and their associated costs have been compared and presented in Table 1. These impacts have been objectively scored to provide an overall assessment of acceptability. This identifies all the Mellis/Wortham options as well as Wetheringsett as the preferred options.

A summary of the impact in terms of predicted changes in water levels at wetland conservation sites and surface waters for the Mellis/Wortham options and the Wetheringsett option is presented in Table 2.

Whilst the Wetheringsett option offers the best environmental solution, the Wortham option (Mellis/Wortham Option 1) would lead to considerable environmental benefit at Redgrave and Lopham Fen. As the Wetheringsett option estimated to cost £5.2M is £2.6M more than the Wortham option it is recommended that the Wortham option should be pursued to licence application stage, without at this stage excluding the Wetheringsett option.

Both Wetheringsett and Wortham relocation options will require associated river restoration works and an extensive programme of fen management.

River restoration works are subject to detailed design but involve the retaining of water levels in the section of the Upper Waveney adjacent to Middle and Great fen. The cost of these works is estimated at £120k.

TABLE 1. SUMMARY MATRIX OF HYDROMETRICAL AND ENVIRONMENTAL EFFECTS OF GROUNDWATER DEVELOPMENT OPTIONS SHOWING OVERALL PREFERENCE

Option	Wetland Conservation Sites[1]			Groundwater Abstraction		Rivers			Overall Impact Ranking	Development Costs £'000K	Overall Preference
	No. wetlands benefiting from water level rise	No. wetlands affected by water level fall	Impact ranking (score)	No. groundwater licences affected	Impact ranking (score)	No. rivers benefitting from option	No. rivers adversely affeted by option	Impact ranking (score)			
Do Nothing	0	11	Severe (30)	0	Nil (0)	0	2	Mod. (10)	40	0	6
North Lopham	6	7	High (15)	1	Low (5)	2	1	High (15)	35	1.9	5[2]
North Lopham and Augmentation borehole	2	11	High (15)	10	Mod. (10)	0	4	Severe (30)	55	1.9	
Mellis/Wortham (F/G) - Option 1	5	6	Mod. (10)	0	Nil (0)	1	2	Low (5)	15	1.2[3]	1
Mellis/Wortham (B) - Option 2	4	7	Mod. (10)	3	High (15)	1	1	Low (5)	30	1.5	3
Mellis/Wortham (B + F/G) - Option 3	7	7	Mod. (10)	3	High (15)	1	1	Low (5)	30	1.6	2
Wetheringsett	11	0	Nil (0)	2	Low (5)	2	2	Mod (10)	15	3.9	4[2]
Wetheringsett and Augmentation borehole	11	0	Nil (0)	19	Mod. (10)	2	3	High (15)	25	3.9	

Note: [1] - Impact on wetland conservation sites is based on "worst case predictions" by Howard Humphreys "Redgrave and Lopham Fens Restoration Project: Hydrological and Environmental Impact Assessment"
[2] - An option with and without augmentation pumping is considered together in determining overall preference
[3] - The development cost for Site G only = £1.2M. The development cost of Site G with an additional site 500m = £1.5M

TABLE 2. INDICATIVE HYDROLOGICAL IMPACT OF CURRENT ABSTRACTION LICENCES AND PROPOSED DEVELOPMENT OPTIONS

				Impact of Existing Abstraction		Impact of Development Options[1]			
						Mellis Option 1	Mellis Option 2	Mellis Option 3	Wetheringsett[2]
Wetland Site	Size (ha)	Importance (Status)	Site Sensitivity to Chalk Groundwater Level Changes	Change in Drift Water Level (m)	Deterioration Observed	Change in Drift Water Level (m)	Change in Drift Water Level (m)	Change in Drift Water Level (m)	Change in Drift Water Level (m)
1. The Marsh, Wortham	2.50	Local (County Wildlife Site)	Low	N/A	No	N/A	N/A	N/A	N/A
2. Gypsy Camp meadows	2.46	National (SSSI)	Moderate	N/A	No	-0.09	-0.08	-0.09	N/A
3. Thrandeston Marsh	5.00	Local (County Wildlife Site)	Moderate	N/A	No	-0.10	-0.08	-0.09	N/A
4. Spring at Spring Farm	N/A	Not Known	Moderate	N/A	Not known	-0.11	-0.10	-0.11	N/A
5. Redgrave Park Lake	20.00	Local (County Wildlife Site)	High	-0.19	No	0.06	0.08	0.07	0.19
6. River Waveney	1.60	Local (County Wildlife Site)	High	-0.35	Yes (some enrichment)	0.27	0.14	0.21	0.35
7. Hall Farm Meadow, Wortham	1.20	Local (County Wildlife Site)	High	-0.08	No	-0.02	-0.13	-0.08	0.08
8. Wortham Ling	51.30	National (SSSI)	High	-0.06	Yes (population extinction)	-0.03	-0.11	-0.07	0.06
9. Roydon Fen	15.08	Local/National (Site of Nature Conseravation Interest, proposed SSSI)	High	-0.03	Yes (scrub and woodland invasion, some localised drying out adiacent to ditches)	-0.05	-0.10	-0.08	0.03
10. Horse Fen, Bressingham	4.39	Local (County Wildlife Site)	High	-0.14	Yes (scrub invasion)	0.06	-0.08	-0.01	0.14
11. Bressingham Fen	7.28	Local (County Wildlife Site)	High	-0.21	Yes (scrub and woodland invasion)	0.14	0.03	0.09	0.21
12. Blo' Norton and Thelnetham Fen	21.03	National (SSSI)	High	-0.14	Yes (scrub and woodland invasion, summer drying out of certain areas. Some eutrophication)	N/A	N/A	0.14	0.14
13. Bugge Hole	4.00	National (SSSI)	High	-0.08	No	N/A	N/A	0.08	0.08
14. Hopton Fen	14.37	National (SSSI)	High	-0.03	Yes (localised drying out with some scrub and woodland invasion and some eutrophication)	N/A	N/A	0.03	0.03
15. Weston Fen	48.60	National (SSSI)	High	N/A	No	N/A	N/A	N/A	N/A
16. Middle Harling Fen	12.70	National (SSSI)	High	N/A	No	N/A	N/A	N/A	N/A
17. East Harling Common	14.90	National (SSSI)	High	N/A	No	N/A	N/A	N/A	N/A
18. River Whittle	23.17	Local (County Wildlife Site)	High	N/A	Yes (scrub and woodland invasion of fen, localised drying out	N/A	N/A	N/A	N/A
19. Hay Fen	9.67	Local (County Wildlife Site)	High	N/A	Yes (scrub and woodland invasion)	N/A	N/A	N/A	N/A
20. Copinces Fen	6.96	Local (County Wildlife Site)	High	N/A	Yes (scrub invasion)	N/A	N/A	N/A	N/A
21. Kenninghall & Banham Fen with Quidenham mere	48.90	National (SSSI)	High	N/A	Generally no. Possible enrichment from agricultural runoff	N/A	N/A	N/A	N/A
22. Redgrave & Lopham Fen	124.92	International (Ramsar site); National (SSSI); National (NNR)	High	-2.30	Yes (transition of fen to degraded highly fertile fen communities, scrub and woodland invasion, some localised drying out of fen)	2.23	2.16	2.20	2.30

Note
1 Changes in drift water level include the effect of cessation of abstraction at Redgrave sourceworks
2 Wetheringsett option is with and without augmentation pumping

N/A = not applicable as greater than 6km from proposed site or definitely not chalk groundwater fed

Future Fen Management is proposed as detailed in *Appendix I* and forms an intricate part of the EC grant requirements. The EC grant allocates £800k to fen management over the next 4 years and is included in the total scheme costs. This is based on costs provided by Suffolk Wildlife Trust to support the EC grant application.

Although the Wortham option is the preferred site, there are the following risks:

- The maximum yield may not be available from Site G only and the suitability of an additional site will require assessment.
- Delays and cost implications of securing additional borehole site should this be required as a result of insufficient yield at site "G" alone - Beans Lane, Wortham.
- Water quality implications with the potential requirement for addition treatment (pesticides, high nitrates) at a cost of £2M.
- Delays and cost implications with remedial works associated with derogated existing users.
- Potential difficulties with pipeline easement negotiations.
- Environmental Report in support of licence evaluation may prove this option unacceptable resulting in abortive development costs in the order of £250k and associated delays and costs in developing the Wetheringsett option.

The following programme of additional work is proposed:

- The development of a production borehole(s) at Wortham.
- Test pumping of the production borehole(s) for 50 days and monitoring the impact by a network of piezometers in the wetlands identified likely to be affected by the abstraction and in existing user' boreholes.
- On completion of the test pumping, a full analysis of the likely impacts will be made considering hydrological and ecological impacts, water quality issues, derogation actions, other mitigation or management actions and the overall cost implications. This will be subject to independent technical audit and be used to determine the licence application.
- In parallel with the pilot borehole development at Wortham, a site is to be identified at Wetheringsett and an option taken to purchase, in the unlikely event that the Wortham option proves unacceptable.

The preferred option consistes of three main parts:

a) **Relocation of the PWS source at Wortham - £1.5M. This assumes that Site G with and additional site 500m away will be required**

b) **River restoration works to retain water levels in the Upper Waveney adjacent to Middle and Great fens subsequently raising groundwater levels in this part of the fen - £120k**

c) **An extensive programme of fen management - £800k over 4 years**

Total Scheme Capital Costs:

	Cost (£M)
Current studies/salaries	**0.18**
Wetheringsett site option	**- -**
Borehole Relocation	**1.50**
River Restoration	**0.12**
Fen Management	**0.80**
Sub Total	**2.60**

Split of funding for Capital:

EC Contribution	**1.30**
ESW Contribution	**0.65**
NRA Contribution	**0.65**
	2.60

Additional Operating Costs: **£3,000/annum**
(by ESW on water supply)

10. BENEFITS

Cessation of abstraction from the Redgrave borehole will allow recovery of the local water table. In association with changes to land drainage and a programme of fen management this will provide favourable conditions to allow the previous springs and seepage areas to re-appear. The re-establishment of the fens hydrology and the re-diffusion of chalky water through the site will create a suitable environment for the recovery of the full sequence of communities.

If the original hydrological conditions are restored, the environment will revert from one of peat wastage and mineralisation to one of peat accumulation. Following this reversion, the re-establishment of the rich fen flora and fauna should ensue. The judgement of the success of the cessation in abstraction must be based on the degree to which these environmental conditions can be restored and not upon pre-defined floristic change. This is because of the inherently long term nature of the response of plant communities to environmental change.

Assurances that the fen will recover and commitments to future fen management are contained in *"A Case submission to DOE" Appendix V.*

The benefits of this project have not been quantified as Redgrave was not chosen as a pilot project for the contingent valuation study. Some 5,000 people visit the site annually, this includes both National and International visitors. Visitors are expected to more than treble following successful rehabilitation.

The Benefits of the scheme include:

- Protection of an Internationally Important Wetland SSSI, NNR and Ramsar site.
- An increase in fen valley communities within the Fens, a decrease in the extent of uncharacteristic fen communities, a decrease in scrub invasion, and an increase in floristic quality of fen vegetation.
- An increase in fauna, (eg Great Raft Spider) in terms of population size and area of fen utilised.
- Restoration of the full sequence of fen communities with attendant invertebrate communities throughout the site.
- Prevention of further degradation and loss of Ramsar status.
- Continued enjoyment by the public and future generations of this rare and exceptional wetland.
- Maintenance of a secure public water supply to some 10,000 people in the Hartismere supply zone.

Improved site facilities funded with the EC grant will provide information and promote greater public awareness of the Fens flora and fauna.

11. CONCLUSIONS

1) If the existing ecology of the Internationally Important Wetland SSSI Ramsar site and NNR is to be preserved then the Public Water Supply abstraction must cease. Some changes to land drainage to restore river bed levels are also required.

2) Termination of the abstraction along with river restoration works and associated fen management will provide the most favourable conditions to enable the ecology of the fens to recover to their pre-1950's state provided a comprehensive fen management programme is undertaken following the re-establishment of water levels within the Fen.

3) Meeting the needs of Public Water Supply will require the provision of an alternative licensed abstraction point, water of suitable quality for treatment at the existing Redgrave treatment works, the provision of mains and associated infrastructure. The preferred option is to relocate the abstraction sourceworks at Wortham. Total project costs are estimated at £2.6M.

12. RECOMMENDATIONS

Approval is sought to the preferred option consisting of three parts:

- **Relocation of the PWS source at Wortham - Cost £1.5M (Subject to granting an abstraction licence).**
- **River restoration works to retain water levels in the Upper Waveney adjacent to Middle and Great fens subsequently raising groundwater levels in this part of the fen - £120k**
- **An extensive programme of fen management - £800k over 4 years.**
- **Total project costs £2.6M. (Includes current and previous studies at Wortham)**

Approvals are requested for expenditure of up to £0.65M by the NRA towards the total project cost of £2.6M. The residual funding will be provided by an EC LIFE grant of £1.3M and by £0.65M from Essex and Suffolk Water. The ESW contribution is subject to funding approval by Ofwat as part of their AMP2 Strategic Business Plan. Confirmation to this approval is expected from Ofwat by the end of July 1994.

APPENDICES

APPENDIX I

STRATEGY FOR THE MANAGEMENT OF REDGRAVE AND LOPHAM FENS AFTER THE BOREHOLE MOVE, FINAL DRAFT, MARCH 1993

SUFFOLK WILDLIFE TRUST

Suffolk Wildlife Trust

STRATEGY FOR THE MANAGEMENT OF REDGRAVE AND LOPHAM FENS AFTER THE BOREHOLE MOVE. FINAL DRAFT. MARCH 1993

Background

The borehole is likely to be moved with the prospect of full recovery (ie with groundwater discharge and water levels permanently at the fen surface) five to eight years after relocation, according to NRA forecasts. To support the borehole move a grant application to LIFE will be submitted, which will include remedial management works on the fen. Clearly, before such an application can be submitted, future management works need to be agreed in outline between English Nature and SWT. This paper outlines the proposed post recovery management required.

Ecological changes on the fen; the context for management

Harding (1993) has given a detailed description of changes on the fen since 1959. Key points are :

1. The eutrophication and ruderalisation of all fen communities associated with peat mineralisation on drying.
2. Massive scrub invasion and reduction of open fen habitat
3. Loss of the fined-grained mosaic of plant communities.
4. Loss of low growing rare fen plants associated with progression from short sedge mire and fen meadow to tall herb fen.
5. The loss or decline of important rare invertebrates associated with surface-wet fens.

Some points are interlinked and have their root cause in the same factors. Reduction of water levels is the root cause of all changes, exacerbated by cessation of management over large areas.

Ideal Objectives

The ideal would be to reverse all of the above processes.

Constraints on Management

Merely removing the borehole will not automatically restore the fen. Some of the changes are irreversible, such as peat mineralisation and consequent eutrophication. The eutrophication of the peat is a fundamental change; the reintroduction of management in such situations is unlikely to lead to the re-emergence of previous communities because of the very high fertility of the soil.

Before the War, the fen was managed intensively by the inhabitants of several villages, and the management was economically viable through sale of produce (with sedge, peat and reed harvesting and grazing animals). This labour force is no longer available and fen management now produces negligible return from sales. All costs must be borne by the conservation organisations. There will never be the resources to reinstitute management at the same intensity as occurred historically. Low intensity options must be found

MANAGEMENT

1. Objective: Restore Hydrology

This will be achieved by two prescriptions:

1.1 Move borehole

Relocation must be far enough to allow return of groundwater discharge and water levels permanently at fen surface, and also far enough away from other wetlands not to impinge on them. This is fundamental to the success of all the following objectives.

1.2 Restoration of River Waveney bed levels

The overdeepening of the river must be cured by the restoration of former bed levels. In addition sluices must be installed further downstream to prevent water loss in Great Fen and the eastern end of Redgrave Fen.

2. Objective: Reduce fertility and reverse peat mineralisation

Peat will cease oxidation when water table levels are permanently at the surface, so prescriptions 1.1 and 1.2 will stop mineralisation. However it will not remove the peat that has already been mineralised nor will it reduce fertility.

2.1 Strip surface peat layer and remove from site.

This will reduce the peat surface to below the water table level, ensuring the reinstatement of a peat accumulating environment and provides the conditions for the re-emergence of the short sedge fen communities.

In addition it will reduce the management burden as these will be low productivity areas requiring minimal or no management in the first instance.

Areas to be stripped are not specified here, but should be chosen in areas of deeper peat, where areas of ruderalised and eutrophicated tall herb fen communities are found, as identified by NVC baseline surveys. Areas of Cladium swamp in good condition, fen meadows or short sedge fen of botanical interest should not be selected. Areas should be chosen to ensure a good chance of success and be at or below the level of permanent surface water table conditions.

To help selection of peat areas sample borings should be taken, both to identify priority areas and to advise contractors on the depth to be removed. It is important that stripping retains a cover of peat,

although in some areas this may be thin or even absent in small areas as long as there is mineral soil beneath. Scraping down to sand is not recommended.

Peat must be removed from site due to the quantities involved. This could be carted to neighbouring fields for incorporation but will need a mineral extraction licence.

