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A CORINE MAP OF GREAT BRITAIN BY AUTOMATED MEANS: A FEASIBILITY STUDY

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CONTENTS

EXECUTIVE SUMMARY

1. The European Commission (EC) programme 'Co-ordination of Information on the Environment' (CORINE) includes a major project to map the land cover and land use of member states.

2. The CORINE land cover map, produced by visual interpretation and manual digitising, shows 44 cover types, in vector format (ie as digital map outlines) at 1:100 000 scale, with a minimum mappable unit of 25 ha.

3. The Land Cover Map of Great Britain (LCMGB) gives a raster (ie grid-based) map which records cover on 25 m cell size, identifying 25 cover-types, with a minimum mappable unit of 0.125 ha, showing landscape patterns at the field-by-field scale.

4. This study aimed to:
   - i identify how far automated means could be used to convert the LCMGB to CORINE requirements
   - ii. assess needs and methods for additional contextual and interactive processing
   - iii. to evaluate the methods in terms of effectiveness and efficiency

5. A trial area, 100 km x 100 km in north-east England, mostly in Yorkshire, was subsampled within an image analysis system, to give a 50 m cell size, and filtered to remove the smallest polygons. The resulting map was exported to a geographical information system (GIS) and converted to vector format giving digital outlines of 105 000 polygons. Those polygons less than 2 ha were dissolved into their surrounding class, reducing the total number to about 45 000.

6. Polygons greater than 25 ha were allocated as output to the appropriate CORINE class, giving an archive file covering over 79% of the 100 km square. Then, neighbouring polygons of like cover were grown together and, if greater than 25 ha, allocated to the output. This polygon merging process removed about 4000 polygons and increased the coverage of greater than 25 ha polygons to about 80%.

7. CORINE mosaic classes, were created by removing the boundaries between two or more relevant cover types: if composite polygons were greater than 25 ha they were output to the appropriate CORINE mosaic class. This procedure formed about 6000 composite polygons giving an archive file with 98% cover. The remaining 3000 isolated polygons, each less than 25 ha in extent and in total covering just 2% of the area, were dissolved into the surrounding class.

8. CORINE maps identify elements of land use: the final stage re-examined images and maps, using external data where available, to help identify polygons (or parts of polygons) which needed to be re-coded to give a CORINE land use class.

9. The stepped boundary of the original 50 m pixels, 0.5 mm at the final map scale of 1:100 000 and just visible to the naked eye, were removed by splining between the vertices using GIS smoothing functions.

10. Hard copy output maps were printed at 1:100 000 scale. Results were assessed visually against CORINE output made by the usual visual/manual methods. Agreement and map quality were to the satisfaction of the Advisory Group including members of the CORINE Land Cover Technical Unit.

11. The results of this comparison give a fascinating insight into the impacts of generalisation: 82% of pixels showed equivalent cover types in both the LCMGB and CORINE maps. The other 18% which changed classification showed the effects of generalisation.

12. Through generalisation, the more extensive cover types were consolidated while rarer features were either removed, incorporated into mosaic classes or, in complexes of semi-natural cover, labelled according to the dominant component. Thus the overall proportion of arable land increased. So too, urban areas, captured many pixels representing small open spaces. Conversely, areas of suburban and rural development declined through the loss of isolated rural buildings. Losses were recorded in most semi-natural cover types. Deciduous woodland, which often formed small copses and shelter belts, was halved in total extent, despite gains elsewhere through removal of clearings in larger woods; larger blocks of coniferous plantation survived almost unchanged in area.

13. Most CORINE classes comprised between 70% and 85% of one LCMGB class: the 15-30% of pixels 'captured' by generalisation were cover types dissolved into their background.

14. The allocation of the original LCMGB classes further emphasised these losses. So 98% of sea pixels were re-mapped to estuary on the CORINE map; 93% of extensive arable pixels stayed as arable; 80% of the more disaggregated agricultural grassland pixels remained as pasture. Just 54% water pixels formed areas of sufficient extent to be retained. Only 35% of deciduous woodland pixels remained as such. A remarkably small 5% of rough grassland pixels were retained. These differences are the natural consequence of using a 25 ha minimum mappable unit.

15. The key phases, from initial raster filtering to final vector smoothing of the raster-based outlines, require on average 11.5 days per 100 km square, with 30 squares in total. Overall costs are likely to be between £150k and £160k for full conversion. Depending on the contractor, additional costs might include licence charges of £167k for the LCMGB and satellite images.

16. Alternative costs of a new CORINE photo-interpretation are estimated at around £1.0million, about 6 times the costs of basic conversion and more than 3 times the cost of if licences are included. Even the full economic costs, including the original high resolution LCMGB at £600k plus CORINE conversion, give a grand total of £767k, a 23% saving on normal CORINE mapping costs.

17. The benefits of automated conversion are far greater than just the simple financial ones. If conversion now goes ahead, CORINE maps will be available for use in a European context, while the more detailed LCMGB will continue to be used for Britain's local, regional and national needs. By undertaking a conversion from the LCMGB to CORINE requirements, the end-product is fully calibrated against the existing map (and all its existing uses). The vital link to ground survey is provided via the Countryside Survey 1990. Inter-conversion avoids the dangers of have two conflicting maps of British land cover. The automated conversion of the LCMGB will also provide a valuable insight into the effects of generalisation in the production of all the CORINE maps for other countries. Operation at national scale may demonstrate the way forward for future updates throughout Europe, where other member states can also reap the benefits of high resolution mapping while maintaining the European context provided by CORINE maps.

1. INTRODUCTION

1.1 The European Commission (EC) programme 'Co-ordination of Information on the Environment' (CORINE) includes a major project to map the land cover and land use of member states.

1.2 The CORINE land cover mapping procedure specifies an end-product which is standard for all of the member states and which is being adopted widely for use in bordering countries of Scandinavia, Eastern Europe and North Africa. In brief, it aims to map land cover into 44 types, in vector format, at 1:100 000 scale, with a minimum mappable unit of 25 ha (Anon, 1992). The procedures involve paper-copying of satellite digital data, visual interpretation of outlines and manual digitising of linework. Mapping can draw on any external source of information including existing maps. However, no other CORINE surveys have adopted automated techniques for conversion of existing digital maps.

1.3 In Great Britain there are strong grounds for developing semi-automated techniques. Britain has been mapped by an automated classification of Landsat Thematic Mapper data. The Land Cover Map of Great Britain (LCMGB) gives a raster database which identifies 25 cover-types (Appendix 1), with a minimum mappable unit of 0.125 ha (Fuller, 1993; Fuller & Groom 1993 a & b; Fuller, Groom & Jones, in press), recording landscape patterns at the field-by-field scale (Figure 1). The existence of this detailed cover-map of Great Britain gives the possibility of spatial generalisation and addition of supplementary information from other sources to meet the CORINE requirements.

1.4 The DoE's policy aim in supporting this work is to make a UK contribution to the development of techniques for mapping the land cover of Europe using satellite data and to provide land cover data for Great Britain as a CORINE standard product.

1.5 This study has benefited from the support of an Advisory Group, comprising individuals from relevant departments of the DoE and others with direct experience in CORINE mapping and semi-automated techniques (Table 1).

Table 1. The CORINE feasibility study Advisory Group

Mr R Bendall	Department of the Environment, WACD
Dr S Briggs	British National Space Centre
M. M Cornaert	Commission of the European Communities, DGXI
Dr A Cross	Commission of the European Communities, DGXII
Ms L Farrington	Department of the Environment, EPS
Mrs H Hillier	Department of the Environment, EPS
Mr I Kanellopoulos	Joint Research Centre, Ispra
Mr G Mitchell	Ordnance Survey for Northern Ireland
Mr J Phillips	Welsh Office
Dr P Saunders	Department of the Environment, CSG
Mr C Steenmans	Commission of the European Communities, DGXI
Dr A Stott	Department of the Environment, WACD
M. R Uhel	Institut Francais de l'Environment
Dr S Webster	Department of the Environment, WACD
Mrs D Wikinson	Scottish Office

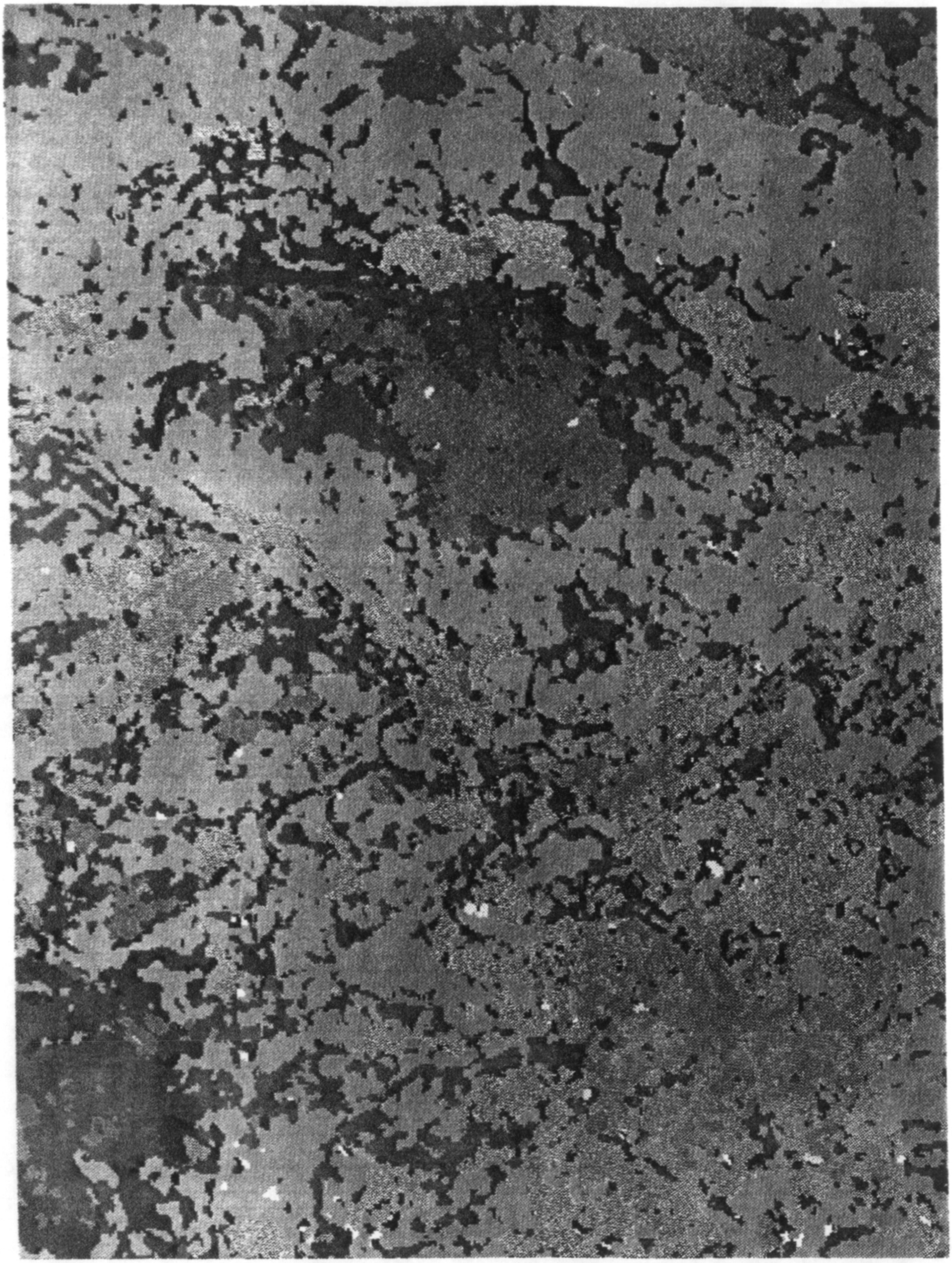

Figure 1. A sample section, around Bradford, Yorkshire, at 1:100 000 scale, of the Land Cover Map of Great Britain. Predominant cover types are: urban development (class P (Appendix 1) - dark grey), suburban / rural development (O - light grey), pasture / meadow / amenity grass (F - green), tilled (N - dark brown), deciduous (K - red), rough pasture / dune grass / grass moor (E - light brown) and grass / shrub heath (H - pink).

