CHAPTER 16

WHP CASE STUDIES IN VISIBILITY AND FRICTION*

Two of the case studies presented here were originally developed in the context of the study of Romanisation and urbanisation in the Wroxeter Hinterland, an area centring on the modern-day village of Wroxeter in the middle Severn valley (Shropshire, UK); the third case study arose from my work on the methodology of ‘cognitive landscape’ analysis presented in chapter 6 of this thesis. All three are presented here together not just because they cover the same geographic area, but also because the GIS techniques on which they are based – line-of-sight and friction modelling – are related and tend to be used for answering related archaeological questions (for a full technical discussion of these techniques and questions and a review of the relevant literature, see chapter 6). For an introduction to the Wroxeter Hinterland Project, see chapter 3 of this thesis; aspects of centralisation and Romanisation in the Wroxeter hinterland have been sketched elsewhere by White and Van Leusen (1997) and again by White and Barker (1998).

1 VISIBILITY AND CONTROL

Some aspects of the Iron Age – Roman transition within the territory of the Cornovii can be modelled using only the highest-ranked settlements of either period. Cornovian society, especially in the later pre-Roman Iron Age, is thought to have become increasingly sophisticated and to have been dominated by an aristocracy based on control over land, livestock, and mineral resources (especially salt). The Wroxeter hinterland is well supplied with hillforts (some 40 in all if we include the ones that lie just outside the WHP study area; most are presumed to date to the Iron Age although only a few have been investigated), which has been taken to indicate that the tribe was politically fragmented and was organised in clans around chiefs. However, an alternative view now takes ground (White & Barker 1998:36) that the hillforts are expressions of conspicuous consumption in a society that had few other outlets for its wealth. Whichever the case may have been, certainly the hillforts would have functioned as places of refuge and control, and viewsheds from these hillforts may therefore tell us something about systems of control and defence in the pre-Roman Iron Age.

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* These case studies were prepared in 1996-7 as part of the Wroxeter Hinterland Project (WHP), directed by Vince Gaffney at the University of Birmingham Field Archaeology Unit (BUFAU). They are based on pre-Conquest digital site data supplied in December of 1996 by Ms Penny Ward of the Shropshire County Council on the basis of the Shropshire Sites & Monuments Records. The data were subsequently checked and enhanced for the WHP by my colleague Roger White. I am particularly grateful to Dr Gaffney, who set out many potential lines of research for me to follow and who himself with a student developed models for the urban resource landscape around Wroxeter (Goodchild 1999). It should be noted that visibility/accessibility modeling has moved on since these case studies were first conceived, and chapter 6 should be consulted for more recent work in this area. Also note that DEM interpolation artifacts, visible in figures 16.3 to 16.6 as stripes or ‘steps’, have not been removed before the analysis. To implement a decision as to whether sites should be visible in these areas, the individual viewshed maps can be put through a simple neighborhood filter.
The indigenous ordering of the landscape of Britain was upset from the middle of the 1st century AD by Roman military encroachment. The land of the Cornovii was first invaded by the Romans by the end of the 40s (AD), and the tribe seems to have come to terms with the conquerors without putting up significant resistance. While the main Roman force arrived in Cornovian territory north of the Wrekin, a smaller force may have followed the Severn valley from the southeast and put up a vexillation fortress on the Severn at Leighton just south of the Wrekin; archaeological evidence indicates that the Wrekin hillfort was attacked and taken from there. Several temporary campaign forts were constructed in the area of Wroxeter, which controlled the main routes across the Severn, in the following years. One of these is an auxiliary fortlet on the Severn just south of Wroxeter which may have secured the main Severn crossing; by the mid-50s the legionary fort at Wroxeter itself was established, probably by Legio XIII Gemina from Mancetter (Warwickshire). The early Roman military strategies may be studied via viewshed analysis of both the vexillation fort at Leighton, the legionary fortress at Wroxeter itself, and the auxiliary fort to its south. As the legionary fortress developed into a town and civil civitas capital after 30 years of predominantly military use, its viewshed may tell us much about its impact within a landscape that had never seen such a population centre before.

1.1 IMPLEMENTATION

We have prepared a similar analysis for the WHP area by regrouping the traditional types of hillforts and multivallate enclosures into more meaningful sets of large (over 2 hectares) and small (less than 1.5 hectares) multivallate enclosures (see table 1; for a more detailed discussion see section 2 on cost surface analysis).

Table 1: 21 multivallate enclosures of the Wroxeter Hinterland, ordered by size. PRN: Primary Record Number. Source: Shropshire County Council.

