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Anglian region joint study on water resources availability for wetland creation

Final Report

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Commissioned by:
Environment Agency
Royal Society for the Protection of Birds
English Nature

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Executive Summary

This study has been commissioned by the Environment Agency/English Nature/ Royal Society for the Protection of Birds (RSPB). Its aim is to investigate the availability of surface water as an opportunity or a constraint to the creation or enhancement of those freshwater wetland habitats with biodiversity priority in the Environment Agency's Anglian region.

Three levels of detail have been used to identify potential areas for wetland creation on a catchment and sub-catchment basis using freshwater availability as a constraining factor. The first level was the coarsest, using land use information and the indicative floodplain area to select suitable lowland sites.

The second level used a combination of soil and hydrological data to select areas where both the soil was suitable and sufficient water was available to support wetland creation. Detailed requirements of wet grassland, reedbed, fen and wet woodland were used to filter the data held within a GIS to create maps illustrating the extent of the potential area of habitat creation.

The third level restricted the area of study to The Fens and Suffolk Coast Natural Areas. A detailed analysis was undertaken by dividing the suitable soil areas according to the tributaries and reaches of river used displayed in the MicroLowFlows package held by the Environment Agency. This enabled an assessment of the water resource availability over areas significantly smaller than catchment scale.

The results of this study indicate that large areas of the Anglian region are suitable for wetland creation. The assumption that 'available' water can be defined as the volume between the mean flow and Q95 low flow gives rise to large quantities for use in the calculations. It is recognised that current restrictions on abstraction would render this water unavailable, but our calculations have been carried out to aid the planning of water-resource allocation rather than to provide a wetland creation scheme. The results should inform the Regional Water Resources Strategy, Biodiversity Action Plan targets and future abstraction licensing policy including the forthcoming Catchment Abstraction Management Strategies process.

The work carried out for this study involved the collation of many data sets and combined hydrological modelling with spatial representation in a GIS. The output of the study is in the form of maps illustrating those areas of the Anglian region which are potentially suitable for wetland creation and a package in ArcView/MapInfo, which will be held by the project partners. The huge geographic area covered by the study meant that only data which were in a GIS compatible form could be used and that assumptions had to be made regarding the hydrological scenario to be modelled. One of the main problems encountered with this study was that of combining water availability in rivers, which is essentially a linear data set, with the spatial data provided by the soils map. It was not possible, within the timescale of this project, to link all of the catchments together with a flow model so that water removed in one catchment was removed from all other catchments downstream. This would form the basis of any further study.

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memo

ENVIRONMENT AGENCY

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From	WENDY BROOKS	Your ref	
Ext. Number	4403	Date	19 July 2000

ANGLIAN REGION JOINT STUDY ON WATER RESOURCES AVAILABILITY FOR WETLAND CREATION

Please find attached a copy of the above study. This study has been undertaken for our water resources and conservation functions, in partnership with English Nature and RSPB.

The aims of this study were 'to investigate the availability of surface water as opportunity and constraint for creation/enhancement of biodiversity priority freshwater wetland habitats in the Environment Agency's Anglian Region'. The objectives for the study:-

1. To inform the Regional Water Resources Strategy of potential demands for water for wetland creation.

2. Identify the potential within the Anglian Region of freshwater availability for wetland creation with respect to BAP targets and habitat replacement in the face of coastal losses.

3. Provide information and a process that can be used to inform and influence future abstraction licensing policy.

4. Contribute to Floodplain Restoration LIFE project and Wet Fens for the Future Initiative, by identifying specific areas where there is potential for wetland enhancement and hence support the work of these projects.

The results of the study are being used to feed into the Regional Water Resources Strategy, Biodiversity Action Planning, and many other projects and initiatives. We also hope to apply the more detailed approach in future within the new Catchment Abstraction Management Plans (CAMs).

Cont/d..

Environment Agency
Kingfisher House, Goldhay Way, Orton Goldhay, Peterborough, PE2 5ZR
Tel: 01733 371811 Fax 01733 231840

I will shortly be arranging a meeting with English Nature and RSPB to discuss how we launch the study and external distribution. I would be grateful for any views you have on the study and how it may assist your work, and contacts for any organisations who you consider would benefit from receiving this study. I would be grateful if I can receive any comments by 11 August 2000.

If you have any further queries please do not hesitate to contact either myself or Pauline Smith.

Wendy Brooks

WENDY BROOKS
Regional Conservation Officer

Copied to: Pauline Smith, Regional Water Resources Planning Manager
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1 introduction

The Anglian region is historically rich in wetland habitats from the Fens to the Broads and along the coast, even though it is has the lowest rainfall in of any region in the country. Much of this wetland heritage has been degraded or lost over the last 150 years through land drainage, improvement for agriculture, development pressure and other land uses. Future losses of freshwater habitats are predicted near to the coastline through sea level rise and natural coastal processes.

This study has been commissioned by the Environment Agency / English Nature / Royal Society for the Protection of Birds (RSPB). Its aim is to investigate the availability of surface water as an opportunity or a constraint to the creation or enhancement of those freshwater wetland habitats with biodiversity priority in the Environment Agency's Anglian region. This desk-based study uses data from a variety of sources, but it is confined to using the best available information held by the Environment Agency, English Nature, RSPB or others where the information was available free of charge and easily extracted. A Geographical Information System (GIS) has been created containing data pertaining to floodplain extent, land use, soil series and water availability. Detailed requirements of wet grassland, reedbed, fen and wet woodland have been used to filter the data held within the GIS to create maps illustrating the extent of the potential area of habitat creation. A package in ArcView/MapInfo has been produced, which will be held by the project partners, detailing the areas in the Anglian region where conditions are suitable for the creation or restoration of target wetland habitats. This report accompanies the GIS package and quantifies the potential water requirements of the wetland habitats, relating them to water availability and other constraints within the Anglian region and pilot study areas of the Fens and Suffolk Coast Natural Areas.

It is intended that this document be used to inform the Regional Water Resources Strategy, Biodiversity Action Plan targets and future abstraction licensing policy including the forthcoming Catchment Abstraction Management Strategies process.

2 Level 1

2.1 Purpose

Three levels of detail have been used to identify potential areas for wetland creation on a catchment basis using freshwater availability as a constraining factor. Level 1 aims to identify large areas within catchments, based on topographical, geological and land use suitability. The data sets used to achieve this are described below.

2.2 Data sources

2.2.1 Indicative flood plain

Tidal and fluvial indicative floodplain maps together with flood risk areas were supplied by the Environment Agency in GIS format. These were combined to give the total floodplain area for the Anglian region. The tidal and fluvial flood risk areas have been kept separate during the modelling process, to indicate which areas are prone to saltwater inundation and future encroachment as sea levels rise and coastal erosion continues, particularly along the Suffolk coast. Potential freshwater wetland sites within the tidal flood risk area can only be regarded as viable in the short to medium term.

2.2.2 Cropping type

MAFF land-use census data from 1994, already held by Cranfield University, was transferred into Arcview from the Spans GIS system. Some problems with this data transfer were encountered, as the two systems are not full compatible. However, this problem was later rectified by importing the raw data straight into Arcview. The data are in the form of the area (ha) of each of six types of crop in each 2 x 2 km square of land. The original census data weres collected and assigned according to the postcode of the farm office, and therefore it is sometimes possible to have the cropped area of two farms within the same 2 x 2 km square, thus giving a much higher cropped area than the theoretical maximum of 400 ha. However, this problem was encountered infrequently.

The six crop types recorded by the census were grassland, cereals, potatoes, sugar beet, top fruit and soft fruit. These were combined into three categories; grassland, arable (cereals, potatoes and sugar beet) and fruit (top and soft fruit). Only data within the Anglian region floodplain, as described in the previous section, are presented (See Maps 1-1 to 1-3).

2.2.3 Urban and forested areas

Where no crop data were present within a 2 x 2 km square it was assumed that the area was either an urban or forested. A new GIS layer was created combining all the crop cover data showing the 'holes' in this data, which represents the urban and forest areas. When checked against maps, large towns such as Northampton, Bedford, Cambridge as well as Thetford Forest can clearly be identified (see Map 1- 4). These areas were then removed from all subsequent GIS maps as they are unsuitable areas for wetland creation.

2.2.4 Major and minor aquifers

GIS layers of the minor and major aquifers within the Anglian region were supplied by the water resources team of the Environment Agency regional office. These were also added to the level 1 data set (Map 1-5).

2.3 Constraints

The most significant constraint to the production of the level 1 area was the quality of the land use data. Although the MAFF census data were able to indicate urban and forested areas which covered at least 400 ha, it was not able to identify smaller towns and villages. Similarly, major transport routes could not be identified. This prevented the exclusion of some areas, which would be unsuitable due to the proximity of housing or industrial developments.

2.4 Discussion

Level 1 is a very coarse interpretation of the suitable area for wetland restoration. The resulting region can only be regarded as loosely relating to the potential area where restoration should be targeted. It provides a similar picture to that given by the Institute of Terrestrial Ecology (Mountford et al . 1999) distinguishing cropped and grassland areas which are on the floodplain and excluding urban and forested areas. An additional feature of this study is the separation of fluvial and tidal floodplain allowing an interpretation of the likely impact of coastal erosion and managed retreat.

3 Level 2

3.1 Purpose

The purpose of level 2 was to refine the area selected by level 1 by examining the suitability of soil types and availability of water within the catchments of the Anglian region. The data sets which were used during the level 2 analysis are described below and were combined within a GIS to define areas where creation of freshwater wetland habitat would be potentially achievable.

3.2 Data sources

3.2.1 Habitat requirements

The target habitats considered were reedbed, coastal and floodplain grazing marsh, fens and wet woodland. A summary of the soil and hydrological requirements of each of these habitats was drawn up (Table 1), based upon previous research and knowledge developed by the Cranfield EcoHydrology Centre. A brief description of each habitat is set out below.

Reedbed. A swamp community dominated by the Common Reed (*Phragmites australis*) which requires the presence of surface water through most of the year. An essential habitat for a number of rare bird and invertebrates species. Corresponds to the community labelled S4 by the National Vegetation Community (NVC) (Rodwell, 1991 *et seq.*).

Coastal and Floodplain grazing marsh. This category includes a range of wet grassland communities including species-poor wet pastures, species-rich meadows and inundation grasslands. In terms of the NVC, these correspond to the following Mesotrophic Grasslands; species-poor wet pastures, MG7C, MG7D, MG9 & MG10; species-rich meadows MG4 & MG8; inundation grasslands, MG11, MG12 & MG13. The species poor pastures may be of limited botanical interest, but nevertheless form valuable habitat for breeding waders and wintering wildfowl. The species-rich meadows have considerable interest botanically, aesthetically and for a diverse invertebrate fauna in addition to providing ornithological habitat and supporting traditional agricultural practice. The inundation grasslands tend to be species poor, but may have some plant species of interest. They again provide potential ornithological habitat and a flood storage role. MG9 species-poor tussocky pasture, MG10 species-poor rushy pasture, MG13 inundation grassland, MG4 species-rich flood-meadow and MG8 species-rich water meadow were chosen as the representative habitat types for modelling purposes.

Fens. The fen communities found on East Anglian floodplains are those typical of circum-neutral substrates with nutrient inputs coming from ground or surface waters (S24-28 according to the NVC). Some of these are species-rich (S24, S25 & S27) and support a range of rare plant species, whilst others have less botanical interest (S26 & S28). All contribute to the landscape of the area and support a diverse fauna. S25 fen was chosen as the representative habitat type for modelling purposes.

Wet woodland. This category includes both floodplain forest, with Alder and Downy Birch as the dominant species, and fen carr, dominated by buckthorns and sallows. The woodland communities included are (W1, W2, W4, W5 & W6). These woodlands are refuges for some rare herbaceous species and are of value for their ornithological and invertebrate habitat. Some of the scrub communities are sometimes removed where they are invading open fen. W5 wet woodland was chosen as the representative habitat type for modelling purposes.

Table 1: Soil and hydrological requirements of target habitats

	MG9 Species poor tussocky pasture	MG10 Species poor rush pasture	MG4 Species rich flood meadow	MG8 Species rich water meadow	MG13 Inundation grassland	S4 Reedbed	S25 Fen	W5 Wet woodland
Hydraulic conductivity (m day^{-1})								
Drainable soil types	>0.3	>0.3	>0.3	>0.3	>0.3	>0.3	>0.3	>0.3
Pondable soil types	<=0.3	<=0.3			<=0.3	<=0.3		<=0.3
Drainable porosity (%)	No preference	No preference	>12	>12	No preference	No preference	>12	No preference
pH	>5.5	>5.5	>5.5	>5.5	>5.5	>5.5	>5.5	>5.5
Organic Carbon (%)	No preference	No preference	No preference	No preference	No preference	No preference	>5	No preference
Presence of winter surface water	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tolerance of spring/ summer flooding	No	No	No	No	Yes	Yes	No	No
Surface water source essential	No	No	No	No	Yes	Yes	No	No
Surface drainage required	Some	Some	Yes	Yes	No	No	No	No
Water nutrient content	Mod	Mod	Mod	Mod	High	High	Mod	Mod
Soil nutrient status tolerated	Mod	Mod	Low- Mod	Low- Mod	High	High	Low-Mod	Mod
Tolerance of summer drying	Yes	Yes	Some	Some	Yes	Some	Some	Some
Ploughed land	Yes	Yes	No	No	Yes	Yes	No	Yes
Sloping land	Yes	Yes	Yes	Yes	No	No	No	Yes

3.2.2 *Soil suitability*

The Soil Survey and Land Research Centre (SSLRC) have supplied a raster map of the entire Anglian region detailing the boundaries of all soil associations taken from the 1 km Soil Map of England and Wales (Soil Survey of England and Wales, 1984). This map was added to the GIS as a separate layer. The area of each soil association on this layer is defined by a polygon and has been given a serial number. A database was then produced in Excel and linked to the GIS so that details of the individual soil series and their extent within the polygons could be interpreted. The Excel database contains parameters, such as pH, organic carbon content, hydraulic conductivity and drainable porosity for a range of depths in a typical soil profile for every soil series present in the region. Each soil series was classified as to its suitability for each wetland habitat type on the basis of matching the habitat requirements, as given in Table 1, with the soil parameters in the database. The soil parameters were taken at 40 cm depth, to give a representative figure for each soil series. As each soil association is made up of a varying number of soil series, the habitat suitability of each association was assigned as that which the majority of soil series within that association were suitable for.

The first level of screening of soil suitability was on pH, as it is considered that soils of less than pH 5.5 would be unsuitable for the range of target habitats. Therefore, areas with a pH of less than 5.5 were dismissed. The soil properties were then used to identify which areas would be suitable for each habitat. Some of the habitats share similar soil requirements and therefore some areas would be suitable for more than one habitat type based on purely the soil information. In these situations it is the water quantity and subsequent site management which differentiates between the wetland habitat types.

A process of 'clipping' was used to select all the suitable soil polygons which occurred within the floodplain area. All the data points which occurred in both data sets were collated to give wetland creation soil suitability maps for each habitat type.

Some of the target habitats were sub-divided into those occurring on draining soil types and those occurring on pondable soil types. Habitats found on pondable soils would be relatively easy to hydrologically isolate whereas those found on drainable soils will depend on the water-regime management of the surrounding area. The soils information was therefore sub-divided on this basis to enable due consideration to be given to sites where there could be potential problems of connectivity between the water-regime of the wetland site and the surrounding land.

3.2.3 *Meteorological data*

Long term (30 years) meteorological data in the form of MORECS (the Meteorological Office Rainfall and Evaporation Calculation System) weekly values of rainfall, potential evapotranspiration (ET) and potential soil moisture deficit (PSMD) were provided for each 40 x 40 km grid square covering the Anglian Region by the Environment Agency. This data was used to calculate the long term mean rainfall, ET and PSMD across the region to be used in subsequent calculations of habitat water demands in levels 2 and 3.

3.2.4 *Hydrology*

A GIS layer of catchments within the Anglian region was provided by the Environment Agency. This was used in conjunction with Institute of Hydrology maps to identify gauging stations within each of the catchments. A gauging station as close to the outfall from each catchment was chosen, and long term daily mean flow (m^3), maximum and mean stage (m) data for each of these gauging stations was provided by the Environment Agency. Records extend for thirty years, or as long as the gauging station has been in operation. This data was used to ascertain the long term daily mean flow and 95 percentile (Q95, a measure of low flow) for each catchment. It was possible to estimate monthly mean flow measurements but Q95 was modelled giving separate values for winter (October – March) and summer (April – September). The quantity of surface water 'available' in each catchment to supplement and sustain wetlands was then calculated by subtracting the Q95 flow from the monthly mean flow, in order to maintain a minimum flow in each catchment. Using mean flow minus Q95 as a measure of 'available' water was suggested by the Environment Agency for the purposes of this report. In practice, not all this water would be available as there are constraints arising from existing licence commitments and also other needs not fully reflected in the simple Q95 assumption. Summer water availability is particularly limited under current allocation policies. However, the purpose of this study is to illustrate how much water would be required to create surface water wetlands in the Anglian region to advise future licensing and water resource allocation.

3.2.5 Assumptions used in the calculation of water-regime tolerances for the target habitats

Annual hydrographs (plots of water tables depth versus season) have been produced from dipwell readings collected from a range of wetland sites throughout the Anglian region as parts of previous research (e.g. Gowing et al, 1997). From this data resource, typical examples of water-table behaviour were chosen for each of the habitats of interest.

The hydrographs were analysed to determine the water-table depth at the end of each of the summer months, during a median year in terms of its rainfall (Table 2). The depth of ponding typically recorded at the end of the winter period (February) was also ascertained. Finally the specific yield of the soil (that is the amount of water required to raise the water table a unit distance) was determined from an undisturbed soil sample taken from the given habitat type.

Using the variables above, a simple water balance calculation was undertaken for each of the habitat types. It was assumed, for this level, that water could only be lost from the soil by evapotranspiration and gained by rainfall or additional inputs supplied from the rivers.

$$Q = \sum_{i=0}^{i=n} S_i.\partial z_i + D \tag{1}$$

where Q is the amount of water lost from the profile over the period
S is the specific yield of soil layer i
z is the fall in water-table elevation within soil layer i
D is the accumulated soil moisture deficit in the unsaturated portion of the profile

The value Q (expressed as a depth per unit area) was thus generated month by month through the summer (Table 3). If the value was less than the depth of water one would have expected to have been lost to the atmosphere via net evapotranspiration (ET minus rainfall) during the period, then it was concluded that an additional source of water was required to partly offset the loss. This was interpreted as an indication of a requirement for an external water source in order to sustain the plant community within the habitat.

$$W = E - Q \tag{2}$$

where W is the amount of water required from an external source

E is the loss by net evapotranspiration

A second calculation was used to estimate the quantity of water required to recharge the soil profile over winter. This was based on the depth of the water table at the end of the summer and the depth of the water table or the depth of surface water at the end of winter. (Effectively the same as Equation (1), but considering the amount of water gained rather than that lost.) If this calculated amount is greater than an area could expect to receive in net rainfall during an average winter (October-February inclusive), then again an additional source of water would be required.

$$W' = Q' - R \tag{3}$$

where Q' is the amount of water gained by the profile over the winter

R is the excess winter rainfall

For level 2 the same water requirement has been calculated for habitats on drainable and pondable soil types. This is because it is not possible to ascertain whether the potentially suitable areas are in connection with the surrounding areas or whether they form hydrologically isolated pockets.

Table 2: Minimum water-table tolerances of target habitats

Community	Water-table depth below ground surface (m)					Soil moisture deficit in unsaturated zone (mm)	Specific yield
	May	June	July	August	February		(@ 150 mm depth)
MG9 Species poor tussocky pasture	-0.2	-0.8	dry	Dry	0	100	0.08
MG10 Species poor rush pasture	-0.1	-0.5	-0.8	Dry	0	0	0.1
MG4 Species rich flood meadow	-0.3	-0.6	-0.8	Dry	-0.1	40	0.15
MG8 Species rich water meadow	-0.2	-0.4	-0.6	-0.8	-0.2	0	0.18
MG13 Inundation grassland	0	-0.6	dry	Dry	0	60	0.1
S4 Reedbed	0.2	0.1	0.05	0	0.3	0	1 (surface water)
S25 Fen	0	-0.4	-0.7	Dry	0	0	0.2
W5 Wet woodland	-0.1	-0.6	-1	Dry	0	60	0.12

Negative values represent water table below ground surface, positive values represent depth of water ponded on ground surface. "dry" indicates the water table is > 1 m deep or that it is below the depth of the permeable soil and as such cannot be recorded by a dipwell.

