Roman marching camps in Britain: GIS, statistical analysis and hydrological examination of known camp sites, resulting in the prediction of possible camp sites.

Steve Kaye, February 2013

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Note: this essay describes the methods developed to predict the possible locations of Roman marching camps in Britain. It does not contain, beyond illustrative examples, any discussion of findings resulting from this method. For those essays, and information concerning Boudica's last battle site, the reader is directed to www.bandaarcgeophysics.co.uk/arch_intro.html.

Introduction

This essay describes an attempt to extend the search for Boudica's last battle beyond the author's earlier work on terrain analysis work (2010) and hydrology (2012). Essentially this is an exercise in identifying aspects of the Boudican conflict that might still be available to modern investigation. Specifically, the camps built by the Roman force under the command of the Governor, Suetonius Paulinus, as it retreated from London while being pursued by the Boudican rebels. As he manoeuvred across southern Britain, his army would have built and occupied a marching camp each night as part of the standard operating procedure for Roman units. These camps should, unless they have been eradicated by the plough or by building, be still present in the soil profile; but even if not, then a determination of the possible locations might aid in the tracing of the legionary footsteps. Such was my reasoning for this exercise. But what are Roman marching camps?

As mentioned, Roman armies always occupied a marching camp at night. Either the camp was newly built, or an old one re-used, often with suitable modification to reflect the new occupying numbers. The camps may have been occupied for days or weeks at a time, especially when the Roman army was campaigning, and not at always by the same unit.

Obviously, these camps were utilised for defensive purposes, but they also imposed a martial regime and mentality on the occupiers, thereby magnifying the disciplined nature of the Roman army. In addition, they were also offensive. Some commentators suggest that the Romans conquered much of the western world by mobile trench warfare, whereby the typically smaller Roman forces advanced into enemy territory camp-by-camp, or trench-by-trench. This was usually a successful strategy because the tribal opposition was rarely capable of mounting a siege on a camp and could only hope to destroy the Roman force during the day and while on-the-move. This is not to say that Roman camps were never overwhelmed, but this typically happened after a disaster in battle.

It should be made clear that there are a number of camp types in the archaeological record: marching, construction, practice and siege. Differentiating between them is difficult, sometimes impossible, and in some cases one type would be used for another purpose, e.g. a former marching camp might become a construction camp for a local fort. To overcome the inherent difficulties in deciphering the type and multi-use nature, archaeologists combine all camp types under the generic term 'Roman Temporary Camp' (this is not meant to imply a lack of further classification).

However in this study we are interested in measuring and classifying some of the physical attributes of camps, that is, where would Roman surveyors place their camps and why. We are not concerned with identifying their type. Nor do we wish to differentiate and classify the camps by period or campaign, for example, the campaigns of Agricola or Severus in Scotland; that is a task best left to academic archaeology. For these reasons, this study makes use of all temporary camps, except those clearly identified as practice camps, and which have measurable extents, i.e. the length and breadth are known. Consequently, this study makes use of 374 UK camps (Figure 1).

The British Isles are blessed with the largest known number of such camps; typically quoted as greater than 500, but this number includes re-occupations. Most are located in Scotland, Wales and the north of England. Unfortunately, probably primarily due to more aggressive and long-standing agricultural methods, there are proportionally fewer in southern England, although they almost certainly did exist in large numbers due to Roman army activity during the conquest phase and the various tribal revolts.

One purpose of the present study is to try and identify the possible locations of these missing English camps.

Finally, readers unfamiliar with the story of the Boudican rebellion, or the author's earlier amalgam of terrain analysis techniques, known archaeology and the written accounts, are invited to read www.britarch.ac.uk/ba/ba114/feat3.shtml and www.bandaarcgeophysics.co.uk/arch/boudica-terrain-analysis.pdf . The former is an article published in British Archaeology (but now without images and maps) and the latter a longer version with maps. The author's website on the subject is at www.bandaarcgeophysics.co.uk/arch_intro.html (case sensitive).

Figure 1: Distribution of Roman forts, fortlets and marching camps (374) in the UK. Please note that the depicted Roman roads cover the entire period of Roman occupation of the islands. Elements of this image are © Crown Copyright. All rights reserved 2013.

The Archaeological Data

Figure 1 shows the distribution of known marching camps used in this study. As already mentioned, there is a lack of camps in southern England, but this does not mean that they were not constructed; their surface expression has probably been eradicated by extensive farming practices and building of many forms. Also, the apparent lack has largely dampened enthusiasm in the archaeological community for searching south of the uplands of northern England.

Conversely, greatest number of known marching camps are located in Scotland and northern England, where there has been a concerted effort to search for them along routes thought most favourable. In Wales the density of camps is lower but this may reflect less interest in finding Roman infrastructure and/or other archaeological demands. It should be noted that there tends to be a clustering of marching camps near to Legionary forts, e.g. Chester and Wroxeter. These may be due to a concentrated effort to study the surroundings of the fort, and/or Roman army units practising the building of camps, visiting units setting up camps near to the fort and the result of punishment details (building a camp is hard work and would probably have appealed to commanders who had a desire to discipline the whole unit).

This study includes the camps adjacent to the Hadrian and Antonine Walls, even though these were probably construction camps. Nevertheless, they will have been sited in locations and on ground that will have much in common with those camps used for campaigning. Removing them from the study would significantly lower the number used in the study (374) and might introduce bias in the statistical analysis. The same argument is applied to construction camps adjacent to fortresses.

The relatively few camps in southern England tend to be scattered, or randomly distributed, except, as mentioned, for those adjacent to forts. However, it cannot be denied that during the conquest period, from 43AD and beyond, the Roman units would have built and re-used camps; that was their *modus operandi*. Whether the camps were still used after pacification is a moot point. It could be argued that the camps in southern England might have become sites of *mansiones* (official stopping or resting places on roads), then villages and finally, in some cases, towns or cities. Indeed, there might be merit in extending this present predictive study of possible marching camps locations to determine if such a development in useage can be statistically matched to the present-day sites of villages and towns, i.e. to help answer the question: 'has much of the building of modern Britain been governed by the location of Roman infrastructure?' This is an old question, already asked many times, with the answer repeatedly pointing to the evolutionary nature of Roman and modern roads and, of course, the towns and cities that grew around the Roman legionary forts, e.g. York, Exeter and Gloucester.

Elsewhere, where the marching camps are more clearly related to operations in hostile territory, the majority of camps follow route-ways into the land to be conquered or subsequently controlled. This is most evident in Scotland where strings of marching camps extend from the south northwards and westwards. Strings are less evident in Wales, but prime route-ways can still be discerned.

Figure 1 clearly shows the marked affinity of camps with Roman roads. Self-evidently the route that the marching legions would take had been decided upon before the start of the campaign; camps followed this route and roads, together with forts, fortlets and towers, were built between the camps. Obviously the marching camp preceded any other form of infrastructure and, as already noted, would be re-occupied by units marching up and down the road system.

The initial aim of this study was to acquire more information that might aid in the hunt for Boudica's last battle, however, the techniques used and the results gained are thought to be applicable to many other events in the Roman conquest and occupation of Britain; future essays will discuss these.

Much could be written in this essay about the known archaeology but instead the reader is encouraged to make use of the primary resources listed earlier.

Grouping of the camps

For this study only those camps with known lengths and breadths were used because a key differentiating attribute is the area the camp occupied. Of the 374 such camps, Lunanhead in Angus at 86.8 hectares is the largest while Haltwhistle Burn 4 in Northumberland at 19 x 16 metres, or 0.03 hectares, is the smallest. However, it may be prudent to consider the possibility that camps less than 50 x 50 metres might have been practice camps.

Camp size is a characteristic which can be used to differentiate and group the camps. Please note that the term 'group' will be used for data arising from this study; this allows a separation from the term 'series' commonly used by archaeologists for similar purposes.

The largest camps, i.e. those greater than 30 hectares in size, were not statistically examined, they being few in number, and grouped as shown in Figures 2, 3 and 4. This resulted in the groups 65-70 hectares, 50-60 and 40-45. Group 65-70 has a camp that appears anomalous (Channelkirk, Scottish Borders) caused by a very low minimum side length (1058 x 512metres and Figure 3) but nevertheless it belongs within this largest group. The reason for Channelkirk's anomalous nature is that it sits atop a triangular shaped peninsular of high ground, bounded by steep slopes on two sides leading down to rivers, hence the boundary of the camp is severely constrained by the topography, which forces it away from the square to semi-rectangular norm of the Roman army.

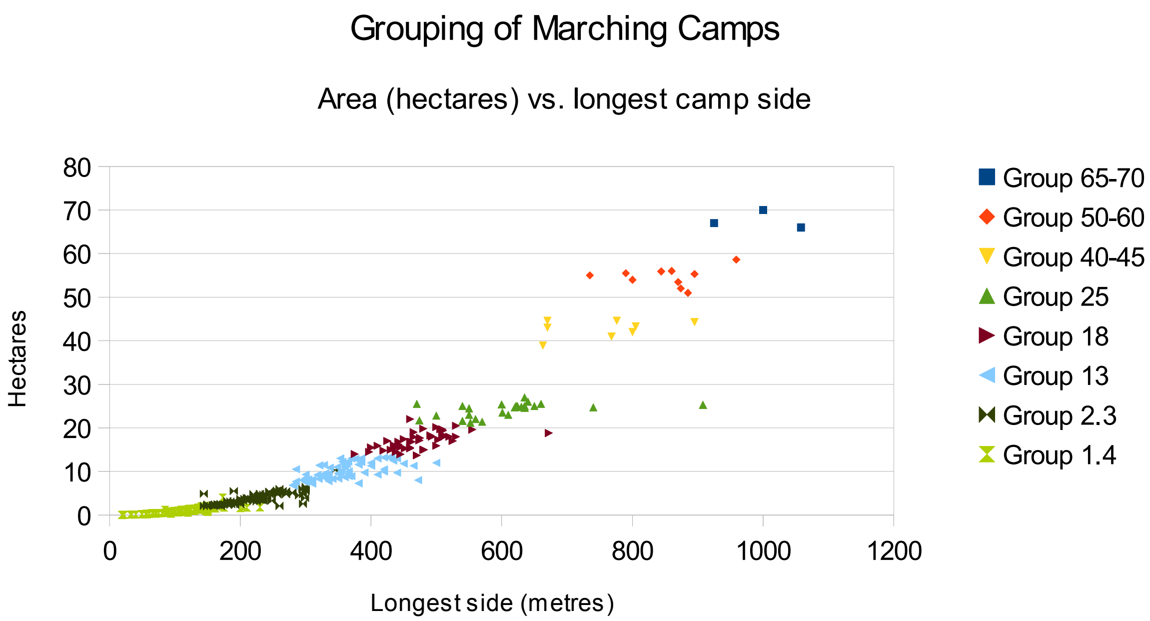

Figure 2: Graph of groups: plot of the area against the length of the maximum side. Elements of this graph are © Crown Copyright. All rights reserved 2013.

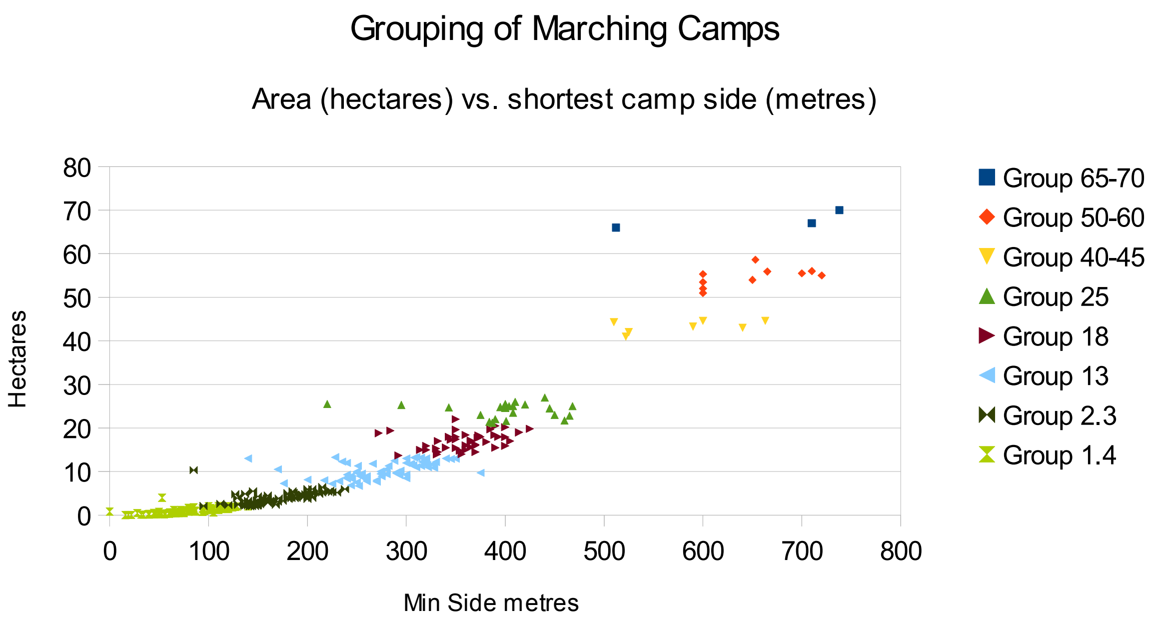

Figure 3: Graph of groups: plot of the area against the length of the minimum side. Elements of this graph are © Crown Copyright. All rights reserved 2013.

An outlier exercise was performed to identify three camps whose size does not fit within any of the groups in Figure 2. The largest known camp, Lunanhead in Angus, together with Dunning in Perth and Kinross, and Raeburnfoot in Dumfries and Galloway are excluded from the groups, but are included in the exercise to extract attributes that will be described later.

The first generalised observation is that the Roman camp surveyors and planners followed a standard rule for specifying the size of a camp. This rule is almost certainly based on the camp area required by a specific unit of legionaries, and this is then scaled to meet the needs of larger groups of men and beasts. Much has been written about this topic over the centuries of discovery; details are available in some of the reference material, above.

The second observation is that the three largest-by-area groups (65-70, 50-60 and 40-45) are distinctly separated on the graphs; a fact well-known to archaeologists. Among the many possibilities for this may be that each group represents the result of individual campaigns, with each having a different-sized army or army composition, for example a differing ratio of soldiers to cavalry.

A third observation is the lack of a group in the roughly 30 to 40 hectare range, although the range is occupied by the outlier-camp Raeburnfoot at 32.7 hectares. This may suggest that groups with areas exceeding 40 hectares were the result of unique campaigning episodes while the rest of the groups, those less than 30 hectares, represent the normal size of camps used by the Roman army as it manoeuvred across Britain. This is not to suggest that units occupying camps less than 30 hectares did not accompany the larger units, or that the smaller units did not campaign alone.

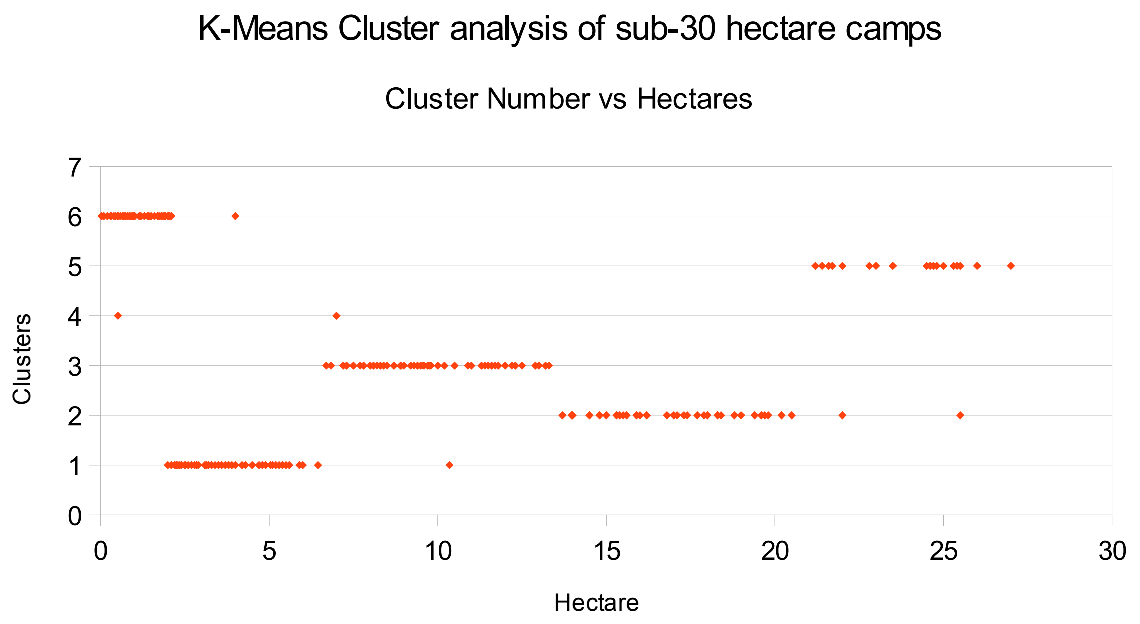

Figure 4: K-means cluster analysis of camps less than 30 hectares in size. Note that Cluster 4, with only two camps, is not designated as a 'group'. Elements of this graph are © Crown Copyright. All rights reserved 2013.