2. AIMS OF THIS STUDY

2.1 The aims of this study were:

- To develop and demonstrate a methodology, using automated techniques, to convert a trial area of the existing ITE Land Cover Map of Great Britain to give a product satisfying CORINE Land Cover Map specifications

- To recommend an optimal methodology for CORINE conversion for all of Great Britain

2.2 Specifically, the objectives were:

- To identify how far automated means could be used to convert the LCMGB to CORINE requirements

- To assess needs and methods for additional contextual and interactive processing to meet CORINE specifications

- To evaluate a range of different methods in terms of their effectiveness and efficiency (ie map quality, and 'cost-benefit')

3. OUTLINE METHODOLOGY

3.1 The aim of the procedure has been to produce an output map which generates results comparable with those from visual interpretation and manual mapping methods as used elsewhere for CORINE Land Cover mapping. The approach has used, as far as was possible, automated methods of data generalisation and class re-assignment (Appendix 2), to deal with the majority of situations. Those cases which were not susceptible to treatment in this way were handled by manual intervention. The procedures have been developed and tested in a 25 x 19 km sample study area, extended to a 25 km square and finally implemented in a 100 km x 100 km 'tile', spanning from the Pennines on the north-eastern outskirts of Manchester, east to the estuary of River Humber near Kingston upon Hull, and north to Richmond and the North York Moors (Ordnance Survey code 'SE', south-west corner British National Grid Reference 400400) selected to encompass a wide variety of landscapes.

3.2 The fundamental process employed in this study is one of map generalization (Appendix 3). An experienced cartographer will often need to simplify detail when generalizing. This may involve the smoothing of boundaries, aggregation of mixtures of cover types into a generalised class, removal of small isolated polygons and/or the inclusion of small outlier polygons with larger nearby polygons of the same class. Conversion of the map to CORINE classes at this stage is done both automatically and interactively. Some LCMGB land cover classes have close CORINE equivalents; these are automatically renumbered to CORINE classes. Some CORINE classes are a combination of two or more LCMGB land cover classes and can be joined together automatically (Appendix 2).

3.3 The methodology to achieve these steps automatically from the LCMGB has comprised the following stages:

- A review of past experience with automated procedures for CORINE mapping
- Filtering of the full resolution land cover map
- Export to GIS as raster data
- Temporary tessellation of the map before vectorisation
- Identification of individual land parcels
- Removal of very small polygons
- Extraction of 25 ha parcels with direct CORINE equivalence
- Growing clusters of smaller polygons together
- Analysis and classification of polygons comprising a mosaic of several classes
- Assignment of parcels less than 25 ha to the most appropriate neighbouring class
- Use of 'exogenous' data and expert interpretation to identify CORINE land uses
- Smoothing of polygon boundaries
- Measurement of differences between input and output maps
- Comparison with CORINE interpretation example.
- Production of output reports and plotting of maps

3.4 The operation of these methods is summarised in Appendix 3. As the procedures progressed, archive copies of the files were kept at each significant stage, so that later analysis could draw on the earlier detail, if needed.

4. THE PROCEDURES IN PRACTICE

4.1 Review

4.1.1 Attempts at automated production of CORINE-standard maps have been made by several groups. Some unpublished details have been supplied by the CORINE Land Cover Technical Unit. These are briefly outlined below.

4.1.2 In the Netherlands (Periodic Report 9/10/90, Wageningen), automated CORINE mapping was based on a 25 m raster-based map produced from Landsat TM and SPOT data. The procedure used filtering (3 times using a 3 x 3 kernel majority filter) before conversion to vector and analysis as vectors in ARC/INFO. Results in the Netherlands caused the decision to opt for the full visual/manual methods of CORINE. However, while many of the procedures used in the Netherlands were similar to those advocated here, many of them differed substantially in practical terms from those proposed for use in Britain: for example, in the rejection of small polygons without clustering or production of mosaics.

4.1.2 In Sweden, a pilot project was undertaken by the Swedish Environmental Protection Agency, the Department of Physical Geography in Stockholm, the National Land Survey in Luleå, the Centre for Image Analysis in Kiruna (Nordic CORINE Land Cover meeting 7-8/9/93). The procedure used ARC/INFO GRID to generalise to CORINE standards. As a result, CORINE mapping of Sweden is to take the form of a combination of automated mapping with manual interpretation.

4.1.3 In Finland (CORINE Land Cover meeting, Helsinki, 4/9/93), researchers combined 1:50 000 topographic maps and statistical data with supervised classification of satellite data. Results were analysed in ARC/INFO GRID. Again, CORINE mapping in Finland is to take the form of a combination of automated mapping with manual interpretation.

4.1.4 A paper by Goffredo *et al.* (1993) outlines vector-based procedures for generalisation. Müller and Zeshen (1992) describe methods for generalisation of multiple small polygons by methods similar to those used in this study.

4.2 Raster filtering

4.2.1 The LCMGB includes land parcels down to 0.125 ha, though these are only shown where a feature has a strong spectral signature which distinguishes it from surrounding classes: realistically, the minimum unit which is mapped consistently is 1 ha in extent (Fuller *et al.* in press) and possibly up to 2 ha (Townshend, 1983). CORINE only shows minimum units of 25 ha. Therefore, spatial generalisation is a key part of the conversion process. Such generalisation is much quicker using raster resampling and filtering, but such raster processes tend to erode polygon outlines if applied too coarsely. CORINE maps are plotted at 1:100 000 scale, where the 25 m raster of the LCMGB will be represented as 0.25 mm units, in vector format, smoothed to remove the serrated raster outlines. So, again, generalisation is required.

4.2.2 Raster pre-processing operations were developed following tests using resampling to 50 m, 75 m, and 100 m grids by subsampling to include every second, third and fourth pixel respectively. Such resampling caused some break-up in image structure which was improved by raster filtering. A 3 x 3 kernel filter was passed across the images and two filtering procedures were used: first, a majority filter which set the central pixel to the class of the majority component of the 3 x 3 kernel window; second, as a final clean-up operation, an isolated filter which only removed singleton pixels in the centre of the 3 x 3 kernel window. Similar procedures were tried using coarser kernels (5 x 5, 7 x 7).

4.2.3 Visually, the coarser 75 m and 100 m cell-sizes over-simplified the image structure and were not felt to be comparable with the products of visual/manual interpretation. Similarly, coarser majority filtering produced eroded shapes, failing to preserve corners of fields, linear features and other potentially relevant detail. It was therefore decided to use a resampled 50 m raster with majority and isolated filtering. This gave a product which did not lose too much of the detail of the original whilst reducing the dataset to a quarter of its original size. The 50 m pixels provided 0.5 mm spacing of vertices on vector outputs at 1:100 000 scale; these have been interpolated in the final smoothing process, thereby giving a structure which is visually acceptable.

4.3 Export to GIS as raster

4.3.1 It is possible to use ARC GRID to handle raster data or alternatively to convert to vector before continuing analyses. Either way, the process must start to handle the data for entire land parcels, whether as grouped raster pixels or as vector polygons.

4.3.2 ARC GRID allowed grouped pixels to be identified and allowed manipulation of such groups to simplify boundaries. But the boundary simplification procedures, when tried in raster, gave unsatisfactory results. It was therefore decided that continuing analyses would be made in vector format.

4.4 Tessellation and subsequent vectorisation

4.4.1 ARC/INFO limits single polygons to a maximum of 10 000 segments. Large or complex polygons cause ARC/INFO software to fail. As a result it was impossible to complete raster-to-vector conversion of the 50 m pixel image. It was therefore necessary to subdivide the 100 km x 100 km (2000 pixel x 2000 pixel) square into smaller units. Rather than cutting the map into smaller sections and then having to repeat every analytical process on each, a 'chequer board' pattern was added to the intact original file thereby artificially subdividing the polygons which exceed the maximum line segment limit (and indeed many others). This chequer pattern comprised 4 large squares across and 4 down, ie each square was 500 x 500 pixels, equivalent to 25 km x 25 km on the ground. Values in the squares of the 'chequer board' were alternate 100s and zeroes. As a result, the raster classes 0-25 became 100-125 in alternate squares and no one polygon could extend further than one-sixteenth of the way across the map area. When vectorized, an 'artificial' join was created across adjoining squares. This was later removed without affecting the subsequent analysis of polygon patterns.

4.5 Identification of individual polygons

4.5.1 In vector form, the data were handled as individual polygons. At this stage, prior to any further simplifications, the 100 km square contained about 105 000 polygons.

4.5.2 It would have been possible at this point to smooth the vector outlines before ongoing analyses. However, it was decided that such boundary generalisations would be better applied when final polygons were completed and hence the final pixel-content had been determined.

4.6 Removal of very small polygons

4.6.1 Many of the original vector polygons were very small in relation to a final mapping unit of 25 ha. It was therefore decided to remove the smallest polygons from the vector map as a first step. A rejection threshold of 2 ha was chosen because:

- there was some uncertainty regarding the consistency of mapping polygons of less than 2 ha (Townshend 1983),

- such a size represents less than 10% of the final minimum mappable units

4.6.2 This size limit determined that less than 8 pixels per parcel should be the rejection threshold. Removal was generally done using a either ARC/INFO 'eliminate' or 'dissolve' functions. 'Eliminate' removed the boundary between the target small polygon and the largest surrounding polygon, reclassifying the small polygon to that of the larger one. 'Dissolve' was used where adjoining polygons were to be combined into one, for instance, where a mixture of ITE land cover classes combine to form a single CORINE class. Elimination of these very small polygons reduced the number of polygons to about 45 000.

4.7 Extraction of 25 ha parcels equivalent in CORINE classification

4.7.1 At key stages throughout the process, polygons corresponding to land parcels of greater than 25 hectares, within the CORINE classification, were saved to an archive version of the file in both raster and vector formats. These polygons formed the basis of the final map as it gradually built together to form a complete coverage of land cover parcels. This process was first carried out after the initial removal of very small polygons. The result was an archive file covering over 79% of the 100 km square. These polygons, along with others, were later re-coded to CORINE classes.