<table>
<thead>
<tr>
<th>PRN</th>
<th>Name</th>
<th>Situation</th>
<th>Enclosed area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1108</td>
<td>Wall Camp</td>
<td>marsh</td>
<td>very large (14)</td>
</tr>
<tr>
<td>1357</td>
<td>Castle Ring</td>
<td>hilltop</td>
<td>large (3.8)</td>
</tr>
<tr>
<td>113</td>
<td>Ebury Hillfort</td>
<td>low hill</td>
<td>large (3.6)</td>
</tr>
<tr>
<td>129</td>
<td>The Berth</td>
<td>marsh</td>
<td>large (3.1)</td>
</tr>
<tr>
<td>1438</td>
<td>Stevenshill</td>
<td>promontory</td>
<td>large (3)</td>
</tr>
<tr>
<td>1050</td>
<td>Earls Hill Camp</td>
<td>hilltop</td>
<td>large (1.4), with annexe (1.6)</td>
</tr>
<tr>
<td>1069</td>
<td>Wrekin camp</td>
<td>hilltop</td>
<td>large (2.6)</td>
</tr>
<tr>
<td>226</td>
<td>Caer Caradoc</td>
<td>hilltop</td>
<td>large (2.6)</td>
</tr>
<tr>
<td>357</td>
<td>The Ditches</td>
<td>hilltop</td>
<td>large (2.4)</td>
</tr>
<tr>
<td>60</td>
<td>The Burgs</td>
<td>low hill</td>
<td>large (2.1)</td>
</tr>
<tr>
<td>135</td>
<td>Haughmond Hill camp</td>
<td>hilltop</td>
<td>large (2)</td>
</tr>
<tr>
<td>1087</td>
<td>Nesscliff Hill Camp</td>
<td>hilltop</td>
<td>small (1), with annexe (1)</td>
</tr>
<tr>
<td>2000</td>
<td>Hurley Brook rect. enc.</td>
<td>no hill</td>
<td>small (1.2)</td>
</tr>
<tr>
<td>1055</td>
<td>Pontesford Hill Camp</td>
<td>low spur</td>
<td>small (1.1)</td>
</tr>
<tr>
<td>3970</td>
<td>-</td>
<td>no hill</td>
<td>small (0.75)</td>
</tr>
<tr>
<td>1740</td>
<td>Nills Hill</td>
<td>low spur</td>
<td>small (0.4)</td>
</tr>
<tr>
<td>1048</td>
<td>Callow Hill Camp</td>
<td>hilltop</td>
<td>small (0.4)</td>
</tr>
<tr>
<td>2418</td>
<td>Bomere Heath</td>
<td>no hill</td>
<td>small (0.25)</td>
</tr>
<tr>
<td>1256</td>
<td>The Lawley, north</td>
<td>hilltop</td>
<td>very small (0.15)</td>
</tr>
<tr>
<td>472</td>
<td>Cotwall No. 1</td>
<td>low hill</td>
<td>very small (0.15)</td>
</tr>
<tr>
<td>2828</td>
<td>&quot;British Camp&quot;</td>
<td>no hill</td>
<td>unknown</td>
</tr>
</tbody>
</table>

Adding the viewsheds of sites within these two groups to obtain the cumulative viewsheds (see figures 1 and 2), it is clear that the areas most intensively viewed are all in the central upper Severn valley and its main tributaries, with the maxima occurring on the western side of the Severn. These results are mildly helpful in interpreting the results of the Thiessen polygon calculation, which argue for a system in which three pairs of hillforts are spaced along the main basin, dominating opposite sides of it (see section 2). The site of Wroxeter is in fact very near the point where four of these territories meet, making it 'neutral territory'. As it is also near one of the main Severn fords, we suggest that this location was well suited to function as a (periodic?) trading post/market/fair, and forms a logical precursor to the legionary fortress and town.
Figure 1:cumulative 15 km radius viewsheds of large multivallate enclosures (red diamonds) on shaded DEM overlain with major streams and Roman road system (white lines). 8 by 1 km box in the centre of the study area indicates zone which cannot suffer from edge effects. In this and all further figures, grid spacing is 10 kms unless otherwise stated.

Figure 2: cumulative 15 km radius viewsheds of small multivallate enclosures (red diamonds) on shaded DEM overlain with major streams and Roman road system (white lines). 8 by 1 km box in the centre of the study area indicates zone which cannot suffer from edge effects.
Roman military campaigns into the region used two major routes, one from Greensforge in south Staffordshire following the southern bank of the Severn via Morvill and Much Wenlock, crossing the Severn near Cressage, the other from Mancetter following the later Watling Street via Red Hill and curving north of the Wrekin. The precursor auxiliary fortlet to Wroxeter, discovered by aerial photography and subsequent partial excavations (St Joseph 1951, Houghton & Wells 1978), is located not on the elevated site of Wroxeter itself but nearly a mile to the south, right on the bank of the Severn and some 15 metres lower. Given the military purpose served by this fortlet and the later fortress, viewsheds based on them may well tell us what they were intended to control (see figure 3).

As expected, the viewshed from the fortlet is much smaller than that from the fortress. Whereas the fortress, like the later town, has an uninhibited viewshed over two-thirds of the compass, the auxiliary fort’s view is limited to just over half the compass. What is more, the fortress viewshed nearly completely encompasses the fortlet viewshed, so whatever the reason was for placing the auxiliary fort where it is, it cannot have been the viewshed. We may therefore speculate that the fortress was placed directly on the river bank for tactical reasons (campaigning across the Severn) rather than strategic ones (control of movement in the area).

