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# Applying Geographical Information Systems (GIS) to Environmental and Resource Economics

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**Abstract.** Many of the analyses undertaken by environmental and resource economics are intimately concerned with spatial variations. This article examines the contribution which Geographical Information Systems (GIS) may provide in incorporating the complexities of the spatial dimension within such analyses. The paper introduces the reader to the types of data handled by a GIS and overviews the practical functionality offered by such systems. A brief literature review is supplemented by a number of more detailed applications illustrating various GIS techniques which may be of use to the applied environmental or resource economist.

**Key words:** benefit transfer, environmental economics, Geographical Information System (GIS), resource economics, spatial analysis, valuation

## 1. Introduction

Environmental and resource economics are, by their very nature, intimately concerned with space. The questions these disciplines ask either explicitly or implicitly invoke the spatial dimension. However, the answers provided by economic analyses are frequently naïve regarding the incorporation of this dimension within studies. This article examines the contribution which Geographical Information Systems, or GIS as they are more usually known, may provide in assisting environmental and resource economists to consider spatial complexities within their analyses.

A GIS is defined as "a system for capturing, storing, checking, integrating, manipulating, analysing, and displaying data that are spatially referenced to the earth" (Department of the Environment 1987: 132). However, use of the term GIS can be confusing. At one extreme it may be employed to describe a piece of software, examples being Arc-Info, MapInfo, or SPANS (Fotheringham et al. 2000). At the other extreme, GIS is sometimes used to refer to operational systems designed to support activities such as traffic management or automated mapping. Within the context of the research environment, the former description is normally more appropriate, and the term is typically taken to comprise a commercially developed software application, along with the data and computer hardware used to run it.

In this respect, GIS are the analogue of the numerous other software applications that are available for the analysis of quantitative data. However, in terms of their functionality, the key factor that separates a GIS from these more traditional applications is encapsulated by the final five words of the above definition; GIS are specifically designed for the analysis of data that are *spatially referenced to the earth*. Hence their real utility in the research environment arises when *geographical* or *spatial* relationships form significant elements in the problem being investigated.

The following section provides an introductory discussion on general issues regarding the conceptual frameworks underpinning the use of GIS and the functionality that these systems can provide for applications within environmental economics. In Section 3 we then present a brief review of certain key papers in the literature. However, this article does not purport to offer a complete review of the application of GIS in this field, or indeed to present a balanced selection of applications. Instead the main body of the paper, given in Section 4, presents a variety of applications carried out at the Centre for Social and Economic Research on the Global Environment (CSERGE), University of East Anglia, UK. Section 5 draws together the various themes that are highlighted throughout and raises various caveats regarding the further potential for applying GIS techniques to the field of environmental economics.

## 2. Spatial Analysis and the Role of GIS in Environmental Economics

Space, as a key concept underlying much of economics, has been discovered (Hotelling 1929) and frequently rediscovered in mainstream economics (e.g., Case 1991; Fujita et al. 1999). Within the fields of environmental and resource economics, space, in the form of distance, has long played a key role in travel cost recreational demand analyses and hedonic models of property price (Freeman 1979) and is starting to play a more formal role in some resource applications (e.g., Sanchirico and Wilen 1998). In this section we discuss how the advanced spatial modelling capabilities recently provided by GIS are beginning to improve such analyses and starting to substantially extend the sophistication of spatially sensitive analyses more generally across the field. We also consider the various ways in which different disciplines tend to encapsulate the influence of space and geography within analyses and the advantages and functionality afforded by GIS are reviewed. The manner in which spatial representations may be generated within packages are also considered and the implications of adopting alternate representations are discussed.

Long before modern GIS became available, there was a recognition that spatial relationships represent an important consideration in many branches of applied economics. Indeed the growth of computing power has provided the springboard for developments within the field of applied spatial econometrics, much of which focuses around the methodological concerns that follow from explicit consideration of spatial effects in econometric models (Anselin 1988). Early work in this field was driven by researchers working on urban and regional econometric models (e.g., Paelinck and Klaassen 1979). They recognised that there existed a need for the systemisation of a branch of economics that united economic theory, mathematical formalisation, and statistical analysis within a spatial framework. The term 'spatial econometrics' was first used to describe this specialty by Paelinck in his address to the Dutch Statistical Society Annual meeting in 1974. These early spatial regional models were built around a desire to model variations in income and expenditure for differing regions within which earning and payment activities took place, populations migrated, and optimal solutions for associated investment activities were sought. The techniques developed in the field of regional science spread to mainstream economics during the 1980s and early 1990s, as exemplified by the work of Case (1991). This transition was motivated by the recognition that many of the issues that had previously been applied to time series analyses were also pertinent to spatial problems. For example, in time series analysis, observations which are made with a short temporal lag tend to be more similar than those made with a long delay between them. In spatial terms, it is also well recognised that observations that are close to each other in space exhibit a tendency to be more similar than those which are further apart. Such effects may take the form of spatial dependence or autocorrelation, in which the values of observations are functionally related, or spatial heterogeneity, in which model parameters are not stable across location (Irwin 2000). Spatial dependence may arise due to data measurement errors or omitted variables, leading to spatial error correlation, or from spatial interaction, which implies a structural interdependence amongst observations. Indeed, such is the importance of spatial dependence, Irwin and Geoghegan (2001) have argued that analysing a problem that is essentially location based while ignoring the potential of spatial interactions among observations is analogous to analysing a time series problem without knowing the chronological order of the observations considered.

It is well known that the failure to account for spatial dependence in models where it is present can lead to a variety of problems (Bell and Bockstael 2000). The exact consequences of not controlling for spatial effects differ according to whether the spatial dependency arises from correlated errors or spatially lagged variables (Klotz 1999). However, the key contributions of spatial econometricians to the environmental economics literature have revolved around quantifying the significance of spatial dependence in modifying the output of commonly employed analytical methodologies, and the development of statistical models that incorporate and mitigate their effects (Anselin and Rey 1997). These models are commonly designed to include explicitly parameterised spatial dependency measures. Often this is achieved by means of the development of a spatial autocorrelation parameter and a weighting scheme, which typically utilises a matrix within which each element corresponds to the relative magnitude of the spatial interaction between pairs of observations (LeSage 1997). This interaction is often modelled to be some function of the *distance* that separates each pair of observations. Hence we return to the importance of geography. If geography is such an central consideration to spatial econometricians then it might be expected that they would make considerable use of GIS. In reality though there are fundamental differences in the way that geographers and spatial econometricians view the concept of space.

In a paper given at a Resources for the Future seminar, V. Kerry Smith (1996) gave an interesting insight into differing interpretations of the analytical role of space that have typically been perpetuated by the econometrics and GIS camps. He noted that when spatial econometricians deal with spatial distributions, they view them as a constraint or some exogenous factor that must be factored out or controlled for. Smith argued that it was rather rare that they were viewed as an explanatory dimension of the issue being studied. It is, however, this latter viewpoint which underpins most GIS applications. Irwin and Geoghegan (2001) paraphrase the differing views of the importance of space well. They argue that in any modelling approach that uses spatial data, there are two key issues: How to use the data "correctly" and how to use it "creatively". The former refers to issues of spatial econometrics. The latter refers to developing ways of creating insights from spatial data that can be used to improve our understanding of the driving forces behind spatial processes. Indeed, as Fotheringham (1999a) notes, many GIS packages actually provide rather little functionality for the types of operation commonly undertaken by spatial econometricians. Whilst some vendors have begun to incorporate limited routines to permit the calculation of simple statistics such as indicators of spatial autocorrelation, the application of more complex techniques such as the fitting of spatially autoregressive models commonly requires the development of new code if attempted in a GIS, or the interfacing of the GIS with a statistical package designed for the analysis of spatial data.[1] Instead, it is the "creative" use of space that has normally provided the motivation for the incorporation of GIS techniques into environmental economics research. Indeed Fotheringham (1999b: 23) highlights this fact by noting:

> "I would argue that it is not necessary to use a GIS to undertake spatial modelling and integrating the two will not necessarily lead to any greater insights into the problem at hand. However, for *certain aspects of the modelling procedure*, integration will have a reasonably high probability of producing insights that would otherwise be missed if the spatial models were not integrated within the GIS".

It is, perhaps, surprising that environmental economists have not been quicker to appreciate the importance of spatial factors in human and ecological processes; the use of GIS in environmental economics is still a relatively recent innovation, despite the fact that the unrealistic spatial assumptions, implicit or otherwise, made by economists in order to implement their analyses have attracted considerable critical comment (Lovett and Bateman 2001). Certainly a review of the characteristics of many human and ecological processes would suggest that spatial considerations may play an important role in shaping observed phenomena. Although GIS were being adopted by organisations such as utility companies throughout the 1980's and early 1990's, their uptake within academia was rather slower. To some extent, the delays associated with the adoption of GIS may be due to a general disillusionment with quantitative geography that prevailed during that period (Fotheringham et al. 2000). This slow uptake by the research community which might be expected to be the early adopters within academia was not surprisingly reflected in a virtual absence of applications in environmental economics. Other negative effects may have resulted from a perception of GIS as simply facilitating the employment, albeit in an easy to use environment, of already well-used techniques that had been previously developed by quantitative geographers. Furthermore, some have suggested that GIS may have been seen as representing a Trojan horse through which quantitative geographers were trying to impose their ideas on the wider research community (Johnston 1997).

In practice, the criticisms of GIS discussed above are somewhat debateable and increasingly of purely historical interest as recent years have seen marked rise in the use of GIS within the applied environmental economics literature suggesting that the benefits of their employment are now becoming more widely recognised. Essentially, the motivation for using data incorporated into a GIS framework is to assemble information on the spatial contexts that shape social and economic phenomena. Put simply, GIS provide an additional means of gathering data by providing information on the biophysical context within which choices and judgements are made (Rindfuss and Stern 1998). This ability to parameterise spatial context and complexity has implications for a variety of environmental economic applications. For example, the conversion of land parcels from agricultural to residential uses will be governed by the spatial process of urban sprawl. Similarly spatial factors such as the distance to nearby amenities, the proximity of pollution sources, or simply what can be seen from a property can have a profound impact on its market price. Likewise, the decisions made by a household regarding which rural recreational site to visit may be substantially influenced by issues of accessibility, substitute availability, and travel time.

Just as spatial context can play such an important role in socio-economic processes, so it can be an important driver of the natural processes with which environmental and resource economists are commonly concerned. This is because the spatial arrangement of factors such as habitat, land-cover, or effluent discharges has been shown to have an important, and often dramatic, effect on outcomes such as species diversity, natural assimilative capacity, and nutrient cycling (Turner et al. 1993). As Nancy Bockstael (1996) illustrates, it is not just the total amount of wetlands in a region that affects assimilative capacity, but also their spatial pattern. Likewise, it is not just the total forested land in a region that matters for species abundance and diversity, but its size, shape, and the conflicting land-uses found along its edges (Wadsworth and Treweek 1999). It the ability to quantify and present these kinds of issues provided by GIS that gives the applications such value.

*Table I.* Selected Web sites containing information about geographical data sources

| Source | URL | Description |
|---|---|---|
| *AGI GIS Resource List* | www.geo.ed.ac.uk/home/giswww.html | Indexed list of several hundred sites |
| *The Data Store* | www.data-store.co.uk | UK, European, and worldwide data catalogue |
| *National Spatial Data Infrastructure* | www.fgdc.gov | Worldwide list of data sources indexed by metadata |
| *GISLinx.com* | www.gislinx.com/Data/ | More than 70 links to data sources |
| *EROS Data Center* | edcwww.cr.usgs.gov | US Government data archive |
| *Geography Network* | www.GeographyNetwork.com | Global online data and map services |
| *GEOWorld Data Directory* | www.geoplace.com | List of GIS data companies |
| *The Data Depot* | www.gisdatadepot.com | Free geographic data depot |

Source: Adapted from Longley et al. 2001.

If the theoretical benefits of applying to GIS to tackle research issues in the field of environmental economics are recognised, then the practical implications of using the systems requires some consideration. One major decision that needs to be faced at the start of a GIS project concerns whether to build or buy a database (Longley et al. 2001). In the early days of GIS, some form of primary or secondary data collection, usually via the digitisation of information from a paper map, was required. Nowadays, such a requirement is far less common, and there are many thousands of datasets available for download from the Internet although the costs of obtaining such data vary substantially.

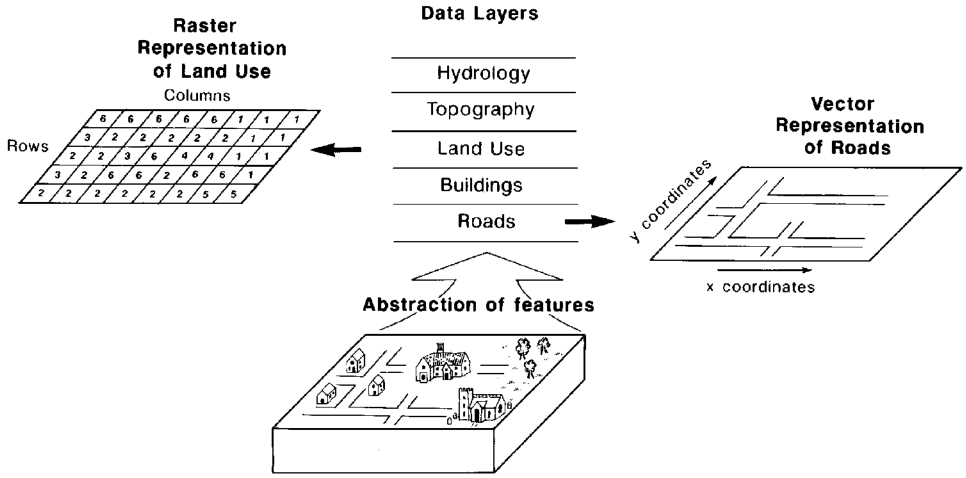
One of the best ways to find suitable data is to undertake an internet search using a specialist geographical search engine. Some World Wide Web sites providing good starting points for such searches are given in Table I. However, it is not always clear how the data provided by these sources was produced. Without information on variables such as map scale, choice of projection, and level of feature generalisation, it can be difficult to determine whether a dataset is suitable for a given task. Hence a critical requirement for online data is the provision of good quality metadata (literally data about data) so that informed decisions can be made regarding appropriate applications. If there is a requirement for a particularly specialised dataset, or one covering an area for which little survey effort has been undertaken, then primary or secondary data collection may still need to be undertaken. If information is digitised from paper maps, then it is important that copyright permission is obtained from the map producers, as the abstraction of digital information from a paper source represents a potential breach of copyright. An alternative method of primary data collection involves the use of field survey technologies such a global positioning systems (GPS). GPS are based around a network of satellites and monitoring stations, and users equipped with an inexpensive receiver may readily calculate the location and altitude of objects to an accuracy of better than 10 metres.

