

A historical GIS for England and Wales: a framework for reconstructing past geographies and analysing long-term change

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**A historical GIS for England and
Wales: A framework for
reconstructing past geographies
and analysing long-term change**

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Thesis submitted for the degree of PhD



Abstract

This thesis describes the creation and possible uses of a Geographical Information System that contains the changing boundaries of the major administrative units of England and Wales from 1840 to 1974. For over 150 years the census, the General Register Office, and others have used these units to publish a wealth of data concerning the population of the country. The key issue addressed by the thesis is that changes in the administrative geography have hampered much research on long-term change in society that could have been done using these sources. The goal of the thesis is the creation of framework to allow the analysis of long-term socio-economic change that makes maximum use of the available data.

This involves not only making use of the data's attribute (statistical) component, but also their spatial and temporal components. In order to do this, the thesis provides solutions to two key problems: the first is how to build a GIS containing administrative units that incorporates an accurate record of their changing boundaries and can be linked to statistical data in a flexible manner. The second is how to remove the impact of boundary changes when comparing datasets published at different dates. This is done by devising a methodology for interpolating data from the administrative units they were published using, onto a single target geography. An evaluation of the accuracy of this interpolation is performed and examples are given of how this type of research could be conducted. Taken together, these will release information locked up within historical socio-economic statistics by allowing space to be explicitly incorporated into any explorations of the data. This, in turn, allows research to explore the past with increased levels of both spatial and attribute data for longer time periods.

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Chapter 1: Introduction

Today a vast amount of spatially referenced data is routinely collected and published by central and local government and a wide variety of other organisations concerning the people of England and Wales and the society and economy in which they live. The amount of data collected and their value in helping to provide an understanding of the geography of the country have both been greatly enhanced by the ability of modern computers to handle large volumes of data and to extract information from these data through analytical and visualisation techniques (see, for example, Openshaw, 1995; Raper *et al*, 1992). The use of Geographical Information Systems (GIS) has been fundamental in allowing a greater understanding of the spatial component of processes that affect the conditions in which we live (DoE, 1987).

Although the use of computers over the past twenty or thirty years has greatly enhanced our ability to collect, manipulate, analyse, and gain understanding from spatially referenced data, many datasets have, in fact, been routinely collected since the first half of the nineteenth century. The collection of data in a modern way, where a central authority routinely collects data using clearly defined sets of administrative units, arguably started in the 1830s with the advent of civil vital registration and the New Poor Law. In both cases a central authority, the General Register Office (GRO) and the Poor Law Commissioners respectively, organised the routine collection and publication of data using clearly defined spatial units and administered by a professional bureaucracy. In addition to its role in vital registration, from 1841 the GRO was also given responsibility for the census, which had first been taken in 1801 (Nissel, 1987).

There are, therefore, a vast wealth of statistics covering England and Wales and its people published in a similar manner for over 150 years. Unfortunately, using these data is often more complex than it may first appear. The main reason for this is that the boundaries of administrative units were subject to frequent change. This leads to two main challenges that form the major themes of this thesis: the first is how to build a GIS database that is capable of linking statistical data to the actual boundaries that were used to publish them. The second is how the data can then be integrated through time in the face of the changing geography of publishing units. Solving these two problems opens up the potential to gain more understanding about long-term socio-economic change from the mid-nineteenth century to the present. This is done by allowing data to be explored through space, time and attribute while preserving the detail of all three. It also opens up two new challenges that will not be explored in any

detail in this thesis as they are substantive research topics in their own right. These are the development of suitable statistical techniques that will allow data to be explored through both time and space in a manner that is sympathetic to the data's limitations, and the development of visualisation techniques that allow the information content of the data to be explored in a way that preserves the data's inherent detail but makes the information they contain understandable to a wider audience.

This thesis is largely methodological but is firmly applied to the practical problems, namely how historical data, those collected before the mid-1970s, can be integrated into a framework similar to that in which modern data are now routinely used and then how they can be integrated to allow long-term change to be explored. To do this it is first necessary to be able to provide accurate administrative boundaries for each dataset collected, and to be able to link the statistical data and their boundaries together in a simple and flexible manner. This adds value to the statistical data by providing a spatial framework in which they can be explored, analysed and mapped. A second and more difficult challenge was to allow the data published using different administrative units to be integrated together to allow, in particular, the analysis of long-term change. The method used has been to attempt to standardise all data onto a single set of administrative units, termed target zones. This allows time-series to be developed that compare data covering exactly the same spatial area. It also allows data from different dates to be integrated together to produce new datasets that are more detailed than it was previously possible to produce and should help develop our knowledge of long-term change in society.

The basic philosophy of the thesis is that data should be used in a way that makes maximum use of their information content. Most socio-economic data have three components: a statistical (or attribute) component, a spatial component and a temporal component. The statistical component refers to the amount of attribute detail by which the data sub-divide the population of an area. The minimum level of detail is simply a count of the total population, at the maximum are some of the very detailed classifications of, for example, occupations and causes of death published by the GRO. The spatial component refers to the extent to which the data sub-divide the population geographically. The top level of sub-division of England and Wales are the eleven Divisions and their modern equivalents, the Standard Regions. Below this there are the counties of which there were approximately fifty depending on date and type, then there are districts which vary from approximately 300 to approximately 1,800 depending again on date and type, then comes parishes and wards of which there are over 10,000, and finally Enumeration Districts (EDs) and unit postcodes that have only had a significant role in data publishing since the 1980s. There have been, of course, many other types of administrative unit used to publish data, but the ones

described here are the most important for census and vital registration data. The temporal component refers to how often the data were published. The data also have geographical and temporal extents that refer to the area covered, from the whole of England and Wales to an individual county or less, and the time period they cover which is potentially from the mid-nineteenth century to the present.

Traditionally, in order to make best use of one of these components or extents, others had to be sacrificed. For example, statistically detailed studies or studies covering a long time period have usually been conducted at county-level in spite of district-level data being available. This seriously reduces the information content of the data and, as will be discussed in more detail later in the thesis, has potentially serious implications for analysis.

The thesis developed out of the design and construction of the Great Britain Historical GIS (GBHGIS) for which I designed the database architecture and was responsible for the initial construction work. It is limited by the fact that it was written while the GIS was being constructed by others, mainly Vicki Gilham¹ and Chris Bennett², and was thus unable to make use of the completed system. In particular, this has meant that the thesis focuses entirely on England and Wales, Scotland is not considered in any form although the principles developed in the thesis will also be applicable to Scottish data.

The GBHGIS, in turn, developed out of the needs of various researchers who were interested in a system that would allow them to map their data and explore them using their spatial component. These researchers were mainly interested in data in the period between the mid-nineteenth century and the First World War and, in particular, in two main themes: economic distress and mortality. The census provides a variety of data vital for the analysis of both of these³. This was fundamental to the choice of data that

¹ Vicki Gilham was employed from 1996 to 2000 to build the parish and Local Government District systems. Her role was to digitise the changing boundaries, add attributes and ensure that these were coded in such a way as to produce topologically consistent coverages. She was also responsible for researching post 1911 boundaries.

² Chris Bennett was employed from 1996 to 1999. His primary role was to research the incredibly complex changes to parish boundaries between the late 1870s and 1911 mainly through limited sources at the Public Record Office.

³ The following projects were all responsible in helping to fund the construction of the GIS and were thus important in defining its goals: the initial impetus came from Dr. Humphrey Southall and Dr. David Gilbert's work on the Poor Law between the 1840s and the First World War. Dr. Derek Keene of the Centre for Metropolitan History provided funds to extend the system in London to assist in a project on mortality in London between 1860 and 1920. Dr. Kevin Schurer of Essex University provided funds to help create the parish-level GIS to help with his work on the 1881 census enumerators' books. The Hearth Tax Project under Prof. Margaret Spufford of the Roehampton Institute, London also provided funds to assist work on early parishes. More recently, large grants from the Economic and Social Research Council and the Wellcome Trust have focused on census and mortality statistics respectively.

the GBHGIS would be required to handle, and led to the project focusing on four main types of administrative unit:

- Registration Districts, the main publishing unit for the GRO between approximately 1840 and 1911.
- Poor Law Unions, closely related to Registration Districts and covering the same time period and used to publish data on the New Poor Law. This mainly concerns economic distress.
- Local Government Districts: these consist of County, Municipal, and Metropolitan Boroughs, and Urban and Rural Districts. They were formed by various acts of parliament from 1872 to 1894 but replaced Registration Districts as the main reporting units for the GRO after 1911. They were also used to publish many other datasets and were replaced by Districts in 1974.
- Parishes, the traditional unit of English local government. After the mid-nineteenth century their importance as a unit for publishing statistical data declined sharply although all censuses have published population counts at this level. This is important information as there were approximately 15,000 parishes compared to only 1,500 Local Government Districts and 630 Registration Districts and Poor Law Unions. These are incorporated from 1876, when accurate data on boundary changes first become available, to 1974.

The thesis follows the following structure: chapter 2 looks at the current state of both academic geography and GIS with regards to the analysis of time and change. The key point is that approaches to the analysis of change through both space and time are relatively weakly developed in both GIS and historical geography. Initially the chapter defines GIS and explores its potential role within geography focusing on the strengths and weaknesses of a GIS-based approach. The concept of time is then examined and an argument for the desirability of using an integrated approach to space and time is developed. The chapter then explores time from a GIS perspective: the difficulties in creating fully temporal databases for GIS are discussed and examples of work analysing and visualising change over time using GIS are given. The current limitations of both the use of GIS in historical geography and attempts by historical geographers to perform analyses thorough space and time are then both reviewed. In the conclusion, some brief guidelines for using the GBHGIS are given.

Chapter 3 sets the background to the thesis by providing a detailed examination of the history of local government units. Without an in-depth knowledge of these it is impossible to understand both the need for building a system such as the historical GIS, and the amount of complexity involved in constructing it. The chapter is based

on a combination of existing literature and research into boundary changes is also discussed.

The fourth chapter gives a detailed account of how the GBHGIS was built. It falls into two sections: the first looks at the architecture of the system and describes how a large spatio-temporal GIS database was designed, the principles behind the software written to extract spatial data from the database, and how the resulting spatial data could be linked to attribute data (e.g. demographic or economic statistics) such that boundaries could be populated with data or data allocated to their proper position in space. The second section discusses the historical research involved in unraveling and understanding boundary changes for periods as early as the mid-nineteenth century. The map and textual sources used are described and then the actual process of using this information to populate the GIS is outlined. Finally, some examples of using the GIS for simple thematic mapping work are given.

Chapter 4 described a database of changing boundaries and how this could be linked to statistical data. The aim of chapter 5 is to explore in detail how the impact of boundary changes can be removed from the statistical component of the data enabling long-term change to be examined. The chapter develops a sophisticated methodology to allow the interpolation of data from a wide variety of dates onto a single standardised set of units. This involves making maximum use of the available data to minimise the error introduced by the interpolation. The chapter looks at the areal interpolation techniques described in the literature and explores their relative advantages in interpolating data from the historical GIS. A set of techniques are then developed that can be used within the framework of the historical GIS and their relative merits are explored using a selection of “synthetic units” created using 1991 Enumeration District data to allow a quantitative exploration of the relative advantages of each technique.

Chapter 6 takes the methodology developed in chapter 5 and applies it to a practical problem in historical geography: the calculation of long-term net migration statistics that allow migrants to be sub-divided by age and sex. Net migration over a decade can be calculated from a start population, an end population and the number of deaths over the decade for all age-groups (other than infants where fertility would have to be included). As net migration is the residual, however, this calculation will be incorrect if the administrative unit has been affected by boundary changes. Age and sex specific data on both population and numbers of deaths have been published at sub-county level decennially since the 1850s. Unfortunately, boundary changes make the calculations very difficult both as a result of the major changes in types of unit in the 1910s and 1970s, and also due to the many relatively minor changes already

outlined in earlier chapters. The GIS, using the methodology described in chapter 5, allows the impact of all boundary changes to be removed by interpolating the datasets onto standardised administrative units. This chapter does this for Gloucestershire in such a way that net migration rates, calculated for men and women divided into ten year cohorts, can be calculated over the period 1881 to 1931. These dates were chosen deliberately to cover the change from the use of Registration Districts to Local Government Districts in publishing these data. Once the GIS is complete the work could be repeated to calculate rates for the whole country for a century and a half of data. The results of doing this, and its implications for research into long-run net migration trends will be discussed, as will the potential impact of the error introduced as a result of the interpolation.

In the seventh chapter the emphasis switches to an applied example of using the GBHGIS to look at long-term change. The chapter describes an example of how a limited version of the GIS could be used to analyse long-term change. The aim of the study was to examine how inequality in England and Wales has changed in the century since Rowntree's seminal work on poverty in York (Rowntree, 1901). Three key variables: infant mortality, overcrowded housing and unskilled labour, are compared at four key dates over the past 100 years. The methodology used meant that a GIS containing the changing boundaries of local government units was essential because the earliest data were published for Registration Districts, the most recent for Enumeration Districts or unit postcodes, and the data in between for Local Government Districts. To allow data from different dates to be compared they had to be interpolated onto a standardised spatial framework. The chapter describes how this was done and presents a discussion of long-term change in each variable over the past century. The results are then drawn together and some conclusions drawn.

The thesis is, therefore, mainly concerned with the integration of data through space and time or, to bring the two together, space-time (Massey, 1999). The key issue is how to cope with boundary changes both in terms of linking data to the administrative units they were published using, and then methods of integrating these over the long-term by removing the impact of boundary changes. Thus the thesis is concerned with creating a spatially and temporally integrated database of routinely published socio-economic statistics linked to their boundaries. This covers the period from approximately 1840, when these records first appear in a reliable format, to 1974. The combination of Local Government reform and the use of computer technology makes it unnecessary to perform similar work for more modern data. Modern data are, however, relevant to the thesis as will be demonstrated in the later chapters.

GIS is the vehicle through which time and space are integrated to allow long-term change to be re-examined from a more detailed perspective in which none of the components of the data need to be fixed in order to allow others to express themselves. The thesis is only a first step dealing largely with integration. It does, however, present a solution to a key problem, that of boundary changes. To take the work further new exploration, analysis and visualisation techniques will need to be developed that allow all the components of the data to express themselves simultaneously.

Chapter 2: GIS, Space-Time and Long-Term Socio-Economic Change

2.1: Introduction

For many years geographers have been arguing for more integrated approaches to their discipline. Two of the more recent attempts to do this have been under the umbrella of GIS (Openshaw, 1991a) and through the use of space-time (Massey, 1999). There is a common theme between these two approaches: that in order to gain the best possible understanding from a dataset the best possible use must be made of all the available components of the data used. The GIS community has, to date, primarily emphasised the spatial component of the data although there is a growing interest in time. The space-time agenda is more concerned with how the spatial and the historical components of data or of information can be brought together to better understand how the present was arrived at and the different paths that different places have gone through to get them there.

This chapter attempts to develop this argument as it applies to long-term change in zone-based socio-economic data such as the census. The chapter draws together three themes that emerge from the literature: firstly, that GIS allows the spatial component of data to be explicitly handled. This offers new opportunities to researchers studying the past, but also leads to some new problems and the resurrection of some old ones. Secondly, that there is an emerging view in the literature that the temporal component of data also needs to be explicitly handled, but that as space and time are intrinsically linked the two need to be handled together. Thirdly, that although there is a relatively recent literature on the need to integrate space and time, historical geographers have been interested in this for many years. Their efforts to carry out research that incorporates both have, however, been hampered by the complexity of their data. This has forced them to simplify the data by aggregation or by reducing the scope of their study and has thus removed much of the potential information content. It is argued that a spatio-temporal approach to GIS removes some of these problems as it allows analysis to be performed that makes the maximum possible use of the source data. It does not, however, remove the limitations of the source data but merely allows them to be analysed without having to first add extra layers of over-simplification.

2.2: Routinely published socio-economic data

As has already been stated this thesis focuses on routinely published, zone-based, socio-economic statistics. The classic source of these is the census (Diamond, 1999) but there are many other rich sources published in a similar manner such as vital registration data and Poor Law statistics. These sources have been regularly published over a length of time and must have been published using administrative units with clearly defined boundaries. As will be explored in detail in chapter 3, data in this form originated in the 1830s and 1840s and was well established by 1851 (Drake, 1972; Tillot, 1972). In order to publish data in this way two main components are required: first, strong central authorities such as the Poor Law Commissioners (Rose, 1971) and the GRO (Nissel, 1987) and, second, systems of administrative units with clearly defined and accurately mapped boundaries (Hasluck, 1936; Lipman, 1949; Owen & Pilbeam, 1992). Since the 1840s data in this format have been published at intervals varying from weekly, in the case of the *Registrar General's Weekly Reports*, to decennially, in the case of the census and the *Registrar General's Decennial Supplements*.

These are massively under-exploited resources. One major reason for this is the sheer volume of data involved, while another is that boundary changes make inherently simple data much more complicated. Advances in computer technology, and in particular processing power, have gone some way towards solving the first of these problems. This thesis offers some solutions to the second.

There are, however, some clear limitations to these datasets. Underlying most of the remainder of the chapter is the basic argument that it is highly desirable in a GIS environment to work with as much detail as possible. In the case of much of the type of data discussed here much of the detail that was present in the real world has already been lost in the collection and publication process. This is especially true prior to the 1970s but remains the case today. As will be discussed in more detail in chapter 3, the richest attribute detail is only available at district-level, meaning that the country is only sub-divided into approximately 630 or 1,500 spatial units depending on date. Temporally the quality of the data is also limited: the census only provides a decennial snapshot, and much of the richest vital registration data, in terms of spatial and attribute detail, is again only available decennially. Unlike the census, however, this data is not a snapshot of a single night but is a count of the total number of events that occurred over the decade. It could be argued from a long-term perspective that this is still snapshot data and that only the length of exposure of the snapshot is longer. The attribute data published also changes over time particularly as a result of changing

definitions and changes in subjects of interest (see Bracken & Martin, 1995; Champion, 1995 and Norris & Mounsey, 1983).

2.3: GIS: New approaches and traditional problems

a. The GIS approach

In this thesis GISes are defined as systems that combine data about an object with a precise description of the object's location in space. The data about the object is typically statistical, while the locational (or spatial) information is based on co-ordinates in Euclidean space. A GIS-based approach is one in which these two components are used together to gain knowledge from the data. The GIS literature generally focuses on doing this by analysing data and by visualising it. A third way that receives less attention but is at least as valid is that knowledge can also be gained simply by integrating data using their spatial location. It will be noted that no mention is made in this definition of the third component of data: time. This will be returned to later in the chapter.

Although this definition is seen as valid for this thesis it is by no means the only definition of GIS and most authors agree that defining GIS is quite problematic. GIS is relatively new, emerging in the 1980s from the environmental and natural resource management fields (Tomlinson, 1990), and has started to be available to a wide audience through desktop computers only since the mid-1990s. This has meant that no definition is yet generally agreed on. Many definitions are computer science based, while others focus on data handling abilities. A good general definition is given by the Chorley Report: that GISes are systems for the automated capture, editing, storage, retrieval, manipulation, analysis and display of spatially referenced data (DoE, 1987). From a computer science point of view, Maguire (1991) argues that GIS can be thought of as an integrated subset of the systems used in computer-aided design, computer cartography, database management and remote sensing. By contrast, Star and Estes (1990) take a more data-led approach when they define GIS as “an information system that is designed to work with data referenced by spatial or geographic co-ordinates” (p. 2). Burrough (1986) focuses on the tools provided to manipulate data spatially when he talks about “a powerful set of tools for storing and retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes” (p. 6). Definitions such as these all have one thing in common, they all approach the subject using a bottom-up approach from a technological or data-driven perspective, rather than a top-down approach that states what GIS should do or has to offer geography as a discipline.

This is because GIS originated with developments in Information Technology and in particular the fields of computer cartography and database management systems

(DBMS) (see Cowen, 1990 or Jones, 1997) rather than from a perceived need within academic geography for the types of approaches and techniques that it now offers. As a result, the role of GIS within geography is still to be fully established and some authors even question the desirability of having it at all. Enthusiasts such as Openshaw argue that GIS will revitalise and re-unite the discipline by creating a cohesive, scientific framework around which all other work can be based (see in particular Openshaw, 1991a; Openshaw, 1992 and Openshaw, 1997). At the other extreme there are those who argue that GIS marks a return to “the very worst sort of positivism” (Taylor, 1990: p. 211), and that it lacks a strong epistemology and any treatment of ethical, economic or political issues (see in particular Curry, 1995; Pickles, 1995a; Pickles, 1995b and Taylor & Overton, 1991).

It is not the intention here to further this debate beyond saying that GIS is a maturing technology and academic sub-discipline. Eventually it is likely to become an integrated part of academic geography and the technologies and techniques that it uses and enables will become part of the toolbox of many geographers. This is because GIS explicitly handles and sub-divides space and should thus be invaluable to researchers studying space. There are two reasons that not all geographers will be able to, or even want to use GIS. The first is that its model of space is crude and will not be suitable for all applications. The second is that its approach is primarily scientific, as is demonstrated by the attempt to re-brand GIS as “Geographic Information Science” (Fisher, 1997; Goodchild, 1992a), and is thus not compatible with some of the more qualitative and humanities-based approaches to the discipline. In this respect it is both similar and complimentary to spatial statistics; it offers ways of handling data more effectively and thus gaining more knowledge from these data. At the same time the roots of GIS is undoubtedly lie in taking a quantitative approach and have both the strengths and limitations of this (Buttimer, 1976; Goodchild, 1995). More recently historians, in particular have started to use GIS in a more humanities-based way to provide a spatial framework for qualitative data. This approach undoubtedly has interesting potential but lies outside the scope of this thesis (see, for example, Ferris & Ray, 2000; Harris, 2001 and Smith *et al*, 2000).

Both pro and anti-GIS writers agree that what has been termed the “GIS revolution” (Openshaw & Clarke, 1996: p. 21) must not merely repeat the mistakes of the quantitative revolution (Billinge *et al*, 1984) in over-emphasising the ability of crude models of crude data to represent the way geographic processes operate. Openshaw (1991b) expresses this well when talking about the integration of GIS and spatial analysis techniques, he says “In reality, even the most sophisticated spatial analysis procedure will probably not progress the user very far along the path of scientific understanding and in some ways the technology appears to be limited in

what it can offer... The purpose of that analysis would typically be to develop insights and knowledge from any patterns and associations found in the data, which will either be useful in their own right or else provide a basis for further investigation at a later date using different, probably non-spatial and more micro-scale, methods” (p. 394). He goes on to argue that rather than merely including traditional spatial analysis techniques within GIS a whole new set of techniques based on exploratory data analysis should be developed that avoid highly formalised scientific designs and over-emphasising inappropriate statistical inference.

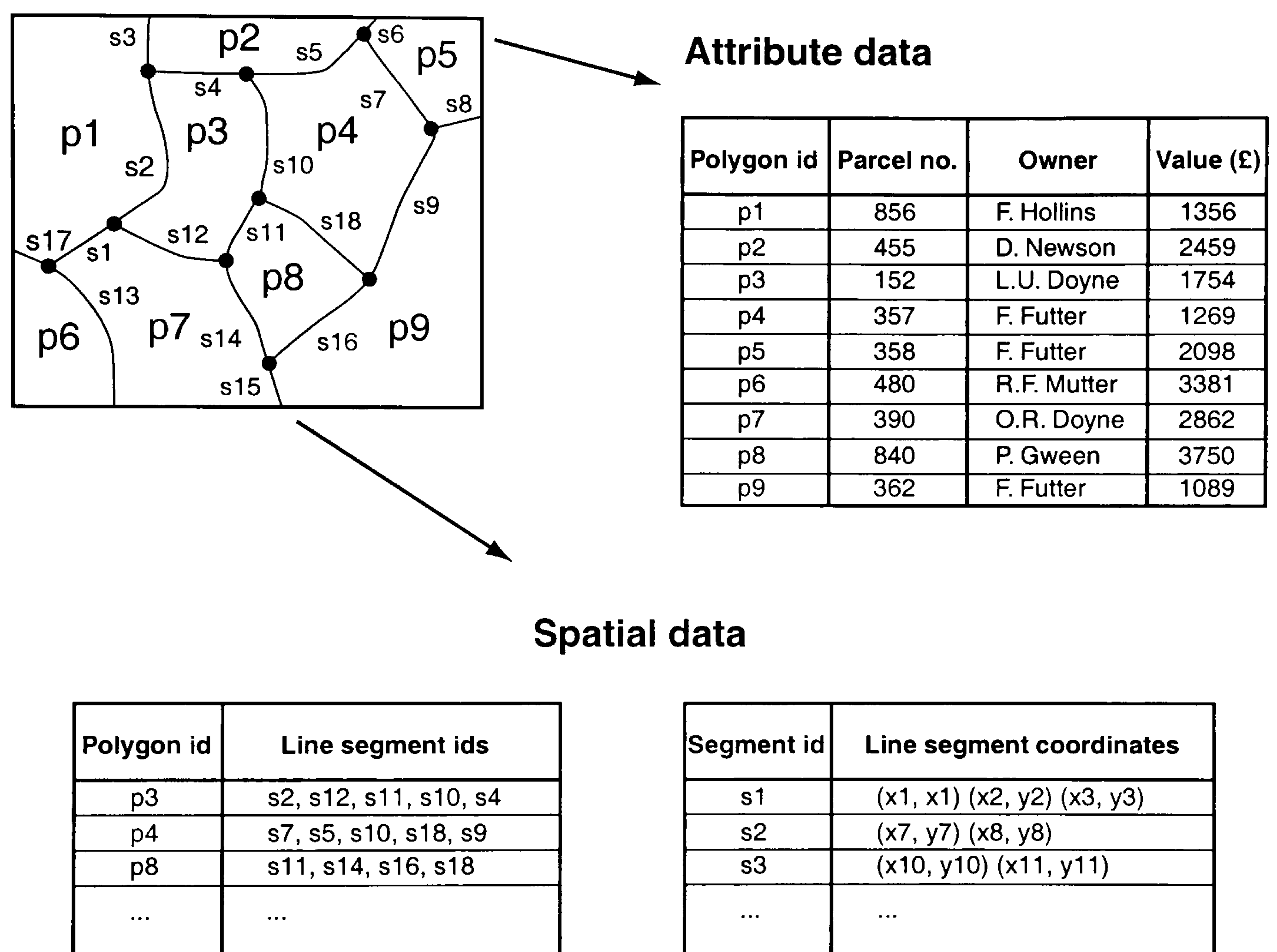


Figure 2.1: How a polygon GIS models the world. Attribute data are linked to their spatial data through unique identifiers. The link between polygons and their boundaries is also based on unique identifiers (Source: Jones, 1997: p. 45).

b. Problems with a GIS approach

To gain an understanding of the strengths and weaknesses of a GIS-based approach it is first necessary to understand a little about the data structures GIS software uses to represent the real world. There are two basic types of GIS: vector-based systems model space based on three graphic primitives: points, lines, and polygons (areas or zones), while raster systems sub-divide space into a large number of regular tessellations, usually squares. This thesis is based on the use of a vector GIS but raster and vector systems have many similarities in approach. Figure 2.1 shows the way a vector GIS represents real world areas using polygon data: in which each zone is completely enclosed by one or more lines that make up its boundaries. The area is attached to one or more columns of either textual or numeric data, termed attribute data. In this way statistical data can be given a spatial reference and areas on the map can be populated with data. By definition these polygons have hard, finite boundaries and, by implication but usually not in reality, the attribute data are evenly dispersed across the entire polygon. It is not necessary to go into more detail about the broad technicalities of GIS as there are many good introductory texts available (see, for example, Burrough, 1986; Clarke, 1996; Jones, 1997; Maguire *et al*, 1991 or Martin, 1991). An understanding of this basic model is, however, needed to understand what follows. Another point that should be noted from this, and one that will be dealt with in more detail in much of the rest of the chapter, is that in this model there are only two components: space and attribute; time is not included.

Many of the traditional problems with quantitative analysis are relevant to GIS-based analysis, and in some cases interest in GIS has led to a re-examination of these issues with a view to finding new techniques for resolving them. Among the most important are issues such as data quality (Openshaw, 1989; Unwin, 1995), error propagation (MacDougall, 1975), the Modifiable Areal Unit Problem (Openshaw, 1984) and ecological fallacy (Robinson, 1950). Most GIS-based analyses will be affected by some or all of these.

i. Data quality

Data quality is especially important in a GIS-based environment as the power of modern computing has contributed to the creation of much larger datasets than were traditionally available. This is combined with the ability to perform analyses more quickly and more powerfully than was traditionally possible. This allows data not only to be used far more effectively but also to be abused far more easily than in the past. In particular it puts far more strain on the quality of all aspects of the data: its spatial, attribute and temporal components. Unwin (1995) distinguishes between: *error*, the difference between reality and the representation of it; *blunders*, which are simply

mistakes; *accuracy*, the closeness of results, computations or estimations to values accepted as true; *precision*, the number of decimal places given in a measurement which is usually far more than the accuracy can support; *quality*, the fitness for purpose of the data; and *uncertainty*, which is a measure of the doubt or distrust that the data should be regarded with. He points out that the results of a series of complex operations on good quality, high precision, error free data can still contain a high degree of uncertainty.

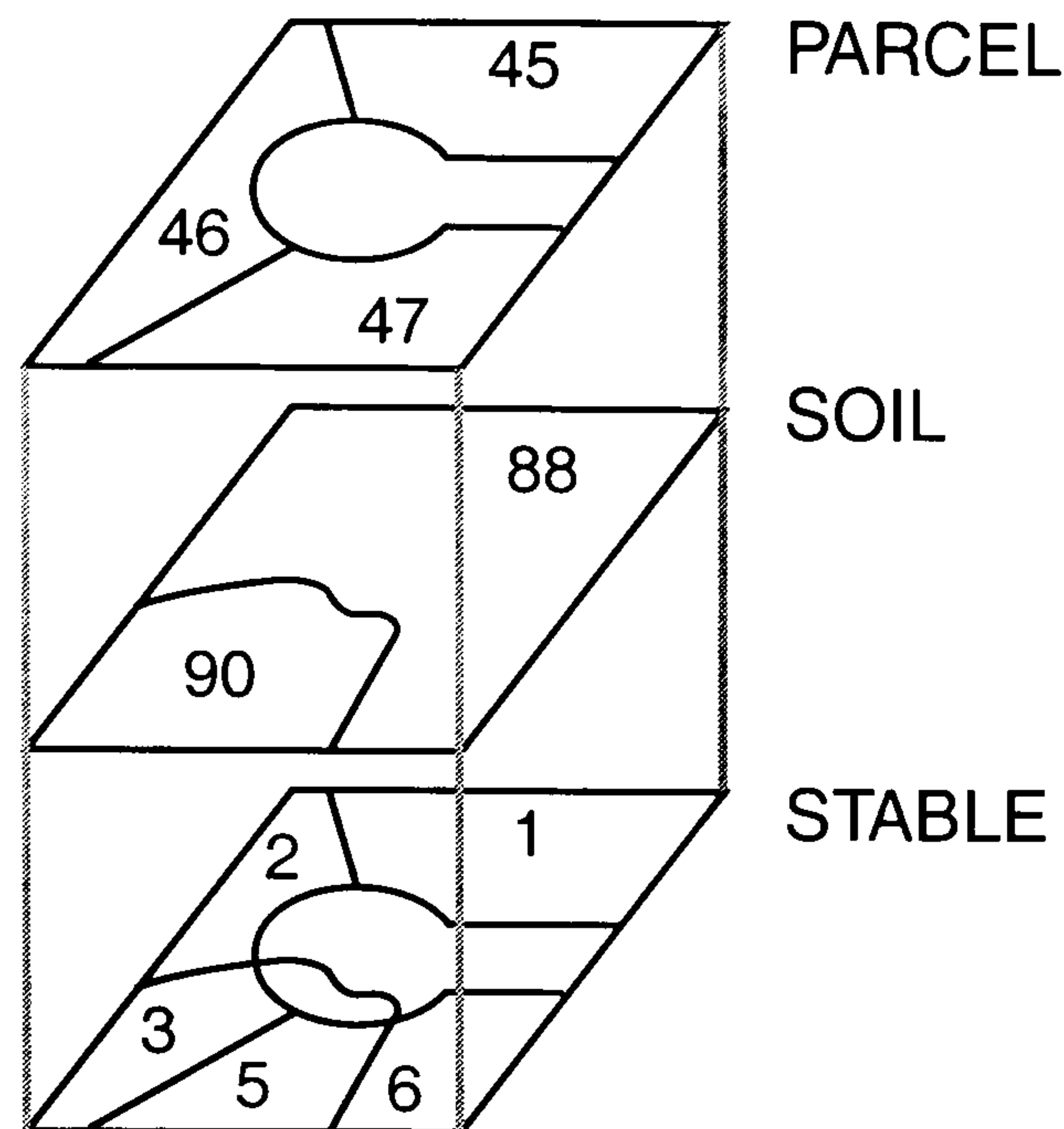
Error and inaccuracy are inherent in all the components of GIS data. As an example, sub-dividing the population of an area is often done using polygons with hard, arbitrary boundaries. This introduces error into the spatial component, an issue that is starting to attract significant amounts of research interest (see, for example, Burrough & Frank, 1996). The way that those boundaries are captured by digitising from paper maps and other secondary sources introduces levels of inaccuracy that will usually be higher than the inaccuracy inherent in the source (see, for example, Peuquet & Boyle, 1990). The attribute component of data will also have problems with both accuracy and error and, although it has received less attention in the literature, so will the temporal component.

The GIS community is not insensitive to these problems. This has led to an acknowledgement that any analysis using a GIS must be sympathetic to the limitations of the data, and to the development of a research agenda to create what Unwin (1995) terms an “error-sensitive” GIS. This is a concept that is still some way from being realised. Until then Openshaw (1995) goes as far as to state that “The basic null hypothesis in GIS is not of randomness but of database error. Only if this can be rejected is it worth applying anything sophisticated... The errors and uncertainties inherent in spatial databases can be handled only if allowance is made for them” (p. 32).

ii. Error propagation

When datasets are combined the impact of errors can potentially increase exponentially. One way GISes combine datasets is through map overlay where two or more map layers are super-imposed to produce a new map layer with new attributes derived from the source layers as shown in figure 2.2. The problems inherent in doing this were recognised as early as the mid-1970s when MacDougall (1975) argued that the error in overlay layers is so significant that many overlay products are potentially useless. More recently this subject has received significant attention (see, for example, Chrisman, 1990 or Goodchild & Gopal, 1989). A particular problem is the appearance of “sliver polygons”, small polygons that are formed as a result of the difference between the same boundary as held in two different sources. The conclusion from this

is that when map overlay is used it must be done bearing in mind the limitations of the sources datasets and that the resulting product will at best be as accurate as the least accurate source but may be as bad as the combined error in both.



This topological overlay joins polygons from two layers to establish the spatial relationship between parcels and soil types. The result contains both sets of polygons.

PARCEL.PAT			SOIL.PAT	
PARCEL-ID	PARCEL_NO	SOIL-ID	STABILITY	
45	121-99-501	88	STABLE	
46	121-99-502	90	UNSTABLE	
47	121-99-503			

STABLE.PAT				
STABLE-ID	PARCEL-ID	PARCEL_NO	SOIL-ID	STABILITY
1	45	121-99-501	88	STABLE
2	46	121-99-502	88	STABLE
3	46	121-99-502	90	UNSTABLE
4	—	—	90	UNSTABLE
5	47	121-99-503	90	UNSTABLE
6	47	121-99-503	88	STABLE
7	—	—	88	STABLE

The polygon-on-polygon overlay joins polygon attribute tables from two coverages into one. All combinations are listed in the new polygon attribute table (PAT).

Figure 2.2: Example overlay operation. Both the spatial and attribute data from “Parcel” and “Soil” are combined to form “Stable” (Source: ESRI, 1997: p. 8-18).

iii. The Modifiable Areal Unit Problem

The Modifiable Areal Unit Problem was first identified in 1934 by Gehlke & Biehl who showed that different results could be obtained where different zones were

used and that, in general, correlations between variables increase as zones are grouped together (Green & Flowerdew, 1996). Openshaw & Taylor (1979) demonstrated an extreme example of this by comparing data on the percentage of the population voting Republican in the 1968 Congressional election with the percentage of the population aged over 60 for ninety-nine counties in Iowa. They found that by aggregating the data to six regions using different zones they could produce correlations from -0.99 to 0.99 with many intermediate results also being possible. Fotheringham & Wong (1991) demonstrate that the same phenomena occurs when simple and multiple regression-based analysis are carried out on increasingly aggregated data.

The problem is due to the combined influence of two effects: the scale effect refers to the influences caused by using progressively larger units which typically causes smoothing or averaging of the data. This results in datasets having an increasingly normal distribution with a strong tendency towards a lower standard deviation, skewness and kurtosis (Clarke & Rhind, 1975). The aggregation effect refers to the impact of different arrangements of aggregated areas on the results of analysis, and is thus very similar to the well known phenomenon of “gerrymandering” where electoral districts are modified in such a way as to influence the results of an election (Wrigley *et al*, 1996).

The issue of how to deal with the modifiable areal units still causes controversy. On the one side pragmatists such as Goodchild (1992b) argue that the spatial impact of the problem can be minimised by using data at the lowest possible level of aggregation. On the other side it is argued that the use of modifiable areal units fundamentally undermines many forms of spatial statistical analysis. Green & Flowerdew (1996) summarise this succinctly by saying, when talking about regression analysis of spatially aggregate data, “we would suggest that the optimum level of aggregation is none at all, and even here we need to include the spatial effects in models.” (p. 54). Others (see, for example, Openshaw, 1984; Openshaw, 1996 and Openshaw & Rao, 1995) have also called for new techniques and models to be devised that can not only cope with modifiable areas but use them as part of an analysis. Some limited progress has been made in this direction using techniques such as geographically weighted regression but even these are still scale dependant (Fotheringham *et al*, 2000).

iv. Ecological fallacy

Linked to the modifiable areal unit problem is the problem of ecological fallacy. This occurs when correlations found in ecological data, i.e. data about groups, are used to infer, either explicitly or by implication, correlations at individual or household-level (Robson, 1969). Robinson (1950) provided an early demonstration of

this by comparing areal-unit based correlations with individual experiences when comparing racial groups with illiteracy levels in the USA. Again, this is a fundamental problem inherent in the data that the researcher must be careful to manage. Some research is attempting to re-examine ecological fallacy in an attempt to create statistical models that will resolve the problem (see Tranmer & Steel, 1998; Wrigley *et al*, 1996) although whether mathematical or statistical solutions can resolve this problem remains to be seen.

c. The potential for GIS

GIS in its current form is, therefore, undoubtedly a quantitative approach to geographical analysis. It allows spatially-referenced data to be analysed in a more powerful way than was previously possible by using modern computing power and by having a data model that combines data with their locations. It also provides an opportunity to devise new techniques for integrating, analysing and visualising data using an integrated approach to the data's spatial and attribute components. This allows the maximum information content possible to be gained from the data. There are, however, risks to this new approach. In particular, many of the traditional problems with quantitative analyses still exist and while GIS may offer new solutions to these problems it also offers the potential to repeat some of the mistakes of the past.

The final question in this section asks what the broad implications of GIS are for historical geography. People doing historical geography are, by definition, interested in space. This means that GIS should have something to offer them provided they are interested in quantitative aspects of the discipline, and the model of space that GIS uses is relevant to their own conception of space. The first of these two criteria will exclude many in the current field of historical geographers, although it is possible that, in the longer-term, concepts of GIS more concerned with multi-media data such as scanned images, photographs, textual sources and sound rather than statistical data, and with less rigid concepts of space may have relevance even here. The second is unlikely to be limiting as many researchers using quantitative techniques use spatially aggregate statistical data such as the census.

The work that has so far been done using GIS to study historical geography will be reviewed later in the chapter. For now, however, it is worth merely stating that GIS should have relevance to many historical geographers because it allows them to explicitly include space into their work. The drawback, however, is that, as discussed above, the impacts of space itself and the way that it is represented in GIS, are more complicated than that they appear at first sight. There are, therefore, many issues that need to be considered by the researcher wanting to use GIS in a historical context and these go far beyond simply how to use a desktop GIS package such as MapInfo.

2.4: Conceptions of time and its interactions with space

Time is in many ways a highly problematic concept. Most people would probably agree with Augustine who stated that he understood what time was so long as no one asked him to explain it (Newton-Smith, 1986).

A very basic concept of time is that it is a unidirectional continuous flow that is similar to a line without endpoints that stretches infinitely into the past and the future (Dragicevic & Marceau, 2000). One way of conceiving of this is as calendar time, where precise dates can be given that dissect linear time into discrete entities. Frank (1998) develops this to say that events occur at points in time similar to Euclidean points. If these points are mapped onto a time line then lengths of time can be calculated. Other conceptions of time have also been offered independently by both Frank (1998) and Hazelton (1998): firstly, cyclical time models time in cycles such as the seasons. A second is container time where discrete models of time have varying resolutions, resulting in the oddity that an event that happens on December 31st may occur in the same week but a different year to an event on January 1st. Branching time occurs where a variety of possible time lines can either lead to or develop from a single point in time. This can either be used to show how a situation was arrived at as a result of several themes converging, or how different themes could develop in the future (Worboys, 1998, develops this further). Finally, time can also have multiple perspectives. For example, the time when an event actually occurs (called real time, event time or valid time) may be different from the time it is recorded (called transaction time, system time, or database time). Both of these may be relevant types of information. A database used for planning may contain both the current situation and planned changes. Over time both of these change and the changes need to be recorded in such a way that they can be reconstructed at a later date (Yearsley & Worboys, 1995; Worboys, 1998).

All of the above approaches to time are similar to Newton's view that time is a dimension that is separate from but similar to space. They do not, however, draw time and space together to form a single, integrated concept. Einstein, Minkowski and others integrate the concepts of time and space to argue that time is a fourth dimension that is inextricably linked with space and that it is over-simplistic to consider either space or time as separate entities. Instead they should be imagined as space-time, a single combined concept. The most elegant way of demonstrating the concept of space-time is through Minkowski's light cones shown in figure 2.3. If the effects of an event travel at a speed not exceeding the speed of light then, in three dimensional space with time as the fourth dimension, this will form a cone of space-time that the event can potentially influence. This is called the event's future light cone and it is

physically impossible that anything in space-time falling outside this cone could have been influenced by the event. Similarly, a past light cone can also be drawn that encloses the space-time that could potentially have influenced the event and excludes areas of space-time that physically could not have (Hawking, 1988).

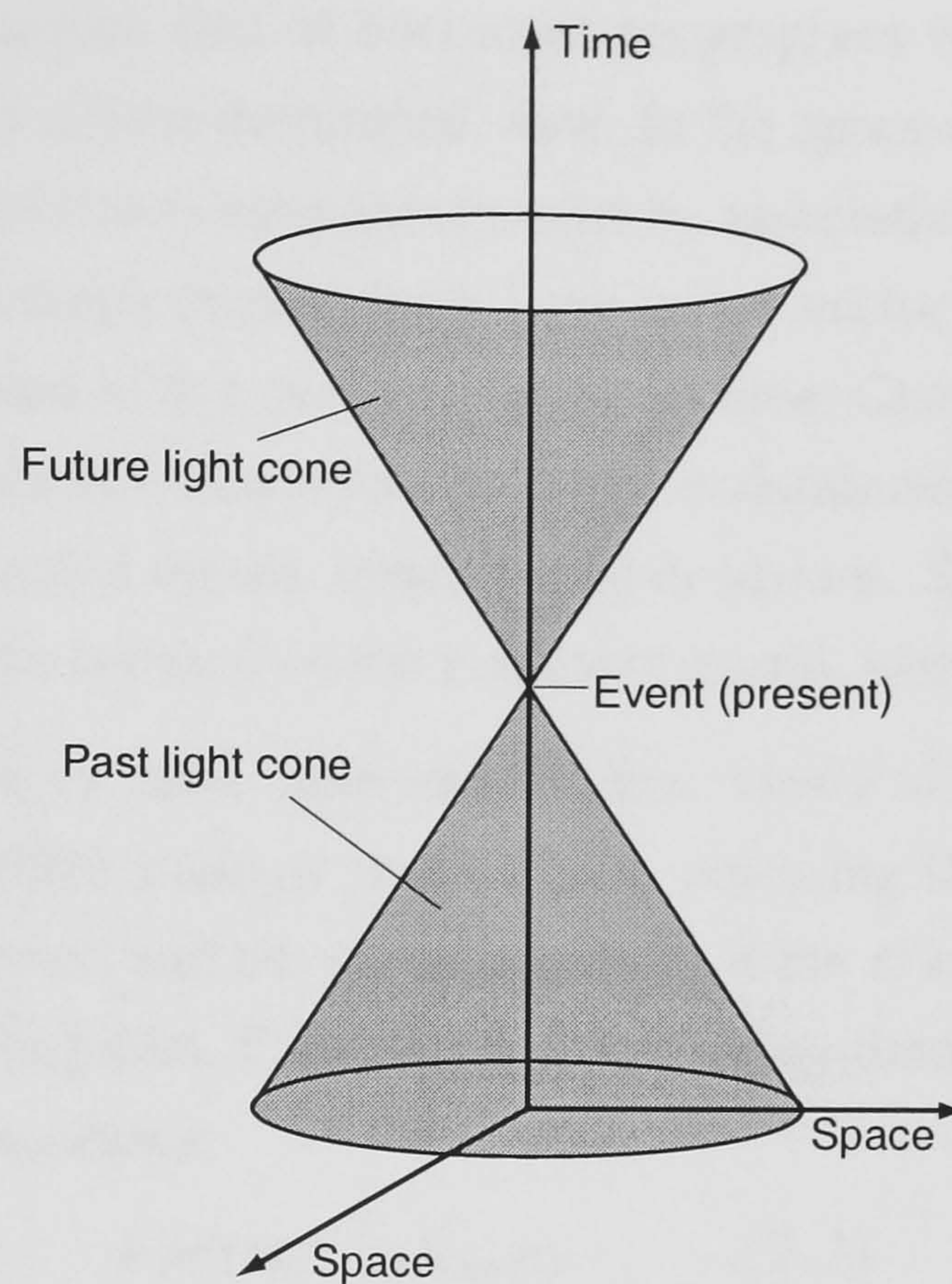


Figure 2.3: An event's future and past light cones (Source: Hawking, 1988: p. 26).

This demonstrates the concept of space-time in theoretical physics working within the confines of the speed of light. Within this framework a four-dimensional geometry can be devised that can calculate the space-time distance between a pair of events as follows:

$$(x-x')^2 + (y-y')^2 + (z-z')^2 - c^2(t-t')^2 \quad (2.1)$$

where c is the speed of light and the events occur at times t and t' and locations (x,y,z) and (x',y',z') . A point in space-time is, therefore, a point in space at a moment in time. The point's history is a four-dimensional line through space-time. It is, however, important to note that the spatial and temporal dimensions are very different as is shown by the fact that there is a different sign in front of the temporal component of equation 2.1 (Newton-Smith, 1986).

Space-time is, therefore, a difficult concept but one that has become well established in physics. It follows that if geographers are fundamentally concerned with space they must also be fundamentally concerned with time. Many geographers have argued for this from many different perspectives (see, for example, Haggett, 1979;

Marsh *et al*, 1988; Parkes & Thrift, 1980 or Thrift, 1977). Physicists, dealing with sub-atomic particles, have been able to demonstrate the importance of this link using laboratory experiments and hard mathematics. Geographers, dealing with the complexities of human behaviour, do not have these luxuries and have been less successful in drawing the two together.

Wachowicz (1999) argues that at best most geographers have either followed a space-dominated view or a time-dominated view. In the space-dominated view space is seen as a container that allows elements to exist by associating them with a layer or theme. This is usually complemented by a layer-based vector or raster model with each layer being associated with a period or point in time. Change is then defined as the similarity or difference between layers. In the time-dominated view time is viewed as a time line with associated events, observations or actions. Space is not seen as an entity in itself and analysis is based on the lineage of events, observations or actions.

The difficulty is how to move from one of these views to an integrated view of space-time. Kelmelis (1998) attempts to do this by replacing the speed of light with the mechanics of the process and the communication of the effects of the process. He terms this the causal propagation. From this he constructs a function to link the spatial and temporal extent of processes:

$$E_s = f(M, E_t, t_e, V_{cp}, A) \quad (2.2)$$

where E_s is the spatial extent of a process, M is the magnitude of the process, E_t is temporal extent of the process, t_e is the elapsed time since the onset of the communicable portion of the event, V_{cp} is the velocity of the causal propagation, and A is an attenuation factor. While this is an interesting idea, implementing it in the real world is likely to be fraught with problems as it relies on accurately quantifying too many things, such as the magnitude of a process, that may be difficult or unrealistic to quantify and whose quantities may vary through space and time in a complex manner.

Massey (1999) puts forward a much more theoretical idea of how the idea of space-time can be conceptualised. She does this by drawing together ideas from various parts of the discipline of geography including Raper & Livingstone (1995) working in GIS; Sugden (1996) and Kennedy (1992) both geomorphologists; and Frodeman (1995) a geologist. She argues that all these authors have argued the case for moving away from what Raper & Livingstone term “timeless geometrical models based on two dimensional planes” (p. 363) and Sugden and Frodeman both describe as the study of short-term processes. These, she argues, need to be replaced by an approach that looks at historical development or evolution as potentially open ended. To explain this she cites Kennedy who distinguishes geomorphologists into those who see history as a progression that says “how we must get *here* from there” (p. 247)

rather than those who see history as a sequence that says “how we got here from there” (p. 247). The difference is that the progressionist argument over-emphasises short-term processes leading to the present becoming an inevitable consequence of the past. The sequence-based approach sees historical development as far less rigid with different outcomes emerging in different places (Massey, 1999: p. 267).

Massey says that this has developed because in the past reality has been represented through spatialisation that fixes time and thus deadens flows. “This historically significant way of imagining space/spatialisation not only derives from an assumption that space is to be defined simply as a lack of temporality (holding time still) but also has contributed substantially to its continuing to be thought of in that way. It is, however, a totally inadequate conception of space” (p. 268). The question she raises from this is how to represent continuous reality using discrete entities or, in other words, how do we move away from spatialising the temporal to conceiving space-time. Time is needed to tell the story of how an individual place developed to become what it is now, space is needed as without it there can only be one development story. We therefore need multiple trajectories through space and time to allow the complex stories of how places change to be told.

	Fixed	Controlled	Measured
Soils data	Time	Theme	Location
Topographic map	Time	Theme	Location
US census data	Time	Location	Theme
Raster data	Time	Location	Theme
Weather reports	Location	Time	Theme
Flood tables	Location	Time	Theme
Tide tables	Theme	Location	Time
Airline schedules	Location	Theme	Time

Table 2.1: The representation of geographic data in various formats (Source: Langran & Chrisman, 1988: p. 2).

How this can be done is still open to question but in the field of GIS there has been interest in the temporal component of data for some time. In 1988 Langran & Chrisman argued that, traditionally, to measure one of the three components of data, theme (their term for attribute), location and time, the second has to be controlled and the third is usually fixed. They provide examples of how this occurs as shown in table 2.1. This, they argue has limited the potential for analysis through space and time. They saw the solution to this as the development of temporal GISes that would allow analysis to move away from what they term “time-slice snapshots” towards what they

term “space-time composites” where none of the three components have to be fixed. This, in turn, allows for a much better understanding of process. Chrisman (1998) links this strand of GIS to the debate on error discussed above by arguing that only by understanding process can change be distinguished from the errors that can arise when comparing snap-shots as a result, for example, of differing measurements. He states that “Change must be seen as a composite of processes (and interactions between those processes) that occur on a wide band of time scales... At a minimum any difference should be carefully distinguished from confounding error and connected to identifiable processes” (p. 86). Recent GIS-based approaches have focussed on using object-oriented technology to implement ideas similar to space-time composites where each object has its own geometry that defines its relationship with time and space or space-time (see, for example, Raper & Livingstone, 1995 and Wachowicz, 1999).

In historical geography it has also been argued that there is a need for a view of the world that jointly incorporates space and time together has also been argued for in historical geography. Langton (1972) used systems theory to identify two approaches to the study of change: *synchronic* analysis and *diachronic* analysis. These are very similar to the concepts of timeless processes (or time-slice snapshots) and space-time composites. In synchronic analysis a system is allowed to reach equilibrium under a set of parameters. The system then undergoes a change in parameters and once this change has reached an equilibrium state in all its parameters the two sets of parameters from the two equilibrium states can then be compared. On the other hand, diachronic analysis “attempts to trace the origins of particular elements of the system and the interrelations and then follows the evolution of the way they function, cutting across a successive series of synchronic pictures of the system” (p. 137). He argues that the concept of a process is central to diachronic analysis. A structure under external forces or through its own energy undergoes actions or acts so that the change affects it. A change will not necessarily cause a process as the sub-systems within a system all have a “range of stability” bound by thresholds in which they can accommodate a change without themselves changing. Langton’s conclusion is that diachronic analyses are necessary for explanation in the social sciences as systems can rarely be assumed to be in equilibrium. This, he argues, means that rather than using synchronic analysis based on snapshots, social scientists should create models of processes to perform diachronic analysis.

There are therefore clear overlaps between the arguments of the various researchers working in a variety of different fields of geography and over a significant length of time. The language used varies with the background of the author, however, the basic argument is the same: that representations of the world need to include time and change over time as an integral part of the representation. Openshaw (1991b) calls

for GIS researchers to “avoid any technique that either implicitly ignores or explicitly removes the effects of space” (p. 396). What Massey (1999) and the other researchers cited above are doing is extending this to cover not just space but space-time. In particular they are arguing that a single spatial snapshot is not an adequate representation but that the temporal component of data needs to be explicitly handled.

2.5: Integrating GIS, space-time and geographical problems

Abstract approaches to space, time and space-time have not been well implemented in GIS and historical geography. This section will consider why this is so by evaluating the treatment of: time and change in GIS, historical applications that use GIS, and time and change in human geography. The reason for this sub-division is that the time and change in GIS section demonstrates the current state of the GIS community in creating an integrated approach to space and time, the section on historical applications of GIS shows that the historical community is still early on the learning curve of using GIS even in the purely spatial sense. The final section on time and change in human geography shows that there is a tradition of the type of work that a GIS that was capable of integrating space and time could be relevant to, but that in the past the complexity of the data has seriously undermined attempts to do this.

a. Time and change in GIS

The literature on temporal GIS is small but growing. As long ago as 1989, Langran claimed that “A reasonable future goal for GIS is that they should be capable of tracing and analysing changes in spatial information over time” (p. 214). As yet, however, no commercially available GIS packages fully integrate a temporal component. The main problem is that using the layer-based GIS data model is that there is no satisfactory way to extend them to incorporate time in such a way that spatial topology is preserved and temporal topology is added (Langran, 1989). In this section, therefore, the main focus is on the theoretical literature. Where examples of empirical work exist these are also discussed.

Langran (1992) argues that a temporal GIS should allow a user to establish the situation at a particular point in time, to examine whether temporal patterns exist, to ascertain what trends are apparent, and to attempt to establish what processes underlie the change. To do this it needs to be able to respond to queries such as:

- Where and when did change occur?
- What types of changes have occurred?
- What is the rate of change?
- What is the periodicity of change?

Peuquet (1994) presents a similar argument stating that a spatio-temporal GIS should be able to answer three types of queries. The first involves simply changes to an object such as “has the object moved in the last two years?”, “where was the object two years ago?”, or “how has the object changed over the last five years?”. The second involves changes to the object’s spatial distribution such as “what areas of agricultural land use on 1/1/1980 had changed to urban by 31/12/1989?”, “did any land use changes occur in this drainage basin between 1/1/1980 and 31/12/1989?”, “what was the distribution of commercial land use 15 years ago?” or “what areas have changed from agricultural land use to urban land use over the last 50 years?”. Finally, the third involve changes to the temporal relationships among multiple geographical phenomena, for example, “which areas experienced a landslide within one week of a major storm event?” or “which area lying within half a mile of the new bypass have changed from agricultural land use since the bypass was completed?”.

Langran (1992) identifies six functions of a temporal GIS: inventory, analysis, updates, quality control, scheduling and display. Inventory refers to the need to store a complete description of the study area and account for changes in both the real world and the computer representation of it. To do this the data structure should be able to supply a complete lineage of a single feature, the evolution of an area over time, and the state of a feature at a moment in time. For purposes of analysis the GIS should be able to explain, exploit or forecast the components contained by the study area and thus allow an understanding to be gained of the processes at work in the study area. Doing this involves statistical analyses of trends, patterns, divergence from the norm, cross-tabulations or autocorrelation, and creating models either to compare the model with reality or approximate the data’s character. Updates refer to the need to supersede outdated information with current information. The outdated data need, however, to be preserved and accessible should the user want to create past states not only of reality, but also of the database. The temporal information should also assist quality control by evaluating whether new data are logically consistent with previous versions and states. Scheduling allows the system to identify and anticipate threshold database states which trigger pre-defined system responses. An example of this might be incorporating information on streetlight burnout rates to inform managers of the need for action. Finally, the GIS needs to be able to display the results of queries. This involves generating a static or dynamic map or tabular summary of the temporal processes at work in the study area (Langran, 1992).

This section does not sub-divide the various aspects of a temporal GIS to the level of detail given by Langran. Instead, three aspects of temporal GISes are discussed: temporal databases for GIS, analysis through time using GIS, and visualising change using GIS.

i. Temporal databases for GIS

Langran & Chrisman (1988) and Langran (1992) describe three possible models that a spatio-temporal GIS database could use. The first, *time-slice snapshots*, only record phenomena at a certain time and is demonstrated for four snapshots in figure 2.4. Time-slices can either be taken at regular intervals or in response to changes. Although this solution is intuitive it is limited as it will answer what exists at T_i but not how this has changed from T_{i-1} or what the frequency of change is. Although states are represented, the events that change states are not. They identify three major problems with this model: firstly, the structure is hidden and thus boundaries between versions are hard to locate. Secondly, as there is no understanding of temporal topology, rules to enforce logical integrity are difficult to devise and thus using the temporal structure to enforce error trapping is difficult. The third problem is that as a complete snapshot is produced at every date, there are large amounts of redundant storage as all unchanged data are duplicated.

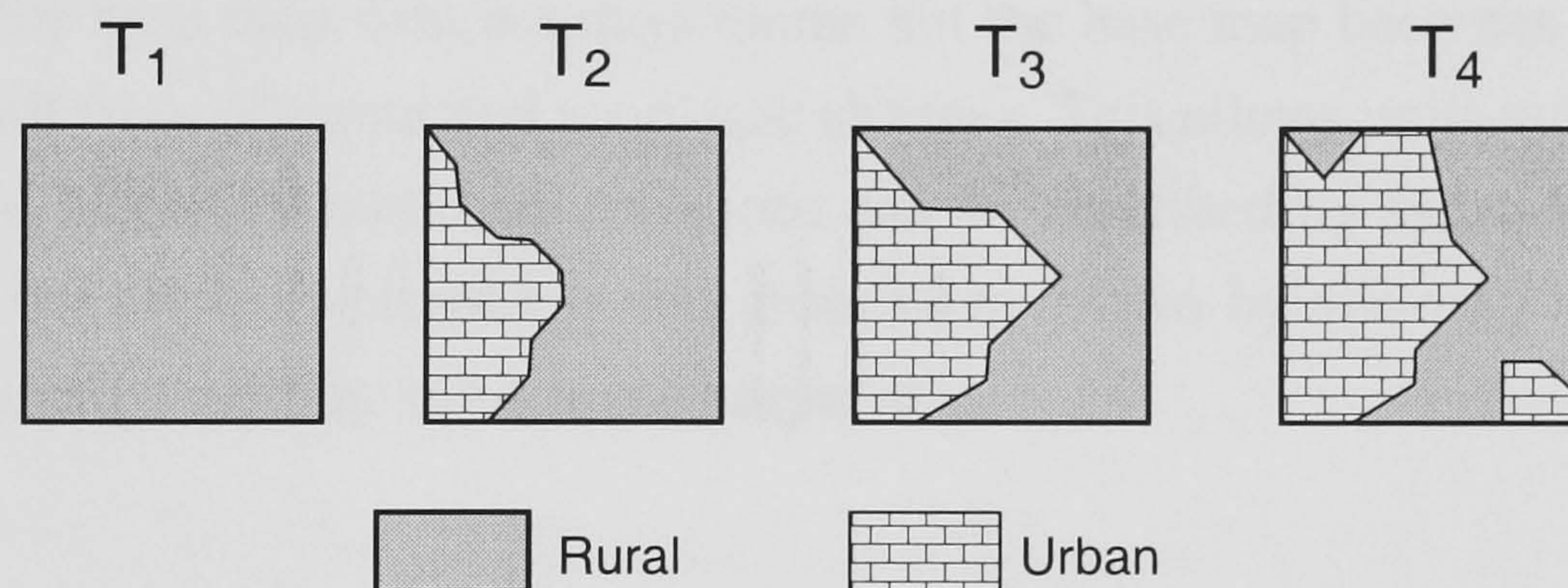


Figure 2.4: Time-slice snapshots representing urban expansion into a rural area
(Source: Langran, 1992: p. 39).

The second model they suggest is what they term *base map with overlays*. This involves standing on a time-line and looking into the past or the future. An opaque base map at T_0 is used to define the data's original state. At appropriate intervals changes that have occurred since the previous update are recorded. The intervals used do not have to be regular. This is shown in figure 2.5. This model allows queries on both states and versions. To answer the query "what was the data at state T_i " T_0 is merged with overlays T_1 to T_i . To answer "what has changed between T_i and T_j " all overlays between T_{i+1} and T_j are merged. To answer "what versions has this object and when did it mutate" each overlay is checked for amendments in the object's location, and finally to calculate the frequency of change the numbers of mutations at each location can be calculated. According to Langran (1992), therefore, using this

model the temporal structure is evident, errors can be trapped and redundancy is minimal.

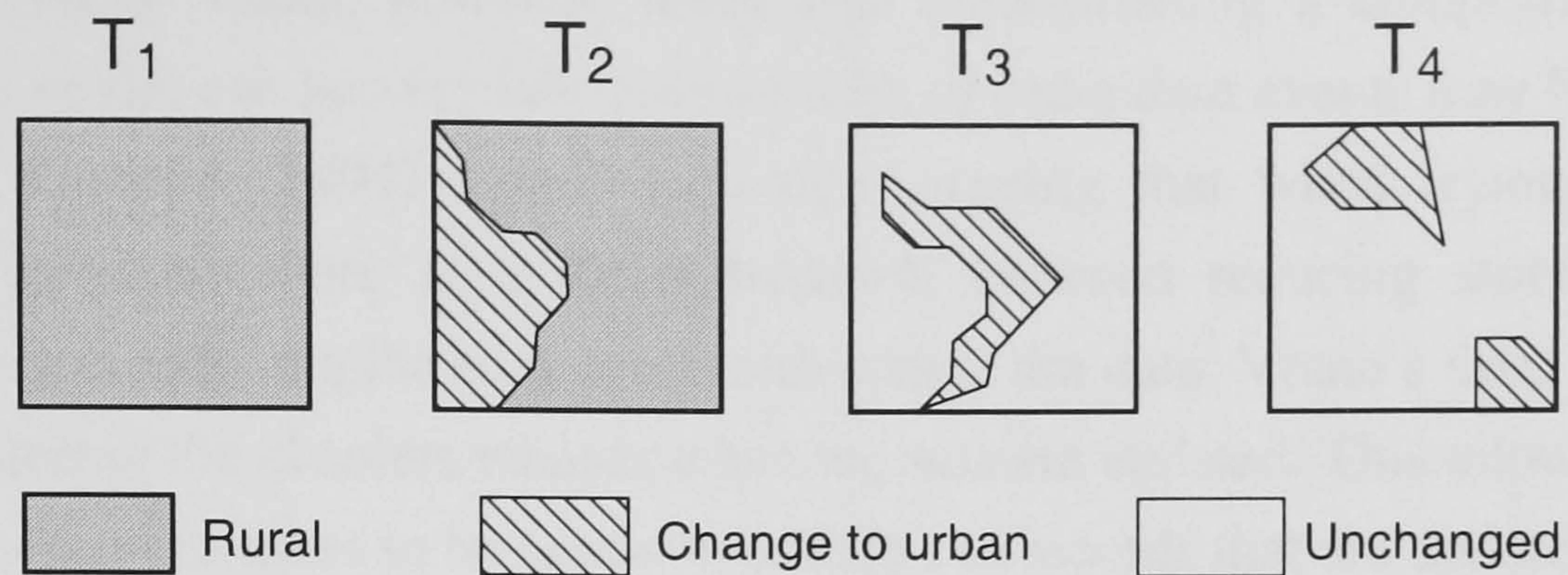


Figure 2.5: Base map with overlays to describe the urban expansion (Source: Langran, 1992: p. 40).

The final model put forward by Langran & Chrisman (1988) and Langran (1992) is what they term the *space-time composite* and is shown in figure 2.6. This is a variation on the base map with overlays theme but the base map becomes a temporal composite built from accumulated geometric changes. This allows units with coherent histories to be identified and their mutations can be described by aspatial attributes. This reduces the components of the data from three to two by allowing space to be treated atemporally and time to be treated aspatially.

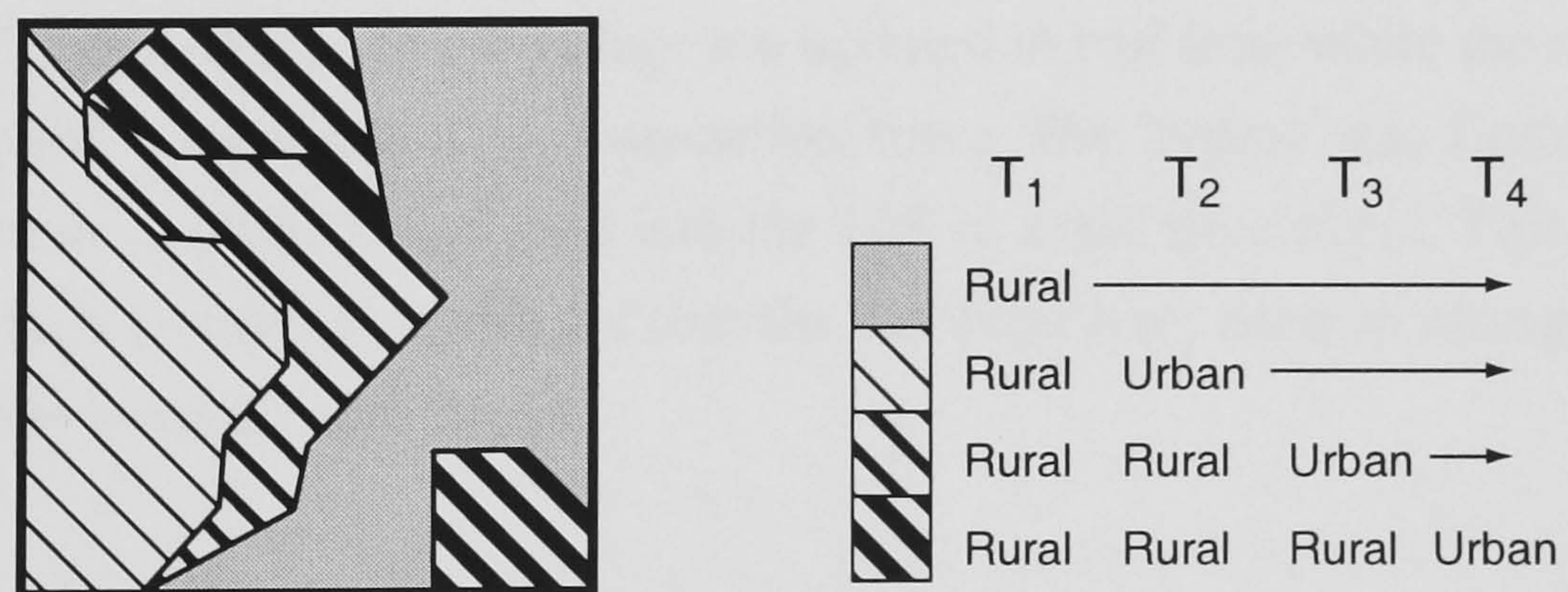


Figure 2.6: A space-time composite of urban expansion. Each polygon has an attribute history distinct from that of its neighbours (Source: Langran, 1992: p. 41).

Around the same time, Vrana (1990), working from the point of view of encoding cadastral information, also identified three models for encoding spatio-temporal data: the first he termed date-stamping, where every feature has its dates explicitly encoded as attributes. This allows the object's location to be determined in time as well as

space but does not provide any reference to previous or subsequent states. The second he termed transaction logs, where a series of events are stored that allow a chain of events to be reconstructed. This is similar to Langran and Chrisman's base map with overlays approach. Vrana, however, notes that reconstructing a composite picture based on this model can be very laborious as a lot of redundant events may have to be assimilated. Kampke (1994) agrees with this, arguing that when trying to store changes to polygons there is a direct trade-off between reducing storage space requirements and reducing the time it takes to access the data. Vrana's third approach is based on storing the obsolete records when records are updated. This allows records updated to correct mistakes to be stored in addition to records that are updated to store change. Both of these, he argues, can be useful to reconstruct the basis of historical decisions. Yearsley & Worboys (1995) and Worboys (1998) develop the issue of records that are changed due to real world change and those simply for database reasons such as to correct mistakes. They refer to these as *real time* and *transaction time*. They build on Snodgrass's (1992) concept of the *bi-temporal elements* of time. By storing these two elements of time on two orthogonal axes the representation of the real world at any time can be retrieved, as can the situation stored in the database at any time. Worboys (1998) describes using commercially available, object-orientated GIS software, Smallworld, to implement this for a small local example. In this the map of a village is stored in a GIS. A bypass is planned and the planned route is also stored. This means that the GIS could retrieve the situation at a future date once the bypass has been built. Changes around the village lead to the plans for the bypass being changed so both the representation of the village and of the planned bypass need to be changed. The changes to the village are updated in real time while the changes to the planned bypass are updated in transaction time. The bypass was finally opened ahead of schedule and this is included into the GIS as a real time event. This is a more flexible approach to time that accepts that the database may need to change in ways that are separate from the real world.

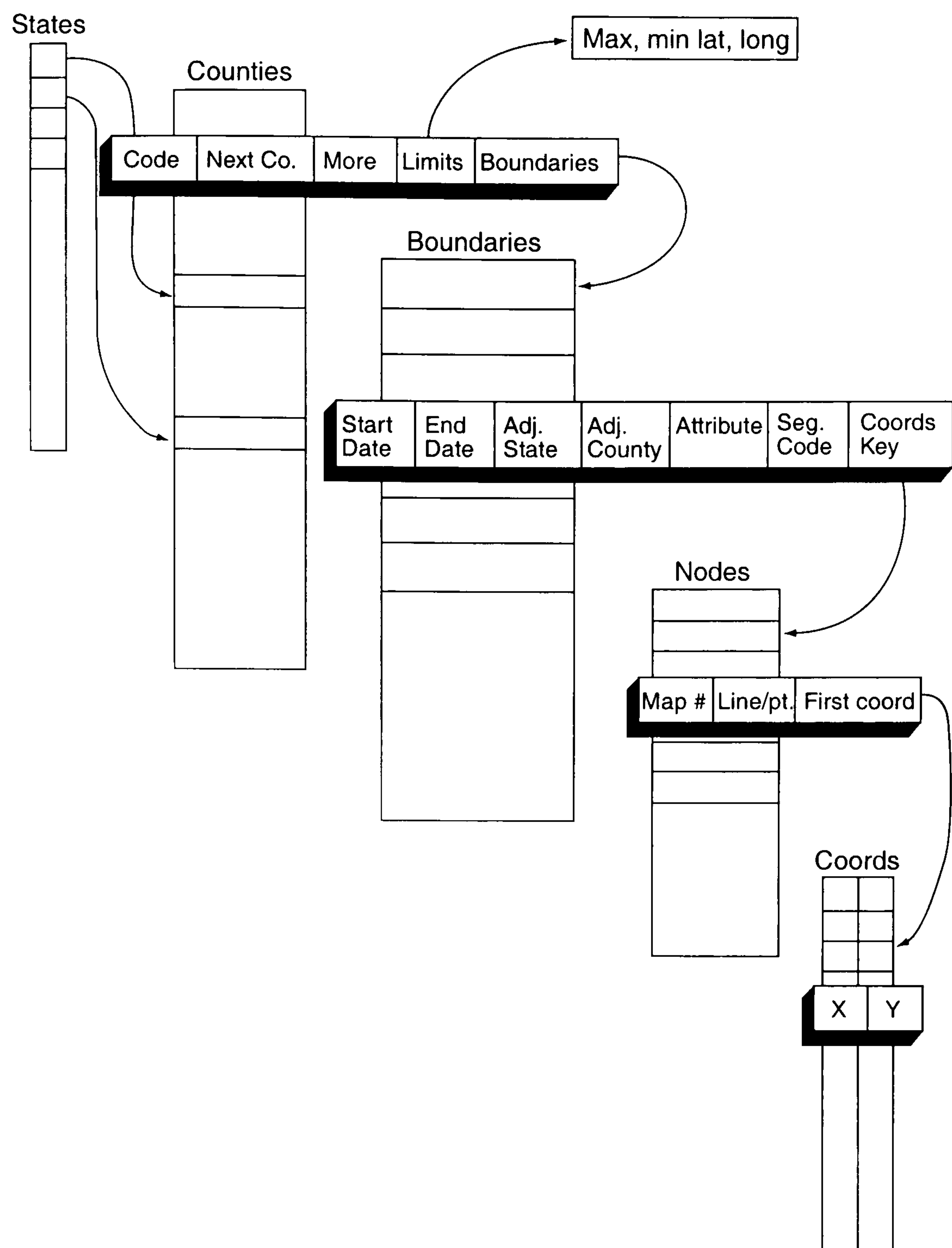


Figure 2.7: The data structure developed to show the changing boundaries of US counties developed by Basoglu and Morrison (1978) (Source: Langran, 1992: p. 13).

There are very few examples of the use of temporal GIS databases. An early attempt at developing a data structure capable of handling change in a GIS was carried out by Basoglu & Morrison (1978) as part of the US County Atlases Project. This was designed to retrieve snapshots of US counties for a given date and the structure developed is shown in figure 2.7. This structure does not describe topological relationships as it pre-dates their common usage and cannot respond to queries about change between two snapshots efficiently. For its time, however, it was remarkably sophisticated but was abandoned as part of the County Atlases Project mainly because of difficulties in implementing it in the computing environment available at the time (Long, 1998).

More recent projects to capture historical administrative boundaries in a GIS have met with more success. These have often started with historical researchers with little or no GIS expertise attempting to generate solutions that would work to solve the problems they were interested in. Good examples of these are the work on Prussia (Winnige, 1999), the Netherlands (Boonstra, 1994), and Belgium (Vanhaute, 1994). In Sweden the Central Bureau of Statistics created a system containing their changing historical administrative boundaries as a resource for researchers (Kristiansson, 2000a). The design of these systems will be discussed in more detail in chapter 4.

Other researchers have approached the issue of changing administrative boundaries from the perspective of recording changes from the present as we move into the future. Wachowicz (1999) describes an object-oriented approach that would allow administrative boundaries to be updated as they are changed over time. This is implemented using the commercial GIS package, Smallworld. It allows boundaries to be classed as either draft, new, old or obsolete and thus allows the difference between real time and transaction time to be incorporated. This allows the user to construct boundaries as they were planned or implemented in the present or at any point in the past.

Although this concept is demonstrated by Wachowicz using examples there do not appear to be any plans by the Ordnance Survey (OS) or others to implement this type of model nationally. One of the few examples of the successful implementation of a GIS of this type is the work done by the Ordnance Survey of Northern Ireland (OSNI) on the Northern Ireland Geographical Information System (Nigis). This is an in-house solution to the problems of a temporal GIS database that archives historical information as well as maintaining the current situation. The system is based on OSNI's 1:1,250 and 1:2,500 scale products. The system stores a current layer that contains the relevant survey dates. When new surveys are carried out any deleted data are date-stamped and written to a historical layer. Any new features are then digitised and added to the current layer to complete the updated map. This allows OSNI to embark on a program of continuous map revision rather than updating a sheet when a threshold number of changes are believed to have occurred. Three types of data can then be retrieved: current information, historical information, and change only information (Atkins & Mitchell, 1996). This model does not conform to any of the theoretical models described earlier as it combines using different layers to represent time in the form of the current and historical layer, with date-stamping that is particularly important on the historical layer.

Most of the examples given above implement a spatio-temporal approach by attempting to combine the spatial and temporal data-models. Bagg & Ryan (1997)

take a different approach by attempting to add spatial and temporal functionality to an existing database rather than create a temporal GIS. They also conceptualise time in a different manner than many studies. Their work focuses on an archaeological database for southern Corsica using a commercially available object-orientated DBMS called Illustra. This has spatial extensions added to it to give GIS functionality and the temporal component is also added to the standard DBMS functionality. This was done by exploiting Illustra's ability to allow time-stamping of individual tuples using a "no overwrite" storage system. Their temporal model includes three data types: *instant*, *period* and *span* that allow both variable granularity and temporal uncertainty to be incorporated independently. An *instant* is defined as a point in time, a *period* is a duration in time between start and end instants, and a *span* is an un-anchored duration of time. Examples of these are shown in table 2.2. To cope with these new data types the boolean algebra used by Illustra's query language (an extended version of SQL) has been extended to include operations such as *before* and *during*.

Based on this functionality Bagg & Ryan built a database to examine kinship, marriage and property in the Quenza commune of southern Corsica from 1681 to the present. The ability to incorporate uncertainty is innovative and the work undoubtedly shows potential in a situation where the data comprises of known attribute and point location but uncertain time. Whether it could be expanded to include line or polygon representations of space and whether uncertainty in space and attribute could also be included is unclear.

External representation	Granularity	Meaning
10/4/1996	Day	Instant located within the single day, 10th April 1996
4/1996	Month	Instant located in April 1996
19xx	Century	Instant located in the twentieth century
4/1996 (2)	Month	Indeterminate instant located in April or May, 1996
10/4/1996-12/4/1996	Day	Period encompassing three days: 10th, 11th and 12th April 1996
1/1/1996 (9)-10/4/1996	Day	Period beginning between the 1st and 9th of January 1996 and ending during the day of the 10th April 1996
10 days	Day	Span of length 10 days
5 (3) years	Year	Span of indeterminate length between five and seven years

Table 2.2: Examples of the temporal date types *instant*, *period*, and *span* used by the Illustra database (Source: Bagg & Ryan, 1997: p. 46).

There is, therefore, a limited but growing literature on incorporating time in GIS but commercial systems do not yet incorporate any real temporal functionality in their database design. One point that comes across clearly in the above discussion is that the practical implementations used by Atkins & Mitchell and Bagg & Ryan are still significantly different from the more theoretically elegant models proposed by, for example, Langran, Vrana and Wachowicz. This suggests that there is still a gap between the theoretical approaches and the practical real-world problems of creating temporal GIS databases.

ii. Analysing socio-economic change using GIS

The literature on analysing socio-economic change using GIS is, to date, extremely limited. The work of Bracken and Martin (Bracken, 1994; Bracken & Martin, 1995; Martin, 1996a) comparing the 1981 and 1991 censuses provides one example. This was based on creating a surface model of the enumerated populations at the two dates and then comparing them. To create the surfaces Enumeration District-level data was reallocated using their population-weighted centroids and a distance-decay model. The aim of this work is to use the maximum amount of spatial detail and this means that it is temporally limited in what it can achieve as the layers it creates cannot be produced for historical censuses where population-weighted centroids are not available. A second point is that the studies deal with changes in the administrative geography by using a surface representation of the data, a process that inevitably introduces a certain degree of error (Martin, 1996b; Robinson & Zubrow, 1997). It has also been argued that using surfaces in this way merely conceals many of the problems of what were originally polygon data (Openshaw & Clarke, 1996).

Openshaw (1994) develops two techniques called STAM (space-time-attribute analysis machine) and STAC (space-time-attribute creature) which he demonstrates by analysing crime clusters through both time and space. STAM is effectively a re-working of Openshaw *et al's* (1987) GAM (geographical analysis machine) idea. GAM attempted exhaustively to test a hypothesis through space to spot clustering among point distributions such as cases of childhood leukaemia. STAM takes this one step further by testing through time as well with events being modelled as points in time as well as in space. STAC is similar in concept but uses artificial life simulations as part of the model. These types of techniques can exploit a modern, data-rich environment but require large datasets with a high degree of both spatial and temporal detail that is unlikely to be found in historical data.

O'Kelly (1994) also develops some ideas by suggesting how traditional spatial analysis techniques could be extended to incorporate a temporal component. There is, therefore, a clear potential to carry out analysis of change through time using GIS. As

yet, however, there are very few actual applications that have done this in a way that can include both temporal and spatial detail. There is a fundamental problem here in that there is as yet very little discussion in the literature about what analysis through space and time together should be attempting to achieve. STAM and STAC represent a first attempt in this direction but they use a point geometry to represent both time and space and merely build on ideas developed in a purely spatial analysis. There is, therefore, plenty of potential for new research in this field but consideration needs to be given to what can be achieved. This will be returned to later in the chapter.

iii. Visualising change using GIS

Maps are traditionally snap-shots of a single instant in time. A few attempts have been made to visualise change through time on paper (see, for example, Hagerstrand, 1970). However, most attempts have focused on using other media that allow dynamic maps to be displayed. Cine film was used to produce animated maps in the 1960s (see, for example, Cornell & Robinson, 1966 and Tobler, 1970) and in the 1970s and early 1980s video was used (see, for example, Mollering, 1980). By the 1990s, GIS and the increase in electronic publication through the internet and CD-ROMs have led to an increase in both interest and in the potential for producing dynamic maps that can demonstrate time as well as space (Koussoulakou & Kraak, 1992).