3. Objective: Remove Scrub

A continued capital programme of scrub removal is required. The long established scrub will be first priority. After restoration high water levels will ensure a reduced rate of re-invasion so that the maintenance burden will be reduced.

3.1 Mature scrub removal

Most of the scrub growing on peat is to be removed, with the exception of two bands of firebreaks running north-south between Little and Middle fens and between Middle and Great Fens, and some of the valuable mature stands of alder and willow at the east end of the reserve should also be left. A width of 50m will be sufficient for the firebreaks.

In some areas scrub cutting with stump treatment will be required, but where scrub removal coincides with areas of peat stripping, scrub will be removed by digger during stripping operations.

3.2 Young scrub and regrowth removal

Recurring scrub growth will be cut on a ten year cycle which produces saleable brushwood, is volunteer friendly and will not pose a threat to the fen. Cutting should include stump treatment and follow-up weed wiping in the third year after cutting.

4. Objective: Promotion of fine-grained vegetation mosaic

This will be achieved through some of the above objectives but principally through management of the fen vegetation itself.

4.1 Extension of fen grazing

Because of the scale of the management requirement, as much as possible should be grazed to free up labour for other management tasks. This should be a combination of cattle in the rougher and wetter areas and sheep on the heathier or grassy areas. A flexible approach should be adopted to the management of the cattle to account for very wet hollows.

Extension will require substantial capital works in the installation of permanent cattle and sheep fencing, particularly in the areas of Sedgrave and Little Fens, but also on areas of Middle Fen. Capital could also be required for the purchase of cattle and other equipment such as pole barns. To encourage extra grazing fen vegetation, particularly tall herb fens, will need cutting for the first year or two to promote fen meadow. Dense stands of Cladium will not be grazed.

4.2 Fen Cutting

A mosaic of fen communities are to be promoted by a combination of litter mowing (2 year cycle), tall herb fen mowing (4year cycle), winter reedbed management (1-year, 2-year and 4-year cycles) and Cladium bed harvesting. Areas which have had peat stripping will not be managed in the first instance. All areas of current fen meadow, spring flush, and heath which might normally be on an annual cut will be grazed, so there will be no annual summer mowing regimes except some footpath rides.

There will be a need within the next five years to add a third warden to cope with the extra work.

5. Objective: Return and increase of rare fen plants

The return of rare fen species will be encouraged by other objectives 1-4. Their success in this respect will be determined by the seedbank and the movement of seed from nearby fens. Spread of seed can be helped:

5.1 Litter spreading

The reintroduction of seed from litter mowings on other sites would benefit the re-establishment of fen plants. Techniques for this must be investigated, and might include seed harvesting and spreading, or spreading of cut litter thinly on the reserve. If litter spreading were too vigorous, it might contribute to the developing thatch, so caution is required. In particular the grazed areas would pound in the seed by hoof action.

5.2 Direct reintroduction

This is not recommended at this stage and would only be reasonable if all other prescriptions had failed.

6. Objective: Promotion of Rare Invertebrates

Most of the above prescriptions will promote rare invertebrates. Special measures may be taken for Dolomedes but these are at too small a scale to be specified here and should be determined each year between SWT and EN

7. Objective: Monitoring

The monitoring of restoration and recovery is of great importance. Fen flora will be monitored by repeats of Bellamy's plots. The methodology should be extended to cover other parts of the fen, and in particular should include areas where significant changes of management are occuring such as peat stripping or reintroduction of grazing. Monitoring of the fauna should be via a continued programme of monitoring the Fen Raft Spider.

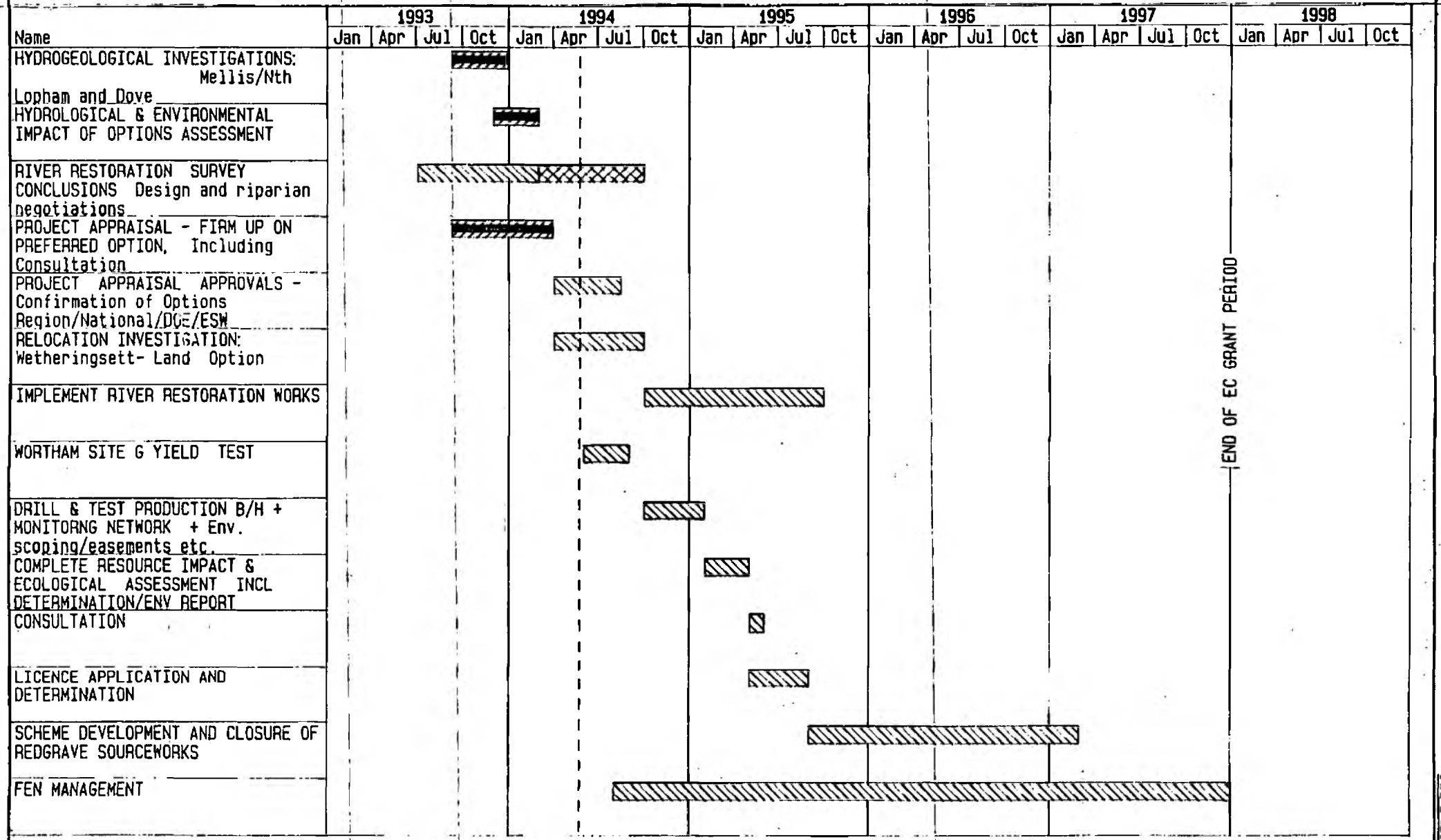
MANAGEMENT PLAN

Once the borehole move is complete and the water levels return, a new management plan should be written which incorporates the above objectives and prescriptions.

APPENDIX II

PROGRAMME

REDGRAVE AND LOPHAM FENS ALLEVIATION SCHEME - PROGRAMME



APPENDIX II

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REDGRAVE AND LOPHAM FENS, EAST ANGLIA, ENGLAND: A CASE STUDY OF CHANGE IN FLORA AND FAUNA DUE TO GROUNDWATER ABSTRACTION

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Abstract

Changes in the fauna and flora of an internationally important British calcareous valley-head mire between 1959 and 1991 are described in detail. Changes in site hydrology and management practices over the same period are also described. Monitoring data document the conversion of Schoeno-Junceta communities into degraded types of Cirsio-Molinietum, Juncus subnodulosus *fen meadow and highly fertile Phragmitetalia fens. The wetland fauna was similarly degraded. Five processes of change were identified: alteration of competitive balance of the community dominants; change in environmental conditions required by individual species; increases in site fertility; increase in scrub cover on the fen; and a change from soligenous to rain-fed hydrology. The underlying cause of change was identified as abstraction of groundwater by a nearby borehole. Other factors such as dredging of drainage channels, lack of management of the herbaceous communities, fire and drought are considered. The implications for the conservation of similar fens are discussed.*

Key words: *East Anglia, calcareous fen, groundwater abstraction, hydrology, extinction.*

INTRODUCTION

Redgrave and Lopham Fen is a 123·47 ha valley mire of international importance for conservation, being declared a RAMSAR site in 1991 and a National Nature Reserve in 1992. It is situated at the source of the River Waveney (TM 046797, Fig. 1) in central East Anglia. It has undergone substantial ecological change over the last 30 years for which many causes have been suggested, principally drying out and under-management. It is the aim of this paper to describe the ecological and environmental change in detail and to assess the cause of such change.

The site is the largest calcareous valley-head mire complex in lowland England (Fojt, 1990), located in the peat-filled valley bottom of the Waveney Valley. The raised sandy margins support dry and humic heath and, over large areas, dry oak *Quercus–Betula* woodland. The largest part of the site is covered by shallow peat supporting a complex mosaic of reed and sedge beds, mixed-species fen ('litter fen') and spring flushes. In phytosociological terms the principal mire plant communities are Cirsio-Molinietum, Cladio-Molinetum, Schoeno-Juncetum and Phragmitetalia. Parts of the site developed as a hydroseral succession on a post glacial lake (Tallantire, 1953), but the Fen as a whole did not proceed to woodland because of deflection by human activity (Price, 1978), principally sedge and litter mowing and peat cutting. The Fen is a noted entomological site (English Nature, 1991).

The Fen remained undrained over the centuries due to the flat and intractable nature of the fen peats, and in 1815 and 1818 became 'Poors land' in compensation for the enclosure of nearby commons. With the arrival of the railways and cheap coal, peat cutting almost ceased by the end of the 19th century. Traditional mowing management declined, and the last major crop of sedge was taken in 1932 (Anon., undated). Some litter mowing may have continued until the Second World War when grazing of the dry margins ceased. After 1945 the Fen was largely unmanaged until the Suffolk Wildlife Trust leased the site as a nature reserve in 1961, when scrub control and limited management of the herbaceous communities resumed.

In the following account the entire site is referred to as 'the Fen'. Nomenclature is according to Clapham *et al.* (1987).

SITE DESCRIPTION

Geology and soils

Generalised underlying stratigraphy for the site is shown in Fig. 2(a). The interrelationship of the layers is extremely complex. There are at least three interleaving layers of clay, and further heterogeneity in permeability is provided by the putty and silt chalk and by the patchy distribution of calcareous marl between the sand and peat. In some areas such as the margins of Redgrave Fen, the chalk is directly overlain by sand then peat, with total hydraulic continuity (Fig. 2(b)). The peat is up to 2 m deep and is extremely heterogeneous in physical structure, depth and chemistry (Price, 1978). Variation in peat salinity may be ecologically significant, with calcareous lenses and acid

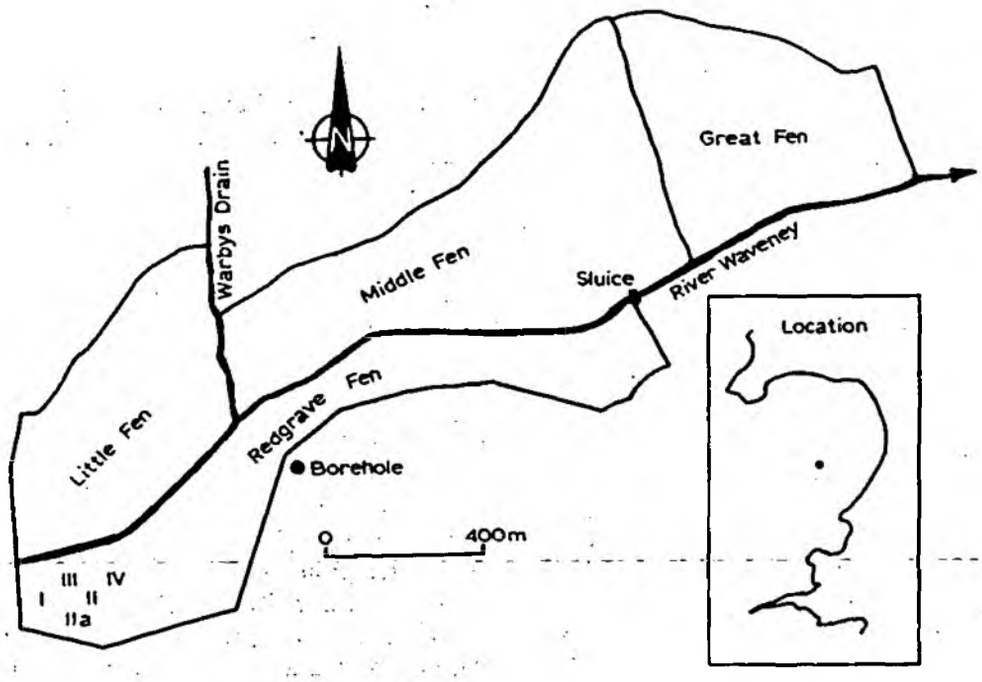

Fig. 1. Location and site map for Redgrave and Lopham Fen showing the position of the abstraction borehole. Bellamy's vegetation plots are shown at the west end of Redgrave Fen, numbered I–IV.

sulphate peat providing a pH range of 2·3–7·4 (Price, 1978; Burton, 1982).

Hydrology

Before the late 1950s, calcareous and nutrient-poor water rose under artesian pressure from the semi-confined aquifer and seeped into the Fen both around the margins and within the peats. Seepage water flowed over the surface even during the summer, sometimes in runnels (Bellamy & Rose, 1960). River flooding was only important at the downstream end of the fen, and then only in the areas adjacent to the river itself.

The extreme heterogeneity of the superficial geology resulted in great spatial variation in the quantity of rising seepage water. This interacted in a complex fashion with base-poor water from the marginal sand and with calcareous and acid peats to produce local variation in soil water chemistry. It is these hydrological conditions which produced the diverse mosaic of mire plant communities observed by numerous ecologists (Bellamy & Rose, 1960; Haslam, 1966; Heathcote, 1973; Ratcliffe, 1977).

Changes in the fen environment

In 1957, two abstraction boreholes were commissioned near to the Fen (Fig. 1) for public water supply and were licensed for 3600 m^3/day in 1965. Warby's Drain (which carries agricultural water from the surrounding upland to the river) and the River Waveney itself were deep-dredged in the 1960s, substantially increasing channel capacity. Outputs were controlled by the installation of a sluice, upgraded in 1979, at the downstream end of Redgrave Fen (Fig. 1). However, by then inputs were so reduced that rising groundwater was eliminated and Warby's Drain was often dry. River levels therefore seldom reach the top of the sluice except in winter and there are no measures to maintain water levels in Great Fen. Over this period great changes in the ecological character of the Fen were observed by conservation organisations, who linked such changes with the described changes in hydrology. As a result a programme of investigation was undertaken, the results of which are presented in this paper.

METHODS

Hydrology

Anglian Water (1977) recognised the potential impact of the borehole and installed a network of dipwells across the Fen to monitor the superficial water table. These have been monitored monthly since 1977. In 1990, an experimental shutdown of the borehole was conducted and the dipwells monitored.

Changes in plant communities

The invasion of scrub onto open fen, which was thought to be a recent phenomenon, was investigated using aerial photographs from 1947, 1971 and 1986. Dispersed scrub, continuous scrub and young woodland were identified and mapped for each year.