4.7.2 Some polygons greater than 25 ha had been artificially split by the addition of the 'chequer board'. It was necessary to 'dissolve' the artificial boundaries created by the 'chequer board' technique, apart from the few exceptional circumstances where they were needed to retain polygons of less than 10 000 segments. It was noted that, for this 100 km square, the polygon size problem was only likely to relate to two land cover classes, arable and grass: less extensive classes were unlikely to form oversize polygons. So boundaries were removed successively (eg a boundary between class 1 (inland water) and class 101 (water plus 100) were deleted). In the event, only arable land was too extensive for all polygons to be stored intact. After the dissolving of all, (except arable) classes crossing the chequer board boundary, 1198 new polygons greater than 25 ha resulted. Eventually it will be necessary to re-aggregate arable polygons that remain artificially divided by the chequer board boundary. However, this problem (common to all CORINE mapping) cannot be solved until the release of Version 7 of the ARC/INFO software.

4.8 Growing polygons together

4.8.1 Image analysis processes have used various filtering techniques to first grow, then re-shrink regions, so as to merge clusters of small polygons. However these processes cause an unwanted 'smoothing' effect on the output shapes. A GIS method has been developed for this project, making use of several processing functions within the ARC/INFO system. In the ARC GRID package several 'raster modelling' functions have been used. First, groups of like pixels were analysed to give the optimum path between them (i.e the shortest distance). Second, the result was converted to a 'cost' per pixel that relates to their distance from the source group of pixels. These values were then 'resampled', preserving pixel size, to give a range of pixel values. These values were zero within source polygons and many hundreds further away from the source. Although fairly low values are produced next to all the source pixels, the lowest are found exclusively where two groups of source pixels are very close together. A series of trials were then carried out by the simple selection of maximum pixel values to assess the most accurate identification of pixels between the source groups. These pixels, as represented in vector form, identify the joining area between close polygons of the same class.

4.8.2 This process was carried out on individual classes and the results combined together. The result is the successful growing together of close polygons thus generalising their shape. Although small indentations in polygon boundaries are also frequently 'filled in', this is a standard feature of cartographic generalisation and was acceptable, even desirable. This process of reclassifying pixels to a completely different class necessarily altered the totals of pixels within certain classes. In broads terms the gains and losses balanced out with only minimal changes in areas. These were compensated by a much better representation, at 1:100 000 scale, of polygon patterns along boundaries, of linear features etc. This polygon merging process removed about 4000 polygons and increased the coverage of polygons greater than 25 hectares to about 80%.

4.9 Analysis and classification of 'mosaic' or composite polygons

4.9.1 At this stage there remained about 35 000 small polygons (i.e. polygons of less than 25 hectares in size). Individually these were too small to include in the final 1:100 000 scale map but collectively they could form significant patterns in the landscape. This was most noticeable where they joined together in complex mosaics. Such classes as '*2.4.2 complex cultivation patterns*' are key features of the CORINE map and require identification within the conversion of the LCMGB.

4.9.2 Appendix 4 gives a flow diagram of decisions leading to the reclassification of these complex areas. In essence it involved making a vector overlay by dissolving the internal boundaries within clusters of adjoining small polygons. This overlay formed about 6000 composite polygons. The resulting vector outlines were displayed on top of the detailed land cover in raster form. The decision rules detailed in Appendix 4 were then applied and the complex polygon assigned the appropriate CORINE target class.

4.9.3 The initial decisions involved automatic processes where many selected polygons were classified with a single command. On completion of this interactive classification the new resultant polygons greater than 25 ha were incorporated into the archive file which was then 98.1% complete. In the CORINE mapping of Britain, this stage would be fully automated using the 'zonal analysis' capabilities of the ARC GRID package.

4.10 Assignment of remaining parcels

4.10.1 The 3000 polygons which remained at this stage were less than 25 hectares in size, separate from other polygons and generally isolated in nature. In the majority of cases they were not significant for mapping at 1:100 000 and were dissolved into the surrounding land cover class.

4.11 Use of 'exogenous' data and expert interpretation to subdivide into CORINE classes

4.11.1 CORINE maps identify elements of land use: for example they differentiate land used for airports, leisure or industry. Such information was not readily classifiable from images despite often being discernible using visual interpretation. The final stage re-examined images using external data to help identify polygons (or parts of polygons) which needed to be re-coded to give a CORINE land use class, such as *Port areas* (1.2.3), *Airports* (1.2.4) or *Sport and leisure facilities* (1.4.2). Within this test square it was deemed sufficient to interpret directly from the raster-map using 1:50 000 Ordnance Survey maps to help identify these land use types. However, in Advisory Group discussions, ITE made it clear that future extensions to all of Britain would draw upon existing external data. Pilot's maps might identify airports in current use. It has been suggested that *Dump sites* (1.3.2) might be identified from the Water Research Centre GIS (D Salathiel, personal communication). Information on mineral extraction sites (1.3.1) might come from DoE (D Salathiel, personal communication). Elsewhere, it will be necessary to overlay the draft vector map onto the original imagery to interpret land use in exactly the same way as the usual manually interpreted CORINE maps.

4.12 Smoothing of polygon boundaries

4.12.1 Until this point, the map retained the stepped boundary shapes resulting from the resampled 50 m pixels. These steps are 0.5 mm in size at the final scale of 1:100 000 and just visible to the naked eye. In order to simplify and smooth the polygon boundaries, it was necessary to 'spline' between the vertices using ARC/INFO line smoothing functions.

4.12.2. Splining was a two-step process. First the ARC/INFO 'generalize' was used to remove the stepped effect by interpolation of pixel sides, using a 60 m 'weed' tolerance (ie distance between vertices). This resulted in the removal of stepped lines in the horizontal/vertical directions but created sharp corners where diagonals met: so, for example, a stepped pyramid took the naturally sloping sides but incorporated a sharp peak. To round these artificially generated angles, the 'spline' process was used with a 'grain size' of 45 m (ie maximum deviation from the original line). This produced the best compromise between retention of false angularity and the creation of artificial curves which would have given features a 'jigsaw' outline. The results were considered fully acceptable at the 1:100 000 examination and plotting scale (Figures 2 & 3), with boundaries retained within a line's width of their original position.

4.13 Outputs

4.13.1 Hard copy output maps were printed at 1:100 000 scale. Figure 2 shows vector outlines of 25 ha polygons derived from the preceding semi-automated analyses. Figure 3 shows the same area as filled polygons using standard CORINE colours.

4.13.2 The full 100 km square has been printed from the vector data on a Versatec plotter using standard ARC/INFO software to write a 'Postscript' file for plotting at 450 dots per inch. This resolution allows the plotting of linework with vector-quality, and permits polygon infilling with solid colour.

4.13.3 It is intended to incorporate the CORINE land cover data for Britain into the Countryside Information System (CIS). The CIS is designed for the desk-tops of planners and environmental managers, who can readily access and manipulate quantitative geographical information via the familiar 'Windows' environment on a personal computer (Haines-Young *et al.*, 1994 & in press). In the CIS, the original 25 m LCMGB data are summarised as percentage cover, per 1 km square, for an aggregated list of 17 classes (Appendix 1): the CORINE map might be summarised on the same basis. With 44 classes, this could potentially add 44 layers of extra data to the CIS. However, the CORINE map with its 25 ha minimum units records details at a resolution which approaches the 1 km summary level of the CIS. It is inappropriate that the construction of the CIS CORINE dataset, based on a generalisation of the LCMGB, would result in an output file 2.6 times the size of the LCMGB input to the CIS. A reduction in the size of the CIS CORINE dataset might be achieved by aggregating classes into a shortlist of CORINE cover types. For example, this might be at CORINE level 2, which would produce just 15 layers of cover (and the 2.1 irrigated category could probably be omitted). But aggregation of broad-leaved (3.1.1) and coniferous (3.1.2) forests might be considered undesirable for applications purposes. Discussions will continue between the DoE and ITE to determine and test a sensible strategy for incorporating the CORINE data into the CIS; this will be completed in time for application throughout Britain.

4.14 Qualitative assessments

4.14.1 The research specification did not require intercomparisons between the automated procedures and the standard methods of CORINE visual interpretation. The DoE decided that such an exercise would be expensive and of little additional benefit at this stage, there being no simple way of determining which map was the more accurate. The aim was, thus, not a final evaluation of alternative methods but rather to ascertain whether the general principles of automated conversion to CORINE maps could work.

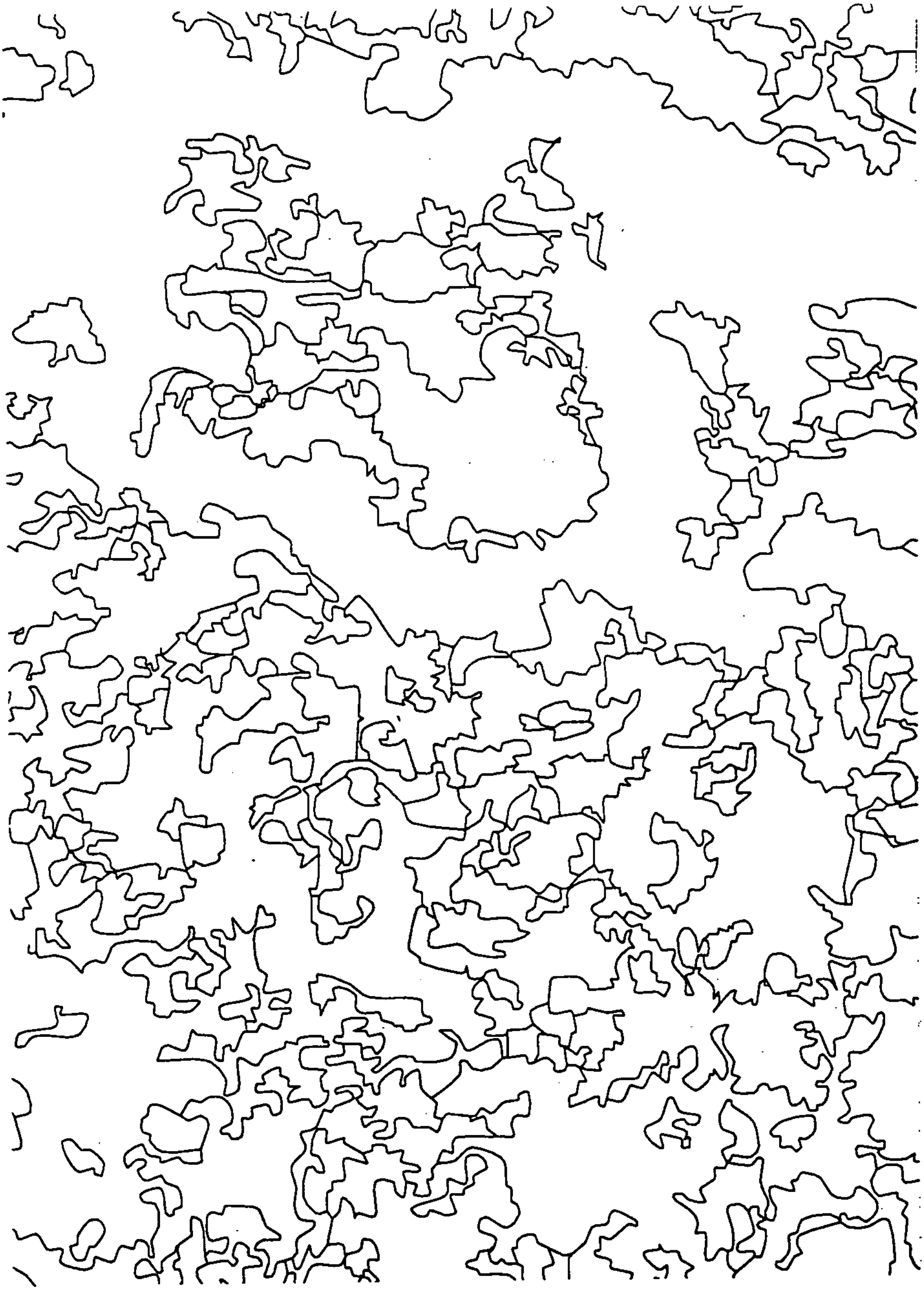

Figure 2. Vector outlines of 25 ha polygons derived from the semi-automated conversion to the CORINE map, plotted at 1:100 000 scale: the map section is as shown in Figure 1.

