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Presented Paper

MONITORING URBAN GROWTH IN THE UK FROM LANDSAT SATELLITE DATA

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ABSTRACT

The Department of Environment (DOE) in the UK is concerned with monitoring urban development. DOE and the Harwell Laboratory have investigated the use of the data from the Landsat satellites for this task. Detailed comparisons have been carried out for four test sites between the Landsat results and results obtained from aerial photography. This work has shown that Landsat can be used to monitor new growth but not to redetermine existing urban areas. The coincidence between the ground truth and the Landsat estimates of new growth is over 80 per cent, but there are some additional errors from commission.

1. INTRODUCTION

During the last few years the Image Analysis Group at Harwell have been researching for the DOE, UK, the possibility of utilising remotely sensed imagery, other than aerial photography, for monitoring new development.

DOE is concerned with collecting information on both the extent and distribution of developed land and especially the rate at which land is being taken up for development. The availability of such information has been primarily collected for other purposes and is often out-of-date (Smith, 1977). DOE have carried out a survey of all "developed areas" of over five hectares in England and Wales (DOE, 1978) using air photography taken in 1969 at 1:60,000 scale and DOE would like to update this data base of developed areas at regular intervals.

Since regular aerial surveys of England and Wales would be expensive and difficult to organise, because of cloud interference, DOE is seeking to establish an alternative survey method coupled with an automated analysis system for extracting the required information in digital form. The method employed at present of visually interpreting aerial photography and

digitising the resultant maps to produce digital data for use with other data bases (eg Census data) is both time consuming and expensive.

Alternative sources of remotely sensed imagery that were considered included airborne side-looking radar and multispectral scanning, operating from the visible through to the thermal infra-red wavelengths, in an aircraft and satellites. Side-looking radar is an active device operating at much longer wavelengths (1-30 cm) and has the great advantage that it is not affected by cloud and haze or restricted to day-light hours. However, not enough work has been done to show that automated digital analysis can be used to extract reliably land-use information. The multispectral scanner is a passive device and captures the sun's reflected radiation or the earth's thermal radiation and its use in an aircraft faces the same organisational difficulties as apply to aerial photography. From an initial study it was concluded that the multispectral scanner in the Landsat series of satellites would be the most useful source of data for DOE's requirements because of the repetitive coverage and the low cost of the data. At present this data is restricted to the wavelength range 0.4 to 1.1μm, which is divided into four spectral bands and it has a rather poor spatial resolution of 80m. However this disadvantage is offset by the fact that the data can be obtained in digital form, and the provision of data in four spectral bands makes it amenable to automated digital analysis. Also its repetitive coverage affords the opportunity of obtaining cloud free imagery on, say, a biennial basis. In addition, future advances will provide data of a higher quality (Landsat D, Spot, LASS).

This paper describes work carried out to check the accuracy of the Landsat data for monitoring urban development. It highlights the difficulties that have arisen and suggests methods for overcoming them.

2.   TEST AREAS AND AUTOMATED PROCESSING OF THE LANDSAT DATA

In order to assess in detail the usefulness of the Landsat data for monitoring urban growth four test sites were chosen as representative of a range of urban/rural relationships. The choice of the actual sites was limited by the requirement for recent aerial photography in order to allow detailed checking of the Landsat results. The four test sites chosen were:

   a)   A new town which is rapidly developing surrounded predominantly by agricultural land - Northampton:

   b)   An intricate urban area of rapid development and complex terrain such as heathland and woodland - Reading/Bracknell:

   c)   An older industrial conurbation made complex by its terrain and proximity to an area of moorland - South Manchester:

   d)   An area comprising of a large estuary with large areas of marshy ground, mudflats, moorland, and towns immediately adjacent to the sea - Preston/Blackpool.

The sizes of the various test areas and other details are given in Table 1.

In order to compare the Landsat results in detail with ground-truth obtained from aerial photography and to make use of data from more than one Landsat scene of an area it is necessary to geometrically rectify the Landsat data to a standard co-ordinate system. Some of the distortions are systematic

such as the effect of earth rotation, band offsets and aspect ratio, but
others may vary from image to other (eg effect of roll, pitch, yaw and
altitude variations) (Bernstein and Ferneyhough, 1975). In order to fully
correct for these effects it is necessary to obtain precisely known Ground
Control Points (GCPs) which permit the derivation of appropriate mapping
functions.