Comparison of historical botanical records with more recent studies (Bellamy & Rose, 1960; Haslam, 1966; Heathcote, 1973; Bray, 1983; Harding, 1990) show a progressive decline in the qualitative character of the herbaceous fen communities. It has been possible to quantify such changes for some parts of the Fen by comparison of 1959 floristic data with those from 1991. As part of a broadscale survey of European mires, Bellamy and Rose (1960) recorded five stands of vegetation on Redgrave Fen (Fig. 1, I, II, IIa, III and IV) approximately 600 m from the borehole. Each stand of 10 × 10 m was sampled in August 1959 by random quadrats, usually 25 per stand of 0·25 m^2, and

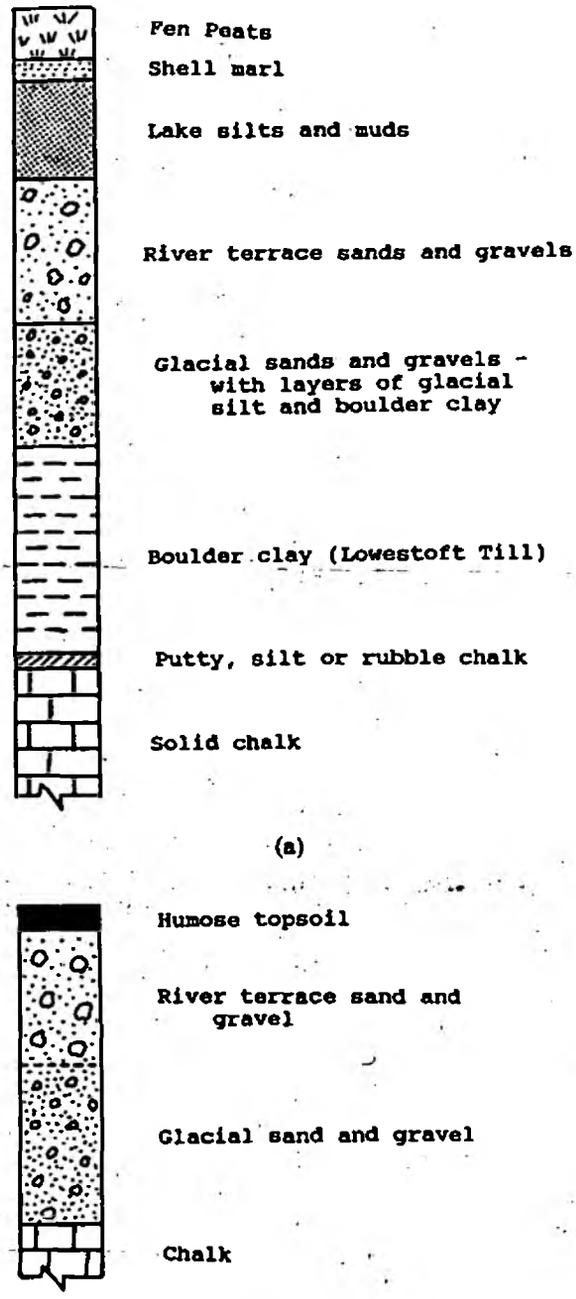

Fig. 2. Stratigraphy of Redgrave and Lopham Fen. The figure is diagrammatic only, so that the vertical scale is arbitrary. Compiled from Tallantire (1953), Heathcote (1973), and unpublished data courtesy of Suffolk Water Company. (a) Generalized stratigraphy of the site; (b) Stratigraphy under Bellamy's plots.

cover values were assigned to each species. As the location of the plots and the methodology were published (Bellamy & Rose, 1960), the data recording could be repeated exactly and thus direct comparisons of the flora in 1959 and 1991 made. Nearly all the plots were readily identifiable in the field from the published descriptions and by Bellamy himself identifying them on site, and the method was replicated exactly. If there was any doubt as to the exact location within an area, the place which most resembled the described flora for that plot was selected. The 1991 data thus represent the minimum change experienced in these communities.

Fen fauna

The Fen was formerly noted as a site of prodigious importance for wetland invertebrate species, also known to be faithful indicators of environmental conditions. In order to complete the analysis of change in this fen ecosystem, changes in the invertebrate fauna were assessed using published and unpublished data on species occurrence.

RESULTS

Changes in the hydrology of the Fen

Dipwells recording water table levels were read immediately before the close-down of the borehole on 5 February 1990 (Fig. 3) and showed a cone of depression of the water table, centred on Redgrave Fen (and Bellamy's plots). After just one week the cone had disappeared and by week four had been replaced by a water table dome as artesian pressure began to return. The dome was replaced by a cone when pumping resumed. In 15 years of piezometer readings the cone has never before been replaced by a water table mound, even in times of very heavy rainfall. The extent of the influence of the borehole clearly extends across the River Waveney and into Little Fen (Fig. 1).

Before the installation of the borehole, water rose from the chalk aquifer under artesian pressure produced by the partial aquiclude of the clay layer (Fig. 2), and escaped onto the fen surface through holes in the clay layer. One such hole was located on the southern margin, in the area of Bellamy's plots (Fig. 2(b)). However, Fig. 3 shows the cone of depression situated over the zone of rising groundwater, which is effectively capturing this artesian water. Seepage on the fen margin no longer occurs, and the zone of groundwater discharge has thus been eliminated. All other areas of discharge on the Fen have similarly been lost in the last 30 years. The hydrology of the site is now controlled by rainfall patterns and river levels (topogenous hydrology) with the principle direction of water movement being down the soil profile, instead of upwards and laterally. It is likely this will be accompanied by a downward movement of bases although no data are available to confirm this. Dipwell data show that the water table fluctuates widely but is predominantly deeply subsurface. This pattern has been emphasised in recent years by the droughts of 1975–76 and 1989–92, but is largely due to the dewatering of the Fen.

Scrub invasion

Maps compiled from aerial photographs (Fig. 4) show the development of scrub since 1945. Invasion only became pronounced during the 1970s. Previously, the Fen was characterised by open herbaceous communities with scattered bushes. Today, mature scrub is mostly *Salix cinerea* and *Betula pubescens*, with the principal colonist in the last decade being *Betula pendula*.

Changes in herbaceous communities

The quadrat data from Bellamy's plots in 1959 and

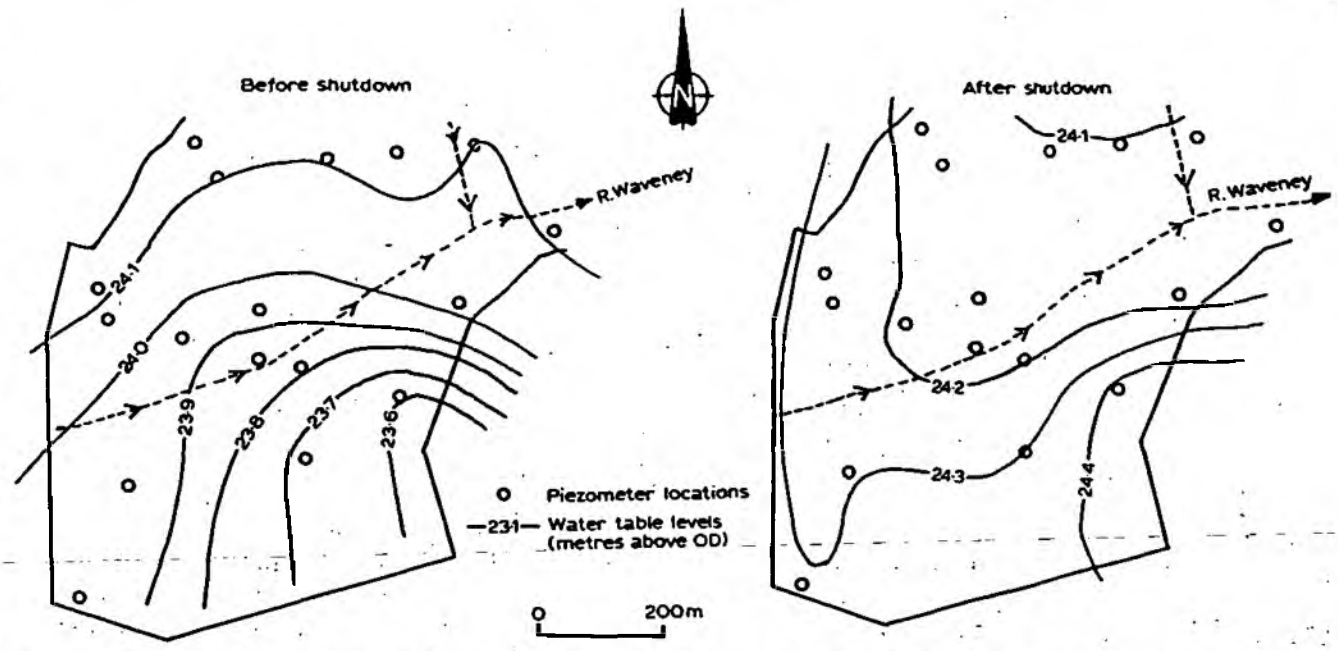

Fig. 3. Piezometer readings around Redgrave and Little Fens before and after the borehole was temporarily closed down between January and March 1990 (Harding, 1990).

1991 were ordinated (Figs 5 and 6) using a DECORANA algorithm (Hill, 1979) to provide more detail on species composition of the communities and the direction of change. The decline in conservation quality of the plots is shown in Fig. 7, using the rarity-weighted principal fen species score which has been developed by Wheeler (1988) to assess the floristic quality of rich fens.

The communities in 1959 were variants of Schoeno-Junceta, short to medium-tall calcareous mires characterised by very high species diversity and a diverse semi-aquatic bryophyte and small herb flora. Their conservation value was very high indeed with many regionally rare plants such as *Dactylorhiza traunsteineri* and high rarity-weighted principal fen species score (Fig. 7). The ordination shows that Plots I, II and IIa were floristically similar, being the more calcareous sub-communities of the Schoeno-Junceta. Plot I was slightly drier, drained by a network of runnels (Bellamy, 1967) and with greater dominance of bulky monocotyledons such as *Schoenus nigricans*, *Juncus subnodulosus* and *Molinia caerulea*. The few acidophilous wetland species present were restricted to occasional tussock tops not irrigated by chalky water.

Plots III and IV form a separate group on the ordination, and are representative of Schoeno-Juncetum ericetosum (Wheeler, 1980*b*) dominated by calcareous mire monocotyledons and wet heath dwarf shrubs with an associated flora which includes acidophilous and calcicolous wetland bryophytes in equal measure. Typically, they were located on slightly elevated sandy tongues and therefore less influenced by the chalky irrigating water. Emerging groundwater was supplemented by base-poor rainwater somewhat acidified by passage through the sands.

The admixture of acidophilous and calcicolous species can be accounted for by their distribution in relation to irrigating water chemistry. Calcicolous species would have been located in runnels and depressions irrigated by calcareous seepage water. Acidophilous species grew above the seepage water on hummocks and ridges supplied by rainfall and seepage water from the sands. The base-poor layer is dependent on the rising groundwater because this supersurface water table impedes the drainage of the hummocks. This patterning has been reported in other fens (Clapham, 1940).

By 1991, all communities show a movement toward the right of the first axis of Fig. 5, which appears from the species ordination (Fig. 6) to be an axis of increasing nutrient, and to an extent also base, availability. It also describes a change from soligenous conditions on the left to a topogenous and reductive hydrology on the right. Axis 2 is not easily interpreted. In all the communities there has been an almost complete loss of wetland species with a close affiliation to acid or base

Table 1. Changes in mire communities in Bellamy's plots 1959–1991

	1959	1991
I	Schoeno-Juncetum typicum	Fen meadow: *Juncus subnodulosus* nodum.
II	Schoeno-Juncetum cladietosum	*Phragmites-Urtica dioica* fen
IIa	Schoeno-Juncetum caricetosum	*Phragmites australis* rank fen
III	Schoeno-Juncetum ericetosum	Cirsio-Molinietum eupatoretosum
IV	Schoeno-juncetum ericetosum	Cirsio-Molinietum nardetosum

Communities are classified under the scheme of Wheeler (1980*a*,*b*,*c*) and Wheeler and Shaw (1987).

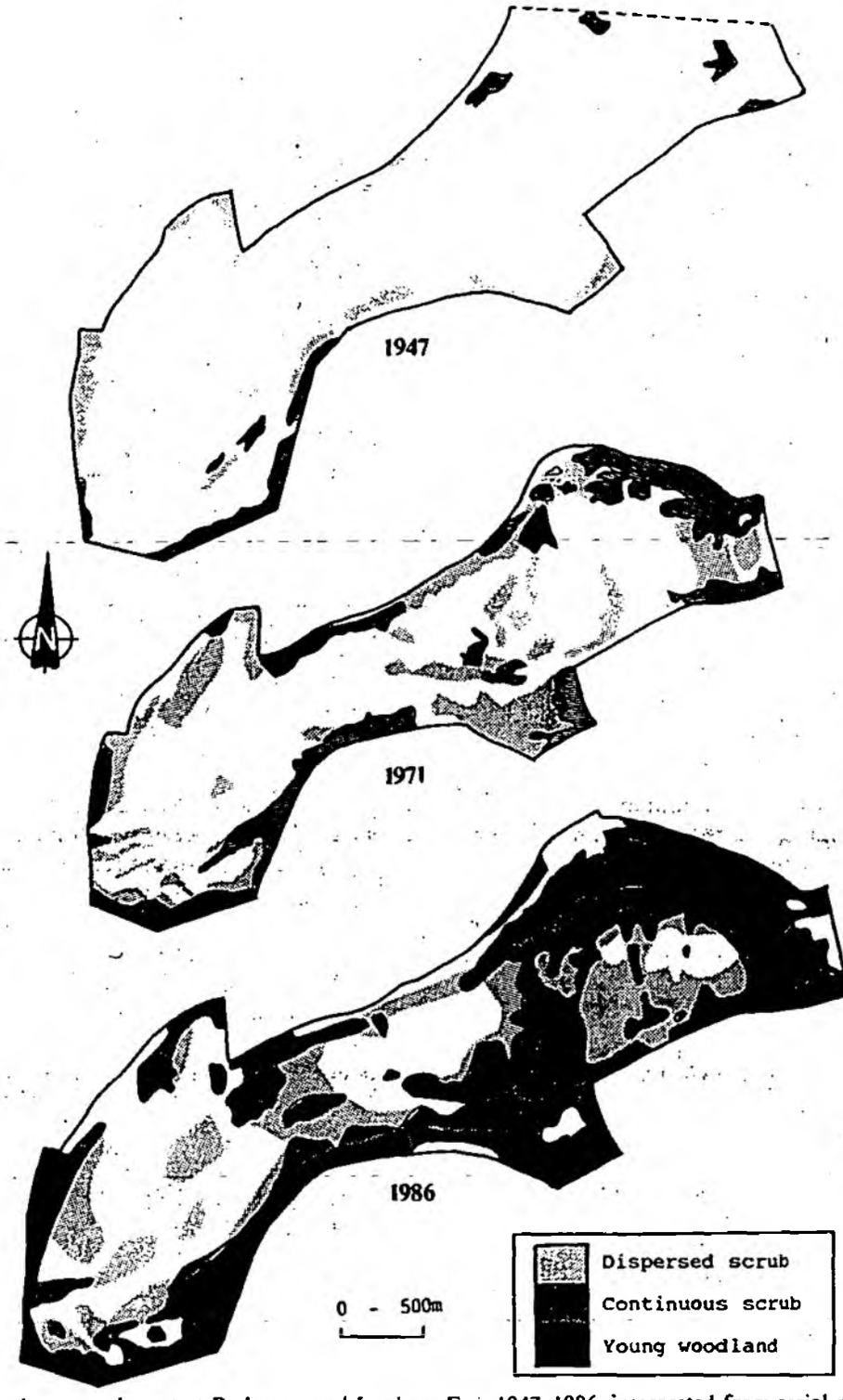

Fig. 4. Scrub encroachment at Redgrave and Lopham Fen, 1947–1986, interpreted from aerial photographs.

reaction. All plots are now characterised by scrub and ruderal species, the remaining species being those which can tolerate low water tables (such as *Phragmites* or *Molinia*) and wetland species which have a very wide ecological amplitude. Indeed, both *Phragmites* and *Molinia* have increased as previous dominants such as *Cladium* and *Schoenus* have declined. The substrates were all extremely dry, with Plots II and IIa appearing to have some peat degradation and Plot I moving very quickly towards scrub woodland. In association with these changes has been a reduction in conservation value as shown by a spectacular decline in rarity-weighted principal fen species score (Fig. 7).

Table 1 describes the changes shown by the repeat survey of Bellamy's five plots in phytosociological terms. It was found that the National Vegetation Classification (Rodwell, 1992, 1993) yielded few insights into community change due to the coarseness of the classification. A more appropriate system in this instance is that erected by Wheeler (1980 *a,b,c*; Wheeler & Shaw, 1987). Table 1 shows that the communities have changed from variants of Schoeno-Junceta to

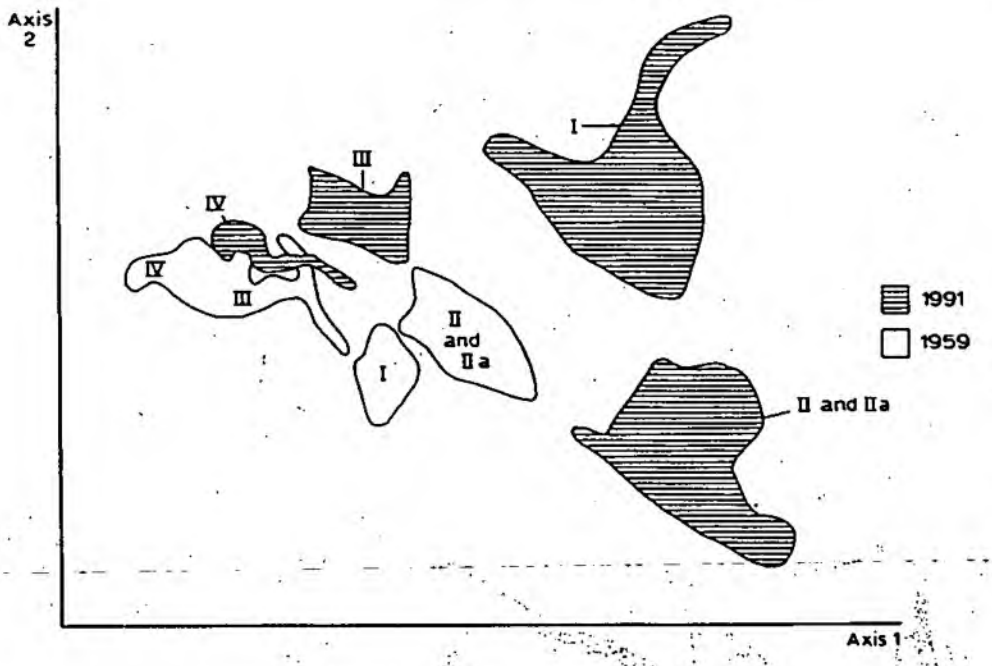

Fig. 5. DECORANA ordination of stands for Bellamy's study areas on Redgrave Fen, 1959 and 1991. From comparison with Fig. 6, the species ordination, Axis 1, appears to be an axis of increasing nutrient, and to some extent base, availability. It also broadly describes a change from soligenous conditions on the left to topogenous conditions on the right. Axis 2 is less easy to interpret.

impoverished Cirsio-Molinieta fen meadows (Plots III and IV), bush-covered *Juncus subnodulosus* fen meadow (Plot I) and fertile, ruderalised Phragmitetalia fens (Plots II and IIa).