Table 3: Water loss tolerated by target habitats

Habitat type	Water loss tolerated by plant community (mm) (Q)			Depth of winter recharge required (mm) (Q')
	March to June	June to July	July to August	
MG9 Species poor tussocky pasture	48	Profile may dry	Profile may dry	180
MG10 Species poor rush pasture	40	30	Profile may dry	100
MG4 Species rich flood meadow	45	30	Profile may dry	175
MG8 Species rich water meadow	36	36	36	108
MG13 Inundation grassland	60	Profile may dry	Profile may dry	160
S4 Reedbed	100	50	50	320
S25 Fen	80	60	Profile may dry	200
W5 Wet woodland	60	48	Profile may dry	180

3.2.6 *Tolerance of summer flooding*

Calculations of the flood risk of each catchment for each month were made from the gauging station data in order to further screen the habitat types identified as being intolerant of spring and/ or summer flooding, as shown in Table 1. The frequency of inundation was calculated by identifying the bankfull stage. Events with a peak stage in excess of the bankfull stage were extracted from the historical stage data set and fitted to a statistical distribution (initially a Poisson distribution). This was used to develop a stage frequency relationship for the individual sites. The result was the probability of days with a flood event occurring within each month of the year for each catchment. This probability data was combined for the months of April, May and June, and for July, August and September, to give a separate spring and summer flood probability for each catchment. A probability of 30% was taken as that which represented a risk to intolerant habitat types, and therefore these habitats were removed from the few catchments which exceeded this probability.

3.2.7 *Water dependent SSSIs*

A GIS layer of water dependent SSSIs was provided by the Environment Agency which shows the location of each site, together with linked information on the current habitat type. This was added to level 2 as a layer which was then used to identify existing sites and to validate the habitats suggested as suitable by this study.

3.2.8 *Air exclusion zones*

RSPB suggested that zones of 10 km diameter around all airfields in the region be excluded from the study. The creation of habitats attracting birds in the vicinity of airfields may cause problems for the planes and disturbance for the birds. The location and extent of air exclusion zones were not available from the project partners hence Defence Estates within the Ministry of Defence were contacted. However, the data requested from the Ministry was not provided.

3.2.9 *Minimum viable area*

The minimum viable area for each habitat type was estimated. It was assumed that habitats where the conservation interest was largely due to breeding and wintering of wetland birds would require a large area as a contiguous unit. A value of 20 ha was therefore taken as the minimum viable area for species-poor tussocky pasture (MG9), species-poor rushy pasture (MG10), inundation grassland (MG13) and reedbed (S4).

Size is less important for the habitats where the conservation interest was largely due to the vegetation, although the cost of undertaking management operations becomes expensive for very small parcels of land. A value of 1 ha was therefore taken as the minimum viable area for species-rich flood meadow (MG4), species-rich water meadow (MG8), fen (S25) and wet woodland (W5).

A query was used within the GIS to eliminate all the polygons where the soil was suitable for each habitat but which were smaller than the minimum viable area. Occasionally, changes in soil type have led to small soil polygons being eliminated even though they were adjacent to larger polygons and conversely, some of the large polygons have narrow offshoots that were not eliminated but these effects were deemed to be small.

3.2.10 *Combination of habitat types*

It was requested by the project partners that consideration be given to the creation of a mosaic of wetland habitat types. Since the number of combinations of habitat type and relative proportions was infinite, it was decided to use the relative proportions chosen for optimum wetland creation on Longdon and Eldersfield Marsh (Gilbert et al., 2000). Two combination habitats were thus selected, one for drainable soils and one for pondable soils (Table 4). The water requirement for the combination habitats were calculated proportionally from the requirements of the constituent habitats.

Table 4 Proportions of each habitat used to create the combination habitat

Community	Proportion of habitat present in combination habitat on drainable soils (%)	Proportion of habitat present in combination habitat on pondable soils (%)
MG9 Species poor tussocky pasture	20	25
MG10 Species poor rush pasture	20	25
MG4 Species rich flood meadow	10	-
MG8 Species rich water meadow	5	-
MG13 Inundation grassland	25	30
S4 Reedbed	10	15
S25 Fen	5	-
W5 Wet woodland	5	5

3.3 Constraints

The major constraint for level 2 was the ability to model the hydrological situation. It was possible to estimate the quantity of flow in any individual catchment, but it was not possible to ascertain whether the pattern of the water courses and relative levels between the rivers and the land were suitable to enable wetland creation. A further problem was that, since the catchments are connected, the choice of habitat in one catchment would affect the water available in the other downstream catchments within the same hydrometric area. In order to overcome this problem it would be necessary to develop a more complex modelling system whereby the interactions between the separate catchments were taken into account and a 'live link' were developed between the habitats selected and the quantity of water available in the related catchments.

The implication of the constraint described above is that it is not possible to create all of the habitat shown on the suitability maps simultaneously. The maps should be used to select suitable areas for habitat creation rather that to illustrate the extent of any potential habitat.

In some areas, the presence of shallow aquifers enables transfer of water beneath soil layers of low hydraulic conductivity. This creates conditions suitable for habitats, such as species-rich flood meadow (MG4), in areas which may have been excluded from the GIS due to the low hydraulic conductivity of the soil.

3.4 Discussion

It can be seen from the level 2 maps that very large areas have been selected as meeting the criteria for creation of the target habitat types. Not many catchments have been excluded on a basis of water availability because when using the assumption that 'available' water is that between the mean flow and Q95 then large quantities of water are present. In reality, much of this water would not be available because it would be either distant from or topographically below the area of wetland creation or currently allocated to other uses. These factors have been considered further in level 3.

It must be borne in mind that the water availability has been calculated on a catchment basis. All of the suitable area for a particular habitat that occurs within one catchment could potentially be created. However, the full extent of the habitat across all the catchments could not be created simultaneously because of the 'double accounting' caused by water as outflow from one catchment forming the inflow to another. This has not created a significant constraint in relation to achieving biodiversity targets as selected individual catchments are large enough to support all the desired area (see Table 6).

The area of pondable soils suitable for wetland creation is much larger than that of drainable soils. Pondable soils occur mainly in the Fens, east Norfolk and the Essex coast. Drainable soils occur mainly along the Suffolk coast and the area close to the south-east of the Fens. Several habitats are suggested as suitable for each area on the GIS. This is because some habitats have similar soil requirements but differing water management and vegetation management. It would be possible in these areas to create the target habitat of choice by implementing a suitable water regime with appropriate vegetation management.

To check that the GIS was selecting suitable habitats, the existing plant communities at important water-dependent SSSIs selected from Gardiner (1996) were compared with the results from the GIS (Table 5). It can be seen that in general, the habitats selected as suitable include the existing vegetation communities from the relevant SSSI. A notable exception is Portholme Meadow SSSI where a shallow gravel aquifer supplies water to the flood meadow community, but the GIS selected habitats suitable for pondable sites since shallow aquifer data cannot be accessed by the model.

An estimation has been made of the area suitable, within selected catchments, for achieving the targets set out in the Local Biodiversity Action Plans (LBAPs). It was necessary to choose specific catchment for this calculation because of the problems of 'double accounting' described above. The results of this analysis are given in Table 6. It can be seen that in every case it would be possible to achieve the LBAP target assuming that the area could be hydrologically isolated and that it were possible to use water from the catchment down to the Q95 flow.

Water demand maps have also been included (Maps 2-10 to 2-17). These display the quantity of water required to create a hectare of target habitat in all the suitable locations across the region. These values can be used to estimate the water resource requirement of each habitat if more refined water availability data become available.

Table 5: Comparison of existing habitat types with those meeting the level 2 criteria at wetland SSSIs

Name of SSSI	Typical communities currently present at SSSI	Habitats meeting level 2 criteria for this location
Woodwalton Fen	Reedbed	MG9, MG10, MG4, MG8, MG13, S4, S25, W5
Chippenham Fen	Fen	MG9, MG10*, MG4*, MG8, MG13, S4, S25, W5
Holme Fen	Wet woodland	MG9, MG10, MG4, MG8, MG13, S4, S25, W5
Wicken Fen	Fen	MG9, MG10, MG4, MG8, MG13, S4, S25, W5
Nene Washes	Species poor rush and tussocky pasture, inundation grassland, species rich water meadow	MG9, MG10**, MG13, S4, W5*
Ouse Washes	Species poor tussocky pasture, inundation grassland, species rich water meadow, reedbed	MG9, MG10, MG13, S4, W5
Benacre to Easton Bavents	Reedbed, species rich flood meadow, fen, inundation grassland	MG9, MG10*, MG4*, MG8, MG13, S4, S25, W5
Minsmere	Reedbed, salt marsh	MG9, MG10, MG4, MG8, MG13, S4, S25, W5
Portholme	Species rich flood meadow	MG9, MG10, MG13, S4, W5
Redgrave and Lopham Fens	Fen	MG9, MG10, MG4, MG8, MG13, S4, S25, W5
Blo'Norton/Thelnetham Fen	Fen	MG9, MG10, MG4, MG8, MG13, S4, S25, W5

* Potential water availability restricted such that 50-99% of suitable area in catchment could support the specified habitat

** Potential water availability restricted such that 1-50% of suitable area in catchment could support the specified habitat

Table 6: Comparison of LBAP target areas with potentially achievable habitat selected by the level 2 criteria for representative catchments

	Coastal floodplain and grazing marsh	Reedbed	Fen
Norfolk BAP target	640	400	?
Area potentially achievable in catchment 34/06 in Norfolk	1360	1370	76
Suffolk BAP target	200	500	100
Area potentially achievable in catchment 34/04 in Suffolk	510	510	310
Lincolnshire BAP target	?	?	?
Area potentially achievable in catchment 30/12 in Lincolnshire	430	1110	320
Northamptonshire BAP target	?	?	?
Area potentially achievable in catchment 32/03 in Northamptonshire	640	950	0
Essex BAP target	1200	100	?
Area potentially achievable in catchment 36/15 in Essex	1300	1300	0
Cambridgeshire BAP target	?	600	?
Area potentially achievable in catchment 33/34 in Cambridgeshire	5650	5650	2530

4 Level 3

4.1 Purpose

The aim of level 3 was to select the area defined by level 2 which fell within the pilot areas of the Fens and the Suffolk Coast Natural Areas and make a more detailed estimation of the potential suitability for the creation of wetland habitats. The smaller size of these areas has made it possible to undertake a detailed analysis of the water requirements of the target habitats and select areas on the basis of the water course pattern, rather than the catchment scale used in level 2. The pilot areas were chosen by the project partners because of the large areas of potentially suitable habitat occurring in these regions.

4.2 Data sources

4.2.1 OS background

Ordnance Survey 1:50,000 grey scale raster files were provided by the Environment Agency for each of the pilot areas. These map tiles provide a background layer of roads, towns, plantations, and other infrastructure which may effect the siting and type of wetland for each of the pilot areas. This background can be switched on and off within the GIS to show the information.

4.2.2 Land use

The land use data used in level 1 was found to be too coarse for use in level 3 since the 2 x 2 km squares covered significant proportions of the area. The OS background, described above, was therefore used to provide information on the presence of urban, industrial and forested areas and locations of roads and railways.

4.2.3 Soil suitability

The level of soil information used in level 2 represents the best available data in digitised format. It was therefore not possible to improve on the selection of suitable soils for level 3.

4.2.4 Meteorological data

The MORECS meteorological data (described in section 3.2.3) was analysed for both pilot areas. Table 7 shows the mean annual rainfall and potential evapotranspiration (PE) for the two pilot areas for the period 1961 - 88. The differences in annual rainfall and not significant ($P = 0.91$). The differences in PE are statistically significant ($P < 0.01$) but are small enough to be of little practical significance in such a broad scale study. The data from a single MORECS square could therefore be used to describe the meteorological conditions. These data were used within a hydrological modelling package described in section 4.3.

Table 7 Comparison of the mean annual (1961 – 88).PE and rainfall for the two pilot areas.

Pilot area	MORECS Square	Annual Rainfall, mm	Annual Potential Evapotranspiration , mm
Fens	128	575.0	647.6
Suffolk	142	573.8	632.7

4.2.5 *Hydrology*

Using a single gauging station to represent a whole catchment was adequate for the level 2 analysis. However, it required too many assumptions to be suitable for the more detailed analysis of level 3; particularly within the Suffolk coastal area where there are ungauged catchments and often more than one river within a catchment. To overcome these problems the MicroLowFlows package was used at the Peterborough regional office in order to estimate the mean flow and Q95 along each reach of river within the Fens and Suffolk pilot areas. Each river was traced from where it entered the pilot area, and the mean flow and Q95 determined for every tributary and reach along the river to its outfall. The package was particularly used in the Fens to determine the main drains and identify as far as possible the direction of flow within the main drainage system. The data was used to determine surface water availability at a much more detailed scale than within Level 2. Every reach was analysed to estimate the proportion of the suitable habitat type which could be sustained based on the calculations made of habitat water requirements in summer and winter (see section 4.3 below). This has enabled water requirements to be calculated locally to the suitable area hence it should be generally possible for water resources required from the river to be supplied by flow under gravity.

As in level 2, the habitats have been split into those which may occur on drainable soils and those which may occur on pondable soils. The use of water storage has been assumed on the pondable soil types where a maximum level of ponding has been specified. Excess winter water is assumed to be stored on the site to provide part of the summer water requirement.

4.2.6 *Water quality*

Water quality data for each sampling site within the Fens and Suffolk coastal area were provided by the Environment Agency. Rankings were defined based on the 90 percentile of nitrate, phosphate and salinity over a three-year period (Table 8). All the water quality monitoring points in the pilot areas were allocated a ranking and their location and associated information was added as a layer to the GIS. It was agreed with the project partners that water quality would not be used to exclude potentially suitable sites for wetland creation but instead, would be included for information purposes since high nutrient and salinity levels may be a constraint requiring further investigation before any actual habitat creation were undertaken.

Table 8: The ranking system used to classify nutrient levels in river water

	Nitrate 90 percentile (mg/l)	Phosphate 90 percentile (mg/l)
Low	<1	<0.3
Medium	1-6	0.3-1.0
High	>6	>1.0

4.2.7 *Existing habitat*

The locations of existing important habitat sites were added to the GIS. Those of National Nature Reserves within the Fens and the Suffolk coast were obtained from English Nature and the water-dependent SSSI data from the Environment Agency (see section (3.2.7) was filtered for the location of sites within the pilot areas. County Wildlife Site locations were available from the Cambridgeshire Wildlife Trust in GIS format and from Lincolnshire Wildlife Trust as a list of grid references. However, the Suffolk County Wildlife sites are only just being put into a GIS format by the County Council and these could not be provided within the timescale of this project.

4.2.8 *Geology/hydrogeology*

The only geological/hydrogeological data in GIS format which it has been possible to obtain were those relating to the extent of the major and minor aquifers shown in Map 1-5. In general, drift deposits containing shallow aquifers are more important for the target wetland habitats than the presence of major and minor aquifers. The possible exception is fen habitat, where some fen communities depend on upwelling water. However, the fen habitat used in this report to represent a typical species-rich fen does not necessarily require upwelling water.

The lack of info on additional water supplied by groundwater and springs may affect additional water requirement of the target habitats, but would only make situation potentially easier to attain than that modelled.

4.2.9 *Archaeology*

The Sites and Monuments Records (SMR) held by Suffolk County Council, were searched for archaeological sites within the Suffolk coast pilot area. It was hoped to get the information on a GIS layer, however, computer problems at Suffolk County Council prevented this, and the records were only obtained manually. Due to the number of sites, a list of grid references and description is provided rather than maps of the entire area (Appendix A). The SMR for the Fens is so large that is was deemed to be unfeasible to obtain entries for the whole area under consideration. However, a map and list of SMR entries for the area east of Lincoln to the north of the River Witham, the location of the Witham flood defence strategy, has been obtained. It is suggested that a similar approach is used in the future as potential sites are considered in actuality for wetland creation, particularly as the SMR is constantly updated and so current information could be outdated by that time.

4.3 Modelling of wetland habitat water requirements

The water requirements for the various wetland communities were calculated using a daily soil water simulation model (WaSim, Hess & Counsell, 2000). The program calculates a daily soil water balance to predict the water table position and water content of the unsaturated zone on a daily basis. Rules are set for minimum soil water conditions for each month of the year. Whenever these conditions are exceeded, the program calculates the amount of water needed to bring the soil back to the minimum condition. The program was modified to allow timing of water application to be controlled by 'saturation deficits' (see 4.3.3) or depth of ponding.

4.3.1 *Soil characteristics*

Each community was ascribed to one of five representative soil types. The physical properties of these soil types are summarised in Table 9.

Soil type A represents a low permeability clay soil. On this soil downward movement of water (seepage) is negligible and the soil water status is the simply result of inputs of water from rainfall and outputs of evapotranspiration. On this soil up to 100mm of standing (ponded) water was allowed before runoff occurred.

Soil types B – E represent more permeable soils with a greater rate of seepage. Sites on these soils cannot be isolated hydrologically and the water supply to the site must meet the evapotranspiration demands of the plants and the seepage loss. No ponding was allowed on these 'draining' soils and once the soil is saturated, any further rainfall would be lost as runoff.

Table 9: Soil physical properties used in the water balance simulation

Soil	Drainable Porosity		Hydraulic conductivity m/d	Rate of seepage loss* mm/d	Example soil association
	Top Soil	Sub Soil			
A	0.06	0.06	0.1	0.1	Carstens – fine silty and clayey soil.
B	0.12	0.08	1.0	2.0	Elmton 2 – file loamy soil
C	0.15	0.12	1.0	2.0	Wix – well drained sandy and loamy soil.
D	0.18	0.10	1.0	2.0	Melford – well drained loamy over clayey soil
E	0.20	0.15	1.0	2.0	Fyfield – well drained loamy and sandy soil.

* seepage was allowed for the June – November period only.

4.3.2 Plant characteristics

For each community, two important plant characteristics were defined; the crop coefficient (ratio of evapotranspiration to potential evapotranspiration, ET) and the maximum rooting depth (Table 10). It was assumed that the grassland habitats evaporated at the same rate as potential reference crop ET, but that both reedbed and wet woodland were able to evaporate 20% faster than potential ET. This assumption incorporates a factor of safety in estimating the water requirements of the habitats (Fermor et al., in press).

Table 10: Plant characteristics for different communities

Community	Crop coefficient	Root depth, m
MG10 Species-poor rush pasture	1.0	0.5
MG13 Inundation grassland	1.0	0.5
MG9 Species-poor tussocky pasture	1.0	0.5
W5 Wet woodland	1.2	1.0
MG4 Species-rich flood meadow	1.0	0.5
MG8 Species-rich water meadow	1.0	0.5
S25 Fen	1.0	0.5
S4 Reedbed	1.2	0.5

4.3.3 Hydrological requirements

For each community, maximum water table depths were specified for each month of the between March and August (Table 11). A saturation deficit was defined as the depth of water required to bring the soil to saturation (i.e. to bring the water table to the surface). If the unsaturated zone is at field capacity, the saturation deficit can be defined as;

$$deficit = z \times 1000 \times S$$

where
deficit saturation deficit, mm
z water table depth, m below surface
S drainable porosity, dimensionless

Given the drainable porosities in Table 9 and the water table depths in Table 11, the water table requirements were expressed as allowable saturation deficits for each month (Table 12). For 'ponding' situations a maximum depth of ponding of 0.1m was allowed. For 'draining' situations, no ponding was allowed.

Table 11: Water table requirements (m below surface) for wetland communities in ponding / draining conditions

	Community	Soil type	March -May	June	July	August
Ponding	MG10 Species-poor rush pasture	A	0.10	0.50	0.80	1.00
	MG13 Inundation grassland	A	0.00	0.60	1.00	1.00
	MG9 Species-poor tussocky pasture	A	0.20	0.80	1.00	1.00
	W5 Wet woodland	A	0.10	0.60	1.00	1.00
Draining	MG10 Species-poor rush pasture	B	0.10	0.50	0.80	1.00
	MG13 Inundation grassland	B	0.00	0.60	1.00	1.00
	MG9 Species-poor tussocky pasture	B	0.20	0.80	1.00	1.00
	W5 Wet woodland	B	0.10	0.60	1.00	1.00
	MG4 Species-rich flood meadow	C	0.30	0.60	0.80	1.00
	MG8 Species-rich water meadow	D	0.20	0.40	0.60	0.80
	S25 Fen	E	0.00	0.40	0.70	1.00

Table 12 Allowable saturation deficits (mm) for wetland communities in ponding / draining conditions

	Community	Soil type	March - May	June	July	August
Ponding	MG10 Species-poor rush pasture	A	6	30	48	60
	MG13 Inundation grassland	A	0	36	120	120
	MG9 Species-poor tussocky pasture	A	12	48	160	160
	W5 Wet woodland	A	6	36	60	120
Draining	MG10 Species-poor rush pasture	B	12	48	67	88
	MG13 Inundation grassland	B	0	56	148	148
	MG9 Species-poor tussocky pasture	B	24	72	188	188
	W5 Wet woodland	B	12	56	88	148
	MG4 Species-rich flood meadow	C	45	78	102	166
	MG8 Species-rich water meadow	D	36	56	76	96
	S25 Fen	E	0	70	115	160

For reedbeds, the water requirements were defined in terms of minimum ponding depths for the period March – August, and a water table depth for September (Table 13).