For camps less than 30 hectares in size the groups were found by K-means cluster analysis (Figure 4). This exercise resulted in five clusters based on area, and minimum and maximum lengths of the side of the camps. Groups 25 hectares, 18, 13, 2.3 and 1.4 were named after the mode of the area in hectares. There is one outlier cluster (number 4) with just two camps: this has not been designated as a separate group. The K-means analysis could be allowed to find more clusters, especially to fill the large apparent gap between Groups 13 and the next, Group 2.3. This may be beneficial if the attributes for the camps were extended beyond the area and perimeter measurements to include others measured in this study; this may be conducted in the future. Table 1 shows all groups, including the sub-30 hectare groups.

Group Name	*Number of Camps*	*Min Size (hectares)*	*Max Size (hectares)*	*Average Size*
Group 65 - 70	3	66	70	67.66
Group 50 - 60	10	51	58.6	54.68
Group 40 - 45	7	41	44.6	43.26
Group 25	25	21.2	27	24.15
Group 18	48	13.7	25.5	17.21
Group 13	72	6.7	13.3	10.18
Group 2.3	88	2	10.35	3.79
Group 1.4	115	0.03	4	1.03

Table 1: some simple area statistics on the various groups. Elements of this table are © Crown Copyright. All rights reserved 2013.

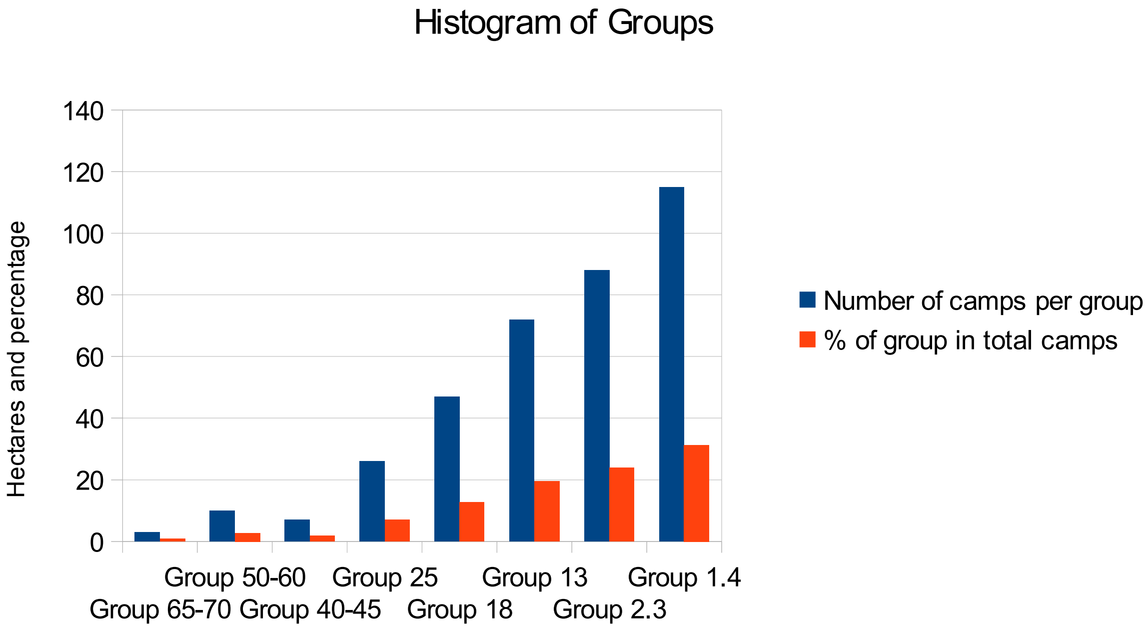

Figure 5: Histogram of groups by number of camps per group and percentage of group's camps in total number (374). Elements of this graph are © Crown Copyright. All rights reserved 2013.

Figure 5 re-emphasizes the unusual nature of the groups larger than 30 hectares; they are relatively few and, self-evidently, very large. Furthermore in differentiation, for camps less than 30 hectares there is a linear relationship between the groups due to the number of camps within each group, such that Group 1.4 terminates the relationship with the greatest number. This observation is probably the simple consequence of far more small units than large ones manoeuvring across Britain, although it should be remembered that the many of the smaller camps will have been used for construction at the frontier walls and fortresses.

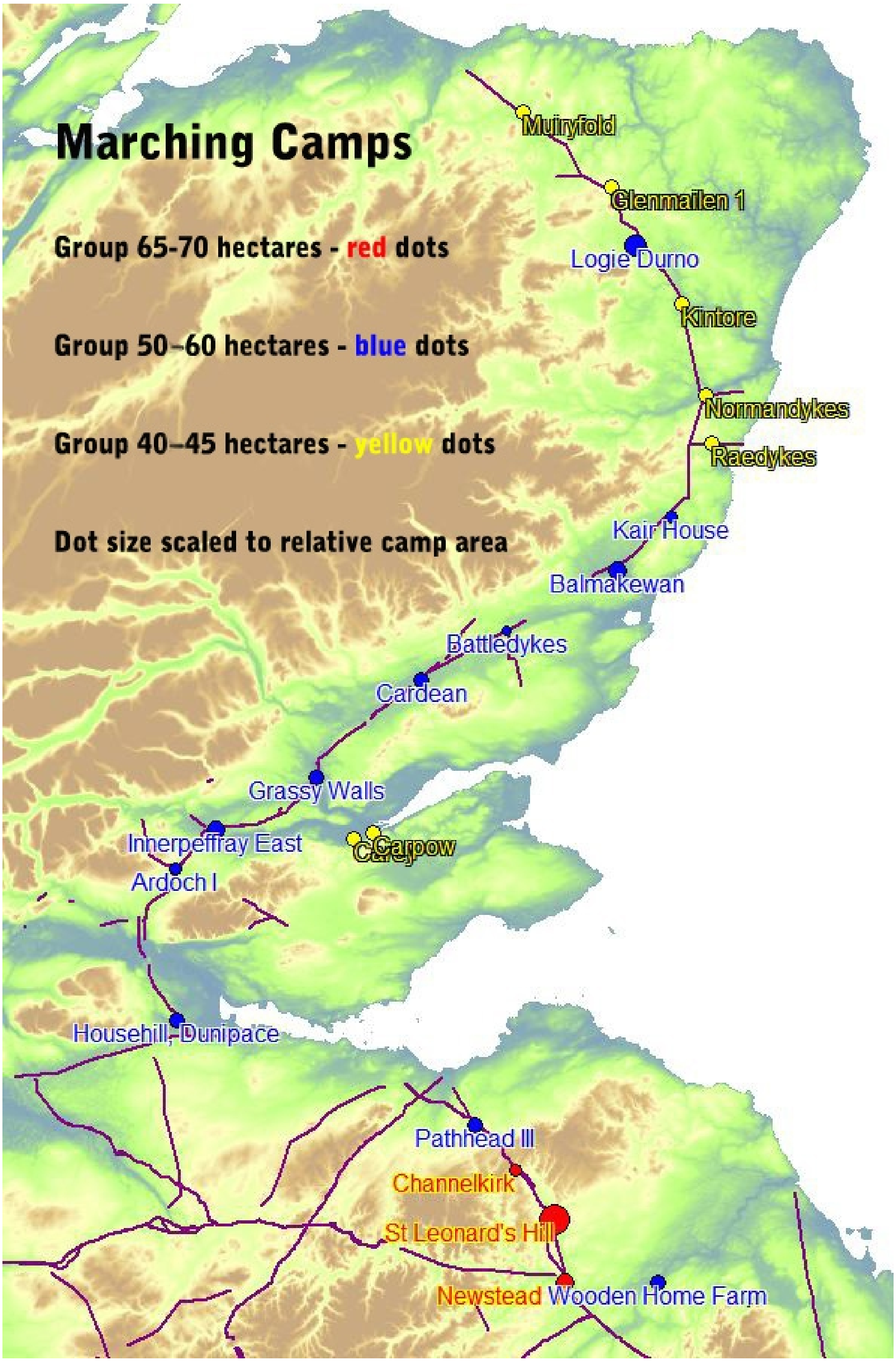

Figure 6: Distribution of the largest Roman camps: Groups 65-70, 50-60 and 40-45 hectares. Note that camps of this size are restricted to the areas shown: there are none in Wales or southern England. Elements of this image are © Crown Copyright. All rights reserved 2013.

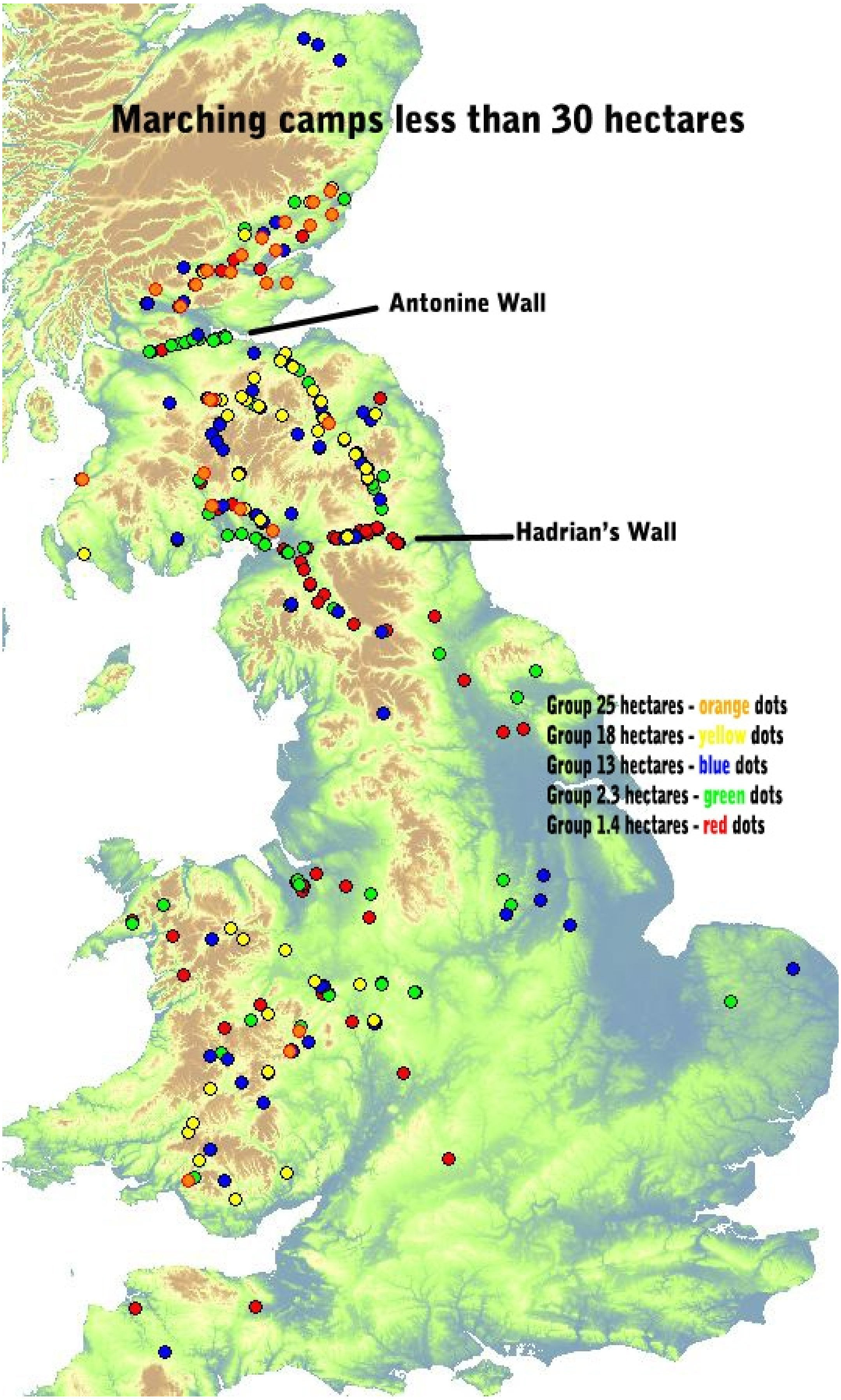

Figure 7: Marching camps less than 30 hectares in size. Groups 25, 18, 13, 2.3 and 1.4 hectares are colour coded. Elements of this image are © Crown Copyright. All rights reserved 2013.

Groups and Series

Archaeologists of many generations have examined the marching camps in Scotland and northern England in an attempt to collate them according to size, number and type of gates, general morphology (e.g. square vs. rectangular), the commonality of routes and, where appropriate, dating or assignment to a particular Roman's conquest excursion. The results are 'series' of camps: the most quoted series are listed in Tables 2 and 3 (it should be remembered that in this study the camps are collated into 'groups').

Archaeologist's Series of Camps	*Groups of camps from this study*
67 hectares (165 acres)	Group 65 - 70 hectares
54 hectares (130 acres)	Group 50 - 60 hectares
44 hectares (110 acres)	Group 40 - 45 hectares
25 hectares (63 acres)	Group 25 hectares
	Group 18 hectares
12 hectares (30 acres) – now thought doubtful	Group 13 hectares
	Group 2.3 hectares
	Group 1.4 hectares

Table 2: Comparison of Archaeologist's 'series' and 'groups' from this study.

There is some commonality between the series and groups larger than 18 hectares in size, but that hides some differences in detail, for example, Group 25 includes three camps located in Wales, whereas the 25 hectare series does not cover Wales.

The creation of groups 18, 13, 2.3 and 1.4 hectares results from relatively simple statistical analysis and without any attempt to differentiate on the grounds of location, specific campaign or any other factor except area and boundary lengths. As such the groups do appear to cohere because they are necessarily predicated on area occupied and therefore the relative size of the Roman army units occupying the camps.

Group 65-70	***Series 67 hectares***
St Leonard's Hill	St Leonard's Hill
Newstead V	Newstead V
Channelkirk	Channelkirk
	Logie Durno

Group 50-60	***Series 54 hectares***
Logie Durno	
Innerpeffray East	Innerpeffray East
Balmakewan	Balmakewan
Grassy Walls	Grassy Walls
Cardean	Cardean
Wooden Home Farm	Wooden Home Farm
Pathhead III	
Househill, Dunipace	Househill, Dunipace
Kair House	Kair House
Ardoch I	Ardoch I
Battledykes	Battledykes

Group 40-45	***Series 44 hectares***
Kintore	Kintore
Carey	
Normandykes	Normandykes
Carpow 1	
Glenmailen 1	Glenmailen 1
Muiryfold	Muiryfold
Raedykes	Raedykes

Group 25	***Series 25 hectares***
Ardoch II	Ardoch II
Forteviot	Forteviot
Keithock	Keithock
Innerpeffray West	Innerpeffray West
Castledykes 1A	
Kirkpatrick-Fleming I	Kirkpatrick-Fleming I
Blaen Cwm Bach	
Lintrose	Lintrose
Forgan	
Edenwood	Edenwood
Eassie	Eassie
Dalswinton, Bankfoot 1	
Craigarnhall	Craigarnhall
Kirkbuddo	Kirkbuddo
Kinnell	Kinnell
Marcus	Marcus
Castledykes 1B	
Auchtermuchty	Auchtermuchty
Brampton Bryan	
Stretford Bridge 1	
Lochmaben	
Girvan Mains (East)	
Durisdeer I	
Scone Park	Scone Park
Bochastle	
Mertoun Bridge	
	Longforgan

Table 3: Comparison of this study's Groups and archaeologist's Series.

In keeping with the aim of this essay to describe the predictive method of finding camps in Britain, the comparison of 'series' and 'groups' will be curtailed, except to say that in future essays work will be described that parses the findings in this study relative to the various series, in an attempt to dovetail the academic archaeological investigations.

Roman army units and the numbers of humans in marching camps

In this, and succeeding sections, the term 'soldier' is used for both a legionary and auxiliary because in discussing the use of a marching camp, it cannot be sensibly envisaged that an auxiliary unit was housed (more accurately, tented), watered, fed and otherwise catered for in a manner differing greatly from that of a legionary. Additionally, auxiliary forts are scattered across Britain (Figure 1) which supposes that there are also an unidentified number of auxiliary marching camps. In these cases the terms legionary and auxiliary are interchangeable, hence the preference for 'soldier'.

The area of each of the 374 selected marching camps can be used to estimate the numbers of soldiers occupying the camp, that is, the density per hectare. However, this is not an exact science as there are no reliable, unambiguous, source statistics. Indeed, this topic has exercised historians and archaeologists for centuries, and still does.

Additionally, the examination of the interiors of UK marching camps has not yet revealed any firm evidence to support the actual densities of those camps, or the overall composition of the occupying force.

Luckily for this study, it appears that a form of consensus has now been reached in selecting three figures of density of soldiers per hectare that reflect the likely range the Roman army may have used. These are 480, 690 and 1186 and are based on various studies of known marching or siege camps, the historical sources, coupled with knowledge of 18th and 19th century use of army camps.