Changes in fen fauna

An analysis of rare invertebrate species recorded on the Fen (Table 2) compiled from English Nature (1991) shows a decline in Red Data Book invertebrates in recent times. The species which have declined most are those dependent on spring-fed and calcareous fens. The rarer categories have suffered most. Comparison of past and recent surveys of the remaining Red Data Book first-category species, the spider *Dolomedes plantarius* (Duffey, 1958, 1991; Kennet, 1985), shows that it has declined to a catastrophic degree and faces extinc-

Table 2. Changes in Red Data Book (RDB) invertebrate species at Redgrave and Lopham Fen

Species	Habitat requirements	First recorded	Last recorded	Status
Vertigo angustior	Mollusca, Short vegetation, calcareous fens and marshes	1909	—	RDB1
Trechus rivularis	Coleoptera. Sedge litter and moss in fens and fen carr	1964	—	RDB1
Limnephilus pati	Trichoptera. Caddis fly of spring-fed fens	1915	—	RDB1
Stratiomys chamaeleon	Diptera. Pool margins with emergent plants	1953	—	RDB1
Dolomedes plantarius	Arachnida. Calcareous fens	1956	1991	RDB1
Anisus vorticulus	Mollusca. Calcareous ditches and water	1909	—	RDB2
Limnephilus tauricus	Trichoptera. Spring-fed fens	1915	—	RDB2
Microdon devius	Diptera. Calcareous grasslands	1966	1985	RDB2
Pherbellia argyra	Diptera. Snail-killing fly of ponds	1978	1985	RDB2
Neon valentulus	Arachnida. Among moss and grass in wet fens	1969	—	RDB2
Vertigo moulinsiana	Mollusca. Calcareous fens and marshes	1908	—	RDB3
Bryoporus cernuus	Coleoptera. No habitat information	1964	—	RDB3
Cercyon bifenestratus	Coleoptera. Water beetle	1981	1981	RDB3
Dryops anglicanus	Coleoptera. Water beetle from shallow standing water	1990	1990	RDB3
Dryops griseus	Coleoptera. Water beetle of fens and bogs	1964	—	RDB3
Senta flammea	Lepidoptera. Fens	1967	1990	RDB3
Doliochocephala ocellata	Diptera. Short wet vegetation	1978	1985	RDB3
Hydrochus megaphallus	Coleoptera. Water beetle of fens	1969	—	RDB3
Aryra elongata	Diptera. Wet woods	1978	1985	RDB3
Dichetophora finlandica	Diptera. Snail-killing fly in thick herbage of fen margins	1978	1985	RDB3
Lyciella laeta	Diptera. No habitat information	1978	1985	RDB3
Eutolmus rufibarbis	Diptera. Dry sandy heaths	1978	1985	RDB3

All records and habitat requirements are abstracted from English Nature (1991).

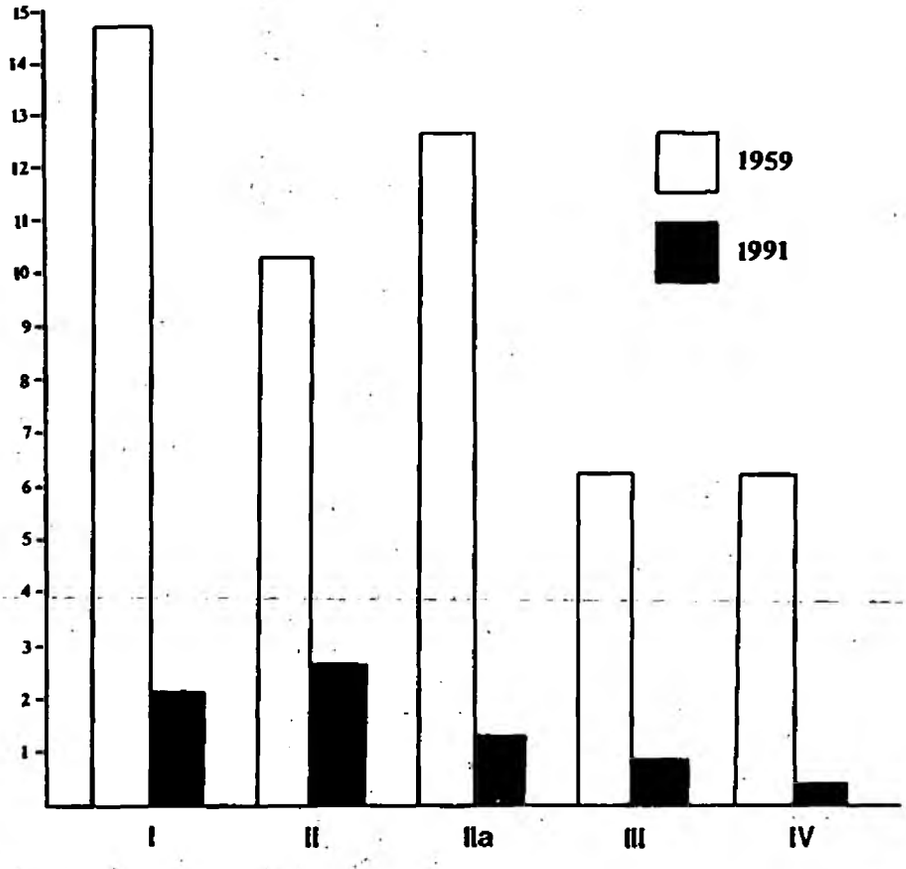

Fig. 7. Histogram illustrating the decline in conservation quality of Bellamy's five areas between 1959 and 1991. Conservation quality is measured by the rarity-weighted principal fen species score, an index developed by Wheeler (1988) to assess the quality of rich fen vegetation based on the number and rarity of true fen species present.

tion on the site. The decline of rarer species is unsurprising because rarer invertebrates have a narrower ecological tolerance and are therefore more susceptible to change. An examination of Invertebrate Site Register Notable Invertebrates (English Nature, 1991) shows a similar trend: 77% of the fen and bog species have been lost, whereas the mean percentage loss for other categories is 66%. Whilst some of the results may be due to the difficulty of re-recording rare invertebrates, intensive surveys of some important indicators (Duffey, 1991; Killeen, 1991) clearly show that the decline is real and parallels changes in the flora.

DISCUSSION

The causes of change

This paper has described in detail the quantitative and qualitative changes in the ecology of the Fen, and the changes in the associated hydrological conditions. The analysis has elucidated five main causes of change.

(1) Water levels have been shown to be the prime determinant of wetland plant communities (Wheeler, 1980*a*,*b*,*c*; Wheeler & Shaw, 1987; Rodwell, 1992, 1993). Reductions of the water table alter the balance of competition toward dry fen species such as *Calamagrostis canescens* (e.g. Plot II) or species typical of other habitats such as *Holcus lanatus* (Plot I), *Festuca rubra* (Plot III) or shrubs (all plots), so that gross community change ensues. *Phragmites*, which is very tolerant of low water levels (Haslam, 1972) can expand through competitive advantage as species such as *Cladium* and *Schoenus* contract, as shown by Foussati and Pautau (1989).

(2) The loss of the calcareous and base-poor seepage water and the reduction of the water table in general removes the specialised environmental conditions required by individual species. This provides floristic detail to the broad community change. Semi-aquatic and surface-rooted species are especially vulnerable, even to reductions in water levels of only 2–3 cms. Different species have different tolerances to dewatering so that losses will be progressive as the water level declines.

(3) Although no direct measurements have been made, it is clearly evident from changes in the flora that site fertility has greatly increased. Levels of N and P availability are normally important in the community ecology of fens. Thus there is a trend of increasing fertility from Schoeno-Junceta to Cirsio-Molinieta and then to ranker types of Phragmitetalia fens (Wheeler & Shaw, 1987; Rodwell, 1991, 1992). Increased fertility can be produced by reduced inputs of oligotrophic and calcareous seepage water which are important in maintaining low fertility in valley mires (Wheeler,

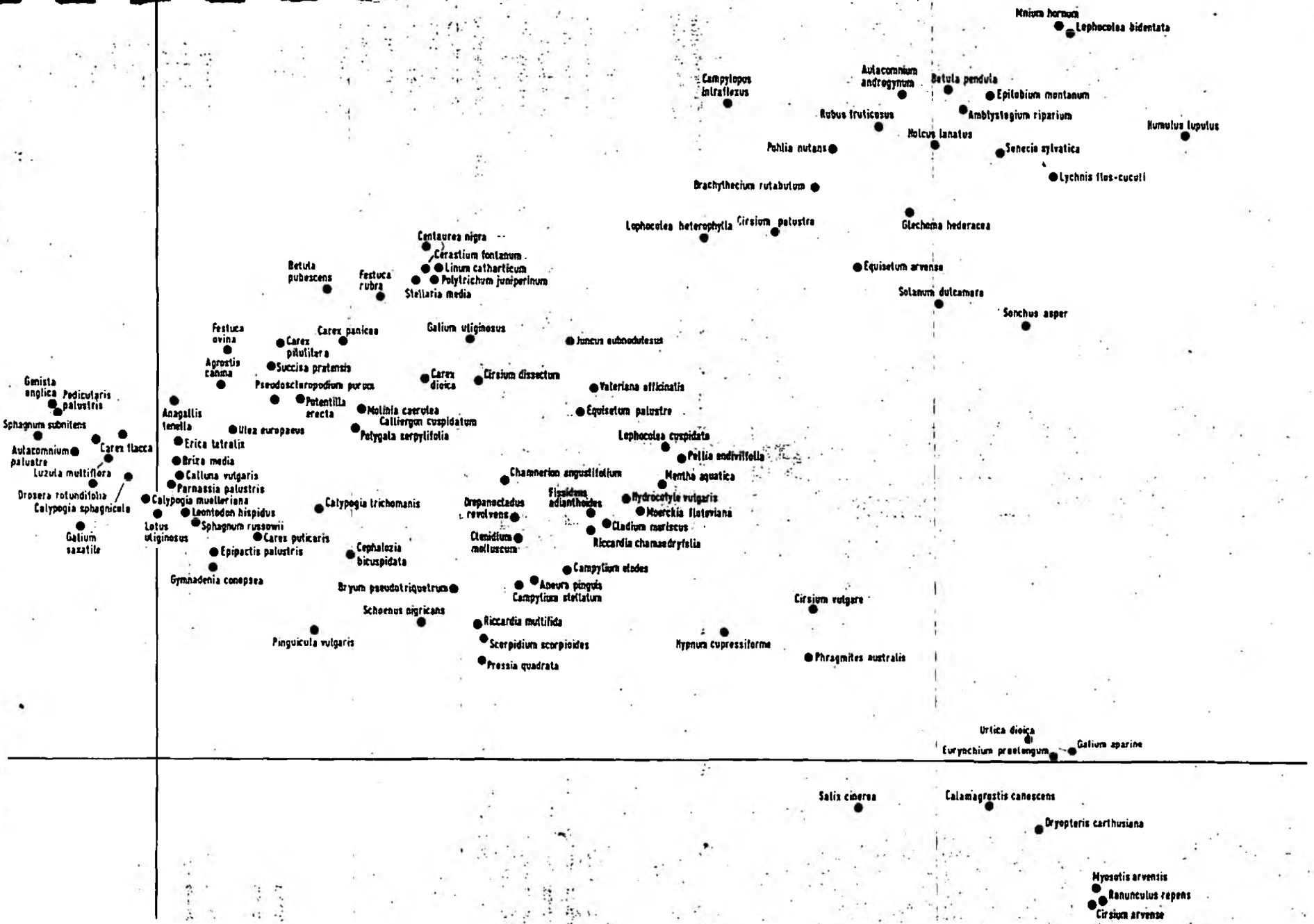

Fig. 6. Species ordination of 1959 and 1991 data. The distribution of species on the diagram is used to interpret the sample ordination of Fig. 5.

1980*b*, Boyer & Wheeler, 1989; Wheeler & Shaw, 1990). The loss of such inputs to the Fen has already been shown. Increased fertility can also be caused by the sudden release of large amounts of stored nitrates through peat wastage (Peterson and Madsen, 1978). Both of these effects have been produced by lowering of the water table at the Fen, so that increased site fertility has greatly enhanced the increase of *Phragmites* in all communities and encouraged the widespread occurrence of eutrophic ruderals such as *Urtica dioica*.

(4) The development of a scrub canopy will induce further changes, directly in the form of shading, and indirectly through changes in the nature of the substrate normally associated with the succession process.

(5) Loss of rising groundwater and dependency on winter rain and flood water is likely to have altered the soil water redox potential by removing soligenous conditions and replacing them with a topogenous hydrology. Work by Wheeler and Shaw (1987) has shown that topogenous situations are associated with higher redox potential, and therefore with a potential increase in iron concentration. Wheeler and Shaw (1990) have shown a negative relationship between increasing reductive potential of the soil and species density. Dutch work has indicated that a change from groundwater discharge hydrology to groundwater recharge produces a change from base-rich fen to base-poor fen communities (Wassen *et al.*, 1989), and that a change from soligenous hydrology to topogenous water supply alters the fine-grained calcareous mire mosaic to a coarse-grained base-poor fen community pattern (Grootjans & Ten Klooster, 1980), all features of the changes described at Redgrave and Lopham Fen.

None of these five processes are independent and may act in synergy. It is impossible precisely to quantify the effect of each identified factor on the Redgrave plots. However, the underlying cause of them all is the dewatering of the Fen.

The role of vegetation management

Management refers to the various treatments applied to vegetation in order either to yield a crop (sedge, litter, forage or peat turves) or to achieve a conservation objective, such as the maintenance of desired plant communities. The two aims often coincide and usually involve mowing, grazing, burning or peat cutting. Management is a vital control on community ecology (Wheeler & Giller, 1982). With valley mire communities, however, numerous studies have shown that water levels and water chemistry can override management factors (Millar, 1973; Daniels, 1978; Tyler, 1979; Grootjans & Ten Klooster, 1980; Giller & Wheeler, 1986; Boyer & Wheeler, 1989; Wassen *et al.*, 1989; Wheeler & Shaw, 1990). Cirsio-Molinieta and Phragmitetalia communities are strongly controlled by management, but transition from the Schoeno-Junceta recorded at Redgrave Fen in 1959 to the communities recorded in 1991 appears most often to be associated with lowering of the water table (Wheeler and Shaw, 1987; Rodwell, 1992, 1993).

None of the plots on Redgrave Fen were managed for at least 30 years before Bellamy's sampling, and yet they retained the flora he described. Despite management of Plots III and IV by the Suffolk Wildlife Trust, the plots have still shown detrimental change.

Lack of management in such communities would lead to very different floristic changes from those described. Without regular management *Cladium mariscus* and *Schoenus nigricans* can form dense stands, whereas on the Fen they have been depleted or lost. Wheeler and Shaw (1990) noted that Schoeno-Junceta can be self-maintaining in the absence of management although some stands which have a great deal of *Cladium* could develop into Cladio-Molinietum. However, at Redgrave they have become depauperate versions of the Cirsio-Molinietum or *Phragmites-Urtica* fen, changes which Wheeler and Shaw (1987) observed could only occur with a reduction in water table and substantial increases in fertility.

Fire

Occasional fires are a normal part of mire ecology and have been used in valley fen management (Haslam, 1966). Indeed, some workers tentatively recommend fire as a management technique for conservation (Tyler, 1984; Wheeler & Shaw, 1987). With above-ground water levels, a fire will burn through the dead vegetation canopy but will not damage subsurface seedbanks or root systems. However, with a low water table, fire could burn the surface peat, causing great damage to plant organs and seeds. In its pre-abstraction state the Fen would not have been adversely affected by fire. Even as late as 1973, Heathcote (1973) noted the regenerating seedlings of wetland plants such as *Drosera* and *Hydrocotyle vulgaris* in an area of Redgrave Fen burnt only months before. Fire is therefore not likely to be a significant factor in the changes described here.

Deep dredging of the River Waveney

The ecological character of the site was determined by rising chalk water interacting with superficial deposits in the manner described. Outputs are therefore less significant, as long as subsurface inputs are maintained. Overdeepening of the River Waveney would have encouraged the drainage of the Fen and exacerbated low water table levels, but only until the installation of the sluice which limited outflow (Fig. 1). Great Fen, located downstream of the sluice, is probably still influenced by river drainage.