TABLE 1

DETAILS OF TEST AREAS EMPLOYED AND LANDSAT SCENES USED FOR ANALYSIS

TEST AREA	DIMENSIONS (km)	TOTAL AREA (ha)	EXTENT OF URBAN AREA 1969 TOTAL (ha) and %	SCENES	
Northampton	25 x 25	62,500	5,653 (9)	218/23	3/7/75
				217/24	8/6/76
Reading/ Bracknell	40 x 50	160,000	30,283 (19)	217/24	2/7/75
				217/24	8/6/76
South Manchester	30 x 25	55,757	12,178 (28)	220/22	8/6/75
				220/22	28/5/77
Preston/ Blackpool	36 x 30	108,00	15,208 (11)	220/22	8/6/75
				220/22	28/5/77

For the present work we have developed a rectification program which uses a
polynomial mapping function (up to quartic terms) to transfer data between
image space and map space. The co-ordinate system used is the UK National
Grid. The data was resampled using a nearest neighbour technique to give a
basis cell size of 50m. Rectification is an extremely tedious process and
in general it was found necessary to use up to 30 or 40 GCP's for each scene
in order to obtain average residual errors of about 50m. For future work
we will use the NASA rectification package DIRS (Wie and Stein, 1976) which
we have recently leased, since it is more efficient and allows interpolation
of the data points to be carried out using a cubic convolution technique.

Classification of the Landsat data into suitable ground categories was
accomplished using a supervised maximum likelihood approach. The method
relies on the various ground categories having different reflectances in the
four spectral bands (two visible and two near infra-red). In general
Landsat premarily distinguishes between vegetation and non-vegetation
covered areas. Vegetation is characterised by a low reflectance, due to
pigment absorption, in the two visible bands and a high reflectance, due to
internal reflection in the internal cellular structure of vegetation, in the
two infra-red bands. Water has a low reflectance in all four bands, while
soils and man-made materials have a reflectance higher than vegetation in
the visible but lower in the near infra-red.

The spectral signatures of the various ground categories were first found by
selecting suitable training areas from a colour display of the Landsat data
using ordnance survey maps as a means of verification. The ground
categories used to analyse the data included high density urban (inner city),

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low density urban (suburban), vegetation with a high infra-red reflectance, vegetation with lower reflectance (mown grassland, parks etc), woods, moorland, heathland, water, marshland and finally areas with very high reflectance in the visible bands. The latter areas ususally consist of areas of concrete and new construction sites. The spectral signatures were not assumed to have a gaussian shape but a smooth fit was made to the actual spectral signatures and this was stored as a look-up table for the actual automatic classification of the entire test areas.

Results have been obtained using the Landsat scenes listed in Table 1 for the various test areas. In general, scenes were chosen to correspond to the spring/summer period when vegetation growth and coverage is at its peak.

2. RESULTS FOR DELINEATING THE OVERALL URBAN AREAS

From the 1969 aerial survey DOE mapped developed areas into five categories:

    a)   predominantly residential use
    b)   predominantly industrial or commercial use
    c)   predominantly educational and community use
    d)   predominantly transport
    e)   predominantly open-space.

In order to obtain numerical results of the accuracy of delineating the urban areas from Landsat data taken in 1975/77 DOE have provided boundary data from aerial photography of the test sites flown in 1976. For this present work categories a) to d) were amalgamated into a single category - urban, while e) was left as a separate category. In addition in order to check results in the computer the boundary data was converted to a 50m grid cell data base to match the rectified Landsat data. This was done by preparing separate sheets at 1:50,000 of the boundaries of the various categories. After photo-reduction these sheets were digitised in a raster mode. Absolute co-ordinates were obtained by digitising accurately positioned crosses on the sheets. The results for the various categories were then merged together to give a data base in which each grid cell is given a code (1, 2, 3 etc) appropriate to its category.

The results for the four test areas showed that the total urban areas were delineated with accuracies that varied from 45 per cent to 80 per cent (i.e. omission > 20 per cent) and rural areas with accuracies of 85 per cent to 95 per cent (i.e. commission > 5 per cent). However, the areas of new development, within these urban areas, appeared to be well delineated. Thus errors of omission corresponded mainly to low density housing particularly the older more mature areas, where the reflected radiation from the trees and gardens gave the area a pseudo-rural signature. The major errors of commission were due to certain rural areas (bare soil, etc) having spectral signatures very similar to urban areas.