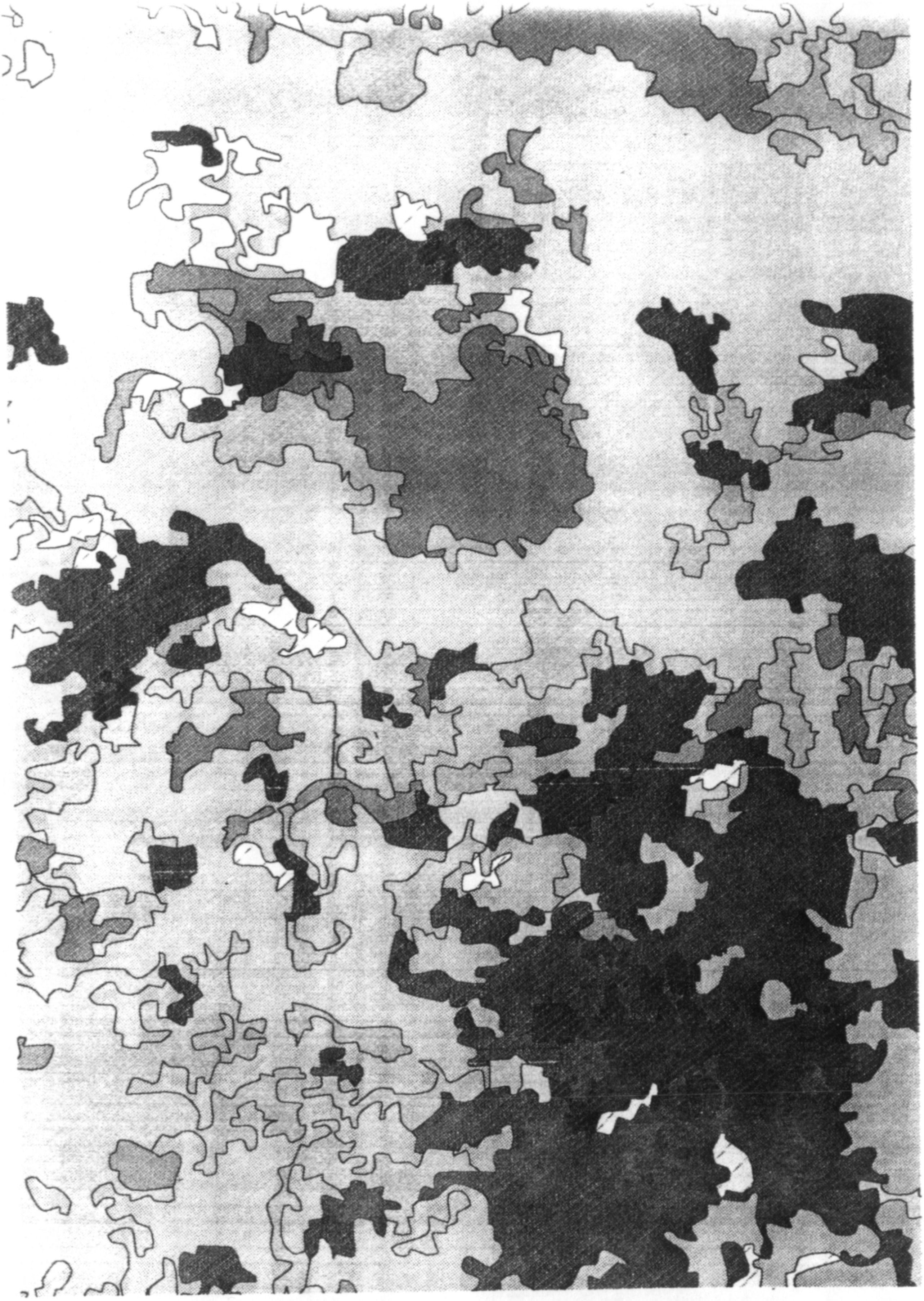

Figure 3. A sample section (area as in Figure 1) of the CORINE map plotted at 1:100 000 scale. Colours are: continuous urban (1.1.1 - red), discontinuous urban (1.1.2 - pink), pastures (2.3.1 - buff), arable (2.1.1 - yellow), complex cultivation patterns (2.4.2 - cream with cross-hatch), broad-leaved forest (3.1.1 - mid-green), mixed forest (3.1.3 - dark green), natural grasslands (3.2.1 - pale green), moors (3.2.2 - grey-blue), peat bogs (4.1.2 - grey-mauve), water (5.1.2 - blue).

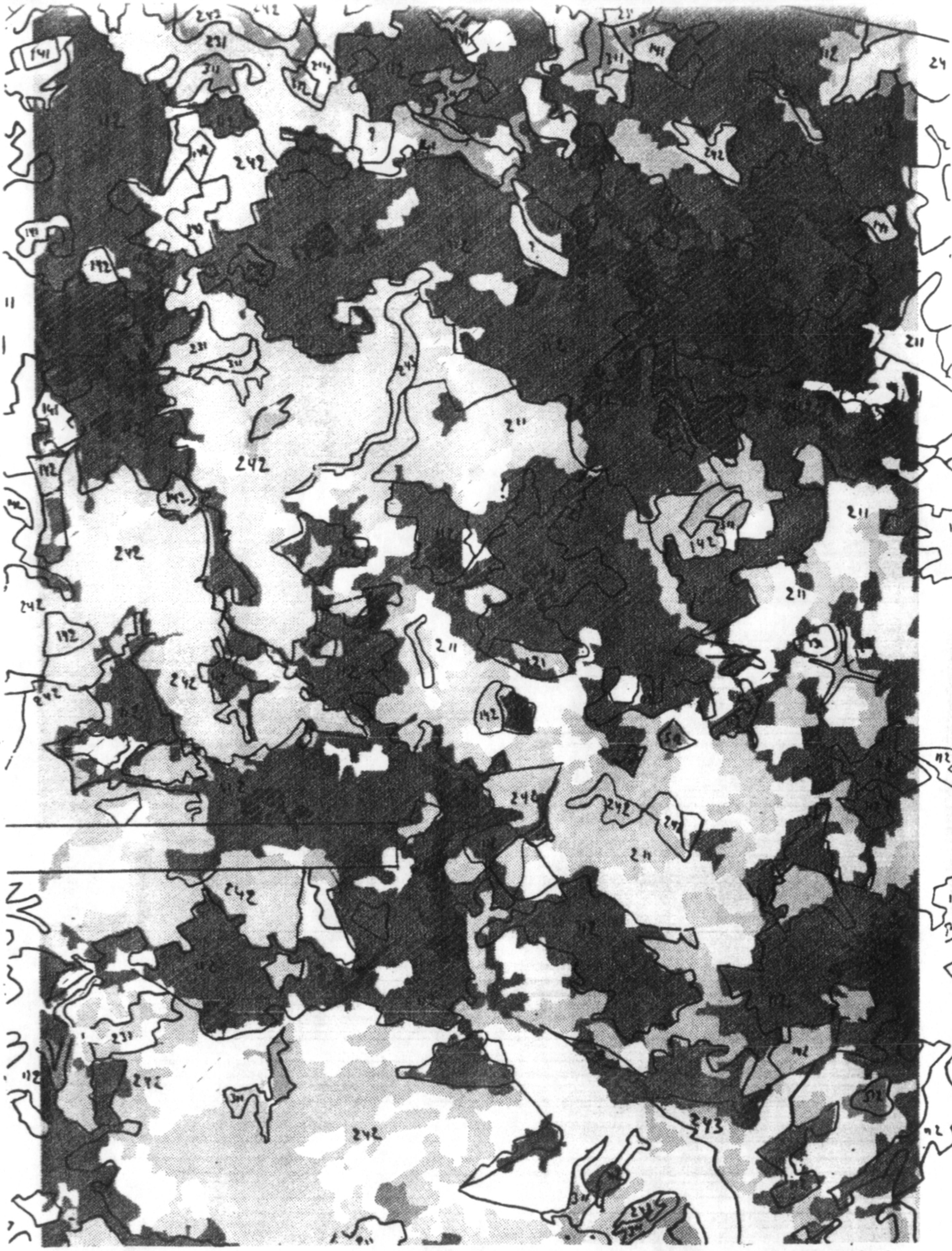

Figure 4. An 18 x 25 km section of the CORINE land cover map, south-east of Bradford (overlapping with Figure 3), at approximately 1:100 000 scale, overlayed with manually interpreted outlines (colours as in Figure 3). Note that the outlines have been drawn and assembled as a mosaic from 6 photographic prints: scale distortions in photographic printing have not been corrected, so exact fit is not possible. The unmapped portion represents a gap in the photographic coverage.

4.14.2 Because the aim was to match visually interpreted products, it was considered realistic for assessments of results to be made visually. For purposes of comparison, Chris Steenmans of the CORINE Land Cover Technical Unit provided maps of cover made by visual interpretation of hard copy images at approximately 1:100 000 scale using a study site representing about one-fifth the original 100 km square. It must be emphasised that this interpretation was preliminary in nature, and was intended primarily as guidance to the output requirements of the semi-automated process.

4.14.3 To make broad comparisons, the GIS automated map was rescaled to match the approximate 1:100 000 scale of the hand-drawn outlines - it is far easier (and perfectly valid for visual assessment) to alter the scale of the GIS product rather than to rescale the tracings on transparent film. The original traced outlines were then overlayed onto a paper print-out of the GIS product. Results (Figure 4) show that hand-drawn outlines match vector outlines very closely at CORINE levels 1 and 2. Often the two overlay so that the one obscures the other. Differences were largely within the bounds of cartographic accuracy or were limited by the accuracy of interpretation. Where significant differences existed, these almost entirely affected CORINE level 3 classifications, reflecting the difficulties for example in dividing the continuous and discontinuous urban areas. It was agreed by both the CORINE team member responsible for the map and the ITE team that the differences were attributable to interpretation where neither could be said to be more correct than the other. It was certainly considered that the automated vector maps were perfectly good alternatives to conventional CORINE manually produced outlines.