Drought

The Fen will have experienced very many droughts through its history without loss of ecological interest. It is only during the last 30 years that substantial and

rapid ecological change has taken place and therefore drought is not considered to be responsible. However, when acting in concert with dewatering, drought can accelerate changes caused by water table lowering.

CONCLUSION

Botanical and zoological data have been presented which describe changes over 30 years in one British valley fen from species-rich, soligenous calcareous mire communities with a very rich associated wetland fauna to degraded topogenous fen communities with a high degree of ruderalisation and an impoverished invertebrate fauna. Associated changes in hydrological conditions have been described and the principal agent of change has been identified as dewatering by an abstraction borehole. Improved land drainage, lack of management of the Fen communities and drought are also thought to contribute to the changes but their role is subsidiary to abstraction. Many studies of change in rich-fens have shown that the replacement of communities in the manner described for Bellamy's plots are directly caused by lowering of water levels (see, for instance, Grootjans, 1979; Grootjans & Ten Klooster, 1980; Giller & Wheeler, 1986; Wassen *et al.*, 1989).

These conclusions have considerable implications for conservation. The affected communities are of the highest importance to nature conservation (Nature Conservancy Council, 1989; Fojt, 1990) and in Britain are under increasing threat from dewatering. East Anglia has the highest concentration of such fens in Britain (Fojt, 1991) and also has a substantial water supply deficit (NRA, 1991), producing severe conflict. It does not require substantial reductions in levels to effect change; in their study of the effects of dewatering on Cirsio-Molinieta, Grootjans and Ten Klooster (1980) noted that communities could be sensitive to change in water levels which are so small that they may not be identifiable with normal hydrological instrumentation. The abstraction location may not need to be as close as in this example. The University of Birmingham (1991) has shown that effects of abstraction boreholes may detrimentally affect spring-fed fens as far as 9 km away. Under these circumstances the outlook for fens such as this is bleak.

ACKNOWLEDGEMENTS

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APPENDIX IV

REDGRAVE ABSTRACTION LICENCE No 7/34/16/048

Serial No. 7/34/16/[illegible]

A.

EAST SUFFOLK AND NORFOLK RIVER AUTHORITY

Water Resources Act, 1963

Water Resources (Licences) Regulations, 1965

LICENCE TO ABSTRACT WATER

THE EAST SUFFOLK AND NORFOLK RIVER AUTHORITY (hereinafter referred to as "the River Authority") licence

EAST ANGLIAN WATER COMPANY,

163 HIGH STREET,

LOWESTOFT,

SUFFOLK.

(hereinafter referred to as "the Licence Holder") to abstract water from the source(s) of supply described in the Schedule hereto, subject to the provisions specified in such Schedule.

This licence shall remain in force until revoked.

The fee payable under Section 57 of the above Act on the grant of this licence and annually thereafter is £5 0. 0. (or such other sum as is for the time being prescribed by order of the Minister of Housing and Local Government).

DATED this first day of April 1969.

Vincent Ellis

Clerk of the Authority

The Cedars,
Albemarle Road,
Norwich NOR 81E.

Offences: It is an offence under the Act -

(1) To fail to comply with the provisions of a licence - penalty, a fine (not exceeding £100 in the case of summary conviction) (Section 49);

Endorsement No. 1

1st August 1973 :

As from the date hereof the quantities of water authorised to be abstracted and the abstraction points shall be in accordance with the Schedule now attached hereto.

Clerk of the Authority

Endorsement No. 2

1 JUL 1930

As from the date hereof, the quantity of water authorised to be be abstracted, the points of abstraction and all other conditions of the within written licence shall be in accordance with the schedule attached hereto.

Divisional Manager

Endorsement Number 3

25 OCT 1982

As from the date hereof, the quantity of water authorised to be abstracted, the points of abstraction and all other conditions of the within written licence shall be in accordance with the schedule attached hereto.

Divisional Manager

(2) to construct or extend any well, borehole or other work whereby water may be abstracted from underground strata, or install or modify any machinery or apparatus whereby additional quantities of water may be abstracted from underground strata, unless the abstraction of the water, or additional quantities of water, is authorised by licence under the Act *and* the well, borehole or other work as constructed or extended, or the machinery or apparatus as installed or modified, complies with the requirements of the licence - penalty as in (1) (Sections 23(2) and 49);

(3) to interfere with a measuring device required by a licence to be installed and maintained, so as to prevent it from measuring correctly - penalty, imprisonment, or a fine, or both (Section 115).

SCHEDULE

PROVISIONS OF LICENCE

SOURCE(S) OF SUPPLY AND AUTHORISED PLACE(S) OF ABSTRACTION

1. Underground strata (chalk) at Redgrave in the County of Suffolk at the point marked Boreholes on plan number 1 attached hereto at National Grid Reference TM.046 792.

2. Underground strata (chalk) at Eye in the County of Suffolk at the point marked Borehole on plan number 2 attached hereto at National Grid Reference TM.1544 7295.

3. Underground strata (chalk) at Mendlesham in the County of Suffolk at the point marked Borehole on plan number 3 attached hereto at National Grid Reference TM.1175 6440.

4. Underground strata (chalk and crag) at Syleham in the County of Suffolk within the area outlined in black marked Boreholes on plan number 4 attached hereto at National Grid Reference TM.209 783.

Amended in accordance with endorsement Number 3 and new pages inserted in the schedule to the licence.

Dated 25 OCT 1982

LAND(S) ON WHICH WATER IS AUTHORISED TO BE USED

N O T A P P L I C A B L E

PURPOSE(S) FOR WHICH WATER IS AUTHORISED TO BE USED

Abstraction Points 1,2, and 4 - The provision of a supply of water in accordance with authorising enactments by the Licence Holder as a statutory water undertaker.

QUANTITY OF WATER AUTHORISED TO BE ABSTRACTED

The aggregate annual quantity from abstraction points 1, 2 3 and 4 shall not exceed 2,500 thousand cubic metres (550,000,000 gallons) a year.

The daily abstraction from abstraction point 1 shall not exceed 3637 cubic metres (800,000 gallons).

The daily abstraction from abstraction point 2 shall not exceed 1091 cubic metres (240,000 gallons).

The daily abstraction from abstraction point 3 shall not exceed 455 cubic metres (100,000 gallons).

The daily abstraction from abstraction point 4 shall not exceed 5364 cubic metres (1,180,000 gallons).

Amended in accordance with endorsement Number 3 and new pages inserted in the schedule to the licence.

Dated 25 OCT 1982

AUTHORISED MEANS OF ABSTRACTION

Abstraction Point 1 - Two boreholes, each 77 metres deep, 750 millimetres diameter, steel lined. Solid steel to 31 metres, slotted steel to 38 metres. Pumping plant capacity 46 litres a second.

Abstraction Point 2 - Borehole 68 metres deep, 250 millimetres diameter, steel lined to 40 metres. Pumping plant capacity 12.7 litres a second.

Abstraction Point 3 - Borehole 107 metres deep, 375 millimetres diameter, steel lined to 49 metres. Pumping plant capacity 7.6 litres a second.

Abstraction Point 4 - (a) Chalk borehole 125 metres deep, 400 millimetres diameter, steel lined to 73 metres.
Pumping plant capacity 10.1 litres a second.

(b) Crag borehole 57 metres deep, 450 millimetres diameter, solid casing to 31 metres Hagusta lining tubes to 57 metres with gravel pack.
Pumping plant capacity 28 litres a second.

(c) Crag borehole 61 metres deep, 600 millimetres diameter, solid casing to 30 metres Hagusta lining tubes to 61 metres with gravel pack.
Pumping plant capacity 35 litres a second.

MEANS TO BE USED FOR MEASURING OR ASSESSING QUANTITIES OF WATER AUTHORISED BY THIS LICENCE TO BE ABSTRACTED

Abstraction Points 1,2, 3 and 4 - Satisfactory water meters recording the quantity of water abstracted are to be provided and maintained by the Licence Holder.

PROVISIONS FOR DETERMINING, BY MEASUREMENT OR ASSESSMENT, THE QUANTITY OF WATER TAKEN TO HAVE BEEN ABSTRACTED DURING THE PERIOD(S) REFERRED TO BELOW

Abstraction Points 1,2, 3 and 4 - Readings of the meters shall be taken and recorded to show the quantity of water abstracted in each month and certificates setting out the monthly quantities abstracted shall be returned to the Authority within five days of the end of December in each year.

Amended in accordance with endorsement Number 3 and new pages inserted in the schedule to the licence.

Dated 25 OCT 1982

OTHER CONDITIONS SUBJECT TO WHICH ABSTRACTION IS AUTHORISED

Abstraction Point 2

For the protection of local sources of supply -

1. If at any time hereafter it shall be proved by the owner of a protected source that pumping by the licence holder at the pumping station has caused a diminution of the supply of water in the protected source, the licence holder shall on the written request of the owner, and at the option of the licence holder either -

(a) afford, or cause to be afforded to the owner a supply of water equal to the amount of the diminution so however that any interruption of such a supply owing to frost, unusual drought or other unavoidable cause shall not be a breach of any obligation under this paragraph: or

(b) at the expense of the licence holder make such alterations in the pumping equipment installed at the protected source, whether by way of enlarging or altering the position of the equipment or of installing fresh equipment as will make good the diminution: or

(c) at the expense of the licence holder deepen the protected source to such extent, or make such borings therein or headings therefrom, as will make good the diminution: or

(d) make compensation in money for the diminution

Provided that -

(i) the licence holder shall not be under any liability under this condition if the owner shall have failed to afford to the licence holder and its officers and servants without charge at all reasonable times after the commencement of this order access to the protected source and facilities for ascertaining the level and quantity of the water therein and such information as the licence holder may reasonably require as to the cost to the owner of operating the protected source;

(ii) where the licence holder elects to afford or cause to be afforded a supply of water under paragraph (a) of this condition, their obligation thereunder shall not extend to the provision of a supply of water for domestic purposes if the water in the protected source is so polluted as to be, or be likely to be injurious or dangerous to health.

(iii) the licence holder shall not be under any liability under this condition to afford or cause to be afforded any greater supply of water than is, together with the supply obtainable from the protected source, reasonably required for use by the owner from time to time.

2. A supply of water afforded by the Licence Holder under paragraph (a) of the last foregoing condition shall be afforded on such terms as may be agreed, or failing agreement, determined by arbitration.

Provided that the charge to be made by the Licence Holder in any year for such a supply shall not exceed the amount by which the cost which the owner would have incurred in that year in obtaining his supply if the supply had continued undiminished exceeds the cost to him of obtaining the diminished supply.

3. The Licence Holder shall pay to the owner

(a) where a supply of water is afforded under paragraph (a) of the foregoing condition 1 the amount by which the aggregate cost to the owner of that supply and of obtaining his diminished supply in any year exceeds the cost which he would have incurred in that year in obtaining his supply if the supply had continued undiminished:

(b) where it makes such alterations as are referred to in paragraph (b) of that condition or execute any work mentioned in paragraph (c) thereof the amount by which the cost to the owner of obtaining thereafter in any year a supply equivalent to his supply before the diminution exceeds the cost which he would have incurred in that year in obtaining his supply if the supply had continued undiminished.

4. All mains, pipes, meters and fittings required for the purpose of supplying water to an owner in pursuance of these conditions shall be provided, laid placed or fixed, and maintained by and at the expense of the Licence Holder.

Provided that fittings other than mains, pipes and meters which shall be placed or fixed upon the premises of the owner shall be repaired, maintained renewed and made good by and at the expense of the owner to the satisfaction of the Licence Holder.

5. An owner shall, without making any charge therefor, give the Licence Holder access and facilities for carrying out works in pursuance of this condition.

6. Any question which may arise between the Licence Holder and an owner under these conditions shall be determined by arbitration.

7. In these conditions -

"protected source" means any well, pond, spring or stream which is situated within a radius of one mile of the centre of the pumping station and is used at the commencement of this licence as an effective source of supply:

"Owner" includes a lessee or occupier.

Abstraction Point 4

8. The boreholes 4(b) and 4(c) shall be constructed in accordance with details to be agreed in writing between the Licence Holder and the Authority so that pumping and rest water levels can be readily measured.

9. The pumping equipment in boreholes 4(b) and 4(c) is to be designed to operate satisfactorily under conditions which will prevail if the rest water level in the boreholes is lowered by 5 metres as a result of additional abstractions by persons other than the Licence Holder coming into operation after the issue of this licence, due allowances being made for natural seasonal changes in water level and the interference effects of existing abstractions. If the pump intakes are not initially installed at such depth as is necessary to comply with the above requirement the Licence Holder shall lower them at his own expense if so requested by the Authority. The Licence Holder shall inform the Authority of the rest water levels encountered when the bores are sunk, the results of any pumping tests and the levels at which the pump and the pump intakes are installed.

Amended in accordance with endorsement Number 3 and new pages inserted in the schedule to the licence.

Dated 25 OCT 1982

The reasons for imposition of the conditions aforesaid are to enable the Authority to:-

(a) maintain records of all water consumed in the Authority's area

(b) check the amount of water abstracted from time to time

(c) ensure that the amount of water abstracted does not exceed the amount authorised by the licence

(d) provide information on underground water levels essential to the Authority for proper management of water resources in underground strata

(e) permit further development of water resources in underground strata in the area without detriment to this source of supply.

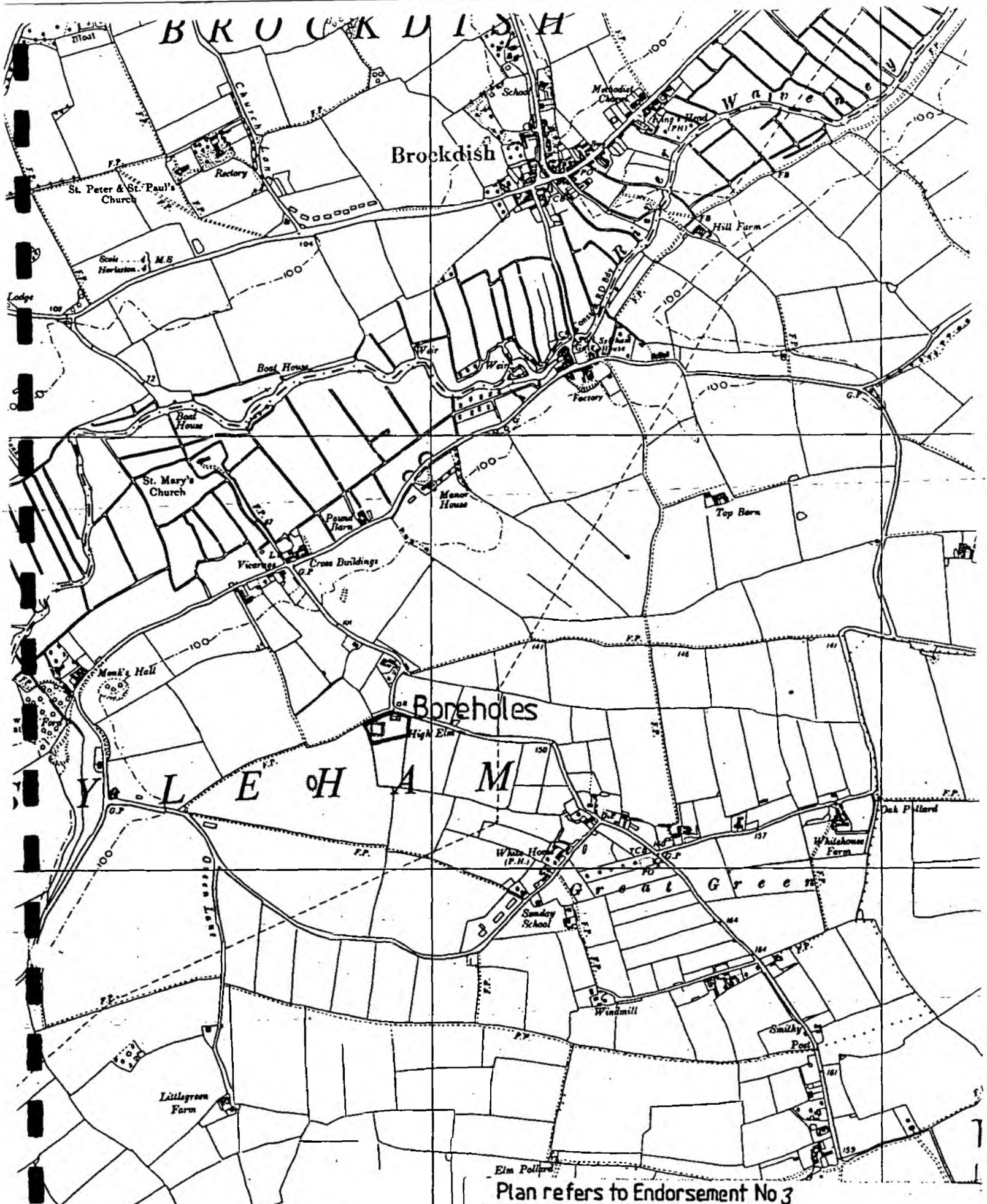
RIGHT OF APPEAL

If the applicant is dissatisfied with the decision of the Authority on his application, he may, by notice served within one month from the date of receipt of this notice, appeal to the Department of the Environment (Local Government and Development) in accordance with Section 39 of the Water Resources Act, 1963 and the Water Resources (Licences) Regulations 1965 (S.I. 1965 No. 534). The Minister has power to allow a longer period for the giving of a notice of appeal.

