

The Integration and Analysis of Historical and Environmental Data using a Geographical Information System: Landownership and Agricultural Productivity in Pembrokeshire c 1850*

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Abstract

Historical maps and documents, such as census returns, estate plans, tithe maps, rent rolls and court rolls, have traditionally provided fundamental data sources for historians. This paper concentrates on the integration of environmental data with such historical sources and their subsequent analysis using a GIS. It demonstrates that the scale and range of enquiries that are made possible by such a methodology increases with the application of the new tools that GIS provides. Although the study concludes by suggesting that the application of GIS is not itself unproblematic, it argues that the work presented does illustrate the potential value of GIS in offering a new dimension to agricultural history research.

IN THEORY, a geographical information system (GIS) offers a simple and exploitable set of analytical tools that provides archaeologists and historians with the opportunity to advance the study of past societies in relation to their cultural and physical environments.¹ It has the capacity to interrelate and integrate spatially referenced data as map overlays and to facilitate the description, manipulation and analysis of these maps and the creation of new data as new map overlays. This paper aims to explore its potential through the analysis of landownership as a factor in mid-nineteenth century agricultural productivity at Newport, Pembrokeshire. A tithe map lies at the heart of the analysis, and it is the integration of this source with topographical data supplied by the Ordnance Survey that demonstrates the integrative

capabilities of GIS software. Analysis of the results is performed using multi-level modelling, a statistical technique that offers enormous potential for future studies of similar nature.

There is no universally accepted definition of GIS. It is most commonly used as a collective term for a suite of individual components or modules that carry out a variety of functions on spatial data. Clearly, definitions depend on the context within which a GIS is operating. Inevitably, one has to qualify the definition of GIS according to the unique hardware and software capabilities available to the study. For the purposes of this study we can view the GIS as an agglomeration of components including a single GIS package (*sensu stricto*) coupled to statistical and cartographic capabilities brought together under the loose heading of GIS (*sensu lato*).

The main software requirements were met by Environmental Systems Research Institute's (ESRI) ARC/INFO as it possesses sufficient data input, digitizing, editing and analysis capabilities for the initial

* The authors wish to thank the following for their kind assistance during the production of this paper: Professor Kelvin Jones and Dr Myles Gould for help with the multilevel modelling; Cordula Bietzker, Paul Carter, Rut Galmeyer, Karen Parsons, and Rosemary Shearer for the production of maps.

¹ S H Savage, 'GIS in archaeological research', in K M S Allen, S W Green, and E B W Zubrow, eds, *Interpreting Space: GIS and Archaeology*, 1990, pp 22-32.

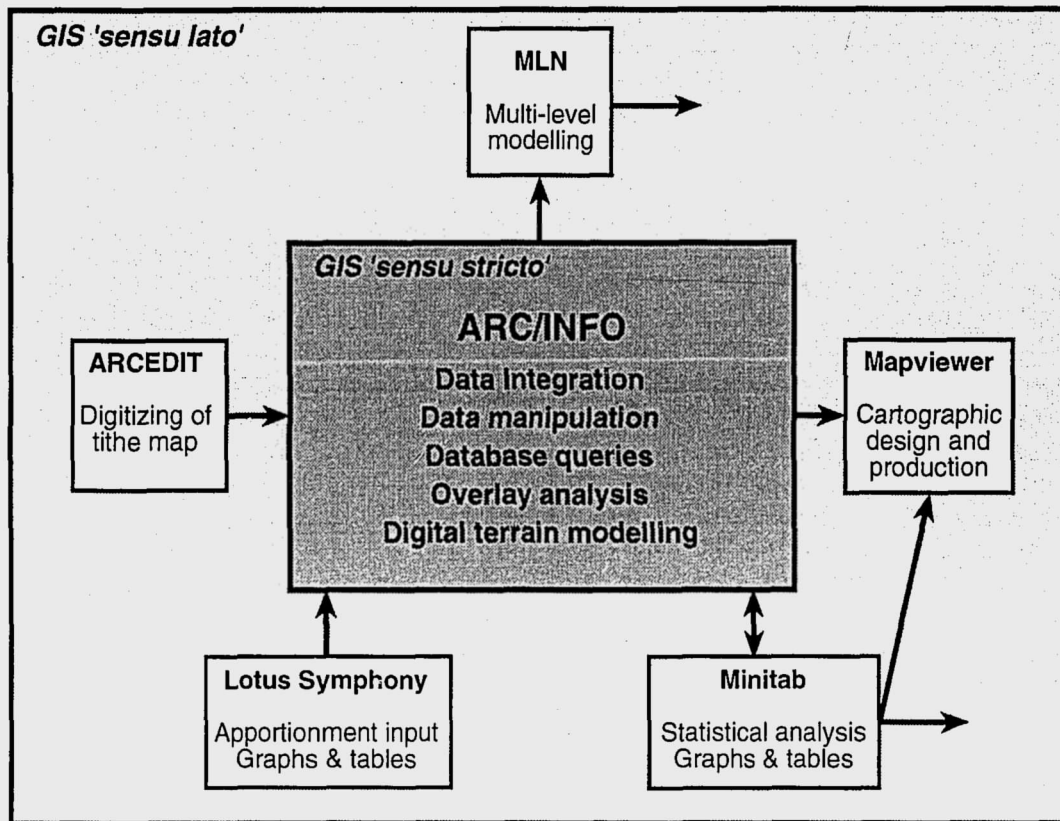


FIGURE 1

Components of the geographical information system, *sensu lato* and *sensu stricto*.

map production and exploratory analysis. ARC/INFO is one of the most widely used systems in the world, being ubiquitous in higher educational establishments, and lay at the heart of most linking components that made up a larger 'system' used for the purposes of this study. The GIS (*sensu lato*) was formed by 'loose coupling' ARC/INFO and the packages used for data capture and processing, statistical analysis, multi-level modelling and cartographic design (Fig 1). The final database consists of a set of layers that includes tithe, soil, topographic and census data (Fig 2).