From these results it was obvious that:

    (i)   new growth could not be detected by simple subtraction of
           the results from two separate Landsat scenes since the
           errors for the individual scenes were too large.

    (ii)   The present Landsat data is not suitable for a complete
           resurvey of all developed areas.

(iii)   Areas of new development can be extracted using new
         techniques (see 4).

4.   TECHNIQUES FOR EXTRACTING AREAS OF NEW GROWTH FROM LANDSAT DATA

The following rules have been adopted to enable areas of new growth to be
delineated by Landsat:

    i)   the classified urban area must be outside the existing developed
          area (1969)

    ii)   part of the delineated area must be within a given distance
          (200m) of the existing urban boundary

    iii) the area must be greater than 2.5 hectares

    iv)   the area must be classified consistently as urban on at least
          two Landsat scenes.

Rules i) to iii) are called spatial elimination rules, since they effectively
restrict the areas of search for new growth, and rule iv) a temporal
elimination rule since it checks for consistency with time (Carter and
Stow 1979 and Carter 1979).   The rules depend on the observation that new
development occurs predominantly around the periphery of the existing
developed area.   Thus if we accept the boundary of the last survey (1969
in this case) as the starting point and only measure growth beyond this then
most of the areas of omission are eliminated.   The extra areas of commission
are greatly reduced by restricting the area of search with ii), and in the
examples used in this paper 200m was chosen, and checking for consistency
with rule iv).   The minimum area requirement serves to eliminate very small
areas and concentrate attention on the major areas of interest.   Provided
good temporal data is obtained for applying rule iv) it has been found that
rule ii) can be greatly relaxed or even ignored completely.   The temporal
rules are carried out by classifying each scene separately and then checking
for consistency in the classified results of the two scenes.

Using these rules new growth has been obtained for each test area from the
base date of 1969 using the pairs of Landsat scenes listed in Table 1.   The
effect of the new rules is demonstrated in plates 1 to 4.   The developed
area for the Northampton test site obtained from the 1969 aerial photography
is shown in plate 1.   Northampton is at the centre and the grid lines
correspond to the UK National Grid.   The total classified urban area
obtained from a Landsat scene which lies outside the 1969 developed area is
shown in plate 2.   A motorway in the bottom left hand quadrant and a
partially dry reservoir above Northampton can be seen.   Plate 3 shows the
result of applying the spatial and plate 4 the temporal rules with a second
Landsat scene to leave the Landsat derived new growth for the years 1969 to
1975.   The use of the elimination rules reduced the initial 5000 hectares
of new growth to about 300 hectareas.

5.   COMPARISON OF EXTRACTED URBAN GROWTH FROM LANDSAT DATA WITH GROUND-
      TRUTH

In order to carry out the rules described in section 4, developed area
boundary data was produced from the 1969 aerial photography and converted to
a grid cell format.   In order to check the Landsat and estimates of growth
DOE have also mapped out all areas of new development between 1969 and 1976

from the two sets of aerial photography for all areas greater than 2.5 hectares, using the same rules and definitions as adopted for the 1969 survey (DOE 1978). However, detailed checking of the Landsat results showed the need for some redefinitions of developed areas. This was because the boundaries obtained by visual interpretation have been drawn (i.e. the curtilage) to the nearest evident boundary rather than the boundaries of the actual buildings. Thus previously the field or waste ground surrounding a factory or open space totally enclosed by buildings would be classified as "developed". Landsat can only monitor the areas covered by "bricks and mortar" and thus it has been necessary to modify the definition and restrict new development to just the "bricks and mortar". Similar a number of other definitions regarding mineral workings, disturbed ground, caravan sites, airfields, market gardens, etc have also had to be restricted to the actual buildings or workings in order to correspond to the Landsat data.