Table 13: Ponding and water table requirements for reedbeds

Community	Ponding depths, m				Water table depth, m
	March - May	June	July	August	at the end of summer
S4 Reedbed	0.20	0.10	0.05	0.00	0.02

4.3.4 Calculated water requirements

For each community type, the daily soil-water conditions were simulated for the period 1/1/70 to 31/12/98 using meteorological data from MORECS grid square 142. The weekly MORECS estimate of potential evapotranspiration for grass and rainfall were used as inputs to the WaSim model. The weekly data were distributed into seven equal days. Figure 1 shows that this time period contains a representative selection of wet and dry years.

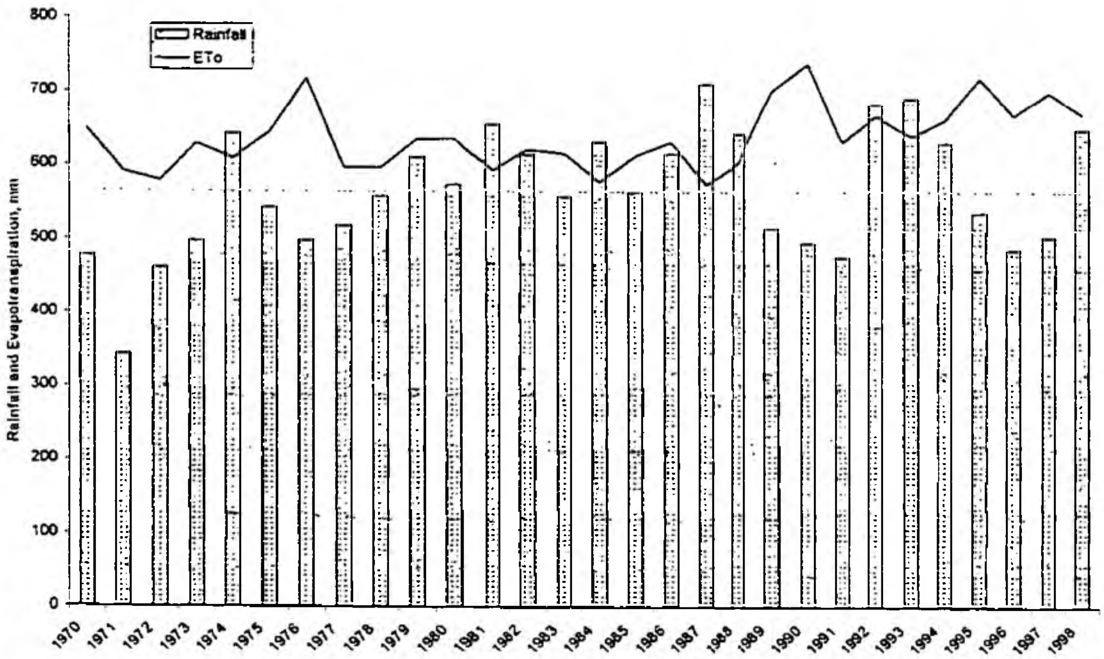

Figure 1 Annual rainfall and potential evapotranspiration, ET, for MORECS grid square 142, 1970 – 98.

In the WaSim model, rules were set such that whenever the hydrological condition became drier than the criteria above, sufficient water was applied to bring it back to the minimum condition. The water requirements were summed for each month of the year and for the winter (October – March) and summer (April – September) seasons. The average and standard deviation of the seasonal water requirements were calculated. Assuming that the seasonal water requirements are normally distributed, the reliable (2 out of 3 year) seasonal water requirement was calculated from;

$$W_{2/3} = \overline{W} + 1.41\sigma$$

where

$W_{2/3}$ 2 out of 3 year seasonal water requirement

$\overline{W}$ average seasonal water requirement

σ standard deviation of seasonal water requirement.

The simulation was started on 1 January 1970, with the soil at saturation (except for the reedbeds where a ponding depth of 0.3m was assumed). The first year was considered a 'warm-up' year and data were not used in the subsequent analysis.

Table 14: Seasonal and annual water requirements, mm, for different communities

Habitat	Soil	Average			2/3 years		
		Summer	Winter	Annual	Summer	Winter	Annual
MG10 Species-poor rush pasture	Ponding	132	2	133	170	5	175
MG13 Inundation grassland	Ponding	54	2	57	76	7	83
MG9 Species-poor tussocky grassland	Ponding	45	1	47	65	4	69
S4 Reedbed	Ponding	116	90	206	150	113	263
W5 Wet woodland	Ponding	186	44	230	221	60	281
MG10 Species-poor rush pasture	Draining	277	211	488	308	240	548
MG13 Inundation grassland	Draining	221	286	507	250	314	565
MG4 Species-rich flood meadow	Draining	200	247	447	235	274	509
MG8 Species-rich water meadow	Draining	267	188	455	301	216	517
MG9 Species-poor tussocky grassland	Draining	163	295	458	191	323	513
S25 Fen	Draining	187	287	474	213	314	527
S4 Reedbed	Draining	287	312	599	324	335	659
W5 Wet woodland	Draining	296	312	608	331	341	672

4.3.5 Calculation of volume requirements

Given the water depth requirements in Table 14 the seasonal and annual water requirements can be easily calculated. For example, Table 15 shows the calculation of water requirements for a 50 ha, MG4 habitat on a 'draining' soil.

Table 15 Example calculation of seasonal and annual water requirements for MG4 habitat on a 'draining' soil.

	Summer	Winter	Annual
2/3 year water requirement, mm	235	274	509
Water requirement, m^3/ha	2,350	2,740	5,090
Water requirement, l/s/ha (assuming constant flow)	0.149	0.174	0.162
Requirement for a 50 ha site, m^3	117,500	137,000	254,500

4.3.6 *Limitations*

The results of the simulations are very sensitive to the soil parameters, in particular the drainable porosity. In this exercise, representative soil parameters were used for soil types, however, in a site-specific study, actual soil data could be used. This would improve the accuracy of the modelling. Secondly, Table 14 shows that the water requirements for the draining situations are much higher than for the ponding sites. This is due to the need to meet water requirements for seepage. In reality, the rate of seepage will depend on site specific factors, such as elevation relative to watercourses and hydrogeology, and will vary through the year. This too could be considered on a site by site basis in a more detailed study.

One underlying assumption of the simulation is that the MORECS data accurately reflect the potential evapotranspiration for the region. There is some evidence that the MORECS somewhat overestimates grass potential evapotranspiration and results in an overestimation of soil water deficits (e.g. see Ragab, et al. 1997). If this were the case, actual water requirements could be slightly less than estimated above. It should also be noted that the crop coefficient values used in this study were those at the upper end of the range, giving a margin of safety. Estimates of water use are therefore likely to over-predict rather than under-predict the true situation.

4.4 Constraints and issues arising

The water availability in level 3 has been calculated using a more detailed method than that used in level 2. It was necessary to divide the soil polygons manually based on the reaches and tributaries of the main rivers. This made the process more time consuming and therefore only suitable for small to medium size areas.

Another main difference between levels 2 and 3 was the assumptions made about hydrological isolation and seepage losses. In level 2 the calculations of water demand were undertaken assuming that all areas where so large that they could be hydrologically isolated. In level 3, seepage losses have been assumed for soils of high hydraulic conductivity (drainable soils). Knowledge of local site conditions and drainage networks is needed to improve the modelling further.

Since the modelling of water requirements and water availability is undertaken outside of the GIS and then added as a layer, it is not possible to update the water availability based on the selection of areas for wetland creation. The implication of this is that it is possible to create wetland in any area shown on the level 3 maps to have sufficient water, but if two areas are selected on the same water course then there may not be sufficient water for both. It may be possible to create a model that could link the hydrological modelling to the GIS but this would involve additional investigation and modelling time beyond that which was envisaged for this study.

A further limitation of level 3 is the lack of information regarding the connection of river to its floodplain. In areas where the water-table in the floodplain is in hydrological connectivity with the river, then the ability to create wetland would depend on the ability to manage the stage level in the river.

4.5 Ranking of suitability

Within the pilot areas, the water availability for each target habitat has been divided into bands. These bands represent the proportion of the potential habitat area for which there is sufficient water. It is suggested that these bands form the ranking of suitability of each habitat. If there is only enough water to supply up to 20% of the area then it would be of low suitability for the habitat in question, whereas if there is enough water to supply more than 80% of the area then it would be of high suitability.

4.6 Ground truthing

A ground-truthing exercise was undertaken, whereby areas specified by the project partners were visited to verify that habitats suggested by the GIS would be potentially viable. All of the ground truthing sites were locations where flood defence works have been proposed.

The location of the River Witham Strategy area in The Fens Natural Area was visited and various potential sites are feasible. The soil profile consisted of a shallow alluvial layer over peat. This would provide a 'drainable' soil suitable for all of the target wetland habitats. The river Witham is a large river, with a stage level above that of the surrounding land. The area is crossed with a network of ditches and it would be possible to manage the water level, with additional water supplied from the river, to achieve suitable conditions for all of the target wetland habitats. The modelling of this area produced gave the same result, also stating that there was sufficient water in the river to achieve all habitat types.

Three areas were investigated in the Suffolk Coast Natural Area. These were the coastline south of Walberswick (TM 500 740), Minsmere Level (TM 460 680) and Sudbome Marshes (TM 460 560). Each of these areas supported a mixture of reedbed and grazing marsh. The modelling of these areas suggested that both reedbed and grazing marsh would be suitable although in Minsmere and Walberswick the river alone could not support the maximum potential extent of these habitat types. This suggests that either the seepage losses assumed for these locations were too large or that groundwater is contributing to the water balance.

The sites visited during the ground-truthing exercise were selected so that the opportunities for wetland creation arising from new flood defence schemes could be investigated. The area of the Lower Witham provides good potential opportunities for wetland creation of all the target habitats. Walberswick and Minsmere Level are already managed for their wetland habitat but are at risk from tidal inundation and flood defence works in these areas could help to sustain the current habitat types. Sudbome Marshes are managed for semi-improved grazing. There are possibilities in this area for enhancing the wetland habitats by altering the water-regime management, provided that the area could be protected from tidal inundation.

4.7 Discussion

The Fens and Suffolk Coast Natural Areas have very different landscapes. The Fens Natural Area consists of a large flat plain, dominated by soils of low hydraulic conductivity (pondable soils). The water courses have largely been straightened and canalised and are often at a higher level than the surrounding land. Almost all of the Fens lie on the fluvial floodplain, with a small part on the area at risk from tidal inundation. It would be possible to create large areas of wetland in the Fens if it were possible to use the rivers for additional water.

The Suffolk Coast Natural Area consists of a number of river valleys which are narrow inland and widen towards the sea. Several of the river valleys already contain large areas of wetland vegetation, such as Easton Broad and Minsmere. However, the extensive areas of wetland habitat occur close to the coastline and are at risk from coastal erosion. Although it is possible to create further wetland habitat inland, it could only be created in the narrow river valleys.

The largest possible areas of potential wetland creation on a single reach of a water course have been calculated for comparison with the LBAP targets. The results of this analysis are shown in Table 16. As mentioned earlier, the calculations of theoretical water availability are valid assuming that only one area on each water course is created. If more than one area is to be created on a single water course then the additional water demand of the habitat would need to be taken into account. It can be seen that the area potentially suitable for each LBAP target is considerably larger than the target itself. Achieving these targets would depend on the co-operation of the land managers and the ability to provide additional water to the area from local water courses. Some water courses, especially in the Suffolk river valley, have very low stage levels in the summer. Careful planning would be required to ensure that the additional water required was abstracted from the river at a location with enough height to allow the supply to be driven by gravity.

Water quality may be a constraint to wetland creation in parts of both the Fens and the Suffolk Coast Natural Areas. Interrogation of the data held in the GIS shows that in The Fens Natural Area, nitrate levels were generally low whereas phosphate levels were medium to high (based on the categories defined in Table 8). In the Suffolk Coast Natural Area nitrate levels were generally low and phosphate levels tended to be lower than in The Fens and range from low to medium, with high measurements from a few locations.

Table 16: Comparison of LBAP targets and areas with potentially achievable habitat selected by the level 3 criteria for representative catchments

	Grazing marsh	Reedbed	Fen
The Fens BAP target	Not quantified	600 ha	Not quantified
The Fens Maximum potentially suitable area on one water course	20350 ha	20350 ha	3940 ha
Suffolk Coast BAP target	Not quantified	200	Not quantified
Suffolk Coast Potentially suitable area	630 ha	630 ha	230 ha

5 Conclusions

5.1 Limitations of study

The work carried out for this study involved the collation of many data sets and combined hydrological modelling with spatial representation in a GIS. The output of the study is in the form of maps illustrating the areas of the Anglian region which are potentially suitable for wetland creation. The huge geographic area covered by the study meant that only data which were in a GIS compatible form could be used and that assumptions had to be made regarding the hydrological scenario to be modelled.

Assumptions regarding the theoretical water availability have enabled estimation of potentially suitable areas for wetland creation based on actual flows in the water courses. However, these assumptions do not take account of minimum flow requirements where these are greater than Q95 or existing abstraction licenses which are not currently fully utilised.

Although potentially suitable areas have been calculated based on the theoretical water availability in the water courses, it would be possible in some areas, to store winter water in a neighbouring area for supply to the wetland during the summer months.

The use of water-regime requirements and maximum tolerated deficits for wetland plant communities is currently being researched and the ranges suggested in this report are still being tested. It has been a useful exercise to utilise the data in a predictive way and has highlighted some interesting points, such as the water requirement for the species-rich meadow communities being higher than for habitats such as reedbed and inundation grassland, where winter excess water can be stored on the site.

The maps produced by this study provide a useful tool for targeting wetland creation towards areas which are most suitable and have the largest water supply. The water demand maps can be used to compare the water resource requirement of wetland creation with other water users. However, the results from this study cannot be used at field scale. Before any wetland creation were planned it would be necessary to investigate the local drainage pattern, relative level of river and floodplain and potential seepage losses.

One of the main problems encountered with this study was that of combining water availability in rivers, which is essentially a linear data set, with the spatial data provided by the soils map. It was not possible to link all of the catchment together with a flow model so that water removed in one catchment was removed from all other catchments downstream.

5.2 Recommendations

There are several possibilities for improving the reliability of the output from this study. The first would be to link the wetland creation GIS with the MicroLowFlows package held by the Environment Agency. It is not known whether this would be feasible but a preliminary investigation would be worthwhile. Linking the two packages would enable the level 3 type analysis to be carried out for the whole region. Different water regime scenarios could be used to investigate their effect on the potential area for wetland creation i.e. predicted regimes under climate change. Existing licensed abstractions which are not fully utilised and minimum flow requirements which are greater than Q95 could also be included to refine the calculation of 'theoretical water availability'.

A further enhancement would be to link the hydrological model used in this study to estimate available water to the selection of wetland creation areas in the GIS. It would be necessary to adapt the model so that the user could interactively select areas for wetland creation and the additional water necessary for this habitat were then removed from the hydrometric area. This would only be possible if the water flow between the catchments within each hydrometric area could be modelled and the user was prepared to select area of preference for wetland creation.

An adaptation of the existing GIS would be to produce data relating the water demand of each habitat type to the requirements for a local storage reservoir. Using soil and climatic data it would be possible to recommend the type and size of reservoir which would be suitable to enable wetland restoration in the absence of summer abstraction.

Lastly, when the data become available, the inclusion of the extent of shallow aquifers in drift deposits and regions where the river was in connection with its floodplain would increase the accuracy of the water demand modelling and the selection of suitable soil types for the target wetland habitats.

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7 Glossary

Crop coefficient. The ratio of evapotranspiration from a particular plant to the potential evapotranspiration.

Drainable Porosity. The volume of pores between saturation and field capacity water contents. i.e. the volume of water that will drain under gravity from an initially saturated soil.

Field capacity water content. The water content in a soil some time after heavy rainfall, when the rate of downward movement of water has effectively ceased. This is the maximum amount of water that a soil can hold before drainage starts.

Hydraulic conductivity. A measure of the rate at which water can move through the soil when it is saturated.

MORECS. The UK Meteorological Office Rainfall and Evapotranspiration Calculation System. MORECS, provides weekly data on rainfall and potential evapotranspiration for each 40 x 40 km grid square of the UK.

Potential evapotranspiration The evapotranspiration from grass that is not under any kind of stress. The potential evapotranspiration, ET, is a function of the weather.

Reliable water requirement. The water requirement that is exceeded, on average only once in three years. Therefore, on average, for two out of three years the actual water requirement will not exceed the reliable water requirement.

Runoff. Rainfall that does not infiltrate the soil or pond on the surface, but flows over the surface to ditches and watercourses.

Saturation deficit. The depth of water required to bring the soil back to saturation (i.e. to bring the water table to the surface).

Saturation water content. The maximum amount of water that a soil can hold, i.e. when all the soil pores are filled with water.

Seepage rate. The rate water is lost from the soil profile due to downward water movement. The seepage rate is related to the hydraulic conductivity of the soil, but will depend upon the elevation of the site in relation to surrounding watercourses.

Unsaturated zone. The soil layer between the water table and the ground surface.

Appendix A: Sites and Monuments records for the Suffolk Coast Natural Area

Parish	SMR number	Description	Grid reference		
Blundeston	22	Turbary	TM	515	964
	22	Decoy	TM	515	964
	21	Blundeston Lodge	TM	5154	9680
	18	Ice-house	TM	517	967
	6	Flint Axe	TM	517	968
	1	Moat. Blundeston Hall	TM	5196	9701
	11	Ring ditch	TM	5242	9789
	12	Ring ditch	TM	5223	9790
	7	Cropmarks - ?Enclosure	TM	510	963
Lound	24	Peat deposits & worked bone	TG	4980	0090
	26	Windmill	TM	498	005
	3	Bronze Bowl	TG	5003	0091
	11	Stone axe	TM	5018	0067
	11	Lound waterworks engine house	TG	5018	0068
	4	Flint implements	TG	5058	0050
Benacre	15	Coin	TM	537	843
	10	Building	TM	522	846
	2	Scatter: flints	TM	525	841
	5	Scatter: flints	TM	516	848
	11	Cropmarks: linear	TM	514	846
	6	Coin	TM	5105	8453
	14	Church. St. Michael's	TM	5112	8445
	13	Scatter: pottery	TM	5119	8443
	20	Benacre hall and park	TM	5042	8382
	21	Latymer bridge	TM	5101	8612
	17	Saltpans?	TM	5335	8311
	19	Well	TM	534	834
	3	Axe, part polished	TM	523	836
	12	Cropmarks: linear	TM	511	828
	22	Ancient woodland (holly grove)	TM	511	825
Covehithe	8	Coins	TM	529	818
	18	Flints	TM	518	818
	1	Pottery	TM	530	823
	17	Flints	TM	525	825
	16	Flints	TM	517	825
	9	Bronze flat axe	TM	524	810
	10	Bronze flat axe	TM	526	810
	2	Flints	TM	523	805
	3	Flints	TM	521	805
	6	Rectangular enclosure fields	TM	522	814
	14	Flints	TM	814	
	27	Urn and cremation	TM	526	813
	12	Scatter: pottery	TM	518	811
	28	Ring ditch	TM	518	810
	25	Trackway cropmark	TM	519	809
	19	Scatter: pottery	TM	519	804
	29	Anti-glider ditches	TM	517	804
Henstead with Hulver Street	1	Axe scrapers	TM	484	865
	3	Flint axe	TM	4695	8710
	5	Ring ditch?	TM	4672	8700