The parish of Newport represents Pembrokeshire in microcosm. It is a small coastal village with a sandy beach situated midway between Cardigan and Fishguard. Though located in the heart of the Welsh-

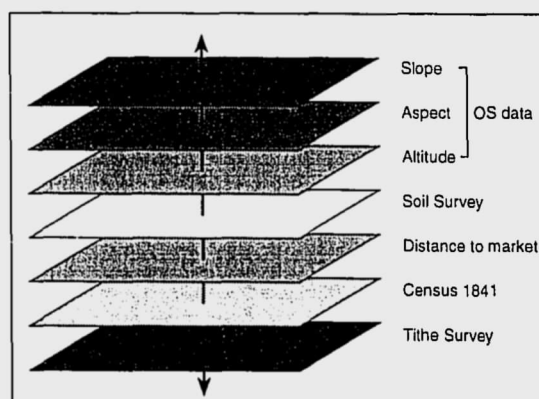


FIGURE 2

Layers within the database. Each layer can be handled separately or combined with other layers.

speaking area of north Pembrokeshire, the village's roots are Norman. Mynydd Carn Ingli, with its formidable hill fort, commands a central position within the parish and indeed appears to have been at the hub of human activity in the area for at least 2500 years.² An open field system of farming was established with Mynydd Carn Ingli remaining an important element, providing communal grazing and a source of fuel for a section of the population. Newport thus offers an engaging history and a stimulating location for the researcher keen to study the interaction of society, nature and place from prehistory to the present day.

I

Tithe maps are an important source for the agricultural historian and have claims to be regarded as the most comprehensive record of the agrarian landscape of any period. Several authors provide a comprehensive description and analysis of tithe maps as a data source.³ Detailed treatment of tithe maps as a data source is therefore not necessary here. However, some consideration of the tithe survey of Newport and its likely accuracy is appropriate.

There is nothing unusual about the tithe survey of Newport. The rent-charge was awarded by the commission and then apportioned field-by-field and a large-scale map and apportionment roll prepared. The maps were made with sufficient accuracy to enable the parties to identify the lands which were subject to rent-charge.⁴ The

absence of the tithe commissioner's seal identifies the map as a second-class tithe map.⁵ It was common practice to compile this class of map from existing sources such as estate plans or parish maps. We must, therefore, be wary of using the tithe map for any other purpose than for reference.

Scrutiny of the tithe file that accompanies the map and apportionment confirms that the implementation of the Tithe Commutation Act followed the guidelines as laid down by the commission. The files provide some reassuring evidence that the survey was carried out by local people who were familiar with the farming practices of the area. Henry Phelps Goode, the tithe surveyor and valuer, was conscious of the variable quality of the land and concerned that this be reflected in the global tithe rent-charge. We can only assume that similar sensitivity is shown in his apportionment of the tithe rent-charge on a field-by-field basis. We must accept, however, that any analysis of the state of cultivation and the productivity of the land as indicated by the tithe rent-charge must ultimately rest on this assumption. The surveyor and valuer were primarily concerned with the survey and allocation of rent-charges within the parish. It is unlikely that they contemplated the information from a geographical point of view. Many of the maps in this paper, derived from the tithe data, are in a form that the surveyor never saw himself. When we consider the pattern of rural settlement as revealed by the tithe surveys, we should be mindful that they were never intended to support such analysis.

II

The tithe map and accompanying apportionment offer a source that is com-

² These findings are discussed in detail by A W Pearson, 'Carn Ingli circa 1500BC to AD1845: the application of Geographical Information Systems to the study of settlement development at Newport, Pembrokeshire', unpublished University of Portsmouth PhD thesis, 1996.

³ R J P Kain and H C Prince, *The Tithe Surveys of England and Wales*, 1985; E J Evans, *Tithes: Maps, Apportionments and the 1836 Act*, Chichester, 1993; H C Prince, 'The tithe surveys of the mid-nineteenth century', *AHR*, 7, 1959, pp 14-26; and H M E Holt, 'Assistant commissioners and local agents: their role in tithe commutation', *AHR*, 32, 1984, pp 189-200.

⁴ BPP, 1837, VI, *Report from the Select Committee on Survey of Parishes (Tithe Commutation Act) with minutes of evidence*.

⁵ An unexpected error appears in the declaration on the tithe map: 'We the undersigned Tithe Commissioners for England and Wales do hereby certify this to be the map or plan referred to in the apportionment... in the Parish of Newport in the County of Radnor' (PRO, IR 30 54/100): right parish, wrong county!

patible with the vector GIS model. As the tithe map consists of field boundaries with unique field numbers that relate to the same field numbers contained within the apportionment, GIS offers the possibility of simply linking the two elements and enabling the display of the apportionment data. Taken further, the tithe map can form the spatial and temporal anchor point to which other data sources, such as the census and topographic data, can be added.

Preliminary investigations of the tithe map and current Ordnance Survey maps showed that the field boundaries had changed little between 1845 and the present day. As a result, the latest Ordnance Survey 1:10,000 scale maps were selected as the most suitable base map to digitize. The relative high accuracy of the positions of field boundaries and the convenience of being able to use the National Grid were advantages that far outweighed any thoughts of digitizing the photocopied reproductions of the tithe map provided by the National Library of Wales. All spatial data could be recorded using the same co-ordinate system for the sake of consistency and compatibility. However, it must be underlined that the digital tithe map is not a 'true' representation of the original document.

Field boundaries on the 1:10,000 Ordnance Survey maps were input using ARC/INFO digitizing module and a pen plot produced on film to the same scale as the tithe map. Editing of the plot to match the tithe map was carried out using simple graphical techniques. The apportionment information on owner, occupant, field name, state of cultivation, acreage and tithe rent-charge were entered into a spreadsheet during the map production phase.

One of the immediate benefits of having the tithe data in a GIS is the ability to display the data. Varying the classification intervals, colour sequences and adjusting scale are no longer time consuming and

error prone tasks. Information on the 'state of cultivation', tithe rent-charge and land tenure can be displayed very effectively.

Figure 3 therefore provides a very clear though not necessarily reliable picture of the distribution and pattern of agricultural land use as classified in the 'state of cultivation' column in the apportionment. A summary of statistics is provided in Table 1 for the main cultivation types as contained within the apportionment. Examination of the land use is made difficult by the broad definitions of land use given by the commission to the tithe surveyors and also the subsequent variations in their interpretation of them. What constitutes 'arable' or 'pasture' varied from place to place and differs from modern interpretations. As Kain and Prince warn, 'Although what tithe valuers recorded as arable may not have been what modern surveyors would record as arable, we may be fairly sure that it was what local contemporaries would have understood by the term'.⁶ According to the commissioners, those lands that were ploughed within the previous three years for crops or fallow were to be classed as arable. Those lands not ploughed were to be classed as grass. Kain and Prince provide substantial evidence of potential pitfalls in interpreting arable land use, particularly in the west of England and Wales. Here, long-leys pastures are often classed as arable. They indicate 16 different definitions adopted by William Hoskins, an assistant tithe commissioner for Pembrokeshire, used to describe long-leys in Pembrokeshire. As a result significant tracts of land are classed as arable even though they may be ploughed only once in 10 years. What constitutes 'pasture' or 'arable' is therefore not unequivocal. The distinction between permanent grassland and rotation grasses is also not clear-cut. This varied from surveyor to surveyor. These deficiencies must

⁶ Kain and Prince, *Tithe Surveys*, p. 140.