MacEachren (1994) identifies three types of change that dynamic mapping can be used to demonstrate: view-point change, time series and re-expression. View-point change does not necessarily involve changing time, instead the position of the observer changes. This often involves zooming and panning to explore spatially complex two dimensional maps (see, for example, Dorling, 1992). Flight simulators are an example of view-point change that also involves temporal change. In time-series maps time is considered as a vector with the viewing time of each frame representing an interval of time. This is common in animations. Re-expression is similar to time-series, however, rather than using time as the variable on which the animation is based, some other variable such as population categories or income is used.

An example of using time-series animations within GIS based work is provided by Koussoulakou's (1994) work on urban air pollution. This uses static maps to represent pollution from point, line and area sources, to map places with high numbers of complaints about pollution and high pollutant concentrations, and to map wind speed and direction. These are then animated to show changes in wind speed and direction, changing traffic flows and other variations in pollutant emissions, and to show changes in air quality for both points and areas. By combining this wide range of information through animations a better understanding of how all these variables are

linked and change over time could be gained. There is no causal analysis in this work, it is merely visualisation of complex datasets to gain a better understanding of process.

A second example is provided by Openshaw *et al* (1994) to help detect patterns of childhood leukaemia in the north of England. They produce animations based on 680 point locations of cases of the disease over a 20 year period. They estimated the density of the disease using a kernel with a 25km radius in space and a 12 month “radius” in time. By playing the movie striking increases become apparent in Middlesbrough for only a few years and the rates in Newcastle and Manchester both seemed to oscillate considerably over time. No obvious anomalies were found near Sellafield. As with Koussoulakou’s work, the animation is used to make complex data more understandable and thus to extract information. Unlike Koussoulakou’s work, however, no explanatory variables are included in the visualisation.

As yet such approaches are in their infancy and much further research is needed particularly on the symbolisation and perception of temporal variation (Shepherd, 1995). Another significant issue is to what extent electronic publishing will replace paper as, unless electronic publishing becomes widespread, the potential for this type of visualisation will remain limited although it will enable researchers to explore their data.

b. Historical applications using GIS

The previous section showed that research on creating temporal GISes and using them to analyse and visualise data is still in its infancy. In this section attempts by researchers working with historical data to utilise at least the spatial abilities of GIS are discussed.

To date North America has a better record of funding major GIS projects in the historical field. Perhaps the most impressive example is the Great American History Machine (Miller & Modell, 1988). This system is effectively a data exploration package and was designed to be used in teaching. When described in 1988, it held all US census and presidential election statistics from 1840 to 1970 at the level of US counties of which there are a total of 3,144. The system was designed to allow a user to explore the data through choropleth mapping and, to this end, by 1987 the system held 900 variables in nine data sets. Both spatial and attribute data are held in a custom written software system in such a way that when a variable is specified it is mapped. To produce more meaningful maps a suitable denominator must be found. Additional functionality includes the ability to place two maps side-by-side to allow comparison, and the ability to include cities, railroads, canals, rivers, and mountains as locational information. This system undoubtedly has the potential to be a major

resource but it suffers from a number of draw-backs: firstly, the data are held entirely within the system and so are not available to users as a resource in their own right and users cannot import their own data. A related problem is that the user must choose denominators themselves and may have difficulties in finding a suitable variable or may, through lack of knowledge, use an inappropriate variable thus producing a meaningless map. Thirdly, the system is based on custom written software that must be maintained and developed by the project team. It appears that the team has disintegrated and this may mean that a final version of the system will never be properly published for a modern PC environment. Lastly, the system lies somewhere between a GIS and an atlas. This means that, unlike a conventional GIS, it can be used only in ways allowed by the custom software, and unlike an atlas, it does not tell the user a story by itself, it merely produces maps and leaves the interpretation to the individual.

A second American project that started using GIS to map historical America is the US County Atlas Project (Long, 1994). This project aimed to produce maps of all the counties in the US and how their boundaries had changed over time. It was generously funded in its early days and put significant amounts of time into developing a GIS capable of handling changing boundaries. As described above, a workable model for a temporal GIS came out of this work (Basoglu & Morrison, 1978) but the GIS side was not a success. The project is still in existence but the methodologies it uses now are entirely based on manual cartography and the only output it produces are a series of high quality paper atlases showing how the county boundaries have changed state by state (see, for example, DenBoer, 1995). By 1997 it had published these volumes for 22 states.

A third large North American project is the Historical Atlas of Canada. This was proposed in 1978 as a three volume atlas, each volume of which was to concentrate on social and economic change over a different period (Pitternick, 1993). Due to the technology available at the time, the use of GIS in the preparation of the atlases was not considered seriously, although Volume II, the last volume to be published, was prepared making some use of ArcInfo mainly to reduce costs. The resulting volumes (Harris, 1987; Louis, 1993 and Kerr & Holdsworth, 1990 respectively) took far less of a data and boundary-driven approach than might have been expected if the whole project had been based on a GIS database. However, the project is now making a large scale move into GIS to attempt to produce electronic products including raw data sets and World Wide Web and CD-ROM versions of the atlas (Moldovsky, 1998). This has led to a large amount of repeating old work using digital rather than traditional methods.

Work in Britain and Ireland has generally been much less well funded and the projects are consequently smaller scale. There are, however, several recent works that have used GIS to map historical data. Examples include Woods and Shelton's (1997) atlas of Victorian mortality, Kennedy *et al* (1999) produced an atlas of the Irish famine, while Dorling (1995) produced an atlas using snapshots to depict a degree of change in British society in the recent past. All of these works used GIS to map historical data and thus produce an atlas however none were really concerned with the GIS and the analytical capabilities it provides as an end product in its own right. Other than the project described in this thesis, the only major national attempt at creating and using a GIS for analytical historical research in England is by Bartley & Campbell (1997). They have examined the *Inquisitiones Post Mortem* of the fourteenth century and used these to create a GIS of medieval land use that, they claim, is potentially the most detailed survey possible until the nineteenth century tithe surveys. Due to the inaccuracies of the sources they have used a raster GIS. The GIS was used to analyse the land-use pattern in pre-Black Death England. This is, therefore, a sub-county level analysis of England but is based on a single source and date.

Another example of the use of GIS in historical geography is Graham's (1995) simplistic use of ArcInfo to explore demographic change in Britain from 1951 to 1981. This was based on county-level analysis as the early data had to be entered by hand and started with 1951 because "to have gone further back in time, say to 1921 or 1911, would have required significant alterations in the data in terms of achieving comparability" (p. 51). Even at county-level and within this limited time frame, this study was hampered by the 1974 local government reorganisation. The study does not go very far in its scope and is described only as an "exploration of the efficacy of a GIS approach" (p.61). He is, however, unclear about what he regards as a GIS approach beyond being the tools that ArcInfo has to offer. The paper also shows that database construction is a major drawback in the use of GIS but that there is a large potential for the use of these resources once constructed.

Other studies in Britain and Ireland have been undertaken at a more local level. One example is Pearson & Collier's (1998) detailed GIS combining environmental data with historical sources to analyse settlement patterns in the area around Newport, Pembrokeshire. Two GIS-based studies of London have been done: Shepherd's (2000) work used a GIS to analyse the late nineteenth century Booth Survey, and Spence (1994) used it to analyse social structure in the 1690s.

All of the studies given above have used GIS to integrate and visualise data. They represent a start but serve to demonstrate that GIS still has a long way to travel before its use and, more importantly, its role in historical research becomes properly

established. At present its role has largely been to provide a “mapping front-end” to statistical databases to allow atlases to be produced. While this is fine as far as it goes there is still far more potential to use GIS to explore the past in a spatio-temporal manner.

c. Time and change in human geography

Although there has been some theoretical debate about the need to move away from snapshot based, synchronic style of analysis, in practice only very limited progress has been made in this area among quantitative historical geographers.

Much effort has been put into looking at change over time using the census although almost all of these studies have only attempted to look at change between two censuses, in particular between the 1981 and 1991 censuses (see Bracken, 1994; Bracken & Martin, 1995; Champion, 1995; Marsh *et al*, 1988; Martin, 1996b; Martin & Gascoigne, 1994) or the 1971 and 1981 censuses (see, for example, Norris & Mounsey, 1983). In many ways, however, the results from these have been limited as this type of work is largely based on comparing two snap-shots. Bracken & Martin (1995) identify four main reasons for this: the data collected change, the definitions used to collect the data change, the confidentiality arrangements used when collecting the data change, and the administrative geography within which the data are collected change. It therefore appears that in “modern” quantitative geography there is only a very limited amount of work that explicitly examines change through time as well as space.

Recently historical geography has moved away from quantitative research, but the sub-discipline has a strong tradition of it. In the 1960s and 1970s research frequently focused on statistical data, spatial analysis and mapping work (Baker, 1972). It is clear looking at this work that the researchers were usually unable to handle the complexity of using all three components of the data at once and so had to either focus on a small study area or time period or had to simplify one or more of the components of the data. An example of doing the former is Lawton’s (1970) study of the population of Liverpool in the mid-nineteenth century. This is based on using census data to study occupations, migrations, and the age-sex structure of the city and its immediate surrounds. By concentrating on a small study area and time period the author is able to use the available data at the most detailed level available and, where necessary, examine change over time for the entire century. The study is, however, restricted to only seventeen separate administrative units and some of the analyses used are hampered by boundary changes.

In a seminal piece Friedlander and Roshier (1965) were able to work with decennial data, the most detailed available, to calculate net migration flows for the

whole of England and Wales in the period 1851 to 1951. Calculating flows was complex and makes as much use of the information in the source attribute data as possible. The drawback here is that they were forced to work at county-level and even at this scale were unable to quantify flows in adjoining counties because of the problems of boundary changes. Lee (1979) faced similar problems. He was able to create detailed standardised occupation structures for men and women from 1841 to 1971. Again, however, he was forced to work at county-level and even here he needed to create two series: one for 1841 to 1911 and one for 1901 to 1971 partly to handle the changing occupation classifications used in the census but also because the census changed the definition of counties after 1911 (see chapter 3).

Darby *et al* (1979) concentrate on spatial detail in their comparison of wealth in England as measured by three key sources: the Domesday Book of 1086, and the lay subsidies of 1334 and 1525. The spatial framework used in this paper was based on Darby's earlier work on Domesday that was started in the 1930s but not published in full until the 1970s (Darby, 1977). This had allocated almost all of the 13,000 place-names given in Domesday Book to 715 sub-county level units. These units could not be directly compared with the areas used to collect the 1334 and 1525 lay subsidies so some aggregation was performed to create 610 units. The study, therefore managed to cover a long-time period but could only fit three sources into its spatial framework. The attribute data was measures of wealth that are computationally simple. This is a spatially detailed national study that uses simple temporal and attribute data. In spite of this it required four authors and was heavily based on nearly a lifetime's work by one of them.

Lawton (1968) manages a national-level analysis that combines spatial and temporal detail but whose attribute detail is weak. He performs a Registration District-level analysis covering the period 1851 to 1911. This means that he has approximately 630 spatial units and seven snapshots. He was also researching net migration but simply looked at rates for the total population giving a very simple level of attribute detail.

The contrasts between Buckatzsch (1950) and Schofield (1965) provides a warning about attempting to include too much detail without thinking carefully about the validity of the sources. Both authors looked at long-term change in wealth distribution in England and Wales from the Middle Ages. Both analyses were county-level and used relatively simple measures of wealth. Buckatzsch used no fewer than thirty property tax-based sources to provide snapshots covering the period 1086 to 1843. Using these he argued that the distribution of wealth remained stable from the Middle Ages to the seventeenth century but changed greatly in the eighteenth century.

Schofield re-examined Buckatzsch's evidence but came to very different conclusions. He based this on the argument that some of the tax assessments that Buckatzsch used were not directly comparable and this went some way to explaining his results. Schofield deliberately limited the temporal extent of his study and only included sources that he felt were comparable after detailed examination. He argued that there were actually major changes in the distribution of wealth in the later Middle Ages similar to those ascribed by Buckatzsch to the eighteenth century.

Although this discussion has been limited to only a few examples they demonstrate that analyses of change through time and space have traditionally been severely limited not just by the data themselves, although these limitations can be important. More significant, however, is the way that researchers have had to represent the data. This has usually meant that in national-level studies the number of snapshots is less than the available data can support, that the data are often aggregated spatially to county-level, and that the full amount of attribute detail is not used. Researchers were, however, attempting to analyse change through time and space but were restricted in what they could achieve by the volume and complexity of the data, and in particular the problems of boundary changes. This often means that Langran & Chrisman's (1988) idea of having to fix one component of the data and control another in order to measure the third is the best that could be achieved but even this was often optimistic.

2.6: Conclusion

GIS usage is still in its early stages. It allows the world to be conceptualised using an integrated model of attribute and space. It also makes use of computing power that was unthinkable until recent decades. Exactly how this should be used in academic research is still unresolved, however, there is a general agreement that methods should explicitly incorporate the spatial dimension and should avoid the most positivist aspects of quantitative research. There is also a growing awareness both within and outside the GIS community that a more integrated approach to space and time is needed in geographical analysis. This is not new, Langton (1972) was arguing for a similar approach almost thirty years ago. However, with the resources available at the time researchers found this very difficult to implement due to the complexity of analysing data through space and time simultaneously. Developments in GIS offer one potential area in which it may be possible to draw together the differing threads of space and time dominated approaches. As yet, however, GIS research on integrating the two are far from completion: in particular, effective temporal databases have not become widely available and the development of analysis techniques that can quantify change in space, time and attribute is still in its infancy.

While it may be theoretically desirable, the limitations of the sources mean that there is no way that routinely published, zonal, socio-economic data will ever be able to be analysed as a full space-time composite. The way in which they were published means that these sources will remain as spatially aggregate, snapshot data. This does not mean that this is an area where GIS has nothing to offer, however. Traditional analyses of these sources have been extremely limited by the complexity of the data and have still fallen far short of examining the data through time and space making maximum use of the all the available components of the data.

This leads to the question of what an examination of data through all of its components should be able to achieve. Both Langton (1972) and Chrisman (1998) argue that the aim should be to gain an understanding of process. This may be the case, but the processes driving long-term change in human activity are extremely complex. Openshaw (1991b) and Massey (1999) both provide warnings that analytical techniques that become too blinkered in the pursuit of process are likely to be flawed as they over-simplify a highly complex reality. Fundamentally, any attempt to examine data as they change through time and space is attempting to extract the maximum amount of information from the available sources. Although statistical analyses provide one way of doing this, there are others. At the most basic level, simply integrating data in space and time at a detailed level will provide new information that it was previously impossible to extract. In this thesis this is the level that is concentrated on as simply doing this over the long-term is highly complex.

In the longer-term there are two distinct but linked seams of research that can be exploited once the data have been integrated effectively. These are spatial analysis and visualisation. The visualisation of change is an area where some progress has been made in recent years, however, there is still a lot of research that remains to be done not just on the technical aspects but, more particularly, on the aspects of how users perceive large amounts of spatially and temporally complex data. The spatio-temporal analysis agenda is even more open as virtually nothing has been done in this area that is relevant to long-term change in socio-economic data. There are some guidelines that should be followed:

- The analysis should do more than comparing one snapshot with another if it wants to draw conclusions about change.
- It is desirable to get away from the constraint of having to fix either the spatial, temporal or thematic component of the data. Ideally the maximum amount of information from all three components of the data should be used.

- Data should be analysed within the limits of the quality of the data and the context within which they were collected. This is especially true where data sets are combined in a way that can lead to error propagation.
- Data should be analysed at as near as possible to their original level of spatial aggregation to avoid loss of detail. Even at this level there will still be problems with modifiable areal units especially where correlation and regression-based techniques are used.
- The ecological fallacy prevents any individual/household level conclusions being drawn from zonally aggregate data.

In summary, GIS-based techniques should allow the researcher to make best use of the available data but these cannot go beyond the limitations of the original source. The GIS's representation of space and time are, therefore, heavily dependant on the source data's representation. What GIS can do, however, is to make use of the data's spatial component to allow change through time to be examined. As was discussed above, a point in space becomes a line through space-time. An administrative unit, therefore, can be regarded as a cylinder through space-time and within this cylinder socio-economic conditions change. This change can be measured as snapshots are available at regular intervals in time that measure various indicators of socio-economic activity. A major problem, however, is that administrative boundaries are arbitrary and change at irregular intervals. This can make it appear as if there as been socio-economic change when all that has happened is that the space-time cylinder has been altered. The main aim of this thesis is to prevent this by allowing the impact of boundary changes to be removed so that any measured change within the cylinder must either be actual change or change in the attribute measure but is not caused by changes in the administrative geography.

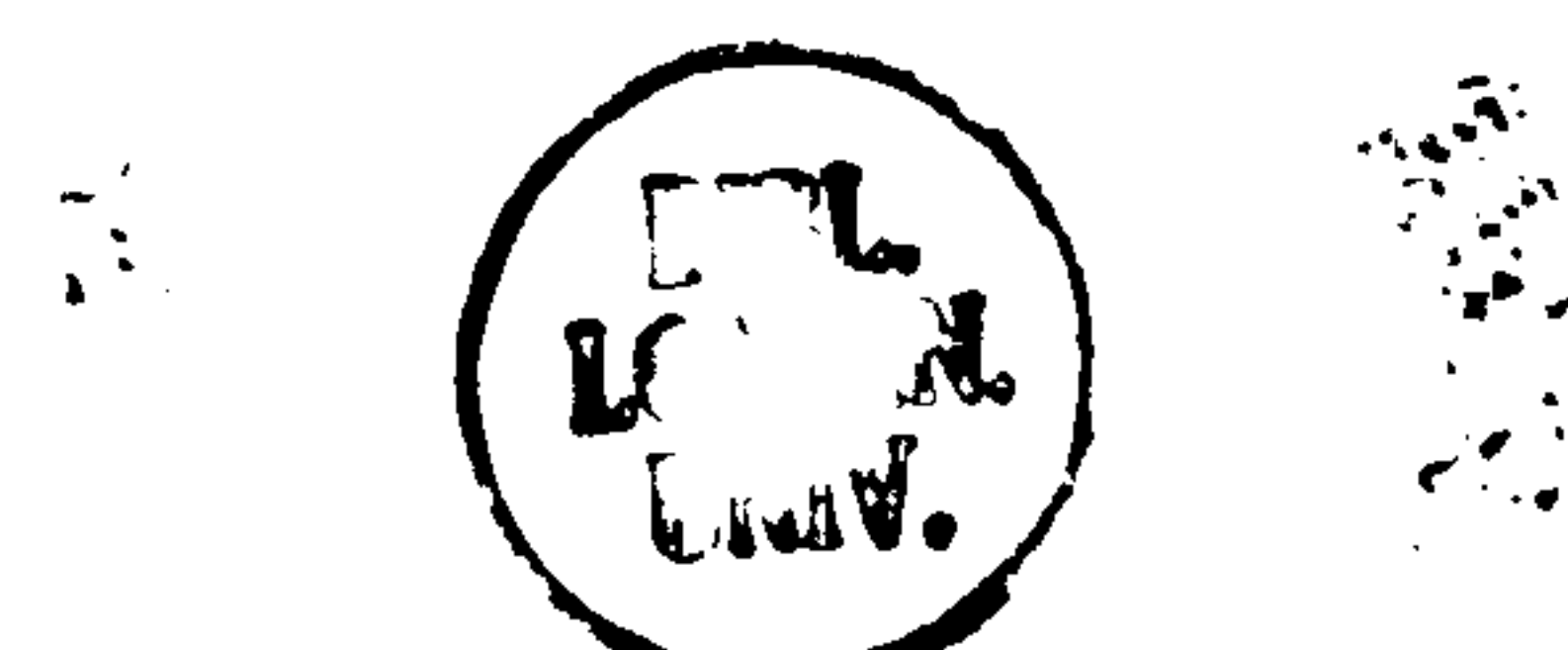
Chapter 3: The Administrative Units of England and Wales: 1830 to 1974

3.1: Introduction

In chapter 2 the desirability of treating space and time as an integrated concept, space-time, was explained. It was also noted that zone-based socio-economic data such as the census have already been abstracted from the real world in such a way as to make a full model of space-time impossible to create, particularly because the data are only available for a limited number of temporal snapshots. It was argued, therefore, that it was desirable to build a system that could incorporate the maximum amount of the three components of the data: attribute, space and time. The aim of the GBHGIS is to provide a framework incorporating all three of these elements with the maximum amount of detail available from the source.

The spatial component is the most complex part of the data. It is also the one that GIS has the most potential to improve and has most hampered analyses in the past. As was also noted in chapter 2, the administrative units used to publish socio-economic data are highly arbitrary and change over time in a way that is not only arbitrary but complex. To understand socio-economic change it is necessary to be able to separate real change from changes in the way that the data were published especially changes that affect the spatial component. In order to draw conclusions from any patterns produced from the data, therefore, it is necessary to understand the limitations of the spatial units used to publish them, and in order to understand long-term change it is necessary to understand how the boundaries of the spatial units changed.

In this chapter each major type of administrative unit is taken in turn and its history and uses for publishing statistical data are given. Counties and parishes, the highest and lowest major levels of civil administration, are briefly discussed but the various types of districts are discussed in detail as these are the units for which the widest variety of data were published over the period. The second section of the chapter provides an overview of the numbers and types of boundary changes that have taken place to the major types of administrative unit included in the GIS. In this way it is hoped that the complexity that the historical GIS is able to cope with can be described, and the advantages of the system in being able to provide an integrating structure for data collected by a variety of organisations, for a variety of reasons, using a variety of different units can be better understood.



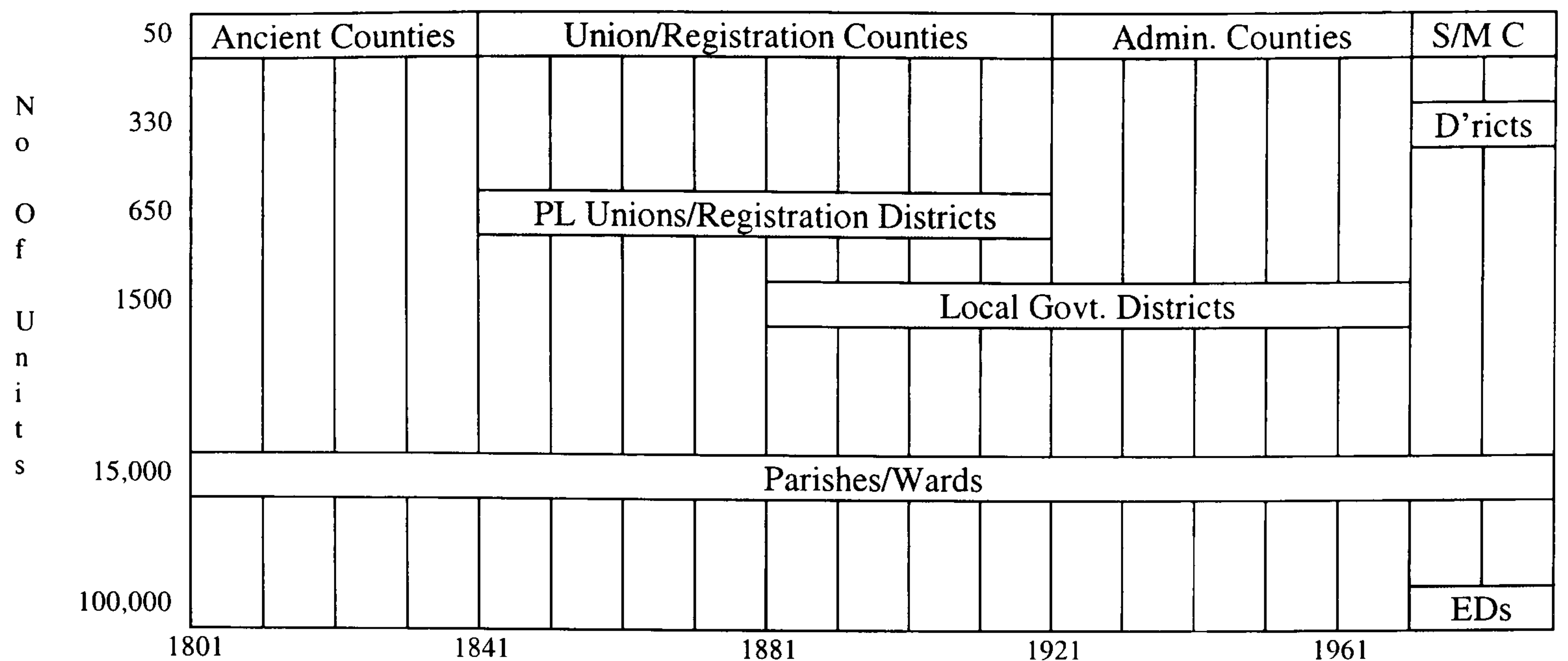


Figure 3.1: Simplified structure of principal administrative and statistical reporting units in England and Wales, 1801 to 1991. Note: S/MC=Shire and Metropolitan Counties; D'ripts=Districts; EDs=Enumeration Districts.

The history of local government in England and Wales in the nineteenth and twentieth centuries consists of periods of intense legislative activity separated by long periods of slow but persistent change. In the intense periods, the organisations responsible for local administration and the units they administered were radically altered. As is summarised in figure 3.1 there have been three major periods of change: the first was in the 1830s when modern local government and statistical data publishing can be said to have started. This period saw the parish, the lowest level major unit of local government, having most of its functions replaced by newly created, district-level units. The most important of these were Poor Law Unions created specifically for the administration of poor relief (Rose, 1971), and, closely related to them, Registration Districts created by the newly formed General Register Office (GRO) for civil registration purposes (Nissel, 1987), and also used as the main reporting area for census purposes from 1851 (Benjamin, 1970). There were approximately 635 Unions and Registration Districts although the exact number depended on date.

The second period, from 1872 to 1899, saw the establishment of the system of local government and local government units that then persisted through most of the twentieth century (Hasluck, 1936; Lipman, 1949). This period saw the formation of Local Government Districts set up to have broad functions rather than the nineteenth century units that tended to be set up for specific purposes. There were five types of Local Government Districts in a hierarchy that reflected their degree of urban importance: London was sub-divided into Metropolitan Boroughs while the rest of the

country was sub-divided into County Boroughs, Municipal Boroughs, Urban Districts and Rural Districts. These were formed based on sub-dividing Poor Law Unions thus giving a more detailed administrative geography; there were around 1,500 of them. Although formed in the late-nineteenth century, these areas came to the fore between 1911 and 1921 when they almost completely replaced the functions of Registration Districts, significantly reduced the importance of Poor Law Unions, and also took on a host of other local government functions. The third period of reform was the 1960s and early 1970s when the 1963 London Government Act and the 1972 Local Government Act radically reformed local government by creating a system of around 330 Districts that were much larger than the preceding units (Keith-Lucas & Richards, 1978; Kingdom, 1991). Also, due to the increased use of computers, large amounts of statistics started to become available for small area geographies such as wards, enumeration districts (EDs) (Coombes, 1995), and unit postcodes (Raper *et al*, 1992).

The periods in between were far from times of stability. There has been a steady flow of small changes to the boundaries of areas that when taken in aggregation resulted in significant changes to the administrative geography. In some cases these have been as a result of specific pieces of legislation or initiatives, examples of which include the reform of Local Government Districts under the County Reviews of the 1930s, and the large number of changes to parish boundaries in the decade after the 1882 Divided Parishes Act. Just as significant, however, have been local responses to changing local conditions. These changes have occurred piecemeal and usually for reasons that are not obvious to the distant observer.

Figure 3.1 shows a simplification of the main strands of local government. It is a simplification: certain types of unit have not been included particularly from the nineteenth century, and some dates are approximate, as are the numbers of units. In addition, with the introduction of Unitary Authorities there have been new changes in the 1990s that are not shown. There are, however, many similarities throughout the period: at the top of the structure there have always been fifty or sixty counties. At the bottom there have been a large number of parishes. The figure of 15,000 is an average around which the actual number has varied by as much as 3,000 depending on the exact definition of a parish, which is complex until the late-nineteenth century, and the date, as the numbers of parishes were significantly reduced in the 1880s. Between parishes and counties have been the district-level units which, in the period between the 1830s and the 1970s, were the most important units of local government, certainly as far as the publication of statistics is concerned. The size of these areas has varied considerably: Poor Law Unions and Registration Districts were set up to approximate to the sphere of influence of a market town; Local Government Districts were subdivisions of Unions where the urban areas were separated from the rural ones thus

providing a much finer level of spatial detail and a distinction between urban and rural areas; and the move to Districts in the 1970s reversed this reflecting the move to a more centralised system of local government in part driven by improved transport and communications. In addition to the units shown in figure 3.1 there were also approximately 2,000 Registration Sub-Districts providing a further level to the hierarchy. These were sub-divisions of Registration Districts, although they were significantly different from Local Government Districts, and were used by the GRO as part of the vital registration system. This chapter examines each of the major types of area in turn. It gives the details of the history and development of the areas and examines the advantages and disadvantages of each as a unit for spatial analysis.

3.2: Local Government Units

a. The County

The county is an ancient concept in England; the word ‘county’ is the Norman term for the Saxon shires which, in turn, date back to the Anglo-Saxon kingdoms. Wales was first divided into counties in 1256 by Prince Edward (Youngs, 1991). Through the medieval period the number of counties in existence varied over time, especially in the north of England, but by the eighteenth century there were forty of what are now termed Ancient Counties in England and a further twelve in Wales (Hasluck, 1936). Although Ancient County boundaries normally followed parish ones, there were exceptions to this; in 1834 there were 122 parishes, tithings or hamlets, or portions of them, geographically separated from the county that they belonged to (Lipman, 1949).

The 1888 Local Government Act set up the system of Administrative Counties with their own county councils. In the process ten new counties were created as follows: the Ancient Counties of both Yorkshire and Lincolnshire which were seen as being too large to be effective administrative units were split into three “ridings”, the North, East and West Ridings of Yorkshire, and the Parts of Holland, Kesteven and Lindsey in Lincolnshire. Sussex and Suffolk were both subdivided into East and West due to the long thin nature of Sussex and the influence of the ecclesiastically controlled medieval franchises of West Suffolk centred on Bury St. Edmunds. Two islands, the Isle of Wight and the Isle of Ely, were created as separate counties. The Soke of Peterborough was formed as the smallest county in England by being split from Northamptonshire partly because of the long thin nature of Northamptonshire and partly because of medieval franchises centred on Peterborough. Lastly the County of London was formed from parts of Middlesex, Surrey, and Kent (Hasluck, 1936).

The Administrative Counties had wide powers invested in their councils. These were elected authorities that took over the powers and duties of the old Justices of the Peace and also gained certain functions of administrative control from central

government (Hampton, 1991). The Administrative Counties were intended to become the most important units in a de-centralised system of local government. They never really achieved the degree of autonomy that was originally envisaged because of the reluctance of civil servants to relinquish their authority, and the large number of County Boroughs that were formed depriving counties of their wealthiest areas and weakening their powers (Keith-Lucas & Richards, 1978).

Administrative Counties were subdivided by the 1894 Local Government Act into Municipal (non-county) Boroughs, Urban Districts, and Rural Districts. County Boroughs were kept separate from the system being beyond Administrative County control. Administrative Counties persisted for nearly 100 years before being replaced by Shire and Metropolitan Counties by the 1972 Local Government Act.

This evolution of counties, from Ancient to Administrative and then to Shire/Metropolitan is the most significant but there were other types of county formed from aggregating other types of unit up to approximately county-level. The best example of these are the Union or Registration Counties formed by aggregating Poor Law Unions or Registration Districts. There were fewer Union/Registration Counties than there were Administrative Counties: Lincolnshire, Sussex, and Suffolk were each considered as only one county (although the three Ridings of Yorkshire were considered as separate), and the Isle of Wight, the Isle of Ely, and the Soke of Peterborough were not considered to be counties in their own right. London was an anomaly in this system: it was not considered to be a county but, as it was a division (a higher level grouping than the county roughly equivalent to the modern Standard Region) consisting of the metropolitan parts of Middlesex, Surrey and Kent, it was usually treated as one. Similarly, the Union/Registration Counties of Middlesex, Surrey and Kent normally only refer to the extra-metropolitan parts of the counties. The Union/Registration County treatment of Wales was ambiguous; although sometimes the twelve counties were treated separately, often they were aggregated together to form two: North and South Wales. In addition to these differences in classification there were also significant boundary differences between the two types of counties. In 1891, for example, the printed census reports list 182 parishes as being in one Union/Registration County and a different Administrative County.

b. The Parish

At the other end of the spectrum, the parish is the traditional lowest unit of local government. Its origins go back to the Saxon vill or township, together with the feudal manor and the ecclesiastical parish. These three should have been geographically coincident but frequently were not, especially in the northern counties where parishes were larger than elsewhere and the township was used to sub-divide parishes (Lipman, 1949). Precisely defining the parish is problematic as their powers and areas had

developed as much by historical accident as through any coherent national system. Youngs (1979) goes as far as suggesting that the parish was not so much a geographic area as a conglomeration of rights, while Lipman (1949) gives several definitions depending on date. He argues that prior to 1844 a parish could be defined as the place for which an incumbent was appointed, while a township was the place for which a constable could be appointed. After 1844 he uses the 1889 Interpretation Act definition as “a place for which a separate Poor Rate is, or can be, levied, and for which a separate overseer is, or can be, appointed” (p. 24). The areas of parishes varied widely; in eighteenth century Suffolk the average parish covered an area of two square miles, in Northumberland it was twelve square miles, while the parish of Whatley in Lancashire covered 161 square miles (Smellie, 1969). Populations also varied; Lipman (1949) notes that, in 1888, 780 parishes had a population of less than 50 and 8,000 of less than 500, while the largest, St. Martin-in-the-Fields in London, had a population of at least 20,000.

The parish became the basis of English local government in the sixteenth and seventeenth centuries when it was made the unit for the administration of the Poor Law acts of 1536 (27 Hen. VIII c. 24) and 1601 (43 Eliz. c. 2) (Lipman, 1949). Other functions, such as highway maintenance, were also given to the parish and it was used for registration purposes from 1538 (Campbell, 1997).

The effects of the Industrial Revolution made the system of government based on the parish unworkable: the population of Britain grew from an estimated 5.5 million in 1695 to 11 million in 1801 and 16 million in 1841. At the start of the nineteenth century only one-fifth of the population lived in towns, by the end of it four-fifths of a much larger population did. This unprecedented urban growth led to slum housing, poor sanitation, and epidemics that affected the entire social spectrum. Large, impersonal, and poorly-lit cities provided opportunities for vice and crime to an extent that had been unheard of in the pre-Industrial age. Factory conditions were harsh and cheap labour, especially from children, working long hours in dangerous conditions became common and a cause for concern. The factories also caused vast amounts of pollution such that natural processes and traditional methods were no longer able to cope (Kingdom, 1991; Smellie, 1969).

The response to this from the 1830s onwards, was to concentrate administrative powers into the hands of *ad hoc* local government bodies using larger units at the expense of the parish. Especially significant was the loss of the administration of the poor law under the Poor Law Amendment Act of 1834. The only concessions to the parishes at this time were the Lighting and Watching Act of 1833 and the Highways Act of 1835 which kept limited powers with the parish (Lipman, 1949).

In spite of the problems with parishes, there was a significant political lobby that opposed the centralisation of power in larger areas and over the next half-century the debate raged. The anti-centralists included people like Toulmin Smith who argued that Anglo-Saxon parish government was the ultimate and most natural form of English democracy, and Disraeli, who, in opposition to the central control of the Poor Law, orated against the “three Bashaws of Somerset House” (Hasluck, 1936). There was a strong political slant to this movement; in 1882 Brodrick classified local authorities by size and the consequent ability of the local population to attend meetings. He argued that as there was on average a distance from the centre of a county to its boundary of eighteen miles, meetings were only available to the county nobility and the gentry. Poor Law Union meetings, with an average maximum travel distance of five and a half miles, were the sphere of the smaller gentry and farmers, while the parish, only a mile on average from boundary to centre, was the only type of area that agricultural labourers could be expected to travel to meetings after a day’s work. This, he argued, meant that the Conservatives favoured the county as an administrative unit as it would be dominated by the gentry, while the Liberals favoured the parish (Lipman, 1949).

The argument came to a head with the debates over the 1888 and 1894 Local Government Acts. Although it had considerable support, the problem with the parish was that in its traditional form it was no longer a practical unit to use for local government purposes as many were too small to be viable. Trying to reform the parishes, for example by aggregation, led to a loss of parochial identity that the pro-parish campaign argued was unacceptable. As one MP stated in parliament, about a proposal that parishes of less than 300 people could be grouped to elect a council, “If the President of the Local Government Board intended by his Bill to put new life into the villages, it was a very funny way to attempt to do so by at once extinguishing almost half the parishes of England” (Lipman, 1949: p. 153).

The 1888 Act did not significantly affect parishes beyond giving county councils the power to reform parish areas. The 1894 Act, however, after vigorous debate, saw the parish reinstated as an area of local government in Rural Districts. This was done by creating two classes of parish: the larger parishes were to have a parish council elected by local ratepayers, the smaller parishes were to have parish meetings where all ratepayers had a vote and additionally could merge with other parishes to elect a parish council. This could, but did not always, lead to the councils merging. It was stated that parishes with over 300 people had to have a council, those with 200 to 300 could have one if they wished, while those of less than 200 people could have one with county council agreement (Hasluck, 1936). The role of the parish councils was, theoretically at least, quite large. It could cover responsibilities for parks and

recreation, street lighting, baths and wash houses, public libraries, fire engines, allotments, limited powers over sanitation, foot paths and rights of way, and fire engines and appliances. The main problem was that the financial resources of the parishes were so restricted that much of their work was in fact left with either the Rural District councils or county councils. This situation remained throughout the twentieth century although many of the powers of parish councils have been taken over by county councils (Kingdom, 1991).

c. The Poor Law Union

Poor Law Unions were the first of the modern district-level units. As such, they were very successful in that they laid the foundations of district-level units that were to last until the early 1970s. The New Poor Law was one of the first reforming achievements of the Whig government of the 1830s (Hasluck, 1936). It established the principles of local administration and government, the influences of which remained long after the Poor Law itself had disappeared. It set two main precedents: it was the first form of local administration for which a comprehensive system of similar units was devised covering the whole country. These were set up so successfully that they were also used by the GRO to administer the collection and publishing of civil registration and census statistics and then by the Local Government Board as the basis for Rural Districts. The second was the use of locally elected officials under the control of a central organisation that oversaw the entire system and the use of paid officers for executive work.

The Old Poor Law had been created in 1601 with a three-level administrative system. The top level was the central authorities of the Crown, the Privy Council, and Parliament. Beneath these were the Justices of the Peace who appointed officers, audited the accounts, settled disputes, and performed other supervisory roles. The bulk of the work however, was done at parish level by unpaid overseers of the poor who collected the poor rate and controlled expenditure. These were responsible for administering poor relief to all destitute people in their parish funded by a compulsory rate levied on every inhabitant and occupier of land in the parish (Knott, 1986).

Even in the eighteenth century there were clear problems with the parish as a unit of poor law administration. In particular, parishes were too small to be able to provide workhouses and skilled supervision for able-bodied paupers, schoolteachers for pauper children, medical care for the sick, and proper attention for lunatics (Lipman, 1949). As a result of this there was *ad hoc* amalgamation of parishes into incorporations under Local Acts through the eighteenth century, leading to Gilbert's Act of 1782 which enabled this to happen without separate pieces of legislation. The precedent for Local Acts of this nature was the Bristol Act of 1696 which amalgamated the nineteen parishes of Bristol "for erecting hospitals and workhouses

within the City of Bristol for the better employing and maintaining of the poor” (Lipman, 1949: p. 36). Over the next century over a hundred more places were to gain similar Local Acts (Lipman, 1949). Gilbert’s Act allowed groups of parishes or individual parishes to become incorporations under a board of guardians and in particular to provide a workhouse as long as two-thirds of the ratepayer agreed and no parish was more than ten miles from the proposed poorhouse. There were at least 65 Gilbert’s Act incorporations formed of 963 parishes. Some of these, such as Great Ouseborn (Yorkshire), Barwick (Yorkshire), and Caistor (Lincolnshire) had over forty parishes each while others were merely a single parish. In addition, the arrangements of these incorporations were often very haphazard, for example the incorporation of Thurgaston consisted of forty-nine parishes nearly all of which were geographically separate (Rose, 1971).

Edwin Chadwick drew up the report on which the New Poor Law was to be based. The report’s recommendations were as follows: there was a need to create a new Poor Law district above the parish and a new administrative system to replace Overseers of the Poor and Justices of the Peace. The new Unions should be based on administrative and geographical convenience rather than historical precedent. They would, it was argued, give economies of scale, a better classification of paupers (by having a greater number to classify) and, by basing Unions on the sphere of influence of market towns, officials would be able to meet on market days. At local level the Boards of Guardians should be set up as the local Poor Law authority with a Poor Law Commission being established in London as a central authority. The executive officials should be paid and auditing done half-yearly under the direction of the Commission (Redlich & Hirst, 1903).

This report formed the basis of the Poor Law Amendment Act that finally gained Royal Assent on the 14th August 1834 (MacKay, 1904). Over the next few years Assistant Commissioners were sent around the country to divide the country into Unions. They started in the South, and moved to the midlands and the west making rapid progress as shown in Table 3.1. It was only when they moved onto the North in the third year after the Act that progress slowed as major opposition and obstacles were encountered. However, by the end of the fourth year of the new system 85% of the population and over 90% of the parishes were covered by unions under the 1834 Act (Lipman, 1949).

Period	Unions formed that year	Parishes absorbed that year	% of pop. under unions
1835-36	112	2066	10
1836-37	239	5846	45
1837-38	215	5138	80
1838-39	17	284	85

Table 3.1: The formation of Unions following the 1834 Poor Law Amendment Act (Source: Taken from MacKay (1904) and Lipman (1949)).

In the south of England there had been only limited opposition and for the most part the system seems to have been brought into operation with little difficulty. There were far more problems in the industrial north where the need for relief was driven by temporary unemployment as a result of fluctuations in industrial employment rather than the seasonal agricultural unemployment that had been most in the minds of the Commissioners (Ashforth, 1976). This led to riots in 1837 and 1838 in places such as Huddersfield, Halifax, Bradford, and Burnley (Knott, 1986) and in Lancashire and the West Riding thirty-one Unions had to be formed initially only for vital registration purposes. In July of 1838 twenty-two of these took over the administration of poor relief but with wider discretionary powers than in other areas and many, such as Todmorden, were slow to introduce the Act fully. Todmorden Union did not have a workhouse for over 30 years (MacKay, 1904).

In spite of these problems, the speed and efficiency that the Assistant Commissioners showed in setting up the new unions was remarkable. MacKay (1904) states that by the end of the fifth year of operation the law was working well in rural areas and “as a rule, to the complete satisfaction of the more intelligent portion of all classes of the population” (p. 243). Lipman (1949: p.43) goes further, stating that “The unions formed in these years provide an orderly and illuminating contrast to all other English local government areas. It was the only time England and Wales were systematically divided up for local government purposes on a logical plan.”

By the end of 1839 the major problem that had emerged were the incorporations under Gilbert’s or Local Acts that could not be included into the New Poor Law. This could also affect surrounding parishes as they could not satisfactorily be included into Unions. The problem with the Gilbert’s Act incorporations was that they could only be abolished by the vote of two-thirds of the ratepayers, something that could rarely be achieved, but needed to be abolished as their haphazard distribution did not fit with the way that the new Unions were being created. The extent of the problem is shown in table 3.2. As an example, in the West Riding the Assistant Commissioners wanted

to set up five new unions based on the market towns of Ripon, Knaresborough, Otley, Tadcaster, and Pontefract each with a radius of about six or seven miles. They were unable to do this as the area was already divided into four Gilbert's incorporations each centred on an obscure village with up to thirteen miles from the furthest township to the workhouse (Lipman, 1949). As the Commissioners could not get the necessary two-thirds majority the situation was deadlocked.

	No. of parishes	No. of inhabitants
Under Local Acts	229	1,298,856
Under Gilbert's Act	288	167,721
Others which could not be unionised due to Local or Gilbert's Acts	259	248,589

Table 3.2: Parishes that could not be unionised in the 1830s (Source: Lipman, 1949).

The Commission's first attempt to solve this was the 1843 Poor Law Amendment Act which allowed them to abolish local authority incorporations of less than 20,000 inhabitants without the two-thirds majority vote. It was not until the 1868 Poor Law Amendment Act and the 1869 Metropolitan Poor Act that most of the incorporations were finally abolished. Even after 1869 eight Unions (East and West Flegg, Exeter, Hull, Norwich, Plymouth, Oxford, and Oswestry) retained the areas of their Local Act incorporations and the Local Acts were not repealed (Lipman, 1949).

The system of Poor Law Unions was, therefore, fully in operation in England and Wales by 1870. Its success was due to its lack of attention to historical boundaries (except those of the parish) and extensive public co-operation in most areas when they were being set up. This was combined with the fact that they were created by a central organisation, the Poor Law Commission, which followed clear guidelines across the whole country, creating a consistent set of areas. There were problems however: the first of these was the large number of Unions that crossed county boundaries, which caused particular problems after the 1888 Local Government Act made the Administrative County an important tier of local government. Secondly, the Unions were laid out at a time of change, in particular it was the beginning of the railway age which was to alter the importance of many towns, and at a time when the importance of the market town was declining.

The system of Poor Law Unions survived through the nineteenth century although the poor law system itself changed over time as the "principles of 1834" were gradually relaxed. In 1905 a Royal Commission was appointed to look into the

administration of the Poor Law. Its conclusions were split between a Majority and a Minority report given in 1909. The Majority report argued that the system was failing in three main ways: firstly, the health of the able bodied was suffering too much as a result of poor medical provision and harsh conditions; secondly, the health of wives and children of those that were refused relief also suffered; and, thirdly, that infirmaries set up to provide care to paupers had extended to help many others, thus there was an overlap between the guardians of the poor and health services run by the boroughs, counties, and districts. This led to the argument that boards of guardians should be abolished and power moved to the Administrative Counties and County Boroughs (Smellie, 1968). The Minority report went far further in arguing that the whole concept of the pauper was an artificial administrative convenience lumping together children, those too old to work, invalids, lunatics, the unemployed, and a very small minority of loafers. It was argued that each group should be dealt with separately; children by local education committees, the sick and invalids by Public Health committees, the aged should be added to the recently formed Old Age Pension Scheme, the unemployed under training by Labour Exchanges, and lastly, any loafers were better dealt with by the police than any other organisation (Hasluck, 1936).

Nothing was done directly as a result of the Commission's report but over the next few years powers were gradually transferred from the Poor Law to other organisations that were either centrally controlled, or controlled by the local counties, boroughs or districts, until under the Attlee government the last traces of the Poor Law disappeared. The first moves came in 1913 when the Mental Deficiency Act gave responsibility for the mentally deficient to the county councils. Also in this year workhouses became officially known as "institutions" and paupers as "poor people" (Smellie, 1968). In 1929 the Local Government Act accepted the principle of the 1909 Minority Report: Boards of Guardians were abolished, the Administrative Counties and County Boroughs became the new poor-relief organisations, poor-relief was renamed "public assistance", and every Administrative County and County Borough had to draw up a report for the Ministry of Health stating to what extent it was prepared to transfer control over care for the poor to specialised committees and departments. This was not yet compulsory but was encouraged (Hasluck, 1936). In 1934 care of the able-bodied unemployed was transferred to the Unemployment Assistance Board. The final traces of the Poor Law were extinguished by a variety of acts between 1946 and 1948 including the National Insurance Act, the National Insurance (Industrial Injuries) Act, and National Health Service Act, the Children Act, and the National Assistance Act which started with the words "The existing Poor Law shall cease to have effect", and removed the word "pauper" from having an effect under English law (Keith-Lucas & Richards, 1978).

d. Registration Districts and the Census

Registration of births, marriages, and deaths before the nineteenth century had been a relatively haphazard affair conducted at parish-level mainly by the Church under various acts of parliament. By the end of the eighteenth century the pressures of the Napoleonic Wars and the debate over population pressures led to the introduction of the Census, under the 1800 Census Act, and then to a comprehensive system of civil registration of births, marriages, and deaths under the Births and Deaths Registration Act and the Marriage Act both of 1836. The administration of these was closely related to the Poor Law as it used the newly created Poor Law Unions as Registration Districts and much of the same local administrative organisations. Registration Districts continued to be used for statistical purposes until the 1929 Local Government Act although over the last few decades of their existence Local Government Districts were increasingly used instead.

Under the two 1836 Acts all births, marriages, and deaths had to be registered with the civil authorities. To enable this to happen the General Register Office was set up based in Somerset House in London. In order to create an efficient system of registration rapidly the Registrar General used much of the newly formed poor law administration for his own purposes. This included using Poor Law Unions as the basis for Registration Districts, making the clerk of the Board of Guardians the Superintendent-Registrar for that district if he was suitably qualified and making the Board of Guardians also supply him with an office and equipment. Registration Districts were sub-divided into Sub-Districts each of which had a Registrar responsible for the registration of births and deaths. By September 1838, 619 Superintendent-Registrars and 2,193 Registrars had been appointed. According to the 1872 *Registrar General's Annual Report* the average sub-district had an area of twenty-six and a half square miles and a population of just over 10,000, although this varied across the country (Nissel, 1987). In a few cases there were differences between Registration Districts and Poor Law Unions. This was usually either because of the problems in setting up Poor Law Unions in areas such as the West Riding and Lancashire, where Registration Districts were created where Poor Law Unions did not properly exist, or in areas where a Poor Law Union was not considered large enough so two were merged to form a single Registration District. An example of this is the Registration District of Dorchester in Dorset which consists of the Poor Law Unions of Dorchester and Cerne.

After the 1888 and 1894 Acts the problems with Registration Districts overlapping administrative county boundaries and the increasing need for statistics at Local Government District level meant that Registration Districts were used less often. The census stopped using Registration Districts as its primary reporting units after 1911,

preferring the Local Government District instead (Dewdney, 1983) and when the Boards of Guardians were abolished under the 1929 Local Government Act responsibility for civil registration, while still controlled by the GRO, became a local authority responsibility (Nissel, 1987).

The first census was carried out on the 10th of March 1801. Its aim was to count the number of males and females in each household and judge whether this was increasing or decreasing. There was also a very crude attempt at occupational classification (Benjamin, 1970). The 1801 to 1831 censuses were organised by John Rickman, formerly a clerk in the House of Commons, and carried out by the overseers of the poor and the clergy in the parishes of England and Wales. However, Rickman was known not to trust the administrative capability of the overseers and so was loath to put too many questions on the schedule (Drake, 1972). The 1840 Population Act put the census under the jurisdiction of the GRO which dramatically improved its administration, detail and accuracy by using the civil registration administration based on Registration Districts for the collection of census data (Nissel, 1987).

The census did not only use Registration Districts (and later Local Government Districts) in its published returns; the 1871 census returns list 17 types of area for which population abstracts were published and listed a further eleven types of areas for which population was not calculated. These are listed in appendix 3.1. The Acts of 1888 and 1894 complicated this still further in the short term, but meant that in the long term Local Government Districts became the standard unit. This remained the case until the 1961 census when increased computerisation led to the data being made available for selected areas at ED-level for the first time (Denham & Rhind, 1983). The 1971 census and those that have followed have built on this and now most census data are published at ED or ward level.

e. Urban and Rural Districts

Urban and Rural Districts formed the backbone of local government away from the metropolitan centres for nearly a century. They grew out of public health agitation and consequently were based on giving urban parishes separate powers while creating Rural Districts out of the remainder of the Poor Law Union. The 1848 Public Health Act was the first step in the establishment of Urban Districts. This Act aimed to create Boards of Health to improve sanitation in all areas but, in particular, in areas with high death rates. The Act made it compulsory for parishes with a death rate of over 2.34% to establish a Board of Health and so mainly affected crowded urban parishes. Any other parish could, if it wished, also establish a Board. However, very few did as, at the time, sanitation was not seen as the issue that it was later to become. A central Board of Health was set up to supervise the work of local Boards but was abolished in 1858 without ever having achieved much dominance (Richards, 1971).

Almost by accident, 1862 became a significant year for Urban and Rural Districts; the Highways Act of that year made it compulsory for parishes to group together into Highway Districts to improve the state of the roads. There were three exceptions to this; parishes that fell under the jurisdiction of a Municipal Corporation, parishes with a Board of Improvement Commissioners, and parishes with a Board of Health. Many parishes resented being grouped into Highway Districts as they did not want to be liable for repairs to roads in neighbouring parishes leading to a rush of towns and even small villages setting up Boards of Health under the 1848 Act, a process that had been deliberately made easy to aid public health. Although this was stopped twelve months later by an Amending Act which required parishes wanting a Board of Health to have a population of at least 3,000, 900 new local authorities “whose name of Boards of Health was a sheer mockery” (Hasluck, 1936: p. 149) had been established, of which 22 had a population of less than 100 and 130 less than 500 (Lipman, 1949). No attempt was made to abolish these new authorities retrospectively.

By the 1870s public health had become a more significant issue and, in response, the 1872 Public Health Act divided all of England and Wales into Sanitary Districts creating a clear distinction between urban and rural areas. Urban Sanitary Districts were set up where parishes had a Board of Health under the 1848 Act or an area was under the government of special Boards of Improvement Commissioners, under a Local Act. Rural Sanitary Districts were created as the remainder of the Poor Law Union. This meant that, in general, Urban Sanitary Districts were set up as individual parishes while Rural Sanitary Districts would be the remainder of the Poor Law Union. Both types of district had Sanitary Boards charged with improving water supply and drainage (Hasluck, 1936).

The 1894 Local Government Act took the existing sanitary areas and increased their powers to give them broad local government functions. The Sanitary Boards were replaced by District Councils with Councillors rather than “Members of the Sanitary Board” and sanitary districts became Urban and Rural Districts. Urban Districts were given more power and more funding than their rural counterparts as their public health problems were perceived to be worse. From this date on, Urban and Rural Districts, along with the boroughs, increasingly became the main sub-county areas for local government and the importance of Poor Law Unions and Registration Districts started to decline.

The next important step in the evolution of Rural and Urban Districts came with the County Reviews of the early 1930s. It was stated that of the 594 authorities whose 1921 population had been less than 5,000 only one could raise over £200 with a penny rate and most could not raise £100, and that areas such as these could not possibly carry out their duties efficiently and effectively (Lipman, 1949). Units found by the

reviews to be too small or too poor were to be merged into a wealthier urban area or amalgamated with other rural areas. The reviews led to what Hasluck (1936: p. 148) describes as “a perfect holocaust of Urban Districts”. Only two counties, Radnor and Rutland, did not submit proposals for a County Review and, in the decade that followed the 1929 Act 206 Urban Districts and 236 Rural Districts were abolished with only 49 and 67 respectively being created (Lipman, 1949). Many anomalies such as detached portions and projecting corners were abolished and the number of Urban Districts in the major urban areas was reduced. From the 1930s, therefore, there were fewer but larger Urban Districts.

The powers of Urban and Rural Districts were very similar, although those for Urban Districts were slightly wider. The main difference between them was that Urban Districts had no subordinate units with any power so that their councils performed all the work of local government not done at county level. Rural Districts were split into parishes so some of their powers were devolved (Hasluck, 1936). The main powers of the district councils were to do with public health as consolidated under statute in 1875. Urban Districts had more power in this regard, had more expected of them, and greater financial resources. In addition, provided that they had populations above a minimum threshold, Urban Districts could start to take on some responsibilities concerned with education, policing, and old age pensioners. After the 1929 Act, in an attempt to improve services in rural areas, Rural Districts were relieved of the heavy burden of highways expenditure which was passed onto the counties. The money saved was earmarked to improve sanitary provision. The county councils were also given responsibilities in Rural Districts such that they could take over any aspect of public health service or pay contributions to a rural district council’s expenses in this regard (Hasluck, 1936).

f. Non-County (Municipal) Boroughs

The local government of large towns has always been kept separate from other areas. The tradition of “borough-status” dates back to Anglo-Saxon times when important towns would be granted it by the Crown under Royal Charter. In theory Municipal Boroughs could also be set up by Act of Parliament but this was rare (Hasluck, 1936). The boroughs were a major target for the Whig government of the 1830s that alleged that nepotism and corruption within them was rife (Kingdom, 1991). The 1835 Municipal Corporations Act gave existing boroughs a new constitution based on an elected council whose major power was the ability to make by-laws. Central government was given the power to insist on proper financial management but central control of the boroughs remained negligible (Richards, 1971). The Act was applied to 178 large towns and allowed large, unincorporated towns to petition for incorporation at a later date. The Act also rationalised the boundaries of

many boroughs by attempting to get rid of such problems as outlying areas, overlapping boundaries, and areas within the boroughs immune from the power of the local authority. This rationalisation continued throughout the nineteenth century (Smellie, 1969).

The Local Government Acts of 1888 and 1894 split boroughs into two distinct types; the County Boroughs were given complete management of their own affairs, while Municipal Boroughs were given powers similar to Urban Districts under the control of the Administrative County.

The powers of a Municipal Borough council were similar after the 1894 Act, to those of an Urban District council. However, their constitutional positions were very different. In theory, a borough council could take over the independent management of the police in its area, however in practice this rarely happened as the Home Office would insist that this power was waived when the borough charter was drafted. A borough council had, until the 1931 Education (Local Authority) Act, the freedom to run a system of elementary schools. It also had the power to appoint inspectors of food and drugs, weights and measures, and diseases of animals, and some duties under the Shops Act, the Old Age Pensions Acts, the Naval & Military Pensions Act, and the Insurance Acts, and the chance to get Home Office approval to appoint a stipendiary magistrate to hear local cases. The older boroughs also had the power to issue by-laws (although many argued that for local consistency this was better done at county-level). The councils had a body of aldermen co-opted to them by councillors and a salaried mayor (rather than the unpaid chairman of a district council). This, it was argued gave the position more prestige and attracted better candidates. Borough status was also argued to give a town increased dignity (Hasluck, 1936).

To become a Municipal Borough after the 1888 and 1894 Acts a petition had to go to the Privy Council. The Privy Council would refer the petition to a special Committee which would required the Ministry of Health (the Local Government Board before 1919), the relevant county council, and other government departments to give reports about the district council, and especially the efficiency of its administration. An inspector, normally a barrister, would be sent to the town to hold a public inquiry. There were several factors that could cause a petition to fail: firstly, the accepted practice was that a town had to have a population of over 20,000. Then, if there was strong local opposition to the petition (for example due to the council being unpopular) or the council had a bad record with central government then this could cause a petition to be turned down. This was particularly true if corporate conduct had been publicly condemned by the government. For example Walthamstow, with a population of 150,000, had several petitions rejected and this was commonly believed to have been due to its council's support for the 1926 General Strike. A final reason

was if either local ratepayers, the county council, or the councils of adjoining districts could raise a petition against the town attaining borough status, in which case a charter would be postponed until both Houses of Parliament had approved it. Assuming that these obstacles could be overcome a town would then be granted a Charter by the Crown (Hasluck, 1936).

The impact of the County Reviews of the 1930s was not as significant for Municipal Boroughs as it was for Urban and Rural Districts but it was, none the less important as 189 of the 256 Municipal Boroughs had their boundaries altered (Lipman, 1949).

g. County Boroughs

Traditionally certain important towns have had the right to conduct their own local government without interference from the counties. These were called “counties of themselves” or “counties of cities” and examples include Chester from 1238, Coventry from 1452 and Nottingham from 1448 (Youngs, 1991). When drafted, the 1888 Local Government Act envisaged sticking to this tradition by keeping a small number, perhaps ten, of the larger boroughs out of county council control. These were to be the exception. Unfortunately for the new Administrative Counties, intense lobbying of parliament by boroughs led to the exception becoming the rule. When the Bill became law sixty-one boroughs, including some with a population of less than 50,000, had achieved county status. The Act further allowed boroughs to apply county status when their population reached 50,000 by getting a Local Government Board (or the Ministry of Health after 1919) Provisional Order. Parliament would need to approve this but the process was fairly straightforward. A borough could alternatively try to gain county status by promoting a Local Act of Parliament (Hampton, 1991).

When a borough gained county status it gained the following powers: it became invested with the entire charge of the poor-law system, it became the sole education authority for elementary and secondary schools, it had to provide a range of services in relation to tuberculosis, venereal disease, maternity and child care, it took over maintenance of main roads, it had to take care of lunatics and the mentally deficient, it became nominally responsible for the police (although in practice the Home Office was in charge of the police force), it had duties to do with registration and licensing, Health Insurance and pensions, and it took over all the powers and responsibilities previously held by the County Council (Hasluck, 1936).

The ease by which boroughs could gain county status caused great resentment among the counties as between 1888 and 1925 twenty-one new County Boroughs were formed, bringing the total to eighty-two, and there were over a hundred extensions to County Borough areas. This resulted in a third of a million acres of Administrative County becoming County Borough, three million people being moved

to county boroughs, and the counties losing fifteen million pounds worth of rateable value (Hasluck, 1936). Counties in rapidly expanding urban areas fared the worst with Lancashire, the West Riding, Staffordshire, Worcestershire, Glamorganshire, Durham, Warwickshire, Hampshire, and Gloucestershire being the heaviest losers (Smellie, 1969). When the Onslow Commission was set up in 1923 to investigate problems of rural areas it quickly became embroiled in the controversy between the counties and the boroughs. It took evidence from both sides, and finally came down in favour of the counties leading to the 1926 Local Government (County Boroughs and Adjustments) Act. This Act made three major changes to the process of creating a new County Borough: first, it raised the minimum population needed to gain county status from 50,000 to 75,000. Second, it stated that in order to create or change the boundaries of a County Borough a Provisional Order could no longer be used, instead the borough would have to promote a Local Act through parliament, a far more costly and time consuming process. Third, it gave counties significant compensation for the loss of areas to new or extended County Boroughs. In addition, to change its boundaries a County Borough also needed a Local Act unless the changes were unopposed in which case a Provisional Order was still sufficient (Keith-Lucas & Richards, 1978).

The Act stopped the wholesale creation of County Boroughs. From 1926 until the Second World War only one, Doncaster, was created. Boundary changes for County Boroughs, however, still continued rapidly in response to urban growth, between 1929 and 1937, 49 County Boroughs (out of 83) had their boundaries extended transferring 110,000 acres to County Borough control (an area significantly larger than the Isle of Wight) and giving each County Borough extended an average of 3,000 more people (Lipman, 1949).

Unlike Administrative Counties, there were no subordinate areas within County Boroughs. Early in the period urban parishes had some limited powers but the 1933 Local Government Act deprived them of even these. This made the councils in County Boroughs significantly more powerful than the county councils of Administrative Counties who had to devolve power to the Municipal Borough, and Urban and Rural District councils (Hasluck, 1936).

h. London

Local government in London stands as a marked exception to the rest of the country mainly for historical reasons and, in particular, due to the power and influence of the Corporation of the City of London which was left out of the Municipal Reform Act of 1835 and, for the next half century, resisted every attempt to reform it and the parts of London beyond its boundaries. Its success in doing this says much about the wealth, power, and influence of the City.

For most of the nineteenth century local government in the Metropolis was in chaos with powers split between a total of 200 bodies including parish vestries, Boards of Improvement Commissioners, Boards of Guardians, and Courts of Sewers (until 1848) “their united efforts leaving London the foulest, most unhealthy, and worst governed urban area in England” (Hasluck, 1936: p. 164).

The first attempt at reform was the 1855 Metropolis Management Act, the very name of which seems to be avoiding any implication of local government that might offend the Corporation. This created twenty-three large vestries of uniform type and fourteen district boards. It also created a central Municipal Board of Works to oversee all of the Metropolis, which did manage to make notable improvements in drainage and to construct the Victoria Embankment, but had far less power than organisations in provincial cities such as Birmingham, Liverpool, and Manchester, and even some lesser towns (Hasluck, 1936).

The next attempt to reform the government of the Metropolis was the 1884 London Government Bill but this was opposed by the Corporation of the City and never became law. Instead some reform came about from the 1888 Local Government Act that replaced the Metropolitan Board of Works with the London County Council (LCC) which was directly elected by ratepayers and had powers similar to other county councils. It was limited in that the county boundary still followed the 1855 Metropolitan Boundary and, due to the need to avoid City opposition, its powers within the City of London area were limited.

The London Government Act of 1899 gave London a system of local government similar to that which had been given to the rest of the country under the 1894 Local Government Act. It abolished district and vestry boards and replaced them with twenty-eight Metropolitan Boroughs. These were similar to the Municipal Boroughs both in their internal powers and their relation to the LCC, but there were some constitutional differences; the LCC had responsibility for the main drainage system, the main thoroughfares, maintaining Thames bridges (outside the City), embankments, tunnels and ferries, parks and recreation grounds, and for the London Fire Brigade. The LCC also had the right of veto over borough by-laws and applications for loans and the two types of organisation shared duties under the Housing Acts and Control of Building Regulations (Hasluck, 1936).

As with the rest of the country the situation in London remained fairly constant until after the Second World War, with the exception of the 1929 London Government Act which allowed LCC powers to be transferred to smaller units by order of the Local Government Board. After the War, however, the pressures of increasing urbanisation and suburbanisation grew rapidly towards crisis and the LCC area, still based on the 1855 urban limit, was too small to cope. Eventually, in 1957

the Conservative government set up the Herbert Commission to look at the problem. In spite of major opposition from the Labour party, which feared a loss of control of the LCC, the commission declared “The primary unit of local government in the Greater London Area should be the borough, and the borough should perform all local authority functions except those which can only be effectively performed over the wider area of Greater London” (Kingdom, 1991: p. 78). It recommended a massive expansion of the LCC area to engulf the whole of Middlesex and parts of Essex, Kent and Surrey, raising the population of London from three million to well over eight million and increasing the area from 75,000 acres to over half a million. Most of the recommendations of the commission became law under the 1963 London Government Act which split the new area into new Metropolitan Boroughs taking the number of these to 32 under the newly-formed Greater London Council (GLC) (Kingdom, 1991). The GLC was responsible for functions requiring management over a wide area such as housing, main roads, traffic management, and public transport, while the boroughs had responsibility in most other areas. The one oddity of the 1963 Act was the retention of the LCC education department as the Inner London Education Authority (ILEA), which retained responsibility for education in the old LCC area. In the outer areas responsibility for education was given to the boroughs (Kingdom, 1991).

The Corporation of the City of London continued throughout the period to resist any external attempts at reform, in particular getting itself exempted from both the 1899 and 1963 London Government Acts. Hasluck (1936: p. 134) describes it as the “anomaly of anomalies”. Although based in the Square Mile, the powers of the Corporation extend beyond these to include it being the sanitary authority for the Port of London (extending from the Isle of Sheppey to Teddington Lock), it maintained large parts of Epping Forest and other distant areas, and, under a charter from Edward III, controlling all markets within seven miles of its boundaries (Hasluck, 1936). The powers of the Corporation go far beyond those of any other local authority with hundreds of unusual privileges and functions, including maintaining its own police force.

3.3: Boundary changes to local government units

There is, therefore, a wide literature that describes the often complex evolution of the major administrative units of England and Wales. A full list of the legislation affecting this is provided in appendix 3.2. Much less has been written about the more localised changes that occurred to these units between the periods of major legislative activity. In the next section these more localised changes are examined based on a major database of textual information concerning boundary changes.

As part of the process of building the GIS a large textual database of boundary changes has been constructed. This was built using the *Registrar General's Annual*

Reports and Decennial Supplements for changes to Registration Districts, *the Annual Reports of the Local Government Board* and its successors for Local Government Districts, and the printed census reports for changes to parishes. This database and its uses will be discussed in more detail in chapter 4, but each row of data contains the name of the district or parish that lost territory from the change, the name of the district or parish that gained from it, a textual description of the area involved in the change, a date, and some measure of the population involved. Figure 4.4 shows an example of the source material from the *Registrar General's Decennial Supplements*.

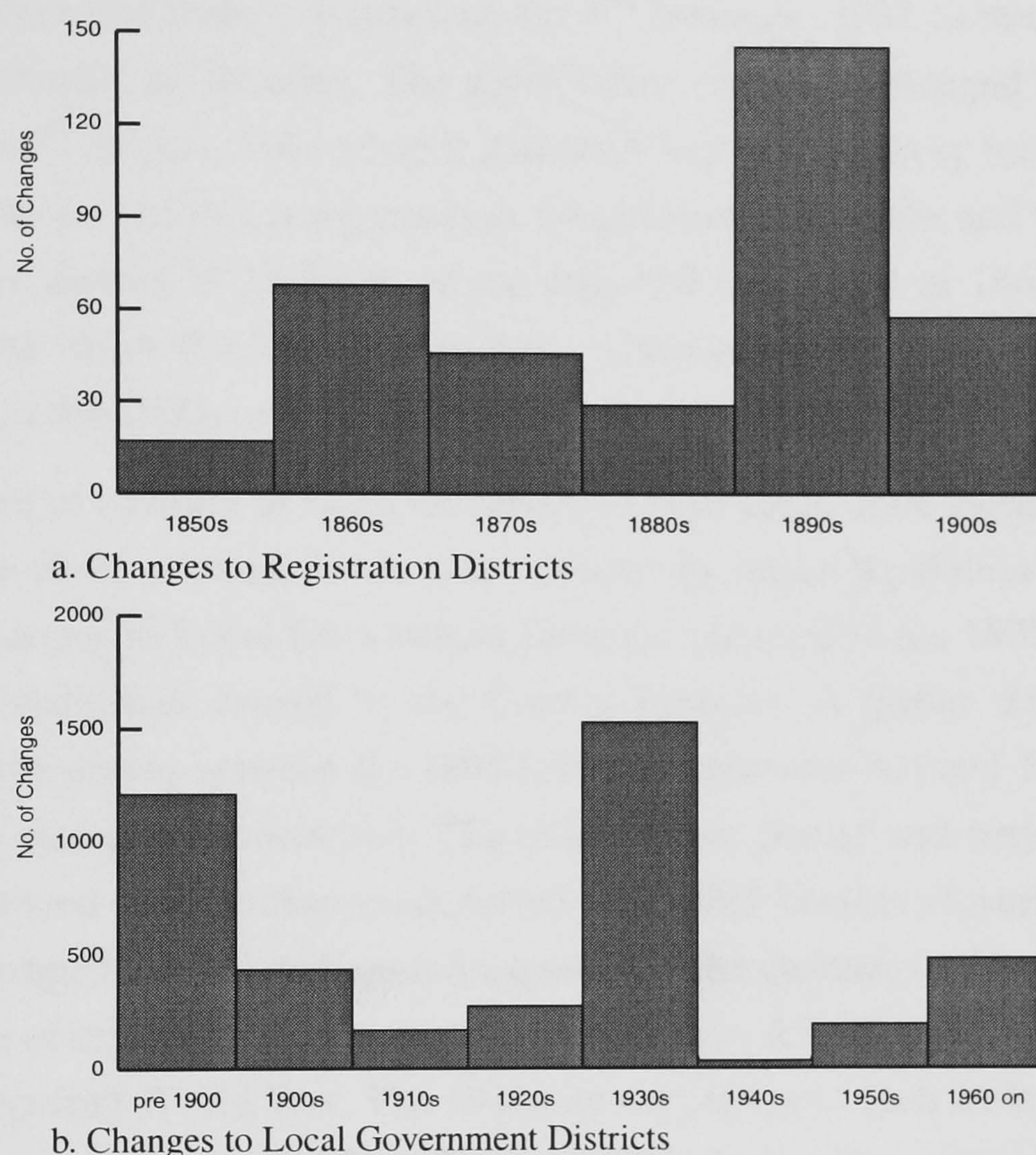


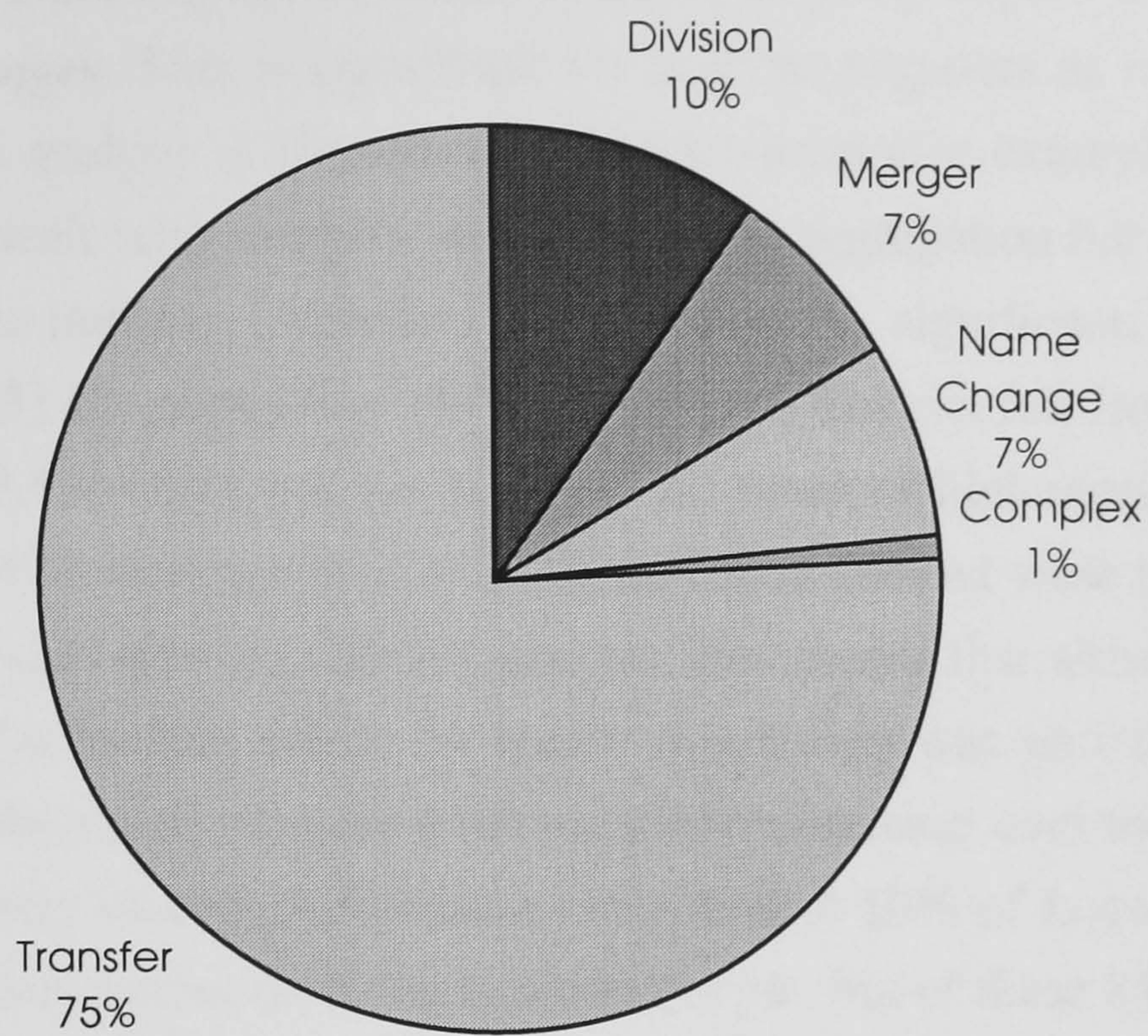
Figure 3.2: Numbers of district-level boundary changes by date.

The database shows that there were 383 changes to the boundaries of Registration Districts between the 1840s and 1910, and 4,247 changes to Local Government Districts from the 1890s to 1973. Figure 3.2 shows these changes divided by date. For Registration Districts the 1890s were the peak decade for change with 40% of the total changes. There is no clear reason for this and the changes were well dispersed geographically. It might be speculated, however, that there was a rush to change Registration District boundaries in this decade as an indirect response to the Local Government Acts of 1888 and 1894. While these acts did not set out explicitly to affect the Registration District system, it seems likely that they did result in changes to Registration Districts in response to either the formation of Administrative Counties

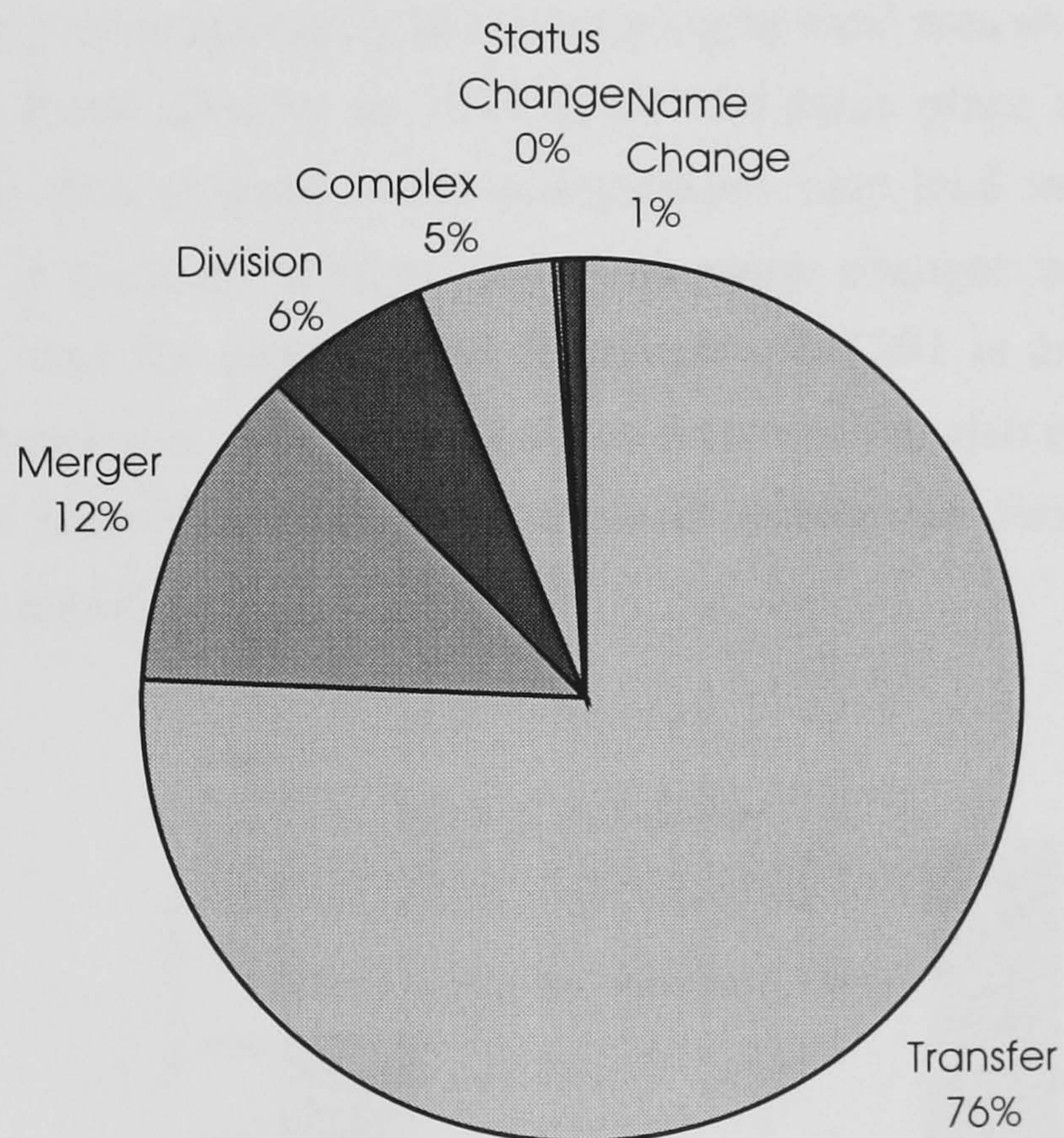
or Local Government Districts. These would, however, have been fairly piecemeal and left many unresolved anomalies. The large number of changes in the 1860s are easier to explain; 45% of these occurred in the West Riding of Yorkshire as a result of opposition to the New Poor Law. This resulted in a large number of major changes to Union boundaries in this decade and these are reflected in the changes to Registration District boundaries. As an example of this, the Registration District of Kirkstall near Leeds was formed from Hunslett Registration District on the 6th November 1862. It then lost two parishes, Beeston and Churwell, to Holbeck Registration District around three weeks later and further territory on the 5th February, 1863 to the newly created Registration District of Bramley. The district then remain unchanged for around six years until the 6th August, 1869 when it was abolished with territory being allocated to six districts. As part of this reorganisation the parishes of Beeston and Churwell were restored to the district of Holbeck, where they had been prior to 1863. Three other districts in the West Riding: Kirkdeighton, Castleford, and Bramham, were also formed early in the 1860s only to be abolished later in the decade.

The pattern of changes to Local Government Districts is more varied, perhaps as a result of these changes being driven more directly by major legislation and reform. A third of all changes to Local Government Districts occurred in the 1930s, largely as a result of rationalisation caused by the County Reviews. A further 28% of changes happened in the period between the 1894 Local Government Act and 1900 as a result of the 1894 Local Government Act. The third highest period was between 1960 and 1973 when around 10% of changes occurred. The 1963 London Government Act had a significant impact on this and around a quarter of the changes in this period were as a direct result of this. Not surprisingly, there were very few changes in the 1940s as a result of the Second World War. The 1910s do not represent such a clear low as there were 146 changes however 105 of these occurred before the outbreak of the First World War.