Thus the areas of growth was reinterpreted from the aerial photography using these new restricted definitions. The final results are presented in Table 2. Their percentage coincidence for the first three test areas is over 79 per cent and is 92 per cent for the largest site. This is in spite of the fact that the ground truth was determiend for a seven year period compared to the Landsat growth over a six year period (on average expect Landsat to detect 86 per cent of the ground truth area). Also a period of seven years is larger than one would wish to use in an operational system since some of the earlier growth may have matured sufficiently to cause Landsat to misclassify it as rural. The poorer results for the South

TABLE 2

COMPARISON OF LANDSAT RESULTS AND GROUND TRUTH (AREA HECTARES)

TEST SITE	GROWTH FROM LANDSAT (1969-75)	GROUND-TRUTH (1969-76)	AREA OF COINCIDENCE	COMMISSION ERRORS
Northampton	1230	919	770 (84%)	460
Reading/ Bracknell	4479	2127	1960 (92%)	2519
Preston/ Blackpool	992	992	540 (79%)	452
South Manchester	593	527	323 (61%)	270

Manchester area is due partially to the poor 1969 photography for this area which has made it difficult to determine reliably the urban boundary. With the Preston/Blackpool test area considerable areas of sand-hills along the coastline were falsly classified as urban but in the figures given in Table 2 it has been assumed that these areas could be easily edited out. Areas of falsly classified sand below high-water mark have been removed by using the digitised high-water boundary for the UK.

An examination of the last column of Table 2 shows that the errors of commission are large. Hence in an operational system some editing facilities will be required which will allow an operator to remove obvious areas of misclassification and also to check areas against any other available information. Thus with the present Landsat data the results should be only used as a guidance unless they can be refined with other information, we anticipate that the new satellites to be launched in the 1980's which will have more spectral bands and better spatial resolution should also help to reduce the commission errors in an operational system.

Finally in plate 4 an example of the Northampton site is given to show the detail possible and the comparison of the Landsat results with ground truth boundaries. As can be seen Landsat not only provides areas of growth but more important their locations as well.

6. CONCLUSIONS

The present Landsat data can be used to determine urban growth provided certain rules are adopted to reduce the errors of commission and omission. In an operational system some manual editing of the results would be required to reduce outstanding commission errors. It is anticipated that future satellites should enable the errors to be reduced still further and allow new categories of interest to be delineated. Future satellites may also provide data which can be used to resurvey existing urban areas which is currently not possible.

7. REFERENCES

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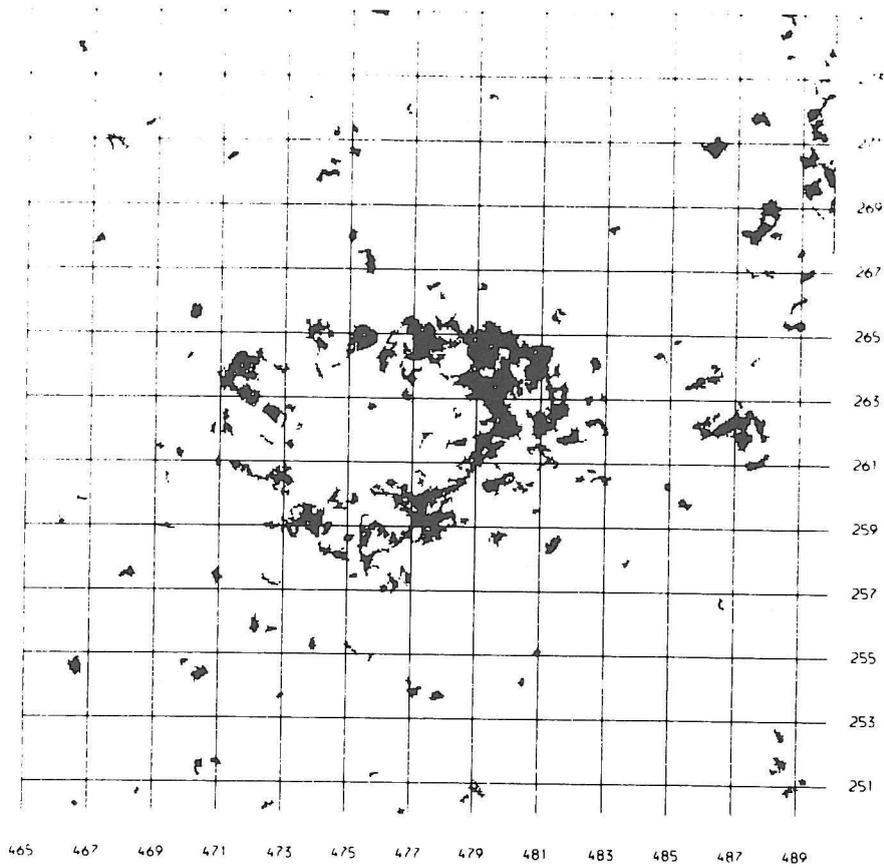
8. ACKNOWLEDGEMENTS