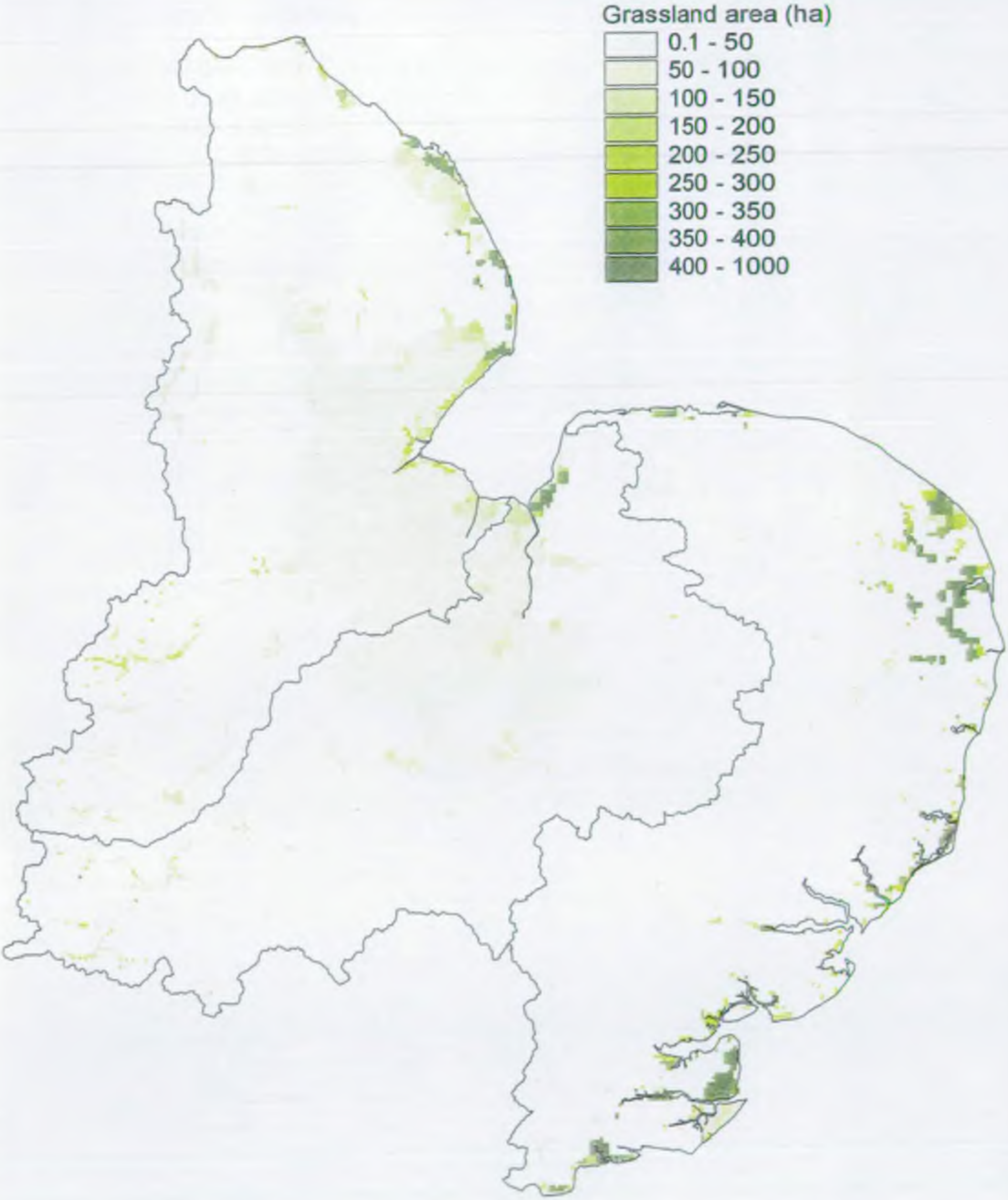
Mutford	6	Scatter	TM	4651	8755
Sotterley	1	Building?	TM	464	870
Ellough	8	Ring ditch	TM	485	873
	6	Building	TM	4470	8836
	7	Ruins'	TM	4450	8815
South Cove	1	Circular mound and ditch	TM	493	803
	8	Potters bridge	TM	508	790
	5	Polished flint axe	TM	5042	7967
Wangford	4	Pottery	TM	4745	7935
	14	Ancient woodland (Reydon wood)	TM	475	789
	3	Pottery	TM	4742	7945
Uggeshall	6	Ring ditch	TM	4450	8069
	5	Ring ditch	TM	4478	8098
Brampton	10	Church of St. Peter	TM	4350	8154
	11	Mile post	TM	4371	8132
Westhall		Boat frogment (steerboard)	TM		
Easton Bavents	4	Brick kiln	TM	5183	7929
	7	Scatter: flint and bone	TM	5165	7871
	5	Pottery sherd	TM	5163	7908
	1	Polished flint axe	TM	515	786
	10	Candle holder	TM	513	772
	2	Brick kiln	TM	518	789
	6	Oil flask, copper	TM	5165	7871
Reydon	5	Settlement, pottery etc.	TM	509	789
	8	Kiln, C17th-18th	TM	499	784
	1	Stone ware, pottery, glass, brick	TM	4888	7934
	3	Round barrow?	TM	4918	7901
	13	Round barrow?	TM	4879	7913
	14	Round barrow?	TM	4886	7915
	15	Scatter: pottery, flint	TM	4892	7917
	16	Ring ditch	TM	4881	7908
	6	Scatter: pottery	TM	489	790
	9	Pottery face mask, C13th-14th	TM	4895	7885
	2	Scatter: pottery	TM	4849	7905
	12	Scatter: worked stone & skull	TM	480	795
	19	Flint knives	TM	488	767
	29	Scatter: roof tiles & pottery	TM	485	768
	20	Road	TM	4820	7680
	7	Lime kiln	TM	476	773
Southwold	11	Gasworks	TM	499	762
	10	Busscreek boat remains	TM	5000	7650
	6	Wolsey bridge	TM	502	768
Blythburgh	27	Lime kiln	TM	4711	7686
	22	Cropmark	TM	471	768
	17	Ring ditch etc	TM	447	765
	10	Cropmark: house	TM	444	725
	19	Cropmark: rectangular enclosure	TM	4389	7136
	20	Windmill & scatter	TM	4385	7127
	24	Pottery	TM	4518	7435
Henham	1	Moat	TM	450	795
	2	Pottery - excavation	TM	450	795
	13	Burnt flint patch - excavation	TM	4493	7694
	14	Subrectangular enclosure	TM	4530	7680
	25	Henham park	TM	4545	7674
	18	Henham deer park	TM	44	76

	19	Canal	TM	44	77
Blyford	10	Statuette, AE	TM	428	763
	2	Bridge	TM	425	764
	9	Blyford bridge	TM	4247	7638
	8	Moat, Blyford hall	TM	4247	7645
	7	Church	TM	4216	7664
	6	Trackway	TM	4245	7675
Wenhaston with Mells Ham	16	Scatter: pottery	TM	419	762
	6	Chapel, remains of	TM	4130	7655
	3	Scatter	TM	4056	7676
	4	Watermill	TM	428	756
	12	Old chapel bridge	TM	4150	7691
	13	Square enclosure/ moat?	TM	4059	7692
	11	Field system	TM	4370	7535
	5	Windmill	TM	4300	7520
	8	Scatter: pottery & iron working slag	TM	425	747
Thorington	26	Scatter: pottery etc	TM	433	745
	9	Earthwork	TM	4283	7410
	12	Scatter: coins	TM	4290	7400
	21	Church	TM	4326	7405
	10	Windmill	TM	4227	7414
Walberswick	13	Reckoning counter, C16th	TM	486	736
	4	Scatter, chruch?	TM	490	740
	12	Scatter: pottery, quay	TM	491	741
	9	Chipped axe	TM	492	741
Darsham	2	Pottery, tiles	TM	416	705
	3	Windmill	TM	421	700
	8	linear cropmark	TM	421	691
	9	flint chisel	TM	422	690
	4	Scatter: coins & pottery	TM	4250	6938
	13	Scatter: broaches	TM	4188	6948
	15	wind pump	TM	419	695
Leiston	16	Ring ditches	TM	4680	6621
	34	Urns	TM	466	653
	4	wreck	TM	446	629
	8	Chapel, remains of, abbey (site of)	TM	480	635
	2	Chipped axe	TM	4732	6598
	3	Pottery waster	TM	476	632
Westleton	6	Scatter: flint	TM	4241	6868
	16	Scatter: pottery	TM	4610	7198
	25	Moat, lymballs farm	TM	4258	6875
	2	Bridge	TM	425	707
Aldringham cum Thorpe	16	Flaked flint axe	TM	446	605
	9	Windmill	TM	4432	6092
	10	cropmarks	TM	468	598
	6	Scatter: pottery: C12th-13th	TM	457	596
Sternfield	8	Axe, polished	TM	3865	6067
	5	Axe, part polished	TM		
	4	Scatter: flints	TM	3871	6046
	7	Crop mark, road?	TM	3880	6075
Saxmundham	3	Decorated stud	TM	386	620
Benhall	26	Bronze die?	TM	3575	6100
	27	Scatter: pottery	TM	3583	6100
	11	Scatter: pottery	TM	3720	6193

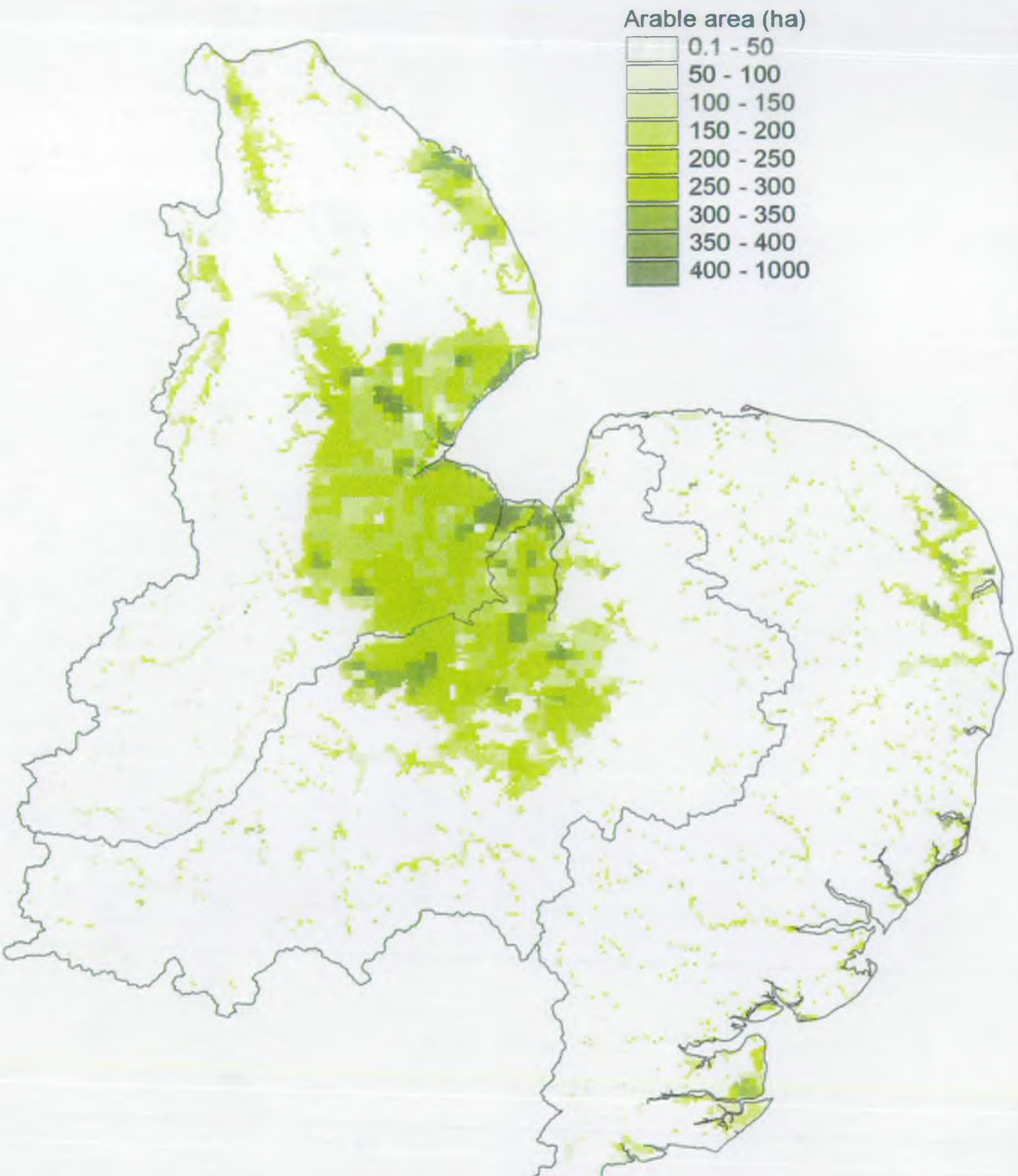
Swefling	6	Bridge	TM	353	628
	12	Pottery sherds	TM	3533	6302
	3	Claudius statue head	TM	353	631
Rendham	1	Wind pump	TM	353	638
Aldeburgh	17	Scatter: pottery	TM	468	583
	9	Scatter: pottery	TM	460	584
	10	Earthwork: bank	TM	458	585
	19	IWW training trenches	TM	4555	5937
	20	Scatter: pottery	TM	455	591
	7	Brick works	TM	444	576
	21	Slaughden martello tower	TM	451	570
	13	Enclosure- cropmark	TM	463	549
Friston	6	Ring ditches	TM	4358	5781
Snape	21	Potter sherds	TM	4024	5819
	22	Salt working site	TM	4122	5782
	23	Water mill	TM	414	573
	25	C13 Barn	TM	3890	5772
	27	Snape bridge	TM	390	579
	36	Cropmark	TM	3920	5762
	38	Flint blade	TM	386	582
	6	Pottery sherds etc	TM	387	595
	5	Pottery	TM	3864	5974
	1	Priory, site of	TM	387	597
	9	Pottery sherds	TM	387	578
Iken	9	Decoy pond	TM	4189	5531
	11	Sword	TM	417	559
	13	Pottery	TM	424	559
	8	Tumuli	TM	410	561
	2	Pottery	TM	403	558
	10	Scatter: pottery	TM	446	566
	5	Scatter: pottery	TM	438	561
Sudbourne	8	Ring ditches	TM	4460	5470
	13	Ring ditches	TM	4375	523
	14	Ring ditches	TM	4379	5298
	15	Ring ditches	TM	4382	5307
	16	Enclosure	TM	4382	5311
	18	Oval ring ditch	TM	4398	5304
	12	Settlement - ring ditches, enclosure	TM	4391	5320
	2	Enclosure	TM	437	531
	26	Ring ditches	TM	4423	5397
	25	Enclosure	TM	4436	5400
	24	Scatter: pottery	TM	4451	5398
	4	Irregular enclosure earthwork	TM	4456	5445
	22	Orfordness experimental estmt	TM	439	514
Orford	21	Pottery	TM	450	500
	6	Oyster bed	TM	423	494
	27	Water mill (pre 1600 AD)	TM	4244	4948
	4	Pottery sherds	TM	4205	4950
	14	Coins etc. pottery kiln	TM	422	501
Blaxhall	2	Bronze spearhead	TM	3732	5765
	8	Langham bridge	TM	3744	5811
	14	Beversham bridge	TM	3750	5815
	13	Scatter: pottery, tile, metalwork	TM	3595	5822
Farnham	3	Bath house	TM	373	583
	1	Church	TM	371	583

	10	Socketed axe	TM	3625	5997
	2	Socketed axe fragment	TM	381	598
Stratford St Andrew	1	Bronze bowl	TM	355	594
Campsey Ash	4	Bronze fitting	TM	317	557
	18	Coin	TM	3176	5540
	3	Small lozenged shaped enclosure	TM	3180	5627
	11	Priory	TM	3156	5581
	2	Bridge	TM	318	545
	13	Decoy pond	TM	317	545
	7	Scatter: pottery	TM	3180	5470
Eyke	3	Polished flint axe	TM	3140	5260
	12	Finds scatter: pottery	TM	3147	5270
Butley	26	Finds scatter: pottery	TM	365	512
	27	Scatter: pottery	TM	364	512
	9	Moat	TM	3680	5115
	32	Field system	TM	369	513
	33	Occupation C12th-C13th	TM	372	514
	5	Scatter: C16th-C17th	TM	372	514
	10	Scatter: pottery	TM	3725	5135
	7	Settlement	TM	380	507
	11	Brooches	TM	371	496
	2	Butley priory	TM	375	492
	2	Field system	TM	375	492
	2	Settlement, axe, scatter: pottery	TM	375	492
	3	Causeway: The Thrift	TM	3688	4993
	18	Ring ditch	TM	388	488
	25	Field system	TM	3905	4939
	30	Trackway	TM	377	497
	31	Burrow Hill, settlement, coins, urn	TM	378	494
	1	Bridge	TM	3900	4855
Wantisden	10	Mill site	TM	3592	5140
	9	Strap end	TM	352	514
Chillesford	13	Cropmark	TM	3825	5235
	15	Clamp kiln	TM	381	524
	8	Tumulus	TM	3773	5183
	6	Tumulus	TM	3733	5272
	4	arrowhead	TM	3738	5275
Gedgrave	6	Cropmarks	TM	411	495
	2	Chape, site of. Skeletons	TM	414	492
	1	Scatter: pottery, brooches	TM	4052	4865
	3	Flint axe	TM	397	482
	5	Stone axe	TM	3982	4810
Capel St. Andrew	11	Bridge	TM	354	480
	20	Field boundaries	TM	388	471
	18	Stone bridge	TM	3766	4836
	19	Stone bridge	TM	3785	4870
	19	Coin	TM	3811	4779
Boyton	10	Pottery, occupation layer	TM	362	468
	5	Bridge	TM	365	468
	17	Ancient woodland (Boyton Wood)	TM	3662	4708
	18	Church	TM	372	472
	16	Frogs Hall - site of	TM	3728	4708
	15	Settlement	TM	387	469
	2	Pot	TM	380	463
Hollesley	16	Enclosure	TM	372	453

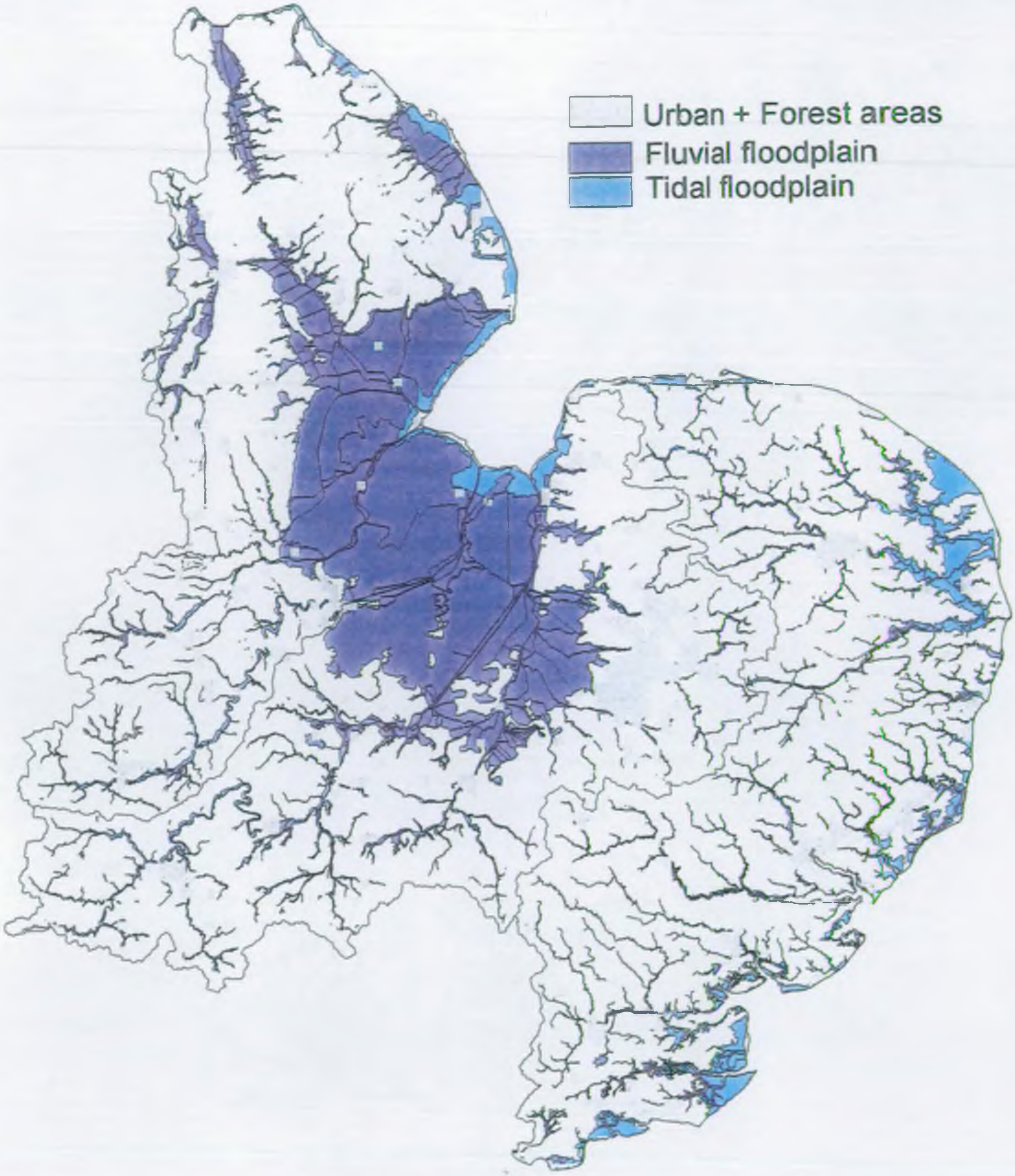
	28	Enclosure	TM	3757	4585
	24	Ring ditch	TM	3776	4604
	23	Ring ditch	TM	3766	4594
	27	Ring ditch	TM	3757	4588
	25	Ring ditch	TM	3754	4587
	26	Scatter: flints	TM	3785	4605
	14	Scatter: pottery C13th	TM	3620	4430
	15	Scatter: flints	TM	3640	4405
	13	Field system	TM	3650	4425
	9	Scatter: pottery	TM	350	434
	12	Flints, pottery	TM	3590	4440
	10	Flints	TM	3580	4440
	8	Martello Tower	TM	3624	4446
Alderton	5	Cropmark: ring ditch	TM	3609	4195
	27	Cropmark: ring ditch	TM	3590	4215
	26	Cropmarks	TM	3582	4218
	9	Ring ditch	TM	360	422
	7	Ring ditch	TM	3600	4223
	8	Cropmark: ring ditch	TM	3607	4225
	40	Scatter: pottery	TM	3564	4308
Bawdsey	45	Scatter: pottery, potsherd	TM	353	409
	44	Scatter: pottery	TM	3500	4083
	43	Pottery sherds	TM	3510	4075
	7	Scatter: metalwork	TM	352	406
	15	Martello Tower, site of	TM	350	404
	17	Martello Tower, No.4	TM	3580	4024
	9		TM	3585	4106