In a separate analysis, a series of viewsheds were calculated from Wroxeter in order to explore its relations with the known hillforts in the study area. In order to circumvent the problem of the low resolution (50 metres) DEM, the viewing position was chosen at 5 metres above ground level at the highest point within the town walls. The result is depicted in figure 4 above and shows that the bulk of the effective (ie ignoring small patches and far off hillsides) viewshed is to the west (from due N to due S) of Wroxeter, and extending some 7.5 kms from the town in those directions. In order to explore the possibility that the viewshed from Wroxeter might be enlarged when taking into account multiple viewing points (watch towers) along the town walls, another viewshed was calculated using the whole of the town walls as the seed area, and setting the viewing height at 5 metres (figure 5). We find that the viewshed is enlarged by 48.5 km$^2$ (a 43% increase over the 112.4 km$^2$ viewshed of figure 4), to cover areas to the northeast and directly across the Severn to the west and southwest of the town. The viewshed for the legionary fortress preceding the town is essentially identical to the latter. Most of the hillforts within a 15 km radius, whether they were occupied during this period or not, are found to lie within this enlarged

Figure 3: the multiple viewshed from the fortlet (5m viewing height, green) is almost completely subsumed (yellow) into that from the fortress (7m viewing height, red). The partly reconstructed pattern of Roman roads is overlaid.
viewshed. However, since hillforts that posed a threat to the Romans were forcibly abandoned after the Conquest, it is not clear that these results have any significance beyond that which was already proven, namely that the location of Wroxeter was in common view and therefore a good ‘neutral’ place to hold markets.

Figure 4: unrestricted viewshed from the highest viewing point within Wroxeter. Red diamonds: large multivallate enclosures.

Figure 5: 15 km max viewshed from Wroxeter wall circuit. Red diamonds: large multivallate enclosures.
1.2 DISCUSSION

From figures 4 and 5 it is not immediately clear how many of the 13 large multivallate enclosures within the study area fall within the Wroxeter viewshed. In fact, both in the unrestrained viewshed of figure 4 and the 15 km radius viewshed of figure 5, only 4 out of 13 are ‘visible’. Field observations have shown this result to be incorrect for at least some of the hilltop locations, and point out a weakness in the line-of-sight technique employed: locations on the visible horizon are not reliably included in the viewshed. One possible technical solution (not pursued here) might be to expand the viewshed by the addition of ‘horizon’ cells; these can be identified by the fact that they a) must lie next to cells that are within the viewshed, and b) must be further away from the viewing point than any neighbouring viewshed cell.

Overlaying the partly reconstructed pattern of later Roman roads on these maps of indigenous hillfort, Roman military, and Roman civilian viewsheds, we can also observe that many sections of road fall within the viewsheds. However, this appears to be due to the generally favourable position of Wroxeter within the bowl-shape of the Severn valley rather than to any conscious decision to build the roads in such a way that they would be visible from the fortress and town. Simulation studies will be presented in section 3 below to support the weakness of the statistical arguments generally adduced for deliberate placement of archaeological feature (see also the example of the Arroux valley Celtic hillfort system discussed in chapter 6, Madry & Rakos 1996).

2 STRUCTURATION OF THE LANDSCAPE

The social, political, and economic organisation of space in the Wroxeter hinterland area throughout the Late Iron Age and the Roman period can be studied from many angles, some of which are amenable to GIS analysis. Specifically, the distances and effort involved in travel and transport can be studied through cost surface analysis (CSA), and have ramifications into such areas as political control, economic spheres of influence, and the social ordering of space. CSA techniques may be used to implement, and improve upon, some classical types of archaeological analysis, including buffer, cluster and distance analysis, tessellation of space, and site catchment analysis. They have also been used to explore some entirely new concepts, relating to landscape accessibility and optimal routes and networks. In chapter 6 I have reviewed the literature and current approaches on this subject; here I will present case studies based on WHP data and problems.

2.1 CATCHMENTS AND TERRITORIES

Although, in archaeological theory, site catchment analysis is a quite complex and flexible concept, the definition of actual catchments (exploitation zones) has been approached generally in a very straightforward manner as a circular area centred on the site focus, with a radius determined experimentally or ethnographically (Chisholm 1968). Catchment boundaries could also be defined by travel time instead of radius, but implementing this requires some way of taking into account the nature of the intervening terrain, and in the absence of GIS has required considerable legwork in the past.

Traditional methods for constructing catchments remain, however, limited by their reliance on plane geometry and choroplethe cartography. GIS-based techniques, in contrast, allow the simple ‘flat’ geographical space to be supplanted by a complex friction surface incorporating many relevant properties of the terrain, and the distance-based rule for defining the catchment to be replaced by a time- or energy expenditure based rule accumulating costs / encountering resistance as it moves further from the focus. In order to lead up to these more complex techniques, I will first discuss some simple variants.
DISTANCE-DEPENDENT TECHNIQUES