PLATE 3   Result of applying the spatial elimination rules to the classified urban areas for the Northampton test area from Landsat scenes of 8/6/76
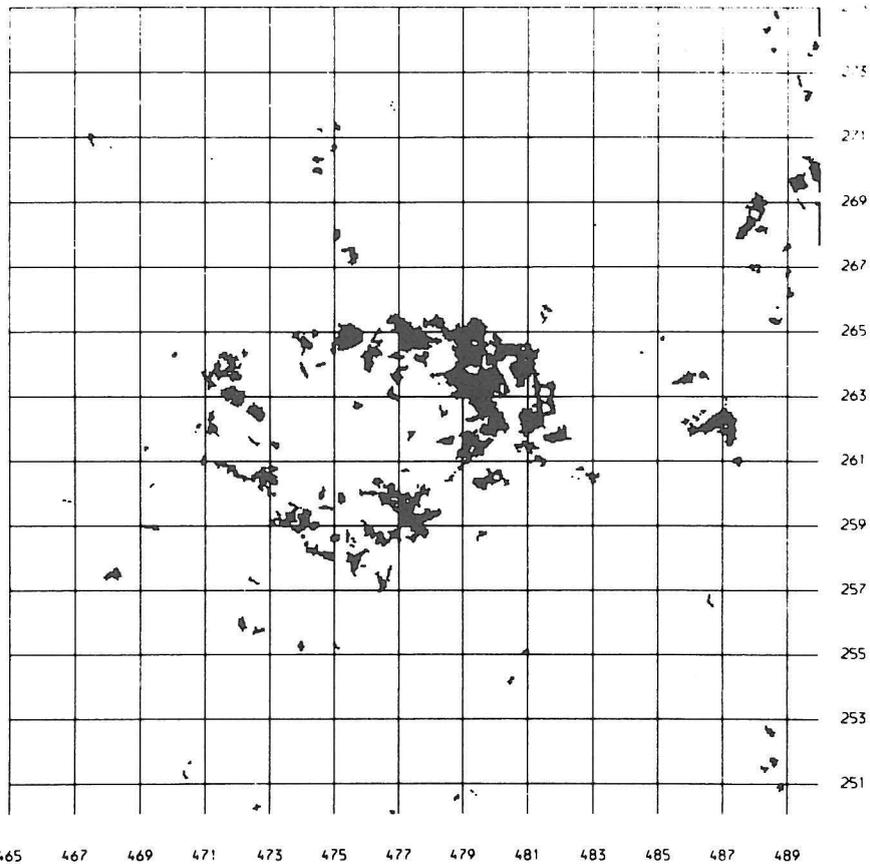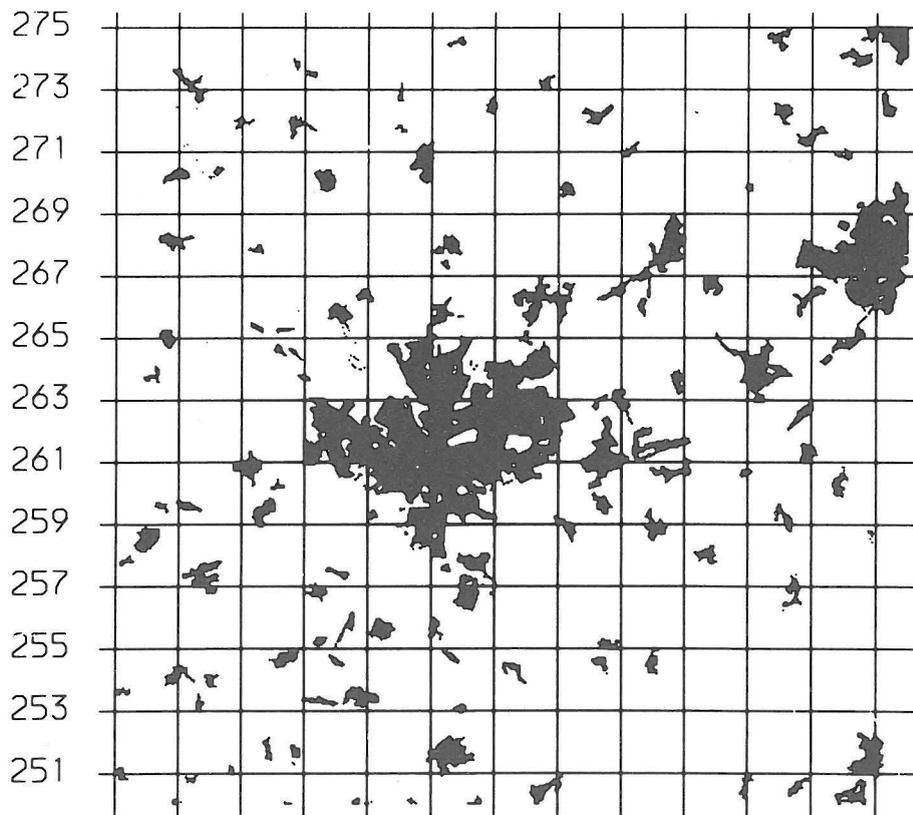