The GBHGIS is not concerned with the potential difference between draft and actual boundaries (Worboys, 1998; Wachowicz, 1999). A fairly simple four-way classification of boundary changes was devised: *transfers* occur when part of a unit is moved from one area to another, *name changes* occur when a unit changes its name without any change of boundary, and *mergers* and *divisions* occur when new units are abolished or created respectively. In addition two other types of change can occur: Local Government Districts can change their status, i.e. the type of unit they are, without any changes of boundary. For example, when a Municipal Borough becomes a County Borough. Finally, when more than one of these changes occurs simultaneously, for example when a unit is abolished and a new one created as a result of the same change, this can be classed as a *complex*.



a. Changes to Registration Districts by type.



b. Changes to Local Government Districts by type.

Figure 3.3: District-level boundary changes by type.

How the GIS deals with changes is described in the next chapter. Figure 3.3 shows the relative frequency of these changes for Registration Districts and Local Government Districts. In both cases transfers make up approximately three-quarters of the total changes. This is significant for analytic purposes as many studies that have attempted to analyse at Registration District-level (for example, Woods & Shelton, 1997) have dealt with mergers and division by aggregation but ignored the impact of transfers. The impact of transfers can, however, be significant, for example, between 1911 and 1921 the population of Swansea Rural District fell from 43,228 to 24,752, a decline of 18,476. This was not however the result of high mortality or out-migration, in October 1918 four parishes in Swansea Rural District were transferred to Swansea County Borough affecting 26,221 people. This means that although the population of the Rural District had fallen by nearly a half this was entirely due to a boundary change and there was actually a net population increase over the decade if the impact of the boundary change is removed. Only around 10% of Local Government District transfers affected more than one hundred people, but of these 84 affected over 10,000. With Registration Districts 22% of transfers affected over one hundred people and five affected over 10,000.

Boundary changes also have important implications for the creation of time-series. If a time-series was created boundary changes mean that the same place name will not necessarily refer to exactly the same geographical area at different dates. For example, Swansea Rural District in 1911 is not the same place as Swansea Rural District in 1921 and thus making direct comparisons may lead to incorrect conclusions. This problem is even more significant with name changes when it may not be clear, for example, that the place called Highworth in 1891 is exactly the same as the place called Swindon in 1901. Mergers and divisions are also important. It is not possible to extend a district's time series back to before its formation or forward after the district's abolition.

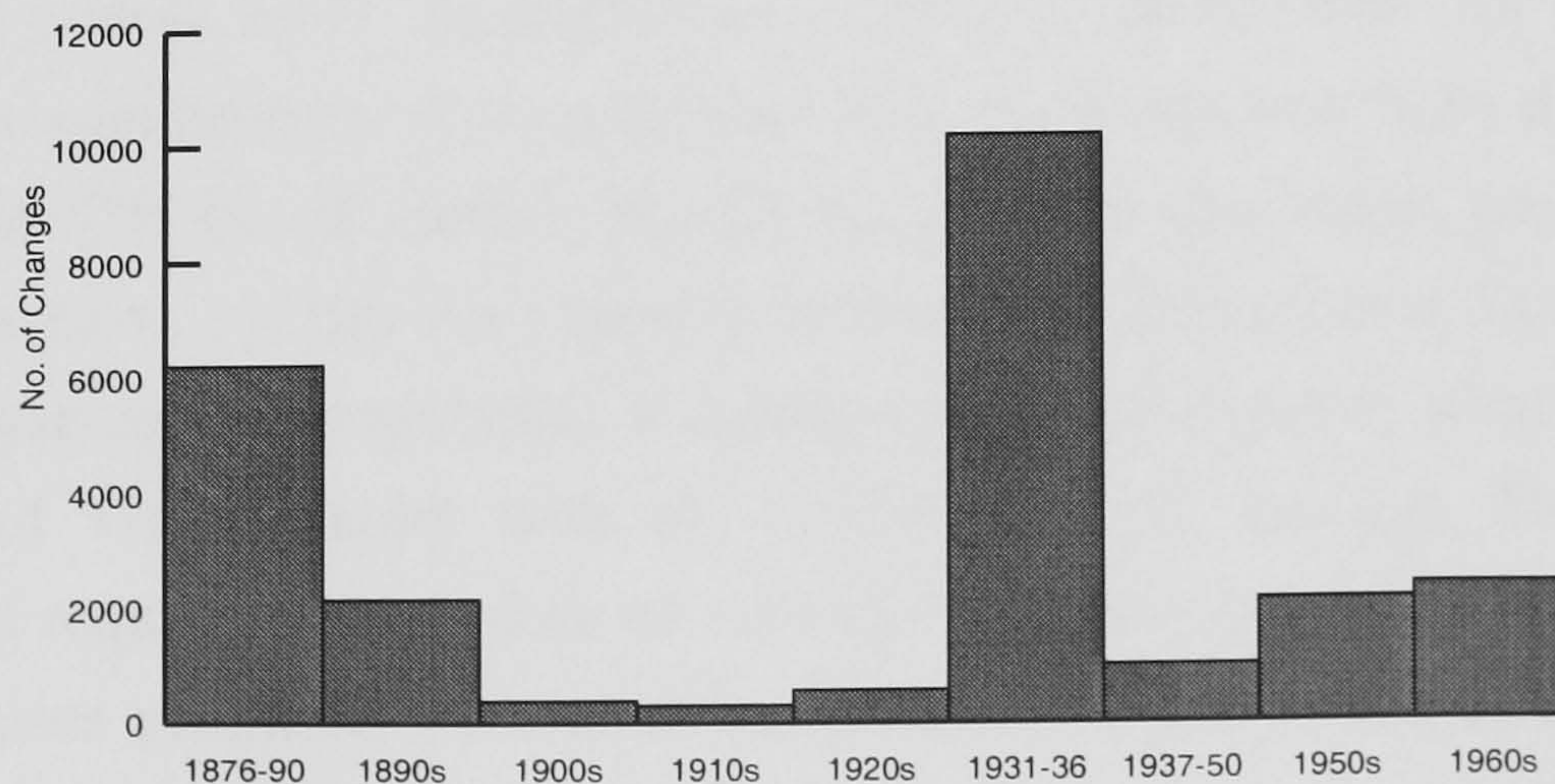


Figure 3.4: Numbers of parish-level boundary changes by date.

Due to the more diverse nature of the sources, it is harder to draw generalisations about parishes in the same way as for Registration Districts and Local Government Districts. The total distribution of changes over time as recorded in the printed census reports can again be calculated as is shown in figure 3.4. However it is important to note that not all of these changes directly affect parishes. As with Local Government Districts, this pattern is heavily affected by major legislation: 25% of changes occur in the fifteen year period ending in 1891 largely as a result of rationalisation of the system under the Divided Parishes and Poor Law Amendment Acts of 1876, 1879, and 1882. The number of changes fell during the 1890s and the period from 1901 to 1930 saw relative stability with only a few hundred changes per decade. The impact of local government reform in the 1930s again has a major impact with 10,095 changes being recorded between 1931 and 1936, 37% of the total. The period after 1937 is relatively stable although there are more changes than in the early decade of the century with between 2,000 and 2,500 changes per decade being the norm.

3.4: Conclusion

Data for England and Wales have been published using arbitrary sets of administrative units based on a system that was set up in the 1830s but whose roots stretch back to Anglo-Saxon times. This system of administrative units has been reformed and overhauled on occasion, notably in the late nineteenth century, the 1930s and the 1970s, although some of the reforms in the late nineteenth century did not have a major impact on data publishing until after 1911. The system has also been exposed to a steady and persistent stream of more minor boundary changes that make comparing data from one date to another fraught with problems.

For the period from the 1830s to the 1970s local government units have mainly been arranged using a three tier system with counties at the top, parishes at the bottom and various types of district in between. As was discussed in chapter 2 many studies have dealt with the complexity of their spatial data by aggregating data published at district level to county level. Aggregation is, however, problematic for two reasons: firstly, it causes a potentially very significant loss of information from the data when the emphasis in GIS-based studies should be to make maximum use of the data available (Openshaw, 1991b). An example of this type of problem is Saville's (1957) attempt to analyse rural depopulation at county-level by comparing what he terms the urban county of Warwickshire with the rural county of Rutland. This is clearly nonsensical and requires a finer scale of analysis. Secondly, and more fundamentally, aggregation causes problems with modifiable areal units (Openshaw, 1984 and see also chapter 2 of this thesis). As was discussed earlier in this chapter, the system of counties that existed in the nineteenth and twentieth century had its origins in Anglo-Saxon times. As a result, their shapes and sizes are extremely irregular and have no

relevance to more recent population distributions. This means that the area and make up of counties varies so much as to ensure that many counties are simply not directly comparable with each other. As an example, in 1851 Rutland, the smallest county, had a population of 23,000, largely the population of two market towns and their hinterlands. This represented 0.13% of the population of England and Wales. The largest, Lancashire, had nearly 100 times as many inhabitants, 13% of the population of England and Wales, and covered not only several cities such as Liverpool and Manchester, but also large amounts of sparsely populated moorland. By 1951 the difference between the counties with the smallest and largest populations (Radnorshire and Lancashire respectively) had risen to over 250 times. Within this range the distribution is heavily skewed with most counties having relatively small populations when compared with Lancashire, the West Riding of Yorkshire or London. The population distribution of counties in England and Wales in 1851, 1901, and 1951 are shown in table 3.3 to illustrate this further.

	Ancient Counties: 1851	Registration Counties: 1901	Administrative Counties: 1951
Minimum	23,400	20,200	20,000
Maximum	2,360,000	4,450,000	5,120,000
Mean	326,000	589,000	436,000
Median	214,000	349,000	322,000
Lower Quartile	98,300	132,000	111,000
Upper Quartile	400,000	665,000	610,000
Inter-Quartile Range	302,000	433,000	500,000

Table 3.3: Population distributions for different types of counties: 1851, 1901 and 1951 (Source: Printed census reports).

Between the 1840s and the 1970s the units most suitable for the purposes of GIS-based analysis are the districts. These were the backbone of spatial data publishing throughout the period and combine a wide data availability with a reasonably detailed spatial framework. As the GRO required coverage of the entire population and, unlike Poor Law Unions, Registration Districts were not used to raise taxation, the coverage of the country was complete and well defined without problems such as Gilbert's Incorporations. The GRO was able to administer changes to boundaries of Registration Districts and Local Government Districts and kept accurate records of these to help in the collection and publication of statistics. The Local Government Districts provide a more detailed system than Unions or Registration Districts with the particular advantage that they provide a rural/urban contrast. In this respect they are perhaps even more useful than Registration Sub-Districts which, although there were more of them, do not provide as clear a distinction between rural and urban areas. The

basic fact, however, is that the data available depends on what was published (Baker, 1997) and the challenge is to take this and make best use of it.

There were 15,000 parishes compared to 635 Registration Districts and 1,500 Local Government Districts, so data published at this level provide far more spatial detail than district-level, however, they are more problematic. The first problem is that prior to the twentieth century precisely defining a parish was difficult. Their boundaries were so heavily influenced by medieval considerations and contained many detached portions and other problems that make them in many ways unsuitable for publishing and analysing data. This problem was largely sorted out by legislation in the late nineteenth century. A more significant problem was simply the lack of data published at parish-level in the period from the 1840s to the 1970s. Until the 1830s the parish provided the spatial organisation for many statistical sources as far back as the *taxatio ecclesiastica* of 1291 (Denton, 1997). From the 1970s wards, a similar scale geography to parishes and usually coincident in rural area, become an important data publishing unit, particularly with the advent of census Small Area Statistics (SAS) (Coombes, 1995). In the period in-between, however, few datasets were published at this scale apart from census head-counts of population. While these provide very useful information about the distribution of the population within districts, they are not very useful in their own right.

Problems with county-level analyses have long been known. As far back as 1911, Welton (p. 3) stated that data at this level were often “not illuminating” and “misleading”. The traditional problem with district-level studies, however, is the complexity of the data, and in particular the problems associated with boundary changes that affect them. The problems associated with boundary changes are absolutely fundamental, in that it may not even be easy to provide a spatial reference for a district. In the case of parish-level data this problem is even more pronounced. This became the first challenge for the GBHGIS: how to create a GIS database that was capable of storing the changing boundaries of Registration Districts, Poor Law Unions, Local Government Districts and Parishes in such a way that these could be extracted for a particular day and linked to statistical data. How this was done is described in the next chapter.

Chapter 4: Building the Great Britain Historical GIS

4.1: Introduction

This chapter describes the actual process of building the GBHGIS¹. The initial system covered Poor Law Unions and Registration Districts before the First World War. It was designed and completed in the academic year 1994/5, the first year of the project's existence. Subsequent expansion of the project then proceeded in a manner that was at least in part determined by what was at times tenuous funding. Put very simply, the GIS was extended to cover parishes from 1876 to 1911 and then to cover Local Government Districts and parishes from 1911 to 1974. Although I designed the system's architecture and built the initial Poor Law Union and Registration District system, the later work on construction has been done by Chris Bennett and Vicki Gilham.

The most fundamental aim of the GBHGIS is to enable data to be united with the units they were collected for, to allow integration, analysis and visualisation of data published at a wide variety of dates. This meant creating a system that would allow a user to specify the following: a date accurate to the day, part of the country down to individual counties, and a type of unit. Using this information the system extracts an ArcInfo "coverage", or "layer", the basic representation of spatial data used by a GIS (see Peuquet & Marble, 1990). The coverage contains the specified boundaries from a large spatial database containing all the changing boundaries of that type of unit. The extracted coverage can then be easily linked to attribute data, such as census data, vital registration data, or Poor Law returns, held in an existing database in the Oracle Relational Database Management System.

To do this two distinct types of challenges had to be overcome: the first was a computer science problem; how to create a GIS system capable of storing changing boundaries in an integrated structure and, related to it, to devise a flexible and transparent system for linking the extracted coverage to attribute data. The second involved historical scholarship in researching changes to local government units using a mixture of sparse map sources and more comprehensive textual sources. Having solved these, a third challenge was how to include the resulting information within the

¹ This chapter was derived from the first draft of Gregory & Southall (1998). The chapter describes my contribution to the work except where otherwise acknowledged. Other sections of this chapter have since been re-written as Gregory & Southall (2000).

system. The remainder of this chapter looks at these three issues in turn and discusses how each was handled. It is worth noting that all three were solved in the first year of the project. Since then more and more boundaries have been added to the system and this has involved some modifications. The architecture of the full system, however, remains essentially the same as the Poor Law Union and Registration District system created in 1994/5. This chapter first reviews the approaches used by other countries to build similar systems. It then addresses the choice of which districts to include. Next, a detailed description of the architecture of the GIS is given that explains how the ability to include boundaries that change over time was incorporated into the system, and how large amounts of data for different types of units were included into an efficient structure. Finally, the sources used to build the GIS and the actual process of construction are documented.

4.2: Approaches from other countries

As was discussed in chapter 2, time is a concept that is poorly incorporated into commercially available GIS software packages and research into fully temporal GIS software is still in its early stages (see also Egenhofer & Golledge, 1998; Langran 1992 and Wachowicz, 1999). A major problem in creating a temporal GIS is that of transaction management, updating the database to reflect changes as they occur (Langran, 1992). This is not a problem for the current system as there is a definite end-date for all the major types of unit involved and there are no plans to extend the system to the present day.

The literature on building GISes containing changing historical administrative boundaries is extremely limited because the GBHGIS was one of the first attempts in this area and is the most comprehensive system of its type in existence in the world today. Several other countries and regions either have built, or are planning, similar systems. These include Prussia, the United States, Holland, Belgium, the Palatinate and Mannheim, and Sweden². From these, three distinct approaches can be identified. The first, similar to Langran's (1992, see also chapter 2 of this thesis) time-slice snapshots, is simply to digitise boundaries at key dates (see figure 2.4). Second, there are hybrid approaches that attempt to reduce redundancy by creating a database from which boundaries for a set date can be extracted. The third takes this approach to its logical extreme by creating a structure similar to Langran's space-time composite (see figure 2.6).

² Much of my detailed understanding of the European projects originated at a European Science Foundation funded meeting held in Florence in June 2000. The meeting was organised by Drs. M Goerke, H Southall, and G Thorvaldsen. I am very grateful to the organisers, and to Goran Kristiansson, Tine De Moor, Luuk Schreven, Frank Swiaczny, and Norbert Winnige for taking the time to answer my questions about their projects.

a. The key dates approach: Prussia and the United States

The key dates approach is undoubtedly the simplest. All that is required is to digitise the boundaries of the administrative units as they existed at certain dates and link these to any suitable socio-economic data. The choice of what dates to use will depend on the history of boundary changes in the country, the socio-economic data required, and the availability of good quality source maps to digitise from. The advantages of this approach are that it is quick and cheap. It is relatively easy to implement as from the historian's perspective it does not require research on changing boundaries, and from a computing perspective it does not require custom software and complex data models. A second advantage is that it is easily extensible as boundaries from other dates can be digitised when required. It could also be used as a first stage in creating more complex data models such as those discussed below. This is, therefore, a good approach where funding is limited or uncertain. It is also a relatively simple approach to manage as the project develops in obvious steps with clear deliverables at each stage.

Obviously, however, this approach has many disadvantages. Firstly, it is not a record of long-term boundary change but simply records snapshots at certain dates. Secondly, it does not necessarily provide accurate representations of the administrative units used to publish the data as often boundaries will change between the date the maps represent and the date the data represent. An inaccurate representation may be adequate for some purposes such as simple choropleth mapping, however, may lead to problems with more analytical applications. A third problem is that, where boundaries do not change they will be digitised from several different sources. This leads to redundancy and will also cause problems with sliver polygons when data are overlaid (Flowerdew, 1991).

A good example of the key dates approach is taken by Winnige (2000) (see also Winnige, 1999) as a first step to creating a historical atlas of Prussia covering the period from the early nineteenth century to 1945. So far they have digitised the boundaries of over 500 counties (Kreise) for 1818, 1850, 1871, 1882, 1907, 1918 and 1925 at a scale of 1:1,000,000. In addition to producing an atlas, it is hoped that the GIS will allow researchers to produce choropleth maps of their data, and will be used for teaching purposes. If further funding is found they hope to be able to create a fully time-variant GIS.

A second example of the key dates approach was taken by the Great American History Machine (Miller & Modell, 1988 and see also chapter 2 of this thesis). This did not incorporate boundary changes in any detail, only using a variety of snapshots as the country was increasingly sub-divided. The designers regarded this approach as

satisfactory as they were simply interested in mapping data for large numbers of polygons. They had neither the resources or the desire to invest large amounts of time investigating boundary changes (Miller, 1998).

b. Adding more sophistication: Belgium and the Netherlands

De Moor (2000) described a more sophisticated version of the key dates approach taken by the Quantitative Databank of Belgian Municipalities (see De Belder *et al* 1992; Vanhaute, 1994). This project is attempting to geo-reference quantitative data from the census and other sources for the area covered by modern day Belgium, a country not formed until 1830. The census data included covers the period 1796 to 1970 and their boundaries cover the period from 1800 to 1961. Researching the early boundaries required bringing together information from the Dutch and French Archives in addition to records held in Belgium. The primary statistical reporting unit in Belgium was the municipality of which there were approximately 2,500 for most of the period. The reason for stopping in 1970 is that at this time the system was rationalised reducing the number of municipalities such that by 1977 there were only 589.

The project started in 1990 and was thus the computing facilities used were limited to Atlas Mapmaker on a 486 PC with 32Mb of RAM. To digitise boundary changes they took a commercially purchased digital map of Belgium's 2,600 towns and villages. This was sub-divided into the nine Belgian provinces with each being stored in a separate file. Every time a boundary change was recorded a new province file was created with the updated boundaries. The core of the system is a concordance table that stores the name of the file that represents each province at each date. If a map of Belgium is required for a certain date, therefore, this is created by giving this date to the concordance file which returns which file represents each province at each date. Linking the province files together produces a map of the whole of Belgium.

This solution has several advantages over a simple key dates approach. Unlike a pure key dates approach it is a complete record of boundary changes over the period, resulting in a spin-off from the project being a three-volume book on the territorial divisions of Belgium (Vrielinck, 2000). It also has the advantage of limiting the degree of redundancy by focusing its organisation at province-level rather than nationally. This means that the entire system only occupies 50Mb of disk space. Careful structuring of the attribute data (see Vanhaute, 1994) means that it is possible to integrate information on statistical change with information on attribute change. There are, however, some disadvantages: firstly, the system does incorporate considerable amounts of redundancy in storing multiple representations of boundaries that do not change. A second disadvantage is that all attribute data must be stored in

the form required by the project thus removing them from the form of the original source. The project has, however, made impressive progress with limited resources. Currently, there are plans to convert the spatial database to ArcView format.

A project that moves more towards an integrated temporal structure is the Dutch NLKAART project described by Schreven (2000) (see also Boonstra, 1990 and 1994). The history of this project has many similarities to the Belgian Quantitative Databank project in that it pre-dated the widespread availability of desktop GIS software and had to develop solutions without major GIS expertise. The project started in 1984 and was originally based on the use of SAS/Graph, software primarily designed for statistical visualisation.

The project focuses on Dutch municipalities from 1811 to 1994 which declined in number from 1,227 in 1830 to 600 in 1994. There were also numerous changes in the boundaries of municipalities, and to the shape of the Netherlands. The base map used by the project was a digital map of municipalities in 1980 purchased from the Dutch Statistical Bureau (CBS). Boundary changes were researched from the CBS and from a list of municipal boundary changes published by Beekink & van Cruyningen (1995). Information from this was combined with a variety of historical maps published at intervals of between 20 and 40 years from 1795 onwards.

The structure of the spatial database is described by Boonstra (1994) using the hypothetical example of a country called Simpleland. It is shown in table 4.1. The application consists of two types of files: concordance files store information about the names and dates of each place with a new entry for the place every time its coordinates change. The coordinate files store the coordinates pairs needed to describe each place between each change. Tables 1a and b show a simplified hypothetical example of this based on four places: Assen, Breda, Cuijk and Delft. In 1880 Delft expands to completely engulf Breda and also take a part of Cuijk while Assen remained unaffected. In 1930 a further change occurred with Assen being completely engulfed by Delft. The concordance and coordinate files can be linked using the ID and data can be added to allow choropleth maps to be drawn by joining by place names.

Name	Dates	ID
Assen	1830-1930	A1
Breda	1830-1880	B1
Cuijk	1830-1880	C1
Cuijk	1880-1994	C2
Delft	1830-1880	D1
Delft	1880-1930	D2
Delft	1930-1994	D3

a. Concordance file

ID	Co-ordinates
A1	0,6 4,6 4,9 0,9
B1	0,3 4,3 4,6 0,6
C1	4,3 8,3 8,9 4,9
C2	4,6 8,3 8,9 4,9
D1	0,0 8,0, 8,3, 3,0
D2	0,0 8,0, 8,3 4,6 0,6
D3	0,0 8,0 8,3 4,6 4,9 0,9

b. Coordinate file

Table 4.1: Sample (a) concordance and (b) coordinate files as used by NLKAART for four simplified example municipalities (Source: Boonstra, 1994: p. 159).

This is still some way removed from Langran's idea of a space-time composite. The most significant limitation of this structure is the lack of spatial topology. In this structure, the coordinate pairs making up each polygon's boundaries are stored for that polygon and thus the coordinates for any boundary between two polygons will be stored twice. The concordance table allows the user to specify a date and will select the appropriate polygons.

The advantages of the structure is that it is far more integrated than the Belgian approach thus reducing the storage requirement for the entire system to only 1Mb. The use of SAS/Graph, however, was seen as too limiting for a project on this scale. As a result, in 1998 the data were moved to MapInfo. MapInfo's data model would not support the structure of coordinate and concordance files described above so, as a result of this and the ability of modern computers to handle far larger volumes of data than previously possible, the project moved from a highly integrated structure to a structure that stores every possible arrangement of its boundaries in a total of 280 separate snapshot files. This introduces massive redundancy as a change to a single

boundary means that every boundary other boundary in the entire country is duplicated. In spite of this the whole file structure only occupies 100Mb. The present structure, however, has two key advantages over a simple key dates approach: firstly it is a comprehensive record of the changing administrative geography. Secondly, as it is derived from an integrated structure, a boundary that does not change will have exactly the same representation in every snapshot.

c. Space-time composites: Sweden and the Palatinate

The two projects described above for Belgium and the Netherlands used hybrid data models devised in the main because when the project started there was a lack of easily available GIS software and GIS expertise. The next two projects, based in Sweden and in the Palatinate and Mannheim areas of Germany, use something that approaches Langran's idea of a space-time composite. This is based on the idea that the administrative units from one date can be created by aggregating polygons. The bottom level polygons from which all units can be aggregated is referred to as the Least Common Geometry (LCG) (Swiaczny & Ott, 2000). Beyond this basic concept the systems and projects differ significantly. In Sweden the National Topographical Database, described by Kristiansson (2000a), was a well funded project based in the Swedish Central Bureau of Statistics (CBS). It was completed in 1994. The Palatinate system, described by Swiaczny (2000) (see also Ott and Swiaczny, 2001; Swiaczny and Ott, 1999), has been developed to investigate the development of the Jewish population in the Palatinate region through the nineteenth and twentieth centuries. At present, however, the system design has been proposed but it has not yet been built. At a more detailed level, the Swedish system uses the parish as its LCG as these were very stable units over time, while the Palatinate system proposes to use polygons defined as a result of boundary changes.

The Swedish system covers the period from 1620 to 1990 and aims to be a complete record in both text and graphical form of the changing boundaries of parishes, districts, municipalities and counties, a total of around 9,000 units. The boundaries can also be linked to external attribute data. At the core of the system is a modern 1:250,000 digital map of parish boundaries purchased from the National Land Survey. Information on boundary changes was added to this using printed maps of parish boundaries dating back to the nineteenth century, information on changes to historical parish boundaries, and information on the relationship between parishes and other administrative units taken. This was researched using the National Archive, Regional Archives, and other sources.

Parish	Code	Province	Dates	County	Dates
Bromma	018027	Uppsala	1654-1714	Sollentuna	-1906
Bromma	018027	Stockholm	1715-1915	Sollentuna	-1906

Table 4.2: Database structure of the Swedish National Topographical Database
(Source: Kristiansson, 2000b).

Information on the relationship between the parish and higher level units was entered into a relational database management system using the structure shown in table 4.2. Each parish has a special code attached to it based on a code assigned by the CBS for planning and statistical purposes but with an extra three digits added to describe its historical development. Small changes in parish boundaries were not stored graphically but simply described in the accompanying text. Larger changes to parishes were stored by creating new objects in the base layer. This gives enough information to recreate the complete administrative hierarchy at any date as is shown in figure 4.1.

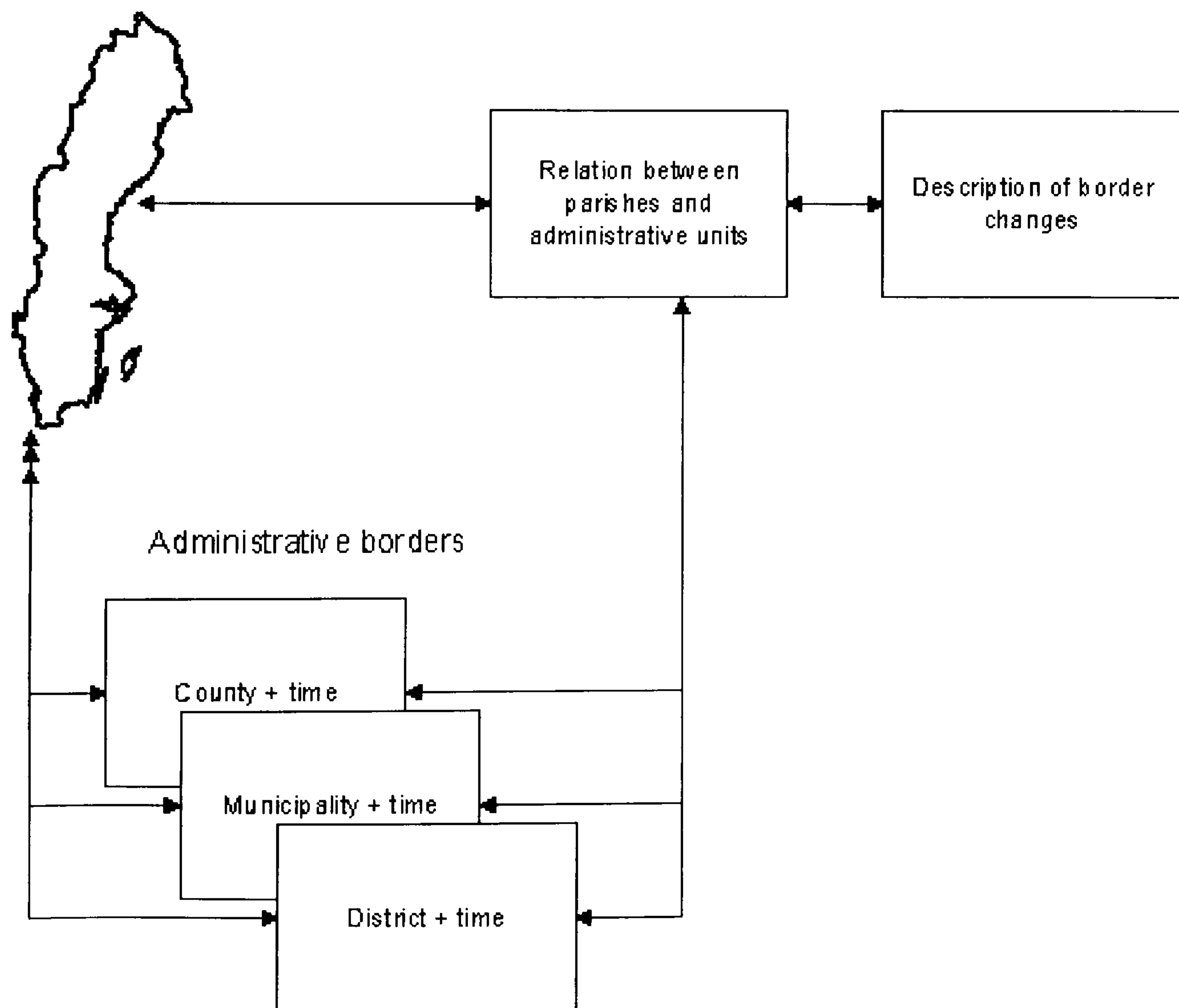


Figure 4.1: Overview of the architecture used by the Swedish system (Source: Kristiansson, 2000b).

The system is held within custom-written software in C++ but based on the MapInfo file format. Users access data by using a time bar at the bottom the screen to chose the appropriate year. Pointing and clicking on a map of Sweden allows the user to work through the levels of the administrative hierarchy for that year. Textual descriptions of boundary changes are also given and the spatial data can be linked to attribute data through the modified CBS code.

Ott and Swiaczny (2001) propose to build the Palatinate system by using the areas created by the impact of boundary changes as their LCG. This can be achieved as follows: firstly, an attribute database is created holding the details of each boundary change. This database holds an ID number for the administrative unit, the dates at which the unit was formed and abolished, and details the date and extent of each boundary change including the area affected as this can be used as a checksum when the spatial data are entered. Next a layer is digitised that holds the administrative units for a base date. This forms the base layer. To enter a boundary change a whole new layer is created showing the situation after the change. This thus duplicates all the information on the base layer with the exception of the boundaries affected by changes. This new layer and the base layer are then overlaid, producing an updated base layer that contains all the original units plus polygons formed as a result of the boundary changes. These new polygons are assigned ID numbers and entries are made in the database that relate these back to the unit that was formed as a result of the boundary changes. At this stage the areas created in the spatial data can be compared with the areas in the boundary change database. This process is repeated with the updated base layer to add the next change. To re-create a layer at a certain date the ID numbers of the administrative units in existence at that date are extracted from the database along with the ID numbers of the LCG polygons that make them up at that date.

The advantages of building a temporal GIS in this way is that it has both a spatial and temporal topological structure. This means that in addition to the spatial querying that conventional GIS data models allow, it is also able to answer temporal queries such as “what administrative unit did this polygon belong to at this date?” and “how did this unit change over time?”. The choice as to whether to use a low-level administrative unit or the polygons created by boundary changes as the LCG will depend largely on the availability of a suitable low-level administrative unit. To be suitable this unit must have very stable boundaries. Another advantage of this approach is that it minimises redundancy, and if the spatial data need to be updated this can be achieved by only changing a single layer rather than multiple features. The disadvantages are that this approach requires considerably more GIS expertise than the earlier approaches. It will also require some software to be custom written either using

the GIS software's macro language or an external language such as C++ in the case of the Swedish project. Once written this software will need to be maintained and updated.

4.3: The units included in the system for England and Wales

Chapter 3 discussed the complexities of the system of local government that was set up in the late 1830s. This can be summarised as follows: Starting in the late 1830s a system of approximately 635 Poor Law Unions and Registration Districts was set up. The two types of unit were very similar but there were some differences between them; both types of unit were formed as aggregations of parishes but did not aggregate exactly into the existing county structure so had their own Union and Registration Counties. Starting in the 1870s, but especially as a result of the Local Government Acts of 1888 and 1894, approximately 1,500 Local Government Districts were formed. These were also aggregations of parishes and were usually formed by designating urban parishes as County or Municipal Boroughs, or Urban Districts, and designating the remainder of each Poor Law Union as a Rural District. There were exceptions to this, particularly near county boundaries, as Local Government Districts had to aggregate up into the newly created Administrative Counties (Hasluck, 1936). Around the same time the parish system was also reformed so as to eliminate many of the medieval anomalies that existed and create a more efficient system of local government areas (Lipman, 1949). Local Government Districts largely replaced the functions of both Unions and Registration Districts in the 1910s although this system did not entirely die out until abolished by the Atlee government after the Second World War (Keith-Lucas & Richards, 1978). Local Government Districts were abolished as a result of the 1972 Local Government Act (Hampton, 1991). The boundaries of all these units were subject to a constant series of boundary changes that ranged from minor alterations to entire areas being abolished or created.

As described in chapter three, there were a wide variety of other local government units in existence particularly in the nineteenth century. The choice was taken, however, to include only these three main types of unit: Poor Law Unions and Registration Districts (which, because of their similarities, can be viewed as one type although the differences between them have been included into the GIS), Local Government Districts, and parishes. Unions/Registration Districts and later Local Government Districts were chosen because they were the major reporting units for publishing demographic data. Parishes were seen as important for two reasons: firstly, although the data published for parishes is largely limited to simple population counts, the greatly enhanced spatial detail in these, compared to other areas, was seen as very important for a variety of analytical purposes. This will be discussed further in later

chapters. Secondly, parishes form the building blocks of almost all other types of local government unit, for example Petty Sessional Divisions, so, as long as the parishes making up the higher level unit are known, using the GIS to create these units is a relatively simple task. The list of units that the 1871 census published population data for is given in appendix 3.1 and gives some idea of the scope and variety of these other units.

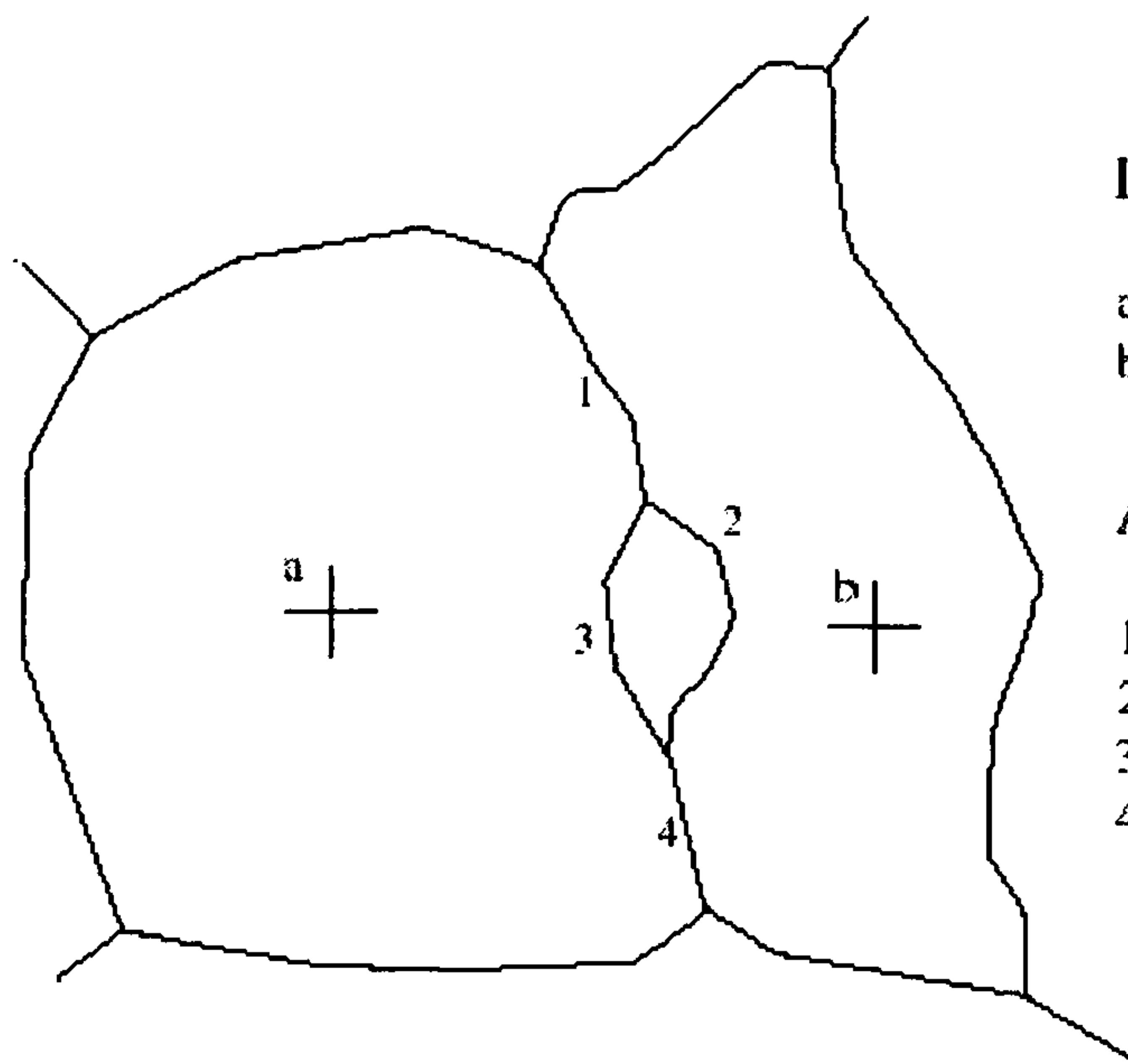
4.4: The Architecture of the GBHGIS

The approach adopted for the GBHGIS is different to those described above. It is based on the concept of date-stamping (Vrana, 1990), whereby all the spatial features for all dates are stored in a single “master coverage” but each feature has a start-date and an end-date attached to it as attributes in such a way that if a date is specified only the features in existence at that date would be selected. This was felt to be a more transparent system than a structure based on coordinate and concordance files as it more intuitively represents the real world situation. The aim, therefore, was to hold all the boundaries for a certain type of unit in a master coverage in such a way that only those in existence at any given date would be extracted. This meant being able to deal with the four main types of boundary changes discussed in chapter 3:

1. **Transfers:** Where part of a unit is transferred from one unit to another.
2. **Name changes:** Where a unit changes name but its boundaries are unaffected.
3. **Mergers:** Where a unit is abolished and its component parts are allocated to another unit or units.
4. **Divisions:** Where a new unit is created from parts of an existing unit or units.

Although some changes were more complicated than this, for example, an existing area can be abolished and a new area with new boundaries created at the same time, all types of change can be built up from these four elements.

One option would have been to write bespoke temporal GIS software from scratch to allow the explicit handling of these types of changes. It was felt, however, that this would be a route that was fraught with potential difficulties and would lead to many challenges that would simply be re-inventing the wheel. Other dangers of this route are illustrated by the Great American History Machine, where bespoke software was written specifically for the project. Their aim was to include all the US census data and its associated boundaries in a single software package. Unfortunately, this was never properly published, not because of any technical difficulties, but largely as a result of key personnel moving on.



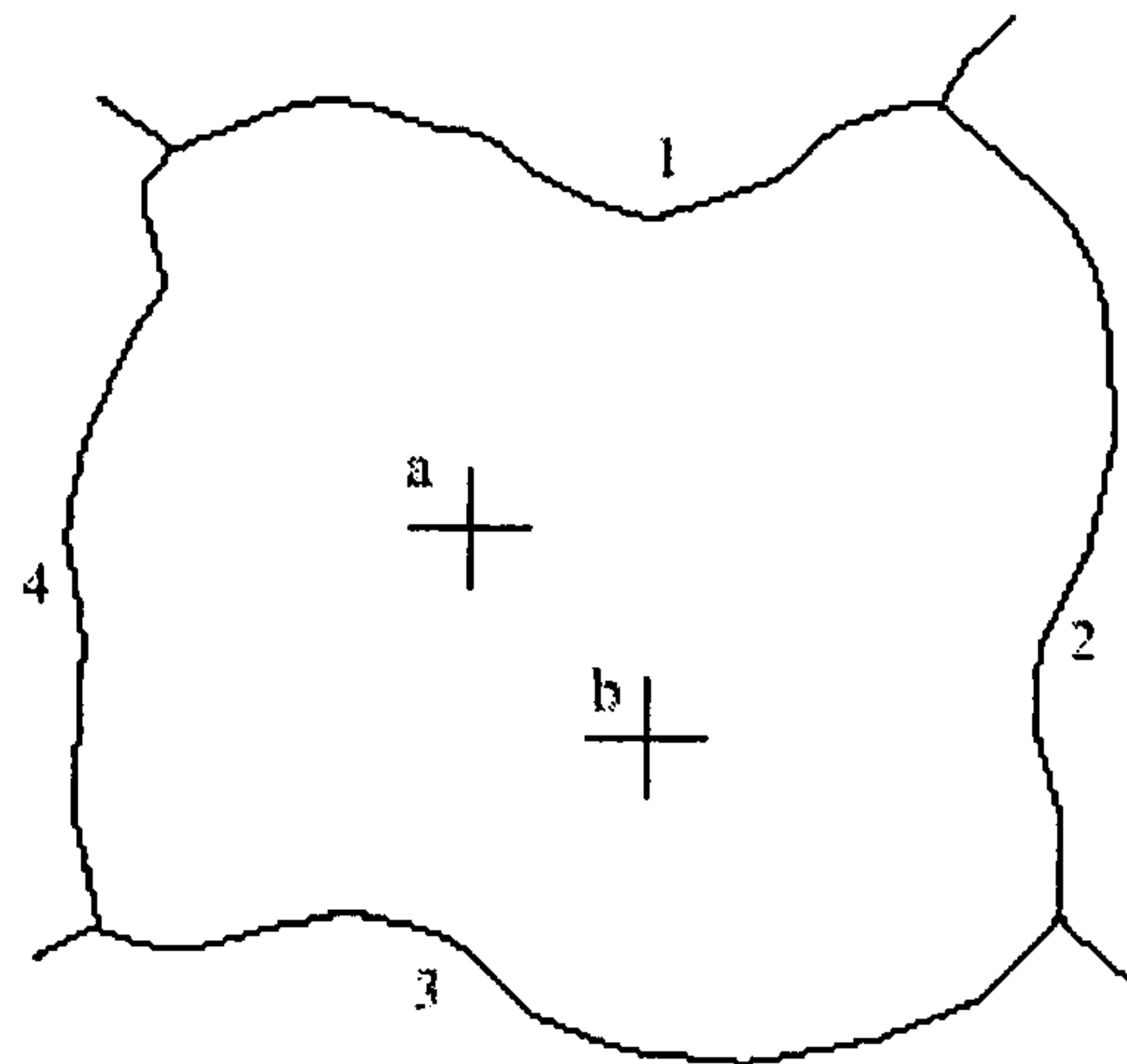
Label Point Name and Date-Stamped:

	Name	Start Date	End Date
a	Anarea	0/0/0000	0/0/5000
b	Elsewhere	0/0/0000	0/0/5000

Arc Date-Stamped:

	Start Date	End Date
1	0/0/0000	0/0/5000
2	0/0/0000	1/9/1894
3	1/9/1894	0/0/5000
4	0/0/0000	0/0/5000

a. Transfer: Part of 'Anarea' is transferred to 'Elsewhere' on the 1st Sept. 1894



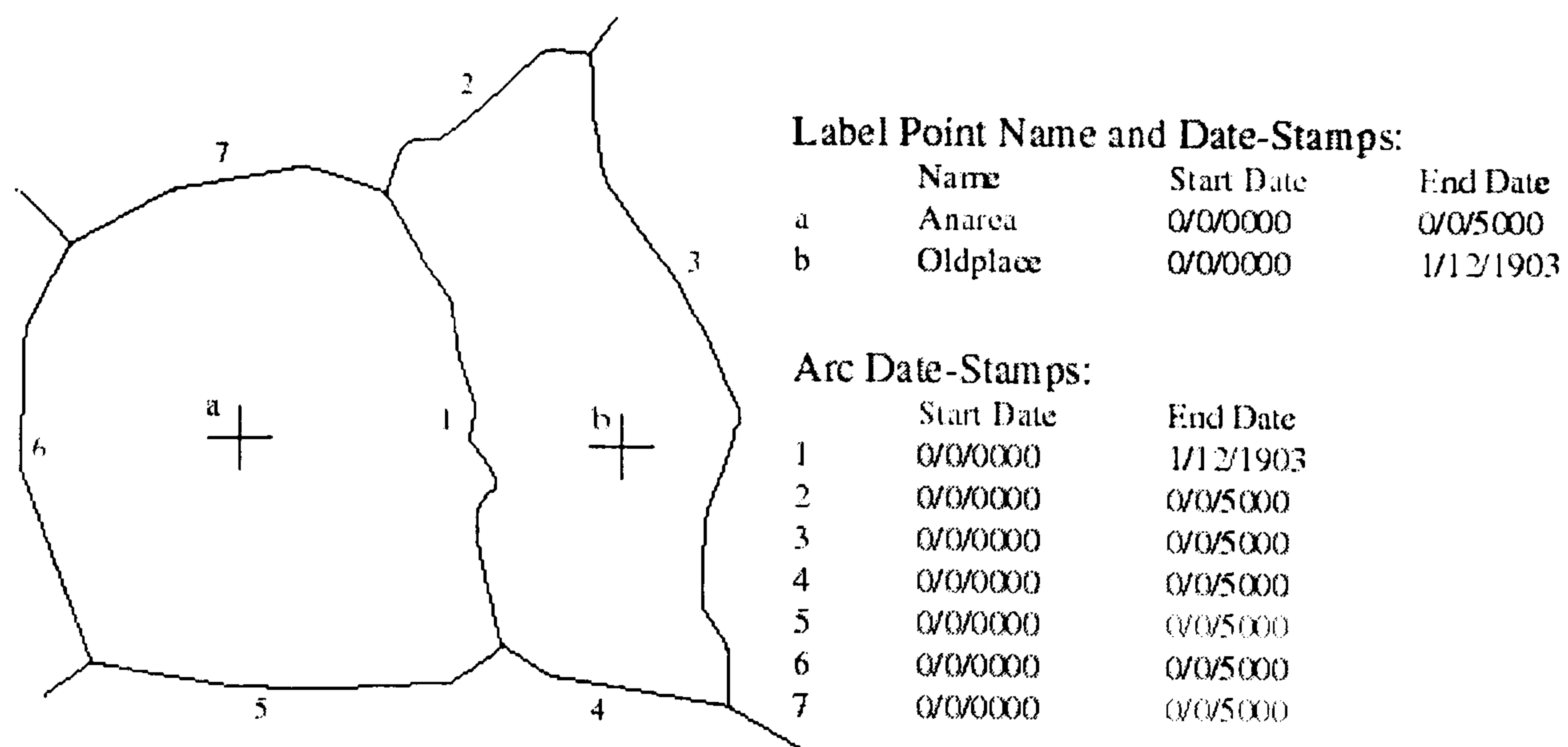
Label Point Name and Date-Stamped:

	Name	Start Date	End Date
a	Oldname	0/0/0000	10/4/1932
b	Newname	10/4/1932	0/0/5000

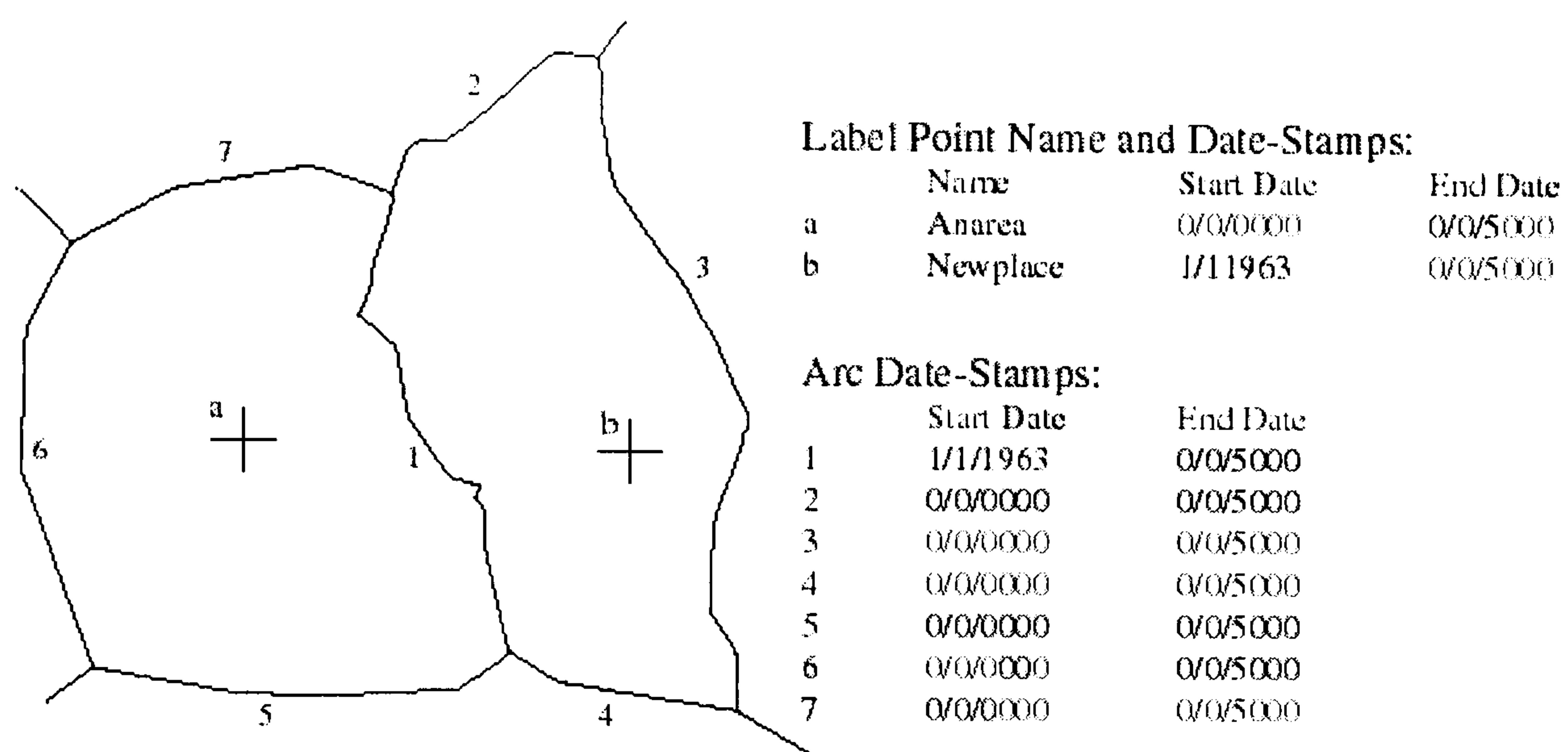
Arc Date-Stamped:

	Start Date	End Date
1	0/0/0000	0/0/5000
2	0/0/0000	0/0/5000
3	0/0/0000	0/0/5000
4	0/0/0000	0/0/5000

b. Name Change: 'Oldname' is renamed 'Newname' on the 10th April 1932



c. Merger: 'Oldplace' is abolished and entirely merged into 'Anarea' on the 1st Dec. 1903



d. Division: 'Newplace' is created entirely from 'Anarea' on the 1st Jan. 1963

Figure 4.2: Date-stamps used to represent the four main types of changes. Label points are represented by crosses identified by letters, arcs are identified by numbers. Features in existence when a type of unit was formed are date-stamped 0/0/0000, those in existence when the type of unit was abolished are date-stamped 0/0/5000.

It was, therefore, felt that the best option was to use an existing GIS software package with bespoke software being written to incorporate handling changes over time. ArcInfo was the package chosen, for the following reasons: it is a well established GIS software package that at the time had been a market leader for many years. Being workstation-based it is powerful and easily able to handle large volumes of data. The data structures used by ArcInfo are far more transparent than those used by many other packages and this allows features to be manipulated at a low level, a factor that was important in incorporating time into the system. This is discussed in more detail below. ArcInfo has a flexible macro language, Arc Macro Language

(AML), that allows custom software to be written within the ArcInfo environment to provide additional functionality with a point-and-click user interface (ESRI, 1993). Finally, ArcInfo provides reasonably comprehensive tools for integrating its spatial data with attribute data held in an external database management system such as Oracle.

Like most GIS software packages, ArcInfo stores its spatial data for areas as polygons. An ArcInfo coverage may consist of arcs (to represent line data), label points (to represent point data), or points and lines with topology created to form polygons (to represent area data). Both arcs and label points may have attributes attached to them that store data about the feature (see Peuquet & Marble (1990) for further details of ArcInfo's data structures). One of the unusual features of ArcInfo, however, is that a coverage can consist of label points and arcs with no topology and thus no polygons. This feature is crucial to the way that temporally referenced spatial data can be stored as it allows us to store the temporal data, in the form of date-stamps, about a unit (attached to the label point) separately from the temporal data about its boundaries (attached to the arcs). The date-stamping for the four types of changes listed above can then be incorporated as shown in figure 4.2 and described below:

1. **Transfers:** Two arcs (or sets of arcs) are used in the master coverage, one representing the pre-change boundary and one the post-change boundary. The pre-change boundary has an end-date set to the date of the change, the post-change boundary has its start-date set to the date of the change. Label points are not affected. Figure 4.2a gives the example of a central area being transferred from 'Anarea' to 'Elsewhere' on the 1st September 1894. Prior to the change the boundary between the two areas is arcs 1, 2 and 4, after the change arc 2 is replaced with arc 3 while all other arcs, and the label points remain the same.
2. **Name changes:** Two label points are used in the master coverage, one with the name of the pre-change unit and one with the name of the post-change unit. Apart from the fact that label points are used rather than arcs, these are handled in the same way as transfers. Arcs are unaffected. Figure 4.2b gives the example of 'Oldname' being renamed 'Newname' on the 10th April 1932.
3. **Mergers:** These affect both label points and arcs. As part of a merger a unit is abolished; this is represented by a label point in the master coverage being given an end-date of the date of the change. By definition boundaries will also be affected. In the simplest form of merger the whole unit becomes part of an adjoining unit, in this case the arc representing the boundary between these two units needs an end-date of the date of the change. In more complicated mergers several units will gain territory from the area that is being abolished but the

principle remains the same; several arcs are given end-date of the date of the change. A merger then has both label points and arcs being date-stamped with end-dates but no features are given start-dates. In figure 4.2c 'Oldplace' is abolished and entirely merged into 'Anarea' on the 1st December 1903. Only the label point representing 'Oldplace' and arc 1 use date attributes to encode this change.

4. **Divisions:** These are similar to mergers in that both label points and arcs are affected, however, the features are given start-dates as a new area and new boundaries are being created. No features are given end-dates. Figure 4.2d gives an example of this and is the opposite to 4.2c: the label point representing 'Newplace' (point 'b') and arc 1 are the only features affected.

Where more complicated changes occur these can be represented by combining more than one of the operations above. For example, if an area is abolished and a new area with overlapping but different boundaries is created at the same time this would be represented by combining the features of a merger, a division, and perhaps transfers as well.

By manipulating arcs and label points in this way it becomes possible to select only the arcs and label points in existence at a single date and use these to create polygons that accurately represent the administrative units for that date.

b. Allowing selection by type of unit and part of the country

There are, however, other methods of selecting features in addition to date that were also seen as being important to include. These were:

1. By major type of unit.
2. By part of the country.
3. To include the differences between Poor Law Unions and Registration Districts.

For ease of data management the decision was taken that the three major types of unit would be stored in separate ArcInfo master coverages. This involves some duplication of data but greatly simplified the construction process and also has the advantage of speeding up the extraction of data, particularly for Unions/Registration Districts and Local Government Districts, by reducing the volume of data that features are to be extracted for.

In many ways the method for allowing selection by area was similar to the method for handling the temporal dimension. It was felt that a user should be able to select features down to county-level. Attempting to allow district-level selection would have been difficult and if areas of less than a county are required this can be achieved by *ad*

hoc modification of extracted coverages. In each coverage both arcs and label points were given locational data, in the form of county names, in addition to the temporal information. In the case of label points this was simply a matter of including a “county” field as part of the attribute data. Arcs were slightly more complicated because when an arc forms a county boundary it needs to be able to be included in both of the counties whose boundaries it forms. This was handled by having two county fields; “county1” and “county2” both of which are checked to see if the arc was in the county to be selected. It was felt desirable to allow users to be able to extract coverages by divisions (the predecessors of standard regions). This was facilitated by including a look-up table which gave the division each county belonged to, so that if a user has specified the Eastern division, for example, this would be known to be the counties of Norfolk, Suffolk, and Essex.

The minor differences between Unions and Registration Districts were again handled using attributes. Two fields were added to the attribute tables of both the arcs and label points for the Union/Registration District coverage. One was used to flag whether the unit was a Union, and the other whether it was a Registration District. In this way only the appropriate feature can be selected. A simplified example from the point and arc attribute tables of the Union/Registration District-level system is shown in table 4.3. It shows some of the feature attributes in the county of Durham. Of the four administrative units, all were both Unions and Registration Districts. Three were in existence throughout the period, while Hartlepool was formed in 1859. All of the arcs shown are also both Union and Registration District boundaries. The last one is also part of the county boundary between Durham and Cumberland. The full structure of the feature attribute tables is described in appendix 4.1.

Name	County	Pl_union	Reg_dist	Start Date	End Date
Stockton	Durham	Y	Y	0/0/0000	0/0/5000
Hartlepool	Durham	Y	Y	25/2/1859	0/0/5000
Teesdale	Durham	Y	Y	0/0/0000	0/0/5000
Durham	Durham	Y	Y	0/0/0000	0/0/5000

a. Label Point Attributes

County1	County2	Un_cnty	Pl_union	Reg_dist	Start Date	End Date
Durham			Y	Y	0/0/0000	0/0/5000
Durham			Y	Y	25/2/1859	0/0/5000
Durham			Y	Y	0/0/0000	0/0/5000
Durham	Cumberland	Y	Y	Y	0/0/0000	0/0/5000

b. Arc Attribute Attributes

Table 4.3: Simplified example of the point and arc attribute tables from the Union/Registration District-level system. (“Un_cnty” flags whether the arc is a county boundary, “pl_union” flags whether a feature represents a Poor Law Union, “Reg_dist” flags whether a feature represents a Registration District).

The attributes for the Local Government District system were very similar to those for the Union/Registration Districts. Obviously those attributes specific to Unions/Registration Districts were not included and one new attribute had to be added to the label point attribute table. This concerns the type of area a label point represents: County, Municipal, or Metropolitan Boroughs, or Urban or Rural District. These were classed as “CB”, “MB”, “LB” (for London rather than Metropolitan Borough), “UD”, and “RD” respectively. Another type of change also had to be handled for Local Government Districts, the status change whereby a unit changes from one type to another, for example a Municipal Borough becoming a County Borough. This is dealt with in an almost identical manner to name changes, except that the type field rather than the name field was affected.

Other attributes had to be held for both units to allow the spatial data from ArcInfo to be linked to attribute data in Oracle. These will be discussed in more detail later, for now it is only worth noting that place-names and other identifiers were also stored against each label point. The parish coverage had to be dealt with in a slightly different manner from the other two coverages to cope with the additional complexity inherent in that system. This will also be discussed in more detail below.

c. Extracting a coverage

The attributes detailed above give sufficient data to allow two coverages, one containing Poor Law Unions or Registration Districts, the other containing Local Government Districts to be created holding all the relevant data to allow a coverage for a day, type of unit, and part of the country to be extracted. To allow this to be done straightforwardly and consistently a program was written in AML that provides a point-and-click user interface to allow a user to specify the relevant parameters and then extracts the relevant label points and arcs from the two master coverages.

Full details of the algorithm used by the AML script is given in appendix 4.2. Simply put, the AML script does the following: firstly, through a series of menus the user is prompted for the type of unit, a date (accurate to the day), and also the method for selecting the area of interest for which there are three options: the whole of England and Wales, by division, or by county. If not selecting the whole country, the user is offered a list of these and can click on the ones required. Once this has been done the program runs. It first decides which master coverage to use, it then selects all the features by area (i.e. the counties or divisions that the user has specified) and copies these to a temporary coverage on which all the remaining work is done. If the user is extracting Unions, then any features that only represent Registration Districts are deleted. Similarly, if the user is extracting Registration Districts then any features solely representing Unions will be deleted. Next all the features that did not exist at the specified date are deleted. The arcs and label points that remain should be purely those that represent the coverage specified by the user. The user is shown the coverage and enters a filename to save it to. Once this has been done the coverage is tidied up by removing any "pseudo-nodes". These are nodes that join two, and only two, arcs a phenomenon caused by features being deleted. The coverage is saved and polygon topology is created using standard ArcInfo functionality. Assuming there are no errors in the master coverage the extracted coverage should have a single label point for each polygon and there should be no "dangling nodes", effectively cul-de-sac boundaries that connect to nothing and can only exist by mistake. Again, standard ArcInfo functionality is used to report on whether these two criteria are met. This leaves a polygon coverage for the type of unit, part of the country, and date that the user specified. For Unions/Registration District or Local Government District coverages this process takes approximately two minutes on a Sun Sparc Station 20 with 133MHz processors.

d. Building the parish-level system

The parish-level system was more complicated than the others for two reasons: the large increase in the volume of the data involved, as there are approximately ten times as many parishes as Local Government Districts and a similar increase in the number of changes, and the relationship between parishes and the districts and counties above them is more complicated than for the other types of unit. There are two aspects to this: firstly, parishes have to be extractable by either the Union/Registration District hierarchy, or by the Local Government District hierarchy. This means that the AML script has to be able to extract either by Union/Registration County, or by Administrative County. Secondly, a new type of boundary change has to be added; the “move”, whereby a unit moves from one district to another without its boundaries being changed in any way.

The basic architecture of the system remained the same as for the other two main types of units; the arcs and label points representing each parish were stored in a single master coverage with date-stamped features to allow the types of boundary changes discussed above to be incorporated. To try to cope with the extra problems of parishes a slightly different algorithm for the AML script was developed that could handle the extra data, the need to extract by either type of county, and the ability to cope with the “move”. To do this an integrated structure was needed whereby the parishes and the districts would work in tandem. This involved making the assumption that a parish-level boundary change would be implemented at exactly the same date as the change to a district. This has been found to be not completely true as changes to the districts are usually published as occurring slightly after the change to the parish. The difference between the two dates is almost always less than a year and, where there is a difference the date of the change to the higher level area has been taken as the date of the change. This is because it was felt that as data were published for the districts far more frequently than for parishes then the temporal accuracy of these was more important than the temporal accuracy of the parishes. Where this has occurred notes have been made to that effect in the system’s metadata.

The modified algorithm works as follows: the user specifies the parameters of type of unit, area (by either type of county), and date in the usual way. The program uses the relevant higher level coverage and extracts the boundaries for the Unions/Registration Districts or Local Government Districts above the parish in the usual way. This is then used to give a bounding box on the parish-level coverage and only parishes falling within this box are extracted using an overlay operation. Only the label points and arcs that were in existence for parishes at that date are then extracted and the final stage is an overlay operation between the parish-level coverage and the

higher level coverage that effectively stamps the higher-level geography onto the parishes.

4.5: Linking to attribute data

a. The database and its relationship to the GIS

ArcInfo comes with its own database management system (DBMS), Info which can store attribute information. All the attributes directly linked to spatial features in the GIS, such as temporal and geographical (in terms of counties and names) data are stored within Info where they are tightly coupled to the spatial features. One possible option would have been to store all attribute data within Info where it would be most closely linked to the GIS. This was felt to be impractical for a variety of reasons: firstly, the attribute database is a significant resource in its own right and tying it too closely to the GIS was not felt to be appropriate. Secondly, Info is not a particularly good DBMS and more specialised relational DBMS (RDBMS) software was felt to be more appropriate as it provides more sophisticated tools for basic handling of relational data in a non-spatial way. Thirdly, ArcInfo includes a Database Integrator module that allows linking of spatial data from ArcInfo to attribute data stored in an external RDBMS (ESRI, 1991). For these reasons it was felt that storing the attribute database in Oracle, a well developed RDBMS software package, and loose coupling this to the GIS through ArcInfo's Database Integrator software was the best way to proceed.

It was felt that the process of linking from the spatial data to the attribute data should be both flexible and as transparent as possible to reduce the risk of data being mis-allocated. The system had to be designed within the limitations of ArcInfo's Database Integrator. This module only provides basic functionality for linking between ArcInfo and an external RDBMS. The core of this is the ability to copy tables between the two packages and the ability to execute Structured Query Language (SQL, the language used by Oracle and other RDBMSes to query and manipulate their data) commands from ArcInfo including those embedded within AML scripts. More advanced functionality is available but generally this has not been used because of its limitations, particularly in the form of poor performance. The extra complexities of parishes again meant that they needed to be dealt with in a slightly different manner to the other two main types of unit. For this reason they will be discussed in more detail below.

The construction of the statistical database itself is not of direct relevance to this thesis. It has been built up over many years by manual data entry by clerical assistants at Queen Mary and Westfield College (QMW), using a scanner and Optical Character Recognition (OCR) system at Queen's University, Belfast, and also by scavenging

data from other researchers. Efforts have been taken when transcribing the data to preserve the integrity of the original source as far as possible. For convenience tables collected in the same way over many years have been amalgamated into a single database table. A wide variety of data are included but the main sources are the printed census reports from 1801 to 1971, the Registrar General's Reports and Supplements, the printed returns of the Poor Law Board, and the Local Government Board's Reports. The database is therefore concerned with a wide spectrum of human activity, the main subject areas represented are demography, health and mortality, and measures of economic distress. There are currently over 130 tables in the database and literally millions of individual data values. The construction of it is an ongoing process so these numbers continue to grow.

b. Linking district-level data to the GIS

The basic structure followed by most tables is as follows. Most rows of data have alpha (textual) data describing location through a place-name, and numeric data about that place. The main challenge in linking to the GIS was to use the place-name data to link to the attribute information attached to polygon label points in extracted coverages from the GIS using a single unique field. It was decided that using the name of the Unions, Registration Districts or Local Government Districts was the best way to do this as this offers the most transparent and flexible system. For Unions and Registration Districts this is relatively simple. The single place-name field for these unit's names is nearly always unique and thus could be linked directly to the place-name field on the polygon label point. There are two problems with this: firstly, there are eight districts whose names are not unique, and secondly, the spellings of place-names varies between different sources and dates. To solve these problems it was decided that a place-name gazetteer needed to be built that would match any spelling of the place-name given in the database, to a single unique spelling of the place-name that would match directly to the spelling attached to the polygon label point.

To enable this an additional field had to be first added to the label point attribute table on the master coverage. This field contains a single unique spelling of the unit's place-name. In most cases this is exactly the same as the place-name field, however, in the eight non-unique cases the county had to be added in brackets to give a unique name. These spellings became: "Richmond (Yorks)" and "Richmond (Surrey)", "Whitchurch (Salop)", and "Whitchurch (Hants)", "Newport (Salop)" and "Newport (Mon)", and "Wellington (Somerset)" and "Wellington (Salop)".

GIS_Name	County	D_Name	C_Name
Hartley Wintney	Hampshire	Hartley Wintney	Hampshire
Hartley Wintney	Hampshire	Hartley-Wintney	Hampshire
Hartley Wintney	Hampshire	Hartley Wintney	Southampton

Table: 4.4: Example from the Poor Law Union/Registration District gazetteer.

“Gis_Name” gives the standardised spelling that matches the “db_name” field in the point attribute table of the GIS. “County” is the standardised county name, “d_name” and “c_name” hold the alternate spellings and combinations of the district and county names respectively.

The gazetteer, therefore, had to be able to match from a variety of possible combinations of place-name and county to this single unique spelling. This was done as follows: first, a single version of all the actual combinations of Union/Registration District names and counties found in the database were read into a database table. These were then copied into a field called “gis_name” that was to hold the unique spelling matching to the GIS. This field was then compared to the unique spellings held in the GIS and where there was not a direct match the record was updated. The resulting updates were all scripted into a large SQL command file to allow more to be added and any mistakes to be corrected in a relatively straightforward manner. In addition, a standardised spelling of the county field was also added using a similar but, due to the smaller numbers involved simpler, system. This was not necessary for linking to the GIS but allows greater flexibility in handling data in the database. An example from the gazetteer is shown in table 4.4.

Linking from the GIS to a column of data in the database was then achieved using an AML script. The basic steps are outlined in table 4.5. A user wants to link a single column of census data from 1891 from a database table that contains a variety of census data for different census years. This table is represented in table 4.5a. The gazetteer is represented in table 4.5b. The user is prompted for a coverage to link the data to. In this example this means a coverage for 1891 whose polygon attribute table (PAT) is represented in table 4.5c. The user is also prompted for the name of the table in the database, and its column names for the column holding district name (“district” in 4.5a), the column holding county name (“county” in 4.5a), and the column or formula holding the data to be linked (“pop” in 4.5a). The user can also enter an SQL “where clause” that allows only a subset of the data within a table to be used. In this example this would be “year=1891”. An AML script then assembles this information into an SQL query which is passed to the database where it creates a “view”. A view appears to be a table in its own right but can hold data created by a relational join

(where two tables appear to be joined together) and may only hold a limited number of rows and columns. The view created will hold the required subset of data from the table with the place names standardised using the gazetteer. The user does not need to know about the gazetteer as this part is performed automatically by the AML script. An example of a view is shown in table 4.5d. It has only three columns: the first has the standardised and unique spelling of the place-name from the “gis_name” field in the gazetteer. The second is the data that the user has selected from the attribute data, in this case the data from the “pop” column for 1891. The third always holds a single “X” in it for reasons that will be discussed below. Once the view has been created it is copied from Oracle to a temporary table in Info. This table is then joined to the polygon attribute table of the extracted coverage by a relational join on the “gis_name” field. This results in the PAT having the specified data joined to it as shown in table 4.5e. The coverage can then be used for mapping and analytic purposes.

There are three potential problems with the process: firstly data from the database may not match due to problems with the gazetteer, secondly, polygons on the coverage may not have data linked to them either due to gazetteer problems or because there is genuinely no data for them in which case, due to a software bug in ArcInfo, rather than being allocated a null-value they will wrongly be given a value of zero, and thirdly the same row of data may join to two polygons where an area is made up of two or more polygons.

District	County	Year	Pop	Male	Female
Llanelli	Carmarthen	1891	52,382	25,912	26,470
Llandovery	Carmarthen	1891	11,622	5,460	6,162
Llanelli	Carmarthen	1901	56,897	27,762	29,135
Llandovery	Carmarthen	1901	9,587	4,587	5,000

a. Database table holding census data for a variety of years (Oracle table).

Gis_name	County	D_name	C_name
Llanelly	Carmarthen	Llanelly	Carmarthen
Llanelly	Carmarthen	Llanelli	Carmarthen
Llandovery	Carmarthen	Llandovery	Carmarthen

b. Gazetteer entries (Oracle table).

Gis_name	County
Llanelly	Carmarthen
Llandovery	Carmarthen

c. PAT of coverage for 1891 (ArcInfo table).

Gis_name	Pop	Pop_X
Llanelly	52,382	X
Llandovery	11,622	X

d. View holding 1891 data with standardised names (Oracle view).

Gis_name	County	Pop	Pop_X
Llanelly	Carmarthen	52,382	X
Llandovery	Carmarthen	11,622	X

e. PAT with data added (ArcInfo table).

Table 4.5: Simplified example of joining attribute data to the appropriate polygon attribute table (PAT). An Oracle table contains a variety of columns of census data for different years (a). The user wants to map the “pop” data from 1891 using a coverage extracted from the GIS (c). The first stage to create a view (d) that holds the required columns of data for the required year with names standardised using the gazetteer (b). This is done using a relational join between “district” from the census table and “d_name” from the gazetteer. Once this has been done the view is copied to ArcInfo and joined to the PAT using a relational join on the “gis_name” column from the view and the PAT.

An AML script has been written that compares place-name data in the temporary table copied from the database to the place-names in the coverage. Where there is no match these can be listed and investigated further. Where there is no attribute data for a polygon the column with the “X” values is used. As null values default to zero there is no way of testing for this using numeric data, instead the column with the “X” values is used as where data has failed to match this alpha data column will contain

null values. Where this column is null the places can be listed and any problems resolved. If the polygon genuinely has no data then in all statistical operations, by using the “X” column, these polygons can be excluded. The third problem, where data has joined to more than one polygon, will lead to duplicated data. Where there is a risk of this an AML script has been written that will spot the problem and deal with it in one of two ways as selected by the user: either all the data will be allocated to the larger polygon and any smaller ones will be given values of zero, or the values will be allocated proportionally to area.

With Local Government Districts the situation was slightly complicated by the fact that in addition to a place-name and county field there is also the type field that shows whether the unit is a County, Municipal, or Metropolitan Borough, or an Urban or Rural District. Frequently there are units of different types with the same place-name. This is especially common where one of the urban types of district has the same as a Rural District. In addition, there are the same possible problems as for Unions/Registration Districts with different units with the same place-name occurring in different counties, and a new problem with units, particularly Rural Districts, that were split over more than one county in an effort to ensure that all the districts aggregated up to Administrative Counties. All these problems could still be coped with by a single unique field incorporating the place-name, type of area, and county and other information in brackets. Normally these names are sensible although in some cases, for example, “Ysgubor Y Coed (Admin By Machynlleth) RD”, they become slightly inelegant.

The gazetteer needed to have three potential database place columns: place-name, type, and county. The type field is not always used as some tables contain the types of district as part of the place-name. For example, in the database the County Borough of Newport may either have a place-name of “Newport” and a type field of “CB” or simply a place-name of “Newport CB”. The gazetteer was able to cope with this by the AML script not testing the type field when no type was specified by the user. A final problem here was the Corporation of the City of London which did not fit properly into the Local Government District structure, as discussed in chapter 3. In the database the Corporation is sometimes given a type of “CC” for City Corporation, or sometimes labelled (wrongly) as a Metropolitan Borough. The label point for the Corporation was given a type of “CC” but the gazetteer was given entries to allow it to convert to this from a Metropolitan Borough. With these minor differences, therefore, data from the Local Government District coverage could be linked to the database in a similar manner to the Union/Registration District GIS.

c. Linking parish-level data to the GIS

The parish system, however, again provided more complexity and needed to be handled in a different manner. Parishes differ from districts in two main ways: parishes may be given a unique name either through the hierarchy of Union/Registration County, Union or Registration District, and parish, or through the hierarchy of Administrative County, Local Government Districts, and parish and need to be able to link to the database through either. Secondly, parishes have much more complicated locational information and may move from one district to another as discussed above. It was, therefore, felt that there was no choice other than to use ID numbers to link parishes to the database rather than merely rely on place-names which would have become too unwieldy due to the extra information that would need to be included along with them, and to use two gazetteers with the system rather than one, one to represent the Union/Registration District hierarchy and one for the Local Government District hierarchy.

The ID numbers were called “par_id”. They were allocated using a transcription of the parish-level table from the 1911 census by multiplying the Registration District number provided by the table by 1,000 and adding a sequence number based on the alphabetical position of the parish name within the Registration District. This formed the basis of the system, parishes that were not in existence in 1911 were allocated numbers on an *ad hoc* basis. The major danger with using ID numbers rather than names is that there is a significant risk of corruption and data thus being allocated to the wrong parish. To avoid this each parish label point was given a name as well as a “par_id”. The gazetteers were constructed in a similar way to the higher level ones: all possible spellings of the name and versions of the hierarchy were extracted from the database. The county and district names were standardised using the appropriate higher level gazetteer, and finally the parish name and par_id were standardised to those given in the coverage. Because of the large volume of data concerned most of the detailed work on this was done by a clerical assistant.

4.6: Adding boundaries to the GBHGIS

Having outlined the architecture of the system, the actual process of building it can now be discussed. This section focuses first on map-based sources of boundary information, and then on textual sources describing boundary changes. The digitising and geo-referencing process is then examined, then the process of adding changes to the system, and finally the most time-consuming process; checking extracted coverages for topological consistency and other errors.

a. Basic digitising

A single series of maps had to be used as the core source for digitising to which the boundaries for other dates could then be added. The choice of which series of maps to use for core digitising was obviously of key importance: it had to be for a suitable date, at a scale that would allow complete digitising of the country, and based on a projection system that would allow counties to be joined together easily. The original choice was based on a suitable series for creating the Union/Registration District system so a relatively early series was needed. It was decided to use a series of half-inch to the mile (1:126,720) Ordnance Survey (OS) county administrative diagrams published between 1906 and 1910. This map used a standard projection system for the whole of England and Wales (Oliver, 1993) and the half-inch scale was felt to provide a suitable compromise between the need for detail and the need to be able to digitise the country quickly. Although they were not considerations at the time of the original choice, there have been two other reasons why this series proved to be fortuitous: firstly, it was produced at the time of the change-over from Unions and Registration Districts to Local Government Districts and show boundaries for both types of areas, and secondly, it is completely free of OS copyright.

Figure 4.3 shows an example from this series. The thick red line near the edge of the figure shows the boundary of Newport Poor Law Union, named in red large letters. The unit shaded pale red in the centre of the map is the County Borough of Newport and the beige units are Urban Districts. Although there are no Municipal Boroughs in this example they are shaded pale blue on the series. The remainder of the Union, as bordered by the thick dark blue boundaries, has been sub-divided into two Rural Districts: St. Mellons and Magor. The thin red lines mark parish boundaries, showing clearly that the larger units are aggregations of these.



Figure 4.3: Sample of the “County Administrative Diagrams” of 1906 to 1910: The Newport area.

b. Map-based sources for change over time

For the twentieth century, updated maps are easy to acquire as the series of county administrative maps continued to be revised and published at regular intervals of approximately once a decade until after local government reorganisation in 1974. Prior to the 1906 to 1910 series however, source maps are more problematic as large scale surveying and mapping of the country was an ongoing process through the nineteenth century. The OS produced its first map in 1801 but did not become significantly involved in large scale mapping of administrative boundaries until the Survey Act of 1841 (Owen & Pilbeam, 1992). This resulted in the country being surveyed at 25 miles-to-the-inch (approximately 1:2,500), a process that was not completed until 1893 due to Yorkshire and Lancashire, initially surveyed at 6 miles-to-the-inch (approximately 1:10,000), being re-surveyed at the larger scale. The fact that this re-surveying work was not completed until the 1890s has serious implications for boundary research as most maps showing administrative boundaries were derived from these surveys thus earlier maps are sparser and lack detail.

There is a series of "Diagrams of Sanitary Districts" for the late 1880s at four miles-to-the-inch (1:253:440) showing Boroughs, Sanitary Districts, Unions, and Civil Parishes but the small scale of this series is problematic. Another source is a set of half-inch to the mile Index sheets to the 1:2,500 maps published around 1900 that show civil parish boundaries. As these are index sheets they are difficult to work with because much of their detail is obscured by index information. The GRO had access to a series of maps compiled from contemporary one inch-to-the-mile OS maps which were cut up into a separate map for each Registration District. The outline of each Registration District was highlighted in red with the boundaries of Sub-Districts added in pink and civil parishes in blue. These maps were clearly used by the GRO for administrative purposes as they contain notes explaining boundary changes. They are now held in the Public Record Office (PRO) in RG.18/198-829. These two series provide information about boundaries for the late 1880s and early 1890s. For the period before this a different set of maps was used. These were listed in the PRO Index volumes as showing the parish boundaries in 1870 and are in PRO class RG.18/1-73. They are a series of OS one inch-to-the-mile sheets probably editions published in the early 1850s and were not cut up in the manner of the 1891 maps. They show Registration Districts and Sub-Districts although the units shown probably do not date from 1870. In fact, several of the boundaries of Registration Districts appear to be those of 1851 as shown by the fact that Gower Registration District, formed in 1857, is not marked. The fact that many of the boundaries have been updated by hand on these sheets suggests that they remained in use for a long period after they were published. Unfortunately, this series was only around 80% complete and where there were gaps yet another series of maps, this time in PRO IR.105/2-74, had to be used. These maps were produced quickly for the Registrar General to show civil parishes as reference material for the 1851 census. They are one-inch maps marked up with tithe districts on the sometimes incorrect assumption that these were the same as parishes (Kain & Oliver, 1995).