The calculation of catchments is only a preparatory step to the actual catchment analysis, which should be based on archaeological theory. For early prehistoric societies this will often be foraging theory; however this does not apply to the largely settled agricultural and pastoral landscape studied by the WHP. More relevant is Bewley’s (1994: 65-8) work basing the economic basis of farming settlement sites in the Solway plain on estimates of soil workability as derived from its moisture capacity and texture. Deriving a circular catchment area within a GIS is a trivial operation, and reporting and tabulating the presence of resources within each catchment (typically the goal of this type of analysis) can be automated. Following Bewley’s classification, we used such a method to derive soil workability data for a 200m radius area around a sample of 111 enclosures within 5 to 7 km of Wroxeter (figure 16a). Comparison of the workability characteristics of these catchments to those of the sample area as a whole (figure 6b) shows that soil workability did not significantly affect the siting of enclosures within the sample area. We could speculate on the causes - some or many of the enclosures might specialise in cattle raising rather than arable; some or many might be Roman in data and might therefore have had access to heavy ploughs - but that is not the aim of this case study. Generally, such speculation points in one of two directions: either soil workability was not among the most significant factors affecting enclosure siting, or the chosen method (circular catchments) is too coarse. The latter direction could be pursued by modeling for ‘a sufficient amount of workable soil (e.g., 2 hectares) within a specific maximum distance (e.g., 400 m)’ from the enclosure sites; this type of model was in fact implemented for the Wroxeter hinterland by Gaffney and Goodchild (Goodchild 1999).

Figure 6a: Soil workability and 200m radius catchments for 111 enclosed sites in a 14 by 11 km area around Wroxeter. Workability classes according to Bewley 1994: dark green easiest – dark red heaviest.

Figure 6b: comparison of workability characteristics of enclosure catchments (dark line) to background (light line). The graph shows a slight avoidance of very heavy soils and an equally slight preference for light soils. Workability classes according to Bewley 1994: Aa very easy, A easy, C average, D slightly difficult, E moderately difficult, F extremely difficult. Area on both vertical axes in hectares.
The binary (inside or outside) result obtained with this type of catchment can also be improved upon by defining multiple distance-based ‘buffer’ zones around sites (or, as will be shown below, around line or area features). This opens up the possibility of deriving distance-dependant relationships between sites and resources. We have employed buffer analysis to look at the most plentiful site group in the study area, that of the enclosures, on the basis of Whimster’s (1989:35) system of morphological classification of crop mark enclosures in the Welsh Marches. Whimster noted a (slight) tendency of rectangular enclosures to cluster around Wroxeter; presumably this signifies or expresses some kind of economic, social, or cognitive link, such as increased demand for agricultural produce or increased status attached to ‘Romanised’ forms of settlement, focusing on the civitas capital itself. Whimster therefore tentatively dates these rectangular enclosures to the Roman period, and the dating has received some support from excavated evidence elsewhere (Bewley 1994). We can begin probing this hypothesis by checking that the clustering is in fact present, and a simple one-sample test for randomness confirms that this is the case – rectilinear enclosures do indeed cluster around Wroxeter more than curvilinear ones (figure 7a).

**Figure 7: Expected/Observed number of a) rectilinear enclosures, b) curvilinear enclosures per distance buffer from Wroxeter.**

Having established the fact of the clustering, we must now probe deeper for possible explanations. Since the clustering is a property of both types of enclosed sites, and curvilinear enclosures are thought to predate the establishment of the town at Wroxeter, we must look for other additional causes for the clustering to occur. We may find such causes by examining other environmental and social factors, and by examining potential bias factors. As a first approach, univariate preferences indicate that nearly all enclosures occur on relatively flat land, of good to medium workability, and not far from major streams. When we map the former two factors using the map algebraic function

\[
\text{Good\_land}=\text{if}(\text{SLOPE} \leq 6) \&\& (\text{WORKABILITY} [\text{A} - \text{D}])
\]

And limit our subsequent analysis to these area of good land, we can examine the relation of the various types of enclosures to major streams (see figure 8 above). It now becomes clear that rectilinear
enclosures were preferentially placed at a certain distance (ca. 500 m) from the nearest major stream, but could easily occur up to about 3 km from such streams. Curvilinear enclosures have a more direct but also weaker preference for closeness to streams.

Obviously, if rectilinear enclosures are indeed Roman in age, it may well be that a constellation of proximity factors (to streams, to roads, to other enclosures, and to the market at Wroxeter) would have been at work to ‘direct’ the choice of a new settlement location. Other rectilinear enclosures may have been 'Romanised' versions of existing enclosed sites, for which a different constellation of location factors would be relevant (esp. the cultural, political and social ambitions of the inhabitant).

Since nearly all enclosures have been discovered by aerial photography, our models should also account for the possibility that systematic biases related to modern crop sensitivity land use account for the observed distance relationships. As I have shown elsewhere (chapter 14, section 2.3), there is a strong univariate correlation between crop and soil marks and modern land use.

TESSELLATIONS

If catchment radii or buffer distances are extended until all available space is divided, a territorial division or tessellation of the landscape results. Archaeological arguments for suspecting the existence of such tessellations abound, albeit the type of tessellation differs by period. For the advanced Iron Age, the sociopolitical structure of Wroxeter hinterland is thought to have been dominated by the sites known as hillforts and perhaps also by multiple-ditched enclosures, and we may therefore be able to model chiefdom territories using some method akin to Thiessen polygons. For the Roman period, a central place model of market functions puts a ring of secondary markets at about 15 km from the main market and civic center at Wroxeter, and introduces the element of ranking in the derivation of territories.