It is instructive to observe that the archaeological consensus holds that the most likely range that reflects the actuality is 480 to 690 soldiers/hectare, and that the 1186 density is simply too compact, leading to numbers of occupants that seem unlikely - see Figure 8.

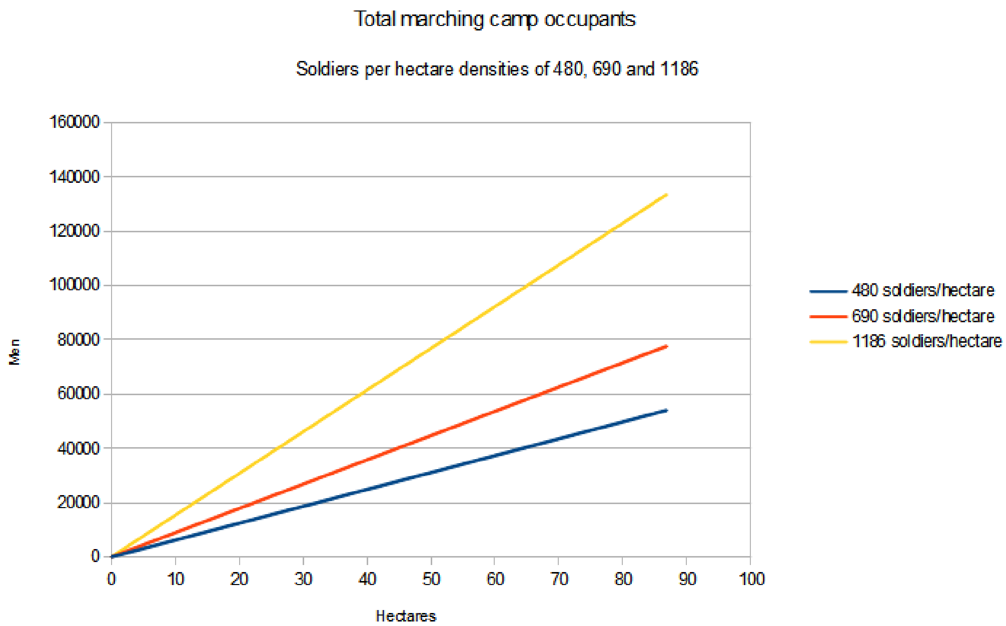

Figure 8: Graph of total number of camp occupants (soldiers and servants) for 480, 690 and 1186 soldiers per hectare. Note the far steeper gradient for the 1186 density that results in large, possibly unreasonable, numbers of occupants. Elements of this graph are © Crown Copyright. All rights reserved 2013.

For this study the figure of 690 soldiers/hectare has been selected because this is the density that *seems* to most closely approach a realistic figure and is close to those suggested by the earliest investigators, who were often British army officers in the 18^{th} and 19^{th} centuries and, therefore, familiar with the camp requirements of marching troops and cavalry.

The acceptance of the 690 soldiers/hectare density figure can be simplified by saying it is the middle-ground – neither too small (480 men/hectare), nor too large (1186 men/hectare). But a 690 soldier/hectare density is not definitive, objective or necessarily all-embracing, for undoubtedly there would have been variations around any density figure depending on the age of camp (1^{st}, 2^{nd} centuries AD etc.), the camp style, the varying topographical features and, most importantly, the configuration of the army occupying the camp. For example, an army with an unusually large cavalry contingent would require a proportionally larger camp than that occupied by a standard legionary force, hence the density of soldiers would be lower.

As an aside, an interesting exercise is to calculate the area available to each soldier within the camp. At a density of 480 soldiers/hectare each man had 16.06 square metres: 11.18 m^2 at 690 and 6.50 m^2 at 1186. These numbers do not take account of the internal layouts of the camps, the roads or the width of the clear ground (*intervallum*) between the soldiers tents and the camp rampart, because these also appear to be variable in a number of ways, i.e. there is no consensus. One might argue that 16.06 m^2 is an overly large space for one soldier, while 6.50 m^2 is too small.

As a further aside, calculating the number of soldiers required to man the ramparts, at an arbitrary spacing of 1 metre, shows that for the 480 soldiers/hectare density there would have been a reserve force of approximately 50%: with 60% for the 690 density and 80% for the 1186 density. These figures clearly indicate the strong defensive nature of the marching camp and supports some of the ancient writers who report that legionary moral was boosted, when facing the enemy in open battle, if there was a marching camp to which they could retreat. These observations re-emphasise the tactical and strategic importance of the Roman marching camps when relatively small armies were used to conquer large tribal units. Generally speaking, the Romans defeated tribal warriors by the use of a disciplined line of fewer men. To state the obvious, these fewer men could not maintain that line at night; hence the need of the camp to stop a greater number of warriors using darkness to overwhelm the Romans. As an example, the 9^{th} Legion was almost destroyed by a tribal army when campaigning with Agricola in Scotland; it had encamped and was attacked at night. The legion was saved by other Roman units rushing to their aid; the fighting was intense, both within the camp and at the gates. In all probability the 9^{th} would have been destroyed without the defensive capacity of its marching camp. Supporting this line of reasoning are the accounts of Roman army units being collectively punished by being made to pitch their tents outside of the camps, an act obviously seen as dangerous.

To return to the primary theme of this section, given the area of each camp and the preferred density of 690 soldiers/hectare, we can estimate the numbers of soldiers, servants and slaves, mules and horses in occupation. These estimates are based on generally accepted standard numbers for Legionary forces, specifically the legionary cohort system of the early Roman Empire of the 1^{st} and 2^{nd} centuries AD. This study does not attempt to vary these legionary numbers due to the presence of auxiliary, siege equipment or additional cavalry units, beyond those cavalry normally assigned to a legion. To attempt to do otherwise would require an extremely complex investigation of each individual camp and, by necessity, lead to a detailed analysis of the historical reasoning for the existence of the camp. In emphasis therefore, the number of soldiers etc. in each camp is anchored on the generally accepted legionary standard of:

a basic unit of 8 soldiers (*contubernium*),

a *centuria* consisting of 10 *contubernium* = 80 soldiers,

a standard *cohors* consisting of 6 *centuria* = 480 soldiers,

a legion consisting of 9 *cohors* of 480 soldiers and one 1^{st} *cohors* of 800 soldiers = 5120 soldiers.

Each *contubernium* was supported by at least two servants and the same number of mules used as baggage transport. Typically 120 cavalry are attributed to a legion, but in this study this is doubled to reflect the probable presence of at least one remount; there may have been more. The resulting figures for a standard legion of 5120 soldiers and for St. Leonard's Hill, the largest known camp, are in Table 4. It should be stated that these numbers exclude officers, their servants and supernumeraries.

Camp	*Area (hectares)*	*Soldiers*	*Servants*	*Mules*	*Cavalry*	*Total humans*
Standard Legion	7.42	5120	1280	1280	240	6520
St. Leonard's Hill	70	48300	12075	12075	2264	61507

Table 4: Numbers of soldiers, servants, mules and cavalry for two camps based on a density of 690 soldiers/hectare. St. Leonard's Hill is the largest known camp in Britain. Lunanhead at 86 hectares is the largest but is thought to be atypical in its use, the boundaries are not confirmed and it is classified as a 'probable' camp by archaeologists. Elements of this table are © Crown Copyright. All rights reserved 2013.

The reader is invited to compare the numbers in Table 4, at a density of 690 soldiers/hectare, with those in Table 5 at densities of 480 and 1186 soldiers/hectare (the area is fixed between the tables).

Camp	*Area(hectares)*	*Soldiers*	*Servants*	*Mules*	*Cavalry*	*Total humans*
Standard Legion at 480	7.42	3561	890	890	166	4534
Standard Legion at 1186	7.42	8800	2200	2200	412	11206
St. Leonard's Hill at 480	70	33600	8400	8400	1575	42787
St. Leonard's Hill at 1186	70	83020	20755	20755	3891	105720

Table 5: Same calculations as for Table 4 but for camp densities of 480 and 1186 soldiers/hectare. Elements of this table are © Crown Copyright. All rights reserved 2013.

Probably the most striking feature of the comparison is the size of the numbers for St. Leonard's Hill at a density of 1186 soldiers/hectare, i.e. 83,020 soldiers, 20,755 servants and 1,945 cavalrymen, giving a total of 105,720 humans. That number of soldiers equates to approximately 16 full legions (at 5200 legionaries per legion); an extremely large legionary force if taken at face value. However, it has been estimated that six legions (that is c.30,000 legionaries) were campaigning under the Emperor Severus when the camp at St. Leonard's Hill was built. If, as seems to have been normal Roman practice, each army consisted of an equal number of legionaries and auxiliaries, i.e. 60,000 soldiers, then the 83,020 figure appears a *little* more credible but, a difference of c.20,000 soldiers is still a large discrepancy and adds weight to the earlier description of the consensus suggesting the density of 1186 is too large.

In comparison, examining St. Leonard's Hill at a density of 480 soldiers/hectare, and assuming that the previously mentioned estimate of c.30,000 legionaries is correct, suggests that the calculated number of soldiers at 33,600 is too low for that campaign, there being an insufficient number of auxiliaries to match the normal Roman practice. Unfortunately the same argument, but to a lesser extent, can be made against the calculation density used in this study of 690 soldiers/hectare. Such is the difficulty of selecting the most appropriate density for the camps in Britain.

Statistical analysis of camps

Having calculated the areal size, numbers of humans, mules and horses for all 374 known marching camps we can now make use of modern topographical datasets to assist in identifying those features and parameters that the Roman camp surveyors thought suitable when choosing a camp site. In this manner we can try to understand what a surveyor was thinking of and what rules he was operating under as he examined the terrain his commander had chosen to advance over.

The primary topographic dataset is the Shuttle Radar Topography Mission (SRTM) with a grid spacing of 90 metres (see the background in Figure 1). Other publicly available datasets at 50 metre spacing were examined but these contained too much detail from the modern era (cities, towns, roads, rail, river alterations, field and drainage lineaments, etc.) which caused a wide range of errors in the processing conducted for this study. Conversely, the SRTM 90 metre spacing produces a relatively smooth topographic surface, largely removed of modern artefacts and can be classed as artificially naturalised, i.e. a gridded surface of topography lacking most of the human additions of the last 2000 years. Nevertheless, a higher definition dataset, devoid of modern attributes, would produce a set of results of finer detail. This observation pertains to all the work presented in this study.

Prior to all computations the SRTM 90 metre spacing was up-scaled to 50 metres which allows for higher definition in the measurements of distances associated with allied datasets, e.g. the precision in locations of the known marching camps. The primary software used in this study, SAGA (see resources above), was used to produce from the SRTM data the following grids of simple attributes for Britain:

1) Curvature (tangential) of the topography - curvature in an inclined plane perpendicular to the surface – a measure of flatness,
2) Openness of the topography – how much the camp would have been over-looked, e.g. a hill over-looking a plain – a measure of camp safety,
3) Ruggedness – the average elevation change between any point on a grid and its surrounding area – a measure of ground undulation or roughness,
4) The SAGA Wetness Index – calculation of soil moisture or saturation – a measure of water-logging,
5) Slope – the standard slope of a surface – a measure of camp drainage,
6) Topographic Position Index (TPI) - the difference between a cell elevation value and the average elevation of surrounding cells – a measure of the type of ground,
7) TPI land form – a classification derived from 6, the TPI – a measure of the type of topography,
8) Distance to Roman roads - a measure of suitability for advancing a campaign, or differentiation between standard manoeuvring and advancing to contact/battle.

Figure 9 is a montage of some of these attributes for the Kennet river catchment in Berkshire.

There are a large number of topographic indices and descriptors that could have been calculated, but those above were chosen for their simplicity and direct relationship to the likely thought processes of the Roman surveyor. Other indices may be calculated in the future if it is thought they provide further insights. Clearly missing in the list is any reference to rivers which will be dealt with in the next section.

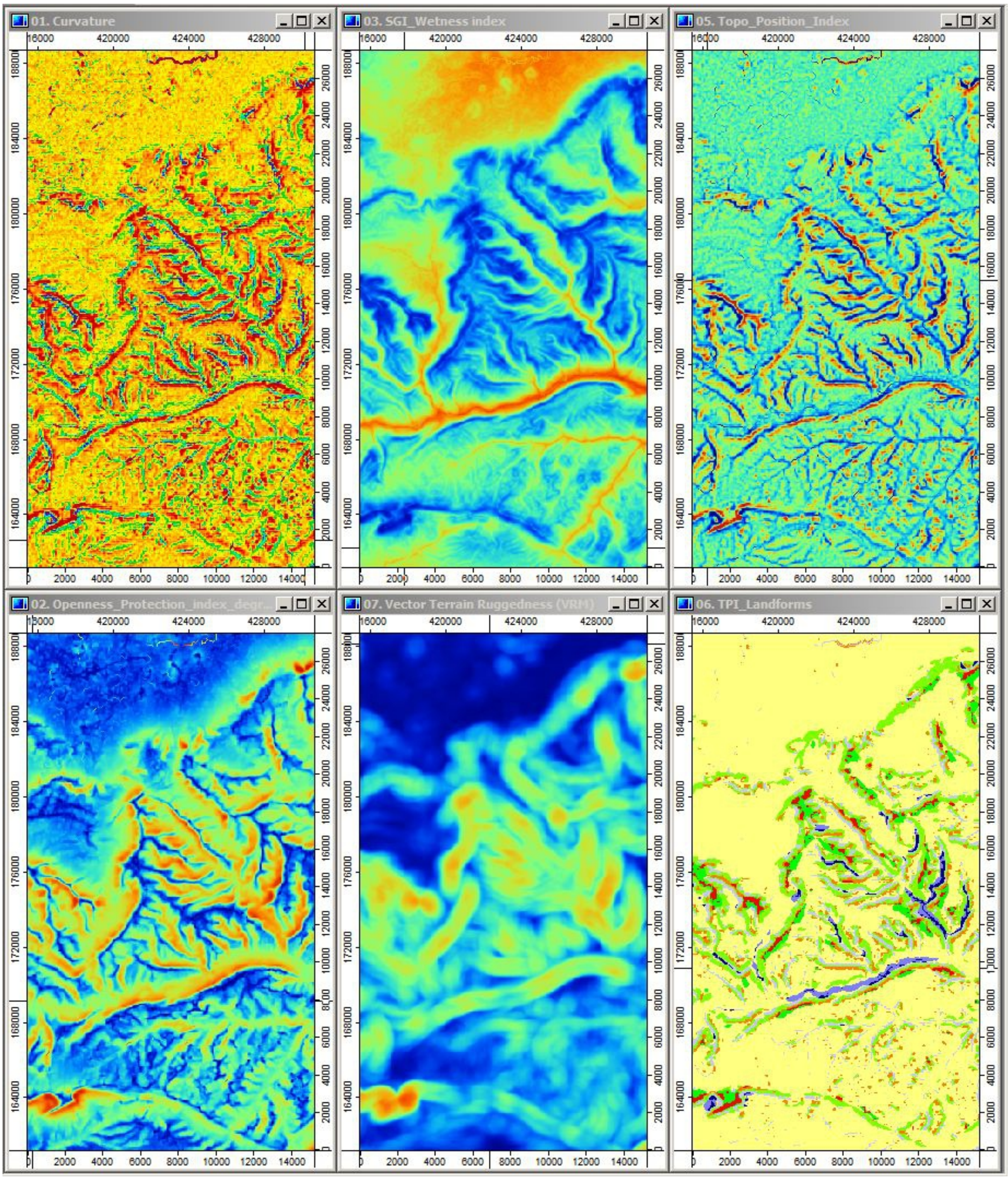

Figure 9: montage of computed topographic attributes for an area with in the Kennet river catchment. The attribute type, clockwise from top left, is curvature, SAGA wetness, topographic position index (TPI), TPI land forms, ruggedness and openness.

Water: calculation of supply and demand

What follows is a précis of the author's primary work on the water needs of the Roman army and the available water supply in Britain – the demand and supply. The full description of the work conducted on this subject can be found in:

Boudica-logistics.pdf (www.bandaarcgeophysics.co.uk/arch/boudica_logistics.pdf)

and the author's website at www.bandaarcgeophysics.co.uk/arch_intro.html .

The primary work concluded that the average soldier needed to drink at least 9 litres of water per day. This figure is for a marching, rampart and ditch digging, foraging and fodder collecting individual, weighted down by 43 kilograms of clothing and equipment, and operating at a temperature of 20-25ºC. In a temperate climate, i.e. a typical August day in Britain. The 9 litre/day figure does not include that required for cooking, washing etc..

Water requirement figures were estimated for hard-working mules and horses at 30 and 70 litres per day, respectively. Table 6 displays the water requirements for a Roman army of 10,000 soldiers plus supporting staff and beasts. Table 7 provides the total for the army from the values in Table 6, and displays the results in cubic metre per second (cumec) corrected for the available daylight in August (the assumption is that night-time collecting of water from rivers would not be allowed – too dangerous). The final figure of 0.00386 cumec was the minimum that the rivers adjacent to the camp would need to supply to match the demand.

	Soldiers	*Servants*	*Horses*	*Mules*
Number of	10000	2500	468	2500
Water required (litre/day)	9	9	70	30
Sum (litre/day)	90000	22500	32812	7500

Table 6: The water requirements of 10,000 soldiers, servants, horses and mules.