A major problem with these two earlier series is that, due to the slowness in large-scale surveying of northern England, only ancient parish boundaries are marked north of a line between Preston and Hull. As there are major differences between ancient parishes and townships, which became civil parishes in the north, this means that many boundaries were never accurately recorded. A second problem, particularly prevalent in the East Midlands, occurs where there were no tithe boundaries marked. In both cases, either the 1888 sanitary district maps or, in exceptional cases, first series six-inch maps were used.

The final series of maps used was the least satisfactory. These were included as sketch maps of Registration District boundaries in the published reports of the 1851

census. Their scale, however, was only 12.5 miles to the inch (nearly 1:800,000) and the detail and accuracy provided was far more limited than any other sources used. These were only used in the creation of the Union/Registration District system when there were insufficient resources to visit the PRO on a regular basis.

c. Text-based sources for change over time

Although maps are the most useful source of spatial information, they only provide snapshots of boundaries at certain dates. Researching the information required to create the date-stamps involved using textual description of boundary changes. These were available in similar formats for the three main types of units giving the name of the area losing territory, the name of the area gaining territory, a description of the area affected, and an exact date of the change. In some cases data such as the population and area affected are also given. Information on changes to Registration District has generally come from the *Annual Reports* and *Decennial Supplements* of the Registrar General, changes to Local Government Districts were taken from the *Annual Reports of the Local Government Board* and its successors, and changes to parish boundaries are included in the printed census reports from 1881 onwards. An example of these lists, taken from the Registrar General's Decennial Supplement for the 1890s is shown in figure 4.4. Changes from the other sources follow a very similar structure.

Changes in Registration Districts in the Ten Years, 1891-1900—continued.

Date when change came into operation.	Date from which the changed areas were adopted for tabulation of Births and Deaths.	District.				Name of Parish Transferred.	Population.	
		Decreased by change.		Increased by change.			1891.	1901.
		Name.	No.	Name.	No.			
1895. 1 June	1895. 1 June	BATTLE	69	HASTINGS	68	Bexhill (<i>part of</i>)	—	—
				EASTBOURNE (See LEWES, 76.)	70			
				HAILSHAM (See LEWES, 76.)	71			
1895. 1 July	1895. 1 July	TICEHURST	72	TONBRIDGE	49	Frant (<i>part of</i>)	211	129
				UOKFIELD (See UOKFIELD, 75.)	73			
1897. 1 June	1897. 1 June	EAST GRINSTEAD	74	GODSTONE	37	Lingfield	3204	3718

Figure 4.4: An example of boundary change reports from the Registrar General's Decennial Supplement, 1901.

As discussed in chapter 3, a large database of boundary changes was constructed based on these reports giving a brief description of individual changes with precise dates and the relevant legal instrument; in all this recorded 383 changes to Poor Law Union and Registration District boundaries, 5,874 changes to Local Government Districts boundaries and as many as 26,944 changes to parish boundaries. These changes range from the transfer of a few acres and a few people from one area to another, to entire areas being created or abolished with over 100,000 people being affected.

d. The construction process

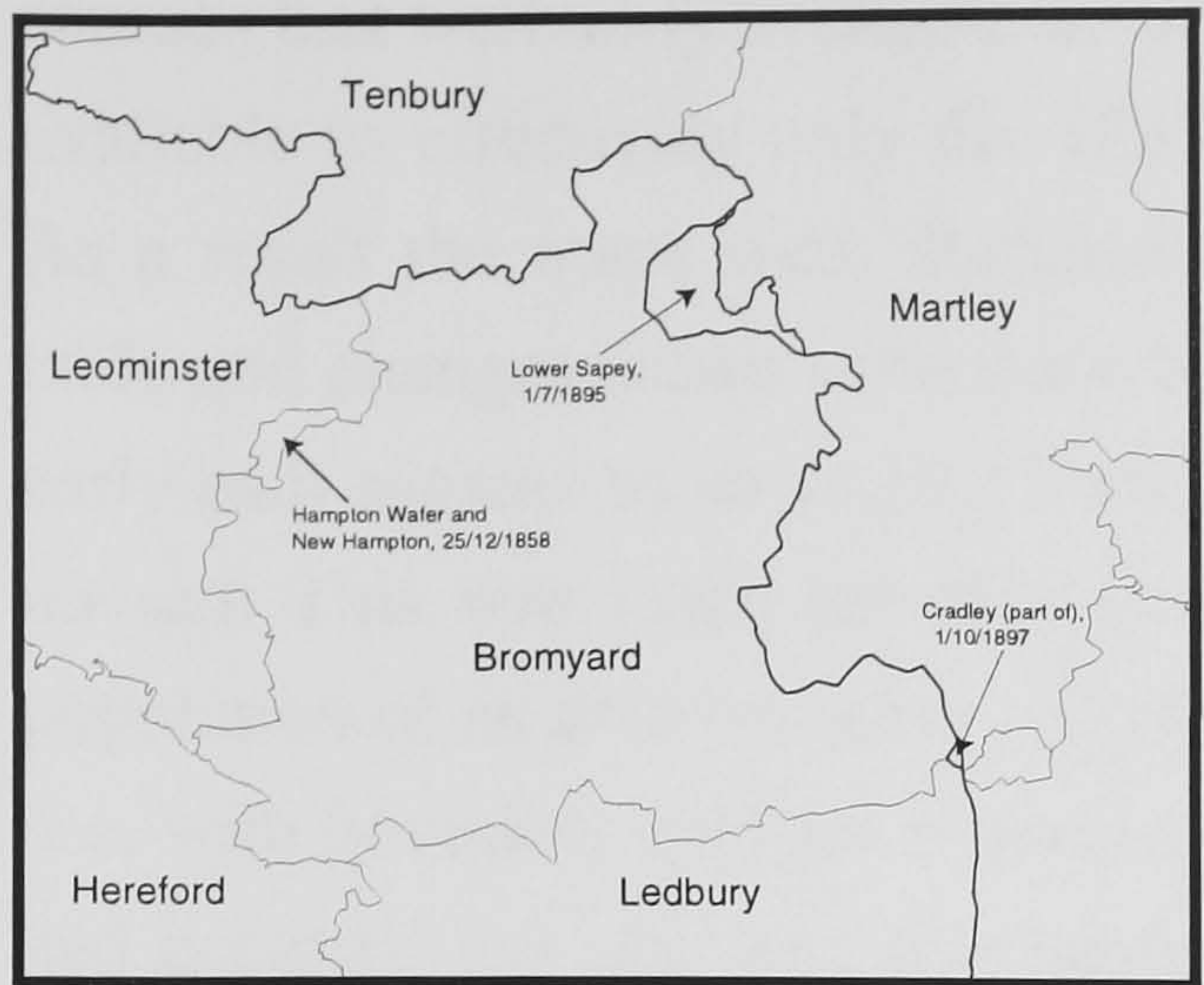
Based on these two sets of sources there was enough information to create a GIS database of changing boundaries. The basic construction process changed slightly after the Union/Registration District system was built due to better hardware resources and the fact that there were more staff available to build the later systems. The later systems were built as follows: first the county was digitised from the appropriate county map from the 1906 to 1910 series and the relevant features copied to each master coverage. Each arc and label point was then given a start date of 0/0/0000 and an end date of 0/0/5000 on the assumption that it existed all the way through the period. After digitising, the resulting coverage then needed to be transformed onto real world co-ordinates, a process known as geo-referencing. The map series used the Cassini projection and included no information on latitude and longitude making geo-referencing slightly complicated. The first step was to find the real world co-ordinates of at least four locations on each map sheet. This was based on features such as churches, stations, and railway junctions that were marked not only on the early maps but also on modern OS 1:50,000 maps and was done by measuring their locations from the modern maps. These features were incorporated into the coverage as “tic points”, point features used by ArcInfo to provide a spatial reference for an entire coverage (Peuquet & Marble, 1990). This allowed the entire coverage to be transformed onto real-world co-ordinates using elementary GIS functionality.

Due to the difficulties of geo-referencing and the fact that the maps had been stored folded for many years a certain amount of error was introduced in addition to that normally caused by the digitising process (Peuquet & Boyle, 1990). The degree of error between the tic points on the source map and their digital representation in the GIS is expressed as Root Mean Square (RMS) error. This is usually expressed in inches on the source map, in which case it is normal to attempt to keep the error below 0.008 inches (ESRI, 1994a). This was found to be hard to achieve, however, with most counties errors of less than 0.01 inches were possible. This equates to an error of slightly over 30 meters on the ground.

Projecting the coverage onto the British National Grid was then a relatively straight-forward process using core GIS functionality. The origin of the Cassini projection on the original maps was at 53 degrees, 13 minutes, 17.274 seconds North, and 2 degrees, 41 minutes, 03.562 seconds West, a point in Cheshire (Oliver, 1996). Using this information ArcInfo was able to project the maps in the appropriate way onto the National Grid (ESRI, 1994b).

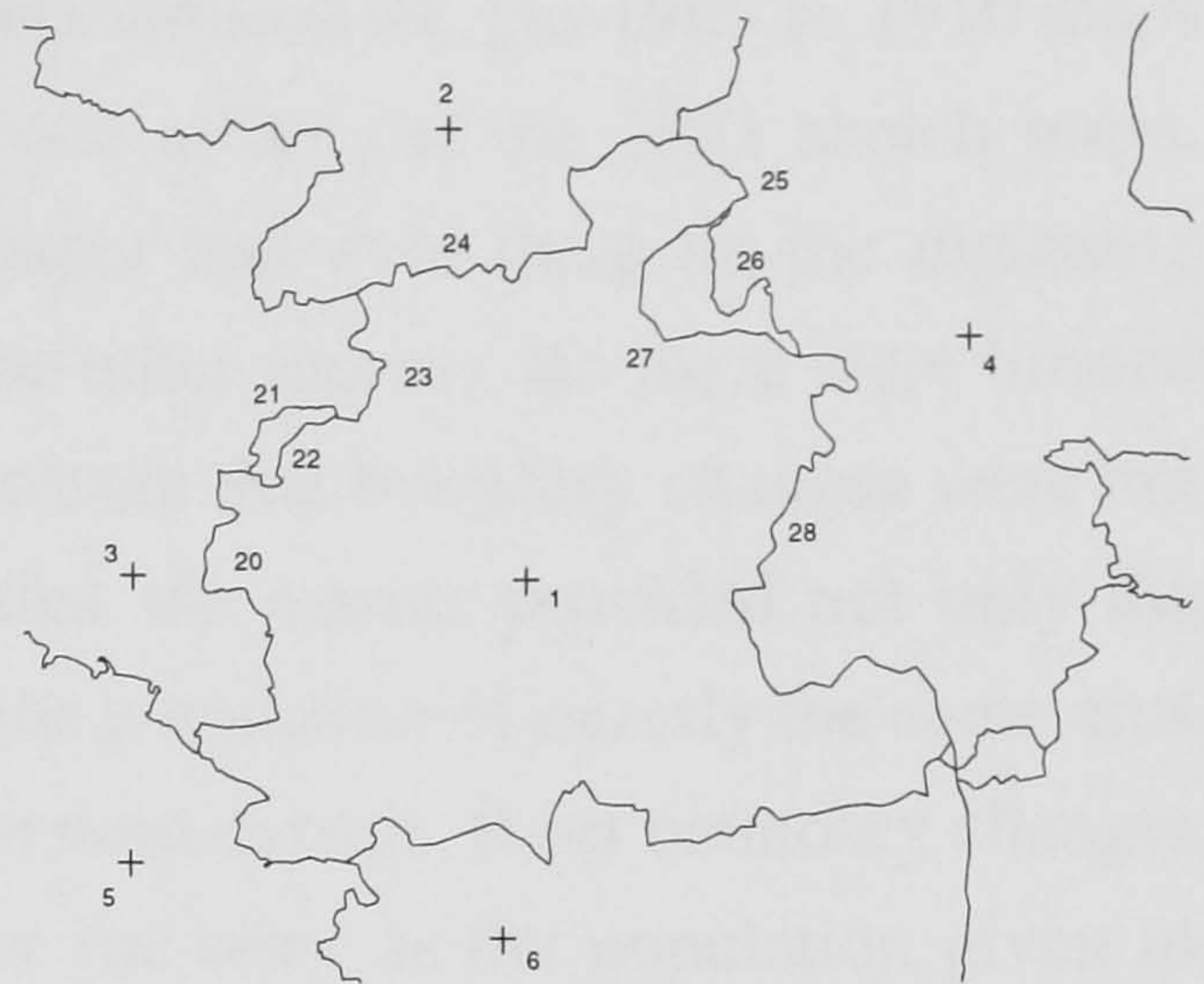
The coverages then needed the temporal information added. This was done by plotting out the boundaries of the county onto tracing paper at a scale that allowed it to be laid over a series of maps from a different date. The maps could then be compared and information from the lists of boundary changes used. Where changes had occurred the alternate boundaries were traced and given a date from the textual sources. The tracings were then taken back to the digitising table, the new boundaries added to the coverage, and attributes added. In cases where a change could not be properly entered a note would be made in the metadata to this effect.

Once the county had been finished it could be joined to existing counties using basic ArcInfo functionality. The results then had to be rigorously checked. This could only be done by extracting that county for all significant dates and checking in particular that there were no “dangling nodes” (boundaries that failed to join any other) or polygons that had either no label points or more than one. In either of these cases the likely explanation was that there was an error and this would be rectified and the county re-checked. When a new county was added to the master coverage any adjoining counties would also have to be re-checked where the county boundaries had been affected by any new changes or there was any other possibility of affects to the county.



Bold lines represent the county boundary

Scale (kms.)



Crosses represent label points

Numbers are ID numbers on the point and arc attribute tables shown below

a. Boundary changes to the district

b. GIS spatial representation

ID	Name	County	Pl_union	Reg_dist	Start Date	End Date
1	Bromyard	Herefordshire	Y	Y	0/0/0	0/0/5000
2	Tenbury	Worcestershire	Y	Y	0/0/0	0/0/5000
3	Leominster	Herefordshire	Y	Y	0/0/0	0/0/5000
4	Martley	Worcestershire	Y	Y	0/0/0	0/0/5000
5	Hereford	Herefordshire	Y	Y	0/0/0	0/0/5000
6	Ledbury	Herefordshire	Y	Y	0/0/0	0/0/5000

ID - Refers to the ID on the spatial data (handled internally by ArcInfo in the real system)

c. Simplified label point attribute table

ID	County1	County2	Un_cnty	Pl_union	Reg_dist	Start Date	End Date
20	Herefordshire			Y	Y	0/0/0	0/0/5000
21	Herefordshire			Y	Y	0/0/0	25/12/1858
22	Herefordshire			Y	Y	25/12/1858	0/0/5000
23	Herefordshire			Y	Y	0/0/0	0/0/5000
24	Herefordshire	Worcestershire	Y	Y	Y	0/0/0	0/0/5000
25	Herefordshire	Worcestershire	Y	Y	Y	0/0/0	0/0/5000
26	Herefordshire	Worcestershire	Y	Y	Y	0/0/0	1/7/1895
27	Herefordshire	Worcestershire	Y	Y	Y	1/7/1895	0/0/5000
28	Herefordshire	Worcestershire	Y	Y	Y	0/0/0	0/0/5000

d. Simplified arc attribute table

Figure 4.5: An example of the GIS structure: The Poor Law Union and Registration District of Bromyard. Note: All changes were transfers in which Bromyard lost territory.

The Union/Registration District system had to be created slightly differently; in particular, when work was done on it we did not own a plotter and as I was the only

person working on it all the work had to be done at QMW so it was impractical to use sources that were only available in the PRO. This reduced the pre-1906 to 1910 maps available to effectively only the 1888 quarter-inch series and the 1851 sketch maps. As a result the maps were digitised, tracing paper laid over them on the digitising table and changes drawn onto these based on the other sources. As there were limited early map sources an extra check was done to ensure that boundary changes were not missed. This was made possible by the fact that the census provided not only the population of an area on census night but also the population of exactly the same area (i.e. with boundary changes removed) at the previous census. If no boundary changes had occurred this previous population would be the same as the population given in the previous census. If, however, the two populations were different this had to indicate boundary changes. This was checked for every inter-censal period to ensure all changes were included. Again, where a change could not be included, or there were problems with the way that the change had to be entered, a note was made in the accompanying documentation.

Figure 4.5 shows the entire process using the example of the Poor Law Union and Registration District of Bromyard in Herefordshire. 4.5a shows the kind of information it is possible to build up using the maps and the boundary change reports: Bromyard lost the parishes of Hampton Wafer and New Hampton to Leominster on Christmas Day 1858, it lost the parish of Lower Sapey to Martley on the first of July 1895, and lost part of the parish of Cradley to Martley on the first of October 1897. The latter two changes also affected the county boundary between Herefordshire and Worcestershire. 4.5b shows how the GIS represents these spatially, while 4.5c and 4.5d show the attribute tables.

4.7: Conclusion

This chapter has described the challenges that have been overcome to allow the GBHGIS to be built. These challenges fall into two distinct, and normally well separated, academic subject areas: computer science and GIS to design a working system, and history to research and populate the GIS database with the real-world units. These two threads have been joined together so that a system could be created whereby exhaustively researched boundaries are entered into the GIS in a manner that allows them to be extracted and linked to attribute data.

The basic system, therefore, is a record of the changing administrative geography of England and Wales over approximately a century and a half. This information in its own right is of limited use, the power of the system comes through its ability to be flexibly linked to a wide variety of attribute data. At a simple level this allows thematic mapping of a wide and diverse variety of data that have never previously

been mapped. Figure 4.6 gives an example of this using Registration Districts for the whole country. A coverage has been extracted for 1871 and linked to mortality data taken from the *Registrar General's Decennial Supplement* of 1871 giving the number of deaths from lung disease among males aged 45 to 64. The aim of this is to visually explore the impact of air pollution on mortality in males in the later stages of their working lives in the 1860s. The advantages of mapping the data in this way are obvious as a clear pattern emerges; the areas with high rates are the major cities and industrial areas such as London, South Wales, Birmingham, and the industrial parts of Lancashire and the West Riding. While these results are perhaps predictable, the map reveals some other patterns that perhaps would not be expected; for example rates in the industrial north-east are not as high as might be expected, and there are several individual districts, such as Reeth in the North Riding and Romney Marsh in Kent, with isolated instances of high rates in rural areas. Features such as this are unlikely to be spotted without the ability to easily map data.

Figure 4.7 shows an example of Local Government District-level mapping. This map uses data from the *Registrar General's Annual Report* for 1911 and shows infant mortality. As there are so many more Local Government Districts than Registration Districts the boundaries of individual districts have not been included, however, the enhanced level of spatial detail is still clear from areas such as East Lancashire. The map also sometimes highlights the relatively high rates in urban areas compared to their rural hinterlands. Several examples of this are found in Lincolnshire.

Finally, figure 4.8 shows an example of parish-level mapping using the 1911 census. The census publishes populations not only for the census year but also for exactly the same unit at the previous census (i.e. with the impact of inter-censal boundary changes removed). This has been used to calculate population change at parish-level for Wales in the inter-censal period and the results have been mapped. Again, the impact of the increased spatial resolution in the data should be obvious as many of the areas visible are extremely small.

The temporal accuracy of the boundary changes held in the GIS led to one interesting issue being uncovered. When complex national-level datasets are being created there is always a tension between publishing them using the units they were collected by, or using the units that are in existence on or around the time of publication which may be several years later. This even causes problems with the census, a source that is meant to provide a snapshot of the country on a particular night, the date of which is readily available in the printed reports. This is demonstrated by the appearance of both the Registration Districts of Guiltcross in Norfolk (abolished in April 1902) and Hawarden in Flintshire (created in January

Mortality rate per 1,000
from lung disease
among men aged 45 to 64

- Less than 27.8
- 27.8 to 38.2
- 38.3 to 58.0
- Greater than 58.0

Legend uses nested-means.
Source: Registrar General's
Decennial Supplement, 1871

0 50
Scale (miles)

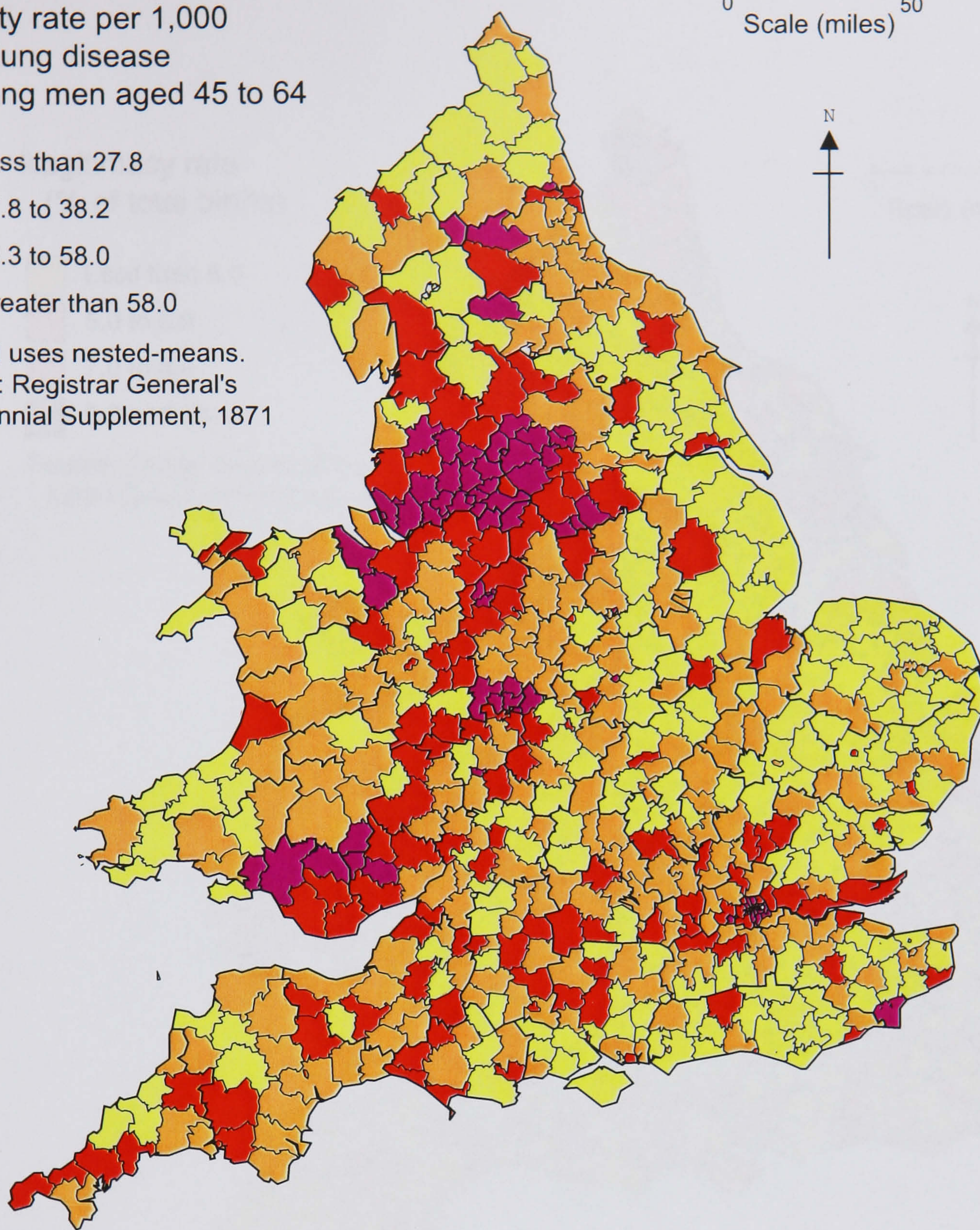
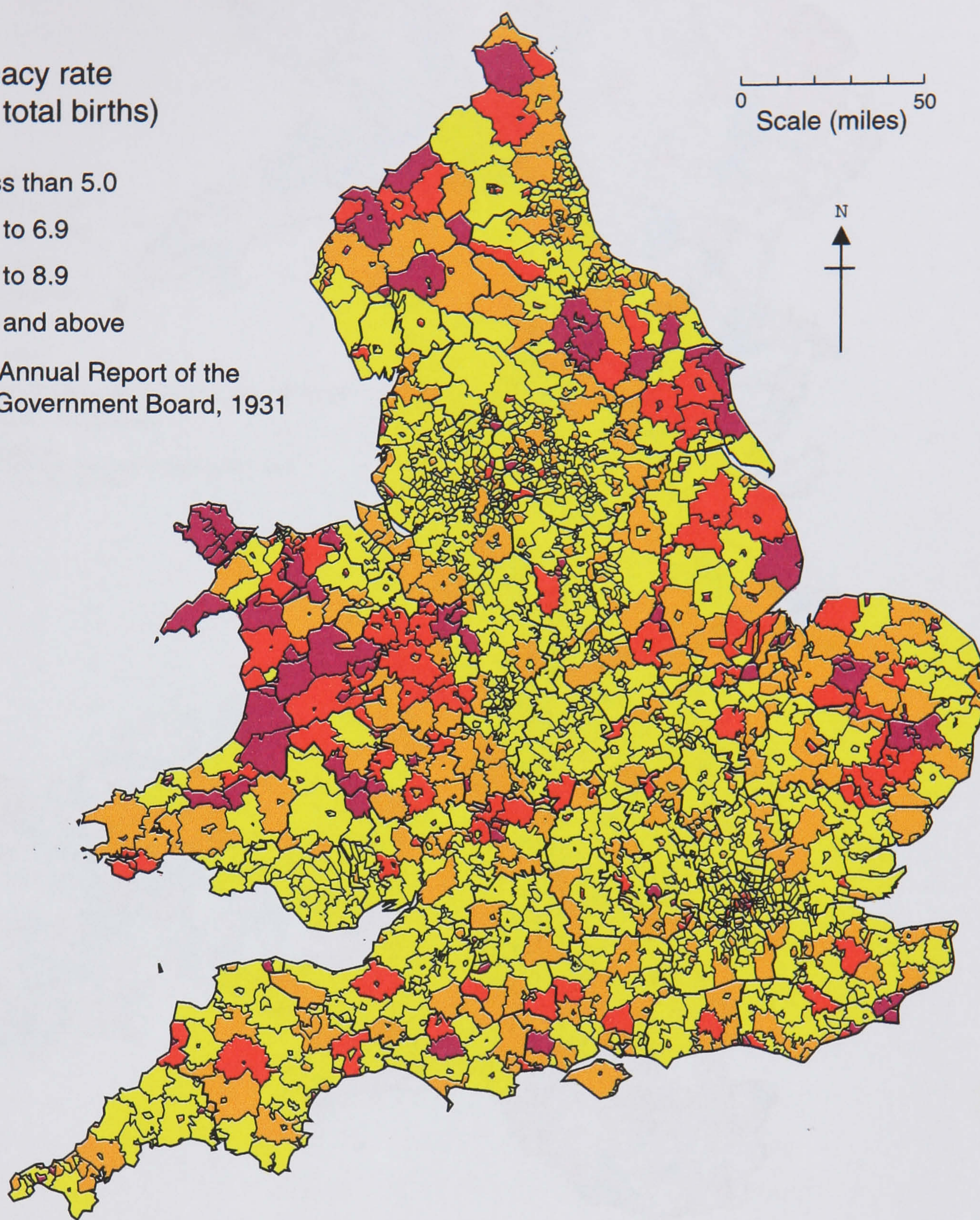


Figure 4.6: An example of Registration District-level mapping: Mortality rate from lung disease among males aged 45 to 64, 1861 to 1870.

Illegitimacy rate
(% of total births)

- Less than 5.0
- 5.0 to 6.9
- 7.0 to 8.9
- 9.0 and above

Source: Annual Report of the
Local Government Board, 1931



**Figure 4.7: An example of Local Government District-level mapping:
Illegitimacy rates, 1931.**

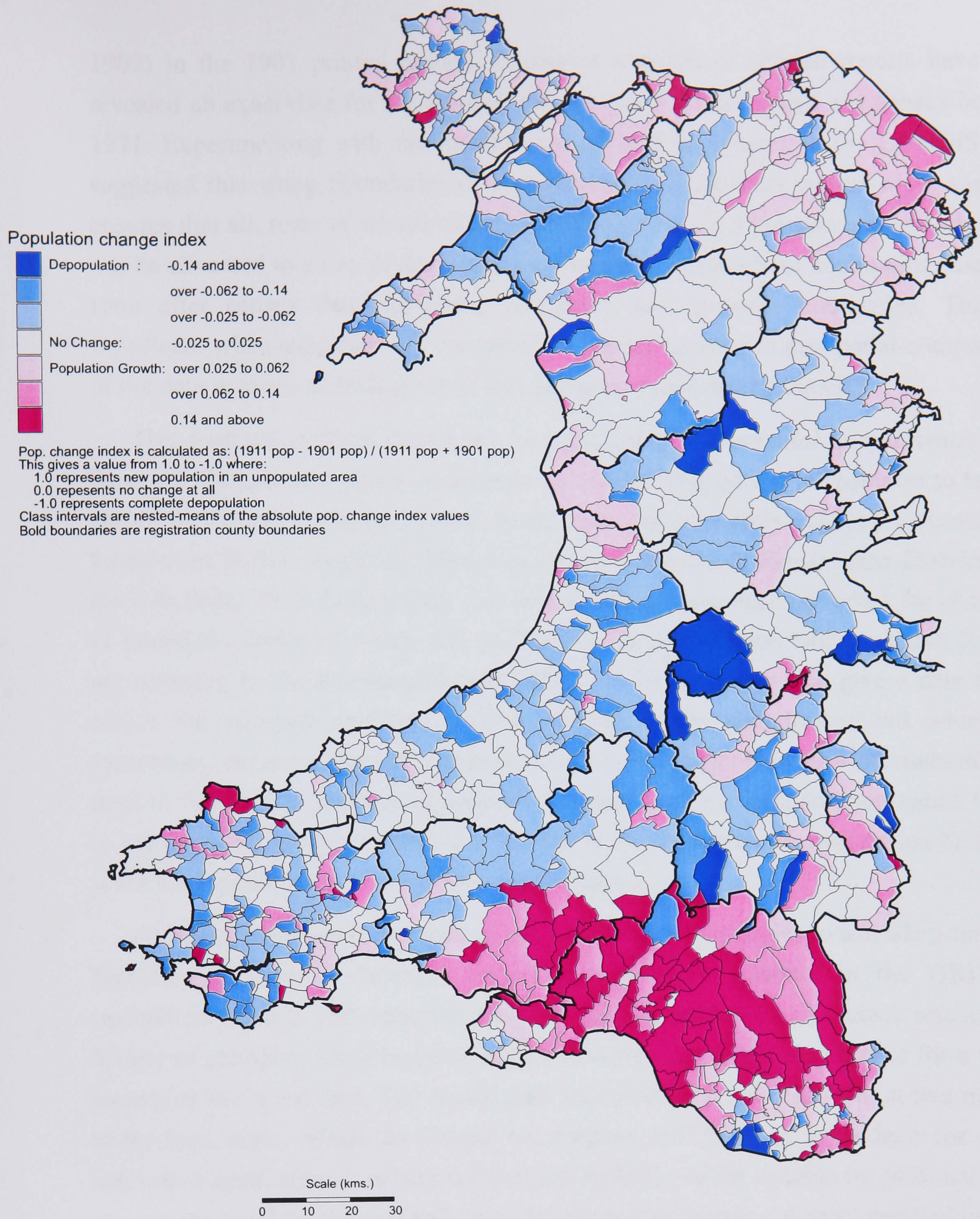


Figure 4.8: An example of parish-level mapping: Population change in Wales, 1901 to 1911.

1903) in the 1901 printed reports. Extensive searches of printed reports have not revealed an exact date for the administrative units used to publish any census before 1971. Experimenting with the Registration District boundaries in the GBHGIS has suggested that using boundaries of approximately a year after census night usually ensures that all rows of statistical data can be allocated to a polygon and all polygons can be allocated to a row of data. Any data linked to a unit whose boundaries changed soon after census date, however, potentially has incorrect boundaries. This is significant when snapshots are compared as it leads to error in the spatial component of the data in terms of both position and any areas calculated by the GIS.

This problem is more significant for data from the *Decennial Supplements*. The Registrar General was aware of the issue and gives information in footnotes to tables and in the boundary change reports. These notes are frequently vague, for example a footnote to Barton Regis and Bristol in the table *Deaths in Registration Districts in the Ten Years 1891-1900* merely state that the data “have been corrected for changes of boundary, details of which will be found at the end of these tables.” These details are referring to the boundary change tables (see figure 4.3) which give a date from which the changed unit was used to tabulate births and deaths, and which is sometimes, but not always later than the date of the change. How this information was used to “correct for changes of boundary” is not clear. The best solution seems to be to use the boundaries in existence at the end of the decade on the assumption that this is the best spatial reference available for the data.

Although there are issues such as the exact date’s boundaries to use when linking boundary data to a statistical source, the boundary database in the GBHGIS undoubtedly makes two important steps forward: it provides a rigorously researched history of changing administrative units, and it provides a spatial reference for a wide variety of statistical data. The spatial data are recorded at national-level at two miles-to-the-inch scale. While its fitness for purpose will have to be judged for each individual application, it is believed that this scale should be suitable for most national and county-level studies and will be useful for people working at more detailed levels. Perhaps the biggest advantage of the GIS is as an integrating technology: boundaries for different dates are integrated, attribute data can be integrated with an accurate representation of the units they were published by, and once the attribute data have been spatially referenced in this way these too can be integrated in ways that were not previously possible. This is the main theme of the next chapter.

Chapter 5: Areal Interpolation of Data to allow Long-Term Comparison

5.1: Introduction

The preceding chapters have focused on the need for the GBHGIS and how it was built. In this chapter and the ones that follow the emphasis moves onto how the wealth of data within the system can be exploited. Chapter 3 described how the administrative units of England and Wales have changed over time with both major reorganisations (see figure 3.1) and a constant stream of minor changes (see figures 3.2, 3.3, and 3.4). Chapter 4 described how the GIS was built to allow a user to create a snapshot of the administrative geography for any date and link this to data published using this geography. In chapter 2 the difficulties of comparing data over long periods of time were considered. It was argued that to do this effectively the maximum possible amount of the detail contained in the data need to be preserved and that this applies to spatial and temporal detail as well as to attribute detail. In particular, it was argued that traditional methods of analysing change involving either aggregating the spatial component of the data to county-level, reducing the amount of temporal data to two snapshots, or just concentrating on a small study area such as a single county severely limited the potential to gain understanding from the data.

In this chapter, a methodology is described that allows data to be compared over time at the national-level based on using a sub-county geography¹. As data from different dates can not be directly compared due to the different spatial units used, any methodology that attempts to compare data over time must use a form of areal interpolation to create a spatial framework that will allow direct comparison. Areal interpolation has been defined as “the transfer of data from one set (source units [or zones]) to a second set (target units) of overlapping, non-hierarchical areal units” (Langford *et al*, 1991: p. 56). This process inevitably introduces a certain degree of error into the resulting data, however, it avoids the loss of detail and other problems related to modifiable areal units introduced by the traditional response to the problem of boundary changes, massive aggregation. Areal interpolation was identified by Fotheringham & Rogerson (1993) as one of the most pressing research areas for GIS-

¹ A cut-down version of this chapter will appear as Gregory (forthcoming). I would like to thank the two anonymous referees for their comments.

based spatial analysis. It is interesting, however, that one of the earliest commonly cited references on the issue comes not from the GIS or geographical literature, but is in *Historical Methods Newsletter* (Markoff & Shapiro, 1973).

In spite of its relatively long history as a research issue, there has been surprisingly little progress in this area and no single technique can be readily identified as better than the others. Many papers focus on the issue of interpolating total population but ignore the sub-population variables that are more likely to be of interest in an analysis. The GBHGIS represents a unique challenge for areal interpolation in that the methodology must allow data from a wide variety of dates, and thus source zones, to be interpolated onto a single set of target zones to allow long-term trends to be analysed. The technique should also be usable to allow data collected for a variety of different administrative geographies to be interpolated onto a single geography for analytic purposes, for example, the provision of independent variables.

As was described in detail in chapter 3 (see figure 3.1), data in the GBHGIS are available at three main levels and these correspond to the three main scales that data have been published at. At the top of the hierarchy there are approximately 50 counties that come in several types: Ancient, Registration, Administrative, and Shire and Metropolitan. This is the level that datasets published at different dates have traditionally been analysed at, based on the assumption that counties were as close to a long-term standard geography as it was possible to create. Counties dis-aggregate into districts. These consist of approximately 635 Registration Districts and Poor Law Unions from the 1830s to the early twentieth century, and approximately 1,500 Local Government Districts from the late nineteenth century to 1974 (Lipman, 1949). In 1974 333 Districts were created and in the mid-1990s these have sometimes been replaced by Unitary Authorities (Hampton, 1991). Until the 1970s, district-level was the scale at which most regularly collected statistical data were published at. This included census data, vital registration data, and a variety of types of data on economic distress. Before the First World War some of these data were also published at Registration Sub-District-level. There were approximately 2,000 of these but they offer a similar scale of data to the other forms of districts.

The third major level is provided by parishes. There were approximately 15,000 parishes but, until the 1970s the only routinely published data at this scale were basic population totals published decennially by the census. While this is limited information, its spatial detail makes it valuable. Advances in computer technology have revolutionised data publishing at this scale with all data from the 1981 and 1991 censuses being available in digital form at ward level. It has also led to the creation of

an even finer scale at which data analysis is possible, consisting of over 100,000 EDs and unit postcodes (see (Coombes, 1995 and Raper *et al*, 1992 respectively). Census data for 1981 and 1991 were published at ED-level and there is a wealth of postcoded demographic data available. There is, therefore, no longer the same trade off between spatial detail and attribute detail that was present until the 1970s, and this has led to a modern Districts and Unitary Authorities having little importance as statistical publishing units.

In this chapter the aim is to develop an areal interpolation technique that allows long-term trends to be analysed at the scale at which the bulk of the data were originally published; district-level, rather than at a significantly higher scale, counties. The data will inevitably still contain problems related to modifiable areal units (Clarke & Rhind, 1975; Fotheringham *et al*, 2000; Goodchild, 1992b; Green & Flowerdew, 1996; Openshaw, 1984 and see also chapter 2 of this thesis), however, this means that the data need to be interpreted and analysed carefully. The role of scale is particularly important here. Curry (1966) notes that the size of administrative units has a filtering affect on data. This filtering removes or conceals the effects of processes that act at more local scales. This means that the results of any analysis must be interpreted in the context of the scale at which the analysis was performed. Tobler (1989) takes this point further when he claims that below a certain level of aggregation data become noisy rather than more detailed and thus becoming too dis-aggregate may be a bad thing as the noise may obscure patterns rather than emphasising detail. He claims that nobody has defined what this minimum level of detail is, however, it seems likely to be data dependent as effectively this is a small number problem.

This chapter first reviews the different approaches to areal interpolation found in the literature and the approaches that have been used to quantify the degree of error that they introduce. It then evaluates their relative merits for interpolating data from the historical GIS with the particular aim of allowing district-level data from all dates to be interpolated onto a single district-level geography to allow long-term comparisons. A relatively simple technique is then outlined that incorporates parish-level information into a district-level interpolation process. Examples are given that show how this can improve the accuracy of an interpolation compared to simply using district-level techniques but that it is still limited in certain situations. To cope with this, a more mathematically and computationally complex process that includes knowledge about the target zones is then described. Complexity, however, does not guarantee accuracy. In the final section the techniques are compared. This can only be done realistically using data published at a sub-parish scale that can be aggregated to replicate source and target districts and parishes. This is done using a variety of variables published at ED-level in Gloucestershire from the 1991 census. These are

aggregated to create synthetic source districts and parishes that are then interpolated onto “synthetic” target districts, created in the same way, to allow the amount of error introduced to be measured. The relative accuracy of a variety of techniques is then compared and the implications of the results are discussed.

5.2: Areal interpolation techniques

The distribution of the population on the earth forms a continuous surface. Data about this distribution are usually presented as an aggregate abstraction of this surface often, but not, in the form of clearly defined administrative units or other zones. The challenge for areal interpolation is to use the information these units provide to create a new abstraction of the population surface with a different spatial form. The techniques for doing this fall into three classes depending on the type of target geography to be created.

- a) Those that use an existing set of discrete spatial units as target zones and interpolate other data onto them.
- b) Those that create a set of spatial units in a manner that seeks to utilise modifiable areal units rather than seeing them as a problem.
- c) Those that interpolate onto a continuous surface rather than onto polygons.

a. Interpolating data onto discrete zones

The basic problem that this approach attempts to address can be summarised as the need to redistribute a variable Y from a set of source zones S onto a set of target zones T . Its simplest form, known as areal weighting, is based on the assumption that Y is homogeneously distributed over each source zone. This assumption can be applied to two types of data: *spatially extensive* data, such as counts and frequencies, while with ratio data, they are referred to as *spatially intensive* (Goodchild & Lam, 1980).

Where a variable is spatially extensive the assumption of homogenous source zones allows the values for the target zones to be estimated using:

$$\hat{y}_t = \sum_s \frac{A_{st} y_s}{A_s} \quad (5.1)$$

while with spatially intensive source data the formula is changed slightly to be:

$$\hat{y}_t = \sum_s \frac{A_{st} y_s}{A_t} \quad (5.2)$$

where \hat{y}_t is the estimated value for the target zone, y_s is the value for the source zone, A_s is the area of the source zone, A_t is the area of the target zone, and A_{st} is the area

of the zone of intersection between the source and target zones (Flowerdew & Green, 1994). Models similar to this can also be used to estimate values of Y for target zones where the target zone is assumed to have a uniform density.

All other techniques attempt to reduce the importance of the assumption that the data for one set of zones, usually the source zones, has a homogenous distribution. This is done either through what are termed *dasymetric* techniques, where information about the source zones provides a “limiting variable” that relaxes the homogeneity assumption, or through the use of control zones where ancillary information from another set of zones, either the target zones or an external set, is used to relax the homogeneity assumption.

Of all the approaches in the literature, dasymetric mapping is perhaps the least developed. It attempts to relax the assumption of homogenous source zones using external knowledge of the locality (Monmonier & Schnell, 1984). A simple example of this is that if parts of a source zone are covered in water these should be allocated a population of zero. This technique originated in thematic mapping (Wright, 1936) and attempts to incorporate it into areal interpolation have so far been limited, however, Fisher & Langford (1995) suggest that it may be an accurate technique.

Models that use control zones take the general form:

$$\hat{y}_t = f(x_1, x_2, \dots, x_n) \quad (5.3)$$

where x_1 to x_n are ancillary (or control) variables relating to the control zones.

Goodchild *et al* (1993) implement this for a situation where neither source nor target zones can be assumed to have homogenous densities. They do this by first interpolating to an external set of control zones that can be assumed to have a homogenous distribution of the variable. Potentially these control zones can be user defined allowing local knowledge to be introduced. Once the density of the control zones has been estimated the values for the target zones can be estimated from areal weighting using the formula:

$$\hat{y}_t = \sum_c \hat{d}_c A_{ct} \quad (5.4)$$

where A_{ct} is the area of intersection between the target zone and the control zone and \hat{d}_c is the estimated density of the variable for the control zone. The difficulty, therefore, is how to calculate the values of \hat{d}_c . They explore a variety of regression-based techniques for doing this including unconstrained ordinary least squares (OLS), OLS constrained to set all negative estimates to zero, OLS constrained so that the total estimated population of the study area equals the total actual population of the study area, a Bayesian approach, and lognormal regression. They demonstrate the technique

by interpolating the total population of 58 counties in California to twelve hydrological basins through the use of four user-defined control zones representing Los Angeles, the Bay Area, the Central Valley, and the rest of the state.

Langford *et al* (1991) used classified satellite imagery to create the ancillary information with the target zones behaving as control zones. Each pixel covered an area of 30x30 meters and was classified as either dense residential, residential, industrial, agricultural, or un-populated (there are many introductions to classifying satellite imagery, for example, Campbell, 1987; Curran, 1985; Lillesand & Kiefer, 1994). Linear regression models were then developed based on the land use area within polygons with the criterion that the regression line must pass through the origin so that zones with zero area have zero population.

It should be noted that neither Goodchild *et al's* or Langford *et al's* models were limited by the so called *pycnophylactic* criterion. This states that the population of a set of target zones should be constrained to match the population of their component source zones, in other words, data from a source zone should only be allocated to zones of intersection from within that source zone. An approach based on using target zones as control zones that meets the pycnophylactic criterion is described by Flowerdew & Green (1994). It uses the Poisson error model and, therefore, assumes that population distribution within a zone is independently random, and does not allow the variable to have negative values. The technique is implemented using the EM algorithm (Dempster *et al*, 1977), a general statistical technique devised primarily to cope with missing data. It is an iterative process based on the expectation stage (E) in which the missing data are estimated, and the model stage (M) in which a model is fitted by maximum likelihood to the entire data set including the data estimated in the E stage. Flowerdew and Green use the idea that the zones of intersection formed where source and target zones overlap effectively have missing data. The values for these zones can be estimated by adding knowledge from ancillary data to the basic knowledge of data for the source zones and the area of the zones of intersection.

Green (1989: p. 4) provides a simple example of implementing the EM algorithm to estimate the population of target zones using binary ancillary data, namely whether the target district is rural or urban. Effectively, therefore, two types of control zones based on ancillary knowledge of the target districts are created. Based on these, the population of each zone of intersection can be estimated using the formula:

$$\mu_{sr} = \lambda_{j(c)} A_{sr} \quad (5.5)$$

where μ_{sr} is the mean population of the area of intersection and $\lambda_{j(c)}$ is the estimated population density for the type of control zone. An initial estimate of the values of λ_j can be made simply by assuming that the population density of both urban and rural

control zones are equal to the average population density of the entire study area. The E-step of the algorithm then becomes:

$$\hat{y}_{st} = \frac{\lambda_{j(c)} A_{st} y_s}{\sum_k \lambda_{j(k)} A_{sk}} \quad (5.6)$$

where \hat{y}_{st} is the estimated population of the zone of intersection, and $\lambda_{j(k)}$ and A_{sk} are the population density and the area respectively of each zone of intersection k that lies within source zone s .

In the M-step the λ_j parameters are re-estimated using the values of \hat{y}_{st} calculated in equation 5.6. This can be done using the formula:

$$\hat{\lambda}_j = \frac{\sum_{st \in c(j)} \hat{y}_{st}}{\sum_{st \in c(j)} A_{st}} \quad (5.7)$$

for both types of target zones. The new values of λ_j are then used to repeat the E-step. The entire algorithm is repeated until convergence. The final step is to calculate \hat{y}_t for the target zones by summing the estimated values of y_{st} for each zone of intersection within each target zone. The values of λ_j , therefore, are estimates of the density of the variable across each control zone. Their relative values for each zone of intersection contained by a source zone help decide how the source data should be allocated. For example, urban control zones have been estimated to have a population density three times higher than rural ones. This will mean that where a source zone has 50% of its area allocated to an urban zone of intersection and 50% to a rural one, the relative values of λ_j will result in 75% of the source zone's population being allocated to the urban zone of intersection and 25% to the rural one.

This basic idea is developed by Green (1990); Flowerdew & Green (1991a); Flowerdew & Green (1991b); Flowerdew *et al* (1991) and Flowerdew & Green (1992). These are summarised in Flowerdew & Green (1994) where they describe how the population born in the New Commonwealth and Pakistan (NCP) were interpolated from 1981 census districts to 1983 parliamentary constituencies in the north-west of England using a variety of ancillary variables. These included the party winning the 1983 general election (a binary variable), car-ownership levels from the 1981 census as either a three-level categorical variable or in ratio form (the number of cars per household), and overcrowding from the 1981 census as a ratio (the proportion of people living at more than one person per room). Green (1990) describes a variant of the EM algorithm for use with binomial data where the desire is to interpolate rates, and Flowerdew & Green (1992) describe a further variant for the interpolation of continuous variables giving the example of interpolating average house prices from wards to postcode sectors in Preston.

b. Creating user-defined areas

The idea behind this method is that the boundaries of census or other administrative units bear little relation to boundaries in the underlying population surface (Morphet, 1993). This leads to the argument that new areas should be created based on aggregating zones together in a way that leads to the creation of homogeneous areas and takes account of the possible impacts of the MAUP. The underlying assumption is that collection zone boundaries rarely represent changes in the underlying population surface, therefore, one way of attempting to model this surface, albeit at a coarser resolution, is to aggregate zones together in such a way that the new boundaries do represent significant changes in the underlying surface. A second argument for doing this is that EDs differ significantly in character: urban EDs are likely to have larger populations but smaller areas than rural ones so any analysis does not compare like with like (Morphet, 1993). The method was pioneered by Openshaw and Rao (1995) who used an Automated Zoning Procedure (AZP) (Openshaw, 1977) to re-engineer the 2,926 1991 EDs in Merseyside to form new units at a similar scale to wards but whose boundaries were determined not by the administrative geography but by trying to aggregate similar units together. They note that ideally the number of source zones should be much larger. In one example they compare the distribution of ethnic minorities in 119 census wards in Merseyside with the same distribution based on regions created from EDs aggregated so as to have the same total population. The results are strikingly different: for wards the highest proportion of ethnic population is over 27% while for the new regions it was less than 5%. Choropleth maps of the two distributions show very different patterns with the ward map showing population being clustered around the major population centers of Liverpool, Birkenhead, and Southport but the region map showing high values largely along the north of Merseyside. They also demonstrate the use of different regions to compare the distribution of unemployment with the distribution of households who do not own a car. At ED-level these have a correlation of 0.99 but it was demonstrated that by aggregating to 20 regions correlations of 1.0, 0.0, or -1.0 could be produced. The patterns produced by these regions varied widely: the 1.0 correlation was fairly continuous across large areas while the -1.0 correlation showed a highly irregular pattern.

The results of this demonstrate a different way of thinking about aggregating spatial zones but leaves many issues unresolved. Openshaw (1996) argues that this approach removes the problem from the modifiable areal unit problem and creates instead user modifiable areal units. Whether having user modifiable areal units instead of the modifiable areal unit problem represents an improved way of modeling an underlying surface is still open to question but the method does offer new ways of

visually exploring data and new methods to look at the modifiable areal unit problem. The technique has not been widely developed in the literature.

c. Using surface models

This group of techniques attempts to model the underlying population surface by creating a continuous population surface rather than dividing the underlying distribution into discrete zones. As with interpolating onto discrete target zones, the challenge is to estimate the underlying distribution of the population within source zones, however, rather than re-aggregating, a continuous surface is created.

Tobler (1979) used a pycnophylactic interpolation using population density as his main example. He estimated the surface based on source zone population figures and attempting to minimise the curvature of the surface. For example, where a source zone has a neighbour to the west with lower values and a neighbour to the east with higher values the zone would have a gradient that rises smoothly from the west to the east. This type of surface may represent a continuous phenomena such as rainfall quite well, however, it does not model human population surfaces realistically.

A more applied approach has been used in Britain to model the 1981 and 1991 censuses, and the changes between them (see Bracken, 1994; Bracken & Martin, 1989; Bracken & Martin, 1995; Martin, 1989; Martin, 1996a; Martin, 1996b; Martin & Bracken, 1991). The underlying assumption is that polygons are not suitable for work on socio-economic geography, and that surfaces give a more realistic representation of the underlying population surface for both mapping and analysis. Rather than using polygons, the source zones are represented by their population-weighted centroids as provided for EDs from both the 1981 and 1991 census. The model assumes that the enumerated count variables are a summary of the size of the distribution, the population-weighted centroid is a summary of its location, and the spatial configurations of centroids is representative of the underlying population distribution. Centroids, therefore, are treated as high information points from which a probability surface can be constructed. The surface is represented as a matrix in which every cell represents an area of land surface, the values for each cell being calculated according to a distance-decay model. To implement the model a moving window (or kernel) whose size varies according to the local density of centroids is applied to each centroid in turn. Cells beyond the kernel are not part of the model, those within it receive a proportion of the centroid data value allocated using the model:

$$\hat{P}_i = \sum_c P_j W_{ij} \quad (5.8)$$

where \hat{P}_i is the estimated population of cell i , P_j is the population recorded for centroid j , c is the total number of data points and W_{ij} is the unique weighting of cell i with respect to centroid j . The weighting factor is calculated according to the formula:

$$W_{ij} = \left(\frac{w_j^2 - d_{ij}^2}{w_j^2 + d_{ij}^2} \right)^a \text{ where } d_{ij} < w_j$$

$$\text{or } w_{ij} = 0 \text{ where } d_{ij} \geq w_j \text{ and } a > 1 \quad (5.9)$$

where W_{ij} is the weighting associated with distance d_{ij} and w_j is the adjusted width of the window centered on point j . An increase in the value a increases the weight given to cells closest to the centroid thus controlling the distribution (Martin & Bracken, 1991).

Once the 1991 census became available these techniques were built upon to examine change in the inter-censal period. Simply creating a new surface for the 1991 census would still cause problems due to the re-definition of EDs and their centroids. In order to create a more meaningful model of change Bracken and Martin (1995) chose to remodel the data from both censuses onto a single surface. To do this all EDs whose centroid lay within 100m of each other were assigned to the 1991 centroid locations. In cases where no direct match could be found, 1981 data were reapportioned to the 1991 centroids using a distance-decay function to preserve the population and variable totals. Where there was no match beyond a certain threshold, typically 1km depending on ED density for that county, isolated 1981 and 1991 centroids were left unchanged.

Martin (1996a) describes a variety of exploratory data analysis techniques that can be used with the 1981 and 1991 censuses. These can be split into five main areas: The first involves aggregation into discrete settlements by identifying groups of continuous or near-continuous cells with non-zero populations and examining data on these such as total populations, number of settlements with a population over a certain size, and change in the number of cells making up a settlement over time. A second technique involves identification of neighbourhoods with defined characteristics by identifying cells that fall above a certain threshold for certain variables. This can then be used to examine change in these cells over time both in density and areal extent. The third method involves indices of neighbourhood difference and change. Merely subtracting one set of cells from the other is likely to be impractical due to small number problems so instead a normalised ratio can be used as follows:

$$c = (a - b) / (a + b) \quad (5.10)$$

where a and b are the two sets of cell based data and c is a change index with values between 1 and -1. These values can then be smoothed before mapping to allow easier

interpretation. Techniques can also be devised to utilise urban form in the analysis of change by splitting a settlement into rings from a central point and looking at attributes and cells and the change between them. Lastly, new geographies can be aggregated from the cell data for example to try to standardise population between zones.

Surface based approaches have also been used in other countries to analyse modern census data, typically by interpolating from the population-weighted centroids onto a regular grid with a fine resolution. Okabe & Sadahiro (1997) describe how this has been done in Japan.

While surface based methods are interesting and versatile method, they rely on having a fine grid of centroids to allow the interpolation, population-weighted centroids are necessary to increase accuracy, and the role of the distance-decay model, and in particular the weighting factor (a in Bracken & Martin's (1991) model) is critical. There are also potential theoretical problems associated with this approach as it may be that rather than removing the problems of working with zonal data, these problems are merely hidden in the surface (see Martin, 1996b, and Openshaw & Clarke, 1996, for different perspectives on this).

d. Investigating the error introduced by areal interpolation

Considering the amount of work that has been done on areal interpolation, surprisingly little attention has been paid to quantifying the error introduced into the resulting data. Much of the work on error that has been done has been by authors evaluating their own methodology using relatively simplistic case studies.

Martin & Bracken (1991) compared their 200m cells derived from the 1981 census with digitised residential areas of South Wales and claimed that 94% of the 80,000 cells were correctly classified as populated or non-populated with the error being concentrated on urban fringes. For the county of Avon they re-aggregated cells to form 61 wards and compared the resulting population totals with the actual census counts. The mean error was found to be 5.0% with a standard deviation of 4.7%. Martin (1996b) looked at the area around Southampton and found that 200m cells do not provide good estimates of ED-level populations but are robust when aggregated to ward level or above. Neither study, however, appears to have calculated the error in any sub-population variables.

Sadahiro (2000) performed some detailed stochastic modeling of the error introduced by areal weighting. Perhaps unsurprisingly he found that interpolating from small source zones to larger target zones introduced relatively small amounts error. He also found that the shape of the source zones could have an impact on the results with a regular square lattice giving the most accurate results. Although

Sadahiro's model was sophisticated, it was based on the assumption that the underlying population were randomly distributed and, significantly, he only investigated areal weighting.

In an earlier paper, Sadahiro (1999) compared different approaches to areal weighting, again through the use of stochastic modelling. His conclusions are that what he terms intelligent methods, such as those used by Goodchild *et al* (1993) and Langford *et al* (1991), are usually more accurate than simple methods, such as areal weighting. He qualified this by saying that the accuracy of the intelligent methods depended critically on the ancillary data used and that a poor choice of ancillary data may actually lead to intelligent methods giving poorer results than simple ones.

Goodchild *et al* (1993) and Flowerdew & Green (1994) both used estimates of error to evaluate their techniques. When Goodchild *et al* interpolated from 58 counties to twelve hydrological basins using four control zones they found that their techniques reduced the amount of error significantly compared to areal weighting but even with this level of aggregation they still reported mean absolute percentage errors of approximately 50% for the total population of the target zones.

Flowerdew and Green compared the EM algorithm using several different ancillary variables with areal weighting for their example of interpolating district-level data on the population born in the NCP onto parliamentary constituencies, the census having published data for both. They used two measures of error using deviance statistics: the first measure, the source deviance, is based on the goodness of fit of the model fitted in the M-step of the algorithm, while the second, the target deviance, compares the estimated values for the target zones with their actual data. The source deviance can always be calculated, the target deviance is only available under test conditions. They show that a simple model using a binary ancillary variable, such as whether the constituency had a Conservative or Labour MP, significantly improved the accuracy of the results compared to areal weighting. Of the variables they used they found that a ratio variable, the number of persons living at over one person per room, gave the least error. They argue that the ancillary variable should be related to the variable of interest but that there does not need to be a strong relationship. They also show (Flowerdew *et al*, 1991) that source deviance does not make a very good predictor of target deviance as persons living at over one person per room, the variable with the lowest target deviance, showed only the third best source deviance.

Fisher & Langford (1995) used a Monte Carlo simulation to compare the three regression models developed by Langford *et al* (1991) with areal weighting and dasymetric mapping. They used total population from the 1991 census at ward level as

source data for three Districts around Leicester. They then created random target zones by aggregating EDs using Openshaw's (1977) algorithm to ensure that continuous zones were created. They agree with Sadahiro's (2000) conclusion that accuracy improves as the number of target zones declines. As with other researchers they found that areal weighting was the least accurate method, but interestingly found that dasymetric mapping introduces the least error. They also found that increasing the complexity of the regression model used did improve the accuracy of the results but not very significantly. This finding perhaps contradicts Flowerdew & Green's assertion (1994: p. 134) that a simple model is more likely to be successful than a more complicated one, but this is not necessarily the case. The EM algorithm with its iterative nature and the pycnophylactic property puts more of its emphasis on the source data as is shown by the fact that the choice of ancillary variable makes comparatively little difference to the results of the interpolation. The regression models developed by Langford *et al*, on the other hand, were designed to make the best use of detailed satellite imagery and lack the pycnophylactic criterion. This puts more emphasis on the control zones and it is perhaps unsurprising that here a more sophisticated model improves the results.

Fisher & Langford's work is expanded in Cockings *et al* (1997) where the mean error for a fixed set of target zones is calculated based on interpolating from multiple sets of randomly created source zones. They demonstrate that when areal weighting is used the degree of error corresponds to the geometric properties of the target zones, particularly the length of the perimeter. For their dasymetric technique, attribute properties such as the population density were more important. This is hardly surprising as in areal weighting the geometries of the source and target zones are exclusively used to allocate data, whereas with the dasymetric technique attribute information is increasingly important.

In conclusion, therefore, work on the error introduced by areal interpolation is, at best, patchy. There is broad agreement that areal weighting is the least accurate method available. It also seems clear that the amount of error introduced decreases as the number of targets is reduced. The trade-off here, however, is that detail is increasingly filtered out and modifiable areal units will become of an issue as this is done. Apart from Fisher & Langford (1995), Cockings *et al* (1997), and Sadahiro (2000), all work on error has been based on interpolating from a single set of source zones to a single set of targets. Much of the research has been focused on total population and little research has looked at the more interesting and perhaps more complicated variables that any applied analysis is likely to require. In particular, it is likely that different sub-population variables will result in different errors due to their differing spatial distributions within the underlying population surface.

5.3: The choice of areal interpolation techniques for historical data

In this section some initial decisions are made about the choice of which approach to use in interpolating data contained in the historical GIS from multiple dates, and thus source zones, onto a single geography. As the majority of the interesting data held in the historical GIS were published at district-level, a source zone will often contain a town and its rural hinterland. However, a single district may contain only a town, or only rural areas. The larger cities such as London, Liverpool, and Manchester were sub-divided into more than one district. This variety obviously severely tests any assumption of homogeneity. Underlying the district-level geography, the parish-level data give a decennial snapshot that provides far more detail of the underlying total population surface. As data are being interpolated from one date to another the same variable for different dates may form both the source and ancillary data. Changes in settlement patterns and transport, however, mean that assumptions about the population distribution at one date may not be valid at another.

The first decision is whether to interpolate onto an existing administrative geography, to create user modifiable units or to use a surface. The fact that the data are not available with the same degree of spatial detail as is found in modern ED level data is a major limitation to how the data can be used. To create user modifiable areas Openshaw & Rao (1995) used a ten-fold aggregation. Doing this with Registration District-level data would create a county-scale level of detail and would have the effect of filtering out the effects of many interesting processes. In addition, the concept of attempting to find meaningful boundaries in the underlying population surface at this scale is less valid than at more detailed scales. Finally, although this is an interesting and visually striking technique, the results of using it are difficult to interpret.

Similar problems would also exist if interpolating data from different dates onto surfaces and comparing them was attempted. District-level units could be allocated a population-weighted centroid based on parish-level populations but there simply are not enough districts to create a meaningful surface. Even if a method could be devised based on parishes the choice of weighting factor (a from equation 5.9) to use would be very difficult as assumptions about population distribution that are valid for the 1990s can not be assumed to be valid a hundred years or more earlier.

Interpolating data onto a single standardised geography is the option that is most sympathetic to the types of data held in the historical GIS because it does not require the same amount of spatial detail to be available in the source data as the other two techniques but will allow data from many dates and sources to be interpolated for long-term comparison and analysis. The key question is what is the best methodology

to use. In section 5.2a of this chapter, five basic options were given: areal-weighting is the simplest option based on the assumption of homogenous source zones. Dasymetric mapping provides the second option. Here some knowledge of the distribution of the variable within the source zone is used to relax the assumption of homogeneity. The remaining options involve the use of control zones. The approach used by Goodchild *et al* (1993) relies on defining user-designated control zones that can be assumed to have a homogeneous population distribution. This may be possible in areas such as California that have widely varying population densities due to environmental factors, but would be very difficult in Britain where population density fluctuates locally as a result of rural/urban variations. The fourth and fifth options use the target zones as controls. Langford *et al*'s (1991) method used linear regression models based on classified satellite imagery. Obviously no such imagery is available for historical data, however, raster scans of old maps could, perhaps, be used instead. In general, maps define human settlements by marking buildings and built-up areas in certain colours and this kind of information could be used in a similar manner to satellite imagery. Unfortunately, scanning a series of suitably scaled maps for the whole country would be expensive and time consuming, and multiple series would be required due to change over time. In addition, although the country has been well mapped during the twentieth century, nineteenth century maps are more problematic (Owen & Pilbeam, 1992). Flowerdew & Green (1994) used an iterative Poisson-based model using a variable published for the target zones. The iterative nature of this technique and the use of the pycnophylactic property would appear to make it more sympathetic to source data collected at different dates than a linear regression-based approach. Another advantage of the EM algorithm is that many of the variables are readily available for both the source and target dates whereas the validity of using satellite imagery for early dates would be limited but there are no other obvious alternatives.

It was decided, therefore, that the two most promising approaches are: to use a dasymetric technique with the parish populations providing a limiting variable containing information about the intra-source district distribution of the variable. The second approach is to use ancillary information from the target zones to provide control zones. In the discussion that follows the EM algorithm is used as this seems more sensitive to the source data at different dates and the pycnophylactic property is seen to be important. Areal weighting was rejected because it is over-simplistic, while regression-based techniques that place heavy emphasis on the target zone data are also rejected as change over time means that source zone data must be stressed in this context.

5.4: Parishes as a source of intra-source district information

Until the advent of Small Area Statistics (SAS) every census published the total population and the number of males and females at parish-level. Some censuses, especially those from 1801 to 1831, published additional statistics at this level but these do not appear consistently. Figure 5.1 shows the parish and Registration District boundaries in Gloucestershire in 1881. It strongly suggests that parish-level data can clearly be used in a dasymetric manner to relax the assumption of source district homogeneity. For the remainder of this section the usefulness and limitations of using this increased level of spatial detail is examined. The discussion focuses on the 1911 census where both Registration Districts and Local Government Districts can be compared. It is believed that the results would be similar for other dates.

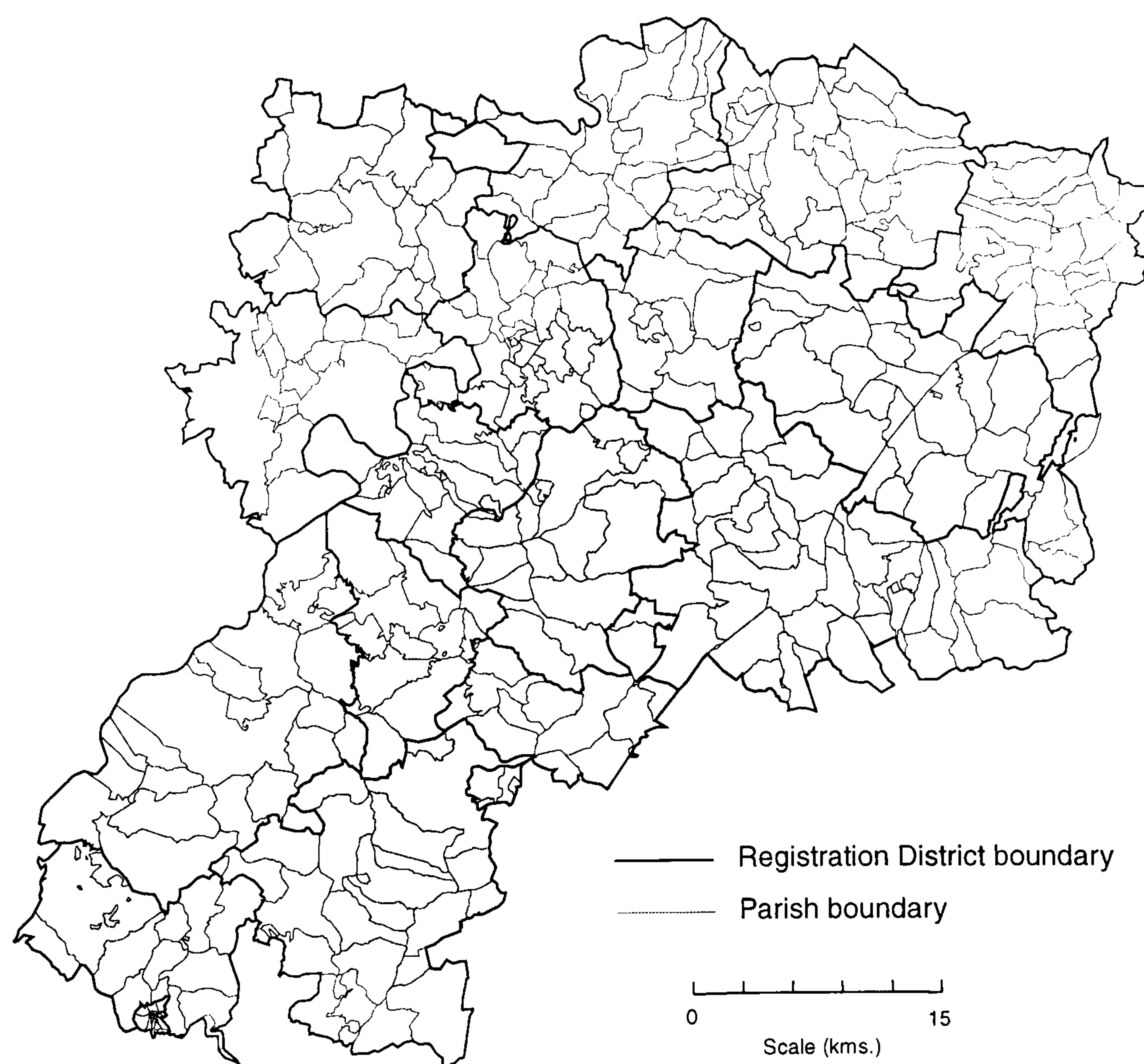


Figure 5.1: Parishes and Registration Districts in Gloucestershire, 1881.

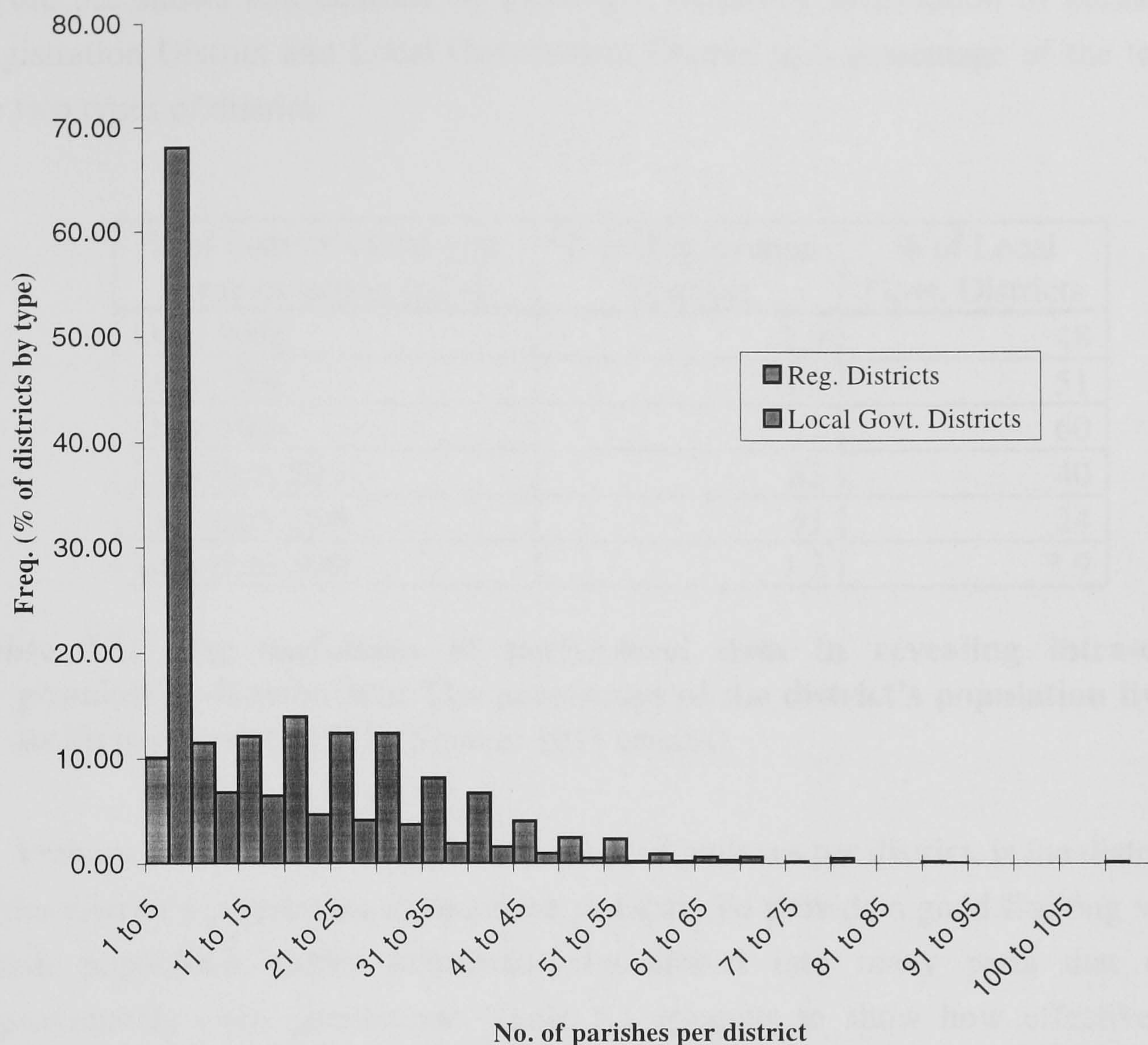


Figure 5.2: Frequency distribution of number of parishes per Registration District and Local Government District, 1911 (Source: 1911 census).

In the 1911 census there were 14,810 places, excluding wards, published in the parish-level table. This gives a mean of 23 parishes per Registration District with the median being 22, but the distribution of parishes per Registration District varied widely. Chester Registration District had the maximum with 108 parishes while ten Registration Districts were made up of only one parish. Over two-thirds of Registration Districts, however, consisted of ten or more parishes. For Local Government Districts, however, parishes are not as evenly distributed: again using the parish-level table from the 1911 census there were 1,894 Local Government Districts giving a mean of 13 parishes per district. While the maximum number of parishes per district remained high, Louth Rural District in Lincolnshire had 88, the distribution was heavily skewed. The median number of parishes per Local Government District was only two and less than 20% of districts consisted of ten or more parishes, while

nearly half consisted of only one parish and two-thirds consisted of less than five. This is because many Boroughs and Urban Districts were formed from a single parish. Figure 5.2 shows this contrast by plotting a frequency distribution of parishes per Registration District and Local Government District as a percentage of the totals of the two types of district.

% of district's total pop. living in largest parish	% of Registration Districts	% of Local Govt. Districts
Over 90%	1.9	48
Over 75%	3.6	51
Over 50%	17	60
Less than 50%	83	40
Less than 25%	41	24
Less than 10%	1.3	3.9

Table 5.1: The usefulness of parish-level data in revealing intra-district population distribution: The percentage of the district's population living in its largest parish, 1911. (Source: 1911 census).

Perhaps more important than the number of parishes per district, is the distribution of the district's population across these parishes. To provide a good limiting variable parish population should sub-divide the district into many parts that contain approximately even populations. Table 5.1 attempts to show how effectively this happens in 1911. For Registration Districts 83% of districts have less than half of their population living in their largest parish and 41% have less than a quarter. In only 1.3% of Registration Districts can the population be said to be so well sub-divided such that less than 10% of their population live in their largest parish. On the other hand, only 3.6% have more than 75% of their population in a single parish. Local Government Districts show a contrasting pattern: as might be expected from the numbers of parishes per district, nearly half of the districts have over 90% of their population living in their largest parish, in most cases because the district consists of only one parish. Only 40% of districts have less than half of their population living in their largest parish. Only at the extreme, where less than 10% of the population live in the largest district, do Local Government Districts perform better than Registration Districts. This is because some Rural Districts, as a result of any towns in the vicinity forming districts in their own right, do come close to being evenly sub-divided by their component parishes.

These statistics show that parishes do provide a more detailed underlying population distribution below district-level. The amount of extra detail, however, varies considerably through space, with Rural Districts and Registration Districts in

rural areas being relatively well sub-divided, but Boroughs and Urban Districts, and Registration Districts in urban areas not being well sub-divided. This may have serious implications for any interpolation methodology. The most challenging areas for any areal interpolation technique are on urban fringes where there may be sudden and dramatic changes in population density. The results above suggest that these are not necessarily areas where parishes will provide much extra information.

5.5: Detailed methodologies for interpolating data in the historical GIS

a. Dasymetric

In this section a computationally relatively simple technique for areal interpolation within the historical GIS is outlined. It is a dasymetric technique that adds the spatial detail provided by parishes to district-level information to relax the assumption of homogeneity. This involves a major overlay operation with a parish-level coverage, however, apart from this, it is computationally relatively straight-forward. Real-world examples are then given that show that this can lead to major improvements in the accuracy of the areal interpolation compared to areal weighting. A second example is then given that demonstrates that due to the limitations of parishes in sub-dividing districts in urban areas the technique sometimes produces dramatic errors that would have a serious impact on any analysis. In the second part of this section, therefore, the technique is enhanced by the addition of ancillary information about the target district through the use of the EM algorithm. This is demonstrated to improve the results considerably. Gloucestershire is used as an example as this provides contrasting types of areas including the rapidly expanding city of Bristol and some sparsely populated rural areas. 1911 Registration Districts are used as target zones.

To re-state the basic problem, most variables are available at district-level. At parish-level total population is available for every census as is the total male and total female population. This can be used to provide a limiting variable on the intra-district population distribution.

Two assumptions are required:

1. That a district-level sub-population variable is distributed evenly through the population of all its component parishes. For example, if 10% of a district's population is aged over 65 then 10% of each of its component parishes' populations will also be estimated to be over 65. Where appropriate, the total male and total female populations could be used to provide slightly more accuracy.
2. That parish-level populations are homogeneously distributed across the area of the parish.

Based on these two assumptions, two formulae are needed to estimate the values of a variable Y for a set of source zones S for one date, onto a set of target zones T using the populations of the source areas P_s and the source parishes P_p . In the first step, the first assumption is used to estimate the value of the variable of interest for each parish:

$$\hat{y}_p = \frac{y_s p_p}{p_s} \quad (5.11)$$

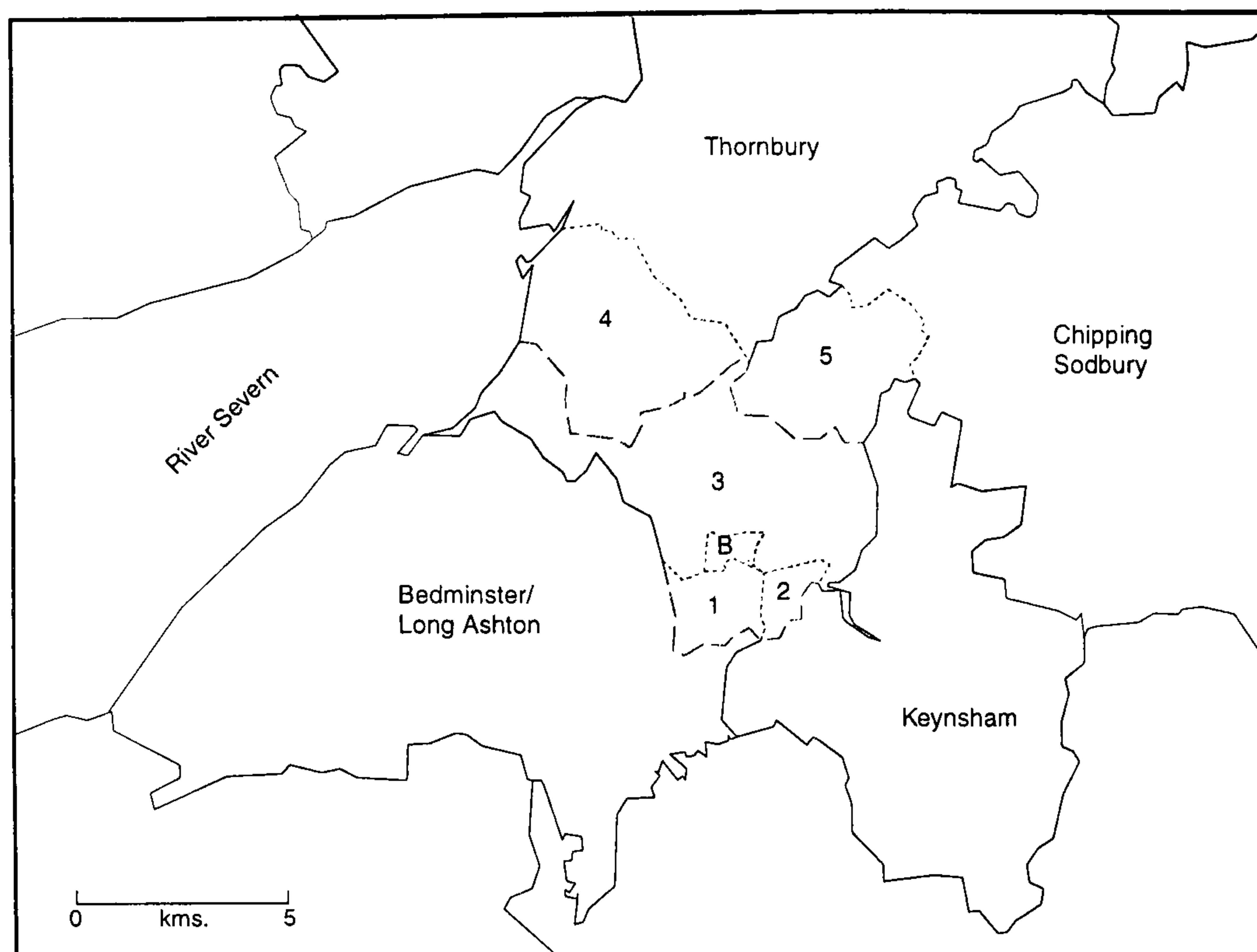
where \hat{y}_p is the estimated value of the sub-population variable for the parish, and y_s is the published value for the variable for the source zone. In the second step, the estimated value for each target zone is calculated using a modified version of the spatially extensive areal weighting formula given in equation 5.1:

$$\hat{y}_t = \sum_s \frac{A_{pt} \hat{y}_p}{A_p} \quad (5.12)$$

where A_{pt} is the area of the zone of intersection between the parish and the target zone and A_p is the area of the source parish.