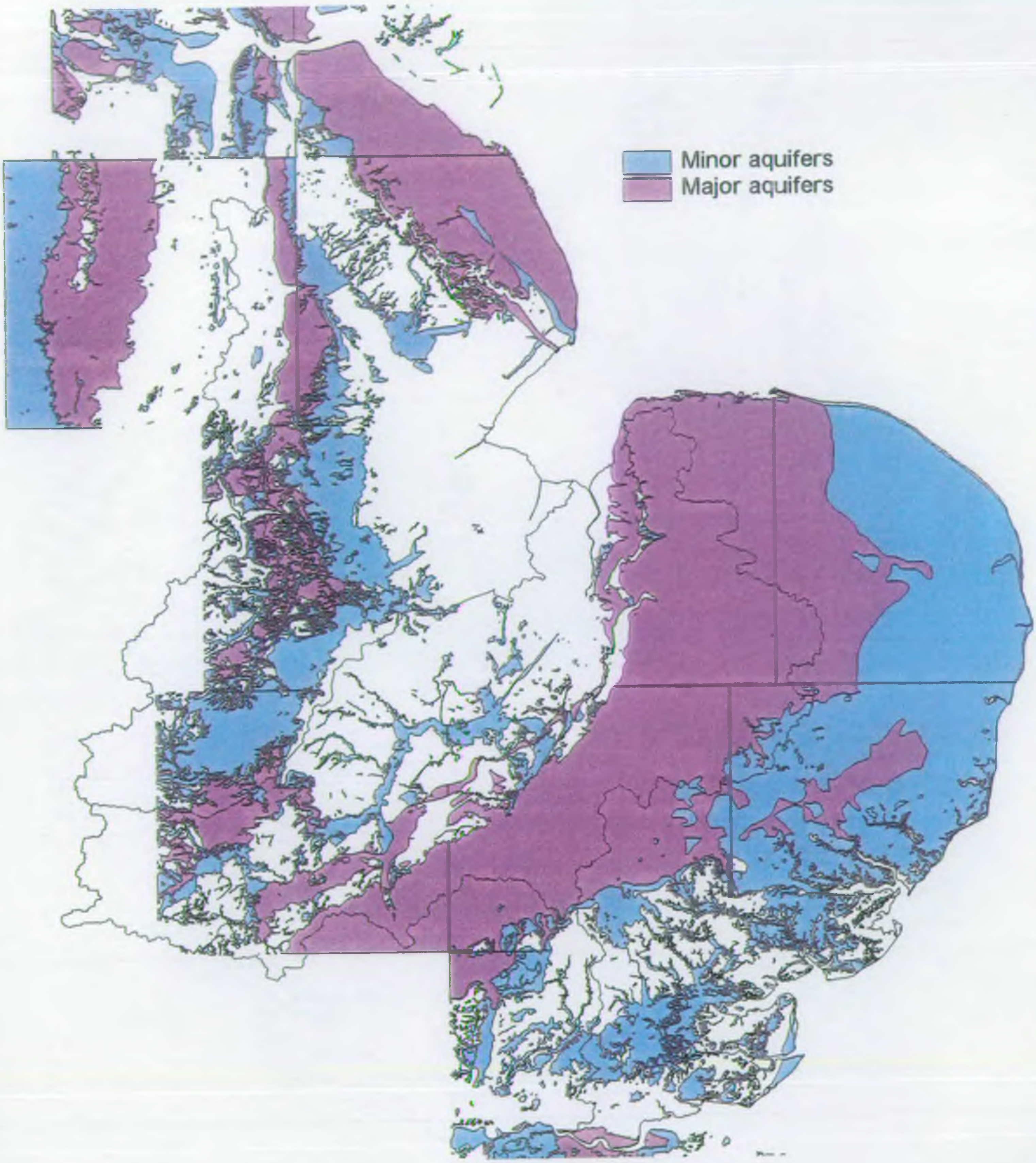
Map 1-1 Area meeting level 1 criteria with grassland land use



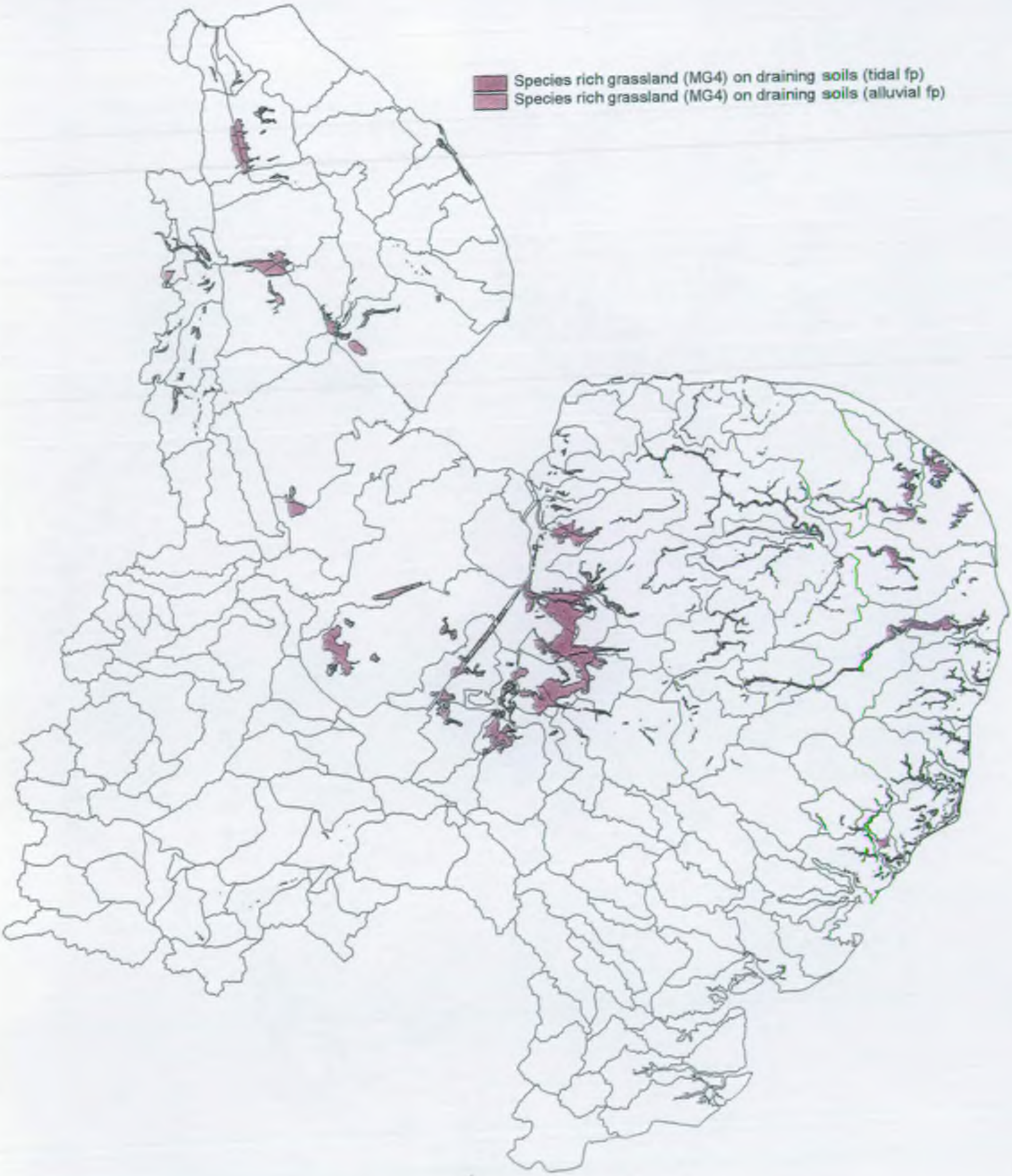
Map 1-2 Area meeting level 1 criteria with arable land use



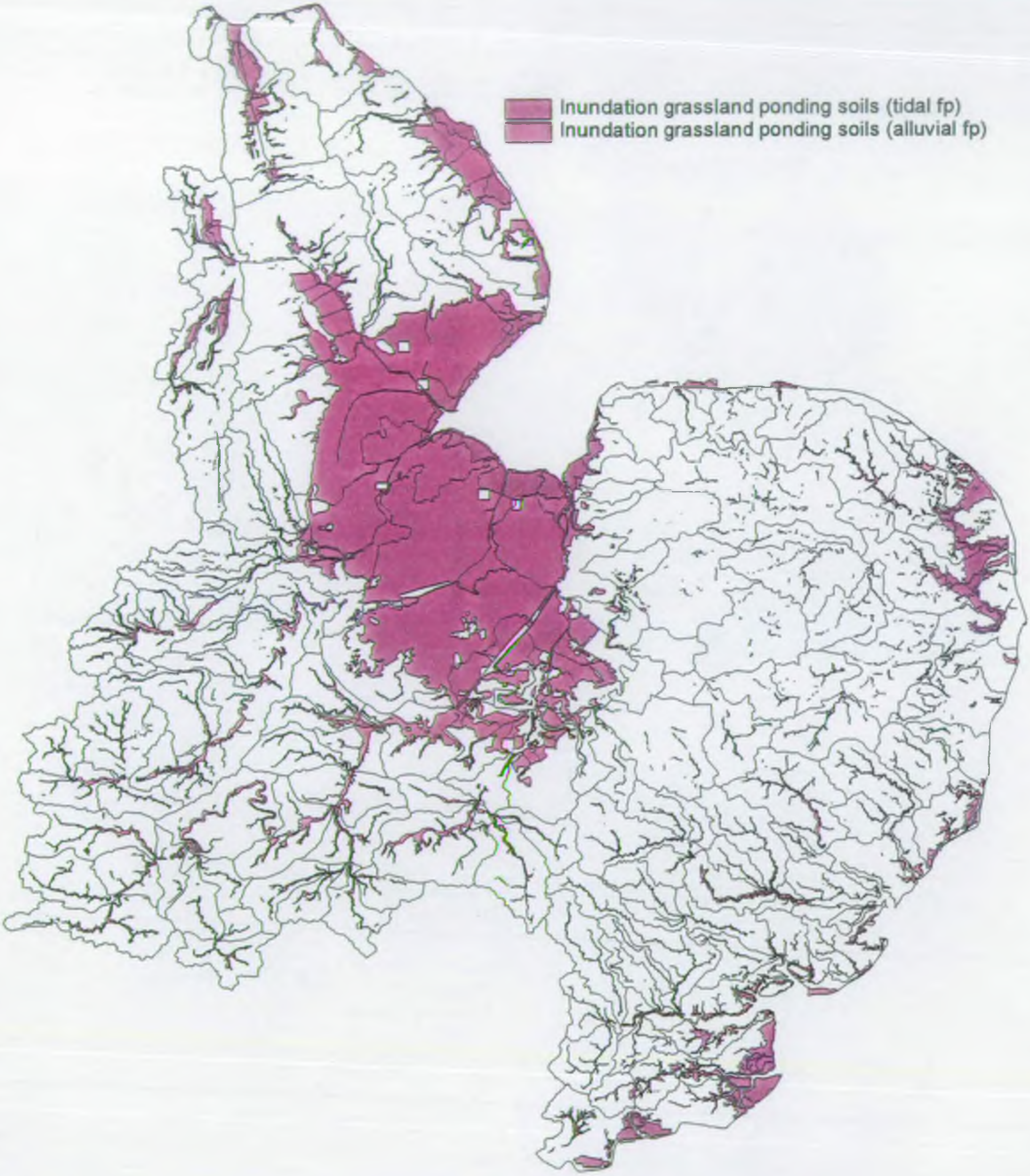
Map 1-3 Urban and forested areas and tidal and fluvial floodplains



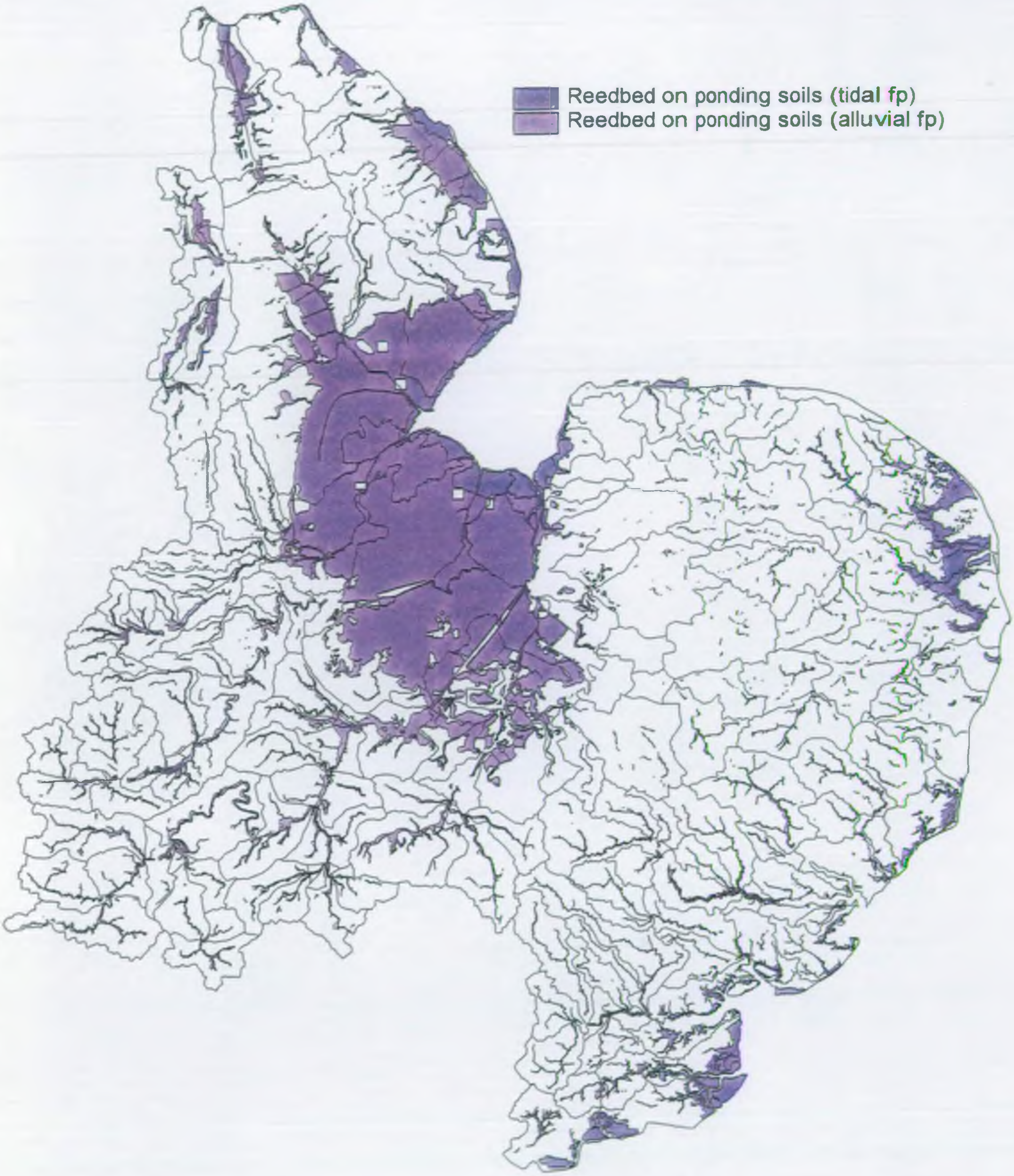
Map 1-4 Major and minor aquifers in the level 1 area



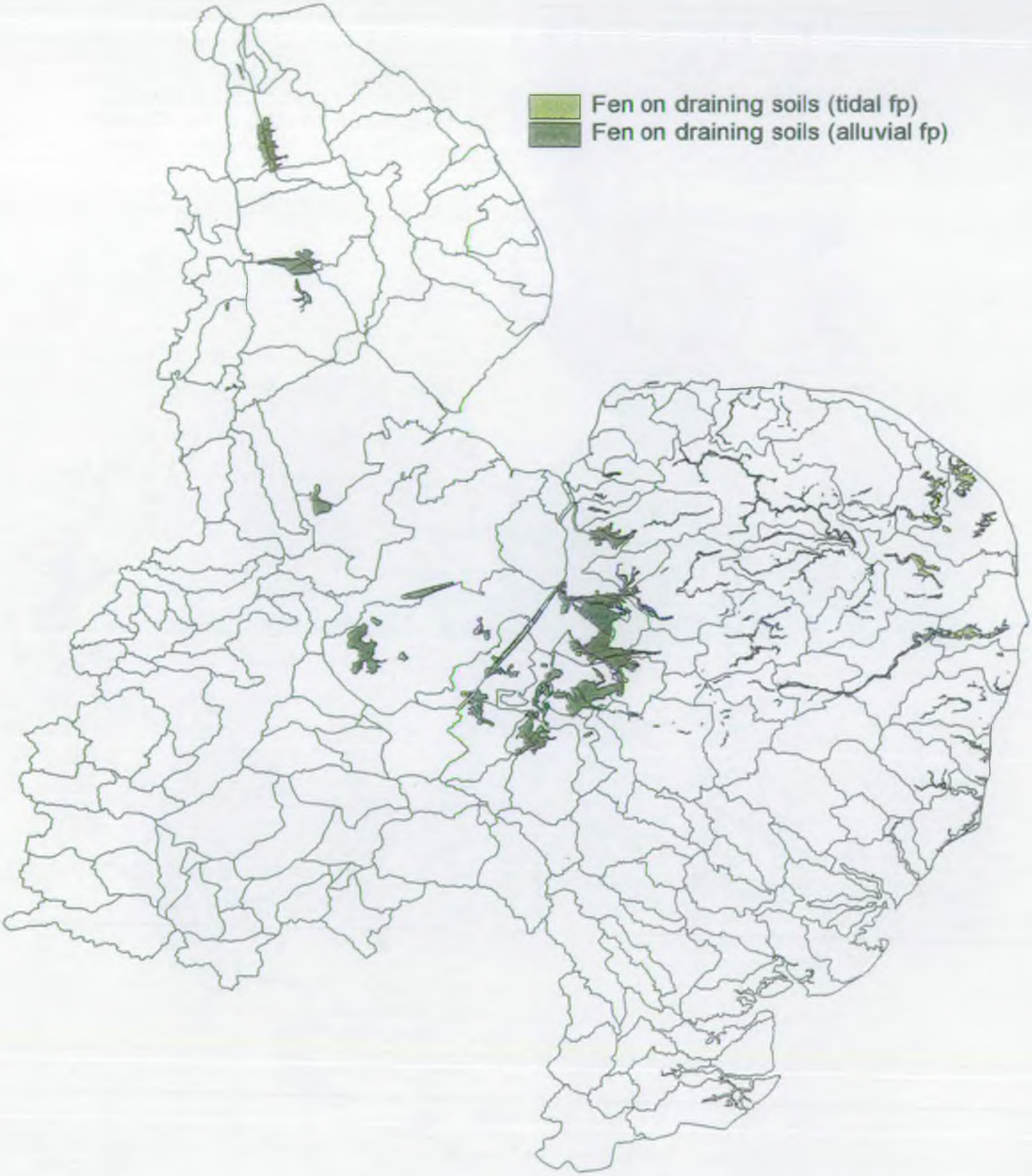
Map 2-1 Area meeting level 2 criteria for MG4 species rich flood meadow on freely draining soils