	Litres	*Cubic metres*	*Cubic metres/second*	*Cubic metres/second - daylight corrected*
Total Army water requirement	220312	220.31	0.00255	0.00386

Table 7: Total army water requirement: sums from Table 6 converted to cubic metre/second (cumec) and corrected for the available daylight in August.

The same calculations were conducted for all 374 known marching camps.

The next stage was to calculate the hydrology for the whole of Britain (Figure 10) which would ultimately indicate where the camps could have been sited alongside rivers with flow sufficient to satisfy the camp demand. Conversely, and equally importantly, the measurement of the river flows in August, the selected month based on the most probable high point of the campaigning season, indicates where marching camps of specific size would *not* be sited. This is not to suggest that marching camps were never placed in locations without sufficient water, but that would probably have been a choice borne of operational necessity, for example, occupying a hill-top in preparation for a localised skirmish or battle the following day. What is undoubtedly true, and for obvious reasons, is that army commanders do not habitually place their units in locations where there is a lack of water: to do otherwise is to court disaster.

The minimum calculation of river flows was limited to 0.0003 cumec because of the inherent inaccuracy of the calculation method at such low rates. Consequently, only those marching camps with a total water requirement exceeding 0.0003 cumec (307), continued in the study. Those removed have areas less than 1.15 hectares and contained less than 793 soldiers – approximately two cohorts at a density of 690/soldiers/hectare.

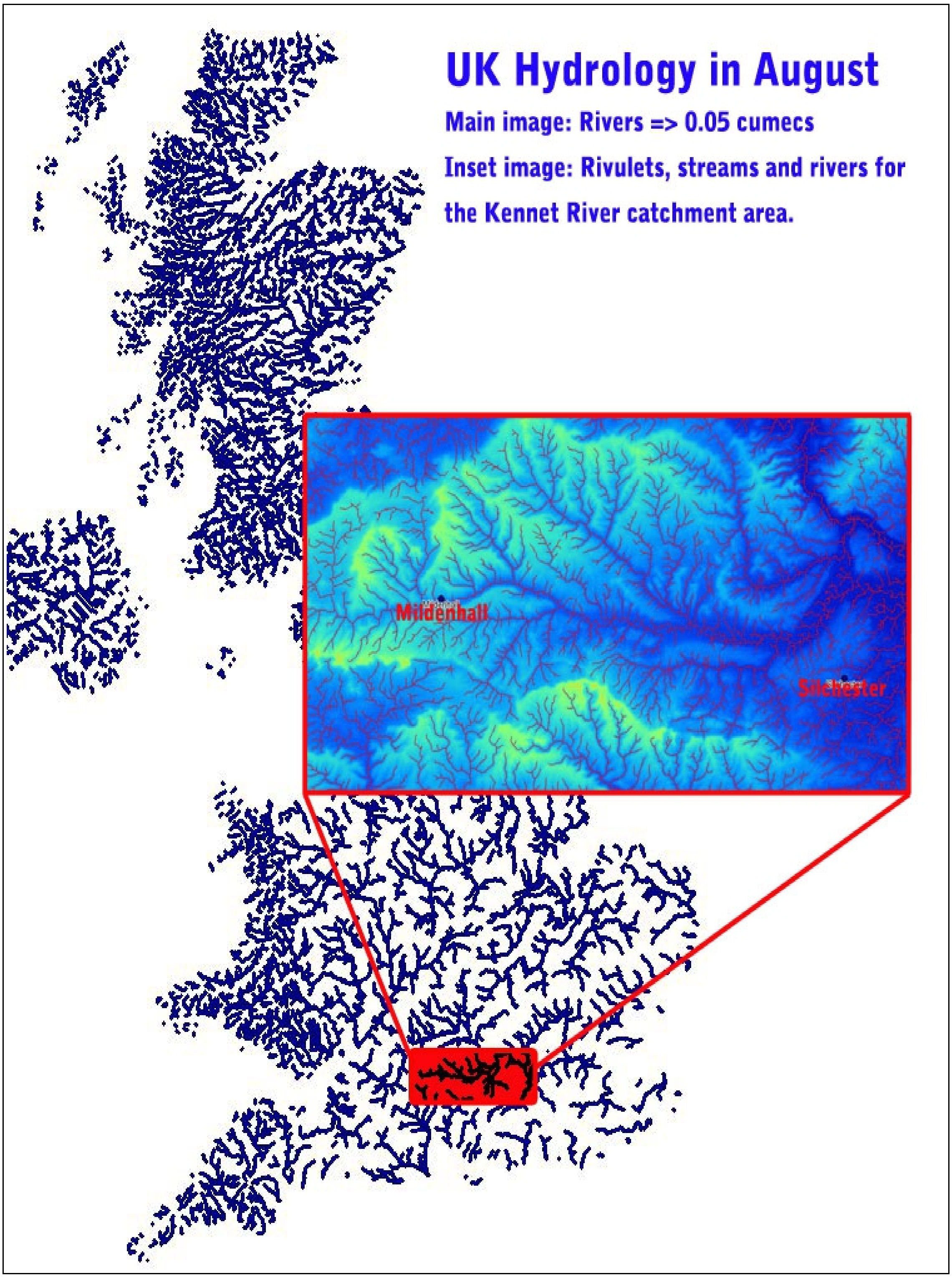

Figure 10: The computed, naturalised hydrology of Britain. Main image shows all rivers that have a flow greater than 0.05 cumec in August. The inset shows all rivulets, streams, and rivers for the Kennet river catchment in August.

Calculation of topographical and hydrological attributes for known marching camps.

Having calculated the grids for topographic attributes, e.g. curvature and slope, and the same for hydrology, e.g. river flow rates, the next stage was to use the locations and known boundaries of the remaining 307 marching camps to extract those attributes that pertained to each camp, and calculate suitable statistics from them. This was a relatively simple exercise, but one cluttered with computational and statistical detail which, it is felt, most readers would probably find tedious to read: for that reason we shall only examine a few key illustrative points.

As a reminder, this exercise was designed to discover some of the factors that a Roman army surveyor might have thought important when choosing the location of a marching camp.

Some attributes are important only within the camp ramparts; others maintain their importance some distance beyond. An example of the former is the ruggedness of the topography, which was used as a proxy for the amount of level ground within the camp suitable for the setting of tents. For the latter, the attribute of openness was determined for a set distance (buffer) around the camp. The openness is a measure of the tactical suitability of the camp, in the sense that a camp ground closely overlooked by a hill would offer an enemy the ability to spy and launch missiles. Therefore, a camp itself located on a hill and surrounded by lower elevation plains or valleys, is very open, i.e. very suitable for the Romans; conversely, a camp sited within, say, within Cheddar Gorge would have a very low openness for obvious reasons, i.e. it is very unsuitable.

An obvious set of attributes that nearly always required the examination of features external to the camp ramparts were those of hydrology; rarely do camps have substantial streams running through them. However, some do contain rivulets with flow rates less than the study's lower limit of 0.0003 cumec. The grid of river flow rates for the whole of Britain was examined around each of the 307 known camps at 50, 100, 200, 300, 400, 500, 750, 1000, 1500, 2000 and 3000 metre distances. Three kilometres might be considered an excessive distance from the camp, but it was chosen to include the possibility that patrolling cavalry might have used rivers at that distance to water their mounts. The added benefit is that some of the rivers at one, two and three kilometres are very large and hence form a barrier to enemy advancement. This factor has not been examined in this study as it is very specific to each camp, but may be in the future.

The total number of topographical and hydrological attributes is listed in Table 8. For the topographical attributes the value of each grid cell was found and the average, mode, median, maximum, minimum and standard deviation were calculated for the 307 camps. A similar exercise was performed on the hydrology cells but statistics were also calculated for both the river flow rate and the distance from the camp rampart to the river(s).

Attribute Type	*Attribute*
Topographical	Curvature
	Openness
	Ruggedness
	Wetness
	Slope
	Topographic Position Index (TPI)
	TPI land forms
	Distance to Roman roads
Hydrological	Height of camp above river
	River flow rates at 50, 100, 200, 300, 400, 500, 750, 1000, 1500, 2000 and 3000 metres
	Distances to first, second, third and fourth rivers
	Flow rates of first, second, third and fourth rivers
	Distance to the first river that supplies sufficient water to the camp
	Distance to the second river (and so on) that supplies sufficient water to the camp

Table 8: Attributes extracted and computed from the topographical and hydrological grids.

Distances of rivers from the marching camps

The examination of the hydrology surrounding the 307 marching camps allows insights into the use of rivers and streams by the Roman army surveyors. The large statistical dataset described in the preceding section can be further computed, resulting in some interesting observations. However, it should be remembered that the base topographical data (SRTM) is at 90 metre resolution which implies that the accuracy of distance measurements of a river to a camp is in the range of 45 metres, whereas, the reality was that rivers may have been closer, in some cases, than that reported in this study; some were also further away. However, because the SRTM data has been made hydrologically sound and naturalised, the reported distances to rivers and streams is in many cases superior to those that would be computed from high resolution, modern maps. This is especially true for smaller streams and rivers which, over the 2000 year history of agricultural improvement, particularly the use of drainage schemes, have either been removed or greatly altered. Nevertheless, a higher density, hydrologically sound and naturalised topographical dataset would produce higher fidelity results, that is, closer to the actuality seen by the Roman army surveyor.

The first set of observations relate to the general distribution of rivers and streams around marching camps. Table 9 and Figure 11 display the distance statistics for the closest river to a camp. Of the 307 camps, 139 (45.27%) have rivers within 50 metres of the rampart. A further 44 camps have rivers within 100 metres, giving a cumulative frequency of 59.61%. Continuing, we can see that almost 90% of camps have rivers within 300 metres. It might appear surprising that 10 camps have rivers further away than 750 metres but, I tentatively suggest, these camps may have a location more tuned to a local tactical need, e.g. occupying a hilltop to deny the enemy. Observations of this nature will be tested in work yet to be conducted.

If 59.61% of all the camps were placed within 100 metres of rivers, then the general observation that water supply was a critical consideration when placing the camps can be supported with confidence. Of course, water supply is not all that rivers provide. They also have defensive benefits and these can be compounded by a second local river, Table 10 and Figure 12.

Distance to 1st river	Frequency	Relative frequency	Cumulative frequency
50	139	45.27	
100	44	14.33	59.61
200	59	19.22	78.83
300	34	11.07	89.9
400	14	4.56	94.46
500	7	2.28	96.74
750	9	2.93	99.67
1000	1	0.3	100
1500			
2000			
3000			

Table 9: Statistics on the distances to the 1st river.

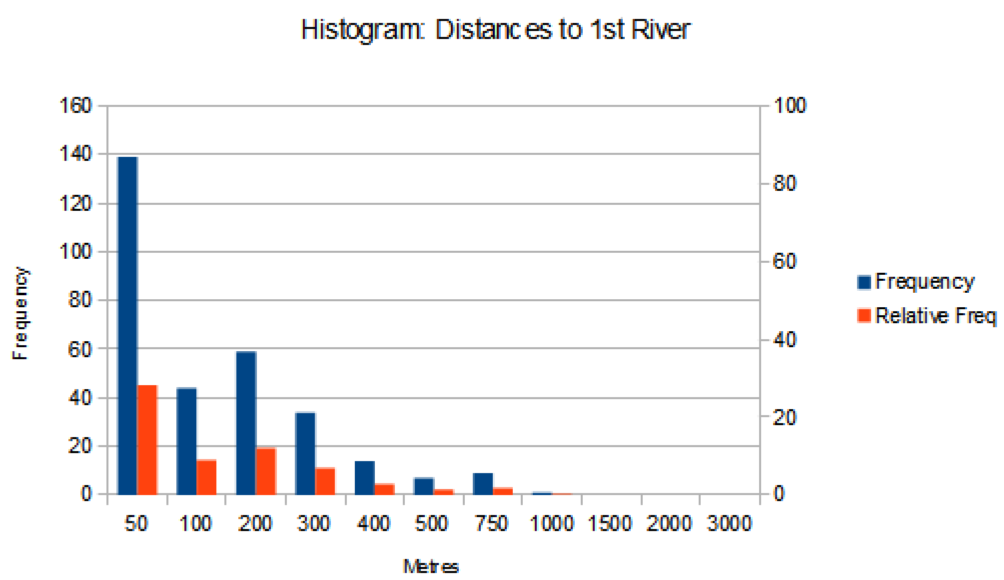

Figure 11: Histogram of distances to the 1st river closest to marching camps.

Distance to 2nd river	Frequency	Relative frequency	Cumulative frequency
50	0	0	
100	45	17.05	17.05
200	66	25	42.05
300	42	15.9	57.95
400	39	14.77	72.72
500	17	6.44	79.16
750	22	8.33	87.5
1000	16	6.06	93.56
1500	7	2.65	96.21
2000	8	3.03	99.24
3000	2	0.75	100

Table 10: Statistics on the distances to the 2nd river.

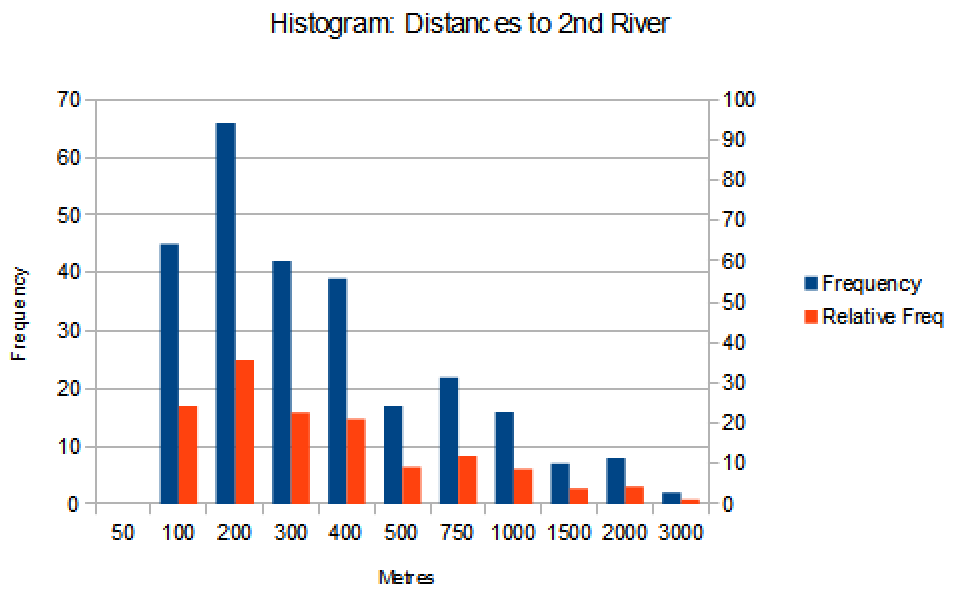

Figure 12: Histogram of distances to the 2nd river closest to marching camps.

Of the 307 camps under examination, 264 had a second river within the 3000 metre examination range. Given that range, and a wet country such as Britain, this is not surprising. More significantly, Table 10 shows that 42% and 72% of camps had 2nd rivers within 200 and 400 metres, respectively. Individual camps have not yet been visually examined, so no comment can be made regarding the flow relationship of the 1st and 2nd rivers, for example, if one is a tributary of another or they are two separate rivers. In either case, it seems probable that the camp surveyors were deliberately choosing sites bounded by at least two river courses and, in some cases, placing the camps close to the junctions of tributaries. The defensive qualities of such arrangements are obvious.

Please note that these apparently large distances to rivers might seem too far away from a camp but, of the 307 camps under study, 103 have boundaries in excess of 400 metres on at least two sides. Therefore, the scale of the camps and the number of men and beasts they contained, was large, thus requiring a similar scale for the supplied resources (water, pasture, forage and fodder) and the defensive qualities of the surrounding land and rivers. Additionally, the nature of Roman legionary warfare, when faced with tribal enemies, suggests that the daylight hours were relatively safe for the Romans. Under normal circumstances they could control the resource hinterland by the use of foot and cavalry patrols, such that they would have warning of an approaching enemy and be able to retreat to the camp, or form-up into a battle array. At night the hinterland was probably vacated by the Romans – hence the punishment of making units site their tents outside of the ramparts – and reclaimed each morning.

We can conclude the discussion of distances by noting that 205 camps have at least three close rivers and that 51% of those have a third river within 500 metres, Table 11 and Figure 13.

Distance to 3rd river	*Frequency*	*Relative frequency*	*Cumulative frequency*
50	0	0	0
100	0	0	0
200	16	7.8	7.8
300	31	15.12	22.93
400	26	12.68	35.6
500	32	15.61	51.22
750	33	16.09	67.32
1000	15	7.32	74.63
1500	24	11.7	86.34
2000	13	6.34	92.68
3000	15	7.32	100

Table 11: Statistics on the distances to the 3rd river for 205 of 307 camps.