To implement this formula a GIS containing boundaries for each date is necessary as this both calculates the areas of zones and provides a relatively simple way of ensuring that each parish's data are allocated to the correct target zone. The following algorithm can then be used to implement these formulae:

1. Use formula 5.11 to calculate the estimated value of y for each parish.
2. Overlay the source parishes onto the target zones to calculate the geometric intersection between them. The GIS automatically calculates the areas of all the resulting zones of intersection.
3. Divide the areas of the zones of intersection by the areas of the source parishes thus calculating A_{pt}/A_p .
4. Multiply the resulting ratio by each parish's estimated value of Y . In many cases the ratio will be 1.00 thus providing the potential for coding this efficiently.
5. Aggregate the estimated parish-level data to target zone level to give \hat{y}_t .



- Registration District boundary in existence, 1891 and 1911
 - Registration District boundary abolished between 1891 and 1911
 - Registration District boundary formed between 1891 and 1911
- Note that boundaries created and abolished between 1891 and 1911 are not shown

B=Bristol

1=Transferred to Bristol from Bedminster (Bedminster changed name to Long Ashton)

2=Transferred to Bristol from Keynsham

3=Transferred to Bristol from Barton Regis (Barton Regis abolished)

4=Transferred to Thornbury from Barton Regis (Barton Regis abolished)

5=Transferred to Chipping Sodbury from Barton Regis (Barton Regis abolished)

Note that changes 1 and 2 increased the county of Gloucestershire at the expense of Somerset

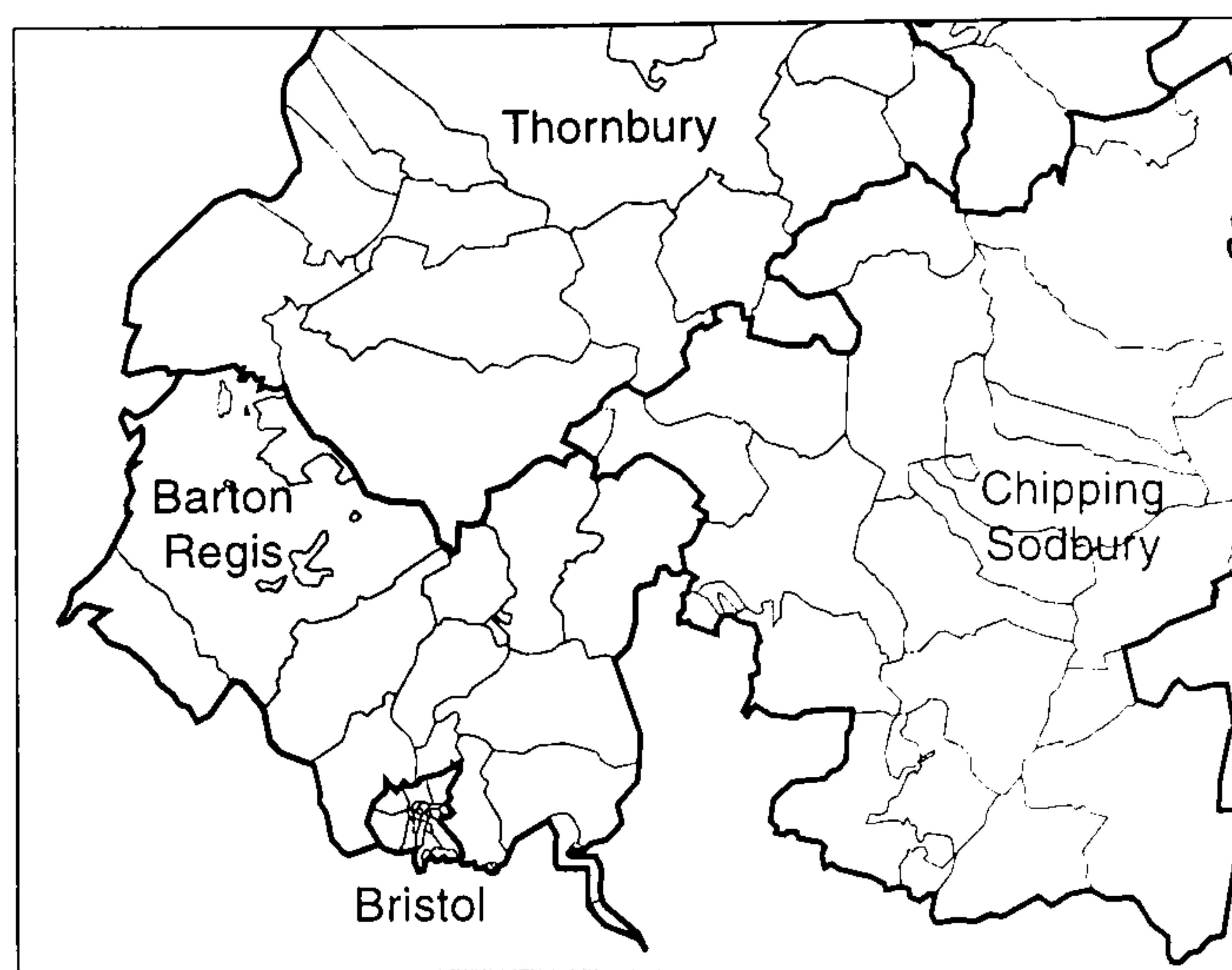
Figure 5.3: Simplified changes to Registration District boundaries around Bristol, 1881 to 1911.

A detailed example of the method is provided by the city of Bristol. The city was growing rapidly in the late nineteenth century and, in response, the Registration District of Bristol also increased in size at the expense of surrounding districts, as is shown in figure 5.3. As a result of changes from 1899 to 1905, Bristol expanded into Long Ashton (whose name had been changed from Bedminster) and Keynsham. These changes affected the county boundary between Gloucestershire and Somerset and are shown in figure 5.3 as zones 1 and 2 respectively. To the north of Bristol, the changes led to Barton Regis being abolished in 1905 with the largest part of the district, zone 3, being allocated to Bristol, but other parts being allocated to Thornbury and Chipping Sodbury. These are zones 4 and 5 respectively.

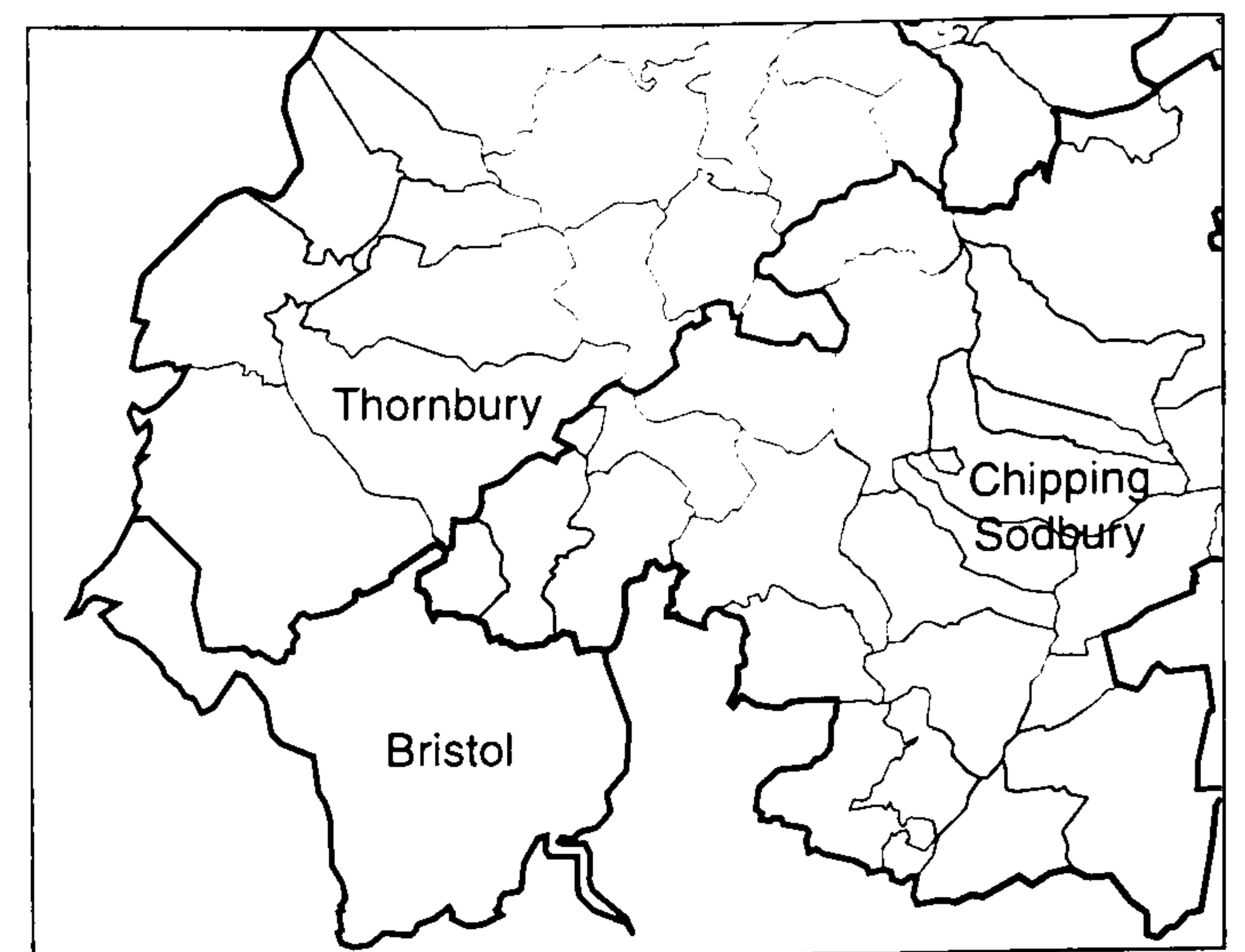
Table 5.2 demonstrates the methodology using the 1881 Registration District of Bedminster as a source zone and the 1911 Registration District of Bristol as a target. Only parishes from Bedminster source zone that overlap with Bristol target zone (i.e. overlapping zone 1 in figure 5.3) have been included. The example of the number of males aged between 15 and 19 is used. Column 2 gives the male population of each parish in 1881. The male population of Bedminster is 31,991 of which 9.69% were aged between 15 and 19. In column 3 this proportion has been used to estimate the numbers of 15 to 19 year old males in each source parish. Columns 4 and 5 give the result of the overlay operation and show, for example, that 57% of the area of Portishead falls in Bristol target zone and 43% falls in Long Ashton. These proportions are then used to allocate the parishes' populations to the target areas in column 6. 2,168 males aged 15 to 19 in 1881 are thus allocated to the target zone of Bristol from Bedminster source district. In addition, Bristol target zone also receives 7,658 from Barton Regis, 21 from Keynsham, and 2,705 from Bristol source zone giving it an estimated total of 12,552 15 to 19 year old males in 1881.

1	2	3	4	5	6
Source Parish	Males in source parish	Est. males 15-19 in source parish	Target district	Proportion of source parish in target district	Est. males 15-19 allocated to target district
Bedminster	21,509	2,083	Bristol	1.0	2,083
Easton in Gordano	973	94	Bristol	0.06	6
Easton in Gordano	973	94	Long Ashton	0.94	88
Long Ashton	1,162	113	Bristol	0.01	1
Long Ashton	1,162	113	Long Ashton	0.99	112
Portsbury	386	37	Bristol	0.26	10
Portsbury	386	37	Long Ashton	0.74	27
Portishead	1,235	119	Bristol	0.57	68
Portishead	1,235	119	Long Ashton	0.43	51

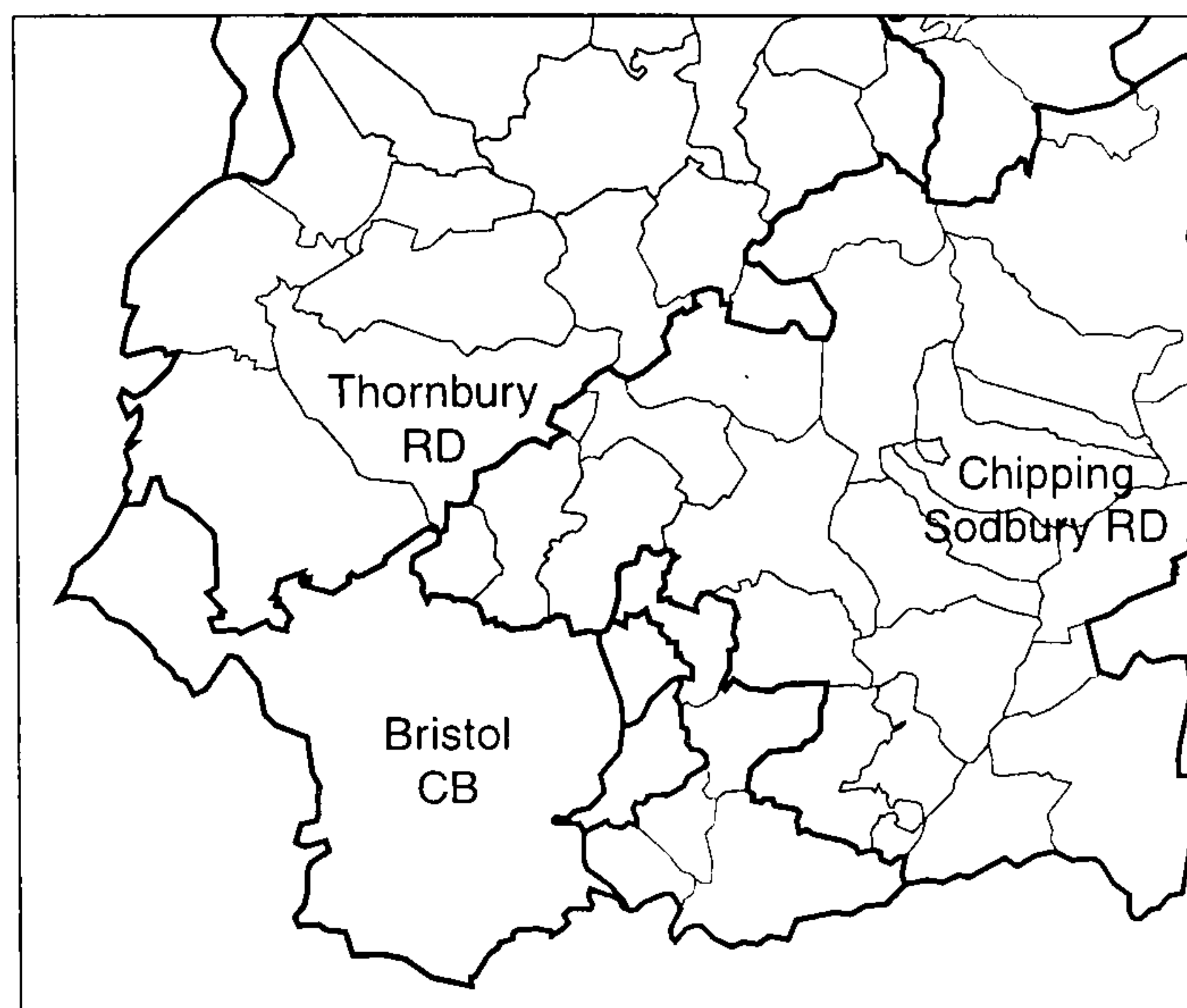
Table 5.2: Estimating populations to allocate to Bristol target area from the 1881 Registration District of Bedminster. 9.69% of the male population of Bedminster Registration District were aged 15 to 19. A total of 2,168 15-19 year old males are allocated to Bristol target district from Bedminster source district.



a. 1881



b. 1911



c. 1931

0 10
Scale (kms.)

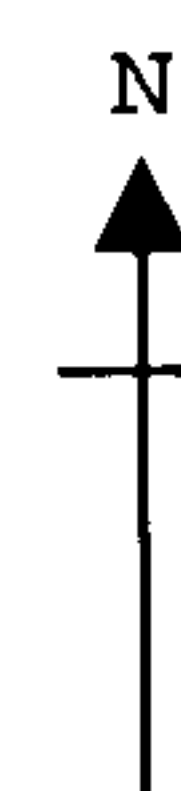


Figure 5.4: Parishes around Bristol and their relationship with districts: 1881, 1911, and 1921. Note: The fainter lines show parish boundaries, the bold lines are combined parish and district boundaries.

The strengths and weaknesses of this methodology can be shown by looking at the estimated populations of the 1911 Registration Districts of Bristol and Thornbury using data from the source years of 1881 and 1921. The parish boundaries for these years and their relationship with the target district boundaries are shown in figure 5.4. The estimated 1881 total populations of these two target districts are 152,000 and 68,000 respectively using areal weighting but were 269,000 and 22,000 using the dasymetric technique. This difference is mainly explained by areal weighting assuming that Barton Regis's population was homogeneously distributed. As figure 5.4a shows, the extra spatial detail provided by the parish-level information allows us to move away from this assumption. From this it becomes clear that the population density was higher near Bristol. This means that areal weighting under-estimates the population of Bristol target zone and over-estimate the population of Thornbury target zone by underestimating the population of the zone of intersection nearest to Bristol

(labeled 3 on figure 5.3) and over-estimating those further away (zones 4 and 5). The majority of the zones of intersection consist of entire parishes so the assumption that parish-level population distribution was homogeneously distributed could only have introduced a small amount of error to the dasymetric result.

To interpolate from 1921, however, a small proportion of Bristol County Borough's population has to be allocated to Thornbury target district to compensate for an expansion of the County Borough's boundaries in 1918. As is shown in figure 5.4b, the zone of intersection involved is a relatively small area to the north west of Bristol (compare figures 5.4b and c). The boundary change reports list the population involved in this change as being only 165 in 1921. Like most urban Local Government Districts, Bristol County Borough consisted almost entirely of one parish. This means that the population density of the small zone of intersection caused by the 1918 boundary change is assumed to be the same as the rest of the County Borough. This is a huge over-estimate that causes the population of Thornbury target district to increase from 19,079 to 38,769 between 1911 and 1921, a highly improbable increase caused almost entirely by error. The size of the error is explained by the lack of parish-level information on the distribution of the County Borough's population and the wide difference in the populations and population densities of the two source zones: in 1921 Bristol County Borough contained 376,975 people living at a density of 830 persons per km² while Thornbury Rural District had only 18,864 people living at a density of only 12 persons per km².

b. Adding the use of control zones

As there is no further information from the source zones that could be used to attempt to improve the interpolated estimates, using the target zones as control zones can also be considered. Green (1989) outlines how the EM algorithm can be implemented using binary, categorical, and continuous ancillary data based on the assumption that the variable of interest follows a Poisson distribution. Flowerdew & Green (1994) compared these techniques and suggest that a continuous ancillary variable introduced the least error and that a binary ancillary variable gave the most error but was still significantly more accurate than areal weighting.

In the context of the historical GIS, the use of continuous or categorical ancillary variables has been rejected for two sets of reasons. The first is the desire to emphasise the source data more strongly than the target data. In the examples described by Flowerdew & Green (1994) the continuous ancillary variables, such as overcrowded housing, will be closely related to the population density. In the application described here, however, data for one date are used to provide a surrogate for the underlying population surface at a different date. It follows from this that a less detailed

classification such as a polychotomous variable is less likely to have changed significantly over time than a more detailed continuous one. The second set of reasons are more practical. The M-step of the algorithm involves a model being fitted by maximum likelihood using the values estimated in the E-step as independent Poisson data. With binary data, or any other number of ordinal classes, this is mathematically and computationally straight forward: the estimated values of λ_j are calculated by summing the estimated values of the variable for all target zones in a class and dividing it by the total area of the target zones in the class as shown by formula 5.7. With categorical or continuous ancillary variables, however, estimating the values of λ_j by maximum likelihood requires iterative procedures to find the maximum of the log-likelihood function (Pickles, 1985). Flowerdew *et al* (1991) describe how this was done by effectively allowing a statistical package, GLIM, to access GIS data from ArcInfo based on modifying the object code of both packages. This was only possible because the software vendors had made the object code of both packages available to them. This was beyond the scope of the GBHGIS it was seen as more practical to implement the EM algorithm within ArcInfo in AML.

Adding a polychotomous implementation of the EM algorithm to the dasymetric technique outlined above is relatively straight forward. Again we start with the assumption that the variable of interest is evenly distributed through the populations of the source districts' component parishes using equation 5.11. Equation 5.12 is modified to include the estimated density of the control zones and becomes the E-step of the algorithm. This gives the equation:

$$\hat{y}_{pt} = \frac{\lambda_{j(c)} A_{pt} \hat{y}_p}{\sum_k \lambda_{j(k)} A_{sk}} \quad (5.13)$$

where \hat{y}_{pt} is the estimated value of the variable of interest for the zone of intersection between the source parish and the target zone. Initially all values of lambda will be the same. In the M-step new values of lambda are estimated based on summing the estimates of y to target zone level and estimating each value of lambda as:

$$\hat{\lambda}_j = \frac{\sum_{pt \in c(j)} \hat{y}_{pt}}{\sum_{pt \in c(j)} A_{pt}} \quad (5.14)$$

The algorithm is then repeated until it converges. Implementing this in AML is conceptually relatively simple. The major difficulty is not the mathematical functionality which can be programmed using a relatively straight-forward routine where each zone of intersection's values are estimated based on its area, its estimated population, the current value of λ for its type of target zone, and the values of these for all the zones of intersection that originated from the same source zone. This is rather slow as it requires cursor processing of each zone of intersection that is not

identical to a source zone in every iteration of the algorithm. The program is made more complicated by the need to standardise all place names when extracting data and joining them to the appropriate coverage. Potentially three different gazetteers may be needed by the program to standardise the place names for the district-level source data, the place names for the parish-level source data, and the district-level place names on the results output for the target zones. Using this, the program is capable of taking a district-level table from Oracle as source data and interpolating it onto a given set of target units using either the dasymetric approach, the EM algorithm, or a combination of the two. When the dasymetric or combined approaches are used parish-level source data is also required. The ancillary data used by the EM algorithm can be either parish or district-level. The main output from the program is an Oracle table that contains standardised target district place names and all the numeric columns of the source table interpolated onto the target districts. The user is made aware that the source data must consist of non-negative count variables. It was felt that interpolating all numeric columns in a table was a better approach than forcing the user to type in the names of all the columns to be interpolated as in large tables this may mean over twenty column names. If the user does not want to interpolate all the columns from a table then a view of the table could be created that only contains the columns required. The program is over 2,000 lines long and its algorithm is given in appendix 5.1.

The control zones can be defined using either the population density of the target parishes or another variable such as the density of the variable of interest at district-level for the target date. Whether at target district-level or target parish-level, almost all ancillary variables used in the historical GIS will be continuous data that need converting into classes to allow them to be used to define control zones. Two questions need to be answered to do this: how many control zones should be used and, how can breaks be found that sub-divide the ancillary data into meaningful groups. The answer to the first question will depend on the number of target zones and the complexity of both the source and ancillary data. For a limited number of target zones with simple source and ancillary distributions it may well be adequate to simply use two control zones, however, in more complex cases more controls may be needed. The second question is concerned with how to actually define these. This problem is in some ways similar to finding meaningful class breaks for choropleth mapping, an area that has attracted significant amounts of research. Evans (1977) argues that breaks should be created based on the statistical properties of the data themselves, for example, to sub-divide a normally distributed dataset into four it may be appropriate to use the mean and the mean plus and minus one standard deviation as the class intervals. Other solutions include having equal numbers of observations in each class,

sub-dividing the range of data values into equal intervals (for example, if four classes were required from a dataset with a minimum value of 0 and a maximum of 100 then breaks of 25, 50 and 75 would be used). With skewed datasets it may be worth taking the minimum value of the dataset and a first increment. The first break becomes the minimum value plus the first increment, the increment is then increased either arithmetically or geometrically to cover the entire dataset. Using a minimum of 0 and a first increment of 2 this gives breaks of 2, 6, 12, 20,... for arithmetic progression, and 2, 6, 14, 30,... for geometric progression. A flexible solution that can deal with normal and moderately skewed data is the use of nested-means. This involves creating four classes with the mean providing the central break, the mean of those above the mean providing the upper break, and the mean of those below the mean providing the lower break. This can be increased to eight classes by taking the mean of the each class as a new break.

A simple example of using the program is given by returning to the problem of interpolating data onto 1911 Registration Districts from 1921 Local Government Districts for Bristol and Thornbury. When interpolating total population, control zones can be defined in two ways: using total population in 1911 at district-level, or using total population in 1911 at parish-level.

Using district-level total population results in the population of Bristol being estimated as 373,037 and the population of Thornbury at 19,738. These represent increases of 3.5% and 4.5% respectively in the decade from 1911 and are thus believable. The reason for this difference is that the small zone of intersection that allocates data from Bristol County Borough source zone to Thornbury target zone is classed as part of the rural control zone. This zone is estimated to have a population density 23.8 times lower than the urban one so far less data is allocated to this zone than if control zones are not used. Using parish-level total population results in a greater difference in the estimated densities of the two types of zone: a factor of 38.3. This has the effect of making the estimated population of the zone of intersection lower and leads to Bristol having a estimated total population of 376,975 and Thornbury having 19,474. Although the differences between these and the estimates derived using district-level data are relatively small, they have the effect of changing the decadal population change to an increase of 5.6% for Bristol and a decrease of 1.9% for Thornbury.

If a sub-population variable is to be interpolated, a third method of defining the control zones can be used: using the variable itself at the target date to provide the district-level ancillary data. If this is done for males aged 15 to 19 it gives an estimated population of 995 in Thornbury, while using total population as the

ancillary gives 991 or 962 with district-level and parish-level control zones respectively. For Bristol these results are 16,476, 16,499, and 16,561 respectively.

These results suggest that using polychotomous ancillary data to define control zones can significantly improve the results of an interpolation. It does not, however, give any idea of how accurate the results are. Even without the gross errors introduced by the simple dasymetric approach the error in the differences in the results given here is significant as is demonstrated by the fact that the total population of Thornbury increases by 4.5% between 1911 and 1921 according to one estimate, and decreases by 1.9% according to another. Combining census data with boundary change reports suggest that the total population of Thornbury is still being over-estimated. In 1921 Thornbury Rural District had a population of 18,864 and the boundary change reports suggest that it had lost 165 people as a result of changes with Bristol County Borough in 1918. Re-allocating these people back to Thornbury gives us an alternative method of calculating the population of the 1911 Registration District. Summing the two populations gives a total population of 19,029, 445 below the lower of the two previous estimates. This confirms that the use of control zones does give fairly accurate results but is still error prone.

The use of boundary change reports allows evaluation of the results only in simple circumstances: it will not evaluate changes over more than a single decade and will only provide results for total population. In the next section an alternative approach to evaluating accuracy is described based on the use of synthetic data.

5.6: Evaluating different methodologies using synthetic units

The examples above show the potential advantages of using a dasymetric technique with a parish-level limiting variable, and using control zones created using ancillary data from the target date when performing areal interpolation within the historical GIS. The EM algorithm could also be used on its own without the assumptions introduced by the dasymetric approach and the user also has the choice of using district or parish-level ancillary data. With the exception of obvious errors such as those introduced in Thornbury in the examples above, however, it is impossible to accurately evaluate how well each approach is performing. What is required is a way of comparing the results produced by each interpolation technique with actual values for target zones. This will allow the amount of error introduced by the interpolation to be quantified but can not be done under real-life conditions as values are required for the same variable for both the source and target zones.

Any attempt to model the accuracy of areal interpolation within the historical GIS, therefore, requires a real-world, sub-parish-level geography that can be aggregated in a variety of ways to produce synthetic versions of parishes and districts as they existed

at different dates. The data from these can then be interpolated in a variety of ways and the results compared to synthetic target zone data.

Six possible methods for interpolating data onto a standardised geography are evaluated:

1. Areal-weighting.
2. The dasymetric technique using source parish populations as a limiting variable.
3. The EM algorithm using the district-level variable of interest for the target zones to create the control zones.
4. The EM algorithm using the total populations of target parishes to create the control zones.
5. The combined dasymetric and EM algorithm methodology using the district-level variable of interest for the target zones to create the control zones.
6. The combined dasymetric and EM algorithm methodology using the total population of target parishes to create the control zones.

Sub-parish-level historical data that could be aggregated to form synthetic parishes and districts are not readily available. The only easily available source of this sort of data is the 1991 census. This was published at ED-level, providing significantly more spatial detail than parishes or wards, especially in urban areas. Synthetic source districts and parishes and the data to populate them could, therefore, be created by aggregating these. Once this was done the data could then be interpolated onto synthetic target districts created in the same way. In some ways, therefore, this technique is similar to those used by Fisher & Langford (1995) and Cockings *et al* (1997).

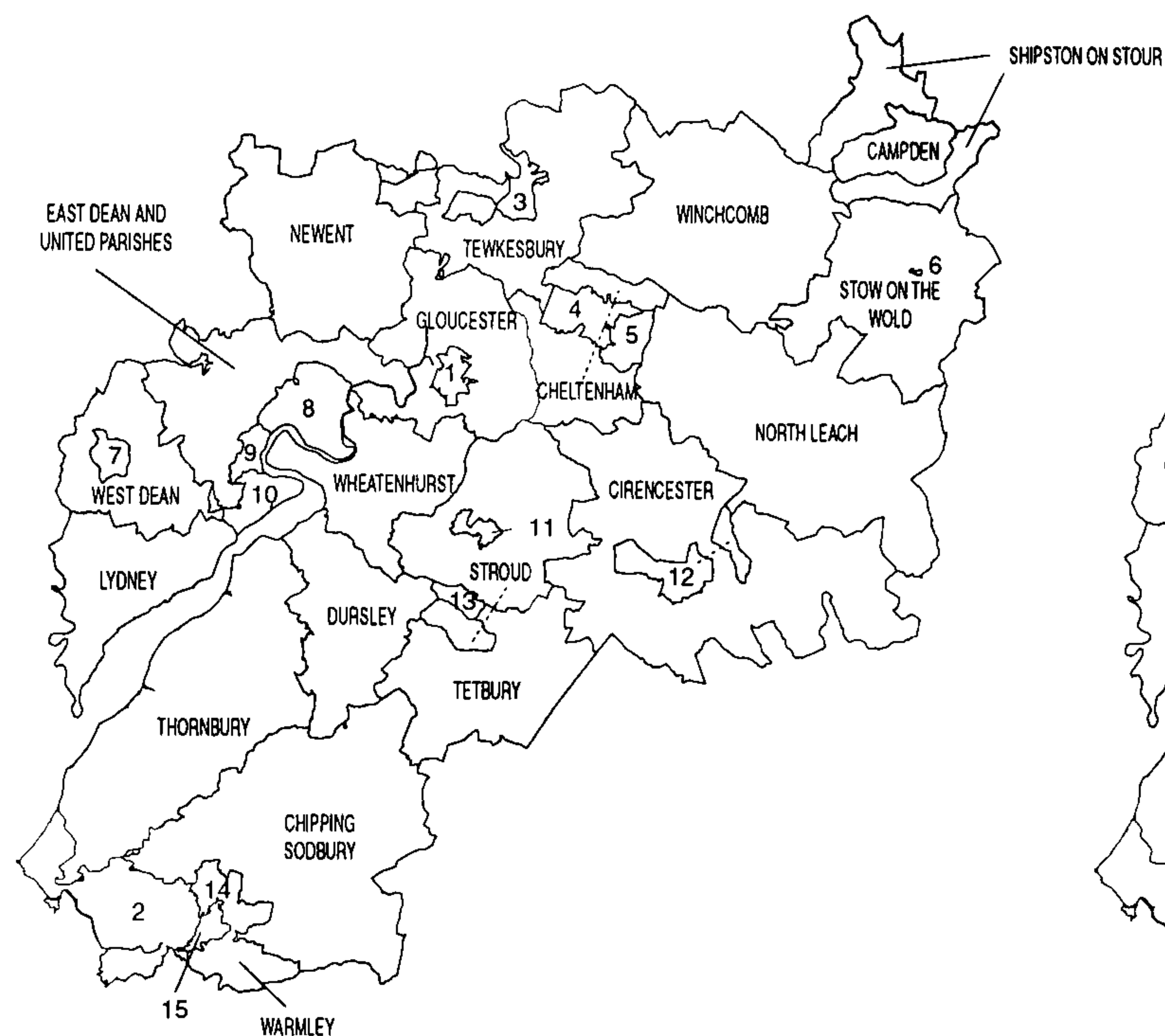
The synthetic parishes were created as follows: the 1991 ED centroids were overlaid with the boundaries of the parishes they were intended to model. This essentially creates a look-up table with the code-name for each ED being allocated a parish name. This look-up table was used to “dissolve” out all ED boundaries that did not represent a boundary between two parishes thus leaving the boundaries of the synthetic parishes. Attribute data for the synthetic parishes could be created by copying the look-up table to Oracle and aggregating the ED-level data to synthetic parish-level. Synthetic districts could then be created by aggregating the synthetic parishes in both the GIS and the database.



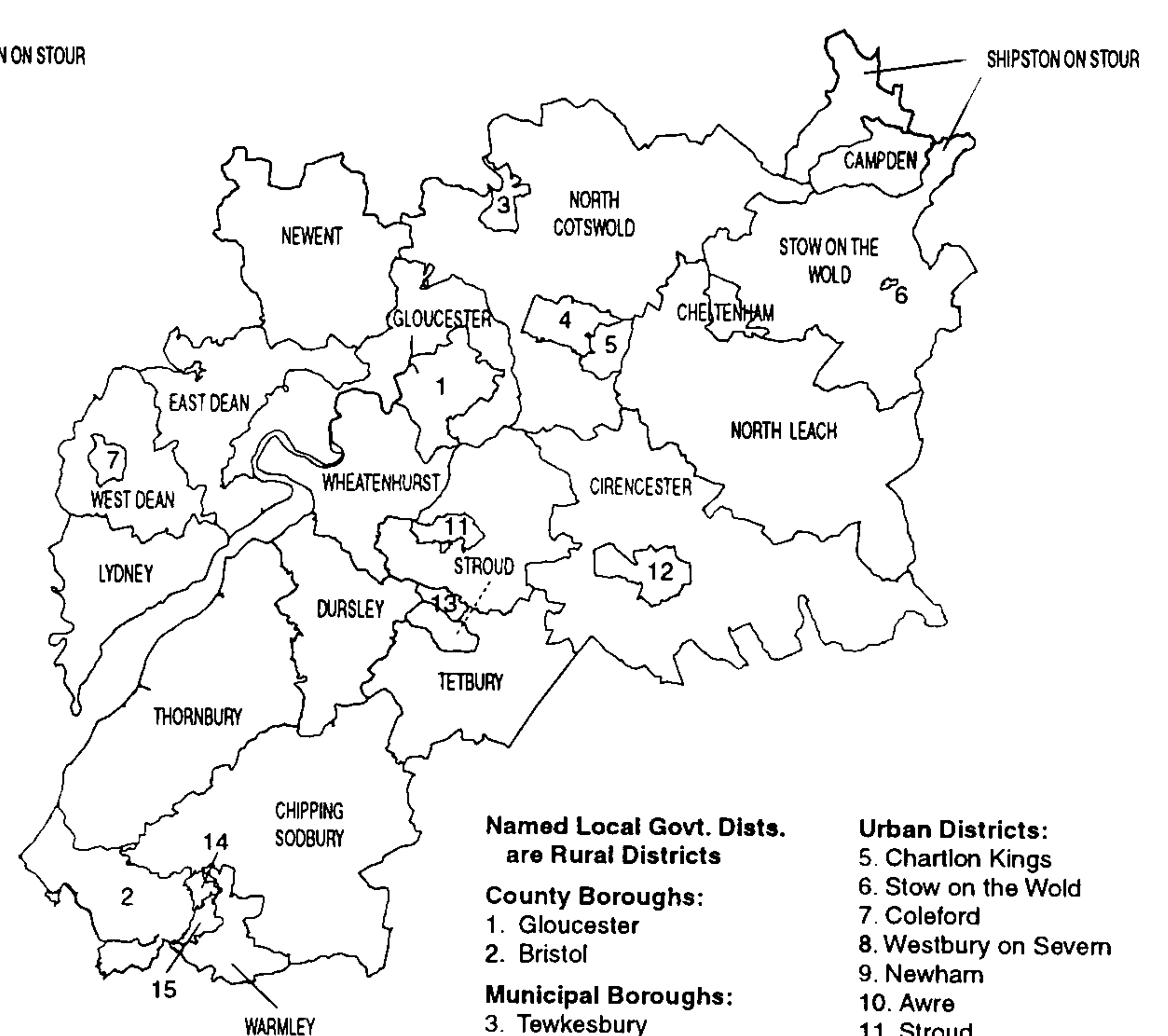
a. 1881 Registration Districts



b. 1911 Registration Districts



c. 1931 Local Government Districts



d. 1971 Local Government Districts

- | | |
|---|-------------------------|
| Named Local Govt. Dists. are Rural Districts | Urban Districts: |
| County Boroughs: | 5. Charlton Kings |
| 1. Gloucester | 6. Stow on the Wold |
| 2. Bristol | 7. Coleford |
| Municipal Boroughs: | 8. Westbury on Severn |
| 3. Tewkesbury | 9. Newham |
| 4. Cheltenham | 10. Awre |
| | 11. Stroud |
| | 12. Cirencester |
| | 13. Nailsworth |
| | 14. Mangotsfield |
| | 15. Kingswood |

Figure 5.5: Boundaries of synthetic districts in Gloucester: 1881, 1911, 1931 and 1971.

Gloucestershire was used for the test as it provides a variety of challenging situations but is sufficiently small for the results to be explored in detail. Synthetic 1911 Registration Districts were chosen to be the target districts with synthetic Registration Districts from 1881 and synthetic Local Government Districts from 1931 and 1971 providing source districts. These give a representation of interpolating from Registration Districts and from pre and post-County Review Local Government Districts. Figure 5.5 shows the four sets of synthetic units used. The similarity between synthetic and real units is demonstrated by comparing their areas. The mean

absolute difference between real units and their synthetic versions is 8.6% with a median of 4.5%. Over two-thirds of the differences were less than 10% and the largest occurred in small urban districts. These differences will not cause artificial population densities to be created as all areas and populations are derived from complete EDs.

As well as total population, four sub-population variables were modelled: the total female population, the number of males aged between 15 and 24, the number of households with no car, and the number of households where the household head is in agricultural employment. This last variable was the sum of three variables from the 1991 census, households who were in the socio-economic group “farmers - employers and managers”, “Farmers - own account”, and “agricultural workers”. Each of these provide a different challenge to the interpolation methodologies: the total population of the target county was 857,519 of which 50.7% were female. Males aged 15-24 made up 7.2% of the population and, from visual inspection, appears to follow the distribution of the overall population fairly well. The number of households without a car represented 11.4% of the total population but was more strongly concentrated in urban areas than the overall population distribution.² Finally, the number of agricultural households represents only 0.05% of the total population³ and is biased towards rural areas. This means that not only does this variable show a negative correlation with the overall population distribution, it also suffers from small number problems as the target county total was only 414 agricultural households, with a minimum of 7 in Bristol target district, and a maximum of 49 in Thornbury.

Fisher & Langford (1995) used root mean square (RMS) error to quantify the error introduced in their simulations. This is based on the average differences between the estimated values of the variable and its known actual values. It is calculated using the formula:

$$E^{RMS} = \left[\frac{1}{m} \sum_m (Y_i - \hat{Y}_i)^2 \right]^{1/2} \quad (5.15)$$

where E^{RMS} is the RMS error and m is the number of target zones. They scaled this by average population to give a coefficient of variation. The example of Thornbury and Bristol given above, however, shows that what appears to be a small error for one target district may actually be a very large error for another. For this reason the RMS error formula used here calculates the proportional errors:

² Were an actual analysis of car ownership or agricultural workers being done, using the total households as the denominator would obviously be more sensible, however, the aim here is merely to explore how different count variables interact.

³ Taken from the 10% sample without scaling.

$$E^{RMS} = \left[\frac{1}{m} \sum_m \left(\frac{Y_t - \hat{Y}_t}{Y_t} \right)^2 \right]^{1/2} \quad (5.16)$$

In addition to an overall measure of the error, its was also felt useful to give the maximum error introduced as a proportion of the actual population. Table 5.3 provides the results. 5.3a gives the combined results for all three years while 5.3b, c, and d give the individual results for 1881, 1931, and 1971 respectively. Some experimentation was done to explore how many control zones should be created and how they should be defined. It was decided that four zones based on nested-means of the target data should be used in all cases. In some cases using eight control zones improved the results slightly, especially where the control zones were created from parishes. In others, where district-level data were used, two zones could be more effective, however, the differences were not strongly significant. It was felt that, as there were only sixteen target zones, four control zones should be used throughout. When the complete GIS is used it will be possible to further explore the impact of control zones.

	Total Pop.		Tot. Female		Males 15-24		No Car		Farmers	
	RMS	Max	RMS	Max	RMS	Max	RMS	Max	RMS	Max
A Weight	26.3	143.3	27.2	149.1	26.3	130.6	52.3	359.4	4.4	28.5
Dasymetric	13.5	83.2	13.8	88.0	13.7	74.9	35.2	280.2	14.0	63.6
EM-District	7.5	28.8	6.4	28.7	6.8	37.8	11.0	55.7	5.4	28.5
EM-Parish	5.6	28.6	5.8	31.0	5.1	19.8	11.4	79.5	14.4	80.2
Comb-Dist	3.6	22.9	4.1	23.5	2.8	14.0	9.9	48.5	13.9	62.8
Comb-Par	3.4	17.8	3.4	16.3	3.9	23.8	6.5	38.3	16.9	73.7

a. Combined results of using synthetic 1881, 1931 and 1971 districts as source zones.

	Total Pop.		Tot. Female		Males 15-24		No Car		Farmers	
	RMS	Max	RMS	Max	RMS	Max	RMS	Max	RMS	Max
A Weight	26.1	84.2	26.3	82.3	27.2	88.7	42.2	120.0	3.5	9.5
Dasymetric	1.9	6.1	1.9	6.1	2.8	7.4	10.2	38.3	13.8	54.6
EM-District	10.7	28.8	10.7	28.7	9.6	26.7	10.9	38.0	5.9	22.5
EM-Parish	5.8	17.8	5.9	18.5	6.0	19.6	10.4	29.2	20.3	80.2
Comb-Dist	2.7	8.8	2.8	8.9	1.9	6.9	10.0	38.3	13.9	55.0
Comb-Par	1.9	7.5	1.9	7.5	1.7	5.6	9.8	38.3	18.5	73.7

b. Synthetic 1881 Registration Districts as source zones

	Total Pop.		Tot. Female		Males 15-24		No Car		Farmers	
	RMS	Max	RMS	Max	RMS	Max	RMS	Max	RMS	Max
A Weight	12.8	49.0	12.9	49.3	13.5	51.6	21.1	83.0	0.9	3.1
Dasymetric	13.1	50.4	13.2	50.7	13.7	53.0	21.6	85.3	1.0	3.2
EM-District	0.2	0.7	0.2	0.8	0.3	1.0	1.8	6.9	0.9	3.1
EM-Parish	1.4	5.4	1.4	5.3	1.6	6.3	2.4	9.4	2.9	11.1
Comb-Dist	1.4	5.4	1.4	5.5	1.5	5.9	1.9	6.9	0.9	3.2
Comb-Par	2.8	9.3	2.8	9.2	2.9	9.2	1.6	5.7	3.2	12.1

c. Synthetic 1931 Local Government Districts as source zones

d	Total Pop.		Tot. Female		Males 15-24		No Car		Farmers	
	RMS	Max	RMS	Max	RMS	Max	RMS	Max	RMS	Max
A Weight	40.1	143.3	42.4	149.1	38.3	130.6	93.6	359.4	8.9	28.5
Dasymetric	25.4	83.2	26.3	88.0	24.6	74.9	73.9	280.2	27.1	63.6
EM-District	11.6	27.8	8.3	23.5	10.6	37.8	20.4	55.7	9.5	28.5
EM-Parish	9.7	28.6	10.2	31.0	7.6	19.8	21.5	79.5	20.0	46.7
Comb-Dist	6.5	22.9	8.0	23.5	4.5	14.0	21.2	48.5	27.4	62.8
Comb-Par	5.3	17.8	5.1	16.3	6.7	23.8	8.0	19.4	28.8	65.8

d. Synthetic 1971 Local Government Districts as source zones

Table 5.3: RMS and maximum errors (expressed as percentages) introduced by the six interpolation techniques. Numbers in bold are the lowest errors for that variable. Key: “EM-District” the EM algorithm using the same variable for both the source and ancillary data; “EM-parish” the EM algorithm using target parish populations as the ancillary; “Comb-Dist” the dasymetric technique incorporating the EM algorithm using the same variable for both the source and ancillary data; “Comb-Par” the dasymetric technique incorporating the EM algorithm using target parish populations as the ancillary. “Farmers” refer to households whose head works in agriculture.

The results show that the combined technique usually works the best with RMS errors of typically less than 3.5% and maximum errors of less than 20%. This is the result of both aspects of the technique offering advantages in different situations: in the case of the 1881 results the dasymetric technique is far more effective than the EM algorithm, producing RMS errors of less than 3% for the three population structure variables. For the same variables the EM algorithm produces errors of around 10%. In 1931, however, this situation is completely reversed with the EM algorithm producing RMS errors of only a fraction of a percent while the dasymetric approach produces RMS errors of over 10%.

These errors mainly occur in the area around Bristol: in 1881 data are being allocated from Thornbury and Chipping Sodbury source districts (and others outside Gloucestershire) to Bristol target district. The source districts are well sub-divided by parishes so the dasymetric technique performs well, only introducing small amounts of error to total population as a result of the assumption of homogeneous parish-level population distribution where parishes are sub-divided. Slightly more error is introduced into other variables because of the assumption of equal distribution of the variable through the total population. The EM approach over-estimates the population density of the zones of intersection to be allocated to Bristol target zone, either because these are zones on the urban fringe and the algorithm fails to calculate the differences in the values of λ correctly, or the control zones do not adequately reflect the complexity of the underlying population surface in these areas. The use of parish-level ancillary data improves the EM algorithm as it gives a better indication of the variations in population densities on the urban fringe, however, the relative values of λ for the zones of intersection allocated to Bristol is still over-estimated. In 1931 data are to be allocated from Bristol source zone, which only consisted of one synthetic parish, to Thornbury target zone. As was described above, the dasymetric technique, lacking any parish-level detail fails spectacularly and over-estimates the population of Thornbury by 50% as a result of a small zone of intersection. The EM algorithm, however, copes well with this situation and estimates the relative values of λ of the zone of intersection to be allocated to Thornbury and the zone of intersection to be allocated to Bristol so well that the error to both target zones is less than 0.5%.

The results also show the dangers of making assumptions about the effectiveness of a technique based on the results for only one variable. They seem to show that the best results are found for total population, and that the stronger the correlation between a sub-population variable and total population the better the results of the interpolation. This is shown most strongly in the dasymetric and combined techniques where the assumption of equal distribution of the variable at parish-level is used. Where this assumption is unrealistic, particularly with lack of a car and agricultural workers, more error inevitably occurs. This causes the results for these two variables to be consistently worse than the results for the more strongly correlated population structure variables.

It is, however, hard to draw precise conclusions from these results about when it is best to use which technique. As might be expected, using parish-level ancillary data works best with total population, then with the total female population, then with the males aged 15 to 24, then those lacking a car, and finally agricultural workers. These give RMS errors of 3.4, 3.4, 3.9, 6.5, and 16.9 respectively. It might also be expected that the same trend be found using the variable itself as a district-level ancillary

variable but that the errors start higher but rise more slowly until, with some of the less well correlated variables, district-level based control zones start to give better results than parish-level ones. With the two extreme variables, total population and agricultural workers, this is the case with average RMS errors of 3.6% for total population, slightly higher than using the parish-level ancillary, and 13.9% for agricultural workers, slightly lower than using the parish-level ancillary. The results for the variables in between, however, do not follow the trend. Males aged 15 to 24 give better results using the district-level ancillary while households lacking a car give better results using parish-level data. This is unexpected but appears robust as it happens with both 1931 and 1971 source zones while the 1881 results are approximately even. It appears, therefore, that where a variable is strongly positively correlated to total population the results back up the assertion that the combined technique using parish-level ancillary data gives the most accurate results. However, with variables that do not correlate to total population as well no clear evidence is found to say whether district-level or parish-level ancillary data provide the best results.

While the combined technique gives results that appear acceptable in most cases, its results for agricultural workers are poor. This is unsurprising as the assumption of the variable being equally distributed through the total population is unrealistic. It is perhaps surprising, however, that areal weighting consistently performs better than the EM algorithm even when the distribution of agricultural households at district-level is used to define the control zones. This is explained by the fact that the distribution of agricultural households must be close to homogeneous within the source zones and that attempts to provide extra information on the intra-source district variation only add error. This finding agrees with Sadahiro's (1999) conclusion that a poor choice of ancillary data may lead to intelligent techniques giving worse results than areal weighting.

A final comment is on the different levels of errors for different years. It appears from the results that 1971 is much more error prone than the two earlier source years. It would be tempting to conclude therefore that this is simply because the greater difference in time has led to more boundary changes and the results are correspondingly inaccurate. This is, however, an over-simplification. It is true that the greater difference in boundaries in this interpolation compared to the other two does lead to a certain number of extra errors but these mainly give very small errors when the combined technique is used. The main reason for the difference is that in the earlier two interpolations the most significant errors are introduced by the changes around Bristol. In 1971, however, there are also changes around Gloucester to include and these are at least as significant as those for Bristol.

5.7: Discussion

Several key themes emerge from the results given above. The use of a dasymetric technique combined with control zones based on ancillary data will usually produce the best results. The strength of the relationship between the variable being modelled and total population, or total male or female populations if these were used, is important in determining the accuracy of the results. The results appear to show that using parish-level total populations to define the control zones is the best technique, however, in real-world situations where the source and target data are for significantly different dates using the variable of interest at district-level may be a safer alternative. Areal weighing is usually the worst approach but provided the most accurate results for a variable whose source zone density did not vary significantly and that suffered from small number problems. Whatever the technique, the results given by areal interpolation will contain error and there is the possibility that this will be significant for certain data values. The example of the synthetic results for Chipping Sodbury target district using the number of households with no car and 1881 source zones demonstrates this well as this persistently produces an RMS error of around 38% regardless of the technique used.

Careful selection of target zones is an important way of reducing error. No single set of zones will be ideal for every situation so choice will depend on exact circumstances. Factors other than error reduction, such as contemporary relevance, may also be important in the choice. The size of target zones is of particular importance: large targets will lead to increased loss of detail and potential problems with modifiable areal units, while smaller zones will lead to increased error from the interpolation. Attempting to interpolate where there are more target zones than source zones is inadvisable because it is likely to result in significant error. Another source of error that has been highlighted in this chapter occurs where data from a densely populated source zone are allocated to a sparsely populated target zone as this can easily lead to very large over-estimates of the target zone even when both dasymetric and ancillary information is used. This was highlighted by the errors introduced to the synthetic results for Thornbury target zone from Bristol County Borough in 1931 and 1971, and Westbury on Severn target zone from Gloucester County Borough in 1971.

The most fundamental choice when selecting target zones is whether real-world units should be used or whether artificial units could be created. With real-world units, post-1974 Districts would introduce relatively little error as they are at the end of the period, thus minimising the urban expansion problems, and are relatively large as there were only approximately 330 of them. The draw-back of these is that they reduce the degree of spatial detail significantly. Selecting target zones with more

spatial detail is more difficult: interpolating even Local Government District data onto Local Government Districts seems problematic due to the lack of parish-level detail underlying the more populous districts and the major differences in population densities between the urban and rural types of districts. Interpolating Registration District-level data onto Local Government Districts is not worth considering. This means that Registration Districts are the only major type of districts held in the historical GIS that would make suitable target districts. The most recent Registration Districts, those from 1911, are probably the best as these include the maximum available extent of urban areas, however, as Thornbury demonstrates, significant error is sometimes likely to be introduced as a result.

Parliamentary Constituencies provide another possible source of target zones. There are approximately the same number of these as there are of Registration Districts, however, their spatial arrangement is significantly different: constituencies are designed to have approximately equal populations and therefore sub-divide urban areas in much more detail than Registration or Local Government Districts, or even parishes, while having larger sizes in rural areas. This means that the results of interpolation in rural areas are likely to be reasonably accurate but results in urban constituencies may be error-prone. There will, however, be ancillary information available as modern census data can be aggregated to constituency level.

Where possible, creating user-defined target zones is likely to lead to lower error. A relatively simple method of doing this would be to aggregate 1973 Local Government Districts to approximately Registration District-level. From the point of view of minimising error, these would almost certainly provide more satisfactory target districts than 1911 Registration Districts as they would minimise the urban expansion problem. More sophisticated methods could also be devised that make use of the fact that all boundaries included in the system have start and end dates. This could involve starting with all boundaries that never change and then adding boundaries to these to create a set of units that seek to minimize the amount of interpolation that will result, especially where the interpolation is between two districts with considerably different population densities. This would, however, involve considerable amounts of programming and experimentation but could perhaps incorporate some of the ideas of Openshaw & Rao's (1995) idea of user-modifiable units.

For any interpolated data, however, some degree of error is inevitable. As was discussed in chapter 2, error and uncertainty are important issues in the GIS literature, however, the conclusions about the best approaches to handling it are still limited, especially in socio-economic applications (see, for example, Goodchild & Gopal,

1989; Unwin, 1995). One approach to handling error is to attempt to quantify the uncertainty in the results of the interpolation. This could be done by not calculating a single value for each target zone, but rather producing a range based on estimated maximum and minimum values, and a statistical summary of the probability distribution between these. This would be a move towards fuzzy reasoning (Kollias & Voliotis, 1991) a methodology that many authors have called to be included in GIS analyses (see, for example, Openshaw, 1991; Wang & Hall, 1996). For variables such as total population, the parish-level data would allow maximums and minimums to be estimated relatively easily, however, deciding on the probability distribution would be more problematic and for sub-population variables estimated maximums and minimums would be harder to determine.

In addition to these practical difficulties, there would also be broader limitations to this approach. GIS data are interpolated for two main reasons: either to produce input data for statistical analysis, or to provide the underlying data for thematic mapping. Current research in both areas has yet to yield widely accepted methods of incorporating uncertainty in either approach. For statistical applications Monte Carlo simulations (Hope, 1968) could be used. This would mean that rather than performing an analysis once based on a single value for each target zone in the dataset, the analysis would be repeated n times using randomised values based on the range of values for each target zones and its probability distribution. The different results could then be compared and conclusions drawn based on statistical summaries of the results. While this approach might be fruitful in certain conditions, it would form another layer of highly computationally intensive analysis.

The leading cartographic textbooks (for example, Keates, 1973; Monmonier & Schnell 1988; Robinson *et al*, 1984) touch on the issue of incorporating uncertainty into thematic maps and research on this area is still in its early stages (see, for example, Battenfield, 1993; MacEachren, 1992). In their work on uncertainty in areal interpolation, Cockings *et al* (1997), simply produce two maps, one of the most likely values and one of the possible error. This does not represent a satisfactory approach where the intention of the map is to present information from a dataset rather than simply to explore error.

A simpler approach to handling error, is to smooth the results temporally. Where data from multiple dates are interpolated onto the districts that existed for the target date, and there is a major boundary change that the interpolation methodology fails to cope with adequately, this will introduce error to all dates either after the boundary change if the target date is earlier than the date of the change, or before it if the change occurs before the target date. This means that ways of identifying unnatural changes

between any two dates could be devised. When changes of this sort are identified their impact could be smoothed out of the results.

It is a mistake to focus on the error introduced as a direct result of the areal interpolation procedure while ignoring other sources of error that will feed through to the results. Any interpolation methodology used in the historical GIS will produce results based on average densities at district and sometimes parish-level. These densities are derived from socio-economic data from the attribute database held in Oracle and areas from the spatial data in ArcInfo. This means that, even assuming that the attribute data were collected, published, and transcribed properly, error can come from three possible sources: digitising, boundary changes, and the link between the spatial and attribute data.

Simple digitising inaccuracy will lead to ArcInfo producing inaccurate values for the areas used as the denominators used when calculating densities. This means that all densities used in the interpolation are inaccurate to a certain degree as they are dependent on the scale and accuracy of the source maps, the quality of the digitising, and the wide variety of other sources of error that occur between a real world administrative unit and its digital representation (Walsby, 1995). Inaccuracy from digitising, however, need not be the result of inaccuracies in creating the digital representation, but may also come from conceptual problems. A zone's density is an average value for the whole zone and there may be considerable intra-zone variation that could not be identified even with the use of dasymetric and ancillary information. An example of this is that administrative boundaries usually follow the low tide mark. Certain districts and parishes may therefore be much more densely populated than they appear in the GIS because a large proportion of the area value provided by ArcInfo may apply to tidal sand and mud. This could be avoided by using an overlay to clip out any areas below the high-tide mark but this would introduce other errors as it would be from a source digitised independently from the GBHGIS.

Boundary changes may cause error in one of three ways that are beyond the scope of an interpolation methodology: they may have been digitised inaccurately, especially those prior to 1888; they may have been missed out altogether; or they may have been given the wrong temporal information. This last case may occur simply as a result of errors when building the GIS but may be more subtle. Most datasets are collected at one date or over a period of time, and are subsequently published at a later date. This undoubtedly led to compromises and *ad hoc* arrangements being made in terms of the units used to publish each dataset. Even for censuses, where the data are meant to refer to the situation on a specific night, the units they were published using were typically for a date some point later, perhaps as much as a year, and detailed

examination of several censuses prior to the Second World War has failed to uncover any descriptions of exactly what units were used when the census was published. This situation is even more complicated, for example, for Decennial Supplement data where the data were collected over ten years.

Finally, if there are any problems in linking the spatial and attribute data this will cause errors. This could be as a result of simple failures in gazetteers to match attribute data to the correct polygon, a particular problem with parish-level datasets which may have entries such as “Soldiers in barracks” without defining which parish the barracks were in, or may be a result of more complicated situations, for example, detached portions of parishes or single-parish districts where the only way to allocate data to each part is to assume equal population density across the entire district and allocate data accordingly.

5.8: Conclusions

Areal interpolation using the historical GIS does provide a method of allowing long-term change to be analysed at district-level. This is far more satisfactory than the traditional approach where counties, highly unsuitable units for spatial analytical purposes, have been used. It also represents an improvement over analyses that attempt to only use two snap-shots to examine change as data on demographic change have often been available for over a century. Being able to interpolate data from multiple dates onto a single standardised geography represents an important methodological break-through as it allows the full spatial and temporal detail available from the data to be incorporated into an analysis.

The combined approach advocated here attempts to make maximum use of the available data while also being sympathetic to their limitations: the parish-level population data provide much more detail on the intra-source zone distribution of population especially for Registration Districts. The use of control zones defined by data from the target date and units improves this especially on urban fringes where the source date parishes do not provide much useful extra information. The implementation of the EM algorithm used here means that while the control zones are defined using target date data their significance in allocating data to zones of intersection is based on the source data and the use of the pycnophylactic criteria means that data from a source zones can not be allocated to zones of intersection outside that source zone.

Error in the interpolated data is, however, a fact of life. In order to minimise this the underlying assumptions of the technique must be looked at in the context of each variable used. Of particular importance is how well the distribution of the variable of interest at district-level can be assumed to follow the parish-level total population

distribution. The weaker this relationship the more error that will be introduced as a result of the dasymetric technique. In cases where there is likely to be a very poor relationship then dasymetric-based approaches should not be used. A second important area is the impact of the control zones and the possibility that they may introduce bias to results for certain target zones for many dates. An example of this would be where pre-World War Two data are interpolated using modern ancillary data, new towns will have an impact on the results of certain target zones even though they did not exist at the source date. Careful choice of target zones is another way of reducing the impact of error, in particular, allocating data from source zones with large, dense populations to target zones with small, sparse populations should be avoided where-ever possible.

Even taking all this into account, however, error will still be present in the interpolated data. This can be handled by some post-interpolation actions such as temporal smoothing or analysing the data in a manner that attempts to incorporate the uncertainty introduced by the error. In addition, when interpreting any patterns produced by either analyses or visualisations of the interpolated data, the possible impact of error must be taken into account.

The presence of error introduced by areal interpolation is a weakness, however, traditional analyses also contained error and inaccuracy that was usually not acknowledged. This error came mainly from over-simplification. Any analysis performed at county-level lost an enormous amount of spatial detail, and thus would filter out the effects of many processes that operate at lower scales. They would also often ignore the fact that counties themselves would be affected by boundary changes that may have a significant effect on their populations, and that any results would tend to produce stronger correlations between variables than was warranted due to the level of aggregation that they used. Analyses that used only two snap-shots to explore change are again over-simplified. The areal interpolation approach allows national-level analyses to be performed using as much of the temporal and spatial detail as possible within the constraints of the original data source. The fact that this introduces a certain degree of error only becomes a major problem if the possible impact of this error is ignored.

Chapter 6: An application of areal interpolation: Long-run trends in net migration

6.1: Introduction

This chapter takes the interpolation methodology described in detail in chapter 5 and applies it to a problem in historical geography: namely the calculation of district-level decadal net migration rates¹. The rates are sub-divided by age and sex and calculated over the long-term. The aim of the chapter is to show how through the manipulation of the spatial component of relatively simple historical data, value can be added to both the attribute and temporal components. The datasets used are census tables concerned with the age and sex structure of the population, and mortality data from the *Registrar General's Decennial Supplements* giving age and sex specific data on the number of deaths over a decade. These basic statistics were published every decade and, although they have a standardised attribute definition, they suffer from the usual problem of changing administrative units. This chapter shows that standardising these units not only allows long-term comparison, it also allows new datasets to be generated concerning net migration. These, in turn, provide a better understanding of the population structure of the past.

The chapter again focuses on Gloucestershire and covers the 50 year period from 1881 to 1931. The aim is to demonstrate the use of areal interpolation using the example of net migration rather than to provide a comprehensive analysis of migration in Gloucestershire. Registration Districts from 1911 are used to provide a standardised administrative geography for the calculation of net migration rates. There are two reasons for using this approach: firstly, it removes the impact of boundary changes and so allows net migration to be calculated, and, secondly it allows long-term time-series to be developed. The five decades chosen allows the demonstration of the technique's ability to handle both the change of administrative units that occurred after 1911, and the constant stream of more localised boundary changes. The fact that the period covers the change in administrative systems means that it is one of the most challenging periods that could have been chosen. The chapter is in many ways a pilot

¹ An earlier version of this paper appears as Gregory (2000). I am grateful to Anne Knowles (Newberry Library, Chicago) and Brian Gratton (Arizona State University) for their comments on the draft of the paper which led to the chapter being significantly improved. I am also grateful to Eilidh Garrett (University of Portsmouth) for her pointers to the literature on migration.

project to demonstrate the strengths and weaknesses of the approach used. Once the GIS is complete the analysis will be repeated for the entire country for the period from 1851 to 1991 and could be extended to 2001 once these data become available.

Chapter 1 argued for analyses through time and space to incorporate the maximum amount of attribute, spatial and temporal detail possible. In the context of studying net migration using data from the printed census reports this means that the following characteristics would be desirable in the data:

- They are at district-level rather than county-level.
- They use every available decade.
- They sub-divide migrants by age and sex.
- The data are created for standard administrative units over the long-term. This allows long-term time-series to be developed that refer to the same spatial area through the series.

The literature review will show that most census-based studies of England and Wales have some of these elements but none have all of them. In this chapter data are created that do have all of these characteristics with two exceptions: they only cover the period 1881 to 1931 and they only cover Gloucestershire, however, the chapter proves that the analysis can be repeated for the entire country for all decades at which data are available.

6.2: Research on historical migration

This literature review is only concerned with migration as the movement of people. It does not attempt to look at migration in terms of its effects or impacts such as the creation of immigrant cultures (Southall, 1991a). Lee (1966) defines migration as “a permanent or semi-permanent change of residence. No restriction is placed on the distance of the move or upon the voluntary or involuntary nature of the act... Thus a move across the hall from one apartment to another is counted as just as much an act of migration as a move from Bombay, India to Cedar Falls, Iowa... Excluded [from this definition] are the continual movements of nomads and migratory workers, for whom there is no long term residence, and temporary movements like those to the mountains for the summer” (p. 49). A different definition is given by the United Nations International Research and Training Institute for the Advancement of Women (INSTRAW) who state “Demographers define migration, whether internal or international, as a change in the place of residence involving movement across a political or administrative border.” (p. 1). Clearly these two definitions are significantly different and the type of definition used depends very much on the data available to the study. Lee’s definition covers the migration of individuals and is thus

very demanding of the data, which need to be spatially and temporally detailed and at the individual level. INSTRAW's definition moves the emphasis from the individual to administrative units so that a change of residence only becomes a migration if it involves crossing an administrative boundary. The amount of migration is, therefore, heavily dependant on the administrative geography and especially the size of units used. The advantage of this approach is pragmatic in that data are more readily available.

Measuring migration according to Lee's definition requires migration to be continuously recorded with a precise date and details of change of residence. In some countries, such as Switzerland, this is a legal requirement, and in many countries information with approaching this level of detail is recorded in, for example, health records. Data in this form are not, however, usually made publicly available. In Switzerland, for example, each year the number of migrations into and out of each parish are published while intra-parish migrations are not (White & Woods, 1980). This means that while the data are collected in the form required to research individual-level migration they are only published in a manner suitable for an administrative geography-based approach.

The study of migration is, therefore, highly dependent on the data available. The spatial and temporal resolutions of data are both very important. Due to data limitations, most studies are reliant on some definition of a place as part of their definition of migration. Where the study is census-based this is likely to be a formal administrative unit, for other studies based on, for example, population registers, a less formal definition of space such as a town may be used. Temporal resolution is also very important. Census-based studies are limited to decennial snapshots, other sources may give more temporal detail but the difficulties of collecting these data usually limit the scope of such studies. The attribute resolution of data is also very important as patterns of migration vary significantly by age and sex, but many studies do not have data in a form that allows them to break migration down in this way.

The study of migration has a long history and migration is inextricably linked to other processes that have shaped the socio-economic landscape of England and Wales (Clarke & Souden, 1987). The main aim of this literature review, however, is not to give a detailed literature review on the study of migration and migrants in England and Wales over the last two centuries. Instead, it attempts to demonstrate how the study of long-term migration trends has been limited by the availability of data and to demonstrate some of the techniques that have been used in the past in an attempt to overcome these limitations.

Before doing this, however, it is important to give some basic definitions. Data on the total number of migrations is termed *gross migration*. It is normally measured as the number of people who entered or left an area. One common measure of gross migration is *population turnover*: the number of migrants entering an area over a period plus the number leaving usually expressed as a ratio of the average population of the area (Woods, 1979). Some modern censuses quantify gross migration by asking people where they lived at a certain time before census night, usually one year or five years. This gives one measure of gross migration over administrative boundaries but, in the case of Britain, has only been available since 1961 (Norris & Mounsey, 1983) and only covers the year prior to census night. Data published in this way can also give information about migration flows: where in-migrants are coming from and where out-migrants are going to.

Where data on gross migration are not available there are several other measures that can be used instead. The first is *birthplace migration*. This is often available from census data in tables that cross-tabulate place of enumeration with place of birth. Birthplace migration does not give any information on the sequence of moves that the migrant took to get from their birthplace to the place of enumeration and knows nothing about the length of stay at either the birthplace, the place of enumeration, or any other places migrated to and from en route. It does, however, give data on flows (White & Woods, 1980).

A derived measure of an administrative unit's migration is *net migration*. This is calculated from population and mortality data using what Woods (1979: p. 166) calls the "basic demographic equation" that measures the change in population from time t to time $t+n$:

$$p^{t+n} = p^t + B^{t,t+n} - D^{t,t+n} \pm NM^{t,t+n} \quad (6.1)$$

where p is the population, B is the number of births, D is the number of deaths, and NM is the net migration. If data on the population at t and $t+n$ and the number of births and deaths between these dates are known then net migration can be calculated as the residual part of population change that is not accounted for by natural increase:

$$NM^{t,t+n} = p^{t+n} - p^t - (B^{t,t+n} + D^{t,t+n}) \quad (6.2)$$

This formula can also be applied to age and sex specific population cohorts by using data on the cohort's population, deaths and, if appropriate, births. A positive number means that the unit was experiencing net in-migration, a negative number shows net out-migration. The results of this formula are error prone as any process that affects the population or natural increase over the period that is not explicitly included into the formula will appear as net migration. These particularly include

census under-enumeration (Champion, 1995), the under-reporting of births and deaths, and incorrect recording of age if cohorts are used (Tillot, 1972; Teitelbaum, 1974; Woods, 1979). The other issue that this formula also relies on is, of course, the absence of boundary changes (see chapter 2 of this thesis). The formula could, more fully, be written as:

$$NM^{t+n} = p^{t+n} - p^t - (B^{t+n} + D^{t+n}) + BC^{t+n} \pm \varepsilon \quad (6.3)$$

where BC refers to the population gained by boundary changes and ε is the impact of error.

The classic work on migration research was performed in the late nineteenth century by Ravenstein (1885). This was mainly based on the birthplace data from the 1881 census and came to the following major conclusions:

1. That the majority of migrants move only a short distance.
2. Migration proceeds step by step, in that the places of out-migrants are filled by in-migrants from more remote areas.
3. Each migration current produces a compensating counter-current.
4. Longer distance migrants tend to go to towns.
5. The urban born are less prone to migrate than the rural born.
6. Females are more migratory than males but migrate over shorter distances.
7. Most migrants are adults.
8. Large towns grow by migration more than by natural increase.
9. Migration increases in volume with economic and transport improvements.
10. The majority of migration flow is from agricultural areas to large towns.
11. The majority of causes of migration are economic.

(summarised from Clark & Souden, 1987: p. 19)

These conclusions seem to be broadly agreed with by most researchers although some have argued with some aspects, for example, Pooley & Turnbull (1996) found no evidence for the idea of migrants moving up the urban hierarchy by steps or the concept of counter-currents, and Lawton (1965) provides figures that refute Ravenstein's claim that migration was a more important factor in the growth of towns than natural increase.

Three main approaches to the study of the history of migration in England and Wales can be identified based on the type of source or sources that they use:

- The first approach uses census and sometimes vital registration data to analyse migration into and out of administrative units based on decennial snapshots. These are

usually concerned with net migration but sometimes include information on gross migration and migration flows.

- Secondly, life histories and record linkages can also be used. These usually provide more spatial and temporal detail than census-based studies and are often based on individual rather than aggregate data. However, they usually consist of a non-representative sample of the population and are restricted by the limitations of a source that was often collected for an entirely different purpose.

- The third type of study are those that use sources such as diaries and oral evidence. These are much more qualitative studies than the other three and can provide information on the reasons for and effects of migration in a much more personal way than the others.

Saville (1957) provides a relatively simple example of a census-based study. He was concerned specifically with rural depopulation between 1851 and 1951, and argued that through the nineteenth century towns had grown rapidly for three reasons: a high rate of natural increase, in-migration from rural areas, and immigration from Scotland, Ireland, and the rest of the world. The main reasons for rural depopulation, he claimed, were a lack of employment opportunities, and this was felt particularly keenly by women who were drawn to towns especially for employment in domestic service. His methods of demonstrating this are crude. He presents a county-level analysis covering the period 1851 to 1931. The reason for stopping in 1931 is not explained but is probably due to the lack of a 1941 census. The analysis is concerned with net migration calculated as a residual in the manner described by equation 6.2. This was done using the data on population and natural increase provided by the printed census reports. The natural increase data are only provided for total population and so do not allow migrants to be distinguished by age or sex. He attempts to get round this problem by commenting on the age distribution and sex ratios of national aggregates of Rural Districts and Urban Districts and attributing the differences in the patterns found to migration. Unsurprisingly, he finds it hard to discuss the differences in rural and urban trends using county-level data, but he attempts to do this by contrasting two examples: Rutland and Warwickshire, which he classes as a rural and an urban county respectively. He also focuses on one part of Devon to provide a detailed example of the experience of a rural area. It is clear, therefore, that this study that attempts to examine long-term change in rural depopulation is fundamentally weakened by its data: it is based on county-level data and is unable to distinguish by age or sex so that surrogate indicators have to be used in highly aggregate form. This results in over a quarter of the pages in the book being based on a detailed case-study of 18 parishes in Devon and even here the author admits that two parishes that should

have been included were not because they were affected by boundary changes (p. 174).

In summary, the study has little attribute detail and has had to sacrifice spatial detail to allow the creation of near constant units that cross the change from Registration Districts to Local Government Districts. The result of doing this has seriously limited the study's ability to achieve its aims.

Cairncross (1949) provides another example of a census-based study. He uses the same data as Saville (1957) to calculate net migration as a residual. It is a national-level study that uses 160 artificially created units formed by aggregating Registration Districts to represent the major towns, coal-fields, and what are termed "rural residues". The author acknowledges that part of the reason for using these aggregates was to remove the impact of boundary changes. It could be speculated that the only types of boundary changes considered when the aggregations were created were mergers and divisions. The results are tabulated by distinguishing north and south and classifying towns into: large, textile, industrial, old, residential, and military. This is, therefore, an attempt to explain the different patterns of migration by type of area. Using what the author admits are arbitrary aggregations of Registration Districts inevitably limits the effectiveness of this.

Cairncross covers the period from 1841 to 1911. He states that "The calculations cannot unfortunately be continued up to 1931. Since 1911, returns of births and deaths have ceased to be made up of the old registration districts, which have been superseded by urban and rural districts. It is not possible, therefore, to compare post-war and pre-war experience on the basis of the statistics given here." (p. 69). The study does manage to use spatial units that are more meaningful than Saville's (1957), but they are still arbitrary aggregations of the source data. Using these, however, has the cost of the study ending in 1911 against the wishes of the author. Like Saville (1957) the study is unable to sub-divide migrants by age and sex.

Lawton (1968) manages to conduct a national study at district-level of long-term net migration. Like the other authors, he uses the residuals of population change and natural increase to calculate Registration District-level net migration figures for the period 1851 to 1911. He publishes some time-series graphs showing population change, natural increase, and net migration for individual Registration Districts but makes no comment on how boundary changes were handled. If a district's boundaries changed over the sixty years, therefore, the graph would not be referring to the same spatial area at the end of the period as at the start. This study also finishes in 1911 because "Not only is this the last census before the First World War ..., but it is also the last in which the Registration District was used as the basis of enumeration of

natural and migrational components of population trends” (p. 73). Again this study is unable to distinguish migrants by age or sex, but it does manage to use district-level data for the whole country for every decade in its period. Unfortunately, the period it covers is ended by the change in administrative geography and, although it generates time-series these are not necessarily for constant units.

Welton (1911) conducts a national-level study that manages to sub-divide migrants by age and sex but that was forced to restrict its spatial and temporal components. He combined specific population data from the census with birth and death data from the *Annual Reports of the Registrar General* that were also age and sex specific. This enabled him to sub-divide net migration into five and ten year age cohorts and by sex. Spatially, he follows an approach similar to Cairncross (1949) by creating 136 aggregations of Registration Districts classed into categories such as “large towns”, “colliery districts”, “residential districts”, and so on. Boundary changes are handled partly through this aggregation process, but also through what he terms “re-transferring” population presumably through the use of the boundary change tables included in the *Registrar General’s Decennial Supplements* that include the number of people affected by a boundary change. The study is national level but only covers the time period from 1881 to 1901. In spite of these limitations, he is able to offer insights that are beyond those provided in the later studies described above. For example, he says that “old towns” tend to gain females aged 15 to 20 through migration and people of both sexes aged over 50, while losing males aged 20 to 30. It is clear that producing his volume took a fantastic amount of work and this may be why it has not been repeated.

An earlier study by Lawton (1958), looked at migration flows rather than net migration. This was done using birthplace data from the census and focused on a relatively short period of time: 1841 to 1861. It only covers the three West Midland counties: Staffordshire, Warwickshire and Worcestershire and was done at Registration District-level. It focuses on out-migration from the West Midlands by looking at where people born in the West Midlands but enumerated elsewhere were enumerated. In-migration to the West Midlands was examined by looking at where people enumerated in the West Midlands but born outside had been born. It is unable to distinguish the age and sex of migrants. This is, therefore, a more detailed study as it uses birthplace data to provide information on flows rather, however, this is achieved by focusing on a short time period, 20 years, and a relatively small part of the country.

Friedlander & Roshier (1965) take the census-based approach one stage further by combining the approach of calculating net migration as a residual with using

birthplace data that, based on certain assumptions, allowed them to combine net migration with migration flows. This was a county-level study based on decennial data from 1851 to 1911 but then the periods 1911 to 1931 and 1931 to 1951. The reason for the longer periods after 1911 was that the birthplace data required were not published in 1921 or 1931 and there was no 1941 census. This meant that 1931 data had to be estimated to allow the analysis to move into the twentieth century, albeit based on a cruder temporal framework. The data used provided cross-tabulations of the county of enumeration and the county of birth. For 1931 data this was estimated using the 1931 data on those born and enumerated in the same county and the total population enumerated in each county and combining this with the more detailed data available for 1911 and 1951 under certain assumptions.

The basic equation to calculate inter-county net migration flows, therefore becomes:

$$\mu_{ij} = m_{ij}' - m_{ij} + d_{ij} \quad (6.4)$$

where μ_{ij} is the migration stream from county i to county j , m_{ij} is the number of people born in county i and enumerated in county j at one date and m_{ij}' is the same data for the following date. d_{ij} represents the number of inter-censal deaths of persons born in i who had migrated to j before the first date. The difficulty for the study was to estimate the values of d_{ij} . This was done based on the somewhat questionable assumption that the age distribution of migrants over time was constant. Using this, the authors were able to produce tables of the inter-censal net migration flows between all counties for the eight periods for which they had data covering the period from 1851 to 1951. Even though this was a county-level study, however, there were still acknowledged problems with boundary changes. This led to the authors only considering migration flows between non-adjacent counties and stating that boundary changes were a major reason for this. The study still provides significant amounts of extra knowledge compared to basic net migration studies showing, for example, that in the 1860s the majority of migrants into Glamorganshire came from nearby parts of south Wales rather than further afield. The study is clearly impressive, being done before modern computing power became available. The fact that it is county-level and that the analysis was only able to consider flows between non-adjacent counties is clearly a limitation as it restricts the authors to only considering long-distance migration. Again migrants are not distinguished by age or sex.

A major limitation of census-based approaches is that due to the nature of their source data they are temporally limited to decennial snapshots and spatially limited by the type of units used, be those districts or counties. To get more detail on individual migrations other researchers have used more detailed sources. Southall (1991b) uses

this approach to analyse the migrations of members of the Steam Engine Makers trades union based on the union's *Annual Reports* from 1835/6 to 1845/6. These provide data on which union branch individual members were registered with, thus providing information on where the member was living. In addition, they also provide a record of the movements' of individuals by recording their movements from branch to branch. This means that migration is not defined as being a change of residence across an administrative boundary, but is a change of residence that requires the individual to register at a different branch. The study, therefore, is spatially limited to branch-level, which roughly corresponds to town-level in areas such as the north-west where these artisans were concentrated.

The results showed that over the period 49% of long-term members did not move at all, 15% moved within a county at least once, 30% changed counties at least once, and 6% went abroad. The paper is particularly interested in migration in response to economic hardship, something that this approach is much more suitable to as opposed to the use of decennial snapshots. In the 1841/2 depression 19% of union members moved and they covered an average distance of 334 miles. The study was also able to sub-divide migrants by age and showed little evidence of the young migrating more than the old. The drawbacks of the study are that it is restricted to members of the union, and to a fairly short time period defined by limitations of the available data. Union members were skilled manual workers who were male, of working age, and strongly biased towards the north-west of England. One of the main reasons unions were set up was because of the mobile nature of this type of employment and the fact that unions existed may well have encouraged their members to be mobile. This study, therefore, has a much better temporal resolution than the census-based studies and also has an improved attribute resolution that allows migrants to be distinguished by age. Spatially the study approximates to district-level. Its drawbacks are that it covers a limited time period, ten years, and, because of the limitations of the source, is focussed on a single occupational group that only covers males and is, concentrated in the north-west of England.

A similar study was carried out by Pooley (1995). This used the police records of Kendal, a market town in the north-west of England. The records list all people charged with crime and detained in prison in Kendal and gives their previous convictions including the place where the offense was recorded, and the occupation, age, sex, place of origin and fixed address of the detainee. Again this allows quite detailed reconstructions of the movement of a small subset of society, namely persistent criminals to be built up but suffers from the same disadvantages as Southall's (1991b) study. Defining the spatial resolution of this study is harder than for Southall's, but is again probably around town-level. This study is not able to

distinguish between mobility and migration as it is unclear whether someone was arrested in the place they lived or a place they were merely visiting.

Pooley & Turnbull (1996 and 1998) attempted to gain similar amounts of information on individual migrations from a wider subset of the population by using information collected by family historians to create a large database of the history of the migrations of people born between 1750 and 1930. They used an extensive network of family historians to create a database of 16,091 people who moved a total of 73,864 times. The data collected included when the individual moved, where they moved from and to, who they moved with, employment and housing change, and other key life events. The definition of migration that they were able to use was not dependent on administrative boundaries or places where recording took place, such as Southall's trades union branches, but is instead much closer to the ideal definition proposed by Lee (1966). They were able to show, therefore, that between 1750 and 1839 average distance moved in a migration was 37.7kms but that 39% of migrations were less than 5km. In the period 1880 to 1919 the average distance of a migration had remained roughly the same but 56% were now moves of less than 5kms. They acknowledge, however, that some of the shorter migrations, especially in the early period, may be under-represented.