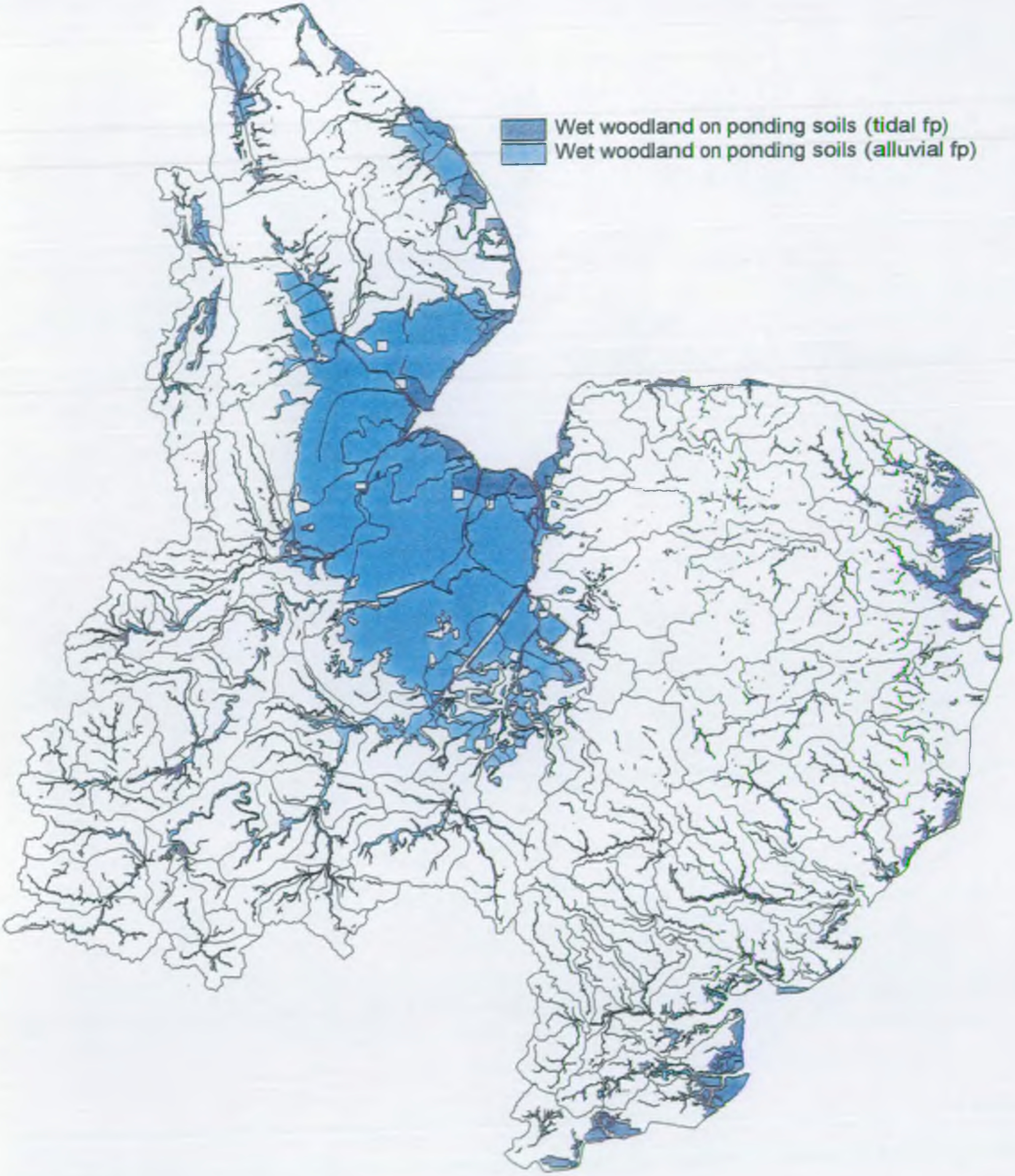
Map 2-2 Area meeting level 2 criteria for MG13 inundation grassland on pondable soils



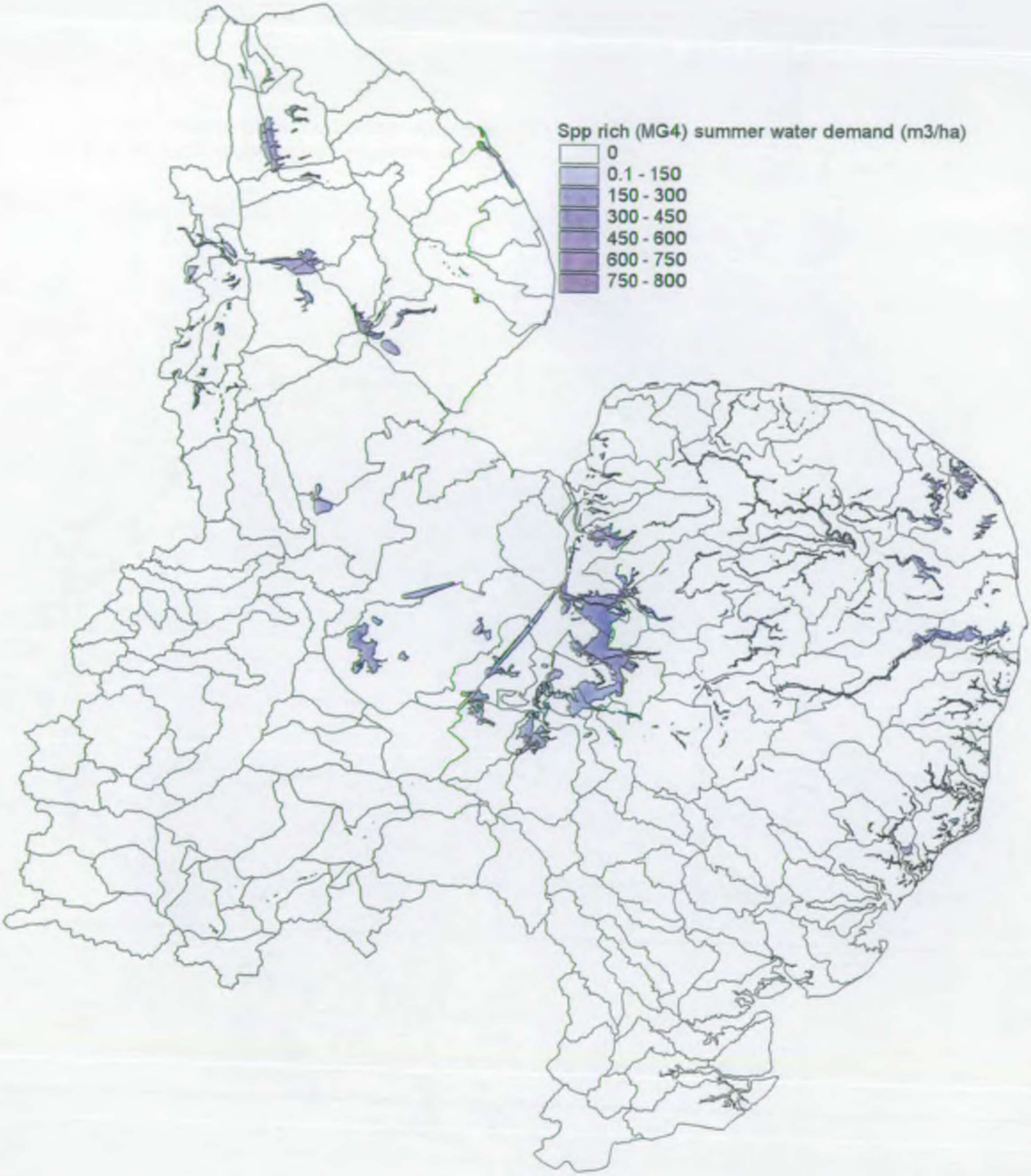
Map 2-3 Area meeting level 2 criteria for S4 reedbed on pondable soils



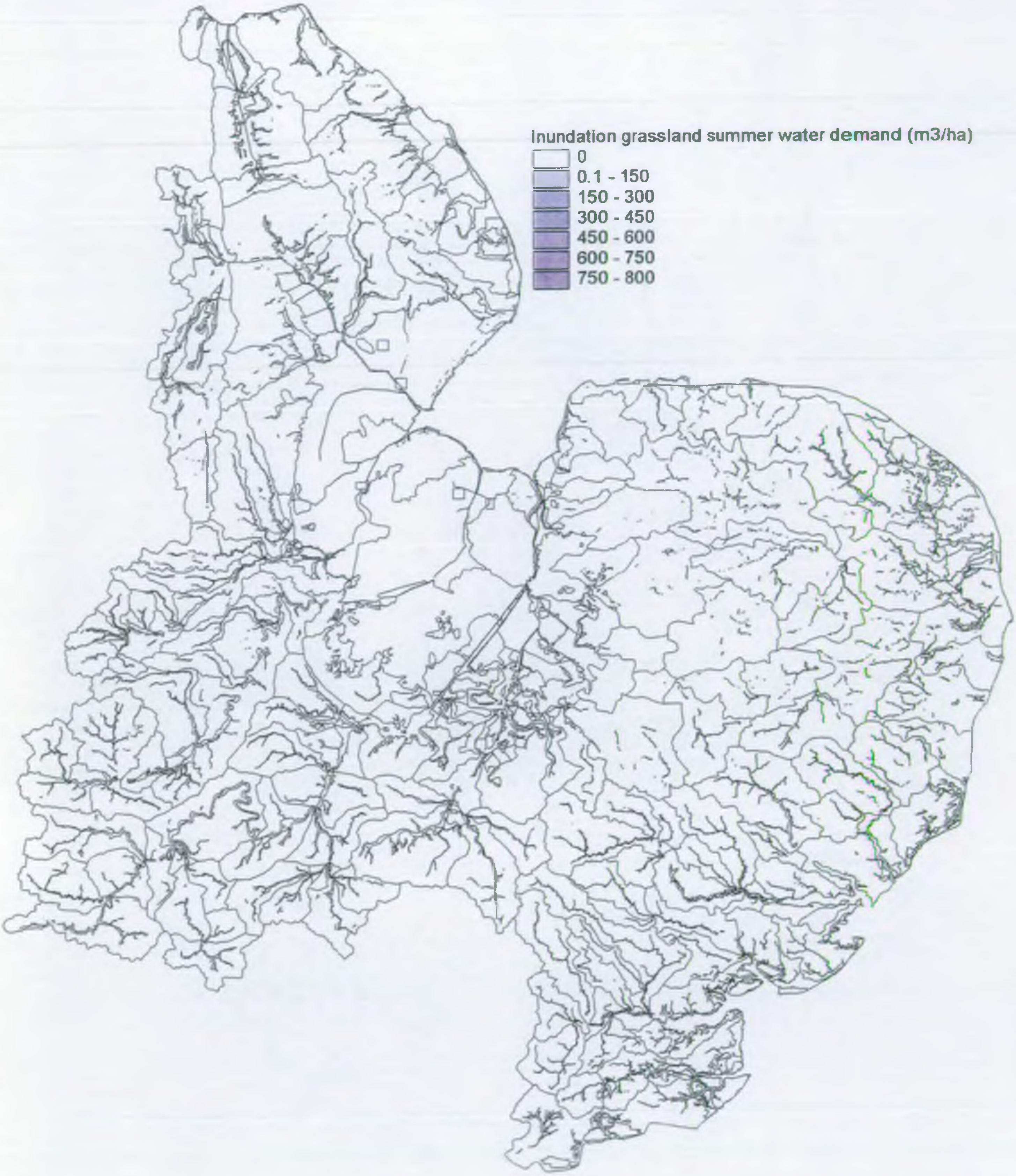
Map 2-4 Area meeting level 2 criteria for S25 fen on freely draining soils



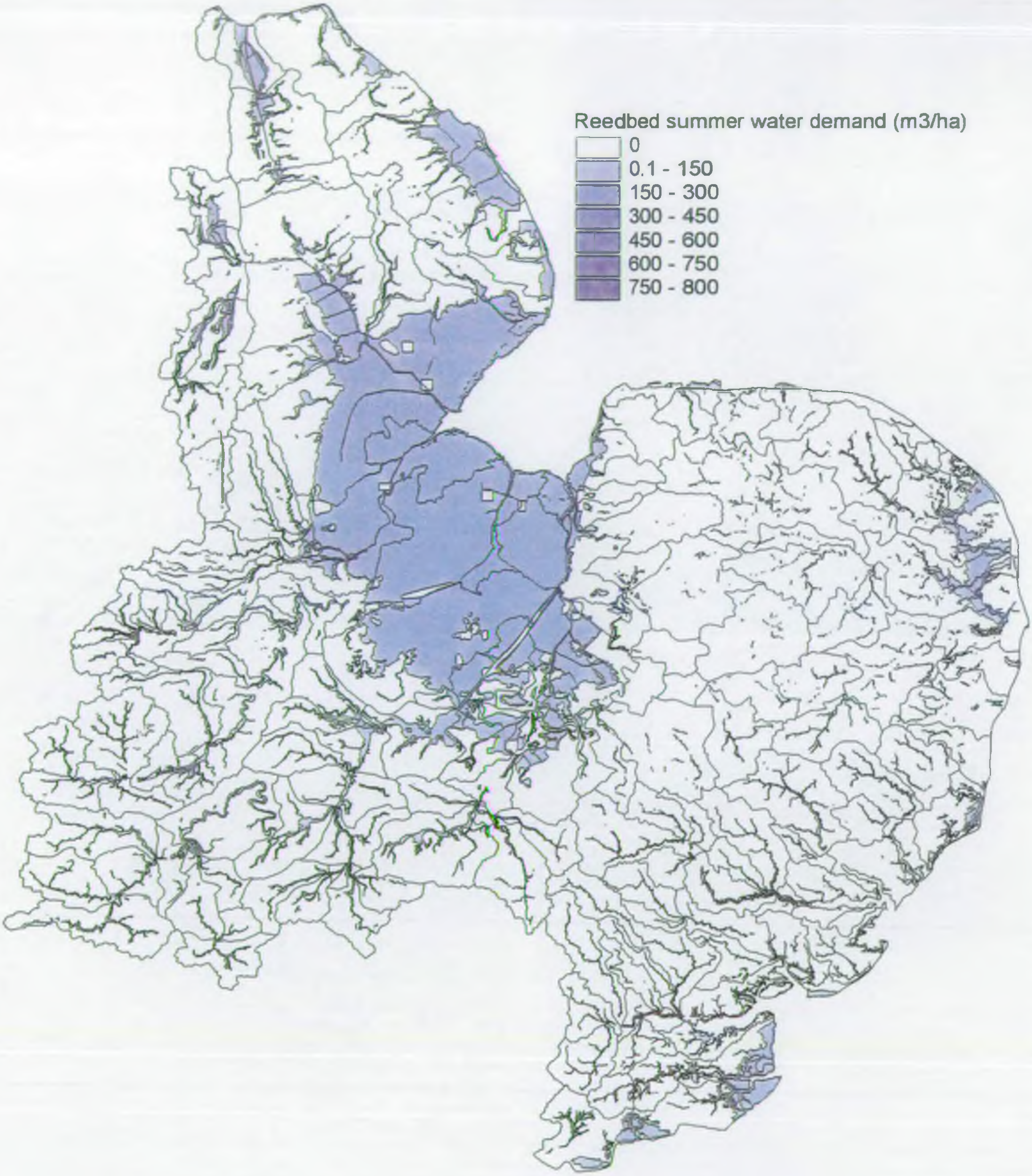
Map 2-5 Area meeting level 2 criteria for W5 wet woodland on pondable soils



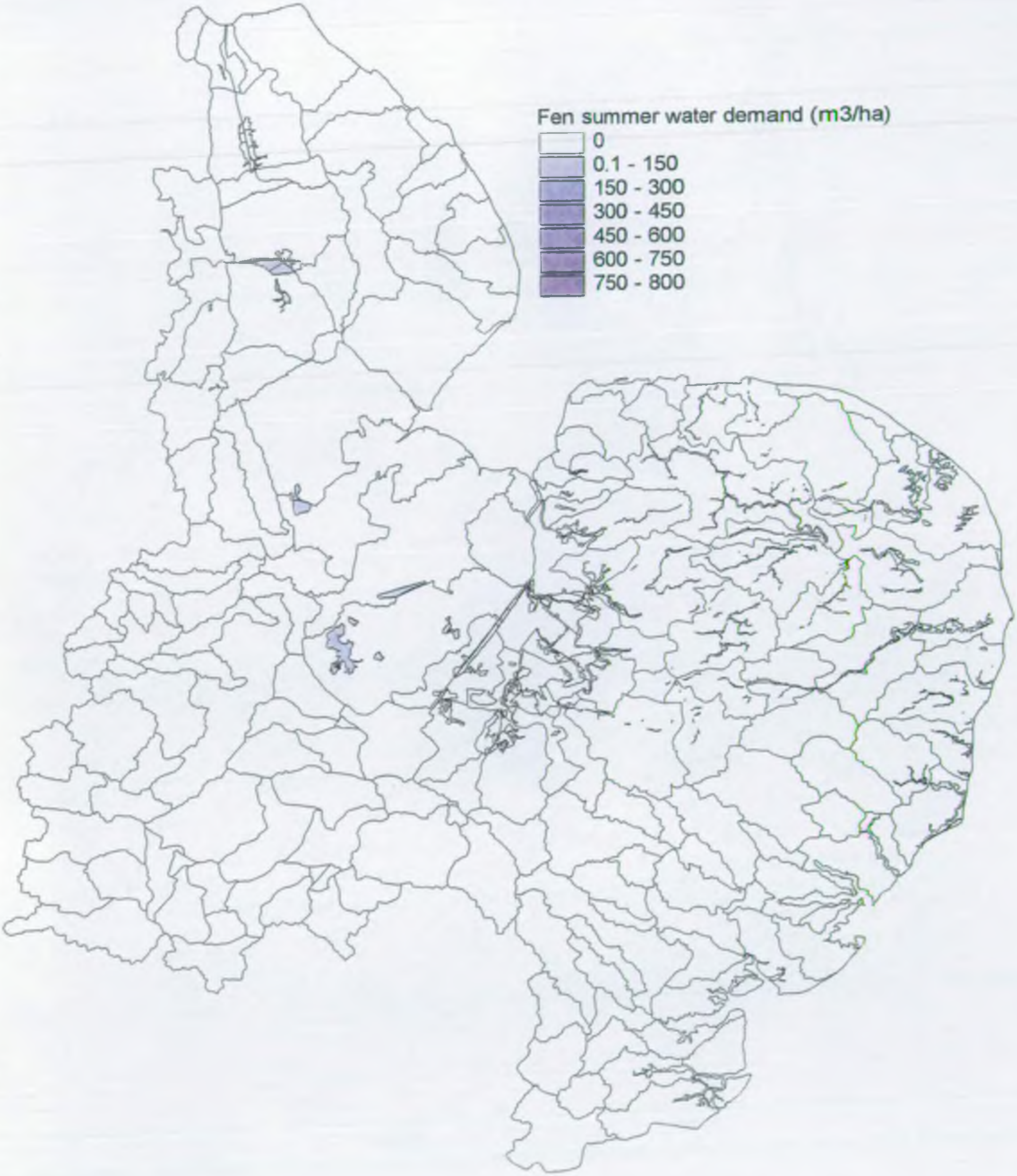
Map 2-6 Summer water demand for MG4 species rich flood meadow