A common problem with data obtained from external sources, such as Internet sites, is that they can be encoded in many different formats (Longley 2001). These formats have evolved in response to diverse user requirements. Many GIS packages are able to directly read files produced in AutoCAD, DWG, DXF, DGN, Shapefile, and VPF formats. However, the specific level of support provided for different file formats differs greatly between GIS. A number of organisations have grouped together with the aim of standardising various aspects of geographical data provision. One organisation of particular note is the Open GIS Consortium, a group of vendors, users, and academics interested in the interoperability of GIS. To date, some progress has been made on metadata standards and web access, although the introduction of a common file format that can be used in all GIS packages is still some way away.

Once the data required for a particular project has been captured, converted into a suitable format, and read into a GIS, then the next consideration concerns the manner in which it is to be used. It may be that the data will be used to create new variables for inclusion within traditional statistical estimation exercises. For example, it might be used to generate new measures of view quality in a hedonic pricing analysis. Alternatively it may be used to create novel ways, for instance by the generation of various types of covariance matrices, of modelling the error component of spatial econometric analyses (Case 1991). Hence, the practical functionality offered by the systems requires some consideration. Earlier, particular emphasis was placed on the fact that the words *spatially referenced to the earth* appeared in our adopted definition of GIS. However, many people who have never heard of GIS are perfectly used to dealing with spatial information on a daily basis. Every time we address a letter we include a postcode or Zip code that acts as a spatial reference for the location of the addressee. Similarly, unfamiliar locations may be readily defined and commonly understood via a grid referencing system. Likewise, every day we navigate through road networks using information on highway names and lane directions. These spatial 'tags' can be entered into any database package that is designed for the storage of quantitative data. A key question that then arises concerns the nature of the functionality that separates GIS from other systems designed for database storage and statistical analysis. The answer lies in the manner in which space is represented, and that by which spatial information can be retrieved and queried between the different systems.

Within traditional database packages such as spreadsheets and off the shelf statistical packages, spatial tags such as postcodes, highway names and even grid references are simply attributes, no different to any others. The attributes may be interrogated and queried to answer simple spatially defined questions such as the determination of the number of households in a dataset sharing the same postcode, or the number lying to the north of a particular line of latitude. If the package incorporates simple mathematical functionality then it may be possible to extend the analysis by calculating straight line distances between pairs of grid references. However, this is where such functionality is likely to end. In a true GIS package, a fundamental difference is that spatial data are usually held separately[2] from other attributes such that a distinct geographical topology (the science and mathematics of relationships) is created. In this case both attribute and, crucially, *spatial* queries may be implemented and it is here that the true power of GIS lies; in a GIS, a spatial model based upon topological relationships is generated, and this may be interrogated and analysed with exactly the same functionality that attribute information can be evaluated elsewhere. Longley et al. (2001) suggest that it is useful to view this GIS model of spatial representation in terms of four different levels of abstraction. Firstly, *reality* is made up of real-world phenomena (such as buildings, streets, wells, lakes). Secondly, the *conceptual model* is a human-oriented, often partially structured, model of selected objects and processes that are thought to be relevant to a particular problem domain. Third, the *logical model* is an implementation-oriented representation of reality that is often expressed in terms of likely spatial interactions between features. Finally the *physical model* portrays the actual data, its physical structure, and the manner in which it is analysed in a GIS. The exact form of the conceptual and logical models will vary greatly between applications, as they will be dependent upon the research issue being investigated, the availability of data, and the views and beliefs of the researchers. Different forms of these models are highlighted in the literature review later in this paper. However, the properties of the physical model will be much more constant, as they are dependent upon the fundamental manner in which a GIS operates. These properties are hence considered below.

The physical data model used to represent the location of entities in a GIS generally conforms to one of two types, either being based on *raster* or *vector* representations of real world topology (Zeiler 1999). Figure 1 illustrates these two main approaches. In the *raster* data model, an array of cells, or pixels, are used to represent real-world objects. The cells can hold attribute values based on one or more encoding schemes including categories, integers, or floating point values. The raster model is particularly suitable for representing information that has been collected from imaging sources such as aerial photography or satellite remote sensing. It is also an especially appropriate way for depicting phenomena such as temperature, soil type or land-cover that vary continuously throughout space. In contrast, the *vector* data model is closely linked with a view of objects that possess discrete boundaries. Here the position of entities such as points (e.g., wells, soil pits, houses), lines (e.g., rivers, roads, power-cables) and areas (e.g., census tracts, county boundaries, groundwater protection zones) are defined by sets of co-ordinates which may be separated in the case of points, or joined to form linear or




Source: Lovett (2000).

*Figure 1.* Representing real-world phenomena as raster or vector layers.

polygonal features. The vector data model is appropriate for the representation of data that has been digitised from paper maps, and has been widely implemented in GIS because of the precise nature of its representation method, its storage efficiency, the quality of its cartographic output, and the wide range of functional tools that may be employed in its analysis.

The specific range of analytical tools that are available in any GIS environment will be somewhat dependent upon both the characteristics of the software package and the data model being used. However, most GIS offer the functionality required to answer a diverse range of spatially grounded questions that are commonly of interest to environmental economists. This diversity is clearly illustrated by the research examples discussed later in this article. Nevertheless, for the purpose of simplification, the analytical capabilities of GIS that make them particularly useful in this field can be grouped into the seven key categories outlined in Table II. The ability to *identify* the presence of features at a specified spatial location is of use in numerous analyses, examples being those of land-use change, where the probability of a land parcel being converted to a new function in the future will depend upon the land-cover type currently present. Here the GIS can be used to map conversion probabilities by linking land-cover data with a model of conversion potential (Fleming 1999). The determination of the *location* of a certain type of feature also has a wide range of uses, such as for the identification of the spatial distribution of neighbourhoods containing toxic landfill sites in studies of environmental equity to pollutant exposure (Pastor et al. 2001).

The ability of GIS packages to quantify spatio-temporal *trends* in data may be useful in a number of applications such as those concerned with the modelling and prediction of urban growth patterns (Irwin 2000), whilst the identification of

*Table II.* Typical questions that a GIS can be used to answer

| Type of question | Example |
|---|---|
| Identification | What is at a particular location? |
| Location | Where does a certain type of feature occur? |
| Trend | Which features have changed over time? |
| Routing | What is the best way to travel between two points? |
| Pattern | Is there a spatial association between two types of features? |
| Buffer | What features fall within a selected distance from a specified feature? |
| What if | What will happen if a particular change takes place? |

Source: Based on Rhind (1990); Kraak and Ormeling (1996).

optimal *routes* through networks like highway systems has obvious applicability for studies using travel cost or hedonic pricing methodologies, where the generation of measures of the spatial accessibility of facilities is important (Brainard et al. 1999). In such cases GIS can be used to generate indicators of travel times and distances which, if required, may be converted into predictors of travel cost. The identification of *patterns* in spatial data has important applications in landscape ecology models, where the mosaic of different habitats in an area may be a key predictor of biodiversity. Here, GIS can assist with the calculation of configuration measures such as fragmentation indices (Bockstael 1996). The ability to create *buffer* zones around features has obvious uses in the delineation of riparian buffers that are designed to intercept and sequester pollutant runoff around streams, lakes, or reservoirs (Belt et al. 1992) but also has application in the generation of noise contours around road networks (Bateman et al. 2001). Similarly the capacity to ask *what if* types of question can enhance the functionality of virtually any application, from the determination of the likely increase in visitation rate that may be associated with the upgrading of a recreational facility, to the identification of the optimal location for the siting of a new eco-industrial park in order to minimise environmental disamenities from commuting activities (Carr 1998). Solutions to such location-allocation problems, where the requirement is for the identification of optimal sites based around user specified criteria, are provided by the majority of GIS.

Empirical illustration of the functionality afforded by a GIS is provided in the following two sections. These applications highlight how GIS may be used to combine environmental and other spatial data in the form of digital maps and satellite imagery with more conventional variables to enhance economic models. They also illustrate how the technology may be used to query and visualise model output, for example in the form of maps. It is this dual capacity to improve modelling and display findings that we feel establishes the potential for GIS to significantly enhance many aspects of economic analysis and decision making.

### 3. Review of GIS Applications in Environmental Economics

Perhaps the most widespread use of GIS within environmental economic applications is to construct a wide variety of variables for use within hedonic property pricing studies. Hedonic pricing methodologies are well established techniques based on consumer theory which attempt to explain variations in house prices in terms of observed differences in preferences for the attributes of the properties in question (Champ et al. 2002). In the case of environmental goods, the aim is to infer a price based upon the marginal variation in property prices associated with their availability.

One of the most basic yet important advantages of employing GIS techniques within hedonic property pricing studies is the ability to automatically calculate explanatory variables for a large number of properties enabling a much larger sample size. Waddell and Berry (1993) use such an approach to assemble a dataset of some 2,300 houses while Doss and Taff (1996) compile records on 32,000 properties. However the benefits of such automation are perhaps exemplified by Clapp et al. (1997) who use GIS to match 65,000 properties to census areas. Such a process would be impractical without the use of GIS.

However, if a GIS only duplicated the procedures used in previous studies then its full potential would not be realised. Spatial data is increasingly available in digital form and this is enabling property price datasets to be integrated with other spatial information using GIS. A common example is the combination of property price information with census data (Metz and Clark 1997; Orford 1999) and the locations of amenities (Waddell and Berry 1993; Doss and Taff 1996; Powe et al. 1997). Less common examples include air pollution (Metz and Clark 1997), building and plot sizes (Lake et al. 2000a), land use (Orford 1999) and environmental noise (Din et al. 2001).

A major advantage of GIS is the ability to perform complex spatial queries on each property. This permits the calculation of variables that would not be possible using any other method. The most common example is the use of car travel times to describe the proximity of an individual property to an amenity (Lake et al. 2000a; Orford 1999). More complex proximity variables can also be created using the GIS. For example, in examining the influence of wetland amenities on sale prices of residential properties in Portland, Oregon, Mahan et al. (2000), use a GIS to consider the shape of the nearest wetland areas in addition to their proximity. Similarly, for the south coast of England, Powe et al. (1997) have approximated forest amenities associated with given property prices by the development of an index variable that measures the ratio of forest acreage to the squared distance away from the home. Geoghegan et al. (1997) have extended this concept further by calculating measures of percent open space, diversity, and fragmentation of land uses around land parcels in the Patuxent Watershed in central Maryland, USA. The authors calculated diversity and fragmentation indices by obtaining 25 class land-cover images from the Maryland Office of Planning. The diversity index was designed to signify the extent to which the landscape was dominated by a few or many land-uses, whilst the fragmentation index was set to represent the variance in landscape parcel types present within an area. Interestingly, the authors found that the marginal contribution of increased diversity and fragmentation to house selling prices was highly context dependent, with a positive association only being observed in the most urbanised areas, possibly reflecting the fact that diversity and fragmentation are valued in these situations as they represent amenities.

In a further aid to hedonic studies, GIS can be used to provide information on topography, which may have a profound effect on the influence of local environmental attributes as it largely dictates what is visible from a property (Paterson and Boyle 2002). Some early hedonic studies included categorical variables to account for the presence of a view of a particular attribute. For example, McLeod (1984) used a binary variable to indicate the presence of a river view in suburban dwellings located around the Swan River in Perth, Australia. However, the use of these simple indicators cannot capture measures of quality, such as how much of the attribute is present. Both Din et al. (2001) and Paterson and Boyle (2002) use GIS to calculate of the area of land visible from each property. The work of Lake et al. (1998, 2000a, b), discussed in more detail later in this article, uses the viewshed (a measure of the features that are visible from a viewpoint) functionality of GIS to develop sophisticated, continuous measures of the visibility of various land-uses from residences in Glasgow, Scotland. All of these studies find that the type and (where assessed) the quality of view available from a property is a significant determinant of its price.

Although hedonic models are often used to place a value on environmental amenities, they may also be utilised to elucidate the potential costs of environmental disamenities such as hazardous sites, and air, noise and water pollution. Lake et al. (2000a) and Bateman et al. (2001) use a GIS to process traffic and road network data to generate estimates of noise pollution at each property. Similarly Ihlanfeldt and Taylor (2001) examined the impact of proximity to hazardous waste sites on commercial and industrial property values in Fulton County, Florida. They used the ArcView GIS package to calculate the distance each property lay from the nearest hazardous waste site listed on an Environmental Protection Agency database. The authors found that the grading of each site had an influence on nearby prices; a distance effect was present around sites graded as ‘high risk’ in that there was a negative pressure on surrounding property prices. However, no effect was apparent for low risk sites.

Most hazardous waste sites are clearly visible and their presence is relatively easy to measure. For more subtle indicators of environmental quality like water pollution, it can be difficult to estimate indicators of exposure, and there are relatively few studies in the literature that have investigated these attributes. Despite this, GIS can provide a superior foundation for attempts to calculate such measures. This is illustrated by the work of Legget and Bockstael (2000) who estimated the potential benefits of a water improvement programme in Chesapeake Bay based on the development of hedonic models linking prices of waterside properties to indicators of nearby water quality. The research used GIS to assign measures of faecal coliform counts taken at sampling stations to property locations using an inverse distance-weighted average of coliform counts based on data from the nearest monitoring stations. The study found that house prices did exhibit a statistically significant negative association with coliforms, suggesting that the housing market is sensitive to such subtle environmental factors.

Closely associated with the application of hedonic models, the development of methodologies to quantify and prioritise the preservation of open spaces has become an important policy topic. Geoghegan (2002) linked a GIS based hedonic pricing model with a theoretical model of how different types of open space are valued by residential owners living close to them. The work showed that permanent open spaces may be three times more valuable to local residents than those which are potentially available for development. Using a case study of Northern Wake County, North Carolina, Smith et al. (2001) combined a GIS database of the road network with information on land-cover, property parcel attributes, administrative boundaries, and housing sales. Their analysis confirmed the importance of private open space for property values. The relationship was found to be particularly strong as the stock of open land declined, a result which is consistent with this use serving as a source of open space amenities. Indeed, questions of land-use and land-cover change have attracted interest amongst a wide variety of researchers concerned with modelling the spatial and temporal patterns of land conversion and understanding their causes and consequences (Irwin and Geoghegan 2001). Among them, geographers and natural scientists have taken the lead in developing spatially explicit models of land-use change at highly disaggregate scales. It is unsurprising that GIS has found a role in many recent studies. Here, the main application of the technology has been to facilitate the use of spatial data sets, often produced from remotely sensed sources, that may be used to quantify the spatial distribution of land-uses and, in cases where a time series of data is available, to describe their change (Mertens and Lamibn 1997).