Their results also show that only 17.8% of migrations were to larger settlements in 1880 to 1919, roughly the same number as moved to smaller settlements. 47.9% of migrations in this period were within the same settlement and 16.9% were to another settlement of a similar size. They found only limited evidence for Ravenstein's concept of stepwise migration with most migrants who moved up the urban hierarchy going directly to the large towns and cities. Movement up the urban hierarchy were likely to occur early in life with movements to smaller settlements occurring later. Most migrants moved as a family but the longer moves and movements up the hierarchy were most likely to be made by the young and single. They found no significant differences in the distances moved by males and females and found that employment and marriage were the most common reasons for moving.

This database, therefore, undoubtedly reveals much more about the migration of individuals than any of the other sources given above. There are, however, questions about the representatives of the source. To investigate this Pooley & Turnbull (1996) compared their database with the census reports of 1801, 1851, 1891 and 1951. This revealed that males were over-represented, especially prior to the 20th century with 22% of the database population in 1801 being female compared to 52% in the census. By 1951 these figures were 44% and 52% respectively. The database also over-represents those who married and lived to old age and those in higher socio-economic

groups but covered the country geographically quite well. The study can, therefore, examine national-level migration over the long-term in a manner that is spatially and temporally detailed enough to measure migration in a manner approaching Lee's (1966) definition. Its drawbacks are the enormous amount of work involved in collecting the data and the biases in the sample.

The final approach, the use of diaries and oral history, is much more qualitative and has been used by authors such as Bartholomew (1991). These focus on a limited number of individuals but provide far more personal information on the causes and consequences of migration.

	Main Source	Spatial detail	Spatial extent	Temporal detail (years)	Temporal extent	Pop. Covered	Sub-division of migrants	Migration type
Saville	Census	County	National	10	1851-1931	All	Tot Pop	Net
Cairncross	Census	160 aggregates	National	10	1841-1911	All	Tot Pop	Net
Lawton (1968)	Census	RD	National	10	1851-1911	All	Tot Pop	Net
Welton	Census	136 aggregates	National	10	1881-1901	All	Age & sex	Net
Lawton (1958)	Census	RD	West Mids	10	1841-1861	All	Tot Pop	Flows
Fried & Rosh	County	County	National	10	1851-1951	All	Tot Pop	Net flows
Southall	Union records	Town	North West	1	1835-1846	Union members	Age	Individual
Pooley	Police records	Town	North West	Variable	1880-1910	Persistent criminals	Age & sex	Individual
Pooley & Turnbull	Family histories	Individual	National	N/A	1750 on	Sample	Age & sex	Individual

Table 6.1: A comparison of approaches to the study of historical migration.

Sources: Saville (1957); Cairncross (1949); Lawton (1958 and 1968); Welton (1911); Friedlander & Roshier (1965); Southall (1991b); Pooley (1995); Pooley & Turnbull (1998). Note: RD-Registration District.

The various approaches described above are summarised in table 6.1. It shows that the census is a relatively crude tool for understanding migration as it is based on decennial snapshots for spatially aggregate data. It does, however, allow national-level research to be performed that focuses on the whole of society rather than the individual migrations of a subset of the population. There are some clear deficiencies in much of the census-based work described above that is highlighted by the findings of researchers such as Southall (1991b), Pooley (1995), and Pooley & Turnbull (1996). A major problem with census-based studies is that they have not been able to subdivide migrants by age and sex, have a relatively crude level of spatial and temporal detail. Potentially, however, if vital registration data can be included, census-based studies allow a study of the national population of district-level net migration from the 1850s to the present, with the lack of a 1941 census being the only

major obstacle. The traditional obstacle to this, as acknowledged by many authors, has been the boundary changes and incompatible administrative units. The methodology outlined below shows how the GIS can solve some of these problems.

6.3: Methodology

In the absence of boundary changes and assuming, for now, that there is no error in the data, net migration over a decade can be calculated as the residual of population change and natural increase as was demonstrated by formula 6.2. In this chapter, however, net migration rates are required for age and sex specific population cohorts. Calculating these for an administrative unit is, in theory, also very simple. If the cohorts do not include infants being born, then the data required are simply the size of the cohort at the start and end of a period, and the number of people in the cohort who died over the period. To calculate net migration among the population of either males or females aged a to $a+9$ at the start of decade t to $t+10$ the formula becomes:

$$NM_{a,a+9}^{t,t+10} = P_{a+10,a+19}^{t+10} - P_{a,a+9}^t + D_{a,a+10:a+10,a+19}^{t,t+10} \quad (6.5)$$

This can be converted to a rate by dividing by the population of the cohort at the start of the decade p^t . The youngest cohort it is possible to estimate in this manner are those age 5 to 14 at the start of the decade, to calculate a younger cohort would require fertility to be included into the equation.

Calculating this for the period from the 1880s to the 1920s, therefore, requires two basic datasets: the population of each administrative unit sub-divided into ten-year age bands and by sex from every census from 1881 to 1931, and the number of deaths in each cohort over the inter-censal periods. These need to be interpolated onto standardised units to remove the impact of boundary changes.

a. The data

Age and sex specific data on the population is provided by the census, while data from the *Registrar General's Decennial Supplements* provides age and sex specific mortality data. The data from the census is particularly unproblematic: every census since 1851 has published district-level data on the population sub-divided into 5 year age bands and by sex up to at least the 90 to 94 year old band.

The mortality data are slightly more problematic. The *Decennial Supplements* from 1881 to 1911 give the number of deaths over the decade for each district in five-year age-bands from ages 5 to 9 to ages 20 to 24. Deaths between the ages of 25 and 74 are given in ten-year age-bands and there is the category for those aged 75 and above. All of these data are sub-divided by sex. This means that the number of deaths in the cohort over a decade has to be estimated. This is relatively straightforward based on the assumption that there is an equal chance of each death occurring in each

year of the decade and at each age covered by the band. This means that, for example, the deaths in the cohort aged 35 to 44 at the start of a decade (aged 45 to 54 at its end) are estimated by adding half of the deaths between ages 35 to 44 over the decade plus half of the deaths between the ages of 45 and 54. The other half of each band's deaths will be allocated to the 25 to 34 and 45 to 54 year old cohorts respectively. Were the elderly or the very young to be included in the analysis this would be problematic. As these data are concerned with ages at which deaths are relatively rare, this is not seen as an important limitation. The amount of potential error this introduces into the net migration estimates will be discussed later in the chapter.

The number of deaths in each cohort can, therefore, be estimated for cohorts aged 5 to 14 to those aged 55 to 64 at the start of the decade. The 65 to 74 year old cohort can not be estimated as the number of deaths among 75 to 84 year olds would be required.

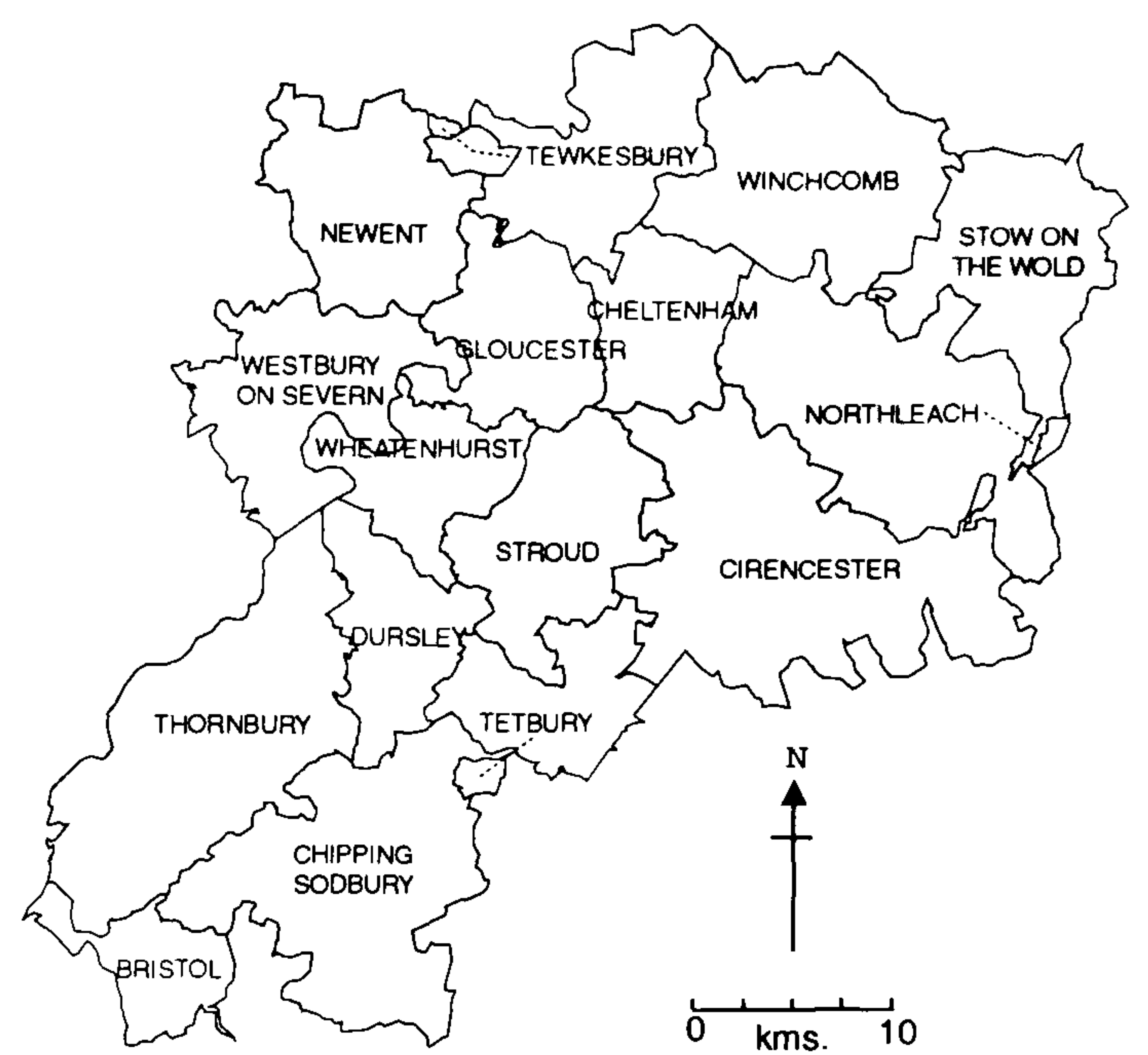
After 1911 the calculation of a cohort's inter-censal mortality becomes more complicated. The 1921 and 1931 *Decennial Supplements* provide the data using the same age-bands, but they are not as geographically comprehensive as the earlier *Supplements*. Rather than providing data for every district these *Supplements* give data for individual County Boroughs, but only give county-level aggregates of Rural Districts and what are termed "other urban districts", namely Municipal Boroughs and Urban Districts. The number of deaths in each district has to be estimated based on each individual district's population, taken from the census data, and the district's type. The implications of this will also be discussed later in the chapter. Once this has been done the number of deaths in each cohort over the decade can be estimated for all cohorts up to the 55 to 64 year olds. Again, the implication of this assumption for the calculation of net migration will be discussed later in the chapter.

b. Removing the impact of boundary changes

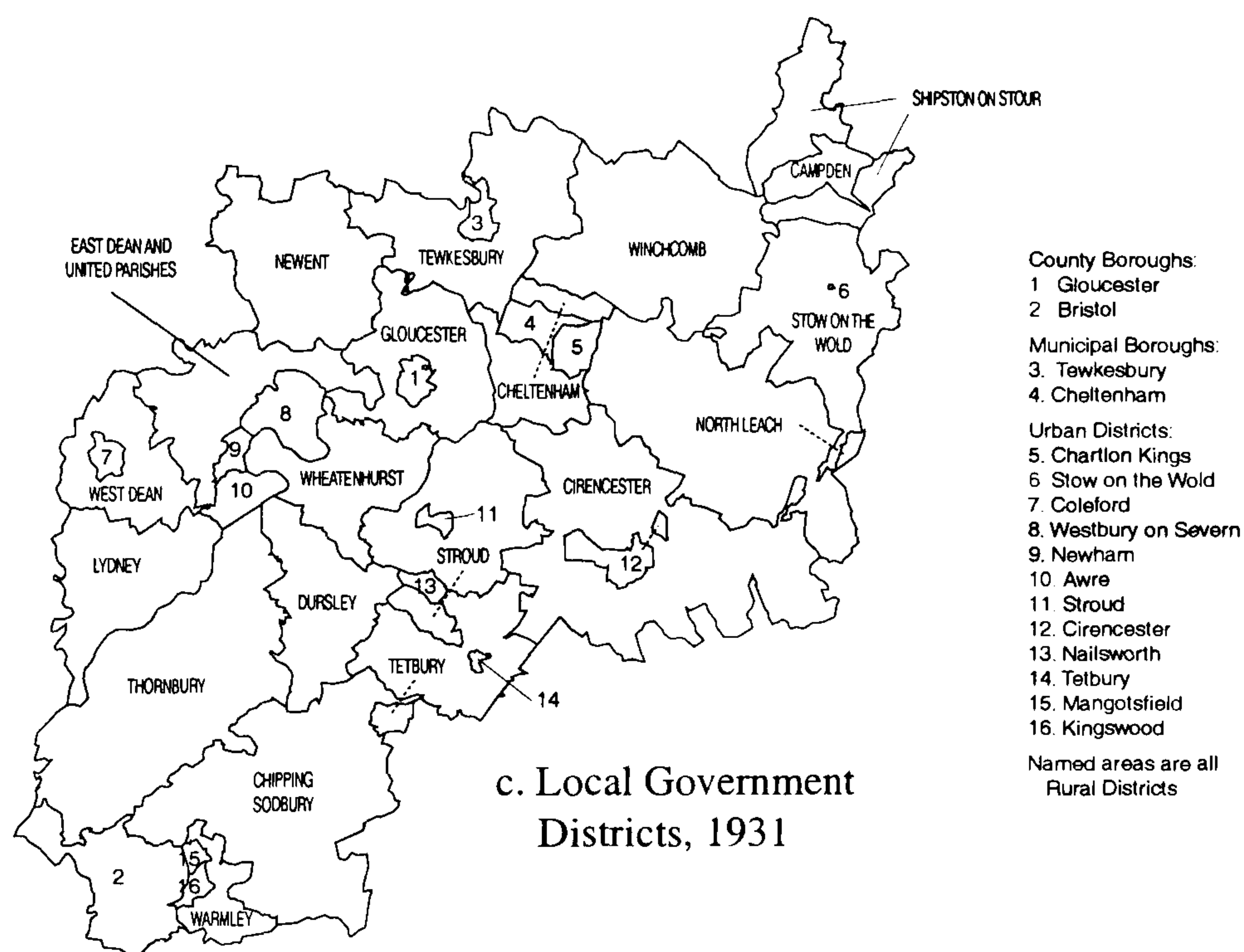
Data are, therefore, available that allow net migration to be calculated in the manner described by formula 6.5. For this to work all the data used must be interpolated onto a single, standardised administrative geography. An additional advantage of doing this is that long-term series time for constant units are derived. The consequence, however, is that a certain amount of additional error will be introduced to the data by the interpolation and this will affect the net migration estimates.



a. Registration Districts, 1881



b. Registration Districts, 1911



c. Local Government Districts, 1931

Figure 6.1: Administrative boundaries in Gloucestershire: 1881, 1911 and 1931.
Dotted lines join detached portions of districts to their main area.

Figure 6.1 shows the district-level administrative geography of Gloucestershire in 1881, 1911, and 1931. It shows the impact of the changes from Registration Districts to Local Government Districts, and also the boundary changes such as the expansion of Bristol Registration District and County Borough and the abolition of Barton Regis in 1905 as well as many smaller changes such as between Stroud and Tetbury in 1893 and Wheatenhurst and Stroud in 1895.

In this chapter, 1911 Registration Districts are again used as the target districts so the migration measured will approximate to the movement from one market town and

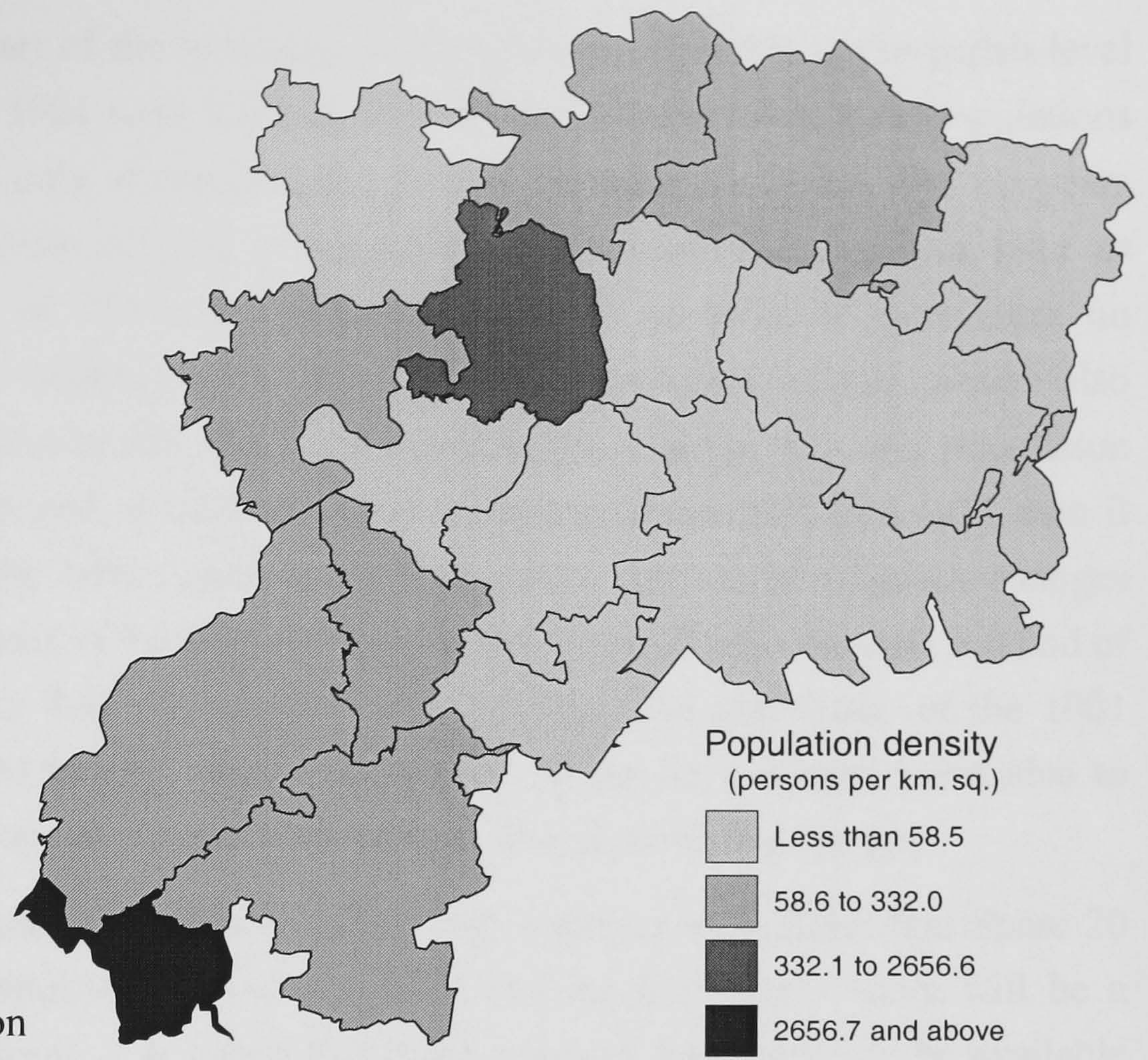
its hinterland to another (Hasluck, 1936), although clearly this was a highly arbitrary definition when the Registration District system was originally set up (see chapter 2) and will have been affected by changes in the population distribution over time. The combined dasymetric and EM algorithm technique described in detail in chapter 5 was used to interpolate all the necessary data onto these target districts. This means that population data and the mortality data are allocated to parish-level and then interpolated onto the target districts using control zones defined by data from the target units. The control zones were defined using nested-means of the density of total population in 1911 for the census data, and the total number of deaths in the 1900s for the mortality data. As is shown in figure 6.2, these produce slightly different patterns: with total population Bristol forms the highest zone by itself, Gloucester is the next highest again by itself and the lowest values are mainly found to the south and east of Gloucestershire. For mortality, Bristol again forms the highest control zone on its own while, Gloucester is joined by the adjacent district of Cheltenham in the second highest class. Thornbury, immediately north of Bristol, and Winchcomb in the north of the county are found in the lowest zone for mortality when they were in the second lowest for population, and Stroud is in the second lowest zone when it was in the lowest for population.

Parish	Reg. Dist	Population	
		1901	1911
Alkington	Thornbury	815	771
Almondsbury	Thornbury	2,213	2,160
Alveston	Thornbury	733	720
Aust	Thornbury	146	150
Berkeley	Thornbury	826	774

Table 6.2: Sample data from 1911 parish-level table (Source: 1911 census printed reports).

The dramatic increase in mortality rates from 1903 to 1911 provides a natural laboratory for testing the hypothesis that the spread of the disease was primarily due to the movement of infected individuals from the high mortality areas to the low mortality areas.

a. Total Population



b. Total Mortality

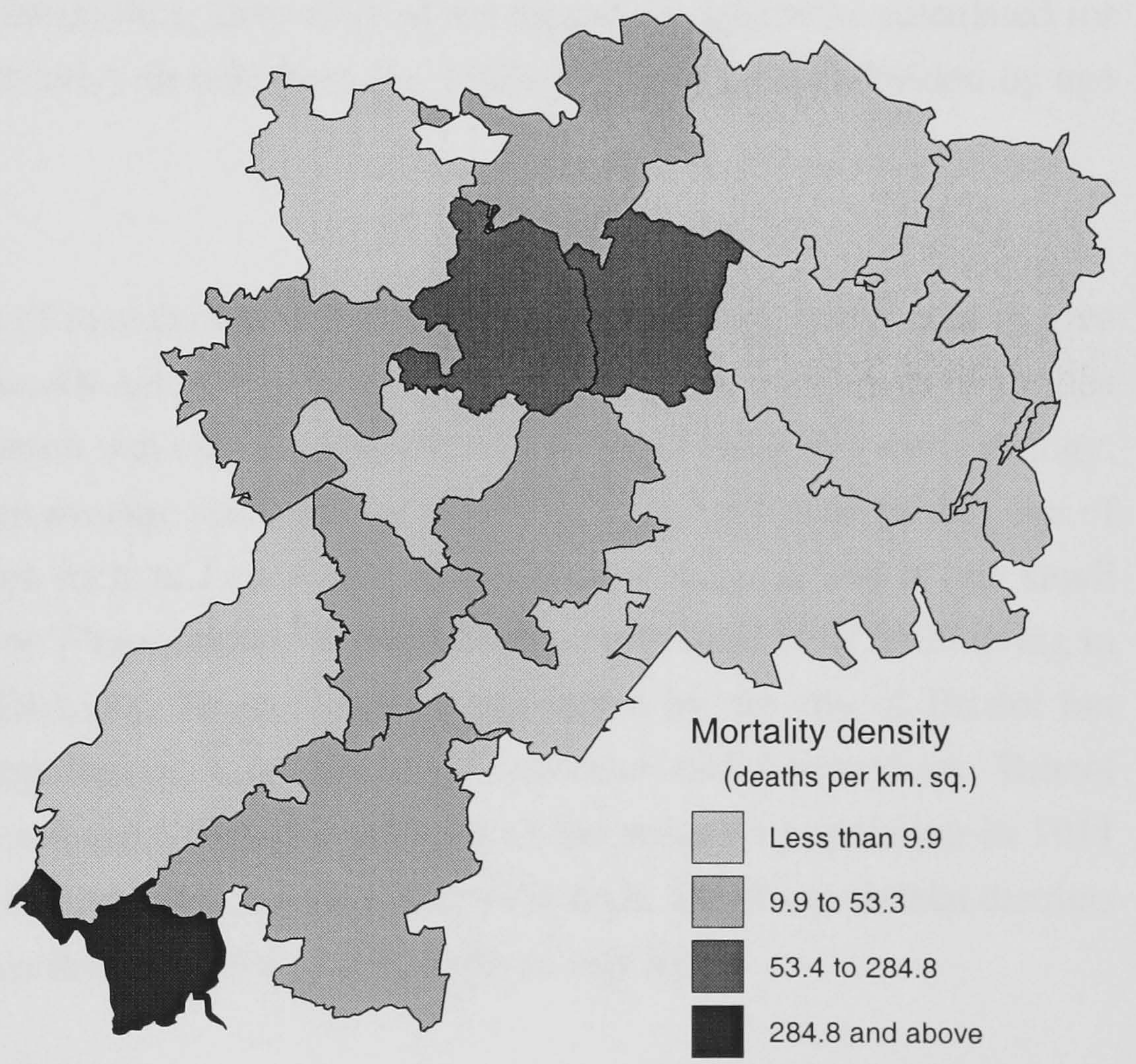


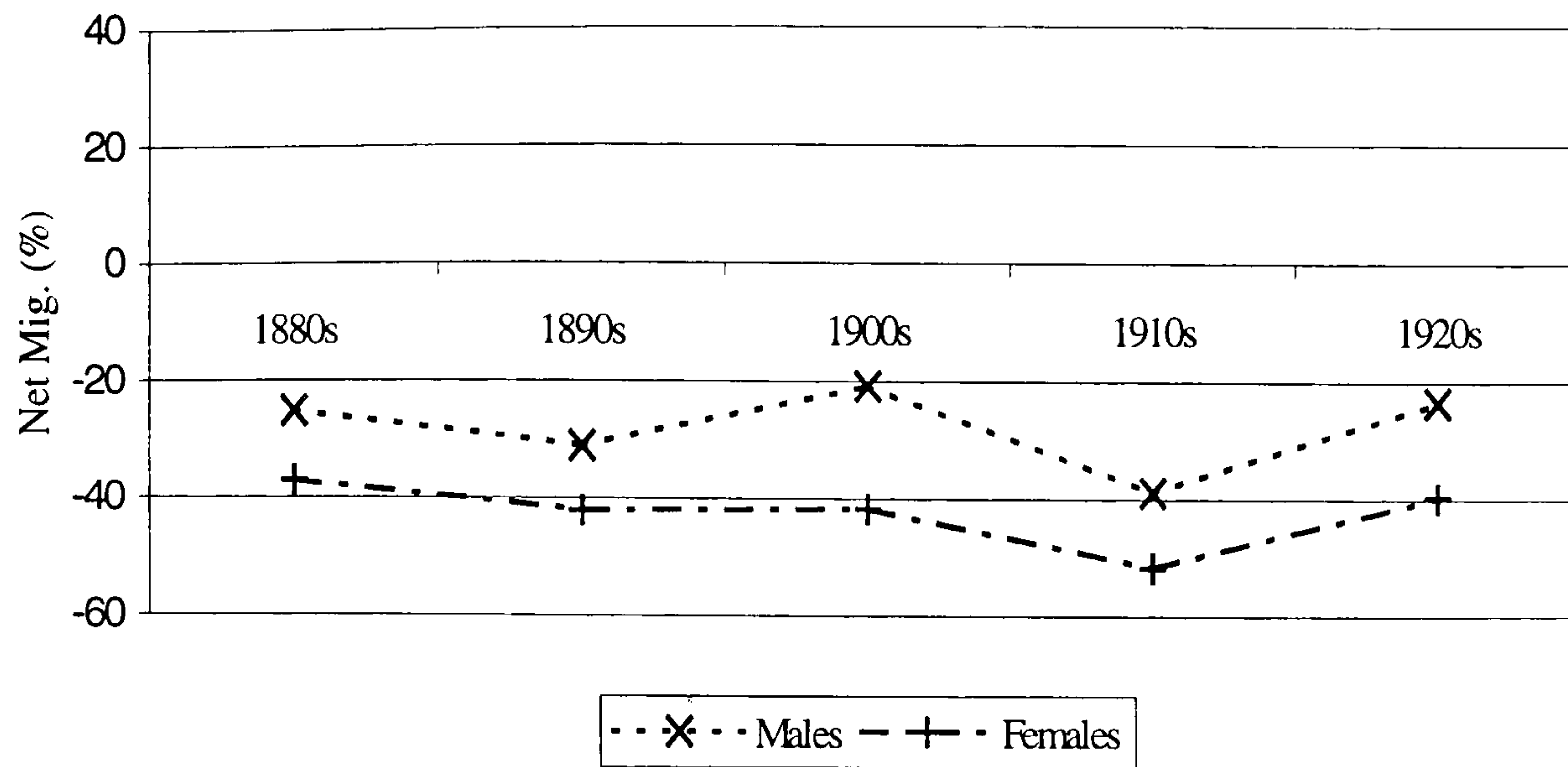
Figure 6.2: Control zones created from nested means of the relevant 1911 dataset.

The dasymetric part of the technique was slightly problematic as the parish-level tables from 1901 and 1921 were not available. All parish-level tables give populations for their parishes not only at census date but also for the same parish area ten years previously. Thus in table 6.2, the parish of Alkington was enumerated in 1911 as having a population of 711 and a population of 815 in 1901. If there were no boundary changes to Alkington in the 1900s then the 1901 census would also enumerate its population as 815. If there was a boundary change, the 1901 population would be different, indeed, if the parish was created between 1902 and 1911 then it would not appear in the 1901 census at all. Fortunately, the lists of boundary changes also give the populations of the area affected by the change at both the start and end of the decade (see figure 4.4). This allows us to calculate the population of the 1901 parishes as configured in 1901 where boundary changes have occurred and also to calculate the populations of parishes that were abolished during the decade.

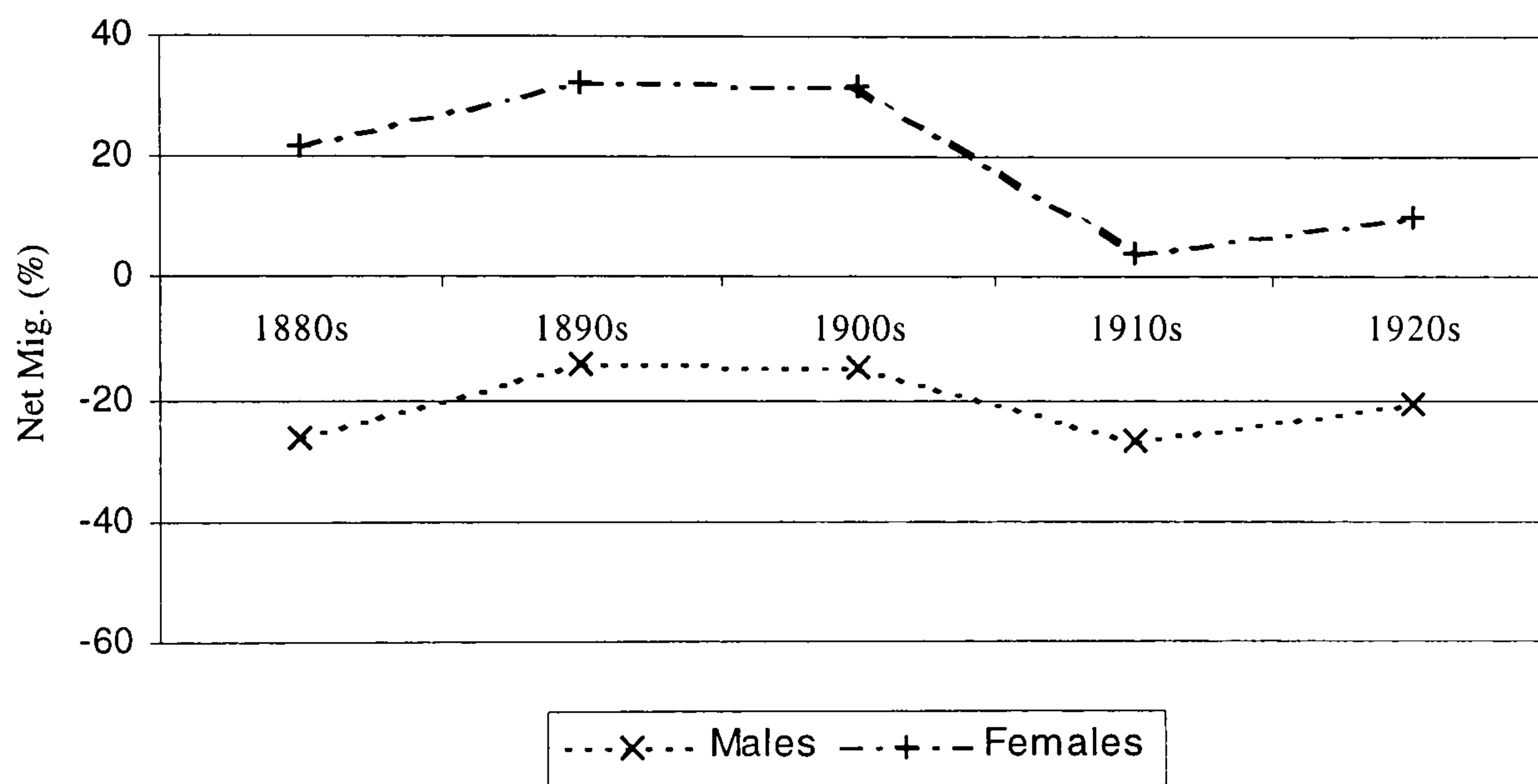
Running the program took approximately two hours on a 133MHz Sun Sparc 20 for each dataset interpolated. Obviously doing this for the entire county will be a lengthy process, however, it is hoped that more powerful hardware will be available before this is done. The resulting data allowed net migration rates to be calculated for each target district for every decade from the 1880s to the 1920s sub-divided by age and sex.

6.4: Results

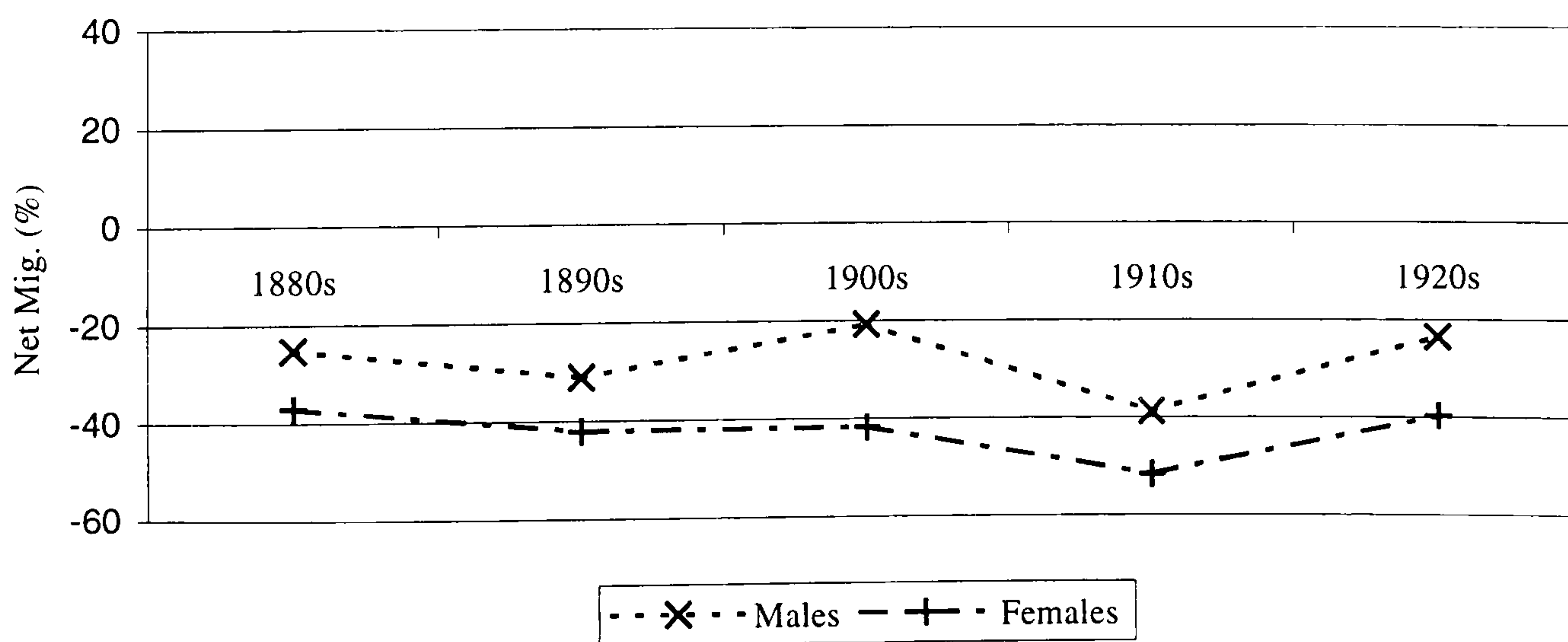
Although the aim of this chapter is to describe a methodology rather than to give detailed results, it is worth describing some of the results found as these give an idea of the type of information that can and cannot be discovered using this methodology. Gloucestershire was an average sized county at least in so far as it was neither one of the very large counties such as Lancashire or the West Riding, or one of the small ones such as Rutland or Westmorland. In 1911 it had a population of 672,570 living in sixteen Registration Districts. The county was dominated by the city of Bristol but had several other large towns, most notably Gloucester and Cheltenham. Bristol Registration District contained slightly over 50% of the county's population in 1911 while Gloucester and Cheltenham had just under 10% each. Six of the sixteen districts had a population of less than 10,000 or 1.5% of the county total.



a. Bristol



b. Cheltenham



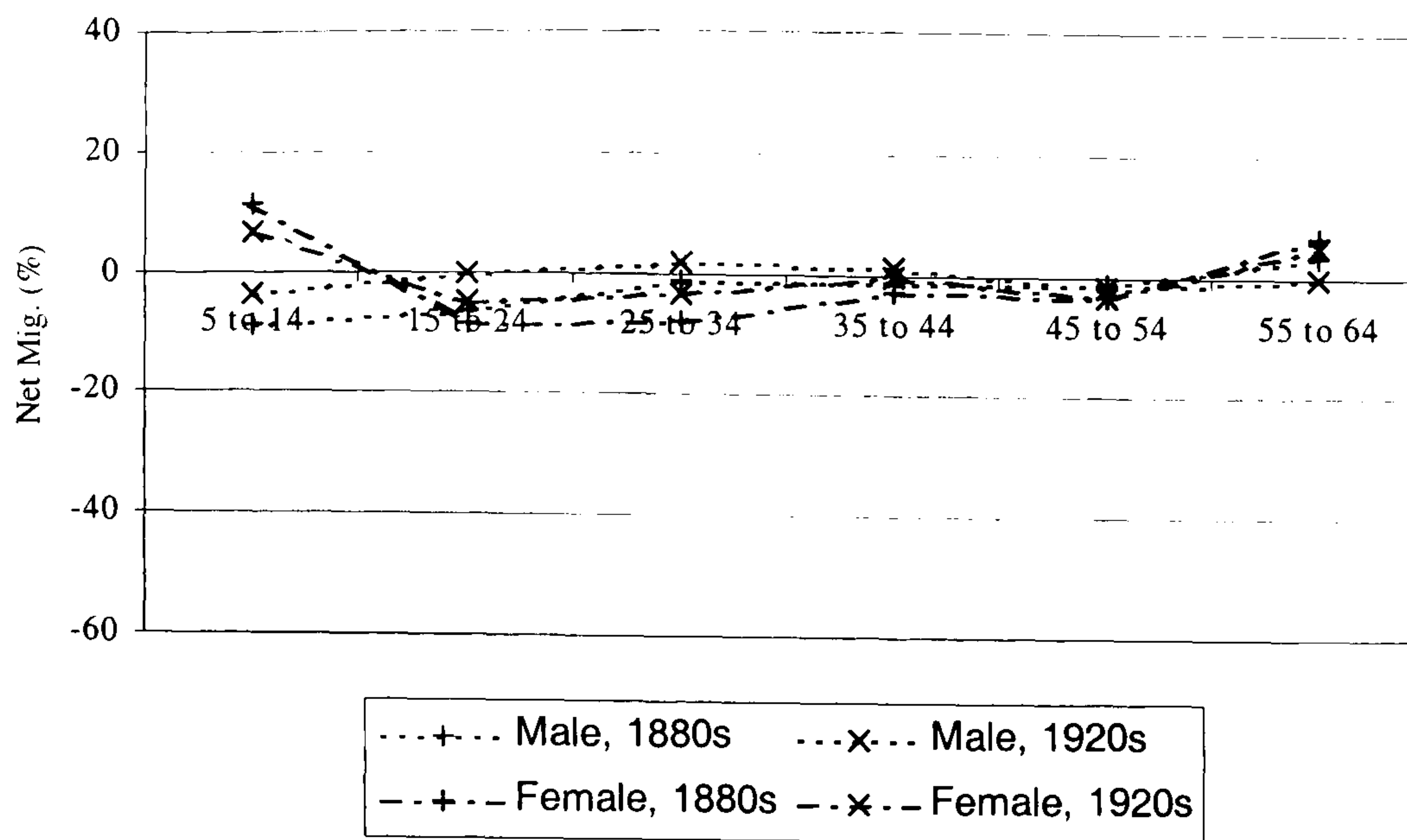
c. Westbury on Severn

Figure 6.3: Net migration time-series for the cohort aged 5 to 14 for three sample target districts.

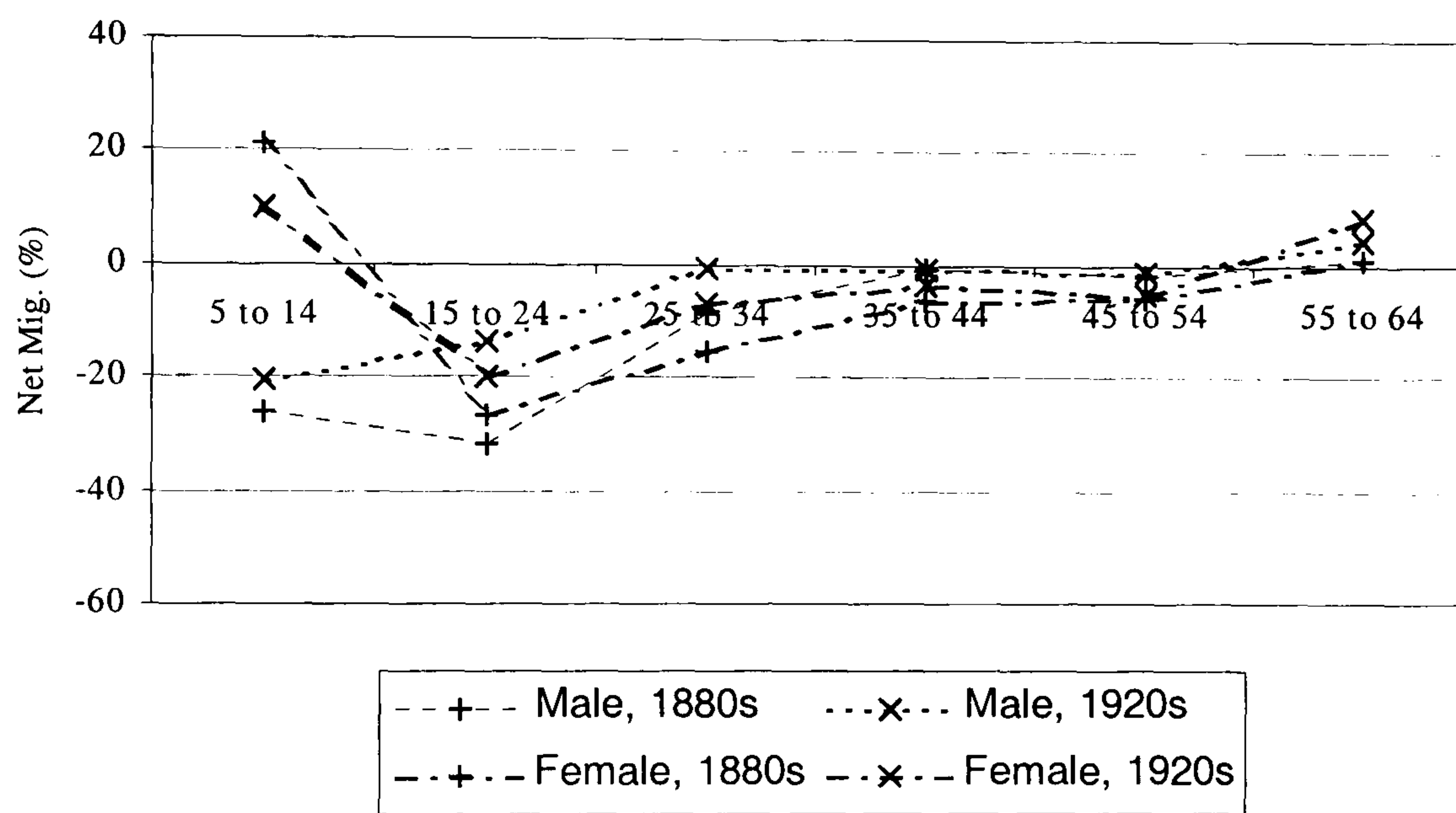
The basic output of the methodology is data in the form of time-series. Figure 6.3 shows a graphed example of this for three districts: Bristol, Cheltenham, and Westbury on Severn. It shows the changes in net migration in the 5 to 14 year old cohort for the five decades used in this analysis divided by sex. Similar graphs could be produced for every target district used in the analysis and for each of the six cohorts used.

Overall, the county's districts are dominated by net out-migration for all decades of the analysis. It is obvious from the district-level results, however, that this is far more prevalent in rural areas than urban ones. This is demonstrated by the graphs in figure 6.3 where Westbury on Severn has high net out-migration throughout the period, whereas Bristol's is much lower. This could be because of a flow from the rural areas to Bristol and the other towns. As there are no data on gross migration or flows, however, it could equally be that fewer people from Bristol are migrating, or that high rates of gross out-migration from Bristol are being canceled out by in-migration from either other parts of the country or abroad.

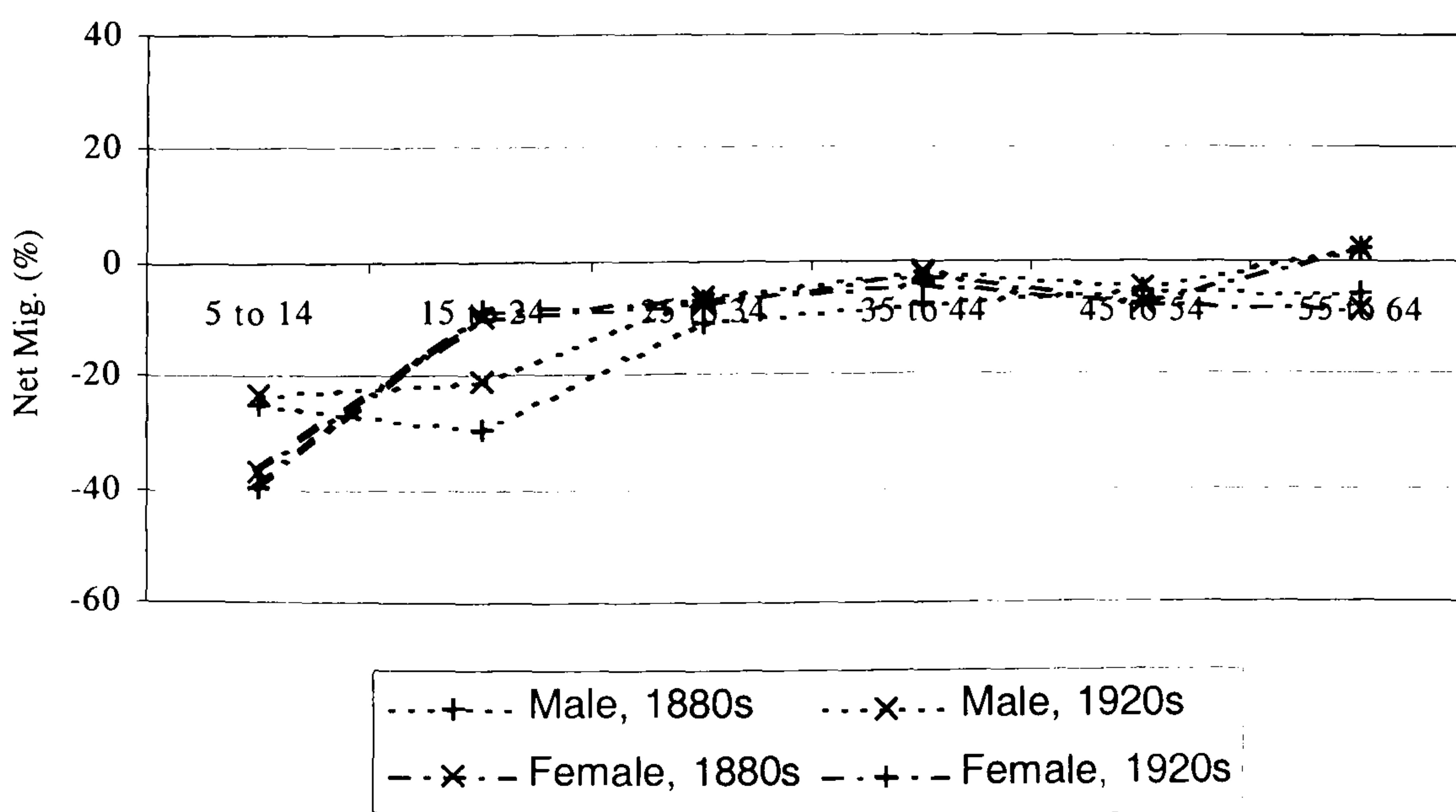
Figure 6.3 also demonstrates the usefulness of dividing migrants by sex as the patterns are frequently different. Westbury on Severn shows net out-migration by both males and females but the rate for males is lower than females, lying between 25% and 40% of the cohort over the decade with the female rate typically being about ten percentage points. In Bristol there are relatively low rates of male net out-migration ranging from around 5% to 20%, while females, on the other hand, show similar rates of net in-migration. Cheltenham, however, shows the most startling contrast. The pattern for males is similar to that for many other districts in Gloucestershire with rates of net out-migration of between 15% and 30%. The female pattern, however, shows the highest rates of net in-migration for any district in Gloucestershire with rates of over 30% in the 1890s and 1900s.



a. Bristol



b. Cheltenham

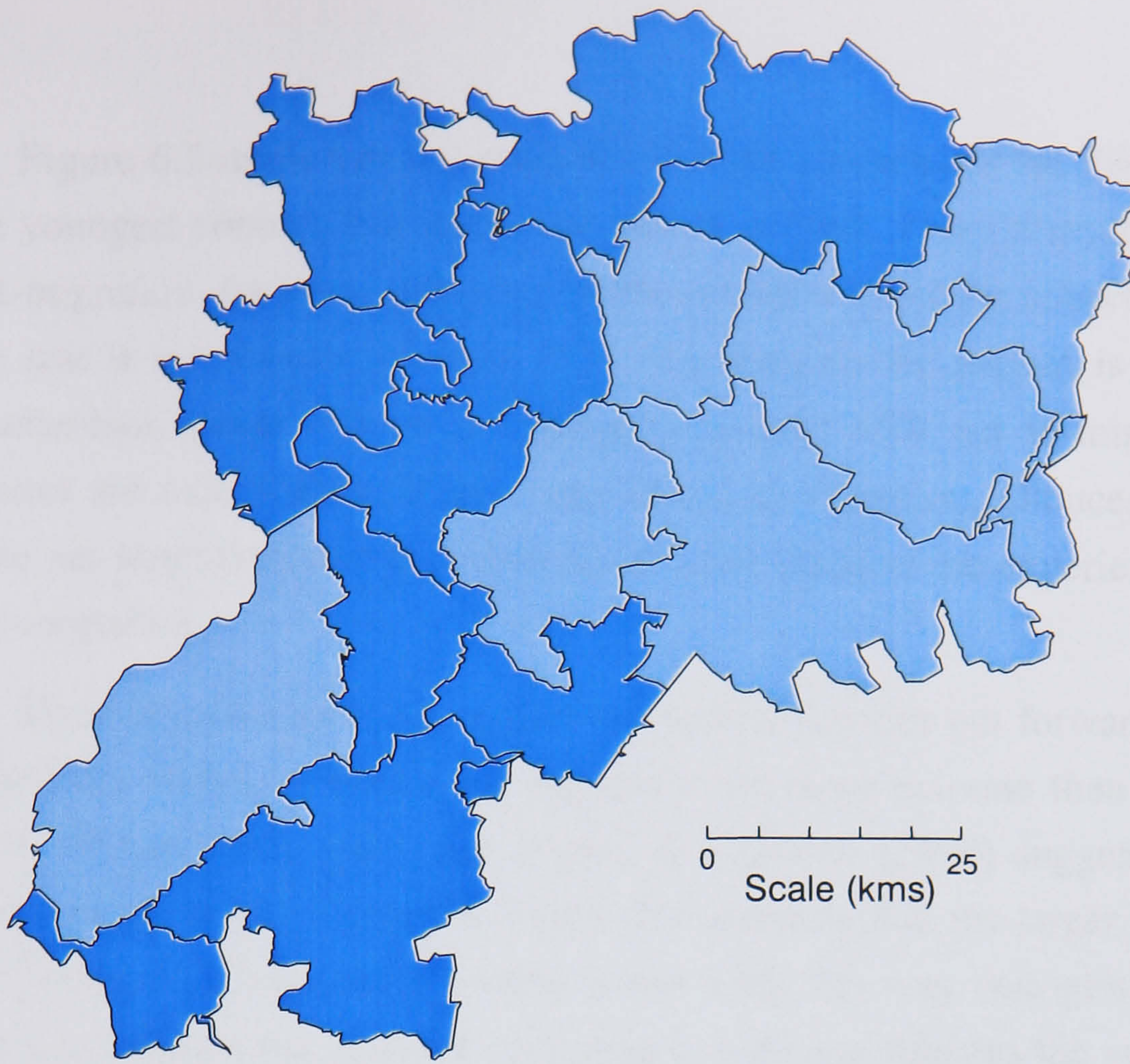


c. Westbury on Severn

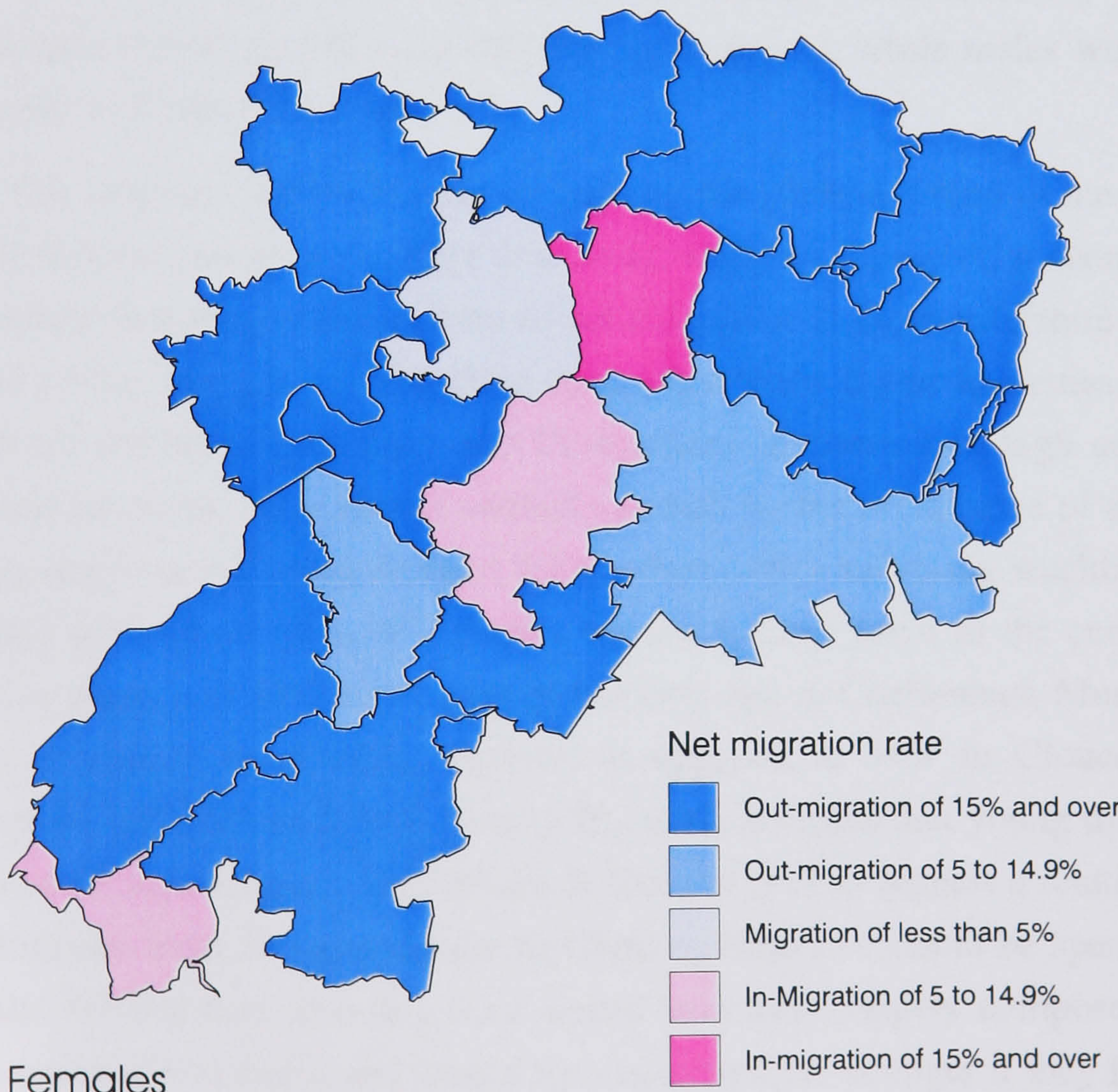
Figure 6.4: Net migration by age and sex for three sample target districts: 1880s and 1920s.

There are also some interesting contrasts in the age of migrants. Figure 6.4 shows net migration rates for all age groups for Westbury on Severn, Bristol and Cheltenham in the 1880s and the 1920s. For Westbury on Severn the pattern between the two decades remains roughly constant, however, the pattern between the age and sex groups is interesting. The highest rates of net out-migration are found among young females with rates of almost 40% for the 5 to 14 cohort over both decades. Rates such as these are only found among this cohort, the 15 to 24 cohort shows net out-migration of slightly under 10% and this remains roughly constant among the older age groups apart from in the 1920s when the oldest cohort, the 55 to 64 year olds, shows slight net in-migration. For males the pattern is noticeably different. Net out-migration among the youngest cohort is less extreme with rates of around 25% in both decades. In contrast to the female pattern, however, this does not decline rapidly but rather the 15 to 24 cohort remains at around this level in the 1920s and is over 30% in the 1880s. The decline in out-migration among males occurs in the 25 to 34 cohort: in the 1880s male out-migration rates remain higher than female until the 45 to 54 cohort, in the 1920s there is little difference between the sexes among the higher age groups.

Cheltenham shows a pattern that is interesting in that it is both contrasting and similar to Westbury on Severn. As already noted, there were high rates of net in-migration among young females into Cheltenham, however, this is only found in the youngest cohort: the 15 to 24 year olds show net out-migration and all the other cohorts show a similar pattern to Westbury on Severn's. With males, the pattern for all ages is similar, but less extreme than for Westbury on Severn. The pattern for Bristol is similar to the pattern for Cheltenham but is less extreme and shows some net in-migration especially among males in the middle cohorts in the 1920s in addition to the raised rates in the 55 to 64 cohort.



a. Males



b. Females

Figure 6.5: Male and female net migration rates among the 5 to 14 cohort: 1900s

Figure 6.5 reinforces the contrasts in male and female net migration rates among the youngest cohorts. For males the pattern is clear: every district is experiencing net out-migration, for ten target districts this is over 15% of the cohort over the 1900s, for the rest it is between 5% and 15%. For females the pattern is more complicated: Cheltenham target district is experiencing over 15% net in-migration, Stroud and Bristol are experiencing lower rates of net in-migration, Gloucester is experiencing little net migration, and the majority of other districts are experiencing over 15% net out-migration.

These results appear to support the general theories put forward by researchers on migration. Rates of female net migration are more extreme than those for males as both “Ravenstein’s laws” and Pooley & Turnbull (1996) suggest. The findings are also consistent with Pooley & Turnbull’s assertion that the larger moves are made by the young. One interesting finding is that while the very youngest women seem most prone to migrate this tails off very sharply with age whereas the youngest males seem less prone to migrate but are likely to migrate in the second cohort. As the cohort that is 5 to 14 at the start of a decade is 15 to 24 at its end it seems likely that the majority of female migration was occurring among teenagers, while males were still likely to migrate well into their twenties.

The intention here is merely to describe the patterns found in the dataset that has been derived and not to attempt any causal analyses, however, it seems reasonable to speculate that the general pattern of net migration in Gloucestershire was part of the trend of the young to migrate from rural areas to the towns and cities. The reason for high net female in-migration into Cheltenham, in contrast to high net out-migration among young males is almost certainly caused by the importance of domestic service as an employer of young women. Cheltenham was a relatively wealthy town that had among the highest rates of domestic service for any town in the country. The 1901 census states that 43% of women of working age in Cheltenham Municipal Borough were employed in domestic service, as opposed to 31% in Gloucester Municipal Borough, and 23% in Bristol County Borough. It seems that young males migrated to beyond Gloucestershire. Friedlander & Roshier (1965) suggest a relatively weak flow of migrants from Gloucestershire to Glamorganshire. It could be speculated from the results derived here that this flow would have been largely composed of the young and especially of males and would have appeared far stronger if they had been able to sub-divide migrants in this way.

6.5: Error in the results

As was stated in the introduction to the chapter any error in any of the data will influence the amount of net migration reported for a unit. If areal interpolation has been used to remove the impact of boundary changes and cohorts unaffected by births are calculated then formula 6.3 can be written as:

$$NM^{t+n} \pm \varepsilon = p^{t+n} - p^t - + D^{t+n} \quad (6.6)$$

As it is impossible to entirely remove the impact of error from the analysis it is worth discussing the sources and impacts of error so that its possible effects can be included in any discussion. There are four main sources of error:

- a) Errors in the raw data due to under or over-enumeration of data or errors in publishing or transcribing data.
- b) Problems in linking data to areal units, for example, for decennial mortality data where the unit has been affected by a boundary change during the decade.
- c) The cohort mortality data are estimates. For Registration Districts, the *Decennial Supplements* published data by age over the decade rather than by cohort, for Local Government Districts this problem is compounded by the fact that the County Boroughs were the only unit where data were published for individual districts.
- d) Areal interpolation inevitably introduces error that, as was discussed in chapter 5, can sometimes be highly significant.

These errors are discussed in more detail below:

a. Errors in the raw data

The data used avoid the worse problems of under-enumeration as these are seen as most significant in the censuses before 1851 (Benjamin, 1970) and mortality data before 1874 (Woods, 1979). Fertility data are also sometimes seen as problematic (Teitelbaum, 1974). Beyond being aware that these problems may exist and checking transcriptions against original sources where problems may exist there is little that can be done to solve these problems.

b. Problems linking to administrative units

The exact date of the boundaries used to publish data sources such as the census and the *Registrar General's Decennial Supplements* are not made clear in the source. Neither are the methods used in the *Decennial Supplements* to allocate people to a district when the place they died in was affected by boundary changes. These are problems that are discussed in more detail in chapter 4.

c. Error in the mortality estimates

As was described above, the *Decennial Supplements* give numbers of deaths by age-band over the decade and this is used to estimate the number of deaths in the cohort over the decade. This was done based on the assumption that there is an equal chance of the death occurring in every year of age of the age band and every year of the decade, thus 50% of deaths aged 25 to 34 in a decade are assumed to have occurred in the 15 to 24 cohort and 50% in the 25 to 34 cohort. It is possible to make some attempt to quantify the likely error introduced by the assumption of a death occurring in each year of age of an age-band. For all five decades used there were between 95,675 and 100,768 deaths in Gloucestershire. The distribution of these deaths by age band and sex in the 1880s and 1920s is shown in figure 6.6. In the 1880s 1.5% or less of all deaths occurred in the younger five-year age-bands. This rises to 2.6% and 2.7% for the 25 to 34 age group, which increases slowly until the oldest two age groups where there is a more sudden rise to a maximum of 6.6% for males and 7.3% for females. The pattern for the 1920s is similar but deaths among the young have declined as a proportion of the total, so deaths among the oldest age group have risen to 10.3% and 10.6% of males and females respectively. This shows that for adult age-groups a larger proportion of deaths occur in the higher ages within each age-group and that this trend becomes more pronounced with age. This suggests that for the older ages, estimating the numbers of deaths in the cohort from the sum of 50% of the deaths in the younger age-band plus 50% of deaths in older age-band is slightly unrealistic. The impact of this rise in mortality among the age groups is likely to have some significance as the total numbers of people in each cohort tends to decline with age. As deaths in the young age groups are comparatively rare, then error in calculating death rates is unlikely to be particularly significant, however, the higher death rate among the elderly means that the results must be treated with more caution.

It would be possible to create more complex models to allocate deaths by age to cohorts, but this is only one of the two assumptions used: the second is that there is an equal possibility of a death having occurred in each year of the decade. This is also a potentially unreliable assumption as annual death rates fluctuate, although to use annual death rates would require a massive amount of data and it seems unlikely that it would influence the estimates of cohortal mortality significantly.

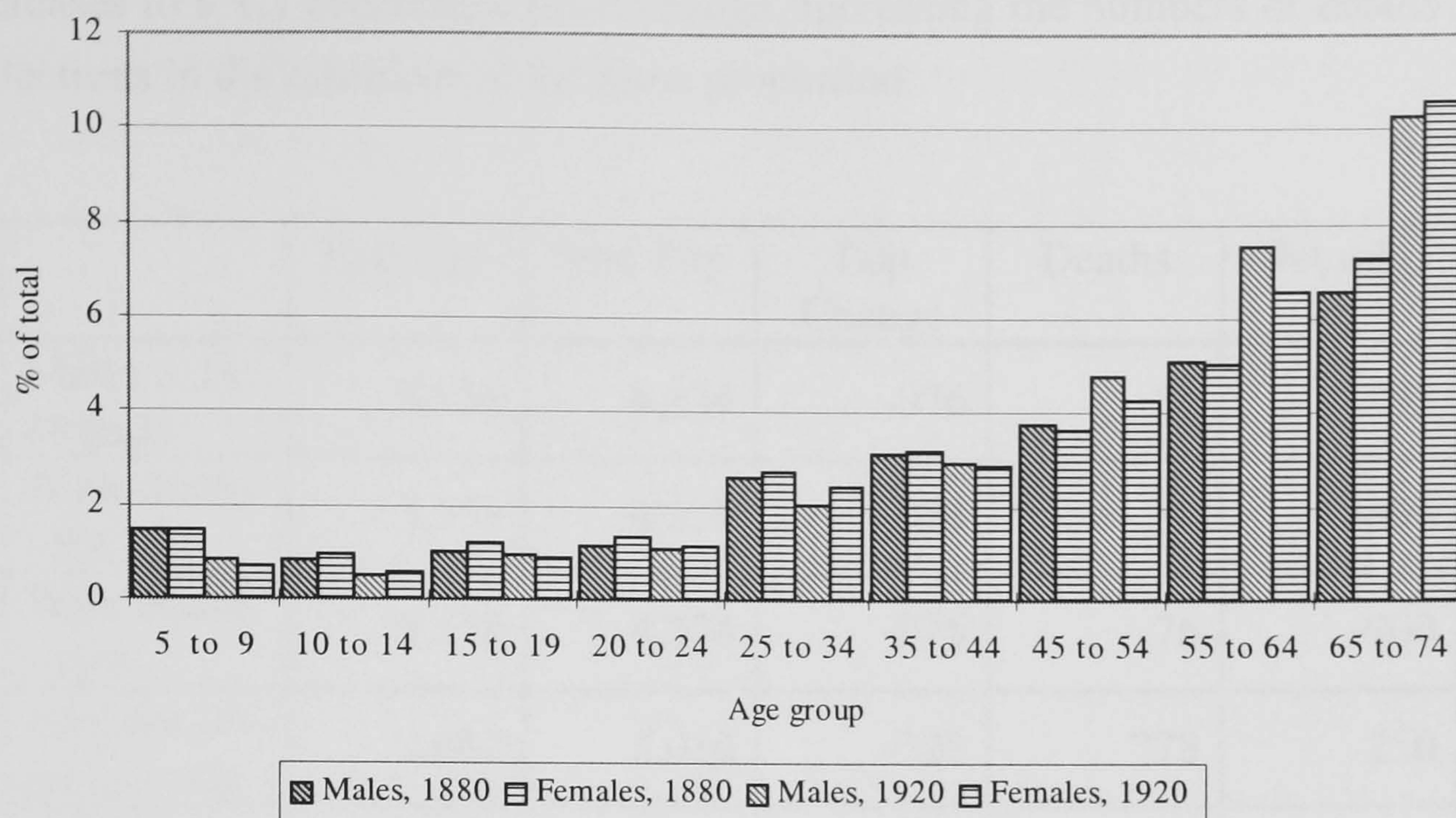


Figure 6.6: Proportion of total deaths in each age-group by sex: 1880s and 1920s.

The final problem with the mortality estimates is that the 1921 and 1931 *Decennial Supplements* do not provide data for every district, but instead show that in the 1920s, for example, there were 46,600 deaths in Bristol County Borough, 6,700 in Gloucester County Borough, 14,100 in “other urban districts”, and 27,600 in Rural Districts. These figures were used with the population data to estimate the number of deaths in each district by assuming that the death rates in each type of district were constant. In the 1910s Bristol County Borough had 133 deaths per 1,000 people, Gloucester had 139, “other urban districts” had 140, and Rural Districts had 129. For Registration Districts in the 1900s the lowest death rate was 128 per 1,000 in Thornbury, a single Rural District, and the highest were Wheatenhurst, a single Rural District at 145, Gloucester, a County Borough and a Rural District, also had a rate of 145, while Bristol, a single County Borough had 158. This suggests that the assumption of equal death rates among types district may introduce some error in the estimation of mortality for the 1910s and 1920s but that this is only likely to introduce a couple of percentage points of error in the calculation of mortality.

Table 6.3 shows the potential impact of error in the mortality data on net migration estimates. It looks at Cheltenham target district in the 1920s for two cohorts, the youngest males and the oldest females. For each cohort row 1 shows the actual values used to calculate the net migration rates. In rows 2 and 3 the numbers of deaths have been reduced by 5% and 10% respectively to simulate the possible impact of error. For the youngest cohort, every 5% of error in the mortality estimates only changes the net migration rate by 0.1 percentage points. For the oldest females, this

increases to a 1.3 percentage point change. Increasing the numbers of deaths leads to reductions in the estimates of the same proportion.

		End Pop	Start Pop	Pop Change	Deaths	Net mig.	Net mig. rate (%)
1	Males 5-14 (actual)	3,358	4,334	-976	84	-892	-20.6
2	With deaths -5%	3,358	4,334	-976	80	-896	-20.7
3	With deaths -10%	3,358	4,334	-976	76	-900	-20.8
1	Females 55-64 (actual)	2,482	3,010	-528	778	250	8.3
2	With deaths -5%	2,482	3,010	-528	739	211	7.0
3	With deaths -10%	2,482	3,010	-528	700	172	5.7

Table 6.3: Demonstration of the impact of error in mortality data in calculating net migration rates: Cheltenham in the 1920s for males aged 5 to 14 and females aged 55 to 64.

d. Error from areal interpolation

The final source of error is areal interpolation. This was discussed in detail in chapter 5 where it was shown that the average percentage error introduced into a target district's data was low, typically around 3% using this technique but that this masks occasional errors that could in excess of 10% (see table 5.3). The impact of this is potentially significant as it will affect both the population change and mortality estimates. For example, in 1899 Barton Regis lost parishes containing over 200,000 people to Bristol. In 1905 it was abolished with approximately 14,000 people being re-districted to Bristol, 3,500 to Chipping Sodbury, and 2,000 to Thornbury. This means that for both the 1890s and 1900s the end population and mortality data will have been interpolated from different boundaries to the start population. As there were no changes in the 1880s, however, all three datasets will have been interpolated from the same data. If there is significant amounts of error, therefore, this will cause clear spikes to appear on the time-series graph. Figure 6.3 does not show this occurring for any of the three districts used. This does not mean, however, that there is no error in these data, merely that any error is not large enough to cause significant problems to appear.

e. Evaluating the combined impact of the possible errors

There are, therefore, many possible sources of error in the results. The most significant three appear to be: firstly, error to either the end population and mortality data introduced by the areal interpolation, secondly, error to the start population introduced by the areal interpolation, and thirdly, error in the mortality data introduced by need to estimate cohort mortality from age-bands and the need to estimate district-level mortality from rural and urban aggregates in the 1910s and 1920s. In this section a simple analysis of the potential impact of these errors is performed. This is done by focussing on males aged 5 to 14 and females aged 55 to 64. After the interpolation was performed error was deliberately added to one or more of the three datasets needed by the net migration equation in a variety of ways. In each case an arbitrary 5% was added to the data as follows:

1. The number of deaths to simulate error introduced to the estimation of district-level mortality from aggregate data.
2. The start population, simulating areal interpolation error caused by errors in the boundaries used as a spatial reference for the population at the start of the decade.
3. The end population and mortality together simulating error introduced by the areal interpolation caused by errors in the boundaries used as a spatial reference for the end population and mortality data.
4. Error from the combined impact of 1 and 2 acting together.
5. Error from the combined impact of 1 and 3 acting together.

	Males 5 to 14		Females 55 to 64	
	RMS Error	Max. Error	RMS Error	Max. Error
Mortality error	0.10	0.13	1.14	1.42
Start boundary	3.26	4.38	4.42	5.34
End boundary	4.29	5.00	4.04	5.11
Start and Mort.	4.09	4.76	3.85	4.86
End and Mort.	4.39	5.10	5.18	6.52

Table 6.4: RMS and maximum error introduced to net migration rates by adding an arbitrary 5% to the component datasets to simulate error. These errors are assumed to have come from: the mortality data alone (for reasons other than areal interpolation), areal interpolation of the start population, areal interpolation of the end population and mortality data, or areal interpolation errors acting with other errors to the mortality data.

Table 6.4 shows the results of doing this. It shows that a proportion of error in one of the source datasets will usually cause a smaller or similar proportion of error in the

net migration calculations. It is also clear that non-areal interpolation error in the mortality data is far less significant as a source of error in the net migration calculations than error introduced by areal interpolation. The work with synthetic units performed in chapter 5 suggests that the average error introduced to a district by this type of interpolation is likely to be around 2% while the maximum is likely to be around 7%. This suggests, therefore, that the results given are likely to be accurate to within approximately this range although clearly they will vary through space and time. It is also possible that errors in the mortality data could have the opposite impact to errors due to areal interpolation, for example the mortality data having being underestimated due to error while the start or end populations are over-estimated. In the younger age groups the impact of this would be minimal as the impact of the mortality is so small. In the older aged groups this would increase the errors by between 1.0 and 1.5%. Overall, however, errors of this order are significant and should be borne in mind when any analysis takes place but are not significant enough to seriously affect any trends. A final point is that while errors in the mortality data leads to higher rates of error among the older cohorts, errors to the start or end populations tend to reduce this affect.

6.6: Conclusion

This chapter has demonstrated the possibility of calculating long-term time-series of age and sex specific district-level net migration rates. The example given has been restricted to a single county over fifty years. Once the GIS is complete it will be possible to calculate these rates at district-level for the whole of England and Wales from the 1850s to the 1980s. Increasing the spatial extent to do this is unproblematic. Increasing the temporal extent will be slightly limited by problems with the data. Extending the study back in time to the 1850s should be relatively unproblematic as both the census and *Decennial Supplement* data required are available. The main problem is that the GBHGIS does not record changes to parish boundaries prior to 1876 as these were not included in the GIS (see chapters 1 and 4). The 1871 parish-level populations are available in the 1881 census and so can be used in the same way as the 1901 population published for 1911 were. Earlier censuses are slightly more problematic as their data would also have to be allocated to 1881 or 1876 parishes. Early attempts to do this suggests that this is not especially problematic, however, accuracy may suffer slightly as a result. The under-reporting of deaths prior to 1874 may also introduce error but this was most significant among infants (Woods, 1979).

The major problem in the twentieth century is the lack of either a census or a *Decennial Supplement* in 1941. This is unfortunate as the period from 1931 to 1951 includes the impact of both the Depression and World War Two. This is thus both a

very interesting period and one in which attempting to estimate data based on the 1931 and 1951 sources would produce woefully inadequate results. It is possible that substitute sources of data could be found from near 1941, for example, based on the National Registration carried out in 1939 in preparation for mobilisation and evacuation. Both the decades affected, however, are likely to be abnormal compared to other decades and it would be very difficult to tell whether abnormal results for these two decades were caused by data problems or were genuine results.

For the period from 1951 and 1961 the quality of the mortality data declines from the 1921 and 1931 situation. These two *Decennial Supplements* did not cover the preceding decade but instead gave information on the situation at around the time of the census, for example the 1961 *Supplement* covers the period 1959 to '63. Data are given in both numbers and rates by sex for the age groups 5 to 14, 15 to 44, 45 to 64, and 65 and over. These data are published for County Boroughs, and county-level aggregates of urban and rural districts (Alderson & Whitehead, 1974). Using these data the number of deaths in each cohort for each district could be estimated using the census populations by multiplying the district's population at the relevant age by the death rate for that type of district and the most appropriate age group and date. For example, to estimate the number of deaths among 15 to 24 year old males in 1961 the number of males aged 15 to 24 would be multiplied by the death rate for 15 to 44 year old males and scaled to cover the entire decade. This means that for the 1950s and the 1940s if required, the numbers of deaths in each cohort could still be estimated if required except for the 55 to 64 year old cohort which would require the number of deaths aged between 65 and 74. The 1971 *Decennial Supplement* is very similar to 1961 except that it restores the detailed age breakdown with ten year age-bands from 5 to 14 to 75 to 84 being included.

For the period after 1981, census data are available at Enumeration District level. This greatly enhances the accuracy of any interpolation but may cause errors when the 1970s are calculated due to the different standards of the source data from 1971 and 1981. From 1981 numbers of deaths by sex and in ten year age-bands from 5 to 14 to 75 to 84 are published annually at ward level. This provides an ideal accompaniment to the 1991 census data and allows the deaths for the 1980s to be estimated at ward level for all cohorts. The 1970s are more problematic. The 1981 *Supplement* publishes data in a similar form to 1961, ten-year age-bands and by sex but the geography used is district level. The full impact of this has not yet been explored, however, the move from rural/urban aggregates to larger administrative units could have implications for the input into the interpolation. The potential for error from this could, however, be explored with reference to the very spatially detailed data available for the 1980s and the aggregate data from the 1960s.

It is clear, therefore, that with the exception of a start population for the 1940s and an end population and mortality data from the 1930s it would be possible to create net migration data using this technique for every decade from the 1850s to the 1980s. There will, however, be certain problems that may introduce error into the results. These problems are concentrated in the mortality data for the 1940s (if required), 1950s, 1960s, and 1970s. The effect of these problems will be that in the 1940s to 1960s no estimates could be made for the 55 to 64 year old cohort and for other cohorts the data are potentially error prone. As the section above showed, however, error in the mortality data does not necessarily lead to significant error in the estimates of net migration especially among the younger cohorts. This means that a completed GIS will allow age and sex specific net migration rates to be estimated for every decade from the 1850s to the 1980s.

This will be a more detailed dataset than any previous study of its type has been able to create, as it will combine spatial detail and demographic detail with a national coverage and a long time-series for the first time. As a result, it will provide more insight into long-term trends in net migration than has previously been possible. The broader lessons that can be learned from this chapter is the power of the GIS to integrate data. By combining the data with the administrative units they were published for and using areal interpolation to make best use of the available data it has been possible to take two relatively simple datasets that have been regularly published since the mid-nineteenth century and combine them to produce a new dataset that contains more spatial and attribute detail than it was traditionally possible to produce and that is fully comparable over time.

Chapter 7: Exploring Long-Term Change: 100 Years of Inequality in England and Wales

7.1: Introduction

The previous two chapters have looked in detail at some of the issues of integrating data focussing on a single county, with the problems inherent in the spatial component of the data being emphasised particularly strongly. In this chapter an applied example of using the GBHGIS to explore change through space and time is given¹. The problem chosen is that of long-term change in the patterns of inequality. One reason for this choice was pragmatic; 1998, when the analysis was done, was the centenary year of Rowntree's work on poverty in York (Rowntree, 1901). This landmark clearly provided an opportunity to explore the capabilities of the GIS when applied to a real problem in socio-economic change.

The chapter is not intended to be a definitive GIS-based study of changing patterns of poverty and inequality in England and Wales over the past century. This would be best done in collaboration with people with more expertise in poverty research, would require a completed GIS, and is not directly relevant to this thesis. It is also not the intention here to look in any detail at the error introduced by the limitations of the spatial component of the data as this has been addressed in detail in chapters 5 and 6. Instead, the aim of this chapter is to take a real-world example of a problem and demonstrate the strengths and limitations of a GIS-based approach to space and time based on integrating data by interpolating onto a standardised administrative geography. The problems focused on are those of long-term comparability of attribute data, and techniques for exploring and summarising complex spatio-temporal patterns.