Ruggles and Church (1996) provide a thorough discussion of the theory, problems and possibilities involved in creating more realistic Thiessen polygons, but in fact the major problem in most studies is how to decide on a set of contemporaneous, equivalent sites to base the analysis on (see also my critique of the tessellations applied to the Archaic polities of the Alban hills area, chapter 15). The definition of potential late Iron Age chiefly residences within the Shropshire SMR is problematic in this respect. Within the Wroxeter hinterland there are three known multivallate enclosures which are not recorded as ‘hillforts’ (PRN’s 472, 1055, and 2000; see table 1), even though one of them is situated on a hilltop; conversely, many sites recorded as ‘hillforts’ are not actually located on hilltops at all - notably, the ‘lowland hillforts’ at Wall Camp and the Berth at Baschurch. Given that hardly any of these sites has been excavated, functional interpretations remain largely a matter of conjecture, and a less subjective partition could be based on the size of their internal area (table 1). We can then distinguish groups of larger (2 to 4 ha) and smaller (0.15 to 1.2 ha) multivallate enclosures; Wall Camp, at 14 hectares, and Bury Walls (12 hectares but just outside the study area) are clearly outliers.

Plotting these two groups on a map of the study area (figure 10), we can see a crest of smaller multivallate enclosures around the fringes of the Long Mynd upland (southwestern corner of the study area), with the larger ones situated more toward its interior. The smaller sites would combine high status (as evidenced through the effort spent on earthworks) with accessibility (= nearness to agricultural land and infrastructure?), and might be residences of chieftains. The set of larger multivallate enclosures are fairly evenly spaced across the landscape, with closer pairs occurring at Caer Caradoc/The Lawley and Haughmond Hill/Ebury Hill. An argument can be made for the idea that these two pairs are either not contemporaneous or not of the same type, and that we should perhaps exclude the lesser of each pair (i.e., Haughmond and the Lawley) from our territorial analysis.

Constructing Thiessen polygons on the basis of the reduced set of larger multivallate enclosures and a simple slope-related cost surface, we obtain a division of the landscape with some interesting properties (see figure 9). Firstly, three pairs of hillforts occur at regular intervals opposite each other along the main Severn corridor, with Wroxeter itself very near a common boundary between four of these. Although pairing has been observed elsewhere (Bowden 1989), the siting of opposing pairs across a river is not
attested elsewhere, and is likely to be due to the particular physical geography of the study area. Given the locations of known fords in the Severn, some of the boundaries between these hillfort territories converge near Wroxeter, a result substantiating theoretical arguments for expecting the location of markets and religious sites at or near territorial boundaries.

Secondly, hillfort territories to the northeast (Wall Camp) and southwest, with the possible exception of the Lawley, are not oriented toward the Severn. Obviously these are marginal territories, the size and shape of which will be influenced by edge effects (in particular, the presence of other large hillforts outside the study area, such as Bury Walls). But the pure fact that these territories are visually and physically isolated from the main Severn valley must make effective control that much harder, and it is unlikely that they played a significant role in controlling the area. Further corrections can be applied by assuming that territorial divisions followed the natural division of the landscape into watershed basins (figure 10).

2.2 MODELLING IRON AGE/ROMAN TRADE NETWORKS

Within the WHP we have attempted to take the tools of cost surface analysis further, using drainage or shortest path calculations to construct a hypothetical Iron Age organic road network that complements the known network of Roman roads. An extensive and intricate network of routes of various types must have existed in the Iron Age landscape around Wroxeter. Not only were there established paths between settlements, but there must also have been paths between settlements and central places such as the hillforts, markets, and cult sites. Since cattle breeding now appears to have been the mainstay of both the Iron Age and the Romano-British economy of the Cornovii, we must also expect to find networks of wider trackways running between upland pasture and lowland settlement and market areas. Such droveways are thought to have followed ridgelines in order to avoid, as far as possible, difficult terrain and intrusion on farming land. Where cattle droves run through farming land, the movement of the animals would have been restricted by parallel hedgerows or fences for which we have ample air photographic evidence. The Shropshire SMR holds 33 trackway records, 10 of which are doubtful and none of which have been dated with any degree of certainty. However, some can be assigned to the Iron Age/Roman period on morphological grounds. A large number of these parallel linear crop and soil marks are directly associated with enclosures and field systems. This is to be expected because crops would need to be protected from cattle being taken along the tracks/droveways; outside these farming areas, the trackways would not need any defined boundaries and could widen out considerably, making them archaeologically invisible. Although the Roman military road network may to some extent have followed and fossilised the main existing routes through the area (see especially the reconstruction of infrastructure by Bassett 1990), we cannot assume that this network is representative of Iron Age infrastructure in any sense. The object of this case study is therefore to reconstruct the Iron Age infrastructure on the basis of what we already know about the locations of enclosed settlements. GIS models based on cost surface analysis can be used to investigate the presence and properties of such networks, either by directly probing relevant existing archaeological records, or by generating hypothetical transport networks based on least cost principles.