Much of the economic work on land use change has focussed on deforestation in less-developed countries (Irwin and Geoghegan 2001). For example, Chomitz and Gray (1996) develop a simple model of deforestation in Belize using GIS data in which landowners maximise expected profits so that optimal use is determined by the uses with the highest rents. In a more sophisticated analysis, Geoghegan et al. (2001) apply Landsat TM satellite data to model tropical deforestation in the southern Yucatan peninsular region of Mexico. They link a GIS based model of landscape change with one founded on survey information gained from interviews with farmers in order to make comparisons between the predicted and actual deforestation practices of individuals. Other examples of economics models of deforestation using remotely sensed data and GIS include the work of Pfaff (1999) and Nelson and Hellerstein (1997). In the urban planning literature, Landis and Zhang (1998) provide a spatially explicit and disaggregated land use model. Their unit of observation is a one hectare cell of the landscape, and they use a discrete choice approach to model development and redevelopment in urban settings.

Outside of developing nations, one of the main centres of research into the application of GIS for the spatially explicit modelling of land use change is at the University of Maryland, USA. Here considerable research has focussed upon the Patuxent River watershed, located in central Maryland. The amount of low-density residential land use in this region has increased by 119% between 1973 and 1994 (Irwin and Geoghegan 2001). Much use has been made of micro-level GIS data on land and land parcels provided by the Maryland Office of Planning. The dataset contains variables that pertain to individual parcels, including land-use, and GIS has been used to augment this information with a wide variety of additional spatial measures including zoning locations, estimates of distance to urban areas, proximity to services such as public sewers, and indicators of soil quality and terrain steepness.

As part of the Maryland work, Bockstael (1996) developed a two-stage approach to modelling residential land-use change. An explicit hedonic model was first estimated as a function of spatially varying landscape features, including lot size, accessibility measures, neighbourhood zoning, and the percentage of land in different uses. This was used to predict a residential value for all developable land in the region, which was then employed in a binary discrete choice model of land use conversion. The modelling approach can be utilised to predict the effects of different land-use policies. For example, Bockstael and Bell (1998) analyse the influence of a number of alternative land use policies on landscape change, including the effects of different regulatory constraints. Further refinement of this work is found in Geoghegan and Bockstael (2000) and Irwin and Bockstael (2001). In these papers, a dynamic model of urban-rural fringe development is developed in which land use change over both space and time is considered.

The same research group have also embarked upon a range of studies that use similar GIS-based methodologies to investigate the effect of farmland preservation programmes on spatial patterns of preserved, privately owned farmland, and farmland prices. These programmes aim to preserve the amount of farmland in areas where they operate by providing payment to landowners in exchange for the imposition of development constraints that restrict the land from being converted to developed uses by current and future occupiers. Nickerson and Lynch (2001) used the Arc-Info GIS package to link 224 individual parcels of farmland sold in three Maryland counties between 1994 and 1997 with data on soil, land-use, and distance to facilities. Contrary to expectations, they found little evidence that voluntary permanent preservations significantly decreased the price of farmland in Maryland, possibly because landowners do not expect land use restrictions to be binding in the future. Nickerson and Bockstael (2001) undertook an analysis of the spatial pattern of preserved land resulting from these preservation programmes. Interestingly, they found that the presence of parcels of preserved land was more associated with areas of low development pressure than with stated policy objectives such as the prevention of urban sprawl.

GIS applications have also been extensively used in numerous recent studies that have investigated the manner in which environmental quality may be maintained by either the targeting of conservation objectives, or the delineation of zoning systems in order to prevent environmental contamination. In many cases, the degree of overlap with the considerations of environmental economists is slight. However, some applications merit attention here. Azzaino et al. (2001) use GIS to model the optimal riparian buffer to sequester pollutant run-off in the lake. Two models were tested, and the authors found that quantifying the desirability of outcomes based on criteria scoring and pollutant weighting approaches gave rather similar results. In related work, Ferraro (2001) has recently used GIS to investigate the targeting of conservation contracts in heterogeneous landscapes. The term conservation contracting describes the contractual transfer of payments from one party (usually the government) to another (usually the landowner) in exchange for the development of land use practices that contribute to the supply of an environmental amenity such as biodiversity. A key issue in the design of conservation contracting initiatives is the manner in which information about spatially variable biophysical and economic conditions may be integrated into a cost-effective conservation plan. Using biophysical and economic data from the GIS system of the City of Syracuse, New York State, an environmental benefit score for conservation initiatives designed to maintain good water quality was calculated for land parcels around Lake Skaneateles. Each parcel was scored according to its acreage, zoning position, distance to drinking a water intake, area of hydrologically sensitive land, and length of stream frontage. The work found that approaches that incorporate both biophysical and economic data are likely to generate much greater environmental benefits than those that include only one factor. Hence approaches that involve data integration in a GIS should convey considerable benefits.

In order to provide more detail regarding the diverse range of issues which can benefit from the application of GIS techniques, the following section provides a more in-depth insight into a number of studies conducted and ongoing at CSERGE.

## 4. Further Applications of GIS to Environmental Economics

Our discussion of empirical applications opens with Section 4.1 which presents a brief and straightforward study of the potential contribution of GIS techniques to the aggregation of expressed preference data such as is commonly collected in contingent valuation or discrete choice experiments. Although trivial in terms of the degree of GIS sophistication required, we include this example because we feel that it may help contribute towards improving a generally under-researched yet vital part of the valuation process which can typically induce greater variability into final valuation estimates than do many of the study design issues which commonly fill the pages of many journals.

Section 4.2 considers the area of research which has attracted the most widespread use of GIS by environmental economists to date; hedonic pricing. Here we show how GIS can contribute to the improved availability and consistent definition of a wide range of the structural, accessibility and neighbourhood variables which are the standard fare of any hedonic property price application. However, it is in the definition of environmental variables that GIS promises the most substantial improvement to data availability for such studies. The ability of such systems to quantify spatially defined effects and to generate such data in an automated manner represents a very substantial advance in the practical remit of hedonic applications and permits the extension of the technique into new areas of valuation which had previously involved impractically large data collection budgets. As such we believe that GIS will come to be seen as the standard tool of the hedonic analyst.

The ability of a GIS to automate and standardise spatial measurement and assessment tasks also provides the basis for its contribution to travel cost assessment of open-access recreation values. In Section 4.3 we discuss how such routines can not only improve individual applications but also how such standardisation and improved access to spatially defined data (including travel cost measures, substitute availability, socio-economic variables, and site quality data) substantially enhances the potential for successful transfer of valuation functions between sites. Amongst a number of such benefit transfer applications we present an application which generates maps of potential woodland recreation benefits across the entire country of Wales, an area chosen for analysis both because of its physical and socio-economic diversity and because long term decline in the dominant agricultural sectors means that the value of farm subsidies far outstrip the value of production (National Assembly for Wales 2001) making the area ripe for land use conversion into multipurpose woodland. In Sections 4.4 and 4.5 we retain this study area as we examine the timber and carbon sequestration benefits generated through such land-use change. These applications illustrate the use of GIS techniques in bringing spatial realism into analyses and so obviating the need to resort to strong and sometimes debateable assumptions.

Section 4.6 concludes our review of empirical applications and contrasts with the cost-benefit focus of preceding sections by considering the role of GIS in providing assessments of the equity of access to environmental quality. While the emphasis here is no longer upon monetary assessment, we show how the spatial outputs of a GIS are directly compatible with those provided in the valuation exercises presented in previous sections and thus allow the decision maker to inspect the consequences for social distribution of differing cost-benefit outcomes and so obtain cost-effective measures of the provision of change to such distributions.

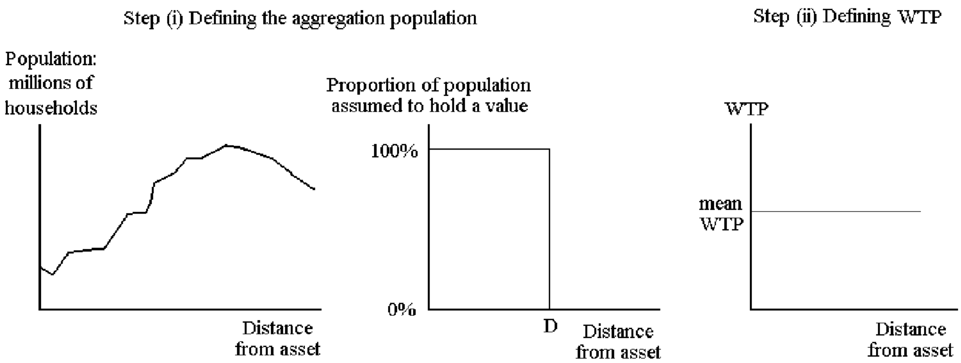
### 4.1. INCORPORATION DISTANCE INTO THE AGGREGATION OF NON-MARKET VALUATION ESTIMATES

Our discussion of the use of GIS techniques within applied environmental economics opens with a simple illustration which serves to demonstrate how consideration of a spatial perspective can, where such a perspective is pertinent to the issue at hand, obviate the need for simplifying assumptions and thereby result in very substantial improvements in the accuracy of analyses. This illustration concerns the aggregation of willingness to pay (WTP) responses obtained from expressed preference valuation studies, the empirical example being taken from a contingent valuation (CV) study.

In the UK concern regarding the aggregation of WTP estimates was brought into sharp focus in the late 1990s through a high-profile public inquiry concerning water abstraction rates from the River Kennet near Marlborough, a small town some 75 miles west of London. The case arose when the UK Environment Agency (EA) sought to reduce abstraction by a private water company and, as part of its deposition to the inquiry, presented estimates of the direct and passive use value losses incurred by such abstraction. These values were obtained through a somewhat simplistic benefits transfer exercise conducted by the EA in which lower bound WTP values estimated by Willis and Garrod (1995) for another river were, with some adjustment, applied to the Kennet. However, the principal source of controversy concerned the way in which these estimates were then aggregated to yield annual and NPV totals. Following contemporary guidelines (Foundation for Water Research 1996) the EA specified the relevant non-user population for aggregation purposes as being the entire customer base of the relevant water company, which in this case amounted to some 3 million households. Simply multiplying this population by a constant WTP per household value resulted in an estimate for the passive use benefits of reduced abstraction of nearly £1million per annum, a sum which dwarfed the £145,000 per annum estimated for all direct use values (Moran 1999).

Although the EA's case was rejected principally on the grounds that their physical modelling was considered unreliable, it was the use of benefits assessment techniques by the EA which attracted attention in the media which reported this result as a 'savage blow to cost-benefit assessment' (ENDS 1998: 16). In an assessment of the EA valuation study, Moran (1999) identifies 'the vexed issue of how to aggregate the results of valuation studies' (p. 425) as the key research issue arising from this case. Certainly the 'administrative area' approach adopted here appears crude in that the relevant population was defined in an arbitrary manner and no allowance was made for a possible decay in unit values with increasing distance away from the site (the 'distance decay' effect).

Figure 2 illustrates the two steps of the administrative area approach as two functions with respect to distance from the asset. In Step (i) the distribution of population is taken (left hand graph) and everyone living within a certain distance of the asset, (described by the chosen administrative boundary, illustrated in the central graph as distance D) is included in the aggregation population whereas




Source: Bateman et al. (2002a).

*Figure 2.* The administrative area approach.

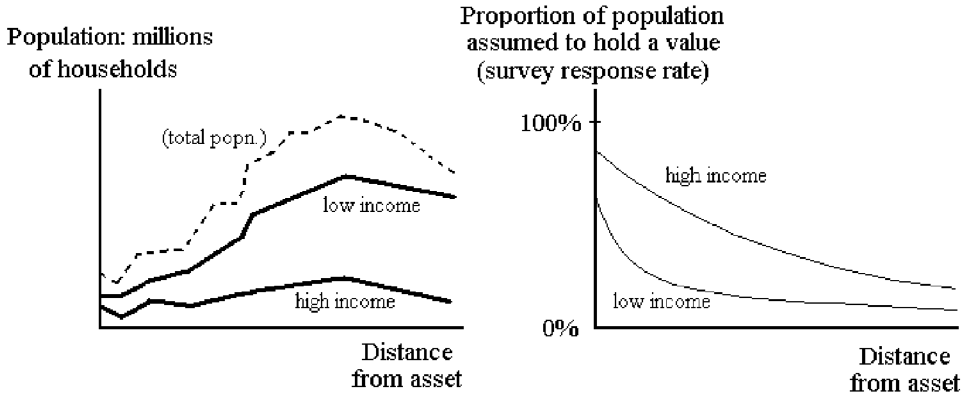
everyone residing beyond this distance is excluded. Step (ii) shows the constant mean marginal WTP, estimated from the sample (right hand graph). The method calculates total WTP by effectively multiplying these functions together.

As inspection of Figure 2 clearly shows, there is a potential spatial dimension to aggregation issues concerning fixed resources such as a river. However, in the absence of information regarding this dimension the EA made some simple implicit assumptions that the aggregation population can be defined discretely with respect to distance while marginal WTP values are invariant across space.

The use of a GIS allows the analyst to relax these very strong assumptions and so introduce some much needed realism into the aggregation process. To illustrate we consider the passive use valuation data collected by Bateman and Langford (1997) in a CV study of values for preventing saline inundation within the Norfolk Broads freshwater wetland in Eastern England. This data was collected using a postal survey of just over 1000 addresses across Great Britain. Bateman et al. (2000) reanalyse this data implementing a number of aggregation routines, two of which we report here.

First, for comparative purposes, the administrative area approach was adopted as illustrated in Figure 2. Here, given that the Norfolk Broads is a unique, National Park status, asset which attracts visitors from all areas of the country, the appropriate administrative boundary for defining the aggregation population was set as being the whole of the country.[3] Again following the approach illustrated in Figure 2, WTP was then set at the sample mean and applied across the aggregation population to derive an estimate of total WTP for preventing saline flooding. Such a methodology follows that used by the EA in the River Kennet example discussed above.

An alternative methodology is developed by Bateman et al. (2000) who employ a GIS to calculate distances from the wetland to each of the addresses to which survey questionnaires were sent. These distances were initially used to allow identification of the relevant aggregation population who hold values for the flood




Source: adapted from Bateman et al. (2002a).