PLATE 4   After application of the temporal elimination rules to the classified urban areas from the Landsat scenes of 8/6/76 and 3/7/75 for the Northampton test area

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PLATE 1   Developed areas for the Northampton test area obtained from 1969 Aerial Photography
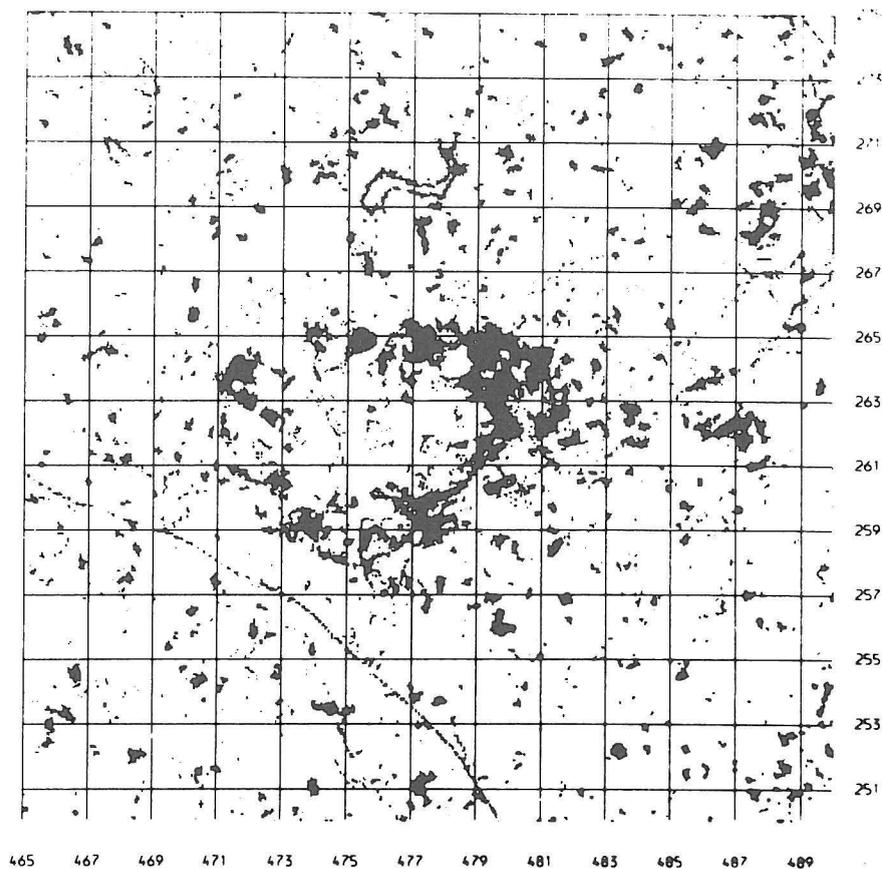
PLATE 2   Classified urban areas from a Landsat scene (8/6/76) which lie outside the 1969 developed areas