IMPORTANT NOTICE

TO A SUCCESSOR OF THIS LICENCE

If you have become the holder of this licence, in accordance with Section 32(1) or regulations made under Section 32(3) of the Water Resources Act, 1963 by succeeding to the previous Licence Holder's occupation of land specified in the licence as land on which water abstracted in pursuance of the licence is to be used you should note that, by virtue of Section 32(2) of the above Act (or corresponding provisions in the regulations under Section 32(3)), you will cease to be the holder of the licence at the end of a period of one month from the date on which you became the occupier of the land in question unless before the end of that period you have given the Authority notice of the change in the occupation of the land.



Plan refers to Endorsement No 3

ANGLIAN WATER AUTHORITY

PLAN NO. 4 REFERRED TO IN LICENCE

7/34/16/6/48

RESOURCE PLANNING DEPT. OF THE NORFOLK AND SUFFOLK RIVER DIVISION

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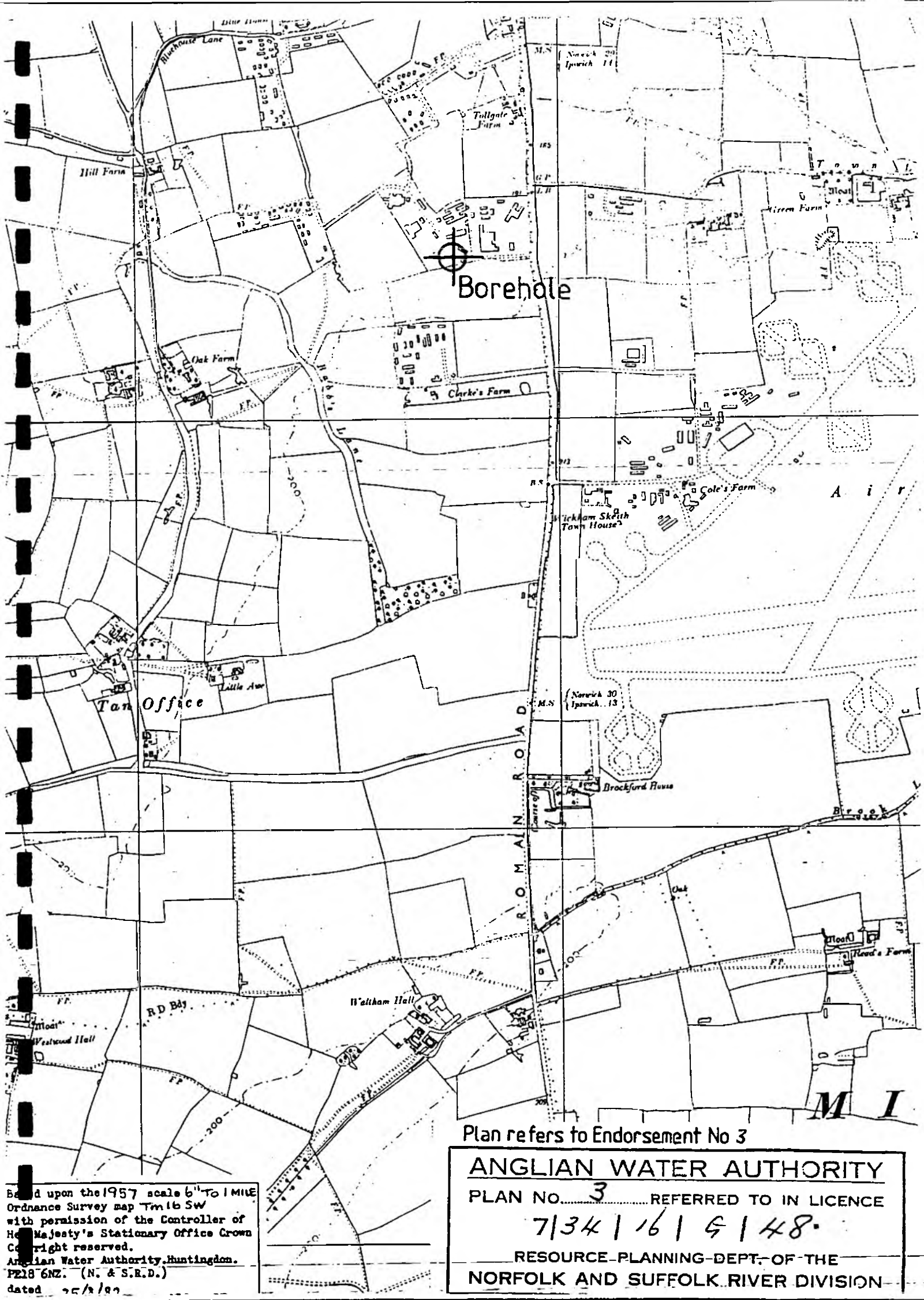
...ted 25/8/82



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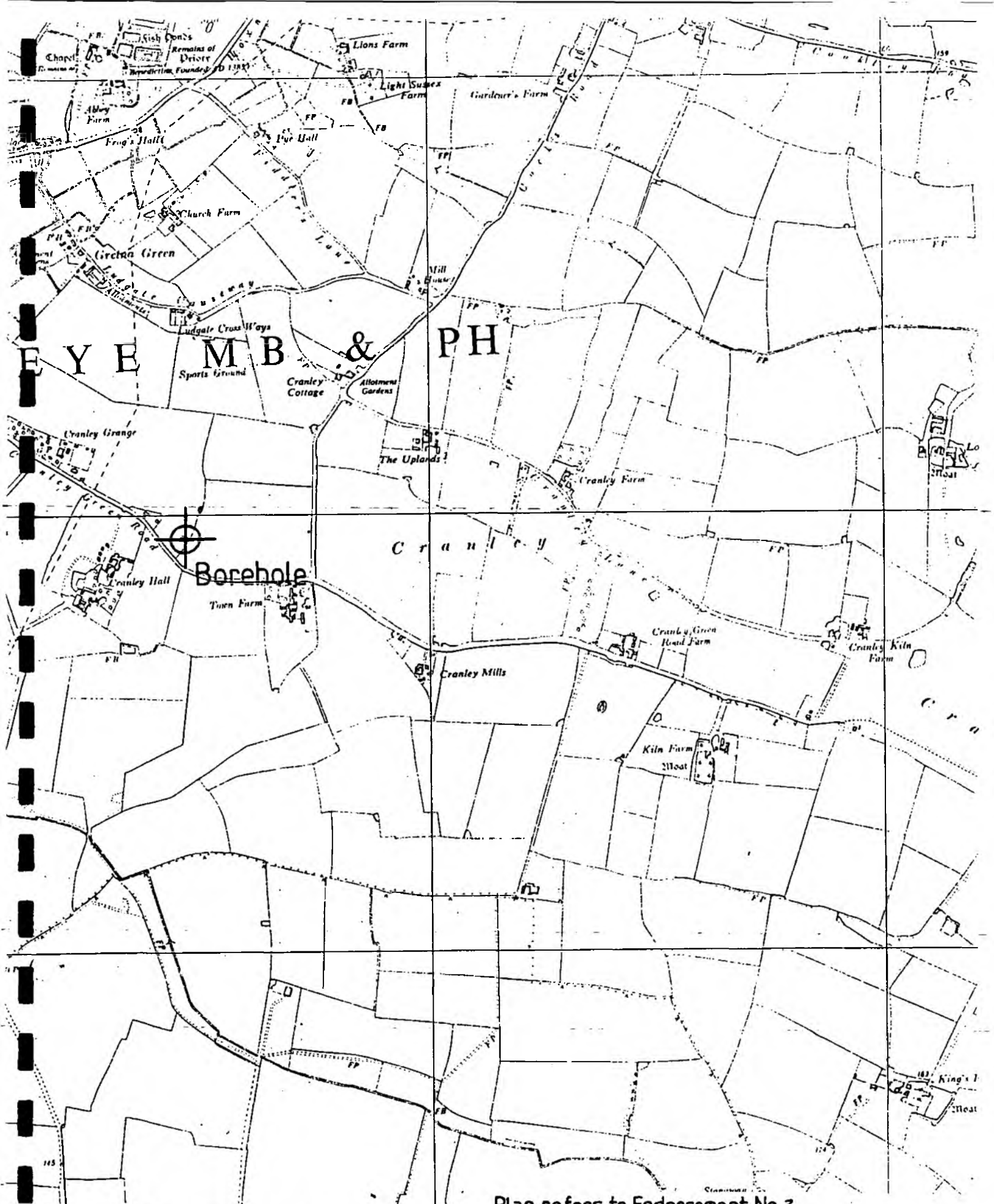
ANGLIAN WATER AUTHORITY

PLAN NO. 3 REFERRED TO IN LICENCE

7/34/16/S/48.

RESOURCE PLANNING DEPT. OF THE NORFOLK AND SUFFOLK RIVER DIVISION



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ANGLIAN WATER AUTHORITY

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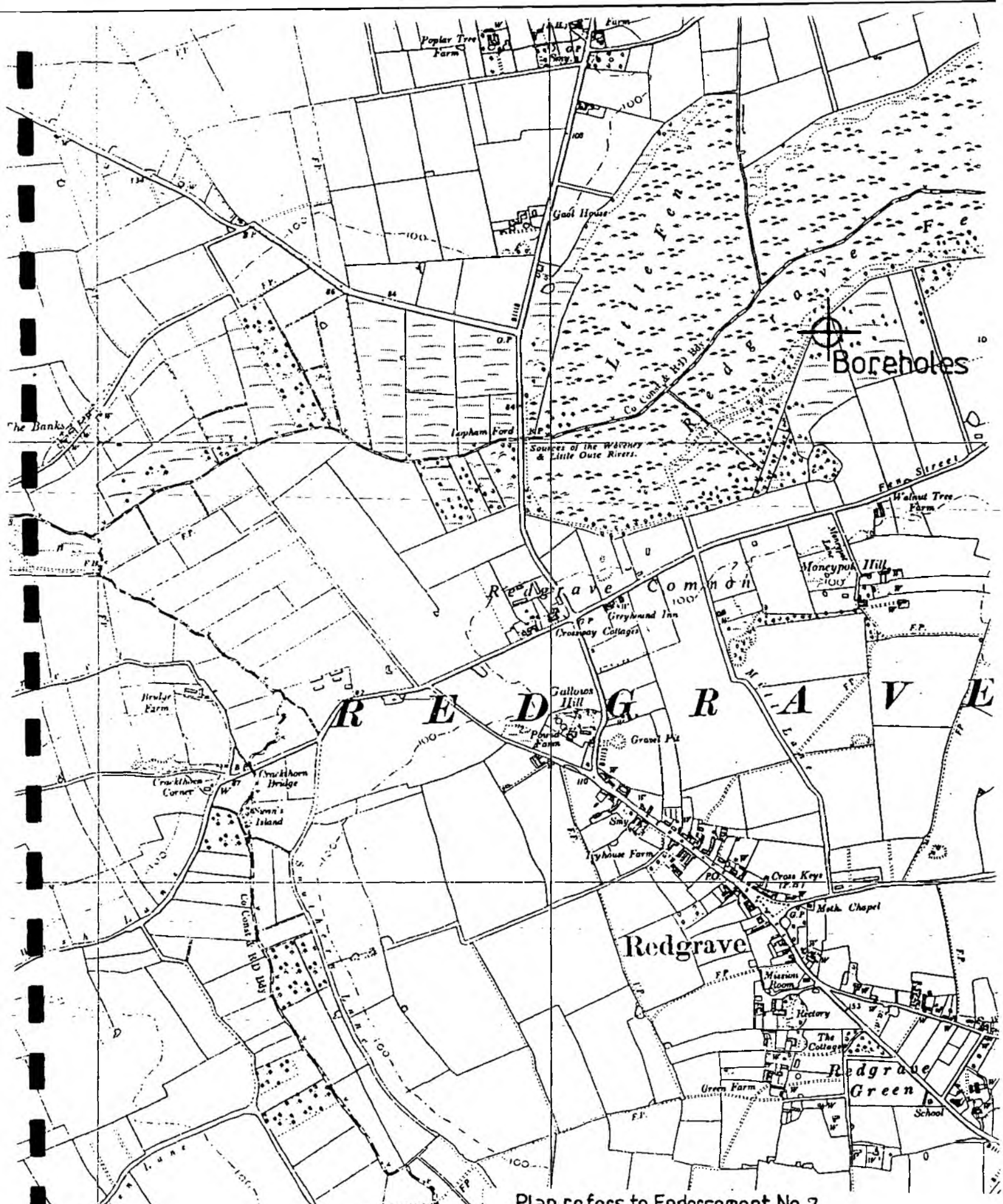
RESOURCE PLANNING DEPT. OF THE NORFOLK AND SUFFOLK RIVER DIVISION



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ANGLIAN WATER AUTHORITY

PLAN NO. 1 REFERRED TO IN LICENCE

7/34/16/G/48

RESOURCE PLANNING DEPT. OF THE NORFOLK AND SUFFOLK RIVER DIVISION

APPENDIX V

RECOVERY OF REDGRAVE AND LOPHAM FENS FOLLOWING BOREHOLE MOVE

CASE SUBMISSION TO DoE

SUFFOLK WILDLIFE TRUST

Suffolk Wildlife Trust

Recovery Of Redgrave and Lopham Following Borehole Move
Case Submission To DoE

1. Statement of Site Status and Present Quality

1.1 Summary of Site Status

Redgrave and Lopham Fen was one of the first sites in the UK to be designated SSSI, in 1954. It is a Grade 1* Nature Conservation Review site, indicating a top quality site of National Nature Reserve potential. In 1991 it was confirmed by DoE as a RAMSAR site, indicating that it is a wetland of international importance for conservation.

Conservation importance is derived principally from the habitat - it is the largest calcareous valley mire in England with a range of extensive and well developed plant and animal communities typical of the habitat but rare in Britain, such as the Black bog rush-Blunt flowered rush community.

In addition there are a large number of rare invertebrates recorded on the site. These include the nationally rare Fen Raft Spider, Dolomedes plantarius, which is recorded at only one other site in Britain. There are four other RDB1 invertebrates recorded on the fen, five RDB2 invertebrates, 13 RDB3 invertebrates and 116 nationally scarce (RDB Notable) species. RDB is an acronym for Red Data Book, a list of the rarest plants and animals which grades them according to threat.

It is important to note that the RAMSAR designation was on the basis of the current state of the fen. That is, even in its somewhat degraded state, the fen is of international importance. It is not a retrospective designation relating to its state before the borehole came into operation.

1.2 National and International Conservation Commitments

Redgrave and Lopham Fen is part of a national network (the SSSI and National Nature Reserve series) of top grade conservation sites. The Government is committed to the conservation of these sites through the Wildlife and Countryside Act 1981.

The Water Resources Act 1991 establishes the Government's intention, through the NRA, to ensure the wise use of water resources, the protection and enhancement of wetlands of special importance, and the conservation of flora and fauna which are water dependent. In addition, the Act provides NRA with powers to revoke Licences of Right where appropriate for these objectives.

The site is part of an international network of wetland conservation sites declared through the RAMSAR Convention. The Government ratified the Convention in 1976. In so doing they accepted the a commitment to promote the conservation of particular sites and the "wise use" of wetlands in their territory.

In the Habitats and Species Directive of the European Community, Annex 1 lists habitats which are deserving of special conservation effort by Member States. Of those listed, some are asterisked, indicating they are of the highest priority because they are particularly threatened, and that the Community has a particular responsibility for them as they are concentrated in Europe. Asterisked habitats include calcareous fens rich in Cladium, which forms the core of the reserve's wetland habitats. Redgrave also contains substantial areas of listed but not asterisked habitats, such as calcareous Molinia fen meadows and eutrophic tall herb habitats. Through the Directive, Member States are committed to measures which maintain or restore such habitats, and measures which avoid the deterioration of these habitats. It is significant that restoration of such habitats is a consistent theme of the Directive.

The Government has further international commitments through the Biodiversity Convention signed at the Earth Summit in 1992. Article 10 of the Convention commits the Government to the sustainable use of habitats and to minimise impacts on habitats which would cause the loss of biological diversity. Article 8 commits contracting parties to the protection of habitats and species' populations in situ, and if damage has already occurred for activities causing damage to be regulated and managed. The Government is currently working on a Biodiversity Action Plan, aimed at putting into practice the commitments of the Convention.

1.3 The Fen as A National Asset

Redgrave and Lopham Fen is one of the most important conservation sites in the UK and is recognised internationally as such. As an SWT nature reserve it is available for the enjoyment of any member of the public free of charge at any time, all year. It has good visitor facilities including car parks, interpretation, wardening, a well maintained path network, a boardwalk for disabled access and a high public profile. Membership of conservation organisations is extremely high, the membership of the Suffolk Wildlife Trust currently stands at 13,000 alone. It therefore stands with other national assets of international importance such as the Great Houses, collections of artwork, and cultural institutions all of which attract very substantial Government funding.