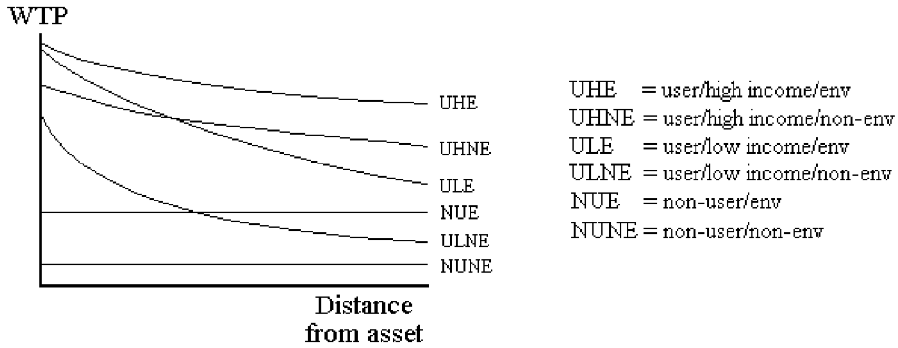
*Figure 3.* GIS based approach to aggregation: 1. Defining the aggregation population.

prevention scheme. This was determined by analysing rates of questionnaire return with respect to distance from the wetland and other possible explanatory factors.[4] As illustrated in Figure 3, while the actual population may vary in any manner with increasing distance from the asset (left hand panel), the proportion of that population which holds significant values for its preservation steadily declines with increasing distance and was also found to have a significant socio-economic component (right hand panel). By combining these data and relationships the aggregation population can be determined.

The GIS derived distance measures were then incorporated within bid function analyses to examine whether WTP levels were responsive to this factor. Results showed a clear distance decay effect amongst respondents who claimed to hold some use value (in addition to any passive use value) for the wetland. Values for this group were also significantly influenced by respondents socio-economic circumstances (e.g., income levels) and their stated interest in environmental issues (e.g., membership of pro-environmental groups). While this latter factor also impinged upon the WTP levels of those solely expressing passive use values, such values did not exhibit distance decay effects. All of these findings seem in accord with expectations.

Figure 4 illustrates these various relationships where six distinct types of respondent are identified via labels. These labels are constructed such that respondents with use values are denoted U and those without are coded NU. Similarly those who were members of environmental groups are denoted E while non-members are coded NE. Finally those with high incomes are coded H and those with lower incomes denoted L. Note that only those with use values showed significant WTP relationships with income and distance. Again this seems plausible.

By combining the aggregation population findings summarised in Figure 3 with the WTP bid functions illustrated in Figure 4 we can estimate a GIS derived aggregate WTP value (details in Bateman et al. 2000). Table III compares the




Source: adapted from Bateman et al. (2002a).

*Figure 4.* GIS based approach to aggregation: 2. Defining WTP functions.

*Table III.* Aggregate value of preserving the present condition of the Norfolk Broads wetland estimated using two procedures

| Aggregation method | Treatment of distance | Aggregate value (£ million p.a.) |
|---|---|---|
| Administrative area approach | Assumes aggregation population is all individuals up to some distance (and zero thereafter) and WTP is constant up to this distance | 159.7 |
| GIS based approach | Incorporates distance decay into both the aggregation population and WTP function | 25.4 |

Note: Responses gathered from an off-site, postal survey across Great Britain.

value derived via this method with that obtained by applying the administrative area approach used by the EA and summarised in Figure 2 to identical data collected in the study of the Norfolk Broads wetland. As can be seen, in this case the administrative area method yields a value more than six times greater than that provided by our GIS based approach. However, the fundamental finding here is that the value provided by the administrative area approach is determined almost wholly by the definition of that area and will increase or decrease with that definition. By contrast by explicitly incorporating the spatial dimension, the GIS based approach eliminates the need for arbitrary definition of the aggregation population allowing this to be data driven.[5]

This first, simple example serves to show that GIS techniques can easily incorporate of distance into environmental economic analyses and so facilitate very substantial improvements to those analyses. However, distance is only one dimension of space and, as our next example shows, a GIS can readily address more complex spatial problems.

### 4.2. HEDONIC PRICING AND GIS

The potential for applying GIS techniques to hedonic pricing exercises was first explored in Bateman (1994). However, our initial applications are given in various studies of the impacts of roads upon roughly 4,000 house prices in the Scottish city of Glasgow (Lake et al. 1998, 2000a, b; Bateman et al. 2001; Day 2002). These techniques are extended in our ongoing analysis of road, rail and aircraft noise as well as air pollution impacts upon 12,000 property sales in Birmingham, England. Here GIS routines are used to calculate or integrate some of the structural and all the accessibility, neighbourhood and environmental variables.[6] In both cases the starting point of the analysis was to translate property addresses into a grid reference using the Ordnance Survey ADDRESS-POINT database (Martin et al. 1994). This provides the common reference point for subsequently assigning the structural, neighbourhood, accessibility and environmental variables which characterise each individual property.

In the case of our ongoing study of the Birmingham property market and its submarkets, structural information was obtained from the Valuation Office Agency, a government department who maintain an up to date database on property characteristics for tax purposes. This database contained information on the number and type of rooms in the property, its age, heating system, etc. However, other important structural variables were not present and were calculated by applying GIS routines to information provided in large-scale digital maps of the area (Ordnance Survey Land-Line.Plus). These included the size of garden and the property perimeter both of which can be seen in Plate 1(a) which illustrates some of the digital map data used in such analyses. Lake et al. (1998) apply factor analysis techniques to address the multicollinearity which is rife in covariate hedonic data, and confirm the key role which structural variables play in fixing property prices.

Accessibility variables define the ease with which local amenities can be reached from a property and as such are expected to influence house prices. Data on the locations of amenities such as retailing stores, railway stations and schools as well as the central business district, etc. were obtained from a database of business locations. The GIS was then used to first convert these locations to grid references and then integrate this data together with detailed digital road network and footpath maps. The modelling capabilities of the GIS were then used to calculate a variety of accessibility measures between each property and these amenities. These measures included distance based assessments such as Euclidean and walking distance and time based measures such as car travel times. The red line drawn in Plate 1(a) illustrates travel distance from a specified property to a store, a variable which can readily be combined with information on travel speeds in order to estimate travel time. Further details regarding the derivation of travel times are presented subsequently with respect to our research on recreation demand. Lake et al. (2000b) find quadratic relationships between property price and the distance to both retail stores and the central business district indicating the presence of an optimal distance from both such facilities.

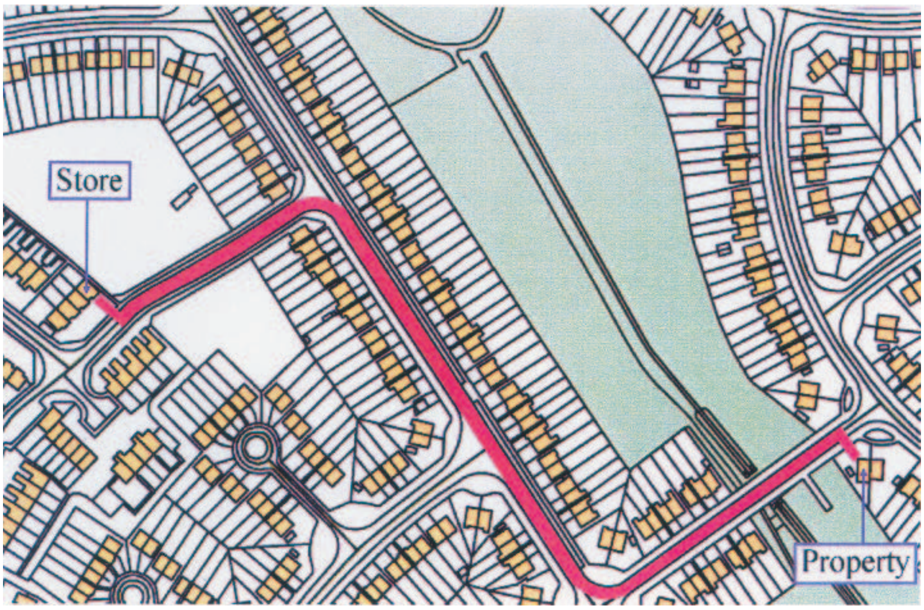



*Plate 1(a).* Obtaining structural and accessibility measures using a GIS.

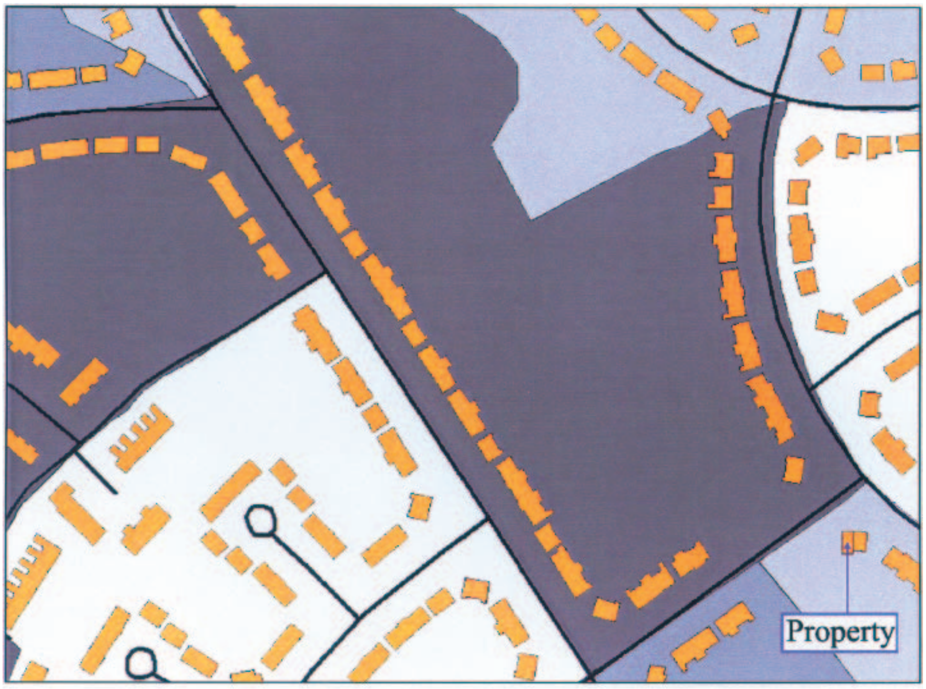



*Plate 1(b).* Obtaining neighbourhood quality measures using a GIS.

It is a well established empirical regularity that the characteristics of the neighbourhood surrounding a given property can be shown to influence its price. Data on such characteristics were obtained by using the GIS to incorporate spatial information on the boundaries of the smallest unit of the UK census[7] and assign each property to its appropriate area. In this way neighbourhood characteristics, such as local unemployment rates (illustrated in Plate (b)), ethnic mix, etc., were assigned to each property. The spatial analysis functions of a GIS enabled such neighbourhood information to be assigned at a variety of spatial scales in order to account for local as well as wider neighbourhood effects. For example, Lake et al. (2000a) find a negative association between the price of a property and the proportion of houses in the vicinity which are unoccupied.

Environmental variables for each property were derived through a variety of methods. In our earlier study of Glasgow, road noise levels were calculated within the GIS through the application of published models (DoT 1988) concerning the amount of noise emitted and how this travels to each property. In such models the noise level being emitted from each road is a function of the traffic volume, its composition (e.g., the proportion of heavy vehicles) and speed, as well as the gradient and surface of the road. The GIS can readily integrate data on road network location and surface, as well as the composition and speed of traffic. Road gradient (a significant determinant of noise levels, although often omitted from consideration) was assessed through combining the above data with a 3 dimensional digital elevation model (DEM) of land heights to estimate the slope of the land upon which each road was built. The level of noise being emitted from each road was then calculated according to the formulae specified in DoT (1988). The propagation of road noise to each property was subsequently estimated so as to account for the changes in sound level that will occur between surrounding roads and a given property. This procedure allowed for air absorption and the dispersion of the sound. Using the GIS the horizontal and vertical distance between the house and road were calculated and the noise level adjusted accordingly. Similarly consideration was given to ground absorption of noise and allowance made for noise reflection from other properties (noise shielding was not a feature of the study area but could have been considered if necessary). Analysis of the findings of this modelling process indicated significant negative relationships between property price and both road and aircraft noise levels within our Glasgow study area (Bateman et al. 2001).[8]

GIS techniques are also useful in providing the base data on distances between properties needed to investigate the possibility of spatial autocorrelation of prices, a phenomena which is likely to occur when properties that are located near to each other in space also share common environmental, accessibility, neighbourhood and perhaps even structural characteristics.[9] In a recent re-analysis of the Glasgow dataset, Day (2002) both identifies a number of housing sub-markets[10] and confirms the presence of spatial autocorrelation across the dataset. Correcting for this via a spatial weighting system, Day shows that road noise was found to be negatively and significantly related to property price across the dataset as a whole, although results suggest that the effect was not uniform across sub-markets.

A set of environmental attributes which are often omitted from hedonic property pricing studies, yet can clearly impinge substantially upon the price of a house, are the types and qualities of the views available at each property. Three dimensional DEMs were derived for our studies of both Glasgow and Birmingham. These allowed for the impact of topography upon the view from a given property. Views were then further constrained by introducing information regarding the location and height of the built environment (e.g., all other houses, factories, etc.). Subsequently the GIS *Viewshed* capability was employed to calculate what can be seen from each face or floor of a property, an example of which is illustrated in Plate 2. The GIS can also be used to integrate viewsheds with land use databases. For each land use within the viewable area, the GIS can calculate the relevant viewing angle subtended at the specified property face and floor. So, for example, the GIS might inform the analyst that 10 degrees of the view from a given property face and floor looks over a factory, while say 12 degrees overlooks open parkland. Furthermore, by combining these findings with information on the distance to such attributes, interactions between viewable angle and distance can be investigated and a visual impact measure calculated for each land use type viewed from each point on every property. Using such techniques, Bateman et al. (2001) report negative associations between property prices and both industrial and obstructed views, while a positive relationship was found for views of parkland.

### 4.3. MODELLING AND TRANSFERRING RECREATIONAL VALUES AND ARRIVALS[11]

The spatial and temporal analytic capabilities of a GIS make it the ideal medium for conducting travel cost assessments of recreational values. GIS routines for measuring distance and travel time from multiple precise outset origins to the plethora of potential visit locations have greatly enhanced the ability for researchers to introduce much needed real-world complexities into their analyses. More fundamentally, these abilities allow the GIS analyst to obtain comparable measures of travel time, distance, substitute availability, socio-economic circumstance, etc., for both sites that have been surveyed (study sites) and others that have not (target sites) but for which value estimates are required. In this way GIS techniques provide the ideal medium for conducting benefit transfer exercises.