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NORTHAMPTON
Urban Growth 1969-75
using scenes at 3 May 1976 and 6 June 1975

According to Satellite
Great Houghton

Determined by DOE from Air Photographs

More than 200 metres away from
1969 Developed Area boundary

Base map revised to 1972
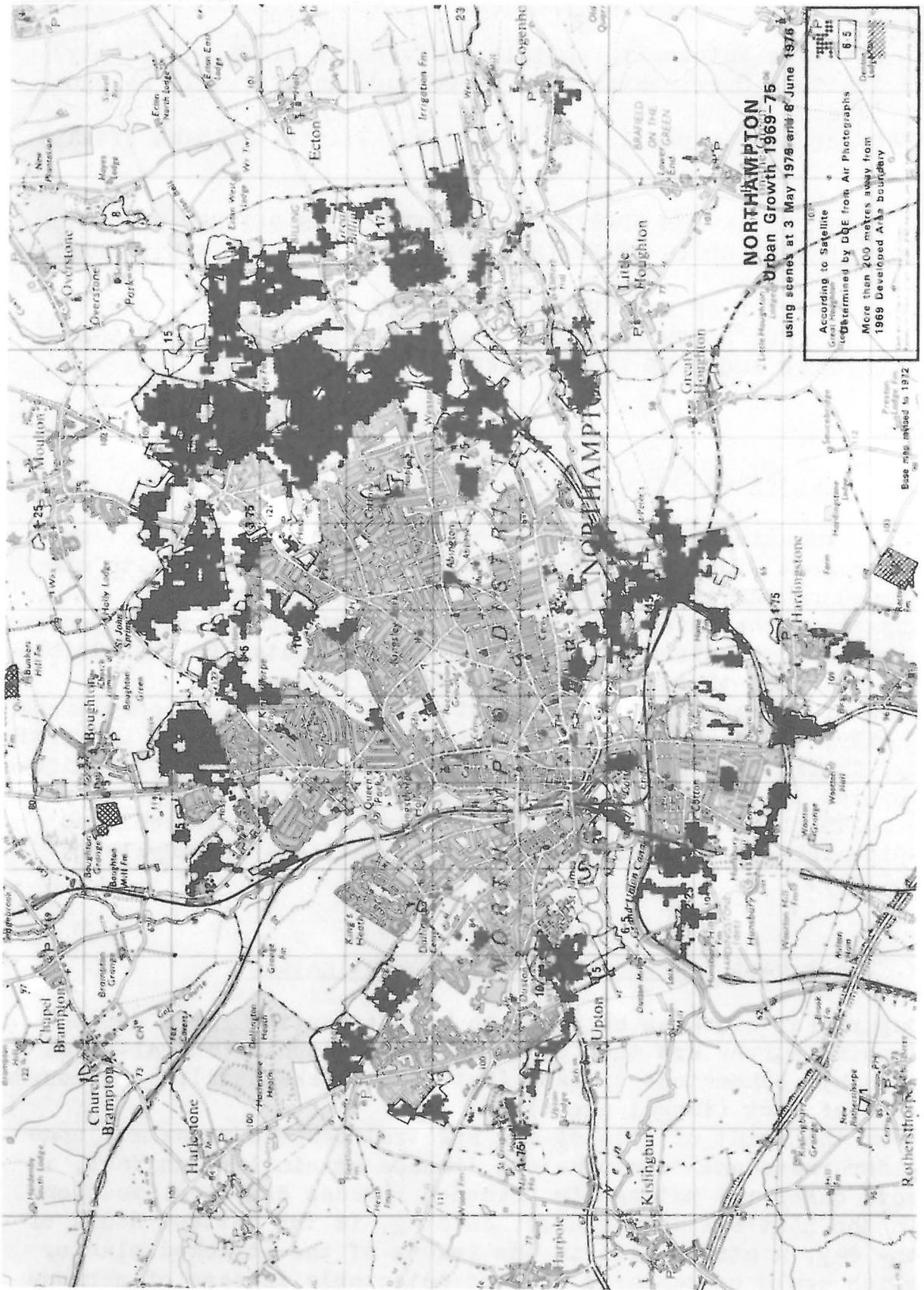
Crown Copyright 1979. Base Map reproduced from the Ordnance   Survey Map (1975)

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