4.15 Quantitative impacts of generalisation

4.15.1 It is an inevitable consequence of mapping that the scale and resolution will substantially affect the results obtained - taken to extremes, on global vegetation maps Britain might be shown to comprise a single class such as 'temperate mixed agriculture'. When this generalisation is intended, it cannot be thought of as erroneous. However, statistics quoted from generalised maps may cause confusions and misunderstandings if compared with more detailed examples. What this study has achieved is to fully quantify the impacts of that generalisation, at least insofar as it affects patterns previously mapped at the field-by-field scale.

4.15.2 The impacts of generalisation on the cover statistics for the 100 km square were assessed by examination of the original raster contents within the derived vector polygons. From this analysis, a correspondence matrix has been constructed. Table 2 shows the overall allocation of individual pixels. Table 3 expresses these values per thousand pixels. Table 4 examines how LCMGB pixels are allocated per thousand. Table 5 records how CORINE classes are made up per thousand pixels. Note that the total number of pixels at 3991626 is smaller than the 4000000 which might have been expected. The raster-to-vector process strips the outer perimeter of pixels from the file in conversion. Thus 3992004 pixels were converted to vector data. In subsequent analyses, a very small number of unclassified pixels on the map edge (378 or 0.009%) persisted, where in the middle of the map they were 'dissolved' out. All these facts emphasise the need to incorporate a buffer zone around squares, overlapping with adjacent squares.

Table 2. The allocation of pixels from the Land Cover Map of Great Britain, 100 km square SE, in the automated conversion to CORINE map classes

	urban	suburb	bare	tilled	grazed	meadow	decid.	conif.	grass hth	rough gr.	bracken	hth/moor	scrub	saltmsh	beach	bog	water	sea	unclass'd	
class number	21	20	22	18	6	7	15	16	5	8,19,23	12	9,10,11, 13,25	14	4	3	17,24	2	1	0	
1.1.1 cont urb	34222	4946	531	2189	840		434	5	663	2	44	248					237	5	2	44368
1.1.2 discont.	*16189*	210743	798	19132	18871		3319	32	3485	221	109	2292	114		5	33	426	29	22	275820
1.2.1 indust.	611	*254*	*52*	*26*	*10*		*6*										35			994
1.2.4 airport	92	166	*3*	405	2083	7	50		174		24	17								3021
1.3.1 mineral	57	124	2734	147	261	10	41		68	41		279				113			1	3876
1.4.2 port	10	356		669	3157		925	43	410		127	42				1				5740
2.1.1 arable	10014	59307	7663	1649340	136544	158	37888	2407	11369	1812	4757	5730	477	54	11	509	1276	214	693	1930223
2.3.1 pasture	5123	24303	2160	85679	801445	1464	26594	1840	33418	1279	11432	6924	1122	1	10	377	1039	41	675	1004926
2.4.3 agric/nat	*410*	*1228*	*159*	*5505*	*5730*	*110*	*5434*	903	*5070*	*117*	*1018*	2049	*83*	42	*25*	206	*263*	*11*	*54*	28417
3.1.1 broadlf	398	934	643	3577	4240	21	49412	2431	3107	78	3036	2380	283			132	139		18	70829
3.1.2 conifer	205	176	58	1554	1303	2	2111	46121	674	305	1108	3264	114			90				57085
3.1.3 mixed		14		10	12		90	50	4		44	14		11						249
3.2.1 nat grass	906	3379	672	6944	18920	60	7075	720	182367	272	3899	15047	796			417	739		159	242372
3.2.2 moor/hth	1319	460	809	3154	5316	8	8537	2711	12970	1498	35484	211144	332			3228	319		108	287397
3.2.4 scrub		7		7	6		4		3				95							122
3.3.1 beach			43	8	3										393			33		480
4.1.2 bogs		213	355	289	362	10	33	56	80	51	1	1023				4988	13		46	7520
5.1.1 wtrcourse		2		36	2		1			2							253			296
5.1.2 wtrbody	234	204	8	377	188	5	391	9	272	2	113	98					5615	6	760	8282
5.2.2 estuary	4	171	7	598	326		69			57				123	66		1	18183	4	19609
total	69794	306987	16695	1779646	999619	1855	142414	57328	254134	5737	61196	250551	3416	231	510	10094	10355	18522	2542	3991626

Values in bold are pixels which map directly to an equivalent CORINE class; those in italics map to a CORINE mosaic class. Class names have been abbreviated from Appendices 1 & 2 (refer to class numbers for correspondences). Zeroes represent presence at <0.5 pixels per 1000

Table 3. The proportional allocation of pixels (per thousand) from the Land Cover Map of Great Britain 100 km square SE in the automated conversion to CORINE map classes

	urban	suburb	bare	tilled	grazed	meadow	decid.	conif.	grass hth	rough gr.	bracken	hth/moor	scrub	saltmsh	beach	bog	water	sea	unclass'd	
class number	21	20	22	18	6	7	15	16	5	8,19,23	12	9,10,11, 13,25	14	4	3	17,24	2	1		
1.1.1 cont urb	9	1	0	1	0		0	0	0	0	0	0					0	0	0	11
1.1.2 discont.	4	53	0	5	5		1	0	1	0	0	1	0		0	0	0	0	0	69
1.2.1 indust.	0	0	0	0	0		0										0			0
1.2.4 airport	0	0	0	0	1	0	0		0		0	0								1
1.3.1 mineral	0	0	1	0	0	0	0		0	0		0				0			0	1
1.4.2 port	0	0		0	1		0	0	0		0	0				0				1
2.1.1 arable	3	15	2	413	34	0	9	1	3	0	1	1	0	0	0	0	0	0	0	484
2.3.1 pasture	1	6	1	21	201	0	7	0	8	0	3	2	0	0	0	0	0	0	0	252
2.4.3 agric/nat	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	0	0	0	0	7
3.1.1 broadlf	0	0	0	1	1	0	12	1	1	0	1	1	0			0	0		0	18
3.1.2 conifer	0	0	0	0	0	0	1	12	0	0	0	1	0			0				14
3.1.3 mixed		0		0	0		0	0	0		0	0		0						0
3.2.1 nat grass	0	1	0	2	5	0	2	0	46	0	1	4	0			0	0		0	61
3.2.2 moor/hth	0	0	0	1	1	0	2	1	3	0	9	53	0			1	0		0	72
3.2.4 scrub		0		0	0		0		0				0							0
3.3.1 beach			0	0	0										0			0		0
4.1.2 bogs		0	0	0	0	0	0	0	0	0	0	0				1	0		0	2
5.1.1 wtrcourse		0		0	0		0			0							0			0
5.1.2 wtrbody	0	0	0	0	0	0	0	0	0	0	0	0					1	0	0	2
5.2.2 estuary	0	0	0	0	0		0			0				0	0		0	5	0	5
total	17	77	4	446	250	0	36	14	64	1	15	63	1	0	0	3	3	5	1	1000

Values in bold are pixels which map directly to an equivalent CORINE class; those in italics map to a CORINE mosaic class. Class names have been abbreviated from Appendices 1 & 2 (refer to class numbers for correspondences). Zeroes represent presence at <0.5 pixels per 1000

Table 4. The allocation of pixels (per thousand) in the automated CORINE map classes of 100 km square SE and their origins in the Land Cover Map of Great Britain

	urban	suburb	bare	tilled	grazed	meadow	decid.	conif.	grass hth	rough gr.	bracken	hth/moor	scrub	saltmsh	beach	bog	water	sea	unclass'd
class number	21	20	22	18	6	7	15	16	5	8,19,23	12	9,10,11, 13,25	14	4	3	17,24	2	1	
1.1.1 cont urb	490	16	32	1	1		3	0	3	0	1	1					23	0	1
1.1.2 discont.	232	686	48	11	19		23	1	14	39	2	9	33		10	3	41	2	9
1.2.1 indust.	9	1	3	0	0		0										3		
1.2.4 airport	1	1	0	0	2	4	0		1		0	0							
1.3.1 mineral	1	0	164	0	0	5	0		0	7		1				11			0
1.4.2 port	0	1		0	3		6	1	2		2	0				0			
2.1.1 arable	143	193	459	927	137	85	266	42	45	316	78	23	140	234	22	50	123	12	273
2.3.1 pasture	73	79	129	48	802	789	187	32	131	223	187	28	328	4	20	37	100	2	266
2.4.3 agric/nat	6	4	10	3	6	59	38	16	20	20	17	8	24	182	49	20	25	1	21
3.1.1 broadlf	6	3	39	2	4	11	347	42	12	14	50	9	83			13	13		7
3.1.2 conifer	3	1	3	1	1	1	15	805	3	53	18	13	33			9			
3.1.3 mixed		0		0	0		1	1	0		1	0		48					
3.2.1 nat grass	13	11	40	4	19	32	50	13	718	47	64	60	233			41	71		63
3.2.2 moor/hth	19	1	48	2	5	4	60	47	51	261	580	843	97			320	31		42
3.2.4 scrub		0		0	0		0		0				28						
3.3.1 beach			3	0	0										771			2	
4.1.2 bogs		1	21	0	0	5	0	1	0	9	0	4				494	1		18
5.1.1 wtrcourse		0		0	0		0			0							24		
5.1.2 wtrbody	3	1	0	0	0	3	3	0	1	0	2	0					542	0	299
5.2.2 estuary	0	1	0	0	0		0			10				532	129		0	982	2
total	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

Values in bold are pixels which map directly to an equivalent CORINE class; those in italics map to a CORINE mosaic class. Class names have been abbreviated from Appendices 1 & 2 (refer to class numbers for correspondences). Zeroes represent presence at ≤ 0.5 pixels per 1000