Our initial applications of GIS to travel cost exercises were primarily concerned with improving the base measurements of travel time and distance which underpin the method, and in assessing the impact upon consumer surplus estimates of such improvement. Up until the 1990s many travel cost studies employed straight line assumptions regarding routing from a given visitors outset origin to the visit site in question, while further oversimplification arose from assuming constant travel speeds (e.g. Rosenthal et al. 1986). Together these simplifications resulted in the

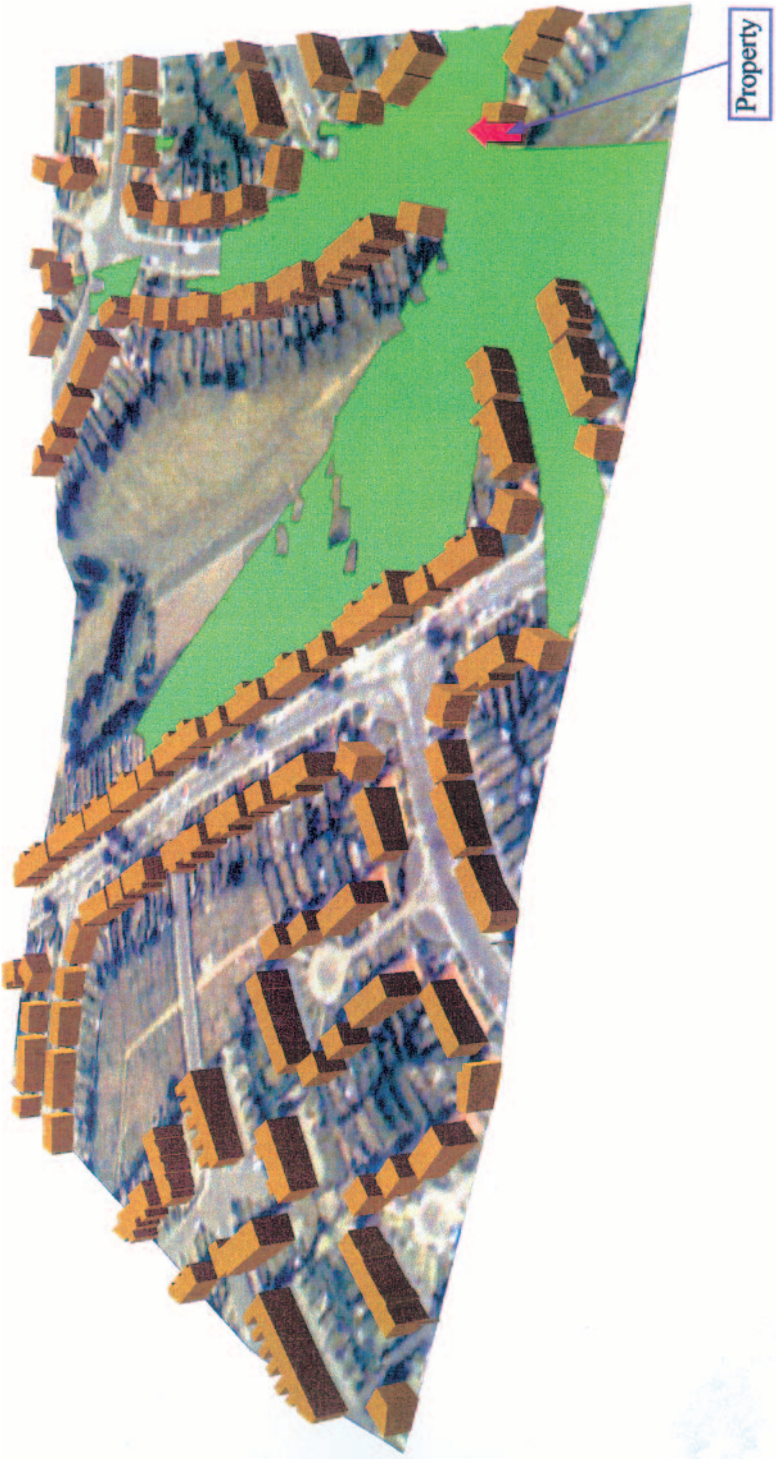



*Plate 2.* GIS viewshed calculation of viewable area from one point on a specified property.

implicit assumption that isochrones (lines of constant travel time) were arrayed in a concentric pattern centred upon the visit site. Such a result could in reality only occur if each site was located in the centre of a perfectly flat plain of road asphalt stretching to infinity (or at least to the distance of the furthest visitor) across which travel times and congestion rates were equal. Bateman et al. (1996) described the use of GIS techniques within travel cost analyses as a means of constructing travel time and distance measures which incorporate both the actual distribution of road networks and the differing quality of those roads as reflected in varying vehicle speeds. Figure 5 illustrates the resulting isochrone map generated in this application which concerned a woodland recreation site in East Anglia, England. As can be seen, real world isochrones are far from concentric, extending out along major road arteries to reflect the higher travel speeds permitted by such routes.

Such techniques are now reasonably commonplace as travel cost analysts have adopted off-the-shelf journey routing packages. However, there are concerns regarding the accuracy of road speeds used and the completeness of the road network data underpinning such packages. These concerns are most pressing for relatively short journeys where the major roads given prominence in such packages may not be the preferred route. Brainard et al. (1997) extend this line of research to consider the impact of a range of assumptions upon isochrone definition.

The overall impact of simplifying travel time and distance assumptions upon resultant travel cost estimates of consumer surplus is considered by Bateman et al. (1999a). Various sensitivity analyses were conducted. For example, consumer surplus estimates obtained by assuming that visitors travel in a straight line were compared to those estimated by using the GIS to account for the available road network. This analysis showed that, as expected, straight line assumptions result in an underestimate of travel times and distances, this error being relatively more pronounced for visitors facing relatively short journeys. This bias translated into an underestimate of consumer surplus values of up to 20% where straight line measures were adopted.

Another focus of this sensitivity analysis concerned the accuracy with which outset origins were specified. Many travel cost studies employ approximations such as the centre points (or ‘centroids’) of administrative areas within which a given outset origin falls (e.g., Mendelsohn et al. 1992; Loomis et al. 1995). However, such points are liable to be systematically biased in that, within any given area, it is the basic tenant of the travel cost method that a larger proportion of visitors will originate from points closer to the site than from more distant outset locations. The use of centroids is therefore liable to systematically overestimate travel times and distances. Furthermore, this overestimation will become more severe as the size of centroid areas is increased. Bateman et al. (1999a) investigated the scale of any resulting impact upon consumer surplus estimates by comparing highly accurate GIS defined outset origins with those obtained from three, successively larger, centroid types. Findings indicated that a shift from GIS defined origins to even the middle of the three sizes of centroid considered (‘District’ level centroids, compar-

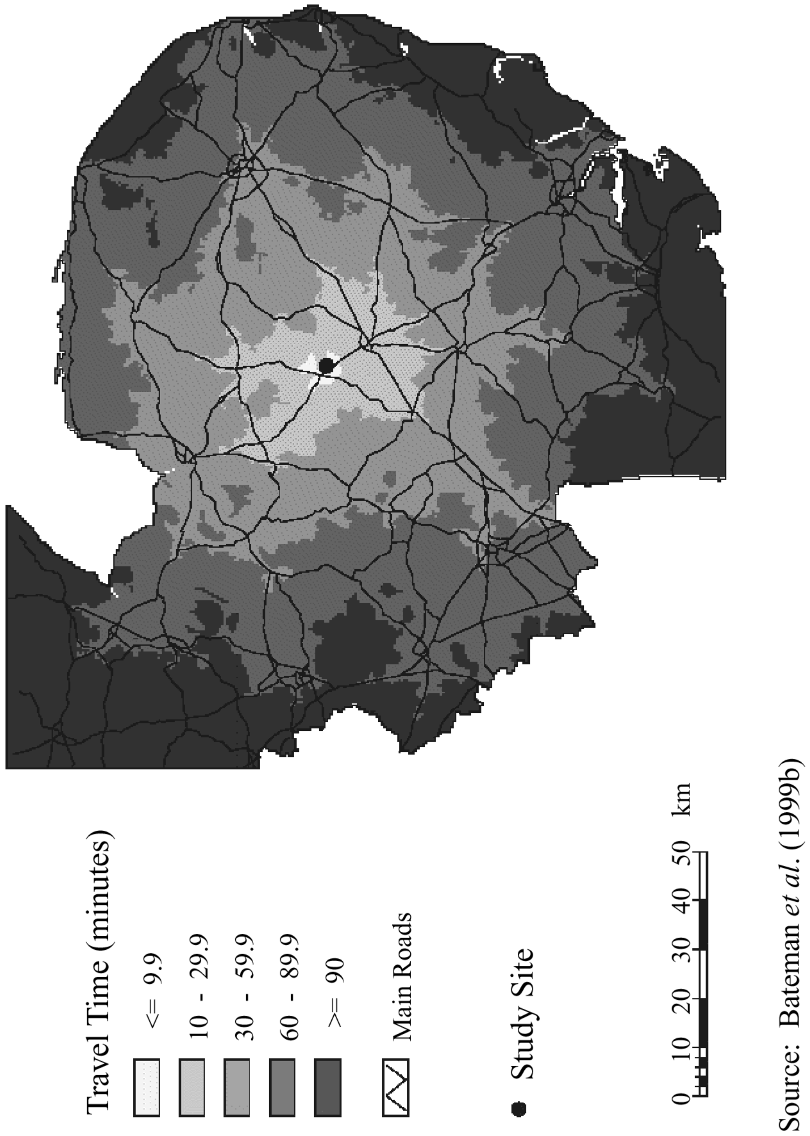



*Figure 5.* GIS generated isochrone map for travel cost analysis.

able in size to those used by Loomis et al. 1995) resulted in an over-estimation of consumer surplus values of up to 28%.[12]

While these techniques can deliver substantial improvement to the accuracy of individual travel cost studies, it is the potential for benefit transfer analyses offered by GIS methods which presents the most exciting opportunities in this field. GIS provides a ready route for obtaining measures of the underlying determinants of consumer surplus including travel time and distance, travel cost, population distribution and outset origins for potential visitors, the socio-economic characteristics of those populations, the spatial availability of substitutes and complements, etc. Furthermore, these measures can be obtained in a consistent manner for both surveyed 'study' sites and unsurveyed 'policy' or 'target' sites. It is this consistency, compatibility, availability and richness of measures which provides the quantitative cornerstone which is a vital prerequisite for successful benefit transfer.

Our initial investigation of the potential for GIS-based benefits transfer is presented in Bateman et al. (1995, 1999b) which transfers visitor arrival functions obtained from a survey of a single woodland site to five other similar sites located in various parts of Wales. The functions used in this analysis are relatively simple incorporating digital road networks and information regarding the distribution of population. Nevertheless, partly because of the high quality nature of these datasets and the robustness of the GIS routing techniques employed, these models perform reasonably well in predicting arrival numbers. Such an analysis is fundamentally reliant upon an uncomfortably large number of assumptions (e.g., site quality factors, substitute availability, socio-economic characteristics, etc., are all implicitly assumed to have no effect here) and was therefore primarily a staging post for methodological developments set out below. However, given this, functions were then used to generate maps of potential visits to woodlands for the entire study area of Wales. This analysis estimates the number of recreational visits which would be generated by creating a new woodland at a given point on a grid network covering the study area. The analysis is then repeated over all points across the grid. Values for predicted visits were subsequently obtained by reference to a meta-analysis of woodland recreation valuations and combined with predicted arrivals to generate the map of estimated values illustrated in Figure 6. This map does not, as might initially be thought, show the effect of afforesting the entire study area because this simple model does allow for the substantial impact which such a policy would have upon the marginal recreational value of woodlands. Rather it shows the recreational value of one new woodland located at any, but not all, of the grid points shown. Despite the severity of assumptions underpinning this analysis, its findings accord with prior expectations that woodlands generate higher recreational values in areas of high population density (such as the south-east or north-east of the country) and/or in highly accessible locations, this latter finding being shown in the elevated values associated with major road arteries.

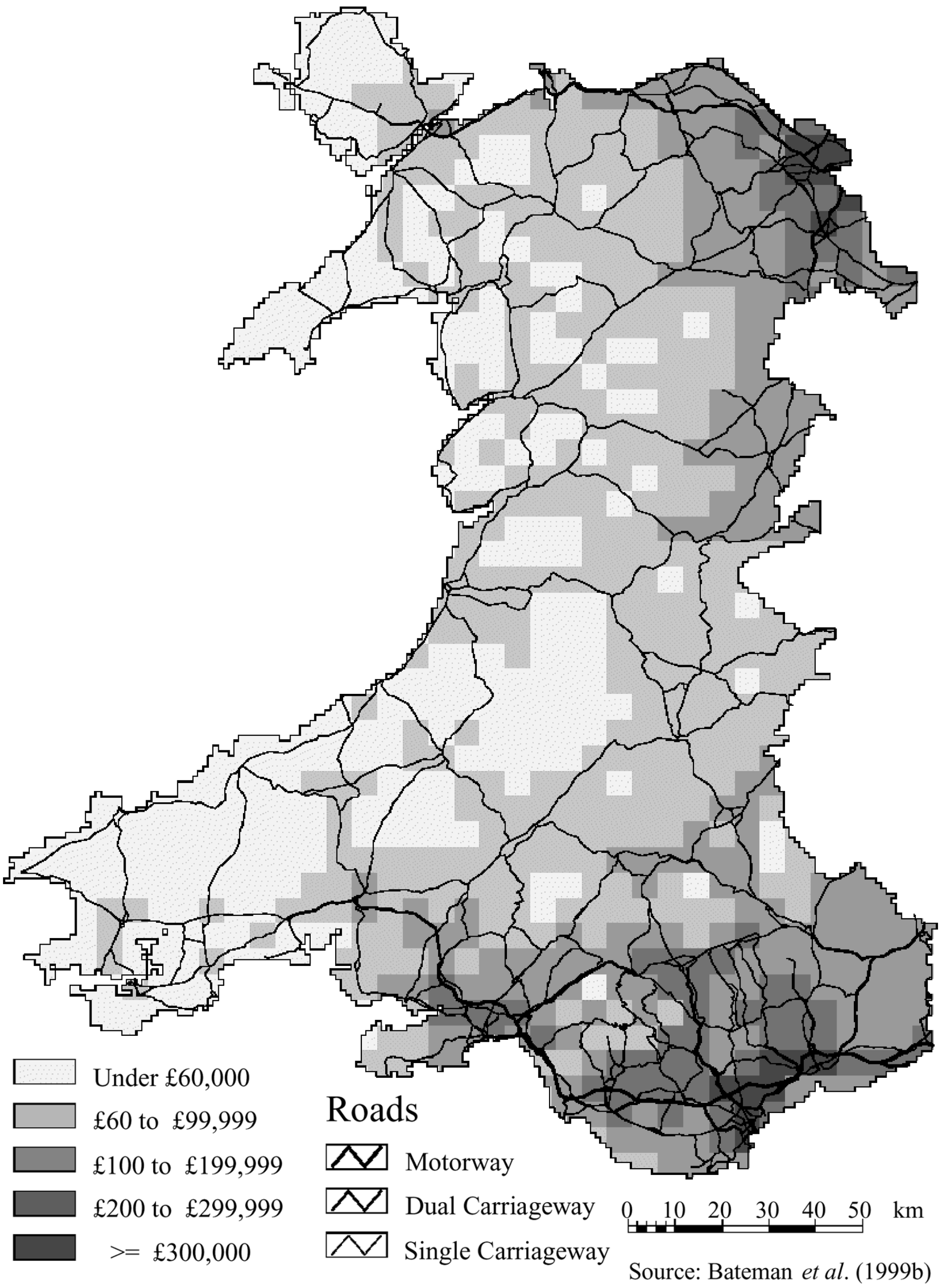



*Figure 6.* GIS generated map of the estimated annual value of predicted visits to woodland recreation demand for potential forest sites in Wales (£ per site per annum).