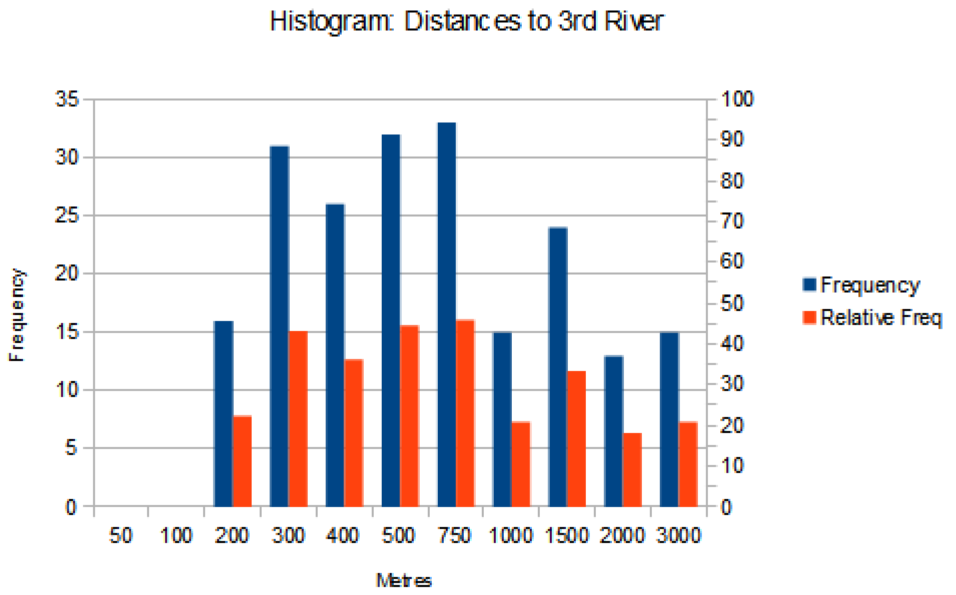

Figure 13: Histogram of distances to the 3rd river closest to 205 of 307 marching camps.

Some comments on the use of rivers

As already mentioned, the placing of marching camps close to multiple rivers and/or their junctions confers an obvious defensive benefit to the Romans. However, there may be other benefits, namely, the use of different rivers for different purposes.

Ancient writers and military officers of the 19th century describe, in general terms, the management of water resources by large bodies of soldiers and beasts. It is advised that the soldiers should extract water for drinking and cooking purposes from the upper reaches of the river. Further downstream the soldiers should use the river for bathing and laundry washing. Lower reaches of the river course are the preserve of the horses and, in the case of a Roman army, the mules. If cattle are being driven with the army, then they should make use of the lowest reach, as they are prone to destroying river banks and muddying and fouling the river. In many accounts it is noted that horses can be difficult, even fussy, about the quality of their drinking water and may require preferential drinking arrangements; mules, being generally more robust, will drink from contaminated water and should be watered below the horses.

Therefore the following string indicates the order of water use (> represents further downstream) :

soldiers drinking and cooking > soldiers bathing and laundering > horse > mules > cattle.

The availability of multiple rivers adjacent to camps offers the possibility of separating the soldiers' use of rivers from that of the beasts, i.e. one river for soldiers, another for horses and possibly another for mules and cattle. This, or similar arrangements, clearly confers benefits to all occupants of the marching camp, but especially the soldiers. Variations of the general scheme can be envisaged; for example, in large camps with many thousands of soldiers, they may have used two rivers while the beasts used another, probably the most distant river they encountered as they were led to grazing.

There is another use of rivers by soldiers that may have occurred - to flush latrines. It is well documented that the Romans used water flows to flush their communal latrines in forts, towns and cities. Although no evidence has yet been found for such use in marching camps, surely it would not be surprising if such were found.

It is worthwhile examining the effluent problem in some detail. A study of civilians in the 1960s produced the first recorded figures on the quantity of human effluent. Unfortunately, the author is not aware of a similar study for active soldiers who require considerably more energy and hydration, with concomitant effluent output, than the average civilian. Nevertheless, we can use the civilian figures to gauge the effluent problem relating to a large marching camp, but also remembering that the figures are considerably underestimated. Hence the study showed that civilian men produce an average of 0.498 kg of solids per day.

Using these figures and applying them to the Newsteads V marching camp (approx. 60k humans at a density of 690/hectare) gives a figure of 37.87 metric tonnes of solids each day which is 265 tonnes a week. As a means of putting these numbers in perspective, this is the weight of 18 London double-decker buses. By volume the solids occupy 37.97 cubic metres each day (Figure 14) and 265 a week.

Figure 14: This trailer has a rated volume of 38 cubic metres, i.e. the same volume of solids produced by 60,000 humans at Newsteads V *each day.*

Clearly, managing the amount of solids produced was a considerable problem, especially so when the marching camps might have been occupied for days or weeks at a time, and re-occupied by varying force-sizes during and after that year's campaigning. We can examine the management issue by relating these production figures to studies conducted by the US Army.

The US army has conducted measurements of the use of a standard 'straddle-trench' latrine, where after use the soldier covers and in-fills the deposit with soil. If the fill ratio of the trench is 75% soil and 25% human solids, then Newsteads V would have needed 548 trenches each day, covering an area of 601 square metres. For a week, this is 3836 trenches covering 4207 square metres or 0.4207 hectares.

To-date none of the pits etc. located within the ramparts excavated in Britain has shown evidence of latrine use. However this does not mean that they did not exist as the remains may have been destroyed over time. Nevertheless the size of the management issue suggests that the latrines were probably located outside the camp but close enough to be readily guarded during the day by patrolling foot and cavalry. Of course, there would have been a need for some latrines within the camp to accommodate any night-time needs.

The amount of continuous effort needed to dig and maintain the large number of latrines, the local proximity by choice of numerous rivers and streams, and the known expertise with which the Romans elsewhere managed effluent by water flow, suggests the possibility that the rivers and streams near camps may have been similarly utilised. Might the camp occupants have simply dug a trench sub-parallel to a river or stream then connected it at either end to allow water to flow through? Simple, effective and well within the engineering capacity and capability of the Romans. And of course, choosing a single river for waste disposal, while using others for water extraction and drinking, literally carries away the possibility of noisome fouling of the camp and grounds, and diminishes the possibility of disease transmission.

It should be made quite clear that there is no evidence, written or otherwise, to confirm this hypothesis but, given the Roman predilection for soldierly-cleanliness and their keenness for engineered solutions, it seems to this author to have merit.

Water: the matching of demand and supply

In this section we shall examine the water requirements of all of the humans and beasts occupying the camps and the water available from rivers and streams, i.e. the demand and supply.

Having used a density of 690 soldiers/hectare, assessed the number of beasts present by commonly accepted ratios, and knowing the water needs of each, we can calculate the total water requirement for each of the 307 measured marching camps (example in Tables 6 and 7), that is, the demand.

The supply side was calculated individually for each river and stream adjacent to the camps out to a distance of 3km. Knowing the distances to, and the supply from, each river allowed the calculation of cumulative supply rates. From these relatively simple statistics some interesting observations can be made.

Of the 307 camps, 23.78% receive their total demand within 50 metres of the ramparts: 37.46% within 100 metres, 63.84 within 200 metres and 78.16% within 300 metres (Table 12 and Figure 15).

Distance to river(s)	*Frequency*	*Relative frequency*	*Cumulative frequency*
50	73	23.78	0
100	42	13.68	37.46
200	81	26.38	63.84
300	44	14.33	78.16
400	30	9.77	87.94
500	16	5.21	93.16
750	13	4.23	97.39
1000	6	1.95	99.35
1500	2	0.65	100
2000			
3000			

Table 12: Statistics on the distances to the river(s) that totally supply the camp demand.

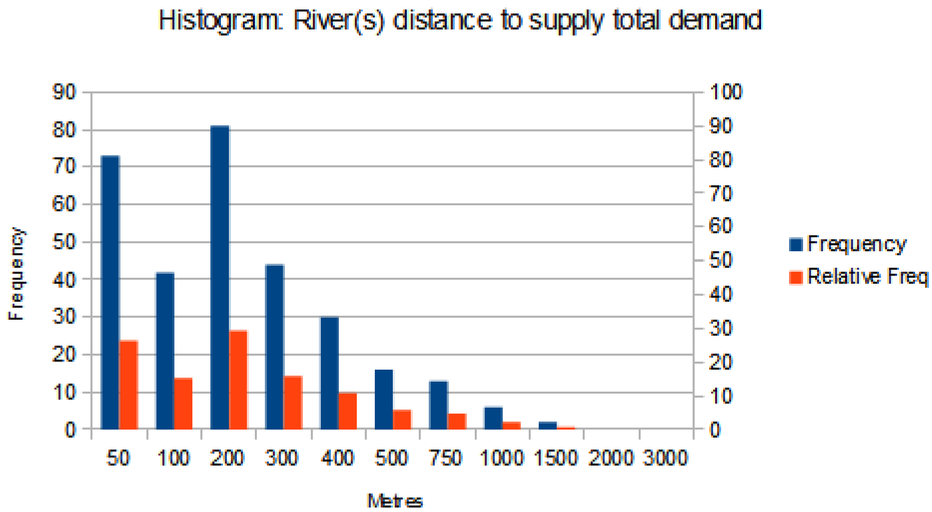

Figure 15: Histogram of distances to the river(s) that totally supply the camp demand.

These statistics again support the observation that the Roman surveyors were placing their camps close to rivers and streams, and that they probably had some method of estimating the supply capacity of the local water sources and matching this to the demand. One might be tempted to think that the statistics simply indicate the obvious, that of course the Romans placed their camps next to rivers that would supply enough water. However, the surveyors selection of sites appears to have been more complicated than that. For example, if water supply was the prime consideration then one might expect the camps to have been placed alongside a river that totally supplied the demand, but Table 12 and Figure 15 shows this was not the case. Other factors were certainly being taken into account, such as the need to use the rivers and streams for defence, the need to distribute the water supply for soldiers and beasts along different water courses, and the acceptance that during the night the camp hinterland and rivers would be no-go areas but reclaimed each morning as the patrols pushed outwards the area of direct Roman control. In other words, the overall defence of the camp may have been deemed more important than the easy, close access to sufficient water. However, it should be remembered that the construction camps for the Antonine and Hadrian walls that are included in this study were probably located primarily for their purpose. For the rest, no doubt other factors in location played an important role, as we shall investigate.

The balance between water supply and other factors is further emphasised by examining the frequency of the closest and second-closest rivers in supplying the total demand (Tables 13 and 14, respectively). Of the 307 camps under examination, there are 194 closest rivers which satisfy the demand of which: 23.78% of the 307 are within 50 metres; 33.22% within 100 metres; and 55.05% within 300 metres. Similarly, there are 72 camps of the 307 which, when the supply from the closest and second-closest rivers are combined, supply the totality of demand, such that: 3.26% are within 100 metres; 13.03% within 200 metres; and 17.91% within 300 metres.

Distance to river	*Frequency*	*Pop. Relative frequency*	*Pop. Cumulative frequency*
50	74	24.1	
100	31	10.09	34.2
200	44	14.33	48.53
300	23	7.49	56.03
400	11	3.58	59.6
500	5	1.62	61.23
750	8	2.6	63.83
1000	1	0.33	64.17
1500			
2000			
3000			

Table 13: Frequency statistics on the closest river that totally supplied the camp demand.

Distance to river	*Frequency*	*Pop. Relative frequency*	*Pop. Cumulative frequency*
50			
100	11	3.58	
200	31	10.1	13.68
300	15	4.89	18.57
400	11	3.58	22.15
500	2	0.65	22.8
750	1	0.33	23.13
1000	3	0.98	24.1
1500			
2000			
3000			

Table 14: Frequency statistics on the closest and second-closest rivers that, in combination, totally supplied the camp demand.

Further examination shows that the closest and second-closest rivers, that either singularly or in combination provide enough water to match the demand, account for 271 of the 307 camps, i.e. 88.27%. Necessarily therefore, 36 camps (11.73%) require the water supply from a third river (31 camps or 10.09%) and a fourth (5 camps or 1.63%) to match the full demand of those camps (Note: a maximum of only four rivers per camp were differentiated in this study; there may be more). The 31 camps that required the use of a third river, all of which lie with the range 200 to 1500 metres from the camp ramparts, suggests that these may have been more sensibly used to water the beasts. This may also be true of the fourth rivers but, at only 1.63% of the total camp population, the water demand and supply calculations border on the unsupportable.

In the quest to discover what it was that the Roman surveyor was thinking of when examining a landscape and rivers, use can be made of the statistics that describe the water required for a camp and the numerical difference compared to that supplied by the rivers. In this way an estimate can be made of by how much the surveyor thought the river capacity should exceed the demand (with the assumption that a surveyor would not have chosen a camp site along side a river(s) that supplied less than was required. However, exceptions may have been made for tactical reasons).

Taking the figures for total water demand per camp, at a density of 690 soldiers/hectare as the base percentage value, then the percentage difference between the demand and supply from the river(s) can be expressed, Table 15 and Figure 16.

% Difference or excess	Frequency of excess	Relative frequency	Cumulative frequency
=< 0.0			
10	5	1.63	1.63
100	44	14.33	15.96
1,000	83	27.04	43
10,000	75	24.43	67.43
100,000	76	24.76	92.18
1,000,000	21	6.84	99.02
10,000,000	3	0.98	100
	Total camps 307		

Table 15: Statistics on the percentage difference or excess between the demand and supply. The excess is expressed as a percentage above the base, the water demand of the camp.

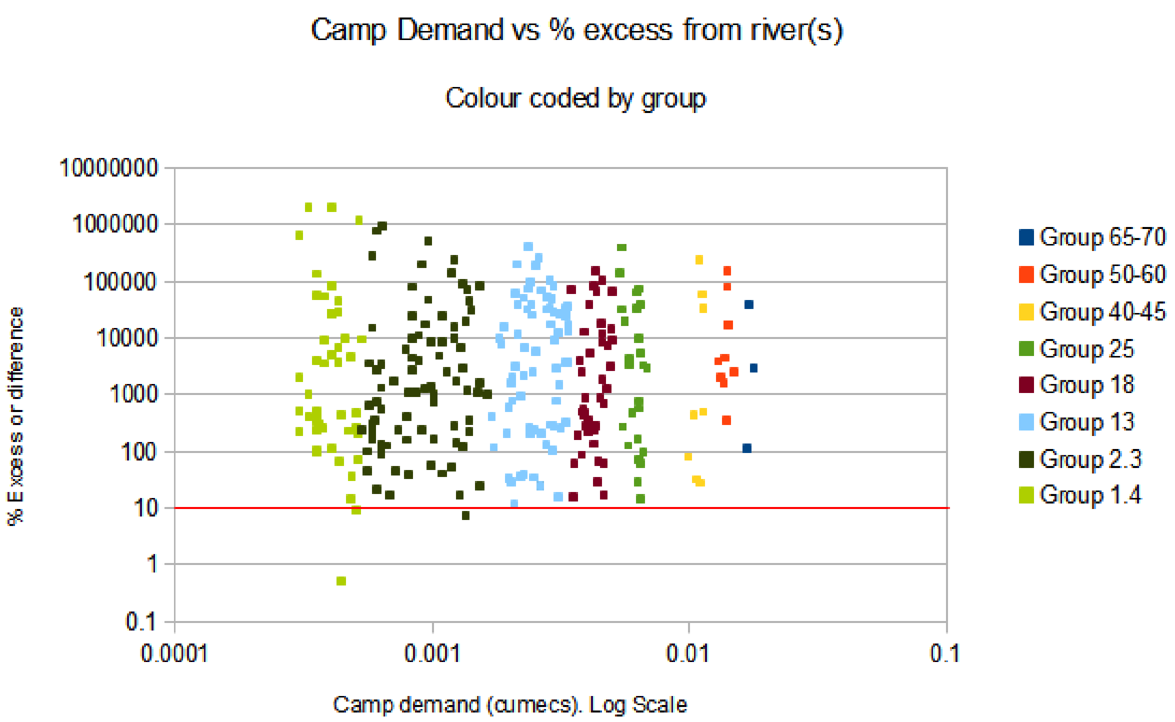

Figure 16: Plot of the percentage difference or excess between the demand and supply. Log scale on both axes. Elements of this image are © Crown Copyright. All rights reserved 2013.

Figure 16 shows a number of interesting features. There is an obvious rectangular block-like nature to the individual groups; re-confirmation of the earlier work to define the groups; the constrictive tapering, top and base, of the range of excess as the camp demand increases; and the presence of filaments of camps within the whole block of data. Of course, the rectangular nature and re-confirmation of the earlier work are consequential on using the area and length of the sides of the camps to define the groups: not so the tapering and filaments.

The constrictive tapering at the base is probably the product of camp surveyors being more careful when selecting ground for large forces. It would be one thing to inconvenience, by a lack of adequate water, a camp housing a few cohorts, but quite another (and likely more career-limiting) to cause extreme annoyance for camps housing multiple legions and the Emperor Severus. In other words, the larger the force, the more conservative the surveyors the surveyors may have become in camp selection. However, it should be mentioned that the larger the Roman force, the larger the camp-site required, and these are more likely to be found in valleys with large rivers.