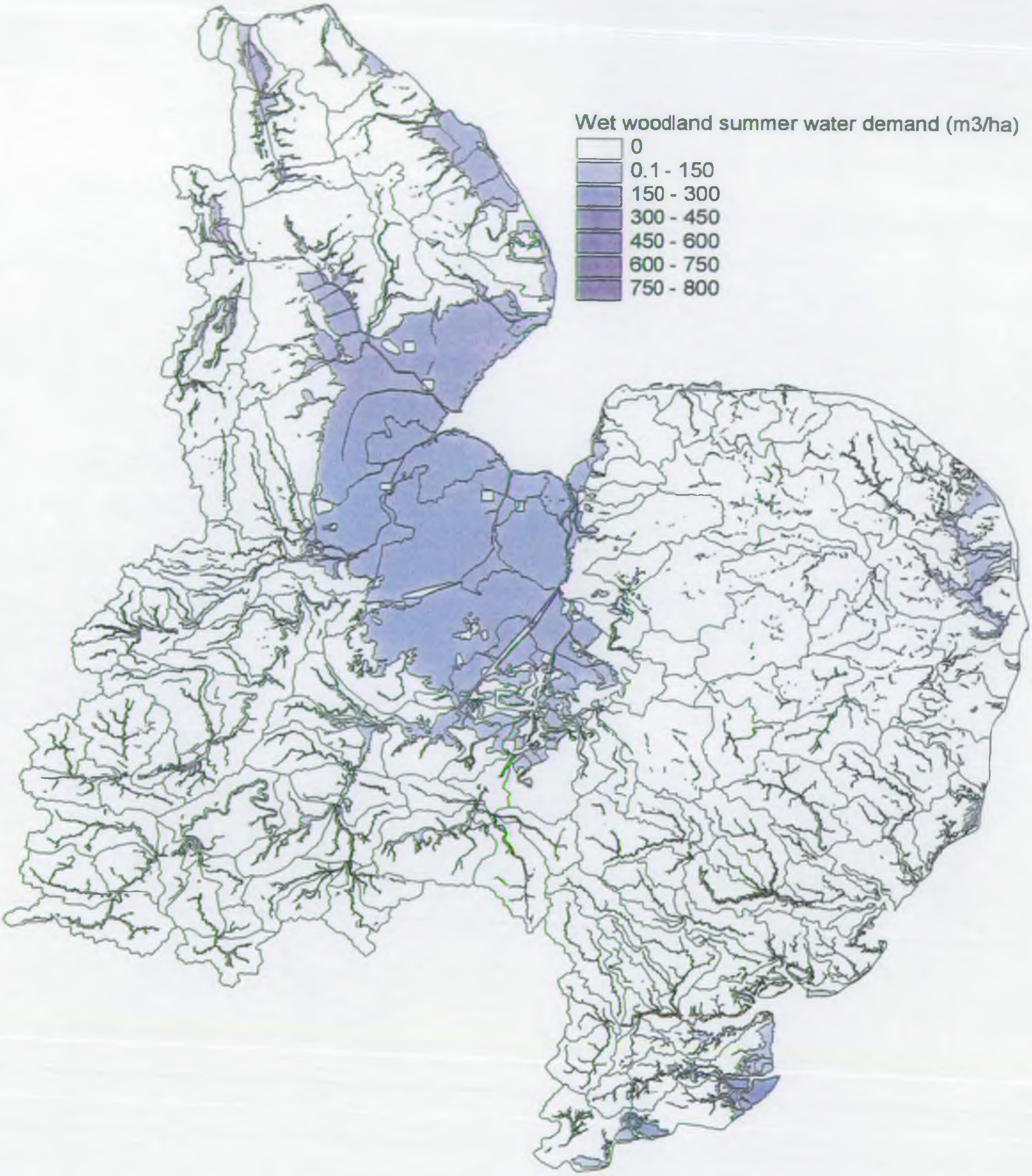
Map 2-7 Summer water demand for MG13 inundation grassland



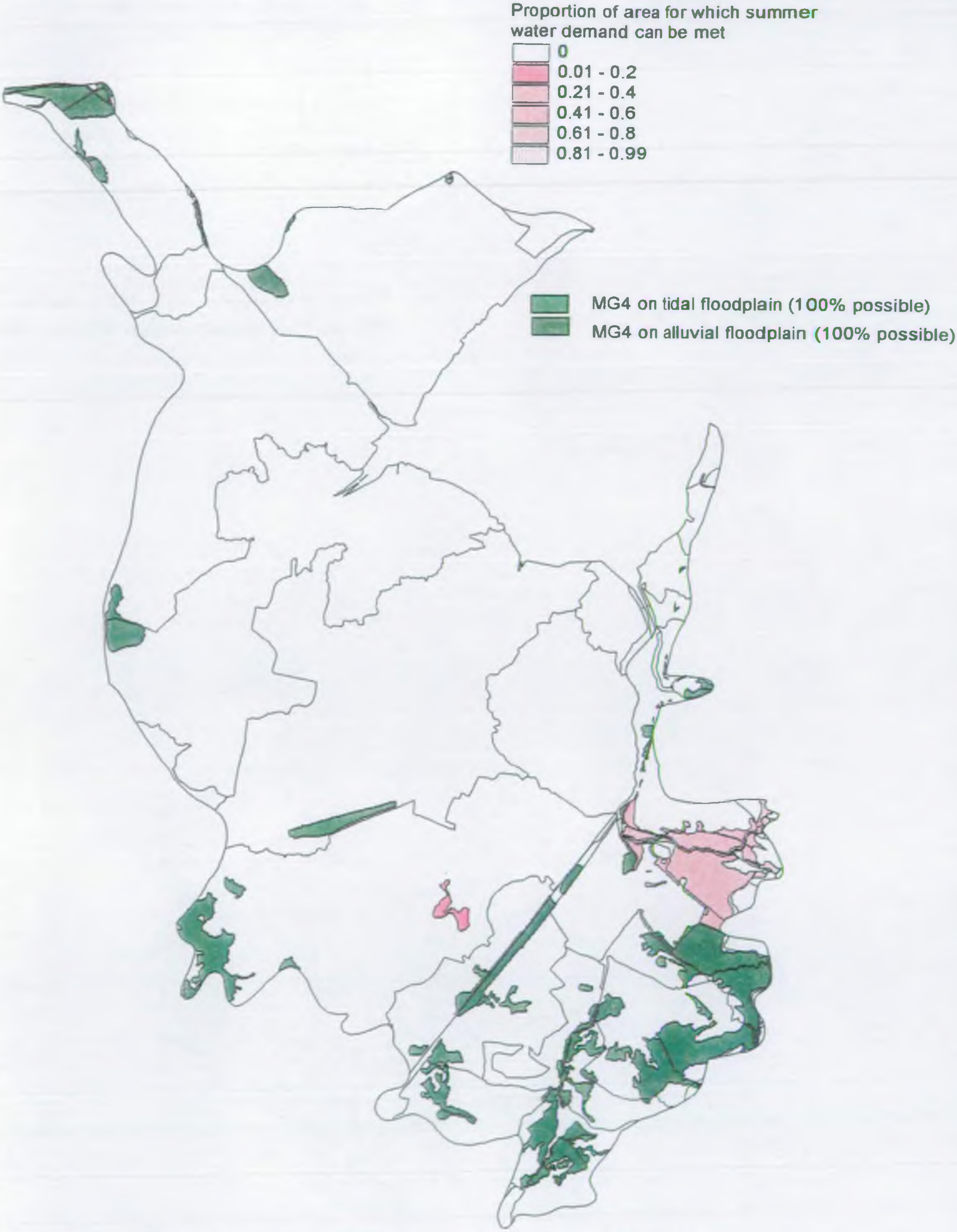
Map 2-8 Summer water demand for S4 reedbed



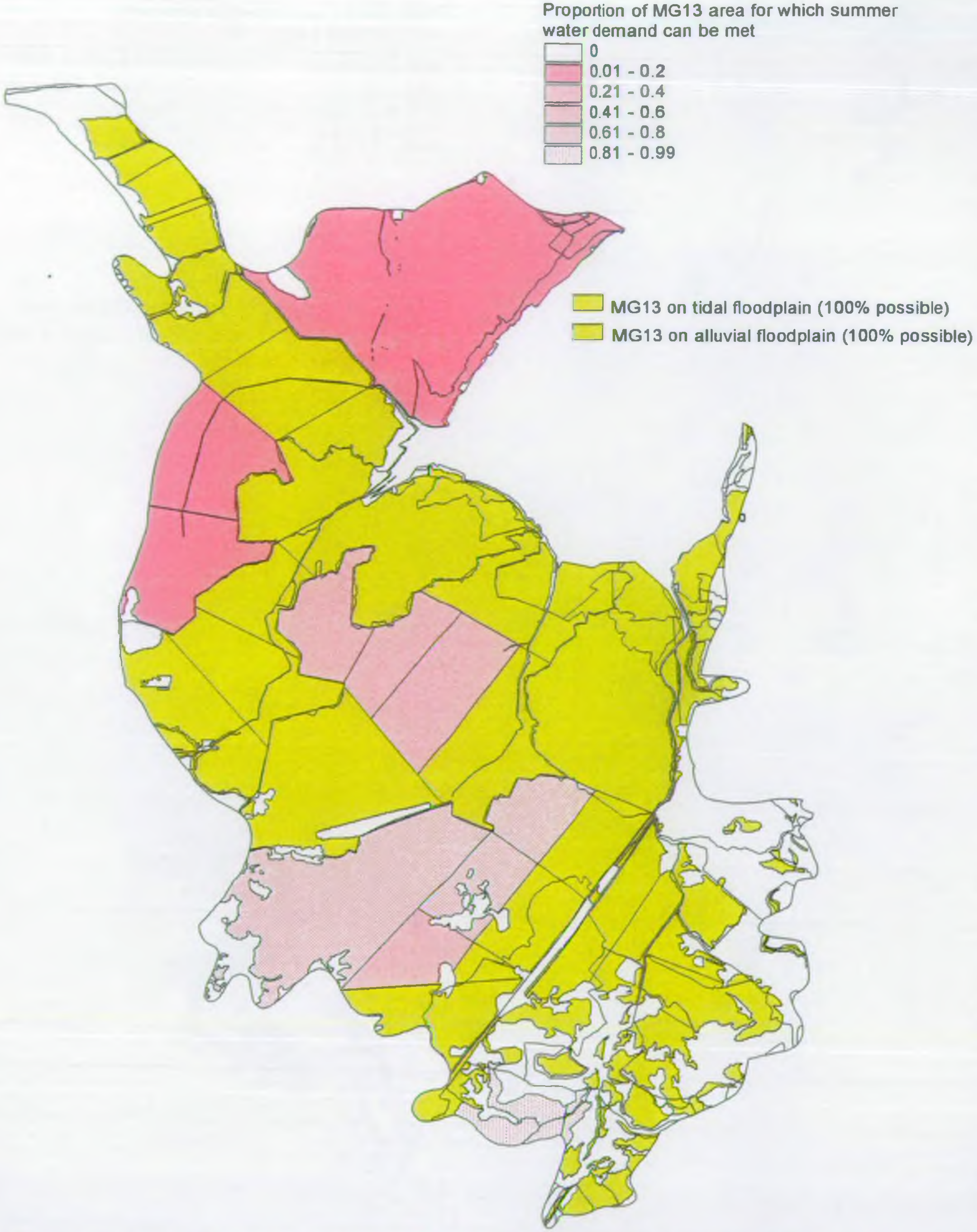
Map 2-9 Summer water demand for S25 fen



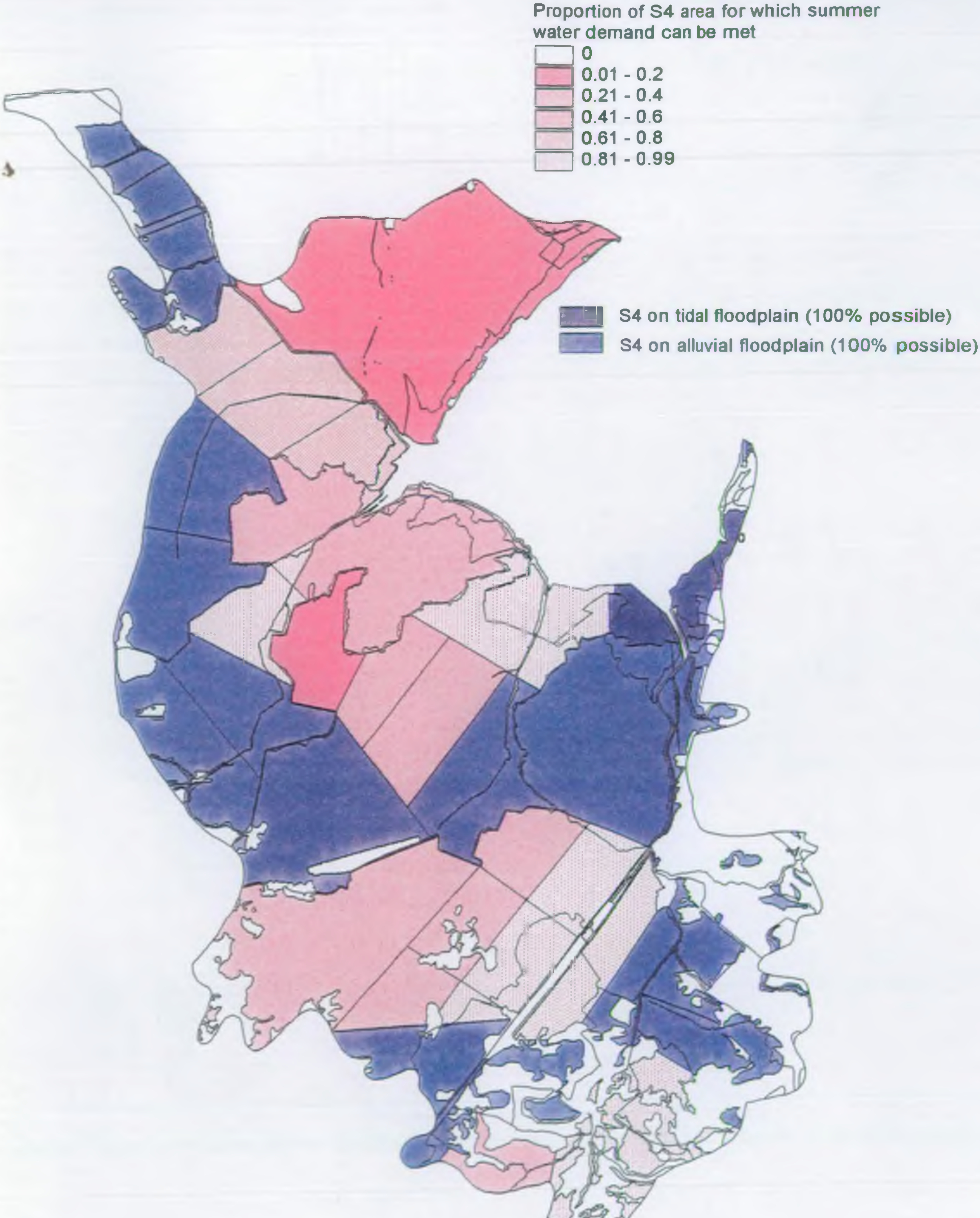
Map 2-10 Summer water demand for W5 wet woodland



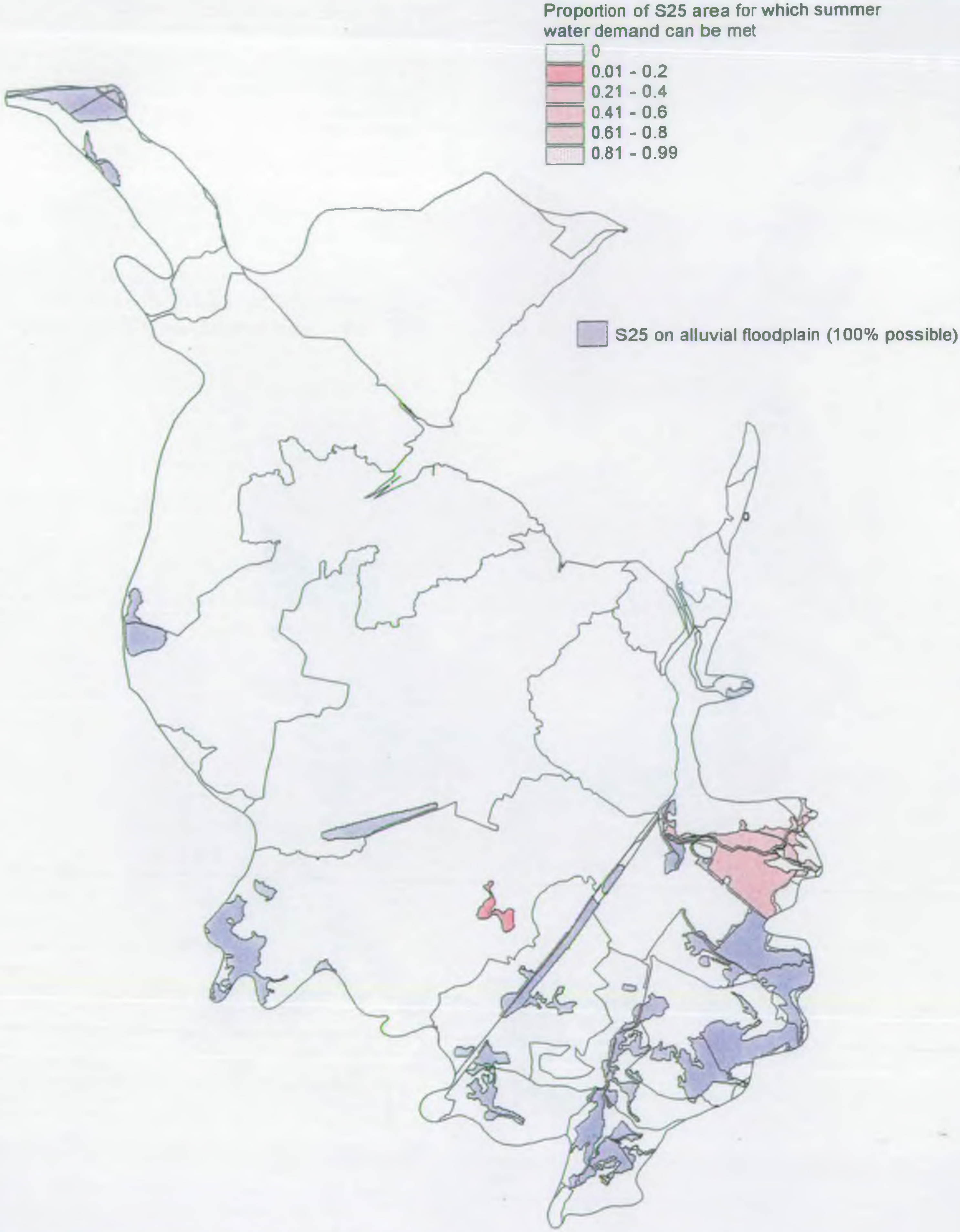
Map 3-1 Area meeting level 3 criteria for MG4 species rich flood meadow on freely draining soils in The Fens Natural Area



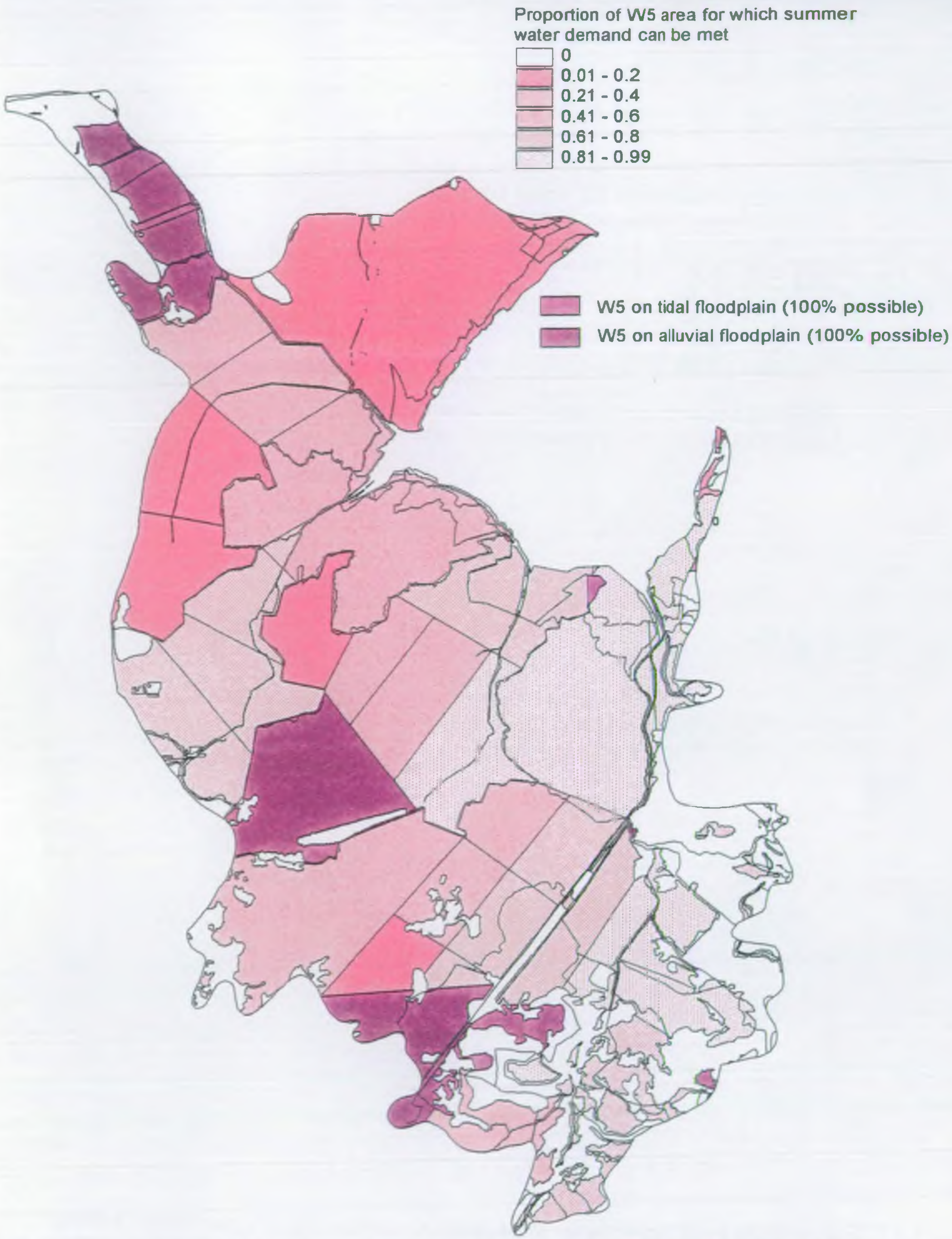
Map 3-2 Area meeting level 3 criteria for MG13 inundation grassland on pondable soils in The Fens Natural Area