The methodology set out above was substantially extended by Brainard et al. (1999, 2001) who estimated an expanded travel cost model of woodland recreation and transferred this to 33 other British sites. Starting with the basic arrivals function used previously, road network and population distribution data was again used to define travel time and distance variables. However, these were enhanced with measures of substitute availability, socio-economic characteristics and site quality. Substitute availability was estimated by using the GIS to calculate travel times from a regular grid of potential visitor outset points across much of Britain to all available alternative woodland sites. By applying empirically derived weights to these distance measures and using the GIS to sum the resultant values, indices of substitute availability were created for direct entry within regression equations. Further sensitivity analyses were conducted by taking the location of potential substitute woodlands from a variety of sources including national surveys of outdoor recreation behaviour, digital maps and satellite data. Comparisons of derived measured confirmed that, as expected, they were very similar and that all were, individually, suitable for inclusion within travel cost analyses the results of which readily satisfied prior expectations that visits to a given site were negatively related to the availability of substitutes. Socio-economic data was extracted via the GIS from the UK Census yielding a number of interesting and significant predictors of demand including household age structure and certain deprivation measures. Finally measures of site quality and the availability of facilities (such as car park size) were incorporated and again proved significant and in accord with expectations.

The various techniques developed in the above studies are combined and substantially extended in recent work concerning the demand for informal open-access recreation at inland waterways (Jones et al. 2001).[13] Data for this study were provided from nearly 7,000 face to face interviews with visitors to 53 British Waterways sites located across Britain. Methodological extensions included the consideration not only of similar resource substitutes (other inland waterways, rivers, lakes, etc.), but a wide variety of alternative recreational opportunities including other open-access resources (e.g., National Parks, heathland and moors, woodlands, beaches, etc.), commercial outdoor attractions (wildlife parks, outdoor theme parks, zoos, etc) and built environment sites (such as historic houses, castles, urban attractions). Substitute availability measures were derived as before, an example of which is given in Plate 3.

The left hand panel of Plate 3 shows isochrones for one category of substitute attraction; wildlife parks. The right hand panel of the plate shows isochrones for one possible visitor outset location, being defined as a point on a regular 500m grid covering the whole of Great Britain. By combining the information shown on these maps the GIS can calculate travel times to all possible substitutes within this category. Inverse distance weighting is applied as before to obtain an availability measure for this substitute from the specified outset location. This exercise is then repeated for all of the other substitute types considered in the study. The entire

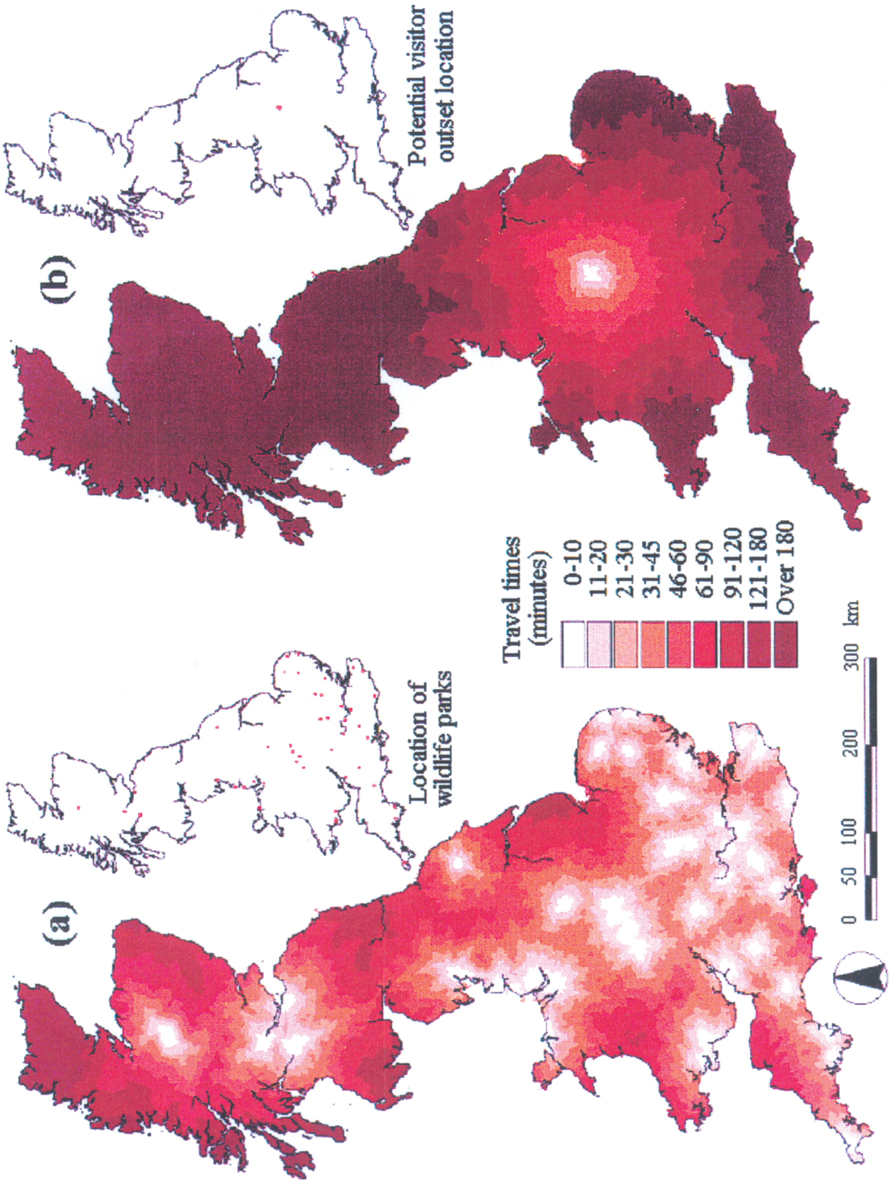



*Plate 3.* Creating substitute availability measures: Isochrones around (a) potential substitute sites and (b) a potential visitor outset location.

operation is then repeated for all other 500 m grid points across the entirety of Great Britain. Such an analysis yields a set of potential predictors which, together with measures of travel time to the waterways sites under consideration, quality measures of those sites, socio-economic predictors, etc., form the basis of our travel cost model of recreation demand. A further refinement was provided by adapting the use of Poisson regression techniques, first applied to GIS-based travel cost data in a single site study by Lovett et al. (1997), and applying these through a series of 'hierarchical' or 'multilevel' models (Bryk and Raudenbush 1992; Longford 1993; Goldstein 1995).

Benefit transfer analysis was conducted by taking subsets of sampled sites from which travel cost functions were estimated and applied to predict arrivals and values at omitted sites. Findings suggested robust relationships determined visit patterns across the country with travel costs to the site being the strongest factor but a host of other determinants proving significant including many of the non-waterway substitutes discussed above (for example, declines in the availability of substitutes such as that described in Plate 3 were associated with increased visitation at inland waterway sites). Significant relationships were also identified for a variety of socio-economic and on-site facility predictors. Comparisons of conventional Poisson models and their hierarchical equivalents showed that the latter provided a significant improvement in explaining the data and were useful in identifying omitted variables which in turn provided further gains in overall fit. The spatial analytic capabilities of a GIS meant that transfer of functions to omitted sites was straightforward and resulted in robust estimates of recreation value and visitation which accorded reasonably well with estimates derived from analyses based solely upon data collected at those sites (e.g., the ratio of observed to predicted visits at the 53 sites considered ranged from 0.63 to 1.72 with a mean value of 1.02 and median of 0.98).

By making available a wide range of consistently measured predictor variables at both study and target sites, GIS techniques provide the ideal tool for the transferral of recreational benefit estimates. However, the general principles set out here are not confined to the study of recreation values alone and in subsequent sections we show how these techniques can readily be applied to the transfer of both market and non-market benefits.

### 4.4. TIMBER YIELD AND ITS VALUE

In the previous section we described a benefit transfer exercise which generated values for woodland recreation across a very wide and diverse study area, the entire country of Wales. As mentioned previously, this area was chosen as the focus of a wider study examining other woodland values. In the following section we consider the non-market value of carbon sequestration generated by woodland while here we show how GIS techniques can be employed to improve the modelling and transfer of market priced timber production values.

Tree growth rates depend upon a variety of species, environmental and silvicultural factors. Early work in this field relied on simple rules of thumb with relatively little supporting data or analyses of single factors. However, from the early 1970s analysts began to undertake studies which combined factors to provide more holistic models of the determinants of timber yield and its value. Nevertheless, until recently these studies were hampered by reliance upon small data sets, typically gathered by the analysts themselves. For example, in the UK prominent studies by Worrell and Malcolm (1990a, b) and Macmillan (1991) drew data from just 18 and 121 plots (known as forest sub-compartments) respectively to produce single species models of timber yield. Furthermore, such datasets frequently lacked variation in those covariates necessary for reliable generalisation of results to other areas. For example, the Worrell and Malcolm studies deliberately selected sub-compartments which were virtually identical in all but elevation.

The application of GIS capabilities directly addresses the issue of data availability and variability and therefore permits the estimation of models which are far more amenable to transfer to unsurveyed locations thereby providing a much more useful tool for the practical forester. Bateman and Lovett (1998) use GIS techniques to combine large scale databases concerning tree growth and its determinants thus permitting a very substantial expansion in the number and variety of observations which can be included within an analysis. This initial analysis took data on over 6,000 sub-compartments across Wales in which the UK Forestry Commission had planted Sitka spruce, the most common commercially grown conifer in the UK. This data provided detailed information on growth rate (known as 'Yield Class') and silvicultural management practices. Information regarding environmental factors such as soil type, elevation, rainfall, etc., was also provided however as this was only held for areas already under forestry this was of little use for estimating transferable yield class functions applicable across the country. Therefore, such data was in the main obtained from the Soil Survey and Land Research Centre's LandIS database (Hallett et al. 1996) which provides uninterrupted coverage for the whole of the country. One omission from this dataset was that of elevation which was obtained through employing the GIS to generate a DEM (see Section 4.2) from a variety of digital map and other data sources.

Yield models were estimated through both standard regression and principal components techniques. Comparison with previous studies in the literature indicated that the very substantial increase in the size and diversity of underlying datasets permitted by GIS techniques had facilitated the estimation of models which were both more robust and much richer than previously reported. Results indicated that growth rates were significantly higher in areas of lower elevation, better soils, high topographic shelter and lower rainfall (Wales is one of the wettest areas of the UK such that waterlogging rather than drought is a limiting factor here). The data covered a 75 year period and significant time series effects were observed with trees performing better in more recent years both because a second rotation benefits from the impact upon soils effected by previous planting and improvements in silvicultural techniques and genetic stock. An interesting opportunity cost was found to be associated with managing trees in a less intensive manner so as to promote more natural woodland areas with non-monoculture sub-compartments, small woodlands and areas left as wildlife reserves yielding lower growth rates. The use of the DEM also permitted inspection of the impact of slope and aspect (i.e., the compass direction which trees face) upon yields. Growth rates were found to be highest for sub-compartments enjoying a south-easterly aspect. This is to be expected as such aspects combine the radiative forcing benefits of the sun while still being protected from the prevailing westerly wind.

By relying upon data for which national coverages were available, the estimated yield class functions could be readily transferred via the GIS to provide estimates of expected tree growth for all locations across the study area. Bateman and Lovett (1998) employ this approach to generate maps of estimated Sitka spruce yield for the whole of Wales. In subsequent work Bateman and Lovett (2000a) extend this approach to produce growth rate maps for beech, one of the most common commercial hardwoods in the UK. These findings are then combined with models of the economic value of timber production under a variety of scenarios (e.g., different discount rate regimes) produced by Bateman (1996). Together these produce maps of the net present value and annuity equivalent of estimated timber yield for both species, that for Sitka spruce being illustrated in Figure 7.

The values given in Figure 7 are strongly in accordance with prior expectations with higher values being recorded in lowland areas away from the ridge of mountains which dominates the central area of Wales. The use of GIS has substantially improved both the modelling process, provided a tool for practical use by forest managers and provided output which can be readily understood be decision makers who may not themselves by forestry experts. However, while the major marketed output of forests, timber values are only one of the value streams generated by multipurpose woodlands and in the following section we consider the application of GIS to assessing one such further value; that of carbon sequestration.

### 4.5. CARBON SEQUESTRATION AND ITS VALUE

Mounting concern regarding global climate change has raised interest in the potential for using forestry as a way of reducing atmospheric concentrations of carbon dioxide (Sedjo et al. 1995; Cannell et al. 1999), the gas which in absolute terms provides the largest contribution to global insulation, and so buying time for the development of long term solutions to global warming. Despite this interest, most analyses of this issue have adopted a number of simplifying assumptions and ignored the spatial dimension which is a major determinant of the degree to which a given forestry investment does or does not sequester carbon. Put simply, some locations are much better than others at storing carbon, while a not inconsiderable minority of locations will result in net carbon liberation if afforested.