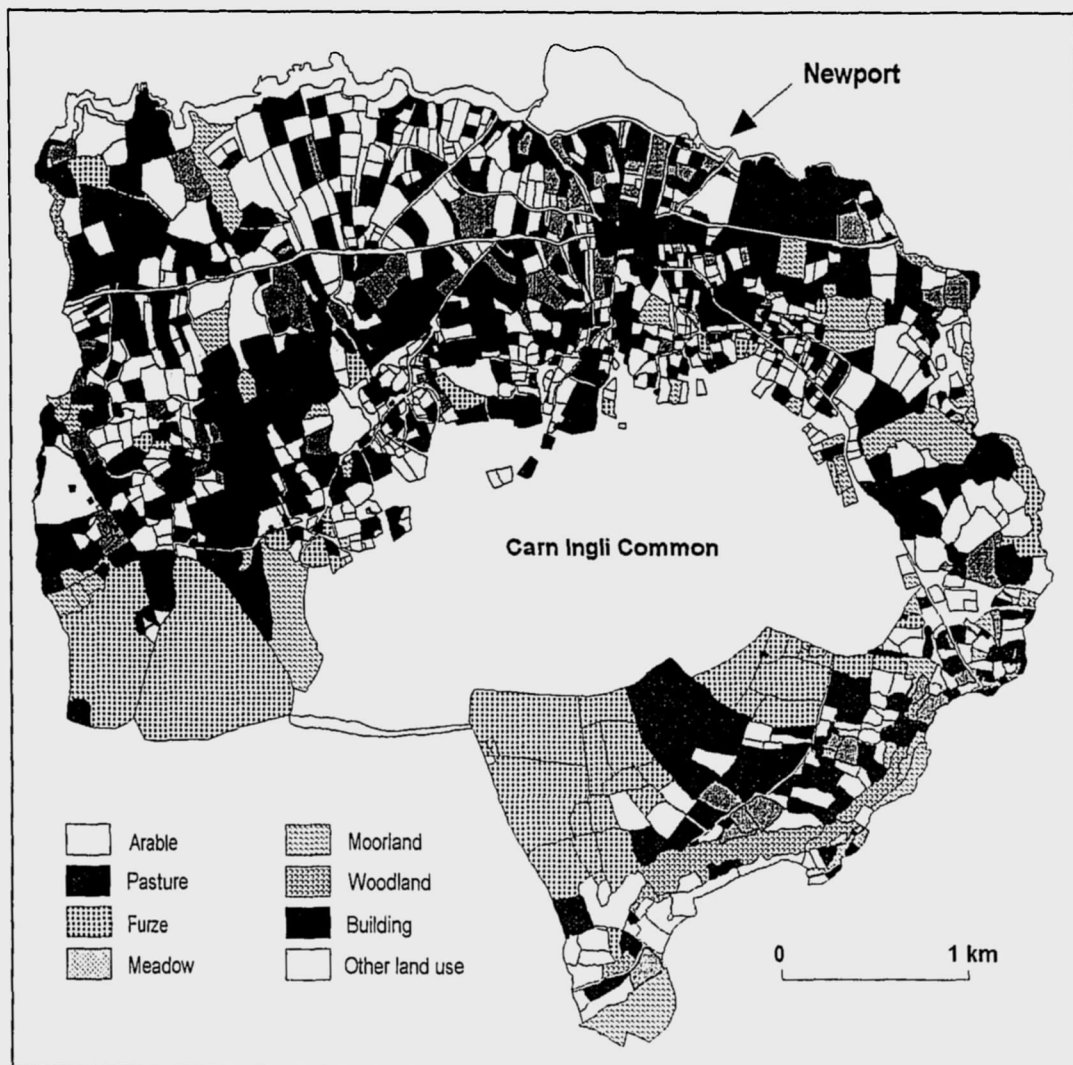


FIGURE 3
State of cultivation as recorded by the tithe survey.

be borne in mind when we consider the land use map.

The most striking feature of the map is the large tract of common land that provided grazing for the commoners of the parish. The vast majority of the common land is contained within the area known as Carn Ingli Common at the centre of the parish. Given its central location and sheer size, the common would have been an important feature of the agricultural practices of the parish.

III

The possibility that the tithe rent-charge might be used as an indicator of agricultural productivity was considered by Chiplen in his study of the rural landscape of Blackmore Vale in Dorset.⁷ He suggested that the variations in tithe rent-charges appear to be very closely related to soil fertility and detailed maps on a field-by-

⁷ R. F. J. Chiplen, 'The rural landscape of the Blackmore Vale circa 1840', unpublished University of Exeter MA thesis, 1969.

TABLE 1
Summary statistics for selected land use types

Land use type	Fields	Acreage	Percentage land use
Arable	496	797.75	17.32
Common	7	1223.74	26.57
Cottage	30	28.69	0.62
Furze	19	45.03	0.98
Garden	21	4.16	0.09
House	109	64.40	1.40
Meadow	89	210.57	4.57
Moory pasture	51	202.20	4.39
Pasture	474	1117.57	24.26
Pasture/furze	23	309.61	6.72
Wood	12	84.36	1.83

field basis showing rent-charge might prove a useful exercise and indicate areal differences. Subsequent research has tended to concentrate on the use of the tithe file data in order to determine the broad pattern of agricultural productivity at the county scale. Gambier assessed the value of using the tithe rent-charge as a measurement of agricultural production using Dorset as her case study area.⁸ Tithe data is viewed as particularly significant as there are few other sources for measuring agricultural production before 1866.