The filaments are probably due to a number of factors. Firstly, the natural consequence of a string of camps within a single river valley; secondly, a single Roman unit moving within one river valley and eventually rendezvousing with a second unit, either within the original river valley or a major tributary junction; and thirdly, the preferences of a particular surveyor. At this point in time, none of these features has been examined in detail because the computational exercise is rather complex. However, it would seem that there are some interesting, possibly enlightening, insights to be revealed.

However, there is one feature within Figure 16 that can be readily identified, namely the obvious line (marked red) at the 10% excess mark on the Y axis that can be drawn under the block of data. In Table 15 it can be seen that only 5, or 1.63% of the 307 camps, are situated below the 10% excess line. Conversely, and stating the obvious for emphasis, 98.37% of all camps had rivers that always supplied an excess greater than 10% of what was demanded. But there is a complication. The numbers presented in this study are for August, the driest month in many parts of Britain, but neither history nor archaeology can definitely state the month of occupation for a camp. If some of the camps situated below the 10% excess line were occupied during the Spring or early Summer, then the adjacent rivers would probably have supplied more water than the statistics show. This means, of course, that those camps would occur further up the block of data in Figure 16.

The significance of the seasonality of the camps becomes clear when the object of the study is to understand what the Roman surveyor thought was the minimum excess required for the location of any camp. Did the surveyor think a 10% excess was sufficient? As we have just discussed, some of the camps are falsely located too low on the Y axis because of seasonality, i.e. their excess is falsely suppressed because the hydrology study is based on calculations for August. Additionally, it is suggested that the Roman surveyor would have been rather brave to select a camp location next to a river that only supplied 10% more than the camp required. It is easy to envisage such a river being dangerously drained, to the extent that it became a muddy morass, or a decrease in the average rainfall for the season dipping the supply below that required.

For these reasons it is thought the answer to the question posed is “No!” It is more likely that the surveyors chose as a minimum rivers that could supply twice as much water as was demanded, i.e. the 100% excess mark on the Y axis, Figure 16. In the following sections these 100% numbers have been used to predict the location of camps throughout Britain.

In comparison, the excess figures for the 307 camps but for a density of 1186 soldiers/hectare are shown in Figure 17. There are 10 camps, or 3.26% of the total, below the 10% excess line, which is approximately double that for a density of 690 soldiers/hectare. Accepting the points made above about seasonality, one could argue that this disparity further supports the conclusion that the lower density is closer to the reality. This may be correct but the overall computational resolution of the data also requires caution when dealing with such a crucial statistic; further work is required.

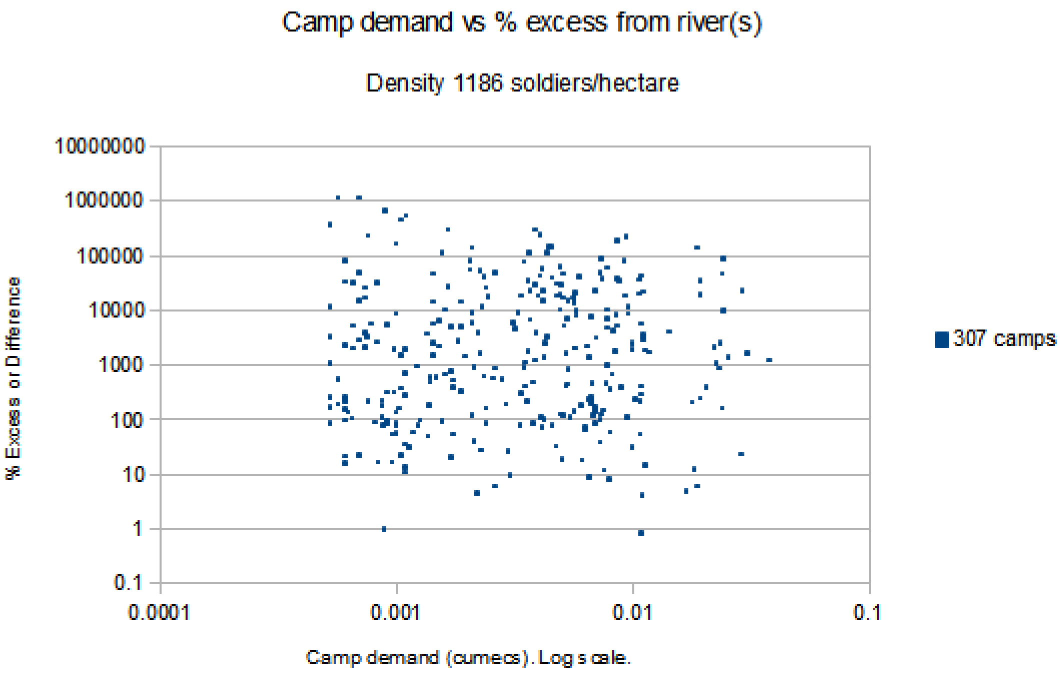

Figure 17: Plot of the percentage difference or excess between the demand and supply for camps with a density of 1186 soldiers per hectare. Log scale on both axes.

Further words of caution regarding these data are thought important. As already noted, the statistics are primarily based on the SRTM 90 metre topographic dataset or grid, and this limits the resolution of the calculations presented to gain information and insights about the camps and rivers. However, these results do merit comment and do provide the first systematic view of the Roman marching camps throughout Britain. The author is not aware of a similar study. Nevertheless, this study should be viewed as a 'first attempt' and would be greatly improved by the use of higher resolution data, especially that of an hydrologically sound topographical dataset.

Although further statistics on the rivers adjacent to camps could be calculated, the author will spare the reader from more figures. Suffice it to say that much more can be gleaned about the Roman use of rivers and, it is hoped, that will be so in the future.

Prediction of marching camp locations in Britain

Having computed and examined the statistics for the known marching camps and the hydrology of Britain, a description can now be given of the steps taken in the use of these data to predict where in the rest of Britain Roman marching camps may have been sited.

Step one: Calculating various attributes (Section: Calculation of topographical and hydrological attributes for known marching camps**)** for each camp within a group (section: Grouping of the camps), and then applying suitable statistical analysis allowed the computation of the range, e.g. minimum and maximum, of attributes applicable to that group.

Step two: This range was then applied to the UK-wide attribute grids produced earlier (section: Statistical analysis of camps**)**, essentially clipping, or limiting, the grid values to the group range, thereby creating a group-attribute-grid. Those grid nodes that did not coincide with the group range were set to null; those within the range were set to one.

Step three: All of these group-attribute-grids were then summed, resulting in a hot-spot grid (there are other more technical descriptions available, but the term hot-spot adequately describes the resulting grids). The hot-spot grid has high values where multiple group-attribute-grids coincide in location, grading to lower values and finally null values where no camp attributes within that group are present, Figure 18.

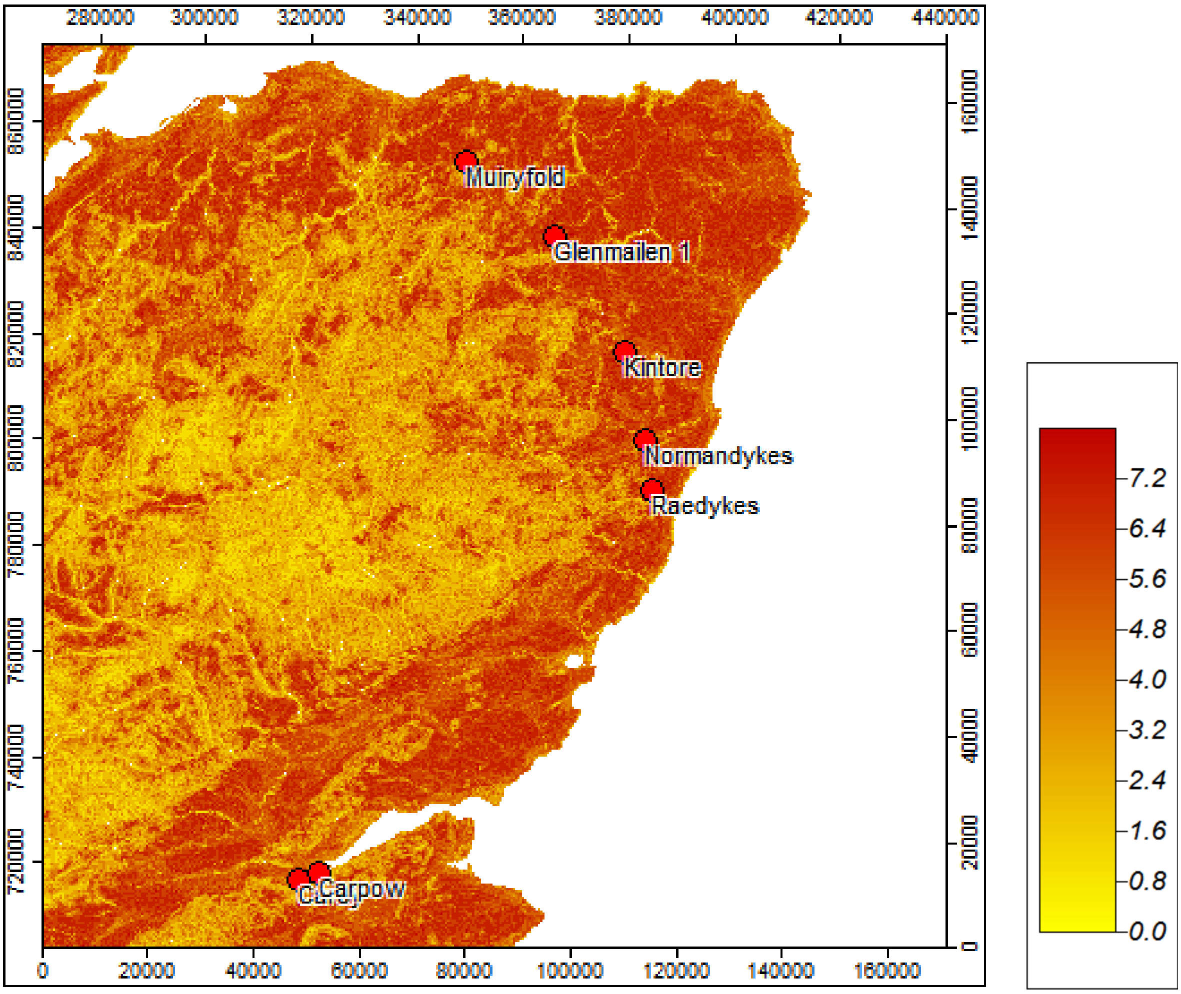

Figure 18: Example hot-spot map for Group 40-45. High values, the red colours, are areas where multiple attributes sum to form hot-spots.

Step four: There was a need to have a measure of the group's maximum distance to the nearest river(s) that supplied adequate water, i.e. to find the probable distance that the Roman surveyor thought was too far away. To calculate this measure the group mean of the distance of the camp boundaries to their river(s), that matched the supply with the demand, was summed with the standard deviation of the same, and to this value added the length of the longest side of the camp, Table 16, column 2. The distance was then used as a boundary from the river, beyond which the values in the hot-spot grids were set to null; i.e. the distance beyond which the Roman surveyor would probably not have sited a camp.

Groups	*Max. distance (metres|) to rivers supplying sufficient water*	*Group value (cumecs) required to satisfy the camp demand*
Group 65 - 70 hectares	1300	0.035458
Group 50 - 60 hectares	1365.8	0.029683
Group 40 - 45 hectares	1434.26	0.022592
Group 25 hectares	1260.65	0.013670
Group 18 hectares	1253.17	0.011144
Group 13 hectares	951.91	0.006737
Group 2.3 hectares	686.34	0.005242
Group 1.4 hectares	692.19	0.002026

Table 16: For each group, the maximum distances to rivers supplying sufficient water (column 2), and the river flow value thought to be a minimum required for the location of a camp in cubic meters per second (column 3). Elements of this image are © Crown Copyright. All rights reserved 2013.

Step five: For each group the maximum value of the total water requirement for all humans and beasts was doubled (Table 16, column 3) to match the findings in the **section: Examination of the water supply,** wherein the 100% value, or twice the required demand, was thought to represent the value most likely to have been the lower limit a Roman surveyor would seek in a river supply. These double values were then applied to the hydrology of Britain to remove all streams and rivers that exceeded the group value. In turn, these clipped rivers and streams were applied to the grids calculated in step four, such that all cells beyond the remaining streams and rivers were set to null. Finally, any summed grid cells remaining that were occupied by streams and rivers were also set to null; this allows the viewing of water courses that would have limited the local placing of camps, there being few known camps with internal streams, and they are minor; see Figure 19 for an example of the output.

These five steps combine all of the measures previously described in this essay and allow the production of maps for the whole of Britain indicating the weighted, probable locations where Roman surveyors might have sited their camps. Figures 20 and 21 show these locations for groups 65-70, 50-60, respectively. Unfortunately, because of the size of the maps, their resolution is greatly diminished in this document. However, readers may download higher resolution Tiffs for all the groups from the author's website at www.bandaarcgeophysics.co.uk/arch/roman_marching_camps_uk.html .

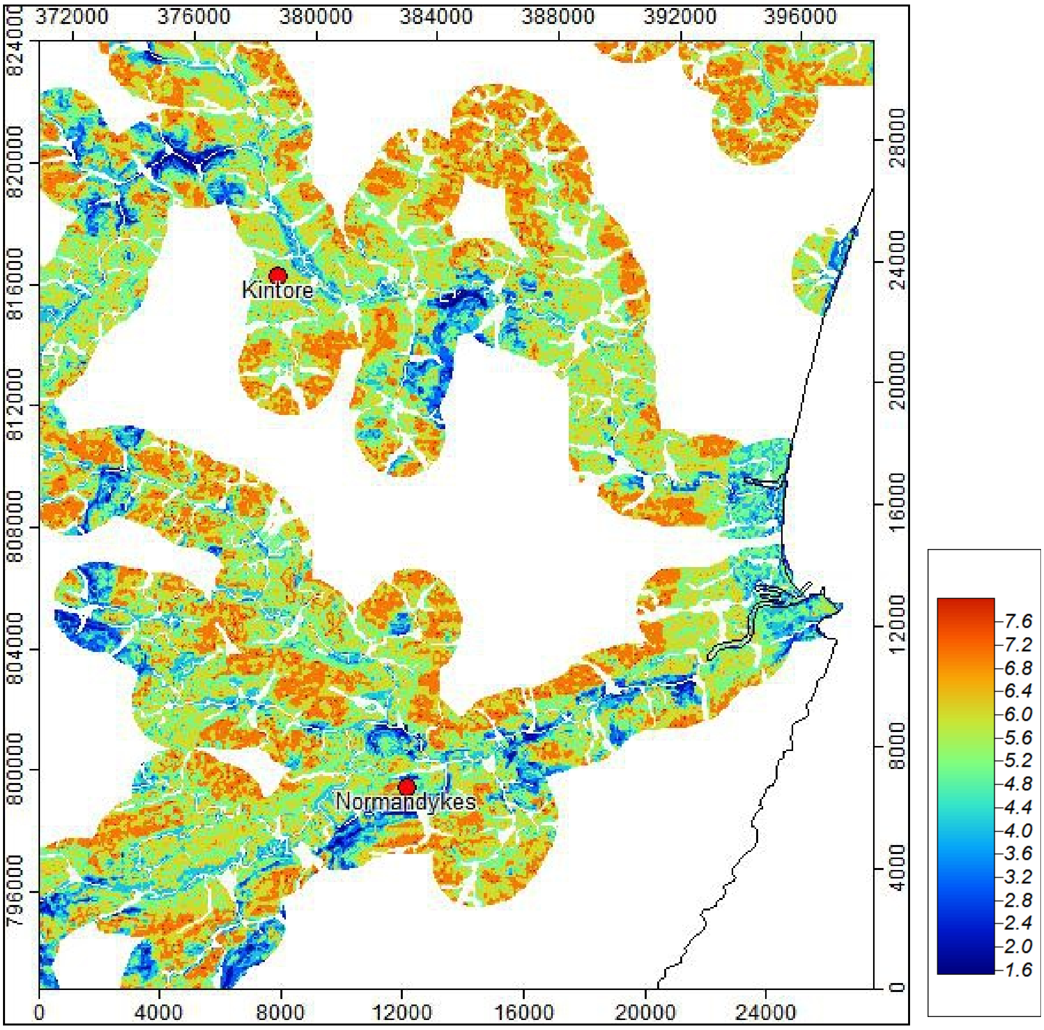

Figure 19: Example of the final grids after the application of steps 1 to 5. The example area is on the east coast of Scotland, and displays the two Group 40-45, marching camps of Kintore and Normandykes. High values, the red colours, are areas where camps are more likely to have been located. Elements of this image are © Crown Copyright. All rights reserved 2013.

Figures 20 and 21 contain a large amount of information about the distribution of known camps, and where unknown camps may have been located. In an effort not to overload this essay, which is primarily designed to cover the method employed, these and other insights will be written about in future essays. However, a few comments covering some general observations are appropriate.

First, the blue to light green areas in Figures 20 and 21 can be viewed as 'no-go' areas for camps of these sizes, i.e. places where the statistical analysis of the known camps suggest the Roman surveyors were unlikely to have placed camps. Clearly this is true for much of southern Scotland and the highland interior, together with much of Wales and, to a lesser extent, the south-west of England. But the low resolution of these particular images hides some suitable camp sites within these more rugged areas, i.e. it is possible that the Romans could have advanced large armies through these regions. This is a large topic, and of some importance to Roman archaeology, and the detail will be dealt with in future essays.