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1 A stream map and a watershed basin map can be constructed through the application of a drainage algorithm on a DEM; by inverting the DEM the same algorithm can be used to generate ridge lines. Any resulting basin not fully within the study area will suffer from edge effects.
Figure 9: Distribution of smaller (diamond) and larger (box) multivallate enclosures in the study area, with a Thiessen network generated on the basis of the larger enclosures.

Figure 10: Distribution of larger multivallate enclosures in the study area, with major watershed basin boundaries generated from the DEM (yellow lines).
Least cost networks

The calculation of multiple least cost paths through the Wroxeter hinterland requires the definition of start and end locations, which in turn depend on the system being studied:

- Our first approach was to use Wroxeter itself as a single ‘end’ point given strong indications that it had been the location of an important fair/market during the later Iron Age. ‘Start’ points varied depending on which type of route was being modeled; for the regular traffic of people and goods start points were taken from the locations of known settlement sites (enclosures).

- A second set of route networks was generated using the larger multivallate enclosures as end points and all enclosures as start points, in order to simulate the infrastructure of the Late Pre-Roman Iron Age settlement system.

- Finally, a third set of networks was generated with end points chosen to represent the developed Roman trade system. This includes, in addition to Wroxeter itself, known secondary roadside settlements at Westbury, Church Stretton, Bridgnorth, Red Hill (Uxaonon) and the lost settlement near Harcourt (Ratunum).

Below we describe the process involved in generating the first of these networks, with a single end point at Wroxeter. This is followed by a discussion of the other networks.

NETWORK GENERATION

The following calculation of the Wroxeter cumulative cost surface (‘cost to market’) and of the subsequent least cost paths (‘cost from start point’) is based on a cost surface obtained using the Pandolf formula for the physiological expenditure M (metabolic rate in Watts) involved in moving over natural terrain, which incorporates total weight (body plus load) moved, a terrain factor describing ease of movement, and percent slope:

\[
M = 1.5W + 2.0(W + L)(L / W)^2 + N(W + L)(1.5V^2 + 0.35VG)
\]

The grade G was mapped as percent slope, a derivative of the 50 metre resolution DEM obtained from the OSGB for the study area. Because the slope calculation is non-directional, no distinction has been made between downslopes and upslopes; my discussion in chapter 6 shows that this has a minor effect on the quality of the model.

The terrain factor N, a cost surface (figure 11a), is constructed on the basis of terrain features known to influence movement - marshy areas, roads, and streams of various widths, with a default value equivalent to the presence of a dirt road assigned to the remainder of the study area. This default value is important in that it assumes the presence of an existing intricate network of paths throughout the area, so that the need to create an entirely new path (which would entail higher energy expenditure) would hardly ever arise (an assumption I have argued for in chapter 6). Coefficients for these terrain features were mostly taken from Marble (1996:5, quoting Machinova 1996 and Givoni and Goldman 1971). We assumed that for small loads the Roman roads would not have a much lower coefficient than ‘organic’ ones. Givoni and Goldman (1971), for example, assign terrain coefficients of 1.0 and 1.1 respectively for metalled roads and unmetalled paths. Although this slight difference in cost resulted in many least cost paths running parallel to each other because of the effective lack of an energy penalty over large stretches of the study area (see, for example, figure 15), it is preferable not to attempt to ‘correct’ for this by artificially lowering the coefficient of the Roman roads or raising that of the default value.

Modelling the terrain factor N revealed several implementation problems. The main problem in the calculation of N proved to be the presence of a major river with tributaries in the study area; it was also noted that in order to properly model seasonal variations in the accessibility of some land types (river
alluvium and peat bogs) it would be necessary to calculate different versions of N. Stream coefficients had to be set relatively high (88 for the Severn, 22 for the larger streams, and 5.5 for the smaller ones) in order to prevent the least cost paths from crossing them repeatedly. We were also forced to include information about fordable places in the Severn in order to differentiate between these and other stretches of the river; fortunately, a cartographic record of Severn fords was available (Pannett 1989). This map identifies
nine good fords between Apley (below the Ironbridge Gorge) and Hayes on the Welsh border, in addition to four lesser fords between Mytton and Cressage (in the centre of the study area), all of which were assigned a value of 1. It was found that the incorporation of these detailed terrain features in our calculations caused the resultant least cost routes to converge more on each other, on occasion skirt around bends in streams, and make more use of the Roman road network. Finally, an unexpected technical problem had to be circumvented. It turned out that, in the raster based GIS used, the cost accumulation algorithm and the drainage algorithm both perform a local search of 8 neighbouring cells to locate the lowest cost neighbour, whereas linear terrain features with a width near that of the map...
resolution (25 metres) were represented by a single corner-connected line of cells (see figure 13). This resulted in the ‘skipping’ of the important high cost terrain features by both the cost and the drainage algorithms, and forced a rerun of the whole analysis - this time with all streams, roads and fords widened by 2 cells so no more ‘skipping’ of high cost linear features was possible.