The overarching assumption is that the apportionment of the tithe rent-charge varied according to the productivity of the land. As there is no contemporary evidence to corroborate the tithe rent-charge, it is difficult to prove that this was in fact the case. However, there is sufficient anecdotal evidence from the tithe file for Newport and tithe files examined elsewhere by Gambier that productivity was a very important factor in affecting the rent-charge levels. At Newport, the assistant

tithe commissioner and several valuers make reference to the varying state of cultivation within the parish, most notably the poor state of cultivation on land recently enclosed from the common. Reference is also made to the poor condition of the roads and that this should be taken into account in the assistant commissioner's calculations of the tithe rent-charge. However, though these variations in the quality of the land were noted during the deliberations on the global tithe rent-charge for the parish, we have to assume that the apportioning of the rent-charge to individual fields was conducted with similar consideration for variations in land quality. Mistakes by apportioners did occur as the apportioners and valuers were working sometimes under extreme pressure.⁹

A map of the tithe rent-charge per acre is provided in Figure 4. The areas recorded in the tithe apportionment have been used for the calculation of the rent-charge per acre. The pattern of rent-charge does confirm at least that the apportionment of rent-charge was not random. The common, where no tithe was levied, is clearly distinguishable at the centre of the parish. In addition, the map clearly shows a marked decay in rent-charge per acre with increasing distance from Newport. The decline is sharpest to the south of the settlement and more gradual from east to west. Pockets of higher rent-charge are evident towards the western edge of the parish and to the south of the common where the small settlements are all isolated from Newport.

Figure 5 shows the rent-charge for arable and pasture land for samples taken every 100 m along a transect from the western edge of the parish to the town of Newport running parallel to the main Newport to Fishguard road. Each sample consists of the average rent-charge for pasture and arable

⁸ J R Gambier, 'Tithes, tithe commutation and agricultural improvement: a case study of Dorset c 1700-1850', unpublished University of Exeter PhD thesis, 1990; and J R Baker (formerly Gambier), 'Tithe rent-charge and the measurement of agricultural production in mid-nineteenth century England and Wales', *AHR*, 41, 1993, pp 169-75.

⁹ Evans, *Tithes: Maps, Apportionments*, p 23.

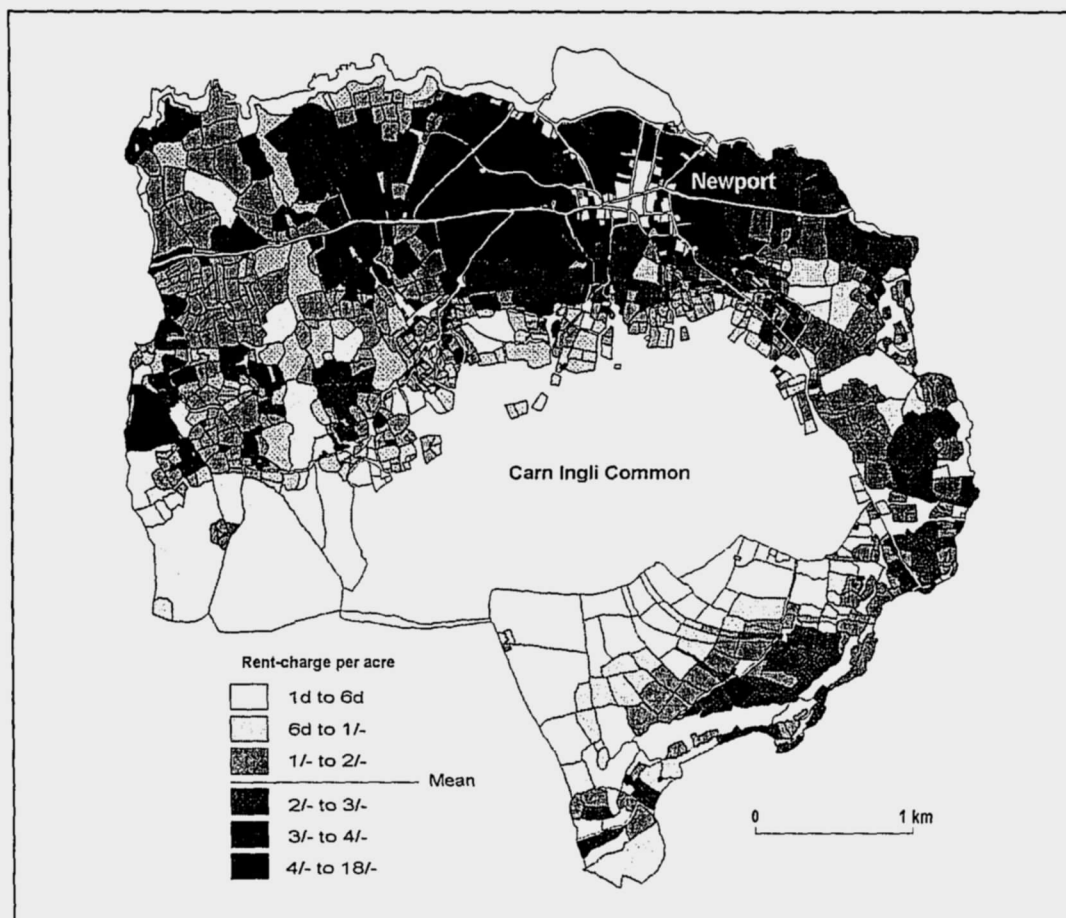


FIGURE 4
Tithe rent-charge per acre.

land use categories for an area 100 by 500 m. It clearly shows that both arable and pastoral land uses at least double in tithe from west to east towards Newport. At this stage it is tempting to suppose that this trend of distance decay is largely determined by the distance of fields from the labour supply and market provided by Newport. However, such an assumption does not take into account environmental and cultural factors.

IV

Landowners typically include a wide range of people from the landed proprietors to

yeomen or freeholders with farms to let or farmers occupying their own farms. By the time of the tithe survey of Newport the vast majority of the land was owned by a few individuals (Figs 6, 7a and 7b, and Table 2). The apportionment lists 73 landowners, but the majority of the land (93 per cent) is in the hands of only 13 owners.

We are fortunate that the histories of the two important families in this part of Wales, the Lloyds of Bronwydd and the Bowens of Llwyngwair, are well documented.¹⁰ Both Thomas Lloyd and

¹⁰ P B Morgan, 'Bronwydd and Sir Thomas Lloyd', *Nat Lib Wales Jour*, 23, 1983, pp 377-403; F Jones, 'Bowen of Pentre Ifan and Llwyngwair', *Pembrokeshire Hist*, 6, 1979, pp 25-57.