Table 5. The allocation of pixels (per thousand) from the Land Cover Map of Great Britain, 100 km square SE, to CORINE map classes

	urban	suburb	bare	tilled	grazed	meadow	decid.	conif.	grass hth	rough gr.	bracken	hth/moor	scrub	saltmsh	beach	bog	water	sea	unclass'd	total
class number	21	20	22	18	6	7	15	16	5	8,19,23	12	9,10,11, 13,25	14	4	3	17,24	2	1		
1.1.1 cont urb	771	111	12	49	19		10	0	15	0	1	6					5	0	0	1000
1.1.2 discont.	59	764	3	69	68		12	0	13	1	0	8	0		0	0	2	0	0	1000
1.2.1 indust.	615	256	52	26	10		6										35			1000
1.2.4 airport	30	55	1	134	690	2	17		58		8	6								1000
1.3.1 mineral	15	32	705	38	67	3	11		18	11		72				29		0		1000
1.4.2 port	2	62		117	550		161	7	71		22	7				0				1000
2.1.1 arable	5	31	4	854	71	0	20	1	6	1	2	3	0	0	0	0	1	0	0	1000
2.3.1 pasture	5	24	2	85	798	1	26	2	33	1	11	7	1	0	0	0	1	1	0	1000
2.4.3 agric/nat	14	43	6	194	202	4	191	32	178	4	36	72	3	1	1	7	9	2	0	1000
3.1.1 broadlf	6	13	9	51	60	0	698	34	44	1	43	34	4			2	2	0		1000
3.1.2 conifer	4	3	1	27	23	0	37	808	12	5	19	57	2			2				1000
3.1.3 mixed		56		40	48		361	201	16		177	56		44						1000
3.2.1 nat grass	4	14	3	29	78	0	29	3	752	1	16	62	3			2	3	1		1000
3.2.2 moor/hth	5	2	3	11	18	0	30	9	45	5	123	735	1			11	1	0		1000
3.2.4 scrub		57		57	49		33		25				779							1000
3.3.1 beach			90	17	6										819				69	1000
4.1.2 bogs		28	47	38	48	1	4	7	11	7	0	136				663	2	6		1000
5.1.1 wtrcourse		7		122	7		3			7							855			1000
5.1.2 wtrbody	28	25	1	46	23	1	47	1	33	0	14	12					678	92	1	1000
5.2.2 estuary	0	9	0	30	17		4			3				6	3		0	0	927	1000

Values in bold are pixels which map directly to an equivalent CORINE class; those in italics map to a CORINE mosaic class. Class names have been abbreviated from Appendices 1 & 2 (refer to class numbers for correspondences). Zeroes represent presence at <0.5 pixels per 1000

4.15.3 The results of this comparison give a fascinating insight into the impacts of generalisation. It was inevitable that such a process would smooth out the variation in the landscape as the smaller land parcels down to 0.125 ha of the LCMGB were removed or aggregated into minimum mappable units of 25 ha. Table 2 records that 82% of pixels show essentially equivalent cover types (bold type) in both the LCMGB and CORINE maps. The other 18% represent some generalisation effects, either through incorporation of pure LCMGB classes into CORINE mosaics (italics in Table 2). If these are considered to be essentially unchanged during generalisation, these raise the total of 'appropriately' classified pixels to 83%. Thus the proportion 'lost' through dissolving into the background occupies 17%.

4.15.4 The overall effect of this generalisation has been for the more extensive cover types to consolidate while rarer features, especially those that form dissected patterns in the landscape, were either removed, incorporated into CORINE mosaic classes (eg 2.4.3 ... *agriculture with ... natural vegetation*) or, where they formed complexes of semi-natural cover, were labelled according to the dominant component. Thus Table 2 shows that the overall proportion of arable land has risen from 44.6% in the LCMGB to occupy 48.4% in the CORINE map. So too, urban areas, though not especially extensive overall, showed such close aggregation in the urban complexes of Leeds and Bradford that they captured many pixels representing small areas of open space. Conversely, areas of suburban and rural development have declined, mainly through the loss of the latter component, comprising mostly small parcels which were lost through generalisation. Deciduous woodlands, which often formed small copses and shelter belts, have been halved in recorded extent, mostly through elimination in arable and pastoral areas; coniferous blocks have survived almost unchanged, mostly being larger areas of plantation. Small losses have been recorded in most other semi-natural cover types, through exclusion in the more intensively farmed areas. The mosaic class, 2.4.3 ... *agriculture with ... natural vegetation* was unique to the CORINE map, as mosaics had not generally been classified in the LCM: its extent (at 0.71% overall) was very small. This suggests a tendency in this square (as elsewhere in Britain (Fuller, Sheail & Barr, in press)) towards consolidation of intensive farming in good areas and abandonment to rough grazing in poorer areas, with relatively small parts of the landscape representing a transition zone with mixtures of agriculture and semi-natural land.

4.15.5 Examination of the new CORINE classes and their make-up (Table 3) reveals that most comprise between 70% and 85% of one LCMGB class, with only the estuary class (5.2.2) substantially above this amount. In most cases the 15-30% pixels 'captured' by generalisation represent cover types included through having been dissolved into the background class as isolated polygons of less than 25 ha. Obviously there are other types which comprise mixtures of cover. So mixed woodlands appropriately comprise deciduous trees with conifers and bracken. In the case of 2.4.3 (... *agriculture with ... natural vegetation*), arable, pasture, deciduous and grass heaths make up about 20% each with several other semi-natural types well represented.

4.15.6 The allocation of the original LCMGB classes (Table 4) further emphasises the patterns. So 98% of sea pixels were re-mapped to estuary on the CORINE map; 93% of extensive arable pixels stayed as arable; 80% of the more disaggregated higher intensity grassland pixels remained as pasture. Just 54% water pixels formed areas of sufficient extent to be kept by the CORINE map. Only 35% of deciduous woodland pixels remained as such. A remarkably small 5% of rough grassland pixels were retained as 3.2.1 *Natural grasslands* in the CORINE output, while most of it was blended into the background classes of arable land, pastures and moor/heath.

4.15.7 At first sight, these impacts of generalisation might seem to point to enormous deficiencies of small scale (eg 1:100 000) maps. However, it should be recognised that the LCMGB *rough grass*, and *inland water* classes, so adversely affected by generalisation, on this map area represent 0.14% and 0.26% respectively. Perhaps of greater concern is the impact on quite significant landscape features such as deciduous woodlands, 3.57% of the 100 km square, according to the original 25 m raster, reduced by generalisation to one-half that extent because of their dissected pattern within the landscape.

4.15.8 The automated conversion from the much more detailed LCMGB to the CORINE map allows users of the product to ascertain the impacts of generalisation so that they can better relate the patterns and the cover statistics to other data sources. Had the CORINE map been produced by conventional means without relation to the finer details of the landscape, the potential was to cause considerable confusion when comparing results with other published statistics and to create the impression of a product with high levels of error whereas, in reality, they are primarily the natural consequence of the 25 ha minimum mappable unit.

5. THE WAY FORWARD

5.1 Methodological improvements and additions

5.1.1 The methods used were successful and changes are not recommended unless good reasons arise: there is currently no obvious need for changes to extend the survey. However, it has to be said that the 100 km square chosen for this study has offered its own problems: so too, other squares will present unique problems requiring methodological developments during processing. Extension to all of Great Britain requires an inventive approach and any organisation undertaking the work must guard against the assumption that all problems have been solved and that the methods are entirely routine.

5.1.2 There are other methodological developments, identified in this programme, not yet adopted, mostly because they are irrelevant when mapping a single 100 km square, or unavailable or inapplicable, but which should be applied in future uses of the methods. Squares larger than the ARC/INFO limit require special treatment. The solution adopted by other CORINE maps either uses the largest class as a background or it artificially subdivides large polygons, just as this exercise has done.. The extension to Britain should continue to adopt the same strategy, until the release of Version 7 of ARC/INFO has addressed the problem.

5.1.3 When mapping adjoining 100 km squares, it will be necessary to allow a generous overlap so that land parcels, hence polygons, are not artificially divided by the 100 km lines of the British National Grid. The 25 ha minimum mappable unit of CORINE is complemented by the mapping of linear features of 100 m width (though none were found in this square). If on any sheet a feature 100 m wide ran for a length of 2.5 km, by either criterion it would be included; a wider feature could be commensurately shorter for inclusion as an areal feature. But if it were artificially cut by the grid, it might be missed. Therefore, a minimum overlap of 2.5 km beyond the 100 km square should be incorporated. Such an overlap will allow seamless blending of adjoining squares using standard software. It is therefore proposed that all squares be 105 km x 105 km (or smaller only if comprising large extents of sea). This will eliminate the problem of stripped perimeter pixels and unclassified edge polygons.

5.1.4 Whereas this study sought to develop, test and demonstrate the principles of conversion, the final mapping of all of Britain should take much greater care over the exact requirements of CORINE (to ensure full compatibility with maps of other EC countries). This task is dependent on full training by the CORINE Technical Unit, and their subsequent role as advisors on the development of the project. It has neither been possible nor appropriate to invest the time nor to ask the Technical Unit spend time in training in the detailed specifics of CORINE mapping. Normally, one week's on-site training precedes CORINE mapping of a new state, followed by regular meetings and quality control procedures. This should be a part of the extension to all of Britain.

5.1.5 Extension to all of Britain should draw upon external data to assist interpretation of CORINE land uses, where needed. Examples such as the use of pilot's maps to identify airports, or DoE information on mineral extraction sites have been mentioned. Reference to OS maps will identify golf courses and race courses as sport and leisure facilities (1.4.2). Elsewhere, it will be possible to overlay the draft vector map onto the original imagery to interpret land use in exactly the same way as the usual manually interpreted CORINE maps. It is recommended that the vector outlines, after automated conversion to CORINE, be plotted onto the satellite image(s) and that vector additions or editing of polygons takes place interactively, directly into the vector file. Support from OS and other data at this interpretation stage will help to identify sites while the images will provide the outlines.

5.2 Calibration against field data

5.2.1 By automated conversion of the LCMGB, end-users will have a calibration of the CORINE product and an understanding of the losses and gains caused through generalisation. However, it would also be valuable to cross-link the CORINE map to field data, using the 508 field-surveyed, 1 km squares of the Countryside Survey 1990 (Barr *et al.* 1993). These squares, mapped at 1:10 000 scale, have been digitised as ARC/INFO vectors, so comparisons with the CORINE vectors for equivalent 1 km areas will be possible: however, the number of files involved and the fact that they will produce 508 individual correspondence matrices, makes the comparison especially time-consuming. Furthermore, the differences between the field survey's minimum polygons of 400 m^2 and the CORINE polygons of 25 ha (625 times that size) makes direct comparisons highly questionable in terms of validity (in many CORINE squares, there may be no vector boundaries at all). In the Land Cover Definitions project (Wyatt, *et al.* in press), comparisons were made using a grid of 25 points to score the cover in 59 field classes and the shortlist of 17 cover types (Appendix 1) of the LCMGB squares: results were closely comparable with full resolution vector comparisons. This subsampling procedure, which would be much quicker since it can readily be automated, might be applied to CORINE *versus* field comparisons. However, it also over-emphasises the spatial differences which are inherent in the two products. The Land Cover Definitions project also used regression analyses to inter-compare summary cover statistics per 1 km square (Wyatt, *et al.* in press): considering the very large differences in spatial resolution between field and CORINE products, this may be the most valid and relevant form of comparison for the general purposes of understanding how CORINE maps relate to detailed field records. It is highly relevant to the comparisons which will be made routinely within the 1 km summaries of the Countryside Information System (Barr *et al.* 1993).

5.3 Timetable

5.3.1 The key phases, from initial raster filtering to final vector smoothing of the raster-based outlines, are estimated to require on average 11.5 days per 100 km square, allowing time needed to adapt and develop the techniques to the peculiarities of each 100 km sheet. If some part-filled squares can be amalgamated with adjoining data, National cover should be completed with about 30 sheets in total, requiring 345 days overall (Table 6).