The other variables involved in the determination of M were kept constant, with weight W at 70 kg, load L at 4 kg, and velocity V at 4.8 km/h. Using these parameters the formula to calculate metabolic rate in watts (M) becomes:

\[ M = 105 + 0.483 + 74N(34.56 + 1.68G) = 105.483 + 2557.44N + 124.32NG \]

The resulting cost surface M, illustrated in Figure 11b, forms the basis for a series of cumulative cost surfaces centering on the intended 'end point(s)'. In order to model a single route network converging on Wroxeter, a cumulative cost surface was calculated using M as cost and NGR 356485 / 308705 (the main forum entrance at Wroxeter) as the end point coordinate (figure 12). Cycling through a list of enclosure site locations used as 'start points', this surface is then drained and the resulting least-cost paths added together using map algebra to yield an 'organic' or 'natural' network for travelling from these sites to Wroxeter. This network indicates not just where, but also how intensively used, routes were. One example of a least cost path is illustrated in figure 14; the full network is depicted in figure 15.

Figure 12: Cumulative energy expenditure surface for Wroxeter, using shaded background.
The representation of linear terrain features in a raster cost surface can introduce significant errors in the resulting cumulative cost surfaces and least cost paths, depending on the algorithms used for cost accumulation and drainage. In this example, on the left, a least-cost path can ‘jump’ a one-cell-wide cost barrier such as a river if the algorithm allows diagonal moves; on the right, the problem has been fixed by widening the cost barrier - forcing the algorithm to look for low cost crossing points such as fords.

Figure 14: Simulated route network based on least cost paths through the cost surface of figure 12, streams and Roman roads included.

The resultant network has some gratifyingly realistic aspects. In particular, it shows avoidance of streams and convergence of routes, and the organic routes generated in the upper Severn valley coincide approximately with the lines of presumed roads into north Wales (north-western part of the study area).

ROMAN SECONDARY MARKETS NETWORK

We can now investigate an alternative model of travel between enclosed settlements and markets, by adding to the single ‘end point’ (market) at Wroxeter five more end points located at known or presumed second-level settlements in the study area – at Harcourt, Westbury, Church Stretton, Bridgenorth, and Red Hill. In this model we will assume equality of ‘attraction’ (that is, of cumulative travel costs)
between Wroxeter and these other sites. The implementation of this model again starts from the cost surface N and the energy surface M (figure 11); the cumulative cost surface (figure 15) uses the six sites mentioned above as start points; and the cumulative least cost network (figure 16) again uses all enclosures as start points.

Figure 15: cumulative cost surface for primary and secondary markets in the Wroxeter Hinterland. Maximum cost boundaries (black), streams (blue) and roads (red) overlaid.

Figure 16: least cost network from all enclosure sites to primary and secondary markets.
Again the influence of terrain costs on territories and paths is clear. The ‘territorial boundaries’ (maximum cost lines) in the cumulative cost surface tend to follow streams, and the fordable places in the Severn exert a strong ‘attraction’ on paths (see, for instance, the convergence of paths near the ford at Strawardine - top left of study area). Also notable is the divergence between the simulated route and the hypothetical Roman road where it crosses the Tern directly north-west of Wroxeter. Whereas the line of the Roman road to the north of the Severn (postulated on the basis of regularities in 19th century field boundaries) requires the presence of an additional bridge across the Tern, the simulated least cost path takes a shorter route and uses the existing Tern bridge some 2.5 km to the south.

This model may be refined still further by adding constraints in the form of known nodes and paths. It has, for example, been suggested that the site of Meole Brace a few km to the west of Wroxeter is important because it is located at a node in the Roman road network, with excavated evidence for redistribution functions (Ellis et al. 1992). Likewise, the known trackways of the Wroxeter hinterland can be used as ‘attractors’ in the cumulative cost surface. Even if the hinterland infrastructure in both the Iron Age and Roman period was largely organic (and there is no reason to believe otherwise), routes may be expected to follow natural lines from settlement to settlement, and to interconnect with the Roman road system. We may therefore expect nodes to occur where natural routes connect with formal roads and other routes routes, and may derive some idea about the relative importance of these nodes by the number of individual least cost that intersect there. Such simulations will not be very accurate but should still indicate areas where we might look for small markets or shrines, and will allow us to re-study the archaeological records from this perspective.

3  EDGE EFFECTS AND BACKGROUND INDICES

Cumulative viewshed analysis is a tool often used to investigate and interpret the ‘social’ placement of archaeological sites and monuments in the landscape. The placement of these sites and monuments in areas of relatively high or (less often) low visibility is often seen as proof that they were intentionally put there. A more sophisticated approach first calculates a ‘background’ CVI which describes the ‘natural’ visibility of all parts of the terrain, then investigates whether the viewshed properties of the sites of archaeological interest are significantly different from this, therefore presumably intentional. However, the quantitative study of viewshed intensity gives rise to several further more or less subtle distorting effects which must be taken into account. Two of these – the edge effect and the influence of viewshed radius on the relation between elevation and CVI - are demonstrated here.