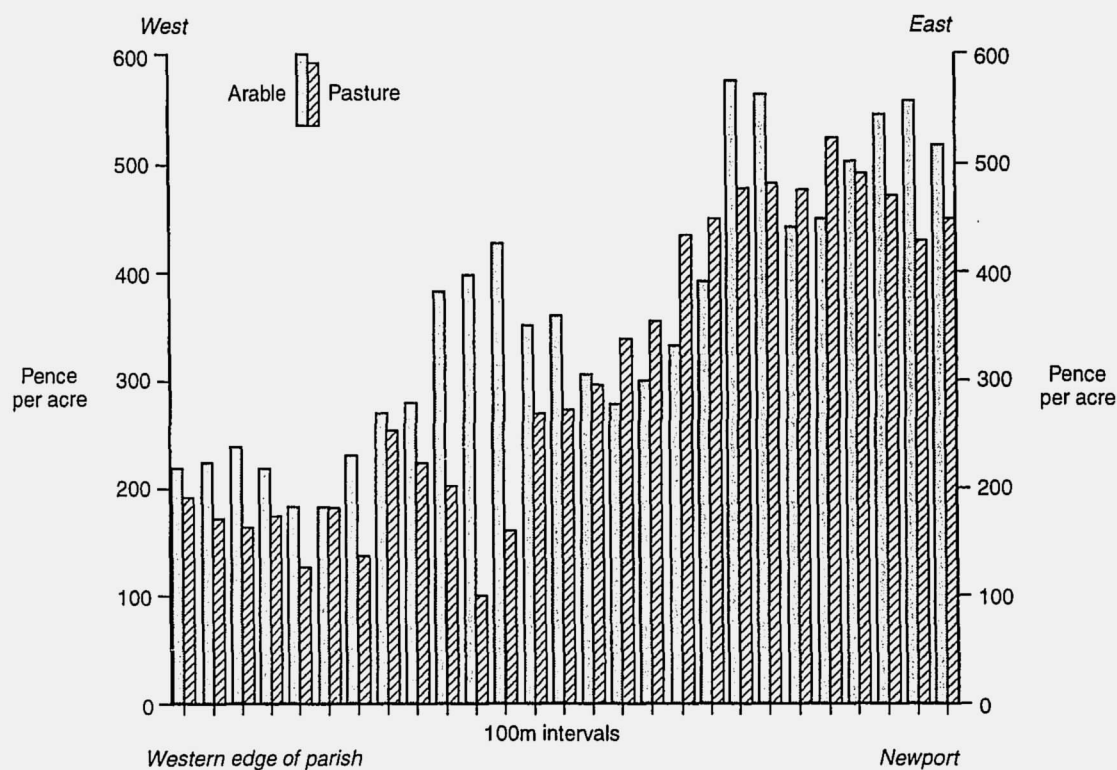


FIGURE 5

Tithe rent-charge per acre along a transect from the western edge of the parish to the edge of the village of Newport.

TABLE 2
Number of fields, total acreage and percentage of land owned by those owning more than 1 per cent

Owner	Fields	Acreage	Percentage
Common (Thomas Lloyd)	8	1223	26.5
George Bowen	445	1259	27.3
Thomas Lloyd	372	335	7.3
Esther Bowen	74	249	5.4
Revd Daniel Davies	29	239	5.1
Lady Mathias	47	185	4.0
Revd Peter Richardson	24	154	3.3
David Hughes	39	151	3.2
Richard Lobant	42	143	3.1
William Harries	65	81	1.8
Benjamin Evans	41	77	1.7
Trustees of Llanglofan Chapel	23	76	1.7
Revd Llew Lloyd Thomas	31	54	1.2
William Morgan	29	53	1.2
Others	331	327	7.1
Total	1569	4606	