1.4 Prevention of Further Degradation

The effects of the borehole are now universally accepted to have caused significant ecological damage to the fen flora and fauna. Relocation of the borehole now will prevent further damage and the longer term retention of its status as a RAMSAR site. This alone is believed to be sufficient justification for the borehole move, although it is recognised that some indication of the measure of recovery will be required before a decision to move is made.

2. Effects of Hydrological Recovery on the Site

2.1 Halting of Peat Wastage

Recovery of the water table will keep the peat wet throughout the year. The loss of groundwater seepage and subsequent drying of the peat has caused the release of nutrients due to the process of mineralisation. As a consequence, the more fertile conditions allows a rank, species poor vegetation to grow rather than the original species rich, low productivity vegetation that characterised the site before the borehole became operational. Recovery of the fen's hydrology will stop further mineralisation of the peat and is an essential first step towards ecological recovery.

2.2 Habitat Requirements of Individual Species

Restoration of the hydrology will restore the conditions required by the specialised plants and invertebrates that are characteristic of fens. Some plants, such as sundews, require water levels at the surface throughout the summer. Without the restoration of such levels, these plants will not return, regardless of habitat management. Many rare invertebrates are similarly keyed into very closely defined habitat conditions. In this way, the level of hydrological recovery will define the level of ecological recovery. Reestablishment of species lost from the Fen through colonisation from nearby sites will also require recovery of the hydrology.

2.3 Germination of the Seed Bank

Botanical recovery will be from germination of seeds stored in the soil and from seed or spores dispersed from other wetlands. The success of both depends on the full recovery of the water table.

2.4 Scrub Encroachment

The rapid rate of scrub invasion has been facilitated by lowering of the fen water levels. The main recent colonist, silver birch, would normally be killed by permanent waterlogging. Reinstatement of such conditions will help with scrub removal and severely retard further colonisation. This will release resources for other beneficial management works.

2.5 The restarting of peat cutting.

Part of the ecological value of the fen was created by shallow peat cutting for fuel. With a low water table this is no longer possible because it opens the dry peat to scrub and ruderal invasion. Recovery of the water table will allow the resumption of peat cutting. This will benefit invertebrates such as the Fen Raft Spider by increasing the fen pool habitat. It will also benefit the flora by providing a range of aquatic and semi-aquatic habitats suitable for colonisation of species typical of the early stages of natural succession.

Peat cutting is likely to be an essential part of recovery management where there is enough peat left. The peat mineralisation process has become far advanced in some areas so that the surface peat layer may need to be stripped off and removed altogether. This will leave an in-tact peat surface for recolonisation. This can only be achieved with restored hydrology.

2.6 Enablement of Normal Fenland Management

Because the peat is so dry, some normal management operations (mowing, removal of scrub stumps, peat cutting etc) are impossible, because these operations open the soil surface and allow non-fen ruderals (nettle, thistles etc) and scrub (especially birch) to seed in. The result is vigorous scrub regeneration and ruderalisation of the herb rich areas. These species cannot survive waterlogged conditions so recovery of the water table will allow such management to recommence.

2.7 Amelioration of Low Flows

Restoration of the hydrology will reverse the role of Redgrave as a zone of aquifer recharge to one of aquifer discharge. This will restore the natural level of baseflow to the River Waveney and therefore ameliorate problems of low summer flows.

2.8 Summary of the effects

Should all the above processes be successfully achieved, the overall effect will be an increase in extent of valley fen communities, a decrease in the extent of ruderalised fen margin communities, a decrease in scrub invasion, and an increase in floristic quality of the fen vegetation. The fauna associated with these conditions (eg Fen Raft Spider) would be expected to show similar recovery, both in terms of population size and area of fen utilised.

3. Commitment To Fen Management In The Future

3.1 SWT Tenure and Commitment

The Suffolk Wildlife Trust owns Middle Fen and has leased other parts of the reserve on sixty year leases. Concern over the plight of the fen was instrumental in setting up the Trust in 1961. It is the Trust's largest reserve and SWT are totally committed to its continued conservation and management.

3.2 Resources Allocated

The Fen receives a larger slice of SWT reserve funds than any other reserve. There are two full time wardening staff, with considerable inputs from other staff. There is additionally a strong volunteer commitment to the reserve with three nearly full time volunteer workers and large numbers of other volunteers. The current management costs of the reserve amount to more than £30,000 annually. This does not include the value of volunteer support which would double this figure.

3.3 National Nature Reserve Status

English Nature have shown their commitment to the management of the Fen by providing 50% of costs since 1990, with lower level grant aid previous to this. By the end of 1992, their commitment will be underlined by the signing of a Nature Reserve Agreement with SWT which formally creates the National Nature Reserve and guarantees payment of an annual contribution (currently 50%) towards management costs for the 31 years of the agreement period. This will be the only NNR of its kind in Eastern England, and only the second in the rest of England.

3.4 Additional Fen Raft Spider Help

The Species Recovery Programme of English Nature has targetted the Fen Raft Spider as a flagship species and has directed several thousand pounds in grant (additional to that mentioned in 3.3) specifically for research into ecological requirements of the spider, the monitoring of its population and specific management projects to aid recovery. It is proposed that funding will continue into 1993/4.

3.5 Adjustments of Management With Recovery

The management of the site will be regularly reviewed during and after recovery. Resources will be redirected as the effects of recovery become evident, to enable the most effective ecological recovery to take place.

4. Monitoring The Recovery of The Fen

4.1 Hydrology

Monitoring of the fen water table will be continued through the recording of the current network of piezometers.

4.2 Plant Communities

Recovery of the vegetation will be monitored by the resurveying of Bellamy's Plots (surveyed in 1959 and 1990/91) at suitable intervals. Additional vegetation monitoring will be initiated in new areas, associated with the management regimes. Experimental management (eg peat cutting) will also be the subject of further monitoring.

4.3 Fauna

Recovery of the Fen Raft Spider will be monitored annually, with grant aid at least initially from English Nature's Species Recovery Programme. The monitoring programme will also take account of the spread of the spider through the fen, as well as population size in core areas.

5 Degree of Ecological Recovery

The ecology of the site is inseparable from its hydrology, both in terms of water quantity and water quality. Thus degree of ecological recovery outlined above is entirely dependent on the level of hydrological recovery.

While important improvements would accrue merely from restoration of the water, recovery will only be maximised if habitat management is continued.

5.1 Timescale of Recovery

Ecological systems are not deterministic so therefore predictions on the rate of ecological recovery are extremely difficult. Such predictions are further obscured by the fact that this type of recovery has not been attempted before.

However, assuming full hydrological recovery occurs between 5 and 10 years, we would expect gross changes in the habitat (reduction of ruderals, reduction of scrub invasion, killing of birch, and increase in valley fen dominants such as Cladium, Schoenus and Juncus) to begin

within this 10 year period. Numbers of Fen Raft Spiders should stabilise and hopefully increase within the core areas. We would subsequently expect the recolonisation of rarer fen species of smaller stature such as the marsh orchids, and the re-establishment of rich fen bryophytes. Peat will then be accumulating rather than wasting as at present. Similarly, in this second period we expect Fen Raft Spider numbers to increase and their range on the fen to expand.

The degree of recovery of the fen would depend on the degree of hydrological recovery and the continuance of management. If the hydrology is restored, we are fully confident of recovery in the pattern described, but we are uncertain of the exact timescale.

Mike Harding
Reserves Manager
Suffolk Wildlife Trust

Jeremy Clitherow
Conservation Officer
English Nature

APPENDIX VI

REDGRAVE AND LOPHAM FENS HISTORY OF EVENTS

HISTORY OF EVENTS RELATING TO THE FEN — APPENDIX VI

Circa 1820 - Allocation of the fens to the poor under the General Enclosures Act.

Up to c.1920 - Two large springs at Lopham Ford (formerly Lopham Gate) NGR TM0392 7900. Local knowledge reports springs covered over in early 1920's - un-confirmed but book held by parishioner has been viewed by SWCo.

Up to c.1930 - Fen maintained for peat excavation and sedge cutting.

c.1932 - Land drainage improvements through the fen.

1939-1946 - Fen taken over by Air Ministry, used as bombing range.

c.1940 - Change in land use on north side of fen; gorse removed for agricultural production.

1949 - Importance of Site for Nature Conservation recognised by Tansley, Watt & Ellis.

1950 - Redgrave Borehole No 1 constructed for Hartismere RDC for rural public water supplies.

1954 - Redgrave Borehole No 2 constructed for Hartismere RDC for rural public water supplies.

1954 - Redgrave & Lopham fens first notified as SSSI under the National Parks & Access to the Countryside Act 1949.

1956 - Great Raft Spider first officially recorded on the fen.

1956-57 - Redgrave waterworks constructed and water pumped into supply. Earliest available abstraction return indicates 1.8 Ml/d in 1960.

1958 - Bellamy and Rose Investigation published 1961. "The Waveney/Ouse Valley Fens of the Suffolk-Norfolk Border".

Early 1960's - Stop Log water retention structure constructed at NGR TM0538 7963 to retain water levels in the fen following downstream river re-grading.

1961 - Suffolk Naturalists Trust (now SWT) founded to protect the fen.

1965 - Licence of Right issued to EAWCo under Water Resources Act 1963. Statutory provision under which entitled to claim - General Powers of Public Health Act 1936 part (iv), then Anglian Water Order 1963 Statutory Instrument 1595. Licence Authorises 3.637 tcmd within 2500tcma aggregate for 4 No sources.

1973 - Anglian Water Authority Norfolk & Suffolk River Division take over functions of East Suffolk &Norfolk River Authority for main rivers.

c.1976 - At NCC's request AWA installed network of observation piezometers within the fen for monitoring groundwater levels.

1979 - Radial sluice gate installed at NGR TM0539 7964 to retain groundwater levels in the fen. Jointly funded by AWA and WWF.

1985 - Fens re-notified under Wildlife & Countryside Act 1981.

1986 - EAWCo agree to reduce abstraction at Redgrave to around 2.8 tcmd.

1989 - National Rivers Authority formed.

1989 - Site recommended by NCC for inclusion in the list of Wetlands of International Importance under the Ramsar Convention.

1989 - NCC and SWT request NRA revoke EAWCo Redgrave abstraction licence.

1991 - Redgrave & Lopham Fens SSSI designated as Wetland of International Importance under the Ramsar Convention.

1991 - Redgrave borehole switched off for 1 month - changes in groundwater levels monitored.

1991 - Support pumping to spider pools implemented.

June 1992 - NRA & SWCo issue joint press statement that abstraction at Redgrave is to cease as soon as a suitable alternative borehole is developed.

March 1993 - Joint application made for contribution towards funding to EC "LIFE" Fund Committee. Initial approval received in May for 50% contribution. Agreed SWT to be fund manager.

April to Dec 1993 - Mellis/Wortham investigations. Drill and test 5 boreholes for yield assessment.

June 1993 - Redgrave & Lopham fens SSSI designated as a National Nature Reserve.

July 1993 - 40 day test pumping at North Lopham river support b/h.

December 1993 - Approval in principle from NRA Board and DOE

January 1994 - 4 year EC "LIFE" grant commenced.

April 1994 - Howard Humphreys & Partners complete "Hydrological and Environmental Impact Assessment.

May 1994 - Southern Science commence investigations for yield and WQ at Wortham sites.

APPENDIX VII

OPTION COSTINGS AND NPC CALCULATIONS

APPENDIX VII

RELOCATION OF REDGRAVE

Option 1: 3.6Ml/d Borehole at Mellis Wortham Area
Treatment at existing
Redgrave Treatment Works

This document must be read in association with document reference: 005NRA.RED

		£
1.	Borehole drilling, development and EA	150 000
2.	Borehole pump to Works	93 000
	Civils	50 000
3.	Treatment Works at Redgrave based on (i) Iron removal	-
	Civils	-
4.	Treatment Water Storage on Site 2Ml	-
5.	Pumping into Supply	-
6.	Land Acquistion	20 000
7.	Mains Raw Water;	
	a Mellis/Wortham to Redgrave	842 160
8.	Lagoons	-
9.	Diesel Generator	35 000
10.	Electricity supply and site services	70 000
11.	Design Costs:	
	a Mains	42 108
	b M & E	43 600
	c Civils	5 000
	Total (i)	1 350 868
	Total with Iron & Manganese Removal (ii)	1 494 868
12.	Increased OPEX Costs (p.a.)	3 000

RELOCATION OF REDGRAVE

Option 1: 3.6Ml/d Borehole at Mellis Wortham Area
Treatment at existing
Redgrave Treatment Works

This document must be read in association with document reference: 005NRA.RED

		£
1.	Borehole drilling, development and EA	150 000
2.	Borehole pump to Works	93 000
	Civils	50 000
3.	Treatment Works at Redgrave based on (i) Iron removal	-
	Civils	-
4.	Treatment Water Storage on Site 2Ml	-
5.	Pumping into Supply	-
6.	Land Acquistion	20 000
7.	Mains Raw Water;	
	a North Lopham to Redgrave	1 232 520
8.	Lagoons	-
9.	Diesel Generator	35 000
10.	Electricity supply and site services	25 000
11.	Design Costs:	
	a Mains	61 626
	b M & E	34 600
	c Civils	5 000
	Total (i)	1 706 746
	Total with Iron & Manganese Removal (ii)	1 850 746
12.	Increased OPEX Costs (p.a.)	3 000

RELOCATION OF REDGRAVE

Option 1: 3.6Ml/d Borehole at Mellis Wortham Area
Treatment at existing
Redgrave Treatment Works

This document must be read in association with document reference: 005NRA.RED

		£
1.	Borehole drilling, development and EA	150 000
2.	Borehole pump to Works	26 000
	Civils	16 000
3.	Treatment Works at Redgrave based on (i) Iron removal	550 000
	Civils	440 000
4.	Treatment Water Storage on Site 2Ml	385 000
5.	Pumping into Supply	140 000
6.	Land Acquistion	30 000
7.	Mains inot Supply;	
	a Wetheringsett to Thorndon	556 200
	b Wetheringsett to Thwaite	324 960
	c Thorndon to Yaxley	800 000
8.	Lagoons	1 900
9.	Diesel Generator	52 000
10.	Electricity supply and site services	75 000
11.	Design Costs:	
	a Mains	84 058
	b M & E	174 600
	c Civils	84 290
	Total (i)	3 890 008
	Total with Iron & Manganese Removal (ii)	3 908 008
12.	Increased OPEX Costs (p.a.)	9 000

Document Ref: 005NRA.RED

REDGRAVE RELOCATION DRAFT COST ESTIMATES

The following aspects and caveats should be read in association with the attached draft costings (Ref: Redgrave.Op2):

1. The estimates have not as yet been audited by Suffolk Water Company or the NRA.

2. All estimates are based on 1993 costs.

3. No allowance has been made for ammonia removal or nitrate stripping.

4. Costs have been prepared without any on site survey (walking the route).

5. Mains costs are subject to finalisation of routes.

6. Network analysis for sizing of mains has been calculated on a 'snap shot' approach. Further runs considering 24 hour solutions are currently underway but not complete.

7. Wetheringsett option assumes new site is close to existing NRA site and that electricity supply is only 80m distant. Costs will increase if the final site is further away from an electricity supply.

8. An allowance of £150,000 has been allowed for the drilling, developing, testing and Environmental Assessment of one trial production borehole. If that site is not suitable on any grounds, no allowance has been made for further drilling, testing etc. (Based on recent drilling costs at a new SWC production borehole site.)

9. An allowance of 4ha has been made for land acquisition at Wetheringsett.

10. An allowance of £20,000 has been allowed for land acquisition at either Mellis or Lopham Options. This assumes that no special arrangements will be required for access. (Based on current land acquisition costs at a new Suffolk Water Company production borehole.)