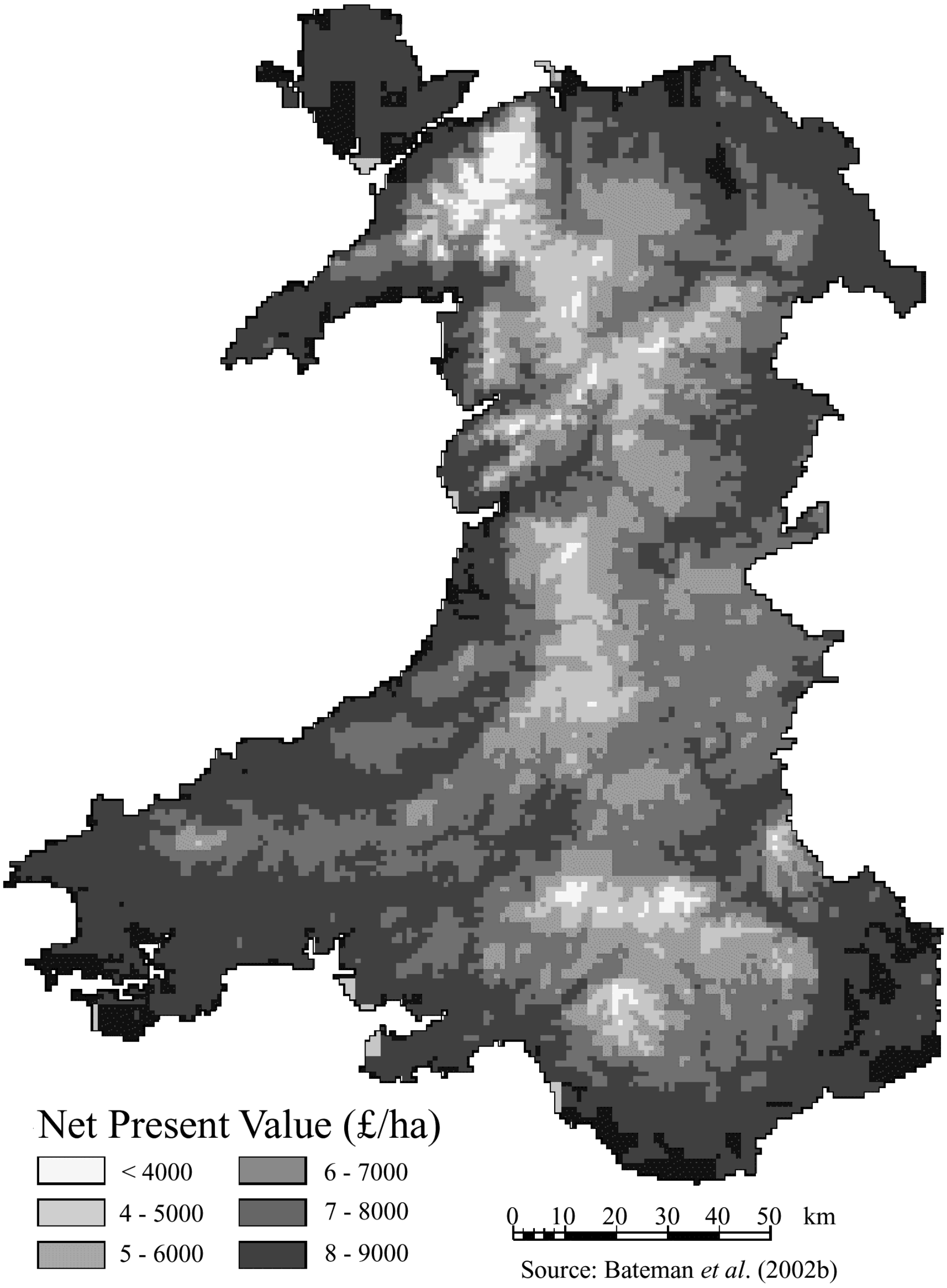


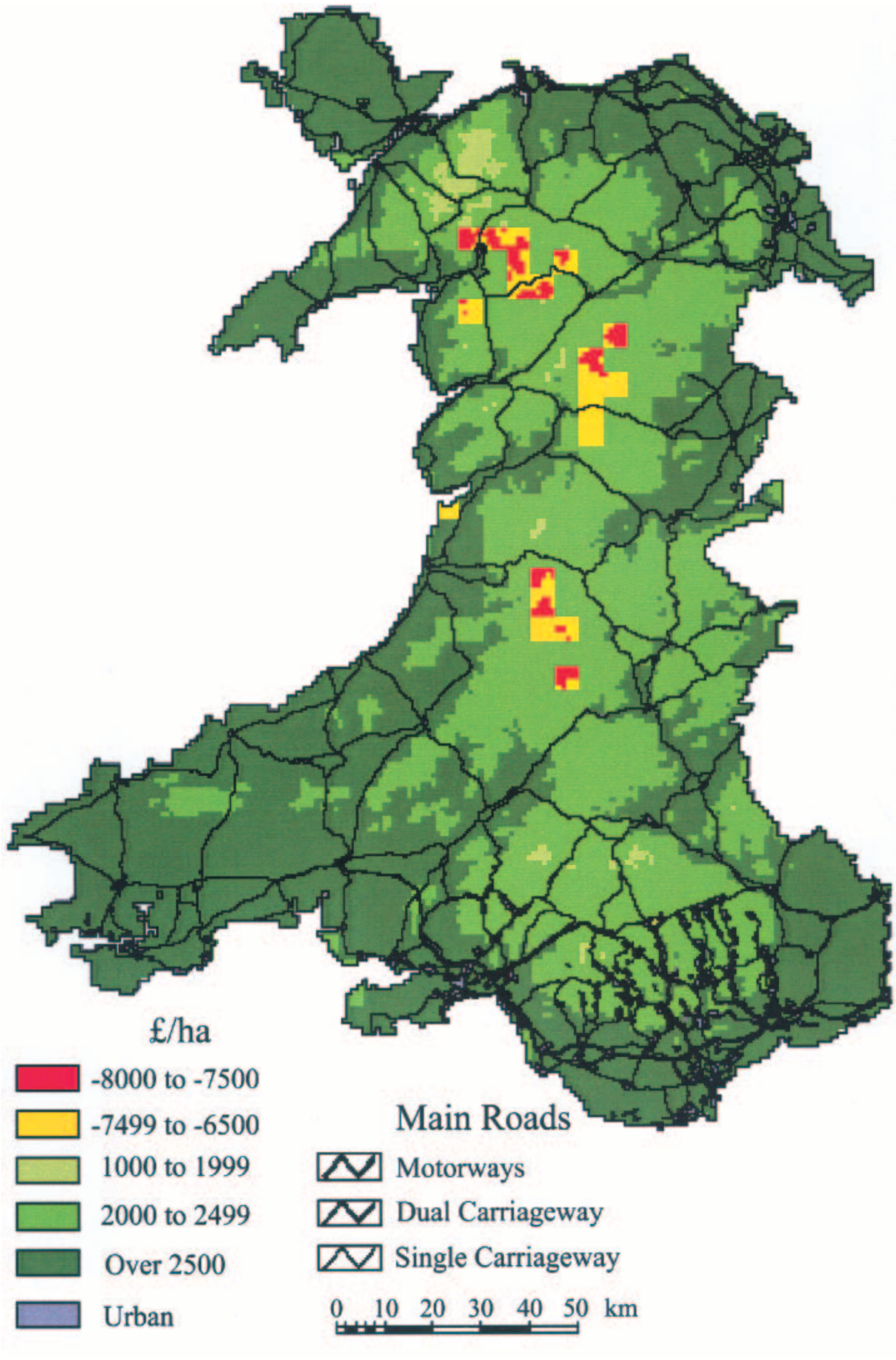

*Figure 7.* Estimated timber values for Sitka spruce (NPV, £/ha, r = 3%).

Bateman and Lovett (2000b) address this issue through development of a GIS based model of the net carbon flux induced by the afforestation of previously unplanted land. The model consisted of three integrated elements: (i) carbon storage in live wood, (ii) subsequent carbon emission from timber products and waste and (iii) soil carbon impacts. Models were constructed for both conifer and broadleaf species and consider a long time period (during which replanting is assumed to follow felling) in order to fully capture the dynamic nature of the processes under consideration. Typical sensitivity analyses such as the impact of changing discount rates were built into the model.

Each element of the model was necessarily complex. For example, the livewood carbon storage element considers not only maincrop timber but also such things as wood thinnings removed early on in a managed rotation, branchwood, and below ground rootwood. Similarly the analysis of carbon emissions from products incorporated the differing enduses and consequent unique temporal liberation profiles of each species. Likewise the soil carbon flux model allowed for the fact that, while afforestation of previously agricultural land typically results in a gradual increase in below-ground carbon storage, the reverse can apply where forests are planted on thick peat soils which are drained as part of the planting process.

Elements (i) and (ii) of the model produced outputs defining carbon sequestration and emission paths for a species / growth rate matrix. These paths could therefore be directly linked to the various species specific yield models discussed in the previous section. The GIS was thus used to combine these outputs and generate maps for the whole of Wales detailing the combined effect of carbon storage in livewood and its liberation from wood products and waste. The GIS was also used to take models of the way in which trees gradually alter soil carbon levels and apply these to digital soil type maps for the country. These various maps of storage and liberation were then combined through the GIS to generate maps of overall net carbon storage. These were then monetised through application of carbon storage benefit estimates provided by Fankhauser (1994) and endorsed by the Intergovernmental Panel on Climate Change (IPCC). Plate 4 illustrates one of the maps generated by this research. In general this reflects the underlying pattern of growth rates revealed in the previous section. However, the most striking difference from the previous distribution occurs in the areas of peat soils, which are in the main concentrated in the upland areas which form the central spine of Wales. Here, soil carbon losses completely overwhelm storage in livewood such that afforestation of such locations results in negative carbon flux values.

Once adjustment is made to a common time period (for example, by taking annuity equivalents and bearing in mind the impact which increased afforestation may have upon the marginal value of each benefit[14]) the valuation maps for carbon flux, timber yield and recreation value can be combined to provide more complete assessments of the overall value of woodland (accepting that this is still an incomplete assessment omitting values such as those associated with biodiversity, etc.) than would be provided by market values alone.




Adapted from Bateman and Lovett (2000b).

*Plate 4.* Net present value of carbon flux for Sitka spruce (live wood, products, waste and soils; £/ha, r = 3%).

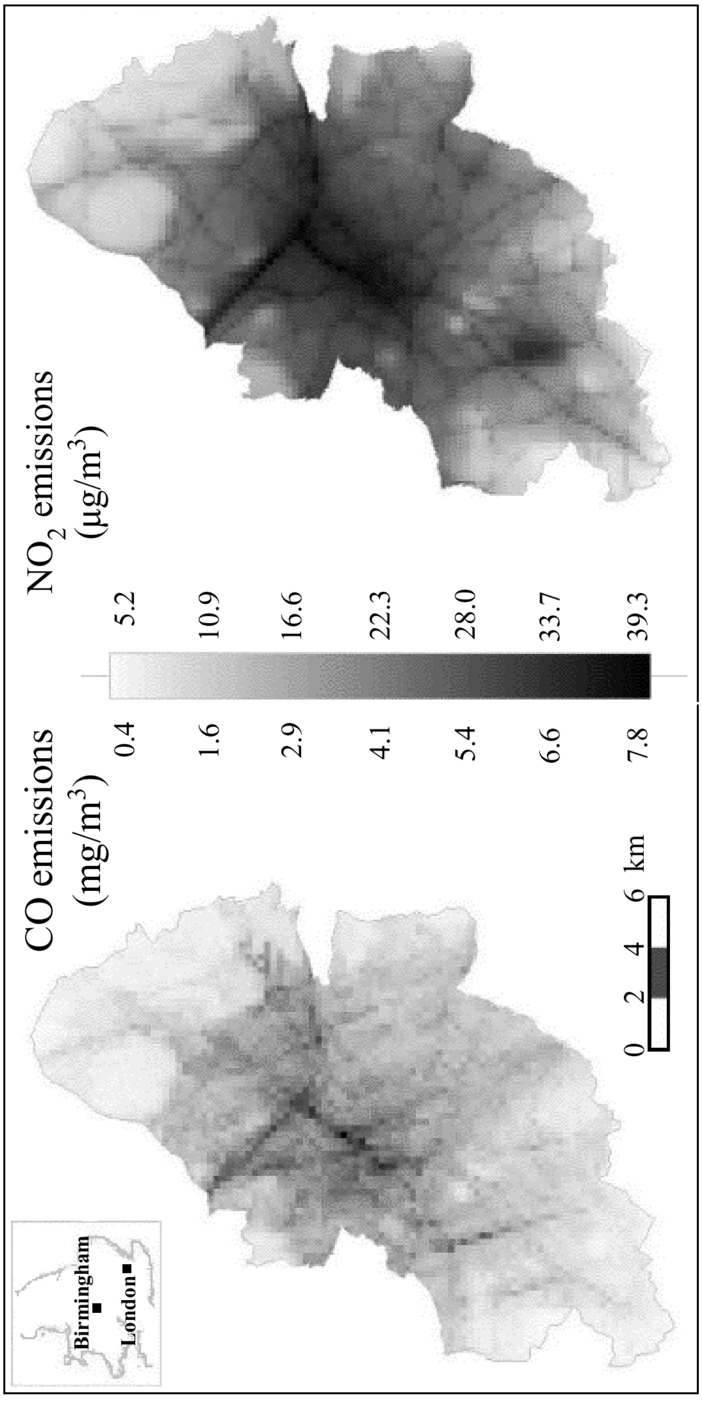
The research described in the preceding sections is extended elsewhere. Bateman et al. (1999c) detail a two-sector, GIS-based benefit transfer model for agricultural values within the Welsh study area. In effect these yield estimates of the opportunity cost of land use change out of farming and into forestry. Bateman et al. (2002b) provide a cost-benefit analysis of all of these various value streams which finds substantial scope for the generation of efficiency gains through such land use conversion. However, from a GIS perspective the techniques used in these analyses are simply further applications of those outlined above. Given this, our last empirical example moves from considerations of efficiency to those of equity.

### 4.6. INCORPORATING EQUITY IMPACTS

The applications discussed above concern the use of GIS techniques to enhance analyses of the economic efficiency of policy decisions. However, GIS methods can also readily be applied to the assessment of the equity implications of such decisions. In particular, a GIS is highly suited to examination of the equality of access of various social groups to different spatially defined assets (or disamenities) such as those provided by the environment (or arising from environmental degradation). Furthermore, the potential exists for using these techniques to examine the trade off between efficiency (which typically relies upon assumptions regarding the optimality of the current distribution of income) and equity. In effect traditional cost-benefit analysis could be modified to permit cost-effectiveness studies of improvements in equity of access to environmental quality.