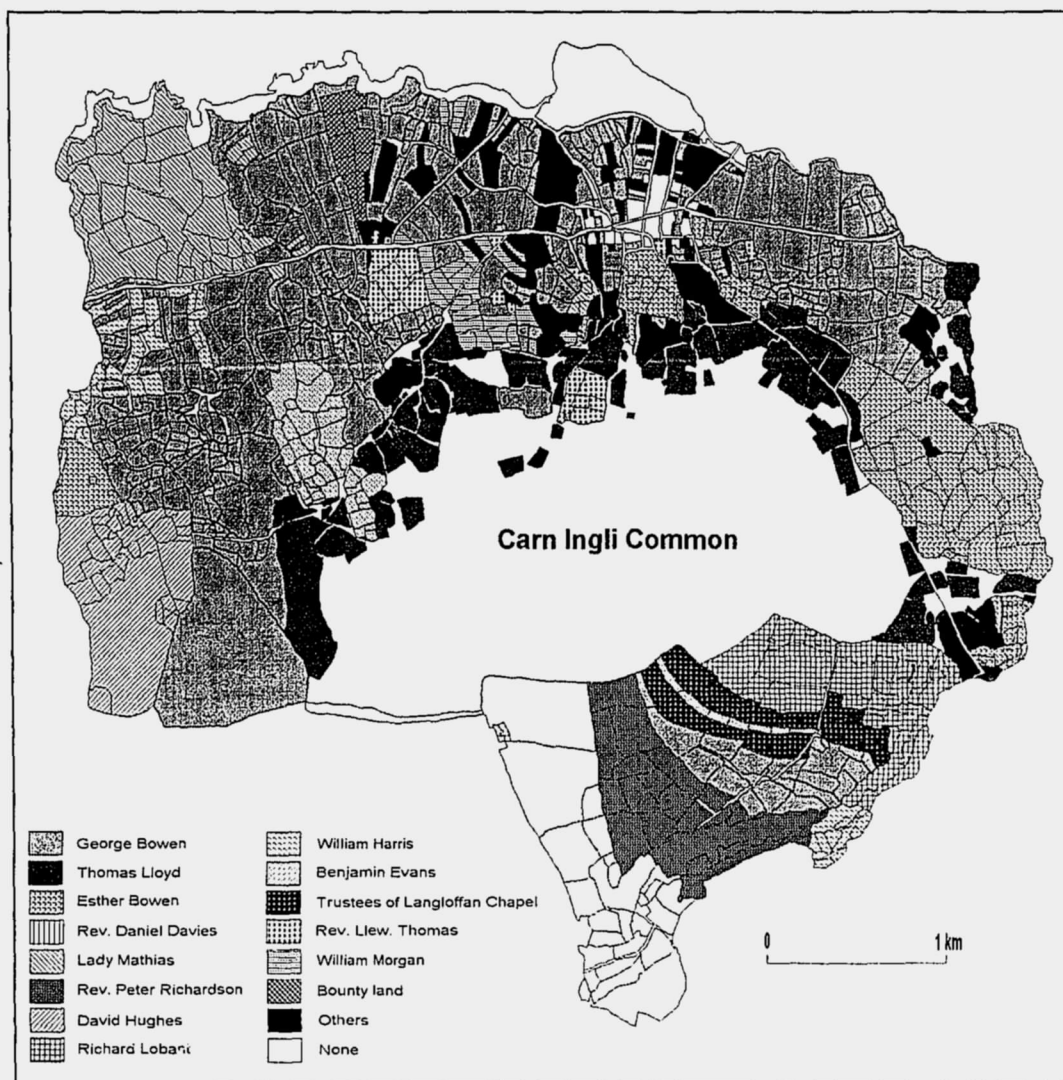


FIGURE 6

Landownership as recorded in the tithe survey.

George Bowen were reputed to be active promoters of new agricultural practices. George Bowen has been described as one of the leading agricultural improvers in the last quarter of the eighteenth century.¹¹ He was well known as an improving landlord and particularly keen to introduce fertilisers

and experiment with the use of seaweed for enriching the soil. He acquired a special machine for grinding bones into powder which he added to seaweed and marl and spread this mixture over the fields 'with most beneficial results'.¹²

Some insight into the mentality of the more typical Pembrokeshire farmer is pro-

¹¹ D W Howell, 'The economy, 1660-1793', in B E Howells, ed, *Pembrokeshire County History; Volume III: Early Modern Pembrokeshire*, Haverfordwest, 1987, pp 299-332.

¹² Jones, 'Bowen of Pentre Ifan', p 52.

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¹⁴ Ibid.

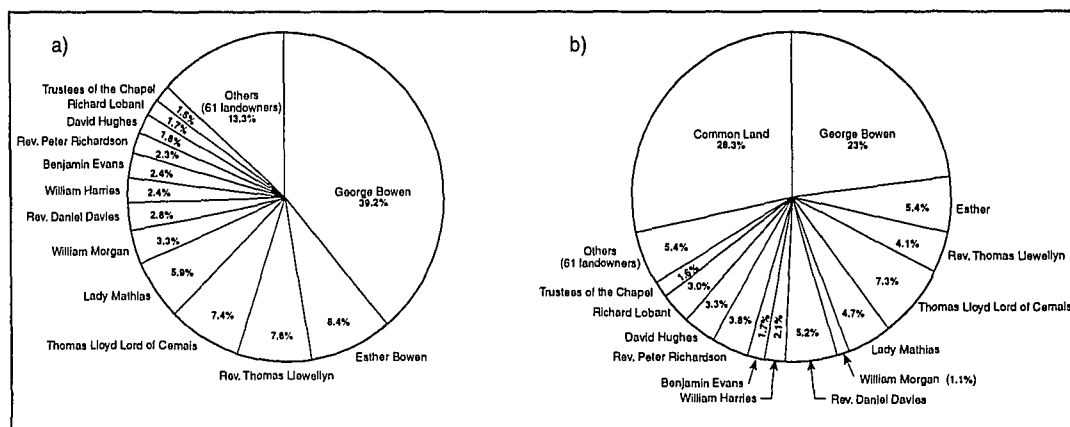


FIGURE 7

A. Percentage of total rent-charge per landowner, B. Percentage of land owned per landowner.

vided by an illuminating description by Sir Charles Hassall in 1794. He writes on the rotation of crops:

He sows as his own sagacity and caprice dictates, and generally turns his fields out of tillage when he finds by sorrowful experience it will not return him crop enough to pay his expenses. Sometimes he begins with a fallow, then limed and dunged, for wheat.

barley.

oats, or barley.

barley again, or oats.

oats

oats

and ends in weeds and disappointment.¹³

Furthermore, Hassall describes the Welsh plough and is certainly not impressed:

this is intended to turn the furrow, which it sometimes performs, sometimes not; so that a field ploughed with this machine, looks as if a drove of swine had been moiling in it.¹⁴

One can sense a certain amount of frustration on the part of Hassall with the prejudice that pervaded the Pembrokeshire farmers against anything new and particularly against adopting English fashions lest their neighbours laugh at them. Though the farmers were aware of new techniques

of improving the soil, very few actually implemented them. There are strong grounds perhaps to condemn the conservative nature of the mid-nineteenth century Welsh farmer who was deeply suspicious of innovation. However, the climate and soil conditions generally operated against the growing of heavy root crops in western Wales. Moreover, many small farms were semi-subsistence by nature and the introduction of a basic four-course rotation would reduce by half the amount of arable land devoted to the production of directly consumable food. The high cost of growing turnips and the worry of the crop being destroyed by turnip fly further discouraged its introduction.¹⁵ Some idea of the soil conditions faced by the farmers at Newport is provided by John Johnes, the assistant tithe commissioner, in his letter to the Tithe Commission on 2 February 1844. Enclosures fringing the common were described as:

very small, that boulders are now to be seen in many instances through the corn, that they grow potatoes, barley-oats generally, that oats are put in as a first crop sometimes, they manure for potatoes or peat and burn, that the cultivation is chiefly

¹³ Sir Charles Hassall, *General View of Agriculture in the County of Pembroke with Observations on the Means of its Improvement. Drawn up for the Consideration of the Board of Agriculture and Internal Improvement*, 1794, p 16.

¹⁴ *Ibid*, p 18.

¹⁵ R. J. Colyer, 'Crop husbandry in Wales before the onset of mechanization', *Folklife*, 21, 1983, pp 49-70.

manual on the common on account of the large stones.¹⁶

Newport provides a fascinating contrast in terms of its physical characteristics and geographical location to those areas of eastern England noted for agricultural improvements. Theoretically, if there were areas that lagged behind in terms of agricultural improvement then the parish of Newport would be one of them. It is geographically remote from major urban centres and has an average altitude of 97 m (318 ft), with some 41 per cent of the parish above 200 m. It has a mild but wet climate. The soils are predominantly acidic due to the high rainfall and acid parent rock making the seaborne limestone, burned locally, important. The agricultural potential of the land is further restricted by frequently strong salt-laden winds blowing in from Cardigan Bay.