5.3.2 The estimated time in Table 6 allows for one week's training with the CORINE Technical Unit and/or ITE's Environmental Information Centre. A small amount of time should also be set aside for checking and, if necessary, for refinements of the existing 100 km square CORINE map. Thus, commencement of the project should start with a review of the completed sheet under CORINE Technical Unit supervision. The project time in Table 6 also includes allowances for quarterly meetings with an Advisory Group and/or the CORINE Land Cover Technical Unit. The project management timetable also incorporates time for continued review of relevant literature. So too, time has been allowed for liaison with the EC Joint Research Centre at Ispra who are active in areas of automated mapping and map-generalisation.

5.3.3 In view of the potential importance of this work for wider use of automated procedures throughout the EC, about 40% of the proposed time for project management is devoted to reports and publications which would present the methods in some detail.

5.3.4 Readers should be aware that these figures are estimated averages and that times could vary substantially between sheets for the various steps. Furthermore, the time allocated to the various tasks assumes that the funding agency requires no outputs or further developments other than those outlined in this report. It is important therefore to see these estimates as provisional.

5.3.5 Calibration against field data is an optional (though very desirable) extra over and above the basic conversion from LCMGB to CORINE formats: such elaborate validation against field data has not been the norm in other CORINE maps. It is therefore itemised separately to distinguish this extra cost from the standard map production elements. In making an estimate of costs, it is assumed that the vector and 25-point comparisons will not be adopted and that comparisons will use summary cover per 1 km square. Extraction of data, calculation of regression and correlation statistics, compilation of a report and publication of results will require at least 4 weeks (20 days) of a technical assistant, with 5 days supervision by a senior manager.

Table 6. Estimated staff requirements for the CORINE conversion of the Land Cover Map of Great Britain

task	grade	days
Pre-processing	project manager	2
	technical advisor	7
	GIS technician	60
Extraction of 25 ha polygons	project manager	3
	technical advisor	15
	GIS technician	135
Interactive edition & checkin	project manager	4
	technical advisor	15
	GIS technician	105
post-map processing	project manager	1
	technical advisor	3
	GIS technician	45
Project management	project manager	25
	technical advisor	25
	GIS technician	20
Reports & publications	project manager	15
	technical advisor	15
	GIS technician	10
TOTAL STAFF	project manager	50
	technical advisor	80
	GIS technician	375

Table 7. Estimated costs of CORINE conversion of the Land Cover Map of Great Britain, based on full economic costs using ITE rates for staff of grades as used in the feasibility study

	PERSONNEL	DAYS	££
TOTAL STAFF	project manager (UG7)	50	19400
	GIS technical advisor (HSO)	80	17440
	GIS technician (HSO)	375	81750
			118590
EQUIPMENT/TRAVEL	Unix work station + GIS software		20000
	Travel & subsistence		10000
	Equipment & supplies		8000
TOTAL STAFF/ EQUIPMENT/TRAVEL	(based on ITE costs)		**156590**
LCMGB LICENCE	(depending on contractor)		71000
LANDSAT IMAGES	(costs approx., depending on contractor)		96000
TOTAL	(contractor other than ITE)		323590
OPTIONAL EXTRA INTERCOMPARISON	project manager (UG7)	5	1940
WITH FIELD SURVEY	data analyst (HSO)	20	4360
TOTAL			6300

5.4 Costs & benefits of automated conversion

5.4.1 Overall time and staff requirements are listed in Table 6. If staff time is translated into costs, using as a model the staffing used in the feasibility study (namely project management at Unified Grade 7 and GIS research, development and technical support at Higher Scientific Officer) these costs work out as shown in Table 7. To these costs should be added the cost of a work station with ARC/INFO GIS which will be allocated full time to this project. Costs of travel and subsistence include foreign travel to the CORINE Technical Team (in Brussels or Copenhagen), to the Joint Research Centre in Ispra, and to CORINE scientific and technical meetings in Europe. Other costs will be incurred in computer support and maintenance, hard copy reproduction, reports and other publications. Overall cost are likely to be between £150k and £160k for full conversion. Additional cost elements include licence charges of £71k for use of the LCMGB and the cost of the images, at *c.* £96k, to be used for added interpretations. If the contract were to be done by ITE, these two amounts, totalling £167k in value, would be treated as the ITE contributions to the project.

5.4.2 Costs of a new photo-interpretation are estimated at around £1.0million (based on CORINE overall costs elsewhere which have been estimated at 5 ECUs per square kilometre). This amount is more than 3 times the full cost of LCMGB conversion, or about 6 times the costs if ITE were to undertake the work on the basis outlined in the previous paragraph.

5.4.3 It is important to note that the overall costs of the original LCMGB at £600k, plus ITE's CORINE conversion cost would total £767k. This represents a 23% saving on normal CORINE mapping costs. This is despite the fact that the overall project (automated mapping and CORINE conversion) will have satisfied CORINE objectives in providing maps for use in a European context, while having produced for Britain the added benefits of the high spatial resolution map for local, regional and national uses.

5.4.4 The benefits of automated conversion are far greater than just the simple financial ones and go beyond the added advantages of having two different spatial scales for local or European uses. The DoE will also avoid the dangers of have two conflicting summaries of the British land cover. The EC will have a far greater understanding of the meaning of the GB CORINE map through calibration with high resolution data. Perhaps more importantly, the automated conversion of the LCMGB will also provide a valuable insight into the effects of generalisation in the production of all the CORINE maps for other countries. By undertaking a conversion from the LCMGB to CORINE requirements, the end-product is also related to the existing uses of the LCMGB. The vital link to ground survey is already provided via the established links between the LCMGB and the field data of Countryside Survey 1990. Extending this link to directly compare field and CORINE maps will complete the three-way inter-comparisons between field, LCMGB and CORINE products. It points a potential way forward for longer term European mapping.

6. CONCLUSIONS

6.1 The methods outlined above have clearly achieved the aim of automatically converting the LCMGB to a CORINE format. They have demonstrated the means of using standard GIS procedures, to convert the LCMGB's spatially detailed raster record into CORINE's generalised vector patterns. The methods are applicable throughout all of Great Britain.

6.2 The pilot study has shown that the needs for additional contextual and interactive processing are small; the study has identified the means whereby a combination of external data, maps and the original images might be used to meet CORINE's needs for additional land use information. These have been achieved quickly and relatively easily because the vector-conversion provides the basic framework on which to build the interpretations.

6.3 The results match the quality and appearance of visually interpreted, manually recorded, CORINE products giving an output that has satisfied the Advisory Group and the CORINE Technical Unit.

6.4 The study has shown the methods to be efficient in operation. The methods have shown direct cost-benefits in term of substantial savings over the cost of a new CORINE mapping exercise. They have indeed suggested substantial cost-benefits even when the initial investment in high spatial resolution mapping are taken into account.

6.5 By undertaking a conversion from the LCMGB to CORINE requirements, the end-product is fully calibrated against the existing map. Inter-conversion thus avoids the dangers of having two conflicting maps of British land cover. The vital link to ground survey is provided via the Countryside Survey 1990.

7. ACKNOWLEDGMENTS

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Appendix 1. The land cover classification to the original 25 'target' cover types, giving class numbers used in other Tables, and showing aggregation to 17 'key' cover-types used in Countryside 1990 Series of reports (Barr *et al.*, 1993; Wyatt *et al.*, 1993) and depicted in Figure 1.

target cover (25 class)		**key cover (17 class)**	
20	Continuous urban	P	Urban development
21	Suburban/rural development	O	Suburban/rural development
22	Inland bare ground	Q	Inland bare ground
18	Tilled land	N	Tilled (arable crops)
6 7	Mown/grazed turf Meadow/verge/semi-natural	F	Pasture/Meadow/Amenity grass
14 15	Scrub/orchard Deciduous woodland	K	Deciduous/Mixed wood
16	Coniferous woodland	L	Coniferous/Evergreen woodland
5 9	Grass heath Moorland grass	E	Rough pasture/Dune grass/Grass moor
8 19 23	Rough/marsh grass Ruderal weed Felled forest	G	Marsh/Rough grass
12	Bracken	J	Bracken
25 10	Open shrub heath Open shrub moor	H	Grass/shrub heath
13 9	Dense shrub heath Dense shrub moor	I	Shrub heath
4	Saltmarsh/Intertidal vegetation	D	Saltmarsh
3	Beach and coastal bare	C	Beach/Mudflat/Cliffs
24 17	Lowland bog Upland bog	M	Bogs (herbaceous)
2	Inland water	B	Inland water
1	Sea/estuary	A	Sea/estuary

APPENDIX 2. CORINE cover-types and their equivalents based on the Land Cover Map of Great Britain. CORINE code numbers are those used in other Tables.

1.1.1 Continuous urban fabric
    Urban (21)
1.1.2 Discontinuous urban fabric
    Suburban (20) and polygons which are aggregations of a dominant urban area with any other cover-type
1.2.1 Industrial or commercial units
    Urban/suburban/bare (20/21/22) - selection methods to determined
1.2.2 Road and rail networks and associated land
    Urban, suburban and bare (20/21/22) polygons coincident with Bartholomews roads and railways
1.2.3 Port areas
    Urban, suburban, bare polygons (20/21/22) plus associated water (1/2) interactively edited in conjunction with navigation maps
1.2.4 Airports
    Urban, suburban, bare and grass polygons (20/21/22/6/7) interactively edited in conjunction with pilots' maps
1.3.1 Mineral extraction sites
    Bare areas (22) interactively edited with reference to DoE data sources (if available)
1.3.2 Dump sites
    Bare areas (22) interactively edited with reference to DoE data sources (if available)
1.3.3 Construction sites
    Bare areas (22) interactively edited with reference to DoE data sources (if available)
1.4.1 Green urban areas
    Grasslands (6,7) surrounded by urban/suburban
1.4.2 Sport and leisure facilities
    Urban/suburban/bare areas (20/21/22) shown as ports on navigation charts - green open space (6,7) on Bartholomews maps as golf-courses, parks, race-courses etc
2.1.1 Non-irrigated arable land
    Arable (18)
[2.1.2 Permanently irrigated land - not applicable]
[2.1.3 Rice fields - not applicable]
[2.2.1 Vineyards - not applicable at 25 ha units]
2.2.2 Fruit trees and berry plantations
    Scrub/orchard (14), interactively edited to select orchards only (few regions, selected by reference to Ordnance Survey maps)
[2.2.3 Olive groves - not applicable]
2.3.1 Pastures
    Agricultural grasslands (6,7)
[2.4.1 Annual crops associated with permanent crops - not applicable]
2.4.2 Complex cultivation patterns - not widely applicable - mixtures of arable (18) and pastures (6,7)
2.4.3 Land principally occupied by agriculture with significant areas of natural vegetation - aggregate of polygons <25 ha to level-1, showing mixed arable (18), agricultural grass (6,7) and seminatural vegetation (5,8-15)
[2.4.4 Agro-forestry areas - not applicable]