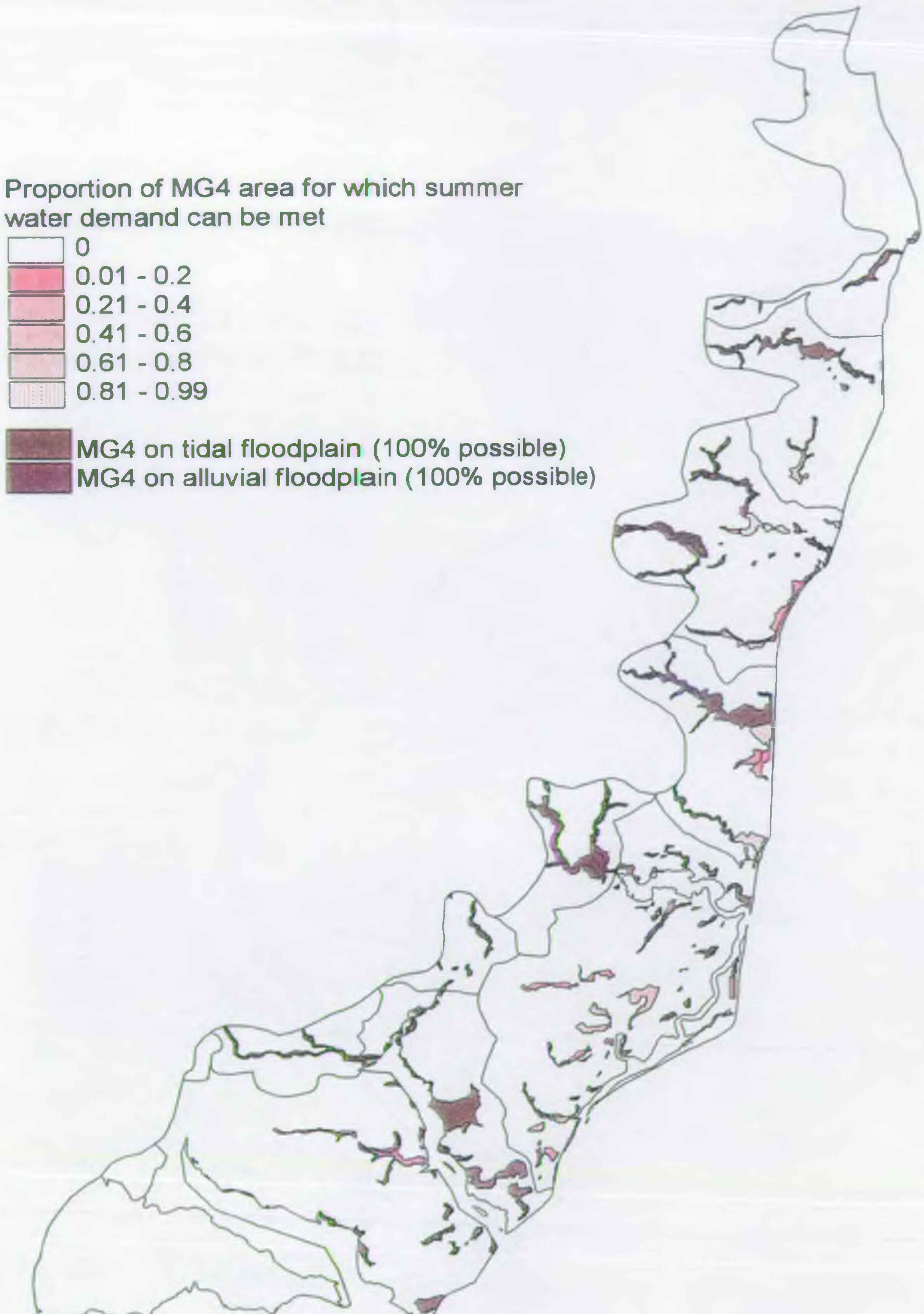
Map 3-3 Area meeting level 3 criteria for S4 reedbed on pondable soils in The Fens Natural Area



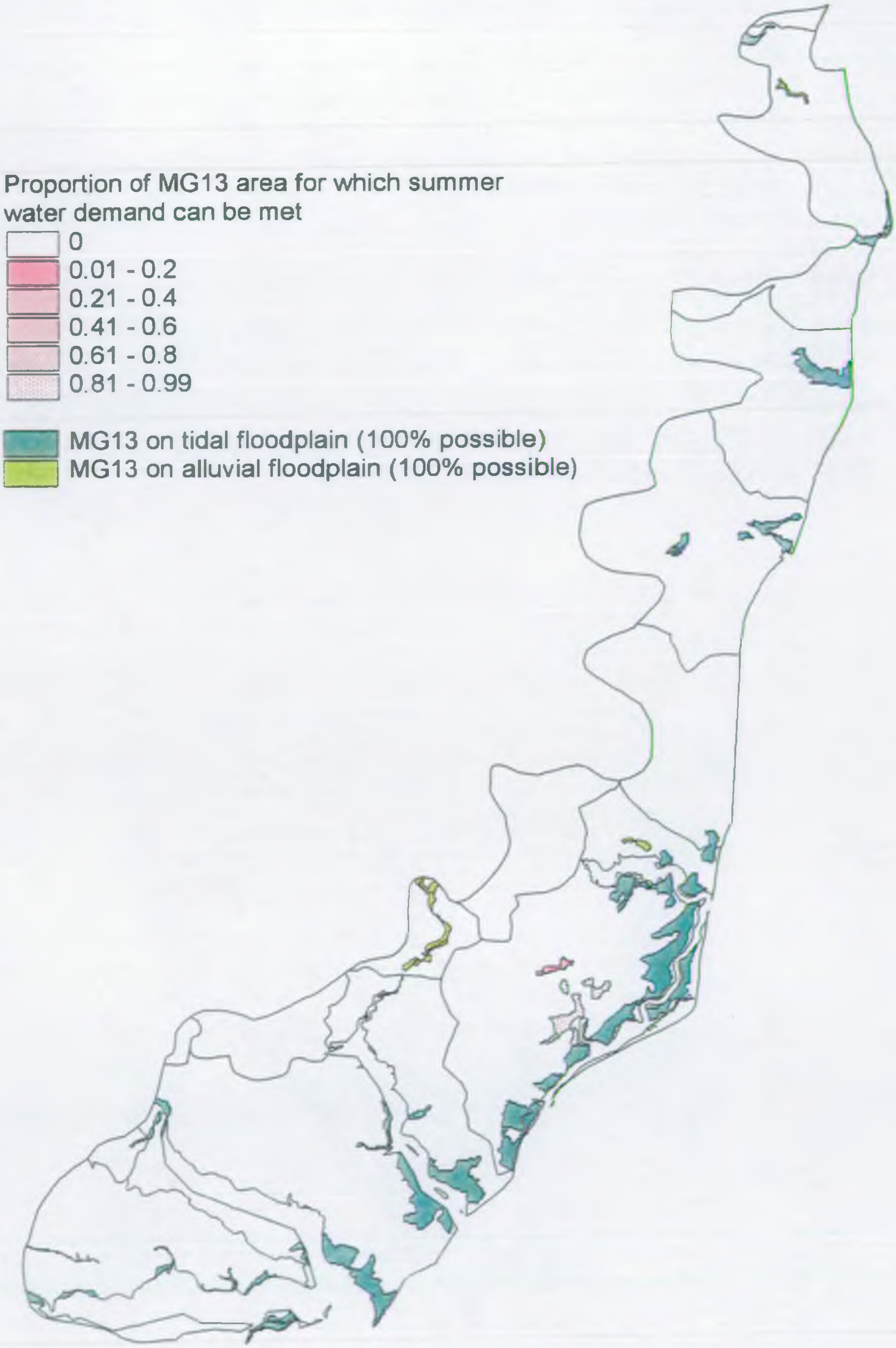
Map 3-4 Area meeting level 3 criteria for S25 fen on freely draining soils in The Fens Natural Area



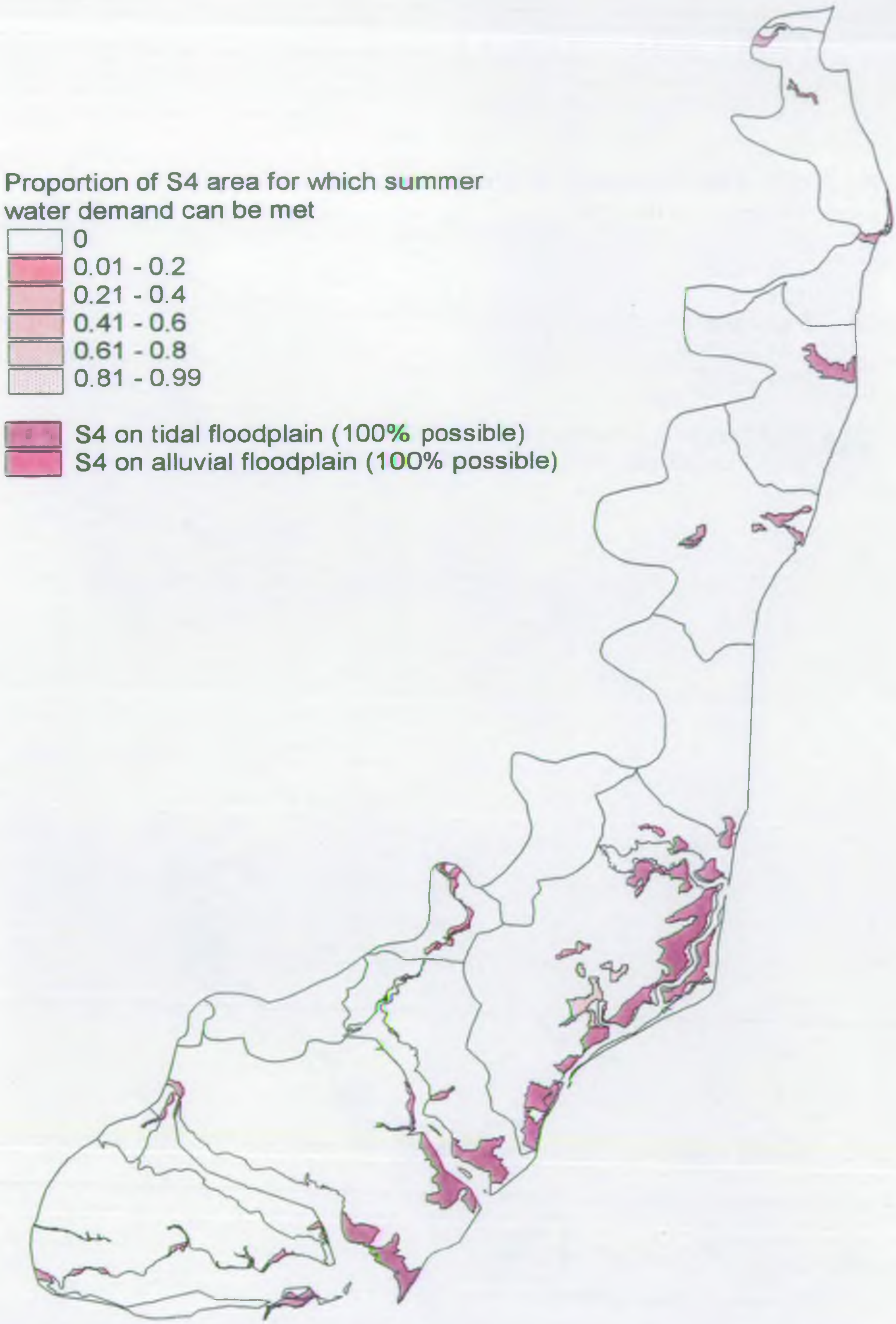
Map 3-5 Area meeting level 3 criteria for W5 wet woodland on pondable soils in The Fens Natural Area



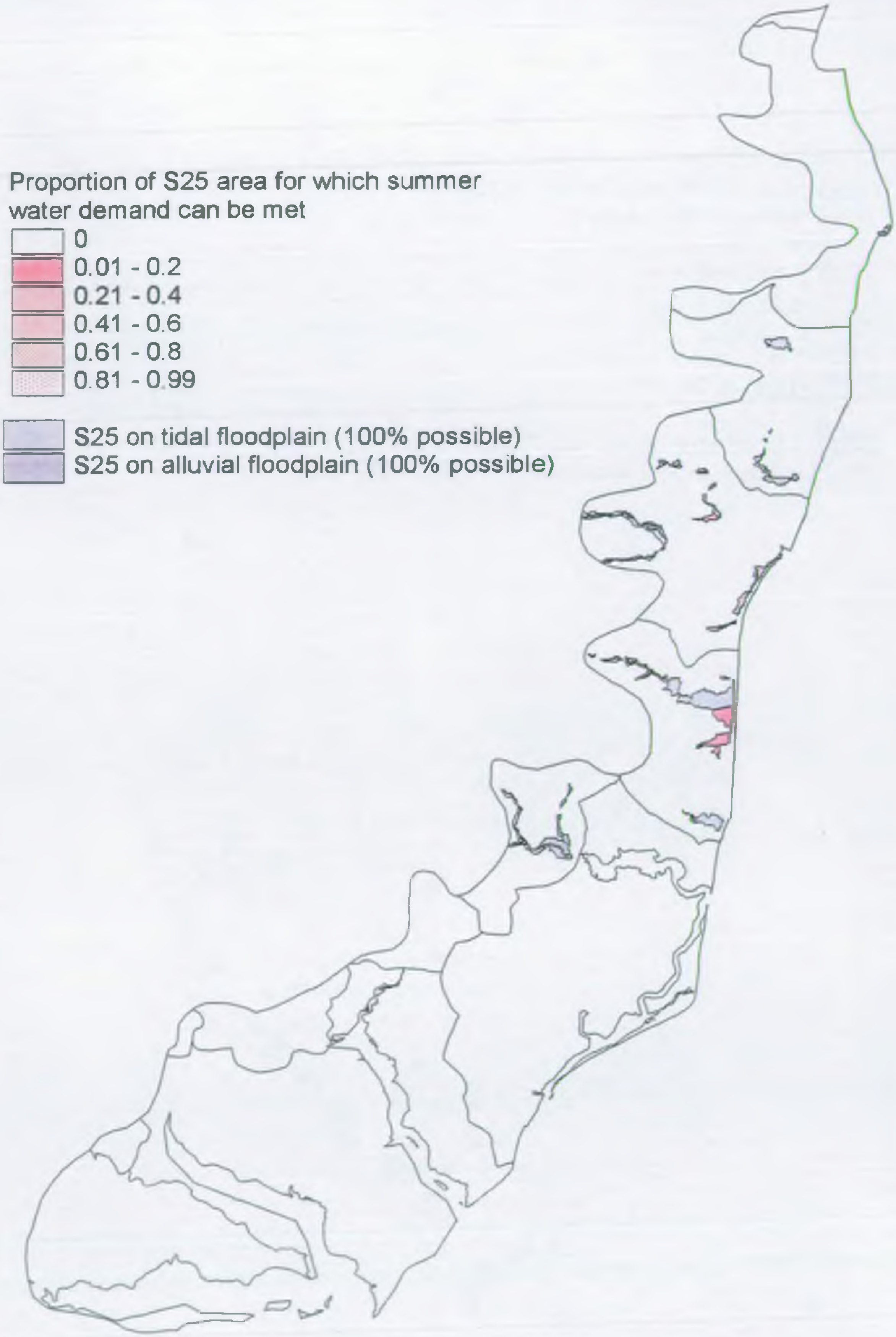
Map 3-6 Area meeting level 3 criteria for MG4 species rich flood meadow on freely draining soils in the Suffolk Coast Natural Area



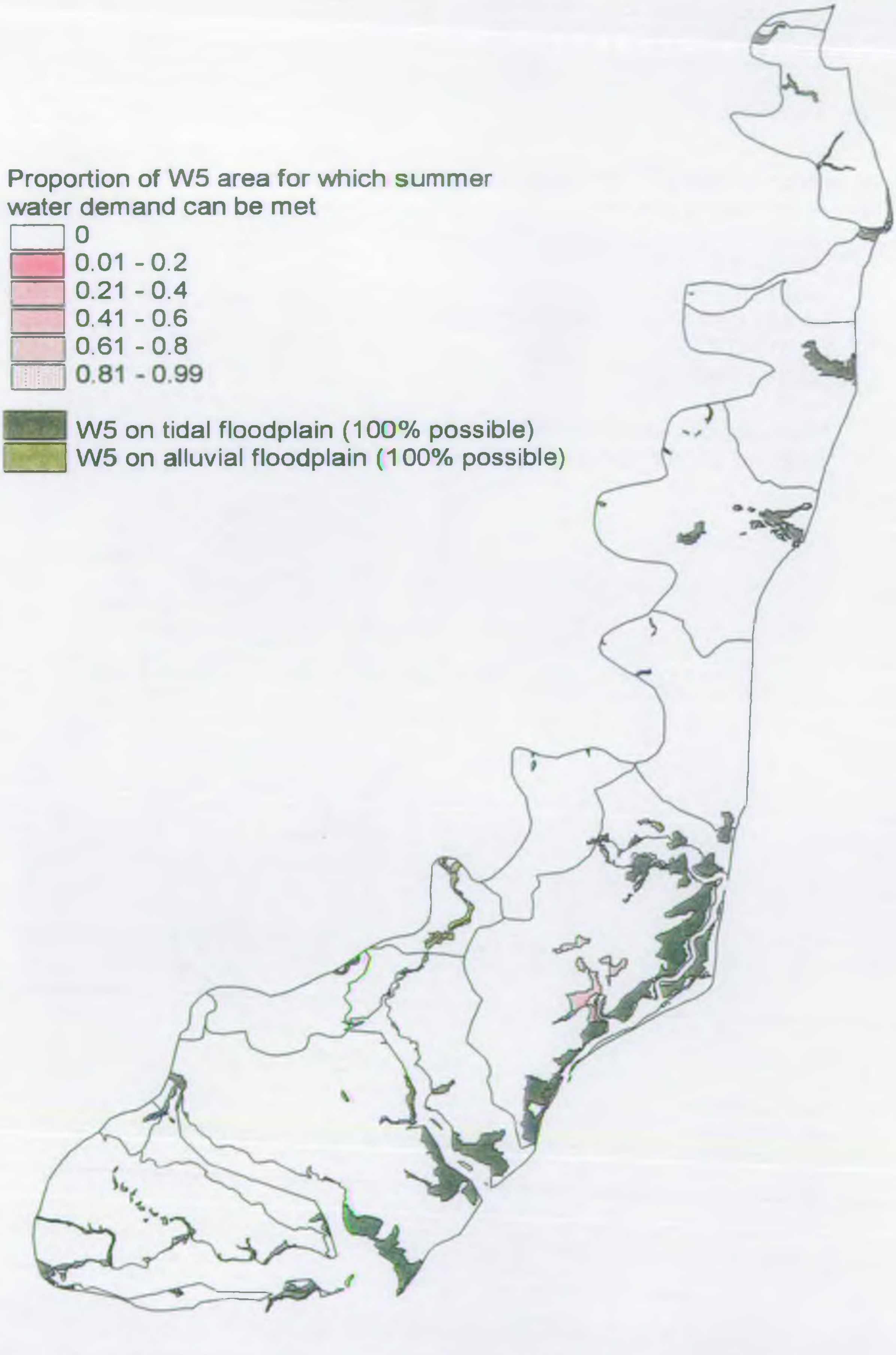
Map 3-7 Area meeting level 3 criteria for MG13 inundation grassland on pondable soils in the Suffolk Coast Natural Area



Map 3-8 Area meeting level 3 criteria for S4 reedbed on pondable soils in the Suffolk Coast Natural Area



Map 3-9 Area meeting level 3 criteria for S25 fen on freely draining soils in the Suffolk Coast Natural Area



Map 3-10 Area meeting level 3 criteria for W5 wet woodland on pondable soils in the Suffolk Coast Natural Area