Though the agricultural revolution may not have had the same effect in south-west Wales as it did in England, some of the landlords did attempt to make improvements by land consolidation, promotion of turnpike trusts and enclosing wastes. Employing better farming techniques on the home farm and the support of agricultural societies were attempts to encourage emulation amongst tenants and other neighbouring farmers. If this was the case it is interesting to examine whether we can detect any variation between holdings in terms of their agricultural productivity when all available physical constraints are equal. Theoretically, land of similar potential should not vary significantly in tithe rent-charge from landowner to landowner or occupant to occupant if the same agricultural practices were being carried out. Conversely, if there are variations in rent-charge, can we interpret these variations as due to variations in farming practices? If we compare data for agricultural land within the parish we may gauge the relative

influence of owners and occupants by building a multilevel model. Prior to this we need to integrate topographical information within the data set in order to take into account factors such as altitude and slope.

V

Ordnance Survey provided the necessary altitude data. This data consisted of a grid of height points at an interval of 50 m for an overall area of 10 × 10 kms. The altitude, slope and aspect values were calculated and then averaged for each field. Clearly, the method of integrating the height data had introduced a variable amount of generalization for each of these variables that depended on the size and topographical characteristics of the field. Nevertheless, given that the tithe data (ie, state of cultivation and tithe rent-charge) were also generalized observations, it was felt that such a smoothing in the data was compatible with the tithe data and the aims of the analysis.

Given the apparent distance decay of the tithe rent-charge from Newport the Euclidean distance from the centre of each field to Newport was calculated using ARC/INFO. Other data sets were added to the database. The final data set includes both the soil survey data for the area and the Census Returns for 1841.¹⁷

VI

The need to recognize hierarchical data structures where they exist has been the main catalyst in the development of multilevel modelling. In the past it would have been necessary to decide whether to carry out statistical analysis at the level of the owner or at the occupant or field level. In the case of the tithe data, ordinary regression analysis would require that mean

¹⁶ PRO, IR18/14707.

¹⁷ The soil data and census returns, though part of the GIS, were not used in the final statistical analysis in this instance.

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values would be calculated for each landowner and environmental factor. Ordinary regression would be carried out to estimate the relationship between mean landowner productivity and mean environmental conditions relating to each landowner's area. Any interpretation of the results cannot take into account the individual occupants and the variations between individual fields. In a field-level analysis an average relationship between tithe rent-charges would normally be estimated using data for all 1568 fields and the variation between landowners would be modelled by using separate terms for each landowner. Such a procedure is inefficient, and inadequate for the purpose of generalization. Conventional multiple regression is viewed as inefficient as it involves estimating many more coefficients than the multilevel procedure and does not recognize that the landowner's fields are a random sample and provides no information about the variation in the underlying population of occupants.

School education can be used as an appropriate example of a population with a multilevel structure. The education system has a typical hierarchical structure with pupils learning in classes, classes being taught within schools and schools being administered by education authorities or school boards. Such a system fits a multilevel structure with pupils assigned to level 1, classes to level 2, schools to level 3 and authorities to level 4. Units within one level are viewed as being nested within units at the next highest level. Each of these levels may be a factor in determining the performance of a child. We would assume that it is at the level of the individual pupil that most of the variation can be explained and that the impact of the other levels will decrease as one goes up the hierarchy. Multilevel analysis would give us an indication of the statistical significance of each level on the performance of the child. Similarly, taking our tithe survey, the level-1 units can be viewed as individ-

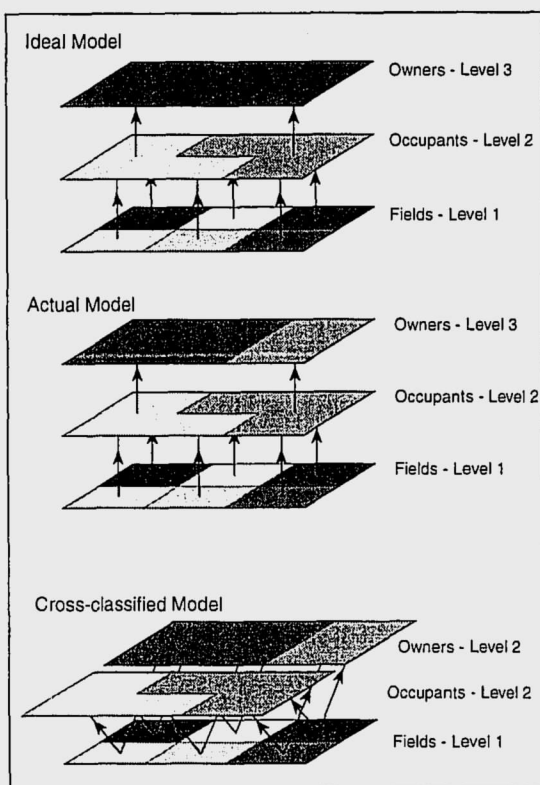


FIGURE 8

Ideal, actual and cross-classified multilevel models. Note that the ideal model differs from the actual model in that occupants are not perfectly nested within owners.

Some occupants rent land from more than one landowner thus making the cross-classified model appropriate.

ual fields that nest into two sets of overlapping level-2 units, that is occupants and owners, forming what is known as cross-classified multilevel structure as demonstrated in the following analysis (Fig 8).¹⁸ If we are to measure agricultural productivity as indicated by the tithe rent-charge per acre we have to examine how this structure affects the measurement of interest. Theoretically, if landownership affects the level of productivity, then tithe rent-charges should vary between landowners. This means that occupants of land owned by the same landowner should be

¹⁸ H Goldstein, 'Multilevel cross-classified models', *Sociol Methods and Research*, 22, 1994, pp 364-75; *idem*, *Multilevel Statistical Models*, 1995.