3.1.1 Broad-leaved forest
Deciduous broadleaved woodland (15)
3.1.2 Coniferous forest
Coniferous forest (16)
3.1.3 Mixed forest
Aggregate polygons >25 ha, comprising polygons <25 ha of deciduous (15) and coniferous (16) woodland
3.2.1 Natural grasslands
Grass heath (5), rough grass (8), upland grass (9)
3.2.2 Moors and heathland
Dwarf shrub and grass/dwarf shrub mosaics (upland and lowland) (10,11,13,25)
[3.2.3 Sclerophyllous vegetation - not applicable]
3.2.4 Transitional woodland-scrub
Scrub (14)
3.3.1 Beaches, dunes, sands
Beaches (3) defined interactively or using ITE/DoE Key Habitats maps to remove intertidal zones
3.3.2 Bare rocks
Bare ground (22) except that which is interactively identified as man-made
3.3.3 Sparsely vegetated areas
Aggregate polygons >25 ha, comprising polygons <25 ha of mixed semi-natural vegetation and bare ground
[3.3.4 Burnt areas - not applicable]
[3.3.5 Glaciers and perpetual snow - not applicable]
4.1.1 Inland marshes
Rough grass (8) in key wetlands (defined interactively or using Key Habitats maps)
4.1.2 Peat bogs
Lowland (24) and upland (17) bog
4.2.1 Salt marshes
Salt marshes (4)
[4.2.2 Salines - not applicable]
4.2.3 Intertidal flats
Beaches (3) excluding those of 3.3.1 (above)
5.1.1 Water courses
Inland water (2) defined by Bartholomews maps as linear features
5.1.2 Water bodies
Inland water (2) excluding water courses
5.2.1 Coastal lagoons
Sea or inland water (1,2) selected interactively (very few examples in GB)
5.2.2 Estuaries
Sea (1) defined interactively or automatically on basis of 'enclosure' by land
5.2.3 Sea and ocean
All remaining sea (1)

Note that of 44 CORINE classes, 11 do not apply in Britain. The final list therefore includes 33 relevant CORINE cover types, many with direct equivalents in the land cover map.

APPENDIX 3. Technical processing - command details

ACTION		*COMMENTS*
A.	**I^2S PROCESSES**	
INPUT - original 25 m classified image		
1.	c'pi SE2 (b:e@2; b:e@2) SE_AT2_P1	*Input sub-sampled to 50 m pixels*
2.	m 'v' mode-file SE_AT2_P1_NO0 SE_ AT2_K3	*Mode filter 3 x 3 Kernel: file now has 50 m pixels with, on average, parcels >4 pixels (2 ha) however, many small 'polygons' persist. Hence a final isolated filter.*
3.	SE-AT2-K3 m 'v' mode _ SE_CORINE 1 only = ISOL	
B.	**TRANSFER FILE TO HORIZON GIS**	
1.	C'DISKTRANSFER	*Creates standard array*
2.	DTI2TXT file called SE_CORINE. ASC	*ASCII file created for transfer*
3.	Copy to user for ARC processing	*Direct route now available. ITE now has full land cover map in ARC/GRID format, so future processing might take data direct*
C.	**ARC/INFO PROCESSING**	
1.	Import file with ASCIIGRID First GRID file = SEFIRST	*Archived as SERCLASSK to 18 required land cover codes.*
2.	a) Checked ARC file with same TIC values as SEFIRST.	*Vectorize test showed not possible due to attempt to form a single polygon of greater than 10,000 arcs.*
	b) ARCEDIT added 16 'squares' (25 Km square)	*Version 7 of ARC/Info has no limit. 'Chequer board' technique used to work around the 10000 arcs problem.*
	c) Clean and build as a polygon file	
	d) Change attributes to alternate 1,100 etc. "Reselect CHEQTEST poly many *" "Calculate CHEQTEST poly grid-code = 1"	
	e) Rasterize to 50 m grid file "Polygrid cheqtest cheqgrid grid-code" "Cell size 50 m.	*Output grid file = 1998 pixels square (edges stripped)*

3. Add 2 grid files

"SE1DO = CHEQGRID + SERCLASSK

4. Test 'dissolve' of artificial boundaries

Note This test may need to be run on each 100 km square to ascertain which class contains any polygon exceeding 10000 arcs. Most likely classes are:- Arable (18), Grass (6). In test square only Arable failed so all other classes dissolved.

a) Add item to vat file
b) All classes (except 18) copied to new item.
c) Vectorize (Gridpoly) to SEVECT

5) "Eliminate sevect smallgone"
Reselect area <17510.0
Keepedge

6) Renumber 'chequer' 100 values back to proper land cover values.

7) Dissolve all boundaries caused by chequer board pattern except class 18's.

Eventually fails on one last large polygon. Leave this as a separate polygon in the file. May need to combine and separate arable file back with the main file with 'Union' command.

8) a) Using Info and Arc plot reselects.
b) Identify biggest 10 class 18 polygons.
c) Successively change attribute (grid-code) back to 18 and test dissolve on this class 18.

9. Saving of polygons greater than 25 hectares

Reselect command

Also save as a grid version of the data with polygons less than 25 hectare give 'nodata' grid value in output.

This procedure is repeated at subsequent stages of the whole process to gradually update and increase the % of the target complete map achieved. Use of ARc update. 79% completed to 25 hectare polygons.

10. Growing Polygons together
(or removal of outliers)

a) Create remap tables
(COR2.RMT) 1) 1 for target class 'nodata' — *use for 'source' file creation*
(COR3.RMT) 2) 1 for target class 2 the rest — *use for 'cost' file creation*

b) outgrid 1 = reclass (i/p file corridor 3, COR2.RMT, nodata)

c) outgrid 2 = reclass (in/fil corridor 3, COR3.RMT)

d) outgrid 3 = cost distance (outgrid1, outgrid 2, Backgrid, gridall)

Delete backgrid and gridall after process complete

e) outgrid 4 = focalsum (outgrid 3)

Gives values 0 to 5000+

Do above, class by class in order suggested below:
2, 5, 6, 10, 15, 16, 18, 20, 21, 22. (class 15 could be first?). Assess level of individual change for classes by doing sum area on individual classes by listing value item in VAT file in INFO on both pre and post process files.

Pixels <437 gave best aggregation of close outliers without unwanted expansion elsewhere.

11. Re-vectorize file with gridpoly

12. Reselect out new polygons >25 hectares

These will include all previously saved ones (effectively replaced). Target now about 81% complete

13. Analysis and classification of 'mosaic polygons'

a) Add item to vector file

b) Reselect polygons less than 25 ha into new item with their grid-code attribute with 'calculate' command. Polygons greater than 25 ha to get dummy code eg 100.

Allows small polygons to be treated independently of large polygons.

c) Need to pre-prepare files to assist with interactive classification

i) Select all polys <25 hectares from FILEA

ii) Give same class attribute in a new item

iii) Dissolve all these internal lines

iv) FILEA divide on semi-natural classes all polys <25 ha (FILESEMI)

v) Dissolve on urban/suburban (FILEURB)

about 98.5% complete

14. Remaining Polygons - see appendix 3

Visually examine to see if 'close together' and forming a significant effect on the landscape pattern at 100,000. Delete where appropriate

The vast majority are now small, 'isolated' and can be safely lost to the surrounding class.
100% complete

15. Conversion to CORINE Classes

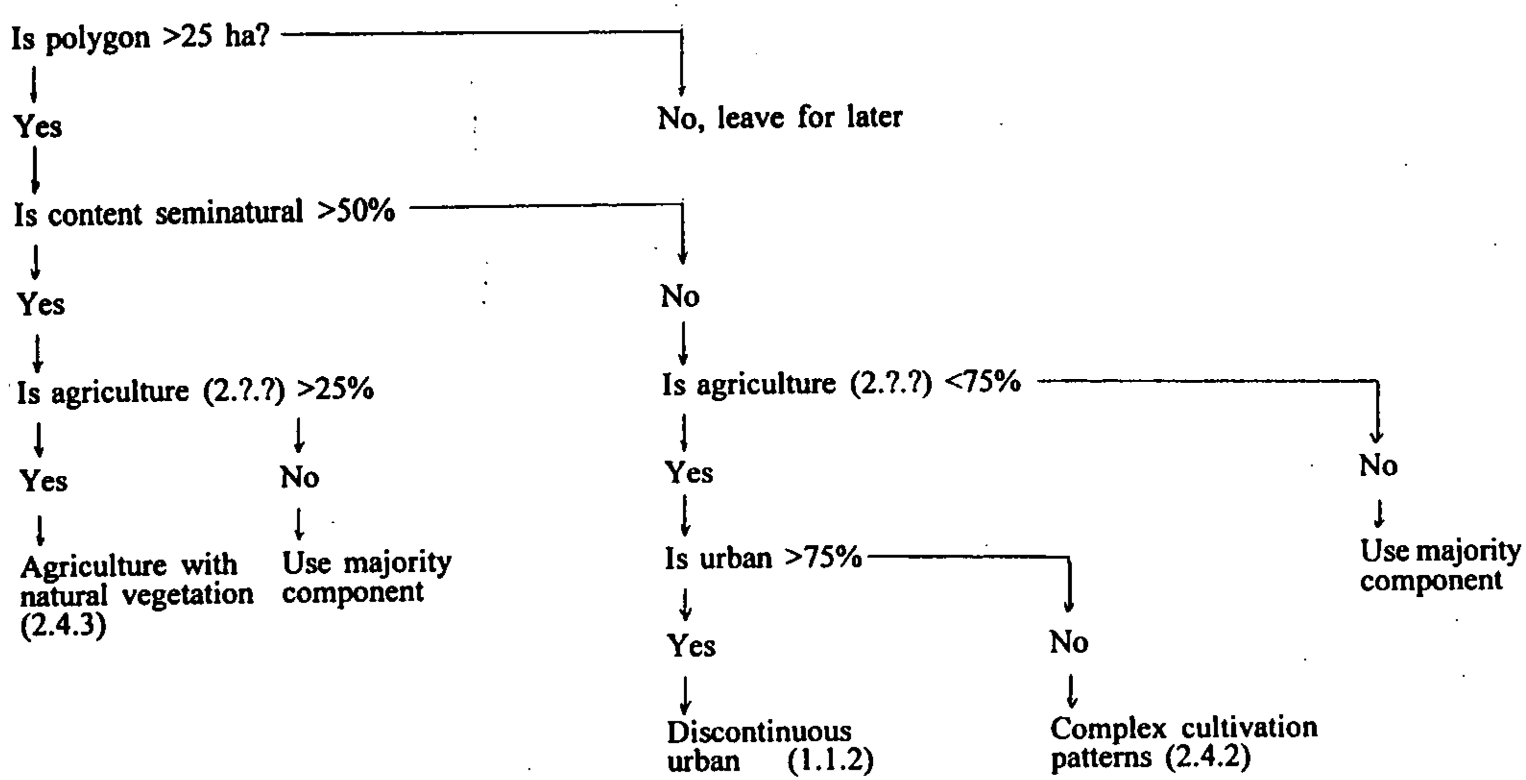
Earlier major polygons are renumbered to CORINE classes

16) Classification to CORINE 'land use' classes not individually identified in land cover classes.

17) Generalize/smooth to final line style

18) Comparisons with original Statistical comparison Visual examination

APPENDIX 4. Classification of mosaic polygons to corine classes.



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