3.1  EDGE EFFECTS

The edge effect has been discussed in general terms in chapter 6, and in the case study presented in section 1 above its maximum reach was visualised as a box outlined in red (figures 1 and 2), but no attempt was made to further quantify it. In the following such an attempt is made, employing an idealised circular raster ‘world’ with a radius of 20 km and a resolution (cell size) of 500 by 500 m. The total number of cells within this area is 4977. Three cumulative viewshed indices (CVI’s) were generated using 50 (1%), 250 (5%), and 500 (10%) samples of randomly chosen seed cells and a 10 km viewshed radius (see figure 17a). It may be observed that the relatively large viewshed radius yields a consistent area of high visibility near the centre of the world even with a very small sample of ‘seeds’. As the number of seeds rises, so the CVI approximates the ideal distribution which would have resulted from a 100% seed sample; but the 10% seed sample used for the right-hand CVI is already clearly sufficient for investigating the edge effect.
In order to obtain a graph of the relation between CVI values and distance from the edge, a normalised index of edge distance (EDI) was constructed in which 0 represents the edge and 100 represents the centre of the world. Next, the median CVI per EDI value was tabulated and is represented in the graph below.

The three CVI images come progressively nearer the ‘ideal’, where all areas over one viewshed radius (20 cells) from an edge have an identical CVI. It is noteworthy that even a 5% random seed sample can yield a CVI that still deviates significantly from this ideal – so we cannot accept this as a rule of thumb (contra Lake et al. 1998). Within the circular and ‘flat’ universe used for this test, the edge effect diminishes linearly with distance, as predicted. With a 10% sample of ‘seed’ cells, CVI rises steadily from 12% at the edge to 77% at one viewshed radius from the edge, then holds steady at about 80% before dipping to 72% at the center of the universe due to the random nature of the seed locations. The absolute CVI at the edge of the universe and on the ‘plateau’ depends on the precise combination of viewshed radius and average distance between seed points used, and a formula could be derived to predict both, but in a viewshed study of a real terrain both parameters would obviously be significantly and unpredictably lowered.

### 3.2 VIEWSHED RADIUS EFFECT

The further away from the viewer, the more likely it is that an object will be masked by intervening terrain, hence the more elevated it has to be in order to be seen. With increasing viewshed radius the
Figure 16.22a - Background CVI for the Wrenster basin, based on a $-1\%$ random seed sample of viewpoints with a 2km viewshed radius. Total number of cells in region: 471,000.

Figure 16.22b - Background CVI for the Wrenster basin, based on a $-0.1\%$ random seed sample of viewpoints with a 10km viewshed radius.
amount of terrain far from the viewer increases exponentially whereas the amount of terrain near the
viewer remains constant; therefore elevated locations will obtain a higher CVI at larger viewshed radii. In
order to investigate and demonstrate the effect of changing viewshed radius on the types of
geomorphological units preferentially ‘seen’, digital elevation data from the WHP were used to calculate
several random ‘background’ CVI’s at varying radii.

This showed up some important effects straight away. The cumulative short-range (2 km) viewshed
generated from a set of 5,000 points (approximately 4 points per km$^2$) contains visibility values ranging
from 0 (completely secluded) to 54 (highly visible), but these are not randomly distributed. In fact, they
correlate directly with the size of the convex and concave geomorphic units in the study area, especially
when these are larger than an individual viewshed (say, over 4 km$^2$). Conversely, a cumulative long-range
(10km) viewshed generated from 500 points (approximately 1 point per 6 km$^2$; random3.los) shows the
high visibility index, not surprisingly, correlating with high ridges and hillsides, an effect which would be
expressed even more strongly if, as is current practice in many GIS studies, the viewsheds were
unconstrained.

4 CONCLUSIONS

As a consultation of chapter 6 will make clear, the case studies presented in sections 1 and 2 no longer
represent the ‘state of the art’ in GIS modeling of visibility and accessibility. The modeling of ‘energy and
resource landscapes’ in a GIS environment with the help of cost surface techniques has become
increasingly sophisticated in the last few years. Cost is now measured in real terms as energy expenditure
in Watt or kCal; cost surfaces have become anisotropic to reflect the importance of the effect of direction
of movement on costs; the interpretation of visibility and accessibility models is now informed by a better
understanding of statistical complexities; and, last but not least, the limitations of the underlying theory
are now beginning to be understood.

Further work will be needed in order to develop sufficient understanding of ‘background’ visibility and
accessibility indices such as the ones developed above in section 3, and by Llobera (2000). Of equal
importance is the testing of GIS-generated models, firstly by a comparison with extant historic,
archaeological, and cartographic data, and thereafter by targeted fieldwork.

Although the simulations presented in section 3 do not constitute conclusive proof, it would appear that
simply by increasing the viewshed range used, the higher visibility values will concentrate on areas of
higher ground, ridges and peaks. Any sufficiently large sample of archaeological viewpoints will tend to
generate a cumulative viewshed similar to these simulated ones, depending on the viewshed radius used.
Furthermore, any such viewshed based on points located on or near ridges and peaks will further
emphasise the visibility of other ridges and peaks. These results, together with those obtained in similar
simulation studies that found little correlation of viewshed intensity with elevation (Franklin & Ray 1994),
need further evaluation. Cumulative viewshed analyses must take such effects into account, or they
become nothing more than vehicles for our prior convictions.

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