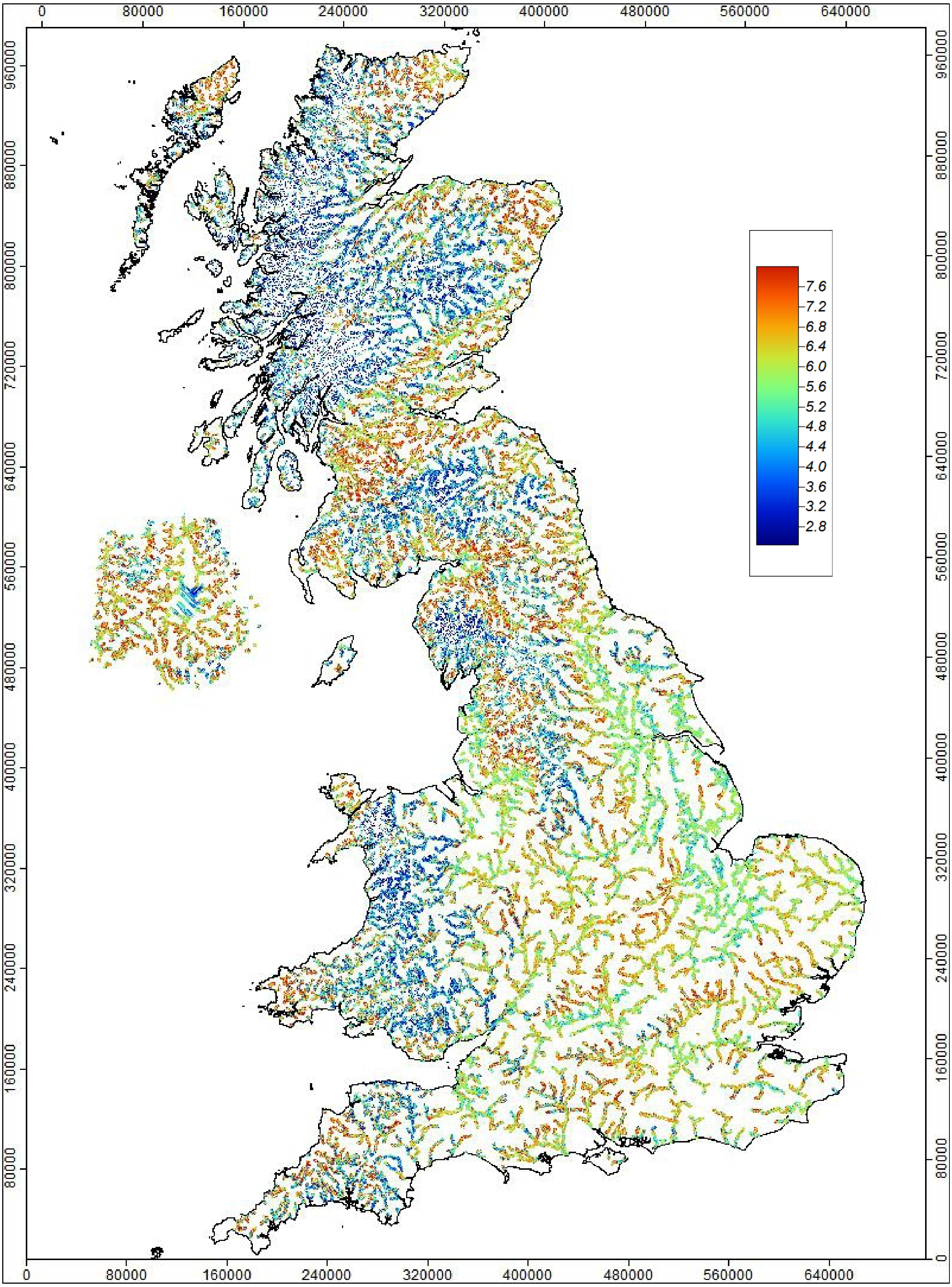

Figure 20: Possible Roman marching camp locations in Britain for the Group 65-70 hectares. The blue to light green areas are locations which do not match the attributes well for known camps and are less likely to have been selected. Yellow to red areas increasingly match the attributes of the known camps and are more likely to have been selected.

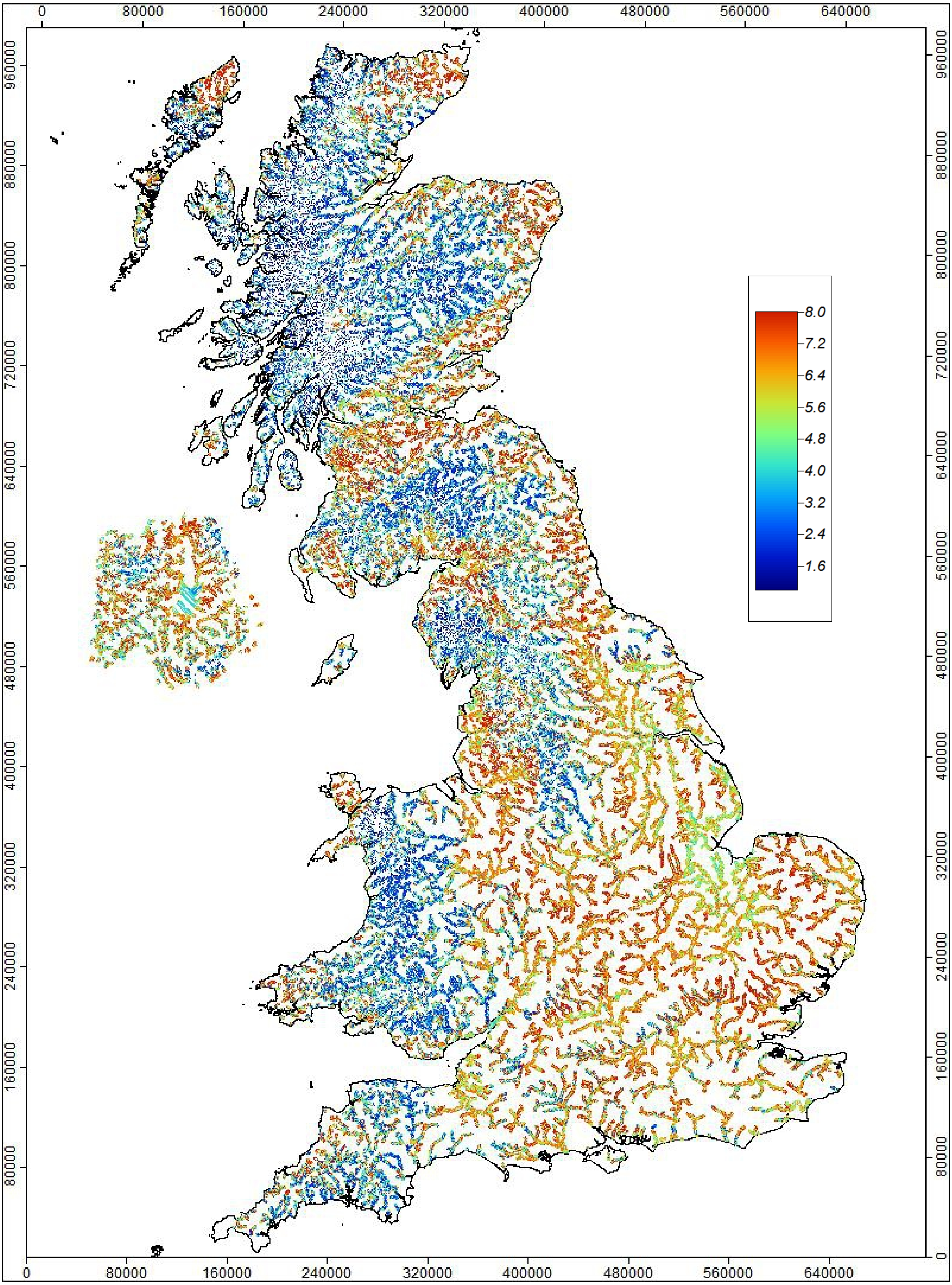

Figure 21: Possible Roman marching camp locations in Britain for the Group 50-60 hectares. The blue to light green areas are locations which do not match the attributes well for known camps and are less likely to have been selected. Yellow to red areas increasingly match the attributes of the known camps and are more likely to have been selected.

Secondly, the south and south-east of England is a relatively dry area and river flows are correspondingly low, and with therefore a limited capacity to satisfy the needs of large armies. The result is that the density or frequency of suitable rivers in southern England is low in comparison to, say, Scotland or Wales. Consequently, the density of strings of possible camp locations in Kent, Surrey and Sussex is far lower than regions further west and north. This simple, some might say even obvious, observation has implications for the account of the Roman invasion of Britain in 43AD, which will also be explored in a later essay.

Thirdly, from the location of camps and roads it is apparent that the Roman army traversed Britain either by direct march along suitable river valleys, or placed roads and camps so that army units journeyed from one river valley to the next. A classic example is that part of Akeman Street that joins Cirencester with Bicester (more properly the vexillation fortress at *Alchester*), see Figure 25. Additionally, in largely unfavourable landscapes that are inimical to marching units, by the standards defined in this study, the Romans may have sought infrequent but suitable camp sites, and used these as stepping-stones to advance.

Fourthly, it might be thought when viewing Figures 20 and 21, and the intersections of camp site locations, Roman roads, forts and towns, that the Romans in Britain had a fundamentally sound appreciation of the topography and hydrology of the island. It appears that this understanding allowed the Roman military to move across, and reside within, the landscape in a manner probably not emulated again until the modern era. There will have been local considerations for the placing of camps, forts and the like, but this study suggests that there may have been an overriding understanding and plan for the whole of Britain, possibly a plan first promulgated before the original invasion with information supplied by traders etc. and the earlier invasion of Julius Caesar. What is clear from the distribution of known camps, roads, etc. is that the Romans did not advance their campaigns into hostile territory without foreknowledge of the allowable possibilities within the constraints imposed by the terrain and hydrology. In emphasis, a present-day graduate of The Royal Military Academy Sandhurst might have a lot of knowledge and understanding in common with a Roman army surveyor or senior officer.

Many more generalised observations could be written but time and space preclude, so we now turn to the amalgamation of marching camp and hydrology data with another Roman army infrastructure, namely, Roman roads.

The amalgamation of marching camps, hydrology and Roman roads.

The Roman road system known today is the result of a mixture of military and civilian needs, Figure 22. This is especially true for England but less so for Scotland and Wales. Indeed, it can be argued that all Roman roads in Scotland, as few as have been found, are solely due to the military. Self-evidently the distinction between military and civilian use is important in the present study but, for this 'first attempt', the two provenances have not been differentiated in the computations discussed in the following passages.

To put the roads in context we shall examine their initial raison d'être. Roman army commanders planned their tribal-conquest-campaigns on controlling the terrain, the indigenous but non-military people (those who produced the foodstuffs) and critical navigation pinch-points (passes, fords, navigable river intersections and the like). Typically, they operated in the lowland areas of the tribes to be conquered. This last point is not meant to imply that Roman units did not advance to some form of engagement in upland areas, but that would have been a secondary strategy followed after establishing control in the lowlands. In general terms, the Romans conquered tribes by firmly establishing their lines of advance, in expectation that the tribes would engage the whole army in battle. If not, then they controlled the productive land, starving and debilitating the warriors, and then engaged them either en-masse or piecemeal within the margins of the controlled area, the uplands or other non-productive regions: i.e. advance, control and then conquer.

Support for this concept comes from Frontinus, a Roman writer of the 1st century AD, when he supposedly quotes Julius Caesar: "*I follow the same policy toward the enemy as do many doctors when dealing with physical ailments, namely, that of conquering the foe by hunger rather than by steel";* a reference to the policy of controlling supply and support to the warriors.

Necessarily, the main Roman advance would have been by the river valleys or broader lowland areas with rivers capable of supplying the main army. This form of advance is exemplified by the routes taken in Scotland (Figure 22) where most roads have been found skirting the upland and highland regions. (As an aside: other roads within the higher ground may have existed but have not been located yet. The same may be true of much of Wales and parts of England, especially the south-west).

Figure 22: Roman roads of Britain, military and civilian undifferentiated. Sources: Royal Commission on the Ancient and Historical Monuments of Wales, Royal Commission on the Ancient and Historical Monuments of Scotland and English Heritage. Elements of this image are © Crown Copyright. All rights reserved 2013.

Of course, wherever the main Roman army advanced it built marching camps and, because of the need for rapid and secure supply, communication and reinforcement, it linked the camps by road. This leads to the main supposition of this section; places where streams and rivers with sufficient flow to satisfy the army unit's demand are intersected by roads would have been a very favourable location to build a marching camp. However, there are complications.

The primary source of complication arises from the simple fact that an army advancing into unconquered territory does not move as quickly as one moving through an already conquered land, where the infrastructure of roads and pre-existing camps is already in place. This observation is further complicated by realising that the speed of advance into hostile land is greatly determined by the size of the army: larger equals slower. These factors are the simple consequence of moving bodies of men and equipment from camp-to-camp during daylight hours and, crucially, without a pre-existing road. Of course, there were other contributing factors that created variability in the speed of advancement, such as increased terrain ruggedness or the aggressiveness of the opposition,.

The corollary is that the rearward areas have a faster movement rate and it is thought reasonable that the Roman army would have adjusted the distance between marching camps accordingly, thereby improving the efficiency of supply, communication and reinforcement. To be clear, if the advancing head of the army moved at 15 km/day, then that is the distance between the initial marching camps. Meanwhile, the rear of the army might have been capable of 25km/day, and that would be the optimum distance between marching camps to the rear of the advancing units. Possibly, even necessarily therefore, in the rear areas some advance camps would be abandoned as being quite literally out-of-step, and new ones built to enable the increased day-to-day cadence.

Furthermore, once the area was fully conquered then the process of re-adjustment probably continued as the Roman army matched the camp and road infrastructure to its marching capabilities. Probably the most common cadence between camps would be 29km, the frequently quoted daily marching rate of legionaries. However, 29km/day is too fast for less agile traffic, e.g. ox-drawn wagons at c.12km/day, and indeed may not have been the preferred peace-time marching rate of the legionary. Therefore, set between the 29km camps would have been other camps with a lower cadence.

Clearly, the comments in the last paragraphs point to a complex evolution of the camp and road infrastructure as territories transformed from hostile to Romanized in nature; a complexity that, at this early examination stage, makes it difficult to posit assured claims for probable, as opposed to possible, camp locations. Regardless, producing maps of the intersections of rivers and roads is beneficial.

To that end, and taking the example of Suetonius Paulinus' army during the Boudican uprising of 60 or 61 AD of probably 10,000 'armed men', 2,500 servants, 2,500 civilians, 3,000 mules and 937 horses, maps of river-road intersections were produced by GIS techniques from the datasets already described.

The figure for 'armed men' is given by Tacitus, while those of servants, civilians and beasts are the author's. It is a total of 15,000 humans. To maintain correspondence with the statistics already computed during this study, the known marching camp of Carstairs Main in Scotland, a member of the Group 18 hectares, was used as a surrogate for Suetonius' army: 11,592 soldiers, 2,898 servants, 2,898 mules and 543 horses; a total of 15,033 humans. This camp covers an area of 16.8 hectares, and the complement of humans and beasts described requires a minimum of 0.004255 cumecs from an adjacent river. This is doubled to 0.00851 cumec to produce the river flow figure thought in this study to be the minimum a surveyor would find acceptable.

The GIS task is now to define a region around the possible camp that would be used firstly to extract a suitable attribute range from the statistical grids produced earlier (example in Figure 19), and secondly to define the size of the possible camp ground surrounding the river-road intersections. The former was achieved by simply selecting only those grid cells that had 7 or more summed attributes in the group-attribute-grid for the Group 18 hectares. The latter was achieved by taking the half of the average side-length of the Group 18 hectare camps and summing with the mode of the distance to the rivers that supplied an excess of water to the same group, i.e. 200 metres, giving a total of 406 metres. This is a conservative measure as the mode of the first-river distances from camps for Group 18 hectares is only 50metres.

Using these parameters, 0.00851 cumec of flow for the rivers and the sub-selected group-attribute-grid values, in combination with the 406 range limit around river-road intersections, allows the production of a map showing the most favourable camp locations across Britain. Unfortunately, the scale of detail and the limits of this medium preclude the display of a map of Britain. However, interested readers can download higher resolution Tiffs files for all the groups described in this essay at www.bandaarcgeophysics.co.uk/arch/roman_marching_camps_uk.html .

As an example of the output, Figure 23 shows the river-road intersection locations in central-southern England for camp sites suitable for 15,000 humans, i.e. Carstairs Main, as a proxy for Suetonius Paulinus' army.