Three variables are explored: infant mortality, overcrowded housing and unskilled workers. These are compared at four key dates representing the period prior to the First World War, the inter-War depression, the post-War boom, and the present day. The chapter uses Registration Districts as configured in 1898 as target districts as these represent the largest districts used to publish data used in the study. Due to the

¹ An earlier version of this chapter appears as Gregory *et al* (2000). The modern data were provided in interpolated form by Prof. Danny Dorling (University of Leeds). Dr. Humphrey Southall (University of Portsmouth) provided valuable assistance in determining which datasets were suitable for use in the analysis. Other than these contributions the chapter is entirely my own work.

incompleteness of the GIS, rather than use the sophisticated interpolation techniques described in chapter 5, simple areal weighting (Goodchild & Lam, 1980) as implemented by equation 5.1 is used for interpolating most source data. The modern data, published at either ED or unit postcode-level, required a slightly different way of working. Initially the data were aggregated onto 1981 wards by using the unit's centroid (Davey Smith & Dorling, 1996). This ward-level data was then allocated to the target district that contained the largest part of the ward. For both methods it is likely that the effect of the crude interpolation technique will be to reduce contrasts due to the smoothing affects that the homogeneous population assumption will cause. The interpolation methodology used for the modern data was particularly crude but the impact of this is likely to be significantly reduced by aggregation level involved as there were over 10,000 wards in 1981 and only 635 target districts.

7.2: Multi-variate approaches to the study of poverty and inequality

The concept of poverty has attracted attention from academics and intellectuals for hundreds of years. There remain, however, significant problems with definitions and measurement. Townsend (1993) identifies three approaches to the definition of poverty: the subsistence approach, the basic needs approach, and the relative deprivation approach. The subsistence approach, used by many early researchers including Rowntree (1901) and Beveridge (1942), is based on the idea that individuals or families are in poverty if their incomes are not "sufficient to obtain the minimum necessities for the maintenance of mere physical efficiency" (Rowntree, 1901: p. 86). The basic needs approach, taken up in the 1970s, builds on this by adding the essential services provided by the community such as safe drinking water, sanitation, health and education, to the requirements of the subsistence approach. Both of these require the establishment of minimum requirements that can be very hard to define and measure. The relative deprivation approach moves away from this to measure poverty by comparing the inequality of deprivation and/or income based on comparing these to a society as a whole. People are said to be relatively deprived "if they cannot obtain, at all or sufficiently, the conditions of life – that is, the diets, amenities, standards and services – which allow them to play the roles, participate in the relationships and follow the customary behaviour which is expected of them by virtue of their membership of society" (Townsend, 1993: p. 36).

The relative deprivation approach, therefore, uses the measurement of inequality in a society in an attempt to understand the degree of poverty within that society. The relationship between inequality and poverty is not, however, straightforward as a certain degree of inequality is seen as inevitable and even perhaps desirable. According to the above definition given by Townsend, inequality becomes poverty

when it is present to such a degree that the individuals or families affected are unable to pursue an acceptable role in society. Alcock (1997: p. 7) summarises this by saying “poverty is not just an aspect of inequality, but the unacceptable extreme of inequality”.

For a study examining change over a century the relative deprivation approach is clearly the most satisfactory. Attempting to find an acceptable base line for either a subsistence or a basic needs approach would be impossible as can be illustrated from Rowntree (1901). He used the following as a minimum acceptable standard of clothing for a young woman: “one pair of boots, two aprons, one second-hand dress, one skirt made from an old dress, a third of a cost of a new hat, a third of the cost of a shawl and jacket, two pairs of stockings, a few unspecified underclothes, one pair of stays and one pair of old boots worn as slippers” (taken from Townsend, 1979: p. 50). This is clearly entirely irrelevant for the 1990s.

Many different variables have been used to measure relative deprivation but common themes emerge throughout. Although not concerned directly with relative deprivation, the Beveridge Report (1942) is perhaps a good place to start. This identified five great evils: want, squalor, disease, ignorance, and idleness (see Dorling & Tomaney, 1995). Later researchers have followed similar criteria. Smith (1973) identified seven general criteria associated with social well-being:

1. Income, wealth and employment (income and wealth, employment status and income supplements).
2. The living environment (housing, the neighbourhood and the physical environment).
3. Health (physical and mental).
4. Education (achievement, duration and quality).
5. Social order (personal pathologies, family breakdown, crime and delinquency, public order and safety).
6. Social belonging (including democratic participation, criminal justice and segregation).
7. Recreation and leisure (recreational facilities, culture and the arts and leisure availability).

Other researchers such as Drewnoski & Scott (1968), Gordon & Whittaker (1972), Little & Mabey (1972), Knox (1975), Coates *et al* (1977), and Townsend (1979) have used similar definitions. Although the specifics of all these change, the types of factors examined remain fairly constant with data availability and the nature of the

study often determining the details of the choice of indicators. Table 7.1 attempts to summarise a sample of these. Although the exact details of how some of these factors have been placed could be argued about, there are five common themes that emerge: income, wealth and employment; health; education; housing and the environment; and the broader society.

	Beveridge	Smith	Coates <i>et al</i>	Knox
Income, wealth and employment related	Want	Income, wealth & employment	Surplus income	Affluence
				Employment
				Social status
	Idleness			
Health related	Disease	Health	Health	Health
			Nutrition	
Education related	Ignorance	Education	Education	Education
Housing and environment related			Shelter	Housing
	Squalor	The living environment	Physical environment	General physical environment
		Recreation & leisure	Leisure	Leisure
Society related		Social order	Social stability	Social stability
			Security	Social security
		Social belonging		Democratic participation
				Demographic structure

Table 7.1: A variety of measures of social well-being used by different authors (Taken from: Beveridge, 1942; Coates *et al*, 1977; Knox 1975; Smith, 1973).

7.3: The Measures of Inequality

Ideally, this study would have been able to use a similar number of criteria as those given above to measure social well-being. Unfortunately, however, only variables relating to health, housing, and employment could be found that could be compared over the long-term. Education related factors had to be omitted both because of a lack of geographically disaggregated data, and because of changing educational standards. Similarly, factors relating to society were also had to be omitted due to a lack of consistently available data on areas such as crime, family breakdown and segregation. The three variables that were used are:

Infant mortality: This is a health-related variable that provides perhaps a broader indicator than might be expected as rates are affected not just by the conditions into which the infant is born, but also by the health of the mother (Staines, 1998). It is defined as the death rate for children aged under 1 and is easily calculable for different dates with few problems of consistency.

Overcrowded housing: This is defined as households living at more than one and a half persons per room and provides a direct indicator of the quality of housing. It uses information that has been gathered by every census this century. However, the definition of a household and the method of counting rooms are both problematic and will be discussed in more detail below.

Unskilled workers: This is used to look at the quality of employment available in an area. Although not available for all dates, the Registrar General's Social Classification is used as the basis of an examination of the proportion of people in Social Class V. This is routinely used as an indicator of poverty to due to the low wages, economic insecurity and the lack of control over their work that these people endure (Bartley *et al*, 1998). Again, there are difficulties in producing consistent definitions, from the lack of detail provided by the 1911 census, to the large numbers of people who had never worked and who were allotted no social class in 1991. Never the less, comparable statistics can be constructed as is discussed below.

These three variables, therefore, are used to indicate broader inequality in society. Ideally, more variables would be used. In addition to including variables to represent education and social well-being, it would be desirable to have several variables representing each theme. For health this would be possible using other mortality-based indicators, Standardised Mortality Ratios (SMRs) (Woods, 1979) offer one obvious option. For the other themes, however, this is more difficult. Unemployment was considered as a possible choice for an income, wealth and employment indicator variable, however, the definition of unemployment is problematic and changes

regularly (Green, 1995). The census provides a relatively stable definition of unemployment, however, this has only been published since 1931. Earlier sources, such as the *Poor Law Returns* are not directly comparable. Other measures offer similar problems: car ownership is often used as a surrogate for wealth in modern census-based studies, and housing conditions can also be examined through variables such as access to household amenities including indoor toilets and fixed baths or showers. Unfortunately, these data have only been collected by the census relatively recently: 1971 in the case of car ownership and 1951 in the case of many questions on amenities (Norris & Mounsey, 1983). This led to the decision that only one variable would be used to measure each theme.

Variable	Period	Source	Date
Infant Mortality	Pre-WWI	RG's Decennial Supplement	1891-1900
Infant Mortality	Inter-war	RG's Annual Report	1928
Infant Mortality	Post-war boom	RG's Annual Report	1958
Infant Mortality	Modern	Individual Death Certificates	1990-'92
Overcrowding	Pre-WWI	Census	1901
Overcrowding	Inter-War	Census	1931
Overcrowding	Post-war boom	Census	1961
Overcrowding	Modern	Census	1991
Unskilled Workers	Pre-WWI	Census	1911
Unskilled Workers	Inter-war	RG's Decennial Supplement	1931
Unskilled Workers	Post-war boom	Census	1951
Unskilled Workers	Modern	Census	1991

Table 7.2: Long-term inequality in England and Wales: Sources used to measure inequality (Abbreviations: RG's: Registrar General's).

Ideally, each variable would be compared for every decade for which data had been published, however, both as a result of the database not being complete enough to allow this, and because these are variables that only show very slow change over time, only four key dates were used. The dates chosen provide the pre-First World

War period when British industrial power was at its height, the inter-War depression, the post-War boom, and the present day. The exact dates used depended on data availability and are given in table 7.2 along with the data sources and their original publishing units.

Data Set	Published by	Spatial reference in GIS
Pre-WWI Infant Mortality	1901 RDs	1901 RDs
Inter-War Infant Mortality	1928 LGDs	1928 LGDs for the North, 1910 LGDs for remainder
Post-War Infant Mortality	1958 LGDs	Approximated 1951 LGDs
Modern Infant Mortality	1990s Unit Postcodes	1981 wards
Pre-WWI Overcrowding	1901 LGDs	1901 LGDs for the North, 1910 LGDs for remainder
Inter-War Overcrowding	1931 LGDs	1931 LGDs for the North, 1910 LGDs for remainder
Post-War Overcrowding	1961 LGDs	Approximated 1951 LGDs
Modern Overcrowding	1991 EDs	1981 wards
Pre-WWI Unskilled Workers	1911 LGDs*	1910 LGDs
Inter-War Unskilled Workers	1931 LGDs**	1928 LGDs for the North, 1910 LGDs for remainder
Post-War Unskilled Workers	1951 LGDs	Approximated 1951 LGDs
Modern Unskilled Workers	1991 EDs	1981 wards

Table 7.3: Long-term inequality in England and Wales: Publishing units and spatial referencing units. Notes: the “North” means the Lancashire, Cheshire, the four Northern counties and Yorkshire excluding the West Riding. *Urban Districts with populations of less than 5,000 were only published as county totals. These were interpolated onto LGDs with a population of less than 5,000 based on the populations of these districts. **These data had to be re-allocated to LGDs before the analysis could be done – see the section on unskilled labour for full details.

This study is concerned with relative inequality and a simple method of measuring this is used. Townsend (1993) argues that the lowest decile or quintile of the population is an effective cut-off to use in defining relative poverty so in many of the figures provided the data have been divided into equal-population quintiles to show where the best and worst parts of the country are. In addition, an “inequality index” is used that compares the mean rate of target districts containing the best decile of the population with the mean rates for target districts containing the worst decile, thus the larger the ratio, the larger the disparity between the areas containing the best and worst-off ten percent of the population.

The sources and results from the three variables will now be discussed individually. The key quantitative results are given in table 7.4. As this study is so dependent on spatially referenced data, a large number of maps have been produced to illustrate how relative patterns have changed. In maps for single dates (such as figures 7.1 and 7.2) a standard scheme for choosing class intervals has been used. The data have been ranked and split into five classes such that each quintile holds approximately twenty percent of the population. This means that the maps show the inequality in the variable at that date. When maps are compared they demonstrate how relative inequality has changed but the absolute levels may have changed significantly over time and this can only be seen by referring to the legend. Some of the maps (figures 7.3, 7.6, and 7.9) explicitly map change over time relative to other areas. This is done by comparing the quintiles for the pre-WWI period with the modern quintiles. Where an RD's ranking has improved by two or more quintiles it is classed as having improved significantly, where it has declined by two or more quintiles it is said to have become significantly worse. These maps therefore have three classes: significant relative improvement, significant relative decline, and no relative change.

Each map is provided in two different forms: the one that will be most familiar to people is the choropleth map where an accurate spatial representation of the units are shaded according the intensity of a value or rate recorded across them. The problem with these is that they tend to over-emphasise the importance of sparsely populated rural units, while cities can all but disappear. This is well demonstrated by the choropleth in figure 7.1 where the class with the lowest rates dominates the map and the class with the highest rates all but disappears, even though both classes hold similar numbers of people. This is because the highest rates of infant mortality were found in the densely populated urban districts and the lowest rates in sparsely populated rural ones. While most people are aware of this as a problem, the extent to which it occurs is not always clear and will vary over time. For this reason, the decision was taken to also include area cartograms as an alternative representation. These attempt to emphasise the variable's impact on the people in the study area, rather than the choropleth approach that emphasises its impact on the earth's surface. This is done by making the size of the administrative unit proportional to its population while attempting to preserve its relative spatial location as much as possible. Continuous area cartograms, that attempt to preserve the boundaries between adjacent units are, as yet, difficult to program. The cartograms used here represent administrative units with circles whose position is determined in such a way as to attempt to preserve their position relative to their neighbours. Dorling (1996) describes this approach in more detail, while Dorling (1995) gives an extensive example of their use. In the context of the GBHGIS cartograms have an additional

advantage: over time the population distribution of England and Wales has changed resulting in some areas becoming more heavily populated while others have declined. The use of cartograms at different dates demonstrates this clearly, for example, comparing the cartograms in figures 7.1 and 7.2 shows that by the 1990s the population of districts in central London had declined over the century, while the area around London had grown in importance. One problem with cartograms, particularly at Registration District-level, is that the location of administrative units is heavily distorted so it is hard to what area is being looked at. Another is that, as yet, they are not a widely accepted representation of space and users may have problems understanding them. For this reason the two representations have been put side by side to provide two alternative and sometimes contrasting visual alternatives.

7.4: Infant Mortality

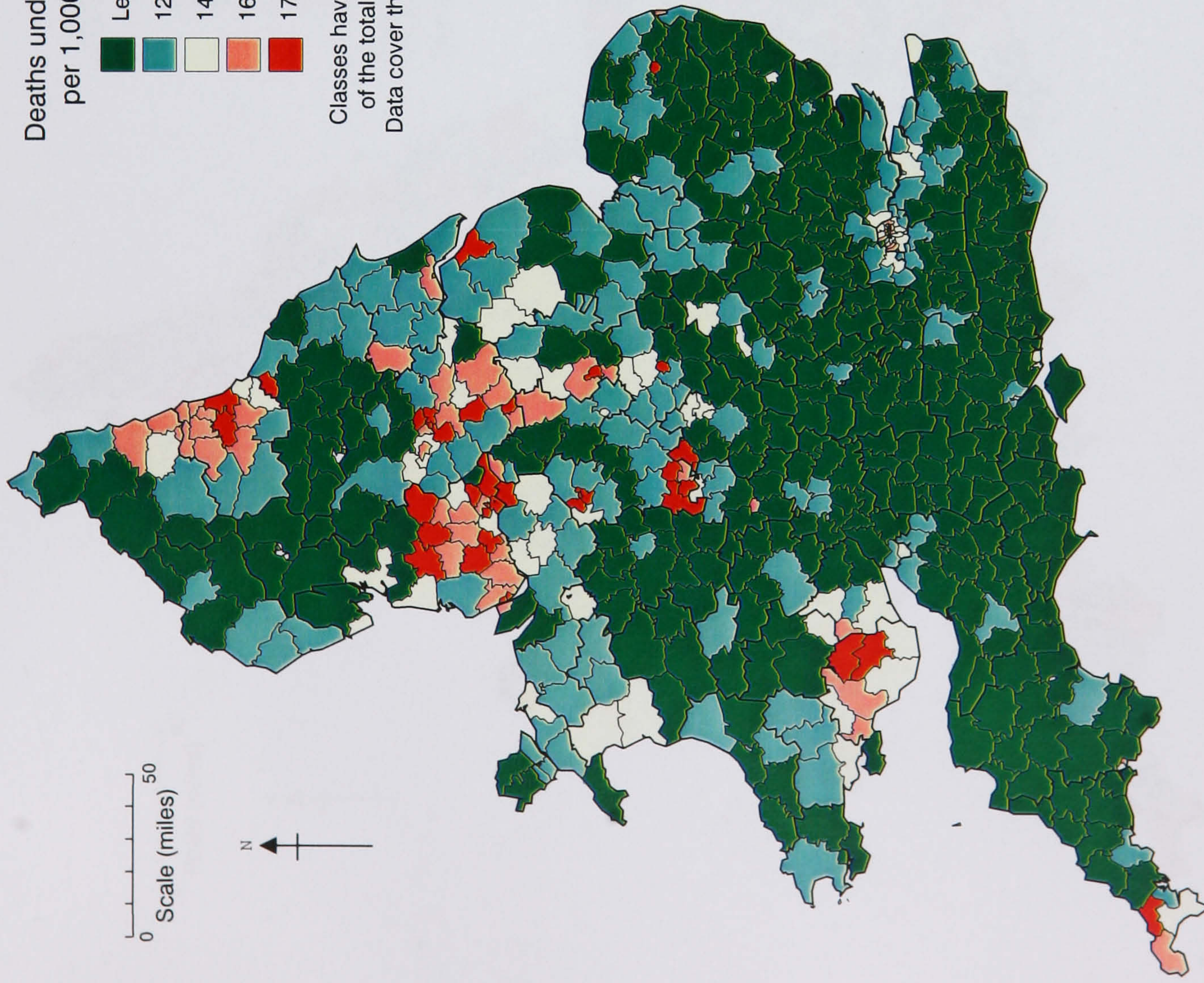
These data provide the most straight forward comparison as the definition of infant mortality has changed little over the last 100 years. The only change of any note has been the recent move to using the number of babies as the denominator, rather than the number of births, caused by the need to avoid distortions due to the increase in migration of families with infants in recent times. The pre-First World War data were from the 1901 *Registrar General's Decennial Supplement*, listing deaths per 1,000 births for the ten years from 1891 to 1900 at Registration District-level. The Inter-War and Post-War data were taken from the 1928 and 1958 *Registrar General's Statistical Reviews* giving data for the single year at LGD level. The modern data were taken from individual death certificates using the fatality's postcode to provide a spatial reference to allow interpolation. Data for the three year period from 1990 to 1992 were used to avoid small number problems as a result of low modern rates (Davey Smith & Dorling, 1996).

Standardising these data reveal just how dramatic the fall in infant mortality over the century has been. In the pre-WWI period the median standard target district rate was 121 deaths per thousand births, the modern standard target district median was only four deaths per thousand babies. As shown in figure 7.1, there was a very clear geographical pattern in the 1890s. The worst areas were the industrial areas: South Wales, the West Midlands and the North, especially Lancashire and the West Riding. Tyneside was relatively healthy, and in London the worst conditions were in a small number of central districts. Rural parts of the country were almost uniformly more healthy. By 1928 Lancashire and the West Riding had experienced a significant relative improvement and some rural areas had fallen back in the ranking, particularly in Wales and East Anglia. This is perhaps because conditions in urban areas were being improved by public health measures while rural areas were starting to suffer

from relatively poor access to medical care. The more recent dates show a continuation of this trend. Figure 7.2 shows the modern situation where, with the exception of Birmingham which has had consistently high relative rates, the pre-WWI pattern almost seems to have been inverted with the high rates now being in widely scattered rural areas, while urban areas are generally in the relatively low categories.

Figure 7.3 summarises this by mapping change over the century as described above. The areas that have improved are predominantly the traditional industrial areas and inner London, while the areas that have experienced relative decline are a broad spread of rural areas. Birmingham is the urban exception, perhaps as a result of the extent of inequalities in the West Midlands.

Perhaps the most surprising result from the infant mortality data, however, is the changing inequality ratio. In the pre-WWI period the decile of the population living in the worst areas had rates only twice as high as those living in the best decile. By the post-war period this had risen to the ratio being just over three, and by modern times the gap had risen to a seven-and-a-half fold difference between the best and worst deciles.



Deaths under age 1
per 1,000 births

- Less than 123.4
- 123.4 to 145.3
- 145.4 to 161.7
- 161.8 to 176.3
- 176.4 and above

Classes have equal proportions
of the total population in them.
Data cover the period 1891-1900.

Circle size is proportional
to total pop. (1901)

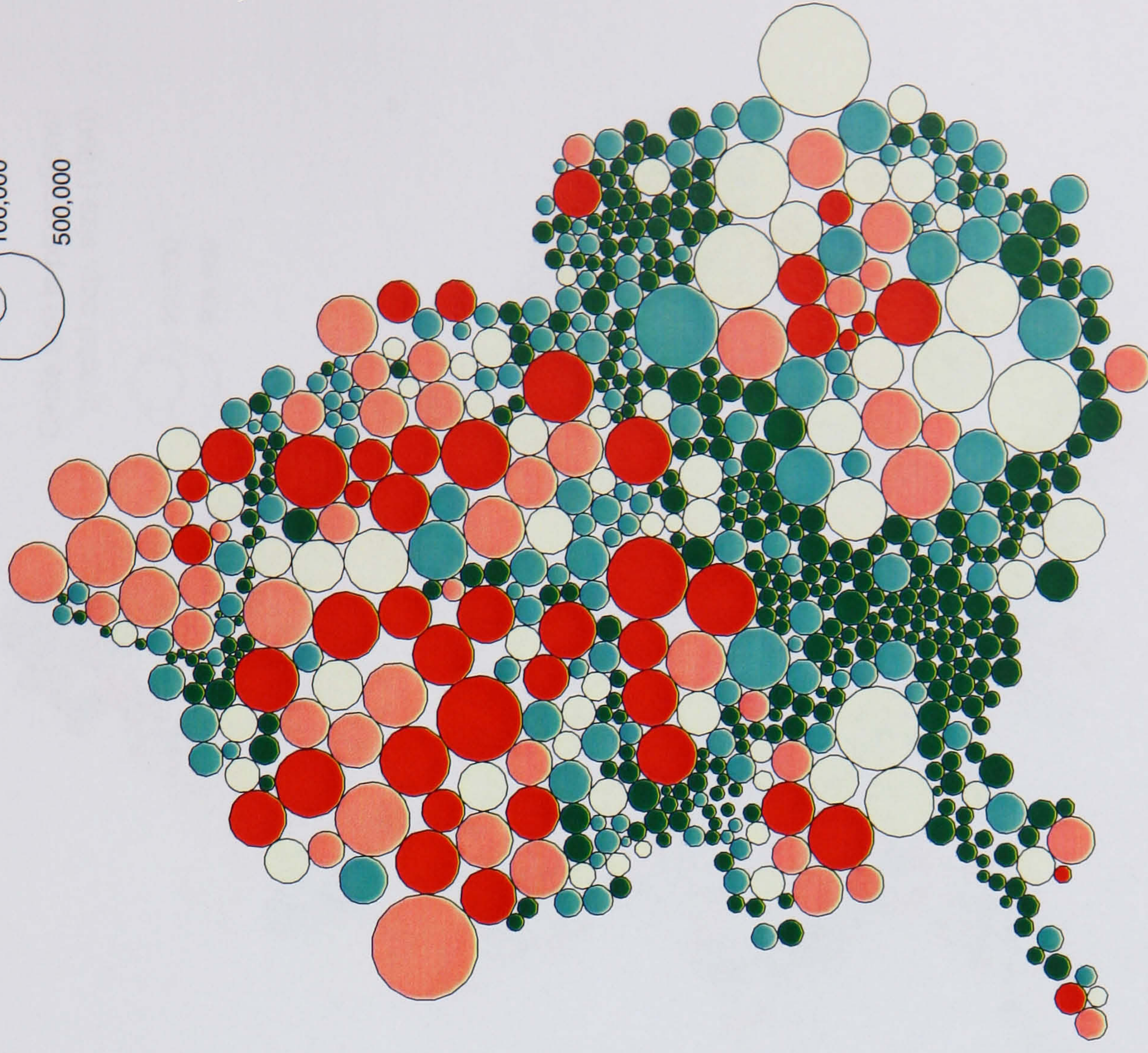
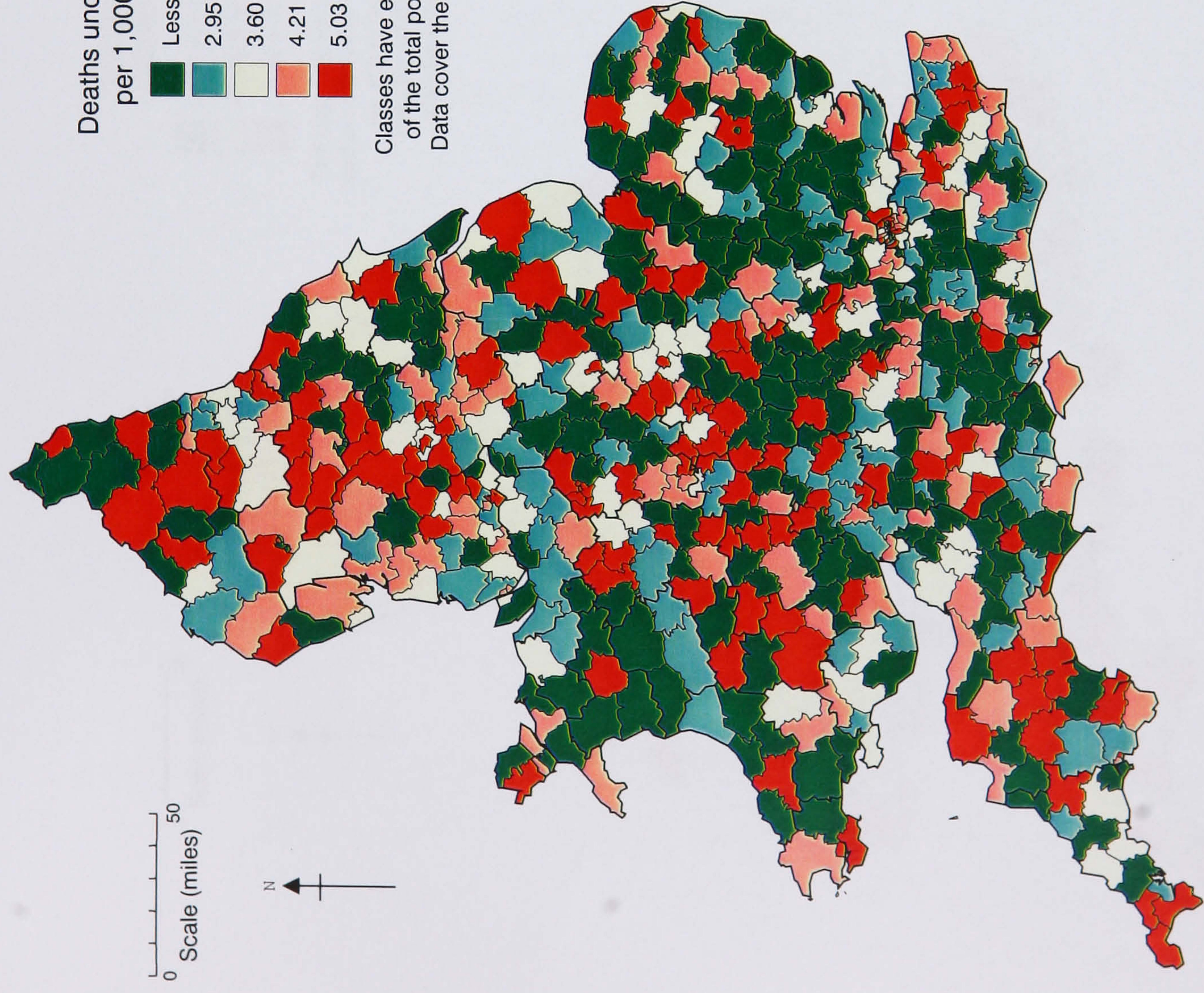


Figure 7.1: Infant Mortality in the pre-WWI period on 1898 Registration Districts



Deaths under age 1
per 1,000 babies

- Less than 2.95
- 2.95 to 3.59
- 3.60 to 4.20
- 4.21 to 5.02
- 5.03 and above

Classes have equal proportions
of the total population in them.
Data cover the period 1990-92.



Circle size is proportional
to total pop. size (1990)

- 200,000
- 525,000

Figure 7.2: Infant Mortality in the modern period on 1898 Registration Districts

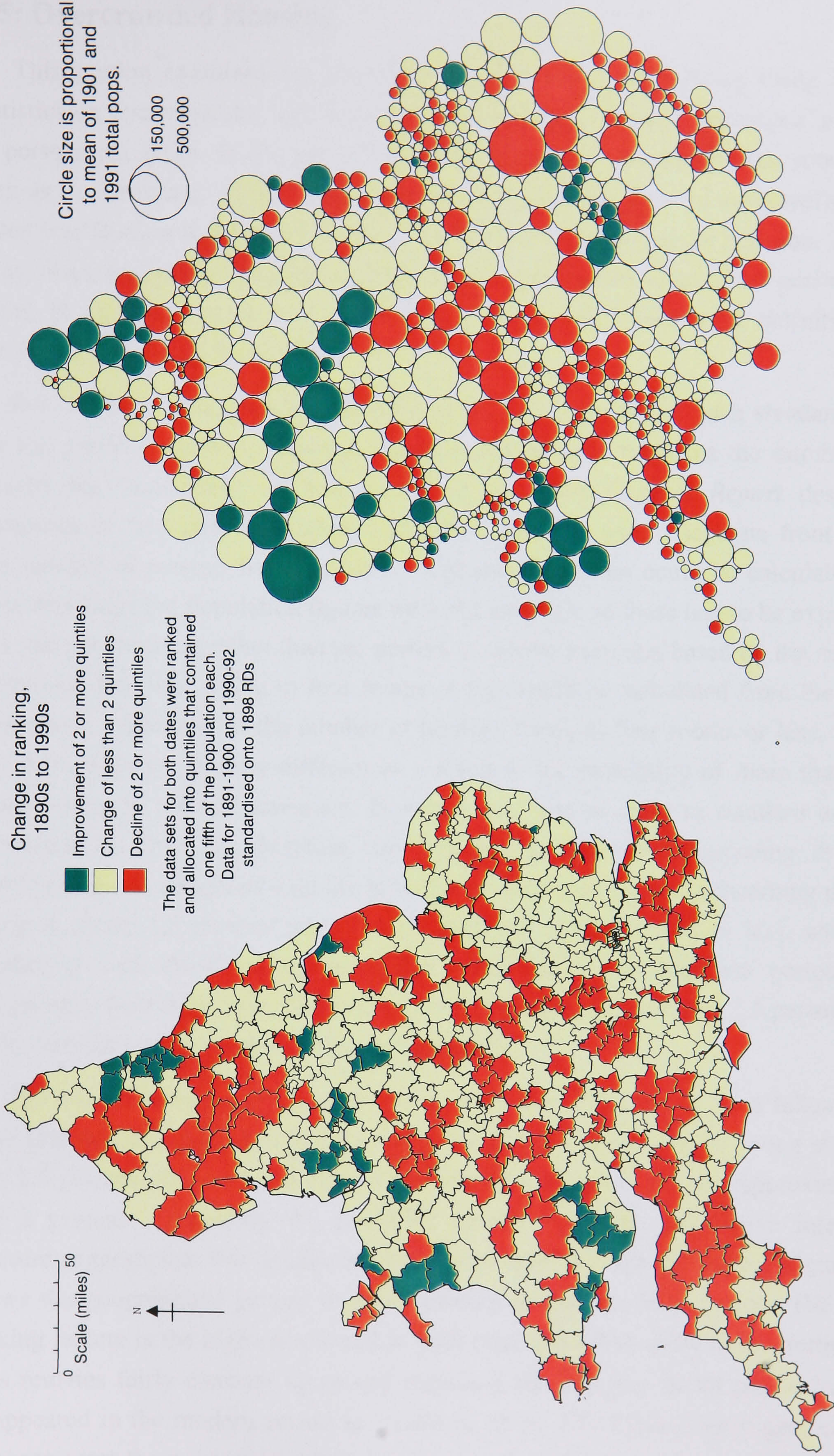


Figure 7.3: Relative change in Infant Mortality: Pre-WWI to the present

7.5: Overcrowded Housing

This section examines the changing geography of poor housing using census statistics on overcrowding. The degree of overcrowding is usually measured in terms of persons per room. In the pre-WWI period more than two persons per room was seen as overcrowded. As with many statistics however, the level of acceptability has fallen (see Dorling & Simpson, 1998) and now more than one person per room is seen as an unacceptable level of overcrowding. Here a compromise level of 1.5 persons per room, the standard used in the 1931 census, has been used as a definition of overcrowded housing for all dates.

For the three later dates this measure could be calculated for each standard RD. For the pre-WWI period, however, the 1901 census only tabulates the numbers of persons for “tenements” of four rooms or less. The *General Report* describes tenements as “separate occupations” (p. 39), a dwelling with a separate front door. The number of persons living at over 1.5 persons per room could be calculated for these dwellings but population figures were not available so these had to be expressed as a rate per dwelling rather than per person. A similar measure, based on the number of “private families” living in four rooms or less could be calculated from the 1931 census as a proportion of the number of families living in four rooms or less. These two definitions are slightly different as a result of the possibility of more than one family living in a single tenement. However, they are as close to standard as it is possible to be. There are, therefore, two different measures of overcrowding: the pre-WWI period was compared with the inter-war period based on data concerning people living at above 1.5 persons per room in dwellings of four rooms or less, with the number of such dwellings providing the denominator. The inter-War period was compared to later dates using the total number of people living at over 1.5 persons per room with the total population as the denominator.

The overall standardised rates of overcrowded housing seem to have fallen even more dramatically than for infant mortality; the median rate of people living at more than 1.5 persons per room was 12% in the inter-War period but is now approximately half a percent. Comparing the pre-WWI measure with the alternative inter-war measure suggests that this decline has been present all through the period. Figure 7.4 shows the geographical pattern of overcrowding in the pre-WWI period. The most striking feature is the high rates found in both rural and urban areas of the north-east. This remains fairly constant up to and including the post-war boom period but has disappeared in the modern period as shown in figure 7.5. It has been suggested that this represents the poor nature of the housing stock in that part of the country, and in particular the “Tyneside flat”. It is also clear that in the pre-WWI period a far higher

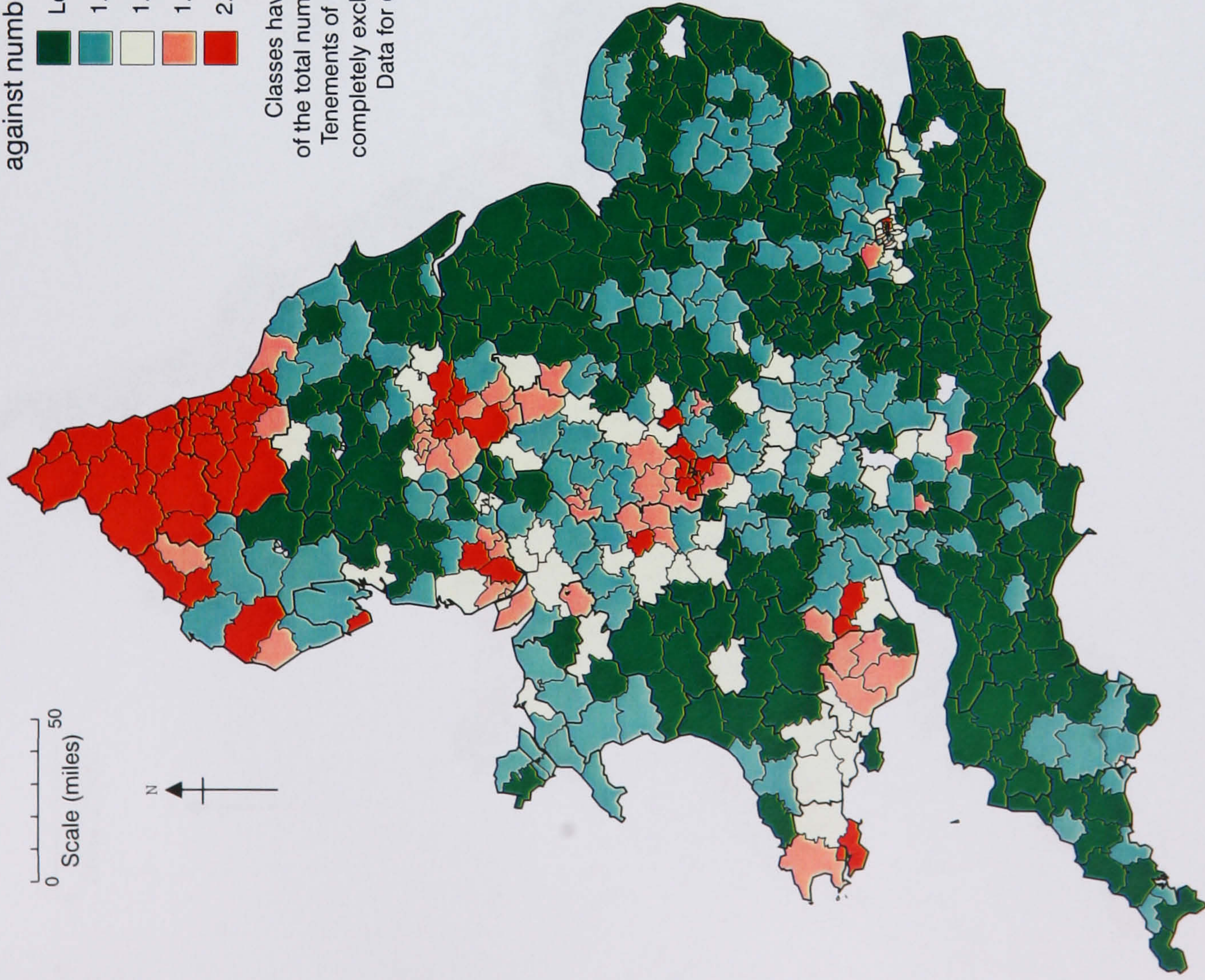
proportion of tenements were of four rooms or less than in any other region. The change since the post-war boom period reflect the impact of specific policies, and in particular the urban renewal and slum clearance programs in Tyneside. The West Midlands conurbation and London also have relatively high rates of overcrowding at their cores, but interestingly, the conurbations in Yorkshire and the north-west, with the exception of Liverpool, do not have rates that are as high as might be expected.

Figure 7.6 shows change over the century. Unlike infant mortality, the spatial distribution of overcrowded housing has remained fairly stable with the exception of improvements in the north-east. Areas that have become relatively overcrowded are mainly in the south-east, particularly the London commuter areas. Like infant mortality, the map again suggests that urban areas have improved relative to rural ones. The inequality ratio again shows a clear rise over the century from around three-and-a-half before the First World War to nearly thirty now. Again, the majority of this rise has occurred between the two most recent dates used.

Ratio of persons living at over 1.5 persons per room against number of tenements



Classes have equal proportions of the total number of tenements in them. Tenements of more than 4 rooms are completely excluded from this analysis. Data for census day 1901.



0 50
Scale (miles)



Circle size is proportional to number of tenements (1901)

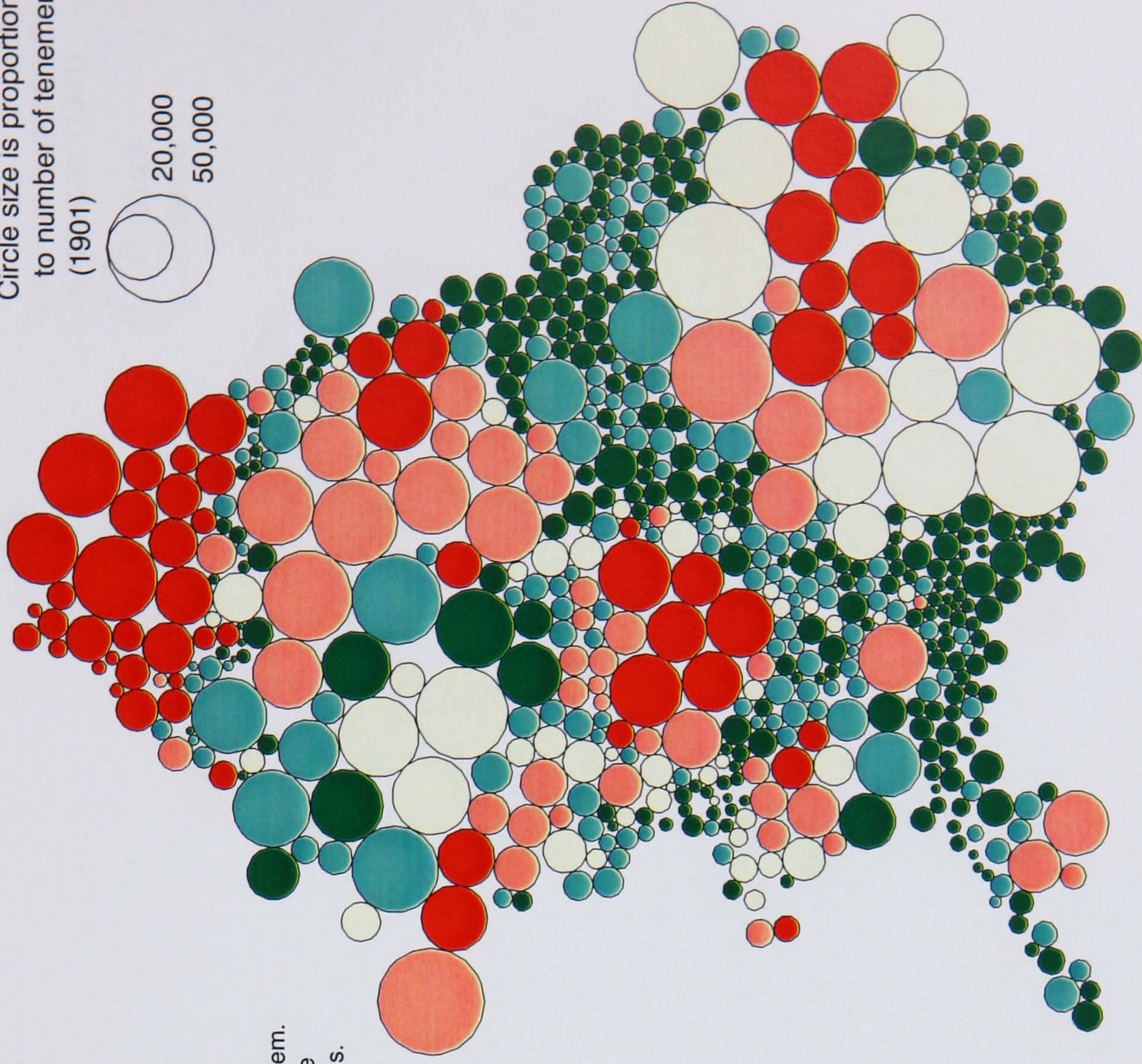
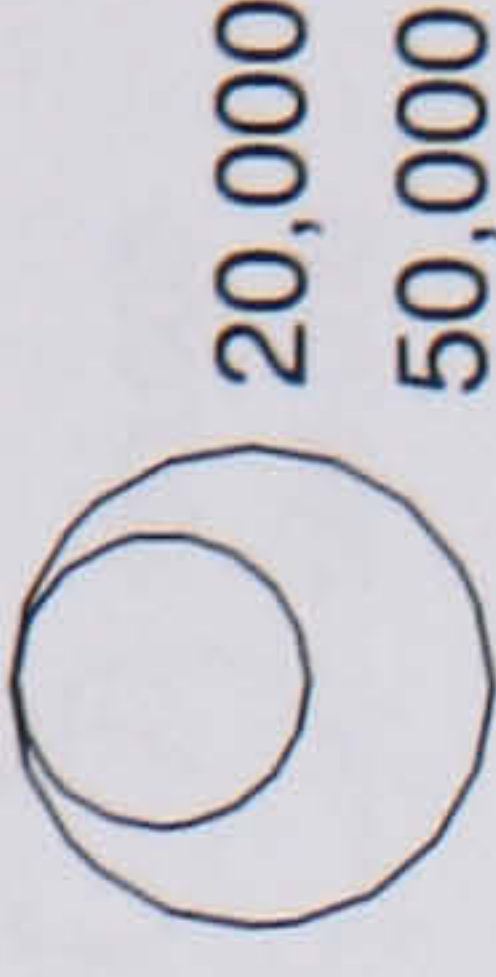


Figure 7.4: Overcrowded Housing in the pre-WWI period on 1898 Registration Districts



Figure 7.5: Overcrowded Housing in the modern period on 1898 Registration Districts

Change in ranking,
1901s to 1991

- Improvement of 2 or more quintiles
- Change of less than 2 quintiles
- Decline of 2 or more quintiles

The data sets for both dates were ranked and allocated into quintiles that contained one fifth of the population each.
Data for 1901 and 1991 standardised onto 1898 RDs.

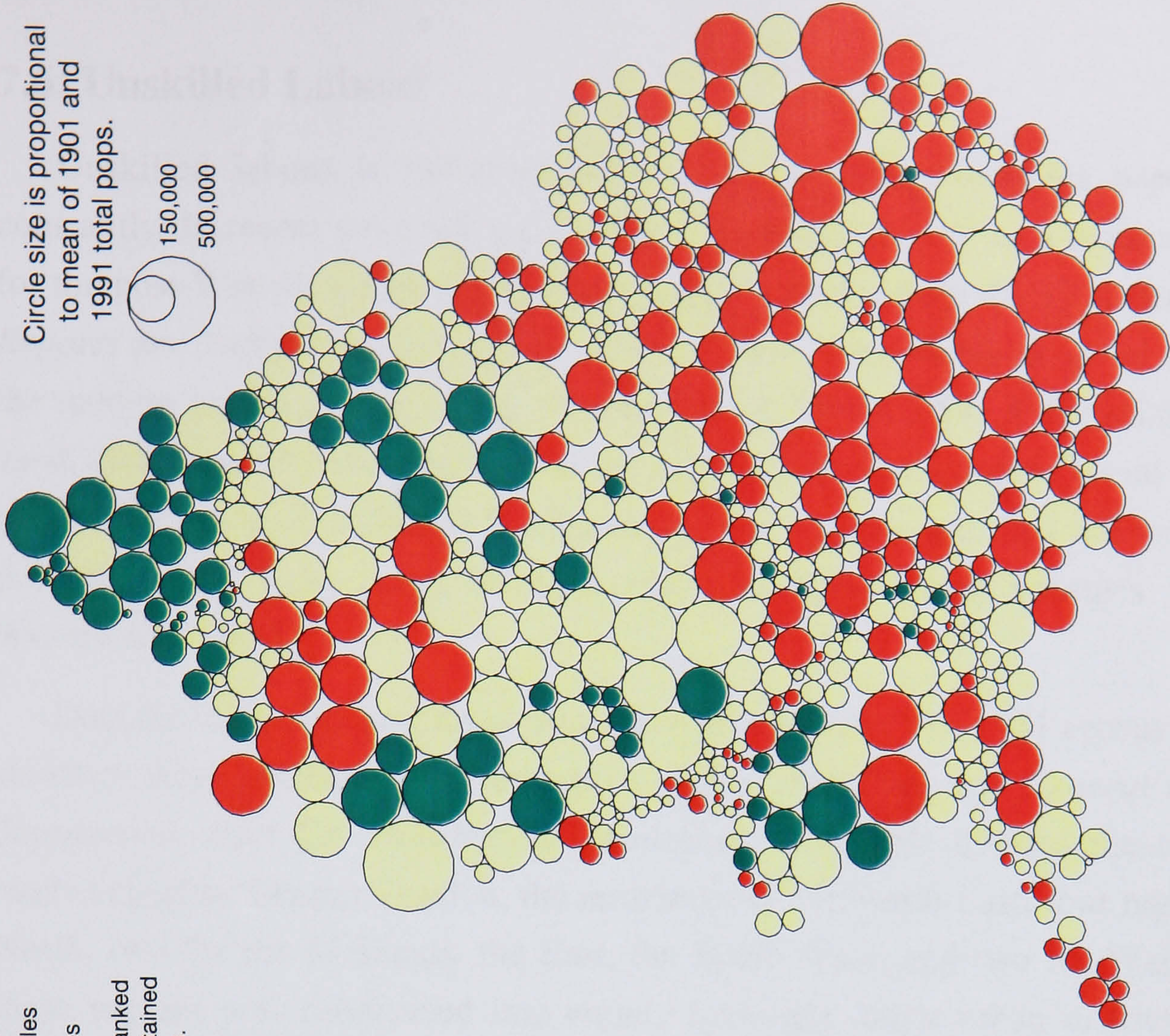
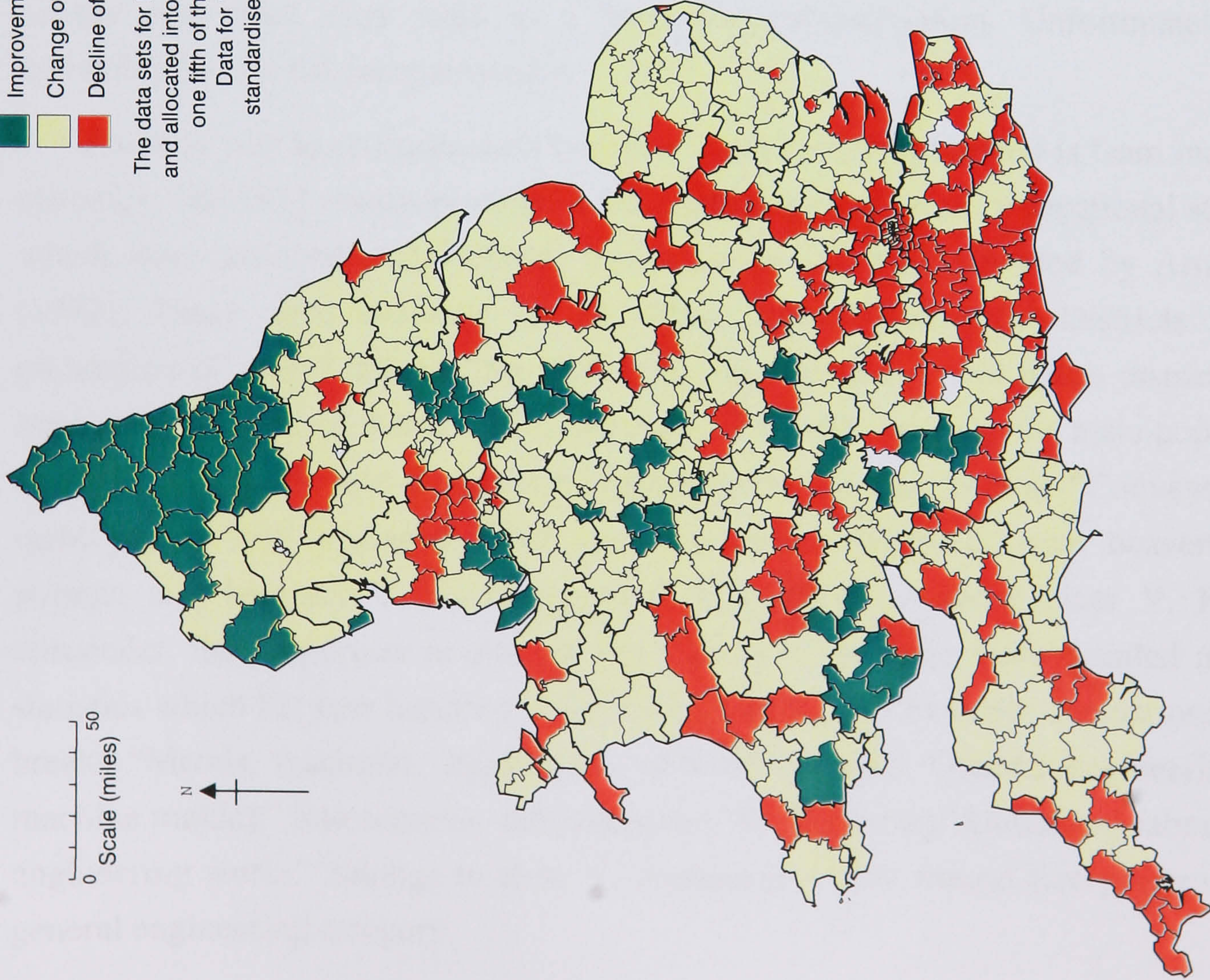


Figure 7.6: Relative change in Overcrowded Housing: Pre-WWI to the present

7.6: Unskilled Labour

Unskilled labour is the most difficult of the three variables used to define constantly. In recent years the census has used social class V as a measure. The data for the post-War period are the simplest and were taken from the 1951 census *County Reports* and include the number of occupied and retired males in social class V. For the modern period data from the 10% sample of the 1991 *Small Area Statistics* were used; these concern economically active males defined as being in social class V. To make the data more comparable with earlier years males who had not worked in the past ten years were added as were males on government schemes (Dorling & Woodward, 1996).

Data for the earlier two dates were more problematic. The 1931 census social class statistics were tabulated in table twelve of the 1931 *Registrar General's Decennial Supplement, Part IIa, Occupational Mortality*. This table divided the country into twelve regions: Greater London, the remainder of the South-East, four regions for the North, two for the Midlands, the East, the South West, and two for Wales. Each of these regions was subdivided into county boroughs, other urban districts and rural districts and the number of males aged 16 and up in social class V was thus provided for thirty-three units (not all regions had all three types of unit). These data were reallocated to Local Government District level using population data from the 1931 census and these were used as a basis for standardisation. Unfortunately, this inevitably lowers the inequality ratio.

The only way to estimate class structure for the pre-WWI period is from industrial statistics. The 1911 census provides a reasonably detailed set of occupational statistics which were assigned social classes based on the structure provided by Armstrong (1972). These were available for all urban Local Government Districts with a population of over 5,000 and for the county aggregates of other urban districts and, separately, of all rural districts in each county. The tables classify the male population aged ten and above into 42 occupational categories. A few such as “Conveyance of men, goods, and messages: Dock labourers, wharf labourers, coal heavers, coal porters, and labourers”, can be assigned as a whole to social class V. For the remainder, the proportion in class V was estimated from the more detailed national statistics which list four hundred occupational classes. For example, the national table breaks “Metals, machines, implements, and conveyances: General engineering and machine making” into fourteen sub-categories, of which only “Undefined labourers in engineering works” belongs to class V, representing only around five percent of the general engineering category.

One final point is the variation in the minimum age covered by these tabulations: in the pre-WWI period boys as young as ten are included, in the inter-War period this had risen to fourteen, and by the modern period was sixteen. This reflects the changing age of starting work and no attempt has been made to adjust for this.

The overall proportion of occupied males in class V rose slightly between the pre-WWI and inter-war dates, possibly reflecting the limitations of the data. By modern times it had halved from this peak. Figure 7.8 shows the modern geography of unskilled workers with relatively high rates being concentrated in London and the old industrial areas, and relatively low rates in rural areas, especially in the South East. The patterns for the post-War and, allowing for the lower quality of the data, inter-War data periods are similar. The pre-WWI pattern, shown in figure 7.7, shows intriguing differences: the relatively high values are found in London and especially the East End and almost all of southern England had higher rates than the Midlands or the North. Figure 7.9, mapping change over the century reflects this further. Areas of the rural South have improved the most over the century, while Wales, the West Midlands, western parts of Norfolk, Nottinghamshire, Derbyshire, southern Yorkshire, and what are now County Durham and west Cumbria have become relatively worse. This arguably reflects major changes in the industrial bases of the different areas; the North has lost staple industries that employed large numbers of skilled and semi-skilled workers (coal miners, for example, are in class IV), while the rural south has been increasingly populated by white-collar workers.

The inequality ratio for unskilled workers tells a broadly similar story to the other measures but the pattern is less dramatic: until 1951 the worst-off areas had around three times as many unskilled workers as the best-off, by modern times this had risen to over four.

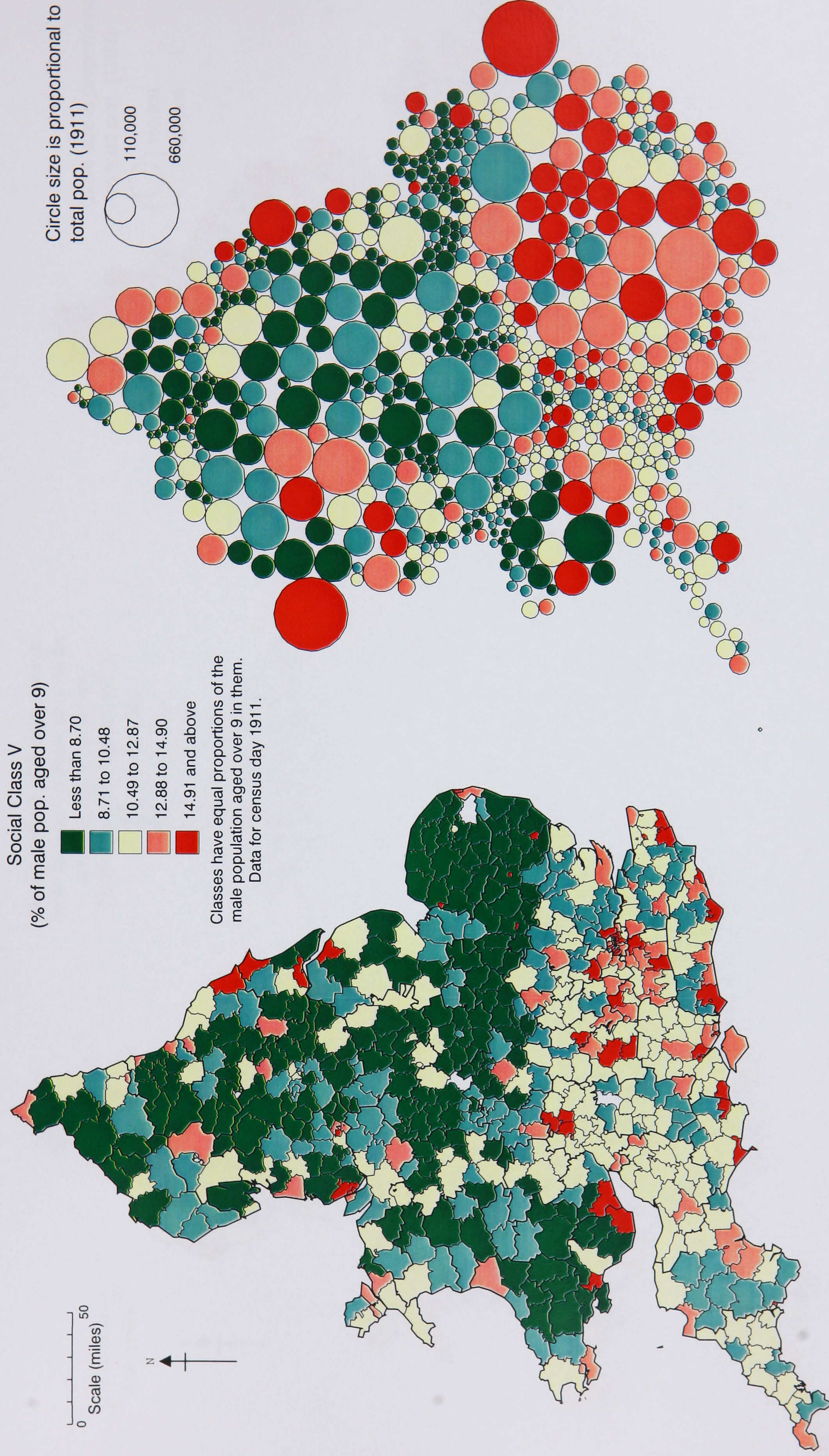


Figure 7.7: Unskilled Workers in the pre-WWI period on 1898 Registration Districts



Figure 7.8: Unskilled Workers in the modern period on 1898 Registration Districts

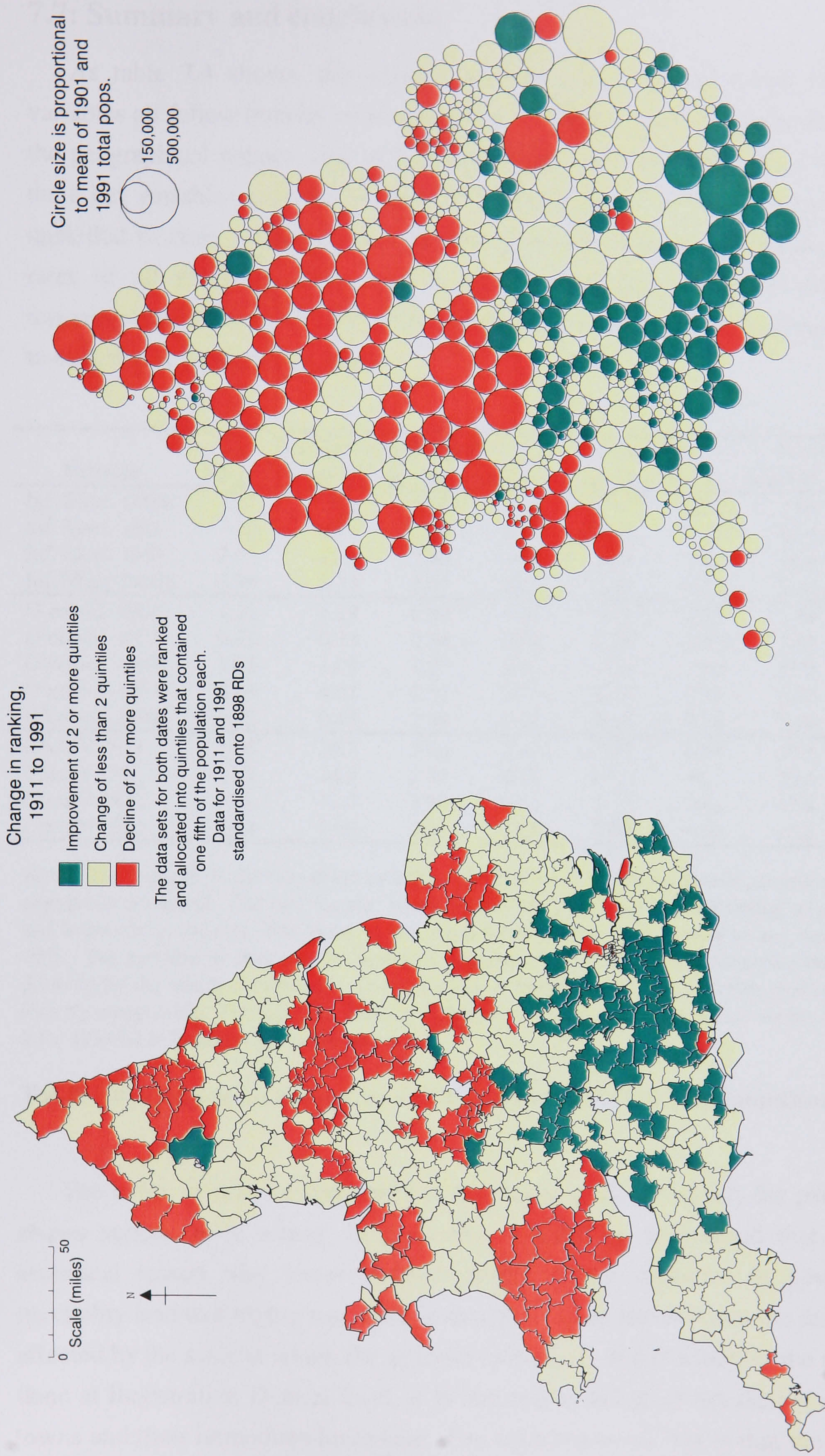


Figure 7.9: Relative change in Unskilled Workers: Pre-WWI to the present

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7.7: Summary and conclusions

As table 7.4 shows, the analysis presented here clearly shows that the three variables all follow broadly similar patterns for median rates, the inequality index, and the geographical pattern. Figure 7.10 shows how median rates have changed for the three key variables over the century. With the exception of the early two periods for unskilled workers, where the data must be treated with particular caution, the median rates of all three variables have dropped considerably over the century. Infant mortality has fallen to only 3% of its pre-WWI rate, while overcrowding has dropped to only 6% of its inter-war rate.

Variable	Descriptive Measures:				Best 10%:		Worst 10%:		Ratio
	Mean	Median	St Dev	Skew	Cut-off	Mean	Cut-off	Mean	
Inf. Mort. 1890s	127	121	28.6	0.58	109	95.6	186	204	2.14
Inf. Mort. 1928	56.0	54.9	16.9	0.20	45.3	34.3	86.5	93.3	2.72
Inf. Mort. 1958	21.1	21.1	7.40	0.02	16.3	10.7	28.0	33.1	3.10
Inf. Mort. 1990s	3.86	3.73	2.65	0.14	2.39	1.04	5.59	7.86	7.57
O'crowd. 1901 ¹	1.31	1.19	0.50	0.73	1.01	0.82	2.49	2.93	3.53
O'crowd. 1931 ¹	0.82	0.73	0.34	0.82	0.58	0.48	1.68	1.79	3.73
O'crowd. 1931 ²	14.5	11.9	7.97	0.97	9.3	8.0	31.2	40.6	5.07
O'crowd. 1961 ²	4.63	4.01	2.57	0.71	2.81	2.16	9.69	13.01	6.01
O'crowd. 1991 ²	0.85	0.43	2.08	0.43	0.28	0.20	2.00	5.78	29.4
Class V 1911	10.6	10.3	2.96	0.36	7.78	6.84	17.0	19.2	2.80
Class V 1931	14.7	14.8	2.52	-0.12	12.2	11.3	20.0	22.3	1.97
Class V 1951	11.8	11.0	3.90	0.62	8.72	7.48	17.8	21.6	2.88
Class V 1991	8.43	7.60	3.93	0.65	5.08	4.30	13.8	17.7	4.12

Note: The 'cut-off' is the rate above or below which the top or bottom districts containing 10% of the population are found. The two 'means' to the right of the table refer to units falling respectively above and below these cut-offs. The 'ratio' is the mean for the worst 10% divided by the mean for the best 10%. The measure of skewness is calculated by subtracting the median, multiplying this by three and dividing by the standard deviation. Overcrowding is calculated by two different methods that are not directly comparable. Method 1 for 1901-31 is based on households living in four rooms or less, method 2 for 1931-91 is based on the entire population.

Table 7.4: Long-term inequality in England and Wales: Key quantitative results

The index of relative inequality is inevitably crude, however, the patterns that it shows appear to be robust. In particular, it must be emphasised that there is no statistical reason why lower absolute levels of our measures of poverty should inevitably lead to a higher inequality index. It must be stressed that the results may be affected by the scale at which the analysis took place. In particular, as the analysis was done at Registration District-level, it is sub-county but does not distinguish between towns and their immediate hinterland. The significance of this is that the results may reflect a change in where different social groups live. As communications have improved and spatial divisions of labour have become more enlarged through the

century it is possible that different sections of society now live further apart. This may have resulted in target districts containing a less diverse population today and this has affected the inequality ratio at target district-level. The cartograms demonstrate however, that much of the population was, and still is, concentrated into areas that are relatively small spatially and so this problem should not be exaggerated.

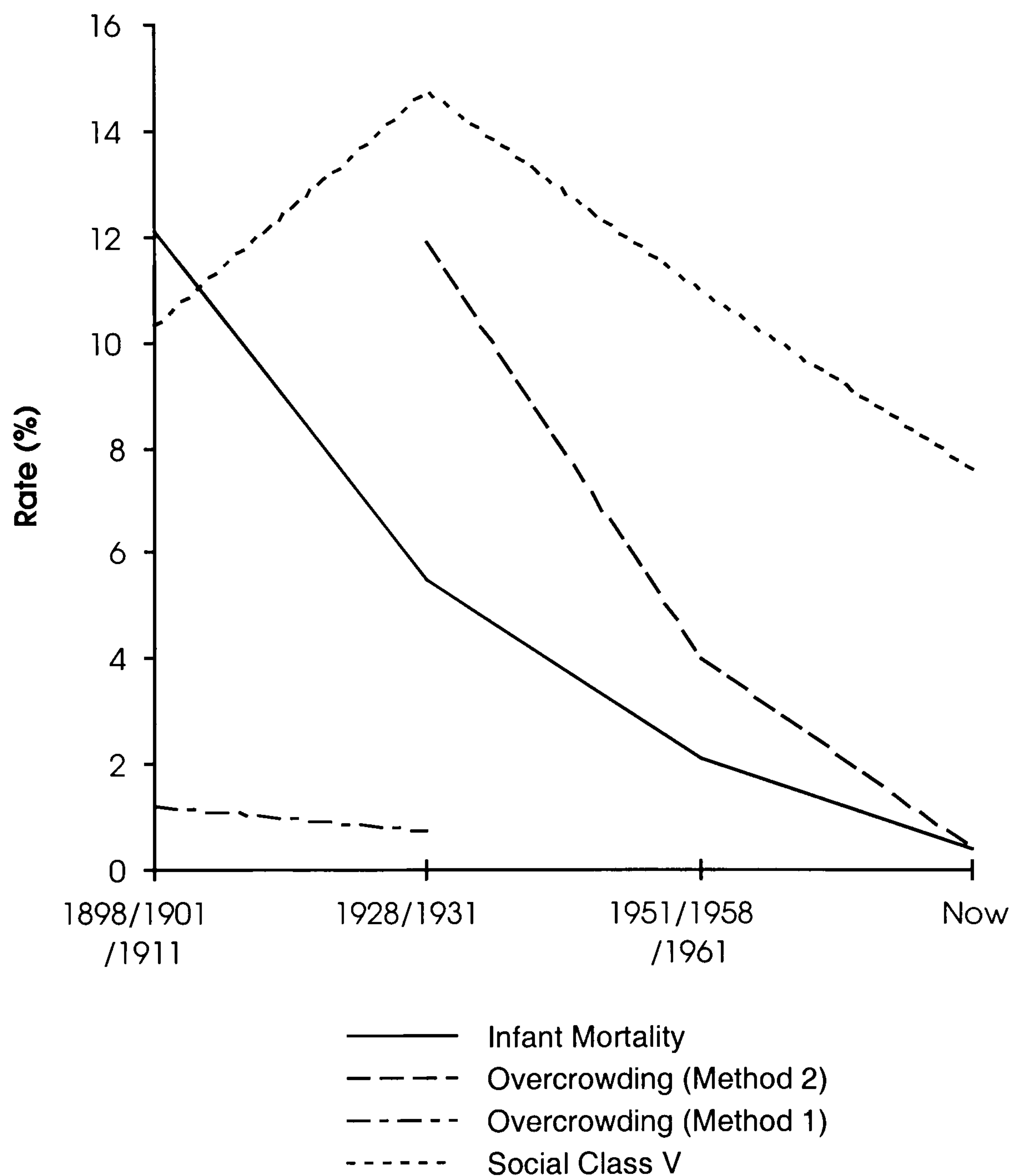


Figure 7.10: Change in overall rates of Infant Mortality, Overcrowded Housing, and Unskilled Workers: Pre-WWI to the present. Note: The definition of Overcrowding is households living at more than 1.5 persons per room. Method 1 refers to households living in less than five rooms as a rate per tenement. Method 2 refers to all households as a rate per household.

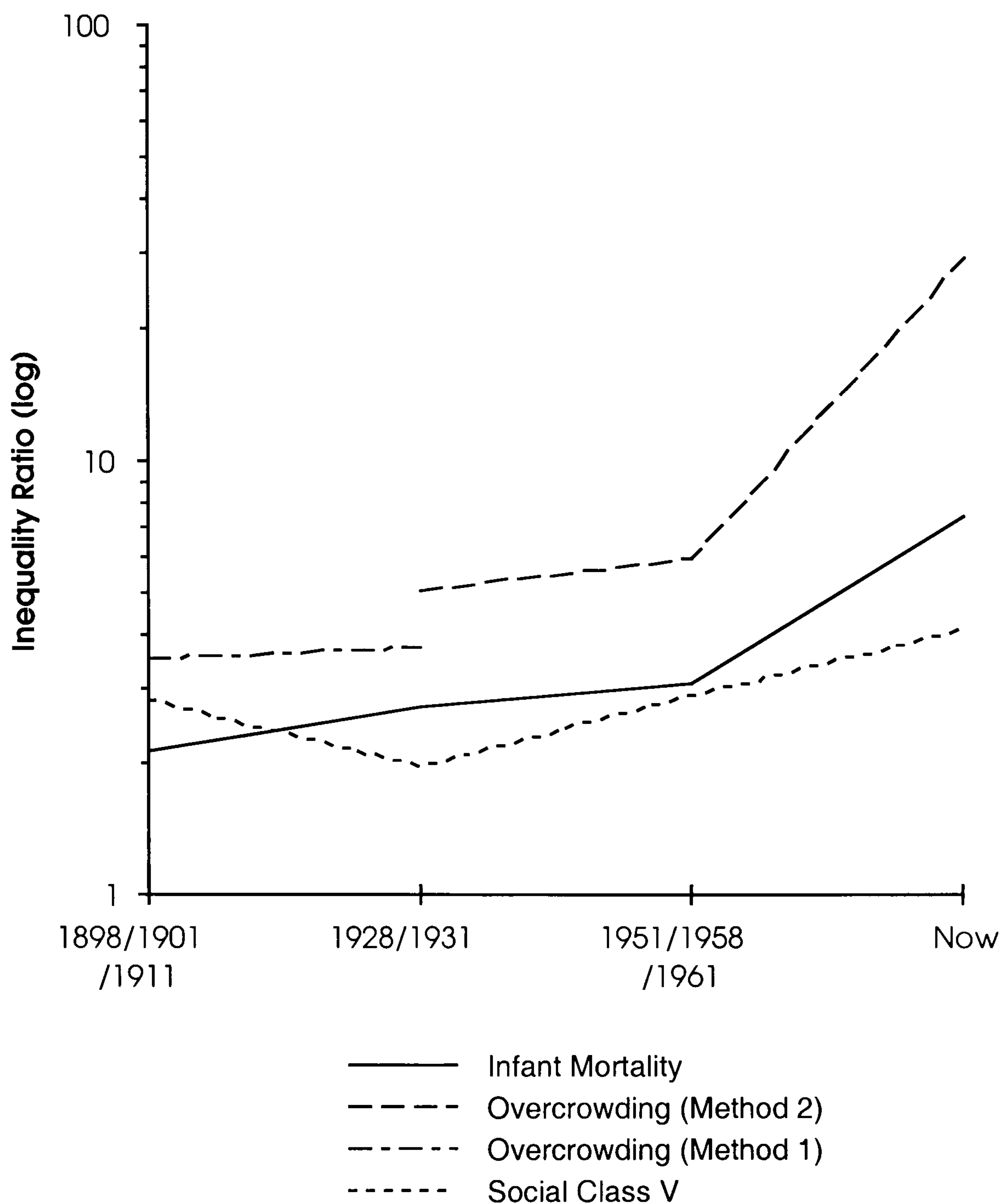


Figure 7.11: Change in inequality ratio for Infant Mortality, Overcrowded Housing, and Unskilled Workers: Pre-WWI to the present. Note: The definition of Overcrowding is households living at more than 1.5 persons per room. Method 1 refers to households living in less than five rooms as a rate per tenement. Method 2 refers to all households as a rate per household.

The changes in the inequality ratio, therefore, do present a meaningful and interesting result. Figure 7.11 graphs how these have changed over the century. With the exception of the inter-war unskilled worker data, the problems of which are discussed above, the trends for all three variables are the same: a steady rise over the century that has become far more pronounced in the past thirty years.

The geographical patterns, again excluding the early unskilled workers data, show a marked persistence of relatively high deprivation in the periphery; the North, South

Wales and often the remoter parts of the South West. In general, the major conurbations fare relatively poorly compared to adjacent rural areas, although increasingly rural deprivation seems to be becoming apparent. London generally contains substantial deprived areas relative to the affluent South East, but these are not generally as severe as in the North. The increase in rural relative poverty may be due to major improvements in urban areas, but may also reflect the problems of access to health care facilities, especially maternity units.

The aim of this chapter was to demonstrate the possibilities and problems of using the GIS to investigate long-term change in inequality in England and Wales through the use of a standardised administrative geography. This allows comparison through space and time at a level of spatial detail determined by the limitations of the data themselves rather than aggregating to county-level for methodological reasons. By reducing the temporal extent of the study, it would have been possible to have increased the limitations of spatial detail. A study that did not include the period before the First World War could use Local Government District-level target districts, while a study of 1971 or 1981 onwards could use much more detailed geographies (see, for example, Martin, 1996a).

In chapter 2 it was argued that as much temporal detail as possible should be included in any analysis. This has not been done in this chapter partly because of the limitations of the data available. It would have been possible, however, to have attempted to include data from the nine snapshots between 1901 and 1991 (with 1941 inevitably missing). This would have more than doubled the volume of data that needed to be interpolated and would have increased the complexity of handling changing attribute definitions considerably. In most cases this probably would not have added much information as, as was noted above, the long-term changes in these processes are slow. Where additional information would be interesting is in recent decades to attempt to answer when the large rises in inequality occurred. Of particular interest is whether there has been a steady upward trend since the end of the Second World War, or whether there has been a sudden marked increase more recently. This would lend some more information to the question of to what extent the results are due to changes in the scale at which spatial inequality operates, with increased personal mobility being a major cause, or whether they may be due to changes in economic policy such as the advent of Thatcherism.

Although the GIS can help with the limitations of the spatial and sometimes the temporal components of the data the attribute component remains a fundamental limitation. The literature review to this chapter gives examples of the numbers of variables that have been used by many studies concerned with one date. Typically

there have been many variables falling into between five and twelve key areas. This obviously provides a much broader conceptualisation of poverty and inequality than is provided here. Unfortunately, where data are not available in a consistent form, the GIS cannot create them and this limits the avenues that could be explored. Even when data were available, changing definitions have meant that in some cases extensive work had to be done to ensure consistency through time. The result of this inevitable meant that some of the data, particularly those for unskilled workers, must be treated with caution.

Statistically the chapter has only attempted a relatively simple exploration of the patterns of three key variables. No attempt has been made to create an index variable to summarise the individual patterns of the three variables, and no attempt has been made to perform any causal analysis. Instead the data have only been analysed using a simple measure of inequality. There are two reasons for this: firstly, the patterns described here represent a significant contribution to knowledge in their own right, and secondly, chapter 2 argued for analyses through space and time not to be overly statistical. This chapter follows this paradigm.

The chapter has been more adventurous when it comes to visualisation. Visualisation is a field that GIS has a lot to offer to as it allows data to be explored in new ways and makes the map an integral part of the research process (Hearnshaw & Unwin, 1994). The cartogram representations of the data provide a very different, but at least as valid, representation as the choropleth maps. It is hoped that printing these together in the manner used by many of the figures gives a more insightful examination of the data than would be provided by merely using the more traditional choropleths. The use of a GIS allows these maps to be produced very quickly and as part of the work maps were produced for every variable at every date. This allows a much more detailed exploration of the spatial aspects of the problem than would be available using traditional means.

8. Conclusions

This thesis has taken some initial steps down a potentially long road of gaining a better understanding of long-term socio-economic change from routinely published zone-based statistics such as the census. It has done this by using a GIS-based approach to help to integrate the spatial, temporal and attribute components of data. In chapter 1 these components were introduced. Chapter 2 argued for the spatial and temporal components to be more fully integrated in an analysis but said that even if full integration could be achieved, there were still limits to the understanding that could be gained using a quantitative, GIS-based approach. In the chapter the idea that administrative units could be regarded as space-time cylinders whose shape and size changes over time was introduced. Socio-economic data are published with these cylinders, however, they are still snapshot-based whether these snapshots are intended to represent the situation on a single night, such as the census, or cover a whole decade like, for example, the *Registrar General's Decennial Supplements*. Therefore, attribute change has to be understood based on information from snapshots thorough space-time cylinders whose spatial dimensions change.

Chapter 3 concentrates on the spatial component of these cylinders. It described how England and Wales have been arbitrarily sub-divided into administrative units using a system that was set up in the 1830s in response to the need for improved civil administration, especially for the relief of the poor. This system was based on the core idea that a district should represent a market town and its hinterland to allow administrators to meet in the town on market days. Ironically, it was implemented at the same time as the Industrial Revolution and the beginnings of the railway age were starting to significantly reduce the importance of both market towns and the limits of personal mobility. Although the system created in the 1830s is arguably the closest England and Wales have come to setting up an entirely new system of local government, it was still rooted in units that stretch back to Anglo-Saxon times. The impact of these were that Poor Law Unions and thus Registration Districts were created as aggregations of parishes, and it was felt necessary to be able to aggregate to a top-level tier that approximated as closely as possible to a horrendously arbitrary system of counties whose distribution had long ceased to provide any meaningful sub-division of the population, if indeed it ever had.

This system has been overhauled and reformed on occasion, notably the move from Poor Law Unions and Registration Districts to Local Government Districts in the late nineteenth and early twentieth centuries, the reform of parishes in the late

nineteenth century, the County Reviews of the 1930s and the Redcliffe-Maud reforms of the 1970s. It has also been subject to a myriad of smaller changes, however, at its heart it remains a highly arbitrary and very conservative system.

Chapter 4 described how the GBHGIS was designed as a database to store and retrieve administrative units with changing boundaries and how these boundaries were rigorously researched. It then demonstrated how the GIS could be used to link socio-economic data to the administrative units used to publish them. The chapter, therefore, approaches the GIS as an integrating database that, by storing changing boundaries, allows snapshots of the changing spatial and attribute structure of the data to be produced to represent different moments in time. Effectively, therefore, this provides a situation where it is possible to reproduce the spatial and attribute components of a time-slice through the past. It does not, however, offer new data but rather offers a temporally integrated structure for linking data to the units used to publish them.