TABLE 3
Results of multilevel analysis

	Model 1 Estimate (standard error)	Model 2 Estimate (standard error)	Model 3 Estimate (standard error)
Fixed Terms			
Constant	1.72	1.73	1.75
Logged acres	-0.24(0.01)	-0.26(0.01)	-0.26(0.02)
Height	-0.002(0.000)*	-0.002(0.000)*	-0.002(0.000)*
Slope	-0.007(0.001)	-0.005(0.001)	-0.006(0.001)
Distance	0.00003(0.000)*	0.00004(0.000)*	0.00004(0.000)*
Mixed arable	-0.06(0.03)	-0.06(0.03)	-0.06(0.03)
Buildings	0.11(0.02)	0.10(0.02)	0.11(0.02)
Other land use	-0.10(0.03)	-0.10(0.03)	-0.12(0.03)
Clover	0.02(0.05)	0.02(0.05)	0.02(0.05)
Furze	-0.47(0.04)	-0.48(0.04)	-0.46(0.05)
Meadow	0.18(0.02)	0.18(0.02)	0.17(0.02)
Moor	-0.26(0.03)	-0.24(0.03)	-0.23(0.03)
Pasture	-0.03(0.01)	-0.04(0.01)	-0.05(0.01)
Mixed pasture	-0.24(0.05)	-0.28(0.05)	-0.29(0.05)
Random Terms			
<i>Level 1: Field</i>			
Variance: constant	0.034(0.001)	0.04(0.001)	0.034(0.002)
<i>Level 2: Occupants</i>			
Variance: constant	0.008(0.002)	n/a	0.005(0.002)
<i>Level 2: Owners</i>			
Variance: constant	n/a	0.005(0.002)	0.004(0.002)

* Denotes a standard error estimated to less than three decimal places.

more alike, on average, than occupants of other owners' land. A key aim of this part of the analysis is to determine whether certain landowners are more effective than others in promoting agricultural productivity, taking into account variations in the environmental conditions of the land.

The results of multilevel analyses were estimated using the *Mln* software package.¹⁹ Table 3 provides summary statistics for the model. Model 1 is a two-level model where fields (level 1) are nested within occupants (level 2), whereas fields are nested within owners (level 2) in Model 2. Both models include a number of predictors (logged acreage, height, slope, distance from Newport and land uses) in an attempt to explain the logged tithe rent-charge as used for exploratory single-level

regression models. The constant is allowed to vary at both levels one and two,²⁰ and thus two variances are estimated for both models: fields and occupants in Model 1, and fields and owners in Model 2. The estimates for all the fixed terms in Models 1 and 2 are statistically significant²¹ with the exception of the estimate for the contrast term for field under clover, and stable for both models.

It is the interpretation of the random terms that is important. The variation in tithe-rent charge between occupants is estimated as 0.008 in Model 1 and as 0.005 for owners in Model 2. These level-2 variations are both considerable and statistically significant. It is worth noting that

¹⁹ J Rasbash and G Woodhouse, *Mln Command Reference - Version 1.0*, London, 1995.

²⁰ K Jones, 'Specifying and estimating multi-level models for geographical research', *Trans IBCG*, 16, 1991, pp 148-60.

²¹ Using a pseudo-Z test (Jones, 'Specifying and estimating multi-level models').

there is greater variation in rent for occupants (Model 1) than that for owners (Model 2), and accounts for 19 and 11 per cent respectively. However, the majority of the variation (over 80 per cent) is associated with individual fields in both cases.

In an attempt to assess *simultaneously* the contribution of both sets of level-2 units (that is occupants and owners), a cross-classified 2-level multilevel model was also fitted. The fixed terms associated with the level-1 predictors in Model 3 are almost exactly the same as those estimated for Models 1 and 2 and can be interpreted in exactly the same way. It is the estimates associated with the random terms of Model 3 that are interesting. The variation in rent associated with fields (level 1) is estimated as 0.034 and is the same as that estimated for Model 1 and close to that for Model 2, and accounts for 79 per cent of the total variation in the tithe-rent. The estimated variance for occupants (level 2) and owners (also level 2) are close in value (0.005 compared to 0.004), with 12 per cent of the total variation in rent-charge being associated with occupants and 9 per cent being associated with owners. There is a considerable (three-eighths) reduction in the variation in rent-charge between occupants having fitted the cross-classified model (Model 3 compared to Model 1). In conclusion it appears that variations in tithe-rent is greater and more considerable for occupants than owners having allowed for a number of level-1 predictors in the fixed part of models. It seems that the occupant rather than the owner provides a slightly greater source of contextual variation in the tithe rent-charge as one would expect. The occupant does appear to be an influential level suggesting that the holdings varied in their success at coping with environmental conditions.

It is difficult to draw too many conclusions from such statistical analysis given the rather narrow geographical extent of

the study area. However, the results are given some credence by Howell's observation that in Pembrokeshire the efforts of the larger landowners were probably largely unsuccessful: 'Furthermore, it may have been that the minor gentry and those large freeholders and tenant farmers below them did most to advance the techniques of agriculture by dint of patient trial and error'.²² Expansion of the study area to neighbouring parishes would clearly improve the validity of the results and help to identify the varying success of farmers in adapting to the physical conditions of the area.

VII

It is important to appreciate that no single GIS (*sensu stricto*) is necessarily going to provide all requirements. The research carried out here necessitated the transfer of data from one package to another using interchange files. Conversion programs tended to be necessary when moving and transferring graphics data. It is perhaps possible to view ARC/INFO as merely a storage device performing an inventory role. However, though it undoubtedly fulfilled this role, it performed many tasks that were specific to its capabilities. Analytical and integration functions that are generally viewed as distinctive features of GIS, such as reclassifying attributes, dissolving boundaries, merging polygons and topological overlay, were indeed vital to the study. Yet it is the broad functionality of GIS using the broader definition (*sensu lato*) that offers the greatest potential to the historian. The integrative power of ARC/INFO combined with the statistical modelling capabilities of Mln provides enormous scope for similar studies elsewhere.

The success or failure of the application of GIS to this type of study depends on

²² Howell, 'The economy, 1660-1793', p 315.

the willingness of the researcher not to forsake the traditional methods and techniques appropriate to the analysis of a diverse range of sources. Though methodologically eclectic, adopting a broad landscape approach in combination with the analytical power of GIS offers a formidable overarching methodology for studying the past. It is easy to see GIS packages as magic boxes where speed, consistency and precision are impressive. Its graphic quality is certainly difficult to resist. Perhaps it is

wise, however, to adopt the philosophy that as our experience with GIS matures, we realize that GIS should become simply an extension of one's own analytical thinking. After all, it has no inherent answers, only those of the analyst and as Eastman suggests: 'It is a tool, just like statistics is a tool. It is a tool for thought'.²³

²³ J R Eastman, *IDRISI Version 4.0 User's Guide*, Worcester, Mass, 1992, p 32.

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Abstract
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