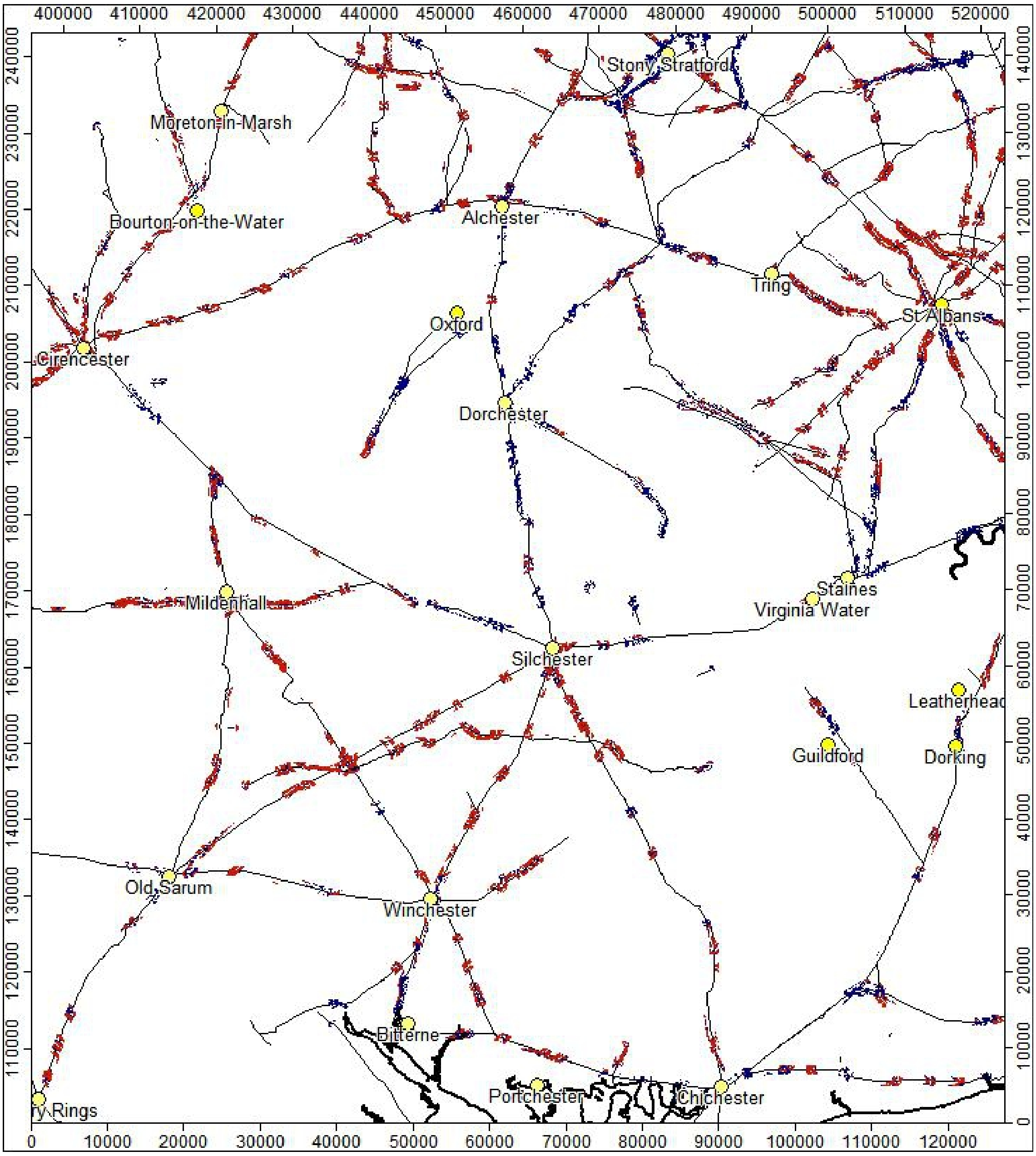

Figure 23: The most suitable Roman marching camps locations, the blue and red patches, at river-road intersections in central-southern England for an army of 15,000 humans (known camp Carstairs Main, Group 18 hectares). Red patches are locations with a full compliment of attributes: blue patches one less. Roads are black. Elements of this image are © Crown Copyright. All rights reserved 2013.

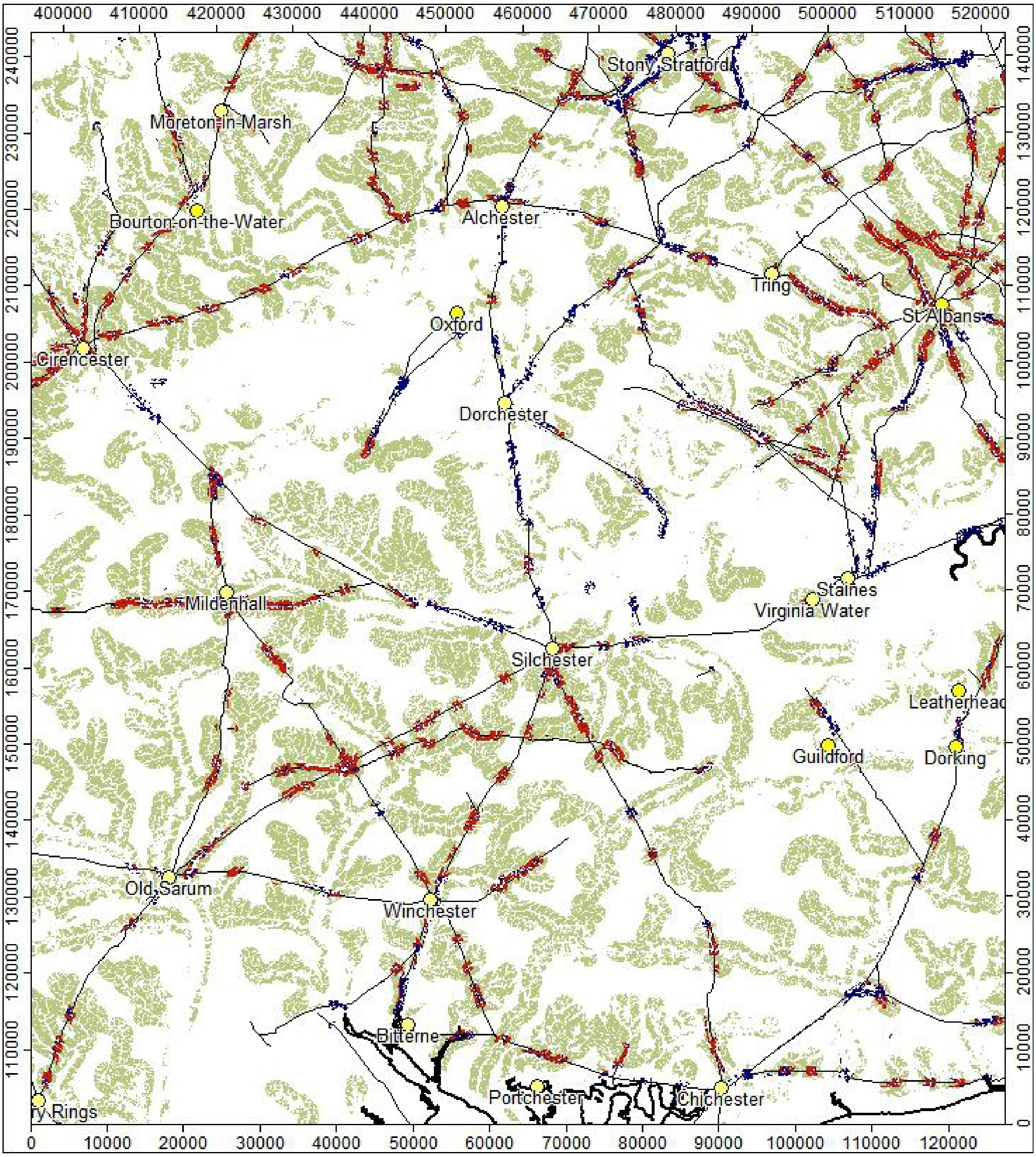

Figure 24: The most suitable Roman marching camps locations, the blue and red patches, at river-road intersections in central-southern England, plus, camp grounds alongside rivers, the light-green worm-like structures. The data is derived from the statistics for an army of 15,000 humans (known camp Carstairs Main, Group 18 hectares). Red patches are locations with a full compliment of river-road attributes: blue patches one less. Roads are black. Elements of this image are © Crown Copyright. All rights reserved 2013.

The full benefit of the methods discussed becomes more apparent when both the river-road intersections and camp grounds alongside rivers are displayed together (Figure 24). When viewing this image, it is important to recall that the roads have not been differentiated between military and civilian, that not all roads have yet been found, and that less favourable road and river grid cells, i.e. those with a lower attribute count, are not displayed.

This essay is primarily designed to describe the methods employed to produce such maps, not to describe the maps themselves, as this in itself a huge task and requires detailed local knowledge. Nevertheless, to demonstrate some of the information that can be extracted from these maps we will discuss Akeman Street between the vexillation fortresses at Cirencester and *Alchester* (modern Bicester), Figure 25. This road traverses approximately WSW-ENE while crossing the southern margin of the high Cotswolds, north of the Thames river valley.

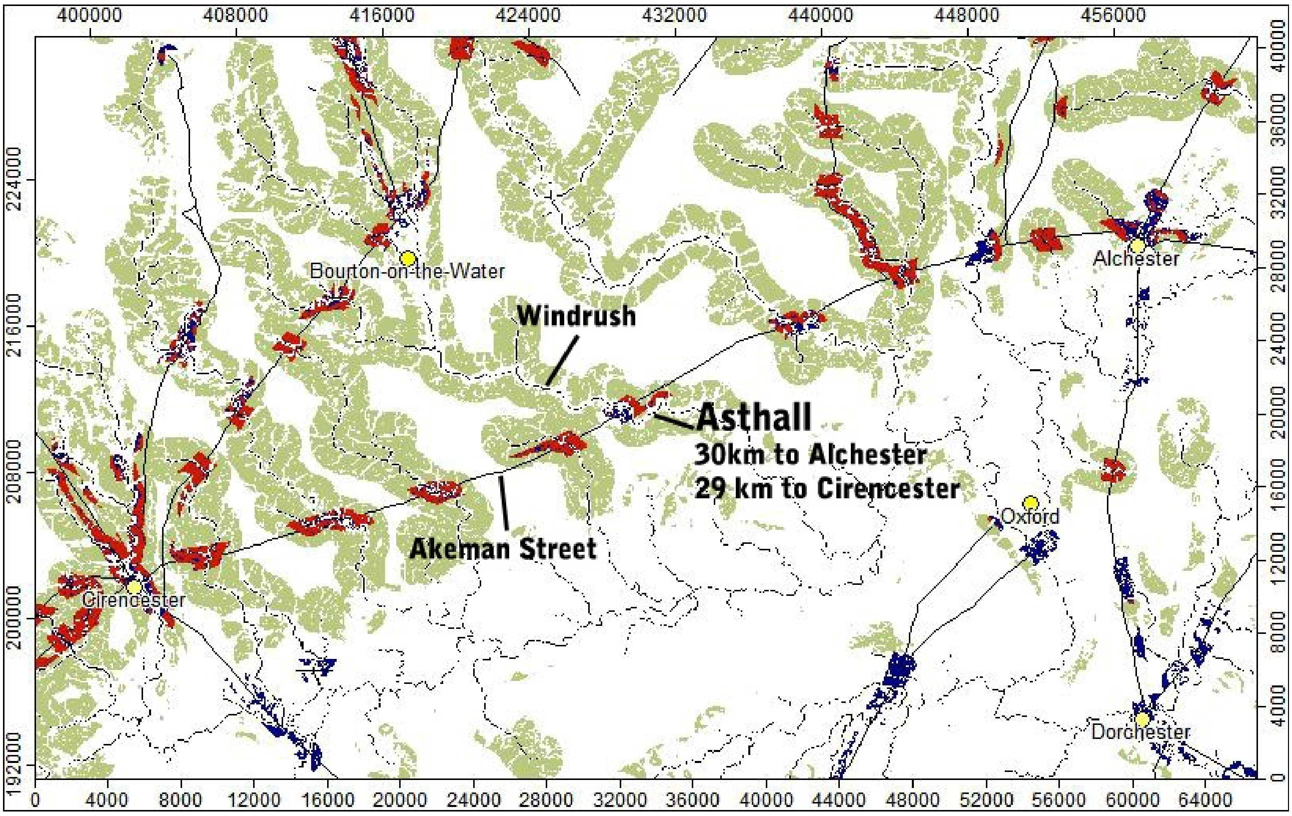

Figure 25: The Roman road Akeman Street between the vexillation fortresses at Cirencester and *Alchester*. Colours as for Figure 24. Elements of this image are © Crown Copyright. All rights reserved 2013.

The river Windrush is a major tributary of the Thames, and flows at a rate of 0.45 cumecs at the village of Asthall during August. This is more than sufficient for the largest Roman army that marched in Britain. It will be remembered that the standard legionary marching rate is 29km/day. Asthall is located 30km from Alchester and 29km from Cirencester, that is, the journey would take exactly two days, and this correspondence with the marching rate is possibly no accident. Also, the Windrush at Asthall has the highest flow rate of all the rivers between Cirencester and Alchester, except for the Cherwell which is only 8km west of Alchester. Therefore, Asthall appears to be perfectly located along Akeman street to satisfy the movement of the legions. Other river-road intersections, the red and blue patches in Figure 25, are typically 5 to 8 km apart, with one section being 10 km long, which is a distance between water and night stops that would suit heavy oxen-drawn carriages. A simple conclusion might be that the road has been engineered, even fine-tuned, to match the needs of the various types of traffic. If this is so, then clearly not only was distance an important design factor, but also the availability of sufficient water at the stopping places.

These observations, based on the river-road and other camp defining attributes, are supported by the archaeological record for Alchester. For example, finds suggest Roman settlement occupation from

1st to 4th centuries AD and it is postulated that one larger building may have been a mansio (a governmental building and facilities maintained for travellers.) A camp of 86 x 97 metres and aligned to Akeman Street was found 1.5 km south-west from the crossing point at Asthall. However, there is no near-by water supply. The English Heritage website does not state what sort of camp this might have been, however Welfare and Swan (see primary references at the beginning of this essay) have it as an addendum in their work on English Roman camps. This areal size matches that for the known marching camp at Langwathby Moor in Cumbria which, at a density of 690 soldiers/hectare, would have held 552 soldiers, 138 servants and mules and 25 horses, requiring 0.00021 cumecs of water. However, as the Asthall camp is water-deficient it would seem, on the basis of the findings in this study, that it was probably not a marching camp for the military.

In conclusion, this simple examination of Akeman Street and Asthall is an example of what can be deduced from the method and maps presented in this essay.

Further examples will be written in the future and placed on the author's website at www.bandaarcgeophysics.co.uk/arch_intro.html .

Appendix 1: Limitations and caveats

The work described in this essay will be improved as new data and techniques are investigated, meanwhile, the following points outline the limitations and caveats the author considers most important.

1) The majority of the findings are derived from SRTM data at a grid spacing of 90 metres. This spacing limits the resolving power of many of the techniques. The author is hopeful of acquiring a sound topographical dataset at a higher resolution: 50 or more preferably, 25 metres.

2) The hydrology calculations are based on the SRTM 90 metre data and consequently suffer from the limitation of resolution discussed in point 1). The author hopes to acquire a sound hydrological grid in the future.

3) The method used to calculate the river flow statistics is based primarily on rainfall, evapotranspiration and surface flows. It does not involve calculations of ground water processes, for example, aquifer discharge to rivers. Additionally, the naturalised flow calculations are at the very extreme of what is thought possible given the minimal flows involved; consequently, some postulated battle sites, located alongside rivers supplying the minimum of demand, may not be viable. Nevertheless, the present results are surprisingly well-correlated with the limited published data from the Centre for Ecology & Hydrology (CEH).

4) Due to the SRTM limitations already mentioned, the width and breadth measurements of the Roman marching camps were not used to extract the various indices used in the study. Instead a simple, circular buffer was placed at the known centre of the camp, the radius of which was based on the longest known side of the camps. This is thought to be acceptable at a 90 metre resolution, but not so if the base grid is improved in the future to 50 or 25 metres.

5) The SRTM 90 metre grid described above limits the resolution of all resultant calculations and, necessarily, creates some location 'jitter' in the placement and calculation of factors related to rivers, roads and various attributes. This 'jitter' has its most obvious effect at the 10s of metre scale but does also effect larger measures of scale, size and attributes resulting from calculations based on these scales.

6) The Roman road dataset has not been parsed to separate those built and used by the military from those of civilian construction and use. It could be argued that most, if not all, roads in Scotland and Wales are military, but that is not the case for England. These issues will be tackled in future work.

7) Much of the prediction of marching camp locations is based on the selection of various statistical methods thought most applicable to the issue at hand. Therefore, there exists a subjectivity in the methods selected. This is unavoidable in most cases, and will theoretically always be the case, nevertheless it is hoped to improve the statistical methodology after the resolution and hydrological issues have been solved (points 1 and 2).

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Primary software:

SAGA, System for Automated Geoscientific Analyses, http://www.saga-gis.org/en/index.html

Primary dataset:

Shuttle Radar Topography Mission (SRTM), Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2006, *Hole-filled seamless SRTM data V3*, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org.

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