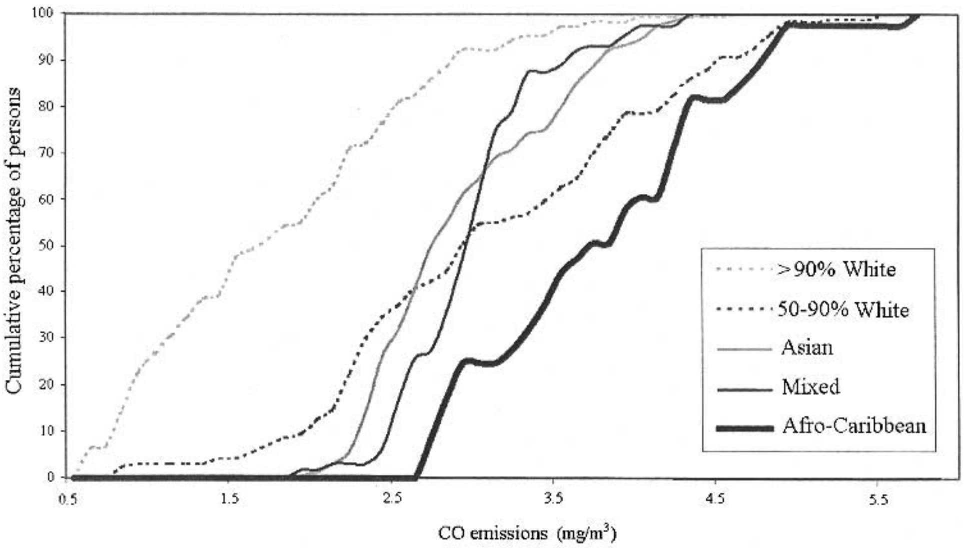
An example of research into the accessibility of environmental quality is provided by Brainard et al. (forthcoming) who use GIS techniques to examine the distribution of air quality measures[15] across the Birmingham conurbation in central England, an area comprising more than 2 million individuals. Information on modelled concentrations of two pollutants, average hourly carbon monoxide (CO) and annual mean (hourly) nitrogen dioxide ($NO_2$), were supplied by Birmingham City Council. The data were generated using a proprietary software package (Airviro, from the Swedish Meteorological and Hydrological Institute), and incorporated information about land use and pollution sources. The model assumed a Gaussian dispersion of pollutants to estimate concentrations at 2 metres above ground level. The resultant output of air pollution measures were initially mapped on a regular grid of 250 $\times$ 250 m cells. However, this relatively course grid embraces significant variation in socio-economic and ethnic mix indicators (extracted via the GIS from the UK Census). Therefore, air pollution measures were interpolated to 20 $\times$ 20 m cells using standard routines within the GIS.

Figure 8 presents GIS derived maps of the spatial distribution of both pollutants across the study area. Both maps indicate higher levels of pollutants around major roads and the central business district although associations with outlying industrial areas can clearly be seen on the $NO_2$ map.




Adapted from Brainard et al. (forthcoming).

*Figure 8.* Modelled emissions of CO and $NO_2$ in Birmingham, UK.




Adapted from Brainard et al. (forthcoming).

*Figure 9.* Cumulative frequency of persons in five ethnic groups with respect to exposure to CO pollution.

The GIS was used to extract pollution measures and various socio-economic and ethnicity indicators for each 20 × 20 m cell across the entire conurbation. Statistical analyses indicated highly significant associations between pollution levels and measures of deprivation and ethnicity. Figure 9 illustrates an association between levels of CO and cumulative frequency of five ethnic groupings. As can be seen, the overall distribution of the non-immigrant, native ethnic group (labelled as '>90% White') enjoys substantially lower levels of CO pollution than does the Afro-Caribbean group.

Further investigation indicated that much of the variation indicated in Figure 9 could actually be attributed to socio-economic factors. However, multiple regression analyses showed that, even after controlling for various deprivation indices, significant associations with some but not all ethnic groupings could be identified. For example, allowing for variation in socio-economic circumstances, age distributions, household size, etc., Afro-Caribbean populations were still significantly more exposed to both CO and $NO_2$ pollution then were other groups, including many of immigrant origin. This suggests that, while both non-immigrant and some immigrant groups are responding to improvements in personal socio-economic circumstances in similar ways (by relocating to lower-pollution neighbourhoods), other groups are less responsive to such improvements. This causes a dilemma for decision makers as it suggests that sole focus upon efficient improvements of incomes and other socio-economic indicators may not lead to evenly distributed improvements in access to environmental quality across ethnic groups. This implies that 'trickle-down' philosophies, assuming that gains in efficiency lead to improvements in equity, need, if not to be rejected, then at least to be qualified. Given this, explicit consideration of the equity implications of CBAs may well be justified.

## 5. Concluding Remarks

As demonstrated throughout our review of the literature and empirical studies, the functionality provided by GIS can considerably enhance the incorporation of spatial issues within applied environmental and resource economics. However, it must be emphasised that a GIS is not a universal panacea for improving data analysis. Indeed, the quality of results obtained depends upon a range of factors common to any quantitative analysis, such as the accuracy of the input information, the appropriateness of the data structures used to store it, and the choice of analytical tools employed. In addition the application of GIS introduces a set of new concerns that include issues of spatial representation and data confidentiality. These matters are significant and warrant some consideration here.

Decisions regarding the appropriate spatial data scale, level of data aggregation, and frequency of measurement must be made at an early point in any GIS analysis (Chrisman 1997). These decisions are not trivial, and indeed may have a significant impact on the manner in which the results ultimately obtained can be interpreted. On a *theoretical* level, the appropriate units for spatial analysis depend upon the questions being asked (Rindfuss and Stern 1998). For instance, issues of population travel and migration tend to turn on the decisions of individuals and households, whilst questions of equity of access to environmental quality may require analysis at the scale of neighbourhoods. Indeed some problems require consideration at multiple scales. For example, enquiries into changes in land-use and land-cover typically require simultaneous information at the level of the individuals and households that may own the land, the local administration bodies that regulate land-use and make decisions concerning infrastructure, and the regional governments that dictate strategic development strategies (Rindfuss and Stern 1998). In *practice* however, the presence of limitations regarding the availability of data often has at least as great influence on the choice of aggregation employed as does any theoretical consideration regarding the appropriateness of different scales.

In cases where remotely sensed data are being employed (such as in our recreation study reported in Section 4.3), the characteristics of the sensing instrument will place the greatest limitations on the spatial scale of analysis, as they will dictate the resolution of the available images and the frequency with which measurements can be made (Ryerson 1998). Recent improvements in civilian satellite systems mean that imagery with a resolution of 10 metres or better is increasingly common, although even at the finest levels there can be difficulties in determining the location of objects such as utility lines and transportation infrastructures, or in distinguishing subtle land-cover differences. Furthermore, from a social perspective, there is certainly no remote sensing unit equivalent to the individual, and households can only be identified from the location of the buildings within which they reside. Where vector data that has been digitised from paper maps is employed, then the scale and detail present will be dependent upon issues such as the precision of the digitising process, the scale of the original maps and their degree of cartographic generalisation (the selective depiction of objectives so as to preserve visual clarity). Hence the topological relationships depicted in the GIS may be a considerable simplification of those present in the real world.

Even in cases where the scale and resolution of data are acceptable, further limitations may arise as many spaces within which social interactions take place cannot be easily depicted in a GIS; cartographic depictions of the real world tend to represent physical entities, not social activity spaces. Whilst some social units, such as urban areas or delineators of land ownership, do have a natural georeferent, the majority do not. For this reason, the delineation of spaces such as communities or neighbourhoods can be problematic. This issue is commonly circumvented by the use of pre-existing aerial units such as census tracts. However, such units have often been developed to expedite local administration activities rather than delineate areas of a particular social character. An alternative and more sophisticated view is to define neighbourhoods based on some measure of mobility. In, say, a developing world setting where the chief economic activity is farming and the primary means of transportation is walking, the delineation of a neighbourhood based on a measure of walking distance may be sensible (Entwisle et al. 1998). However, as modes of transportation evolve to enable travel over ever greater distances, the validity of defining neighbourhoods in this way becomes questionable for many purposes. In the USA the average daily commuting distance is now almost 30 kilometres from home to workplace (Rindfuss and Stern 1998). A question arises as to whether such spatial scales should constitute neighbourhoods. Even in situations where neighbourhoods can be delineated based on travel to work measures, the units generated will undoubtedly contain many individuals who are immobile or are unable to travel more than a short distance from their house. Hence perceived neighbourhoods will be present at a wide range of overlapping spatial scales.

There is rather little understanding of how complex spatial structures such as overlapping neighbourhoods can and should be represented in a GIS. A solution to this problem is to represent features at a highly aggregated scale by depicting large geographical units within which it may be assumed that social activity spaces are more likely to be confined. However, many potentially important process may not be visible at these high levels of aggregation. Issues regarding the abstraction and representation of certain aspects of the ‘real’ world by digital means are by no means unique to GIS; the matters are universal in many kinds of information system (Martin 1996). It must nevertheless be recognised that the assumption that a single objective reality exists and can be measured is a naïve view; the choices made regarding the way in which information will be incorporated into the system will always be grounded in either subjective or arbitrary reasoning. Hence any GIS representation can only provide a selective view of reality.

A second issue for the application of GIS technologies to the field of environmental and resource economics concerns issues of data confidentiality and access to the technology. Remotely sensed data are increasingly becoming available for public use, fostering the ability of researchers to discern in ever more detail the footprints of economically important activities (Rindfuss and Stern 1998). This trend, coupled with the growing availability of socio-economic data that has been disaggregated to small geographical areas (an example being the output of national censuses of population), means that there are increasing opportunities to link observed environmental features such as the change in use of parcels of land, with their social drivers. Whilst this capacity for linkage is undoubtedly opening up many novel research possibilities, it is also generating new conflicts and uncertainties. Although there are some legal precedents regarding privacy rights with respect to high resolution aerial photography, there are many unresolved issues of international law (Morain 1998). Even in countries like the UK that have relatively well defined data protection legislation, it is unclear whether the provision of postcodes constitutes a breach of spatial confidentiality. In the USA concerns have been expressed by landowners that data from remotely sensed images analysed in the research environment could be used to expose confidential information regarding land-use practices, possibly revealing to government officials that those practices are violating land-use regulations (Rindfuss and Stern 1998). In addition to issues of data confidentiality, GIS have been criticised as being undemocratic due to the fact that the technologies and their associated data are generally only available to 'elite' individuals situated in commercial, administrative, and research environments (Pickles 1995). Recent advances, such as the development of internet based GIS solutions may partially redress these concerns. However, the fact remains that, whilst observational research may be somewhat impervious to this analysis, projects involving the development of market interventions or those that may play a direct role in policy formation do carry equity related concerns.

Notwithstanding the above caveats, there is, we believe, very considerable scope for the continuing development of GIS applications in the field of environmental economics. The techniques directly address many of the limitations in data handling and modelling that have restricted previous investigations. As illustrated by the work presented in this article, a wide variety of research papers have been produced using GIS based techniques during the past few years. These exemplify how the functionality provided by GIS packages allows the researcher to incorporate spatial complexity directly within applications. The ability to incorporate detailed isochrones into travel cost studies, to assess what can and cannot be seen from each property in a hedonic pricing study, or to include the aspect angle in models of timber yield, *and* to conduct all of these various assessments in an automated fashion, constitutes a substantial improvement in the data availability and consequent robustness of all such studies.

It is our belief that further advances in the computing power and functionality of GIS packages will stimulate development in further areas of environmental economic research in the future. At the moment one particularly active area of development concerns techniques for the production of virtual reality representations from GIS databases. Such Virtual Reality GIS (VRGIS) systems are beginning to be marketed. These allow the two dimensional output of traditional systems to be transformed into three dimensional 'virtual' environments which can be viewed or explored by users (Fisher and Unwin 2002; Appleton et al. 2002). The development of VRGIS opens up the possibility to convey environmental information in new ways, and may deliver particular benefits in expressed preference techniques such as contingent valuation and choice experiments where such systems could be used to deliver scenarios depicting the likely future states of environmental goods being considered. Furthermore, a current emphasis on the integration of GIS technologies into World Wide Web sites will open up more opportunities for the sharing of both experience and data, and for the design of new survey methodologies that are able to capture much more heterogeneous samples of individuals that it has been possible to include in the past.

This paper has sought to highlight to environmental and resource economists the great potential which GIS techniques offer for incorporating the spatial dimension into applied studies. The diversity of studies discussed illustrates the great flexibility and applicability of such techniques to a range of issues. Such application offers the potential to significantly enhance the ability of economists to successfully incorporate the complexity of the environment within their empirical analyses. Indeed the promise of GIS is to turn the spatial dimension from one to be either ignored or inadequately represented, into a key element of empirical economic investigations of the real world.

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## Notes

1. Examples of statistical packages that have been specifically designed so as to work with GIS systems include S-Plus for ArcView GIS 3.2, produced by Insightful Corporation, and SpaceStat for ArcView GIS, produced by Terra Seer Incorporated. However, GIS data can usually be transferred into other statistical packages not specifically designed to work with a GIS via the medium of ASCII text or D-Base files.
2. Arguably this problem is becoming less prevalent as software, such as Oracle, begin to integrate spatial information.
3. The precise definition is, for our purposes, irrelevant; the issue of interest being that resultant aggregation sums are wholly dependent upon this arbitrary definition of the administrative area.

4. This sample self selection was addressed in a conservative manner by assuming that non-respondents had zero WTP for the good in question (as per Bishop and Boyle 1985).
5. Note also that, as WTP levels are also spatially determined in the GIS based approach so aggregate values will be much less subject to the vagaries of analytical decisions regarding the treatment of valuation responses. Bateman et al. (2000) illustrate this by truncation of the upper and lower 2.5% of WTP responses (i.e. 5% in all). While this resulted reducing aggregate WTP by over one-third when calculated via the administrative area approach, this decline was just 5.5% for the GIS based approach.
6. Details of how these various variables were extracted and prepared using the GIS are given in the various papers cited with the fullest details being given in Bateman et al. (2001).
7. In Scotland this is the 'Output Area' whereas in England and Wales the smallest census unit is the 'Enumeration District'.
8. This noise modelling process has been avoided in our ongoing study of Birmingham, were previously calculated digital maps of road, rail and aircraft noise and air pollution have been obtained via the UK Department for Transport, Local Government and the Regions (DTLR). These data have been integrated via the GIS and each property assigned a value dependent upon its location.
9. Ignoring spatial correlation results in biased estimates of the standard errors of parameter estimates. In the case where the residuals are positively spatially correlated, as is to be expected with hedonic property price regressions, OLS estimators will underestimate the population residual variance and the resulting *t*-statistics will be biased upwards leading to erroneously high significance being attached to the influence of property attributes on selling prices.
10. Tests indicate that significant differences exist between both overall hedonic price functions and selected parameter estimates for these different property sub-markets. Cluster analysis identifies a number of distinct of property types within each sub-market.
11. Further detail of the use of GIS in the examples given in Sections 4.3 to 4.5 are given in the various papers cited with the fullest details being given in Bateman et al. (2002b).
12. There is, as might be expected, an interaction between the accuracy with which the outset origin is defined and the bias noted between straight line and GIS based measures of travel cost such that, where outset origin is derived from large area centroids, there is less difference between these alternative measures of travel cost.
13. The same authors are currently applying similar techniques within an ongoing study of a larger dataset of nearly 14,000 face-to-face party interviews conducted between 1995 and 1998 by the UK Forestry Commission at 159 sites across Great Britain. Results to date confirm the general relationships reported with respect to inland waterways.
14. This is particularly important in the case of recreational benefits where increases in the number of forests will reduce the recreational value of the marginal woodland. This issue is discussed in greater detail in Bateman et al. (2002b).
15. Other GIS-based work by this group of researchers includes analyses of the distribution of noise, open-access recreational areas, health and social services, retailing and banking facilities, etc.

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