Chapter 5 described an areal interpolation technique designed specifically to make best use of the data available in the GBHGIS. It was demonstrated that this allows data from many dates to be interpolated onto a single district-level target geography. Doing so results in error being added to the attribute component of data. The advantage, however, is that rather than space-time cylinders forming a complex honeycomb, their spatial dimension becomes constant through time. This allows real world change to be more easily distinguished from change in the arrangement of the spatial units. This represents a major step forward as it means that data can be compared over the long-term at a scale determined by the source data rather than by the need to aggregate up to allow comparison.

Chapter 6 gives a detailed example of this focusing on a short period of time for a single county. Concentrating on the example of net migration, it showed that integrating data using a standardised administrative geography not only allows the comparison of data through time, it also allows value to be added to the source datasets. This was demonstrated as in the past most studies of long-term net migration have used high spatially aggregate statistics of net migration rates for the total population. The chapter demonstrated the creation of district-level statistics for the population divided into ten year age bands and by sex. It was shown that different patterns could be found for different districts and also different age and sex cohorts. The chapter also demonstrated that improvements in the way that the spatial component of that data was handled led to error in the attribute component. This error is not significant enough to invalidate the technique but needs to be considered in the context of any interpretation of patterns.

Finally, chapter 7 gives a broader exploration of change through time and space. By looking at 100 years of change in inequality in England and Wales, it demonstrated that important new perspectives can be gained by using a standardised administrative geography. It also demonstrated that the limitations of the source data still fundamentally limit the analyses. In addition to meaning that analysis of long-term change is spatially restricted to district-level patterns, it also showed that changes in the attribute data published do limit what can be achieved. In spite of these limitations, it is believed that analyses of this kind do offer new potentials to explore long-term change that give new perspectives on the current situation. Doing this has been achieved in this chapter using very simple statistics and more complicated visualisation techniques.

The early part of the thesis is heavily concerned with the boundaries of arbitrary administrative units and how they changed. Later sections attempt to remove the impact of boundary changes. This allows real world change to be distinguished from changes in the administrative geography used to publish the statistical data that provide the information about change. Cartograms are introduced in the last chapter as these provide another method of distinguishing real world patterns from patterns created by arbitrary administrative geographies.

To analyse the socio-economic structure of the population from secondary sources requires the real world to be abstracted twice. In the first abstraction the real world is simplified into the secondary source. The census, for example, simplifies the complex patterns of human activity as snapshots of spatially aggregate data taken once every ten years in which various aspects of peoples lives, such as household structure, employment, education and social conditions, are allocated to crude classes. In the second abstraction the data are reallocated to the structure in which they are to be analysed. This involves choice of spatial arrangement and spatial extent, choice of temporal snapshots and temporal extent, and choice of variables. Traditional limitations on the ability to manipulate large amounts of complex data often meant that this layer of abstraction involved aggregating data to county-level or focusing on a small study area, restricting the number of temporal snapshots used and simplifying attributes. This means that much of the information content of the data is removed which, in turn, means that the information that can be gained from an analysis is limited.

The GBHGIS attempts to remove much of the abstraction involved in the second of these in allowing data to be analysed in as close to their original form as possible, with a minimum of loss of information content at this stage. Any analysis will,

however, still be inherently bounded by the limitations of the secondary source used. This means in particular:

1. That the data are still snapshot-based and the most detailed data are only available once every ten years.
2. That the data are still dependent on arbitrary spatial units and that the scale at which an analysis can be performed is still limited by the least detailed scale at which the data were originally published.
3. That the attribute component of the data is still limited and analyses of long-term change will be hampered by what data were published at which dates and the definitions used at that date. In addition to this, the solutions to the spatial complexity lead to increased error in the attribute component and this will vary through time and space.

This means that tradeoffs still need to be made between the three different components. It is possible to analyse change at very detailed spatial scales but it is only possible to compare 1991 with 1981 and perhaps 1971. On the other hand, analysing change as far back as the mid-nineteenth century is possible but this has to be done at district-level and the number of themes for which there is attribute data in a consistent form will be limited. Long-term change from census data is, therefore, approached using a district-level spatial structure and a decennial temporal structure. Any processes whose effects are too localised in time and space will simply be filtered out by this publishing framework.

A historical GIS-based approach can offer ways of attempting to add information to the available data. This was demonstrated in chapter 6 where, by combining two simple datasets, age and sex specific population totals and age and sex specific mortality data, a new attribute dataset could be produced that gave age and sex specific net migration rates. It may also be possible to attempt to reduce the impact of the snapshot nature of the data. Dragicevic & Marceau (2000) explore this in a planning context by using fuzzy logic to estimate the probability of the land-use of a parcel of land between two snapshots. This type of procedure may also be useful in attempting to estimate attribute data in a polygon between two snapshots. Unfortunately, the time for which this would be useful, change between 1931 and 1951, is the time for which models are least likely to be effective.

The thesis has, therefore, been concerned with creating a GIS that holds data published over a long period of time and devising methodologies that allow these data to be integrated through time by standardising their spatial component. This puts an enormous amount of information into an integrated structure. This is not, however,

the end of the problem but opens up a whole new area, namely how to extract information about change through space and time. There are two different but overlapping approaches to this: statistical analysis and visualisation.

As far as statistical analysis is concerned, the challenge is to devise techniques that are able to summarise patterns through space and time by making maximum use of the available data, while remaining sympathetic to both the source data and the error component introduced by the areal interpolation and, perhaps, other sources. This may involve devising highly complex techniques but this is not a necessity. Chapters 6 and 7, for example, both uncover spatio-temporal patterns without resorting to complex statistics. One part of this that requires significant amount of research is the development of a better understanding of error, error propagation, and the incorporation of the knowledge about potential error into analytical techniques. This is an area that is receiving attention in the GIS literature (Unwin, 1995) but where there is still a considerable distance to travel before a truly error-sensitive approach can be derived.

In the past it has been common to argue that analysis through space and time should seek to uncover process (Langton, 1972). Chrisman (1998) also calls for this, however, in the context of long-term socio-economic change it must be asked whether this is realistic or even desirable. These two authors are using a mechanistic definition, whereby process is seen as explanatory (Johnston *et al*, 1994: p. 478). This leads to two questions:

1. The GBHGIS allows the information content of a century and a half of census and similar data to be accessed in a more powerful and flexible manner. Even assuming all of the information content within these sources could be used to the full would this be enough to allow explanatory models of process to be developed?
2. If this were possible would this lead to a better understanding of the past, how the present was arrived at, and what the future is likely to hold, or, would it merely be a return to what Massey (1999) argues should be avoided; namely, timeless mathematical models that deaden flow and attempt to state how the present is an inevitable consequence of the past?

The answer to the first is that while sources such as the census contain a lot of information, they are fundamentally crude. Thus, while there is a wealth of information and understanding still to be derived from these sources, they will never offer a complete understanding of even simple spatio-temporal processes in human society. The answer to the second is more difficult, but it seems likely that models that attempt to create a detailed explanation of the development of a phenomena in

one place are likely to only have limited application to other, different places, while models that attempt to be explanatory for all places are likely to be vague or oversimplistic.

Rather than go down this route, in the shorter term at least it seems desirable to attempt to follow a more exploratory approach. This would attempt to discover and describe patterns without over-emphasising causality. Bailey (1994: p. 15) refers to this as spatial summarisation rather than spatial analysis. There is an increasing recognition in the GIS literature that exploratory analyses are a valid and valuable approach (see, for example, Fisher *et al*, 1996, Fotheringham & Rogerson, 1993; Openshaw, 1991b).

Visualisation is another way in which it is possible to explore and summarise data that could be invaluable in the attempt to gain information and understanding from the GBHGIS. As was discussed in chapter 2, in the GIS community there has been more work on the visualisation of change than on the spatial statistical analysis of change. This work is still, however, limited. The basic problem is the same for the two areas: how to simplify large amounts of data in such a way as to gain the maximum understanding of the information held within the data without resorting to oversimplification.

The thesis has been concerned with integrating data through time. This can be thought of as creating space-time cylinders in which the spatial component of the cylinder is held constant at the maximum scale the data allow. The spatial units are, arbitrarily defined but are constant through time. The more detailed the spatial geography becomes, the more error the attributes will contain. By removing or at least simplifying the complexity of the spatial component of the data, therefore, the attribute complexity has been increased. Within the cylinders not all of the attribute information is known, as there is very little information about the intra-district spatial variations, or the intra-snapshot temporal variations. There is, however, an integrated structure in which the spatial framework in which attributes change over time is fixed to allow the spatial and temporal patterns within the attribute data to express themselves.

The GBHGIS, therefore, represents a first step in unlocking the information about long-term change that is held in over 150 years-worth of census, vital registration and other statistics. It does not achieve a fully spatio-temporal approach as the source datasets do not support this. However, it goes some distance towards this and, importantly, offers a way of integrating data over the long-term. This is a major step forward but, never the less, only a first step. The next is to gain a better understanding of long-term socio-economic change and how it has occurred.

Appendices

Appendix 3.1: Administrative units listed in the 1871 census

The following are “the principal sub-divisions of England and Wales of which the population is given ... in the census abstracts of 1871, or which are included in the tables of territorial sub-divisions” (IUP, 1970: p. 175)

1. Counties

Formed in Saxon period (England) or post-Conquest (Wales).

Lord Lieutenant for each county plus Tower Hamlets (also the governor of the Tower), the Ridings of Yorkshire, Liberty of the Isle of Ely, Town of Haverfordwest, and Lord Wardens (with similar powers) of the Cinque Ports, and the Stanneries.

Have a High Sheriff appointed annually by the Crown, and a Clerk of the Peace appointed by the Justices.

Expenditure regulated by justices in Courts of Quarter or General Sessions.

2. Parliamentary Divisions and Parliamentary Boroughs

Larger counties divided into two or more divisions.

All large Municipal Boroughs plus a few large towns return MPs and are thus Parliamentary Boroughs.

Wales has eleven “Districts of Boroughs”, up to eight Boroughs grouped together to form one Borough Constituency. The individual boroughs are called “Contributory Boroughs.”

3. Hides, Tythings, Hundreds, Wapentakes, Wards, etc.

Most ancient subdivisions of the kingdom.

A hide was 100 or 120 acres (enough to support 1 free family), 10 hides is a tything, 10 tythings is a hundred.

Only really in Southern England and Wales.

Boundaries of hundreds and wapentakes normally used for parliamentary divisions.

Many counties use hundreds as petty sessional divisions and lieutenancy subdivisions.

Note that hundreds are known as wapentakes in Yorkshire, Lincolnshire, Leicestershire, Notts., Derbyshire, and Rutland, and as wards in Northumberland, Durham, Cumberland, and Westmorland (Lipman, 1949).

4. Municipal Boroughs

All cities and towns to which charters of Incorporation have been granted and are governed by the Municipal Corporations Reform Act.

Some older boroughs are not governed by the Act and either the functions of the corporation have fallen into disuse or the corporate body has ceased to exist.

Municipal Corporation consists of aldermen and councilors elected by the burgesses, and a mayor elected by the aldermen and councilors.

The mayor and ex-mayor of every municipal borough are also its justices of the peace, some also have salaried justices.

The corporation is normally entrusted with management of police, paving, lighting, drainage, and local improvements. Also in some cases water and gas supplies.

5. Lieutenancy Sub-Divisions

Used for raising the militia.

Lieutenancy of a county can alter boundaries or create new ones as convenient.

6. Petty Sessional Divisions

Hold the petty sessions for administration of justice for minor offenses under justices of the peace appointed by the Lord Lieutenant.

Mayors and ex-mayors are the justices of the peace in 193 municipal boroughs granted Commissions of the Peace.

Cases beyond the jurisdiction of county and borough justices in petty sessions are sent for trial in Quarter Sessions or to the Assizes.

97 more important boroughs have their own Courts of Quarter Session under a judge appointed by the Crown.

Minor civil offenses are tried in county courts whose districts are arranged "with little or no reference to county boundaries". There were 56 of these (down from 59) plus the City of London Court. County court judges do circuits of their districts and hold courts at stated periods and places.

There were still 25 Borough, Hundred, and Manorial Courts with jurisdiction over civil cases.

7. Police Divisions

The Act 2 & 3 Vict. cap. 93 gave power to justices in each county to establish a police force for the whole county or for any of the petty sessional divisions; the entire force of each county or parliamentary division being under a Chief Constable.

The Act 3 & 4 Vict. cap. 88 allows justices to split the county into police districts to pay for their constables.

The Act 19 & 20 Vict. cap. 69 made it compulsory to establish a police force in every county, consolidating those in Petty Sessional Divisions into them. Power was reserved for the formation of Police Districts.

The 167 Municipal Boroughs and Non-corporate towns had a separate independent police force.

8. Highway Districts

Consist of numbers of parishes united by the county justices for better management of highways.

Each district has a Highway Board consisting of elected waywardens and the county justices.

The following places are not included in Highway Districts:

Any part of a county in South Wales

The Isle of Wight

Any district under the Public Health Act of 1848 or the Local Government Act of 1858

Any parish or place whose highways were under the superintendence of a board established under sec. 18 of the Principal Act (5 & 6 Will. IV cap. 50) within six months of the act being passed

Any parish within the Metropolis

Any parish, part of a parish, or place whose highways are maintained by Local Act

9. Local Board Districts

At the time of the 1871 census these had been established in 146 Municipal Boroughs and 575 other towns under the 1848 Public Health Act or the 1858 Local Government Act.

10. Boroughs and Towns with Improvement Commissioners under Local Acts

At the time of the 1871 census there were 37 municipal boroughs and 51 other towns with improvement, paving, lighting, or other commissions under Local Acts.

By the 1872 Public Health Act municipal boroughs, local board districts and towns with improvement commissions, became urban sanitary districts with the town councils (of the boroughs), the improvement commissioners, or the local boards becoming the sanitary authorities.

In the remainder, except the metropolis, the boards of guardians for the poor law became the sanitary authorities. These became rural sanitary districts and included all towns with no municipal authorities, local boards, or commissions.

These authorities got the powers previously held by any other authorities in their district relating to local government, utilisation of sewage, removal of nuisance, regulation of common washhouses, bath and lodging houses, and the prevention of disease.

11. Civil Parishes and Townships, and Extra-Parochial Places

A "civil parish or township" is a place or locality which has its own overseers and in which the poor rate is separately levied.

Civil Parishes are generally identical to Ancient Ecclesiastical Parishes except in the six Northern Counties, where ancient parishes have usually been divided into two or more civil parishes generally known as townships.

Extra-parochial places are those not included in a parish or township for ecclesiastical or poor law purposes. Most of these had been formed into separate parishes under the Acts of 1857 and 1868 but a few are still not included in any union.

85 civil parishes and townships are in two or more counties.

Many ancient ecclesiastical parishes have been subdivided for ecclesiastical purposes into ecclesiastical districts or new parishes. Many of these ecclesiastical districts comprise parts of two or more ancient parishes.

12. Military Districts and Sub-Districts

Originally formed in 1792 but reformed in 1870.

Sub-districts were a new development under the Secretary of State for War.

In many cases a sub-district comprises a whole county, larger counties are split, and in several cases small counties are aggregated to form a sub-district.

13. Post Office Districts

11 Surveyors Districts, each comprising counties or parts of counties.

Resident Surveyor in charge of postmasters and postmistresses in the district.

14. Inland Revenue Districts

Two distinct purposes; one for excise duties, and one for income tax and house tax.

For Excise duties there are Supervisor's districts sub-divided into divisions in urban areas (which can be as small as one building, e.g. a distillery), and rides in rural areas.

For tax purposes there are Surveyor's districts.

15. Poor Law Unions

Consist of several civil parishes or townships united for the administration of relief to the poor.

Each parish or township has a board of guardians elected by rate payers and each parish or township one or more overseers.

There are also single parishes where a separate board of guardians is elected. These behave in the same way as unions.

Almost all unions or separate parishes have a workhouse, and most have a school for poor children and an infirmary or ward for the sick poor.

Lunatic asylums are managed by counties or boroughs.

Some cities, boroughs, and other places are Incorporations under Local Acts with local authorities with similar powers to boards of guardians.

Unions, single parishes, and incorporations are divided into relief districts with a relieving officer, and medical districts with a medical practitioner.

16. Registration Districts and Sub-districts

A registration district normally comprises one poor law union or single parish with a board of guardians but sometimes comprises two or more unions.

A registration district has a superintendent registrar and a Register Office where civil marriages may be performed.

Each district was sub-divided by the board of guardians, with the Registrar General's approval, into sub-districts where a registrar appointed by the guardians registers all the births and deaths.

17. Census Enumeration Districts

Made for the 1871 census but similar to those used for earlier ones.

Each register of births and deaths divided his sub-district into enumeration districts so that one efficient enumerator could visit all the houses in it in one day - in towns this meant less than 200 houses, in rural areas a walk of less than fifteen miles and less than 200 houses.

Often enumeration districts were one parish or township but in more populous areas there would be more than one district.

627 large public institutions were treated as enumeration districts.

18. Other subdivisions

Dioceses, archdeaconries, deaneries, ecclesiastical districts, judges circuits, county court districts, coroners districts, and polling districts were not include in the census.

Source: Irish University Press Series of British Parliamentary Papers (1970) 1861 and 1871 Censuses of England and Wales, Population 15 Irish University Press: Shannon

Appendix 3.2: A Chronology of Local Government: 1800 to 1974

The most significant events are given in bold text.

1800: Census Act

Led to the first census

1801: The first census

1832: Reform Bill

Led to the Poor Law Commission of 1832 which investigated the running of the Poor Law in around 300 parishes and an inquiry into the running of boroughs that was scathing about them.

1833: Lighting and Watching Act

Parish established as the basic unit for these purposes.

1833: Factories Act

Inspectors sent to manufacturing areas to.

1834: Poor Law Amendment Act

Formed the Poor Law Commission in London as a central body to oversee the running of the Poor Law.

Set up Poor Law Unions by uniting parishes (ignored traditional divisions such as counties). Unions were to build workhouses.

Set down strict rules about entitlement to relief.

Workhouses were run by Local Boards of Guardians elected by local rate payers.

Effectively ended the parish as an important unit of local administration

1835: Highways Act

Used the parish as the basic unit

1835: Municipal Corporations Act

Gave boroughs a new constitution and insisted on proper financial management.

Borough councilors elected by local rate payers.

Central control still negligible.

Major task of boroughs was to administer law and order and to make bye-laws.

Applied to 178 towns.

City of London not included.

1836: Births and Deaths Registration Act and Marriage Act

Led to GRO being set up in 1837. The start of civil registration

1837 and '38: Riots in some Northern towns (Huddersfield, Halifax, Burnley, and Bradford) against Poor Law reform.

1840: Population Act

Put the census under the jurisdiction of the GRO and led to the 1841 census being seen by many as the first modern census.

1843: 7 & 8 Vict. c 101

Allowed Poor Law Commission to dissolve local authority incorporations (e.g. Gilbert's incorps.) if they had a pop. of less than 20,000 without a vote of rate payers

1847: Poor Law Board Act

Poor Law Commission replaced by Poor Law Board

1848: Public Health Act

Authorised the establishment of local Boards of Health to provide water supply and drainage.

Municipal Corporations became the Boards of Health for their own areas.

Work of Local Boards supervised by General Board of Health created along the lines of the Poor Law Commission.

Parishes with a death rate of over 2.34% as shown by the RG's reports had to establish a Board of Health, others could voluntarily but few did.

Many large villages became established Boards of Health to avoid becoming Highway Districts - stopped in 1863 when the min. size of a parish applying for a Board of Health became a population of 3000.

1855: Metropolis Management Act

Formed London into 23 large vestries of uniform type and 14 District Boards under a central Metropolitan Board of Works

1856: Bristol and Exeter Local Act Unions agree to join the New Poor Law.

Many others follow to 1865

1858: Local Government Act

General Board of Health abolished (never achieved much dominance), its legal powers were given to the Local Government Act Office under the Home Secretary.

1862: Highways Act

Compulsory grouping of parishes into Highway Districts unless they came under the jurisdiction of a Municipal Corporation, a Board of Improvement Commissioners, or a Board of Health.

Led to a rush of parishes to get a Board of Health with no motivation to actually improve health. About 900 parishes got Boards.

1863: Amending Act

Stopped the rush of areas getting Boards of Health under the 1862 Act by setting a min. pop. of 3,000 for parishes wanting a Board of Health.

1866: Poor Law Amendment Act

Defined the civil parish as “a place for which a separate poor rate is or can be made, or a separate overseer can be appointed or elected”

1867: Poor Law Amendment Act

Allows Poor Law Board to alter boundaries of detached parishes by Provisional Order if petitioned by rate payers - little effect on divided parishes problem

1868: Poor Law Amendment Act

Remaining incorporations under Local Act or Gilbert’s Act brought under the New Poor Law

Any extra-parochial place to be incorporated into parish it shared longest border with.

1869: Metropolitan Poor Act

Brought the Metropolitan parishes under the New Poor Law

Poor Law Board could adjust boundaries without petition or Provisional Order in the Metropolis

1871: Royal Sanitary Commission Report

Local Government Board formed

1872: Public Health Act

Led to county being divided up into urban and rural sanitary districts - parishes with a Board of Health under the 1848 Act, areas with special Boards of Improvement Commissioners established under Local Acts, and Boroughs all became urban sanitary districts. Rural Sanitary Districts were poor law unions minus any urban areas.

Urban authorities had wider powers; Boroughs Improvement Commissioners and local Boards of Health administered urban areas, Poor Law Guardians took over the remainder.

1874: Births and Deaths Registration Act

Onus on registration moved from registrars to the parent (births) or the nearest living relative (deaths).

1875: Public Health Act

Consolidated previous public health legislation

1876: Divided Parishes and Poor Law Amendment Act

Allowed Local Government Board to form new parishes from divided portions or amalgamate them into surrounding portions.

1879: Poor Law Amendment Act

Cleared up problems with the 1876 act

1882: Divided Parishes and Poor Law Amendment Act

After 25/3/1883 any detached part of a parish entirely surrounded by another parish would be amalgamated to it or form a separate parish. Local Government Board to resolve disputes. Only applied outside the Metropolis.

1884: London Government Bill

Attempted to rationalise local government in London but failed due to City opposition.

1888: Local Government Act

The basis of English Local Govt. until the 1970s

Created County Councils elected on rate payer franchise:

Created the county of London, Yorkshire and Lincolnshire both split into three, Cambs, Northants, Hampshire, Suffolk and Sussex split into two, therefore 62 county councils formed out of 52 counties.

Defined relationship between county councils and boroughs:

Boroughs given separate powers from counties if they had a pop. of over 50,000. Burton-upon-Trent, Canterbury, Chester, and Worcester also given county status. These boroughs became known as County Boroughs.

Smaller boroughs fell under the aegis of County Councils.

Reorganised financial relationships between central and local govt.

Rural Districts reshaped or split so as not to overlap county boundaries.

responsibility for parish boundaries moved to county council with Local Government Board overseeing it.

1894: Local Government Act.

Urban and Rural Sanitary Districts became Urban and Rural Districts with Councils rather than Boards of Health and wider powers.

1899: London Government Act

Formed 28 Metropolitan Borough Councils in the London County Council.

1905: Royal Commission on the Poor Law set up

1907: Union of Parishes Act

Merged the 112 parishes in the City of London to form one civil parish. Two areas, Inner and Middle Temple, remained as non-parochial places.

1909: Report of Royal Commission on the Poor Law

Recommended abolition of Poor Law Guardians due to wide disparities in Poor Law administration.

1913: Mental Deficiency Act

Responsibility for mentally deficient moved from Poor Law guardians to the County Councils

The term “workhouse” replaced by “institution” and “pauper” replaced by “poor person”

1923: Royal Commission on Local Government (Onslow Commission) set up

Originally to investigate poor sanitation in rural areas but looked extensively at the county/county borough power struggle

Stayed sitting for six years.

Led to the 1926 County Boroughs Adjustment Act and the 1929 Local Government Act

1926: An Act

Gave Ministry of Health the power to take over from Poor Law Guardians if administration was found to be defective. Done to Bedwellty, Chester-le-Street, and West Ham.

1926: Local Government (County Boroughs and Adjustments) Acts

Resulted from the report of the Onslow Commission

Became harder to form a County Borough

Population needed to form a County Borough raised to 75,000. This now had to be done by a Private Bill rather than a Provisional Order (meant that from 1926 to 1964 only one new CB was formed).

1929: Local Government Act

Shifted responsibilities for highways and also sanitation from RDs to the counties

Meant that in the 1930s urban and rural districts were rationalised through the 1930s by reviews carried out by county councils.

Resulted in the number of UDs falling from 786 to 573 and RDs from 650 to 477.

Also led to the abolition of Poor Law Guardians with counties and county boroughs taking responsibility. Poor relief became known as “public assistance” and the 1909 Minority report’s recommendations were accepted so many poor law functions given to education committees, public health committees, maternity and child welfare departments, welfare of the blind departments, and so on.

Registrar General retains responsibility for births, marriages, and deaths but the administration moved to local authorities.

1930:

Poor Law Guardians disappeared under the 1929 Local Government Act, duties passed to county councils, county boroughs, and central government.

1931: Education (Local Authorities) Act

Took the power to independently manage elementary schools away from local authorities. County boroughs kept this power.

1933: Local Government Act

Last powers of urban parishes removed

Became harder for a UD to gain borough status

1934: Unemployment Assistance Boards set up and take over responsibility for the able-bodied unemployed.

1945: Local Government Boundary Commission set up - limited terms of reference - abolished 1949

1946: National Insurance Act and National Insurance (Industrial Injuries) Act

1948: Children Act and National Assistance Act

Final break up of the Poor Law when counties and county boroughs took over caring for children, the aged and the infirm.

1949: Local Government Boundary Commission wound up.

1958: Separate Boundary Commissions set up for England and Wales - limited terms of reference - abolished 1965

1963: London Government Act

Set up the GLC

Boundaries of Greater London spread far wider than old LCC boundaries

1965: Boundary Commissions for England and Wales abolished

1969: Royal Commission on Local Government reports

The Redcliffe-Maud report - recommended a simple system of 58 unitary authorities and three Metropolitan authorities with community councils below them

1972: Local Government Act

Created 47 shire counties and 6 metropolitan counties divided into 333 districts

1974: Urban Civil Parishes abolished in England & Wales, rural Welsh ones become Communities

Appendix 4.1: Attributes used by the three master coverages

1. Union_ew: The Union/Registration District Coverage

a. Labels/Polygons:

Name: The usual spelling of the place name

Db_name: A unique version of the place name

County: The county the label is in

Un_county: Flags whether the label represents a Union/Registration County

Pl_union: Flags whether the label represents a Poor Law Union

Reg_dist: Flags whether the label represents a Registration District

Start_day: The day of the month the area was formed

Start_month: The month the area was formed

Start_year: The year the area was formed

End_day: The day of the month the area was abolished

End_month: The month the area was abolished

End_year: The year the area was abolished

Notes:

Pre_1847_rd: Many Registration Districts prior to 1847 were listed as aggregates of two or three districts. This field allows only those ones to be selected.

b. Arcs:

County1: The name of the county the arc is in

County2: If the arc represents a county boundary this is used to hold the name of the second county

Un_county: Flags whether the arc represents a Union/Registration County boundary

Pl_union: Flags whether the arc represents a Poor Law Union boundary

Reg_dist: Flags whether the arc represents a Registration District boundary

Start_day: The day of the month the area was formed boundary

Start_month: The month the boundary was formed

Start_year: The year the boundary was formed

End_day: The day of the month the boundary was abolished

End_month: The month the boundary was abolished

End_year: The year the boundary was abolished

Notes:

Pre_1847_rd: Many Registration Districts prior to 1847 were listed as aggregates of two or three districts. This field allows only those ones to be selected.

2. Lgd_ew: The Local Govt. Districts Coverage

a. Labels/Polygons:

Name: The usual spelling of the place name

Unit: The type of area (i.e. County Municipal, or London Borough, or Urban or Rural District)

Db_name: A unique version of the place name

County: The county the label is in

Start_day: The day of the month the area was formed

Start_month: The month the area was formed

Start_year: The year the area was formed

End_day: The day of the month the area was abolished

End_month: The month the area was abolished

End_year: The year the area was abolished

b. Arcs:

County1: The name of the county the arc is in

County2: If the arc represents a county boundary this is used to hold the name of the second county

Start_day: The day of the month the area was formed boundary

Start_month: The month the boundary was formed

Start_year: The year the boundary was formed

End_day: The day of the month the boundary was abolished

End_month: The month the boundary was abolished

End_year: The year the boundary was abolished

3. Parish_ew: The Parish Coverage

a. Labels/Polygons:

Par_id: The unique ID number for each parish

Parish: The parish name

Start_day: The day of the month the area was formed

Start_month: The month the area was formed

Start_year: The year the area was formed

End_day: The day of the month the area was abolished

End_month: The month the area was abolished

End_year: The year the area was abolished

b. Arcs:

Start_day: The day of the month the area was formed boundary

Start_month: The month the boundary was formed

Start_year: The year the boundary was formed

End_day: The day of the month the boundary was abolished

End_month: The month the boundary was abolished

End_year: The year the boundary was abolished

Appendix 4.2: Algorithm used to extract coverages

Complete program length: 1841 lines.

1. Selector.aml: The main control program (479 lines of code)

- 1.1. Set up aml/menupaths
- 1.2. Go into ArcEdit
- 1.3. Set up the display
- 1.4. Read in the type of unit required using menus
- 1.5. Select the appropriate edit coverage (this will be the higher level coverage if parishes are required) and set the method of selecting area (whole country, by division, or by county) and the date using menus.
- 1.6. Call select.aml (2) to select by area and unit type
- 1.7. Call sel_date.aml (3) to select by date
- 1.8. Move the scale bar to the correct position
- 1.9. Draw the coverage
- 1.10. Call save.aml (4) to save the coverage and extract parishes if required
- 1.11 Tidy up and exit

2. Select.aml: Selects by area and type of unit (454 lines)

- 2.1. Choose which areas to select using menus
- 2.2. Select labels by area from the original coverage
- 2.3. Reselect labels by unit
- 2.4. Add the appropriate labels for the scale bar
- 2.5. Copy labels to a temporary coverage
- 2.6. Select arcs by area from the original coverage
- 2.7. Reselect arcs by unit
- 2.8. Add the appropriate arcs for the scale bar
- 2.9. Copy arcs to the temporary coverage
- 2.10. Change to editing the temporary coverage
- 2.11. Select tics by area
- 2.12. Delete others
- 2.13. Return to selector.aml (1)

3. Sel_date.aml: Selects by date (179 lines)

The program is split into stages for both arcs and labels, first arcs are selected then label points. In both cases stages 3.3 to 3.6 are only gone through if required thus improving efficiency by reducing database queries:

- 3.1. Start by editing labels on the temporary coverage
- 3.2. Delete features that were formed after or were abolished before the user selected year
- 3.3. If required delete features that were formed in the user selected year but after the user selected month
- 3.4. If required delete features that were abolished in the required year but the before the user selected month
- 3.5. If required delete features that were formed in the user selected month and year but after the user selected day
- 3.6. If required delete features that were abolished in the user selected month and year but before the user selected day
- 3.7. Change to editing arcs and go back to stage 3.2
- 3.8 Return to selector.aml

4. Save.aml: Saves the coverage and selects out parishes if required (563 lines)

- 4.1. Read in save options from menus
- 4.3. Remove pseudo nodes
- 4.4. Delete the scale bar if not required
- 4.5 Save the coverage (this is the district-level coverage parishes are being extracted)
- 4.6. If parishes are being selected:
 - a. Build the coverage (NB: All that has been extracted so far is the district-level coverage)
 - b. “Clip” out an area from the parish coverage delimited by a box around the district-level coverage
 - c. Run sel_date.aml (3) on this newly extracted parish coverage
 - d. Build the extracted parish level coverage
- 4.7. Leave ArcEdit
- 4.8. If not selecting parishes build the coverage

OR if selecting parishes: Build the parish level coverage and overlay the higher level coverage onto the parishes to “stamp” the higher level geography onto them
- 4.9. Create any graphics files as required using create_map.aml (5)
- 4.10. Create an ArcInfo export file if required
- 4.11. Give the user information about the coverage
- 4.12. Return to selector.aml (1)

5. Create_map.aml: Creates any graphics files required (166 lines)

5.1. Read in options for producing a map

5.2. Go into ArcPlot

5.3. Create an ArcInfo graphics file (*.gra) using the required options

5.4. Leave ArcPlot

5.5. Convert the graphics file into other formats if required.

5.6. Return to save.aml (4).

Appendix 5.1: Algorithm used by areal interpolation program

Program length: 2,202 lines

1. Main program

1.1. Read in variables

2. Add_target routine

The raw ancillary data must already have been joined to the target coverage. This routine copies the place name items on the target coverage to new items called "tar...". This is necessary because when the source and target coverages are overlaid the original target coverage place name items will be duplicated and lost.

2.1. Add items tar_parid, tar_parish, tar_dist, and tar_cnty to the PAT of the target coverage if it is a parish level coverage or items tar_dist and tar_cnty if it is a district level

2.2. Update these items with the values of par_id, parish, db_name, and county (or just db_name and county)

3. Get_source routine

Extracts the source data from the specified Oracle table and reads the names of its numeric columns into an array

3.1. Create a temporary table in Oracle containing all the source data

3.2. Read the names of all numeric columns from this table into an array.

4. Join_par or join_higher routines (join_par is used for parish level source data, join_higher for district level)

Joins the extracted data to the source coverage. Note that if the dasymetric of combined techniques are used the extracted data will be district level but this will be joined to a parish level source coverage using the district level place names. This means that at the end of this routine every parish has district level data joined to it and this district level data may be duplicated many times

4.1. Update the temporary table to set the place names to standardised versions derived from the gazetteers

4.2. Copy the temporary table from Oracle to Info

4.3. Join the Info version to the PAT of the source coverage

4.4. If parish level source data are being used, aggregate any polygons in the source coverage as defined by the parish level gazetteer.

5. Add_xs routine

Adds an 'X' item to the PAT of the source coverage to flag rows where district level data has not joined successfully.

5.1. Create a view of the temporary Oracle table containing only gis_name or par_id and a second column which holds only a single character 'X'

5.2. Copy this view into Info

5.3. Join the resulting Info table to the PAT of the source coverage. This means that any rows in the PAT that do not have an 'X' item have null values for their data.

6. Update_parish routine

The main function of this routine is that when dasymetric or combined techniques are used it updates all the district level data joined to the PAT of the parish level source coverage by multiplying it by the parish level population and dividing it by the district level population. This implements formula 5.11. It also has the function of adding an items s_area to all source coverages and setting it to their initial areas.

6.1. Add item s_area to the PAT of the source coverage

6.2. Set this to hold the same values as the area item

6.3. If using the dasymetric or combined techniques:

- a. Create an Oracle table containing the parish level data. This has three columns: par_id, the population of the parish (parish_pop), and 'X' (parish_pop_x).
- b. Copy this into Info
- c. Join it to the PAT of the source table
- d. Set the district level 'X' variable to null for all parishes where the parish_pop_x is null
- e. Update all the data from the source coverage PAT that was extracted from the source table by multiplying it by parish_pop and dividing by the district level population item

7. Dup_name routine

Where a parish or district consists of more than one polygon the joined data will have been duplicated up to this point. In this routine it is allocated to each polygon based on the assumption that all the polygons making up the district or parish have the same population density.

7.1. Find the par_ids or db_names of all parishes or districts from the source coverage consisting of more than one polygon.

7.2. Calculate the total area of these parishes or districts

7.3. For each variable joined to the PAT from the source data table multiply its value by the area of its polygon and divide by the total area of the unit

8. Add_lambda routine

Allocates each polygon on the target coverage to a control zone and estimates the initial values of lambda for each control zone

8.1. Add items lambda and anc_class to the target coverage. Lambda will hold the initial densities of the user-defined total population column while anc_class will state which control zone the polygon belongs to

8.2. Calculate lambda to be the density of the user-defined total population variable for each polygon

8.3 Calculate the nested-means of the densities and use these to set anc_class to numeric values with 1 being the class with the lowest values

8.4. For computational efficiency use the maximum density of each control zone as its initial value of lambda except for the top class where the lowest density is used

8.5. Read the total area of each control zone into an array

9. Main program

9.1. Overlay the source and target coverages to form an intersect coverage that holds the zones of intersection

If using the dasymetric technique:

10. Calc_das routine

Estimate the values of all variables for all zones of intersection that do not consist of an entire source parish using areal weighting and use the results to create the final table in Oracle

10.1. Select all polygons on the intersect coverage whose area does not equal s_area (i.e. that are not an entire source zone)

10.2. Multiply the values of all their source items by the new area and divide by the values of s_area. This performs equation 5.12.

10.3. Copy the PAT of the intersect coverage to a temporary Oracle table

10.4. Create the final table by aggregating the data in the temporary table to target district level using the values of tar_name.

If using the EM or combined techniques:

10. Calc_alg routine

Estimate the values of all variables in all zones of intersection that do not consist of an entire source zone using the EM algorithm. Use the results to create the final table in Oracle.

10.1. Add an item est_y_st to the PAT of the intersection coverage. This will hold the estimated values of each variable at the end of each iteration of the algorithm.

10.2. Take the first item from the array of numeric variables created in get_source

10.3. Select all zones of intersection whose area is less than s_area and go through each one in turn

10.4. Read all the initial values of the variable into an array

10.5. Go through each polygon in turn performing the E-step of the algorithm

a. Estimate the value of the variable for this zone of intersection using formula 5.13 and save the result to est_y_st

b. Calculate the change in the variable in this iteration as a proportion of the new value. If this is the largest proportional change in this iteration then save it

10.6. Perform the M-step of the algorithm by going through each control zone in turn

a. Select all the polygons in this control zone

b. Estimate a new value of lambda for this zone by dividing the sum of est_y_st by the sum of the area of all the polygons in the zone. This performs equation 5.14.

10.7. If the largest change for any zone of intersection exceeds the convergence threshold for the algorithm then perform a new iteration of the algorithm by going back to 10.5

10.8. Update the item holding the initial values of the variable with the final values of est_y_st

10.9. Select a new variable from the area of numeric variables defined in get_source and go back to 10.3

11. Adj_data routine

Takes the results produced by the EM algorithm and uses them to create the final table in Oracle

11.1. Copy the PAT of the intersection coverage to a temporary table in Oracle

11.2. Create the final table by aggregating data in the temporary table to target parish or district level using the values of tar_parid or tar_name as appropriate

For both techniques:

12. Report_success routine

Gives statistics that report on the possible impact of failing to correctly join any source data to the source coverage

12.1. Report the names of all polygons that did not have any source data successfully joined to them.

12.2. Give the area of these polygons as a percentage of the total area of the source coverage

12.3. Give the total population of the target table and the percentage difference between this and the total population extracted from the source table

12.4. Give the number of zones of intersection with missing source data and express this as a percentage of the total area of the intersection coverage

12.5. Give the percentage of the data from the intersection coverage allocated to unnamed target zones

13. Exit routine

Delete temporary tables and tidy up.

References

- Alcock P (1997) Understanding Poverty, Second Edition MacMillan: Basingstoke
- Alderson M and Whitehead F (1974) Reviews of United Kingdom Statistical Sources: Volume II Heinemann Educational Books: London
- Armstrong WA (1972) "The use of information about occupation" in Wrigley EA (ed.) Nineteenth Century Society: Essays in the Use of Quantitative Methods for the Study of Social Data, Cambridge University Press: Cambridge, pp. 191-310
- Ashforth D (1976) "The Urban Poor" in Fraser D (ed.) The New Poor Law in the Nineteenth Century MacMillan Press Ltd.: London, pp. 128-148
- Atkins P and Mitchell G (1996) "Yesterday's and today's data" GIS Europe, 5, pp. 24-26
- Bagg J and Ryan N (1997) "Modeling historical change in southern Corsica" in Kemp Z (ed.) Innovations in GIS 4 Taylor & Francis: London, pp. 42-55
- Bailey T (1994) "A review of statistical spatial analysis in geographical information systems" in Fotheringham AS and Rogerson PA (eds.) Spatial Analysis and GIS Taylor & Francis: London, pp. 13-44
- Baker ARH (1972) "Historical geography in Britain" in Baker ARH (ed.) Progress in Historical Geography David & Charles: Newton Abbott, pp. 90-110
- Baker ARH (1997) "'The dead don't answer questionnaires': Researching and writing historical geography" Journal of Geography in Higher Education, 21, pp. 231-243
- Bartholomew K (1991) "Women migrants in mind: Leaving Wales in the nineteenth and twentieth centuries" in Pooley CG and Whyte I (eds.) Migrants, Emigrants, and Immigrants Routledge: London, pp. 174-190
- Bartley K and Campbell BMS (1997) "Inquisitiones Post Mortem, GIS, and the Creation of a Land-Use Map of Medieval England" Transactions in GIS, 2, pp. 333-346
- Bartley M, Davey Smith G and Blane D (1998) "Making sense of health inequality statistics" in Dorling D and Simpson S (eds.) Statistics in Society: The Arithmetic of Politics Arnold: London, pp. 234-243
- Basoglu U and Morrison JL (1978) "An efficient hierarchical data structure for the US historical boundary file" in Dutton G (ed.) First International Advanced Study Symposium on Topological Data Structures for Geographic Information Systems. Volume 4 - Data Structures: Hierarchical and Overlaid Laboratory for Computer Graphics and Spatial Analysis, Harvard University: Cambridge, MA
- Beekink E and van Cruyningen P (1995) Demografische Databank Nederlandse Gemeenten, 1811-1850 Den Haag
- Benjamin B (1970) The Population Census Heinemann Educational Books: London
- Beveridge WH (1942) Social Insurance and Allied Services HMSO: London

- Billinge M, Gregory D and Martin R (1984, eds.) Recollections of a Revolution: Geography as Spatial Science MacMillan Press: London
- Boonstra OWA (1990) "NLKAART. A dynamic map of the Netherlands, 1830-1990" in Smets M (ed.) Histoire et Informatique V Contract France: Montpellier, pp. 315-324
- Boonstra OWA (1994) "Mapping the Netherlands, 1830-1994: The use of NLKAART" in Goerke M (ed.) Coordinates for Historical Maps Max-Planck-Institut für Geschichte: Gottingen, pp. 156-161
- Bracken I (1994) "A surface model approach to the representation of population-related social indicators" in Fotheringham S and Rogerson P (eds.) Spatial Analysis and GIS Taylor & Francis: London, pp. 247-260
- Bracken I and Martin D (1989) "The generation of spatial population distributions from census centroid data" Environment and Planning A, 21, pp. 537-543
- Bracken I and Martin D (1995) "Linkage of the 1981 and 1991 UK census using surface modeling concepts" Environment and Planning A, 27, pp. 379-390
- Buckatzsch E (1950) "The geographical distribution of wealth in England, 1086-1843: An experimental study of certain tax assessments" Economic History Review Second Series, 3, pp. 180-202
- Burrough PA (1986) Principals of Geographical Information Systems for Land Resources Assessment Clarendon Press: Oxford
- Burrough PA and Frank AU (1996, eds.) Geographic Objects with Indeterminate Boundaries Taylor & Francis: London
- Buttenfield BP (1993) "Representing data quality" Cartographica, 30, pp. 1-7
- Buttimer A (1976) "Grasping the dynamism of the lifeworld" Annals of the Association of American Geographers, 66, pp. 277-292
- Cairncross AK (1949) "Internal migration in Victorian England" The Manchester School of Economic and Social Studies, 17, pp. 67-87
- Campbell B (1997) Personal Communication
- Campbell JB (1987) Introduction to Remote Sensing Guildford Press: New York
- Champion AG (1995) "Analysis of change through time" in Openshaw S (ed.) Census Users' Handbook GeoInformation International: Cambridge, pp. 307-336
- Chrisman NR (1990) "The accuracy of map overlays: A reassessment" in Peuquet DJ and Marble DF(eds.) Introductory Readings in Geographic Information Systems Taylor & Francis: London, pp. 308-320
- Chrisman NR (1998) "Beyond the snapshot: Changing the approach to change, error and process" Egenhofer MJ and Golledge RG (eds.) Spatial and Temporal Reasoning in Geographic Information Systems Oxford University Press: Oxford, pp. 85-93
- Clarke JI and Rhind DW (1975) The Relationship between the Size of Areal Units and the Characteristics of Population Structure Census Research Unit Working Paper 5, Department of Geography, University of Durham

- Clarke KC (1996) Getting Started with Geographic Information Systems Prentice Hall: New Jersey
- Clarke P and Souden D (1987) "Introduction" in Clarke P and Souden D (eds.) Migration and Society in Early Modern England Hutchinson Education: London pp. 11-49
- Coates B, Johnston R and Knox P (1977) Geography and Inequality Oxford University Press: Oxford
- Cockings S, Fisher PF and Langford MJ (1997) "Parameterization and visualisation of the errors in areal interpolation" Geographical Analysis, 29, pp. 314-328
- Coombes M (1995) "Dealing with census geography: Principles, practices and possibilities" in Openshaw S (ed.) Census Users' Handbook GeoInformation International: Cambridge pp. 111-132
- Cornell A and Robinson AH (1966) "Possibility of computer animated films in cartography" Cartographic Journal, 3, pp. 79-82
- Cowen DJ (1990) "GIS versus CAD versus DBMS: What are the differences?" in Peuquet DJ and Marble DF (eds.) Introductory Readings in Geographical Information Systems Taylor & Francis: London, pp. 52-62
- Curran PJ (1985) Principals of Remote Sensing Longman: Harlow, Essex
- Curry L (1966) "A note on spatial association" Professional Geographer, 18, pp. 97-99
- Curry M (1995) "GIS and the inevitable ethical inconsistency" in Pickles JJ (ed.) Ground Truth: The Social Implications of Geographic Information Systems Guildford Press: New York, pp. 68-87
- Darby HC (1977) Domesday England Cambridge University Press: Cambridge
- Darby HC, Glasscock RE, Sheail J and Versey GR (1979) "The Changing Geographical Distribution of Wealth in England: 1086-1334-1525" Journal of Historical Geography, 5, pp. 247-262
- Davey Smith G and Dorling D (1996) "I'm all right John: Voting patterns and mortality in England and Wales, 1981-'92" British Medical Journal, 313, pp. 1573-1577
- DeBelder J, Vanhaute E and Vrielinck S (1992) "Naar een Kwantitatieve Databank van de Belgische Gemeenten, 19^{de} en 20ste eeuw. Verslag van een proefproject" in Belgische Tijdschrift voor Nieuwste Geschiedenis / Revue Belge de l'Histoire Contemporaine, pp. 255-414
- De Moor M (2000) Belgium: Quantitative Database of Municipalities. Paper presented at Mapping Europe's Historic Boundaries and Borders: An Exploratory Workshop, Florence, 3rd June, 2000
- Dempster AP, Laird NM and Rubin DB (1977) "Maximum likelihood from incomplete data via the EM algorithm" Journal of the Royal Statistical Society B, 39, pp. 1-38
- DenBoer G (1995) Kentucky, Atlas of Historical County Boundaries Long, JH (ed.) Simon & Schuster: New York

- Denham C and Rhind DW (1983) "The 1981 Census and its results" in Rhind DW (ed.) A Census User's Handbook Methuen & Co.: London, pp. 23-34
- Denton JH (1997) "Towards a New Edition of the *Taxatio Ecclesiastica Angliae et Walliae Auctoritate P. Nicholai IV circa 1291 A.D.*" Bulletin of the John Ryland University Library of Manchester, 79, pp. 67-79
- Department of the Environment (1987) Handling Geographic Information: Report of the Committee of Enquiry chaired by Lord Chorley HMSO: London
- Dewdney J (1983) "Censuses Past and Present" in Rhind D (ed.) A Census User's Handbook Methuen & Co.: London, pp. 65-79
- Diamond I (1999) "The census: The biggest and best data source in the UK?" in Dorling D and Simpson S (eds.) Statistics in Society Arnold: London, pp. 9-18
- Dorling D (1992) "Stretching space and slicing time: from cartographic animation to interactive visualization" Cartography and Geographic Information Systems, 19, pp. 215-227
- Dorling D (1995) A New Social Atlas of Britain John Wiley & Sons: London
- Dorling D (1996) Area Cartograms: Their Use and Creation Concepts and Techniques in Modern Geography, 59 University of East Anglia, Environmental Publications: Norwich
- Dorling D and Simpson S (1998, eds.) Statistics in Society: The Arithmetic of Politics Arnold: London
- Dorling D and Tomaney J (1995) "Poverty in the old industrial regions: A comparative view" in Philo C (ed.) Off the Map: The Social Geography of Poverty in the UK Child Poverty Action Group: London, pp. 103-122
- Dorling D and Woodward R (1996) "Social polarisation 1971 to 1991: A micro-geographical analysis of Britain" monograph in the Progress in Planning series, 45(2), pp. 1-67
- Dragicevic S and Marceau D (2000) "A fuzzy set approach for modeling change through time" International Journal of Geographical Information Science, 14, pp. 225-245
- Drake M (1972) "The Census, 1801-1891" in Wrigley EA (ed.) Nineteenth Century Society Cambridge University Press: Cambridge, pp. 7-46
- Drewnoski J and Scott W (1968) "The level of living index" Ekistics, 25, pp. 266-275
- Egenhofer MJ & Golledge RG (1998, eds.) Spatial and Temporal Reasoning in Geographic Information Systems Oxford University Press: Oxford
- Environmental Systems Research Institute (1991) Managing Tabular Data: Design, Construction, and Management of feature attribute databases Environmental Systems Research Institute Inc.: Redlands, CA
- Environmental Systems Research Institute (1993) Arc Macro Language: Developing Arc/Info Menus and Macros with AML Environmental Systems Research Institute Inc.: Redlands, CA

- Environmental Systems Research Institute (1994a) Arc/Info Data Management: Concepts, Data Models, Database Design, and Storage Environmental Systems Research Institute Inc.: Redlands, CA
- Environmental Systems Research Institute (1994b) Map Projections: Georeferencing Spatial Data Environmental Systems Research Institute Inc.: Redlands, CA
- Environmental Systems Research Institute (1997) Understanding GIS: The Arc/Info Method: Fourth Edition GeoInformation International: Cambridge
- Evans IS (1977) "The selection of class intervals" Transactions of the Institute of British Geographers, 2, pp. 98-124
- Ferris W and Ray B (2000) "An internet witch-hunt: Digitizing Salem village. A conversation with Ben Ray" Retrieved on the 21st February 2001 from World Wide Web URL: <http://etext.lib.virginia.edu/salem/witchcraft/neh/NehSale.html>
- Fischer MM, Scholten HJ and Unwin D (1996) "Geographic Information Systems, spatial data analysis and spatial modeling" in Fischer MM, Scholten HJ and Unwin D (eds.) Spatial Analytical Perspectives on GIS Taylor & Francis: London, pp. 3-20
- Fisher PF (1997) "Editorial" International Journal of Geographical Information Science, 11, pp. 1-3
- Fisher PF and Langford MJ (1995) "Modeling the errors in areal interpolation between zonal systems by Monte Carlo simulation" Environment and Planning A, 27, pp. 211-224
- Flowerdew R (1991) "Spatial data integration" in Maguire DJ, Goodchild MF and Rhind DW (eds.) Geographical Information Systems: Principles and Applications, Volume 1: Principles Longman, Harlow, pp. 375-387
- Flowerdew R and Green M (1991a) Inference Between Incompatible Zoning Systems Using the EM Algorithm North West Regional Research Laboratory, Research Report 6: Lancaster
- Flowerdew R and Green M (1991b) "Data integration: Statistical methods for transferring data between zonal systems" in Masser I and Blakemore M (eds.) Handling Geographic Information: Methodology and Potential Applications Longman: Harlow, Essex pp. 38-54
- Flowerdew R, Green M and Kehris E (1991) "Using areal interpolation methods in Geographic Information Systems" Papers in Regional Science, 70, pp. 303-315
- Flowerdew R and Green M (1992) "Developments in areal interpolation methods and GIS" Annals of Regional Science, 26, pp. 67-78
- Flowerdew R and Green M (1994) "Areal interpolation and types of data" in Fotheringham S and Rogerson P (eds.) Spatial Analysis and GIS Taylor & Francis: London pp. 121-145
- Fotheringham AS, Brunsdon C and Charlton M (2000) Quantitative Geography: Perspectives on Spatial Data Analysis Sage: London
- Fotheringham AS and Rogerson PA (1993) "GIS and spatial analytical problems" International Journal of Geographical Information Systems, 7, pp. 3-19

- Fotheringham AS and Wong D (1991) "The modifiable areal unit problem in multi-variant statistical analysis" Environment and Planning A, 23, pp. 1025-1044
- Frank AU (1998) "Different types of times in GIS" in Egenhofer MJ and Golledge RG (eds.) Spatial and Temporal Reasoning in Geographic Information Systems Oxford University Press: Oxford, pp. 39-59
- Friedlander D and Roshier RJ (1965) "A study of internal migration in England and Wales, Part 1: Geographical Patterns of internal migration, 1851-1951" Population Studies, 19, pp. 239-280
- Frodeman R (1995) "Geological reasoning: Geology as an interpretive and historical science" Bulletin of the Geological Society of America, 107, pp. 960-968
- Gehlke C and Biehl H (1934) "Certain effects of the grouping upon the size of the correlation coefficient in census tract material" Journal of American Statistical Association, Supplement, 29, pp. 169-170
- Goodchild MF (1992a) "Geographical Information Science" International Journal of Geographical Information Systems, 6, pp. 31-45
- Goodchild MF (1992b) Research Initiative 1: Accuracy of Spatial Databases. Final Report NCGIA, University of California, Santa Barbara
- Goodchild MF (1995) "Geographic Information Systems and geographic research" in Pickles JJ (ed.) Ground Truth: The Social Implications of Geographic Information Systems Guildford Press: New York, pp. 31-50
- Goodchild MF, Anselin L and Deichmann U (1993) "A framework for the areal interpolation of socio-economic data" Environment & Planning A, 25, pp. 383-397
- Goodchild MF and Gopal S (1989, eds.) The Accuracy of Spatial Databases Taylor & Francis: London
- Goodchild MF and Lam NS-N (1980) "Areal interpolation: a variant of the traditional spatial problem" Geo-Processing, 1, pp. 297-312
- Gordon I and Whittaker R (1972) "Indicators of local prosperity in the South-West region" Regional Studies, 6, pp. 299-313
- Graham D (1995) "The use of a Geographical Information System in historical demography" History and Computing, 7, pp. 50-63
- Green AE (1995) "A comparison of alternative measures of unemployment" Environment and Planning A, 27, pp. 535-556
- Green M (1989) Statistical Methods for Areal Interpolation: The EM Algorithm for Count Data North West Regional Research Laboratory, Research Report 3: Lancaster
- Green M (1990) "Statistical models for areal interpolation" in Harts J, Ottens H and Scholten HJ (eds.) EGIS '90: Proceedings of the First European Conference on Geographical Information Systems, 1 EGIS Foundation: Utrecht pp. 392-399
- Green M and Flowerdew R (1996) "New evidence on the modifiable areal unit problem" in Longley P and Batty M (eds.) Spatial Analysis: Modeling in a GIS Environment GeoInformation International: Cambridge, pp. 41-54

- Gregory IN (2000) "Longitudinal analysis of age- and gender- specific migration patterns in England and Wales" Social Science History, 24, pp. 471-504
- Gregory IN (forthcoming) "The accuracy of areal interpolation techniques: Standardising 19th and 20th census data to allow long-term comparisons" Computers, Environment and Urban Systems
- Gregory IN and Southall HR (1998) "Putting the past in its place: The Great Britain Historical GIS" in Carver S (ed.) Innovations in GIS 5 Taylor & Francis: London, pp. 210-221
- Gregory IN and Southall HR (2000) "Spatial frameworks for historical censuses – the Great Britain Historical GIS" in Hall PK, McCaa R and Thorvaldsen G (eds.) Handbook of Historical Microdata for Population Research Minnesota Population Center: Minneapolis, pp. 319-333
- Gregory IN, Southall HR and Dorling D (2000) "A century of poverty in England & Wales, 1898-1998: A geographical analysis" in Bradshaw J and Sainsbury R (eds.) Researching Poverty Ashgate: Aldershot, pp. 130-159
- Hagerstrand T (1970) "What about people in regional science?" Papers of the Regional Science Association, 24, pp. 1-21
- Haggett P (1965) Locational Analysis in Human Geography Arnold: London
- Haggett P (1979) Geography: A Modern Synthesis, Third Edition Harper & Row: New York
- Hampton W (1991) Local Government and Urban Politics Longman Group: Essex
- Harris R (1987, ed.) The Historical Atlas of Canada Volume I: From the Beginning to 1800 University of Toronto Press: Toronto
- Harris T (2001, forthcoming) "Moving GIS: Exploring movement in prehistoric cultural landscapes using GIS" in Lock G (ed.) Beyond the Map: Archaeology and GIS Oxford University Press: Oxford
- Hasluck EL (1936) Local Government in England Cambridge University Press: Cambridge
- Hawking S (1988) A Brief History of Time: From the Big Bang to Black Holes Bantam Books: New York
- Hazelton N (1998) "Some operational requirements for a multi-temporal 4-D GIS" in Egenhofer MJ and Golledge RG (eds.) Spatial and Temporal Reasoning in Geographic Information Systems Oxford University Press: Oxford, pp. 63-73
- Hearnshaw HM and Unwin DJ (1994, eds.) Visualization in Geographical Information Systems John Wiley & Sons: Chichester
- Hope A (1968) "A simplified Monte Carlo significance test procedure" Journal of the Royal Statistical Society B, 30, pp. 582-598
- Irish University Press Series of British Parliamentary Papers (1970) 1861 and 1871 Censuses of England and Wales, Population 15 Irish University Press: Shannon
- Johnston RJ, Gregory D and Smith DM (1994, eds.) The Dictionary of Human Geography, 3rd Edition Blackwell: Oxford

- Jones C (1997) Geographic Information Systems and Computer Cartography Addison Wesley Longland: Essex
- Kain RJP and Oliver RR (1995) The Tithe Maps of England and Wales Cambridge University Press: Cambridge
- Kampke T (1994) "Storing and retrieving changes in a sequence of polygons" International Journal of Geographic Information Systems, 8, pp. 493-513
- Keates JS (1973) Cartographic Design and Production: 2nd Edition Longman Scientific & Technical: Harlow, Essex
- Keith-Lucas B and Richards PG (1978) A History of Local Government in the 20th Century George Allen & Unwin: London
- Kelmelis J (1998) "Process dynamics, temporal extent, and causal propagation as the basis for linking space and time" in Egenhofer MJ and Golledge RG (eds.) Spatial and Temporal Reasoning in Geographic Information Systems Oxford University Press: Oxford, pp. 94-103
- Kennedy BA (1992) "Hutton to Horton: Views of sequence, progression and equilibrium in geomorphology" Geomorphology, 5, pp. 231-250
- Kennedy L, Ell PS, Crawford EM and Clarkson LA, (1999) Mapping the Great Irish Famine, An atlas of the Famine Years Four Courts Press: Belfast
- Kerr D and Holdsworth D (1990, eds.) The Historical Atlas of Canada Volume III: Addressing the Twentieth Century University of Toronto Press: Toronto
- Kingdom JE (1991) Local Government and Politics in Britain Philip Allan: Hemel Hempstead
- Knott J (1986) Popular Opposition to the 1834 Poor Law Croom Helm: London
- Knox P (1975) Social Well-Being: A Spatial Perspective Oxford University Press: Oxford
- Kollias VJ and Voliotis A (1991) "Fuzzy reasoning in the development of geographical information systems" International Journal of Geographical Information Systems, 5, pp. 209-223
- Koussoulakou A (1994) "Spatio-temporal analysis of urban air pollution" in MacEachren A and Taylor F (eds.) Visualisation in Modern Cartography Elsevier Science: Oxford, pp. 243-267
- Koussoulakou A and Kraak M (1992) "Spatio-temporal maps and cartographic communication" Cartographic Journal, 29, pp. 101-108
- Kristiansson G (2000a) Sweden: National Archival Database (NAD) Paper presented at Mapping Europe's Historical Boundaries and Borders: An Exploratory Workshop, Florence, 3rd June, 2000
- Kristiansson G (2000b) "Building a National Topographic Database" Retrieved on the 23rd February 2001 from World Wide Web URL: http://www.geog.port.ac.uk/hist_bound/proj_rep/NAD_more_info.htm
- Langford MJ, Maguire DJ and Unwin DJ (1991) "The areal interpolation problem: Estimating population using remote sensing in a GIS framework" in Masser I and

- Blakemore M (eds.) Handling Geographical Information: Methodology and Potential Applications Longman: New York, pp. 55-77
- Langran G (1989) "A review of temporal database research and its use in GIS applications" International Journal of Geographical Information Systems, 3, pp. 215-232
- Langran G (1992) Time in Geographic Information Systems Taylor & Francis: London
- Langran G and Chrisman NR (1988) "A framework for temporal geographic information" Cartographica, 25(3), pp. 1-14
- Langton J (1972) "Systems approach to change in human geography" Progress in Geography, 4, pp. 123-178
- Lawton R (1958) "Population movements in the West Midlands" Geography, 43, pp. 164-177
- Lawton R (1968) "Population changes in England and Wales in the later nineteenth century: an analysis of trends by registration district" Transactions of the Institute of British Geographers, 44, pp. 55-74
- Lawton R (1970) "The population of Liverpool in the late-nineteenth century" in Baker A, Hamshere J and Langton J (eds.) Geographical Interpretations of Historical Sources David & Charles: Newton Abbot, pp. 381-415
- Lee C (1979) British Regional Employment Statistics, 1841-1971 Cambridge University Press: Cambridge
- Lee S (1966) "A theory of migration" Demography, 3, pp. 47-57
- Lillesand TM and Kiefer RW (1994) Remote Sensing and Image Interpretation John Wiley & Sons: New York
- Lipman VD (1949) Local Government Areas 1834-1945 Basil Blackwell: Oxford
- Little A and Mabey C (1972) "An index for designation of educational priority areas" in Shonfield A and Shaw S (eds.) Social Indicators and Social Policy Heinemann: London, pp. 67-93
- Long JH (1994) "Atlas of historical county boundaries" Journal of American History, 81, pp. 1859-1863
- Long JH (1998) Personal Communication
- Louis R (1993, ed.) The Historical Atlas of Canada Volume II: The Land Transformed, 1800 to 1891 University of Toronto Press: Toronto
- MacDougall E (1975) "The accuracy of map overlays" Landscape Planning, 2, pp. 23-30
- MacEachren A (1992) "Visualizing uncertain information" Cartographic Perspectives, 13, pp. 10-19
- MacEachren AM (1994) "Time as a cartographic variable" in Hearnshaw HM and Unwin DJ (eds.) Visualization in Geographical Information Systems John Wiley & Sons: Chichester, pp. 115-130

- MacKay T (1904) A History of the English Poor Law, Volume III PS King & Son: London
- Maguire DJ (1991) "An overview and definitions of GIS" in Maguire DJ, Goodchild MF and Rhind DW (eds.) Geographical Information Systems: Principles and Applications, Volume I: Principles Longman Scientific and Technical: London, pp. 9-20
- Maguire DJ, Goodchild MF and Rhind DW (1991, eds.) Geographical Information Systems: Principles and Applications, Volume I: Principles Longman Scientific and Technical: London
- Markoff J and Shapiro G (1973) "The linkage of data describing overlapping geographical units" Historical Methods Newsletter, 7, pp. 34-46
- Marsh C, Arber S, Wrigley N, Rhind DW and Bulmer M (1988) "The view of academic social scientists on the 1991 UK Census of population: A report for the Economic and Social Research Council Working Group" Environment and Planning A, 20, pp. 851-889
- Martin D (1989) "Mapping population data from zone centroid locations" Transactions of the Institute of British Geographers, 14, pp. 90-97
- Martin D (1991) Geographic Information Systems and their Socio-Economic Applications Routledge: Hampshire
- Martin D (1996a) "Depicting changing distributions through surface estimations" in Longley P and Batty M (eds.) Spatial Analysis: Modeling in a GIS Environment GeoInformation International: Cambridge pp. 105-122
- Martin D (1996b) "An assessment of surface and zonal models of population" International Journal of Geographical Information Systems, 10, pp. 973-989
- Martin D and Bracken I (1991) "Techniques for modeling population-related raster databases" Environment and Planning A, 23, pp. 1069-1075
- Martin D and Gascoigne G (1994) "Change and change again: geographical implications for intercensal analysis", Area, 26, pp. 133-141
- Massey D (1999) "Space-time, 'science' and the relationship between physical geography and human geography" Transactions of the Institute of British Geographers: New Series, 24, pp. 261-276
- Miller D (1998) Personal Communication
- Miller D and Modell J (1988) "Teaching United States History with the Great American History Machine" Historical Methods, 21, pp. 121-134
- Moldovsky B (1998) Personal Communication
- Mollering H (1980) "Strategies in real-time cartography" Cartographic Journal, 17, pp. 12-15
- Monmonier MS and Schnell GA (1984) "Land use and land cover data and the mapping of population density" International Yearbook of Cartography, 24, pp. 115-121
- Monmonier MS and Schnell GA (1988) Map Appreciation Prentice Hall: New Jersey

- Morphet C (1993) "The mapping of small area data - a consideration of the role of Enumeration District boundaries" Environment and Planning A, 25, pp. 267-278
- Newton-Smith WH (1986) "Space, time and space-time: A philosopher's view" in Flood R and Lockwood M (eds.) The Nature of Time Basil Blackwell: Oxford, pp. 22-35
- Nissel M (1987) People Count: A History of the General Register Office HMSO: London
- Norris P and Mounsey HM (1983) "Analysing change through time" in Rhind D (ed.) A Census User's Handbook Methuen: London, pp. 265-286
- Okabe A and Sadahiro Y (1997) "Variation in count data transferred from a set of irregular zones to a set of regular zones through the point-in-polygon method" International Journal of Geographical Information Science, 11, pp. 93-106
- O'Kelly M (1994) "Spatial analysis and GIS" in Fotheringham AS and Rogerson PA (eds.) Spatial Analysis and GIS Taylor & Francis: London, pp. 65-79
- Oliver RR (1993) Ordnance Survey Maps: A Concise Guide for Historians Charles Close Society: London
- Oliver RR (1996) Personal Communication
- Openshaw S (1977) "Algorithm 3: A procedure to create pseudo-random aggregations of N zones into M zones, where M is less than N " Environment and Planning A, 9, pp. 169-184
- Openshaw S (1984) The Modifiable Areal Unit Problem Concepts and Techniques in Modern Geography, 38 Geobooks: Norwich
- Openshaw S (1989) "Learning to live with errors in spatial databases" in Goodchild MF and Gopal S (eds.) The Accuracy of Spatial Databases Taylor & Francis: London, pp. 263-276
- Openshaw S (1991a) "A view on the GIS crisis in geography or using GIS to put Humpty-Dumpty back together again" Environment and Planning A, 23, pp. 621-628
- Openshaw S (1991b) "Developing appropriate spatial analysis methods for GIS" in Maguire DJ, Goodchild MF and Rhind DW (eds.) Geographical Information Systems: Principles and Applications Longman Scientific and Technical: London, pp. 389-401
- Openshaw S (1992) "Further thoughts on geography and GIS - a reply" Environment and Planning A, 24, pp. 463-466
- Openshaw S (1994) "Exploratory space-time-attribute pattern analysers" in Fotheringham AS and Rogerson PA (eds.) Spatial Analysis and GIS Taylor & Francis: London, pp. 83-104
- Openshaw S (1995) "Developing spatial analysis functions relevant to GIS environments" in Fischer MM, Scholten HJ and Unwin D (eds.) Spatial Analytical Perspectives on GIS Taylor & Francis: London, pp. 21-38

- Openshaw S (1996) "Developing GIS-relevant zone-based spatial analysis methods" in Longley PA and Batty M (eds.) Spatial Analysis: Modeling in a GIS Environment GeoInformation International: Cambridge pp. 55-74
- Openshaw S (1997) "The truth about Ground Truth" Transactions in GIS, 2, pp. 2-24
- Openshaw S, Charlton M, Wymer C and Craft AW (1987) "A mark 1 geographical analysis machine for the automated analysis of point data sets" International Journal of Geographical Information Systems, 1, pp. 335-358
- Openshaw S and Clarke G (1996) "Developing spatial analysis functions relevant to GIS environments" in Fischer MM, Scholten HJ and Unwin D (eds.) Spatial Analytical Perspectives on GIS Taylor & Francis: London, pp. 21-38
- Openshaw S and Rao L (1995) "Algorithms for re-aggregating 1991 Census geography" Environment and Planning A, 27, pp. 425-446
- Openshaw S and Taylor PJ (1979) "A million or so correlation coefficients: Three experiments on the modifiable areal unit problem" in Wrigley N (ed.) Statistical Applications in the Spatial Sciences Pion: London pp. 127-144
- Openshaw S, Waugh D and Cross A (1994) "Some ideas about the use of map animation as a spatial analysis tool" in Hearnshaw HM and Unwin DJ (eds.) Visualization in GIS John Wiley & Sons: Chichester, pp. 131-138
- Ott T and Swiaczny F (2001, in press) "The analysis of cultural landscape change: A GIS approach for handling spatio-temporal data" History and Computing
- Owen T and Pilbeam E (1992) Ordnance Survey: Map Makers to Britain since 1791 HMSO: London
- Parkes D and Thrift N (1980) Times, Spaces and Places: A Chronogeographic Perspective John Wiley and Sons: Chichester
- Pearson AW and Collier P (1998) "The integration and analysis of historical and environmental data using a Geographical Information System: Landownership and agricultural productivity in Pembrokeshire c. 1850" Agricultural History Review, 46, pp. 162-176
- Peuquet DJ (1994) "Its about time: A conceptual framework for the representation of temporal dynamics in Geographic Information Systems" Annals of the Association of American Geographers, 84, pp. 441-461
- Peuquet DJ and Boyle R (1990) "Interactions between the cartographic document and the digitizing process" in Peuquet DJ and Marble DF (eds.) Introductory Readings in Geographic Information Systems Taylor & Francis: London, pp. 215-221
- Peuquet DJ and Marble DF (1990) "ArcInfo: An example of a contemporary Geographic Information System" in Peuquet DJ and Marble DF (eds.) Introductory Readings in Geographic Information Systems Taylor & Francis: London, pp. 90-99
- Pickles AR (1985) An Introduction to Likelihood Analysis Concepts and Techniques in Modern Geography, 42 Geobooks: Norwich
- Pickles JJ (1995a) "Representations in an electronic age: geography, GIS, and democracy" in Pickles JJ (ed.) Ground Truth: The Social Implications of Geographic Information Systems Guildford Press: New York, pp. 1-30

- Pickles JJ (1995b) "Towards an economy of electronic representation and the virtual sign" in Pickles JJ (ed.) Ground Truth: The Social Implications of Geographic Information Systems Guildford Press: New York, pp. 223-240
- Piternick AB (1993) "The Historical Atlas of Canada: The project behind the product" Cartographica, 30 (4), pp. 21-31
- Pooley CG (1995) "The mobility of criminals in North-West England" Local Population Studies, 53, pp. 15-28
- Pooley CG and Turnbull J (1996) "Migration and mobility from the eighteenth to the twentieth centuries" Local Population Studies, 57, pp. 50-71
- Pooley CG and Turnbull J (1998) Migration and Mobility in Britain since the Eighteenth Century University College London Press: London
- Raper J and Livingstone D (1995) "Development of a geomorphological spatial model using object-oriented design" International Journal of Geographical Information Systems, 9, pp. 359-383
- Raper J, Rhind DW and Sheperd JW (1992) Postcodes: The New Geography Longman: Harlow, Essex
- Ravenstein E (1885) "The laws of migration" Journal of the Royal Statistical Society, 48, pp. 167-235
- Redlich J and Hirst F (1903) Local Government in England, Volume I MacMillan & Co.: London
- Richards P (1971) The New Local Government System George Allen & Unwin: London
- Robinson AH, Sale D, Morrison J and Muehrke PC (1984) Elements of Cartography: 5th Edition John Wiley & Sons: New York
- Robinson J and Zubrow E (1997) "Restoring continuity: Exploration of techniques for reconstructing the spatial distribution underlying polygonized data" International Journal of Geographical Information Science, 11, pp. 633-648
- Robinson W (1950) "Ecological correlations and the behavior of individuals" American Sociological Review, 15, pp. 351-357
- Robson BT (1969) Urban Analysis Cambridge University Press: Cambridge
- Rose M (1971) The English Poor Law 1780-1930 David & Charles: Newton Abbot
- Rowntree BS (1901) Poverty: A Study of Town Life MacMillan: London
- Sadahiro Y (1999). "Accuracy of areal interpolation: A comparison of alternative methods" Journal of Geographical Systems, 1, pp. 323-346
- Sadahiro Y (2000) "Accuracy of count data transferred through the areal weighting interpolation method" International Journal of Geographical Information Science, 14, pp. 25-50
- Saville J (1957) Rural Depopulation in England and Wales, 1851-1951 Routledge & Kegan Paul: London
- Schofield RS (1965) "The geographical distribution of wealth in England, 1334-1649" Economic History Review Second Series, 18, pp. 483-510

- Schreven L (2000) Netherlands: NLKAART Paper presented at Mapping Europe's Historic Borders and Boundaries: An Exploratory Workshop, Florence, 3rd June, 2000
- Shepherd IDH (1995) "Putting time on the map: Dynamic displays in data visualization" in Fisher P (ed.) Innovations in GIS 2 Taylor & Francis: London, pp. 169-188
- Shepherd I (2000) "Mapping the Poor in late-Victorian London: A Multi-Scale Approach" in Bradshaw J and Sainsbury R (eds.) Getting the Measure of Poverty. The Early Legacy of Seebohm Rowntree Ashgate: Aldershot
- Smellie K (1969) A History of Local Government Unwin University Books: London
- Smith DM (1973) The Geography of Social Well-Being in the United States McGraw Hill, New York
- Smith DM, Crane G, and Rydberg-Cox J (2000) "The Perseus Project: A digital library for the humanities" Literary and Linguistic Computing, 15, pp. 15-25
- Snodgrass R (1992) "Temporal databases" in Frank A, Campari I, and Formentini U (eds.) Theories and Methods of Spatio-Temporal Reasoning in Geographic Space. Lecture Notes in Computer Science, Volume 639 Springer-Verlag, pp. 22-64
- Southall HR (1991a) "Mobility, the artisan community and popular politics in early nineteenth-century England" in Kearns G and Withers C (eds.) Urbanising Britain: Essays on Class Community in the Nineteenth Century Cambridge University Press: Cambridge, pp. 103-130
- Southall HR (1991b) "The tramping artisan revisits: Labour mobility and economic distress in early-Victorian England" Economic History Review, 44, pp. 272-291
- Spence C (1994) "Mapping London in the 1690s" in Bocchi F and Denley P (eds.) Storia & Multimedia: Proceedings of the Seventh International Congress of the Association of History and Computing Grafis Edizioni: Bologna, pp. 746-756
- Staines A (1998) "Poverty and health" in Dorling D and Simpson S (eds.) Statistics in Society: The Arithmetic of Politics Arnold: London, pp. 244-251
- Star JL and Estes JE (1990) Geographic Information Systems: An Introduction Prentice Hall: New Jersey
- Sugden D (1996) "The East Antarctic ice sheet: Unstable ice or unstable ideas" Transactions of the Institute of British Geographers: New Series, 21, pp. 443-454
- Swiaczny F (2000) Germany: Jewish Population in C19 & C20 Pfalz. Paper presented at Mapping Europe's Historic Boundaries and Borders: An Exploratory Workshop, Florence, 3rd June, 2000
- Swiaczny F and Ott T (1999) "Das Problem der Modellierung historischer Prozesse mit Geographischen Informationssysteme" Historical Social Research, 24, pp. 75-100
- Swiaczny F and Ott T (2000) Time-integrative Geographic Information Systems. Management and Analysis of Spatio-Temporal Data Springer: Berlin
- Taylor PJ (1990) "Editorial comment: GIS" Political Geography Quarterly, 9, pp. 211-212

- Taylor PJ and Overton M (1991) "Further thoughts on geography and GIS - a preemptive strike" Environment and Planning A, 23, pp. 1087-1090
- Teitelbaum M (1974) "Birth under-registration in the constituent counties of England & Wales, 1841-1910" Population Studies, 28, pp. 329-343
- Thrift N (1977) An Introduction to Time Geography Concepts and Techniques in Modern Geography, 13 Geo-Abstracts Ltd.: Norwich
- Tillot PM (1972) "Sources of inaccuracy in the 1851 and 1861 censuses" in Wrigley E (ed.) Nineteenth Century Society Cambridge University Press: Cambridge, pp. 82-133
- Tobler W (1970) "A computer movie simulating urban growth in the Detroit region" Economic Geography, 46, pp. 234-240
- Tobler W (1979) "Smooth pycnophylactic interpolation for geographical regions" Journal of the American Statistical Association, 74, pp. 519-530
- Tobler W (1989) "Frame independent spatial analysis" in Goodchild MF and Gopal S (eds.) The Accuracy of Spatial Databases Taylor & Francis: London pp. 115-122
- Tomlinson RF (1990) "Geographic Information Systems – a new frontier" in Peuquet DJ and Marble DF (eds.) Introductory Readings in Geographic Information Systems Taylor & Francis: London, pp. 18-29
- Townsend P (1979) Poverty in the United Kingdom: A Survey of Household Resources and Standards of Living Penguin: Harmondsworth, Middlesex
- Townsend P (1993) The International Analysis of Poverty Harvester Wheatsheaf: New York
- Tranmer M and Steel DG (1998) "Using census data to investigate the causes of the ecological fallacy" Environment and Planning A, 30, pp. 817-831
- Tukey JW (1977) Exploratory Data Analysis Addison-Wesley: London
- United Nations International Research and Training Institute for the Advancement of Women (1994) The Migration of Women: Methodological Issues in the Measurement and Analysis of Internal and International Migration Santo Domingo: INSTRAW
- Unwin DJ (1995) "Geographic Information Systems and the problem of 'error and uncertainty'" Progress in Human Geography, 19, pp. 549-558
- Vanhaute E (1994) "The quantitative database of Belgian municipalities (19th/20th centuries): From diachronic worksheets to historical maps" in Goerke M (ed.) Coordinates for Historical Maps Max-Planck-Institut für Geschichte: Göttingen, pp. 162-175
- Vrana R (1990) "Historical data as an explicit component of land information systems" in Peuquet DJ and Marble DF (eds.) Introductory Readings in Geographic Information Systems Taylor & Francis: London, pp. 286-302
- Vrielinck S (2000) De Territoriale van België (1795-1963) Bestuursgeografisch en Statistisch Repertorium van de Gemeenten en de Supracommunale de Algemene Volkstellingen Univeritaire Pers Leuven

- Walsby J (1995) "The causes and effects of manual digitizing on error creation in data input to GIS" in Fisher P (ed.) Innovations in GIS 2 Taylor & Francis: London pp. 113-122
- Wachowicz M (1999) Object-Oriented Design for Temporal GIS Taylor & Francis: London
- Wang F and Hall GB (1996) "Fuzzy representation of geographical boundaries in GIS" International Journal of Geographical Information Systems, 10, pp. 573-590
- Welton TA (1911) England's Recent Progress. An Investigation of the Statistics of Migrations, Mortality, &c in the Twenty Years from 1881 to 1901 as Indicating Tendencies Towards the Growth or Decay of Particular Communities Chapman & Hall: London
- White P and Woods R (1980) "The foundations of migration study" in White P and Woods R (eds.) The Geographical Impact of Migration Longman Group: London, pp. 1-20
- Winnige N (1999) "Alphabetisierung in der Frühen Neuzeit, oder: Wie visualisiere ich raumbezogene historische Daten?", in Ebeling D (ed.): Historisch-thematische Kartographie. Konzepte, Methoden, Anwendungen Bielefeld, pp. 82-97
- Winnige N (2000) Germany: Historical Atlas of Prussia Paper presented at Mapping Europe's Historic Boundaries and Borders: An Exploratory Workshop, Florence, 3rd June, 2000
- Woods R (1979) Population Analysis in Geography Longman: London
- Woods R and Shelton N (1997) An Atlas of Victorian Mortality Liverpool University Press: Liverpool
- Worboys M (1998) "A generic model for spatio-bitemporal geographic information" in Egenhofer MJ & Golledge RG (eds.) Spatial and Temporal Reasoning in Geographic Information Systems Oxford University Press: Oxford, pp. 25-39
- Wright J (1936) "A method of mapping densities of population with Cape Cod as an example" Geographical Review, 26, pp. 103-110
- Wrigley N, Holt T, Steel D and Tranmer M (1996) "Analysing, modeling, and resolving the ecological fallacy" in Longley PA and Batty M (eds.) Spatial Analysis: Modeling in a GIS Environment GeoInformation International: Cambridge, pp. 25-40
- Yearsley C and Worboys M (1995) "A deductive model of planar spatio-temporal objects" in Fisher PF (ed.) Innovations in GIS 2 Taylor & Francis: London, pp. 43-51
- Youngs FA (1979) Guide to the Local Administrative Units of England Vol. 1: Southern England Royal Historical Society: London
- Youngs FA (1991) Guide to the Local Administrative Units of England Vol. 2: Northern England Royal Historical Society: London