11. It has been assumed that there are no planning constraints or special requirements at any of the sites.

12. No assessment of betterment has been included in the estimates.

RELOCATION OF REDGRAVE

OPTION 1: 3.6 ml/d Borehole at Mellis/Wortham Area
Treatment at existing Redgrave Treatment Works

		ASSET LIFE			
		- £K	60 YRS £K	20 YRS £K	
1.	Borehole drilling etc.		150.0		
2.	Borehole pump to Works			93.0	
	Civils		50.0		
3.	Treatment Works at Redgrave based on			-	
	(i) Iron removal			-	
	Civils		-		
4.	Treated Water Storage on Site 2 ml				
5.	Pumping into Supply				
6.	Land Acquisition	20.0			
7.	Mains Raw Water				
	a. Mellis/Wortham to Redgrave		842.2		
8.	Lagoons				
9.	Diesel Generator			35.0	
10.	Electricity Supply and Site Services	70.0			
11.	Design Costs				
	a. Mains		42.1		
	b. M & E			43.6	
	c. Civils		5.0		
12.	Addition for Manganese Removal			144.0	
Total Initial Capital Costs		90.0	1089.3	315.6	= 1494.9

RELOCATION OF REDGRAVE

OPTION 1 :

		ASSET LIFE			NET PRESENT COST @ YR 0
		-	60 YRS	20 YRS	
		£K	£K	£K	£K
Initial Capital Costs		90.0	1089.3	315.6	
	Year 0	20.0	197.1	43.6	260.7
	1	70.0	50.0	93.0	200.9
	2	-	842.2	144.0	877.7
	3	-	-	35.0	29.4
Replacement of Assets					
	Year 20			43.6	13.6
	21			93.0	27.4
	22			144.0	40.0
	23			35.0	9.2
Replacement of Assets					
	Year 40			43.6	4.2
	41			93.0	8.5
	42			144.0	12.5
	43			35.0	2.9
Total Discounted Capital Costs					1487.0
Increased Operating Costs @ £3K p.a. for 60 years (Year 4 to 63)					40.7
Total Discounted Capital/Additional Operating Costs					£1527.7K

RELOCATION OF REDGRAVE

OPTION 2: 3.6 ml/d Borehole at North Lopham
Treatment at existing Redgrave Treatment Works

		ASSET LIFE			
		- £K	60 YRS £K	20 YRS £K	
1.	Borehole drilling etc.		150.0		
2.	Borehole pump to Works			93.0	
	Civils		50.0		
3.	Treatment Works at Redgrave based on				
	(i) Iron removal			-	
	Civils		-		
4.	Treated Water Storage on Site 2 ml				
5.	Pumping into Supply				
6.	Land Acquisition	20.0			
7.	Mains Raw Water				
	a. North Lopham to Redgrave		1232.5		
8.	Lagoons				
9.	Diesel Generator			35.0	
10.	Electricity Supply and Site Services	25.0			
11.	Design Costs				
	a. Mains		61.6		
	b. M & E			34.6	
	c. Civils		5.0		
12.	Addition for Manganese Removal			144.0	
Total Initial Capital Costs		45.0	1499.1	306.6	= 1850.7

RELOCATION OF REDGRAVE

OPTION 2 :

		ASSET LIFE			NET PRESENT COST @ YR 0
		-	60 YRS	20 YRS	
		£K	£K	£K	£K
Initial Capital Costs		45.0	1499.1	306.6	
	Year 0	20.0	216.6	34.6	271.2
	1	25.0	50.0	93.0	158.5
	2	-	1232.5	144.0	1225.1
	3	-	-	35.0	29.4
Replacement of Assets					
	Year 20			34.6	10.8
	21			93.0	27.4
	22			144.0	40.0
	23			35.0	9.2
Replacement of Assets					
	Year 40			34.6	3.4
	41			93.0	8.5
	42			144.0	12.5
	43			35.0	2.9
Total Discounted Capital Costs					1798.9
Increased Operating Costs @ £3K p.a. for 60 years (Year 4 to 63)		-			40.7
Total Discounted Capital/Additional Operating Costs					£1839.6K

RELOCATION OF REDGRAVE

OPTION 3: 3.6 ml/d Source and Treatment Works at Wetheringsett

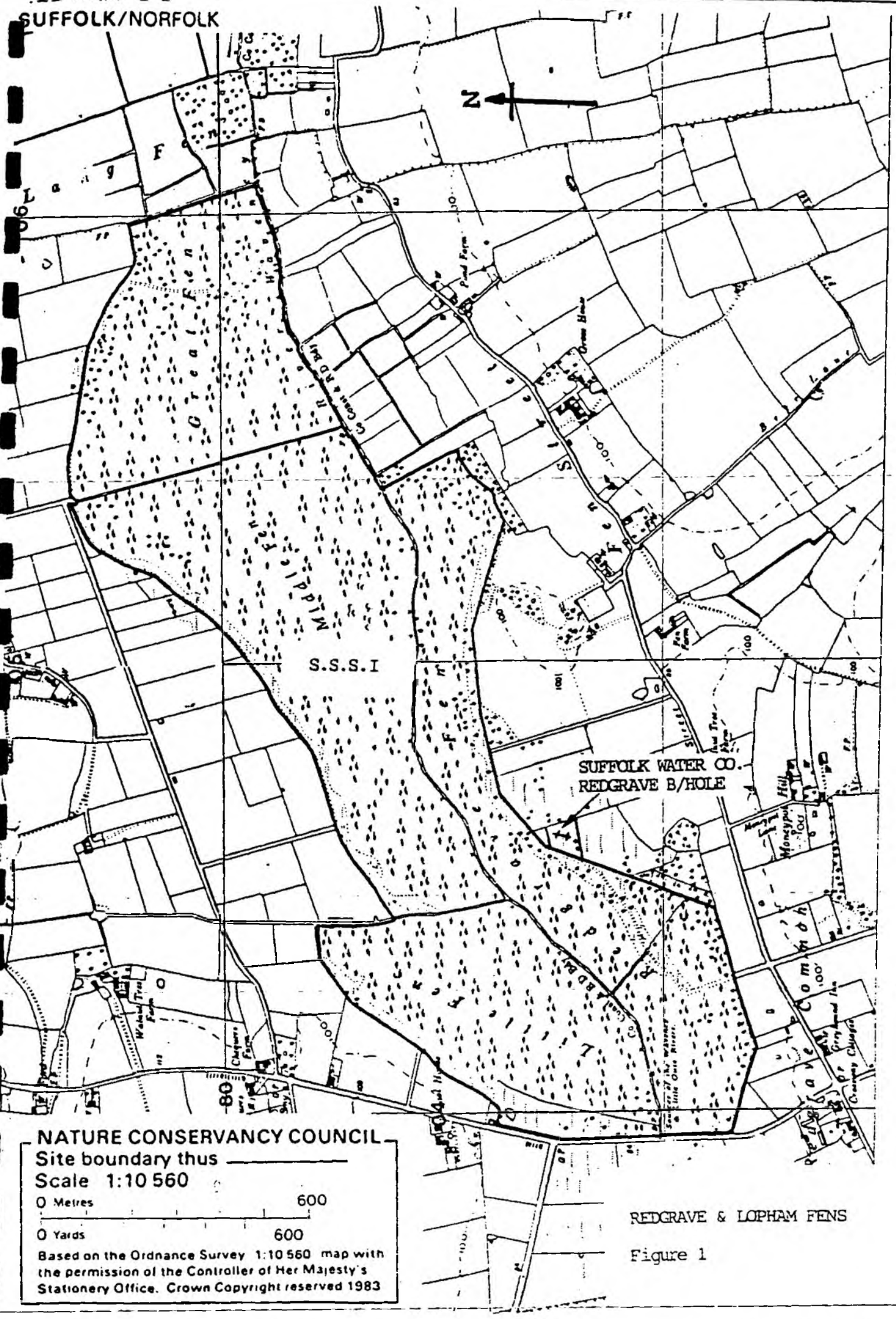
		ASSET LIFE			
		- £K	60 YRS £K	20 YRS £K	
1.	Borehole drilling etc.		150.0		
2.	Borehole pump to Works			26.0	
	Civils		16.0		
3.	Treatment Works at Wetheringsett based on				
	(i) Iron removal			550.0	
	Civils		440.0		
4.	Treated Water Storage on Site 2 ml		385.0		
5.	Pumping into Supply			140.0	
6.	Land Acquisition	30.0			
7.	Mains Raw Water				
	a. Wetheringsett to Thorndon		556.2		
	b. Wetheringsett to Thwaite		325.0		
	c. Thorndon to Yaxley		800.0		
8.	Lagoons		1.9		
9.	Diesel Generator			52.0	
10.	Electricity Supply and Site Services	75.0			
11.	Design Costs				
	a. Mains		84.0		
	b. M & E			174.6	
	c. Civils		84.3		
12.	Addition for Manganese Removal			18.0	
Total Initial Capital Costs		105.0	2842.4	960.6	= 3908.0

RELOCATION OF REDGRAVE

OPTION 3 :

		ASSET LIFE			NET PRESENT COST @ YR 0
		-	60 YRS	20 YRS	
		£K	£K	£K	£K
Initial Capital Costs		105.0	2842.4	960.6	
	Year 0	30.0	318.3	174.6	522.9
	1	75.0	456.0	576.0	1044.4
	2	-	2068.1	158.0	1981.2
	3	-	-	52.0	43.7
Replacement of Assets					
	Year 20			174.6	54.4
	21			576.0	169.5
	22			158.0	43.8
	23			52.0	13.6
Replacement of Assets					
	Year 40			174.6	17.0
	41			576.0	52.8
	42			158.0	13.7
	43			52.0	4.2
Total Discounted Capital Costs					3961.2
Increased Operating Costs @ £9K p.a. for 60 years (Year 4 to 63)					122.1
Total Discounted Capital/Additional Operating Costs					£4083.3K

FIGURES



REDGRAVE & LOPHAM FENS

Figure 1

REDGRAVE & LOPHAM FENS ALLEVIATION SCHEME

Area of Interest - Wetland Conservation Sites

Figure 2

River Whittle

Hay Fen

Copinces Fen

East Harling Common

Kenninghall and Banham Fens with Quidenham Mere

Middle Harling Fen

Hopton Fen

Blo' Norton and Thelnetham Fen

Bugg's Hole

Weston Fen

Redgrave and Lopham Fen

Bressingham Fen

Horse Fen, Bressingham

Hall Farm Meadow, Wortham

Roydon Fen

Wortham Ling

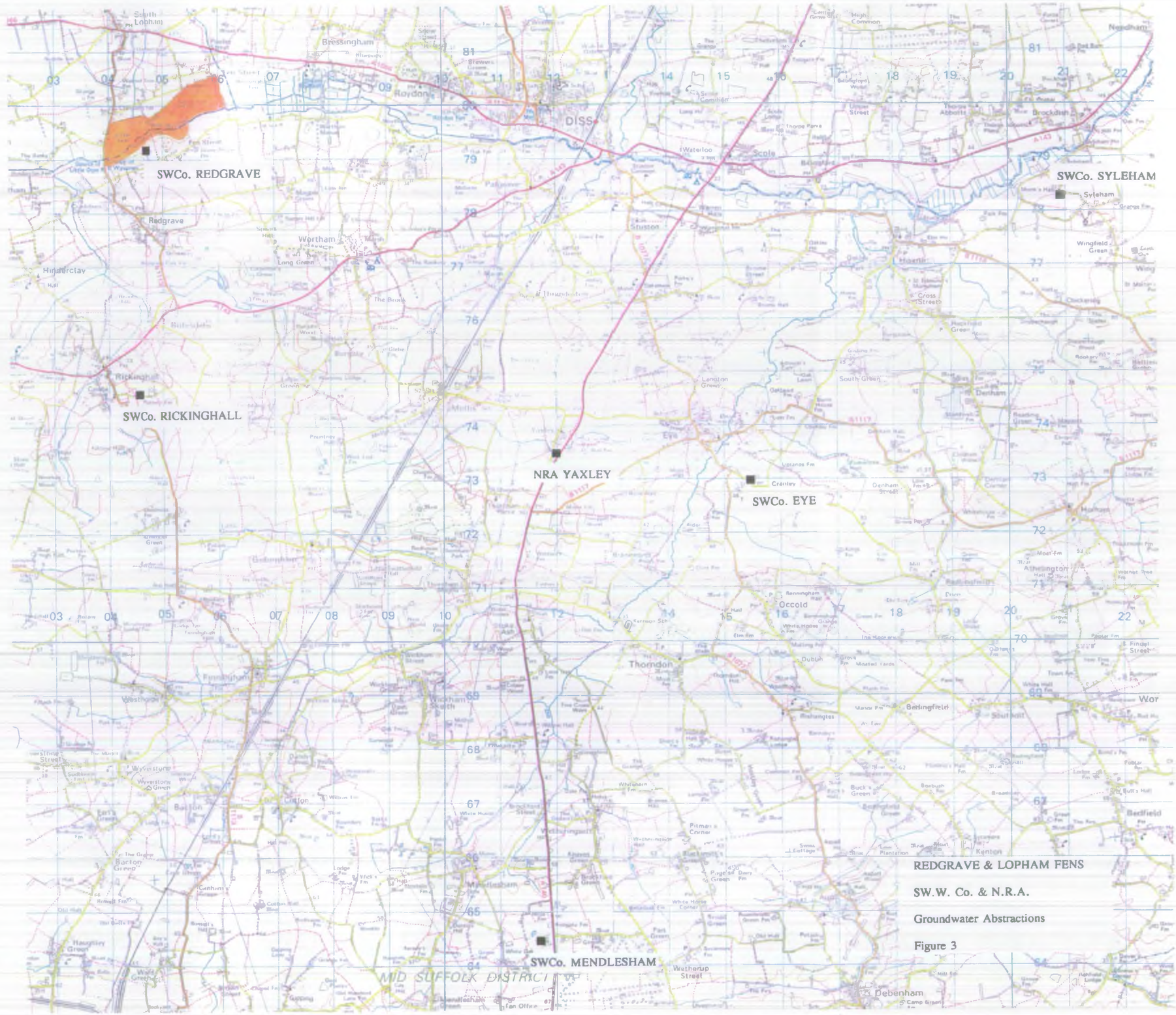
Spring at Spring Farm, Palgrave

Gypsy Camp Meadows, Thrandeston

The Marsh, Wortham

Thrandeston Marsh

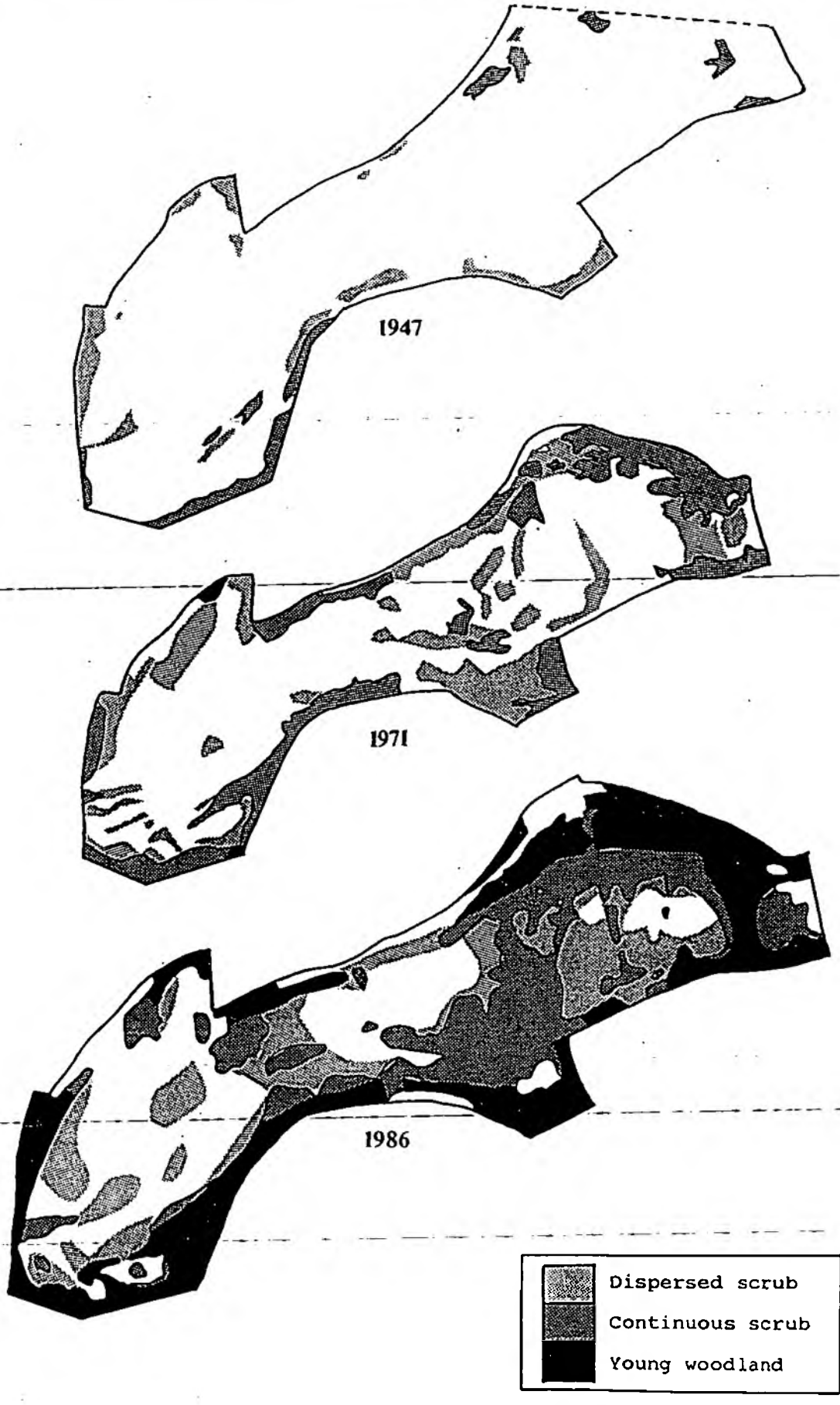
Redgrave Park Lake


SWCo. REDGRAVE
SWCo. RICKINGHALL
NRA YAXLEY
SWCo. EYE
SWCo. SYLEHAM
SWCo. MENDLESHAM
MID SUFFOLK DISTRICT
REDGRAVE & LOPHAM FENS
SW.W. Co. & N.R.A.
Groundwater Abstractions
Figure 3

REDGRAVE & LOPHAM FENS ALLEVIATION SCHEME

Relocation Options Site Map

Figure 4



Scrub encroachment at Redgrave and Lopham Fen, 1947-1986, interpreted from aerial photographs

Plate 1